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Process Visualization Techniques for Multi-perspective Process Comparisons

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Abstract. Organizations executing similar business processes need to understand the differences and similarities in activities performed across work environments. Presently, research interest is directed towards the potential of visualization for the display of process models, to support users in their analysis tasks. Although recent literature in process mining and comparison provide several methods and algorithms to perform process and log comparison, few contributions explore novel visualization approaches. This paper analyses process comparison from a design perspective, providing some practical visualization techniques as analysis solutions (/to support process analysis). The design of the visual comparison has been tackled through three different points of view: the general model, the projected model and the side-by-side comparison in order to support the needs of business analysts. A case study is presented showing the application of process mining and visualization techniques to patient treatment across two Australian hospitals.

Keywords: comparative visualization, process mining, business process management.

1 Introduction

Recently, the necessity of managing and analyzing a large number of processes together with their growing complexity has brought an increasing interest towards methods and technologies to support the representation and comparison of process models. The need to examine and contrast the characteristics of different processes also applies to different aspects of process modeling, i.e. event logs, process variants and distinct process models. The comparison activity might then need to focus, for example, on the discrepancies between the event log and the reference model, the analysis of variants in process change as well as cross-organizational comparisons to describe the peculiar characteristics of each system and to identify the best practices for process improvement. Process mining [2] a research domain formed by combining data mining and process analysis techniques, has developed some techniques to compute and spot the differences between process models. Nevertheless, within the reference literature related to process mining and business process management, the visualization dimension of comparison is still in an exploratory stage and there is a demand to elaborate effective solutions to facilitate this activity for both process analysts and stakeholders.

At the same time we note the availability of a broad and deep corpus of research in the information visualization field, containing techniques generally not applied to business process data, resulting in a lack of specific contributions extensively exploring the aspect of visualization for process comparison [4]. Research has shown the superior utility of visual representations as compared to table data [24], thus simple tabular representations of performance data are assumed to be lacking in effect for many use cases. In particular, we argue that the intended audience for this research, business analysts, cognate about business systems from a control flow perspective, with processes represented as temporally ordered activities shown as a graph to match their internal model of the business [24]. In addition, there are a number of perspectives to these processes; control, resource and data [3], that need to be understood clearly by the analyst to improve the business process aligned with the model. We thus motivate our multi-perspective approach in this paper by noting that since particular analysis tasks are aligned with these perspectives [1], any visualization approach, sensitive to these requirements [23], should be able to visualise these perspectives effectively. One of the ways to better understand how to improve business processes of an organization is to compare the behaviour and performance of processes within the organization against others who are carrying out similar kinds of business operations.

Process variants represent alternative ways of performing business activities to accomplish a goal. Unnecessary variations in process behaviour can result in duplications of effort, cost overruns and significant loss in productivity. Hence, it is important to understand the reasons for these variations as well as the effects of such variations on process performance in order to make process improvement recommendations. In order to compare process variants and their respective performances in an objective manner, it is necessary to take a multi-perspective approach, i.e., we should compare not only how a process is conducted, but also how many resources are used and for how many process instances to achieve these performance levels. Such detailed comparisons of process variants and their actual observed behaviours from multiple-perspectives have immense potential to empower organisations to learn about the behaviours of their business operations and unearth opportunities for significant productivity gains. Regrettably, this potential is not fully realised yet as the majority of existing process mining techniques analyse a single log at a time and this step then needs to be repeated for all the process variants of interest [13, 10, 15]. As a result, the comparison between the behavioural and performance aspects of different process variants is carried out by manually (and potentially subjectively) interpreting the results. This concept of process benchmarking or learning from the results of other similar processes in businesses is a well-accepted notion in business process management, which will be applied in this paper to the main perspectives of process models.

In Section 3 we present a framework designed for comparative process visualization to address process mining multiple perspectives, for assessing performance differences and identifying sub-groups and cohorts variation across process models and event logs. The new framework engages the comparative perspective through three different views, viz. *general model*, *projected model* and *side-by-side comparison* in order to specifically address the different points of view and the needs of analysts and stakeholders, with the ultimate goal of extracting indications for process assessment and process improvement. Section 4 continues with a description of the preliminary evaluation we have performed, including example visualizations we have created using real hospital process data and the feedback from presentation to hospital management stakeholders. The paper finishes with an analysis of related visualization work in Section **??** and conclusion in Section 5.

2 Related Work

Our exploration stems from two streams of BPM research, process visualization and process comparison. At the same time our research refers to more general concepts belonging mainly to information visualization, in order to find possible intersections and useful techniques applicable to process comparison.

As more and more organizations rely heavily on IT systems to support their business operations, a vast amount of detailed records of business operations (i.e., which activities are carried out by whom at what time for which customer and at which cost) becomes available for analysis. Sophisticated data and process analysis techniques can be applied to this data in order to reveal the real behaviour and performance of the organization's business operations. Furthermore, It also enables a detailed comparative analysis of processes from different organizations or benchmarking of process behaviours of different cohorts from the same organization (e.g., understand process variants for different types of customers).

Recently, we register an important BPM research shift emphasising process mining, which integrating techniques from data mining and process modeling represents the main stream of research in this field. While visualization techniques have been widely recognized as crucial for supporting decision making and analysis tasks as well as the emergence of behavioral patterns [25, **?**,**?**,**?**], within BPM we register just a few relevant contributions with an interest in visualization aspects, especially regarding personalized views [21], process change [14, 27] and dynamic visualization [17].

The time dimension also emerges from process visualization literature as particularly significant for process data [4, 17]. Although processes are intrinsically characterized by the time dimension, process modeling has rarely visualized it. Currently the only time structure that is represented in process graphs is the ordering of activities as a workflow sequence, without any indication of duration of activities or waiting time between them.

A number of papers recently explored the aspects related to process comparison in different ways. Kleiner [13] analyzed the technique of delta analysis for comparing the actual process represented by a process model with some reference process considered as a prescriptive process model. Delta analysis provides a basis for process comparison by generating a similarity measure between reference and discovered process model on the basis of equivalence of event logs. The analysis though remains at a data level and does not focus on the implementation of a graphical model. A number of contributions concerning the relationship between several process variants with a reference or general model have emerged in the literature. Küster [16] focuses on the consolidation of process models though the automatic detection and resolution of differences, looking at process versions. Li, Reichert and Wombacher [18] concentrate their analysis on the minimization of the derived reference model from a set of process variants. Process similarity has been studied by Dijkman [10] mostly in terms of metrics and search algorithms for business process model repositories for information retrieval, focusing on node matching similarity, structural similarity and behavior similarity metrics. The technique can be usefully applied to the computation of a difference map, which together with the side-by-side arrangement represents the main approach to layouting of process comparison. While the second one mainly relies on the user's visual memory to operate the comparison by pulling the models alongside, the difference map consists in computing a merged model summarizing the differences and similarities of the compared processes. The two types of layouts are equally useful for comparison tasks, responding to different process configurations (simple VS complex) and different analysis tasks. A few contributions consider though the two different approaches together. [14, **?**] A few papers also tackle the aspect of comparison of process variants with graphical representations, using mostly the color variable to represent the differences across both activities and links. [7, **?**,**?**,**?**,**?**,**?**] Most of the visualization approaches besides performing the comparison only on two process models, use color-coding and present the difference analysis as a comparison to a reference model, referring to differences as "deletion", "addition" and "changes", thus needing to always use one of the two processes as a reference to operate the comparison. By focusing on instance traffic Kriglstein et al. [15] explore some visualization techniques to compare process models. A difference analysis is performed between two process models and the visualization specifies the discrepancies on activities and edges for instance traffic through a color-coding approach. From the same authors [14] a similar approach has been more appropriately adopted for the visualization of changes in business processes to highlight the intermediate steps that lead to an updated process. Andrews [5] instead presents a semantic graph visualizer to calculate and visualize the similarity of graph components. The approach applies a difference map visualization by associating a color to each graph and merging the two hues in a gradient for common nodes in a difference map. A different color-coding has been applied by Buijs [8] for a dual comparison visualization of process models and their executable logs. The alignment matrix visualization revealed to be too complex and though the difficulty for participants during the case study to interpret the alignment matrix diagram, as well as the need of more visual anchors and the demand for more emphasis on the time and resource perspectives. The research explored also contributions outside BPM and information systems disciplines, such as graph drawing [6] and information visualization [12, **?**,**?**]. The field of uncertainty visualization has also been investigated for the representation of similarity measures. [9, **?**,**?**]

The literature review has highlighted the lack of significant disciplinary connections between the specific fields of BPM and process mining and the information visualization disciplines, suggesting the need of a design approach to guide the development of novel visualization techniques to support process comparison activities.

3 Comparative Visualization Technique Design Approach

Process mining is a well-established research discipline that provides a novel approach that facilitates exploitation of event data using a combination of process analysis and data mining techniques [2]. Using process mining techniques, one can automatically discover a process model (and related resource usage and performance metrics) from an event log [2]. However, the majority of existing process mining approaches makes use of one event log (i.e., one event log to discover one process model or one event log to replay on a corresponding process model), not multiple event logs. In order to carry out a comparative analysis of processes, process mining techniques are first applied to a single log (optionally with a single process model) and this step is then repeated for all processes of interest. As a result, the comparison between behavioural and performance aspects of different processes is then carried out by manually interpreting the results. As most existing process mining techniques do not cater for comparisons in an automated and straight-forward manner, there are also challenges in making use of existing visualizations from process mining frameworks and tools such as ProM[3] or Disco[4]. For instance, in order to perform a side-by side comparison of two fuzzy process models with performance information, it is necessary to ensure that the placement of activities between these two models is relatively comparable and that the abstraction levels used for discovered fuzzy models are also comparable. Hence, there is a real need for novel comparative visualizations that can highlight key differences in terms of process behaviour and performance.

3.1 Systems requirements and data preparation

In this paper, we address the key requirements in process analysis to be able to visualize the differences in terms of process behaviour and performance of

[3] Process Mining Tools - http://www.promtools.org/
[4] Disco - http://www.fluxicon.com/disco/

two or more processes while making use of different process-related information including process models and historical records of process executions. The main input for the proposed visualization solutions is one or more event logs. The event log(s) are used to extract data regarding process behaviour and performance. In particular, the information regarding the set of completed activities, the frequency of those activity executions and the min/max/avg duration of those activities will be used as objective measures for the visualizations. An event log could be as minimal as having only one transition type (i.e., 'complete' events). With richer logs such as those with start and complete timestamps, additional customer information or employee data, it is possible to have a more accurate picture regarding wait times, bottlenecks and resource utilizations. Furthermore, our proposed visualization solutions heavily rely on the existence of one or more process models to project performance differences upon or to compare and contrast different ways of executing processes. So, another key input for the visualization framework is one or more process models. It is, of course, possible to use the input event log(s) to discover these process models using existing process discovery techniques. Although the visualizations are presented as a natural extension to existing process mining research where one of the remaining research challenges is to enable cross-organizational process mining [2], in reality, the framework is agnostic to how process models and performance measures are derived. We identify the three main inputs to the visualizations: logs, process models and visualization configurations. Such an approach provides a strong functional foundation for the effective usage of the visualization techniques we describe in Section 3.2. In Section 4 we show an example where a visualization is configured and viewed for hospital data case studies. We now proceed to describe in detail the design of these visualizations from basic principles.

3.2 Visualization techniques

The requirements analyzed in the previous section have motivated some design examples to tackle representational issues in process comparison. Design solutions were developed for cohorts comparison in general, in one single organization or across multiple organizations. The comparison has been tackled from different perspectives in order to capture the different aspects of variability in the processes. In order to bridge some of the gaps identified in the literature we directed the design efforts to the different perspectives of process mining, in particular the time, performance and resource perspectives. Concerning the comparative perspective we consider the possibility to compare more than two models. Although the comparison of multiple models has already been explored in [8, 26], none of the analyzed contributions examines the design of an actual difference model that considers the characteristics of all compared models. The proposed visualization techniques have been conceived to allow the exploration both globally as an overview and individually on the single processes, supporting the user moving across different abstraction levels [20]. All three views have been designed aiming at comparing processes both at the model level and event log data, in order to include information regarding the performance, time and resource perspectives.

General model The aim of the general model view is to observe the differences between models from a general point of view, with a focus on the performance and resource perspective(Fig. 1). The process data related to the different models are computed through clustering algorithms by matching activity labels to generate a single merged model for the different cohorts represented with Petri-Nets. In the log table we consider data related to activity median duration, frequency and the resources associated to each activity. Median duration and frequency data are normalized on each activity proportionally for each cohort, to obtain performance related data. This view also implements the resource perspective in order to compare the different cohorts. Resource data is aggregated per organizational level for each activity and divided per each cohort. The examples thus indicate the different resources levels performing the particular task, shown by circles with differing colour fills, (refer to the left part of Fig. 2). The merged model is used for the general structure, while log data is used to create visual annotations on the comparative perspective. The data can be represented with different types of glyphs to replace the activity blocks in the process model.

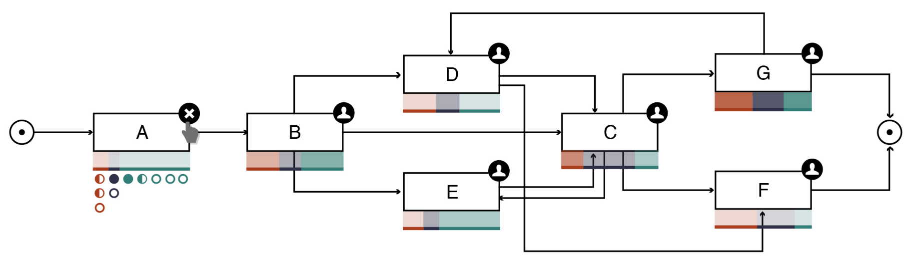

Fig. 1. General model example, with merged model and log data annotations.

Different visual patterns, by way of glyphs (see Fig. 2), have been explored for the representation of performance variations across different cohorts at the activity level. In each case, the different blocks of colour represents a different cohort performing the activities. The stacked bar (Fig. 2a) constitutes an immediate way to project the differences across activities from the log directly to the model, allowing to obtain both an analytic and global view. By implementing also other colour dimensions, other information such as the absolute frequency of each activity can be mapped within the stacked bar, allowing for comparison across other processes. Color transparency has been rendered through a range of four different levels, instead of using a continuous mapping, in order to maintain readability. A similar alternative for the representation of this data type is a space filling visualization of hierarchies such as a treemap representation

(Fig. 2b). Keeping the hue variable associated to cohort categorical values and transparency to map frequency data, the performance/temporal value is represented on the space (area), providing more uniformity in case of a high variability in values. A different solution applies overlapping circle sections for each cohort (Fig. 2c), by mapping the frequency to the radius and the median duration on the arc section subtended angle. An overlapping principle has been explored also through triangle shapes (Fig. 2d) associated to each cohort, allowing a mapping of the performance values, i.e. frequency and median duration, exploiting the two main dimensions, respectively height and base width. This type of pattern might be more appropriate for models that are not particularly complex, when the design goal is directed to highlight more the comparison at the activity level than the control-flow one. For particularly complex models a more suitable solution is to concentrate on the control-flow perspective and eliminate all possible sources of visual occlusion, thus delegating the comparative perspective on single activities to interaction elements that can be activated and deactivated whenever necessary.

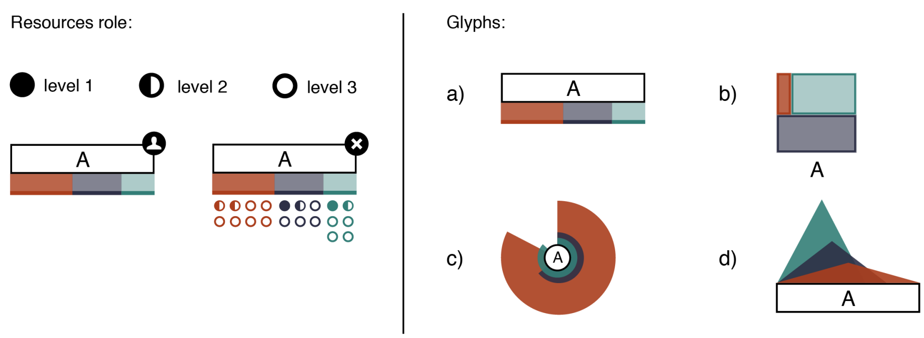

Fig. 2. Visualization of the resource perspective + glyphs

Projected model For the case of comparison mapped in the projected model perspective, the main aspect is the correspondence of activities in the model which could be visualized through the alignment and superposition of an activity element as in [11] (Fig. 3) The similarity level of activities, can be based on different values depending on the aspect to be observed, varying from the execution time, the frequency or an index synthetizing the general performance. The proposed visualization of the similarity scores applies a blur to the activity box with a similar technique to [9]. The projected model view considers mainly the perspective of one process model, that we identify with the first cohort (C1). The model projection is based on the match of activity position within the process flow across the different cohorts. The presence of each activity is checked in the three models, as well as its direct predecessors and successors, to establish a shift in the ordering of activity execution, forward or backwards.

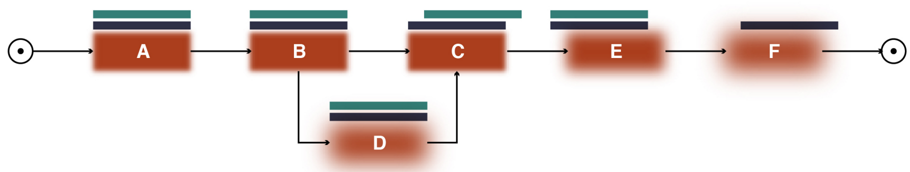

Fig. 3. Visualization of projected model - C2 and C3 - over C1

Log data is used to calculate the similarity level of each activity of C1 process model with respect with the other cohorts. Similarity is obtained by the ratio between the frequency and the median duration of each activity in C1 compared to the average value of the same ratio for C2 and C3. The resulting values are grouped by level of similarity in three partitions: high, medium and low. The visualization is based on C1 for the process model and the activity matches across the different cohorts are mapped as stacked rectangles on the top of each activity. The rectangle is then slightly shifted towards the left when the same activity is founded in the model but in a different position, earlier in the flow. The rectangle is slightly shifted towards the right when the same activity occurs at some point later in the flow. The similarity level of activities in C1 with respect to C2 and C3 is mapped by blurring the activity box applying three levels of blur according to the partitions, where the highest level of blur corresponds to the lowest similarity level for the activity across the cohorts.

Side-by-side This type of comparison technique aims at exploring, more deeply, the time perspective of the processes at a broader level, by integrating the information on the waiting time between an activity and its successor: a very common event that causes the delay of completion times for the whole process.

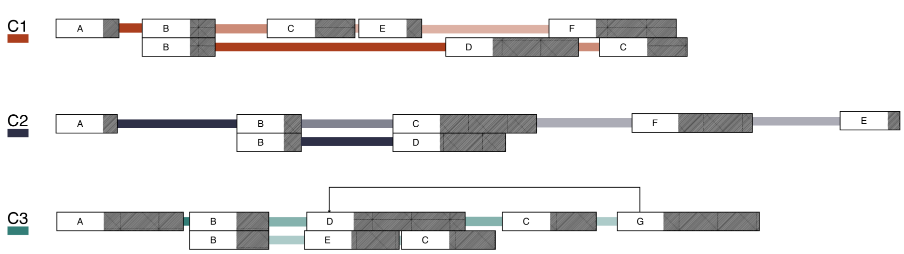

Fig. 4. Side by side visual comparison

The proposed diagram (Fig. 4) exploits the process model logical flow to describe temporal dependencies between activities through predecessor and successor nodes of a directed graph [19]. The three models are analyzed separately, focusing specifically on the ordering of activities. The waiting time between each couple of activities is represented by the length of the arcs while activity duration is displayed by extending the activity box with a grey texture. This visualization method is also consistent with a configurable process model approach [22]. In order to capture the variability across the models we applied a model projection approach that highlights just the matching flows that correspond to the comparison scenario leaving the irrelevant branches in the background.

4 Evaluation

The evaluation approach adopted for the proposed visualization framework is three-fold. Firstly, we made use of event logs and discovered process models from two hospitals (H1 and H2)[5] and developed a set of visualizations by hand. This serves as a preliminary evaluation and feasibility analysis of the proposed design principles. Secondly, we showed the resulting visualizations to the stakeholders in order to 1) gauge the understandability and usefulness of proposed visualizations and 2) to solicit further user requirements from stakeholders. Finally, we are in the process of developing a set of software plug-ins for the process mining framework, ProM, based on their input and are also preparing an anonymous online survey in order to obtain the opinions of BPM practitioners and academics from around the world. In this paper, we present the evaluation outcomes from the first two steps: visualizations created using real datasets and stakeholder feedback about the visualizations. Please note that due to the lack of resource information in the datasets, the visualizations do not include the resource perspective.

Hospital 1 One of the comparative analysis questions from stakeholders at Hospital 1 (H1) is "Are there any differences in terms of process behaviour and durations for patients who present at ED at different times of the day?" In order to answer this question, patients are put into 4 cohorts depending on their arrival times at ED (i.e., midnight - 6am, 6am - 12noon, 12noon - 6pm and 6pm - midnight). A process model, together with dominant paths, is discovered from the event log containing data for all four cohorts. The names of the activities, their frequencies and median execution times of activities are calculated for each cohort.

Figure 5 depicts the resulting visualization. From this figure, it is easy to see the performance comparison across two dimensions (frequency and duration) for four different cohorts. As the number of cases for each cohort varies across the

[5] These event logs represent patients presenting for treatments at Emergency Departments (ED) of two QLD hospitals. These two datasets are made available to researchers in the context of an AusSHI stimulus grant.

different time periods (i.e., 147, 244, 320, 173), the relative frequencies are used in the visualization. The visualization made use of a number of metric classes: the absolute frequency for activities (the height of the triangles), and the absolute frequency for paths (the strength of the edges and activity darkness), and the median duration from one activity to another (the width of the triangles).

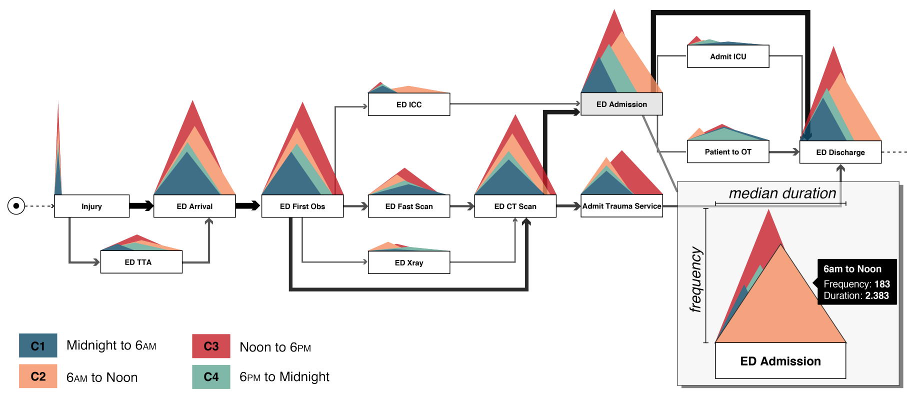

Fig. 5. Visualizing the behaviour and performance differences between four patient cohorts in H1. The ED Admission activity is blown up on the bottom right.

One example of a pattern being easily seen is the difference for the 6am to Noon cohort, compared to the others, for the ED Admission activity, shown by the wide triangle indicating a large difference in duration compared to other cohorts (see highlighted box bottom right in Fig. 5). As this was the first visualization created with the real data sets, further refinements to the original design were necessary. For instance, we needed to adjust the dimensions of the visualization elements in order to accommodate very high/low frequencies. We also realised that it might be necessary to set the maximum limit with respect to the number of cohorts being compared. This visualization was presented to stakeholders (including doctors from the emergency department at H1 as well as healthcare researchers from different QLD Hospitals) as a part of three presentations to demonstrate preliminary results from the process mining analysis being conducted at H1. These stakeholders found the visualization to be intuitive and they were very receptive to being presented with visual comparisons of the four cohorts across the two performance dimensions.

Hospital 2 One of the comparative analysis questions from stakeholders at Hospital 2 (H2) is "What are the differences in terms of process behaviour and durations for patients who are discharged from ED within 4 hours of arrival and those who stayed longer than 4 hours?" In order to answer this question, the dataset is split into two cohorts, those who stayed in ED for less than or equal to 4 hours and those who stayed for more than 4 hours. All three types of visualizations were created using the data from H2. Process models were created for both cohorts as well. For this evaluation we concentrate on the projection and side by side visuals as the performance general model visualization is similar to the example for Hospital 1.

Figure 6 depicts the visualization that reflects the side-by-side comparison of patients in the two cohorts. Here, the emphasis is on the time perspective whereby cases in Cohort 1 have throughput time of up to 4 hours and cases in Cohort 2 has throughput time of over 4 hours. The design also allows the comparison of dissimilar models by the selection of two similar segments of the H1 and H2 models for comparison. As seen in the example the portion of process between Medical Note final and Discharge Letter is significantly longer in Cohort 1, due to the waiting time as well as the median duration of both activities involved.

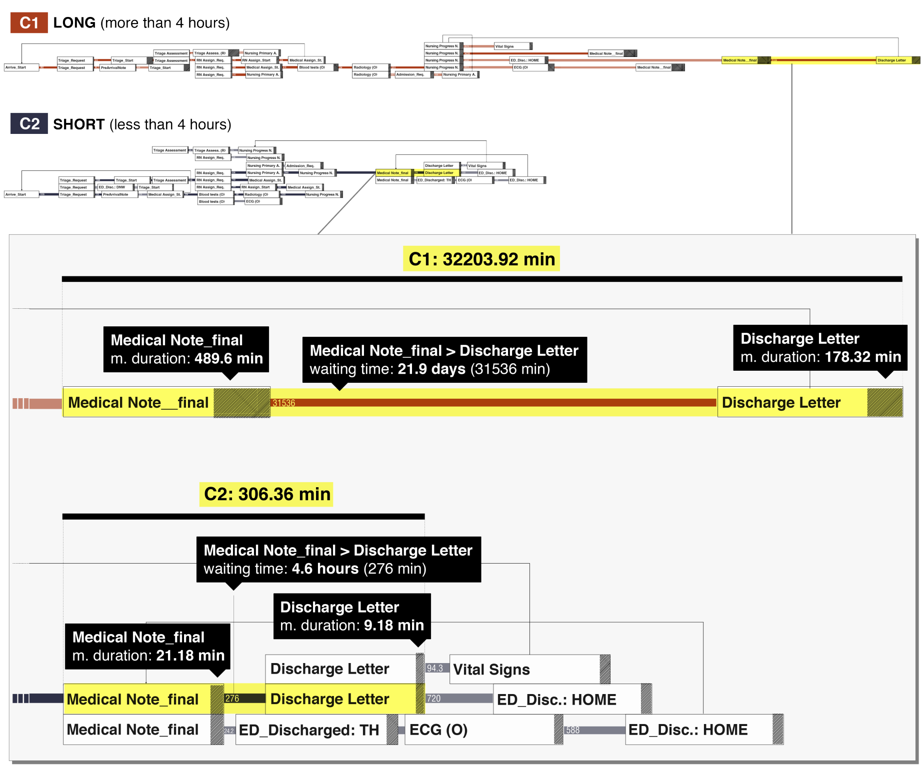

Fig. 6. Side-by-side comparison of two patient cohorts in H2, with a blown up selected example at the bottom.

Figure 7 depicts the projection of the process model for Cohort 1 onto the model for Cohort 2 with the emphasis of whether the activities are being shifted forward or backward in relation to a model. The example shows that the activity related to ECG (ordered) is executed later in the model in C2 with respect to C1, while Medical Note final has the same position in both cohorts but with a lover level of similarity, as displayed by the blur.

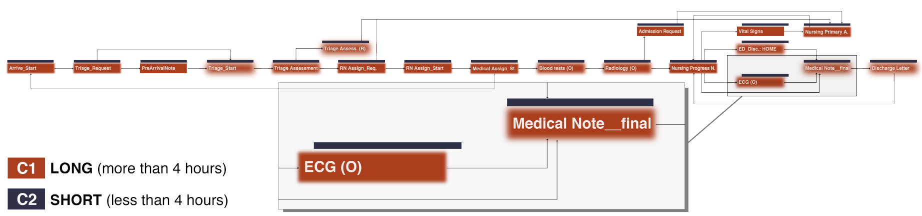

Fig. 7. Projected model of two patient cohorts in H2, with a blown up selected example at the bottom.

These two visualizations were shown to the head of the emergency department from H2 as part of a debriefing session to discuss the findings from the process mining analysis conducted at H2. This doctor found all three visualizations to be useful for different purposes. He noted that the performance models (eg. Figure 5 provides salient patterns that pop-out easily. Figure 6 showing time-based visuals using alignment analysis was seen as useful due to it highlighting the differences in time easily, and then seeing related activities in particular antecedents. Figure 7 which highlights the differences between process behaviour of the two cohorts was found to be not very useful for this dataset due to a high degree of similarities found across the two cohorts; thus minimal blurring. However, he recognized the potential use of this type of visualization in comparing different departments or different hospitals with a high level of variation in process behaviour.

Findings from these preliminary evaluations also highlight the need for an integrated system starting at a high level, and filtering and drilling down to activity comparisons, with interactions assisting with insight in real time. We are currently working on a software plug-in to support these visualizations with interaction and filtering capabilities.

5 Conclusion

In this paper we have presented research on a multi-perspective visualization framework for process comparison. The study emerging from the need to better analyze and communicate the results of process comparisons within the process mining domain. Our research has highlighted the lack of a design approaches for process comparison visualization, and the scarcity of efforts in visual patterns innovation for the representation of processes, creating a misalignment with the research carried out on flexibility and Process Aware Information Systems (PAIS). In particular we developed a design approach to tackle representational issues within process comparison activities and a visualization framework for display techniques comparing multiple cohorts across multiple perspectives, namely control-flow, time, performance and resources. The displayed three level view system allows to address the multiple perspectives as well as different levels of detail (clustering) and points of view from which users might approach the comparison.

For future work we intend to explore more deeply the aspects of clustering and interaction presented in the approach section, focusing in particular on interaction. In addition, we plan to work on the implementation of the proposed visual solution within a dynamic environment, such as ProM. We also aim to expand the evaluation of the visualizations with a systematic survey to assess the effectiveness of the different patterns. As a general objective, we intend to continue to broaden the research in process visualization and search for improvements in the visual patterns and interaction modes for process mining analysis activities.

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