



Innovative informatics methods for process mining in health care

1. Introduction

Process mining is an emerging discipline which encompasses a wide variety of methods to extract process-related knowledge from process execution data recorded by information systems [1]. Process mining methods are often used for discovering treatment trajectories with their associated clinical outcomes, and assessing the adherence of a treatment trajectory to a normative process model such as a clinical pathway [1–3]. In this special issue, innovative methods use process mining to determine the adherence to clinical guidelines [4] and take process data-driven decisions on the resources needed for new hospital facilities [5]. Within a health care context, normative process models include clinical pathways and computer-interpretable guidelines [2,3]. The data that logs the actual execution of tasks, which is used as the starting point for process mining is typically readily available in health information systems such as electronic medical records [3]. However, unlike other domains, in health care there is an enormous variation of the treatment trajectory among patients, especially if the decision-making semantics is considered rather than the simple high-level workflow of diagnosis-management-and secondary prevention. Such decision making involves complex arguments in favor and against different care options, which are far beyond simple decisions that rely on a single parameter value [6]. Despite the challenging variation that is an inherent nature of health care processes, process mining methods offer great potential, given the significant societal relevance of methods aimed at improving the health care system [7]. In particular, the generated process-related insights can be leveraged by health care professionals to identify areas for process improvement [3]. As a consequence, the development of innovative methods for process mining in health care is of great interest to both research and society.

To advance and document the state-of-the-art on process mining in health care, the Journal of Biomedical Informatics organized a special issue on the topic “Innovative informatics methods for process mining in health care”. After a thorough review process, from among 42 submissions, 12 articles were accepted for inclusion in the special issue: nine original research articles, and three special communications. Table 1 provides an overview of the accepted articles, structured by the topic of their contribution. This overview shows that the special issue covers a wide spectrum of the field: a systematic literature review and characterization of the field to get a better understanding of the intersection of process mining and health care (two articles), methodologies to apply process mining in health care (two articles), innovative methods to use process mining to analyze the specific domains of clinical pathways (two articles) and capacity management (two articles), articles that explore process mining techniques beyond discovery, such as

conformance and enhancement (two articles), and finally articles on how to gain explainable insights into health care processes, one of the strong points of process mining compared to other computer science disciplines (two articles). The remainder of this editorial will elaborate on the variety of topics covered within this special issue.

2. Understanding process mining in health care

In order to successfully use process mining in the health care domain or to conduct relevant research, it is necessary to first understand the current state of this interdisciplinary research area. This involves understanding its specific characteristics, where process mining has been already successfully applied in health care, which challenges have been addressed and what the existing research gaps are. The special issue includes two articles that contribute to the understanding of the area.

De Roock et al. [8] present an extensive systematic literature review on process mining in health care, in which 263 papers have been included in the literature analysis. This study not only updates previous reviews on the field, such as Rojas et al. [2], but also discusses new perspectives on the literature such as the Key Performance Indicators (KPI) used to measure the impact of process mining, the involvement of domain experts, and the process mining project stages that received attention. This study confirms process mining in health care as a research area in full development, identifying trends as well as open research challenges.

Munoz-Gama et al. [9] present the outcomes of a four-year community effort which involved 55 highly relevant researchers and practitioners in the field, in order to convey a unified view on process mining in health care as a research domain. To this end, they identify the distinguishing characteristics to be considered to successfully leverage process mining in the health care domain, as well as identifying open challenges that need to be addressed by the community in the future. In particular, ten key distinguishing characteristics arise from the study – from the use of medical guidelines and protocols, to the different abstraction levels of the health care data– as well as ten key challenges – from minding concept drift, to the need of process mining techniques beyond discovery. These ten distinguishing characteristics and challenges both highlight some key ongoing research, but also provide a framework for future research in the area.

3. Methodologies for process mining in health care

Methodologies and step-by-step procedures to support the application of process mining in health care are highly important given the complexity of the health care domain. This special issue contains two

Table 1

Articles included in the special issue.

Reference	Title	First Author
[8]	Understanding process mining in health care Process mining in healthcare – an updated perspective on the state of the art	De Roock, E.
[9]	Process mining for healthcare: characteristics and challenges	Munoz-Gama, J.
	Methodologies for process mining in health care	
[10]	Process mining-driven analysis of COVID-19's impact on vaccination patterns	Augusto, A.
[11]	Multi-level process mining methodology for exploring disease-specific care processes	Vathy-Fogarassy, A.
	Analyzing pathways with process mining	
[12]	Assessment of the feasibility of developing a clinical pathway using a clinical order log	Lim, J.
[13]	Signal from the noise: A mixed graphical and quantitative process mining approach to evaluate care pathways applied to emergency stroke care	Noshad, M.
	Process mining for capacity management	
[5]	Supporting capacity management decisions in healthcare using data-driven process simulation	van Hulzen, G.
[14]	Process data analytics for hospital case-mix planning	Andrews, R.
	Beyond discovery: conformance and enhancement	
[4]	Are we ready for conformance checking in healthcare? Measuring adherence to clinical guidelines: A scoping systematic literature review	Oliart, E.
[15]	How can interactive process discovery address data quality issues in real business settings? Evidence from a case study in healthcare	Benevento, E.
	The search for explainability	
[16]	A framework for the automatic description of healthcare processes in natural language: Application in an aortic stenosis integrated care process	Fontenla-Seco, Y.
[17]	Explainable process trace classification: an application to stroke	Leonardi, G.

articles related to this topic.

Augusto et al. [10] show how process mining and traditional data mining can be applied to analyze a COVID-19-related health care scenario. To this end, they customized the PM² methodology to this context and, hence, applied a three-step procedure: prepare the health care process data for conducting a process mining analysis; select and apply suitable process mining solutions for successfully executing the analysis; and extract valuable insights from the obtained results. This analysis shows the similarities and differences between pre-COVID and COVID periods from a process perspective, e.g., the reduction of General Practice activities during this period did not represent a change in the variety of process behavior, with the exception of drug prescriptions and vaccinations. The work illustrates how the challenges of addressing improper timestamp granularity and unbounded process traces in health case studies with large amount of data as in this COVID impact study. Following these steps, they generated relevant clinical insights regarding the health care service utilization patterns during the COVID-19 pandemic.

Vathy-Fogarassy et al. [11] propose a novel methodology to apply process mining, called Methodology for Exploring Disease-specific Care Processes (MEDCP). In particular, MEDCP distinguishes itself by being multi-level, disease-specific, and involving expert knowledge in terms of taxonomies. Results show that the methodology can provide efficiency improvements of standard process mining methods, and generate

conclusions that are easy to interpret by domain experts.

The aforementioned two articles show that both the customization of existing methodologies to a specific healthcare scenario, as well as the development of novel methodologies are relevant for process mining in health care. The need to adapt methodologies or propose new ones highlights that *one size does not fit all* due to the great diversity of use cases in process mining in health care. Using a clear methodology contributes to the rigor of the study as well as its reproducibility, which is key for the future development of the research field.

4. Analyzing pathways with process mining

The analysis of clinical and care pathways is one of the most extensively explored use case for process mining as pathways are one of the most common forms of processes in the health care domain. The special issue includes two innovative studies that contribute to the state-of-the-art in this direction.

Lim et al. [12] address the issue of variability of health care data when trying to define clinical pathways. Before applying process mining methods to establish a clinical pathway, it is important to assess whether a care process can be standardized. In this respect, the study proposes a novel method for assessing the clinical pathway feasibility based on the clinical complexity process. The proposed approach consisted of three steps: data preparation, activity and trace homogeneity evaluation, and process inspection using process mining. For each step, the article proposes novel metrics and visualization methods.

Noshad et al. [13] present a study that utilizes the Electronic Health Records (EHR) as an event data source for the application of process mining. The study illustrates the use of an unsupervised process mining algorithm which generates process graphs with the most common process patterns, but also enables calculating the conformity of clinical pathways.

The articles on pathways illustrate the variety of use cases of event logs within the context of clinical pathways. It can be used to assess whether a care process can be standardized in a clinical pathway, but also to assess whether the real process conforms to an already established clinical pathway.

5. Process mining for capacity management

In order to execute health care processes, various resources are typically required such as medical equipment (e.g. radiology devices) and staff (e.g. physicians and nurses). Capacity management relates to determining the required level of resources, as well as their allocation within the process [18]. Two articles in the special issue focus on the use of process mining within the context capacity management in health care.

van Hulzen et al. [5] use Data-Driven Process Simulation (DDPS) to support capacity management decisions at the radiology department of a hospital. These decisions are situated within the context of the construction of new facilities and relate to the required radiology equipment, waiting room space, and receptionists in the future new setting. Particular attention is attributed to the interaction between process execution data and domain expertise within the context of DDPS.

Andrews et al. [14] present an approach to use process mining in the patient case-mix planning of a hospital. The patient case-mix describes the type and volume of patients which are treated at a hospital and will have a direct impact on the resource utilization and, hence, on what can be achieved with a particular volume of resources. The proposed approach has been developed in collaboration with the Queensland Children's Hospital.

Many hospitals are confronted with the challenge of providing the best possible care with limited financial means when making capacity-related decisions. Process mining can be an instrument to provide insights that can objectivize and support decision making. In particular, the capacity management papers included in the special issue highlight

the potential of process mining to support decision-making at hospitals regarding both human and non-human resources, both at the strategic and the operational level.

6. Beyond discovery: Conformance and enhancement

Process mining techniques can be classified in three main types [1]: *discovery* (i.e., to build a process model from the event data), *conformance* (i.e., to compare an existing process model with the event data), and *enhancement* (i.e., to extend or modify an existing process model with information from the event data). Discovery is the most common process mining use case in health care, representing the majority of studies in the literature. Nonetheless, conformance and enhancement techniques are also highly relevant, as demonstrated by two studies included in this special issue.

Regarding conformance, Oliart et al. [4] study the role that process mining could play in measuring the degree to which health care organizations adhere to clinical guidelines. To this end, they review the criteria used in literature to assess adherence over the past 20 years and explore the suitability of using process mining techniques. The 31 studies included in the review show that there are several threats to the applicability of process mining to measure adherence, including a lack of clear and concise rules, the fact that process models are not defined in most cases, and the availability of unstructured and incomplete data which require human interpretation.

Regarding enhancement, Benevento et al. [15] explore the idea of interactive process mining as a means to improve the quality of the process models obtained. Their approach combines the available event data with domain knowledge in order to improve the process modeling results when noisy and incomplete data is used, which is common in health care. The results of the study show that, in that context, interactive process mining constitutes a more suitable approach than traditional process discovery techniques.

The aforementioned articles illustrate that, besides discovery as the dominant use case, innovative process mining methods are also needed regarding conformance and enhancement. These articles show that requirements to conduct such tasks in a health care context are still missing or in need of improvement (e.g. clarity of rules and data quality). In this way, the special issue contributes to tackle the challenge ‘Deal with reality’ highlighted in Munoz-Gama et al. [9], which is key to success when conducting conformance and enhancement tasks in health care environments.

7. The search for explainability

End-users value process mining as a means to understand what is going on in their process execution data. While other techniques in data science are often considered *black boxes* (i.e., an input is introduced, and an output with the suggested next step is produced as output, without understanding the reason for this suggestion), process mining techniques are considered *white box* (i.e., the final goal is not to produce an output, but the help to understand process data, in order to take a better decision). The special issue includes two studies that explore process mining as a mechanism to explain the data.

Fontenla-Seco et al. [16] explore a recent research trend: the combination of process mining with Natural Language Processing. This is a promising research line in interdisciplinary domains, such as health care, where domain experts are more familiar with textual descriptions than other process modeling graphical notations. The article presents a novel framework for the automatic generation of natural language descriptions of health care processes, combining quantitative and qualitative data, and medical domain knowledge. The study shows promising results in terms of the understandability, usefulness and impact of the natural language descriptions on the medical experts’ work.

Leonardi et al. [17] explore a different problem: the classification of process traces. Trace classification can be used to check or predict if an

execution will fulfill some expected criteria (e.g.: it gets completed in less than a certain time). This information is useful both for a better planning of resources and to identify non-complying cases. As an alternative to more black-box input-output alternatives, this work proposes a novel concept – *trace saliency maps* – as a way of providing an explanation for the output, making it easier to interpret for medical users.

Despite their different focus, both aforementioned papers attribute attention to the interpretability of process mining outcomes by medical experts. As process mining aims to support the improvement of health care processes, it is key that medical experts can understand and interpret the outcomes. Consequently, research focusing on the understandability of process mining outcomes is a promising research avenue, as demonstrated by these articles.

8. Summary

The papers collected in this special issue cover a wide range of topics on process mining in health care. Besides papers which aim to structure the research field, various innovative methods are presented with the ambition of providing rich data-driven insights in health care processes. The variety of topics illustrates the broad applicability of process mining and its associated (research) challenges. Besides the variety in topics, the contributions to the special issue also exhibit a diversity in terms of the country of origin (from South-Korea and Australia, over Italy, Spain and Belgium, to the United States), the health care department considered (such as cardiology and radiology) and the health care organizations considered (such as children’s hospitals and university hospitals). This illustrates the general attention for process mining in health care across continents and care contexts. While many open challenges remain and new challenges have been identified in the accepted papers, this special issue will move the state-of-the-art in this promising research domain forward.

This special issue provides an update of the process mining in health care state-of-the-art [8], as well as challenges that researchers in this area should tackle to move the field forward [9]. Papers on new methodologies [10,11] show the adaptation of classic process mining methodologies to the health care context, and also the need of more methodologies to enable process mining projects for novel use cases. [12] details how to assess the feasibility of standardizing a clinical pathway, and [13] depict a novel method to find the most common pathways through graphs. Capacity management has also been addressed in this special issue, supporting decision-making on resources’ requirements of future [5] and present [14] health care departments. Similarly, studies beyond discovery make visible the challenges that emerge when dealing with reality, such as the lack of rules’ clarity [4] and data quality issues that can be addressed involving domain experts [15]. Finally, all these contributions will provide actionable insights if domain experts understand them. To tackle this issue, [16] provides a framework to communicate results using natural language and [17] designed an explainable process trace classification algorithm to help doctors understand the results. Researchers can consider all these contributions as input for their projects, which all together expose the directions that innovative methods for process mining are promising to health care.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Problem or Issue

Process mining is a discipline that bridges the gap between traditional process analysis and data-centric analysis. This discipline has gained popularity to analyze organizational and clinical health care processes. However, there is still a need for expanding the research in the field.

What is Already Known

The current world's most valuable resource is data. The biomedical and health domains can benefit from extracting valuable knowledge and insights from existing data. Regarding the execution of clinical processes, more and more data are being captured in the form of event data, which constitutes a key source of information to analyze and improve clinical processes.

What this Paper Adds

In this “Innovative Informatic methods for process mining in healthcare” editorial, we summarize twelve articles included in the special issue with the same name. These articles show a broad update on the state-of-the-art, challenges to be tackled, novel methodologies, requirements solved with techniques beyond classic process mining tasks and methods to provide easy-to-understand insights to doctors. These contributions are provided to researchers and practitioners interested in process mining applications for healthcare.

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