Enhancing Semantic Interoperability in Healthcare using Semantic Process Mining

Silvana Pereira Detro[*,**], Dmitry Morozov[*], Mario Lezoche[*], Hervé Panetto[*], Eduardo Portela Santos[**], Milan Zdravkovic[***]

[*] Research Center for Automatic Control of Nancy (CRAN), Université de Lorraine, UMR 7039, Boulevard des Aiguillettes B.P.70239, 54506 Vandoeuvre-lès-Nancy, France.

[**] Graduate Program in Production Engineering and Systems (PPGEPS), Pontifícia Universidade Católica do Paraná (PUCPR), Curitiba, Paraná, Brasil

[***] University of Nis, Mechanical Engineering department

{silvana.pereira-detro, dimitrii.morozov, mario.lezoche, herve.panetto}@univ-lorraine.fr, eduardo.portela@pucpr.br, milan.zdravkovic@gmail.com

Abstract—**Semantic interoperability plays an important role in healthcare domain, essentially it concerns the action of sharing the meaning between the involved entities. The enterprises store all the execution processes data as event log files. The process mining method is one among the possible methods that enable the processes analysis behavior in order to understand, optimize and improve them. However, the standard process mining approaches analyze the process based only on the event log label strings, without consider the semantics behind this label. A semantic approach on the event logs might overcome this problem and could enable the use, reuse and sharing of the embedded knowledge. Most of the research developed in this area focuses on the process dynamic behavior or in clarifying the meaning of the event log label. Therefore, less attention has been paid in the knowledge injection perspective. In this context, the objective of this paper is to show a procedure, in its preliminary state, to enhance the semantic interoperability through the semantic enrichment of event logs with domain ontologies and the application of a formal approach, named Formal Concept Analysis.**

I. INTRODUCTION

Healthcare organizations are under constant pressure to reduce costs while delivering quality care to their patients. However, this is a challenge task due the characteristics of this environment.

Healthcare practices are characterized by complex, non-trivial, lengthy in duration, diverse and flexible clinical processes in which high risk and high cost activities take place and by the fact that several organizational units can be involved in the treatment process of patients [1], [2].

In this environment organizational knowledge is necessary to coordinate the collaboration between health care professionals and organizational units.

The knowledge is the most important asset to maintain competitiveness. Defined from different points of view, in this research we consider that the knowledge is composed by data and/or information that have been organized and processed to convey the understanding, the experience, the accumulated learning, and the expertise as they are applied to a current problem or activity [3].

The knowledge representation is the result of embodying the knowledge from its owner's mind into some explicit form. It enables external agents to perform some specific operations for achieving their particular needs. The knowledge representations act as the carriers of knowledge to assist collaboration activities [4].

Interoperability is the ability of two or more systems to exchange information and to use the information that have been exchanged [5], thus supporting collaboration. This research has as focus the semantic interoperability, which is concerned with the meaning of the elements. In healthcare, achieving semantic interoperability is a challenge due to many factors as: the ever-rising quantity of data spread in many systems, the existed ambiguity between the different terms, the fact that data are related to organizational and medical processes, to cite only the most known problems [6], [7], [8].

In healthcare, collaboration between processes is of the utmost importance to deliver a quality service care. To improve the collaboration between processes is necessary to understand how the processes collaborate. Many authors claim the existence of a gap between what happens and what is supposed to happen. The process mining approach extracts information from the event log, providing a real image of what is happening, showing the gap, if it exists, between the planned and the executed process [9].

However, there is a lack of automation between business world and IT world. Thus, the translation between both worlds is challenging and requires a huge human effort. Besides, the analysis provided by process mining technology are purely syntactic, i.e. based in the string of the label. These drawbacks leads to the development of Semantic Business Process Management.

The use of semantics in combination with event logs analysis is a bridge between the IT world and business world. It brings advantages to both worlds, as less human effort in the translation between them, the possibility to reason on processes, the possible analyses to complex processes, etc.

In this context, this paper proposes a formal approach to enhance the semantic interoperability in healthcare through the semantic enrichment of the event log. We highlight that this is a preliminary work and not yet validated.

The article is organized as follows: In section II, the research problem is presented. The section III introduces the proposed approach to the enrichment of the event log. The section IV provides the required background knowledge. In Section V, the conclusions and the future works are discussed.

II. OVERVIEW OF THE PROPOSED APPROACH

Nowadays the enterprises have been extremely efficient in collecting, organizing, and storing a large amount of data obtained in their daily operations. Healthcare is an information rich environment and even the simplest healthcare decisions require many pieces of information. But, the healthcare enterprises are also 'knowledge poor' because the healthcare data is rarely transformed into a strategic decision-support resource [10].

In this environment, the success in the activities depends of different factors such as the physician's knowledge and experience, the availability of resources and data about patient's condition, and the access to the domain models (which formalize the knowledge needed for taking decisions about the therapeutic actions). All this information must be uniquely accessed and processed in order to make relevant decisions [11], [12], [13].

However, the wide variety of clinical data formats, the ambiguity of the concepts used, the inherent uncertainty in medical diagnosis, the large structural variability of medical records, the variability of organizational and clinical practice cultures of different institutions makes the semantic interoperability a hard task [6], [7], [8].

The semantic interoperability between processes in the healthcare environment is mandatory when the processes need to collaborate during the patient treatment. The analysis of the event log provide knowledge about how processes collaborate and how improve it.

However, the event log may contain implicit relations. The semantic enrichment of the event log enables the discovery of unknown dependencies which can improve the semantic interoperability. Formal Concept Analysis is applied in our approach to discover these unknown dependencies, enabling an improvement in the semantic interoperability.

Ensuring the semantic interoperability between medical and organizational processes is of the utmost importance to improve patient care, reducing costs by avoiding unnecessary duplicate procedures, thus reducing time of the treatment, errors, etc.

III. LITERATURE REVIEW

A. Process Mining

The Process mining technique aims to enable the understanding of process behavior and in this way to facilitate decision making to control and improve that behavior.

However, process mining can have different types of results and is not reduced only to the discovery of process models [14]. In the last decade, process mining techniques were implemented under different perspectives and hierarchy levels: either for the identification of the business process workflow, for the verification of conformance and machine optimization, for the monitoring of the system performance, among others [15].

The application of process mining in healthcare allows one to discover evidence-based process models, or maps, from time-stamped user and patient behavior, to detect deviations from intended process models relevant to minimizing medical error and maximizing patient safety and to suggest ways to enhance healthcare process effectiveness, efficiency, and user and patient satisfaction [16].

The base of process mining are the event logs (also known as 'history', 'audit trail' and 'transaction log') that contain information about the instances (also called cases) processed in systems, the activities (also named task, operation, action or work-item) executed for each instance, at what time the activities were executed and by whom, named respectively as timestamp and performer or resource. The event logs may store additional information about events as costs, age, gender etc. [17], [18].

Fig. 1 shows that the three basic types of process mining are discovery, conformance, and extension.

The discovery is the most prominent type. It takes an event log and produces a model without using any a-priori information.

The second type is conformance checking which compares an a-priori or reference model with the observed behavior as recorded.

The extension is the third type, the idea is to extend or improve an existing process model using information

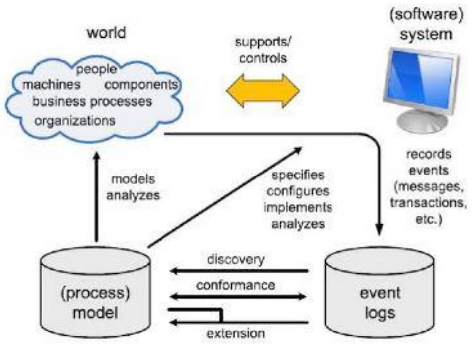

Figure 1. Three main types of process mining

about the actual process recorded in some event log. The mining techniques are aimed at discovering different kinds of models for different perspectives of the process, namely: the control-flow or process perspective, organizational perspective and the data or case perspective. The format of the output model will depend on the technique used [9], [14], [16], [17] [19], [20], [21], [22], [23].

However, despite the benefits of process mining technique there are still some issues to be overcome. One problem is related to the inconsistency of the activity labels. Naming the activity is realized freely by the designer, this action may create complex and inconsistent models generating difficulties in the model analysis. The result of this situation is that the mining techniques are unable to reason over the concepts behind the labels in the log [24]. It is very common the situations where different activities are represented by the same label or different labels are described by the same activity.

Besides, Business Process Management suffers from a lack of automation that would support a smooth transition between the business world and the IT world. This gap is due to the lack of understanding of the business needs by IT experts and of technical details by business experts. One of the major problems is the translation of the high-level business process models to workflow models, resulting in time delays between design and execution phases of the process [25], [26].

In this way, moving between business and IT world requires huge human effort which is expensive and prone to errors [27].

To overcome these issues, the semantic technologies were combined with BPM, enabling the development of the Semantic Business Process Mining approach, which aims to access the process space (as registered in event logs) of an enterprise at the knowledge level so as to support reasoning about business processes, process composition, process execution, etc. [25], [28].

B. Semantic Business Process Mining

The basic idea of semantic process mining is to annotate the log with the concept in an ontology, this action will let the inference engine to derive new knowledge.

The combination of the semantics and the processes can help to exchange process information between the applications in the most correct and complete manner, and/or to restructure business processes by providing a tool for examining the matching of process ontologies [29].

The ontologies are used to capture, represent, (re) use, share and exchange knowledge. There is no official definition about ontology but the most accepted one is from [30] that states that the ontology is an explicit specification of a conceptualization, meaning that the ontology is a description of the concepts, relationships and axioms that exist in a domain.

The ontology is built, mostly, to share common understanding of the information structure among people or software agents. The ontology is also used to separate domain knowledge from the operational, to analyze and to reuse domain knowledge and to make assumptions about a domain explicit [31], [32], [33], [34], [35].

The ontology describes the domain of interest, but for knowledge sharing and reuse among applications and agents, the documents must contain formally encoded information, called semantic annotation.

The annotation process enables the reasoning over the ontology, so to derive new knowledge. Annotation is defined by [36] as "a note by way of explanation or comment added to a text or diagram". An annotation can be a text, a comment, a highlighting, a link, etc. According [37], semantic annotation is the process of annotating resources with semantic metadata. In this way, semantic annotation is machine readable and processable; and it contains a set of formal and shared terms in the specific context [4].

There are three options to annotate the event log. The first one is to create all the necessary ontologies, or to use the existing ones, about the chosen domain and to annotate the elements. The second option is to use tools to (semi-) automatically discover ontologies based on the elements in event logs. In this case, these mined ontologies can be manually improved. The third option is a combination of the previous two in which models/logs are partially annotated by a person and mining tools are used to discover the other missing annotations for the remaining elements in logs/models. The discovery and extension process mining techniques can play a role in the last two options [25].

The idea of adding semantic information to business processes was initially proposed by [38], which aimed to improve the degree of mechanization on processes by combining Semantic Web Services and BPM.

A similar idea was proposed in SUPER (Semantic Utilized for Process Management within and between Enterprises), an European project, which fundamental approach is to represent both the business perspective and the systems perspective of enterprises using a set of ontologies, and to use machine reasoning for carrying out or supporting the translation tasks between both worlds [28].

Reference [39] addressed the problem of inconsistency in the labeling of the elements of an organizational model through the use of semantic annotation and ontologies. The proposed approach uses the i* framework, one of the most widespread goal-oriented modeling languages, and the two i* variants Tropos and service-oriented i*. However, the proposed approach can be applied to other business modeling techniques.

In [40] semantic annotation was use to unifying labels on process models that represent the same concept and abstracting them into meaningful generalizations. The business processes are semantically annotate with concepts taken from a domain ontology by means of standard BPMN textual annotations, with the semantic concept prefixed by an '@'.

Reference [41] proposes an approach for (semi-) automatic detection of synonyms and homonyms of process element names by measuring the similarity between business processes models semantically modeled with the Web Ontology Language (OWL).

An ontological framework was introduced by [42] for the representation of business process semantics, in order to provide a formal semantics to Business Process Management Notation (BPMN). Reference [43] introduces a methodology that combines domain and company-specific ontologies and databases to obtain multiple levels of abstraction for process mining and analysis.

Reference [44] proposes an approach to semantically annotated activity logs in order to discover learning patterns automatically by means of semantic reasoning. The goal is automated learning that is capable of detecting changing trends in learning behaviors and abilities through the use of process mining techniques.

The most of the studies developed in this area focuses on process behavior analysis and in clarifying the meaning of the event log label. Thus, less attention has been paid in the knowledge injection perspective and the semantic discovery perspective [40], [45].

C. Formal Concept Analysis

The Formal Concept Analysis (FCA) is a mathematical formalism based on the lattice theory whose main purpose is structuring information given by sets of objects and their descriptions. It brings knowledge

representation framework that allows discovery of dependencies in the data as well as identification of its intrinsic logical concepts [55].

The FCA theory was introduced in the early 1980s by Rudolf Wille, as a mathematical theory modeling the concept of 'concepts' in terms of lattice theory. The FCA is based on the works of Barbut and Monjardet (1970), Birkhoff (1973) and others for the formalization of concepts and conceptual thinking [46], [47], [48].

During recent years the FCA was widely applied in research studies and practical applications in many different fields including text mining and linguistics, web

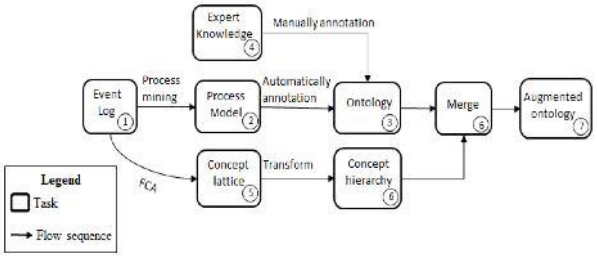

Figure 2. Procedural model of the research

mining (processing and analysis of data from internet documents), software mining (studying and reasoning over source code of computer programs), ontology engineering and others.

In ontology engineering, the FCA is mainly used for construction of a conceptual hierarchy. The resulting taxonomy of concepts with "*is-a*" relation serves as a basis for successive ontology development. An FCA diagram of the concepts visualizes the structure and, therefore, is a useful tool to support navigation and analytics [49]. Another application of FCA is merging of ontologies, where its power in discovering relations is exploited in order to combine several independently developed ontologies from the same domain [50][26] [46] [51] [52].

IV. Proposed Approach

The proposed method, yet to be validated, for semantically enrich the event log on domain ontologies using Formal Concept Analysis is presented in Figure 2.

The "Step 1" is related to the capture of the event log, which must contain the information about the process executions. The process mining techniques will be used to obtain the process model in the "step 2". The process model provides knowledge about how the activities are connected, who performed the activities, the social network, the time of execution, and others. This acquired knowledge can also be helpful in the annotation process.

The Process Mining Framework (ProM) [53] was the first software developed to support process mining techniques. Initially, ProM accepted as input process execution data in the form of MXML log files, which has been extended to SA-MXML to support semantic annotation. The advance of process mining leveraged the development of another tools as Disco, Interstage Business Process Manager and Perceptive Process Mining [53], [54].

Thus, ProM will be used to discover automatically the ontologies based on the elements of the event log in the "step 3". The resulting ontology will be improved with the expert knowledge (step 4).

The method suggested in our research to enhance the standard event log is the application of Formal Concept Analysis.

The application of FCA (step 5) produces a conceptual structure organizing the domain knowledge. It gives a better understanding about the interoperability between processes and also can be helpful in the discovery of knowledge gaps or anomalies.

In order to establish the correspondence between the concepts in the ontology with the concepts suggested by the FCA knowledge discovery procedure we propose to apply following methods. Firstly, we can identify the ontology concepts within the formal concepts of the FCA. We will consider attributes as concepts. The goal is to build a concept network to express in the best way possible the knowledge [50], [49].

The lattice produced by FCA can be transformed into a type of concept hierarchy (step 6) by removing the bottom element, introducing an ontological concept for each formal concept (intent) and introducing a sub-concept for each element in the extent of the formal concept in question [49].

In our approach, the patients are used as objects and the processes activities (events) are used as the attributes. For the transformation of the lattice in the concept hierarchy we can consider just the attributes. Thus, as proposed by [56], before the transformation we can eliminate lattice of extents (objects) and get as result a reduced lattice of intent (attributes) of formal concepts.

In step 5, it is necessary to incorporate the new data into the ontology. This can be done manually or we can apply a method for ontology merging. Some methods to merge (semi) automatically ontologies have been developed as Prompt, OM algorithm, Chiamera, OntoMerge, FCA-Merge, IF-Map and ISI [57].

The resulting ontology has an augmented knowledge (step 7), thus improving the semantic interoperability.

The proposed approach is under validation procedure. The Nancy University Hospital applications will represent the first case study. The goal of the hospital direction is to optimize the processes interoperability to reduce the costs and increment the quality.

V. Example of Application

An hospital stores the data of the patients, the associated medical data set, the department organizational data, and laboratory data. It stores also the data related to the costs of all events (appointments, treatments, surgeries, exams, materials, and medicines).

The recovered data are stored and related to the patient, doctor, department, and laboratory ID, the events, the date of the event and requests.

Initially one process, for example, the breast cancer treatment is chosen to be analyzed. Following our approach, processes mining techniques can be applied to provide process behavior. The ontology related to the processes is built and annotate. The new concepts will be added in the ontology after the application of the FCA

approach that will semantically enrich the event log showing the implicit relations.

Through process mining techniques is possible to analyze the length of stay, treatment time, pathway followed by the patients, if guidelines or protocols are been followed, etc.

However, normally process model resulted from this kind of data are complex and difficult to analyze. The proposed approach enable the analysis of these complex processes showing the roots of the problems, for example, the causes of the increased length of stay, the lack of some essential care interventions in the treatment, the problems in following clinical guidelines, the discovery new care pathways, the discovery of best practices, the anomalies and the exceptions which may exist in the process providing a better understood where to take action to improve the healthcare processes.

VI. CONCLUSION

In healthcare domain the access to the information at the right place and at the right time is crucial to provide quality services. In this environment, organizational and medical processes are constantly exchanging information.

The processes analysis shows what are really happening, thus it is providing knowledge about possible improvements. Besides, the data related to the traces of the processes may show problems related to the interoperability, and also ways to improve it.

The process mining techniques enables this kind of analysis. In healthcare, this method is normally used to discover clinical pathways, to discover best practices, adverse events, conformance checking between medical recommendations and guidelines, etc.

Due to the limitations of the process mining techniques, the semantics was combined with the event logs. This combination brings many benefits to process improvement and for knowledge management.

There is a lack of studies about knowledge injection perspective. This research aims to fulfill this gap. Our objective is the enhancement of the semantic interoperability in the healthcare domain using semantic process mining.

Our approach proposes to apply the formal concept analysis method to capture knowledge from the event log, which is not implicit in the ontology, thus improving the semantic interoperability. The semantic enrichment of the event log may also provide knowledge about processes improvement.

The next step is related to the operational development of the proposed approach and the following validation.

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