A visual approach for analyzing readmissions in intensive care medicine

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Abstract

Intensive care units (ICUs) are under constant pressure to balance capacity. ICUs have a limited number of resources and therefore effective monitoring of planned and unplanned transfers is crucial. Transfers can result in critical readmissions, i.e. "down" transfers from ICUs to a normal ward or an intermediate care unit (IMC) and back "up" to an ICU within a short time span. In this work, we present a tool to visually analyze such readmissions. Patient transfer data is extracted from a clinical data warehouse via HL7-FHIR. The interactive prototype consists of a timeline of readmission cases, an aggregated view of transfer flows between wards, and histograms and calender heatmaps to show a set of key performance indicators. The aim of our tool is to support identifying peaks, discovering temporal patterns, comparing wards, and investigating potential causes. We report on our user centered approach, describe the data pipeline, present the visualization and interaction techniques of the functional prototype, and discuss initial feedback.

Keywords: patient transfers, intensive care units, temporal sequence visualization, flow visualization

1 Introduction

The performance of intensive care units (ICU) is an indispensable criterion for indicating high quality care in hospitals. Transfers between different ICUs, between ICUs and intermediate care units (IMCs) as well as between ICUs and normal wards are common occurrences in the clinical routine. Transfers from the ICU "down" to an IMC or normal ward, followed by a rapid readmission back "up" to an ICU is a potential quality issue [2, 4]: the patient may not have been ready for transfer to a non-ICU ward in the first place. Such ICU readmissions should be monitored as they cause additional unplanned work for the involved care teams, and may result in longer hospital stays, higher mortality and higher costs [3].

Information visualization is being widely used to analyze health care data. In recent years, understanding how patients flow through the health care system has been recognized as beneficial [1]. In their survey on electronic health record (EHR) visualizations, Rind et al. distinguish between systems for single patients and for collections of patient records [6]. For understanding the full spectrum of ICU readmissions, and identifying common readmission causes, analyzing collections of patient records is necessary. The two works most related to ours both visualize time-oriented data of multiple patient records. EventFlow [5] can be used to visualize patient flows but does so in a tree diagram view. In contrast, Outflow [7] visualizes disease progression paths as a graph resulting in converging flows.

While EventFlow is a general tool and provides powerful query and filter mechanisms, our prototype is specifically aimed to support analyzing readmissions. From Outflow we adopted the graph view in order to also show patient transfers back into the same wards. Lastly, our system aims to support characteristics of critical readmissions beyond their temporal aspects.

2 Motivation

Initiated by an internal inquiry at the University Hospital Mannheim (UMM) on how to support mitigating the aforementioned challenges, we utilized intra-hospital patient transfer data to better understand the causes for ICU readmission. In order to align the target system with the actual needs, we employed a user-centered approach. As part of the exploratory data analysis, we created a set of initial visualizations showing basic information such as ICUs with most outgoing patients. We discussed these with physicians and supervisors of the ICUs in order to understand the challenges they are facing in regard to ICU readmissions. We repeated these user feedback rounds with iteratively more expressive visualizations two times. Through an informal expert interview and workshop, we identified a collection of tasks, and three design goals.

The general objective of the tool is to support investigating ICU readmissions by visualizing patient transfers. The tool aims to support (**T1**) identifying the originating ICUs, (**T2**) discovering peaks and temporal patterns, (**T3**) comparing wards, and (**T4**) investigating potential causes. The design goals are to provide (**D1**) up-to-date intra-hospital transfer data in order to enable analyzing recent cases, (**D2**) querying and filtering mechanisms in order to enable the free exploration of any ICU for any time span, and (**D3**) a multi-view dashboard offering different perspectives into the data in order to support the tasks.

3 Data Preparation

The first essential step for the data preparation is the understanding of the hospital's organizational hierarchy and the identification of relevant ICUs within the administrative data. After we identified four ICUs and relevant IMCs in collaboration with administrative staff and ICU department leads, we could query the respective data sets from the total 30 clinics and institutes.

The prototype is based on a backend using *Fast Healthcare Interoperability Resources* (FHIR). As part of the MIRACUM project[1], data integration centers (DIC) are being developed at all participating university hospitals in Germany. These clinical research data warehouses are aligned by following the implementation of the core datasets (*MII-Kerndatensatz*) using FHIR, OMOP, and i2b2 instances. All use cases defined in the MIRACUM project require the analysis of patient and patient related data (laboratory and other diagnostic results, application of therapies and procedures, but also stays and transfers). We employ the existing data pipelines for our ICU readmissions prototype to meet D1, and to prepare its deployment to other MIRACUM sites in the future.

The UMM DIC was one of the first to migrate patient transfer data from a clinical research database onto a FHIR server. After retrieving the resources via a REST API, we perform further data transformations and analysis (D1). We extract all cases with at least one readmission transfer chain and use admission timestamps of the surrounding ICU and IMC stays for calculating the duration.

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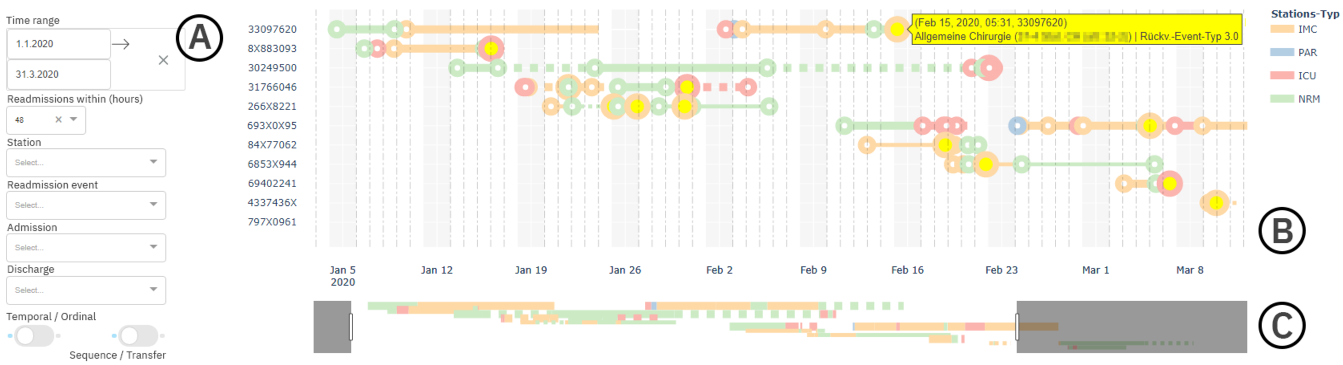

Figure 1: Top part of dashboard with filter section (A), the detailed timeline with readmission cases (B), and an overview timeline (C).

4 Visualization Prototype

The visualization system consists of the following components (D3): A **filter section** (Fig. 1A) to pick date ranges, adjust the duration threshold for readmissions, and select readmission type and station of interest (D2). **Histograms** show frequency of readmission event types and distribution of the stations involved (T1, T3). A **detailed timeline** (Fig. 1B) displays all patient transfer chains for the current time span (T2, T4) selected in the **overview timeline** directly beneath (Fig. 1C). The layout and marks of the detailed timeline are inspired by transit maps and lean on visual elements like circles for stopovers. We opted for using this visual metaphor to ease the legibility of the timeline, to distinguish between admissions and stays. Larger yellow circles highlight the readmission events for quicker visual identification. The timeline can be switched from temporal to ordinal arrangement for better comparison between cases and occurred transfers between wards. In ordinal mode, cases are aligned by the first re-admission event.

A **Sankey diagram** (Fig. 2) visualizes the flow between readmission wards in an aggregated view (T1, T3, T4). Throughout, the ward types are encoded with the same color mapping: green for normal ward (NRM), red for ICU and orange for IMC. Lastly, a **timeseries bar chart** shows numbers of transfers from ICUs per day, both with and without later readmissions (T2, T4). All views can be zoomed and panned, details on demand can be viewed when hovering over elements (see yellow tooltip in Fig. 1). The Sankey diagram enables the user to hover over wards to identify the amount of transfers.

The visualization frontend was developed in Python using the Dash / Plot.ly framework. This enabled rapid prototyping and provided standard functionality such as zooming into the visualizations. In contrast to our goal D1, we used a static extract from the API including further transformations and annotations for rapid development. It will be straight-forward, however, to switch to the real-time data pipeline in the future.

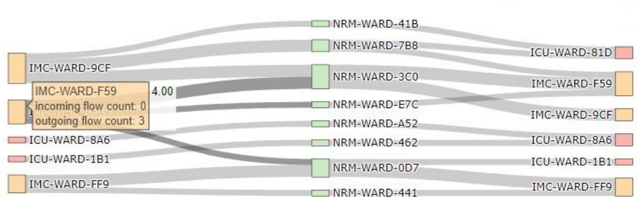

Figure 2: Sankey diagram for Q1 2020 and readmissions in 72 hours.

5 Conclusion and Outlook

In this abstract, we presented our approach to visually analyze critical ICU readmission. For the current prototype, we opted for a wide range of visualization techniques so stakeholders can try them out and understand why specific techniques support their tasks better. We learned that demonstrating early interactive visualizations also helps to find a common language.

First expert feedback at UMM found the timeline-oriented visualization useful for gaining a general overview (e.g. number of cases, type of readmission). The prototype has been found to be helpful in selecting and inspecting extreme cases (readmission $<$ 24 hours) in specified time ranges. The Sankey diagram (Fig. 2) helped to view all involved wards, e.g. to identify ICUs where unusual numbers of "down" transfers originated. As a next step in the user-centered design process, we have planned a larger workshop with users to reduce the dashboard to the most suitable views. Lastly, we are planning to deploy a future iteration of our system to other university hospitals, gather feedback in a more formalized manner, and generalize our findings. Deployment to other hospitals will be facilitated by the FHIR-based approach.

Acknowledgments

This work was funded in part through by the German Federal Ministry of Education and Research through the MIRACUM project (Grant IDs 01ZZ1801I, 01ZZ1801E).

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