Visual-Interactive Exploration of Pathogen Outbreaks in Hospitals

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Abstract

Clinicians and hygienists need to identify outbreaks and transmission patterns of pathogen infections among hospital patients. Such analysis requires the combination of the microbiological laboratory results with the location and contacts among patients. Currently, this is a cumbersome manual and time-consuming task that includes reading multiple textual reports. We present a visual-interactive interface that offers a set of linked visualizations for the identification of outbreaks and patient contacts. The evaluation of our interface with clinicians and hygienists has shown a high applicability for the task and ease of use.

CCS Concepts

• ***Human-centered computing*** → *Information visualization; Visual analytics;*

1. Introduction

Pathogen outbreaks in hospitals are a threat for the patients health and are costly for the hospital, especially, when the pathogens are multi-drug resistant [GG11]. Clinicians and hygienists (for simplicity 'experts') seek to identify or contain pathogen outbreaks. Thus, they need to detect pathogen clusters as soon as possible and understand pathogen transmission among patients. The experts need to answer the following questions: (Q1) Were more patients infected than usual (and at which ward)? (Q2) Were the patients infected before or after the hospitalization (i.e., "non-nosocomial")? (Q3) What are possible transmission paths among patients? Currently, the experts browse microbiological laboratory results for suspicious records. In case of pathogen clusters, they track down which patients at which hospital locations (wards, rooms) were infected. Subsequently, search for possible contacts with other patients. This analysis is done highly manually, thus is time-expensive and error-prone. The data is split among multiple software systems, which show the information separately as text or table.

Related work exists for the visual analysis of patient treatments and results, contagion and transmission paths, e.g., [MLL*13, BH13, vLDBF15, RWA*13, RFG*17]. However, there is currently no combination of both to assist the experts in their task of outbreak identification. We developed an interactive visual interface in close cooperation with the experts. In our requirement analysis, the five experts asked for easy to use visualizations to support their workflow for answering the questions mentioned above. Our contributions are: The integration of data from multiple primary systems used in the hospitals; A visual-interactive interface combining known visualization techniques for detecting pathogens and infected patients with their contacts; A flexible interface mapping the experts analysis workflow. We present the interface and interactive visualizations with a use case and summarize the evaluation with the expert users hereafter.

2. The Visual Interface & Use Case

Our visual interactive interface (cf. Figure 1) shows the number of infected patients (*epidemic curves*) for multiple pathogens and for the different hospitals' wards. Furthermore, it shows when patients were diagnosed as infected as well as the contacts between patients (i.e., possible pathogen transmission paths). Therefore, we include in the visualized data the patients' position (wards, rooms) in the hospital at each time and their laboratory results (positive/negative pathogen tests). The integrated and pre-processed data is stored in an SQL-database. The visual interface is accessed via a recent webbrowser and implemented with React [Rea], D3 [BOH11], and Node.js [Nod]. We describe the interface's features with a typical workflow of an hospital's hygienist (cf. supplemental video):

(1) Load the data for one hospital. The hospitals which provide anonymized data are displayed on a geographic map. The hygienist interactively chooses the hospital of his interest for the analysis.

(2) Gain an overview of the detected pathogens. The hygienist opens the view that shows the *epidemic curves* for the five most relevant pathogens. For each pathogen, a bar chart shows the number of infected patients within the time frame of interest (two weeks). The expert may chose to see only patients with new pathogen evidence or all evidences so far (i.e., "copy-strained"). Summary statistics (e.g., the sum and median value) are displayed in a tooltip. The exemplary *epidemic niveau* indicates the number of 'normal'

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Figure 1: *The interactive visual interface. Affiliated hospitals are shown in a map view (1). For a selected hospital, the epidemic curves for the most relevant pathogens are shown at the top (2). For a selected pathogen, epidemic curves are also shown per ward (3). Infected stations of a ward are shown with the duration of infection (4) and with other they had contact with (5).*

infections (Q1) and is often chosen based on the experts' experience. If the number of infected patients was above the epidemic niveau on at least one day, the corresponding epidemic curve turns red to raise the hygienist's attention.

(3) Inspect the distribution of infected patients among the wards. For one selected pathogen with a high occurrence of infections (st.epi), the hygienist inspects the epidemic curve per ward. It can be seen that the pathogen has been evidenced at multiple hospital wards whereas for one of the wards (EFGH), the number of infected patients was particularly high on several recent days (Q1).

(4) Identify possible nosocomial infections. For the analysis of an outbreak, it is crucial whether the patients were infected within the hospital (i.e., "nosocomial") or were infected before the admission to the hospital (Q2). For this reason a stacked bar chart shows the infected patients at a hospital ward in a given timespan. Each bar represents one patient and the total length of the bar shows the duration of the hospitalization. The bars' colors indicate the infection status with blue for no proof of pathogen and orange for a proven infection. The later a pathogen is evident after the admission to the hospital, the likelier it is a nosocomial infection.

(5) Examine the contact network of suspicious patients. For a patient with a probably nosocomial infection (P833), the hygienist examines the patient's contact network. It contains the patients as vertices and their contacts as edges. The edge width represents the duration of the contact. The vertices' background color represents the infection status (blue for no proof and orange for a proven infection, as in (4)). When and where the patients were in contact is displayed in a tooltip. Then, the hygienist may, e.g., isolate the infected patient from patients that were not infected yet, or arrange examinations for the patients that had contact after the infection to check for pathogen transmissions (Q3).

3. Evaluation & Further Work

We evaluated our visual interface with 13 experts working in the area of infection control (including the experts of our requirement analysis). They were presented the interactive interface and asked for their opinion on the functionality, comprehensibility, usefulness, and desired extensions. The visualizations were rated as highly understandable and useful (mode 4 and 5 respectively on a five point Likert scale based on SUS [B*96]). Especially the visualizations of step (4) and (5) were new to the experts but highly appreciated ("find this view extremely good", "this view is very clear"). Furthermore, it showed that the interactive visual interface design fits to the analysis workflow. One expert explicitly commented that "all steps are performed in such way". Some experts commented on domain-specific characteristics such as the value of the displayed epidemic niveau. However, this is caused by the problem of competing definitions in the experts' field.

The experts wished to extend the interactive visual interface in future: wards should be included visually in the contact network and the laboratory results should be differentiable depending on the examined material. Based on the experts' feedback, the epidemic curve will be extended by one epidemic niveau per pathogen. Furthermore, we will work on the challenge of scalability for a larger timespan and more patients per ward.

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