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Making the Radiology Workflow Visible in Order to Inform Optimization Strategies

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Abstract. Medical imaging is undergoing rapid change, induced by the increasing amount of image data, and advances in fields such as artificial intelligence. In order for a radiology service provider to respond to these challenges, it needs to adapt its workflow. To inform optimization strategies, the way that processes and resources interact in the real world must be understood. We report on our experiences with an approach that consists of merging a variety of data sources into a data model that allows efficient interactive queries, and then providing highly interactive visualizations to explore the data. Two examples are discussed: animation of patient flow through the radiology workflow, and the use of energy consumption patterns to characterize operational modalities.

Keywords. radiology workflow, process optimization, exploratory visualization

1. Introduction

The radiology workflow is defined by how the various activities that are performed in a radiology department of a hospital and the corresponding actors are orchestrated in order to deliver the desired medical imaging services.

Medical imaging in hospitals is undergoing rapid change. Standard modalities are being commoditized, new modalities are entering the field, and the role of imaging in the treatment path is shifting [1]. New technologies based on artificial intelligence and start-up companies offer services that are changing the landscape [2]. In order for the radiology department to respond to these challenges and to improve productivity, it needs to adapt its workflow and practices [3].

Before investing in reorganizations and new tools however, there must be an understanding of current processes. The way that processes and resources are planned and scheduled in theory does not necessarily correspond to the real world situation. The workflows in use therefore need to be assessed and measured in order to enable decisions that are based on evidence.

Standard approaches try to derive KPIs (e.g. throughput, length of stay) that are displayed in dashboards, or they focus on optimizing specific steps in an individual's work process (e.g. voice recognition for dictation of reports). While these approaches provide valuable insight into specific aspects of the radiology workflow, they are

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typically limited to summaries with low temporal resolution or few dimensions. They suffer from the keyhole effect [4], where only a small slice of the problem is visible at any one time, and users have to shift their point of view to see other limited slices.

In order to support sense-making [5] there is a need for tools that can answer more complex and open questions such as:

- What are the common event patterns of the workflow?
- Are there unusual patterns or bottlenecks, and why are they unusual?
- Is it possible to shift scans in time to orchestrate overall operations and optimize resources?
- And the ultimate: Is there anything interesting that could spark new ideas entirely?

In this paper, we report on our work-in-progress to develop tools and methods that can answer such questions. Our approach is based on making the radiology workflow visible in order to inform optimization strategies.

2. Methods

The methods that we use to build such tools are based on the insight that the various stakeholders do not precisely know at the beginning of the process, what data they need to see in what form in order to answer their question. Alas, in many cases the questions themselves are not known and need to be crystallized first. We therefore use the following two-step approach to iterate on a solution.

First, all the data sources that can potentially contribute to provide insights into the problem at hand are collected, and wrangled (assessed, cleaned, transformed, etc.) into a form that is conducive for analysis. Data Wrangling is a process that is often underestimated [6], and we find that we spend at least as much time on it than the actual analysis process.

Data sources include the obvious RIS and PACS systems, but also unlikely ones such as device logs, accounting systems, or energy meters. These heterogeneous sources are merged into a common in-memory data model that allows efficient interactive queries.

Second, we develop graphical representations that make the complex structures in the data visible and provide the big picture. Details are seamlessly embedded in this overview through various interface techniques (focus&context, zooming interfaces, distortion, etc.). We then provide exploratory access to this visualization with highly interactive interfaces.

3. Results

We use this approach to develop various tools for different aspects of the radiology workflow. In the following sections, we present two current examples:

- Understand the flow of patients through the different process stages of the radiology workflow
- Characterize the operational modalities of imaging devices by correlating energy consumption, device logs and RIS information

3.1. Animation of patient flow through process stages of the radiology workflow

The workflow of radiology is entirely computerized. Various systems and databases track patients as they flow through the different stages of order entry, examination, up to the reporting and discharge. While all the stages are well documented and understood, the overall workflow is never visible in its entirety.

We created an interactive animation that visualizes the current state of each patient in the radiology workflow for any given time in the past. Patients flow along their individual waterfall from top left to bottom right, leaving traces whose lengths correspond to their speed. The different stages are colored accordingly (Figure 1).

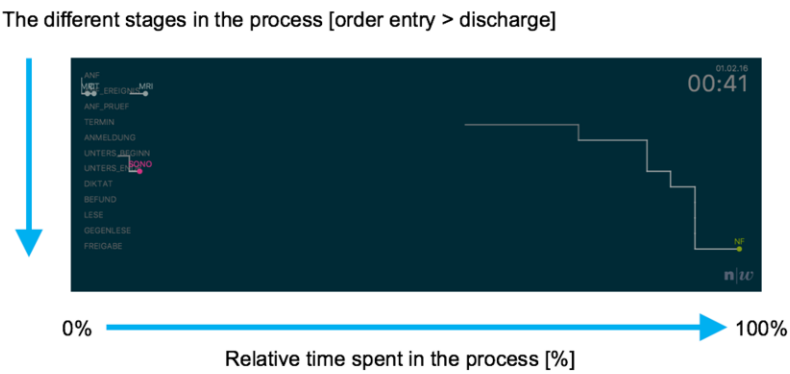

Figure 1. The visualization of the radiology workflow uses a waterfall metaphor. Each patient is represented by a colored dot: order entry (grey-yellow), examination (orange-red), reporting (blue-green). The dots flow from top left to bottom right along the x- (showing progress relative to the overall time that a patient spends in the process) and y-axes (showing the different stages in the process).

The animation can be paused at any time. An interactive time slider allows to move forward and backward in time randomly. This allows users to switch between the visually rich and cognitively dense mode when running the animation like a movie, and the possibility to examine interesting patterns in time and position in detail with fine control of the frame at a time point of interest.

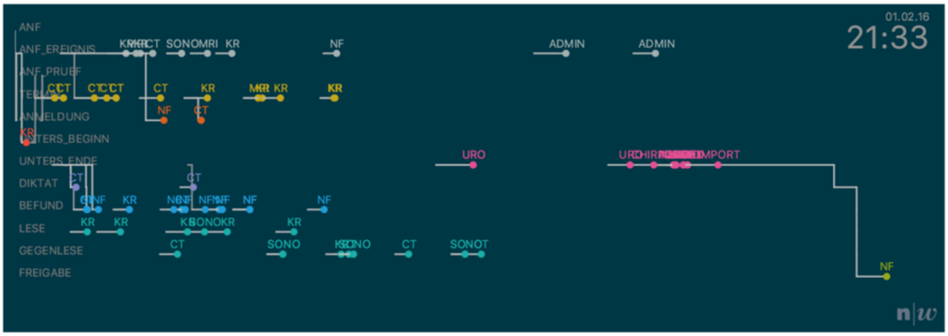

Figure 2. Animation showing patients flowing through the different stages of the radiology workflow: order entry, examination, reporting (top to bottom). The snapshot shows the state of the radiology department in the evening (21:33). At the bottom left a blue-green wave of patients is waiting for reporting the next morning. On the right side an emergency patient is moving very fast and is about to finish the process. Note that a static snapshot cannot reproduce the insights gained from watching the animation

Figure 2 is a sample snapshot from the animation during one evening, showing a wave of examinations waiting to be read and reported the next morning, while emergency cases bypass them in the fast lane. Watching the animation provides the big picture of what is going on in a radiology department at different times and creates an intuition about relationships and dependencies.

The visualization is implemented as a particle system. This makes it possible to easily experiment with different configurations of the paths that patients take along the workflow. Figure 3 shows an alternative scheme, where the workflow is shown using the metaphor of a circle, and patients travel along the perimeter counter-clockwise.

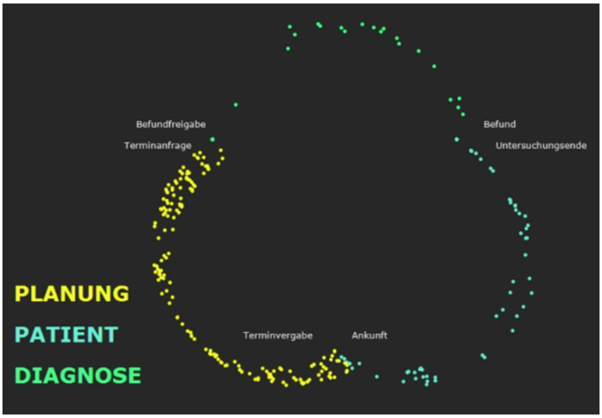

Figure 3. Animation using an alternative periodic visual metaphor where patients move counter-clockwise around a circle through the different stages of the workflow.

The first animations raised great interest with the radiologists. They add a visceral quality to the otherwise sober display of data in dashboards. Combining them with sonification could further enhance this aspect. Possible uses that we envision are as ambient visualizations in public spaces, e.g. for patients in the waiting room. The overall satisfaction of patients with their time spent in the radiology workflow, depends among other factors on how they experience the time waiting between the various stages. Externalizing the state of the workflow and a patient's position within it, has the potential to positively influence their satisfaction.

Internally, an externalization of the current state of the workflow could be used by the radiology staff to inform them about questions such as, how many patients have we already done today? How many will be coming? Will there be enough resources? Where is the bottleneck? The visual metaphor of the waterfall would have to be adapted from using retrospective historic data towards using real-time data feeds where the future is not known. We will also look further into the possibility of using such types of animations for predictive tasks.

3.2. Correlation of energy consumption, device logs and RIS information to characterize operational modalities

Energy consumption and the reduction of the carbon footprint gain increasing interest, also in a clinical context. Vendors start to advertize it as a key feature. Radiology is one of the large energy consumers in a hospital. How can you inform an energy reduction strategy?

The first step is to install energy meters for each device. But this is not enough. We need to know when an examination begins and ends, why it was done, and what happened on the other devices at the same time to assess if scans can be shifted in time and orchestrated. Next to the energy measurements (one sensor per device, 0.1-1 Hz) we used data from device logs (various formats, 103 entries per day per device, 102 event types) and RIS (20-40 examinations per device per day). All data was recorded simultaneously for one year.

There are specialized tools for each of these data streams in their respective fields (facility management, log file analysis, EHR) but they don't provide the big picture and don't allow temporal and causal correlations across data boundaries.

We therefore developed a highly interactive data exploration tool that allows visual analysis of heterogeneous temporal event sequences (Figure 4).

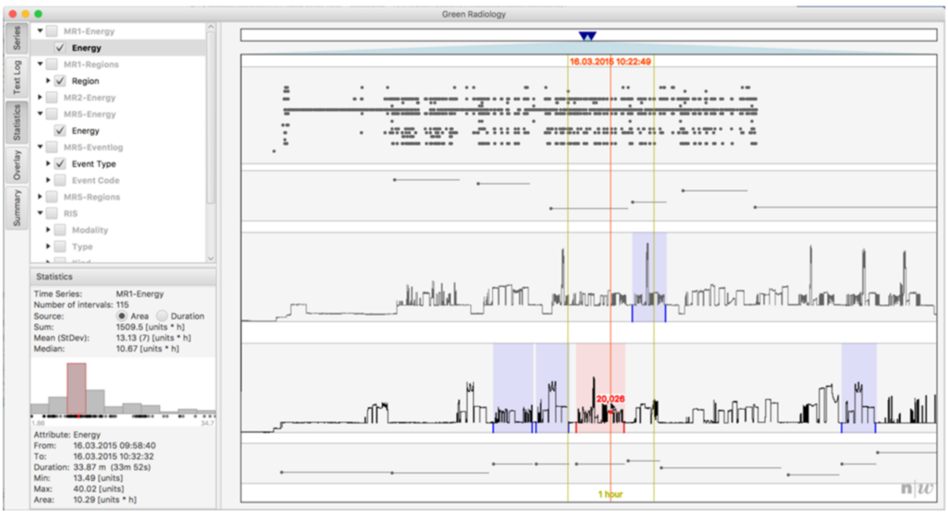

Figure 4. Data exploration tool for correlation, characterization and quantification of radiology events along time and across devices. On the right (from top to bottom): scanner log events, examination periods extracted from the RIS, and energy use of two different MRIs. As an example, head scans extracted from the RIS are marked as segments. Summary information about these segments is shown in the statistics view in the lower left panel.

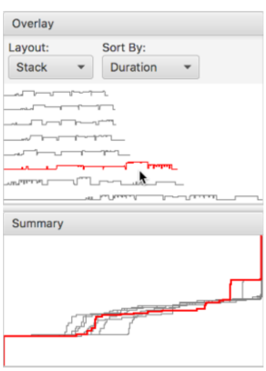

Figure 5. Additional views show a chosen segment (red in Figure 4) in the context of all other scans with the same modality, but potentially different scan protocols. The summary view at the bottom is created by plotting the sorted values of a segment in order to compare plateaus.

It features efficient navigation in time both across large time spans and between different scales by using rapid semantic zooming [7]. Signals can be correlated leading to event identification, characterization, and quantification.

Next to insights into the energy consumption issues, the data and the tool also provide opportunities for workflow analysis and process optimization. This is very interesting for the vendors of the imaging devices, as they typically do not have insights into how their devices are used in practice, outside of their controlled environments. The radiologists that are planning the scan protocols are interested to see, how what they plan matches with reality of how the scan protocols actually perform. Finally, the system was well received by the users controlling the radiology department, and various analysis initiatives are underway.

4. Conclusion

Interactive exploratory visualizations of abstract data that cover all aspects of the radiology workflow, are essential tools to explore complex relationships, detect unexpected evidence, and generate new hypotheses. They complement the operational dashboards and reporting, and have shown great potential to inform optimization strategies for various aspects of the radiology workflow.

Future work will include the evolution of the workflow animation into a real-time monitor that shows the current state of the radiology workflow, and allows to optimize operations. In another effort the insights will be used to provide feedback to patients about their position in the workflow in order to improve their experience. Results from analyzing the energy data will be used to inform energy reduction strategies, and to improve the design of scan protocols.

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