Semantic interoperability platform for Healthcare Information Exchange

Xavier Aimé, Lamine Traoré, Amina Chniti, Eric Sadou, David Ouagne, Jean Charlet, Marie-Christine Jaulent, Stefan Darmoni, Nicolas Griffon, Florence Amardeilh, et al.

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AIMÉ Xavier[a], TRAORE Lamine[a], CHNITI Amina[a], SADOU Eric[a], OUAGNE David[a], CHARLET Jean[a], JAULENT Marie-Christine[a], DARMONI Stefan[a,b], GRIFFON Nicolas[a,b], AMARDEILH Florence[c], BASCARANE Lydia[c], LEPAGE Eric[a,d], DANIEL Christel[a,d]

[a] *INSERM, U1142, LIMICS, 15 rue de l'école de médecine, F-75006, Paris, France ;*
Sorbonne Universités, UPMC Univ. Paris 06, UMR_S 1142, LIMICS, F-75006, Paris, France ;
Université Paris 13, Sorbonne Paris Cité, LIMICS, (UMR_S 1142), F-93430, Villetaneuse, France.
xavier.aime@inserm.fr ; {laminet,eric.sadou,david.ouagne}@gmail.com ; amina.chniti@yahoo.fr ; {jean.charlet,marie-christine.jaulent}@crc.jussieu.fr ;

[b] *Service d'informatique biomédicale & équipe CISMeF, CHU de Rouen, 1 rue de Germont, F-76031 Rouen Cedex, France.*
{stefan.darmoni,nicolas.griffon}@chu-rouen.fr

[c] *Mondeca, 35 boulevard de Strasbourg, F-75010 Paris, France.*
{florence.amardeilh,lydia.bascarane}@mondeca.com

[d] *CCS SI Patient - Hôpital Universitaire Henri-Mondor, Assistance Publique-Hôpitaux de Paris, France.*
{eric.lepage,christel.daniel}@sap.aphp.fr

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Abstract

Objectives: An important barrier to electronic healthcare information exchanges (HIE) is the lack of interoperability between information systems especially on the semantic level. In the scope of the ANR (*Agence Nationale pour la Recherche)* / TERSAN (*Terminology and Data Elements Repositories for Healthcare Interoperability*) project, we propose to set and use a semantic interoperability platform, based on semantic web technologies, in order to facilitate standardized healthcare information exchanges between heterogeneous Electronic Healthcare Records (EHRs) in different care settings.
Material and methods: The platform is a standard-based expressive and scalable semantic interoperability framework. It includes centrally managed Common Data Elements bounded to international/national reference terminologies such as ICD10, CCAM, SNOMED CT, ICD-O, LOINC and PathLex. It offers semantic services such as dynamic mappings between reference and local terminologies.
Results: A pilot implementation of semantic services was developed and evaluated within a HIE prototype in telepathology for remote expert advice. The semantic services developed for transcoding local terms into reference terms take into account the type of message and the exchange context defined within standard-based integration profiles.
Conclusion: The TERSAN platform is an innovative semantic interoperability framework that (1) provides standard-based semantic services applicable to any HIE infrastructure and (2) preserves the use of local terminologies and local models by end users (health professional's priority).

Conflict of interest: none.

1 Introduction

Health Information Exchanges (HIE) entail the ability for multiple care providers and stakeholders to appropriately, efficiently, and securely access patient's medical information. Electronic HIE initiatives have been undertaken across numerous health systems in a range of nations for improving efficiency and quality of care [1, 2]. System interoperability has been identified as a key challenge, critical to success. It is now well established that semantic interoperability relies on the adoption of interoperability standards (reference information models/templates and terminologies) that support information sharing among systems [3].

In other words, healthcare information (clinical facts, decisions, activities, workflows) need to be standardized in order to be interoperable and used by actors – humans and machines – in contexts different from the original one. Semantic interoperability permits the independence with respect to the geographical area (health facility, region, country, etc.) or the data processing context (care activities, research or public health) [4]. Despite efforts from Standards Development Organizations (SDOs) (*Health Level Seven International* (HL7), *Digital Imaging and Communications in Medicine* (DICOM) or *CEN Technical Committee 251* (CEN TC251)) and regardless of the international initiative of "Integrating the Healthcare Enterprise" (IHE), most clinical data in Electronic Healthcare Records (EHR) applications are still not natively interoperable.

Nevertheless, the emergence of operational solutions for semantic interoperability is hampered by the inability of EHR applications to conform to interoperability standards. These applications provide interfaces to health professionals in order to collect data in a way adapted to their use and incorporated with their daily practice but usually not conform to standards.

In order to collect healthcare information in an evolutionary manner taking into account local organizations and clinical characteristics, EHR applications are often based on clinical information models that are legacy systems, specific and locally implemented. Even when several care settings use the same commercial EHR application, there is very little sharing of common clinical information models between institutions. Finally, within the same institution, the principles of structuring and coding of clinical information and the level of granularity of information can also vary depending on the health profession (doctors, nurses, physiotherapists, social workers, etc.) and within these professions, depending on the specialty (cardiology, psychiatry, imaging, biology, etc.) or the activity mode (hospitalization, consultation, hospital medicine, general practice, home-hospital, outpatient care, etc.). EHR applications usually make an intensive use of interface terminologies. Rosenbloom *et al.* define *interface terminologies* as "a systematic collection of clinical phrases (terms) defined to facilitate the information entered by users in the Health Information System (HIS)" [5]. Interface terminologies are built for specific actors, they represent a solution of flexibility with respect to the problems of incompleteness and slow updating of reference terminologies.

Local practices for clinical documentation induce constraints for information sharing or exchange solutions between institutions. At the time of generation, clinical information is not readily interoperable, and semantic interoperability solutions are needed for communication and processing of this information beyond the perimeter where information was generated i.e. using reference terminologies.

The *reference terminologies* are defined by Rosenbloom *et al.* [5] as "terminologies designed to provide a complete and accurate representation of a given domain concepts, their relationships and which are optimized for classification and clinical research data." To enhance the communication along the continuum of care, the participating EHR applications will need to speak the same language either by adopting the same information models and

terminologies (which is not practical) or to efficiently use dynamic semantic mappings between of heterogeneous terminologies used by various participating applications.
Several tools are available to realize these mappings: ITM-Match (by Mondeca), PTS, TME, and ONAGUI. In some cases, the mappings are done using an Excel Worksheet.
The aim of the TERSAN (*Terminology and Repositories for Healthcare Interoperability*) project is to develop a standard-based expressive and scalable semantic interoperability framework in order to facilitate standardized healthcare information exchange between heterogeneous electronic healthcare records in different care settings. At first, the project focuses on exchanges of structured and coded healthcare information within standard-based integration profiles defined by IHE in the laboratory, radiology and anatomic pathology (AP) domains.
Our hypothesis is that semantic interoperability solutions developed in this project will enable the exchange of standardized healthcare information between health facilities while preserving and authorizing the use of local information models and terminologies within each care setting. Our specific objective is to validate the proposed approach by demonstrating the use of semantic resources and services within a prototype of HIE developed in the field of telepathology. This consists of specifying and implementing semantic interoperability services so that advice requests from pathologists from hospital A – with local principles for structuring and coding information – are effectively interpreted by a recipient in hospital B where pathologists use different principles. This paper is organized as follows. First, the semantic interoperability framework proposed by the TERSAN project is presented in section 1. In section 2, we exemplify the use of the semantic interoperability framework proposed by the TERSAN project in the context of telepathology. Then, section 3 presents the strengths, limitations and perspectives of the work.

2 Material and methods

Exchanging information collected from heterogeneous sources is a part of the more general problem of schemas mapping [6]. As part of the mediation approach [7], we are particularly interested in the data integration work guided by an ontology [8, 9, 10, 11], and in particular the approach of the type "global as view" in which an overall ontology is used as a source of mediation. In this case, each data source aligns its data to this pivot representation.
The TERSAN vision is that integrating EHR applications from different care settings requires a standard-based expressive and scalable semantic interoperability framework based on centrally managed Common Data Elements (CDEs) as part of the pivot representation and allowing dynamic mappings of semantics of varying data sources.
The TERSAN semantic interoperability framework provides tools and services for:

1. *authoring and maintaining shared semantic resources* (TERSAN reference semantic resources);
2. *supporting the authoring and maintenance of mappings* between reference terminologies and local interface terminologies;
3. *providing semantic services* to semantic-enabled application developers.

2.1 General architecture of the platform

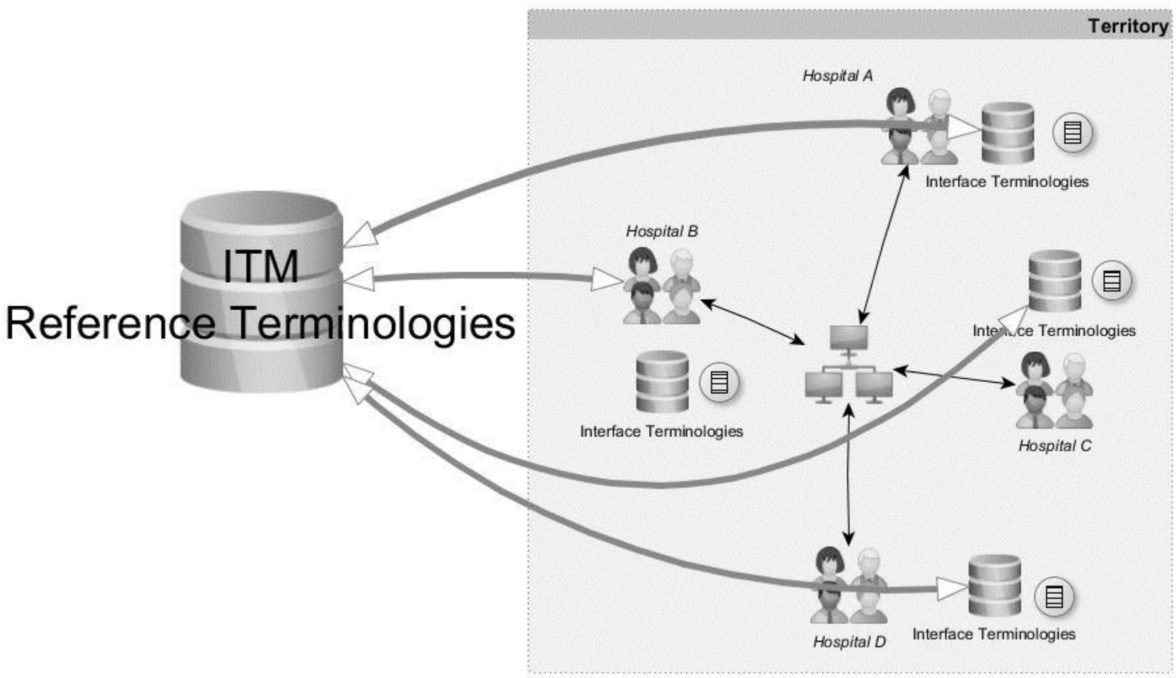

***Figure 1** – General architecture*

The TERSAN semantic interoperability platform is proposed as a component of an HIE infrastructure developed for an "Affinity Domain", as defined by IHE i.e. a group of healthcare enterprises that have agreed to work together using a common set of policies and share a common infrastructure.
Within the affinity domain, the semantic interoperability platform is based on a central server (ITM by Mondeca [12]), local servers located at each care setting and a set of semantic services.
The central server manages different versions of shared semantic resources (TERSAN reference semantic resources) and ensures the distribution of reference terminologies in the different local servers. Local servers manage local terminologies and their mappings with shared reference terminologies.

2.2 Semantic resources and services

The TERSAN semantic interoperability platform includes tools developed for managing a common standard-based healthcare information model used to mediate clinical information between different sources, called the "pivot model".

2.2.1 Reference information models and terminologies

Depending on the corresponding integration profile defined by IHE, different standards may be used for the different transactions between applications. Therefore, the TERSAN semantic interoperability platform was developed to manage the different models defined by the main healthcare standard development bodies. Among these standardization bodies, we distinguish:

- *organizations* such as *Health Level* Seven (HL7) [13], CEN TC251 [https://www.cen.eu], the *Association of Electrical Equipment and Medical Imaging Manufacturers* (NEMA) [14] that define information models of messages or documents;

- *entities* such as *World Health Organization* (WHO), *International Health Terminology Standards Development Organization* (IHTSDO), the Regenstrief Institute or IHE that define reference terminology systems (terminologies, coding systems or ontologies) such as:
  - *International Classification of Diseases* 10th edition (ICD-10),
  - *International Classification of Diseases for Oncology* (ICD-O),
  - *Anatomical Therapeutic Chemical* (ATC) Classification,
  - *Systematized Nomenclature of Medicine* (SNOMED CT),
  - *Logical Observation Identifiers Names and Codes* (LOINC)
  - *Anatomic Pathology Lexicon* (PathLex).

Hopefully, the different standard healthcare information models are based on common principles which are:

- several *modeling at multiple abstractions levels* with the ability to define specific patterns of usage context;
- a *common modeling* of data types based on ISO 21090:2011 ("Types of harmonized data interchangeability information" model standardizing the semantics of types of health data (e.g. physical quantity, encoded data associated to value sets of encoded values optionally sorted).
- several *rules* defining how to use the terminology systems (terminology, coding systems, ontologies, etc.) during the instantiation of these models – a property commonly referred to as the "terminology binding" [15]. The association between information and terminology model is specified in terms of "data elements" that make up the smallest piece of information in the standard models. ISO/IEC 11179-3:2013 standard "Metadata registries" is increasingly used in healthcare to share reusable unambiguous definitions of data elements referring to concepts of terminology systems.

The pivot representations developed in the TeRSan project refer to the different standard specified by the IHE integration profiles in the domains of laboratory, radiology and anatomic pathology (AP). For these three domains, different types of centrally managed data elements (observations, procedures, etc.) exchanged within HL7 CDA or HL7 v2 data structures need to be formally defined and encoded using reference terminologies such as ICD10, ICD-O, ATC, SNOMED CT, LOINC, and PathLex.

2.2.2 Mappings between reference and interface terminologies

Since healthcare information exchanges are based on standard-based transactions defined by IHE integration profiles, the problem of the mismatch of clinical information across different care settings within the HIE domain is reduced to the capacity of appropriately link the interface terminologies used in hospitals to the appropriate reference terminologies selected in the IHE integration profiles.

2.2.3 Semantic services

The semantic services developed in the TeRSan project rely on the functional specification of *Common Terminology Service* 2 (CTS 2). As part of the Healthcare Services Specification Project (HSSP) [16], a joint endeavor between HL7 and the Object Management Group (OMG) [17], CTS 2 service defines both the expected behaviors of a terminology service and a standardized method of accessing terminology content.

The semantic interoperability platform provides semantic services allowing semantic-enabled applications to query and use the TeRSan semantic resources. We extended the functional scope of CTS 2, so that in the TeRSan project, the accessed semantic content involves templates and data elements which are beyond the scope of CTS 2 covering only value sets, terminologies and mappings. Depending on the care settings, the semantic services used for the dynamic transcoding between interface terminologies and reference terminologies are available centrally or locally (within the care settings).

2.3 Evaluation context

In the TERSAN project, healthcare information exchanges between care settings (e.g. hospital A and B in figure 2) is based on standard-based IHE integration profiles that meet the need of the different scenarios of cross-enterprise exchange in the laboratory, radiology and anatomic pathology domains (subcontracting or telemedicine). To be interoperable, EHR applications in hospital A and B shall first be able to conform to the requested IHE integration profile. In other words, EHR application shall be able to retrieve the information to be exchanged and to structure it in accordance with the standard model of the IHE integration profile.

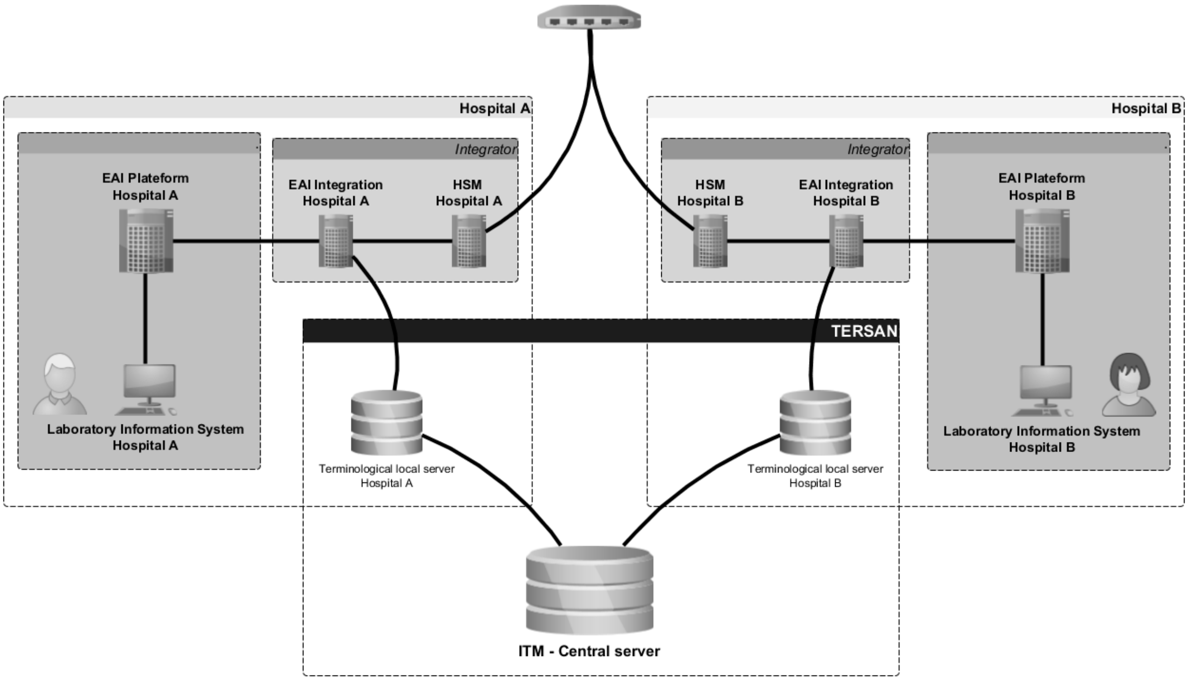

***Figure 2** – Use of TERSAN semantic interoperability services during healthcare information exchange between two care settings*

The TERSAN semantic interoperability platform was evaluated in the specific context of telepathology. Platform components and exchange flow (messages/documents) are shown in Figure 3.

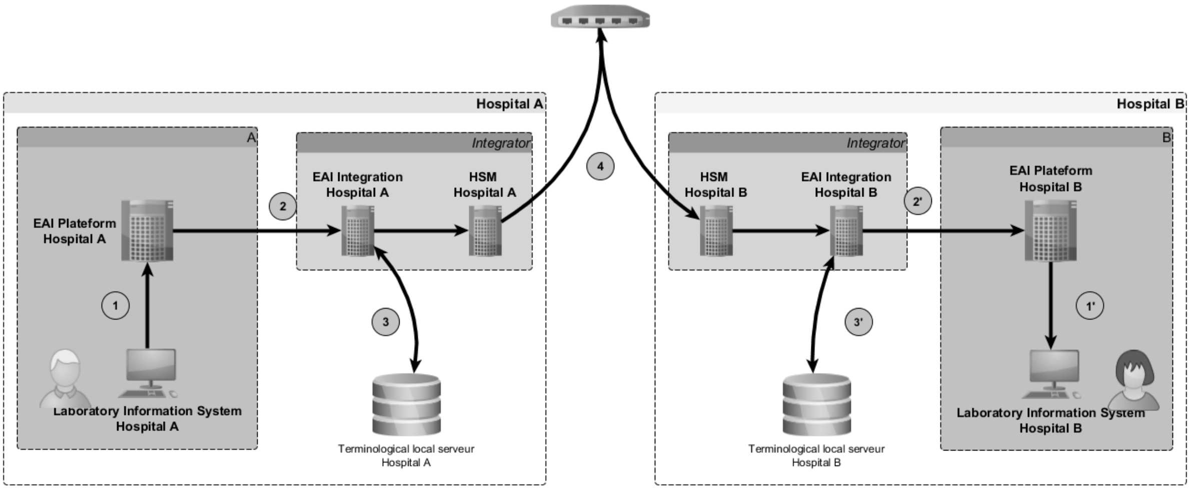

Figure 3 *– Components and exchange flow of messages and documents.*

When a pathologist requests an advice using a telepathology system, the process is composed of 4 steps:

1. **Message creation**: The pathologist of the applicant hospital (hospital A) enters in the laboratory information system (LIS) an expert advice request for an ongoing anatomic pathology exam. The LIS generates an HL7 message with the clinical information encoded in the local interface terminology.
2. **On site-message transcoding**: the semantic services available at the local server (hospital A) transcode local terms of the HL7 message into pivot reference terms.
3. **Exchange-message sending**: HL7 message is sent to the LIS of the recipient hospital (hospital B).
4. **Recipient site-message transcoding**: semantic services available at the local server (hospital B) transcode pivot terms into local terms.

3 Results

The TERSAN semantic interoperability platform provides a normalization pipeline supporting the EHR applications in different care settings to conform to standard-based integration profiles.

3.1 Semantic resources and services

TERSAN semantic interoperability framework supports the different actors in accomplishing their tasks for 1) the management of various semantic resources (templates, data elements, terminologies, mappings) shared within an Affinity Domain (AD) and 2) the alignment between local interface terminologies and shared reference terminologies.

3.1.1 Central server (ITM)

The central server (ITM by Mondeca / TERMAPP by INSERM) is used by:

- The *AD Semantic Resource Provider* – the actor (individuals or organization) responsible for the development of the AD semantic resources: templates, domain-or application-specific data elements and terminology value sets, terminologies (including external *resources provided by other organizations*). The AD Semantic Resource Provider uses ITM to validate the resources.
- The *AD Semantic Resource Administrator* for ensuring the availability and overall maintenance of the TERSAN semantic services (loading content into the server, and making available the required functionality to address the specific needs of users).

- The *AD Resource Author / Curator* to develop new resources – templates, domain-or application-specific data elements and terminology value sets, terminologies.
- The *AD Terminology Human Language Translator* to translate semantic resources
- The *AD Terminology Mapper* for validating and/or importing mappings provided by external providers (e.g. mappings between SNOMED CT/ICD-10) or for creating or maintaining mappings between reference terminologies.

AD Resource Authors / Curators use is an online collaborative editor enabling the edition of templates and data elements based on HL7 or CEN TC 251 healthcare information models that integrate ISO 21090:2011 data models. This editor implements a solution for unambiguously bind data elements to terminologies in a similar manner as described by Rector *et al.* (Code Binding Interface) [15] based on the model of ISO/IEC 11179-3:2013 standard ("Metadata registries (RM)"). Templates and data elements are created in SKOS format and stored into the ITM central server.

3.1.2 Mapping tools

Depending on the care settings, specific mapping tools are used centrally (ITM, by Mondeca) or locally (local server) by a Terminology Mapper for creating or maintaining mappings between interface and reference terminologies.

3.1.3 Semantic services

Semantic services are used by Semantic Enabled Application that makes explicit use of different types of semantic resources: templates, data elements, value sets, concepts.

3.2 Evaluation in the anatomic pathology domain

In our evaluation settings, the central server manages the different versions of data elements and reference terminologies used in telepathology. Local servers (A and B) manage local terminologies and their mappings with shared reference terminologies. In the example of an advice request in the context of telepathology, transcoding services enable care settings A and B to exchange standardized clinical information (coded in SNOMED CT) while continuing to use their local terminologies (*Association pour le Développement de l'Informatique en Cytologie et Anatomie Pathologique* (ADICAP) thesaurus and ICD-O).

3.2.1 Instantiation of the reference information model in anatomic pathology

The online collaborative editor was used to model the anatomic pathology advice request pivot model specified based on the HL7 model of the message used in the context of the subcontracting transaction between laboratories. HL7 messages are used to convey information in fields organized into segments. The fields of an HL7 subcontracting message contain information about the message itself, the patient, insurance elements involved in billing and the subcontracting request itself.

This HL7 model has been extended to fit the use case of the advice request in the telepathology context. The subcontracting request information consists of general information about the query, relevant clinical observations of its context, information related to the associated samples (specimen) and information related of previous relevant examinations application or observations in the context of the subcontracting request. A number of fields – mainly observations - of the message template are instantiated by information using interface terminologies.

We modeled the data elements corresponding to these fields. Each data element was associated with a medical concept from a reference terminology (PathLex, LOINC, and SNOMED CT) and its range of values was formalized based on the ISO 21090:2011 standard.

Regarding the coded data elements, each possible value of value domain (range) has been explicitly associated with a medical concept from a reference terminology in the field.
Table 1 provides the data structure of 4 observations – diagnostic hypothesis, clinical information (problem), current treatment and the result of a lab test (CA 15.3) – and instantiation examples using terminologies (local and reference) to encode the information.
Each *Data Element Attribute Code* of observations (OBX-3) is associated with *a medical concept* from a reference terminology domain (LOINC or SNOMED CT). Its domain values (*Attribute Value* (OBX -5)) was formalized based on the ISO standard 21090:2011. When the value of the observation is coded (*data type of the Attribute Value* (OBX-5), *Coded Element* (CE) or *Coded With Exception* (CWE)), each of the possible value domain has been explicitly associated with medical concept from a reference terminology of the domain (PathLex, LOINC, and SNOMED CT).

TABLE 1 – Specific comments (observations) of HL7 v2.5 message for advice request with used local and reference terminologies.

	Field HL7 v2.5	Information	Example	Local coding system	Pivot coding system
1	OBX-3	Observation *(Attribute Code)*	Diagnostic hypothesis (histological type)	Observation Interface Terminologies	SNOMED
	OBX-5	Value of the observation *(Attribute Value)*	Infiltrating ductal carcinoma of the breast	ADICAP or CIM-O	SNOMED or PathLex
2	OBX-3	Observation *(Attribute Code)*	Clinical information (problems)	Observation Interface Terminologies	SNOMED
	OBX-5	Value of the observation *(Attribute Value)*	Insulin dependent diabetes	Local Interface Terminologies ICD10	SNOMED, ICD10
3	OBX-3	Observation *(Attribute Code)*	Current treatment	Observation Interface Terminologies	SNOMED
	OBX-5	Value of the observation *(Attribute Value)*	Nolvadex	Local therapeutic booklet	ATC
4	OBX-3	Observation *(Attribute Code)*	CA 15.3	Interface Terminologies of Biological results	LOINC
	OBX-5	Value of the observation *(Attribute Value)*	40	-	-
	OBX-6	Unit	U/mL	Interface Terminologies of Local units	UCUM

3.2.2 Mapping of the local/reference terminologies in AP

At each partner hospital, HL7 message fields corresponding to clinical information encoded with local interface terminology were identified. Interface terminologies used in these identified fields were extracted, modeled according to the principles established under the project TERSAN and integrated to local servers. The mapping of interface terminologies with reference terminologies were identified or created. In the case of an expert advice request, the key information is the diagnostic hypotheses (assumptions) formulated as lesions by the applicant pathologist. In France, according to the anatomic pathology laboratory, local coding system used for encoding these lesions is either ADICAP (1930 topography codes and 1638 morphology codes) or ICD-O (264 topography codes and 1181 morphology codes). ADICAP / SNOMED CT and ICD-O /SNOMED CT mappings were performed.

3.2.3 Prototype demonstrating semantic services

The implemented prototype enables transmissions of expert advices requests between two different care settings). In this prototype, we mainly focused on the fields of "diagnostic hypothesis", "clinical information (problems)", "current medications" and "recent laboratory results" of an advice request. In our experimental context, if we consider the example of the information "diagnostic hypothesis", the field "diagnostic hypothesis" of the message sent by hospital A contains the value "*adénocarcinome canalaire infiltrant*" – that corresponds to ADICAP code ***A7A0*** at – the received advice request message will mention for the same field the value "*carcinome canalaire infiltrant*" that corresponds to the ICD-O code ***M8500/3***.

When sending the advice request, the exchanged information ***A7A0^adénocarcinome canalaire infiltrant^ADICAP*** is dynamically transcoded to ***82711006^infiltrating duct carcinoma^SNOMED CT***. During the reception, symmetrically, the exchanged information ***82711006^infiltrating duct carcinoma^SNOMED CT*** is dynamically transcoded into ***M8500/3^carcinome canalaire infiltrant^ CIM-O.***

The transcoding service involves:

- Applying rules for identifying, depending on the context, the terms of the message that need to be transcoded
- Triggering the appropriate service providing a code from the appropriate terminology reference for each of the interface code used in the message.
- Using only the exact match between concepts.

4 Discussion

Our contribution to HIS interoperability solutions consists in the proposed platform for the standardization of exchanged clinical information while respecting the "habits" of health professionals who continue to use their interface terminology as input terms and which is adapted to their daily practice.

In addition to the establishment of infrastructure sharing within the borders of exchange – beyond the scope of this article – with regard to semantic interoperability, our approach requires the establishment of *i)* a central server for sharing pivot models and reference terminologies, and *ii)* within each institution of the network, a local server to manage transcoding rules and terminology mapping between local interface terminologies and reference terminology.

The implemented prototype is based on an information pivot model and semantic services. The proposed approach is part of the implementation of web services that enable to enrich semantically standard transactions between EHRs in different care settings [18, 19]. In this context, the first contribution is to propose a method and a tool for modeling HL7 messages or documents incorporating models types of health data ISO 21090 and a solution of semantic annotation of these models based on the standard ISO/IEC 11179-3:2013 to define how to use the terminology systems (terminology, coding systems, ontologies, etc.) during instantiation of these models.

Ongoing work offers web services to transform clinical information represented by different standards or different versions of standards [18]. However, our approach aims at adapting these services to respect the use of local terminologies and models in exchanges of a standardized clinical information between healthcare institutions.

There are several attempts to build operational solutions to provide semantic interoperability services. BioPortal is a result of a research work lead by the National Center for Biomedical Ontology (NCBO) [20] and provides a centralized server for biomedical resources management and re-use (394 terminologies and ontologies) [21]. These resources can be queried through a SPARQL End-Point or a graphical user interface that helps users to find relevant resources, browse existing mappings between the resources, annotate biomedical documents with these resources and also find the most appropriate resources based on a document. There are two implementations of the CTS 2 functional specification done by Mayo Clinic and Phast [22]. The Standard Terminology Service (STS) developed by Phast provides a standard-based interface to access a set of international and national terminologies about several domains such as Medication, Laboratory, Anatomic Pathology, and STS also proposes mapping services between these terminologies, allowing transcodification. Compared to Bioportal and STS, the TerSan semantic services cover a broader scope since they provide a standard-based interface to access not only value sets, terminologies and mappings but also more complex semantic patterns such as data elements and templates. Accessing data elements and templates is a key functionality for the developers of semantic enabled applications.

The implemented prototype was used to validate the proposed approach in the specific context of sending an anatomic pathology advice request for expert opinion where the number and type of transcoded clinical information (diagnostic hypotheses, problems and ongoing treatment) is limited.

On the methodological level, we aim at the generalization of the approach and at greater flexibility. Practically, we will implement transcoding rules that enable the identification of the information requiring transcoding in the course of message exchanges.

On the application level, we will extend the functional scope of the prototype in order to allow the transmission of responses to advice requests. In addition, we also have to formalize the links between exchanged clinical information and the related anatomic pathology images, within the proposed models of advice requests and responses.

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