

Interoperability of electronic health records using Semantic Knowledge Graphs. A use case applied at the UTPL University Hospital

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Abstract — Patient medical information is diverse, extensive and of high value in supporting informed medical decision-making. This information is highly complex, is distributed among different systems, presents high heterogeneity, is stored in different formats, and has different structuring levels. The management of this information poses interoperability challenges in tasks related to data integration and reuse. In this paper, an alternative is presented to face these challenges using semantic technologies. We propose to transform this heterogeneous, distributed, and unstructured information in a way that ensures high interoperability, reuse, and direct processing by machine agents. The pilot of this proposal was developed at the UTPL Hospital.

Keywords — *data integration, knowledge graphs, semantic web, semantic interoperability, electronic health records.*

I. INTRODUCTION

The national health ecosystems encompass public and private medical care systems, individuals, organizations, technologies, protocols, and processes involved in the management of different forms of information on patients' health. Each technology of the health system has specific information management languages and standards. These specific capabilities hinder the connection of the systems that intend to integrate, share, exchange, and access to all the forms of health information. This information includes clinical notes, surgical descriptions, medical examinations, complementary laboratory studies, diagnostic imaging, pharmacological prescriptions, billing data, insurance information, social and cultural information of the patient, and multimedia, among others.

These environments are home to many disparate systems, and few are interconnected or automatically exchange information between each other. For example, for a doctor to have a complete view of the medical history of a patient, they will have to be authorized and login in several systems to see the previous procedures, the x-rays, the medical prescriptions, and the laboratory results. The information is often duplicated, ambiguous or incomplete, which impairs patient care.

In view of the lack of standardization and of architectures that enable integration and interoperability, different ecosystems are experimenting and implementing strategies to connect their systems. The use of electronic medical records based on universal standards is encouraged, with programs exerting pressure towards a generalized adoption that improves information integration and the interoperability of the health systems.

The objective of interoperability is to eliminate the information silos across the health data sources, as well as to connect the systems that are related to the patients' outcomes. In a general manner, the main types of architectures that are used to coordinate the exchange of medical care data are the following: centralized architectures - the patient's data are stored and managed in a central database with full control over the information; decentralized architectures - the databases are interconnected but are independent and the information exchanges are specific; and the hybrid architectures[1].

Interoperability allows that the medical care systems work together, which ultimately leads to better provision of medical care and to better outcomes for the patients. By means of interoperability, the efficiency of the processes is enhanced because paperwork can be replaced by digital tools that reduce the opportunity cost of time and resources. By using privacy and security measures, the patient' medical records and other confidential information can be safeguarded.

In Ecuador, the Public Health Ministry (*Ministerio de Salud Pública*, MSP), by means of the IS4H (Information System for Health) projects promoted by the Pan American Health Organization, works towards strengthening the health information systems through the implementation of electronic clinical documents and interoperability standards, enabling greater capability in the management of the medical information generated in the Public and Complementary Health Network (for-profit and non-for-profit private health providers), with the aim of consolidating the National Electronic Clinical History project. Currently, the MSP has implemented the Electronic Clinical History System in more than 1,500 operational units, recording around 15 million service appointments [2]. On the other hand, the institutions from the complementary network, as is the case of the UTPL Hospital (*Hospital UTPL*, HUTPL), have trademark systems for the management of electronic clinical histories.

Due to the heterogeneity present in the storage formats, standards and structuring level of the data, the health management systems are complex and expensive in tasks related to information integration and exchange. This complexity imposes challenges in process automation and in decision-making. Further, diversity of electronic medical record systems in health institutions warrants a strategy to exchange information without having to resort to a unified national system, but to the use of semantic web technologies. The objective of this work is to contribute to the interoperability efforts of medical data in our region through an architecture for the semantic transformation of information

related to electronic medical records. Specifically, our work focuses on improving the ability to exchange data and meanings of electronic medical records, using the Semantic Knowledge Graphics approach. Therefore, an architecture for the semantic transformation of medical data is proposed and a case study was developed to pilot this architecture. The pilot was developed from electronic medical records managed by a private hospital that is part of the Complementary Health Network of Ecuador.

This article includes a related works section, where semantic techniques and resources (controlled vocabularies, thesaurus, and ontologies of biomedical concepts) used in medical information projects were reviewed, as well as approximations based on medical standards, the Semantic Web [3], Linked Data and Semantic Knowledge Graphs. In the Proposed Architecture section, the extraction, cleaning, anonymization, semantic modeling, transformation, linking and publication of medical data cycle is described; as an important aspect, we must mention the identification of classes, relationships and properties based on the Unique Clinical History Forms[4], which are the standard at the national level for recording clinical information. An ontology was created, in which concepts, properties, relationships and restrictions were coded; and the classes, entities and properties were mapped to SNOMED CT and ICD 10 terminologies. A transformation process is defined, for the transformation process, the information conversion process to RDF was performed, observing the design guides of the linked data (URIs, HTTP, RDFx/SPARQL and linked). Below we report a case study in the outside consultation service of the HUTPL in Ecuador. Finally, the results obtained are discussed, and conclusions and future papers are reported.

II. RELATED PAPERS

This section analyzes the scientific literature related to the semantic description of medical data, as well as the current ways to improve the capability of exchanging data and meanings across heterogeneous systems. Semantic interoperability improves the capability of exchanging information related to the medical care provided to the patients. Attaining semantic interoperability in medical information is a challenge.

In [5] present below a partial selection of implementations of interoperability standards gathered from different countries, such as French, United Kingdom, United States of America, The Netherlands, Australia, and Turkey. These countries have implemented HL7-CDA R2, LOINC, SNOMED CT, HL7 FHIR, among others. In order to improved interoperability in their national health systems.

In Ecuador, in ministerial agreement 1190, the Ministry of Public Health approves the use of the Health Level Seven (HL7) standard and ISO / TC 215[6]. TC 215 is the technical committee that works on the standardization of Information Technologies and Communications in Health (ICT), to allow compatibility and interoperability between independent systems. Among the standards that the TC 215 working groups have delivered, is the ISO 13606 standard, Health Informatics. Then again, the Ecuadorian Institute for Standardization (INEN), the body in charge of the analysis and adoption of quality standards in the country. By ministerial agreement 1190, it has carried out the analysis and adoption of parts 1 and 5 of the international standard ISO

13606. In order to the country's health institutions to have a standard that regulates the communication of information generated in electronic health records.

A proposal made by [7], [8], [9] to promote semantic interoperability in electronic health records presents the most used health standards, such as openEHR, HL7, DICOM, and EN13606. On the other hand, they define the challenges implied in attaining semantic interoperability in electronic health records, first due to the excessive number of existing pieces of information, to the different standards used in information storage, and to their reduced structuring. The authors propose the use of diffuse ontologies, along with the use of medical terminologies as a way to solve these challenges and attain interoperability in health information systems and, as future work, they mention applying their proposal on real data in a hospital.

In the [10] paper, a model for the conversion of clinical information to RDF is described; the use case is applied to information of patients with dengue. The Text2Ontology framework is used to extract text relationships, with a limited capacity. In addition, the TypedDependency algorithm based on the analysis of typified dependency is used to extract RDF data from the of the patients' case sheets and for their later conversion in RDF models. A semantification approach was also designed to map the clinical data extracted from the patients' reports to their corresponding triplets, for their later conversion to RDF.

On the other hand, [11] presents a semantic transformation approach with three steps: 1) transformation of medical data from heterogeneous sources to RDF, 2) application of semantic conversion rules to obtain data as instances for the CDM (Common Data Models) ontological model, and 3) population of the repositories, which meet the CDM specifications, by means of processing the RDF instances generated in step 2. The proposed approach has been applied in real health care environments where the Observational Medical Outcomes Partnership (OMOP) has been chosen as the common data model.

Other work related to the use of semantic web technology is [12]. This research paper proposes an interoperability solution for the tuberculosis treatment and follow-up scenario in Brazil supported by an ontology. Like a result an interoperability layer was developed to retrieve data with the same meaning and in a structured way enabling semantic and functional interoperability. Thus, health professionals could use the data gathered from several data sources to enhance the effectiveness of their actions and decisions. On the other hand, in [13], a mechanism is proposed to build ontologies of healthcare data, which are subsequently stored in a triplestore. Subsequently, for each built ontology, the syntactic and semantic similarities with the different HL7 FHIR Resources ontologies are calculated, based on their Levenshtein distance and their semantic fingerprints accordingly. That work concluded, that according to the mechanism's evaluation results, it is almost impossible to create syntactic or semantic patterns for understanding the nature of a healthcare dataset. Therefore, further work should be done in evaluating the developed mechanism, comparing it with similar ontology matching mechanisms and medical data of multiple nature.

Finally, in [14],[15],[16],[17],[18], and [19] show the use of knowledge graphs to improve queries of complex medical

information. To identify hidden and unknown relationships between patients and treatment outcomes, or drugs and allergic reactions for given individuals. To create knowledge graphs to identify specialized classes for tumor diagnosis or improve biomedical relationship extraction tasks. Additionally, frameworks to provide a secure and semantic approach to facilitate secure data sharing among healthcare organizations.

The future roadmap for semantic interoperability in healthcare systems is highly promising. The efforts of several of the papers reviewed focus on the creation of standards, class identification mechanisms, certification, and security. This paper presents an application case to model the clinical data stored in the electronic clinical records as Semantic Knowledge Graphs, by using the Semantic Web view and the Linked Data technologies.

III. BACKGROUND AND MATERIALS

A. Approach overview

In general, the patients receive care from a series of clinics, independent medical offices, and hospitals. These individual interactions constitute the totality of their medical history. This history documents past symptoms, procedures applied, vaccines, vital signs along time, medical examinations, allergies, and complications, among others. Not having access to all those data points due to lack of integration is dangerous as maximum, and at least extremely inconvenient for the patient.

The main benefit of interoperability is total visibility and access to the patient's data, both for the health institution and

for the patient. In this sense, the general model of this work has focused on the integration of the various sources of information generated from the different clinical areas. This information should be processed through extraction, anonymization, and cleaning tasks. Then to be mapped to EHR standards, terminologies, as well as with ontological and non-ontological resources.

In Fig. 1, the EHR component describes patient information that is collected through different health systems. In the context of Ecuador, the Public Health Ministry of Ecuador has established the use of the Unique Clinical History forms as the national standard. We have used these forms as a base for the identification of the concepts and relationships of the outside consultation service that we intend to model. Most of the data in the electronic health records systems are not normalized under standards; the systems present interfaces for free text digitalization, where the health professionals describe the information briefly or with acronyms, lacking the necessary attributes to be quality data. This hinders text processing and information understanding by machine agents. Together with techniques such as natural language processing and ontologies, the UMLS (SNOMED CT - Systematized Nomenclature of Medicine - Clinical Terms, ICD-10 - International Classification of Diseases, etc.) thesaurus or terminologies help to identify the meaning and the relationships existing between the entities of an electronic health record, as can be seen in Fig. 1. Therefore, it is necessary to apply strategies that facilitate information management.

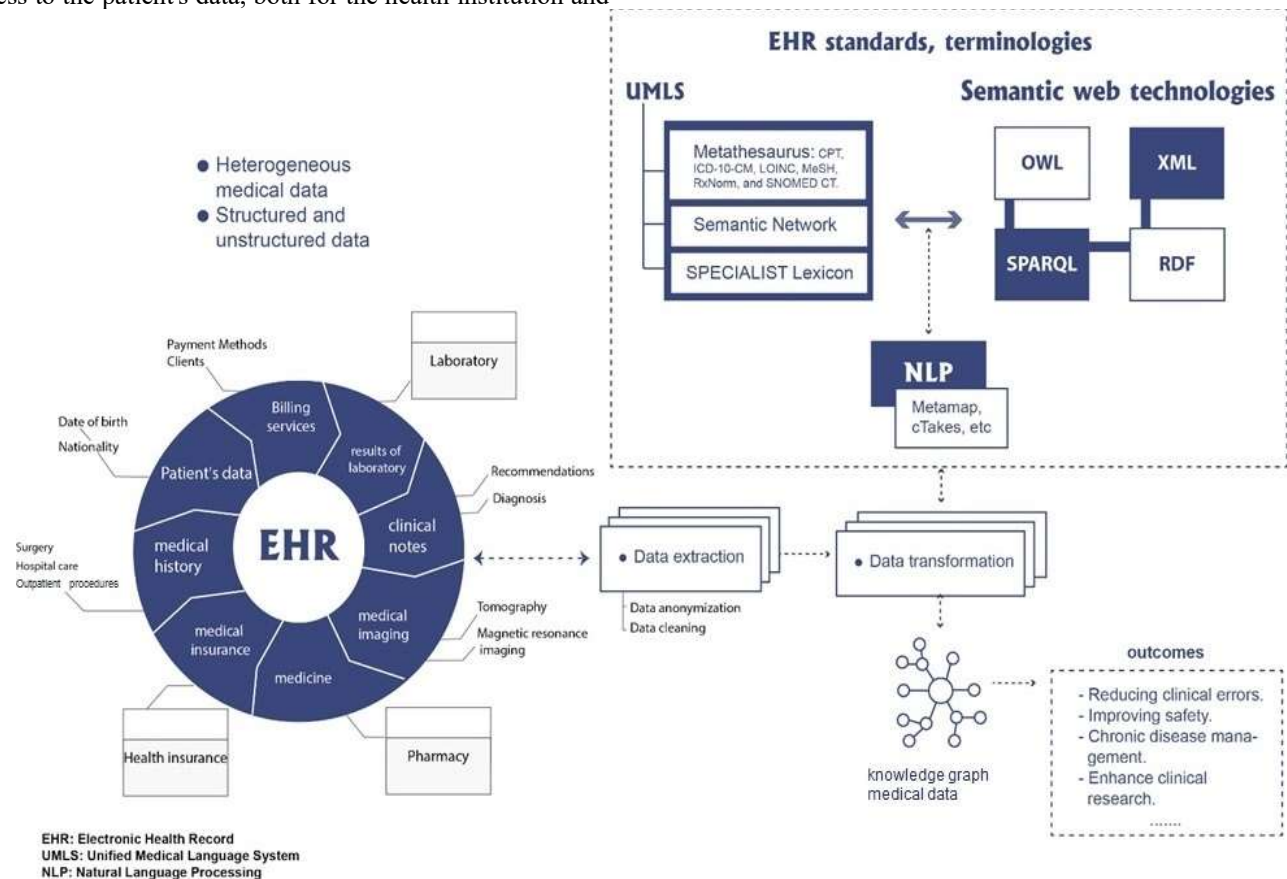


Fig. 1. Overview of the proposal. The scope of the information sources is the UTPL Hospital.

The information extracted and mapped with ontological resources must then be transformed into a medical information knowledge graph. The resulting semantic knowledge graph has the potential to be used in actions focused on improving the semantic exchange of electronic medical records, reducing clinical errors, improving safety, chronic disease management, enhance clinical research, see Fig. 1.

B. Interoperability standards

Among the main standards that include reference models, clinical data structure definitions, message exchange, are ISO 13606, openEHR, HL7 FHIR, the objective of these standards is to support the representation of clinical information. One of the most popular interoperability standards to join heterogeneous systems and implement applications for interoperability and health information exchange is FHIR, or Fast Healthcare Interoperability Resource. FHIR provides the specification required by the systems to exchange data. The standard is proposed by Health Level Seven International (HL7)[20], a non-for-profit standard development organization accredited by ANSI devoted to providing a comprehensive framework, as well as standards related to the exchange, integration, and recovery of electronic health information.

OpenEHR is a health informatics standard, consisting of open specifications, clinical models and software that can be used to create standards and create information and interoperability solutions for healthcare[21].

ISO 13606 is an International Organization for Standardization (ISO) standard, originally designed by the European Committee for Standardization (CEN). This standard defines a rigorous and stable information architecture for communicating part or all of a patient's electronic health record (EHR) between EHR systems, or between EHR systems and a centralized EHR data repository system[22].

An important work in relation to promoting the creation of interoperable medical systems is Unified Medical Language System (UMLS), a set of files and software that gathers health and biomedical vocabularies (CPT, ICD-10, MeSH, SNOMED CT, DSM-IV, LOINC) and standards. UMLS integrates and distributes key terminology, classification and coding standards, and associated resources to promote the creation of more effective and interoperable biomedical information systems and services, including electronic medical records, classification tools, dictionaries, and language translators[23].

The Semantic Web[3] is one of the current paradigms that improve interoperability and data structuring in the Web. The Semantic Web is a Web extension that adds semantics to the

current format of data representation. The semantic web technologies are driven by W3C (World Wide Web Consortium). These technologies allow for the global identification of information resources, for the creation of knowledge items in the Web, for the creation of vocabularies, and for writing rules to handle the data through RDF (Resource Description Framework) and SPARQL[24]. Linked data refers to the application of best practices in order to publish and connect the information[25] so as to improve interoperability in the systems[26].

Among the different ways to represent knowledge in the Semantic Web are the ontologies and the vocabularies. They are used with the objective of attributing sense and meaning to the content of the documents, serving as a tool for knowledge representation, for example, OWL (Web Ontology Language), RDFS (Resource Description Framework Schema) and SKOS (Simple Knowledge Organization System)[24].

In [27], an ontology is defined as a common, sharable and reusable view of a specific domain. Therefore, ontologies can be used to construct semantic representations of the domain knowledge so that they can be interpreted by machine agents, which will allow them to make inferences on assertions in a specific domain model. In addition, ontologies accelerate the implementation of interoperability due to the availability of robust tools and technological frameworks that promote information reuse[28].

IV. PROPOSED ARCHITECTURE

The overall medical data transformation moves through a life cycle, as depicted in Figure 2. Through the six phases, we explore how established best practices can be used to transform medical data into a graph of semantic knowledge. The stages in life cycle are: 1) Visioning process - developing a requirements specification by identifying the intended purpose and scope; 2) Selection of data sources - the phase analyzes and specifies the internal and external data sources to perform the data transformation; 3) Ontology development, the phase includes the process of acquisition of medical knowledge and re-using related resources from which the ontology will be built. 4) RDF generation and publication, including data cleansing, disambiguation, anonymization, transformation, linked and publication; 5) RDF Exploitation, the phase covers the production of end-user interfaces that provides discovery and enhanced navigation. 6) Continual improvement is the ongoing improvement of the data or processes through incremental improvements.

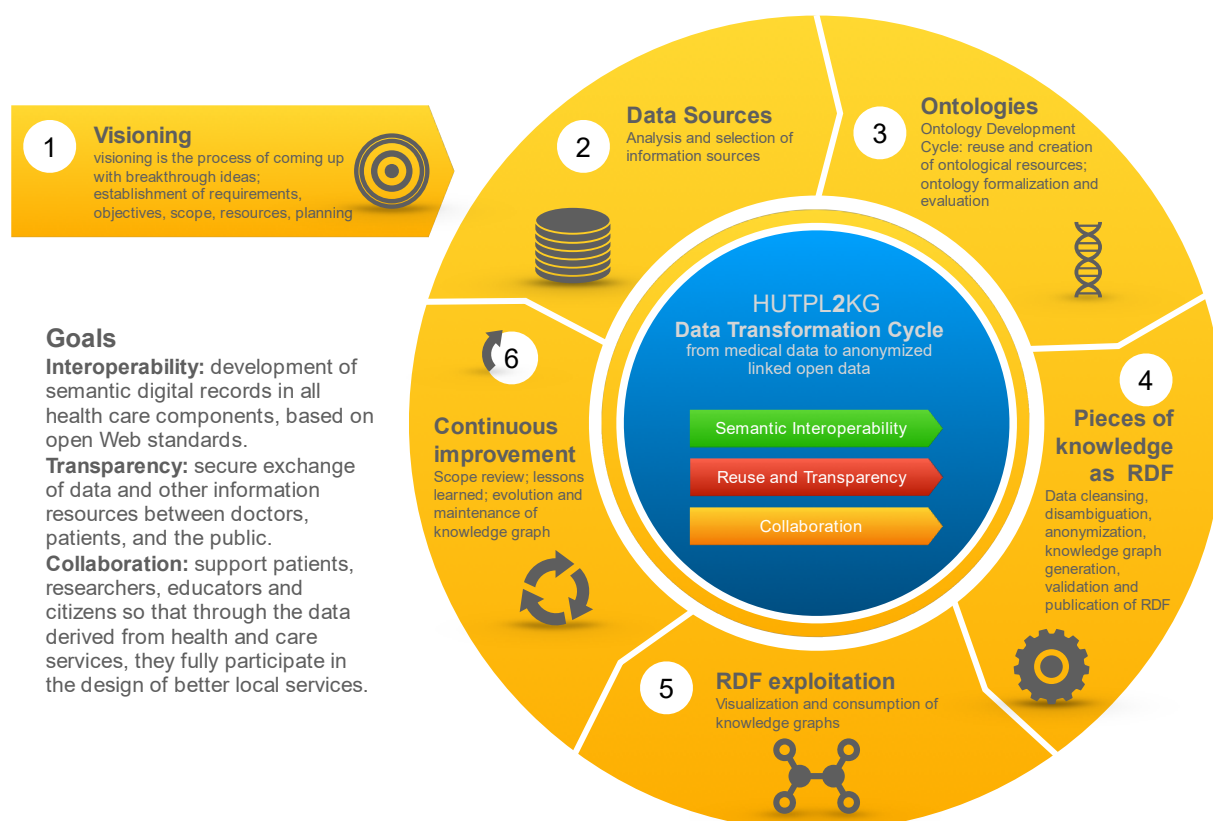


Fig. 2. Data Transformation Cycle

A. Analysis of the data sources

The purpose of this phase is the verification and selection of the various sources of information in which a health medical record is stored, such as structured and unstructured data, documents, videos, among others.

The modeled clinical information was obtained from the database of electronic health records maintained by the UTPH Hospital. The tables involved correspond to information of patients, medical staff, medical specialties, record of personal and family history, record of vital signs, record of visits in outside consultation, orders for complementary tests such as laboratory tests, diagnostic imaging, and drug prescription.

B. Personal data and legislation

Ecuador recognizes the protection of personal data as a fundamental right, based on its Constitution, as well as on international human rights treaties that protect privacy, but it lacks an internal legal structure to guarantee such protection, which leaves patients defenseless. Ecuador is one of the few countries in Latin America that does not have a Personal Data Protection Law, while other countries in the region have done so for more than 20 years or have recently approved it [29]. However, Ministry of Public Health (MSP) of Ecuador supports its action in the health legislation and the principles contained in the Constitution in order to protect the privacy of

personal data. On September 19, 2019, the President of the Republic of Ecuador submitted to the National Assembly the Draft Organic Law on Personal Data Protection. This law is still under discussion in the assembly. Once this norm is approved, it will guarantee security in the handling of Ecuadorians' information. In addition, it will make it easier for health institutions to create robust regulations that facilitate access to information without risking the privacy of their patients.

In the context of this work, the data that are part of the scope of the case study were anonymized. According to the legal framework in force in Ecuador, there is a prohibition to disclose medical information without the express authorization of its owner, because it contravenes the right to confidentiality and protection of personal data of Ecuadorians. The following legislation has been considered in this case study: The Constitution of the Ecuadorian State, in its Art. 66¹, numeral 19, establishes as a citizen's right "to protection of personal information, including access to and decision about information and data of this nature, as well as its corresponding protection. The gathering, filing, processing, distribution or dissemination of these data or information shall require authorization from the holder or a court order.". Art. 7 of the Organic Health Law² states that every person has the right to have a "single clinical history written in precise,

¹ Constitution of the Republic of Ecuador (2008), see https://www.asambleanacional.gob.ec/es/noticia/constitucion_de_la_republica_del_ecuador_version_en_ingles

²Organic Health Act of Ecuador (Ley Orgánica de Salud - 2006), see <https://www.salud.gob.ec/wp-content/uploads/2017/03/LEY-ORG%C3%81NICA-DE-SALUD4.pdf>

understandable and complete terms; as well as confidentiality with respect to the information contained therein...". Art. 4 of the Ecuadorian Law of Protection of the rights of patients³, states that: "Every patient has the right to have the consultation, examination, diagnosis, discussion, treatment and any type of information related to the medical procedure to be applied to him/her, have the character of confidentiality". Art. 6 of the Law of The National System of Public Data Registry⁴ declares confidential personal data, such as state of health, and other data related to personal privacy. Access to this data will only be possible with the express authorization of the owner of the information, by law or by court order.

C. Data anonymization

Differences exist between nations in the definitions, approaches, and legal practices about de-identification or anonymization[30]. Data holders can mitigate patient privacy risk through data reduction techniques. Anonymization is a data processing technique that eliminates or modifies personal identification information; its result is anonymous data that cannot be associated with any person. In this way, patient privacy is improved, and the risk of data breaches and cyberattacks is reduced. It is also a critical component of the commitment inherent to the HUTPL and of the scope of this paper regarding privacy.

By ensuring anonymous data, safe and valuable semantic features will be available, all while safeguarding the users' identities. We can also share anonymous data externally in a safe manner, making them useful for others without compromising patient privacy.

The recommendations proposed in [31] are that data holders generate de-identified datasets by masking or generalizing direct and some indirect identifiers. Additionally, access control and the use of appropriate security levels to transfer data or providing access; one solution is the use of a secure "locked box" system.

D. Reuse of ontological resources

Attaining the integration of computerized health systems depends on an interoperability base semantically rich in systems, processes, and information. The interoperability standards and the use of ontologies related to medical care

can facilitate access to information, by increasing the accuracy of the searches for information which would otherwise present problems like polysemy, ambiguity and synonyms that increase and diffuse the results. Through the state-of-the-art, ontological, and non-ontological resources related to Health Care and Life Sciences have been detected.

Among the ontologies that we have used to model the information is the SNOMED CT multilingual taxonomy, which includes more than 300,000 concepts of clinical terms divided into 19 categories and with support in five languages[32]. The concepts and relationships of this taxonomy are available for download, as well as the OWL SNOMED CT guide, which includes detailed information on the structure, content and use of OWL reference sets[33].

The ICD 10 international classification of diseases was also used for the representation of the medical diagnoses. These classifications are part of the set of UMLS files and software[34].

Another ontological resource used is the Anatomical Therapeutic Chemical Classification (ATC) ontology[35], which allows for the classification of drug active components according to the organ or system on which they act and to their therapeutic, pharmacological, and chemical properties. Ecuador has adopted this international classification to elaborate the National Chart of Basic Medications, which is the regulation in effect in the pharmacological scope in the country[36].

These ontologies add context to the patient's medical history documents, and automatically create links between the concepts, terms, medications, diagnoses and procedures, laboratory tests and exams. As a result, the queries are more effective, and the results are closer to the search terms.

E. Creation of the ontology

The ontology has been developed in Protégé and covers the domain of the electronic clinical documents of the outside consultation area. The definition of classes, relationships and properties is based on the Unique Clinical History forms established by the MSP. A partial view of the ontology can be seen in Fig. 3.

³ Ecuadorian Law of Protection of the rights of patients, see <https://www.salud.gob.ec/wp-content/uploads/downloads/2014/09/Normativa-Ley-de-Derechos-y-Amparo-del-Paciente.pdf>

⁴Law of The National System of Public Data Registry (2010), see <https://www.global-regulation.com/translation/ecuador/3350052/law-of-the-national-system-of-public-data-registry.html>

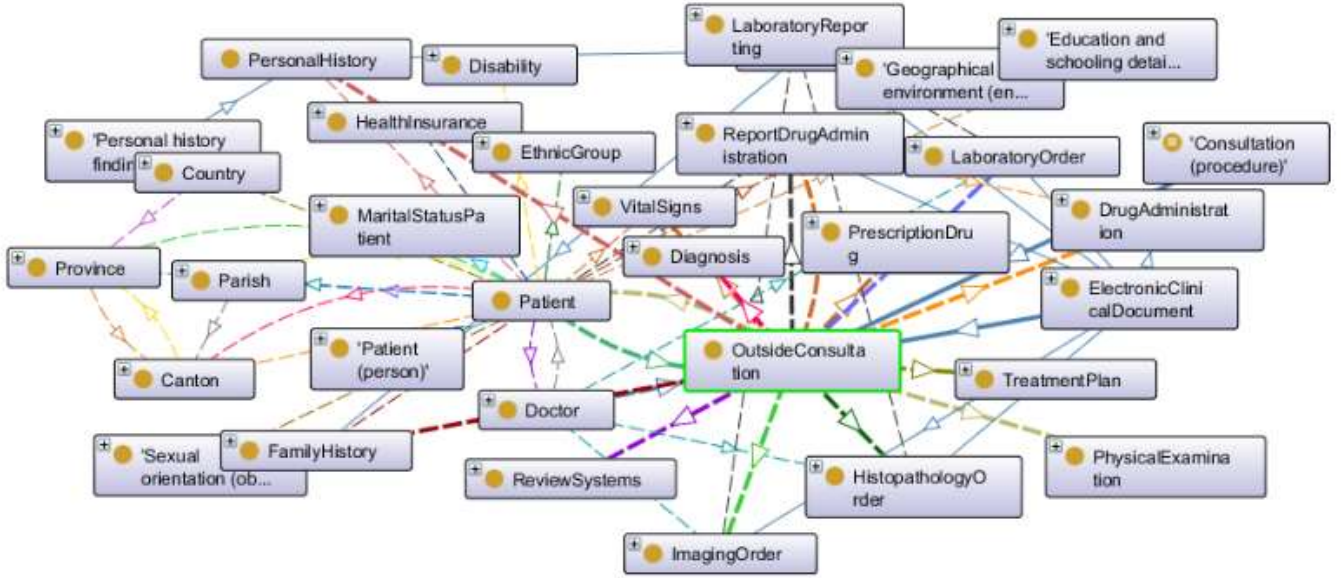


Fig. 3. Partial snapshot of the external consultation ontology.

F. Data mapping and ontology

In this part, the work consisted in mapping some classes of the electronic health records system with the existing ontologies (OWL Snomed CT, ICD10CM, ATC).

The SNOMED CT version of February 2020 was downloaded from the official site of the National Library of Medicine[37]. In order to transform the taxonomy concepts to OWL, the Snomed OWL Toolkit[38] was used, which is an open code kit that is used in SNOMED's international audit environment. The transformation can be performed through the command line or by implementing an API (Application Programming Interface) in Java[39].

G. Data cleaning and conversion to RDF

For the extraction of information from the electronic health records system, views in SQL were created. The identification information corresponding to patients and doctors was anonymized through an MD5 hash function of the database. The process performed in this stage is described in detail in the following section.

V. APPLICATION CASE: UTPL HOSPITAL

The system for the electronic management of the medical records maintained by the HUTPL allows obtaining information required by the State health bodies, such as the MSP, through the Unique Clinical History forms. With the current computerized system, the doctors working in the HUTPL must assume the daily task of typing all the medical information into the electronic clinical history system. This hinders the processing of the content stored as free text, added to the fact that it is not possible that both data and meanings are directly understood by the machine agents.

The motivation of the present paper lies in improving the medical care practices and the development of better medical products from the capability of sharing and linking the medical data collected. By obtaining results in real time from different systems, the medical practices can reduce the number of repetitive tasks and enhance the quality of the care

provided, and even treat more patients. The patients will have more control over their own data in an environment where their privacy is safeguarded. The remaining administrative, clinical and information reporting functions will be simplified due to the integration of data and knowledge coming from dispersed systems.

A. Project scope

A sample of medical records from 1,300 patients of the outside consultation service of the HUTPL was considered. Both the patients' and the medical staff's identification information was anonymized, ensuring due privacy.

B. Data sources

The information was extracted from the relational database that manages the electronic medical records systems maintained by the HUTPL. Around 40 tables of the database scheme were used. The data dictionary of each table was obtained in order to identify the field to be used for the SQL views. This allowed us to reduce the complexity of data extraction. As an example, Table 1 presents the information of the Patients entity. Although the ontology gathers all the patient's identification information, this information is not modeled for the case study.

A mirror version of the HUTPL database was created and modification techniques were applied, such as the combination/substitution of characters, which allowed masking some of the data. This hampers to the extremes or even make impossible to conduct reverse engineering or detection.

The individual identification data of the clinical history were anonymized in order to minimize the risk of disclosing patient's information.

TABLE I. TABLE SCHEME: PATIENTS

Field	Type of data	Size	Comment
numero_hc	Number	22	Clinic history identifier

<i>Field</i>	<i>Type of data</i>	<i>Size</i>	<i>Comment</i>
apellido paterno	Varchar2	20	Paternal Surname
apellido materno	Varchar2	20	Maternal Surname
primer nombre	Varchar2	20	First Name
segundo nombre	Varchar2	20	Middle Name
nacionalidad	Varchar2	3	Nationality
fecha_nacimiento	Date	7	Date of Birth
sexo	Char	1	Gender
direccion_domicilio	Varchar2	240	Home Address
telefono	Varchar2	32	Phone Number
email	Varchar2	240	E-mail
cedula	Varchar2	20	ID Card
prq cnt codigo ncm	Varchar2	2	NCM Code
prq codigo ncm	Varchar2	2	NCM Code
lugar nacimiento	Varchar2	20	Birth place
estado civil	Char	3	Marital Status
instruccion	Varchar2	2	Schooling
prq cnt prv codigo	Varchar2	2	Province Code
prq cnt codigo	Varchar2	2	Canton Code
prq codigo	Varchar2	2	Parish Code
barrio	Varchar2	20	Location
zona	Varchar2	1	Zone
grupo cultural	Varchar2	3	Cultural group
tipo seguro	Varchar2	3	Insurance type
ocp codigo	Varchar2	2	Occupation Code
empresa trabajo	Varchar2	50	Work company
tipo discapacidad	Char	3	Disability type
			Disability card identification number
id_conadis	Varchar2	20	

C. Data anonymization

There are certain data elements that connect more easily to certain individuals. To protect them, we use generalization to eliminate part of the data or replace some part with a common value combined with some level of diversity in the sensitive values. For example, when substituting segments from all the ZIP codes or telephone numbers by the same sequence of numbers, combined with certain level of diversity. Therefore, we would not be able to identify any person by their ZIP code.

In addition, differential privacy [40] has been used to identify each individual; this is a technique to add mathematical noise to the data, so as to mask them. It is to be noted that, in this way, it will be difficult to determine if a person is part of the dataset, because the output of a given algorithm will look essentially the same, regardless of whether the person's information is included or omitted.

Anonymization is a process that we use to maintain our commitment to the privacy of the people involved. Other data governance processes to ensure a consistent level of protection in the entire system include the following: strict controls over the access to the user's data, policies to control and limit the use of datasets that can identify the users, and centralized review of the anonymization techniques[41].

D. Ontology design

In this phase, the ontology classes, and properties (coming from data and from object properties) were identified, as well as the base classes of the existing ontologies with which they are linked were determined. The latter action helps to attain interoperability of the HUPTL data with other systems.

In order to simplify the names of the classes, prefixes are used to identify the name spaces. Thus, *hutpl* corresponds to the name space of the outside consultation ontology. The prefix *scf* identifies the classes of the SNOMED CT taxonomy. For the description of the person-type classes (*Person* class), the name space *foaf* is used and, for the semantic description of organizations (*Organization* class), the name space *org* is used.

According to the data sources contained in the scope of this paper, 49 concepts were identified. Classes are described in Table II. The classes were categorized according to the SNOMED CT taxonomy. The main class is *hutpl:OutsideConsultation*, which is linked to all Electronic clinical document classes. From this class, requests for complementary examinations, medication prescription, and patient personal and social data are generated.

TABLE II. CLASSES IDENTIFIED

<i>Class</i>	<i>Description</i>	<i>Related Semantic Resource</i>
Electronic clinical document		
hutpl:ElectronicClinicalDocument	Electronic document that records all the health events of a patient.	scf:423876004 Clinical document
hutpl:OutsideConsultation	Record of visit in outside consultation	scf:11429006 Consultation
hutpl:LaboratoryOrder	Laboratory test order (electronic clinical document).	scf:721965002 Laboratory order
hutpl:LaboratoryReporting	Laboratory test results (electronic clinical document).	scf:4241000179101 Laboratory report
hutpl:ImagingOrder	Electronic clinical document for requesting diagnostic imaging studies.	scf:360037004 Imaging modality
hutpl:ImagingReporting	Electronic clinical document of results of diagnostic imaging studies.	scf:4201000179104 Imaging report
hutpl:HistopathologyOrder	Electronic clinical document for requesting histopathology tests	scf:108257001 Anatomic pathology procedure
hutpl:HistopathologyReporting	Electronic clinical record of histopathology test results	scf:116784002 Pathologist report
hutpl:ConsultationSpecialty	Electronic clinical document for requesting specialty consultations.	scf:53923005 Medical consultation on inpatient
hutpl:ConsultationSpecialtyReporting	Electronic clinical document of the results of the specialty consultations.	scf:371530004 Clinical consultation report

<i>Class</i>	<i>Description</i>	<i>Related Semantic Resource</i>
Environments and geographical locations		
hutpl:Province	Provinces in Ecuador	http://es-la.dbpedia.org/page/resource/Provincias_de_Ecuador
hutpl:Canton	Cantons in Ecuador	http://es-la.dbpedia.org/page/resource/Cantones_de_Ecuador
hutpl:Parish	Parishes in Ecuador	http://es-la.dbpedia.org/page/resource/Categor%C3%ADa:Parroquias_de_Ecuador
hutpl:Country	Countries	sct:223369002 Country
Location within hospital premises		
hutpl:Department	Services in the hospital area	sct:284548004 Department
hutpl:HealthInstitution	Health services institutions	foaf:Organization
Areas	Units or service areas in health care institutions	org:OrganizationalUnit
hutpl:OperationalUnit	Operating units of a health care institution	sct:43741000 Environment or geographical location
Social concept		
hutpl:Person	Individual belonging to the human species	foaf:Person, sct:125676002 Person
hutpl:Patient	Sick person who is seen by a doctor or receives medical or surgical treatment.	sct:116154003 Patient
hutpl:HealthcareWorker	Healthcare professionals: doctors, nurses, health technicians, laboratory staff, biochemists, and pharmacists.	sct:223366009 Healthcare professional
hutpl:EthnicGroup	Ethnic group self-identified by the patient	sct:389109008 Group
hutpl:IndigenousPeopleNationalities	Peoples and nationalities of Ecuador	sct:372148003 Ethnic group
hutpl:Occupation	University education - occupations	sct:14679004 Occupation
Procedure		
hutpl:Procedure	Clinical procedures	sct:71388002 Procedure
hutpl:Laboratory	Laboratory tests	sct:15220000 Laboratory test
hutpl:Imaging	Imaging studies	sct:371571005 Imaging by body site
hutpl:Histopathology	Histopathology and cytology studies	sct:714797009 Histology test
hutpl:PrescriptionDrug	Record of the pharmacological treatment, additional recommendations to the treatment	sct:33633005 Prescription of drug
hutpl:ReportDrugAdministration	Record of updates on the evolution of the patient's health status and drug administration	sct:444754002 Hospital inpatient progress report (record artifact)
hutpl:DrugAdministration	Drug administration compliance record	sct:18629005 Administration of drug or medicament (procedure)
hutpl:ReviewSystems	Symptoms in organ systems	sct:415300000 Review of systems
hutpl:Reference	Summary of patient's clinical episode for referral to another health institution.	sct:306685000 Referral to establishment
hutpl:VitalSigns	Registration of vital signs, related to Formulario 002: Consulta externa	sct:61746007 Taking patient vital signs
hutpl:PhysicalExamination	Signs found in physical regions on exploration.	sct:5880005 Physical examination procedure
Standards / terminologies		
hutpl:AnatomicalTherapeuticChemicalClassification	Classification of active ingredients of drugs according to the organ or system in which they act and their therapeutic, pharmacological and chemical properties.	http://biportal.bioontology.org/ontologies/ATC Anatomical Therapeutic Chemical Classification
hutpl:Diagnosis	Coding of diseases according to ICD 10.	http://purl.bioontology.org/ontology/ICD10 International Classification of Diseases, Version 10
Clinical history/examination observable		
hutpl:History	Patient's medical history	sct:404684003 Clinical finding
hutpl:PersonalHistory	Previous health problems	sct:307294006 Personal history finding
hutpl:SexualOrientation	Sexual Orientation - source RDACAA	sct:66621004 Sexual orientation

<i>Class</i>	<i>Description</i>	<i>Related Semantic Resource</i>
hutpl:GenderIdentity	Gender Identity – source RDACAA	sct:12271241000119100 Transgender identity (finding)
hutpl:FamilyHistory	Health problems of family members.	sct:416471007 Family history of clinical finding
Qualifier value		
hutpl:UnitMeasure	Measurement units	sct:767524001 Unit of measure
hutpl:PharmaceuticalDoseForm	Pharmaceutical dose form	sct:736542009 Pharmaceutical dose form
hutpl:MedicalSpecialty	Medical specialties	sct:394733009 Medical specialty
hutpl:Routes	Administration routes.	sct:284009009 Route of administration value
Pharmaceutical / biologic product		
hutpl:Drug	Biologic pduct / drugs	sct:373873005 Pharmaceutical / biologic product
Body structure		
hutpl:Organ	Part of the human body that performs a function.	sct:272625005 Entire body organ
Material (structure, substance, device)		
hutpl:Sample	Sample information for histopathology and cytology tests	sct:123038009 Specimen

In addition, in Table III shows a description of the properties identified.

TABLE III. PROPERTIES IDENTIFIED

<i>Information Element – Relationships</i>	<i>Property</i>	<i>Domain</i>	<i>Range</i>
The drug is administered by the physician	administeredBy	hutpl:Drug	hutpl:Doctor
Doctor sees patient	attend	hutpl:Doctor	hutpl:Patient
Patient is seen by Doctor	attendBy	hutpl:Patient	hutpl:Doctor
Patient attends medical appointment	attendsPatient	hutpl:OutsideConsultation	hutpl:Patient
Canton of birth	bornCanton	hutpl:Patient	hutpl:Canton
Parish of birth	bornParish	hutpl:Patient	hutpl:Parish
Province of birth	bornProvince	hutpl:Patient	hutpl:Province
Reverse Patient Referral Process	counterReferenceto	hutpl:CounterReference	hutpl:HealthInstitution
Sample data from a histopathology order	dataSample	hutpl:HistopathologyOrder	hutpl:Sample
Doctor who responds to an inter-physician communication	doctorConsultation	hutpl:ConsultationSpecialty	hutpl:Doctor
Medication prescribed in pharmacological treatment	drugOrdered	hutpl:DetailsPrescriptionDrug	hutpl:Drug
Identifies the patient's gender	gender	foaf:Person	hutpl:GenderIdentity
Area of a health care institution	hasArea	hutpl:HealthInstitution	hutpl:Areas
Basic cytology data	hasCytologyData	hutpl:HistopathologyOrder	hutpl:BasicCytologyData
Patient's diagnosis	hasConsultationDiagnosis	hutpl:CounterReference hutpl:Reference hutpl:OutsideConsultation	hutpl:Diagnosis
Contraceptive methods	hasContraception	hutpl:BasicCytologyData	sct:13197004
Care departments or care services	hasDepartments	hutpl:Areas	hutpl:Department
Test request	hasDeterminationsTest	hutpl:Histopathology hutpl:Imaging hutpl:Laboratory	hutpl:DeterminationsTest
Patient's disability	hasDisability	hutpl:Patient	hutpl:Disability
Contains a medication	hasDrug	hutpl:DrugAdministration	hutpl:PrescriptionDrug
Has a pharmacological prescription	hasDrugAdministration	hutpl:OutsideConsultation	hutpl:ReportDrugAdministration
Has family history	hasFamilyHistory	hutpl:OutsideConsultation	hutpl:Patient
Has health insurance	hasHealthInsurance	hutpl:Patient	hutpl:HealthInsurance
Diagnosis of test results	hasHistopathologyDiagnosis	hutpl:HistopathologyReporting	hutpl:Diagnosis
Has histopathology order	hasHistopathologyOrder	hutpl:OutsideConsultation hutpl:ConsultationSpecialtyReporting	hutpl:HistopathologyOrder
Has histopathology test	hasHistopathologyTest	hutpl:HistopathologyOrder hutpl:HistopathologyReporting	hutpl:Histopathology
Diagnosis of test results	hasImagingDiagnosis	hutpl:ImagingReporting	hutpl:Diagnosis

<i>Information Element – Relationships</i>	<i>Property</i>	<i>Domain</i>	<i>Range</i>
Has imaging order	hasImagingOrder	hutpl:OutsideConsultation hutpl:ConsultationSpecialtyReporting	hutpl:ImagingOrder
Has imaging test	hasImagingTest	hutpl:ImagingOrder hutpl:ImagingReporting	hutpl:Imaging
Patient is from a nationality	hasIndigenousPeople	hutpl:Patient	hutpl:IndigenousPeopleNationalities
Patient signs informed consent	hasInformedConsent	hutpl:TreatmentPlan	hutpl:InformedConsent
Has an interconsultation	hasInterconsultation	hutpl:TreatmentPlan	hutpl:ConsultationSpecialty
Diagnosis of interconsultation	hasInterconsultationDiagnosis	hutpl:ConsultationSpecialtyReporting	hutpl:Diagnosis
Has laboratory order	hasLaboratoryOrder	hutpl:OutsideConsultation hutpl:ConsultationSpecialtyReporting	hutpl:LaboratoryOrder
Has laboratory test	hasLaboratoryTest	hutpl:LaboratoryOrder hutpl:LaboratoryReporting	hutpl:Laboratory
Occupation of patient	hasOccupation	foaf:Person	hutpl:Occupation
Patient attends medical appointment	hasOutsideConsultation	hutpl:Patient	hutpl:OutsideConsultation
Patient has personal history	hasPersonalHistory	hutpl:OutsideConsultation	hutpl:Patient
Dose form of a drug	hasPharmaceuticalDoseForm	hutpl:Drug	hutpl:PharmaceuticalDoseForm
Procedure of Physical Examination	hasPhysicalExamination	hutpl:OutsideConsultation	hutpl:PhysicalExamination
Pharmacological prescribing in outside consultation	hasPrescriptionDrug	hutpl:OutsideConsultation	hutpl:PrescriptionDrug
Province of a country	hasProvince	hutpl:Country	hutpl:Province
Refers the patient to another health institution	hasReference	hutpl:TreatmentPlan	hutpl:Reference
Results of test order	hasReport	hutpl:ConsultationSpecialty hutpl:HistopathologyOrder hutpl:LaboratoryOrder hutpl:Reference hutpl:HistopathologyOrder hutpl:ImagingOrder	hutpl:HistopathologyReporting hutpl:ConsultationSpecialtyReporting hutpl:HistopathologyReporting hutpl:LaboratoryReporting hutpl:ImagingReporting
Patient has medication administration record	hasReportDrugAdministration	hutpl:OutsideConsultation	hutpl:Patient
Review systems in outside consultation	hasReviewSystems	hutpl:OutsideConsultation	hutpl:ReviewSystems
Patient has sign in an anatomical part	hasSignIn	hutpl:PhysicalExamination	hutpl:AnatomicalPart
Health worker has university training in a health area.	hasSpecialty	hutpl:HealthcareWorker	hutpl:MedicalSpecialty
Diagnosis condition	hasStatusDiagnosis	hutpl:Diagnosis	sct:2931005
Symptoms in organic system	hasSymptomIn	hutpl:ReviewSystems	sct:91689009
Medical appointment generates treatment plans	hasTreatmentPlan	hutpl:OutsideConsultation	hutpl:TreatmentPlan
Vital signs found on physical examination in medical care.	hasVitalSign	hutpl:OutsideConsultation	hutpl:Patient
Patient's level of instruction	hasEducationReceived	hutpl:Patient	sct:224285004
Patient is from a ethnic group	hasEthnicGroup	hutpl:Patient	hutpl:EthnicGroup
Department or place of medical care in a hospital	healthcareServices	hutpl:ConsultationSpecialty hutpl:CounterReference hutpl:HistopathologyOrder hutpl:HistopathologyReporting hutpl:ImagingOrder hutpl:ImagingReporting hutpl:LaboratoryOrder hutpl:LaboratoryReporting hutpl:Reference	sct:284548004
Patient's home zone	homezone	hutpl:Patient	sct:288500009
Inverse property of isprovinceof	iscantonof	hutpl:Canton	hutpl:Province
Parish (Geographical environment)	isparishof	hutpl:Parish	hutpl:Canton
Part of body system structure	ispartof	hutpl:Organ	sct:91689009
Inverse property of iscantonof	isprovinceof	hutpl:Province	hutpl:Canton
Kinship	kinship	hutpl:FamilyHistory	sct:125677006
Canton of patient's residence	livesCanton	hutpl:Patient	hutpl:Canton
Parish of patient's residence	livesParish	hutpl:Patient	hutpl:Parish
Province of patient's residence	livesProvince	hutpl:Patient	hutpl:Province
Canton of location of the health institution	locatedCanton	hutpl:HealthInstitution	hutpl:Canton
Country of location of the health institution	locatedIn	hutpl:HealthInstitution	hutpl:Country

<i>Information Element – Relationships</i>	<i>Property</i>	<i>Domain</i>	<i>Range</i>
Parish of location of the health institution	locatedParish	hutpl:HealthInstitution	hutpl:Parish
Province of location of the health institution	locatedProvince	hutpl:HealthInstitution	hutpl:Province
Action, procedure or process performed by healthcare worker	madeBy	hutpl:ConsultationSpecialtyReporting hutpl:HistopathologyReporting hutpl:LaboratoryReporting hutpl:ImagingReporting	hutpl:HealthcareWorker
Action, procedure or process performed by healthcare worker	makeConsultation	hutpl:Doctor	hutpl:OutsideConsultation
Action, procedure or process performed by healthcare worker	makeCounterReference	hutpl:Doctor	hutpl:CounterReference
Action, procedure or process performed by healthcare worker	makeReference	hutpl:Doctor	hutpl:Reference
Patient's marital status	maritalstatus	hutpl:Patient	hutpl:MaritalStatusPatient
Nationality of patient	nationality	hutpl:Patient	hutpl:Country
Doctor requests a consultation specialty	orderInterconsultation	hutpl:Doctor	hutpl:ConsultationSpecialty
Procedure performed by a doctor	orderProcedures	hutpl:Doctor	hutpl:ConsultationSpecialty
Receiver of a report	receivedBy	hutpl:HistopathologyReporting hutpl:ImagingReporting hutpl:LaboratoryReporting	foaf:Person
Transferring a patient to another health institution	refersTo	hutpl:CounterReference hutpl:Reference	hutpl:HealthInstitution
Route administration of drugs	routeAdministration	hutpl:DrugAdministration	hutpl:Routes
Patient's sexual orientation	sexualorientation	hutpl:Patient	sct:66621004
Specialty of medical consultation specialty	specialtyconsultation	hutpl:ConsultationSpecialty	hutpl:MedicalSpecialty
Category of a drug in the Anatomical Therapeutic Chemical Classification System	tiencodigoatc	hutpl:Drug	hutpl:AnatomicalTherapeuticChemicalClassification
Therapeutic treatment plan carried out on the patient	treatmentPlanGiven	hutpl:Reference hutpl:CounterReference hutpl:ConsultationSpecialty	hutpl:TreatmentPlan
Therapeutic treatment plan proposed to patient	treatmentPlanProposed	hutpl:Reference hutpl:CounterReference hutpl:ConsultationSpecialtyReporting	hutpl:TreatmentPlan
Operational unit in a health institution	unit	hutpl:HealthInstitution	hutpl:OperationalUnit
Health personnel working in a hospital	workIn	hutpl:HealthcareWorker	hutpl:HealthInstitution
Action of prescribing drugs	prescribedBy	hutpl:Drug	hutpl:Doctor

E. Semantic Description of Outside Consultation

The Ecuadorian national standard for medical data collection is composed of 18 Unique Clinical History Forms. The forms that were modeled through the ontology are the following: Form 002 – Outside Consultation, Form 010 – Clinical Laboratory, Form 012 – Imaging, Form 013 – Histopathology, Form 007 – Consultation specialty (interconsultation), Form 022 – Drug Administration, Form 053 – Reference. In the ontology for outside consultation, 12 of the 19 categories from the OWL SNOMED CT class hierarchy were used. Fig. 4 shows the categories that were reused. Around 1,500 concepts were exported among classes, properties, axioms, and equivalences between classes. The outside consultation ontology classes were created as subclasses of OWL SNOMED CT. This enhances the interoperability of the Unique Clinical History Forms, which are mapped to one of the most widely used terminologies at the international level.

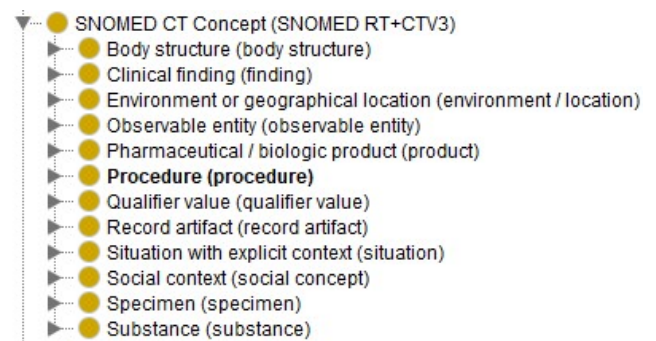


Fig. 4. Screenshot of the OWL SNOMED CT class hierarchy used in the outside consultation ontology.

Other ontologies used are ATC and ICD 10 – CM, which were fully loaded into the outside consultation ontology.

F. Mapping of data sources with the ontology

In this stage, the data obtained in the Ontology design section are represented with the classes of the outside consultation ontology. We describe the mapped classes in Table IV.

TABLE IV. MAPPING OF HUTPL INFORMATION ELEMENTS WITH THEIR ONTOLOGICAL REPRESENTATION

<i>Information Element – Entities</i>	<i>Source (table in the medical system)</i>	<i>Class/Subclasses</i>	<i>Comment</i>
Patient	pacientes	hutpl:Patient	Personal information must be anonymized.
Medical staff	personal	hutpl:HealthcareWorker	Personal information must be anonymized.
Visit in outside consultation	turnos_ce, motivos_de_consultas, hojas_de_evolucion	hutpl:OutsideConsultation	Booking of outside consultation appointments
Drug prescription	prescripciones_medicas, detalles_prescripcion	hutpl:PrescriptionDrug	Pharmacological treatment, recommendations
Notes on the evolution of the health status	hojas_de_evolucion, momentos_cumplimiento, detalles_prescripcion	hutpl:ReportDrugAdministration	Evolution of the patient's health status and drug administration
Laboratory test order	solicitudes_de_examenes, variables_de_examenes, detalles_de_examenes, examenes, tipos_de_examenes	hutpl:LaboratoryOrder	Is a communication from the treating physician/practitioner requesting that a diagnostic test be performed for a patient. The order may be part of the medical record.
Laboratory test results	solicitudes_de_examenes, variables_de_examenes, detalles_de_examenes, examenes, tipos_de_examenes	hutpl:LaboratoryReporting	The laboratory reporting may be part of the medical record.
Diagnostic imaging study order	solicitudes_de_examenes, variables_de_examenes, detalles_de_examenes, examenes, tipos_de_examenes	hutpl:ImagingOrder	The order may be part of the medical record.
Results of diagnostic imaging studies	solicitudes_de_examenes, variables_de_examenes, detalles_de_examenes, examenes, tipos_de_examenes	hutpl:ImagingReporting	The imaging reporting may be part of the medical record.
Histopathology tests order	solicitudes_de_examenes, variables_de_examenes, examenes, tipos_de_examenes, biopsias_detalle, papanicolaous	hutpl:HistopathologyOrder	The histopathology order may be part of the medical record.
Report of histopathology test results	solicitudes_de_examenes, variables_de_examenes, examenes, tipos_de_examenes, biopsias_detalle, papanicolaous	hutpl:HistopathologyReporting	No results information is recorded in the system.
Record of drug administration to the patient	hojas_de_evolucion, momentos_cumplimiento, detalles_prescripcion	hutpl:DrugAdministration	It applies only for hospitalized patients
Order for inter-physician communication with another specialty	interconsultas	hutpl:ConsultationSpecialty	It does not apply for outside consultation.
Results of inter-physician communications	interconsultas	hutpl:ConsultationSpecialtyReporting	It does not apply for outside consultation.
Order to transfer patient to another health institution	contra_referencias	hutpl:Reference hutpl:CounterReference	Reference and counter-reference, public sector.
Record of vital signs	signos_vitales	hutpl:VitalSigns	Only those recorded in outside consultation
Patient's health history		hutpl:History	Patient's health history
Record of health problems prior to the reason for consultation	antecedentes_personales tipos_antecedentes_personales	hutpl:PersonalHistory	Health problems prior to the reason for consultation
Health problems relevant to the family members.	antecedentes_familiares tipos_antecedentes_familiares	hutpl:FamilyHistory	Health problems of the family members.
Record of symptoms stated by the patient in the questioning by the doctor	revision_de_sistemas	hutpl:ReviewSystems	Symptoms in organic systems
Signs found in the physical examination	exploraciones_fisicas	hutpl:PhysicalExamination	Signs found in physical regions during exploration.
Units of measure		hutpl:UnitMeasure	
Medical specialties	especialidades	hutpl:MedicalSpecialty	The MSP coding is used
Diagnosis catalog	enfermedades	hutpl:Diagnosis	Coding of diseases according to ICD 10.

Information Element – Entities	Source (table in the medical system)	Class/Subclasses	Comment
It records data from the samples of cytology, pap tests, etc.	Papanicolaous, biopsias_detalle, biopsias	hutpl:Sample	Sample information for histopathological and cytological tests
Drug administration routes	cg_ref_codes cod	hutpl:Routes	Administration routes.
Ecuadorian provinces	provincias	hutpl:Province	Ecuadorian provinces
Ecuadorian cantons	cantones	hutpl:Canton	Ecuadorian cantons
Ecuadorian parishes	parroquias	hutpl:Parish	Ecuadorian parishes
Country	países	hutpl:Country	
Ethnic self-identification	pacientes, cg_ref_codes cod	hutpl:EthnicGroup	Record of ethnic groups with which the patients identify themselves
Self-identification of indigenous peoples and nationalities	pacientes, cg_ref_codes cod	hutpl:IndigenousPeopleNationalities	Ecuadorian peoples and nationalities
Self-identification of sexual orientation	pacientes	hutpl:SexualOrientation	Sexual orientation - Source: RDACAA
Self-identification of gender		hutpl:GenderIdentity	Gender identity - Source: RDACAA
Operational units of the health institutions		hutpl:OperationalUnit	Operational units
Occupations of the patients and of the medical staff	ocupaciones, cg_ref_codes cod	hutpl:Occupation	Professional training - Occupations
Clinical, surgical, laboratory, imaging procedures, etc.	cargos	hutpl:Procedure	Clinical procedures
Laboratory tests	cargos	hutpl:Laboratory	Laboratory tests
Imaging studies	cargos	hutpl:Imaging	Imaging studies
Histopathology and cytology studies	cargos	hutpl:Histopathology	Histopathology and cytology studies
Drugs/Medications	items	hutpl:Drug	Medications
Classification of the drug active components		hutpl:AnatomicalTherapeuticChemicalClassification	Not Applicable
Pharmaceutical presentations		hutpl:PharmaceuticalDoseForm	Presentation of a medication for its administration.
Organs		hutpl:Organ	Parts of the human body with a specific function.
Departments/Services of a hospital	departamentos	hutpl:Department	Care services in the hospital area
Health institutions	empresas, establecimientos_de_salud	hutpl:HealthInstitution	Institutions that provide health services
Units or Areas of the health institutions	areas	hutpl:Areas	Service units or areas in the institutions that provide health services

G. Data pre-processing, prior to conversion to RDF

SQL views were created in order to dynamize the conversion process and reduce the complexity of the extraction of data stored in multiple tables in the electronic health records system.

Table V presents the sentences to extract the views in outside consultation.

TABLE V. EXAMPLE OF SQL VIEWS TO OBTAIN OUTSIDE CONSULTATION DATA.

SQL REPORT - OUTSIDE CONSULTATION	
SELECT	TCE.NUMERO_ID "numeroturno",
to_char(TCE.FECHA, 'yyyy-mm-dd hh24:mi')	
fechaConsulta",	HEV.NUMERO "numeroRegistro",
MD5_COLUMN_VAR(HEV.PCN_NUMERO_HC)	"historiaClinica",
mcs.motivo "motivoConsulta",	mcs.enfermedad
"enfermedadActual",	to_char(HEV.FECHA, 'yyyy-mm-dd
hh24:mi')	"fechaEvolucion",
"descripcionEvolucion",	HEV.DESCRIPCION
	DGP.DGNPCN_ID

SQL REPORT - OUTSIDE CONSULTATION	
diagnostico_consulta,	DGP.ENF_CODIGO
"codigoDiagnostico",	'DX' DGP.TIPO
"condicionDiagnostico",	mcs.plan_tratamiento
"descripcionPlan",	to_char(TCE.HORA_FIN, 'yyyy-mm-dd
hh24:mi')	fin_consulta, TCE.PRS_CODIGO CODIGO_MEDICO,
md5_varios(tce.prs_codigo)	"codigoPersonal"
FROM	TURNOS_CE TCE, PERMANENCIAS_Y_ATENCIONES PYA,
HOJAS_DE_EVOLUCION HEV	LEFT JOIN diagnosticos_paciente
DGP	ON (HEV.DGNPCN_ID=DGP.DGNPCN_ID) LEFT JOIN
motivos_de_consultas	mcs
(HEV.NUMERO=MCS.HJAEVL NUMERO)	LEFT JOIN CG_REF_CODES
COD	ON (COD.RV_DOMAIN='TIPO DIAGNOSTICO' AND
COD.RV_LOW_VALUE=DGP.TIPO)	LEFT JOIN ENFERMEDADES ENF
ON (DGP.ENF_CODIGO=ENF.CODIGO)	
WHERE	HEV.PCN_NUMERO_HC=PYA.PCN_NUMERO_HC AND
HEV.PRMTN_NUMERO	= PYA.NUMERO AND
PYA.TRN_NUMERO_ID=TCE.NUMERO_ID	AND TCE.ESTADO='A'

H. Transformation to RDF

The mapping schemes indicated in the *Ontology design y Mapping of data sources with the ontology* sections were used and applied to the information obtained in the pre-

processing. Based on that, the information was transformed to RDF. Fig. 5 shows the RDF graph of a patient's visit in outside consultation.

Table VI shows a partial representation in N-Triples of this visit.

TABLE VI. EXAMPLES OF N-TRIPLETS OF A VISIT IN OUTSIDE CONSULTATION.

VISIT IN OUTSIDE CONSULTATION N-TRIPLETS	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/hasConsultationDiagnosis></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/26131></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/hasLaboratoryOrder></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/15527></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/hasVitalSign></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS376562020-02-0300:00:00></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/hospitalProgressNote></code>	
<code>"SOLICITO BH"</code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/numberAppointment></code>	
<code>"166869"^^<http://www.w3.org/2001/XMLSchema#integer></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/timeEndConsultationSpecialty></code>	
<code>"2020-02-03 10:52"</code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://www.w3.org/1999/02/22-rdf-syntax-ns#type></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/OutsideConsultation></code>	

VISIT IN OUTSIDE CONSULTATION N-TRIPLETS	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/hasConsultationDiagnosis></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/26131></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/hasLaboratoryOrder></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/15527></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/hasVitalSign></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS376562020-02-0300:00:00></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/hospitalProgressNote></code>	
<code>"SOLICITO BH"</code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/numberAppointment></code>	
<code>"166869"^^<http://www.w3.org/2001/XMLSchema#integer></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/timeEndConsultationSpecialty></code>	
<code>"2020-02-03 10:52"</code>	
<code><http://data.utpl.edu.ec/hutpl/resource/37656></code>	
<code><http://www.w3.org/1999/02/22-rdf-syntax-ns#type></code>	
<code><http://data.utpl.edu.ec/hutpl/resource/OutsideConsultation></code>	

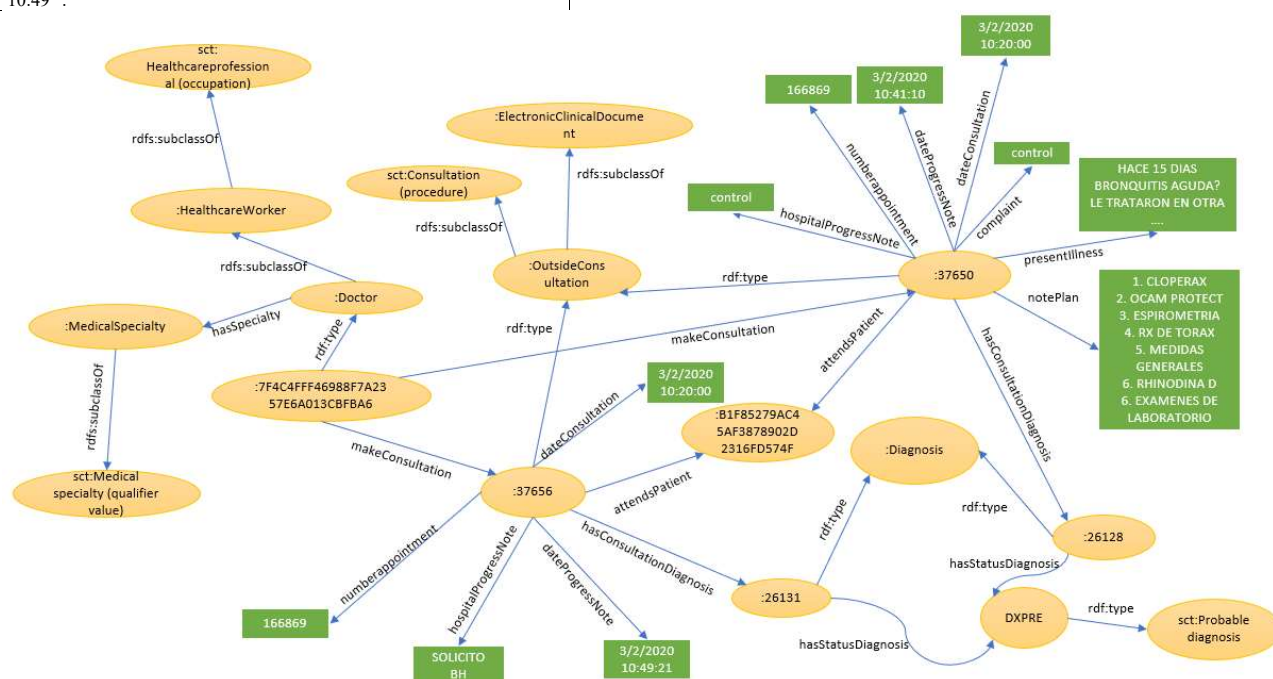


Fig. 5. RDF graph of a record of visit in outside consultation

Fig. 6 shows the RDF graph of a patient's vital signs in outside consultation.

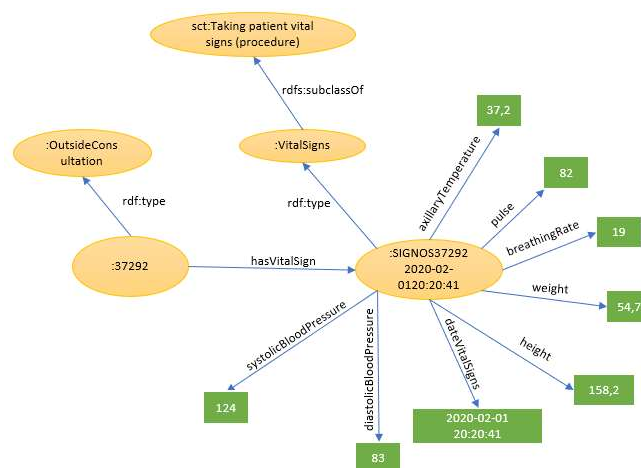


Fig. 6. RDF graph of vital signs

Table VII shows the representation in N-Triplets of the RDF graph of vital signs.

TABLE VII. EXAMPLE OF VITAL SIGNS N-TRIPLETS.

VITAL SIGNS N-TRIPLETS
<code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/axillaryTemperature></code> <code>"2"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/axillaryTemperature></code> <code>"37"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/dateVitalSigns></code> <code>"2020-02-01 20:20:41"</code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/diastolicBloodPressure></code> <code>"83"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/breathingRate></code> <code>"19"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/height></code> <code>"158"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/height></code> <code>"2"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/pulse></code> <code>"82"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/systolicBloodPressure></code> <code>"124"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/weight></code> <code>"54"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://data.utpl.edu.ec/hutpl/resource/weight></code> <code>"7"^^<http://www.w3.org/2001/XMLSchema#integer></code> . <code><http://data.utpl.edu.ec/hutpl/resource/SIGNOS372922020-02-0120:20:41></code> <code><http://www.w3.org/1999/02/22-rdf-syntax-ns#type></code> <code><http://snomed.info/id/61746007></code> .

The complete ontology can be downloaded from Github at [https://github.com/monisilla/ontologia-ce\[42\]](https://github.com/monisilla/ontologia-ce[42]).

I. RDF storage

The information was stored in GraphDB, an RDF[43] database that handles large volumes of linked data. In Fig. 7 shows the active repository of the electronic clinical documents that were uploaded. A total of 2 million medical consultation triples were uploaded to the RDF database.

Active repository

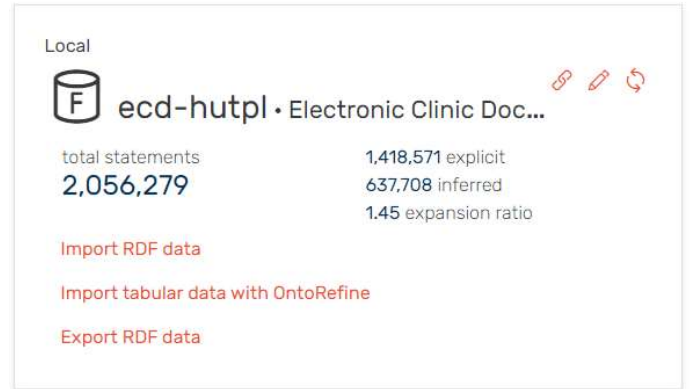


Fig. 7. RDF repository of outside consultation clinical information.

GraphDB allows navigating the class hierarchy. An example of a class is shown in Figure 8. Class OutsideConsultation is presented with domain and range.

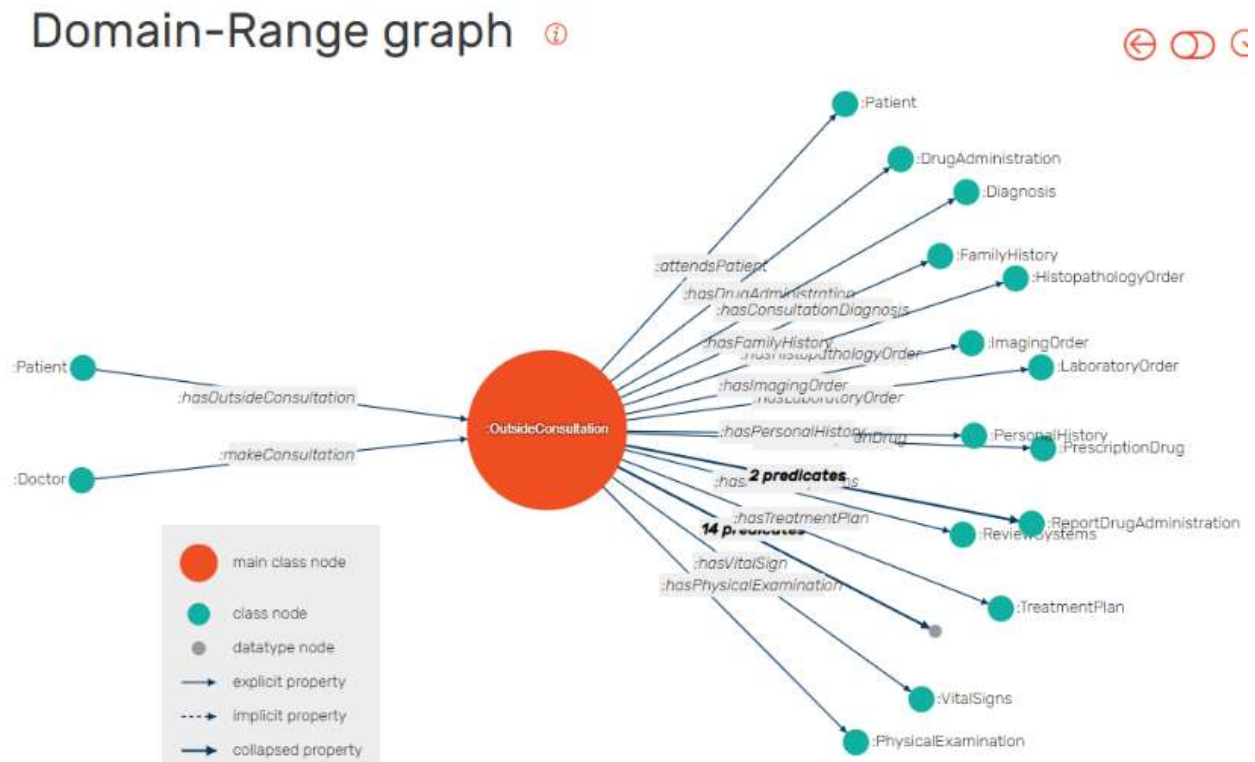


Fig. 8. Class OutsideConsultation in GraphDB.

Figure 9 shows the dependencies between 10 classes.

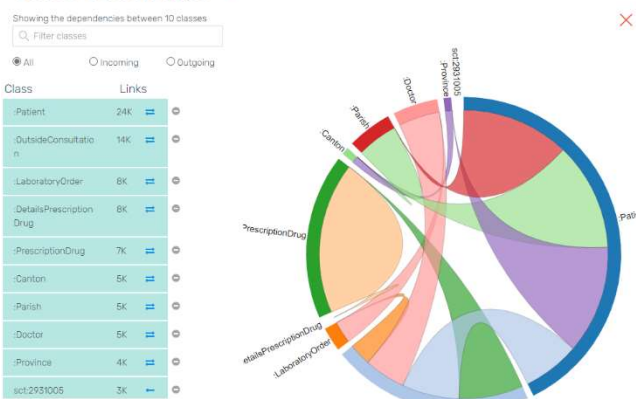


Fig. 9. Class relationships in GraphDB.

The resource explorer facilitates the navigation of RDF data. In Fig. 10, it shows the statements of a lab order.

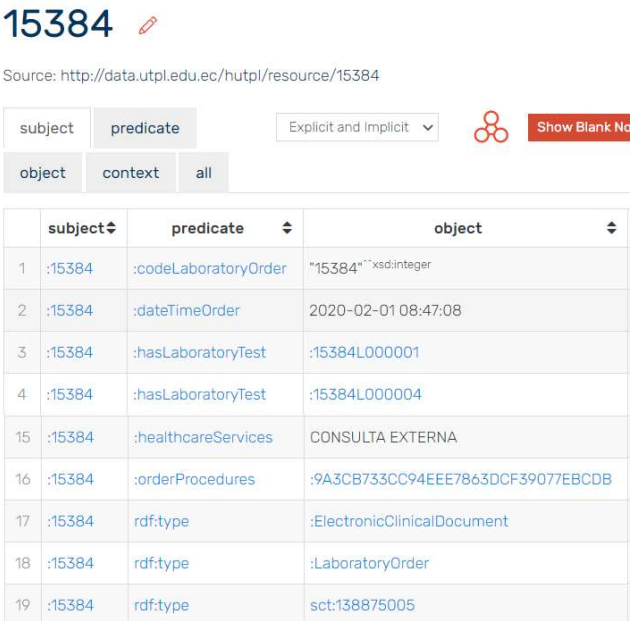


Fig. 10. Clinical laboratory order in the RDF resource explorer in GraphDB.

Another option to query RDF data is through SPARQL. Fig. 11 shows a query of patients diagnosed with diseases of the respiratory system.

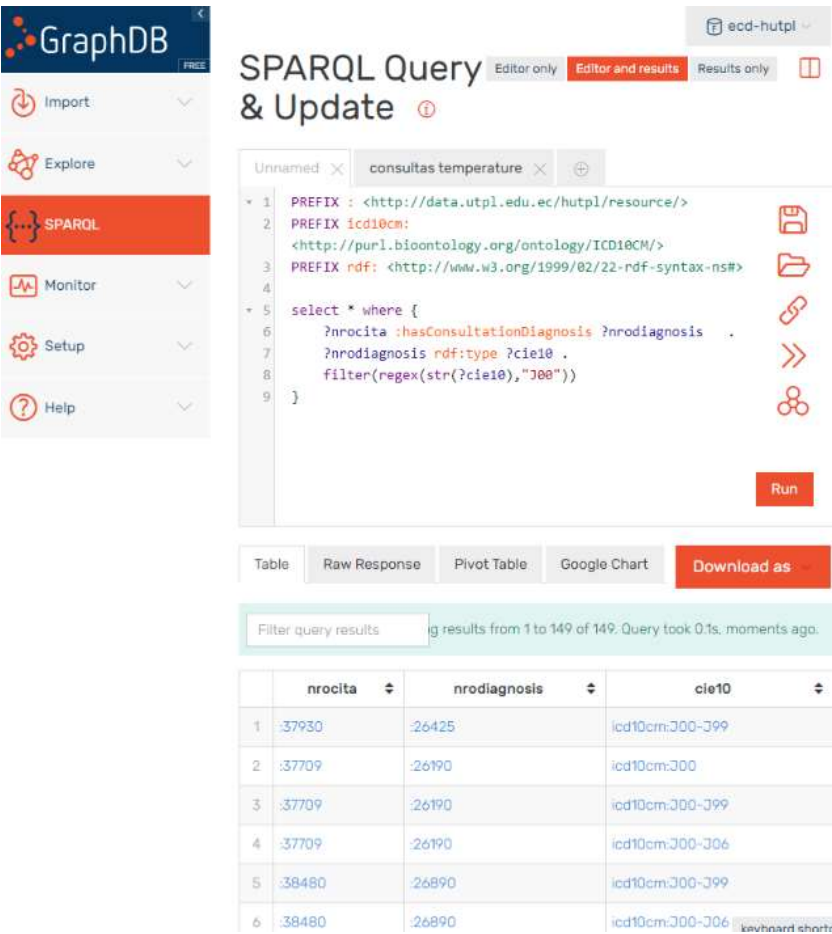


Fig. 11. Query of patients with respiratory diseases in SPARQL.

VI. DISCUSSION

One of the most challenging problems in the health systems is the capability to integrate data and interoperate across the different information systems. However, some clinical management systems are not standardized with clinical standards, which makes it difficult to map information with medical terminologies and standards. In our case study, the UTPL Hospital's clinical data management system only has a national standard for data collection (Unique Clinical History Forms). Its architecture does not contemplate the HL7 standards for data transmission and exchange, and it is not associated with any semantic clinical terminology such as SNOMED CT. To this fact it is added that, generally, the data are not complete, that is, they do not contain sufficient information to describe the context that is necessary to adequately understand them. The input of information into the system is not adequate, we have evidenced the use of non-formal terms of medical description and the use of acronyms or abbreviations. The use of medical data without an adequate processing does not contribute enough value. In this work the costliest tasks have been data cleaning and mapping of data sources with the ontological resources, due to the difficulties mentioned above.

The semantic web uses vocabularies and ontologies to create a common language that results in more precise and unambiguous specifications. This is a key aspect, to enable the exchange of information between healthcare institutions. In fact, the Semantic Web establishes a relationship between the different information sources by mapping the data with repositories of biological, medical, and clinical practice terminologies and taxonomies. And it allows the extracted knowledge to be modeled. For example, if myocardial infarction is described in the medical history of a patient, it acquires meaning according to the specific context. The meaning could be a statement indicating that the patient was diagnosed with myocardial infarction or that it is a family history of the patient. It could also be used to document a smoking complication or a drug counter-indication. It can refer to the application of a protocol in a cardiac complication or be considered as a possible diagnosis that justifies a laboratory test or diagnostic imaging, or even the exclusion of a diagnosis because of the tests. The terminologies and ontologies of the medical scope allow mapping this information according to the context, which not only allows improving the quality of the patient's clinical history but also facilitates an accurate recovery of the data; for example, it is incorrect to recover those with a family history of myocardial infarction when searching for patients with a myocardial infarction diagnosis.

VII. CONCLUSIONS AND FUTURE WORKS

The preliminary case study results showed that the Semantic Web approach and the linked data technologies applied to the electronic medical records worked as expected. The use of interoperability standards (URI, RDF, SPARQL, OWL) also reinforces the Semantic Web to attain high levels of interoperability, as they allow representing the diversity of information sources in different types of formats[26]. By

means of this paper, we have experimented how the Semantic Web technologies are a feasible alternative to solve data interoperability and integration problems, as well as to improve data semantics in the electronic clinical histories. The use of semantic resources like SNOMED CT or ICD 10 CM facilitates the identification of the knowledge contained in the clinical histories and allows us to have quality data because the specifications are more accurate and unmistakable.

The proposal offers a perspective to solve the need to have a health ecosystem at the national level for the exchange of data and semantics across different health organizations and networks. This would be significantly useful for the patients and reduce the costs for all members of the ecosystem, as the providers gradually adopt more intuitive and faster systems and become connected to all the necessary data sources.

The proposal is aligned with the view to structuring medical information towards a global database, with linked entities and meanings. These linked entities and meanings are important to improve the current health tools for doctors and patients, as well as to further enhance the local and national health services. Medical information interoperability is the driving force to provide real-time results and improve quality of care. Ultimately, both health professionals and patients want sanitary efficiency and efficacy.

The benefits for the researchers are centered on the fact that information semantics will allow them to find more evidence to propose more accurate therapeutic treatments for the diseases, while the doctors will have better tools at their disposal for individualized clinical treatments of their patients. The States also reap benefits from the information, which allows them to elaborate evidence-based public policies and allocate resources to the areas that need them most.

As we have already exposed in this work, information exchange in medical care, as is the case with the all the other facets of modern life, is fundamental for the digital transformation. While interoperability addresses this need, it also increases the quality of the health care received, improves medical care efficiency and even its optimization. In this sense, the capability to transform structured and unstructured medical information into a Semantic Knowledge Graph is a key component in the process to advance towards the availability of patient-related information in semantic medical records capable of allowing high levels of integration and interoperability.

Having an efficient and effective way to manage health data at their disposal can help doctors achieve a high probability of adequate diagnoses and treatments. The main challenge to attain this ambitious objective, which is our future work, is not only to allow for the integration of data encompassing heterogeneous sources and formats but also the development of instruments and good practices that allow conducting flexible searches, searches based on natural language processing, medical assistants, automated annotations of medical texts, data analysis, and easy-to-use interfaces.

We plan to advance towards the mining and machine learning techniques to find useful patterns and knowledge in the unstructured data which are freely introduced in the

medical records. Refine identification of knowledge in the Spanish language and in written text in acronyms or abbreviations of medical terms. This will enable techniques for the detection or typing of symptoms and signs related to certain diseases. Tasks of medication and adverse drug event relation extraction. On the other hand, identification of hospital processes to reduce costs due to excessive requests for unnecessary complementary diagnostic studies. Finally, given that the HUTPL is a university hospital that supports the training of medical students, it is an important step to transform the anonymized medical information into linked data that can be used in various educational resources[44].

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