UNIVERSIDADE ESTADUAL DE CAMPINAS

Faculdade de Engenharia Elétrica e de Computação

JAN CARL BEECK PEPPER

USING ONTOLOGIES TO RETRIEVE EVIDENCES FROM CLINICAL NOTES

USANDO ONTOLOGIAS PARA RECUPERAR EVIDÊNCIAS DE ANOTAÇÃO CLÍNICAS

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Using ontologies to retrieve evidences from clinical notes
Usando Ontologias para Recuperar Evidências de Anotação Clínicas

Dissertação apresentada à Faculdade de Engenharia Elétrica e de Computação da Universidade Estadual de Campinas como parte dos requisitos exigidos para a obtenção do título de Mestre em Engenharia Elétrica, na Área de Engenharia de Computação.

Supervisor: Prof. Dr. Ivan Luiz Marques Ricarte

Este exemplar corresponde à versão final da tese defendida pelo aluno Jan Carl Beeck Pepper, e orientada pelo Prof. Dr. Ivan Luiz Marques Ricarte

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A ata de defesa, com as respectivas assinaturas dos membros da Comissão Julgadora, encontra-se no processo de vida acadêmica do aluno.

ABSTRACT

There are many barriers to the process of making clinical decisions based on the latest available health and medical evidences, such as the continuously growing volume of health and medical scientific information and the health professionals' lack of time for searching for these evidences. This thesis presents a strategy to search evidence databases directly from clinical notes, such as those taken in electronic health records (EHRs), using ontologies to capture specific health-related domains and the characteristics of evidence databases. We used the PRISMA methodology for the literature review. Thus, we did two searches, the first one to identify the barriers and facilitators to find relevant evidences, and the second one to know the techniques proposed related with the integration between EHRs and evidence based practice (EBP). The tools that we used through the study are: Protégé for the ontology creation and generation of the OWL document, MySQL database for the storage of raw information, and the Jena API for the RDF creation and retrieval. As a proof of concept, two ontologies are defined, one for the domain of adult asthma and another for evidence databases. Two evidence databases were used, one generic (PubMed) and one specific (PEDro). A scenario demonstrates how it is possible to search for evidence from electronic records notes, helping health professionals to receive relevant information as they assist patients.

Keywords: Evidence-Based Practice, Bibliographic Databases, Semantic Web, Ontology

RESUMO

Existem muitas barreiras para o processo de tomada de decisão clínica baseada nas evidências médicas disponíveis, tais como o crescimento contínuo no volume de informações médicas científicas e a falta de tempo dos profissionais da saúde em buscar essas evidências. Essa tese apresenta uma estratégia para procurar base de evidências diretamente das notações clínicas, tais como registros eletrônicos de saúde (RES), usando ontologias para capturar específicos domínios relacionados a saúde e as características das bases evidências. Nós usamos a metodologia PRISMA para a revisão da literatura. Sendo assim, fizemos duas pesquisas, a primeira para identificar as barreiras e os facilitadores para encontrar evidências relevantes e a segunda para saber as técnicas relacionadas com a integração entre os RES e práticas baseadas em evidências (EBP). As ferramentas que usamos neste estudo foram: o Protégé: para criação de ontologias e geração do documento OWL; o banco de dados MySQL: para o armazenamento de informações brutas; e a API Jena para a criação e recuperação do documento RDF. Como prova desse conceito, duas ontologias foram definidas, uma para o domínio de asma em adulto e a outra para base de evidências. Duas bases de evidências foram usadas, sendo uma genérica (PubMed) e outra especializada (PEDro). Um cenário demonstra como é possível procurar evidências de registros de notas eletrônicas, ajudando os profissionais de saúde para receber informações relevantes enquanto cuidam de pacientes.

Palavras-chaves: Prática Baseada em Evidências, Bases de dados bibliográficas, Web Semântica, Ontologia

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1 INTRODUCTION

Healthcare professionals usually have to take decisions related to their patients assistance. Ideally, such decisions should be based not only on their experience, but also on the most current information available. This is the essence of Evidence-Based Practice (EBP) or, specifically in the case of physicians, Evidence-Based Medicine (EBM) (SACKETT, 1997). However, the daily volume of published health and medical research makes it impossible for these health professionals to become fully informed about their fields of knowledge (ALPER *et al.*, 2004).

Knowledge translation is a process to promote EBP. It includes the synthesis, dissemination, exchange and ethically sound application of knowledge to improve health, provide more effective health services and products, and strengthen the health care system (STRAUS *et al.*, 2009). One resource related to knowledge translation are evidence databases, bibliographic databases with focus on published evidence. They keep synthesized information potentially useful to healthcare professionals.

Availability of these databases is not enough to support EBP. Health professionals have difficulties to formulate appropriate queries, with structured clinical questions about issues related to specific patients, and even to know where to search for evidences (CALDWELL *et al.*, 2012). Lack of time and not perceiving information needs are also identified as barriers to the adoption of EBP (RANDELL *et al.*, 2009).

Semantic Web technologies are the key to integrate the huge volume of information currently available in digital format (SHADBOLT *et al.*, 2006). Among these technologies, computer-based ontologies have the most expressive power to represent a field of knowledge. An ontology is an explicit specification of a conceptualization, which is the set of objects, concepts, and other entities that are presumed to exist in some area of interest and the relationships that hold them (GRUBER, 1993).

This work shows how ontologies can be used to extract, from clinical notes taken by health professionals while assinting their patients, the elements required to perform a query to specialized evidence databases, also described by ontologies. With this integrated approach, it becomes possible to bring evidence to health professionals without demanding from them any additional effort on structuring clinical questions, knowing each evidence database and corresponding search interface, and spending extra time performing these searhes.

1.1 Defining the Problem

The problem that we are going to solve: is to find relevant information from clinical notes and to use this information to query heterogeneous evidence databases. This will help to make the evidence search transparent to the health professionals. Thus, help to save time and improve the patient care by using the best evidence available.

Our specific problem statement is: *The development of effective and efficient methods (computer ontologies, storage method, and retrieval queries) for a transparent integration between clinical notes and medical evidence. The question is whether it would be possible to integrate EHR with EBP.*

1.2 Objectives

Our objectives are:

1. Creation of two types of ontologies; one for the knowledge specification in a certain domain of interest, for this study we selected to work within the Adult Asthma; and the other ontology for the knowledge-structure specification of two evidence databases, PubMed PICO and PEDro Physiotherapy Evidence Database.
2. Creation of two knowledge repositories; one for the adult asthma domain and the other for the medical evidences.
3. Integration of the two knowledge repositories with the clinical notes from the electronic health records.

2 LITERATURE REVIEW AND THEORETICAL BACKGROUND

In this chapter we will present and discuss extensively the concepts necessary to understand our contributions and the state-of-art on the subject. At first, we will show how we did the literarure review through a metodology. In the sequence, we will introduce the basic concepts of the Semantic Web.

2.1 Literature Review

This literature review was done using the principles of systematic reviews, as stated in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses framework (PRISMA) (MOHER *et al.*, 2009). The review procedure can be summarized as follows. Initially, the main concepts related to the review question are identified, and a set of terms corresponding to each concept, including synonyms and abbreviations, is established. These terms are used to create search queries for each bibliographic database that may contain papers related to the subject of interest, and the results are scanned to identify relevant papers, also the exclusion criteria are applied in this step.

We do not have a specific interval of time for the queries. We selected the papers that best addressed our problem. One limitation that we have in our literature review using the PRISMA methodology is that we do not have judges in the process of selecting the papers to study; therefore there might be some subjectivity in the process. Another limitation is that we only considered papers that were indexed by the selected databases, however maybe there are some relevant papers for our study that could be scattered on the internet because we did not make a query in a search engine (i.e. Google search engine).

The first focus of the review were Barriers and Facilitators to find relevant Evidences. We performed a query in four different databases, PubMed, ScienceDirect, ACM Digital Library, and IEEExplore. The result was 1770 papers to scan. We selected 25 papers to study. Then we did a second review where the scope is the integration between Electronic Health Record and Evidence-Based Practice, we search in the same four different databases as the first review, obtaining 339 articles, where 8 articles were selected to study. All the steps of the methodology can be seen in (Figure 1). The following sections synthesize our findings.

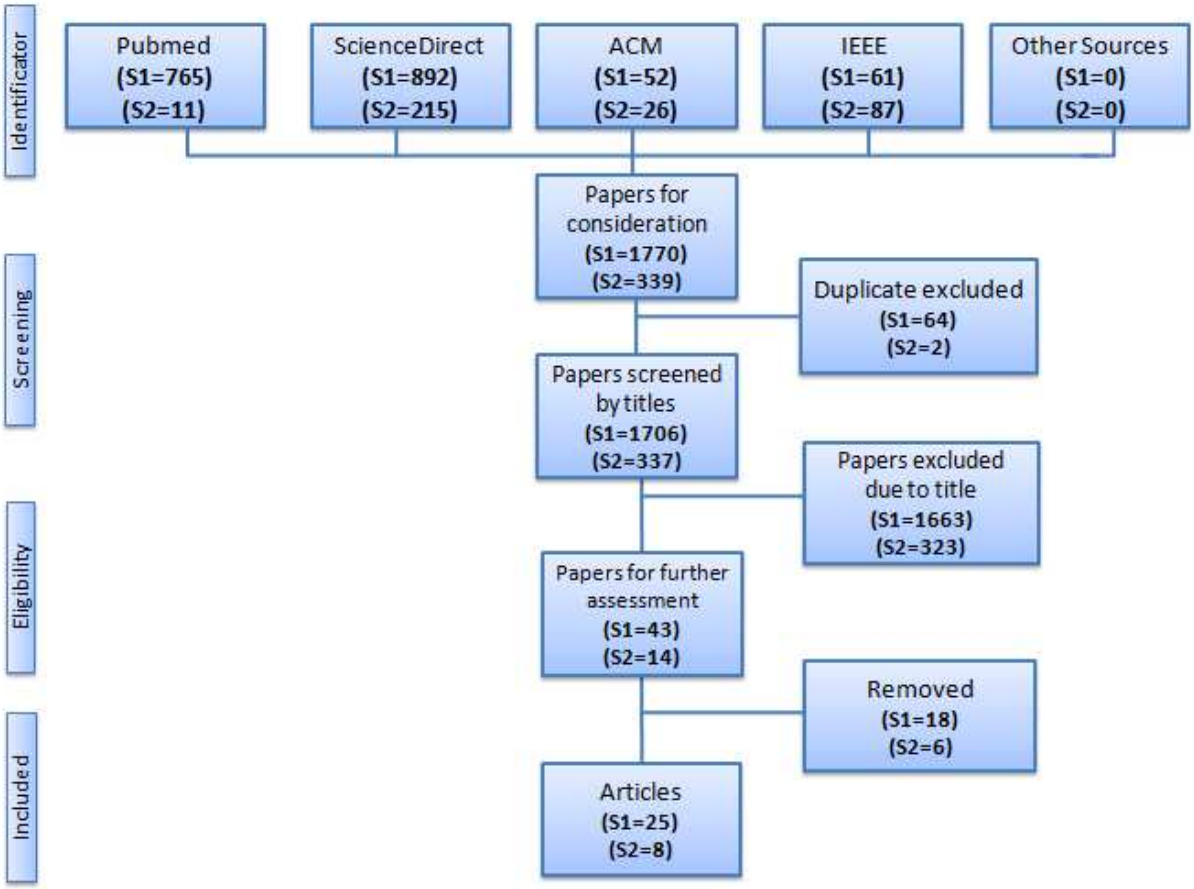

Figure 1 – Summarization of the application of the PRISMA framework in this study.

2.1.1 Barriers and facilitators to find relevant evidences

For this first part of our literature review, we first identified the key concepts: barriers, problems, difficulties, facilitators, advantages and benefits. Then we create a search query with abbreviations, synonyms and logical operators for each database selected. The below Table 2.1 is an example of how we did the search by a query in one database.

2.1.1.1 Summary of the first review

The number of physicians performing their own searches is increasing significantly, however the medical literature published is enormous and is increasing at a rapid rate, and is not immediately accessible to most health professionals (STEWART; MOORE, 1998). A study (FONTANAROSA, 1999) addressed the potential of the use of EBM as an approach to assist the clinical decisions by conducting a systematic method for identifying, retrieving, evaluating, classifying, and synthesizing the scientific information. Thus, the use of EBM is an approach to reduce the gap between research and practice by assessing the available evidence, determining how solid the evidence might be, and judg-

Database	IEEE Xplore
Query	(barriers OR problems OR disadvantages OR advantages OR facilita*) AND ("clinical,evidence" OR CE OR pubmed OR Cochrane OR "information seeking" OR "clinical,decisions" OR "databases") AND ("health professional" OR "medical persons" OR,"physicians" OR "nurses")
Results	61
Selected	6

Table 1 – Example of the search query with abbreviations, synonyms and logical operators, and its results in the IEEE Xplore database.

ing whether the evidence is applicable to patient care. Nevertheless we have identified from the literature review some education's barriers like: difficulty in searching the best evidence, because most of the time they are heterogeneous and fragmented, which leads to the difficulty of making accurate decisions (KNEAFSEY, 2007). Another obstacle for the use of EBM is that not always is disseminated correctly, because the terminology used in the evidences most of the time is difficult to interpret and also exist a lack of motivation to change the current clinical practice to stimulate the attitude towards adopting research-based knowledge into practice (TAYLOR-PILIAE, 1998), all these issues generate the absences of awareness of evidence databases. On the other hand we have identified the education's facilitators: training and motivation, both facilitators lead to the acceptance and use of EBM for the decision-making in medicine. The study of (GRAVEL *et al.*, 2006) points the advantages of EBM for a positive impact on the clinical process on the patients outcomes, (1) improved knowledge, (2) produced more realistic expectations, (3) lowered decision conflict, (4) increased the proportion of people active in decision-making, (5) reduced the proportion of people who remained undecided, and finally (6) produced a greater agreement between values and choices.

We have identified that also exist technology issues to the use of EBM, some barriers are: lack of investment in computing resources which leads to no access to evidence databases; also the health professionals have to be able to use correctly the tools provided for the use of EBM. (KERSTEN *et al.*, 2008) point that there could be probably a sense of loss of autonomy by the physicians, as well as workload in the use of EBM. An article from (SJöBORG *et al.*, 2006) indicates the need for the develop of advanced clinical decision support systems (CDSS), which is one solution to provide the evidences directly into the working processes of physicians and other healthcare staff. Nevertheless, new technologies are changing rapidly the way physicians access and use medical information, but these new tools have to be simplified in order to be effective. Also it is possible to note the existence of a generational shift toward using computer-based systems, younger

physicians accessed online resources more frequently and in greater percentages, both at work and home, and also they are more familiar with available resources and with how to find full-text articles online (BELLMAN *et al.*, 2005). We have also detected that currently exist some technology's facilitators: one solution may be to "push" the information through-mail and Web 2.0 tools such as wikis and Twitter in a "just the facts" format, the former were proposed by (SOLOMONS; SPROSS, 2011), these tools will allow the dissemination of the EBM practice through all the organization, because the medical literature has to move from journals to practice more expeditiously than at the present rate.

Time and tradition-based practices are real constraints for the use of EBM (TAYLOR-PILIAE, 1998), also some problems could eventually arise in the integration of EBM with the classic way of doing medicine, because the former is a disease-oriented and not a patient-oriented. The majority of the patients have symptoms that do not fit exactly in the diagnostic criteria formulated by the researches, this is because of the randomized clinical trials approach. Thus, EBM and patient-centered medicine are two prevailing paradigms, the challenge is the integration of both approaches (BENSING, 2000). The sensation of loss of authority by physicians is another barrier that we found in the use of EBM, therefore they could create resistance to the adoption of EBM (CARRASCO, 2002), besides there is also the fact that the health professionals have not enough authority, neather the time to change patient care procedures in a workload environment (MCKENNA *et al.*, 2004). An import advance toward the use of EBM is that currently some hospital executives' boards, insurance companies and consumers recognize that EBM may help prevent unsafe or inefficient practices, as part of a strategy to achieve quality improvement in healthcare (MAASKANT *et al.*, 2013).

From this first review we have concluded that the barriers are: (1) Lack of time; (2) Difficulty in the search, the professional do not have a methodology neither the know-how to search on the evidence databases; (3) Lack of knowledge of the evidence databases; (4) Lack of authority to change procedures; (5) Lack of investment in computing resources, the institutions do not buy computers neither appropriate systems; (6) Unfavorable clinical environment, exits a lack of technological culture in many organizations; (7) Heterogeneity, the professionals usually find inaccurate information, inconsistent data and weak evidences; (8) Difficulty in interpreting the medical evidences, not enough preparation for the use of evidence; and (9) Lack of access to the evidence databases. The facilitators are: (10) Knowledge of evidence-based medicine; (11) Training and motivation of the staff; (12) Access and investment in resources, the organizations have a tecnological infraestructure; and (13) Favorable clinical environment, the institutions have a tecnological enviormental and cultural.

We have grouped our study in three global categories for the barriers and facilitators in the use EBM. The first category is technology, with the barriers (5) – (6) – (7) – (9) and facilitators (12) – (13); second is evidence medicine practice, with just two barriers, (1) and (4); and the third category is education, with barriers (2) – (3) – (8) and facilitators (10) – (11).

From this first literature review we find the existence of difficulties in the use of EBM like: time constraint and lack of knowledge to do the search. We can conclude that there is a need to turn the search "transparent" for the users, that means inserting the latter activity as an automatic task while the health professional performs his/her regular duties like for instance doing annotations in an EHR, this will facilitate the use EBM on a daily basis. One limitation of this literature review is that we have not considered the issue of privacy, therefore we assumed that privacy must be considered implicitly in any application related to the healthcare in order to be a valid solution.

2.1.2 Integration between electronic health records and EBP

This literature review presents the state of the art related to the relationship between clinical notes taken by health professionals, usually registered in Electronic Health Records, and EBP or, more specifically, to the access of evidence databases to support clinical decisions.

Using the principles of systematic reviews, as stated in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses framework (MOHER *et al.*, 2009), initially the main concepts related to this review question, Electronic Health Record and Evidence-Based Practice, and the set of terms corresponding to each concept are defined. As an example, the concept Electronic Health Record is also referred to in the literature as Electronic Medical Record and by their abbreviations, EHR and EMR. Thus, the string query should be *("electronic health record" OR "electronic medical record" OR ehr OR emr) AND ("evidence based practice" OR "evidence based medicine" OR ebp OR ebm)*

This search, performed on PubMed, ScienceDirect, ACM Digital Library, and IEEExplore, returned 339 papers. From these, two were excluded for being duplicate; 323 were excluded by scanning their titles; and six papers were excluded upon analysis of full text. Table 2 presents the eight remaining papers considered in this review. The following paragraphs synthesize their findings.

2.1.2.1 Summary of the second review

One of the problems in integrating the clinical notes to scientific papers is that the terms used to classify the papers, usually taken from the Medical Subject Headings (MeSH) vocabulary, are not the same used in clinical notes. The Medline Button (MEN-

Reference	**Problem**	**Proposed solution**
(MENDONçA *et al.*, 2001)	Search query formulation	Controlled terminologies
(LEONG *et al.*, 2007)	Guidelines integration	Open source software
(SARTIPI *et al.*, 2007)	Clinical data mining	Decision support services
(BOROVICKA, 2008)	Multiple sources of information	Ontologies and semantic annotations
(WIESNER; PFEIFER, 2010)	Recommender systems	Extract health information from Wikipedia
(HSU *et al.*, 2012)	Clinical text mining	Ontologies and semantic annotations
(MANE *et al.*, 2012)	Visual presentation of guidelines	Mapping patient data to guideline
(VALKENHOEF *et al.*, 2013)	Clinical decision support	Unified data model for evidences

Table 2 – Summary of literature review.

DONçA *et al.*, 2001) integrates to EHR an automatic search for papers in the Medical Literature Analysis and Retrieval System Online (MEDLINE), taking as starting point not the text, but diagnosis and procedures codes from the International Classification of Diseases (ICD). To translate ICD codes to MeSH terms, the authors used the Unified Medical Language System[1] (UMLS), which combines, into an integrated metathesaurus, hundreds of terminologies and classifications. However, this approach requires an established diagnosis for the patient; limiting the access to relevant information to a later moment in the assistance.

Information overloading is a potential problem when working directly with the text in clinical notes, since not all data stored in EHR is relevant for the search that must be performed. Hsu et al. use ontologies to analyse clinical data on EHR (HSU *et al.*, 2012), with the objective of synthesizing clinical patient data to ease comprehension by health professionals. Although it was not the objective of Hsue et al. to integrate a scientific literature search to EHR, the use of ontologies to extract only the information that is relevant for the task to be performed is promising. Another approach is to represent the extracted data using graph-based structures, such as semantic networks. This approach was adopted by Wiesner and Pfeifer to integrate a recommender system to a personal health record (PHR) system (WIESNER; PFEIFER, 2010). Their proposal was to map entries from PHR to concepts in a health graph data, extracted from Wikipedia, using a concept distance measure. In their study they referred to another work (GABRILOVICH; MARKOVITCH, 2006), the latter represents the meaning of texts by a high-dimensional space of concepts derived from Wikipedia, and the semantic relatedness is computed by the distance between two concept.

Having access to scientific information to support clinical decisions is the goal of the Aggregate Data Drug Information System (VALKENHOEF *et al.*, 2013). ADDIS

[1] http://www.nlm.nih.gov/research/umls/

is an evidence-based drug-oriented strategy decision support system, based on the premise that clinical trials are the main source of information for the efficacy and safety evaluation of medical treatments. According to these authors, there are no established systems that inform strategic (rather than operational) decisions, such as identifying the best treatment practices based on risk-benefit analyses. They claim that evidence-based decision making systems are difficult to implement because of the substantial effort required to systematically review the literature for relevant studies and to manually extract the data from these studies.

A workable integration between EHR and EBM has to be affordable, interoperable, and adaptable. Such requirements are difficult to meet in traditional closed, proprietary, vendor and application specific health care IT models. For this reason, free and open-source (FOS) software systems, are good alternatives to overcome some of these issues. Protégé (LEONG *et al.*, 2007) is a general ontology editing framework developed in Java by the Stanford Medical Informatics group. It has an extensible architecture for the creation of customized knowledge-based tools, and it assists users in the design of knowledge-acquisition forms and in entering domain knowledge. Protégé is also a library, which other applications can use to access and display knowledge-bases.

This literature review has shown that there are proposals to integrate clinical data and evidence information through knowledge capture. Concepts in these proposals are organized either in ontologies, in conceptual graphs, or in high-dimensional space of concepts capturing the meaning of texts. There also exists systems developed to promote EBP, but these systems did not address the integration of evidences with EHR using ontologies.

2.2 Theoretical Background

For the development of our work it is important to first define and explain the main concepts related to the Semantic Web, being the former our set of tools for the rest of our work. The definitions where taken from (YU, 2011).

2.2.1 Semantic Web

It is build on top of the current Web, besides the HTML it contains some statements that can be collected by an agent, the latter organizes and connects these statements into a graph format, this lead the possibility to an automatic data integration on the Web for information discovery and retieval. Web of Data is the concept used for interchangeable terms for the Semantic Web.

2.2.2 Statement (or triple)

It is a small piece of knowledge, a single fact, and it has Subject-Predicate-Object as a structure. The subject (resource) and object (value) are the names for things in the world. The predicate (property) is the name of a relation that connects two things. Below are some examples of statements.

- PEDro is a physiotherapy evidence database: where "PEDro" is the subject and "physiotherapy evidence database" is the object , and "is" is the predicate.
- PEDro and PubMed are physiotherapy evidence databases: where "PEDro and PubMed" and "physiotherapy evidence databases" are the subject and object respectively, and "are" is the predicate.
- Asthma is a respiratory disease: where "Asthma" and "respiratory disease" are the subject and object respectively, and "is" is the predicate.
- Asthma is a respiratory disease who belongs to respiratory physiotherapy: where "Asthma is a respiratory disease" and "respiratory physiotherapy" are the subject and object respectively, and "belongs" is the predicate.
- PEDro and PubMed have evidences for asthma: where "PEDro and PubMed" and "evidences for asthma" are the subject and object respectively, and "have" is the predicate.
- Allergy is a symptom of asthma: where "Allergy" and "symptom of asthma" are the subject and object respectively, and "is" is the predicate.
- Stuffy nose is a consequence of allergy: where "Stuffy nose" and "consequence of allergy" are the subject and object respectively, and "is" is the predicate.

It is possible to see that different facts in a certain domain can be organized in the form of statements, this allows us to create a knowledge base or a set of facts that can be understood by computers.

2.2.3 Resource description framework (RDF)

RDF stands for Resource Description Framework, and it was originally created in early 1999 by W3C as a standard used to represent distributed information/knowledge in a way that computer applications can use and process in a scalable manner, also is a standard for encoding metadata. The RDF concept and model can directly help to promote interoperability between applications that exchange machine-understanble information on the Web. Below is the sumarization of an RDF; and a example where

there is a node of an RDF's document and/or graph which is related to a property of a particular domain, in this case is 'symptom' that is related with the asthma domain, we can see that the node has its own ID and also has a name and description as attributes.

- RDF is the basic building block for supporting the vision of the Semantic Web.
- RDF is for the Semantic Web what HTML has been for the Web.

```
<rdf:Description rdf:nodeID="A3">
<j.0:symptomName>Classical symptoms</j.0:symptomName>
<j.0:symptomDescription>Eye symptoms</j.0:symptomDescription>
    <j.0:symptomDescription>Watery rhinorrhoea</j.0:symptomDescription>
    <j.0:symptomDescription>Nasal irritation</j.0:symptomDescription>
    <j.0:symptomDescription>Itching</j.0:symptomDescription>
</rdf:Description>
```

2.2.3.1 RDF data store

RDF data store is a special database system built for storage and retrieval of RDF statements. It is like a relational database in that we can store RDF statements there and retrieve them later by using a query language. It can be built as a specialized database engine from scratch, or it can be built on top of existing commercial relational database engines.

2.2.4 Computer ontology

An ontology is an explicit specification of a conceptualization, which is the collection of objects, concepts, and other entities that are presumed to exist in some area of interest and the relationships that hold them (GRUBER, 1993). Is a common language, or a vocabulary, where classes, subclasses, properties, and also the relation between the classes and properties are defined. Is also domain-specific and it allows the creation of distributed RDF documents. It also can be seen as the concepts' structure. Thus, is the model to represent the knowledge in an easy and readily processed (understood) by machine. In an ontology the facts are expressed as RDF statements.

Figure 2 is a high level conceptualization of the Asthma computer ontology.

2.2.4.1 Web ontology language (OWL)

OWL stands for Web Ontology Language, and it is currently the most popular language to use when creating ontologies. It is build upon RDFS (RDF Schema), the former is a common language, or a vocabulary, where classes, subclasses, properties, and also the relation between the classes and properties are defined. Is also domain-specific and it allows the creation of distributed RDF documents. It has the same purpose as RDFS: classes, properties, and their relationships for a specific application domain. It also provides capability to express much more

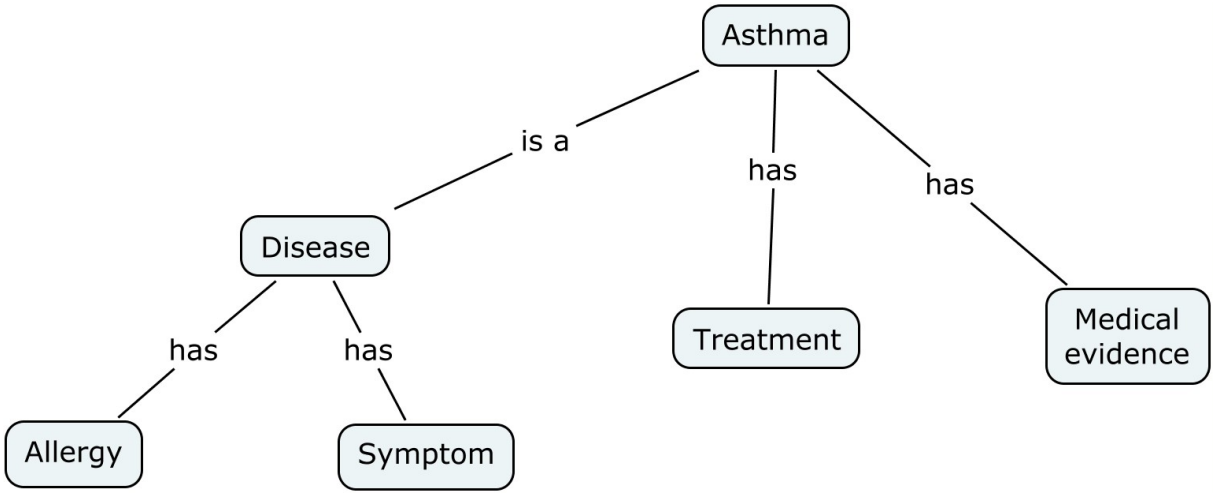

Figure 2 – Example of a high level conceptualization of a specific ontology.

complex and richer relationships (better expressiveness). OWL can be viewed as a collection of terms or/and axioms. Below are the definitions of the OWL building blocks: axiom, entity, and IRI. And an example of part of an OWL document created with the Protégé tool; where we can see two IRIs, the firt IRI is a property of class defined in the second IRI.

- Axiom: is the basic statement or basic piece of knowledge. A collection of axioms is an OWL ontology. For example the following statements: "Disease" class is a subclass of the "Asthma" class; "Allergy" is a subclass of the "Disease" class.
- Entity/Object: are classes, properties, and individuals.
- IRI: stands for Internationalized Resource Identifiers, it is like URIs but with Unicode characters. It provides a mechanism to uniquely indentify a given resource, and specifies a uniform way to retrieve machine-readable description about the resource being identified by the IRI.

```
<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies
                        /2014/5/asthma#allergyName">
        <rdfs:range rdf:resource="&xsd;string"/>
        <rdfs:domain>
            <Restriction>
                <onProperty rdf:resource="&owl;topObjectProperty"/>
                <someValuesFrom rdf:resource="http://www.semanticweb.org
                                /jan/ontologies/2014/5/asthma#Allergy"/>
            </Restriction>
        </rdfs:domain>
    </DatatypeProperty>
```

2.2.5 Linked Data

Also know as the Web of Linked Data, the idea behind this technology is to create a machine-readable Web. It is done by publishing machine-readable data, such as RDF documents on the Web, and make all these documents connected to each other, so that can be processed by machines. Also Linked Data refers to a set of best practices for publishing and connecting structured data on the Web. Below are the rules required in the Linked Data.

- Rule 1: Use URIs as names for things.
- Rule 2: Use HTTP URIs so that client (machine or human reader) can look up these names.
- Rule 3: When someone looks up a URI, useful information should be provided.
- Rule 4: Include links to other URIs, so that a client can discover more things.

It can be seen as a big collection of RDF triples, where the subject of any triple is a URI reference in the namespace of one dataset, and the object of a triple is a URI reference in the namespace of another. Below are some examples.

- http://diseases.com/respiratory.rdf#asthma has http://evidencedb.com/asthma.rdf#allergy: where the first URI is reference to a dataset related with diseases, and the second URI referenced to a evidence's dataset; "has" is the conceptual connection between both URIs.
- http://diseases.com/respiratory.rdf#allergy has http://ncbi.nlm.nih.gov/pubmed/25733374: where the first URI is a reference to a dataset related with respiratory diseases, and the second URI referred to a specific evidence in PubMed database; "has" is the conceptual connection between both URIs.
- http://diseases.com/respiratory.rdf#allergy has http://search.pedro.org.au/search-results/record-detail/11684: where the first URI is a reference to a dataset related with respiratory diseases, and the second URI referred to a specific evidence in PEDro physiotherapy evidence database; "has" is the conceptual connection between both URIs.

2.2.6 Query-based-language

Due to the large ammount of RDF documents that have been published on the Internet, and a machine-readable Web that has started to shape, there is a need to locate specific information on this data Web. So one solution is a query language that we can use on this data Web; by simply submitting a query we should be able to directly get the answer.

2.2.6.1 SPARQL

SPARQL is an RDF query language and data access protocol for the Semantic Web. Its name is a recursive acronym that stands for SPARQL Protocol and RDF Query Language.

It was standardized by W3C's SPARQL Working Group. SPARQL is a query language that we can use to query the RDF data content, besides it also provides a protocol that we need to follow if we want to query a remote RDF data set. Below are the befenits of a having a query language such as SPARQL. And also three examples of queries, the first one find all the attributes related with the property *symptomName* in an ontology that is specified in an RDF document, it has the namespaces asthma and DC defined, then is the query that use the 'select and where' clauses; the second query retrieved all the URLs associated with the property *queryString* in an RDF document; and the last query does the same as the second query but for the property *queryProblem*.

- Query RDF graphs to get specific information.
- Query a remote RDF server and to get streaming results back.
- Run automated regular queries again RDF dataset to generate reports.
- Enable application development at a higher level, i.e., application can work with SPARQL query results, not directly with RDF statements.

```
"PREFIX j.0:<http://www.semanticweb.org/jan/ontologies/2014/5/asthma#>" +
"PREFIX j.1:<http://purl.org/dc/terms/>" +
"SELECT *" +
"WHERE {" +
"?x j.0:symptomName ?symptomName" + "." +
"}"

"PREFIX j.1:<http://www.semanticweb.org/jan/ontologies/2014/5/evidences#>" +
"PREFIX j.0:<http://purl.org/dc/terms/>" +
"SELECT *" +
"WHERE {" +
"?node j.1:queryProblem ?value." +
"?node j.1:queryProblem ?queryString." +
"?node j.1:evidenceURL ?url ." +
"}"

"PREFIX j.1:<http://www.semanticweb.org/jan/ontologies/2014/5/evidences#>" +
"PREFIX j.0:<http://purl.org/dc/terms/>" +
"SELECT *" +
"WHERE {" +
"?node j.1:queryProblem ?value." +
"?node j.1:queryProblem ?queryProblem." +
"?node j.1:evidenceURL ?url ." +
"}"
```

2.2.7 Triple pattern

An RDF model is built on the concept of a triple, a three-tuple structure consisting of subject, predicate, and object. The difference between RDF triple and SPARQL triple pattern is that the latter can include variables: any or all of the subject, predicate, and object values in a triple pattern can be a variable. For example this is a SPARQL triple pattern: *?node evidences:queryProblem ?value*; where the subject of this triple pattern is the variable node that has the character ? in front, the predicate is evidences:queryProblem that comes from the evidences' namespace, and the object component is the variable ?value.

2.2.8 Graph pattern

Is a collection of triple pattern. It is used to select triples from a given RDF graph, but it can specify a much more complex "selection rule" compared to a simple triple pattern. Below is an example, and the steps used to retrieve a solution.

```
"?node evidences:queryProblem ?value."
?node evidences:queryProblem ?queryProblem."
"?node evidences:evidenceURL ?url."
```

- Step 0: Create an empty set called 'resultSet'.
- Step 1: Get the next resource from the given RDF graph. If there is no more resource left, return 'resultSet' and stop.
- Step 2: Process the first triple pattern; if the current resource does not have a property instance called evidences:queryProblem, go to step 6. Otherwise, bind the current resource to variable ?node and bind the value of property evidences:queryProblem to variable ?value.
- Step 3: Process the second triple pattern; if the current resource (represented by variable ?node) does not have a property instance called evidences:queryProblem, go to step 6. Otherwise, bind the value of property evidences:queryProblem to variable ?queryProblem.
- Step 4: Process the third triple pattern; if the current resource (represented by variable ?node) does not have a property instance called evidences:evidenceURL, go to step 6. Otherwise, bind the value of property evidences:evidenceURL to variable ?url.
- Step 5. Collect the current resource into 'resultSet'.
- Step 6. Go to step 1.

2.3 Concluding remarks

We have showed that exists barriers and facilitators in the use of EBM, for our work are important the technological issues. Thus, we are going to address the problem of integration between EHR and EBP. We also have analyzed the existence of proposals to resolve that issue, however, none of them address the integration of evidences with EHR using ontologies and Semantic Web technologies. In the next chapter we are going to describe the methodology that we use to develop an ontology, describe our general proposal, the software architecture that we have defined and its implementation.

3 PROPOSAL

Our proposal is explained in detail in this chapter. Considering that health professionals must already register clinical notes while assisting patients, it would be valuable for them to have access to relevant evidence related to these notes. To achieve this goal, the following questions are proposed:

1. How to extract relevant search terms from clinical notes?
2. How to represent an evidence?
3. How are evidence databases organized and searched?
4. How to integrate searches and results from distinct evidence databases?

To answer these questions, knowledge from specific fields and from their corresponding evidence databases need to be captured and encoded. In this proposal, both are expressed as ontologies. By having the general knowledge about evidence databases expressed as an ontology, simultaneous searches can be performed in distinct databases and their responses can be integrated transparently.

3.1 Conceptual proposal

In order to bring relevant evidence for each patient and be used by the health professionals, we have designed the following proposal.

Figure 3 illustrates this proposal. A Health Knowledge Ontology is used to extract, from the clinical notes taken by the health professional, relevant terms to define a general query, that is, a set of terms and their metadata, which are not specifically linked to specific evidence databases, available in the Web. Knowledge about these databases is represented in an Evidence Databases Ontology. Thus, with this knowledge and from the general query, it is possible to create appropriate queries for each evidence database. This specific knowledge is used again to interpret and to integrate the responses from each evidence database, and the set of Web resources with evidence information becomes available to the health professional.

In the Semantic Web, the Resource Description Framework (RDF) is used to encode specific knowledge. RDF describes Web resources and their existing relations in the real world, being the building block for the Semantic Web (YU, 2011). It is a standard to represent metadata, describing data contained in the Web. It is machine understandable, providing interoperability and domain independence. An RDF document is composed by a sequence of statements, each statement being a triple representing a small piece of knowledge, a single fact, with a Subject-Predicate-Object structure. The subject (resource) and object (value) are the names for things in the world. The predicate (property) is the name of a relation that connects two things.

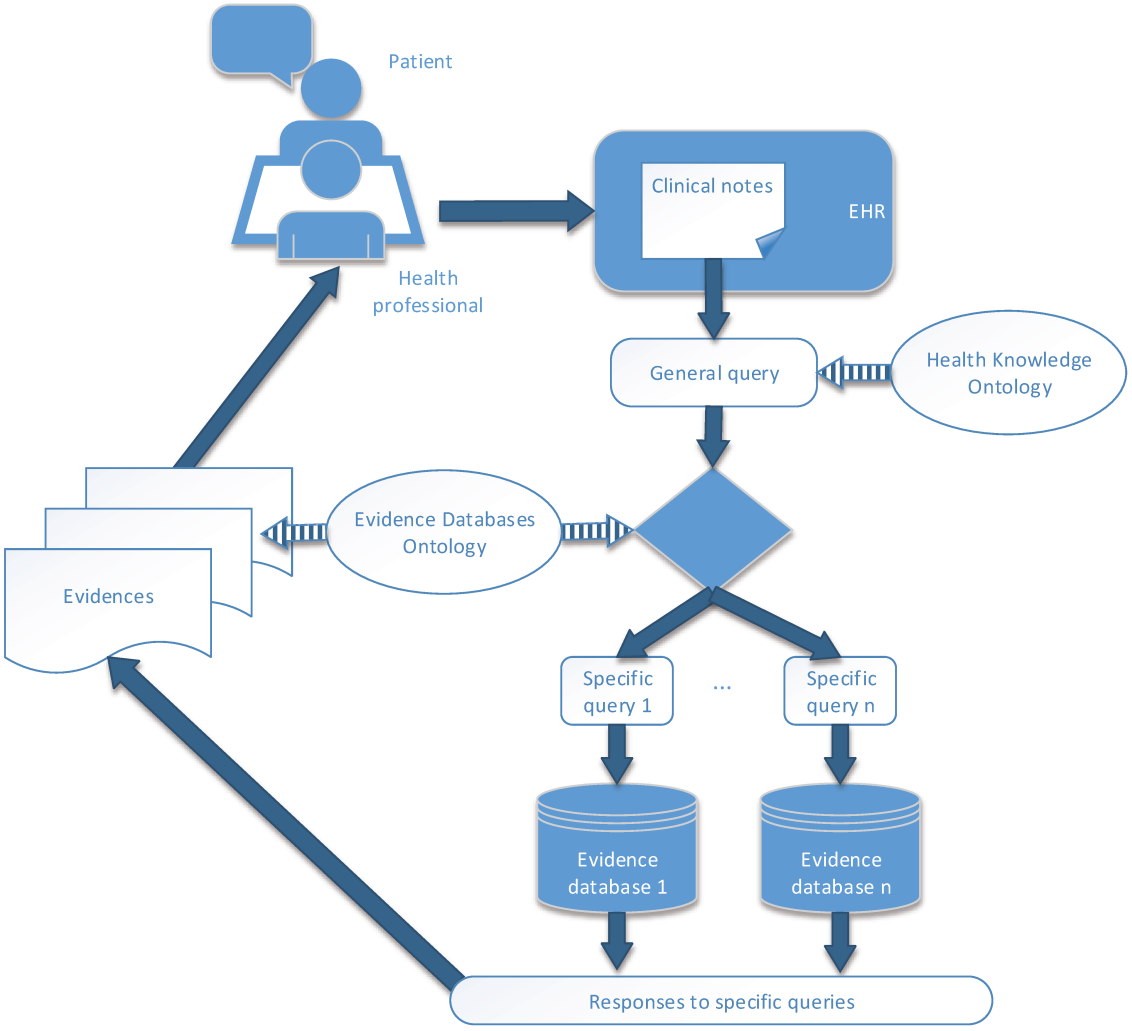

Figure 3 – From the clinical notes to the evidences using ontologies.

In Figure 3, the information flowing from the query to the returned evidences are expressed as RDF documents. There are Application Programming Interfaces (API) to process information using RDF, such as the Jena framework[1], as well as to store RDF statements. The RDF data store is a special database system built to store and retrieve RDF statements, in which every record is a short statement in the form subject-predicate-object. Nevertheless, relational database systems, such as MySQL[2], can be used to store RDF statements.

On top of RDF, the Web Ontology Language (OWL) is used to describe ontologies. Actually, OWL is built on top of RDF Schema (RDFS), which is a common language, or vocabulary, in which classes, subclasses, properties, and relations between the classes and properties are defined. RDFS is domain-specific and allows the creation of distributed RDF documents. OWL also describes classes, properties, and their relationships for a specific application domain,

[1] https://jena.apache.org
[2] http://www.mysql.com

but it provides the capability to express complex relationships, with better expressiveness (YU, 2011). The two ontologies in Figure 3 are represented using OWL. Dublin Core (DC), a standard to describe electronic resources, is also integrated as a framework to describe Web resources in retrieved information.

In this figure, there is a need to integrate ontologies and RDF documents, for which the SPARQL query language can be used. SPARQL (recursively defined as the SPARQL Protocol and RDF Query Language) enables to find specific information on the Web of Data, the gigantic RDF database associated with the Semantic Web. A SPARQL engine matches triples contained in graph patterns with RDF graphs. Once a match is found, it will bind variables from a graph pattern to graph nodes, and each variable binding is a query solution.

3.2 Software architecture

A three-layer architecture is proposed to support the described conceptual model: (1) knowledge domain creation, (2) knowledge capture and creation, and (3) knowledge retrieval.

In Figure 4, we can see the three layers: (1) with the Protégé tool we will generate the OWL documents for the asthma and evidence ontologies; then (2) we will put and store the raw data, which are the IRIs from the OWL documents and its value, for some attributes of the RDF's graph we will use the standard terms from the DC Schema, the latter more specific in the creation of the evidence's RDF, with the raw data in the database and with the Jena framework we will create one RDF for the asthma domain, and the other RDF with the evidence' information; and finally in the last layer (3) the information that is required for both RDF will be retrieved through SPARQL queries.

3.3 Implementation

In this section we describe the implementation of the three layers: (1) knowledge domain creation, (2) knowledge capture and creation, and (3) knowledge retrieval.

We have chosen adult asthma as our domain for the creation of a Health Knowledge Ontology and PEDro[3] physiotherapy and PICO PubMed[4] as the databases for the Evidence Databases Ontology. Both ontologies are going to be designed with a methodology and created in the free-tool Protégé[5] that generates an OWL document.

Adult asthma was selected as the domain of study in this work, because we are familiar with that disease. Thus, it is more convenient to us due that we have some knowledge about that domain. With the latter and the help of a specialist we built a map of concept of that

[3] http://www.pedro.org.au
[4] http://pubmedhh.nlm.nih.gov/nlmd/pico/piconew.php
[5] http://protege.stanford.edu

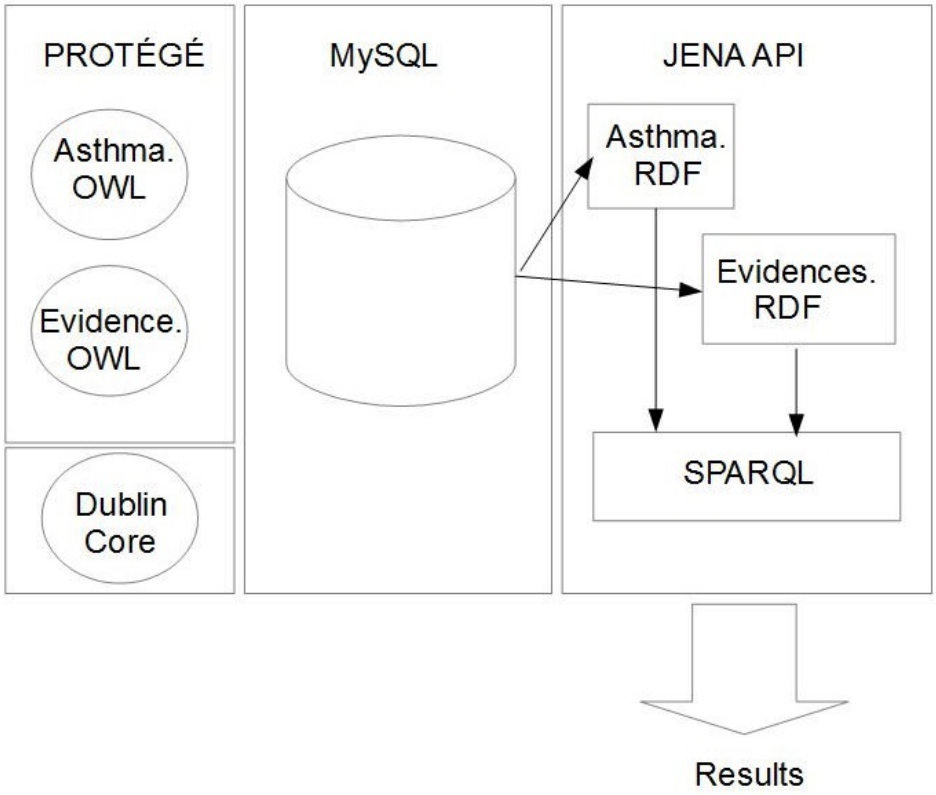

Figure 4 – Three-layer achitecture

disease. The map of concept was validated by one specialist with the following characteristics: a masculine physiotherapy who studied asthma at the university, and who does not work with asthma on daily bases.

For the knowledge capture and creation layer: we are going to generate the models as RDF documents using the Jena framework[6] and MySQL database engine[7], the former will be used for the knowledge model creation which include also the formalization of the statements, and the latter to store the raw data in order to create the RDF documents. The models will be created with the specification of our two crafted ontologies and the Dublin Core Schema (DC) which is already a standard in the Semantic Web.

And for Knowledge retrieval: we will retrieve the information through queries that will be parsed and executed by the SPARQL from the Jena framework. This is going to be done by reading the RDF documents that were created in the previous layer.

[6] https://jena.apache.org
[7] http://www.mysql.com

3.3.1 Knowledge domain creation

The capture and knowledge representation were done through ontologies, first we defined the domain of the ontology and then followed the steps from a chosen methodology, the latter was our roadmap for the ontology creation. After that we implemented it in the Protégé free-tool which gives us an OWL document.

It is important to adopt a methodology for modeling an ontology in order to avoid jumping from the knowledge acquisition process directly to the implementation phase. Also there is a fine line where the ontology ends and the knowledge-base begins. The methodology selected for this work is proposed by (NOY; MCGUINNESS, 2000).

3.3.1.1 Health Knowledge Ontology on Adult Asthma

The first step towards the creation of an ontology is to determine its domain and scope. Four basic questions have to be answered:

1. Which is the ontology domain? In this case, physiotherapy respiratory care for untreated and newly diagnosed adult asthma.
2. What is the ontology purpose? This ontology represents and maps concepts related to adult asthma to find them in clinical notes.
3. For what types of questions the ontology should be able to provide answers? This ontology provides clinical evidence related with adult asthma health problems and interventions based on clinical notes about patients.
4. Who will use and maintain the ontology? This ontology is used by physicians and physiotherapists, and it is maintained by this system developers.

It is necessary to consider the use of existing ontologies. By reusing ontologies, it is possible to make sure that systems can communicate with other applications that have already been committed to those ontologies. However, no adult asthma ontology was found.

The third step is to enumerate important terms in the ontology. This step precedes defining classes and the class hierarchy. At this moment, it should be simply a list of terms in a given domain, without worrying about overlapping concepts, relations among terms, or any properties that concepts may have. Terms for the asthma ontology were: asthma, respiratory physiotherapy, spirometry, chest x-ray, allergy tests, future tests, allergic rhinitis, risk factor, nose, throat, eyes, ears, nasal irritation, clear watery nasal drainage, nasal drainage, eye symptoms, purulent nasal drainage, bacterial infection, nasal polyps, histamine, mannitol, dry air, vasomir rhinitis, bacterial infection, loss of sense of smell, purulent nasal drainage, changes in temperatures, allergy investigation, radioallergosorbent, antihistamines, watery rhinorrhoea allergy investigation, allergic conditions, environment, occupation, anticholinergic sprays, oral

corticosteroids, symptoms, skin prick tests, regular preventer, challenge tests, itching, allergy, congestion.

The next step is to define classes and the class hierarchy. The top-down approach is used, starting from general to specialized classes. The general classes for the asthma ontology are Problem, Intervention, Allergy, and Drug (Figure 5). Related terms, defining specialized classes, are associated to these general classes as described in Table 3.

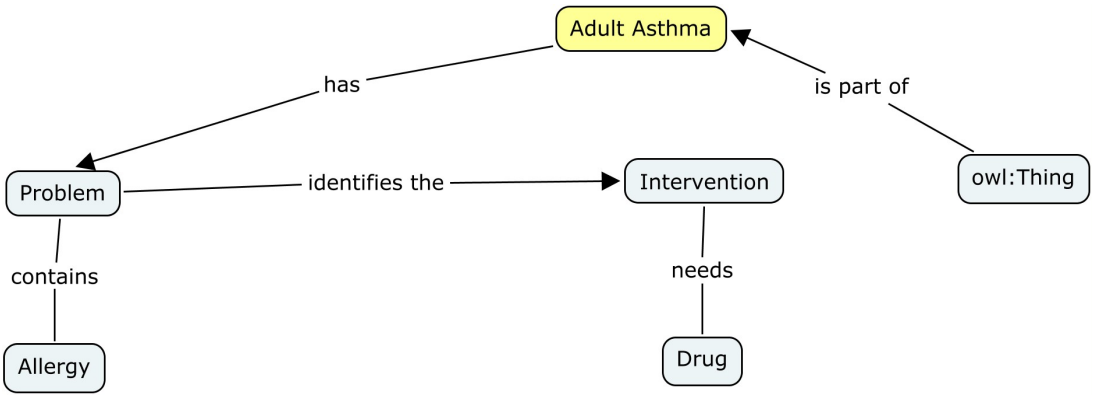

Figure 5 – Asthma ontology description.

Problem:	Intervention:	Allergy:	Drug:
Changes in temperatures	Future tests	Radioallergosorbent	Salbutamol
Clear watery nasal drainage	Spirometry	Vasomotor rhinitis	RAST
Persistent asthma	Physical examination	Ears	Radioallergosorb
Eye symptoms	Chest x-ray	Eyes	Ipratropium bromide
Watery rhinorrhoea	Allery investigation	Throat	Anticholinergic sprays
Nasal irritation	Allergy skin prick tests	Nose	Antihistamines
Itching	Challenge tests	Allergic rhinitis	INCS
Loss of sense of smell			Inhaled nasal corticosteroids
Congestion			Antihistamines
Nasal polyps			INCS
Occupation			Ipratropium bromide
Environment			Oral corticosteroids
Allergic conditions			Methacholine
Risk factor			Histamine
Purulent nasal drainage			Mannitol
Bacterial infection			Hypertonic saline
Risk factor			Dry air

Table 3 – List of terms from the adult asthma ontology in their respective classes.

It is also necessary to define the properties (slots) for each class. For the adult asthma ontology, main class properties are presented in Table 4.

The final step is to add constraints to the properties (facets). Property constraints, such as cardinality, value type, domain, and range are defined in this step. In this case, String

Class or subclass:	Property:
Problem	problemName
Problem	testName
Intervention	interventionName
Allergy	allergyName
Allergy	allergyTestName
Drug	drugName
Drug	drugDescription
Drug	drugType

Table 4 – Asthma ontology properties.

was defined as the range for all properties (slots). The object property describes relationships between two instances, and data property describes relationships between instances and individuals. For the asthma ontology, object properties are: is, are, aka, avoid, co-exist, consider, develop, diagnosis, focus, has, have, include, lessEfective, likely, of, recommend, and require. Data properties are: allergyName, allergyTestName, asthmaTerm, daytimeSymptom, description, drugDescription, drugName, drugType, exacerbation, interventionDescription, interventionName, measuringBreath, nighttimeSymptom, problemName, symptomDescription, symptomName, and testName.

We have choosen Problem and Intervention from the P.I.C.O model to do our string query because both criteria are enough for searching in the selected databases, and also both resolve our problem in this study. The latter might be considered one limitation of the ontology depending of the point of view of the specialist.

3.3.1.2 Evidence Databases Ontology

The same methodology, applied to create the ontology for evidence databases, results in:

Domain: Clinical evidences from PEDro and PubMed PICO databases.

Purpose: To retrieve evidence information as statements stored in RDF documents.

Types of question: Evidence information related to adult asthma procedures and interventions.

Users and maintainers: The ontology will be used by physicians and physiotherapists and maintained by system developers.

When considering to reuse existing ontologies, properties from the Dublin Core Schema[8] are integrated with the properties of the evidence databases ontology. DC is a small set of vocabulary terms used to describe web resources (e.g., video, image, web page), as well as

[8] All the DC terms are accessed through its namespace IRI, at http://purl.org/dc/terms

physical resources (book, CD, artwork). In the DC namespace, each term has a Unique Resource Identifier and is defined using RDF properties.

The important terms in this ontology are: evidence, database, query, title, author, URL, journal, DOI, evidence type, database type, year, PubMed, PEDro, term, identifier, abstract.

The general classes for the evidence database ontology (Figure 6) are Database, Evidence, and Paper in Journal.

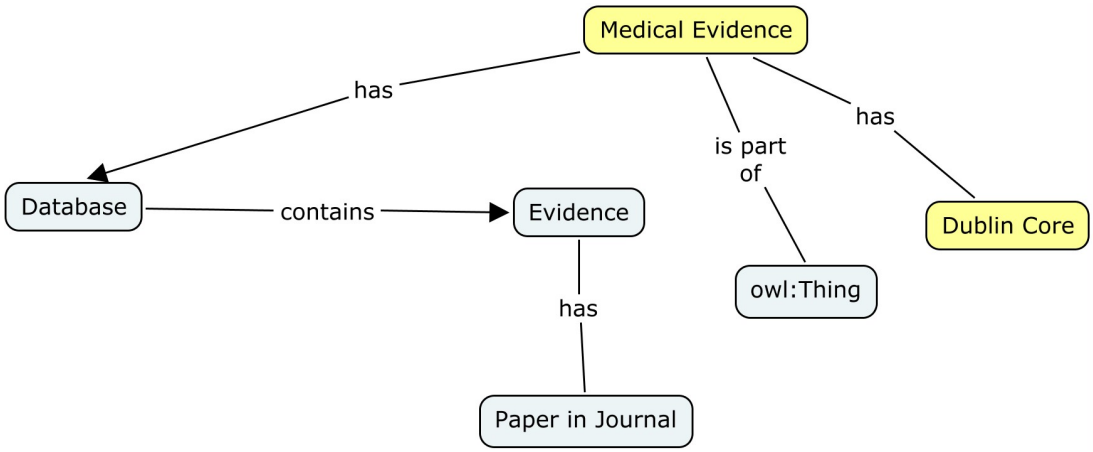

Figure 6 – Medical evidence databases ontology description.

The main properties for this ontology are presented in Table 5. As for the adult asthma ontology, String is the range for all properties. Object properties are: belong, has, is, and link; data properties are: queryString, queryProblem, queryIntervention, createDate, databaseName, databaseType, databaseURL, evidenceURL, evidenceDOI, evidencePedroID, evidencePubmedID, evidenceURL, journalInformation, journalName, journalType, journalPage, journalYear, and meshTerm. Additionally, some attributes from the DC Schema are integrated in this ontology: abstract, identifier, title, type, creator, description, contributor, date, issued, language, publisher, and subject.

3.3.2 Knowledge capture and creation

In this layer, knowledge bases were created by modelling RDF documents based on the specifications of the previous created ontologies. For the asthma ontology, concepts and their relations were firstly modelled using a concept map (i.e. figure 7), which was validated by a specialist in that domain. Although the Jena framework provides a persistent triple stores using relational databases (SDB), its use is not recommended for new applications. Thus, this

Class or subclass:	Property:
Database	queryString
Database	queryProblem
Database	queryIntervention
Evidence	createDate
Evidence	evidenceURL
Paper in Journal	journalName
Database	databaseName
Database	databaseURL
Dublin Core	identifier

Table 5 – Evidence ontology properties.

implementation created a MySQL relational database with two tables, one for the model name and the other for the ontology URI and its value, as Figure 8 shows. The two tables are:

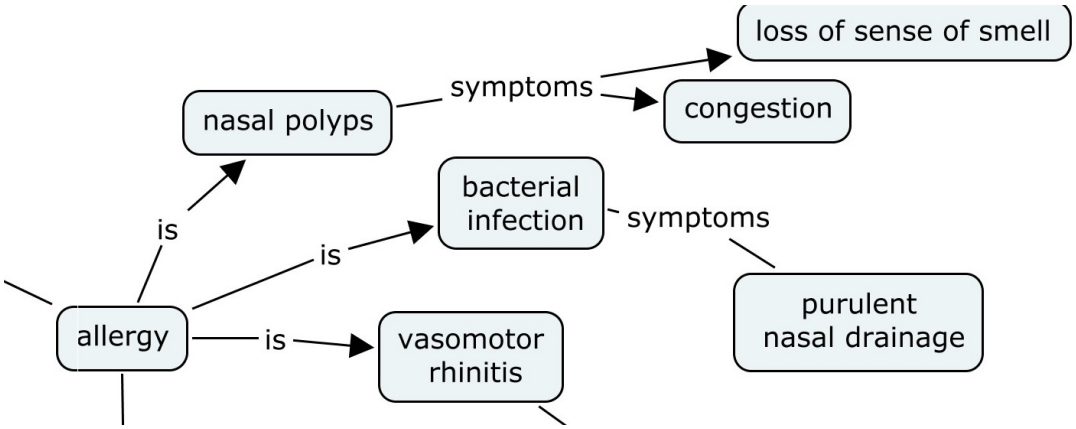

Figure 7 – Partial view of the asthma concept map.

rdf_node represents the node in the RDF graph; attributes are the *node_id* (primary key) and *model_name*;

rdf_property has the content of each node; *property_id* is its primary key; *id_node* is a foreign key that connects the record with the *rdf_node* table; *property* is the field where the URI from the OWL document is inserted; and *property_value* keeps the URI value.

In our three-layer architecture, the Protégé tool is not integrated. Thus, we use the latter tool to define the class hierarchy, properties and constraints of a specific ontology. We use a MySQL database to store the raw information, which are the model, and its URIs with

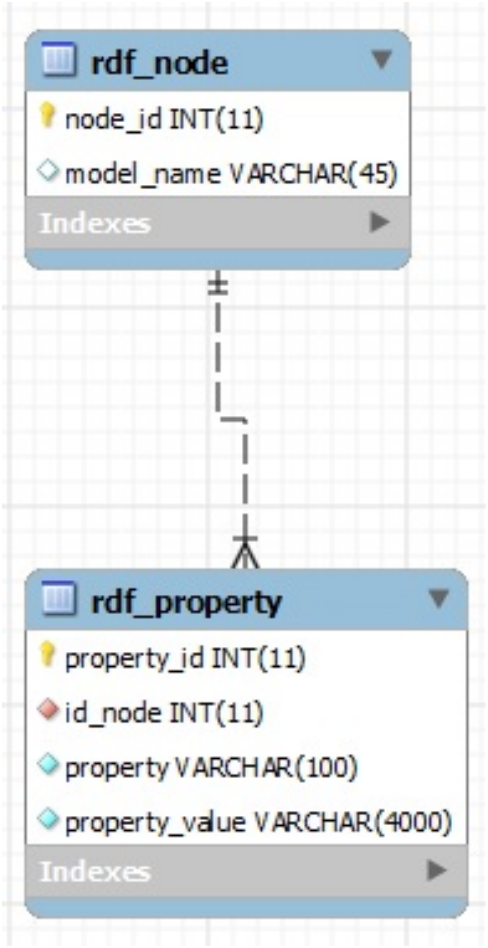

Figure 8 – Model entity-relationship diagram.

their values. Finally our three-layer architecture could integrate external ontologies through the second layer: knowledge capture and creation, in the MySQL database.

3.3.3 Knowledge retrieval

This layer used SPARQL queries to search and retrieve evidence information. To create these queries, relevant words were extracted from clinical notes using the knowledge stored on the adult asthma ontology, producing a corresponding RDF statements. With these statements and the knowledge from the evidence database ontology, each evidence database was queried and the corresponding results were also stored as RDF statements. Finally, results were translated to a format suitable for user presentation.

3.3.3.1 Text processing and information retrieval algorithm

These are the steps of our algorithm:

1. Tokenize all the text (removing characters: ',' or '.' or ';').
2. Remove all the tokens with length less than three.
3. Find the concepts related with the class Problem in the asthma ontology through SPARQL queries in the RDF document generated from that ontology specification.
4. Find the concepts related with the class Intervention in the asthma ontology through SPARQL queries.
5. Match the input tokens from the result of step 2 with the concepts related with Problem (step 3) and Intervention (step 4) from the asthma ontology.
6. Join the results from step 5 in order to have a list of strings to be used in the queryString property from the evidence ontology for the retrieve of information from PEDro physiotherapy database.
7. Retrieve the information required from the matched concepts from step 5 and step 6 through SPARQL queries in the RDF created from the evidence ontology.

3.4 Concluding remarks

In this chapter we have detailed our conceptual proposal for the integration of evidences and EHR. Also we have described our software architecture, which is a three-layer architecture: (1) knowledge domain creation (for the ontologies), (2) knowledge capture creation (for the RDF generation), and (3) knowledge retrieval (our text processing and information retrieval algorithm). With the framework that we have developed, in the next chapter we are going to show our proof of concept in order to validate our proposal.

4 RESULTS

In this chapter we show the results of this study. First we show the Knowledge repositories that we have obtained based on the specification of the ontologies, these repositories are distributed through RDF documents, one is related with adult asthma and the other is for evidences. Then we present the proof of concept that we have developed, it is an example of an input of a clinical note; also we show the matched terms with the asthma ontology and the retrieved evidences links related with that specific clinical note, the former are expressed as URLs. Finally we demonstrate how is the matching flow of the proof of concept; also we show how are the concepts interrelated in a graph-based document, which is the RDF. Therefore we show how the ontology drive the creation and specification of an RDF document.

4.1 Knowledge repositories

The knowledge repositories are based on the specification of the ontologies and are distributed through RDF documents. We have created one for adult asthma and the other for evidences.

Below we can see the basic structure of two nodes in an RFD's graph for evidences: one with queryProblem and queryIntervention properties for the search in PubMed PICO; and the other node with queryString for PEDro physiotherapy database. Also we can see in the header of the document the URLs where are located the specifications of the properties.

```
  <rdf:RDF
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:dc="http://purl.org/dc/elements/1.1/"
   xmlns:j.0="http://purl.org/dc/terms/"
   xmlns:j.1="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#"
   xmlns:owl="http://www.w3.org/2000/01/rdf-schema#" >
 <rdf:Description rdf:nodeID="A0">
   <dc:identifier>9648699</dc:identifier>
   <j.1:databaseName>Search MEDLINE/PubMed via PICO</j.1:databaseName>
   <j.1:journalYear>1998</j.1:journalYear>
   <j.1:evidenceURL>http://www.sciencedirect.com/science/article/
                  pii/S0091674998703021</j.1:evidenceURL>
   <j.0:creator>Shusterman DJ; Murphy MA; Balmes JR</j.0:creator>
   <j.0:title>Subjects with seasonal allergic rhinitis and nonrhinitic
              subjects react differentially to nasal provocation with
              chlorine gas.</j.0:title>
```

```
    <j.1:createDate>15/09/2014</j.1:createDate>
    <j.1:queryIntervention>Allergy tests</j.1:queryIntervention>
    <j.1:queryProblem>Nasal irritation</j.1:queryProblem>
  </rdf:Description>
  ...
  <rdf:Description rdf:nodeID="A27">
    <j.1:journalYear>2010</j.1:journalYear>
    <dc:identifier>20816546</dc:identifier>
    <j.1:databaseName>Pedro physiotherapy evidence database</j.1:databaseName>
    <j.1:evidenceURL>http://search.pedro.org.au/search-results/record-detail/
                    40008</j.1:evidenceURL>
    <j.0:creator>Abernethy AP, McDonald CF, Frith PA, Clark K, Herndon JE, II,
                 Marcello J, Young IH, Bull J, Wilcock A, Booth S, Wheeler JL,
                 Tulsky JA, Crockett AJ, Currow DC</j.0:creator>
    <j.0:title>Effect of palliative oxygen versus room air in relief of
               breathlessness in patients with refractory dyspnoea:
               a double-blind, randomised controlled trial</j.0:title>
    <j.1:createDate>16/09/2014</j.1:createDate>
    <j.1:queryString>Nasal irritation</j.1:queryString>
  ...
  </rdf:RDF>
```

4.2 Proof of concept

The proof of concept to validate our proposal have the following limitations: (1) the knowledge repositories from adult asthma and the other of evidences were not created with the help of any specialists. Thus, the quality of the selected evidences are not guarantee at all; (2) The proof concept was not performed by any specialist, this is due the time constraint that we had in this study and also because our goal was to prove the technical aspect of our work, therefore we validated our algorithms, including the three-layer architecture. We created a basic clinical note because it contains a simple but real scenario where a patient describes some symptoms related with asthma. Consider the following example of a clinical note taken for a patient:

> *Patient CC, 30 years old, says it has been five weeks since he starts to sneeze in the nights. After checking his nose, we can see little nasal polyps in the right hole; also we have noticed that the nose is irritated. The patient states he has stuffy nose daily lately and also he has noticed a loss of sense of smell. We believe that he has developed allergy and asthma.*

After tokenizing the text, the first task was to find relevant concepts in the adult asthma RDF document using SPARQL queries. After running the text processing and information retrieval algorithm, the following concepts from the adult asthma ontology were found from the *Problem* and *Intervention* classes:

Problem: Nasal irritation; Allergic rhinitis; Changes in temperatures; Watery rhinorrhoea; Classical symptoms; Vasomotor rhinitis; Eye symptoms; Nasal polyps; Clear watery nasal drainage; Bacterial infection; Itching; Loss of sense of smell; Congestion; Purulent nasal drainage.

Intervention: Spirometry; Ipratropium bromide; Challenge tests; Future tests; Antihistamines; Allergy tests; Chest x-ray; Anticholinergic sprays; INCS; Radioallergosorb; Drug Intervention; Salbutamol; Inhaled nasal corticosteroids.

Table 6 summarizes the result from this task.

Tokenize	Reduce	Problem	Intervention
75	42	14	14
Match-P	Match-I	Merge	Query
5	2	7	60

Table 6 – Summary of the result from the text processing and information retrieval algorithm

The next task was to match these concepts from *Problem* and *Intervention* classes with the useful tokens from the patient information text. In this case:

Matches related with Problem: Nasal irritation; Clear watery nasal drainage; Nasal polyps; Loss of sense of smell; Purulent nasal drainage.

Matches related with Intervention: Allergy tests; Inhaled nasal corticosteroids.

These concepts were matched with the useful tokens, and the concepts were retrieved using SPARQL queries in the RDF representation of the evidence databases ontology. Finally, the algorithm retrieved the information to be presented to the health professional who has inserted the clinical note. In this case, 60 links with evidence information related to that specific patient were presented (see Table 9 to Table 15). Table 7 summarizes the results obtained from PubMed, and Table 8, from the PEDro database.

We validated in table 6 that our ontologies are the driven tools to identify and extract key terms from the input text, also they allow us to retrieve relevant information for the users in the knowledge repositories (RDFs documents). Table 6 also shows the results after applying the text processing and information retrieval algorithm, the latter finds 5 terms that matches with the class Problem and 2 matched terms with the class Intervention, both classes are from the asthma ontology. Also the algorithm with both set of matched terms finds 60 links that are associated to the evidences in the evidence's ontology.

queryProblem	Results	queryIntervention	Results
Nasal irritation	11	Allergy tests	16
Nasal polyps	12	Inhaled nasal corticosteroids	12
Loss of sense of smell	4	-	-

Table 7 – Summary of the result after querying the PubMed evidence database

queryString	Results
Nasal irritation	1
Allergy tests	4

Table 8 – Summary of the result after querying the PEDro physiotherapy evidence database

queryProblem: Nasal irritation
http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2222.2011.03921.x/abstract;jsessionid= BB8CA8AA8A9F6BD499ACAF2AFEF37BAE.f03t03
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=1102148&dopt=abstractplus
http://www.sjweh.fi/show_abstract.php?abstract_id=458
http://informahealthcare.com/doi/abs/10.1080/08958370590904508%20
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=2244675&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=9109952&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=1958002&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=6771116&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=3052188&dopt=abstractplus
http://www.sciencedirect.com/science/article/pii/S0091674998703021
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=6394263&dopt=abstractplus

Table 9 – Links retrieved for the matched term Nasal irritation

queryProblem: Nasal polyps
http://archotol.jamanetwork.com/article.aspx?articleid=624174
http://www.rhinologyjournal.com/abstract.php?id=918
http://erj.ersjournals.com/content/28/1/68.long
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=6344703&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=2813924&dopt=abstractplus
http://oto.sagepub.com/content/146/5/834.long
http://link.springer.com/article/10.1007%2Fs00405-006-0061-7
https://www.jstage.jst.go.jp/article/jnms/77/1/77_1_21/_article
http://oto.sagepub.com/content/135/5/680.long
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=18984264&dopt=abstractplus
http://onlinelibrary.wiley.com/doi/10.1002/lary.24196/abstract
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=22730816&dopt=abstractplus

Table 10 – Links retrieved for the matched term Nasal polyps

queryProblem: Loss of sense of smell
http://onlinelibrary.wiley.com/doi/10.1111/j.1398-9995.2008.01870.x/abstract
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=9177615&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=22865728&dopt=abstractplus
http://onlinelibrary.wiley.com/doi/10.1002/lary.20075/abstract

Table 11 – Links retrieved for the matched term Loss of sense of smell

queryIntervention: Allergy tests
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=9177615&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=1102148&dopt=abstractplus
http://oto.sagepub.com/content/135/5/680.long
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=2222351&dopt=abstractplus
http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2222.2011.03921.x/abstract;jsessionid= BB8CA8AA8A9F6BD499ACAF2AFEF37BAE.f03t03
http://www.sjweh.fi/show_abstract.php?abstract_id=458
http://onlinelibrary.wiley.com/doi/10.1002/lary.20075/abstract
http://informahealthcare.com/doi/abs/10.1080/08958370590904508%20
http://onlinelibrary.wiley.com/doi/10.1002/lary.24196/abstract
http://erj.ersjournals.com/content/28/1/68.long
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=2813924&dopt=abstractplus
http://oto.sagepub.com/content/146/5/834.long
http://onlinelibrary.wiley.com/doi/10.1111/j.1398-9995.2008.01870.x/abstract
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmedCmd=Retrieve&list_uids=22865728&dopt=abstractplus
http://www.sciencedirect.com/science/article/pii/S0091674998703021
http://www.rhinologyjournal.com/abstract.php?id=918

Table 12 – Links retrieved for the matched term Allergy tests

queryIntervention: Inhaled nasal corticosteroids
http://archotol.jamanetwork.com/article.aspx?articleid=624174
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=6394263&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=1958002&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=9109952&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=9109952&dopt=abstractplus
https://www.jstage.jst.go.jp/article/jnms/77/1/77_1_21/_article
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=22730816&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=6344703&dopt=abstractplus
http://link.springer.com/article/10.1007%2Fs00405-006-0061-7
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=2244675&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=3052188&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve&list_uids=18984264&dopt=abstractplus
http://www.ncbi.nlm.nih.gov/pubmed?Db=pubmed&Cmd=Retrieve

Table 13 – Links retrieved for the matched term Inhaled nasal corticosteroids

queryString: Nasal irritation
http://search.pedro.org.au/search-results/record-detail/40008

Table 14 – Links retrieved for the matched term Nasal irritation

queryString: Allergy tests
http://search.pedro.org.au/search-results/record-detail/33311
http://search.pedro.org.au/search-results/record-detail/4265
http://search.pedro.org.au/search-results/record-detail/25138
http://search.pedro.org.au/search-results/record-detail/17736

Table 15 – Links retrieved for the matched term Allergy tests

4.2.1 Matching flow of the proof of concept

In this section we describe how is the linkage between the ontology represented as an OWL document and the knowledge repository expressed in an RDF. In Figure 9 we can see the conceptual flow of the classes Problem and Thing (a default class in Protégé) from the asthma ontology, therefore we see that class Problem has class Allergy and the latter has allergyName as a property. In our proof of concept the term Nasal irritation was a matched term between the clinical note and the asthma ontology, and this term is assigned to the attribute allergyName. If we want to know which are the associated ontology's concepts that are related with allergyName we have to find which are the concepts assigned to the general class Thing, therefore we have the data properties symptomDescription and symptonName.

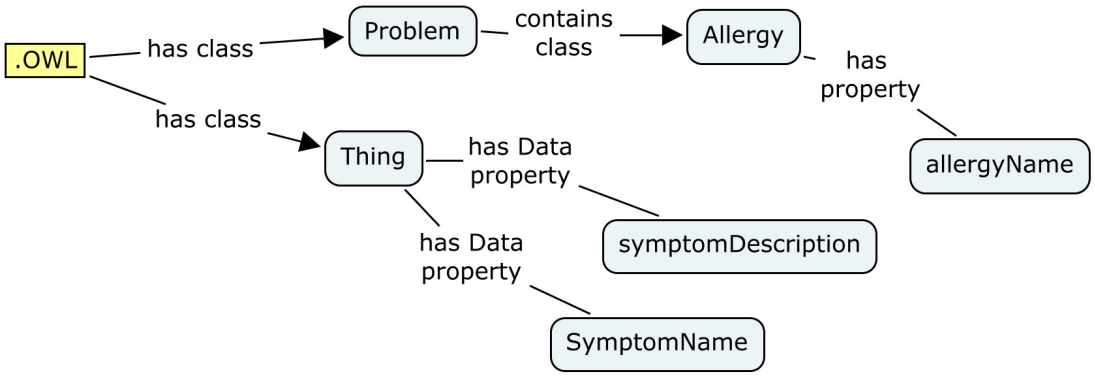

Figure 9 – Flow example of the class Problem and its properties in our OWL document for the Health Knowledge Ontology on Adult Asthma.

Next, In figure 10 we see that asthma's RDF has one properties-container node where are located the properties: symptomName, symptomDescription, and allergyName. Then we see that there is another node which has the property symptomDescription and its value, in this case is Nasal irritation. Below are the mentioned fragments expressed in the RDF file. In summary we see that in the OWL file we define the classes and its properties, whether in the RDF document the information is joined by nodes. Having each node different information, the SPARQL query engine could match the information according to the nodes' data, in this case we see that node ID=A5 is a set of properties and node ID=A3 is an information node. Both nodes are related by its similar concepts; the latter is the way that the graph represents its associations, therefore it is possible to retrieve all the information related with those concepts, that is how the SPARQL engine navigates through the RDF or graph.

```
<rdf:Description rdf:nodeID="A5">
    <j.0:problemName>http://www.semanticweb.org/jan/ontologies/2014/5/
    asthma#allergyName</j.0:problemName>
    <j.0:problemName>http://www.semanticweb.org/jan/ontologies/2014/5/
```

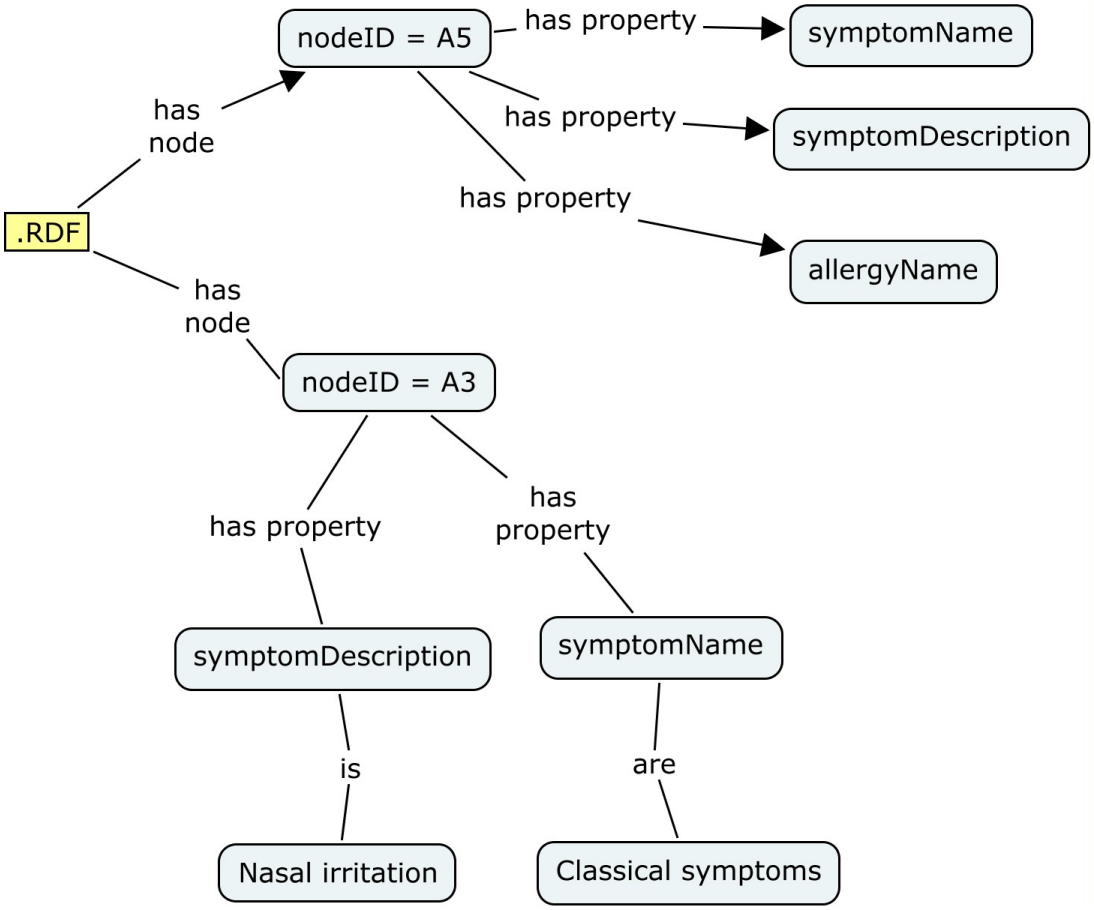

Figure 10 – Example of two nodes in our Health Knowledge Ontology on Adult Asthma RDF and their relationship through its properties.

```
    asthma#symptomDescription</j.0:problemName>
    <j.0:problemName>http://www.semanticweb.org/jan/ontologies/2014/5/
    asthma#symptomName</j.0:problemName>
  </rdf:Description>

  <rdf:Description rdf:nodeID="A3">
    <j.0:symptomDescription>Eye symptoms</j.0:symptomDescription>
    <j.0:symptomDescription>Watery rhinorrhoea</j.0:symptomDescription>
    <j.0:symptomDescription>Nasal irritation</j.0:symptomDescription>
    <j.0:symptomDescription>Itching</j.0:symptomDescription>
    <j.0:symptomName>Classical symptoms</j.0:symptomName>
```

For our Evidence Database Ontology we have a class Database, the latter has queryProblem as a property as seen in figure 11. The RDF file has one node that has the property queryProblem which value is Nasal irritation, also this node has all the information that we wanted to know about this evidence that is related with the Problem Nasal irritation. In summary the SPARQL query engine finds the property queryProblem where is value matched with Nasal irritation. Below are the mentioned fragments expressed in the OWL file and its

RDF document.

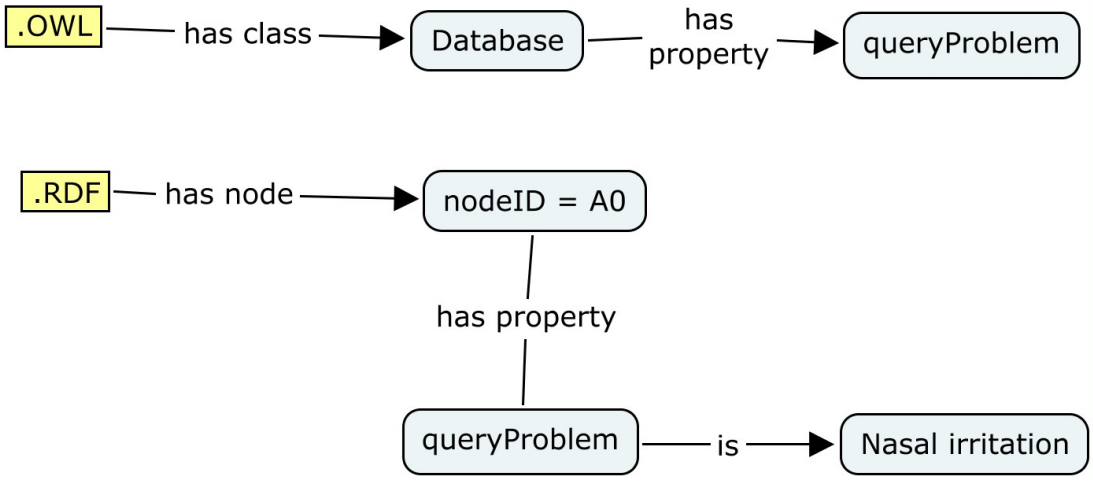

Figure 11 – Flow of the class Database and its property queryProblem in our OWL document for the Evidence Database Ontology; and the node where is located queryProblem in its RDF.

```
<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/
                        ontologies/2014/5/evidence#queryProblem">
        <rdfs:range rdf:resource="&xsd;string"/>
        <rdfs:domain>
            <owl:Restriction>
                <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
                <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/
                                    ontologies/2014/5/evidence#Database"/>
            </owl:Restriction>
        </rdfs:domain>
    </owl:DatatypeProperty>

<rdf:Description rdf:nodeID="A0">
    <dc:identifier>9648699</dc:identifier>
    <j.1:databaseName>Search MEDLINE/PubMed via PICO</j.1:databaseName>
    <j.1:journalYear>1998</j.1:journalYear>
    <j.1:evidenceURL>http://www.sciencedirect.com/science/article/pii/S0091674998703021
    </j.1:evidenceURL>
    <j.0:creator>Shusterman DJ; Murphy MA; Balmes JR</j.0:creator>
    <j.0:title>Subjects with seasonal allergic rhinitis and
                nonrhinitic subjects react differentially ...</j.0:title>
```

```
    <j.1:createDate>15/09/2014</j.1:createDate>
    <j.1:queryIntervention>Allergy tests</j.1:queryIntervention>
    <j.1:queryProblem>Nasal irritation</j.1:queryProblem>
  </rdf:Description>
```

5 CONCLUSION

At the beginning we had some issues designing the ontologies, because we were modeling them with the logic of object oriented programming, by seen the concepts as objects with just attributes. Then we realized that we have to change our approach and see the problem of designing an ontology as a concept oriented programming; because the former is based on the semantic, context and interconnection that can be assigned to each concepts, and the latter is a way to design a solution based more on the creation of models instead of source code.

This work addressed the use of ontologies to automatically retrieve evidence information for health professionals while they insert clinical notes in electronic health records. A proof of concept in the field of adult asthma was presented to illustrate the proposal. The main results were: (1) creation of OWL ontologies for adult asthma and evidence databases; (2) generation of RDF documents that are knowledge repositories based on the specifications of these ontologies; and (3) an algorithm to perform information retrieval using these ontologies and knowledge repositories.

One of main advantages of using ontologies is the possibility of creating flexible models, capable of integrating different domains and heterogeneous sources. Another observed benefit in this ontology-based solution was the effectiveness of finding relevant concepts in a specific domain through queries using Semantic Web tools.

The use of Semantic Web technologies brings the potential to integrate evidence resources with other Web resources, in the spirit of Linked Data. By using Dublin Core to describe evidence information resources, this framework can potentially become part of the Linked Data cloud. Dublin Core may be used for multiple purposes, from simple resource description, to combine vocabularies of different metadata standards, and to provide interoperability for metadata vocabularies in the Linked data cloud and Semantic Web implementations. Linked Data enables to represent a collection of machine-understandable statements published without having them related to any website at all, and is one of the main applications in the Semantic Web.

The presented implementation can be improved. One limitation in this solution is that all the models (RDF documents) raw data are stored into a single database table. As this solution may affect the scalability, creating one table per model (domain) in the database could overcome this limitation.

This work has shown that it is possible to take advantage of the semantic richness from ontologies to find relevant information from a patient clinical note and to use this information to query heterogeneous evidence databases. By integrating these results in a transparent and uniform way to health professionals, ontologies with Semantic Web technologies enabled the promotion of Evidence-Based Practice among users of Electronic Health Records.

5.1 Future Works

In order to have the evidence knowledge repositories updated contantly with useful information we need a crawler. A crawler is a piece of software that is capable of traversing the Web by downloading web pages and following links from page to page. Knowing the latter, our future work will be the develop of a crawler. This is possible because the medical literature is published in different web sites and databases. Thus, one problem that we have is that the data on these web sites are normally mixed together with other data that we do not need, to handle this situation our crawler will visit these web sites one by one, it will identify the data that we need, and only will collect the relevent information that we define for us. After it collects the information, it will store them into the data format (raw data) that we want. Once it finishes with one web site, it will move on to the next one until it has visited all the web sites that we are interested in. More specific for each URL, the crawler downloads the web document on this URL and finds all the hypertext links on that page that point to other web pages. It then picks one of these new links and follows that link to download a new page, and finds more links on the new page, so on and so forth, until it decides to stop or there is no more links to follow. As a summary, the following are the main tasks of a given by our crawler:

1. A URL server sends a list of URLs to the crawler for it to visit.
2. Download the web page.
3. Parse through the downloaded page and retrieve all its links.
4. Identify and store the data that we need.
5. For each new link retrieved, repeat steps 2, 3 and 4.

After the crawler has collected the raw data of the databases that we want, then we have two operations: (1) see if the raw data is already an information that we have in our RDF document, if the former is true we modify all the necessary properties; i.e. in the property createDate we put the date of the updated. (2) if the data is new, we create the new nodes into the RDF document, and fill the corresponding properties; i.e. databaseName, databaseType, databaseURL, evidenceURL, queryIntervention, queryProblem, queryString.

Also as a future work we will create the Health Knowledge Ontology with the terms of SNOMED – CT, the latter is the most comprehensive and precise clinical health terminology product in the world. Thus, it will give us a more standardized ontology. Then we will study the creation of one ontology extracted organically from a given text, this approach could be more effective and be used in a general way, therefore that ontology could identify the specific domain of a given text or clinical note.

The source code of this project is available at: https://github.com/jcbeeck/SematicWeb

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Annex

ANNEX A – ASTHMA ONTOLOGY

```
<?xml version="1.0"?>


<!DOCTYPE rdf:RDF [
    <!ENTITY owl "http://www.w3.org/2002/07/owl#" >
    <!ENTITY xsd "http://www.w3.org/2001/XMLSchema#" >
    <!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema#" >
    <!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns#" >
]>


<rdf:RDF xmlns="http://www.w3.org/2002/07/owl#"
     xml:base="http://www.w3.org/2002/07/owl"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     xmlns:owl="http://www.w3.org/2002/07/owl#"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">
    <Ontology rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma"/>



    <!--
    ///////////////////////////////////////////////////////////////////////////////////////
    //
    // Object Properties
    //
    ///////////////////////////////////////////////////////////////////////////////////////
     -->




    <!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#aka -->

    <ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#aka">
        <rdfs:range>
            <Restriction>
                <onProperty rdf:resource="&owl;topObjectProperty"/>
                <someValuesFrom rdf:resource="&owl;Thing"/>
            </Restriction>
        </rdfs:range>
        <rdfs:domain>
            <Restriction>
                <onProperty rdf:resource="&owl;topObjectProperty"/>
                <someValuesFrom rdf:resource="&owl;Thing"/>
            </Restriction>
        </rdfs:domain>
    </ObjectProperty>



    <!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#are -->

    <ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#are">
```

```
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#avoid -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#avoid">
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Drug"/>
        </Restriction>
    </rdfs:domain>
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#co-exist -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#co-exist">
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Allergy"/>
        </Restriction>
    </rdfs:domain>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#consider -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#consider">
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
```

```
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#develop -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#develop">
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#diagnosis -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#diagnosis">
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#focus -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#focus">
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
```

```
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#has -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#has">
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#have -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#have">
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#include -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#include">
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
</ObjectProperty>
```

```
<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#is -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#is">
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#lessEfective -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#lessEfective">
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Drug"/>
        </Restriction>
    </rdfs:domain>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#likely -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#likely">
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#of -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#of">
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
```

```
    </rdfs:domain>
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#recommend -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#recommend">
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
</ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#require -->

<ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#require">
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
    <rdfs:range>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:range>
</ObjectProperty>



<!--
///////////////////////////////////////////////////////////////////////////////////////
//
// Data properties
//
///////////////////////////////////////////////////////////////////////////////////////
 -->



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#allergyName -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#allergyName">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <Restriction>
```

```
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Allergy"/>
        </Restriction>
    </rdfs:domain>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#allergyTestName -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#allergyTestName">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Allergy"/>
        </Restriction>
    </rdfs:domain>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#asthmaTerm -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#asthmaTerm">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#daytimeSymptom -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#daytimeSymptom">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Problem"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#description -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#description">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#drugDescription -->
```

```
<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#drugDescription">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Drug"/>
        </Restriction>
    </rdfs:domain>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#drugName -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#drugName">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Drug"/>
        </Restriction>
    </rdfs:domain>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#drugType -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#drugType">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Drug"/>
        </Restriction>
    </rdfs:domain>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#exacerbation -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#exacerbation">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Problem"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#interventionDescription -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#interventionDescription">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Intervention"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#interventionName -->
```

```
<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#interventionName">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Intervention"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#measuring-breath -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#measuring-breath">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Intervention"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#night-timeSymptom -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#night-timeSymptom">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Problem"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#problemName -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#problemName">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Problem"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#symptomDescription -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#symptomDescription">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
</DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#symptomName -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#symptomName">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <Restriction>
            <onProperty rdf:resource="&owl;topObjectProperty"/>
            <someValuesFrom rdf:resource="&owl;Thing"/>
        </Restriction>
    </rdfs:domain>
</DatatypeProperty>
```

```
<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#testName -->

<DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#testName">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Problem"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</DatatypeProperty>




<!--
///////////////////////////////////////////////////////////////////////////////////
//
// Classes
//
///////////////////////////////////////////////////////////////////////////////////
 -->




<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Allergy -->

<Class rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Allergy"/>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Drug -->

<Class rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Drug"/>




<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Intervention -->

<Class rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Intervention"/>




<!-- http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Problem -->

<Class rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Problem"/>




<!--
///////////////////////////////////////////////////////////////////////////////////
```

```
    //
    // General axioms
    //
    ///////////////////////////////////////////////////////////////////////////////////////
     -->




    <rdf:Description>
        <rdf:type rdf:resource="&owl;AllDisjointClasses"/>
        <members rdf:parseType="Collection">
            <rdf:Description rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Allergy"/>
            <rdf:Description rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Drug"/>
            <rdf:Description rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Intervention"/>
            <rdf:Description rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#Problem"/>
        </members>
    </rdf:Description>
</rdf:RDF>



<!-- Generated by the OWL API (version 3.4.2) http://owlapi.sourceforge.net -->
```

ANNEX B – EVIDENCE ONTOLOGY

```
<?xml version="1.0"?>


<!DOCTYPE rdf:RDF [
    <!ENTITY owl "http://www.w3.org/2002/07/owl#" >
    <!ENTITY xsd "http://www.w3.org/2001/XMLSchema#" >
    <!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema#" >
    <!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns#" >
]>


<rdf:RDF xmlns="http://www.semanticweb.org/jan/ontologies/2014/5/untitled-ontology-36#"
     xml:base="http://www.semanticweb.org/jan/ontologies/2014/5/untitled-ontology-36"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     xmlns:owl="http://www.w3.org/2002/07/owl#"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">
    <owl:Ontology rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences"/>



    <!--
    ///////////////////////////////////////////////////////////////////////////////////////
    //
    // Object Properties
    //
    ///////////////////////////////////////////////////////////////////////////////////////
     -->




    <!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#belong -->

    <owl:ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#belong">
        <rdfs:range>
            <owl:Restriction>
                <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
                <owl:someValuesFrom rdf:resource="&owl;Thing"/>
            </owl:Restriction>
        </rdfs:range>
        <rdfs:domain>
            <owl:Restriction>
                <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
                <owl:someValuesFrom rdf:resource="&owl;Thing"/>
            </owl:Restriction>
        </rdfs:domain>
    </owl:ObjectProperty>



    <!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#has -->

    <owl:ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#has">
```

```
    <rdfs:range>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="&owl;Thing"/>
        </owl:Restriction>
    </rdfs:range>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="&owl;Thing"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#is -->

<owl:ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#is">
    <rdfs:range>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="&owl;Thing"/>
        </owl:Restriction>
    </rdfs:range>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="&owl;Thing"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:ObjectProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#link -->

<owl:ObjectProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#link">
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="&owl;Thing"/>
        </owl:Restriction>
    </rdfs:domain>
    <rdfs:range>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="&owl;Thing"/>
        </owl:Restriction>
    </rdfs:range>
</owl:ObjectProperty>



<!--
///////////////////////////////////////////////////////////////////////////////////
//
// Data properties
//
///////////////////////////////////////////////////////////////////////////////////
```

```
 -->



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#createDate -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#createDate">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Evidence"/>
    <rdfs:range rdf:resource="&xsd;string"/>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#databaseName -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#databaseName">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Database"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#databaseType -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#databaseType">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:subPropertyOf rdf:resource="&owl;topDataProperty"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Database"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#databaseURL -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#databaseURL">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Database"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#evidenceDOI -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#evidenceDOI">
```

```
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Evidence"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#evidencePedroID -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#evidencePedroID">
    <rdfs:range rdf:resource="&xsd;integer"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Evidence"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#evidencePubmedID -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#evidencePubmedID">
    <rdfs:range rdf:resource="&xsd;integer"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Evidence"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#evidenceURL -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#evidenceURL">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Evidence"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalInformation -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalInformation">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
```

```
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Journal"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalName -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalName">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Journal"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalPage -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalPage">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:subPropertyOf rdf:resource="&owl;topDataProperty"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Journal"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalType -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalType">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Journal"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalYear -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#journalYear">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Journal"/>
        </owl:Restriction>
    </rdfs:domain>
```

```
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#meshTerm -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#meshTerm">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="&owl;Thing"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#queryIntervention -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#queryIntervention">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Database"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#queryProblem -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#queryProblem">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Database"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>



<!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#queryString -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#queryString">
    <rdfs:range rdf:resource="&xsd;string"/>
    <rdfs:domain>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&owl;topObjectProperty"/>
            <owl:someValuesFrom rdf:resource="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Database"/>
        </owl:Restriction>
    </rdfs:domain>
</owl:DatatypeProperty>
```

```
    <!--
    ///////////////////////////////////////////////////////////////////////////////////
    //
    // Classes
    //
    ///////////////////////////////////////////////////////////////////////////////////
     -->




    <!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Database -->

    <owl:Class rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Database"/>



    <!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Evidence -->

    <owl:Class rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Evidence"/>



    <!-- http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Journal -->

    <owl:Class rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Journal"/>



    <!--
    ///////////////////////////////////////////////////////////////////////////////////
    //
    // General axioms
    //
    ///////////////////////////////////////////////////////////////////////////////////
     -->

    <rdf:Description>
        <rdf:type rdf:resource="&owl;AllDisjointClasses"/>
        <owl:members rdf:parseType="Collection">
            <rdf:Description rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Database"/>
            <rdf:Description rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Evidence"/>
            <rdf:Description rdf:about="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#Journal"/>
        </owl:members>
    </rdf:Description>
</rdf:RDF>



<!-- Generated by the OWL API (version 3.4.2) http://owlapi.sourceforge.net -->
```

ANNEX C – ASTHMA RDF

```
<rdf:RDF
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:j.0="http://www.semanticweb.org/jan/ontologies/2014/5/asthma#"
    xmlns:owl="http://www.w3.org/2000/01/rdf-schema#" >
  <rdf:Description rdf:nodeID="A0">
    <j.0:aka>SPT</j.0:aka>
    <j.0:allergyTestName>Radioallergosorbent</j.0:allergyTestName>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A1">
    <j.0:symptomDescription>Changes in temperatures</j.0:symptomDescription>
    <j.0:symptomDescription>Clear watery nasal drainage</j.0:symptomDescription>
    <j.0:symptomName>Vasomotor rhinitis</j.0:symptomName>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A2">
    <j.0:asthmaTerm>Persistent asthma</j.0:asthmaTerm>
    <j.0:description>Patients1</j.0:description>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A3">
    <j.0:symptomDescription>Eye symptoms</j.0:symptomDescription>
    <j.0:symptomDescription>Watery rhinorrhoea</j.0:symptomDescription>
    <j.0:symptomDescription>Nasal irritation</j.0:symptomDescription>
    <j.0:symptomDescription>Itching</j.0:symptomDescription>
    <j.0:symptomName>Classical symptoms</j.0:symptomName>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A4">
    <j.0:has>Patients3</j.0:has>
    <j.0:has>Patients2</j.0:has>
    <j.0:has>Patients1</j.0:has>
    <j.0:has>Group of adults with asthma</j.0:has>
    <j.0:asthmaTerm>Adult asthma</j.0:asthmaTerm>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A5">
    <j.0:problemName>http://www.semanticweb.org/jan/ontologies/2014/5/asthma#allergyName</j.0:problemName>
    <j.0:problemName>http://www.semanticweb.org/jan/ontologies/2014/5/asthma#symptomDescription</j.0:problemName>
    <j.0:problemName>http://www.semanticweb.org/jan/ontologies/2014/5/asthma#symptomName</j.0:problemName>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A6">
    <j.0:symptomDescription>Loss of sense of smell</j.0:symptomDescription>
    <j.0:symptomDescription>Congestion</j.0:symptomDescription>
    <j.0:symptomName>Nasal polyps</j.0:symptomName>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A7">
    <j.0:testName>Future tests</j.0:testName>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A8">
    <j.0:asthmaTerm>Regular preventer therapy</j.0:asthmaTerm>
    <j.0:description>Patients2</j.0:description>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A9">
    <j.0:focus>Spirometry</j.0:focus>
    <j.0:focus>Ears</j.0:focus>
    <j.0:focus>Eyes</j.0:focus>
    <j.0:focus>Throat</j.0:focus>
    <j.0:focus>Nose</j.0:focus>
```

```
  <j.0:description>Physical examination</j.0:description>
</rdf:Description>
<rdf:Description rdf:nodeID="A10">
  <j.0:of>Occupation</j.0:of>
  <j.0:of>Environment</j.0:of>
  <j.0:of>Allergic conditions</j.0:of>
  <j.0:description>Family and personal information history</j.0:description>
</rdf:Description>
<rdf:Description rdf:nodeID="A11">
  <j.0:asthmaTerm>Allergic rhinitis</j.0:asthmaTerm>
  <j.0:description>Patients3</j.0:description>
</rdf:Description>
<rdf:Description rdf:nodeID="A12">
  <j.0:require>A need to exclude other conditions such as pneumonia</j.0:require>
  <j.0:require>Symptoms not explained by asthma</j.0:require>
  <j.0:require>If diagnosis is uncertain</j.0:require>
  <j.0:testName>Chest x-ray</j.0:testName>
</rdf:Description>
<rdf:Description rdf:nodeID="A13">
  <j.0:interventionDescription>Salbutamol</j.0:interventionDescription>
  <j.0:interventionDescription>RAST</j.0:interventionDescription>
  <j.0:interventionDescription>Radioallergosorb</j.0:interventionDescription>
  <j.0:interventionDescription>Ipratropium bromide</j.0:interventionDescription>
  <j.0:interventionDescription>Anticholinergic sprays</j.0:interventionDescription>
  <j.0:interventionDescription>Antihistamines</j.0:interventionDescription>
  <j.0:interventionDescription>INCS</j.0:interventionDescription>
  <j.0:interventionDescription>Inhaled nasal corticosteroids</j.0:interventionDescription>
  <j.0:interventionName>Drug Intervention</j.0:interventionName>
</rdf:Description>
<rdf:Description rdf:nodeID="A14">
  <j.0:develop>Asthma</j.0:develop>
  <j.0:description>Risk factor</j.0:description>
</rdf:Description>
<rdf:Description rdf:nodeID="A15">
  <j.0:lessEfective>Antihistamines</j.0:lessEfective>
  <j.0:asthmaTerm>INCS</j.0:asthmaTerm>
</rdf:Description>
<rdf:Description rdf:nodeID="A16">
  <j.0:is>Ipratropium bromide</j.0:is>
  <j.0:asthmaTerm>Anticholinergic sprays</j.0:asthmaTerm>
</rdf:Description>
<rdf:Description rdf:nodeID="A17">
  <j.0:has>Classical symptoms</j.0:has>
  <j.0:diagnosis>Physical examination</j.0:diagnosis>
  <j.0:diagnosis>Family and personal information history</j.0:diagnosis>
  <j.0:diagnosis>Allery investigation</j.0:diagnosis>
  <j.0:is>Risk factor</j.0:is>
  <j.0:avoid>Oral corticosteroids</j.0:avoid>
  <j.0:co-exist>With asthma</j.0:co-exist>
  <j.0:has>Drug therapy1</j.0:has>
  <j.0:allergyName>Allergic rhinitis</j.0:allergyName>
</rdf:Description>
<rdf:Description rdf:nodeID="A18">
  <j.0:symptomDescription>Purulent nasal drainage</j.0:symptomDescription>
  <j.0:symptomName>Bacterial infection</j.0:symptomName>
</rdf:Description>
<rdf:Description rdf:nodeID="A19">
  <j.0:recommend>Patients3</j.0:recommend>
  <j.0:recommend>Patients2</j.0:recommend>
  <j.0:recommend>Patients1</j.0:recommend>
```

```
    <j.0:allergyTestName>Radioallergosorbent</j.0:allergyTestName>
    <j.0:allergyTestName>Allergy skin prick tests</j.0:allergyTestName>
    <j.0:consider>Asthma diagnosis is made</j.0:consider>
    <j.0:testName>Allergy tests</j.0:testName>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A20">
    <j.0:allergyName>Allergic rhinitis</j.0:allergyName>
    <j.0:allergyName>Vasomotor rhinitis</j.0:allergyName>
    <j.0:allergyName>Bacterial infection</j.0:allergyName>
    <j.0:allergyName>Nasal polyps</j.0:allergyName>
    <j.0:asthmaTerm>Allergy</j.0:asthmaTerm>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A21">
    <j.0:aka>SPT</j.0:aka>
    <j.0:allergyTestName>Allergy skin prick tests</j.0:allergyTestName>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A22">
    <j.0:require>The person has not benefited from asthma treatment</j.0:require>
    <j.0:include>Methacholine</j.0:include>
    <j.0:include>Histamine</j.0:include>
    <j.0:include>Mannitol</j.0:include>
    <j.0:require>The diagnosis is uncertain</j.0:require>
    <j.0:require>Occupational asthma is suspected</j.0:require>
    <j.0:include>Hypertonic saline</j.0:include>
    <j.0:include>Dry air</j.0:include>
    <j.0:testName>Challenge tests</j.0:testName>
    <j.0:include>The person has not benefited from asthma treatment</j.0:include>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A23">
    <j.0:testName>Spirometry</j.0:testName>
  </rdf:Description>
</rdf:RDF>
```

.

ANNEX D – EVIDENCES RDF


```
<rdf:RDF
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:dc="http://purl.org/dc/elements/1.1/"
    xmlns:j.0="http://purl.org/dc/terms/"
    xmlns:j.1="http://www.semanticweb.org/jan/ontologies/2014/5/evidences#"
    xmlns:owl="http://www.w3.org/2000/01/rdf-schema#" >
  <rdf:Description rdf:nodeID="A0">
    <dc:identifier>9648699</dc:identifier>
    <j.1:databaseName>Search MEDLINE/PubMed via PICO</j.1:databaseName>
    <j.1:journalYear>1998</j.1:journalYear>
    <j.1:evidenceURL>http://www.sciencedirect.com/science/article/pii/S0091674998703021</j.1:evidenceURL>
    <j.0:creator>Shusterman DJ; Murphy MA; Balmes JR</j.0:creator>
    <j.0:title>Subjects with seasonal allergic rhinitis and nonrhinitic subjects react differentially to nasal provocatio
    <j.1:createDate>15/09/2014</j.1:createDate>
    <j.1:queryIntervention>Allergy tests</j.1:queryIntervention>
    <j.1:queryProblem>Nasal irritation</j.1:queryProblem>
  </rdf:Description>
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