An Approach for the Semantic Interoperability of ISO EN 13606 and OpenEHR archetypes

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Abstract— The communication between health information systems of hospitals and primary care organizations is currently an important challenge to improve the quality of clinical practice and patient safety. However, clinical information is usually distributed amongst several independent systems that may be syntactically or semantically incompatible. This fact prevents healthcare professionals from accessing clinical information of patients in an understandable and normalized way. In this work, we address the semantic interoperability of two EHR standards: OpenEHR and ISO EN 13606. Both standards follow the dual model approach which distinguishes information and knowledge, this being represented through archetypes. The solution presented here is capable of transforming OpenEHR archetypes into ISO EN 13606 and vice versa by combining Semantic Web and Model-driven Engineering technologies. The resulting software implementation has been tested using publicly available collections of archetypes for both standards.

KEYWORDS:

Electronic Healthcare Records, Semantic Interoperability, Archetypes, Ontology, Model-driven Engineering

1 INTRODUCTION

Semantic interoperability of electronic healthcare records (EHR) systems is a major challenge in eHealth [1], because it would allow healthcare professionals to manage the complete EHR of patients, independently from the institutions that generated each clinical session. Recent recommendations of the European Commission [1, 2] have stated that the semantic interoperability of EHR systems is essential to improve the quality and safety of patient care, public health, clinical research, and health service management.

An increasing number of countries have been making efforts in the digitalization of EHRs since the GEHR project [3] began the design of an electronic health architecture in the late 80s. As a consequence of those efforts, several EHR standards were proposed, including HL7 [4], OpenEHR [5] and ISO EN 13606 [6]. The availability of multiple standards causes the clinical information to be distributed amongst several independent systems that may be syntactically or semantically incompatible. Therefore, the development of methods for transforming information between different EHR standards becomes crucial.

Most advanced EHR architectures and standards are based on the dual model-based architecture [7], which defines two conceptual levels: (1) reference model; and (2) archetype model. The reference model defines the set of entities that form the generic building blocks of the electronic healthcare record. It contains the non volatile features of the electronic healthcare record, so clinical information is defined at this level. On the other hand, archetypes define clinical concepts in the form of structured and constrained combinations of the entities contained in the reference model, so clinical knowledge is defined at this level. Both OpenEHR and ISO EN 13606 use this modeling architecture, which has also influenced HL7 CDA. In dual model approaches, archetypes constitute a tool for building clinical consensus in a consistent way and they are considered basic to deliver fully interoperable EHRs [8].

In this work, we address the semantic interoperability of EHR standards based on the dual model architecture, more concretely, OpenEHR and ISO EN 13606. This selection is due to the fact that most of the currently available archetypes are described for OpenEHR, and ISO EN 13606 is likely to be widely used in European countries. Recently, ISO EN 13606 has been selected as the official EHR standard for national projects such as in Sweden [9] and in the Region of Madrid in Spain. Moreover, the European project epSOS (Smart Open Services for European Patients) [10], whose consortium includes twelve European countries, is currently in the process of selecting the reference model for this pilot project, and ISO EN 13606 is one of the candidates. The situation is similar in Spain with the project run by the National Health Service for facilitating the exchange of EHR extracts. Moreover, the usage of this standard has been recommended in the final report of the Semantic Health project [11]. It should be noted that ISO EN 13606 and OpenEHR are likely to coexist in the near future, so the exchange, sharing and re-use of archetypes between these standards becomes an important issue.

This work has been done in the context of a research project which aims at providing mechanisms for representing archetypes in Semantic Web-manageable manner and achieving semantic interoperability between EHR systems, combining Semantic Web and Model-driven Engineering technologies. The solution presented here will be capable of transforming OpenEHR archetypes into ISO EN 13606 and vice versa. Our approach will re-use some of the technological infrastructure developed in previous work, such as ontologies for EHR standards and methods for obtaining semantic representations of archetypes.

Finally, the structure of this work is described next. First, Section 2 provides the technological background required to understand this work. Section 3 discusses the conceptual relation between both EHR standards. Our technological solution is presented in Section 4. Some discussion and conclusions will be provided in Section 5.

2. BACKGROUND

This section provides an introduction to the technologies used in this work and describes some previous work that will be helpful to understand the approach presented in further sections.

2.1 Technologies

The most important technologies included in our approach, namely, archetypes, ontologies and Model-driven Engineering (MDE), are introduced in this section to provide the technical foundations of this work.

2.1.1 Archetypes

Archetypes are detailed and domain-specific definitions of clinical concepts in the form of structured and constrained combinations of the entities of the reference model. They refer to clinical concepts and represent healthcare and application specific concepts such as blood pressure, examination of the chest, heart rate, etc. The ISO EN 13606 and OpenEHR communities specify them using the Archetype Definition Language (ADL). This language provides an abstract syntax, which can be used to express archetypes for any reference model in a standard way. An archetype can include other archetypes and can be used in combination to form templates. Moreover, archetypes are envisaged as a clinical guide for clinicians.

Figure 1 shows an extract of the OpenEHR ADL archetype for recording the heart rate and rhythm of a patient. An ADL archetype has four sections: header, description, definition and ontology:

- Header: it includes the name of the archetype (openEHR-EHR-OBSERVATION.heart_rate.v1), the language it is written in (ISO_639-1::en), and so on.
- Description: it accounts for audit information, such as original author (unknown), lifecycle state (Initial) or purpose (To record the rate...).
- Definition: it contains the structure and restrictions associated with the clinical concept defined by the archetype. In our example, this section defines the heart rate (OBSERVATION[at0000]) as a history (HISTORY[at0001]) of events. For each event (POINT_EVENT[at0002]), the following information can be recorded: the rate of the heart as beats per minute (ELEMENT[at0004]), the rhythm of the heart beat (ELEMENT[at0006]), if the pulse rate is present (ELEMENT[at0008]) and the position of the patient when the heart rate was measured (ELEMENT[at0011]).
- Ontology: it includes the terminological definitions for each concept and bindings to other terminologies. For instance, in the example the linguistic expression associated with the concept identified by the code at0000 (Heart rate) is provided.

<Figure 1>

2.1.2 Ontologies

The Semantic Web [12] is a vision of the future Web in which information is given explicit meaning, making it easier for machines to automatically process and integrate information available on the Web. There are different basic technologies for the success of the Semantic Web, amongst which the cornerstone technology is the ontology. In the literature, multiple definitions for ontology can be found [13, 14]. An ontology represents a common shareable and reusable view of a particular application domain. It gives meaning to information structures that are exchanged by information systems [15].

The advances in the Semantic Web community make the ontology a candidate technology for supporting knowledge-intensive tasks related to archetypes and EHR systems. Moreover, they have been identified in the final report of the Semantic Health project [11] as one of the basic technologies for the achievement of semantic interoperability of health information systems. The use of ontologies for representing biomedical knowledge is not new, since they have been widely used in biomedical domains for the last few years with different purposes [16, 17].

Clinical archetypes are usually represented in ADL. However, this language has important drawbacks for achieving the goal of semantic interoperability, such as its syntactic orientation. Consequently, the formalization of the exchange and transformation processes is more difficult than using semantic oriented models such as ontological ones. In addition to this, syntactic approaches also make important archetype-related tasks, such as comparing and classifying archetypes, difficult.

Hence, ontologies will be used in this work to provide a formal, semantic model for representing clinical archetypes of both OpenEHR and ISO EN 13606 standards. These ontologies will be built using the Web Ontology Language (OWL) [18], which is the current W3C recommendation for the exchange of semantic content on the Web.

2.1.3 Model-driven Engineering

Model-driven Engineering (MDE) is based on the idea of using models at different abstraction levels for developing systems. The Object Management Group [19] defines a four-level meta-modeling architecture [20], amongst which models (e.g., an ADL archetype) and metamodels (e.g., the ADL language) are relevant for this work. A model is an instance of a particular metamodel. MDE approaches facilitate the development of formal, maintainable solutions, so they constitute an optimal technological infrastructure for achieving our goals.

In this work, the ontologies developed for both EHR standards will be expressed as metamodels. For this purpose, the Ontology Definition Metamodel [21] standard, which defines the semantics of the transformation of OWL ontologies to models, will be used. This transformation is implemented by the Protégé environment [22]. Consequently, this will be used to obtain metamodels from OWL ontologies.

In MDE, model transformation is the process of converting a model Mx conforming to metamodel MMx into a model My conforming to metamodel MMy. In recent years, several model transformations languages have been defined. RubyTL [23] is a rule-based hybrid transformation language for defining transformation rules in both declarative and imperative ways and includes significant features as the organization of rules in phases. In this work, model transformations expressed in RubyTL will be used for transforming a model representing an OpenEHR ADL archetype into ISO EN 13606 one and vice versa. Finally, models will be represented in ADL using the model to text language MOFScript [24].

2.2 Previous work

Some previous results of our research group have been re-used in this work. On the one hand, we have developed ontological representations for ISO EN 13606 and OpenEHR archetypes. Such ontologies were the result of the semantic interpretation of both reference and archetype models of the standards [25]. The resulting ontologies allow for representing archetypes as semantic models and, therefore, they allow performing knowledge-intensive tasks. Two main ontologies were built for each standard: (1) the (ISO EN 13606/OpenEHR)-SP ontology, which represents the clinical data structures and data types defined in the reference model of each standard and (2) the (ISO EN 13606/OpenEHR)-AR ontology, which defines the archetype model and re-uses the SP one. They are available in a public repository [26], and constitute the basic technological infrastructure for our research work.

On the other hand, we have also developed methods for transforming ADL archetypes into OWL [27]. In order to make our transformation approach easy to maintain and to adapt to other ontological languages, a Model-driven approach was used for designing and implementing our transformation architecture. The methodology proposed in the first approximation [27] was optimized in [28] for getting better quality OWL archetypes. The evolution is purely technical, and it comes from the lessons learnt from our previous work. The transformation process is divided now in the following three phases (see Figure 2):

1. The input ADL archetype is expressed as a syntactic model. The textual ADL archetype is transformed into a model conforming to the archetype object model.
2. This syntactic model is transformed into a semantic model by using a model to model transformation. A set of rules has been defined for the model to model mappings between the syntactic archetype metamodel and the ISO EN 13606/OpenEHR semantic one.
3. The semantic model is transformed into OWL according to the EHR ontologies by using a model to text transformation.

<Figure 2 >

3. CONCEPTUAL APPROACH TO THE TRANSFORMATION PROCESS

In this section we address the process of transforming archetypes between OpenEHR and ISO EN 13606. Given that both standards follow the dual model architecture, reference and archetype models are available for them. However, their reference models were designed with different objectives. OpenEHR was devised to fully support the construction of EHR systems, whereas ISO EN 13606 was designed for exchanging EHR extracts.

The analysis of the OpenEHR and ISO EN 13606 EHR models reveals their similarity. They use the same syntactic model for defining archetypes but they differ in the definition of the reference model. Every ISO EN 13606 entity has a similar one defined in OpenEHR, but the opposite does not happen because OpenEHR provides richer data structures and data types.

Let us analyze next how data are structured in both standards (see Figure 3). First, OpenEHR organizes data in *COMPOSITIONs*, which are included within an optional *FOLDER* hierarchy. The *COMPOSITIONs* contain *ENTRYs* and *GENERIC_ENTRYs*, which are optionally contained in a *SECTION* hierarchy. *ENTRYs* are classified in *ADMIN_ENTRY*, *OBSERVATION*, *INSTRUCTION*, *ACTION*, etc and they contain *ELEMENTs*, which are optionally organized within a *CLUSTER* hierarchy. *GENERIC_ENTRYs* are included in OpenEHR to facilitate the interoperability with other standards, as will be described later. OpenEHR also allows defining data structures such as table, *(ITEM_TABLE)*, tree *(ITEM_TREE)*, list *(ITEM_LIST)* or as a single *ELEMENT (ITEM_SINGLE)* and provides other ones to represent information as a *HISTORY* of *EVENTs*.

Second, ISO EN 13606 also organizes data in *COMPOSITIONs*, which are optionally contained in a *FOLDER* hierarchy. These *COMPOSITIONs* include *ENTRYs*, which are optionally contained in a *SECTION* hierarchy and *ENTRYs* include *ELEMENTs,* which are optionally organized within a *CLUSTER* hierarchy.

<Figure 3>

It should be noted that some entities (*ELEMENT*, *CLUSTER*, *ITEM*, *SECTION*, *COMPOSITION*, *FOLDER* and *ENTRY*) are common to both reference models, although their definition and properties might differ. For instance, the OpenEHR *ENTRY* is an abstract concept with a number of specializations but the ISO EN 13606 *ENTRY* is a concrete entity without specializations. Thus, all OpenEHR *ENTRYs* have to be transformed into the same concept in ISO EN 13606. This transformation requires adapting their internal structure by means of *CLUSTER* and *ELEMENT* entities in ISO EN 13606. Moreover, the OpenEHR reference model contains more entities than ISO EN 13606. For instance, the OpenEHR *ITEM_STRUCTURE* hierarchy has no direct correspondence in ISO EN 13606. Consequently, these entities are also represented in ISO EN 13606 as a *CLUSTER/ELEMENT* composition.

It can be deduced from the above paragraph that the mappings from OpenEHR to ISO EN 13606 might be interpreted as a generalization. In order to keep the meaning of the clinical data, each ISO EN 13606 data structure preserves the name of the OpenEHR property and type in the *meaning* property, which is defined for every ISO EN 13606 data structure. This information could be used in the target system to interpret more accurately the transformed archetype.

Otherwise, every ISO EN 13606 concept has a corresponding one in OpenEHR, although their properties might also differ. In this case, the property can be mapped into a *CLUSTER* or *ELEMENT*, and the name of the ISO EN 13606 property is preserved in the *uid* property of OpenEHR data structures. This attribute has been used because it is not currently needed in OpenEHR.

With regard to data types, each standard defines its own set. The number of data types in ISO EN 13606 is lower than in OpenEHR, and some common ones are defined differently. Moreover, a *CLUSTER/ELEMENT* composition plus using the meaning property is not applicable for data types. Therefore, lossless mappings cannot be granted for some data types.

Taking into account all that has been stated, the mappings between OpenEHR and ISO EN 13606 were defined at two different levels, namely, concept and property, and are detailed in [29]:

- *Concept mapping*: This is defined for entities and data types. There are two possible situations:
    - There is a concept with the same or similar meaning in the other standard. In this case, the mapping is directly done. For instance, *ELEMENT* and *CLUSTER* are shared by both standards. The OpenEHR *GENERIC_ENTRY* is provided to make the representation of data from other standards with no entry specializations, such as the ISO EN 13606 *ENTRY,* possible.
    - There is no concept with the same meaning in the other standard. Then, the concept is mapped into a more general one. For example, the OpenEHR *ITEM_TREE* and *OBSERVATION* are respectively mapped into a *CLUSTER* and an *ENTRY.*

- *Property level mapping*: This is defined for the properties of the concepts matched in the previous level. The following situations may happen:
    - Two properties have the same meaning and type in both standards. Then, the mapping can be directly defined. This is the case of the properties *value* of ISO EN 13606 *PQ* and *magnitude* of OpenEHR *DV_QUANTITY.*

      Two properties have the same meaning but different type in the standards. In case it is possible, a transformation between the types is defined. This is the case of the properties *units* of the *PQ* and *DV_QUANTITY* concepts. In ISO EN 13606, *units* has the type *CS_UNITS*, but in OpenEHR it is represented as a string value.

- There is no property with the same or similar meaning in the other standard. In this situation, there is no possible mapping for the data types. An example is *property* of *PQ* in ISO EN 13606, which does not have any correspondence in OpenEHR *DV_QUANTITY*. However, in the data structures case some entities include generic properties, such as *items* in ISO EN 13606 *ENTRY*, therefore any property can be matched to a *CLUSTER/ELEMENT* composition, whenever the property type can be used as an element value. For instance, the property *encoding* of the OpenEHR concept *OBSERVATION* does not have any corresponding property in the ISO EN 13606 *ENTRY* concept. Nevertheless, it can be embedded into the value of an ELEMENT of *items*. The same happens with the ISO EN 13606 *ENTRY info_provider* property. In this case, when this concept is transformed into an OpenEHR GENERIC_ENTRY concept, this property cannot be embedded as an element value.

The result of transforming the OpenEHR archetype introduced in Section 2.1.1 into ISO EN 13606 by applying the mapping rationale described in this section is shown in Figure 4. Both archetypes share the same concept codes in order to simplify the transformation validation. For instance, it can be observed that the entity *OBSERVATION[at0000]* is represented as an *ENTRY* and the data type *DV_QUANTITY[at0005]* is transformed into *PQ*. Amongst property-level mappings, the *units* of *DV_QUANTITY[at0005]* is transformed into the *units* property as a string, and *magnitude* is transformed into *value* keeping the same type.

<Figure 4>

4. TECHNICAL SOLUTION

In this section we explain the technical approach developed for the transformation of OpenEHR archetypes into ISO EN 13606 and vice versa. First, the technological solution will be presented. Second, an example describing the modus operandi of our solution will be described. Finally, the software implementation of our approach will be presented.

4.1 Architecture of the solution

Our solution combines a series of technologies, namely, archetypes, ontologies and MDE, which have been described in Section 2. The input to our transformation process is an OpenEHR or ISO EN 13606 ADL archetype and the output is an ISO EN 13606 or OpenEHR archetype respectively. It should be noted that the approach permits the production of the output archetype in ADL or in OWL, by re-using our previous developments. However, this section is focused on the generation of ADL archetypes.

The architecture of this solution is depicted in Figure 5. There, two layers can be distinguished, namely, ontology and MDE. The ontology layer comprises a series of ontologies that model EHR-related knowledge for the different standards. The MDE layer contains the metamodels corresponding to the semantic representations defined in the ontology layer. The transformation mappings are formalized and the transformation of the archetypes is done in the MDE layer. Next, more details about each layer are provided.

<Figure 5>

4.1.1 Ontology Layer

The ontology layer provides the formal semantics of our domain, and is composed of a series of OWL ontologies developed for the EHR standards. In particular, our current semantic infrastructure includes ontologies for ISO EN 13606 and OpenEHR, as described in Section 2.2. These ontologies might be enough to define the transformations between both standards. However, we aim to develop a generic and extensible architecture, capable of dealing in the future with other standards such as HL7 v3 or the Detailed Clinical Models [30]. This self-imposed requirement led us to develop a common ontology for EHR standards. This ontology covers the global aspects of archetypes in dual model approaches and offers a common representation for them. Figure 6 shows the relationship between the common ontology and the specific ones of the clinical standards.

<Figure 6>

This ontology was built by identifying the common and disjoint knowledge defined in the ontologies of both ISO EN 13606 and OpenEHR, so it is not a global EHR ontology. The detection of the equivalent concepts and data types was supported by the ontology integration methodology developed in our research group [31]. The structures shared by both standards were merged into a single concept by combining their properties. Concepts such as *FOLDER*, *COMPOSITION*, *SECTION*, *CLUSTER* or

ELEMENT are common to both standards. Thus, they were added to the common ontology as a single concept.

On the other hand, some concepts are defined only in one standard. In this case, they are included in the Common ontology. For instance, *ACTIVITY* and *ISM_TRANSITION* are defined only in OpenEHR.

The same rationale is applied to data types. For instance, the type *URI* in ISO EN 13606 corresponds to *DV_URI* in OpenEHR, and both have been merged into the concept *URI* in the Common one.

4.1.2 MDE layer

In this layer the transformations between the standards are formalized. Consequently, metamodels for the ISO EN 13606, OpenEHR and the Common ontologies were developed by using the the Ontology Definition Metamodel [21] standard and the Protégé environment [22] as previously mentioned in Section 2.1.3. Once the metamodels have been obtained, the correspondences amongst them were defined. In order to transform OpenEHR archetypes into their ISO EN 13606 representation and vice versa, the mappings were defined between the particular standard and the Common metamodel. These mappings have been conceptually defined at concept and property levels and implemented using the model transformation language RubyTL. In addition, model to text rules have been defined in MOFScript and applied to the target metamodel to obtain the ADL archetype textual representation.

The transformation of OpenEHR archetypes into ISO EN 13606 (and vice versa) requires the definition and implementation of two sets of mappings [29]:

- Mappings from the OpenEHR/ISO EN 13606 metamodel to the Common one
- Mappings from the Common metamodel to the ISO EN 13606/OpenEHR one

Every concept and property of the metamodels of the standards can be modeled according to the Common representation. The Common metamodel is derived from the Common ontology, and it represents archetypes of both standards in a lossless manner. Such mapping rules permit the definition of two different workflows in the transformation process:

a) The transformation of ADL OpenEHR archetypes into ADL ISO EN 13606
b) The transformation of ADL ISO EN 13606 archetypes into ADL OpenEHR

The transformation of ADL OpenEHR archetypes into ADL ISO EN 13606 consists of the following phases:

1. The ADL archetype input is transformed into its MDE representation, which is a model conforming to the OpenEHR metamodel (OpenEHR model).
2. The OpenEHR model is transformed into the common archetype representation (Common model).
3. The Common model is transformed into ISO EN 13606 (ISO EN 13606 model).
4. The ISO EN 13606 model is transformed into ADL code (ISO EN 13606 ADL archetype).

As it has already been mentioned, the last phase of the workflow can be configured to produce an OWL archetype instead of an ADL one. The transformation from ISO EN 13606 to OpenEHR is similar, as the main difference between both workflows is the set of mapping rules applied in phases 2 and 3.

4.2 Illustrating the approach through an example

A practical example is described now to facilitate the understanding of the architecture and the modus operandi of the transformation process. This example will be the transformation of the OpenEHR ADL archetype introduced in Section 2.1.1 to ISO EN 13606. As has already been mentioned, four steps are necessary to complete this process:

1st step: Transformation of the ADL archetype into MDE.

The ADL archetype is transformed into an OpenEHR metamodel-compliant model. This transformation is done by applying the methodology presented in [27] and briefly described here in Section 2.2. After its application to the OpenEHR ADL heart rate archetype, the model depicted in Figure 7 is obtained. It shows the main features of the transformation of its definitional part. This transformation produces the semantic representation of the archetype.

<Figure 7>

2nd step: Transformation of the OpenEHR model into the Common model

Once the archetype is expressed as an OpenEHR model, the second step is its transformation into a model conforming to the Common metamodel. For this purpose, the mappings defined between the

Common and the OpenEHR metamodels are applied to the OpenEHR model. As a result of this process, the model shown in Figure 8 is obtained. As can be observed, every OpenEHR concept has a corresponding one in the Common representation. An OpenEHR *OBSERVATION*, a *HISTORY*, an *ITEM_TREE*, a *CLUSTER*, etc are all represented in the same way in the Common metamodel.

<Figure 8>

3rd step: Transformation from the Common model into an ISO EN 13606 model

The transformation of the Common model into an ISO EN 13606 model requires the application of the mappings implemented between both metamodels using model to model transformation rules. Figure 9 depicts the resulting ISO EN 13606 model. The transformation from OpenEHR into ISO EN 13606 implies a generalization. The first reference model is richer in concept and data types, which means that more specific concepts will be transformed into more generic ones. For instance, the OpenEHR concepts *OBSERVATION* or *HISTORY* are transformed into *ENTRY* and *CLUSTER* in ISO EN 13606. Each concept preserves the name of the ISO EN 13606 property and its type in the *meaning* property. It can be observed in the example that for instance, the *HISTORY* concept is transformed into a *CLUSTER* with the "*data::HISTORY*" string as the value of *meaning*.

<Figure 9>

4th step: Transformation of the ISO EN 13606 model into ADL

Finally, the archetype is transformed into ADL by means of model to text rules, which combine ISO EN 13606 model information with ADL code. The result of this process is the ADL archetype partially shown in Figure 4. It can be noted how the specific OpenEHR concepts and data types have been changed, respectively, into ISO EN 13606 *ENTRY*, *CLUSTER* and *ELEMENT* concepts or PQ, SIMPLE_TEXT, BL, CODED_TEXT data types.

4.3 Implementation of the approach

We have developed the Poseacle Converter (http://miuras.inf.um.es/PoseacleConverter), which is a software tool that implements our approach and executes two main tasks:

- Transformation of an ADL archetype into OWL.
- Transformation of ADL ISO EN 13606 archetypes into ADL OpenEHR ones and vice versa.

This tool combines the different technologies and languages included in our approach. Model Driven-Engineering technologies are incorporated into the tool through MOFScript and RubyTL. Semantic Web technologies are included in the tool by using OWL for representing and managing the semantic content. Its usage is straightforward, and the user has to perform the following steps: The user inputs the ADL archetype by browsing the local file system or entering its URL; Then, (s)he selects the source and target EHR standard (ISO EN 13606 / OpenEHR) and the target representation format (ADL/OWL) and finally, (s)he presses convert and gets the result.

Apart from the online access to the tool, a RESTful service for doing the transformation and an API to invoke it have been provided.

In order to test the tool, OpenEHR archetypes from the OpenEHR repository [32] have been transformed. The results are available in the Poseacle web repository [26]. At this moment, there are not many ISO EN 13606 archetypes, but the tested ones are also in this repository.

5. DISCUSSION AND CONCLUSIONS

In this work the transformation of archetypes from ISO EN 13606 to OpenEHR ones and vice versa has been addressed. Our results show that such exchange and sharing is possible, and we believe that our approach could be applied to other dual model based standards. The present work re-uses some of our previous results, such as the ontological infrastructure [25] and the ADL to OWL transformation tool [27]. This has allowed the simplification of the development process, and to keep the good properties of the combination of ontologies and Model-Driven Engineering in terms of formalization of the semantics of the domain, and maintainability of the mappings and transformations amongst archetypes, models and ontologies. This reinforces our methodological decisions and will be the technological support for our future research and developments.

The architecture used in this work distinguishes two layers: (1) the ontology layer comprises a series of ontologies that model EHR-related knowledge for the different standards; and (2) the MDE layer contains the metamodels corresponding to the semantic representations defined in the ontology layer. The MDE layer processes and transforms the specific archetypes by using the corresponding mappings. Thus, the core of the transformation process is located in this layer by means of applying model to model and model to text transformations rules. Given the development of a series of ontologies, it might be argued that the mappings and transformations could have been defined between the ontologies rather than the metamodels. However, two main reasons led us to make this decision: (1) the availability and maturity of tools based on metamodels is higher than based on ontologies; and (2) using the metamodels, the mappings are purely conceptual, without being linked to a particular ontology model such as the one provided by OWL. The definition of the concrete mappings come from our understanding and experience with both standards, but they do not correspond to any community consensus. So far, these mappings have not been formally expressed. We are currently evaluating different mapping languages from both the Semantic Web and Model-Driven Engineering areas, since having a formal representation of these mappings will be useful for extending our approach to new standards.

To the best of our knowledge, this is the first implementation of archetype transformation between such standards, although there are other proposals pursuing similar goals. In [33], mappings between a proprietary EHR system from Sweden and openEHR archetypes were established to perform automated bidirectional conversion between openEHR archetypes and that system. The authors show that interoperability between a proprietary system and OpenEHR is feasible, although in some cases there is also some information that might not be transformed. Such work provides interesting hints for facing the interoperability with non-dual standards and we hope this kind of work contributes to extend the use of EHR standards. We think that the combination of efforts for achieving semantic interoperability between proprietary system and EHR standards with those for achieving the same objective between EHR standards is certainly a good way for achieving global semantic interoperability.

Also, the OpenEHR Foundation in [34] is also defining a set of mappings between OpenEHR and ISO EN 13606 reference models, although they have not been completed and implemented to date. These mappings rules have been defined from the OpenEHR reference model to the ISO EN 13606 reference model and not backwards. Such rules are highly similar to the ones defined in our approach at conceptual level, and this effort could contribute to validate our mapping rules and tools. At the moment, the OpenEHR effort is producing mappings between the reference model data structures.

There are some differences with our approach, such as the use of the property *name* instead of *meaning* for preserving the original concept name that is transformed. In our approach, the ISO EN 13606 *meaning* and the OpenEHR *uid* properties are used for preserving the original semantics of some data structures and their properties.

In Section 3, we have mentioned that the transformation approach might lose some information in particular situations. Some concept properties and data types cannot be mapped into the target representation. There is an on-going effort for defining a set of common data types to facilitate the interoperability between EHR standards [35]. Since such set of types is not available yet, the ones defined in the standards, which are backed by ISO recommendations, have been used. With regard to concept properties, this situation is not the most common. However, these two issues do not prevent the possibility of getting the transformed archetype. We are currently keeping the trace of the transformation process, which can be optionally obtained as a report by the users of the tool. This trace provides detailed information about the transformation process, and this would include the concepts properties or data types of the input archetype, if any, that may have not been transformed.

On the other hand, ISO EN 13606 *ENTRY*s are transformed into OpenEHR *GENERIC_ENTRY*s given that an OpenEHR *ENTRY* is an abstract concept. Therefore, this entity was defined by the OpenEHR community to facilitate the interoperability with other standards such as ISO EN 13606. In our opinion, this does not seem the best modeling decision. Some ISO EN 13606 *ENTRY* properties such as *info provider*, *subject of information* or *other participations* do not have any similar property in the *GENERIC_ENTRY* entity. This could be solved if the entity were reallocated in *ENTRY* hierarchy or merged with the *ENTRY* concept, which should then become instanceable. Nevertheless, we expect to research other options in the future. One of them is the study of the terminological bindings associated with the terms included in the ISO13606 *ENTRY* for deciding the specific OpenEHR *ENTRY* specialization concept to be transformed.

This work is considered as an initial step towards the transformation of data instances. Generally speaking, the transformation of archetyped data instances would require two steps: (1) archetype transformation; and (2) data transformation. Thus, the second step requires knowing the transformations applied at archetype level. For this purpose, the trace of the transformation process will be used.

Our solution is capable of generating ADL and OWL archetypes in the target EHR standard, hence the different representations can be used for different purposes. For instance, we are currently doing research on the automatic generation of EHR applications from ISO EN 13606 archetypes, therefore the resulting ADL archetypes can be the input for such system. On the other hand, the OWL representation is currently used in our archetype management system [36] for performing activities at clinical level such as comparison or classification.

In the last few years, the different EHR communities have discussed the best way for defining shareable clinical knowledge units. The goal of that discussion process was to provide mechanisms for defining those units in a technology independent way. In this context, archetypes might be considered technology-dependent since they are based on a particular modeling architecture. In [37], the need for providing such generic model usable in different standards and technologies was identified, and the notion of Detailed Clinical Models (DCM) emerged as part of the harmonization works needed. They aim to contribute towards semantically interoperable clinical data, and thereby to the safer and richer processing of health records. This harmonization effort is currently partnered by ISO [38], CEN, CDISC [39] and HL7, and is related to the two EHR standards used in this work. Unfortunately, DCMs are not likely to be available soon, so the current approaches and standards for achieving semantic interoperability are needed. When DCMs become available, transformation approaches will become even more necessary, since the DCM would represent an EHR standard-independent knowledge specification, which will have to be translated into the different EHR standards that will certainly co-exist. Hence, we believe that all the efforts that are currently pursuing the semantic interoperability amongst particular EHR standards will make the adoption and success of DCMs easier. We also believe that the availability of DCMs would be positive for our work. In this hypothetical scenario, our work could be very useful because it includes methods for transforming clinical knowledge based on a common semantic model. This semantic model might be an ontological representation of DCMs, with the corresponding maintenance of the ontologies, the metamodels and the mappings. Therefore, DCMs would also contribute to improve our solution and increase the impact of our results.

In summary, we have developed methods for transforming archetypes between two important EHR standards, namely, ISO EN 13606 and OpenEHR, which will be the basis of our further research towards semantic interoperability at data level. This work opens a series of new research challenges for our group, such as archetype transformation supported by SNOMED-CT, application of our transformation methods to HL7 CDA, the transformation of data instances and the evolution of our approach for DCM environments.

ACKNOWLEDGEMENTS

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```
archetype (adl_version=1.4)
   openEHR-EHR-EVALUATION.check_list-surgical_procedure.v1
specialize
   openEHR-EHR-EVALUATION.check_list.v1draft
concept
   [at0000.1]
language
   original_language = <[ISO_639-1::en]>
description
   original_author = <
       ["name"] = <"unknown">
   >
   lifecycle_state = <"Initial">
   details = <
       ["en"] = <
           language = <[ISO_639-1::en]>
           purpose = <"To record a systematic review about surgical … ”>
           …
       >>
definition
   EVALUATION[at0000.1] matches {  -- A check list about surgical procedures
     data matches {
       ITEM_TREE[at0001] matches {  -- Tree
         items cardinality matches {0..*; unordered} matches {
           CLUSTER[at0004] occurrences matches {1..*} matches {-- Question group
             items cardinality matches {0..*; unordered} matches {
               CLUSTER[at0002] occurrences matches {1..*} matches {  -- Question
                 items cardinality matches {1..2; unordered} matches {
                   ELEMENT[at0.7] occurrences matches {0..1} matches {  -- Surgical procedure
                     value matches {
                       DV_CODED_TEXT[at0009] occurrences matches {0..1} matches {  --
                          defining_code matches {  [local::]  }
                       }
                     }
                   ELEMENT[at0003] occurrences matches {1..*} matches {*}  -- Answer
                   ELEMENT[at0005] occurrences matches {0..1} matches { -- Answer comment
                     value matches {
                       DV_TEXT[at0010] occurrences matches {0..1} matches {*}  --
                     }
                   }}}}}
           ELEMENT[at0006] occurrences matches {0..1} matches {  -- Summary
             value matches {
               DV_TEXT[at0008] occurrences matches {0..1} matches {*}  --
             }
           }}}}}
ontology
    terminologies_available = <...>
    term_definitions = <
        ["en"] = <
            items = <
                ["at0.7"] = <
                    text = <"Surgical procedure">
                    description = <"Name of surgical procedure">
                >
            …
            >>> …
    constraint_definitions = < >
    term_binding = < >
    constraint_binding = < >
```

Figure 1. Extract of the OpenEHR “check list surgical procedure” archetype

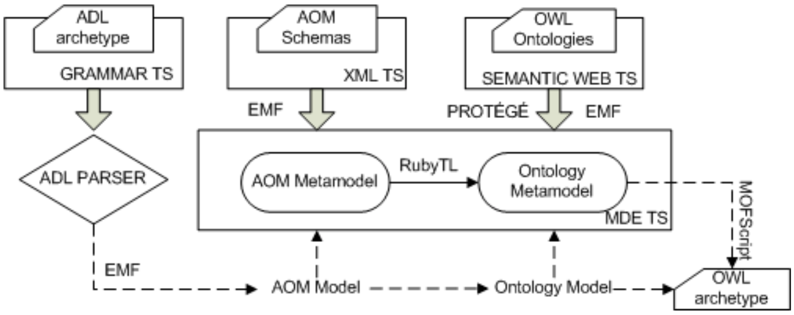

Figure 2. Architecture of the solution

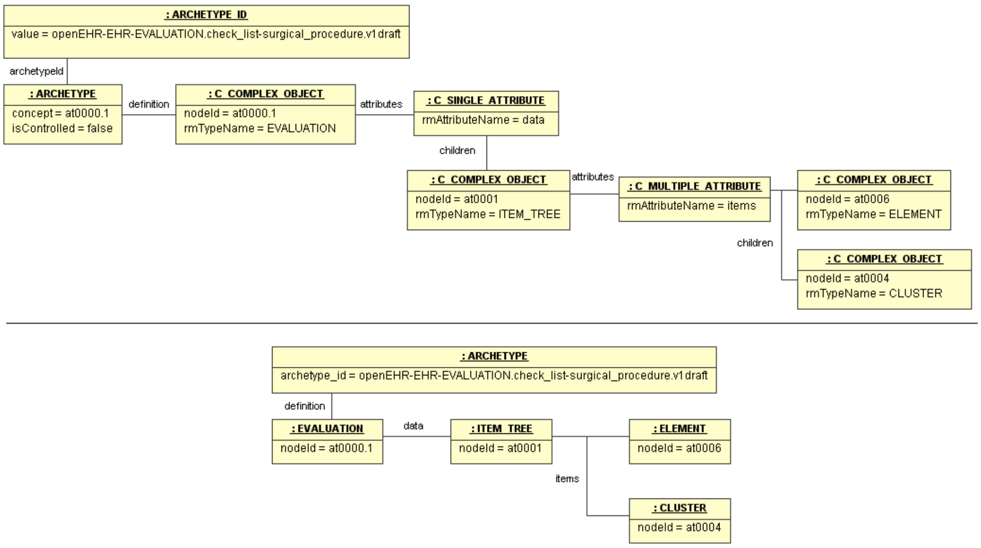

Figure 3. (Top) Fragment of the AOM representation of the “check list surgical procedure” archetype; (Bottom) Fragment of the semantic OpenEHR representation of the “check list surgical procedure” archetype

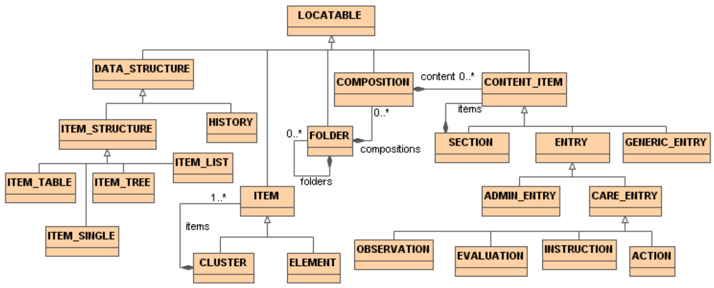

Figure 4. OpenEHR RM main data structures

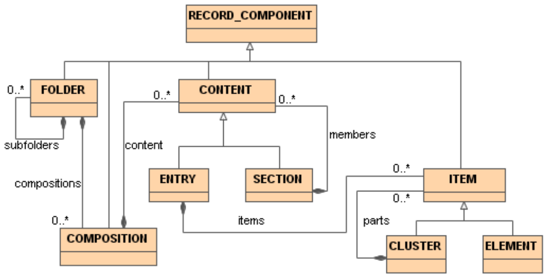

Figure 5. ISO 13606 RM main data structures

```
archetype (adl_version=1.4)
    CEN-EN13606-ENTRY.check_list-surgical_procedure.v1
...
definition
  ENTRY[at0000.1] matches {-- A check list about surgical procedures
    items matches {
      CLUSTER[at0001] matches {-- Tree
        parts cardinality matches {0..*; ordered; unique} matches {
          CLUSTER[at0004] occurrences matches {1..*} matches {-- Question group
            parts cardinality matches {0..*; ordered; unique} matches {
              CLUSTER[at0002] occurrences matches {1..*} matches {-- Question
                parts cardinality matches {1..2; ordered; unique} matches {
                  ELEMENT[at0.7] occurrences matches {0..1} matches {-- Surgical procedure
                    value matches {
                      CODED_TEXT[at0009] matches {
                        codedValue matches {
                          CD[at0007] occurrences matches {0..1} matches {
                            codeValue matches {*}
                            codingSchemeName matches {"local"}
                          }
                        }
                      }
                    }
                  }
                  ELEMENT[at0003] occurrences matches {1..*} matches {-- Answer
                    value matches {*}
                  }
                  ELEMENT[at0005] occurrences matches {0..1} matches {-- An answer comment
                    value matches {
                      SIMPLE_TEXT[at0008] matches {*}
                    }
                  }
                }
              }
            }
          }
          ELEMENT[at0006] occurrences matches {0..1} matches {-- Summary
            value matches {
              SIMPLE_TEXT[at0000] matches {*}
            }
          }
        }
      }
    }
```
Figure 6. Extract of the ISO 13606 representation for the archetype of section 2.1.1

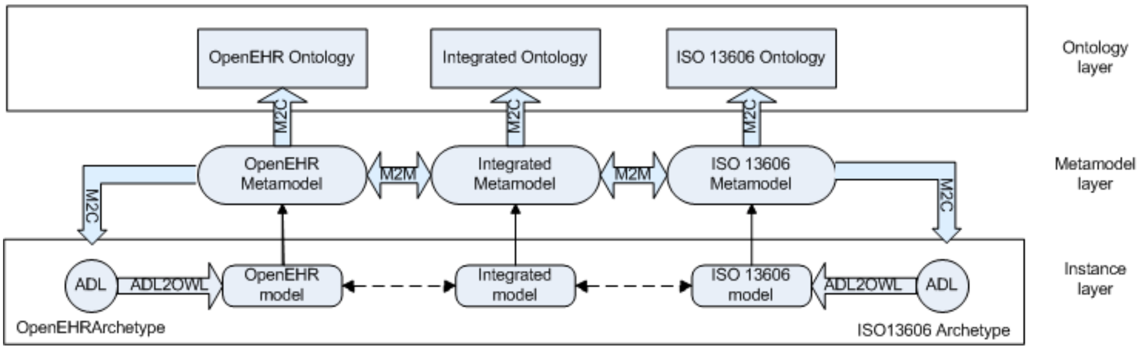

Figure 7. Architecture of the technological transformation process

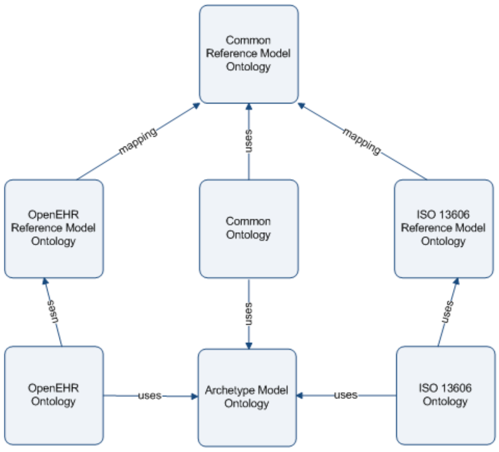

Figure 8. Ontologies relations map

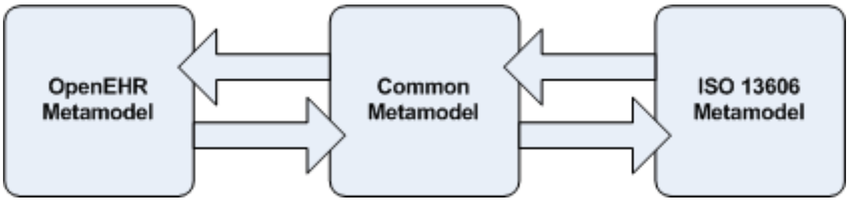

Figure 9. OpenEHR and ISO 13606 mappings definition

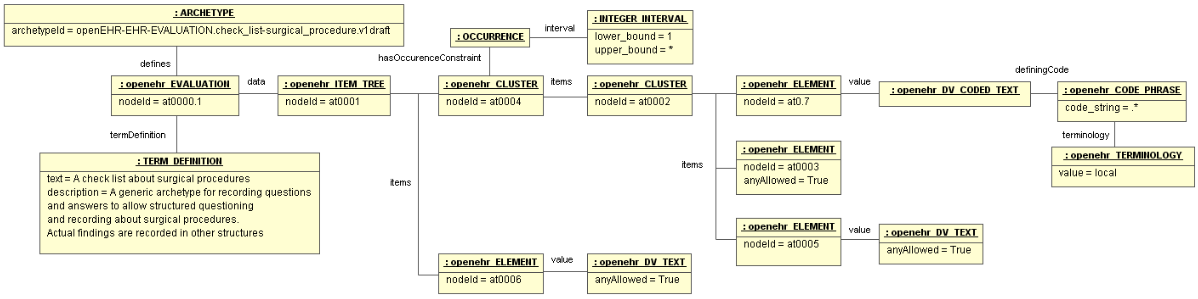

Figure 10. OpenEHR check list about surgical procedure archetype model

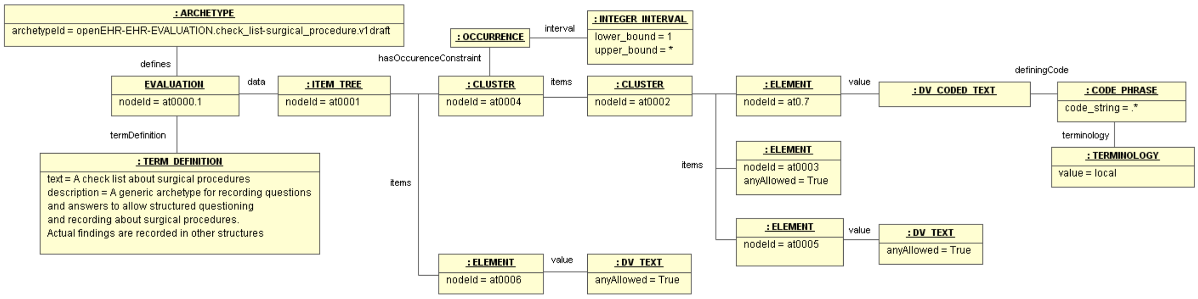

Figure 11.Common check list about surgical procedure archetype model

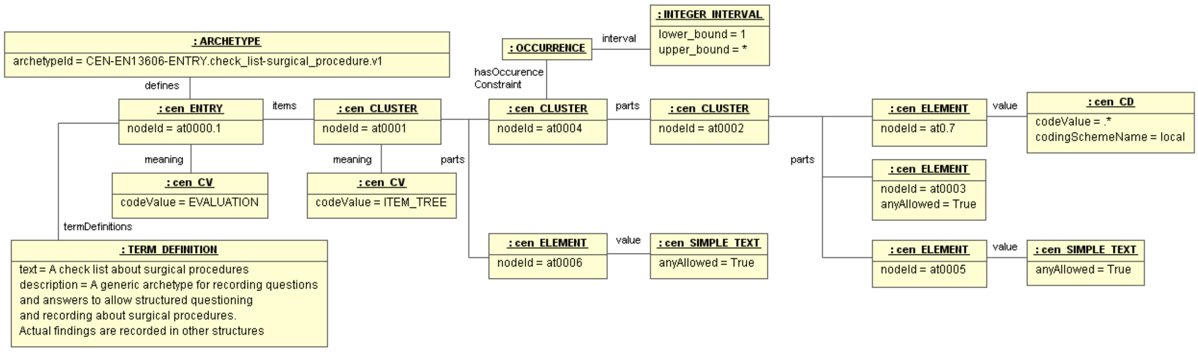

Figure 12. ISO 13606 check list about surgical procedure archetype model

Figure 13. Visual appearance of the tool

Table 1. Metrics of the ISO 13606 and OpenEHR ontologies

Ontology	Classes	Datatype properties	Object properties	Restrictions
ISO 13606-SP	68	16	92	227
ISO 13606-AR	122	76	142	462
OpenEHR-SP	87	14	156	302
OpenEHR-AR	144	75	210	524

Table 2. Metrics of the Common ontologies

Ontology	Classes	Datatype properties	Object properties	Restrictions
Common-SP	108	9	165	447
Common-AR	161	64	211	598