Clinical Pathway Ontology for Generating Patient Specific CarePlans

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Abstract

Clinical pathways translate evidence-based recommendations into locally practicable, process-specific algorithms that reduce practice variations and optimize quality of care. Our objective was to abstract practice-oriented knowledge from a cohort of real clinical pathways and represent this knowledge as a clinical pathway ontology. To accomplish this, we employed a four step methodology: 1) knowledge source identification through exhaustive searching and classification of clinical pathways according to variations in setting, stage of care, patient type, outcome and specialty; 2) iterative knowledge abstraction (grounded theory); 3) ontology engineering as adapted from Model-based Incremental Knowledge Engineering; and, 4) ontology evaluation through encoding a sample of real clinical pathways. We posit that our Clinical Pathway Ontology is novel – i.e. it is the only ontological model that describes clinical pathways. Our ontology can potentially integrate with a healthcare semantic web, and ontologies for clinical practice guidelines, patients and institutions to form the foundational knowledge for generating patient-specific CarePlans.

1. Introduction

Clinical Pathways (CPs) are evidence-based patient care algorithms that describe the process of care for specific medical conditions within a localized setting to reduce variations in practice and optimize quality of care [1]. From a practical standpoint, CPs can be operationalized at the point-of-care because they are sensitive to the resource constraints of the healthcare institution such as the availability of medications, procedures, and diagnostic interventions. We posit that these localized CPs can be further ‘adapted’ to the evolving healthcare needs of individual patients to generate patient-specific CarePlans [2] that can guide patients’ process of care.

Existing paper-based CPs are static, stand-alone, disease-specific, and isolated from clinical applications [3]. Operationalization of CPs is premised on their ‘computerization’ so that they can be integrated within clinical workflow to provide point-of-care decision-support. In this paper we address the following two challenges: (i) abstracting practice-oriented knowledge from paper-based CPs; and, (ii) representing CP knowledge and structure in a semantically-rich formalism [4].

The objective of our research program is to generate patient-specific CarePlans [2]. As a first step, we take a knowledge management approach to ontologically model CPs in terms of their content, structure and function. In this paper, we present our CP Ontology that entails a semantic abstraction of CPs in terms of practice-related knowledge, structural elements and relationships between elements. We describe our CP Ontology development methodology through the following tasks: (a) knowledge source identification and classification; (b) knowledge abstraction from real CPs; (c) ontology engineering and (d) ontology evaluation.
2. Developing a Clinical Pathway Ontology: Our Approach

2.1. Knowledge identification and classification

In identifying sources of CP knowledge, we considered (i) tacit knowledge of domain experts; (ii) previously developed CP ontologies; (iii) published literature on CPs; and (iv) existing CPs in use at healthcare institutions. However access to the tacit knowledge of CP developers, researchers and clinicians was not practical and, there was no available ontology that describes CPs. We found a substantial number of paper-based CPs, and these served as the primary source of practice-related knowledge to guide our CP ontology engineering. We classified CPs along five axes: (i) setting; (ii) stage of care; (iii) patient condition; (iv) intervention; and, (v) medical specialty. For ontology engineering purposes, the classification of the available CPs along these five axes ensures that the final ontology purports a reasonable representation of the spectrum of CPs in use in healthcare institutions.

2.2. Knowledge abstraction

The knowledge abstraction process was guided by the principles of grounded theory which involves building understanding from the ground up such that the resultant framework is grounded in the artifact itself [5]. Our reverse engineering approach involved an iterative analysis and constant comparison of emerging theory to that derived from the previous iteration. This process yielded eleven descriptors of CPs: collaborative, targeted, process-specific, institution-specific, time-oriented, quality-focused, evidence-based, adaptable, variance-conscious, patient-centered, and documentation and communication medium. Over five iterations, we extended and refined our model of CPs by applying it to 25 CPs.

2.3. Ontology engineering

Our ontology engineering process was adapted from the Model-based Incremental Knowledge Engineering (MIKE) Process, comprising cyclical iterations of knowledge acquisition, model design, implementation, and evaluation [6]. Using our CP model as a starting point, we used a middle-out approach to define the most salient concepts first, and generalized and specialized as needed [7]. We identified a class hierarchy, classes, slots and their facets (cardinality, value type, and domain) [8] to describe the structure and content of paper-based CPs. We refined this preliminary CP ontology through a process of instantiation – i.e. using our ontology to encode CPs from our sample and examining its representational adequacy and accuracy. Based on our cyclical engineering approach, we redefined, added and/or deleted classes, slots and relationships as required. The final outcome of the ontology engineering step was an ‘expressive’ ontology based in Protégé-Frames [9] that semantically represented CPs.

2.4. Ontology evaluation

We adapted a task-based evaluation strategy [10]. The evaluation task was to encode real CPs with our CP Ontology. We chose a broad sample of five new CPs that varied along the five CP classification axes. Next, we mapped concepts expressed in the paper-based CP to our CP Ontology which required qualitative judgments about the meaning and intent of lexical items. Through concept mapping, we identified ontology deletions (missing concepts), substitutions (ambiguous concepts) and insertions (superfluous concepts).

3. Description of Our CP Ontology

Our CP Ontology represents the practice-oriented knowledge inherent in CPs. Using the knowledge elements abstracted from our sample of CPs, we defined 124 classes,
192 slots, and 937 instances. The class hierarchy is linked by the class subsumption relation (the is-a relationship). Class names are denoted using SMALL CAPS and slots with italics. Below we describe classes from our CP Ontology.

**CLEARING INFORMATION** specifies maintenance information for the CP.

**TARGET POPULATION** defines the patients for whom the CP is intended, using Age, Sex, InclusionCriteria, and ExclusionCriteria. Criteria may be linked using logical operators. For example, the Acute Coronary Syndrome (ACS) Pathway [11] specifies inclusion of patients with: chest pain at rest for more than 15 minutes OR suspected acute myocardial infarction.

**GOAL** describes the overall aim or intention of the CP. For example, the goal may be to reduce length of stay to three days. This class differs from OUTCOME which is patient-centered and indicates the intention or purpose of particular processes and tasks. Both goals and outcomes should be specific and measurable.

**SETTING** describes the location or environment in which the CP is to be carried out, with the understanding that some CPs integrate care across multiple care settings.

**ROLE** indicates the parties to whom accountability for particular tasks is assigned. The slots specify the Name, InstitutionalAffiliation, ClinicalPathwayAffiliation, DescriptionOfDuties, and tasks (AccountableFor).

**KNOWLEDGE SOURCE** denotes the evidence from which the CP is derived.

**PROCESS** denotes the larger processes that comprise a CP, where each process has a specified start and end point. Processes may have outcomes and are comprised of tasks. **TASK** specifies the action(s) that are to be carried out by the healthcare team, where the patient is the subject of the task. For example, the ACS Pathway comprises admission, assessment, diagnosis, treatment and decision processes. The assessment process comprises four tasks that are carried out concurrently: attach the ECG monitor, estimate patient weight, measure the patient’s blood pressure, and apply the pulse oximeter. Tasks can be carried out in parallel or in series. In our conceptual framework, tasks are related based on finish-to-start relationships – i.e. the next task does not begin until the predecessor tasks are complete. Unless otherwise specified, successive tasks are assumed to be eligible to commence immediately upon completion of the preceding task. Lags or waits can be specified via CLINICAL PATHWAY CONTROL or implied through the task time interval. **TASK** has 14 subclasses that capture task type such as ASSESSMENT, PRESCRIPTION, and DECISION-MAKING.

**DECISION-MAKING** has two types: **DECISION BY USER**, denoting those decisions that necessitate the use of human judgment; and, **AUTOMATED DECISION**, denoting decisions that can be made by a computerized system using available information. **DECISION BY USER** includes the additional slot UrgencyLevel to communicate the urgency with which the user should undertake the decision.

Decision-making involves the evaluation of a set of decision options, represented using: **BINARY LOGIC**, **CRITERIA** and **DECISION LOGIC**. **BINARY LOGIC** expresses logical conjunctions. **CRITERIA** includes CriterionDescription, LogicalConjunction (instance of **BINARY LOGIC**) and the option of recursively specifying the NextCriterion (instance of **CRITERIA**). **DECISION LOGIC** represents DescriptionOfDecisionOption and CriteriaToEvaluateOption (instance of **CRITERIA**). **BRANCH TASK** encodes the pathway branches that correspond to the different decision options. Taken together, these classes
and slots allow our CP Ontology to present a decision-making task, the set of decision alternatives, the criteria along which each alternative is to be evaluated and the CP branches contingent on the decision.

**VARIANCE** describes deviations from the program of care outlined in the CP, as noted during CP execution. It includes documentation of **VARIANCE_DATA**, allowing clinicians to describe the nature of the variance. Variance data are used as inputs for **VARIANCE_ANALYSIS**.

**AUDIT** describes a process of CP assessment or evaluation. **AUDIT** is a superclass of **VARIANCE_ANALYSIS** and also includes classes that describe baseline audit, implementation analysis and clinical performance analysis.

Drawing on the OWL Time Ontology, we defined classes to describe the concept of time in the CP Ontology. **TEMPORAL_PROPERTY** specifies duration and frequency. **MILESTONE** represents a significant event or stage in patient care such as completion of a procedure or discharge from care. It was necessary to represent the concept of milestones as many CPs are specified in terms of these units rather than proper units of time. **TIMEAXIS** has defined start and end points and is comprised of a series of intervals. An **INTERVAL** also has specified start and end points, where interval duration is the elapsed time.

**CLINICAL_PATHWAY** captures the CP as a whole, describing the way in which patient care, for a specified cohort, should unfold for a specified episode demarcated by a time axis. Through instances of the classes described, **CLINICAL_PATHWAY** directly relates to **CLEARING_INFORMATION**, **TARGET_POPULATION**, **GOAL**, **TIMEAXIS**, and **PROCESS**.

To write constraints, we used Protégé’s EZPal plugin to specify 10 constraints. For example, using EZPal’s template statement “Every instance of class __ must have a unique value in slot __” we wrote the following constraint: “Every instance of **KNOWLEDGE_SOURCE** must have a unique KnowledgeSourceCitation.” The specification of constraints was limited by EZPal’s template, so we were not able to specify all constraints.

### 4. CP Ontology Evaluation

Overall the CP Ontology performed well in the instantiation of five diverse CPs (638 instances). We noted six deletions, four substitutions and five potential insertion errors.

Three deletion errors related to concepts outside the scope of our ontology: (1) representation of reference knowledge; (2) documentation for the patient record; and, (3) representation of institution-specific constraints. These would be best addressed by linking our CP Ontology to a reference knowledge base, a patient record, and an institutional resource database, respectively. Other deletions related to the task of obtaining patient consent, task discontinuation activities, and delivering test results to the patient. These may be addressed by refining the **TASK** class and its slots.

The most significant substitution was the specification of task duration and its impact on the finish to start relationships with succeeding activities. The ontology worked well for: (a) tasks that represented one-time occurrences; and, (b) proper time driven CPs where the interval is specified for each task. However, some CPs do not fit these patterns, thus demanding minor modifications to our CP Ontology.
We identified five potential insertion errors such as the class **VARIANCE**. Each of these classes was superfluous with respect to the instantiation of particular CP documents. These are meant to be populated when CPs are executed in real time.

5. Concluding Remarks

We described our knowledge management approach toward capturing the practice-oriented knowledge in CPs through: (i) knowledge source identification and classification; (ii) knowledge abstraction; (iii) ontology engineering; and, (iv) ontology evaluation. We demonstrated the functionality of our CP Ontology by instantiating a sample of diverse CPs. We posit that our CP Ontology is the only ontological model to date that describes the structure and function of CPs in their entirety.

Abstracting and articulating the knowledge in CPs has led to a deeper and more formal understanding of the characteristics of CPs. Translating our ontological framework into practice will help standardize CP development across healthcare institutions and facilitate point-of-care CP availability for decision support and care planning.

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6. References