Adaptable Personalized Care Planning via a Semantic Web Framework

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Abstract. This paper presents a longitudinal patient care planning system that automatically and pro-actively generates adaptive patient-specific *healthcare plans*. The objective is to assist medical practitioners to determine the best discourse of clinical care based on (a) the patient's current medical profile, (b) latest medical knowledge (c) institution-specific clinical pathways, and (d) personalized healthcare educational programs. We present a novel semantic web framework that allows for the synthesis of heterogeneous operational and medical information and knowledge resources, and renders the technical basis for a services-oriented architecture to generate and orchestrate patient-specific healthcare plans.
Keywords: Medical Knowledge Management, Clinical Pathways, Care Planning, Semantic Web, Web Services

1. Introduction

In Canada, and likewise around the world, there is a growing realization that health human resource planning and evidence-based practices are vital to deliver effective healthcare services. Currently, clinical care is discharged in a reactive and sub-optimal manner without due consideration to optimization of available healthcare resources and the proactive planning of the care regime. Despite recent developments in health information collection, sharing and processing infrastructures, there is a realization that the health informatics research agenda should include the development of new methods, leveraging emerging knowledge-mediated technologies, for optimal clinical care planning and informed decision-making as per the individual patient's profile and healthcare site's operational requirements.

Lifelong patient care management, in its entirety, is a complex process that can be investigated from a variety of perspectives. Our belief is that the systematic application of advance knowledge management approaches—in particular the emerging semantic web framework—can lead to the development of a knowledge-mediated patient care planning systems that automatically and pro-actively generate adaptive patient-specific healthcare plans that may guide the long-term clinical, therapeutic and rehabilitation care process for individual patients within a specific healthcare setting.

Our approach is to investigate proactive patient care management, whereby a patient-specific care plan accounts and satisfies the evolving healthcare needs of a patient in the continuum of care. Functionally speaking, for each individual patient a care plan is to be conceived through a systematic interplay between (a) patient information sourced from online health reporting documents; (b) best evidence manifested in clinical practice guidelines, (c) clinical pathways stipulating the care process, resource constraints and therapeutic costs; and (d) a (semantic) web of heterogeneous medical knowledge resources. The systematic synthesis of these determinants for patient care realizes a process-oriented and knowledge-mediated solution to patient-centric healthcare—the solution is ***CarePlan***.

In this paper, we present a semantic web based framework [1] [2] for patient care planning. The featured CarePlan framework generates adaptive patient-specific *CarePlan* depicting a roadmap of prospective events, actions, schedules, (site specific) resource implications and expected outcomes. Here, we discuss the functional components of the CarePlan framework.

2. CarePlan: A Conceptual Overview

A patient-specific CarePlan can be envisaged as a personalized clinical pathway that encapsulates: (a) a chartered discourse of clinical care activities—mandated by clinical guidelines/knowledge and validated by intelligent proof engines—to address a patient's current healthcare needs; (b) a recorder of the temporal sequence of medical events, actions and outcomes as they occur in the longitudinal continuum of care; (c) the gateway to source case-specific evidential and experiential medical knowledge, for both practitioners and a computer system, in order to both reason about the patient's diagnosis, prognosis and to formulate the patient's therapy and rehabilitation; and (d) the basis for generating patient-specific educational interventions. *CarePlan* can therefore be regarded as a rich temporal, process-centric, patient-specific abstraction of the ever-evolving dynamics of total patient care management in a specific healthcare setting. In practice, when a patient with a chronic health problem enters the healthcare system, his/her personalized CarePlan will be generated based on his/her current health profile; and as the patient evolves his/her CarePlan will dynamically adapt to meet the patient's current conditions, new medical knowledge, physician's inputs and institutional workflows.

The prime requirement for the CarePlan framework is to access, integrate, adapt and manipulate heterogeneous healthcare knowledge in response to available patient information (as shown in Figure 1). The emerging *semantic web framework*, in the realm of knowledge management, provides both the theoretical basis and the applied methods to (a) represent knowledge in ontology guided formalisms; (b) reason over the knowledge using proof engines; (c) morph the different knowledge modalities to form a unified knowledge object; (d) adapt standard care plans towards personalized healthcare plans by reasoning and morphing the available knowledge; (e) integrate web-services for the composition of healthcare plans; and (f) establish trust over the personalized CarePlan by way of validation through knowledge-based proofs.

The abovementioned *CarePlan* objectives demand a sophisticated info-structure that features the following ten core functionalities:

a) Ability to collect patient information from multiple sources and in different modalities to create a patient information model.
b) Ability to abstract patient information from the information model to yield an episodic profile of the patient, which would be the basis for selecting the relevant clinical practice guideline(s).

c) Semi-automatic methods to transform paper-based Clinical Practice Guidelines (CPG) and also clinical pathways to standard representational formalisms.
d) Functional links between the patient information model and the CPG model to ensure that patient information can be seamlessly input to a computerized CPG to chart evidence-driven actions.
e) Functional and conceptual links between CPG and the actionable clinical pathways to generate a *CarePlan* which is based on best clinical evidence and congruent with institutional resources.
f) A semantic web of best medical knowledge serving as the *knowledge backbone* responsible for maintaining currency, quality and validity of the *CarePlan* solution.
g) An interface to the semantic web that allows to (a) seek both evidential and experiential knowledge pertaining to the medical problem at hand; (b) morph the different knowledge modalities to realize a seamless holistic knowledge object that can be used by the *CarePlan* info-structure.
h) A library of CPG objects characterized and indexed based on domain ontology.
i) A library of clinical pathway components characterized and indexed based on domain ontology and the institutional workflow.
j) A web service orchestration framework that incorporates logical proof engines for creating valid web services—i.e. the personalized *CarePlan.* The *CarePlan* web services framework leverages on the semantic web of medical knowledge, the domain ontology, the institutional workflows and the proof engines. The output is a dynamically composed *CarePlan* personalized to an individual's needs and is compatible with the institutional workflow and is guided by the best current medical knowledge.

2.1. CarePlan in action

The full cycle of the CarePlan framework starts with (a) abstracting patient data from the information layer; (b) passing episodic patient information to the knowledge layer to select case-specific knowledge; (c) processing the knowledge, though the semantic web engine to generate a CarePlan at the planning layer; (d) validating the CarePlan both by logic engines and practitioner input; and (e) passing the CarePlan to the medical practitioner. The CarePlan interface is a key element of the cycle as it provides practitioners access to the semantic web of heterogeneous healthcare knowledge bases and distributed patient information. The CarePlan interface presents recommendations and pathways based on the patient condition and protocols. Most importantly, this interface accepts physician's decisions and his/her resolutions in the cases of contradictory evidence or unusual circumstances.

The role of the semantic web is central in generating a CarePlan. Given the medical knowledge, patient-specific facts and medical practice logic, the semantic web engine allows the inferring of new facts in the process of finding the best care plan for an active patient at the time of consultation (or point of care). The semantic web proof engines ensure that the actions prescribed in the patient's care plan take into account all relevant information and are consistent with the best knowledge and medical practice. It also ensures that the outcomes generated from an action are taken into consideration as input to the next step in the CarePlan. The CarePlan is manifested in terms of adaptable workflows that are represented and executed as web services and are activated when a new patient enters the system or any new information about an existing patient becomes available.

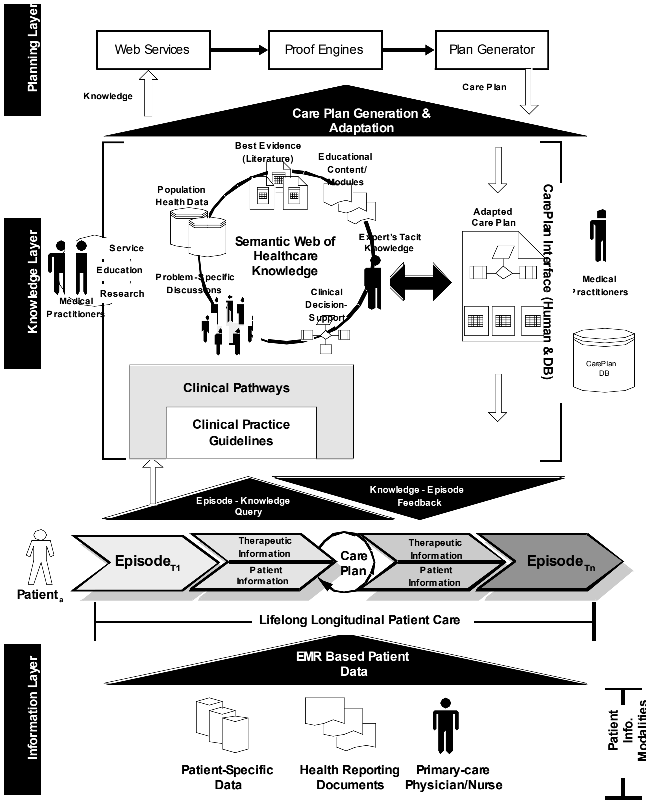

Figure 1: The functional diagram for CarePlan, illustrating the three functional layers

3. CarePlan Functional Components

The CarePlan technical solution features a confluence of technologies to support the description, discovery, composition, and operationalization of a patient-specific CarePlan in terms of automatically choreographed web services (see Figure 1). Five main functional components constitute the CarePlan framework.

3.1. Patient health profile generation

A comprehensive patient health profile is the starting point for the generation of a patient-specific CarePlan. Patient health profile generation involves the collection, aggregation and representation of patient information originating from multiple EMR sources. The patient profile encompasses patient-defining measurements, operational, diagnostic and/or therapeutic details. We use the XML based Clinical Document Architecture (CDA) to formulate a high-level patient profile that will allow HL-7 linkages for information collection. For semantic interoperability between different information sources, we use the MESH medical terminological system.

3.2. Healthcare knowledge semantic web

Semantic Web is a logic-oriented framework for both representing and connecting heterogeneous knowledge resources [1]. Given that healthcare knowledge exists in a variety of modalities, ranging from tacit to experiential to explicit, we are working on the development of a *healthcare semantic web* to interconnect the various healthcare knowledge resources. Our approach is to use CPG as an interface between the patient data and the healthcare semantic web because computerized CPG incorporate constructs to represent and manipulate both CDA based patient data and ontology-based medical knowledge. Our idea is to decompose CPG and Clinical Pathways (CP) into process-centric objects that entail decision logic, knowledge constructs and constraints that can be analyzed and validated by logic-based proof engines. A systematic collection of such knowledge objects will yield the CarePlan

The healthcare knowledge semantic web will serve as the *knowledge backbone* responsible for maintaining currency, quality and validity of healthcare knowledge used to develop CarePlans. We have developed a prototype ontology using Protégé [2] and a set of n3 rules. Having patient information in CDA format and the CPG content in RDF, we are able to use the domain ontology and rules to simulate the knowledge needs for specific clinical pathways using the Jena rule-based inferencing engine.

3.3. Healthcare knowledge morphing

The healthcare knowledge semantic web provides an interconnected encapsulation of the available healthcare knowledge. So, what is needed next is a mechanism for case-specific morphing (or fusion) of multi-faceted knowledge object detailing all available solutions, viewpoints and documented outcomes in response to the conditions reported in the patient's profile. Our plan is to pursue knowledge morphing as a knowledge modeling activity that interpolates a knowledge link between two or more knowledge objects that share a discrete notion of contextual compatibility [3]. The knowledge link will allow for reasonable inferencing over the parent knowledge objects in order to establish the trust and comprehensiveness of the derived CarePlan.

Our knowledge morphing approach is to (a) leverage a semantic web of knowledge resources, whereby the knowledge contents are conceptually identified and semantically annotated based on a global domain ontology; and (b) employ a view integration approach whereby the underlying conceptual schemas of the knowledge resources are integrated into the global schema of a CarePlan.

3.4. Adaptive CarePlan generation

Given a patient profile, this activity aims to generate a patient-specific CarePlan by dynamically adapting standard clinical pathways. We envisage the CarePlan as a specialized clinical pathway that is dynamically generated, through a semantic web based web services framework, based on the patient information, the morphed knowledge and the semantically annotated clinical pathways. The semantic web proof engines will ensure the validity and applicability of the CarePlan vis-à-vis the patient profile. The adaptive nature of the healthcare plan will ensure that it is proactively modulated to meet the changes in the patient profile, discovery of new healthcare knowledge, changes in institutional workflows or resources.

3.5. Personalized patient educational content generation

The patient-specific CarePlan entails a decision logic that orchestrates the clinical workflow to support optimal care planning. We believe, that the same care planning logic contained in a CarePlan can be used to tailor patient educational interventions in order to inform the patient about his/her medical conditions and to educate him/her to self-manage the disease at each stage of the care process. We foresee that, as the patient passes through the staged CarePlan the clinical decision points, actions and recommendations listed in the CarePlan will be used to guide the selection of relevant healthcare educational content [4].

To ensure that the patient education content imparts maximum impact we argue that psycho-social and behavioral change models need to be incorporated within the information tailoring algorithm. Our proposed patient education framework will offer the following functionality: (a) generation of the patient's user model; (b) a library of customizable educational content; (c) an information personalization algorithm; and (d) proactive delivery of personalized patient educational material corresponding to the patient's CarePlan.

4. Concluding Remarks: The Way Forward

In this project we aim to develop an evidence- and knowledge-mediated longitudinal patient care environment that automatically stipulates patient-specific healthcare plans for both lifelong wellness maintenance and episodic illness management. The emergence of the semantic web as a viable mechanism for both representing and operationalizing domain knowledge, whilst ensuring the trust of the derived solution, renders the semantic web as an apt framework for developing knowledge-mediated services for medical decision support and care planning.

In our work, we are pursuing the development of the constituent elements of a semantic web framework for patient care planning. In this regard, we are developing domain ontologies for specific medical issues using Protégé and OWL [2], semi-automatic annotation methods to annotate clinical practice guidelines in RDF, proof engine workbench comprising using Jena (that integrates with Protégé), a knowledge morphing engine that incorporates a healthcare semantic web, and intelligent information personalization methods for patient education using medical logic modules (MLM) and Transtheoretical Model (TTM) for staged behaviour changes. We believe that the semantic web will be the way forward for knowledge-intensive and validated healthcare decision support activities, yet this brings forth many interesting challenges!

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