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Abstract

Objective: Waiting time for a consultation for chronic pain is a widespread health problem. This paper present the design of an ontology use to assess patients referred to a consultation for chronic pain.

Methods: We designed OntoDol, an ontology of pain domain for patient triage based on priority degrees. Terms were extracted from clinical practice guidelines and mapped to SNOMED-CT concepts through the Python module Owlready2. Selected SNOMED-CT concepts, relationships, and the TIME ontology, were implemented in the ontology using Protégé. Decision rules were implemented with SWRL. We evaluated OntoDol on 5 virtual cases.

Results: OntoDol contains 762 classes, 92 object properties and 18 SWRL rules to assign patients to 4 categories of priority. OntoDol was able to assert every case and classify them in the right category of priority.

Conclusion: Further works will extend OntoDol to other diseases and assess OntoDol with real world data from the hospital.

Keywords

Clinical Decision Support System, Chronic pain, Ontology

Introduction

Chronic pain is reported by 30% of people in occidental countries and 7% of them suffer from neuropathic pain [1]. The increase in demand for access to specialized pain management services continues, and waiting time for an appointment with a specialist is a problem in many countries [2]. Therefore methods to prioritize patients with the greatest need becomes of increasing importance. Contrasting with other domains where algorithms may be learnt from data bases (e.g., image classification), patient triage relies on explicit gudelines-based criteria established by medical associations. The International Association for the Study of Pain (IASP) published guidelines about the waiting time for some disease and painful situations. In France, the Health Authorities published guidelines about the pathway that patients should follow before being referred to a Pain Clinic. Patients must go through a pre-defined list of exams, including biological tests and specialized consultation (e.g., consulting a rheumatologist for chronic low back pain). Only when all these tests have been performed, the general practitioner may ask for an advice by the pain physician. Patient is referred with a letter. The pain physician has to make a decision about the rank of priorities of the referral according to the queue and a list of criteria. Many determinants that influence the risk of chronic pain have been identified, regarding for example the risk of transition from acute to chronic pain after surgical procedures [3].

The aim of the project was to develop and implement a triage system for referrals to a pain clinic. It would create a standardized automated process based on evidence and guidelines thus ensuring equity for patients; improve access to the pain clinic leading to prompt assessment based on patient needs; and overall improve the referral system to increase referrer satisfaction and the quality of patient care. In order to ensure explainability and adherence to guidelines, the first step consisted in building a knowledge base of expert rules based on a domain ontology. The ontology provides formal definitions of concepts and their relationships using the Web Ontology Language (OWL 2) [4], as well as inference capabilities to classify patients. In this paper, we present the design of our ontology, called OntoDol, as well as the results obtained on virtual patients' cases of complex regional pain syndrome.

Methods

OntoDol is intented to be used by physicians when they manage a new referral into a pain consultation center. Therefore, OntoDol requires concepts associated with pain findings and characteristics, painful diseases and comorbidities (present or past), drugs (substances and products), procedures either for pain treatment or causing pain, anatomic descriptors, functionnal activities, biologic or imaging data, risk factor of chronic pain, demographics data and social context information. The following principles guided the design of OntoDol: reuse of existing ontologies as much as possible, coverage driven by the content of the international guidelines related to chronic pain, alignment with reference ontologies like SNOMED CT® (Systemized Nomenclature of Medicine – Clinical Termes) to make the clinical decision system interoperable with EHR systems, use

of the capabilities of descriprion logics to classify patient cases, and addition of rules if needed.

Reuse of existing ontologies

We explored the National Center for Biomedical Ontology (NCBO) Bioportal and OBO Foundry repositories to search for existing resources. We found that '*Pain*' was a class present in 71 ontologies, and '*Neuropathic pain'* in 31 ontologies. None of the corresponding ontologies provided a complete coverage for patient triage for a first consultation in a pain clinic.

We decided to use SNOMED CT® as reference ontology since it is the most comprehensive international clinical terminology. The 2021-01-31 release contains more than 350 000 concepts. and is broadly used to document patients' signs, symptoms, and diagnoses in EHRs.

We also imported the TIME ontology to model temporal aspects such as duration of symptoms, the date of onset of a disease, or demographic data like date of birth and age.

Identification of key clinical entities

Two clinical practice guidelines (CPGs) related to chronic pain were explored, namely, the CPGs from IASP [5], which are based on CPGs from Canada, the United Kingdom, Finland, Norway, and Australia, and the CPGs established in France by the French Health Agency , "Haute Autorité de Santé' and the French Society for the Study and Treatment of Pain (SFETD). Moreover articles published on PubMed, were reviewed by a clinicial specialist in chronic pain. Based on these resources, a set of key clinical terms that are central to the domain of chronic pain management were identified to populate the core OntoDol ontology. Starting from this seed ontology, we used a broad medical ontology, namely SNOMED-CT to extend its coverage, provide mapping to standard concepts, and enrich the seed ontology with further concepts and relations.

Design of OntoDol

We used Python module Owlready 2 to create our ontology from the key clinical concepts and SNOMED-CT [6]. Owlready 2 uses the release 2020AB-full of the Unified Medical Language System (UMLS) to import Metahthesaurus terms. Every term is mapped to SNOMED CT® Terminology. The PyMedTermino module from Owlready 2 mapped a list of terms with SNOMED CT® identifiers. Axioms were generated using object properties of interest. When some terms were not mapped within SNOMED CT®, experts had to map them manually to the closest concept, using the SNOMED CT® browser. Experts were asked to choose the smallest level of granularity with a significant clinical definition. We developed a bottom-up method to extract the parents in SNOMED-CT® and integrate them in OntoDol. When the level of granularity of the mapped concept was too coarse, we used a top-down a to collect the descendants. Thus Owlready 2 created *an automatic hierarchy with an is_a* relationship between classes.

Object properties, i.e., relations between classes are defined in the SNOMED CT® as attributes of the *Concept Model Object Attribute* top class. Starting from the list of concepts obtained from the SNOMED CT®, we selected a set of object properties of interest. Then, a Python script using Owlready was used to retrieve all axioms using all defined classes and object properties. When relations between concepts were missing, new object properties were created, e.g. the relation between a disease and its phase.

Data properties are relations between an individual and a primitive data type. In OntoDol, they are used to describe time and duration data using TIME i.e. *'Date of symptom onset'* and *'Time since symptom onset'* and value of pain assessment i.e. *'has Value (EVA) xsd:int [0-10]'*

Create SWRL rules

We implemented the clinical reasoning extracted from CPGs in the form of SWRL rules. According to IASP guidelines, there are four categories of priority: *'Immediately'*, '*Most urgent'*, *'Urgent or Semi-urgent'* and *'Routine or regular'*. Using SNOMED CT® concepts, we defined four categories of priority: *'Immediate'*, *'High'*, *'Delayed'* and *'Normal'*. The objective was to support the classification of all patients in one of those categories.

Most of OntoDol classes are defined classes. SWRL rules and built-in rules were added to support deductive reasoning, i.e. 'antecedent' → (implies) 'consequent', assumptions where antecedent and consequent are conjunctions of atoms.

We used SWRL rules to:

- Define priority rules,
- Define diseases as an association of findings,
- Calculate time duration between dates (date of onset of symptom, current date, date of an event like a surgery…)

Evaluation of the ontology

We conducted a two-stage evaluation of OntoDol. First, we evaluated its intrinsic properties, then we performed a user evaluation. Our ontology should respect some properties:

- Clarity : all terms are given an understandable *rdfs:label* based on SNOMED CT® terminology.
- Accuracy and reliability: OntoDol is based on guidelines published worldwide.
- Completeness of content coverage: OntoDol covers key elements of the domain, allowing a closed-world assumption.
- Consistency checking: Pellet was used for consistency checking

The ability of the OntoDol to classify parients was tested on a set of 5 virtual cases of complex regional pain syndrome (CPRS). This disease is characterized by a neuropathic pain on a limb and can be associated with a disability for walking. Considering the previous clinical guidelines, the proirity depends on the clinical findings (disease or finding), duration of the pain, pain intensity, and associated disabilities.

Results

OntoDol ontology

We used the open source editor Protégé developed by Stanford in its version 5.5.0. We chose Pellet as the reasoner, as it supports Semantic Web Rule Language (SWRL) and SPARQL queries[7]. OntoDol ontology is encoded in OWL 2 file format using Protégé 5.5.0. Metrics are listed in Table 1.

Owlready imported understandable *rdfs: label*, *rdfs:Prefered US Terms* and *rdfs: Synonym US Terms*. We provided textual *rdfs:definition*.

Top hierarchy of OntoDol is shown on Figure 1, it reuses the hierarchy of SNOMED CT® so it could be interoperable with EHR data. TIME, as a recommandation of W3C, infered temporal concept from SNOMED CT® as *time:instant* or *time:duration*.

Table 1: OntoDol metrics

Metrics	Values
Number of classes	762
Axioms	4368
Object properties	92
Data properties	30
Individuals	62
SWRL rules	18

Asserted properties come from Owlready 2. Eighteen SWRL rules were implemented. An example of axioms in SWRL used for triage is shown in Table 3.

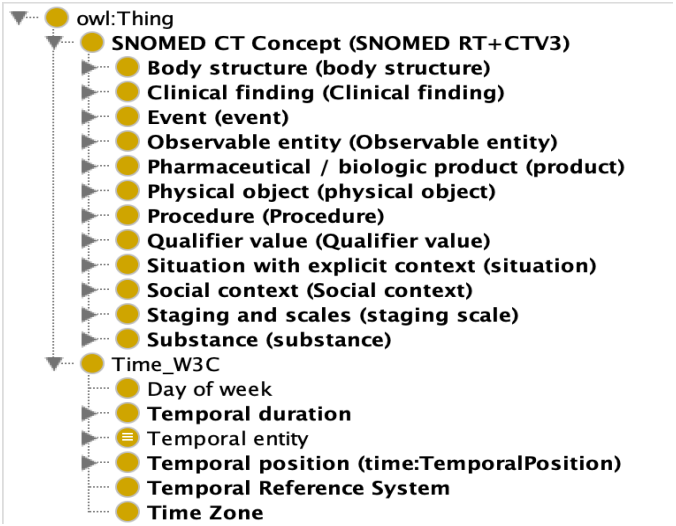

Figure 1: Top hierarchy of OntoDol' using a part of SNOMED CT® top-hierarchy and TIME.

Testing with a focus on clinical case

We ran Pellet reasoner in OntoDol to classify five virtual patient referred for a consultation for an acute phase of CPRS of the right foot, with different evolution phases and different levels of pain.

OntoDol was able to classify the 5 patients in the correct categories 'immediate priority', 'high priority', 'delayed priority' or 'normal priority', according to the recommandation of IASP (Table 2), Ontodol was able to:

- Infer that the association of findings reported by the virtual patient was a CPRS (Figure 2);
- Determine the acute or chronic phase of CPRS depending on the duration, less or more than 3 months since the onset of symptoms, using TIME data properties;
- Provide an assessment of the level of pain according the 0 to 10 visual analogic pain scale as a mild, moderate or severe pain;
- Determine the priority of the consultation for pain (Figure 3 & Figure 4);

Table 2: Priorities inferred by OntoDol in a set of fictional training cases comparing to IASP guidelines. All the patients were accurately classed in the correct category.

#	Situation	IASP guidelines	OntoDol
1	Acute CPRS and moderate pain and walking disability	Urgent	High Priority
2	Acute CPRS after surgery and severe pain and walking disability	Immediate	Immediate
3	Chronic CPRS and mild pain and no disability	Routine	Normal
4	CPRS > 6 months and severe pain and walking disability	Semi-urgent	Delayed
5	CPRS > 12 months and moderate pain and walking disability	Routine	Normal

Table 3: An exemple of SWRL rules to classify an acute phase of CPRS according to the IASP recommmandation

Priority	IASP Recommandation	SWRL Rule
Most urgent:	A painful severe condition with the risk of deterioration or chronicity, such as the acute phase of complex regional pain syndrome (CRPS) [...]	'Consultation for pain (procedure)'(?c), 'has Focus'(?c, ?f), 'Complex regional pain syndrome (disorder)'(?f), 'has Phase'(?f, ?ph), 'Acute phase (qualifier value)'(?ph), 'has Priority'(?c, ?p), 'Priorities (qualifier value)'(?p) → 'Consultation for pain (procedure)'(?c), 'has Focus'(?c, ?f), 'Complex regional pain syndrome (disorder)'(?f), 'has Priority'(?c, ?p), 'High priority (qualifier value)'(?p)

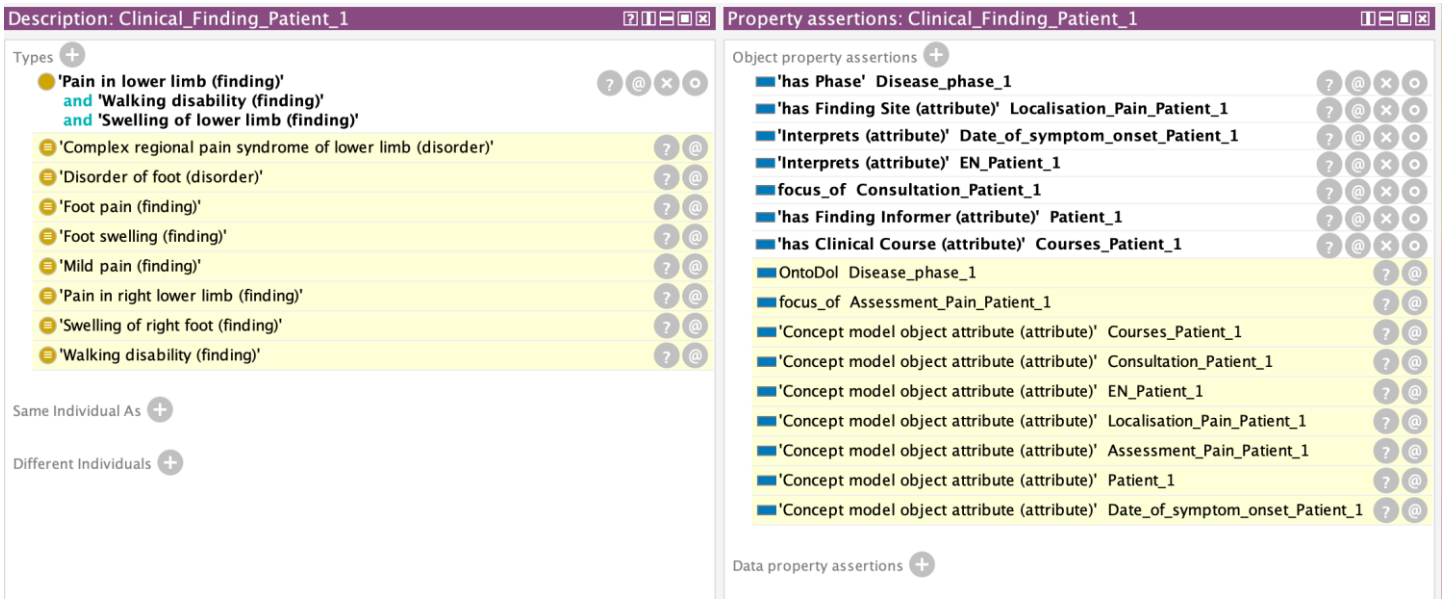

Figure 2: Example with a fictional patient having 'Swelling of lower limb (finding) and a Pain in lower limb (finding) and a Walking disability (finding). Object property assertions make relations with qualifier value related to clinical course, an evaluation of pain using a visual analogic pain scale and date of symptom onset.

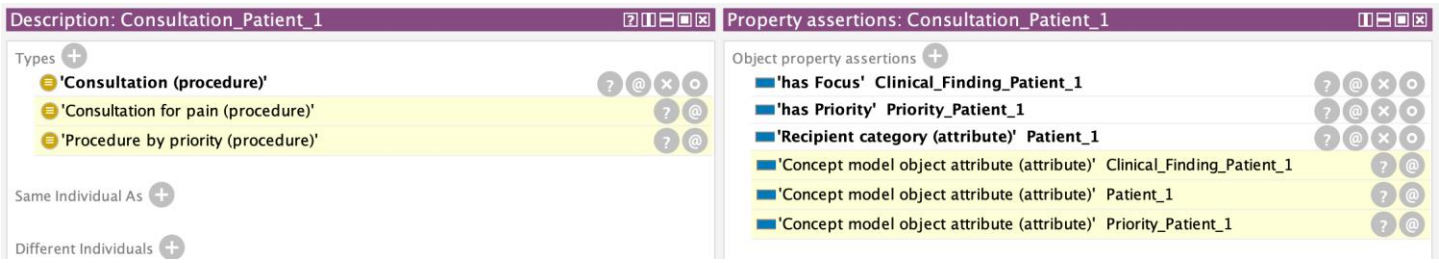

Figure 3: The fictitious patient is related to a consultation (procedure). OntoDol is able to infer that the consultation has a focus on painful disease,

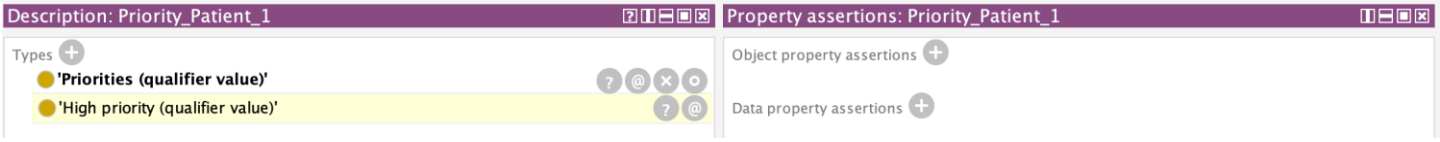

Figure 4:The inferred priority of the fictitious patient is an individual of 'Priorities (qualifier value)' class. OntoDol inferred, according a SWRL rules that the consultation for pain of the fictitious patient has a priority which is 'High priority (qualifier value)'

Discussion

We developed OntoDol ontology as a basis for a clinical decision support system and we presented it with a focus on a set of five cases of CPRS with different assessments of pain intensity, clinical courses, and disability due to the pain. OntaDol was able to assign all the virtual clinical cases to the correct category of priority for a consultation in a pain center.

The solution adopted in OntoDol provides a high-level ethical framework that can be used to guide decision-making in the domain of chronic pain. Whereas data-driven AI algorithms may be questionable for patient triage, the algorithm implemented in OntoDol is a knowledge-based one, thus it is :

- Transparent, i.e. the decisions and their justifications are explicit;
- Consistent, i.e. all cases in the same category are classified in the same way;
- Accountable, i.e. the decisions rely on the guidelines established by the domain experts.

Although further external evaluation is required before using OntoDol for automated triage, the preliminary results are encouraging. The originality of this work is that we directly use parts of SNOMED CT® making it interoperable with EHR. The pain domain has not been covered entirely in OntoDol yet. We need to add more clinical findings related to pain, body structures related to those clinical findings and scales use in assessment of pain, mood or disability. A new version of the SNOMED CT® is published every six months. An updating system is necessary to collect new terms or new relations.

Chronic pain has been defined as a global public health priority during the last decade [8]. The high prevalence and incidence of chronic pain, its substantial and growing comorbidities, contrasting with the limited number of specialists in pain medicine provide ample justification for providing computerized aids to clinicians. Patient triage and priority setting have been identified as major concerns for all health systems. When specialized resources are limited, setting priorities is required, but choices must be explicit and based on shared recommendations. Some authors created ontologies of pain [9], but the clinical application for referral management is limited. Some previous work designed web-based clinical decision support for patients with low back pain in primary healthcare in the Netherlands [10]. In other domains, similar solutions have been designed for triage, for exemple in emergency department [11] using concepts of a web semantic computing.

Further works will map OntoDol with ICD11 for diagnosis and LOINC for clinical, biological and scales concepts and ATC for drugs labels. The 10th version of the ICD is currently used in most countries and the 11th version is about to be released with a new classification regarding painful diseased [12]. In the future, OntoDol will be plugged to our clinical data warehouse to evaluate it on real cases extracted from the hospital information system and to compare the classification made by OntoDol against the classification by a pain specialist.

Conclusions

Using a semi-automatic method, we designed OntoDol, an ontology for chronic pain referral management, based on expert guidelines. Further work will add more classes, and more rules according to specific pathologies, defined indicators for risk of chronic pain and will have to evaluate validity compared to standard of care using real patient case from the clinical dataware house.

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Protégé 5.5.0 is available on http://protege.stanford.edu/

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https://pypi.python.org/pypi/Owlready2 (stable version).

UMLS was downloaded on:

https://download.nlm.nih.gov/umls/kss/2020AB/umls-2020AB-full.zip

References

[1] D. Bouhassira, M. Lantéri-Minet, N. Attal, B. Laurent, and C. Touboul, Prevalence of chronic pain with neuropathic characteristics in the general population, *Pain*. **136** (2008) 380–387. doi:10.1016/j.pain.2007.08.013.

[2] I. Gilron, and A.P. Johnson, Economics of chronic pain: How can science guide health policy?, *Can J Anesth/J Can Anesth*. **57** (2010) 530–538. doi:10.1007/s12630-010-9307-3.

[3] P. Glare, K.R. Aubrey, and P.S. Myles, Transition from acute to chronic pain after surgery, *The Lancet*. **393** (2019) 1537–1546. doi:10.1016/S0140-6736(19)30352-6.

[4] OWL 2 Web Ontology Language Document Overview (Second Edition), (n.d.). https://www.w3.org/TR/owl-overview/ (accessed January 15, 2020).

[5] IASP_Wait_Times.pdf, (n.d.). http://www.iasp-pain.org/files/Content/NavigationMenu/EducationalResources/IASP_Wait_Times.pdf (accessed February 1, 2021).

[6] J.-B. Lamy, Owlready: Ontology-oriented programming in Python with automatic classification and high level constructs for biomedical ontologies, *Artificial Intelligence in Medicine*. **80** (2017) 11–28. doi:10.1016/j.artmed.2017.07.002.

[7] K. Dentler, R. Cornet, A. ten Teije, and N. de Keizer, Comparison of reasoners for large ontologies in the OWL 2 EL profile, *Semantic Web*. **2** (2011) 71–87. doi:10.3233/SW-2011-0034.

[8] D.S. Goldberg, and S.J. McGee, Pain as a global public health priority, *BMC Public Health*. **11** (2011) 770. doi:10.1186/1471-2458-11-770.

[9] B. Smith, W. Ceusters, L.J. Goldberg, and R. Ohrbach, Towards an Ontology of Pain, (2011) 13.

[10] W.O. Nijeweme-d'Hollosy, L. van Velsen, R. Soer, and H. Hermens, Design of a Web-based Clinical Decision Support System for Guiding Patients with Low Back Pain to the Best Next Step in Primary Healthcare:, in: Proceedings of the 9th International Joint Conference on Biomedical Engineering Systems and Technologies, SCITEPRESS - Science and and Technology Publications, Rome, Italy, 2016: pp. 229–239. doi:10.5220/0005662102290239.

[11] G. Wunsch, C.A. da Costa, and R.R. Righi, A Semantic-Based Model for Triage Patients in Emergency Departments, *J Med Syst*. **41** (2017) 65. doi:10.1007/s10916-017-0710-y.

[12] R.-D. Treede, W. Rief, A. Barke, Q. Aziz, M.I. Bennett, R. Benoliel, M. Cohen, S. Evers, N.B. Finnerup, M.B. First, M.A. Giamberardino, S. Kaasa, B. Korwisi, E. Kosek, P. Lavand'homme, M. Nicholas, S. Perrot, J.

Scholz, S. Schug, B.H. Smith, P. Svensson, J.W.S. Vlaeyen, and S.-J. Wang, Chronic pain as a symptom or a disease: the IASP Classification of Chronic Pain for the International Classification of Diseases (ICD-11), *PAIN*. **160** (2019) 19–27. doi:10.1097/j.pain.0000000000001384.

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