Medical Process Modeling: 
an Artifact-Centric Approach

Position Paper

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Abstract. In this position paper we argue that just as traditional business process modeling has been adopted to deal with clinical pathways, also the artifact-centric process modeling technique may be successfully used to model various kinds of medical processes: physiological processes, disease behavior and treatment processes. We also discuss how a proposed approach may be used to deal with an interplay of all the processes a patient is subject to and what are the queries that might be imposed over an overall patient model.

Keywords: healthcare process modeling, knowledge representation, artifact-centric systems, formal verification, process compliance.

1 Introduction

Recent development of information technology has significantly affected the way how a healthcare industry operates. Medical Information Systems have advanced from Electronic Health Record solutions to sophisticated clinical decision support systems and clinical pathways management systems. While the former are usually rely on evidence-based machine learning and hypothesis generation, the latter is mostly based on workflow technologies, originating from Business Process Modeling (BPM).

A common drawback of classical healthcare process modeling approaches is being activity-centric: they mainly focus on the control-flow perspective, lacking the connection between the treatment process and the patient data manipulated during its execution. Therefore, such approaches are more focused on curing a particular disease, rather than treating a concrete patient. Moreover, whenever a patient suffers from several diseases at the time, it becomes particularly difficult to align several clinical pathways, since the combinations of those might lead to life-threatening conflicts difficult to trace over time.

To tackle the similar problem in knowledge-intensive business domains, the artifact-centric paradigm has recently emerged as an approach in which processes are guided by the evolution of business data objects, called artifacts \([7,3]\). A key aspect of artifacts is coupling the representation of data of interest, called information model, with lifecycle constraints, which specify the acceptable evolutions of the data maintained by the information model. Current research in artifact-centric business process management
mirrors the development of traditional business process formalisms. On the one hand, new modeling notations are being proposed to tackle artifact-centric processes. A notable example is the Guard-State-Milestone (GSM) graphical notation [4], which corresponds to way executive-level stakeholders conceptualize their processes [2]. On the other hand, formal foundations of the artifact-centric paradigm are being investigated in order to capture the relationship between processes and data and support formal verification [5][1][6]. This form of reasoning support is particularly important in the artifact-centric setting, due to the subtle interactions between the data and process components.

In this position paper we argue that just as traditional business process modeling has been adopted to deal with clinical pathways, also the artifact-centric process modeling technique may be successfully used to model various kinds of medical processes: physiological processes, disease behavior and treatment processes. We also discuss how a proposed approach may be used to deal with an interplay of all the processes a patient is subject to and what are the queries that might be imposed over an overall patient model.

The rest of the paper is organized as follows. Section 2 provides an overview of artifact-centric systems and the current state-of-art. Section 3 introduces the proposed approach to medical process modeling. Section 4 concludes the paper with a discussion.

2 Overview of artifact-centric systems

The foundational character of artifact-centric systems is the combination of static properties, i.e., the data of interest, and dynamic properties of a business process, i.e., how it evolves. Artifacts, the key entities of a given domain, are characterized by (i) an information model that captures domain-relevant data, and (ii) a lifecycle model that specifies how the artifact progresses through the process. In this paper, we focus on the Guard-Stage-Milestone (GSM) approach for artifact-centric modeling, recently proposed by IBM [4]. In this section, we introduce the full expressive power of the GSM methodology, using its original business-related terminology and a relevant example, while in the next section we narrow down the approach to application in the medical processes domain.

2.1 Guard-Stage-Milestone modeling

GSM is a declarative modeling framework that has been designed with the goal of being executable and at the same time enough high-level to result intuitive to executive-level stakeholders. The GSM information model uses (possibly nested) attribute/value pairs to capture the domain of interest. The key elements of a lifecycle model are stages, milestones and guards. Stages are (hierarchical) clusters of activities (tasks), intended to update and extend the data of the information model. They are associated to milestones, operational objectives to be achieved when the stage is under execution. Guards control the activation of stages and, like milestones, are described in terms of data-aware expressions, called sentries, involving events and conditions over the artifact information model. Sentries have the form \[ \text{on } e \text{ if } \text{cond} \], where \( e \) is an event and \( \text{cond} \) is a condition over data. Both parts are optional, supporting pure event-based or condition-based sentries. Tasks represent the atomic units of work. Basic tasks are used
to update the information model of some artifact instance (e.g., by using the data payload associated to an incoming event). Other tasks are used to add/remove a nested tuple. A specific create-artifact-instance task is instead used to create a new instance of a given artifact type; this is done by means of a two-way service call, where the result is used to create a new tuple for the artifact instance, assign a new identifier to it, and fill it with the result’s payload. Obviously, another task exists to remove a given artifact instance. In the following, we use model for the intensional level of a specific process described in GSM, and instance to denote a GSM model with specific data for its information model.

The execution of a business process may involve several instances of artifact types described by a GSM model. At any instant, the state of an artifact instance (snapshot) is stored in its information model, and is fully characterised by: (i) values of attributes in the data model, (ii) status of its stages (open or closed) and (iii) status of its milestones (achieved or invalidated). Artifact instances may interact with the external world by exchanging typed events. In fact, tasks are considered to be performed by an external agent, and their corresponding execution is captured with two event types: a service call, whose instances are populated by the data from information model and then sent to the environment; and a service call return, whose instances represent the corresponding answer from the environment and are used to incorporate the obtained result back into the artifact information model. The environment can also send unsolicited (one-way) events, to trigger specific guards or milestones. Additionally, any change of a status attribute, such as opening a stage or achieving a milestone, triggers an internal event, which can be further used to govern the artifact lifecycle.

Example 1. Figure 1 shows a simple order management process modeled in GSM. The process centers around an order artifact, whose information model is characterized by a set of status attributes (tracking the status of stages and milestones), and by an extendible set of ordered items, each constituted by a code and a quantity. The order lifecycle contains three top-level atomic stages (rounded rectangles), respectively used to manage the manipulation of the order, its payment, and the delivery of a payment receipt. The order management stage contains a task (rectangle) to add items to the order. It opens every time an itemRequest event is received, provided that the order has not yet been paid. This is represented using a logical condition associated to a guard (diamond). The stage closes when the task is executed, by achieving an “item added” milestone (circle). A payment can be executed once a payRequest event is issued, provided that the order contains at least one item (verified by the OCL condition order.items → exists). As soon as the order is paid, and the corresponding milestone achieved, the receipt delivery stage is opened. This direct dependency is represented using a dashed arrow, which is a shortcut for the condition on Order paid, representing the internal event of achieving the “Order paid” milestone.
2.2 Operational semantics of GSM

GSM is associated to three well-defined, equivalent execution semantics, which discipline the actual enactment of a GSM model [4]. Among these, the GSM incremental semantics is based on a form of Event-Condition-Action (ECA) rules and is centered around the notion of GSM Business steps (B-steps). An artifact instance remains idle until it receives an incoming event from the environment. It is assumed that such events arrive in a sequence and get processed by artifact instances one at a time. A B-step then describes what happens to an artifact snapshot $\Sigma$, when a single incoming event $e$ is incorporated into it, i.e., how it evolves into a new snapshot $\Sigma'$ (see Figure 5 in [4]).

The evolution of a GSM system composed by several artifacts can be described by defining the initial state (initial snapshot of all artifact instances) and the sequence of event instances generated by the environment, each of which triggers a particular B-step, producing a sequence of system snapshots. This perspective intuitively leads to the representation of a GSM model as an infinite-state transition system, depicting all possible sequences of snapshots supported by the model. The initial configuration of the information model represents the initial state of this transition system, and the incremental semantics provides the actual transition relation. The source of infinity relies in the payload of incoming events, used to populate the information model of artifacts with fresh values (taken from an infinite/arbitrary domain). Since such events are not under the control of the GSM model, the system must be prepared to process such events in every possible order, and with every acceptable configuration for the values carried in the payload. The analogy to transition systems opens the possibility of using a formal language, e.g., a (first-order variant of) temporal logic, to verify whether the GSM system satisfies certain desired properties and requirements. For example, one could test generic correctness properties, such as checking whether each milestone can be achieved (and each stage will be opened) in at least one of the possible systems’ execution, or that whenever a stage is opened, it will be always possible to eventually achieve one of its milestones. Furthermore, the modeler could also be interested in verifying domain-specific properties, such as checking whether for the GSM model in Figure [4] it is possible to obtain a receipt before the payment is processed.

3 Artifact-centric medical processes

In this section we show how the artifact-centric process modeling technique may be used in order to model various kinds of medical processes a patient is involved in. As a matter of fact, it is the patient, or his Electronic Health Record (EHR), what becomes the key entity of the domain, i.e. the main artifact type. The current state of the patient is described by a set of attributes, each of which corresponds to a particular entry in the EHR. Such attributes may either have a certain atomic datatype (e.g. blood pressure, oxygen level, etc) or be of a semantic nature (e.g. having a headache, being pregnant, etc). In the latter case, such semantic attributes may be borrowed either from an existing or from a specifically developed ontology. We then model all the relevant medical
processes as a lifecycle of the Patient artifact type. In particular, we distinguish the following types of processes:

- **Physiological processes.** These are the processes that every human is subject to: digestion, breathing (oxygen metabolism), blood circulation, other physiological dependencies.

- **Disease behavior.** Each disease may, in fact, be described by a set of processes, which model different phases of the disease and its influences on various physiological processes.

- **Treatment processes.** By these processes we understand both different treatment procedures (e.g. surgery) and drug treatment. While the former may be described by the patient-data-driven workflows, the latter is usually described by pharmacokinetics and pharmacodynamics of the particular drug.

We then model each of the aforementioned processes in the artifact-centric manner, where such processes are described as the evolution of the patient data along the execution of such process. However, the specific character of the processes at hand implies several peculiarities:

- Since we model patient data as the main artifact type, we can safely exclude the create-artifact-instance service calls since that will imply “creation” of new patient.

- For the similar reason we consider only incoming one-way events triggered by the environment, which may correspond to updating test results or exposure to some external reagents (e.g. poisons).

- We also consider only basic tasks, performed by an external agent (e.g. surgeon, nurse, etc), which update the current state of patient data.

Having modeled all physiological, disease and treatment processes one could obtain very interesting inferences and deductions over such model. For instance, analyzing the process depicted on Figure 2 one could infer that using an artificial ventilation as treatment procedure for loss of consciousness in case of asthma may potentially lead to a specific kind of pneumonia. Another potential usage of such process model originates from the operational semantics of GSM. Verification of a reachability property

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1. Although one could also model aforementioned processes on the molecular level, we assume that they are described on the semantic level. As a matter of fact, models of both granularities may coexist, since processes on molecular level may be modeled as subprocesses on the semantic level.

2. All the examples are purely fabricated and may be not aligned to real clinical cases.
for the resulting transition system may be used to obtain the sequence of specific actions, treatments and other external events, which may be used to achieve the desired state of the patient. For instance, one could formulate the following query over an instance of a model (i.e. specific patient data):

_Having the current state of this particular patient, are there any drug treatments that will result in healing the diabetes but will not result in arrhythmia?_

4 Discussion

In this work we have given an insight on how an emerging methodology for business process modeling may be used to model various medical processes. Applying this methodology to healthcare processes allows to benefit from already existing mechanism of the formal verification of the GSM artifact-centric paradigm for a very rich first-order temporal logic, tailored to the artifact-centric setting [6]. Moreover, such approach eliminates a so-called “data and process engineering divide”, which affects many contemporary process-aware medical information systems and due to which such systems are more focused on curing a particular disease, rather than treating a concrete patient.

The results presented in our paper can be used to generalize this approach towards more complex models. Future work towards application of the artifact-centric modeling to healthcare processes also includes further studies of the domain of interest in order to determine relevant usecases and required queries for further assessment of the approach.

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