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Predicting treatment process steps from events

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ABSTRACT

Motivation: The primary economy-driven documentation of patient-specific information in clinical information systems leads to drawbacks in the use of these systems in daily clinical routine. Missing meta-data regarding underlying clinical workflows within the stored information is crucial for intelligent support systems. Unfortunately, there is still a lack of primary clinical needs-driven electronic patient documentation. Hence, physicians and surgeons must search hundreds of documents to find necessary patient data rather than accessing relevant information directly from the current process step. In this work, a completely new approach has been developed to enrich the existing information in clinical information systems with additional meta-data, such as the actual treatment phase from which the information entity originates.
Methods: Stochastic models based on Hidden Markov Models (HMMs) are used to create a mathematical representation of the underlying clinical workflow. These models are created from real-world anonymized patient data and are tailored to therapy processes for patients with head and neck cancer. Additionally, two methodologies to extend the models to improve the workflow recognition rates are presented in this work.
Results: A leave-one-out cross validation study was performed and achieved promising recognition rates of up to 90% with a standard deviation of 6.4%.
Conclusions: The method presented in this paper demonstrates the feasibility of predicting clinical workflow steps from patient-specific information as the basis for clinical workflow support, as well as for the analysis and improvement of clinical pathways.

1. Introduction

1.1. Motivation

The substantial amount of patient-specific information in clinical information systems helps physicians and surgeons obtain increasingly comprehensive overviews of patients. This information is available but is insufficiently structured and poorly searchable, particularly in the large Hospital Information System (HISs) such as SAP i.s.h.med. There are several reasons for the poor structuring of this information, but it is mainly due to the primary economy-driven documentation goals of hospitals. Mature IT solutions are still lacking for a primary focus on treatment decision making, for hierarchically organizing patient-specific results, and for summarizing the results of relevant pretreatment investigations. This situation leads to inefficient processes in daily clinical routine and to considerable time spent searching documents that are relevant in the current treatment phase. Unfortunately, physicians do not have the ability to simply and quickly obtain the most relevant documents for the specific therapy phase. Furthermore, scientific questions such as "Show me all of the clinical documents that are generated during surgical interventions for patients with laryngeal carcinoma" cannot readily be answered using the currently available clinical information systems.

To improve clinical workflows, to relieve physicians and surgeons from time-consuming activities, to improve patient safety and to reduce costs, developing user-friendly and intuitive capabilities for searching and accessing clinical data is of critical importance. A fundamental prerequisite is knowledge of treatment processes in general, as well as specific knowledge regarding the current treatment phase of the patient. Knowledge of the overall treatment process can be acquired through a workflow analysis in the specific clinical disciplines or departments. Statistical models such as Hidden Markov Models (HMMs) are good methods for subsequently transferring the workflow analysis results into a mathematical representation that can subsequently be used to

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infer workflow phases from given patient-specific information that originates from clinical information systems, i.e., the so-called observations [1].

In this work, a completely new approach for automatically inferring the current step of a clinical patient treatment process from clinical data is presented. First, patient-specific information from different clinical information systems is used as training data for creating a probabilistic model of the underlying treatment process. Subsequently, patient-specific information that was not a part of the training process can be provided to the model for predicting the most likely treatment step. Finally, each patient-specific information entity, such as disease codes, procedure codes or laboratory results, contains additional meta-information regarding the originating process step. This meta-information is very valuable for the development of sophisticated workflow assistance or clinical decision support systems.

Additionally, a mathematical representation of clinical workflows provides an important basis for a wide variety of analyses. The model can identify both the most likely course of treatment as well as outliers for patients with complex cases. Subsequently, this information provides the basis for improving clinical pathways or for serving as a metric for clinical quality management.

1.2. Goals of this work

The primary objective of this work is to develop a new method for predicting single phases of the oncological treatment process based on patient-specific information entities originating from clinical information systems. The first step is to develop a probabilistic model based on HMM that is able to represent clinical workflows in different granularity levels. This model should then be able to predict the current treatment phase for a set of unknown clinical patient-specific information entities. We developed two types of HMM models with 3 and 7 therapy phases and with additional exception-handling approaches to address different types of variations in clinical workflows. The exception-handling approaches consider both the hierarchical properties of International Statistical Classification of Diseases and Related Health Problems (ICD10) and International Classification of Procedures in Medicine (ICPM) codes, as well as others, to improve the HMM prediction rates. These models are then trained with anonymized real-world clinical datasets from patients with primary head and neck tumor diagnoses. Finally, two types of HMM models are evaluated in terms of their recognition rates and the results of their exception-handling algorithms.

2. Background

2.1. Clinical context

A stochastic model for workflows can only be realized with thorough knowledge of their underlying processes. Thus, the clinical workflow that provides the basis for this work is briefly described in this section and is illustrated in Fig. 1.

The Ear, Nose & Throat (ENT) clinic at the Leipzig University Medical Center is an independent clinic that consists of ambulance, ward, phoniatry and operating rooms. Generally, 250 patients with a primary tumor diagnosis in the head and neck area are treated annually with full in-house services for cancer therapy, from pre-op consultation to post-op evaluation, check-up and therapy.

The clinical workflow for patients with head and neck cancer is divided into three major phases with a minimum duration of at least 5 years. The therapy begins with a clinical diagnostics phase, during which important patient-specific information is acquired. A first consultation is performed to document the medical status of

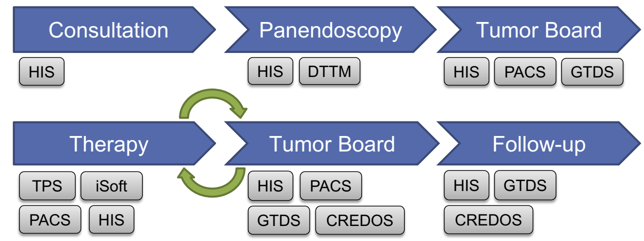

Fig. 1. Treatment process in oncological ENT surgery with clinical information systems. The leading information system is the HIS. The supporting systems during therapy are PACS, DTTM, iSoft laboratory documentation and the Treatment Planning System (TPS) for radiation therapy. Cancer Retrieval Evaluation and DOcumentation System (CREDOS) and Giessener Tumordokumentationssystem (GTDS) support the tumor documentation.

the patient and to clarify the actual disorders. The consultation consists of an anamnesis, in which the physician investigates the patients current medical condition, allergies, comedication, previous interventions and lifestyle, as well as a clinical examination of the patient's ears, nose, oropharynx and larynx. During the diagnostics phase, morphological and functional medical imagings are performed, such as Computer Tomography (CT), Magnetic Resonance Imaging (MRI) or Positron Emission Tomography (PET) in combination with CT or MRI (PET/CT or PET/MRI). The results are recorded in the local Picture Archiving and Communication System (PACS). When a tumor is suspected, the patient receives a panendoscopy, which is an examination performed under full anesthesia that provides a better contouring of the tumor extension. During the panendoscopy, biopsy samples of potential tumor tissues are collected and immediately sent to the pathology department for a histopathological examination. Subsequently, the biopsy locations and clinical TNM Classification of Malignant Tumors (TNM) classifications are recorded in the Dornheim Tumor Therapy Manager (DTTM) [2]. In the case of positive histopathological findings, the local head and neck tumor board[2] decides on the most appropriate therapy for the patient based on all previously acquired information.

The following therapy phase consists of either surgical interventions, adjuvant and neoadjuvant radiotherapy or chemotherapy, or a combination of these steps, to improve the therapy outcome. In a post-therapeutic tumor board, the achieved therapy outcomes are discussed, and the patient either receives further therapies or is released into follow-up. During this last phase of the tumor treatment process, the patient attends regular follow-up consultations to ensure that recurring tumors are quickly identified.

2.2. Scientific background

Knowledge of workflow information from surgical interventions and from perioperative processes is important for the development of intelligent clinical workflow assistance systems. Therefore, statistical models such as HMMs [1] are appropriate for the recognition of workflow steps and are commonly used in the medical field.

The course of a surgical intervention can be represented as a sequence of 5-tuples, the individual Surgical Process Model (iSPM), which contain process step information such as activity, actor, surgical instrument, target structure and time [3]. Subsequently,

[2] The head and neck tumor board is an institution in which physicians from different medical disciplines, such as ENT and maxillofacial surgery, radiation therapy, radiology, nuclear medicine, oncology and pathology, meet to discuss patient cases and different therapy approaches.