A Telepsychiatry Domain Ontology Applied to Healthcare Information Systems

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ABSTRACT  
Mental illness has always been target of debate and criticism by the society (modern or ancient). Several problems and challenges regarding Psychiatry, Telepsychiatry specifically are found in literature. The lack of information and the fear of the unknown have long been seen as a barrier for people with mental illness as well as all those involved in the process, such as family and the medical team. In the past, the lack of knowledge led the society to adopt harsh punishment for the patients, under the pretext that the same were possessed by some supernatural force. In this context, the lack of knowledge about this field was and remains as the central problem. Therefore, this paper proposes the OntoPsic, a domain-ontology for psychiatry applied to Healthcare Information System to define a common vocabulary about mental illness and Telepsychiatry. Besides relying on this base of knowledge to assist all involved in the treatment of mental disorders, this article also describes the OntoConsult, a system for the deduction of facts to support the decision making. In order to motivate the use of OntoPsic, the article reviews some applications and some practical results with the ontology.

Categories and Subject Descriptors  
H.4 [Medical Informatics and Semantic Web applications]: Miscellaneous

Keywords  
Psychiatry, Ontology, Healthcare Information System

1. INTRODUCTION  
Since the beginning, the humanity has large interests in topics, issues and problems related to health, specifically in development of Healthcare Information Systems (HIS) to give support in solving these problems. With the advent of ICTs - Information and Communications Technologies, was defined the term Telehealth, a special case of HIS, for which the medical assistance to patients is made at a distance, that is, geographically separated, whenever any difficulty prevents qualified professionals to diagnose and treat diseases in person.

Telepsychiatry, in turn, has emerged in the context of Telehealth as a subcategory of HIS which aims to provide assistance to patients suffering of insanity, many times with unknown symptoms, diagnoses and treatments. The medical specialized field to deal with these patients (called homme spécial), it is called Psychiatry, which emerged in the mid XVIII century with the French Phillipi Pinel[2].

Psychiatry is a relevant research area and has been undergoing a continuous reform. According to [1] “there are a number of politics, social and cultural initiatives that are radically transforming the psychiatric assistance, the health politics and, more importantly, the lives of countless people and the everyday social practices”. Several problems and challenges regarding Psychiatry and Telepsychiatry are found in the literature, either in the traditional or modern medicine. Nevertheless, one of these problems stands out amongst many others, the lack of a public, formal and standardized information model, which should strengthen the dissemination and standardization of all know-how among all professionals involved with health mental, like psychiatrist, psychologist and psychoanalyst.

In this context, we propose a domain-ontology known as OntoPsic, which fits in the field of Telepsychiatry. OntoPsic aims to serve as common knowledge base among those involved in the process of treatment and care of patients with

theoretical concepts and best practices.
mental disorders, but also to assist them whenever a decision regarding either a disease prognosis or the most appropriate treatment (i.e., extracted from a history of similar cases) need be taken, even if not physically present. Further, this article discusses the OntoConsult, a HIS that queries the proposed ontology as a knowledge base, but also an inference engine to deduce remarkable information to support decision-making regarding the treatment, diagnosis and assistance.

This paper is organized as follows. Section 2 presents all theoretical that surrounds the general theory, which the proposed work is based: Telehealth, Telepsychiatry and Ontologies. Section 3 details the proposal, its architecture, as well as their inner-components. The evaluation and results obtained in real experiments carried through with the OntoPsic and OntoConsult are visited in section 4. Finally, the conclusions and future work are outlined in Section 5.

2. TELEHEALTH, TELEPSYCHIATRY AND ONTOLOGY IN A NUTSHELL

In this section, all the necessary foundation for understanding the rest of the paper is briefly described. It is important to note that the multidisciplinary nature used in this article shows how computational methods and techniques (not so complicated) can assist other research areas, such as the disorders associated with mental health.

2.1 Telehealth

Telehealth is discussed as the use of ICTs to promote health services and exchange of medical information, whenever the distance is a crucial factor for those involved [4]. In accordance with [16] Telehealth has had a remarkable development and consolidation in Brazil with the incentive received from research funding agencies and government actions, making possible the creation of research teams in several Brazilian universities institutions.

Also according to [16] one of the important points in maturation of Brazilian Telehealth was the conscience of, besides the technological aspects, telehealth is an effective application of technology solutions for the purpose of optimization of education, logistic planning, assistance regulation and the implementation of methods to provide multi-centric research, based on sustainability management strategies and the development of new models.

Usually Telehealth information system has the following elements: people management, processes, medical supplies, spreadsheets costs and other support activities that are necessary for the functioning of a health institution with the help of the media. Nowadays there are several Telehealth and HIS applications such as telephone appointment, telepsychiatry, long-distance diagnostic, clinical case discussions and even telesurgery (that is, remote surgery).

2.2 Telepsychiatry

Psychiatry has emerged in the XVIII century; asylums were replaced by proper lunatic ones, only intended for the mentally ill patients. Throughout this century, were developed several experiences and treatment at hospitals in France and, subsequently, throughout the Europe [2]. The care with mental health is widely used in telehealth, known as Telepsychiatry, taken by [17] either as the service delivery and mental health care, or the information exchange for this purpose, with those involved geographically distributed.

The first record of Telepsychiatry date of the early ’60s at the Institute of Psychiatry at the University of Nebraska in the United States [17]. At that time, an internal circuit of TV with the proposal of psychiatric education was used, having as its target audience: students, teachers, psychotherapy groups, medical researchers and other collaborators of mental health. The practice of telepsychiatry requires a synchronous link (that is, at real time) due the lack of time to wait for medical diagnosis data or a medical report. In fact, the real time assistance leads to a very promising but challenging technique for the professionals and HIS.

2.3 Ontology

Since century XVII, the term ontology has been used to name the general discipline of metaphysics, in the traditional first philosophy of Aristotle, as the science of being qua being. It is, many times, faced as a complement to the idea of epistemology (science of knowledge) [7]. Various definitions have appeared to describe what an ontology in the computer field is. The best known is “a formal and explicit specification of a shared conceptualization” [9], where:

- **Formal** refers in being declaratively defined, therefore, understandable for agents and systems;
- **Explicit** means that the elements and their constraints are clearly defined;
- **Conceptualization** deals with an abstract model either of an area of knowledge or a limited universe of speech;
- **Shared** means a consensual knowledge, i.e., a common terminology of the modeled area, or agreed amongst the developers of the communicative agents.

Thus, ontologies, specified in a higher level of abstraction, provide a common and non-ambiguous terminology for the domain under discussion. For Guarino [10], ontologies are a computational artifact composed of a vocabulary of concepts, their definitions and possible properties, a graphical model showing all possible relationships amongst the concepts and a set of formal axioms that constrain the interpretation of concepts and relations, representing in a clear and unambiguous way the knowledge of the domain. Several advantages have been presented in literature for the adoption of ontologies. Amongst them, the following are highlighted [6]:

1. It encourages the developers to reuse knowledge, even with adaptations and extensions. This is explained by the fact that the construction of bases of knowledge is one of the most expensive, complex and slow task of a specialist and/or agent system. Therefore, reusing ontologies promotes a significant gain in terms of effort and investment;
2. The wide availability of “ontologies-off-the-shelf”, ready for use, reuse and communication between agents, which may be further extended and complemented with concepts of specific domains;

3. On line access to servers of ontologies, capable of storing thousands of classes and instances, giving support to companies or research groups, once they work as tools to keep the integrity of shared knowledge between them, ensuring thus, a uniform vocabulary.

Recently, the use of ontologies has been spread through several other sub-areas of Computer Science, such as: Software Engineering, Database and Information Systems, motivated by the Semantic Web (which is indeed a direct consequence of the use of ontologies [15]).

3. PROPOSAL

In this work we present the OntoPsic, a domain-ontology according to classification adopted by [10], which classifies the types of ontologies in: i) generic, ii) domain, iii) task and iv) application. The ontology proposed intends to be the basis for possible solutions of knowledge-based systems in the context of Telehealth, specifically in the telepsychiatry sub area, in order to assist the professionals (Psychiatrists, Psychoanalysts and Psychologists) involved in the disorders mental identification and treatment. OntoPsic emerges, thus, as a common health care knowledge base, leveraging the disease treatment, diagnosis, severity, as well as a road map with the actors and their assignments.

This proposal takes a step beyond, discussing also an inference engine called OntoConsult, extremely flexible, customizable for each environment and giving support for the professional in real time. The architecture, components and features of the proposed system, and the OntoPsic will be presented in the following subsections.

3.1 OntoPsic

OntoPsic was developed using the following methodologies of Ontology Engineering: Methontology [5] IEEE Standard [11] for software and Knowledge-Based Information Systems development and the Method 101 proposed in [12] as a complement to Methontology. So far, we have used the OWL (Ontology Web Language), which incorporates facilities to publish and share the ontology proposed [13], beyond being proposed as standard for the W3C, enjoying the strengths of previous languages. OWL is also the ontology web language (Semantic Web [15]) largely expressive and powerful for (implicit) knowledge inference. The platform used to edit the ontology was Protégé [14], a extensible, Java-based, free, open source ontology editor and knowledge-base framework.

Some relationships between the main classes defined in the OntoPsic are presented in Figure 1. The outlined diagram was generated by plug in Ontoviz of the Protégé. Nevertheless, we chose to display only a restricted set of classes, for the sake of space.

The following are some of the main Description Logic (DL) axioms classes modeled, in order to infer correct facts regarding the domain under analysis.

Figure 1: The Core Classes and Relationships of OntoPsic

Class Psychoanalyst. This category represents the psychoanalysts who treat patients with mental disorders. Necessary conditions:

\[
\text{Psychoanalyst} \subseteq \exists \text{Realize.Treatment} \tag{1}
\]

\[
\text{Psychoanalyst} \subseteq \forall \text{Treat With.Psychotherapic} \tag{2}
\]

The above expressions indicate that individuals of the Psychoanalyst class may relate with individuals from Treatment and Psychotherapic classes through the property Realize and Treat With, respectively.

\[
\forall \text{Treat With only psychotherapic} \tag{3}
\]

The above axiom restricts the only treatment is through psychotherapy, for example, patients should not be submitted to treatment with drugs.

Class Psychologist. This category represents the individuals that can treat patients with mental disorders only with psychotherapy. As outlined in the ontology, the possible and necessary conditions are the same of Psychoanalyst.

Class Psychiatrist. Professionals with medical authorization to treat patients with drugs, beyond psychotherapy. Necessary conditions:

\[
\text{Psychiatrist} \subseteq \exists \text{Realize.Treatment} \tag{4}
\]

\[
\text{Psychiatrist} \subseteq \text{Doctor} \tag{5}
\]

The above expressions indicate, respectively, the instances of Psychiatrist class may relate to instances of Treatment class through property Realize and indicates that it is a subclass of class Doctor.

\[
\text{psychotherapic or (Treatment with some drugs)} \tag{6}
\]
The above axiom states that the psychiatrist can treat and deliver treatments to users with both drugs and with psychotherapy, rather from the psychologist and psychoanalyst who deal only with psychotherapy, once that they are not necessarily doctors.

Class User. Category that covers individuals who have symptoms or are suffering from mental disorders and should be handled by responsible professionals, i.e., they are the patients themselves. Necessary conditions:

\[ User \subseteq \exists Has\_Disorder\_Disorder \]  
\[ User \subseteq \exists Has\_Symptom\_Symptom \]  
\[ User \subseteq \exists Has\_Mental\_Faculties\_Mental\_Faculties \]  
\[ User \subseteq \exists Has\_Profile\_Profile \]  
\[ has\_disorder \min 1 \text{ disorder} \]  
\[ has\_treatment \min 1 \text{ Treatment} \]

While the four first logical statements include the relationships of the User class (with Disorder, symptom, Mental_Faculties and Profile classes), the last two axioms address the multiplicity of the relationships, demonstrating that a mental patient has at least one disorder (11), and thus must have, at least, one treatment (12).

Treatment Class. The following expressions addresses the necessary conditions for the treatment that should be undertaken for users (User) suffering of insanity.

\[ Treatment \subseteq \forall Associate\_a.Unser \]  
\[ Disorder \subseteq \forall Has\_treatment\_Treatment \]  
\[ associate\_a \min 1 \text{ User} \]

The above expressions models that: individuals in Class Treatment must relate to at least one individual of the User class, instances of Disorder class should relate to at least one individual of Treatment class, and, finally, class Treatment is associated with at least either a user.

Drug Class. This category holds the medicines used in treatments used by psychiatrists.

\[ Drugs \subseteq Treatment \]  
\[ Drugs \subseteq \forall May\_cause\_Side\_effects \]

As observed above, Drugs class is a subclass of Treatment, and as exposed in axiom 17, drug’s instances may cause side effects. Note that every type of drug is associated with side effects, and to ensure this peculiarity, the axiom 18 depicts the minimum cardinality of the association with side effect class, which is at least one.

\[ may\_causes \min 1 \text{ side\_effect} \]

Throughout this section were presented some logical axioms in Description Logic to formalize the OntoPsic. Going forward, the next section explains the details involved with the inference engine able to query and manipulate the ontology, named the OntoConsult.

3.2 OntoConsult

OntoConsult was developed in order to assist in transmission, generation and distribution of knowledge, beyond the manipulation, evaluation and use of OntoPsic by actors involved in the treatment of users with mental disorders. Developed using the Jena framework, it was implemented by Brian McBride of Hewlett-Packard for construction and manipulating of RDF graphs [9].

Amongst the key features of OntoConsult, we can highlight some important: uses the Pellet inference engine for deduction of facts from previous information stored in knowledge base, prints reports about the possible treatments, symptoms, medicines, sanity and possible diagnoses, beyond of a query interface implemented by the SPARQL language. Figure 2 shows the general architecture of OntoConsult: at the client side, there is an user interface (1) to accomplish the functions mentioned above (2), while in the machine side there is the SPARQL inference (5) engine to query the OntoPsic (Knowledge Base)(4), and a component (API Jena)(3) to interconnect both sides.

The application itself has the following main modules:

- **Inference Module.** Allows deducing precise information about OntoPsic on RDF and OWL code, using the Pellet inference engine.
- **Query Module.** Where all the queries undertaken by users takes place. As mentioned earlier, queries are carried through using the SPARQL language and they are transparent to the end user. Obviously, the query module interacts with the inference one.

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2.http://www.w3.org/TR/rdf-sparql-query
Visualization Module. Give access to reports set up according to the needs of professionals involved in the treatment.

4. EVALUATION AND RESULTS
OntoPsic was evaluated by quantitative and qualitative aspects. The ontology, quantitatively, was based on five indicators: (i) amount of named classes, (ii) the average value of properties $P_\text{O}$, (iii) levels of the ontology for the relation is-a, (iv) higher level class of the ontology with respect to is-a relationship and (v) higher level class of the ontology in relation to whole-part relationship. Table 1 outlines these metrics.

Table 1: Quantitative metrics of OntoPsic

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Metrics</th>
<th>OntoPsic</th>
<th>Ontologia</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td>Amount of Named Classes</td>
<td>93</td>
<td>29</td>
</tr>
<tr>
<td>(ii)</td>
<td>Amount of Po</td>
<td>29</td>
<td>0,311</td>
</tr>
<tr>
<td></td>
<td>Po Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(iii)</td>
<td>Level</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Amount of Classes</td>
<td>13</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>93</td>
<td></td>
</tr>
</tbody>
</table>

Higher level class: is-one

<table>
<thead>
<tr>
<th>(iv)</th>
<th>Class/Amount</th>
<th>Symptom(13)</th>
<th>Drugs(6)</th>
</tr>
</thead>
</table>

Table 2: Question 1 Results

<table>
<thead>
<tr>
<th>Query 1</th>
<th>Drugs</th>
<th>Side Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Query 1: SELECT * WHERE { ?Drugs :may_causes ?Side_Effects }</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Question 2 Results

<table>
<thead>
<tr>
<th>Query 2</th>
<th>User</th>
<th>Disorder</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Query 2: SELECT * WHERE { ?User :has_disorder ?Dis-order . { ?Dis-order :has_treatment ?Treatment } }</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Question 3 Results

<table>
<thead>
<tr>
<th>Query 3</th>
<th>Disorder</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Query 3: SELECT * WHERE { ?Dis-order :has_treatment ?Treatment }</td>
<td>Social phobia</td>
<td>Occupational therapy</td>
</tr>
<tr>
<td></td>
<td>Panic Disorder</td>
<td>Group therapy</td>
</tr>
</tbody>
</table>

According to Table 1, we observe that the indicator (i) provides an indication of the size and how much the ontology represents the domain knowledge, such an indicator is useful to compare similar domain-ontology. It is presented in the indicator (ii) the amount of property objects (relationships between classes), given by Po and the average in relation to the total of named classes (n), as a result of the following formula:

$$ MPO = \frac{P_o}{n} $$  \hspace{1cm} (19) 

This indicator helps ontology engineers to evaluate the amount of relations between classes as well as the need to increase the number of relationships between the classes defined. Moving ahead, the indicator (iii) shows that the ontology has 5 levels from the root node to the leaves, being the third level the densest. Indicator (iv) reveals the class with more is-a relationship (with other classes), in such a way contributing with design decisions for their own improvement as for other applications that they intend to reuse it. Indicator (v), in turn, leverages the domain modeling stating the parts of a whole and it is expected that a key-class has the largest number of whole-part relationships (in this sense, the Drugs class is a key one).

Qualitative evaluation was performed using the Pellet inference engine and the Protégé framework and the results were as follows. OntoPsic is consistent as any condition resulted in contradictory conclusions. Further, it is concise and was subjectively evaluated by professionals (doctors and teachers) of the medical school’s Center for Telehealth at the Hospital das Clinicas, Federal University of Pernambuco (NUTES / HC / UFPE) also being contemplated to be used in classroom in disciplines such as Medicine and Psychology. Ontopsic was classified as Shoim(D) expressivity by Protégé and Pellet. Roughly speaking, it means that the ontology holds transitive rules, intersection classes, negation, universal and existential quantification and disjunction between classes.

In order to validate the work, were defined some queries [8] that OntoPsic should be able to answer, and the code for each SPARQL query. Some results are outlined in the following tables. SSRI stands for Selective Serotonin Reuptake Inhibitor.

The queries were carried out to ascertain how the ontology was able to answer correctly. Table 2, for example, queries instances of Drugs class with instances of Side Effect class, just to deduce the relationship between them. As an example, the prolonged use of drugs such as hypnotics, may somehow exacerbate the condition of the patient, leaving them dependent.
Query 3: SELECT * WHERE { ?Disorder :has_treatment ?Treatment . { ?Treatment rdf:type :psychotherapeutic } }

Table 5: Question 4 Results

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Disorder</th>
<th>Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irritability</td>
<td>Mood Disorder</td>
<td>Schizophrenic</td>
</tr>
<tr>
<td>Melancholy</td>
<td>Depression</td>
<td>Depressive</td>
</tr>
</tbody>
</table>


Table 6: Question 5 Results

<table>
<thead>
<tr>
<th>Symptoms related to Syndromes</th>
<th>Syndrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disinterest, hallucinations</td>
<td>Dementia</td>
</tr>
<tr>
<td>Exhaustion, shyness</td>
<td>Affective</td>
</tr>
</tbody>
</table>

Query 5: SELECT * WHERE { ?Symptom :Form_By ?Syndrome }

5. CONCLUSION AND FUTURE WORKS

The OntoPsic and OntoConsult fulfill the role to which they propose and together they consist themselves into a computational tool that can be used for the treatment and use of information about psychiatry in Telehealth, allowing the actors in this scenario to take correct decisions about treatments, disorders, drugs, syndromes, psychological profiles of users, supplying a high-level knowledge model for those involved.

The results obtained so far are very expressive and much of this success comes from the encouraging results obtained with the responses when querying the system based on the Ontopsic. The remarkable gain obtained is the technical support that health professionals are now getting to take any important decision involving a clinical case of any mental disorder patient. Further, also, both patient and doctor need not necessarily be physically in the same place, that is, OntoPsic (and Ontoconsult) is primarily a medical knowledge based system that takes no notice of geographical barriers. Going to a real medical environment, the system behaved as expected, even required as part of some medical courses practical class, as told before.

As future work, we are working on the detection of other types of disorders and treatments, also expanding the number of case studies, and increasing some variations of already undertaken queries as well as adding some classes to OntoPsic. Features are also being inserted in OntoConsult as the statistics module of user’s psychological profiles.

6. REFERENCES


