Towards a Data-Centric Framework for Modelling, Managing and Mining BPM Processes over Pandemic Events*

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Abstract

The *COVID-19 pandemic* exposed significant shortcomings in the ability of modern healthcare information systems to *manage and mitigate pandemics*, especially when faced with unforeseen events. This paper addresses these shortcomings by introducing PROTECTION, a cutting-edge data-centric framework aimed at enhancing pandemic control and prevention, *specifically focusing on BPM processes*. PROTECTION offers a comprehensive approach to handling pandemic-related complexities. We provide an overview of PROTECTION's structure and main functions.

Keywords

Process Modelling, Pandemic Events, Pandemic Control and Prevention.

1. Introduction

Pandemics changed our daily life in many different aspects and, focusing on healthcare and clinical aspects, highlighted the need to manage *Knowledge-, Decision- and Data-Intensive* (KDDI) processes related to the care of swab-positive patients and to the definition of public health policies with the double goal of preventing and controlling the pandemic spread. Besides the short-term support, for which *Information and Communication* and *Artificial Intelligence* techniques can provide methodologies and tools for collecting, analyzing, storing, sharing, and visualizing pandemic-related information, recent pandemic events like COVID-19 also push for long-term research efforts devoted to study and proposal of new approaches able to support healthcare and clinical organizations in planning and analyzing activities, specifically-focused to care, monitor, and prevent pandemic events.

In such context, *process modeling, management, and mining* play a leading role in effectively supporting pandemic control policies at large, with a special emphasis on the integration of these methodologies with the emerging *big data* trend, thus achieving the innovative definition of KDDI process modeling, management, and mining for pandemic scenarios, like in recent COVID-19 related studies.

From this last long-term perspective, we propose PROTECTION, a framework for supporting data-centric process modeling, management, *and mining for pandemic prevention and control*. PROTECTION focuses the attention on methodological issues in modeling, managing and mining healthcare/clinical KDDI processes for the management of worldwide pandemics.

More into detail, our proposed framework's long-term aims are towards providing:

1. *clinical stakeholders* with a set of methodologies/tools to manage KDDI processes for the prevention and management of worldwide pandemics;
2. *healthcare decision-makers* with methodologies/tools for monitoring KDDI processes and resource consumption in their organizations to control the care quality and the social impact of such pandemic-related processes;
3. *software designers* with a set of building blocks and methodologies to support the efficient development of KDDI process systems devoted to managing worldwide pandemics.

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As regards the proper conceptual/software structure, PROTECTION is articulated into the following research assets/components:

1. *clinical and healthcare KDDI process modeling and management* to represent knowledge of the target application scenario, plus its *conceptual interconnections*;
2. *clinical and healthcare KDDI process mining*, to both discover implicit processes (or process fragments) and to perform an "a-posteriori" comparison between designed and actual processes;
3. *specific software architecture* for: (i) modelling, managing, and evaluating healthcare and clinical KDDI processes for preventing and managing pandemic events, and (ii) continuous KDDI process mining to monitor actual processes and obtain useful feedback for improvement.

Following this main vision, this paper introduces and discusses the framework PROTECTION. In more detail, we describe the anatomy and main functionalities of PROTECTION, discussing how the proposed framework can effectively deal with the complex domain of pandemic control and prevention.

2. PROTECTION: The Overall View

In this Section, we provide the reference architecture of PROTECTION, which has the final goal of capturing the many facets of pandemic prevention and control, as also demonstrated by the recent worldwide COVID-19 epidemic. The proposed architecture is modular in nature, and it unveils the complex interaction of process modeling, management methods, and data mining approaches in the context of treating such pandemics.

PROTECTION looks at pandemic events through a scientific lens, and it aims to uncover the fundamental processes that regulate their *transmission patterns*, the efficacy of various intervention strategies, and the critical role of data-driven methods in shaping public health policy. Through rigorous analysis, this study not only elucidates the complexity inherent in pandemic management but also emphasizes the importance of adaptable methods based on strong analytical frameworks, with respect to the specific case studies of pandemic prevention and control. Despite this, the main research results can be extended towards other different context such as *general bio-informatics*, *vaccine campaigns*, *cancer-related population screenings*, *workplace health promotion and well-being initiatives*, etc.

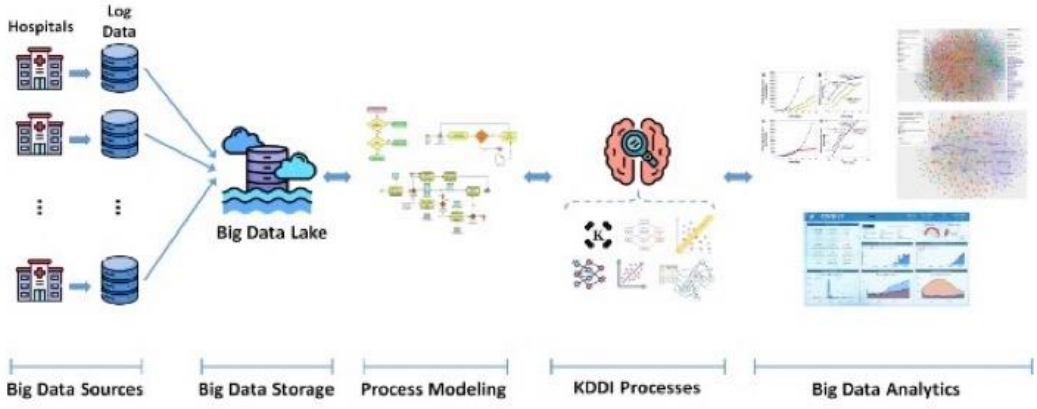

Figure 1: PROTECTION Architecture.

Figure 1 shows the reference architecture of our proposed framework PROTECTION. Our reference architecture consists of several component layers, namely (*i*) *Big Data Sources* layer; (*ii*) *Big Data Storage* layer; (*iii*) *Process Modeling* layer; (*iv*) *KDDI Processes* layer; (*v*) *Big Data Analytics* layer. In the following, we will discuss these layers in detail.

Big Data Sources Layer. Healthcare data logs, often derivable also from Electronic Healthcare/Medical Records, include valuable information such as patient demographics, clinical symptoms, laboratory findings, treatment procedures, and utilization trends. Using such comprehensive facts, we can build *complex models* that reflect the pandemic spatio-temporal development, evaluate the success of containment methods, and improve resource allocation in healthcare settings. Furthermore, using healthcare data logs allows for the inclusion of real-time information, permitting *dynamic-modeling techniques* that react to changing epidemiological patterns and

healthcare demands. The rigorous examination of these massive data sources provides useful insights for optimizing pandemic response efforts and improving public health preparedness measures.

Big Data Storage Layer. *Cloud data lakes* provide scalable and cost-effective storage for pandemic-management data sources such as epidemiological surveillance, genomic sequences, healthcare records, and social media sentiment analysis. Using the flexibility and accessibility of Cloud infrastructures, we can seamlessly combine diverse information, allowing for *holistic modeling techniques* that reflect the complex interaction of numerous factors influencing disease transmission and response tactics. Implementing Cloud data lakes provides a sound background in empowering *data-driven insights*, therefore helping to the refinement of our process modeling framework and to the optimization of pandemic mitigation efforts.

Process Modeling Layer. Such a layer allows stakeholders to suitably represent healthcare and clinical processes that can be related either to the application of clinical guidelines or the specific care pathways within a specific healthcare organization. Such processes need to be suitably considered and modeled because both contain clinical tasks that need the support of data analysis tools and can be suitably inferred through process mining to explicitly describe such kind of organizational knowledge.

KDDI Processes Layer. Incorporating *knowledge-driven decision-making processes within data-intensive techniques applied on extensive Cloud data lakes* is a very effective approach that can be adopted in this layer of PROTECTION. By leveraging advanced methodologies, such as machine learning algorithms, statistical modeling, and natural language processing, we can extract valuable insights from the diverse and voluminous big datasets stored within these repositories. By harnessing the capabilities of big data analytics tools and techniques coupled with the explicit representation of knowledge-driven decision-making processes, we can also gain a comprehensive understanding of the pandemic dynamics. This facilitates informed decision-making in public health policy formulation, resource allocation, and intervention strategies aimed at mitigating the spread of pandemics and minimizing their impact on society.
Big Data Analytics Layer. We can successfully manage and analyze massive amounts of heterogeneous big data stored in PROTECTION repositories by employing advanced approaches such as *distributed computing frameworks* (e.g., *Hadoop*, *Spark*, *Hive*, etc.), *scalable data processing engines*, and *Cloud-native analytics services*. Indeed, machine learning algorithms, deep learning models, and statistical techniques enable the extraction of significant insights from a wide range of datasets, including genomic sequences, clinical data, mobility patterns, sentiment analysis from social media platforms, and epidemiological records. These analytics tools and methodologies enable us to uncover hidden patterns, correlations, and helpful insights, which are crucial for driving evidence-based decision-making and establishing successful public health initiatives in response to pandemics. In particular, the strategy of PROTECTION consists of exploiting recent multidimensional big data analytics methodologies, given their proven effectiveness in several application scenarios, including healthcare analytics. Summarizing, these methodologies predicate the application of knowledge discovery techniques over *multidimensionally-shaped big datasets*, to get the whole benefits from powerful multidimensional modelling paradigms.

3. Related Work

In this Section, we provide a comprehensive analysis of research proposals that are related to our work. Indeed, we can identify three relevant research areas that really influence our actions, namely: (*i*) pandemic data source modeling, (*ii*) clinical guidelines and care pathways representation and management formalisms, and (*iii*) process modeling and mining.

3.1. Pandemic Data Source Modelling

How do we model pandemic data sources? This challenging question can be investigated by carefully looking at the recent COVID-19 pandemic outbreak. Indeed, this critical event has attracted a lot of research in many intertwined fields, from healthcare and medicine to bioinformatics, data science to artificial intelligence, risk analysis to multi-parameter optimization, and so forth. Therefore, the issue of modelling and making publicly available COVID-19-related data and information (e.g., [1,2,3]) has observed a great effort from the worldwide scientific community. Among these emerging data sources, which contains directions for modelling pandemic data with specific reference to COVID-19, we can identify the following ones.

First, the *European Centre for Disease Prevention and Control*, an agency of the European Union, provides a huge amount of *open healthcare data repositories* describing the worldwide history of this

pandemic [4]. One of the main sources related to the evolution of the pandemic is the *COVID-19 Data Repository* at *Johns Hopkins University* [5]. Another example of a repository of multiple datasets related to healthcare and social COVID-related issues is [6]. As for the Italian context, the *Istituto Superiore di Sanità* provides information and historical data about the COVID-19 healthcare situation [3]. Second, *open clinical data repositories* are also relevant to the scope of PROTECTION. Indeed, even though clinical datasets related to COVID-19 are complex to build and share for scientific purposes, some attempts have been made to allow scientists to analyze such data (e.g., [7,8,9]). Further, since the treatment and prevention of COVID-19 patients received attention from worldwide healthcare institutions, which are providing a sort of continuously-evolving recommendations, these can be freely interpreted as authoritative *clinical and healthcare guidelines*, which turn out to be effective under the form of procedures or technical guidance for different social, healthcare and clinical contexts (e.g., [10,11,12]). Finally, even *bibliographic repositories* are important sources of knowledge and information. Indeed, different publishers and health organizations launched different initiatives to achieve some shared effort to put at disposal the most recent scientific articles about COVID-19 (e.g., [2]).

3.2. Clinical Guidelines and Care Pathways

Clinical guidelines (GLs) consist of therapeutic and diagnostic recommendations encoding the "best practice" to care for specific patient categories. GLs are "systematically developed statements to assist practitioner and patient decisions about appropriate health care in specific clinical circumstances". *Care pathways* (CPs) are instead defined as "structured multidisciplinary care plans which detail essential steps in the care of patients with a specific clinical problem" [13]. CPs are often the concrete application of GLs, where it is necessary to explicitly identify decision-based activities and all the complex clinical knowledge and data needed to suitably perform the planned activities. GLs and CPs are very relevant in PROTECTION, as they support knowledge modelling in clinical and healthcare processes.

Several formalisms and tools have been proposed to represent, execute, and verify GLs, often integrating formalized medical knowledge with data and workflow aspects and supporting monitoring of GLs over time (e.g., [14]). A review of the state-of-the-art for these models for *Decision Support Systems* (DSS) has been published in [15] and [16]. When GLs are instantiated into a CP, their execution by various actors needs to be coordinated, and this may be done both by *computerized guideline systems* and *Business Process Management* (BPM) *systems* (e.g., [17,18,19]).

3.3. Process Modeling and Mining

Clinical process management may also benefit from BPM systems [19, 20], which can rely on a growing general interest and work on many proprietary and open-source tools. A plethora of data and information is generated within the execution of the clinical processes, thus fostering the adoption of BPM-like approaches to model and verify the observed behavior. The intrinsic complexity of the health field calls for models that reflect adaptivity to change and that are able to deal with incomplete information, i.e., *models that enjoy flexibility*. At the same time, the involved entities are expected to agree with the specific medical/healthcare knowledge, regulations, norms, business rules, protocols, and temporal constraints (e.g., [21]). Such GL systems (either BPM-based or not) require medical knowledge formalization, often relying on *Ontologies*. They have been extensively used in the medical domain for many years but still deserve research efforts, in particular focusing on process-aware knowledge representation and on data-intensive process models (e.g., [23,24,25,26]). Finally, data from already-executed CPs would help to allow the discovery of "actual" processes, as well as their emerging correlations with healthcare and clinical data. Comparing designed and "actual" processes may help discover either errors in following a clinical guideline or new, partially unknown, *best practices* that could be suitably integrated into clinical guidelines/pathways. Recent approaches treating complex processes try to take advantage of distributed architectures tackling the aspects of both mining new processes (e.g., [27]), complex multidimensional process mining (e.g., [28]), and monitoring the compliance of process executions (e.g., [29,30]).

4. PROTECTION: Methodology

The proposed framework PROTECTION is part of a long-term computer science and artificial intelligence project focusing on theoretical, methodological, and application-oriented aspects for developing KDDI process systems able to deal with the complex domain of pandemic control and prevention. In this Section, we describe some important aspects of the emerging methodology induced by the overall PROTECTION proposal.

From a long-term perspective, our proposed research addresses methodological issues in modeling, managing, and mining KDDI processes for pandemic management in healthcare and clinical organizations, focusing on KDDI pathways and guidelines. Particularly, the proposed framework focuses on process modeling, management, and mining methodologies in order to effectively support pandemic control policies at large, with a special emphasis on the integration of these methodologies with the emerging big data trend, thus achieving the innovative definition of so-called *data-centric process modeling, management and mining for pandemic scenarios*. As a proof of concept, PROTECTION targets the management of pandemics.

While a lot of attention has arose on both healthcare and clinical data analysis and mining for pandemic management, little attention has been paid to some more long-term perspectives, mainly focusing on KDDI processes that use and generate such data. The main goal of PROTECTION is to propose a *methodological approach* and some related software tools to face future pandemics by considering the healthcare and clinical processes to be enacted to fight the pandemics. Summarizing, from an attention to data, we put the focus on KDDI processes, which have to be suitably designed and executed to take such a critical pandemic under control by a seamless integration of knowledge- decision- and data-related aspects.

The information sources used to evaluate and tune the PROTECTION framework are both from open-access repositories and from some specific clinical and healthcare datasets. As for clinical/healthcare guidelines and pathways, we considered guidelines for patients from the US and Europe [4,10]. We also used the technical guidance from WHO related to both the clinical and healthcare actions for pandemics [11]. As for healthcare datasets, we considered the history-oriented dataset from Johns Hopkins University [5] for the worldwide healthcare monitoring of the pandemic. Moreover, we considered specific healthcare datasets related to the pharmacological monitoring of patients receiving therapies with monoclonal antibodies and the forthcoming pharmacovigilance activity related to pandemic-related vaccines. As for clinical datasets, we used some clinical data repositories from the pandemic research database [9] containing electronic medical records of (mainly) ambulatory patients.

In summary, the main aspects of the proposed PROTECTION framework are as follows:

-*Modeling and analyzing healthcare KDDI processes dealing with the management of pandemics*. Such processes must be designed and changed according to the possibly exponential diffusion of pandemics. They are characterized by many decision- and knowledge-intensive tasks. Here, integration with data (e.g., medical records, healthcare population data, and so on) and temporal constraints have to be considered. The simulation of such processes needs to be considered to estimate feasibility, resource allocation, and so on. Different technical questions have to be addressed in this direction: How can medical knowledge of pandemic-related clinical guidelines be represented? How do we merge and evaluate healthcare and clinical guidelines for pandemic prevention and patient management? How do healthcare processes change according to the evolution of the pandemic? May we specialize healthcare pandemic control processes according to data from the vaccine pharmacovigilance?

-*Pandemic-related process mining is used to discover process models from logs*. Whenever it is not possible to have log files to be analyzed in order to mine process models, the main idea is to consider both medical and healthcare records as an indirect kind of log, where therapeutic and specialized exams represent actions, main diagnoses represent (possibly) intermediate states of patients, and decisions for different allowed therapies/interventions/pathways represent knowledge-intensive decisional tasks. Here questions are: May we discover some recurrent patterns of therapeutic actions/decisions not considered in the guidelines? Are the tasks recorded in medical records confirming the main indications of clinical and healthcare guidelines? Are there some suggestions in guidelines never considered in the medical records? May we suggest improvements to the guidelines based on the task patterns discovered from medical records? May we discover specific recurring care patterns for specific high-risk patients undergoing monoclonal antibody therapies?

Reaching such goals would lead to significant advantages for the *National Healthcare System* (NHS) in promptly managing and preventing pandemic events. The progressive adoption of ICT techniques, in fact, can play a strategic role in the current rationalization process aimed at guaranteeing high-quality services while reducing costs, even in a pandemic event, where the management and prevention have to be enacted and monitored in a fast and dynamic way, to promptly react to diseases spreading with an exponential increase. Such a framework motivates the growing attention towards clinical and healthcare process definition and analysis.

PROTECTION pursues such goals through the development of several advanced and innovative research activities. In particular, process management in the clinical and healthcare domains is a significant topic, and we aim to bring new challenges in the following research areas: ontological tools, languages based on different kinds of logics, data models, and design tools for capturing events and temporal constraints, temporal extensions of GLs and CPs representation formalisms, constraint-based temporal reasoning, design-time and run-time GL verification, multidimensional analysis of healthcare processes, declarative and incremental process mining methods.

It should be noted here that, even if the above-mentioned aspects are strictly related, they have been considered in isolation and not yet applied cooperatively to managing worldwide pandemics. Starting from this limitation, PROTECTION aims to provide a set of methodologies and prototype software tools for the process-oriented prevention and management of worldwide pandemics.

5. Conclusions

This paper has proposed PROTECTION, an innovative data-centric process-modelling-managing-and-mining framework for pandemic control and prevention that is based on the well-known KDDI processes paradigm. Future work is actually focused on further experimentally testing the capabilities of the framework.

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