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DEVELOPMENT OF PRACTICAL GUIDELINES FOR HEALTHCARE PROCESS MINING

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Abstract. *Process mining techniques have been widely adopted in many areas such as manufacturing, logistics, and financial services. Although existing application cases of healthcare process mining have been published, practical and detailed guidelines for applying the process mining techniques in healthcare sector are needed due to the characteristics of complex healthcare processes. This paper presents practical guidelines for healthcare process mining, which include an overall architecture, general framework, and detailed procedures and principles for healthcare process mining approach. We have successfully applied the proposed guidelines to several cases in the healthcare sector. The guidelines proposed in this paper are expected to contribute to healthcare process improvement and optimization.*
Keywords: Healthcare process, Process mining, Process analysis, Guideline development

1. **Introduction.** Healthcare processes are perceived as complex and variable according to the characteristics of a patient. Therefore, it is hard to apply traditional BPM (Business Process Management) technologies to the healthcare sector [2,10]. In order to manage healthcare processes properly, unique characteristics of healthcare processes such as complexity, variability, long-running property, and dependency on the current status of a patient should be considered appropriately [1,6]. BPM systems can design, execute, and control healthcare processes in hospitals. However, physicians tend to rely on their own decision makings according to treatment situations rather than following pre-defined procedures [2,3]. Therefore, healthcare processes discovered from HIS (Hospital Information System) event logs are typically spaghetti-type processes. And this necessitates a careful analysis approach while applying well-known process analysis techniques such as process mining.

In this paper, we propose guidelines for applying process mining techniques to healthcare processes in consideration of such characteristics. Although there have been many attempts to apply process mining techniques to healthcare sectors [8], lots of hospitals still struggle to understand process mining concepts and apply process mining tools to analyzing and optimizing clinical processes. In this regard, we develop practical and comprehensive guidelines including an overall architecture, general framework, and detailed procedures and principles for healthcare process mining approach. By applying the proposed guidelines to healthcare process mining cases with the help of health professionals such as physicians and nurses, valuable insights can be suggested to hospital managers. The proposed guidelines enable healthcare institutes to improve and optimize their processes and acquire competitive advantages.

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The remainder of this paper is organized as follows. Section 2 reviews related work and Section 3 presents the overall architecture, general framework of healthcare process mining, and detailed principles for each phase of healthcare process mining. Finally, Section 4 offers conclusions.

2. **Related Work.** In order to provide high-quality medical services, hospitals should analyze and optimize business processes in hospitals continuously. Process mining extracts valuable information from the real event logs of hospital information systems in a process-centric way [3,9]. Three types of process mining – discovery, conformance, and enhancement – enable hospital managers and business analysts to understand and improve healthcare processes.

Process mining has been used in healthcare domains to discover process models from the event logs, to check conformance between the process model and the real log, and to enhance clinical processes. Rojas et al. reviewed various application case studies in the healthcare domain [8]. They provided a useful overview of the healthcare process mining researches. Yoo et al. presented a case study of applying process mining to outpatient care processes in a Korean tertiary hospital [11]. In their work, various process mining techniques such as frequency analysis, performance analysis, pattern analysis, social network analysis, and process discovery were utilized to understand and improve healthcare processes. Rebuge and Ferreira conducted process mining analysis in a hospital emergency room [7]. They introduced a methodology for the application of process mining techniques that leads to the identification of regular behavior, process variants, and exceptional medical cases. Mans et al. introduced a case study in a Dutch hospital [5]. They applied process mining techniques to obtaining meaningful knowledge about "careflows", e.g., to discover typical clinical paths followed by particular groups of patients.

Although there are a variety of existing researches on process mining applications in the healthcare sector, many hospitals are not aware of the potential capabilities of process mining for healthcare process optimization. Therefore, we developed detailed guidelines for utilizing process mining methods in hospitals, which is required in order to analyze and optimize complex and flexible healthcare processes.

3. **Overall Architecture and General Framework.** This section presents an overall architecture and general framework of healthcare process mining. In addition, detailed procedures and principles of healthcare process mining are proposed for the application of process mining to clinical process analysis.

3.1. **Conceptual architecture of healthcare process mining.** Figure 1 shows an overall architecture which illustrates basic concepts and schematic composition of healthcare process mining. Essentially, this figure is based on the typical concept of process mining and extended from the representative figure in [9]. Generally, every treatment activity performed by health professionals or medical resources is recorded as an event in the event logs by a variety of clinical HISs. For example, EMR (Electronic Medical Record) systems are used to manage patients' medical records electronically. CPOE (Computerized Physician Order Entry) systems are used for doctors to enter and transfer their orders electronically, and PACSs (Picture Archiving and Communication Systems) are used to acquire and manage various medical images electronically. Also, HISs for non-clinical work such as ERP (Enterprise Resource Planning), CRM (Customer Relationship Management), SCM (Supply Chain Management), and DW (Data Warehouse) record administrative or managerial events.

A discovery technique takes an event log and generates a process model without using any prior information. For example, the famous α-algorithm takes an event log and creates a Petri net. A variety of process models of clinical or non-clinical work can be discovered from the event logs, which reveal how the actual healthcare processes are performed in

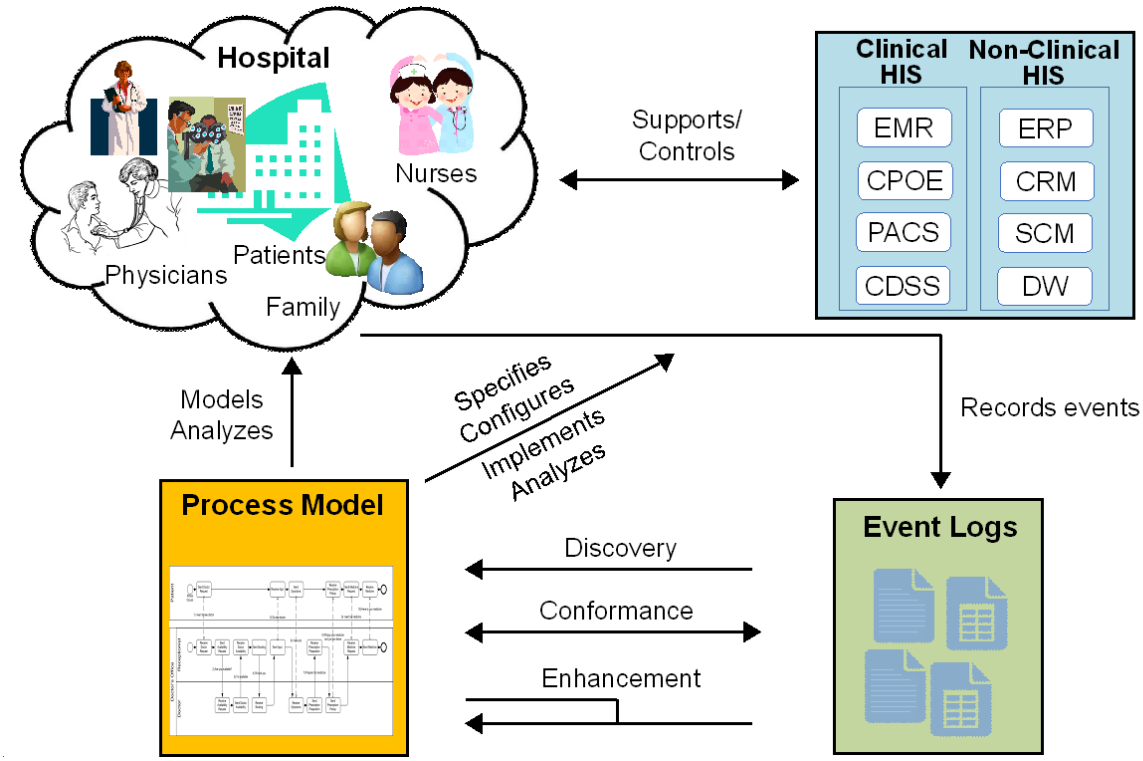

FIGURE 1. Conceptual architecture of healthcare process mining [3,9]

hospitals. Advanced process discovery techniques such as fuzzy mining, genetic mining, and heuristic mining can be applied to process discovery.

The second type of process mining is conformance checking. Conformance refers to the compliance between the discovered process model and the standard process model [9]. We can compare the existing process model and the event log of the same process. By conformance checking, it is possible to check if reality, as recorded in the log, conforms to the model and vice versa. Conformance checking can be used to detect, locate and explain deviations, and to measure the severity of these deviations.

The third type is enhancement. Enhancement represents an improvement or extension of process models using the information from the analysis results [9]. The idea here is to extend or refine an existing process model using information about the actual process recorded in the event log. One type of enhancement is repairs. It is to modify the model to better reflect reality. For example, if two activities are modeled sequentially but can actually occur in any order, we can modify the model to reflect this. Another type of enhancement is to add new perspectives to the process model by cross-correlating the log to the process model. An example is the extension of a process model with performance data.

3.2. **General framework of healthcare process mining.** This section presents the general framework for healthcare process mining. Figure 2 shows four phases in the healthcare process mining framework such as problem definition, data preparation, analysis, and conclusions. The first phase is to identify and define business problems such as inefficient operations, complaints about waiting time, and the need to demonstrate compliance. After the problems are identified, the data requirements are determined accordingly. The first phase is very important, because it affects all of the following phases.

The second phase is the data preparation phase. In this phase, the required data is extracted from the HIS log data. Data preprocessing is required due to data quality issues such as missed attributes, incorrect attributes, and imprecise attributes. Then, the extracted data should be converted to the appropriate data format such as MXML

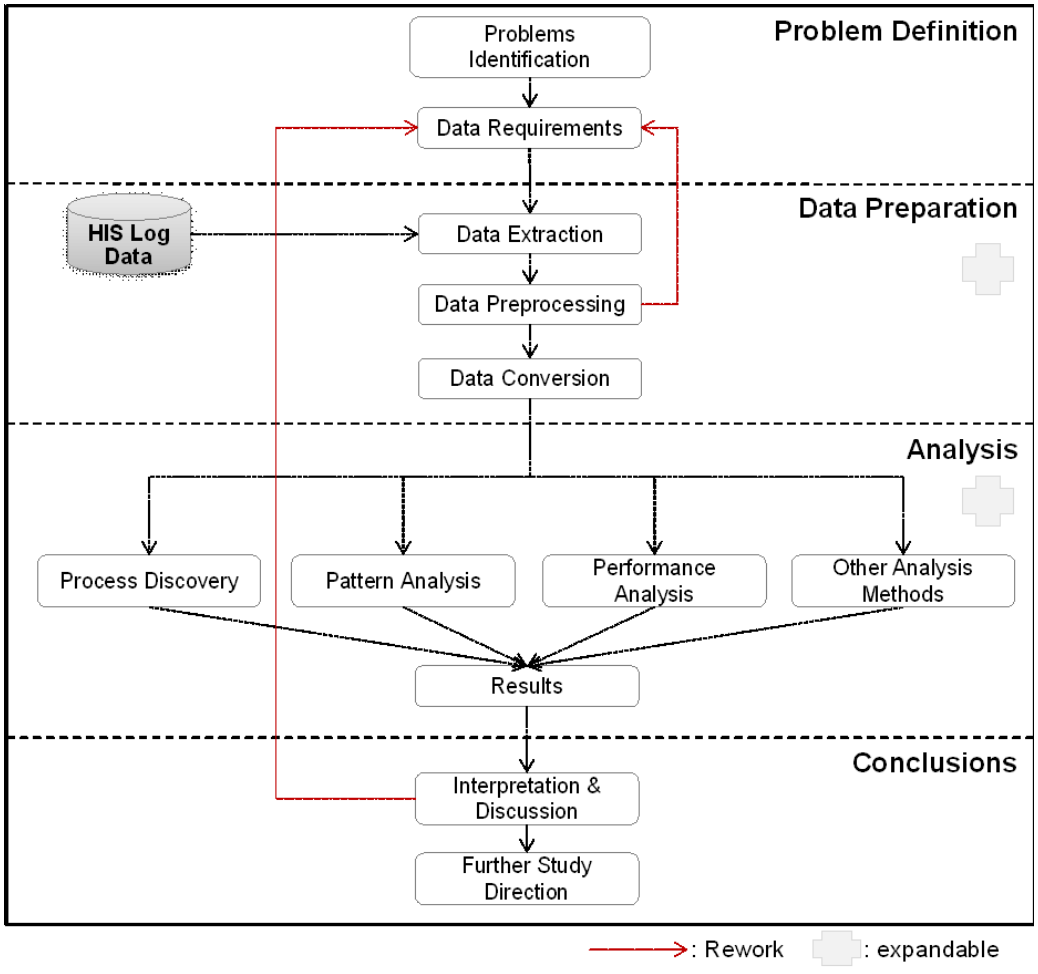

FIGURE 2. General framework of healthcare process mining

(Mining eXtensible Markup Language) or XES (eXtensible Event Stream), which are supported by the process mining tools.

The third phase is the process analysis phase. In this phase, a variety of analytical techniques are applied to preparing healthcare data, such as process discovery, pattern analysis, and performance analysis. Available process mining tools can be used for process analysis [9]. ProM is the most widely used open source process mining tool that includes many useful plug-in modules. ProM has an extensible architecture and plug-ins are the basic mechanism of ProM. Also, there are lots of available commercial software tools such as Disco, Celonis Process Mining, MyInvenio, and Minit. Using these tools, we can acquire process analysis results.

The final phase is conclusions. In this phase, the results are interpreted and effective insights on the analyzed process are suggested to hospital managers. Consultations with domain experts such as physicians, nurses, and other health professionals are required to properly interpret the results and acquire relevant insights. In this step, we can create reports using proper visualization methods such as infographics. If additional analysis is required or new issues are identified in this phase, then it goes back to the data requirements step.

3.3. **Principles for each phase of healthcare process mining.** Table 1 shows important principles and guidelines when conducting healthcare process mining projects.

4. **Conclusions.** In this paper, we proposed practical guidelines for healthcare process mining, which includes an overall architecture, general framework, and detailed procedures

Table 1. Principles of healthcare process mining

Phase	Step	Description of principles
Problem definition	Problem definition	1) Define problems clearly and establish specific analysis goals accordingly. Refer to the following examples. • Why do patients have to wait so long? • Can we analyze and predict waiting times? • How many staffs do we need next week? • Do doctors follow the CPGs (Clinical Practice Guidelines)? • How are expensive medical devices actually used? • How can we reduce costs? • Can we demonstrate compliance? 2) Determine the process scope and information system consequently, based on the defined problems.
	Data requirement collection	3) Gather data requirements as detailed as possible, based on the defined problems. 4) Obtain an approval or exemption from the Institutional Review Board (IRB), since the extracted data may contain sensitive personal medical information.
Data preparation	Data extraction	5) Prepare a data definition document that describes attribute name, data type in the event log, and additional information about the attributes obtained through collaboration with health professionals. 6) Request IT staffs such as database administrators to extract history logs from the HISs according to the data definition document.
	Data preprocessing	7) Perform data preprocessing in order to correct data errors such as missed attribute, incorrect attribute, and imprecise attribute.
	Data conversion	8) Convert the extracted data to a proper data format such as MXML or XES.
Process analysis	Process discovery	9) Apply proper process mining techniques or tools considering the following types of the process analysis [9]. • Type 1: ad-hoc questions requiring data exploration or extraction and problem-driven selection of analysis techniques • Type 2: repeated questions in a known setting but possibly still requiring configuration • Type 3: standard questions in a fixed pre-configured setting
	Pattern analysis	10) Discover frequent process patterns by applying advanced process mining algorithms such as fuzzy mining. 11) Discover daily, weekly and seasonal patterns that can be learned from event data to provide operational support.
	Performance analysis	12) Apply various performance analysis methods in the perspectives of time, organization, and case. 13) Utilize simple but powerful analysis tools such as dotted chart to explore the event data from different angles.
Conclusion	Interpretation and discussion	14) Apply visualization and reporting tools that provide a means to create reports composed of charts, tables, and models. 15) If the applied tool supports data-driven process animations, prepare animations for productive discussions with hospital managers.
	Further study and direction	16) If a further study is required or new issues are identified, then repeat the analysis steps from the data requirements step.

and principles for healthcare process mining approach. The architecture and explanations on it enable easy understanding of process mining approach in the healthcare domain. The proposed framework and detailed principles composed of four phases can be applied to a variety of healthcare process analysis and improvement efforts. We have applied the proposed guidelines to several cases and suggested meaningful insights to hospital managers with the help of domain experts such as physicians and nurses. The proposed guidelines are expected to contribute to healthcare organizations' process improvement and optimization.

In the future, it is required to develop customized detail guidelines for applying process mining to a variety of healthcare services considering the size and specialty of hospitals.

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