Modeling and Building an Ontology for Neuropediatric Physiotherapy Domain

Luciana V. Castilho
Federal University of Technology – Paraná, Av. 7 de setembro, 3165, Curitiba, Brazil
luciana.neurologia@gmail.com

Heitor S. Lopes[1]
Federal University of Technology – Paraná, Av. 7 de setembro, 3165, Curitiba, Brazil
hslopes@pesquisador.cnpq.br

César A. Tacla
Federal University of Technology – Paraná, Av. 7 de setembro, 3165, Curitiba, Brazil
tacla@cpgei.cefetpr.br

Abstract

This paper presents a methodology for modeling and building an ontology for the domain of Neuropediatric Physiotherapy. This is an area of great importance for health sciences and includes diagnosis, treatment and evaluation of patients with neurological injuries. The domain knowledge is, by nature, complex, ambiguous and non-standardized. We present formal methods for knowledge acquisition and representation, and building an ontology for the domain. The completeness and consistency of formal model was verified. The resulting knowledge-base yielded production rules employed in an expert system used by physiotherapists as a decision support aid in diagnosis. Overall, the main contribution of the work is a domain ontology based on consensus vocabulary for an important area of health sciences.

1. Introduction

In Physiotherapy, as well as in Medicine, there are different areas of specialization. One of them is Neuropediatric Physiotherapy that includes diagnosis, technical procedures and evaluation of patients that have motor or postural diseases due to lesions in the central nervous system [1].

There are many reference publications focusing all aspects of the diagnostic procedures in this area, as well as the clinical treatment in Neuropediatric Physiotherapy. However, not all physiotherapists (and related health professionals) have extensive knowledge of such domain.

Recent developments of information technology and the widespread availability of the internet have lead to huge amounts of data in all segments of human knowledge, including those related with health [2]. Physiotherapy in general, and, more specifically, Neuropediatric Physiotherapy, is a domain where knowledge is subjective by nature and concepts are poorly systematisized. This is the main drawback for creating a consensus vocabulary and, consequently, sharing and reuse of data, information and knowledge.

Therefore, we believe that modeling and developing a formal structure for representing knowledge in the domain of Neuropediatric Physiotherapy can be of great interest not only for Physiotherapy, but also, for other health-related areas, where subjectiveness and non-standardized information is present.

The objectives of this work are: (1) Apply formal procedures for modeling knowledge in the Neuropediatric Physiotherapy domain; (2) Develop a reusable and extensible ontology for representing knowledge in that domain; (3) Create a knowledge base capable of allowing inferences about diagnosis of real patients; (4) Develop an expert system for decision support in the domain area, based on the rules from the knowledge base.

2. Neuropediatric Physiotherapy

As mentioned before, Neuropediatric Physiotherapy is an area that includes diagnosis, treatment and evaluation of patients. Such patients, usually babies or young children, have to be frequently evaluated by the physiotherapist in order to observe the progress of treatment [1,3].

[1] This work was partially supported by the Brazilian National Research Council - CNPq, under research grant no. 309262/2007-0 to H.S. Lopes.

978-0-7695-3326-1/08 $25.00 © 2008 IEEE
DOI 10.1109/HIS.2008.58

When a child with neurological lesion is under diagnosis by a physiotherapist, its motricity and movement functionality is evaluated, regarding to the normal motor development. For instance, a normal child of 8 months old of *chronological age* is expected to have also 8 months old of *motor age*. On the other hand, a child affected by a neurological lesion can have 8 months old of chronological age, but 2 months old of motor age. This discrepancy is considered as a motor delay or abnormal condition. Starting from this presupposition, the physiotherapist is in charge of analyzing all the complex components of the normal motor development to be stimulated during the treatment of the patient. The objective is to foster motor development in such a way to make motor and chronological ages to match.

To treat children with neurological lesions, the physiotherapist must know the normal motor development (NMD) of a child, with all its peculiarities, so as to be able to recognize what would be abnormal. Therefore, the several steps of NMD are used as reference in the diagnosis procedure, as well as during treatment [4].

Understanding the underlying complexity, the extension, and non-standardization of terms in Neuropediatric Physiotherapy, it becomes clear the importance of correctly diagnosing to be able to carry out an effective treatment. It is in this scenery where the building an ontology takes place, establishing clear and definite concepts and relationships.

3. Knowledge acquisition & representation and ontologies

Knowledge acquisition or knowledge elicitation can be defined as the extraction, representation and transference of information from a knowledge source, usually a human expert, to a computer program. The objective is to obtain the detailed knowledge used by the expert to solve a given problem. Amongst the several techniques for knowledge acquisition it is worth to mention: text analysis, behavior analysis and interviews (directed, structured and semi-structured) [5].

Knowledge representation is a way to create a formal model of the expert´s knowledge in a given area, such that it can be properly used in a computer program. Many different structures can be used for formalizing and organizing knowledge. Particularly, in recent years, ontologies have received great attention. Ontologies are formal descriptions of a domain knowledge based on concepts and their relationships [6]. They are efficient for creating a common vocabulary between experts in order to share and reuse knowledge, using an accurate semantic.

Gruber [7] defined ontology as a formal and explicit specification of a shared conceptualization. According to Fensel [8], in this definition it is important to understand the meaning of some words: "conceptualization" refers to an abstract model of a given phenomenon; "explicit" means that concepts and their limits have to be clearly and defined; "formal" denotes that the ontology have to be processed by a computer; finally, "shared" indicates that knowledge have to be consensual between experts. Therefore, in this work, the development of an ontology for Neuropediatric Physiotherapy aims at creating a consistent terminology that can be shared and reused and supports a knowledge-based system.

Guarino [9] argues that ontology is a logical theory that considers the aimed meaning of a formal vocabulary. Consequently, the structure of an ontology is formed by: a set of concepts or classes, a hierarchy or taxonomy between those concepts, a set of functions or properties, and a set of axioms [6].

Ontologies are important tools for the development of knowledge-based systems. Knowledge-based models need an ontological commitment because it considers the semantics of a conceptualization [10]. Ontologies are the base of very large projects of knowledge representation, such as CYC [11] and KACTUS [12], and those related to health and medicine, e.g., SNOMED-CT [13].

4. Methodology

The development of ontologies requires an ontology engineer (or ontologist) who has some knowledge about the domain and familiarity with the several approaches for knowledge representation [2]. Building an ontology is a labor-intensive activity and becomes even more complex due to the absence of a standard vocabulary in the Neuropediatric Physioterapy domain.

Uschold [14] emphasizes that there is no unified methodology capable of fulfilling all requirements for modeling any domain. In this work we followed the two steps associated with the development of an ontology, as proposed by Zhou et al. [2]: (i) knowledge acquisition and management of the concepts between different sources of information (management of conflicting opinions), and (ii) implementation of the ontology itself using the represented knowledge.

To ensure the quality of the ontology, the development was based on the following principles:

1. Progressive refinement. We started with the construction of a small prototype, and then extending the terminology progressively by

incorporating more and more concepts and axioms.
2. Consistence evaluation. Evaluating consistency is essential in the building of any ontology, because it may avoid ambiguity and fosters standardization of the vocabulary.
3. Consensus vocabulary. Since multiple sources of knowledge are needed to build an ontology (human experts and updated literature), it is always necessary to establish consensus and manage conflicts of opinion.

4.1 Knowledge acquisition

The classical artificial intelligence suggests that the knowledge engineer should use a single knowledge source (expert) [5]. However, in this work we use an ontology for representing knowledge. The main authors in this area recommend that ontologies should be based by a consensus of a group of experts [7, 9]. Therefore, to cope with such contradiction, we decided to engage three expert physiotherapists. All of them had extensive expertise in Neuropediatric Physiotherapy, including educational (theoretical) and therapeutic (practical) experience.

Experts took part of several individual interviews. First, previously planned semi-structured interviews were used, and then, structured interviews for deepening specific subjects. To meet the requirements of the domain, on those interviews we adopted a six-phase questioning system proposed by LaFrance [15]:

1. Broad overview: a semi-structured interview was applied to the experts aiming at to understand the reasoning used during both diagnosis and therapy.
2. Categories cataloguing: all the classes (concepts) and subclasses relative to the domain were clearly defined.
3. Attribute detailing: structured interviews were carried out for analyzing how frequent was the use of each concept for different types of diagnostic outcomes.
4. Weight determination: weighting factors for each diagnostic class and subclass were obtained
5. Cross correlation: a consistency check was done after experts have exanimate all the information stored necessary for creating the ontology for Neuropediatric Physiotherapy.

Another important issue in the knowledge acquisition process is managing conflicts and divergence of opinions between experts. We used the methodology known as IBIS (Issue-Based Information System) [16] to manage conflicts between experts. This methodology helps to evolve a divergence of opinions to a convergence, thus emerging a consensus. When the knowledge engineer comes upon a question with different answers from the experts, he/she decides in favor of the one with better arguments. That is, the answer that is better supported by approval or justification. When two answers have justifications, one should choose the one with the large number of supporting arguments.

When finished the knowledge acquisition process with the experts, all information collected was checked against the main textbooks in Neuropediatric Physiotherapy [1, 3, 17].

As result of the knowledge acquisition process, the relevant information for diagnosis was grouped into five main classes: reflexes, reactions, movement plans, movement patterns and motor skills. The divisions of these classes were also defined, as well as all relationships between the classes of the ontology.

4.2 Knowledge representation in the ontology

Acquired knowledge was represented in a hierarchical structure of an ontology.

First, a taxonomy of terms was created with the main concepts (classes): *MotorAge* (corresponding to the diagnosis), *NormalMotorDevelopment* (NMD – set of characteristics belonging to a given diagnosis) and *Patients* (representing specific cases). This hierarchy was refined by creating subclasses from derived concepts: *MotorAge* included the 12 first months of life; *NormalMotorDevelopment* included the main components analyzed by the physiotherapist (reflexes, reactions, movement plans, movement patterns, motor skills and values); and *Patients* included some case-studies of real patients. Subclasses of NormalMotorDevelopment were later refined.

Next, the properties pertaining to each motor age (diagnosis) were represented, including their respective components of the NMD. An example is the property *hasReflex* that connects individuals of the *Reflex* class with individuals of *MotorAge* class. For the full description of the domain, the definition axioms of each subclass of MotorAge were declared, thus fulfilling the components of NMD necessary to accomplish the diagnosis.

The tool chosen for knowledge representation was an ontology because it allows the formal representation of tacit knowledge (kept in mind of the experts, but not concretely expressed) usually found in the domain area.

During the development of the ontology, two methodologies were used: Methontology [18] and On-

To-Knowledge Methodology [19]. To model the ontology, the following steps of the life-cycle of Methontology were done: development, managing and support. In the development process the following activities were done: specification, conceptualization, formalization, implementation and maintenance. In the management process, the control and quality assurance activities were done. The support process was done in parallel to the previous mentioned processes, accomplishing knowledge acquisition, evaluation (analysis of competencies issues and coherence of the taxonomy) and documentation activities. It is important to note that in the specification activity, the principles of On-To-Knowledge Methodology were extensively used.

The implementation of the ontology was done using a computational tool for editing, Protégé[2], version 3.3.1. This tool has extensible architecture, allows good level of details, and its interface is user-friendly. The formal language for representation chosen was OWL-DL (Web Ontology Language – Description Logic), which is recommended by World Wide Web Consortium (W3C).

4.3 Consistency checking

Inference mechanisms are not explicitly defined in an ontology, although it is possible to reason about the properties of the domain represented by the ontology. Such inference mechanisms can be used to check the logical structure of the model and make inferences about the domain. Therefore, they can be used to crosscheck the consistency of the model and its generalization capability, as well as its relationships and instantiations.

Ontologies allow the distinction between intentional knowledge (general knowledge about the problem domain) and extensional knowledge (specific knowledge about a particular problem). Typically, in an ontology-based knowledge base, the Description Logic (DL) is composed by two components: a *TBox* and an *ABox* [20]. The *TBox* contains the intentional knowledge in the form of a terminology and it is constructed by declarations that describe general properties of concepts. The basic form of a declaration in a *TBox* is a concept definition. That is, the definition of a new concept based on other previously defined.

For checking the consistency of the developed ontology, we used a tool, named RACER (*Renamed ABox and Concept Expression Reasoner Profissional*), together with the other tools available in the Protégé system. RACER implements the *Tableau* algorithm, with which the following checking were done in a *TBox*:

- Subordination or subclassification: starting from the declared constraints in each class, try to infer if a class is subclass of another one;
- Satisfability or concept consistence: analyze if there is some interpretation capable of satisfying the axiom such that the concept denotes a non-empty set in the interpretation;
- Equivalence: verify if two concepts are equivalent;
- Disjunction: determine if two disjoint concepts share the same instance;

4.4 Expert system development

Representing knowledge using an ontology and the creation of definition axioms in this ontology allowed the thorough description of concepts related to the intended domain of Neuropediatric Physiotherapy. Those axioms made possible to build a knowledge base of 12 rules, each one capable of classifying a patient in a *motor age* between 1 to 12 months old.

Those rules were implemented in a shell for developing expert systems, named SINTA[3]. An expert system using this shell enquires the user for information and checks the rule base. Through forward chaining, it first tries to construct, by deduction, a proof for rule 1. If there is a match between the provided information and the antecedents of the rule, the case is classified as belonging to “month 1” of motor age. Otherwise, it turns to the next rule, trying to prove it, and so on until one of the 12 rules is proved. This simple expert system can be useful for decision-support in the diagnosis of Neuropediatric Physiotherapy.

5. Results and Discussion

This section presents the main results and acquired experience during the development of the ontology.

In the knowledge acquisition phase, during the structured interviews with the three domain experts, 12 questionnaires were requested to be filled in by them. These questionnaires had 49 items each, making up a total of 588 items evaluated.

It is important to note that, in Neuropediatric

[2] http://protege.stanford.edu/

[3] http://www.lia.ufc.br

Physiotherapy, as well as in many health sciences, there are different schools of though that directs the professional practice, giving different approaches to the diagnosis problem. Due to the difference of approaches between schools of though, it could be quite difficult to establish consensual knowledge, thus making impracticable to build an ontology. As consequence of the lack of consensus, the created knowledge base could be inconsistent, thus making it useless for decision-support. Therefore, this work is directed towards the most widely spread school, created by Karel and Bertha Bobath [1, 3, 4], usually referred to as Neurodevelopment Treatment. As mentioned in section 4.1, knowledge acquisition was carried out with three expert physiotherapists. All of them belonged to the same school of though, thus taking more consistency and reliability to the resulting ontology and the knowledge-base. Even so, considering the large number of items to be evaluated by the experts, some divergences of opinions occurred. The occurrence of conflicts was relatively low, corresponding to only 7% of the items (that is, 41 out of 588). Such level of divergence between experts of the same school is promptly manageable and the IBIS methodology was adequate and efficient for this task.

Knowledge representation was carried out using Protégé. Figure 1 shows the high-level class hierarchy of the developed ontology. The classes mentioned in the figure are those defined in section 4.2. Notice that class *NormalMotorDevelopment* includes all components of the NMD (not expanded in the figure) necessary for the diagnosis of the patient in each class of *MotorAge*. Class Values includes the (relative) intensities of each component of the NMD.

This hierarchical structure gives as result the full organization and formalization of diagnostic knowledge in Neuropediatric Physiotherapy. The current version of the developed ontology is composed by 100 classes and subclasses, 30 properties and 200 axioms. This ontology allowed the creation of vast consensus vocabulary for the domain, including concepts with full definitions through their relationships and axioms.

The detailed definitions of the concepts and their relationships allow the creation of a production rule base. Therefore, the terminology and the structured knowledge obtained through the ontology was the base for an expert system used for decision-support. This system helps and guides the user in the diagnosis process, by means of a user-friendly interface. Besides, it can be useful for teaching the decision pathway, since the Expert SINTA shell has debug and explanation tools. It can provide explanation of the results obtained during the inference procedure, in the form of a decision tree with all steps of the diagnosis.

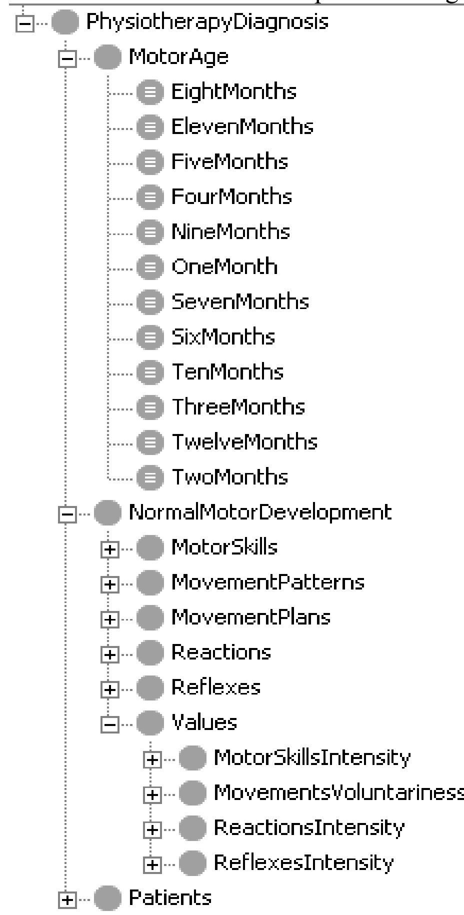

Figure 1. High-level class hierarchy.

6. Conclusions and future work

In this work knowledge was elicited from domain experts and complemented from reference textbooks. Knowledge was represented formally as an ontology, using well-defined methodological procedures. The formalism inherent to the methodology allowed the development of a knowledge-base which completeness and consistency were verified. Such ontology represents a consensus vocabulary in the domain of Neuropediatric Physiotherapy diagnosis, allowing knowledge reuse and sharing. It is important to recall the integration of different artificial intelligence-based methodologies, such as the LaFrance's questioning technique, the IBIS methodology for managing opinion conflicts, the Methontology and On-To-Knowledge Methodology for developing the ontology.

Overall, the use of an ontology for structuring knowledge was helpful not only for categorizing the collected information into hierarchies of concepts, but also, to comprehend the relationships between concepts, and, mainly, allowed full definition of concepts using axioms. These axioms supplied the necessary knowledge for creating production rules for an expert system. According to Russel and Norvig [5], testing an expert system is a complex task, and requests expert-supplied instances of the problem (different from those used to build the system). Usually, it may include other experts to whom the expert system performance will be compared. Although a reasonable level of completeness and consistency is assured by the formal methodology used in the development, extensive testing of the expert system is outside the scope of this work and is left for future work. Another future application of the ontology and the expert system will be in the instructional area. It is believed that the developments described can have great applicability as computer-assisted instructional tools for the Physiotherapy area.

7. References

[1] Bly, L, *Motor Skills Acquisitions in the First Year,* Therapy Skill Builders, USA, 1994.

[2] X. Zhou, Z. Wu, A. Yin, L. Wu, W. Fan and R. Zhang, "Ontology Development for Unified Traditional Chinese Medical Language System", *Artificial Intelligence in Medicine*, vol. 32, no. 1, 2004, pp. 15-27.

[3] Levitt, S, *Treatment of Cerebral Palsy and Motor Delay*, Blackwell Science, Oxford, 1995.

[4] C.A. Torre, "Follow up and Purpose of Physiotherapy Treatment for Teenagers and Young Adults With Cerebral Palsy", *Brain & Development*, vol. 23, no. 3, pp. 170-178, 2001.

[5] Russel, S.J. and P. Norvig, *Artificial Intelligence: a Modern Approach*, 2nd. Edition, Prentice-Hall, New Jersey, 2003.

[6] A. Gómez-Pérez, "Ontological Engineering: a State of the Art", *Expert Update*, vol. 2, no. 3, 1999, pp. 33-43.

[7] T.R. Gruber, "A Translation Approach to Portable Ontology Specifications", *Knowledge Acquisition*, vol. 5, no. 2, 1993, pp. 199-220.

[8] D. Fensel, "The Semantic Web and its Languages", *IEEE Intelligent Systems*, vol. 15, no. 6, 2000, pp. 67-73.

[9] Guarino, N. *Formal Ontology and Information Systems*, IOS Press, Amsterdam, 1998.

[10] N.F. Noy and C.D. Hafner. "The State of the Art in Ontology Design: a Survey and Comparative Review", *AI Magazine*, vol. 18, no. 3, 1997, pp. 53-74.

[11] D.B. Lenat, "CYC: a Large-scale Investment in Knowledge Infrastructure", *Communications of the ACM*, vol. 38, no. 1, 1995, pp. 33-38.

[12] G. Schreiber, B. Wielinga and W. Jansweijer, "The Kactus View on the 'o' Word", *Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing*, **AAAI** Press, Montreal, 1995.

[13] K.A. Spackman, K.E. Campbell and R.A. Cote. "SNOMED-RT: a reference terminology for health care", *Proceedings of the American Medical Informatics Association Fall Symposium*, 1997.

[14] M. Uschold, "Building Ontologies: towards a unified methodology", *Proceedings of the 16th Annual Conference of the British Computer Society Specialist Group on Expert Systems*, Cambridge, 1996.

[15] M. LaFrance, "The Knowledge-acquisition Grid: a Method for Training Knowledge Engineers", *Journal of Man-Machine Studies*, vol. 26, no. 2, 1987, pp. 245-255.

[16] H.W.J. Rittel, and M. Webber, "Dilemmas in a General Theory of Planning", Elsevier, Amsterdam, *Policy Sciences*, vol. 4, no. 2, 1973, pp. 155 – 169.

[17] Flehmig, I. *Normal Infant Development And Borderline Deviations, Early Diagnosis And Therapy*, Thieme Medical Pub, Switzerland, 1992.

[18] M. Fernández, A. Gómez-Pérez, and N. Jurino, "Methontology: From Ontological art Towards Ontological Engineering", In: *Proceedings of the AAAI-Spring Symposium on Ontological Engineering*, AAAl Press, Stanford, 1997.

[19] Sure, Y. and R. Studer, *On-To-Knowledge Methodology: Final Version*, Institute of Applied Informatics and Formal Description Methods, University of Karlsruhe, 2002.

[20] Baader, F., D. Calvanese, D. McGuinness, D. Nardi and P. Patel-Schneider, *The Description Logic Handbook: Theory, Implementation and Applications*, 2nd. Edition, Cambridge University Press, Cambridge, 2007.