Modeling Clinical Pathways as Business Process Models using Business Process Modeling Notation

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Abstract

We present a healthcare knowledge management approach to represent Clinical Pathways (CP) as business process workflows. We have developed a semantic representation of CP in terms of a CP ontology that outlines the different clinical processes, their properties, constraints and relationships, which is able to computerize a range of CP. To model business workflows we use the graphical BPMN modeling language that generates a BPMN ontology-based CP model. To represent a CP as a BPMN business workflow we have developed a high-level semantic mapping between the CP ontology and the BPMN ontology. The ontology mapping allows the alignment of semantic relations between two ontologies and thus ensures that a clinical process defined in the CP ontology is mapped to a standard BPMN workflow element. We execute our BPMN-based CP in the Lombardi workflow engine, whereby users can view the execution of the CP and make necessary adjustments to optimize the CP.

Keywords:

Clinical Pathway; BPMN; Business Process; Lombardi; Ontology Mapping

Introduction

Clinical Pathways (CP) model the sequence of tasks, constraints, decision points and actor roles, to perform a specific clinical procedure, based on existing evidence and the operational policies of the institution [1, 2]. From a business process re-engineering perspective, a CP encapsulates the workflow for how to conduct a specific healthcare procedure for a specific disease/outcome in a specific healthcare setting. The term workflow can be best understood as "*any work process that must go through certain steps and be handled by more than one person on its way to completion. Workflow automation relieves people of some of these tasks. Inherent in workflow are concepts of teamwork, request and approval, routing and tracking of documents, filling out forms and doing things either in series or in parallel*" [3]. The execution of a workflow entails the traversal of the sequenced tasks leading to the generation and consumption of information/work products, in accordance with the specified constraints, inputs and user responses, in order to achieve the desired objective.

Workflow models provide high quality business process models by providing workflow patterns. Workflow patterns can be grouped into the following four perspectives [4]:

- **Control flow perspective** describes activities and different constructors describe the execution ordering that allows the flow of execution control, e.g. sequence.
- **Data perspective** layers business and processing data on the control perspective.
- **Resource perspective** provides an organizational structure anchor to the workflow in the form of human and device roles responsible for executing activities.
- **Operation perspective** describes the actions that are executed by activities, where the actions map into underlying applications.

In order to design operationally and clinically pragmatic CP to ensure data interoperability, resource management and task prioritization, it is important to view CP as 'specialized' process workflows. However, the use of workflow modeling concepts in the design and optimization of CP is not yet well established, and as such there are no standard formalisms for the representation of CP in general, and CP as workflow models in particular. There is a case to explore the potential of business process modeling principles and workflow modeling formalisms—such as Business Process Modeling Notation (BPMN), Business Process Execution Language (BPEL), UML (Unified Modeling Language), etc.—to design standardized CP that can be executed through workflow execution engines. We argue for the use of workflow modeling formalisms to represent CP in order to clearly describe the operational aspects of clinical processes, such as (a) roles and responsibilities of care providers; (b) decision points and care options; (c) well-identified clinical/business rules; (d) operational constraints; (e) task scheduling; and (f) temporal constraints.

We believe that given the complexity of CP and the unique nature of healthcare with its emphasis on care quality and patient safety as opposed to cost, it is important to have a semantic description of each workflow process/task to (a) represent the operational and clinical aspects, implications and outcomes of CP; (b) establish semantically explicit relationships between the different processes/tasks to document the affects and outcomes of each task in both the general context of patient care and in the specialized context of the institution's care environment; and (c) model each healthcare task to a business process whilst maintaining its intent and expected clinical outcomes. Nevertheless, it is a challenge to provide a semantic description of a wide range of healthcare processes that appear in CP.

The Semantic Web (SW) framework provides a semantically rich knowledge modeling and representation formalism in terms of ontologies, reusability of the knowledge models, and reasoning mechanisms. Semantic web technologies offer semantically enabled knowledge representation formalisms, such as OWL ontologies, to both model and execute CP [5].

In this paper we present a CP modeling framework that uses BPMN modeling language to model complex CP. BPMN is a semi-formal modeling language that provides a graphical notation to model business processes through a workflow [6]. Our main goal is to provide a CP design framework that uses a standard modeling notation to (a) capture the control-flow amongst multiple clinical tasks through standard constructs that represent complex workflow patterns [6]; and (b) set institutional business/clinical rules and process management mechanisms to execute and optimize the CP in a visual and interactive setting; and (c) incorporate explicit semantic descriptions of tasks, rules and constraints, whilst ensuring data interoperability and scalability to handle different types of clinical settings.

We take a healthcare knowledge management approach to represent CP as business workflows. We have developed a semantic representation of CP in terms of a clinically-oriented CP ontology that outlines the different clinical processes, their properties, constraints and relationships, which is able to computerize a range of CP. To model CP as business workflows we use a workflow-oriented BPMN ontology that contains a semantic description of BPMN constructs. We have established a semantic interoperability (or ontology mapping) between the CP ontology and the BPMN ontology; ontology mapping allows the alignment of semantic relations between the clinical and workflow ontologies and thus ensures that a clinical process defined in the CP ontology is mapped to a standard BPMN workflow element. We execute our BPMN-based CP in the Lombardi workflow engine (developed by IBM), whereby users can view the execution of the CP and make necessary adjustments to optimize the CP. We have modeled a number of existing CPs using our framework and we will present our results.

Methods

The tenets of our CP modeling framework are as follows:

CP Ontology

This ontology captures the healthcare knowledge of a clinical guideline and CP. It offers a semantic representation to instantiate a CP to render it computerized and executable. We have used an existing CP ontology [7] that represents the knowledge in CP through 50 classes, 161 properties and 589 instances. The CP ontology captures knowledge in a clinical practice guideline and CP.

In our framework, we use the CP ontology to instantiate an existing paper-based CP. Given that the CP ontology is clinically-oriented it is rather easy for health professionals to associate the clinical concepts inherent within a CP with the concepts in the CP ontology. This exercise allows the instantiation of a CP via a CP ontological model.

BPMN Ontology

The BPMN modeling language offers a graphical orientation of workflows, thus making it easy for both domain experts and business process modelers to develop complex workflows [8]. By itself, BPMN does not provide any formal semantics for its constructs [9]; however there exists a OWL-DL (*Web Ontology Language-Description Logic*) based BPMN ontology [10] that offers a formalization of the structural components of the BPMN specification v1.1. BPMN ontology contains a set of axioms that describe the BPMN elements and the way in which they can be combined for the construction of Business Process Diagrams [10]. The BPMN ontology consists of 95 classes, 108 object properties and 70 data properties.

To model the CP as a workflow model, it needs to be represented using a workflow model—i.e. the BPMN ontology. This is achieved through an ontology mapping—i.e. mapping a CP from a clinically-oriented CP ontology to a workflow-oriented BPMN ontology. The idea is to extend the CP model to a workflow model whilst maintaining the clinical aspects of a CP, yet representing it using workflow constructs.

Lombardi Ontology

Lombardi is a workflow design and execution engine developed by IBM. WebSphere Lombardi v.7.1 is one of the first BPM platforms to support BPMN. It provides a platform for rapid delivery and improvement of business process applications. It is an integrated set of Eclipse-based development tools. It provides design, simulation, rules definition, process execution, and monitoring functions.

Figure 1 - Lombardi ontology

Lombardi offers fewer workflow constructs than BPMN ontology, but it offers a workflow execution environment, which is very useful for analyzing the CP as a process workflow. We have developed a Lombardi Ontology to formalize the structure of Lombardi elements. The Lombardi ontology formalizes the structure of Lombardi elements and makes them machine interpretable. The ontology is in OWL language and it has 56 classes, 40 object properties and 25 data properties. Figure 1 represents a snap shot of classes in our Lombardi ontology.

We have developed an ontology mapping representation language between our Lombardi ontology and the BPMN ontology, to provide richer health related specification of concepts for Lombardi elements.

CP → BPMN Mapping

Figure 2 presents the overall strategy for modeling CP as workflow elements. The general idea is to exploit the computerized CP, modeled in terms of the CP ontology, to develop a workflow model of the CP. This is achieved by establishing a high-level semantic mapping between the two ontologies—i.e. from the clinically-oriented CP ontology to the workflow-oriented BPMN ontology, thus achieving a CP represented in terms of BPMN modeling language. Semantic interoperability between these two distinct CP representations is achieved through an ontology mapping framework that establishes an alignment of the semantic relations between the two ontologies such that a clinical process defined in the CP ontology is mapped to a standard BPMN workflow element.

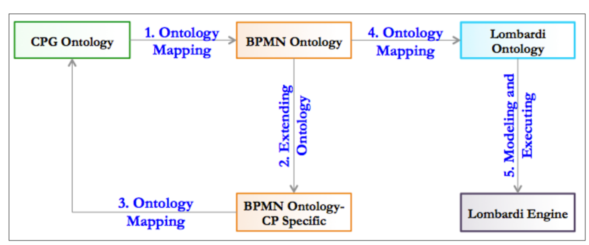


Figure 2 - The methodology for modeling CP as workflow modeling language-BPMN.

We have defined an ontology mapping to express the relations between our CP ontology and the BPMN ontology. For ontology mapping, we try to find semantic relationships between entities of the two ontologies and report these relationships using mapping expressions.

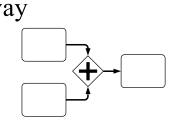
We consider the following definition for ontology mapping [11]: "*Given two ontologies* $\boldsymbol{O}_S$ *and* $\boldsymbol{O}_T$*, mapping from ontology* $\boldsymbol{O}_S$ *to another* $\boldsymbol{O}_T$ *means for each entity in ontology* $\boldsymbol{O}_S$*, we try to find a corresponding entity, which has the same intended meaning, in ontology* $\boldsymbol{O}_T$"*.*

Our ontology mapping expressions contain constructs to express the relations between the different entities of the two ontologies:

- **Class Mapping (37 CCmappings):** Mapping a class to another class (or instance of the class).
- **Property Mapping (48 PPmappings):** Mapping a property (either object or data property) to another property (or instance of the property).
- **Class - Property Mapping (6 CPmappings):** Mapping between a property and a class (or instance of the class).
- **Property-Instance Mapping (79 PVmappings):** An instance may be mapped as a value of a target property.

In our mapping expressions we used a set of OWL properties such as cardinality, union, intersection, and equivalent (*owl:cardinality, owl:UnionOf, owl:IntersectionOf, owl:equivalent, owl:one of*). We provide some examples of relationships between the classes and properties of BPMN-CP ontologies in Table 1.

Table 1 – The example relationships between the BPMN-CP ontologies.

CPG	BPMN
Admission_Step	(User_Task) and (BPMN_Element.Category = "Admission_Step")
Sync_Step	Parallel_Gateway 
Decision_Option	Gate *has_gate_out_seq_flow_ref* *Sequence_Flow*
Property	
Domain	*Range*
condition_to_go_forward	
Sync_Step	Condition
CPG	**BPMN**
Parallel_Gateway	Expression *has_sequence_flow_condition* Condition *has_expression* Expression
notification	
Notification_Step	Notification
User_Task and BPMN_Element. Category="Notification_Step")	Message_Intermediate_Event *has_event_trigger* NT *has_message_event_ref* MES

In our mapping expressions, unlike the MAFRA framework (*an ontology MApping FRAmework for Distributed Ontologies in the semantic web*) [12], we create an instance for a class, and then we map it as a value of a target property, or a property/class may be mapped to a created instance of a target entity.

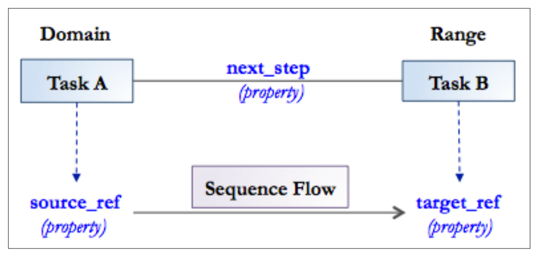


Figure 3 - Mapping the next_step property to the Sequence_Flow class.

Figure 3 represents an example of a mapping between the two given ontologies. In CP ontology, there is a *next_step* property for going from one step to another step. In BPMN ontology, there is a *Sequence_Flow* class, which is used to show the order of the activities that will be performed in a process. It has two properties, *sequence_source_ref* and *sequenece_target_ref.* The range of the *sequence_source_ref* is an object, which is the source of the flow and the range of the *sequence_target_ref* is another object, which is the target of the flow. We map the domain of the *next_step* property to the *sequence_source_ref* property of the *Sequence_Flow* class, and the range of the *next_step* property to the *sequence_target_ref* property. The mapping is shown in Figure 4.

The resulting mappings can be used for data transformation, web-service composition or query answering. In addition the mapping ontology can be used as the input of the merging tools to merge the two given ontologies or to develop an execution engine based on these expressions.

```
#      next_step Property (Domain)
:CP01 a :CPmapping ;
        rdfs:label "(CP01) next_step - Sequence_flow (domain)" ;
        rdfs:comment "next_step (domain) → has_sequence_flow_source_ref property.".
:CP01   :hasSource   :CP1S .
:CP01   :hasTarget   :CP1T .
:CP1S   :hasProperty          cpg:next_step .
:CP1S   :hasThingsToMap       "domain" .
:CP1T   :hasClass             bpmn:sequence_flow .
:CP1T   :mappedToProperty     bpmn:has_sequence_flow_source_ref .
#      next_step Property (Range)
:CP02 a :CPmapping ;
        rdfs:label "(CP02) next_step - Sequence_flow (range)" ;
        rdfs:comment "next_step (range) → has_sequence_flow_target_ref property.".
:CP02  :hasSource   :CP2S .
:CP02  :hasTarget   :CP2T .
:CP2S   :hasProperty          cpg:next_step .
:CP2S   :hasThingsToMap       "range" .
:CP2T   :hasClass             bpmn:sequence_flow .
:CP2T   :mappedToProperty     bpmn:has_sequence_flow_target_ref .
```

Figure 4 - The Property-Class mapping of the next_step property to the Sequence_Flow class.

BPMN → Lombardi Mapping

Lombardi provides fewer workflow constructs than BPMN ontology; therefore it does not provide the same level of workflow expressiveness and abstraction as the BPMN specification. BPMN is a much richer workflow representation formalism.

We have provided a mapping ontology between the BPMN and Lombardi ontologies in order to provide a richer specification of concepts for Lombardi. The result is that a CP modeled in BPMN can now be mapped to the Lombardi ontology and executed by the Lombardi execution engine.

The procedure for creating the mapping ontology is the same as the previous mapping. It has four different constructs to document the expressions, which are in OWL language. There are 46 CCmappings, 57 PPmappings (object and data properties), 6 CPmappings and 2 PVmappings expressions in the mapping file. We provide some examples of relationships between the classes of BPMN-Lombardi ontologies in Table 2.

Table 2 – The example relationships between the classes of BPMN-Lombardi ontologies

BPMN	Lombardi
User_Task	Human Service
Start Event *has_start_event_trigger* Message_Event_Detail	Start Message Event

Modeling CP as Workflow: An Example

We modeled 3 different CP in Lombardi. After modeling each clinical pathway, we can execute the model and go through from the start event to the end event. Figure 5 shows an initial part of Post Mastectomy Radiotherapy (PMRT) CP in Lombardi.

Results

We have modeled a number of existing CP to a BPMN based workflow—the CP are rendered in a visual format and can be interactively executed to study and optimize the CP. The semantic description of the CP tasks ensures that the transformation of a CP to a BPMN workflow maintains the clinical pragmatics of the CP and that it can be actively connected with health data from HIS. The graphical notation of the CP enables rapid user feedback and adjustments to optimize performance metrics.

Each CPG is modeled as an instance of *Clinical_Guideline* class in CP ontology. In order to relate this instance to our BPMN ontology, first we created an instance of *Business_Process_Diagram* class in the BPMN ontology, and then an individual of *ClinicalPathway* class and *has_Business_Process_Diagram* property. Each *Business_Process_Diagram* has a *Pool* and each *Pool* has a *Process*. Each *Process* has graphical elements, which include *Start_Event* and *End_Event*. The process starts from the *Start_Event*, with a trigger property to indicate the inclusion/exclusion criteria for a CPG.

Conclusion and Future work

We have developed a semantic interoperability framework whereby clinical processes/pathways can be conveniently mapped to business process notations thus enabling CP to be executed and simulated for adjusting various cost functions. Our mapping framework allows healthcare professionals to model a CP using modeling constructs that they are familiar with, and then we transform their CP model to a business process model. The use of ontologies, at both representation and mapping levels, allows for the semantic description of concepts and their relations, with provisions for semantic classification of healthcare concepts to ensure the right level of conceptual granularity in the representation scheme.

This research offers a solution for the modeling of CP clinically specific processes in terms of standard business process models, and thus leveraging the standard definitions of processes to represent and optimize clinical environments by incorporating process optimization tools, such as LEAN.

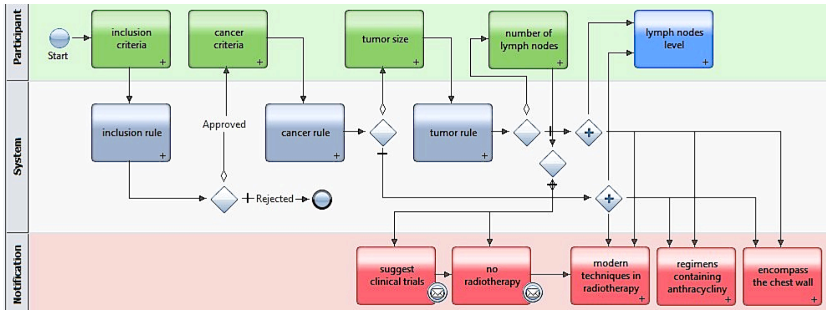


Figure 5 –A part of PMRT CPG in Lombardi

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