MEDINFO 2021: One World, One Health – Global Partnership for Digital Innovation
P. Otero et al. (Eds.)

doi:10.3233/SHTI220037

An Ontology-Based Semantic Model for Sharing and Reusability of Clinical Pathways Across Context (ShaRE-CP)

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Abstract

Clinical pathways (CP) enable a standardized and an efficient management of patients with common pathologies. As operational tools, they take into account knowledge from guidelines and from the context (e.g. availability of resources) in which different interventions are to be carried out. Mastering the coherence of interactions between all these knowledge domains is a major challenge for the implementation of CP. This scientific work led to the development of an ontology called Shareable and Reusable Clinical Pathway Ontology (ShaRE-CP) which integrates four knowledge domains (CP, guidelines, health resources and context) and to the establishment of existing semantic links between them. The consistency of this semantic model has been validated by using reasoners. This ontology can serve as a basis for the development of a decision support system for planning and managing patient care.

Keywords:

Clinical Pathways; Guidelines; Ontology.

Introduction

A clinical pathway can be defined as the planning of care procedures, including diagnostic tests, treatments and consultations, for the purpose of coordinating and making efficient the management of patients [1]. It is considered as quality management tool. Several benefits are associated with the use of clinical pathways, particularly in terms of improving the quality of care through a better organization of care processes, the monitoring of the expected clinical outcomes in patients and the improvement of the efficiency of care through better use of resources [2-6].

Clinical pathways usually integrate not only data from the scientific literature (evidence-based medicine leading to production of guidelines) [3] but more importantly, they take into account the context (e.g., the availability of resources, financial or human aspects) in which required interventions must be performed [7]. It is this match between the choice of interventions and the context's constraints (e.g: availability of resources) that makes it a relevant tool for improving the quality of care.

Mastering the coherence between all these knowledge elements (interventions, outcomes, guidelines, constraints related to context) combined with the complexity of managing their evolution over time, are important challenges for those in charge of developing and implementing clinical pathways. It is therefore important to establish a common semantic model [7] to represent and describe concepts and semantic links of clinical pathways and concepts and semantic links associated to knowledge domains that interact with it.

In the field of knowledge engineering, ontologies enable to represent and model the set of knowledge related to a given knowledge domain [8]. Although several ontology-based semantic models have been proposed to represent clinical pathways and their interactions with various other knowledge domains [2,7,9,10.11], it must be noted that there is no work that has attempted to explicitly formalize interactions that would exist between clinical pathways, guidelines and context.

The objectives of this study were to develop an ontology that describes classes and semantic relations of knowledge domains of clinical pathways, guidelines, health resources and context, and to establish semantic links and interactions between all these knowledge domains.

Methods

The development of this domain ontology was based on the model proposed by Uschold et al. for ontology development [12]. After the identification of goals, the development of this ontology included three sub-steps: capture (identification of key concepts and their relations), encoding (representation of classes and relations through a formal language) and integration (reuse of existing ontologies).

Capture

The capture of key concepts and relations was based on the analysis of following information sources: (i) the published scientific literature on the domains of clinical pathways, guidelines, health resources and context; (ii) the previously existing ontology models, in particular the clinical pathways ontology developed by Yan Ye [9] (iii) and the existing empirical and tacit knowledge on different knowledge domains. This iterative process allowed us to identify main concepts and relations needed for the development of this domain ontology.

Encoding

This domain ontology was developed using the ontology editor Protégé [13]. It supports several formats including RDF, RDFS, OWL, XML, Turtle, etc. The Web Ontology Language Second Edition (OWL2) semantic language developed and published in 2012 by the W3C OWL Working Group was used [14]. This language has emerged as the standard for sharing ontologies across the Web. It allows the formal description of knowledge domains (classes and relations) and to detect inconsistencies and generate new knowledge from a reasoning engine [15].

Integration

Several related ontologies were used for the development of this domain ontology: the ontology for Web services (OWL-S) [16], the ontology of time [17] and the Dublin Core ontology [18].

Results

We developed a domain ontology called Shareable and Reusable Clinical Pathway Ontology (ShaRE-CP). This ontology defines classes related to four knowledge domains: clinical pathways domain (whose prefix is 'cp'), guidelines domain ('gdl'), health resources domain ('res') and context domain ('cont'). It represents also relations that exist between classes within each knowledge domain and those that exist between classes belonging to different knowledge domains. In terms of metrics, ShaRE-CP contains: 254 classes, 225 object properties, 53 data properties and 6'873 axioms. Its consistency has been checked using OWL reasoners such as HermiT 1.3.8 and 1.3.8.413.

Ontology of clinical pathways

The development of clinical pathways ontology (figure 1) was inspired by the ontology model developed by Ye et al [9]. This ontology contains different classes and relations found in clinical pathways. It imports the ontology for Web services (OWL-S) whose prefix is 'process' and the ontology for time (Time-OWL) whose prefix is 'time'.

The main classes of this ontology are the following. The class cp:Clinical_Pathway represents the set of clinical pathways designed for the management of patients with specific clinical conditions. The class cp:Clinical_Condition defines the clinical situation for which a given clinical pathway has been designed and developed. The class cp:Expected_LOS defines the expected length of stay during the management of a patient in a given clinical pathway.

The class cp:Intervention defines the actions or activities specific to a given clinical pathway. It is the equivalent of the class process:SimpleProcess and a subclass of super classes process:Process of the OWL-S ontology and time:TemporalEntity of the time ontology. The class cp:Clinical_Process is a subclass of the class process:Process. It represents the generic clinical actions or activities (defined without taking into account the objectives (outcomes) or the temporal parameters (temporal position, duration and delays of realization) linked to their execution which can be executed during a given care process. An individual of the class cp:Intervention executes a single individual of the class cp:Clinical_Process which can be either of the class process:CompositeProcess or of the class process:AtomicProcess.

The class cp:Outcome represents objectives or clinical results expected for a patient (or his family, and/or his community) after the execution of the specific interventions to a given clinical pathway. These outcomes can be primary (abstract outcomes corresponding to a day or to a phase of care), which may themselves be composed of several secondary or specific outcomes (concrete outcomes). The class cp:Condition_Outcome defines conditions that must be satisfied by a secondary outcome.

The class cp:Care_Phase, which is a subclass of the class time:Interval, represents different phases of care of a clinical pathway. It is composed of two subclasses: the class cp:Care_Step (adapted to clinical pathways organized in care steps whose durations are not predefined) and the class cp:Care_Period (adapted to clinical pathways organized in time periods whose durations are predefined).

The class cp:Variance defines any variance (deviation) that may occurs during the execution of a clinical pathway. It is a subclass of the class time:Instant of the time ontology.

Other classes exist such as the class cp:Repeat_Every, defined as a subclass of the class process:Iterate. It allows to define modalities for the repetitive execution of a clinical process. And finally, the class cp:TemporalConstraints_Between_Interventions, which is a subclass of the class time:TemporalEntity, enables to define time constraints (duration of time before or after) that can be between two interventions in order to position them on a timeline.

Ontology of guidelines

The Guidelines Ontology formally describes some elements of this knowledge domain. It integrates the terminology of the Dublin Core ontology (whose prefix is 'dcterms') to describe metadata and resources associated with the production of guidelines.

Its main classes are the following. The class gdl:Guidelines represents the resource that contains the collection of all recommendations formulated by a given organization and which concern a specific health topic. This class is associated to several classes enabling to describe it. The class gdl:Guidelines_Recommendations describes each recommendation or directive contained in guidelines. This class is associated with other classes. The class gdl:Guidelines_Recommendations_Status defines the status (recommended or not recommended) of a recommendation. The class gdl:Recommendation_Evidence_Quality specifies the level of evidence associated with a recommendation. The class gdl:Recommendation_Strength specifies the strength of the recommendation. The class gdl:Related_Interventions identifies interventions associated with a recommendation. Finally, the class gdl:Recommendation_Conditions specifies conditions required for the execution of a recommendation.

Ontology of health resources

The health resources ontology formally describes resources needed to carry out healthcare interventions. It contains different classes: res:Human_Resources, res:Equipment_Consumable, res:Infrastructure, res:Drug and res:Other_Resources (data or knowledge resources, environmental resources, financial resources).

Ontology of context

The context ontology formally describes some elements of this knowledge domain. Its main classes are the following.

The class cont:Patient describes the patient. The class cont:Patient_Care_Stay_Encounter which is a subclass of the class time:Entity of the time ontology, describes the care stay or visit of a given patient.

The class cont:Community describes family or community to which a patient of the clinical pathway belongs.

The class cont:Health_Institution defines the health institution in which the clinical pathway is deployed.

The class cont:Setting defines the context in which a clinical pathway is deployed. The setting is defined as a physical entity in which elements that constitute may have certain common conditions: territory, resources, infrastructures, political conditions, laws, level of economic and social development, environmental and climatic conditions.

The class cont:Status_Regulation defines the current status and rules of the main components of a given context (patient, community, health institution, setting).

The class cont:Context_Related_Preconditions defines conditions that must be satisfied for an atomic process to be performed. These conditions can be related to the patient, the community, the health institution or the setting.

Finally, the class cont:Causes_Of_Variance which defines different causes of variances. These variances can be due to a lack of resources coming from the patient, the family or the community, the healthcare professionals, the health institution or the setting. They may also be due to other causes, such as failure to achieve patient's clinical outcomes, values of the community, a delay in the execution of a task by a healthcare professional, restrictive rules or norms that apply to a given health institution or setting.

Axioms of the ShaRE-CP ontology

ShaRE-CP ontology defines several axioms representing all identified and relevant interactions between the different knowledge domains.

Axioms between classes of the clinical pathways ontology and those of the context ontology

The class cp:Clinical_Pathway is associated with the classes cont:Health_Institution and cont:Patient_Care_Stay_Encounter by the properties cp:deployed-in and cp:applied-to respectively.

The class process:AtomicProcess is associated with the classes cont:Health_Institution_Departments and cont:Context_Related_Preconditions by the properties cp:is-under-responsibility-of and process:hasPrecondition respectively.

The class cp:Variance is associated with the class cont:Patient_Care_Stay_Encounter by the property cp:occurs-on and with the class cont:Causes_Of_Variance by the property cp:is-caused-by.

The class cp:Clinical-Condition is associated with the class cont:Patient_Care_Stay_Encounter by the property cp:is-clinical-condition-of. This property has two sub-properties: cp:is-clinical-condition-disease-of and cont:is-clinical-condition-procedure-of.

The class cont:Patient_Care_Stay_Encounter is associated with the class cp:Care_Calendar by the property cont:patientcarestayencounter-associated-with-calendar (which is a sub-property of the property cp:associated-with-calendar). It is also associated with the cp:Clinical_Pathway class by the cont:follows property. The property cont:follows is the inverse of the property cp:applied-to. The class cont:Patient_Care_Stay_Encounter is also associated with the class cp:Clinical_Condition by the property cont:has-clinical-condition (inverse of the property cp:is-clinical-condition-of) and has two sub-properties: cont:has-clinical-condition-disease and cont:has-clinical-condition-procedure.

Finally, the class cont:Health_Institution_Departments is associated with the class process:AtomicProcess via the property cont:has-responsibilty-of (inverse of the property cp:is-under-responsibility-of).

Axioms between classes of the clinical pathways ontology and those of the health resources ontology

The class process:AtomicProcess is associated to the class res:Health_Resources via the property cp:requires (inverse of the property res:is-required).

Axioms between classes of the clinical pathways ontology and those of the guidelines ontology

The class cp:Clinical_Pathway is associated with the class gdl:Guidelines_Recommendations by the property cp:implements (inverse of the property gdl:implemented-by).

The class cp:Clinical_Condition is associated to the class gdl:Subjects by the property cp:is-part-of.

The class process:AtomicProcess is associated to the class gdl:Guidelines_Recommendations by the properties cp:supported-by (inverse of the property gdl:supports) and cp:is-not-supported-by (inverse of the property gdl:is-against). These two properties are disjoint.

Axioms between classes of the guidelines ontology and those of the health resources ontology

The class gdl:Related_Interventions is associated with the class res:Health_Resources via the property gdl:requires (inverse of the property res:is-required).

Axioms between the classes of the guidelines ontology and those of the context ontology

The class gdl:Guidelines_Recommendations is associated with each of the classes cont:Patient_Status, cont:Community, cont:Health_Institution_Care_Level and cont:Setting by the properties gdl:concerns and gdl:does-not-concern.

Axioms between the classes of the context ontology and those of the health resource ontology

The classes cont:Patient, cont:Community, cont:Health_Institution and cont:Setting are each associated with the class sharecp:Resource_Statement by the properties cont:has-resource (inverse of the property sharecp:is-resource-of) and cont:does-not-have-resource (inverse of the property sharecp:is-not-resource-of).

The class sharecp:Resource_Statement, directly created within the ShaRE-CP ontology, defines the state of resources and is a subclass of the class time:TemporalEntity. It is associated with the class res:Health_Resource by two properties: sharecp:has-resource and sharecp:does-not-have-resource. The class sharecp:Resource_Statement is also associated with the class cp:Care_Calendar by the property sharecp:resourcestatement-associated-with-calendar (sub-property of the property cp:associated-with-calendar).

The class cont:Health_Institution_Roles is associated with the class sharecp:Resource_Statement by the properties cont:has-skill and cont:does-not-have-skill.

Finally, the class cont:From_Missing_Resources (which is a subclass of the class cont:Causes_Of_Variance) is associated with the class res:Health_Resources by the property cont:is-related-to-missing-resources.

Discussion

Developed according to a modular approach, the ShaRE-CP ontology aims to improve quality and efficiency of care through the support of health professionals in the design, development and use of clinical pathways, taking into account the evolution of knowledge and the context, like other ontologies [2,9,19]. This ontology promotes the sharing and the reusability of clinical pathways from one context to another. It's aslo useful for reasoning (detecting inconsistencies, generating new knowledge) not only during or after the execution of a clinical pathway but also before its execution, by asking for example the question of whether a clinical pathway can be executed in a given context. If not, what needs to be done to be able to perform it?

Moreover, ShaRE-CP ontology has put an emphasis on the reuse of other knowledge domains (import of other ontologies) and on the use of different approaches for its development. It defines temporal constraints (time intervals between two interventions) in OWL rather than by SWRL rules [9,19] in order to allow reasoning directly from an OWL reasoner. It offers the possibility to use SPARQL queries by representing positive and negative relations between classes using two distinct properties with different semantics rather than using the 'Negative Object Property Assertion' function of the Protege tool which can only be used with a reasoner.

Conclusion

This ontology integrates concepts and semantic relations related to the knowledge domains of clinical pathways, guidelines, health resources and context and interactions that exist between these knowledge domains. It can serve as a common basis for the development of a decision support system for planning, managing and optimizing patient care, especially in resource-limited settings.

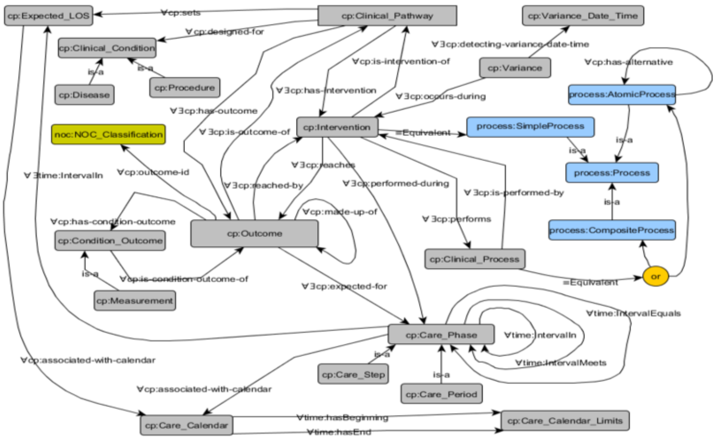

Figure 1: Semantic model of the clinical pathways ontology (a module of the ShaRE-CP ontology)

Acknowledgements

This work was supported by Geneva University Hospitals and University of Geneva.

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