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Interactive Information Visualization to Explore and Query Electronic Health Records

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Abstract

Physicians are confronted with increasingly complex patient histories based on which they must make life-critical treatment decisions. At the same time, clinical researchers are eager to study the growing databases of patient histories to detect unknown patterns, ensure quality control, and discover surprising outcomes. Designers of Electronic Health Record systems (EHRs) have great potential to apply innovative visual methods to support clinical decision-making and research. This work surveys the state-of-the-art of information visualization systems for exploring and querying EHRs, as described in the scientific literature.

We examine how systems differ in their features and highlight how these differences are related to their design and the medical scenarios they tackle. The systems are compared on a set of criteria: (1) data types covered, (2) multivariate analysis support, (3) number of patient records used (one or multiple), and (4) user intents addressed. Based on our survey and evidence gained from evaluation studies, we believe that effective information visualization can facilitate analysis of EHRs for patient treatment and clinical research. Thus, we encourage the information visualization community to study the application of their systems in health care. Our monograph is written for both scientific researchers and designers of future user interfaces for EHRs. We hope it will help them understand this vital domain and appreciate the features and virtues of existing systems, so they can create still more advanced systems. We identify potential future research topics in interactive support for data abstraction, in systems for intermittent users, such as patients, and in more detailed evaluations.

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1

Introduction

Medical decision-making is a complex process. A patient's well-being depends on correct diagnosis and appropriate treatment. Physicians must incorporate large amounts of information such as a patient's status, symptoms, medical history, past and ongoing treatments, which are encompassed in the electronic health record (EHR). In addition, these records are an invaluable data source for clinical research and improvement of clinical quality, as they provide longitudinal health information about patient populations [49, 131, 138].

In recent years, many health care institutions have introduced EHR systems to replace their paper-based health records. However, current clinical information systems have focused on faster and cheaper management, storage, and sharing of EHRs. Unfortunately, EHR systems have been shown to have little positive effects on the quality of care, and in some cases have decreased quality [66]. A 2009 report by a committee of the National Research Council of the National Academies found that care providers spend considerable time entering data into EHRs for billing and legal purposes, but that this data rarely improves the quality of care, largely because EHR systems fail to provide cognitive support to healthcare providers, patients, and families [134].

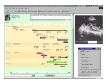
Information visualization has the potential to address those issues and deliver much-needed cognitive support. Indeed, a 2012 report of the US Institute of Medicine [72], which focuses on improving patient safety, recommends "cross-disciplinary research" on "user-centered design and human factors applied to health IT." The report also notes that "Information visualization is not as advanced in parts of clinical medicine as compared with other scientific disciplines."

In the scientific literature, several information visualization techniques have been proposed that encourage users to explore EHR data visually, gain insights, and form hypotheses. Those systems have demonstrated some level of success, but it is difficult to get an overview and compare them. In this work we report on an extensive literature survey of visualization and interaction techniques applied to EHRs. We review and compare state-of-the-art research systems and examine their support for medical care, clinical research, and quality control. The focus is on information visualization techniques as opposed to medical imaging techniques. It also excludes techniques aiming to support the management of administrative or financial data.
This work presents:

(1) A survey of state-of-the-art information visualization systems from academic literature.
(2) A review of the visualization and interaction techniques found in 14 of these systems (Table 1.1) including strengths and weaknesses. These systems are categorized by the tasks and data (type, complexity, and scale) they support. Furthermore, there are compact descriptions of 32 additional EHR visualization systems.
(3) A summary of evaluation studies conducted in medical context.
(4) An overview of data visualization in commercial EHR systems.
(5) Recommendations and future research directions for information visualization in EHR systems.

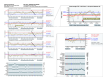
Our analysis of single patient and multiple patient systems is written for both scientific researchers and designers of future user interfaces

Table 1.1. Overview of the 14 systems reviewed in detail.

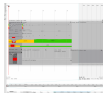


LifeLines (see Figure 4.1)
University of Maryland [110]

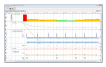
MIVA (see Figure 4.3)
Indiana University [56]



WBIVS (see Figure 4.4)
University of Minnesota [107]



Midgaard (see Figure 4.5)
Otto-von-Guericke University of Magdeburg [32]



VisuExplore (see Figure 4.7)
Vienna University of Technology [123]

VIE-VISU (see Figure 4.9)
University of Vienna [69]

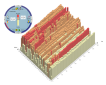
Lifelines2 (see Figure 4.12)
University of Maryland [147, 148]

Similan (see Figure 4.13)
University of Maryland [155]

PatternFinder (see Figure 4.16)
University of Maryland [53]

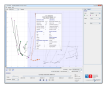
VISITORS (see Figure 4.18)
Ben-Gurion University of the Negev [80, 81]

Caregiver (see Figure 4.21)
Fachhochschule Nordwestschweiz [36]



IPBC (see Figure 4.22)
University of Udine [45]

Gravi++ (see Figure 4.24)
Vienna University of Technology [67]



TimeRider (see Figure 4.25)
Danube University Krems [122]

for EHR data analysis. These interface designers face a substantial challenge in understanding medical care, clinical research, and quality control sufficiently well to create effective interfaces. If these designers appreciate the features and virtues of existing systems, they will be more capable in creating still more advanced systems.

We first provide background information on information visualization in the medical domain, highlight its significance, and compare this survey to existing work. The *Methods* section presents our approach to searching relevant literature and our review criteria. The *Results* section presents 14 information visualization systems and briefly describes related systems. The *Discussion* section evaluates the 14 systems using our review criteria, reports on evaluation studies, gives an overview of commercial systems, explains limitations, and provides recommendations for future work.

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