Towards a Workflow-Centric, Context-Aware Clinical Application Framework

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Abstract. We outline an approach for implementing application support for clinical workflow that is aware of dynamic context of healthcare delivery. This context captures patient specific information, previous and future activities of clinicians involved in patient healthcare and supports clinicians' cognitive models. This application framework leverages some of the concepts and models that have been used to formalize a major, multidisciplinary clinical workflow redesign project at a major US hospital. We present our results and future work.

Keywords. Precision medicine; clinical workflow; ontology;

Introduction

Clinical systems, such as electronic health record systems (EHRs) have the potential to improve the quality of care by enabling structured documentation of care, facilitating access to the patient information, supporting care coordination and providing clinical decision support (CDS). Many commercial EHRs however are considered to be far from optimal from a usability perspective [1], with challenges such as navigation between pages, due to the need to access information scattered across multiple places [2], whereas empirical studies have shown that user-centered, task-oriented interfaces can improve the efficiency of providers by up to 80%. Many EHRs are organized around siloed categories of "documentable" aspects of care delivery, such as encounters, problems, observations, medications and procedures. However, clinicians' mental models are hardly compartmentalized in such a vertical fashion as they look at patient situation holistically, focusing on tasks such as diagnosis or treatment that require information spanning across the different categories.

Our discussions with many clinicians too, suggest a value of developing web-like applications that would dynamically gather and use patient-related information during clinicians' observational and cognitive activities, as part of ongoing clinical workflow. Such an application can be regarded as an actor in care delivery, acting like an intelligent agent and sharing collective awareness about ongoing activities, thus the term *context-aware* - to signify multiple parameters describing the conditions and problems of a patient, and changes occurring during the observations and treatment - to better support planning for future care. *Context* captures many situational factors surrounding the delivery of care for a specific patient, obtained through tests or clinician's observations, and managed using their cognitive models, reflecting their knowledge and evidence-based models of care.

Our model of context leverages results from semantic workflow and process modeling, medical ontologies and CDSs. The central concept of our context model is that of *activity*, serving as the pivotal element for linking roles, artifacts, information and knowledge. The model is grounded in clinical work domain ontology (WDO) that we developed to holistically describe activities from clinicians' and a software perspective, and to serve as a basis for a general application framework that can be mapped on different implementation technologies, including the HL7 FHIR standard[1].

Next section provides motivations about importance of the concept of context to support personalized patient workflow. Section 2 outlines key elements of our context-aware application framework, covering the context model and application framework. Section 3 provides discussion and areas of future work.

1. Motivations

The assertion above that a clinical application should effectively act like an actor, sharing the collective awareness about the ongoing activities, is also supported by recent efforts to build longitudinal applications on top of EHR data, as in the SMART-on-FHIR (SoF) framework [3]. The underlying computational paradigm of the SOF is two-tiered layers, where the EHR provides data as a projection of the clinical workflow, and the (mobile) application renders it in way meaningful for the user. The unidirectional information flow is partly imposed by the constraints of the EHRs regarding writing data back. We argue that, rather than pulling and rendering information based on statically programmed logic, there is an opportunity to adopt a knowledge-driven approach in the definition of an application's business logic. This would support knowledge representation and reasoning techniques to provide a new class of adaptive applications that extend the SoF by enabling a provider's cognitive model to interact with its user(s) as part of the care team.

Consider for example a general internist, Dr. Smith, seeing a patient, Mrs. Jones, in his EHR-enabled practice. Before meeting Mrs. Jones, he logs into the system and retrieves her medical record, allowing him to recall that Mrs. Jones suffers from diabetes, hypertension and mild depression, all conditions for which she is under medication. After entering the room, Mrs. Jones and Dr. Smith start discussing her diabetes, and her complaint of gaining weight despite following her dietary regimen. Since the anti-depressant drug might have affected her weight goal, Dr. Jones reviews the patient's history to see if a correlation between the prescription and the onset of the increasing weight can be established. As this is the case, Dr. Jones reviews his options for alternative anti-depressants and changes Mrs. Jones's prescription.

Even in a scenario as simple as this one, there are multiple opportunities for a clinical application to provide cognitive support to the physician. Reviewing a patient's history requires a dynamically assembled summary view of the patient's conditions, medications and vitals; focusing on the management of diabetes should be matched by a different aspect of the information, which is no longer ranked in terms of recency or severity as normally is the case, but rather by correlation with the problem being considered; focusing on the missed goal calls for the recognition of a drug-goal interaction, but the resulting alert should be delivered timely, and isolated from the potential stream of other alerts that may apply to other aspects of the patient's situation;, investigating a correlation can be helped switching from a summary-oriented to a retrospective presentation of the relevant events on a timeline. While many of these tasks can be modeled as reasoning problems and assisted by a knowledge-driven application (e.g. retrieving information from a graph by strength of association, matching drug-goal patterns, scheduling a communication act and detecting a temporal

[1] Fast Health Interoperability Resources (http://hl7.org/fhir/2016sep/index.html)

correlation), the choice of how and when to provide cognitive support to the clinician depends on the application's awareness of what the clinician(s) are trying to achieve.

2. Context Aware Application Framework

In order to support many context-aware scenarios like this, we propose a general-purpose application framework with strong semantic foundations and designed according to modern web software architectural practices. In this framework, an application maintains an explicit representation of the state of the clinical workflow, used as a vehicle for the bi-directional real-time control of client-side application logic.

2.1. Context model and its foundations

Our context model is grounded in work domain ontology (WDO) that we developed to conceptualize "work domain", from the perspective of a large healthcare organization. WDO has two premises: i) healthcare delivery processes are complex activities that involve different actors, with their capabilities, goals, preferences and commitments, and different resources provided by different parties at different locations, and ii) healthcare is a knowledge intensive domain, where perception and behavior are influenced by descriptive and prescriptive knowledge, interacting with software applications that facilitate information management and communication. The purpose of WDO is to (i) document clinical activities and the role played by information systems in support of clinicians' work, (ii) capture the semantics of the data collected from a number of "source systems", (iii) inform a new generation of context aware applications and (iv) manage knowledge assets within the scope of a broader knowledge management and delivery architecture.

A detailed presentation of the WDO is beyond the limits of this paper, but suffice to say that it is founded in two upper ontologies, BFO [4] and DOLCE [5], and expressed in OWL-DL. BFO is the basis of a number of biomedical ontologies, while DOLCE has been used to formalize activities, plans and their specifications. The core concept of activity in WDO is taken from the DOLCE, and defined as "an action that is dependent on a shared plan adopted by participants ... Intuitively, activities are complex actions that are at least partly conventionally planned". The DOLCE:Activity is further contextualized in the WDO by its related concepts of agent, role, participation fit, etc. formalizing a conceptual model of activity and workflow [6], developed through a workflow analysis methodology for describing domain specific activities in terms of the healthcare context in which those activities are carried out.

The concepts from the WDO are subsequently expressed in a context model in UML (**Figure 1**). Any class, relationship or attribute from the context model has a unique interpretation through exactly one OWL WDO class, property or chain thereof. The WDO concepts capture various kinds of activities, roles, resources and relationships thereof, as also represented in the context model. The concept of activity is further sub-typed to make a distinction between computational activities, such as software-user activities, and clinical workflow activities, to create a separation between the application and its participation in the broader processes of care delivery. An activity can be related to another activity through temporal relationships (e.g. before, after), containment relationship, coordination or dependency relationships to support constructing complex activities. Actors and resources, material, as well as information entities, are scoped by the role they play in the activity. For example, clinical activities may involve information objects (an immaterial entity that carries information, such as a health care record), and also physical objects (material entities such as medical equipment). The space limitations of this paper do not allow for detailed description of the model elements, but they are illustrated in the augmented scenario in section 2.2.

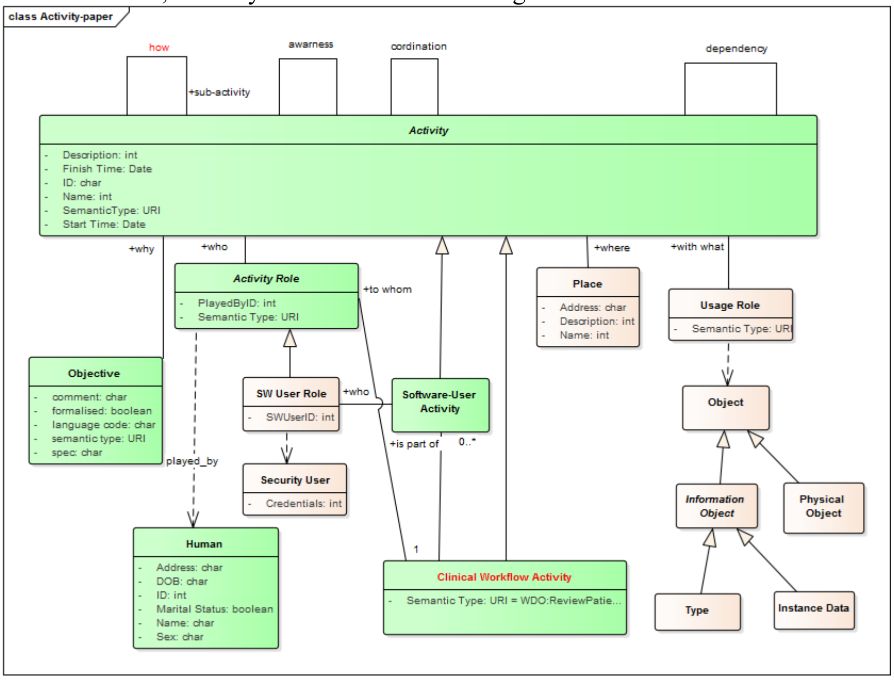

Figure 1: Context model - based on Work Domain Ontology concepts

2.2. Application Framework

The elements of the context model can be considered as ReST resource type specifications and can be exposed through ReSTful APIs as a “context service”. In our framework, such a service is a server-side component of a SoF (grey components in Figure 2), with APIs directly or indirectly exposed to the application UI tier. The services integrates with the UI’s MVC subsystem to provide key functions/capabilities:

- A stateful context by means of a temporally-structured history of user interaction events, linked into a chained sequence built over the course of the session, for each instances of the context model. Each element in this chain is interpreted as an observed instance of a computational activity.
- The latest instance of the computational activity, together with its reference to a representation of the current clinical activity, forms the core of the current context, including links to related resources, e.g. actors, locations, materials and information, so that the application can be aware of their identity.
- Each interaction requiring a change of state is instrumented to update the current context by either adding information (e.g. a new actor or resource) or switching to a different activity. This support is provided by the controller in the UI’s native MVC stack, and done in an asynchronous manner to avoid UI unresponsiveness due to blocking of the UI thread. Unlike in traditional applications, any interaction of the user with the user interface is interpreted not only as a command, but as the most recent clue of user intent.
- Integration with the OAuth 2-based authorization mechanism used to launch and log in to SoF applications.

Client side web pages are generated and augmented dynamically. After back-end logic is executed, including information processing and data retrieval, interface hints for client-side state change can be pushed to the UI asynchronously. Client-side UI components are further enhanced to draw focus on specific areas of content – via highlights, show/hide etc – based on the semantic markers in addition to traditional text matching-based methods. UI controllers receive the current, updated context object as an input, and may use it to determine the appropriate UI-specific state transitions to invoke. This combination of a server-side context service and client-side instrumentation variation rooted in the REST-backed MVC architecture allows for real-time knowledge-based interaction design. Note that the current implementation only provides pull-based context queries, and the controller uses pattern matching techniques and rules to make the associations, but this capability could be generalized to use different techniques such as case based reasoning.

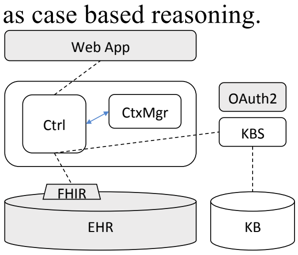

Figure 2: High level architecture for our framework

Consider how this application framework can be used to support the scenario introduced in section 1. Dr. Smith's login and selection of a patient from the list are software activities, and are part of a clinical activity. Dr. Smith's role, general internist ('who'), and login from an ambulatory setting ('where') are both pieces of information built into the context model, determining that the initial clinical activity is, by default, the review of the patient current overall state ('what'). The actual role of patient ('to whom') is added when Dr. Smith selects Mrs. Jones. At this point, the application controller has enough information to invoke the EHR-facing data aggregation services to retrieve Mrs. Jones' data such as problems, medication or allergies. The results are linked to the context ('with what') and are used to feed the UI components of a summary screen page invoked. When Dr. Smith later clicks on the diabetes entry in the problem list, the pre-injected URL is followed to make another call to the context APIs. Diabetes is a focus element, another aspect of the activity model ('of what'), which cause the current activity to be updated accordingly. In turn, the controller determines that the kind of activity (both software and clinical) has not changed, but the data that plays the role of resource needs to be updated. The focus is passed as a parameter to the data aggregation service, which now returns EHR data associated with diabetes. When a goal is further added to the context, a more traditional CDS-as-a-service [7] endpoint is invoked to assess possible goal-drug interactions. This context switch updates the kind of clinical activity, due to a different association specified in the controller's knowledge base, because the doctor is no longer reviewing the patient's overall condition, but is investigating if, and to what extent, a goal is being achieved.

3. Discussion and future work

Using context to enrich an interactive application is not a novel idea, but is less mature in clinical applications, where there is no overall consensus on the scope and features of a "clinical context" [8]. In one interpretation, context awareness is a capability of software to acquire information from devices to deliver more traditional forms of CDS (e.g. [9]) such as alerts, reminders, order sets, "infobuttons", predictive and statistical models and other knowledge-based inferences. Our framework can easily incorporate traditional CDS functions, and use context awareness to trigger and deliver them in a more timely fashion than what EHR systems support.

We are further testing our framework in real clinical setting of the hospital where this project was instigated and anticipate consolidating each aspects of the framework through studying the impact of innovative clinical applications on the clinical practice. We also intend to enhance our framework to support device-mediated integration with the environment, and to evolve it into a full situation-aware platform, as an extension of the existing context-aware framework. This is needed for better recommendations by the system for potential course of actions, and to support predictive aspects of the application. Further, we plan to incorporate normative concepts in WDO, notably various policies and guidelines that constraint actions of clinicians during their participation in clinical workflow, as well as explore beliefs, preferences and other modal aspects. We will also look at declarative process modelling languages to provide models of clinical workflow that could be used to inform the degree of context awareness of an application, as well as drive its behavior. Finally, we intend to compare our approach to the recent developments in the HL7 FHIR community related to the workflow, as a standardised approach to our context model, and test whether our framework can drive a broader spectrum of FHIR applications.

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