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Interpretability challenges for discovered process models: A user study and prototype solution

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Abstract

Process mining discovers process models from an organization's event logs. Discovered process models are used by process analysts to understand and improve real-life processes. Interpretability of such discovered process models by actual users is crucial for efficient and effective usage of models in process analysis. A large body of work, including empirical studies, investigates how users interpret process models and their visualization. However, the focus is on manually created process models for documentation or specification. There is little work on the influence of discovered process models visualization on interpretability by users. Often discovered models are augmented with frequencies and deviations from an event log, which leads to even more complex visualizations. We contribute a user study with 12 participants with varying level of process mining expertise and derive a ranking of 15 issues for interpretability in discovered process model visualizations. We derived five requirements for an improved process model visualization that we, subsequently, implemented in a prototype visualization. A preliminary validation of the prototype among a subset of participants showed promising results and, orthogonal, the identified issues may be useful for future research and work on the interpretability of discovered process models.

CCS Concepts

• ***Applied computing*** → ***Business intelligence;*** • ***Human-centered computing*** → ***Empirical studies in visualization;***

1. Introduction

Process mining at its core is about discovering processes from data. Process models are an essential part of process mining and process analytics where they are discovered from an event log. An event log contains all events related to the process under analysis and the discovered process model provides a representation of all the process behavior observed in the event log. In industry, directly-follows graphs [Aal18] are typically used as representation for the discovered model. However, in some cases more expressive models with semantic information such as parallelism and choice are used, e.g., BPMN models. When combined with a projection of the frequencies of activities and paths observed in the event log onto the model through an alignment [CvDSW18], we obtain a so called aligned process model. In addition, edges may be added for events that only occur in the event log and do not correspond to valid execution of a model element. The interpretability and ease of understanding of such discovered models with additional information [MRC07] is important as it is the central artefact used by a process analyst to obtain information about the underlying process.

Whereas the elements of a, e.g., BPMN model have clearly defined semantics to be interpreted correctly, the complexity and size of discovered process models often presents challenges for the correct understanding of the model [Fig17] by a process analyst. There has been some research on the interpretability of process models by users [MRC07, LRWM*11, Fig17] in general but, so far, little focus has been put on how the visualization of process model that are discovered and aligned affects interpretability. Discovered process models are often differently structured due to the constraints of the used process discovery algorithm and, since they are automatically created, modelling guidelines and best practices cannot be followed without changing the discovery approach. This is the gap that our study aims to address.

We conducted a user study with 12 participants with varying levels of process mining expertise and used process models discovered by UiPath Process Mining. Initially, we identified a set of initial challenges for discovered process models by reviewing the literature and talking to practitioners:

- Process models often contain many gateway nodes taking up space and may be complicated to interpret
- Process models do not clearly show hierarchical process structures, distilling the main process steps may be difficult
- Process models augmented with alignment diagnostics, i.e., paths that only occur in the log additionally obstruct which parts of the process belong together
- Process models make it difficult to interpret where certain (complex) sub-parts of the model start and end

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- Process models are often too dense (number of edges) to convey information on what is being modelled in an intuitive way

We used these five initial challenges to guide the design of the user study and obtained an extended list of user reported *challenges* for the visualization of discovered process models. Through interviews, we ranked the challenges to build a consensus on the most relevant challenges. Then, we synthesised requirements from the identified and ranked challenges and addressed those by implementing a prototype of a novel interactive visualization for discovered process models. A preliminary validation of the the prototype was performed with a subset of the user study's participants.

In Sect. 2 we discuss existing work related to the five challenges. Sect. 3 presents the user study that was informed by the five broad initial challenges. Three datasets were selected, two synthetic and one real-life, on which process models were discovered. The results are discussed and, ultimately, led to the development of a prototype visualization that is briefly described in Sect. 4. Finally, we conclude the paper in Sect. 5 outlining avenues for future work.

2. Related Work

We briefly review existing empirical research aimed at visualization of process models in the process mining context.

Only few studies have conducted user evaluations of process model visualizations, a survey conducted in 2019 finds that only 30% of studies actually test their process model visualizations with users [SDDSFT19]. General guidelines for process modelling have been proposed already in 2010 [MRvdA10] advocating for limiting the number of elements in the model. Indeed, user studies found that larger model size impairs model understandability [MRC07]. Some more recent proposals for user-friendly process model visualization [HSM*14], dynamic process model visualization as opposed to showing a static image [EVR16a], process model animation [AR21], or using augemented reality for process models exploration [ZMK*20] did evaluate their proposed techniques with user studies. However, none of them focused on the setting of discovered process models with alignment information, which have different properties to manually created process models.

In the area of process mining, most work focused on simplifying complex or dense process graphs instead of finding better visualizations of complex models as-is. Conforti et al. [CRH17] filter our so-called noise detected in logs before process discovery, Tax et al. [TSvdA19] attempt to filter out chaotic activities leading to complex process models, and Chapela-Campa et al. [CCML19] aim to simplify complex process models. Event abstraction [vZMdLK20, WTTH18] and clustering [WTTH18] are also discussed in the process mining literature as a means to simplify process models and, hence, decreases the density of the model. However, our objective is to improve the interpretability of discovered process models through better visualization, and to do so without changing the input event log before using it for the discovery. This allows us to focus on the largest amount of use-cases.

In conclusion, user studies on the challenges users perceive when interpreting discovered process models and how visualization techniques could possibly help them is missing.

3. User Study on Interpretability Challenges

We describe our user study that investigates how process mining users perceive the interpretability of discovered process model with the goal of deriving requirement for improved visualization of these models.

3.1. Study setup

The user study has been structured according to the Delphi Method [OP04]. A total of three rounds of interviews have been conducted. During the first round, the users were asked to go through a set of user tasks with a think-out-load protocol to gather as much data as possible. After each user task, a discussion was held with the participant to discuss interpretability of the model. To evaluate the behaviour of users when interacting with the discovered process model, we leveraged a set of typical process mining tasks, such as filtering, pathfinding, and revisitation, as proposed by Mennens et al. [MSW19]. We derived a set of seven tasks for each user to perform and closed each session with an open-ended question regarding further feedback or comments. During these tasks the models remained fixed for all users.

After round one, the user-identified problems were summarized and combined with the challenges, which are based on the problem statement. The consolidated list of interpretability issues was then relayed to the users in round two. The goal of the second round was to reach a consensus on the identified issues and acquire a ranking based on user input. In the third round, the users were given the same user tasks as in round one, but now while using our proposed solution, later described in Section 4. The final round served as a verification and evaluation round to test whether the proposed solution addresses the identified issues found in the previous rounds.

3.2. Study execution

The three discovered process models shown in Figure 1 were used. The first one (A), illustrates a simple laundry washing process that was used to explain the basic process mining and visualization semantics. The second one (B), illustrates a larger and more complex process model, and, the third one (C), is a complex real-life process model discovered on the public BPIC2017 [van17] dataset. Note that the process models produced by the tool are not directly-follows graphs and, thus, already reduce some of the complexity in the data.

The user tasks below were performed by each user. The first served to introduce the users to the basics, for which the discovered process model in Figure 1-A was used. Then, users were asked to perform tasks 2–6 for model B and task 7 for model C. The concluding task 8 is a generic open question.

1. *Are you familiar with an aligned process model and all of the concepts that can be present within it? Could you please explain how you use this model and what semantical concepts (XOR, parallelism & loops) are present within it?*
2. *Try to capture the general process being modelled here and explain what process you are looking at.*
3. *Try to identify key sub-processes, in general, within the process, e.g., the 5 main steps that this process entails from start to end.*

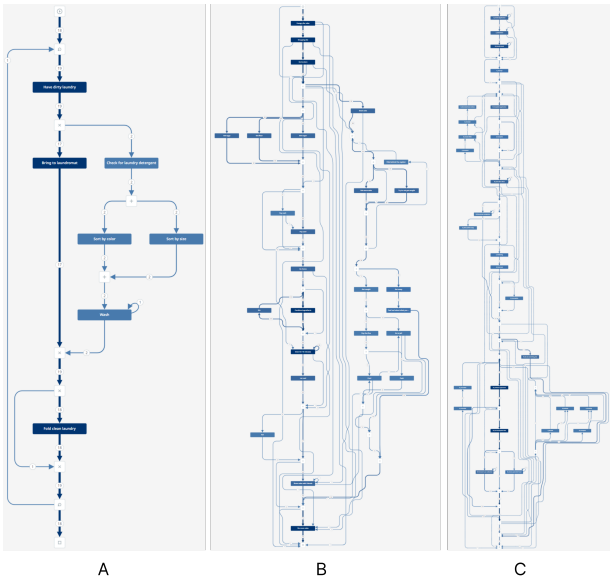

Figure 1: *(A) Simple model used for explaining basic process mining and visualization semantics (B) Larger more complex model on acquiring a cake (C) Largest and most complex model based on BPIC2017 [van17] dataset.*

4. *Try to find the different ways in which a (sub)process can start or end within this process as a whole after the initial start or final ending. We want to get a good look at what deviations are directly clear after the start and end of this process.*
5. *Try to find and explain the difference between two path variants within the model. Try to find a path that does x and a path that does y. Both paths should start on **a** and finish on **b**.*
6. *Try to identify areas in the modelled process which can be repeated or executed more than once. Do the same for parallelism and synchronisation (closing of a parallel block), for these explain what the consequences are.*
7. *Now that you have had a more guided experience within a process model I would like you to find and explain two different variants of processes modelled in a new process model without any guidance. This task is identical to 5. but without any guidance.*
8. *Are there any other things regarding the interpretability of the aligned process model that you would like to share? Anything you noticed during this interview within the model that was either good or bad for the interpretability?*

With these user tasks most of the expected behaviour from a user was captured multiple times. This allowed for discussions after each task to check if the interpretability issues repeated themselves, or if they were only present in certain scenarios. This gave us more insights in how and when users perceive something as detrimental towards the interpretability of a process model.

3.3. Study Results & Requirements Synthesis

A total of 12 participants, ranging in expertise from process mining experts to novices participated in the study. The issues listed in Table 1 were extracted during round one and ranked in this order in round two. Most of the rankings are expected based on the total number of reports each issue received. However, some issues were prioritized by users in round two, such as the use of a legend. This issue was mostly suggested by novice users who had a difficulties understanding the semantics of the model elements.

Based on the identified and ranked issues, we further developed several requirements by grouping together similar issues. The goal of consolidating the issues to fewer requirements listed below is to guide the development of our proposed prototype (Section4).

The different gateways should be easily identifiable and visually concise (R0). This requirement is based on issue 1. Most users reported that they had difficulties understanding what a certain gateway was projecting. In particular, users struggled to distinguish choice (XOR) gateways and parallel gateways. Users also reported that when they were zoomed out or the graph became larger, the differences between the gateways became even more problematic to distinguish. As can be seen in Figure 1 (A) the visual differences between the gateways is small. It also becomes clear why users might not be able to keep the XOR and parallel gateways apart. The cross and plus signs are very similar and can easily be confused.

Gateway pairs (open/close) should be easily distinguishable and visually different (R1). This requirement is based on issues 2 and 8. Users reported having trouble finding which gateway was the closing or opening partner when navigating the model, often when diving into the details. Note that gateways always come in pairs (block structure) in the used process discovery approach. Specifically, larger sub-processes were perceived as difficult to understand if there are multiple consecutive closing/opening gateways. Users reported that it is unclear which of the gateways belonged together. This resulted in users often having to back-track to see where within the sub-structure they were currently located. It was clear that this was breaking their flow within a task.

Activities that belong to a sub-process should be easily identifyable (R2). This requirement is based on issues 5 and 11. When looking for more details within the model, users also reported difficulties seeing which specific activities belonged to the sub-process they were investigating. We defined a sub-process as starting at a gateway and ending at the gateway's closing partner. In this case, users reported this most often in the presence of loop structure which made it difficult to identify which activities belonged within the loop and could be repeated.

Sub-processes of the model should be collapsible, such that an abstraction can be created (R3). This requirement is based on issues 6, 9 and 13. Many users mentioned that they would have liked to be able to abstract the model further, or at least make it less cluttered with model elements. In particular after having seen certain part of the model multiple times when doing tasks in succession, they understood that local part of the model and wanted to either minimize or temporarily remove parts of the model.

#	Reported issue	Reports	Priority
1	The differences between the gateways (XOR/Parallel/Loop) not being clear enough	11	1
2	Not knowing which gateway pairs (XOR/Parallel/Loop) belong together	8	2
3	Not being able to apply a filter on which traces are shown	5	3
4	Not having a legend that gives information on the symbols of the model	4	4
5	Not being able to clearly see which activities belong to a gateway (XOR/Parallel/Loop)	8	4
6	Not being able to collapse certain parts of the model	7	5
7	Not having persistent highlighting of edges/gates	6	6
8	Gateway-pairs not always strictly being beneath each other	4	7
9	Not being able to change the level of abstraction of the model / having auto-generated sections/abstractions	7	7
10	Not being able to remove edges below a certain threshold	7	8
11	Not being able to isolate part of the model for better viewing	1	9
12	The general layout of the model which was top-to-bottom instead of left-to-right	2	10
13	Lack of interactivity to dynamically adjust the layout or rearrange the model	3	10
14	Inability to highlight or emphasize critical paths or bottlenecks in the process	2	10
15	Not being able to compare different parts of the model that are similar	3	10

Table 1: *User study ranked results. The issues are numbered for reference in the requirements, each issue has a number of reports and the final priority ranking. This ranking was created based on what the user study participants reported as ranking during round two.*

Edges should have the option to stay highlighted (R4). This requirement is based on issue 7. When users wanted to follow a long path in the model they often had difficulties ensuring they could consistently distinguish which edge they were following. Users often mentioned that they would like to keep the edge or path highlighted within the model whilst panning around. The reason was to more easily follow a specific path.

We selected these five requirements since they are related to the visualization of process models with a given model layout and were highly ranked by the users. We decided to disregard orthogonal aspects such as adding a legend on symbols, which would not require a change in the visualization.

4. Prototype

We developed a prototype solution in which we proposed solutions for all five listed requirements. This prototype was then evaluated in a third round of the user study where the users were asked to complete the same tasks as before using the new solution. Here we will discuss our design choices as well as report briefly on the final evaluation of the prototype solution.

4.1. Design

The development cycle was equal for each requirement. First the underlying issues were examined further and possible solutions from literature were researched. Then concept solutions were created and their designs were iterated in multiple steps. UiPath engineers and designers were asked to provide feedback on initial concepts leading to further updates on the designs and ideas. Finally the final concept was implemented as prototype in the product to ensure the evaluation could be done in the same environment. We will discuss the prototype solutions and highlight important choices made.

The different gateways should be easily identifiable and visually concise. We saw that depending on the background knowledge of users, e.g., familiarity with BPMN, the gateway icons would be either instantly recognized or elusive for the user. After a few design iterations, we decided that the gateways should be distinguishable from a distance as well as when zoomed in. To achieve this, they were given different shapes with unique icons that were more different from each other than for instance a '+' and 'x'. Examples can be found in figure 3 (B).

Gateway pairs (open/close) should be easily distinguishable and visually different. For this requirement we found that Reichert et al. [Rei13] tried to remove visual clutter by making the closing gateways very small. Eckleder [EFMR09] proposed to color different gateway pairs in workflow graphs to make them visually distinctive. Because of the large number of gateways, after an initial concept we decided not to go with initial coloring but instead color / highlight on hover. This allows users to hover a gateway and its partner will then light up as well. An example of the gateway and its partner being highlighted can be seen in Figure 2 whilst a normal variant that is not highlighted can be seen in Figure 3 (A).

Activities that belong to a sub-process should be easily identify-able. For this feature inspiration was drawn from Emens [EVR16b] who presented a selective highlighting feature in their paper. They opted to highlight only a certain part of the model to draw more attention towards it. We tried multiple concepts and choose to highlight the active sub-process through de-emphasizing the remainder of the process. When hovering a gateway everything that is not within that sub-process becomes more transparent, de-emphasizing it, whilst the sub-process remains unchanged. An example of this selective highlighting can be seen in Figure 2.

Sub-processes of the model should be collapsible, such that an abstraction can be created. For this requirement, we looked at the literature on grouping elements within graphs and model abstracting. We found work on groupings that propose solutions [LRWM*11, EVR16b, BGS01, JHHP17] towards showing a group within a graph. La Rosa et al. [LRWM*11] proposed multiple ways of abstracting algorithms that can be used in process models. We found that users mostly had issues with smaller parts of the

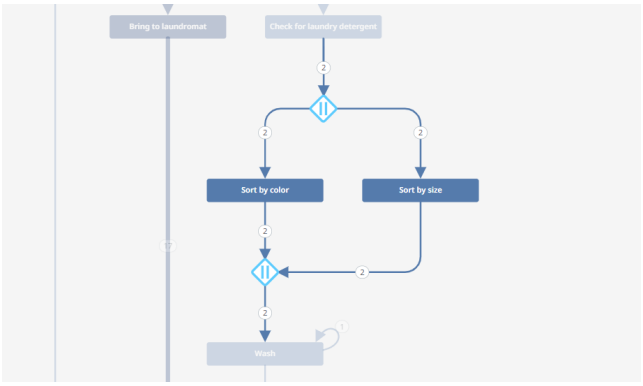

Figure 2: *Selective highlighting implemented in the prototye. When the user hovers the gateway everything but the sub-process in the model is de-emphasized.*

model that they saw much more often and in the beginning when they wanted to get a good overview of what the model depicts in a few steps. We wanted to keep the context of the model the same whilst giving the user some way of abstracting the model. Deurloo [Deu21] suggested to create collapsible nodes that can display information on the amount of activities within. We build on from this idea and used a large language model (LLM) [FC20] to generate names for each sub-process based on a natural language version of the process model. These names were then assigned to each sub-process and users could dynamically collapse sub-processes within the model. An example can be seen in Figure 3 where the same model is shown, but one almost fully abstracted.

Edges should have the option to stay highlighted. To make a more semi-persistent way of highlighting edges we allowed users to highlight all incoming and outgoing edges of an activity and keep them highlighted until another interaction with a activity took place.

4.2. Preliminary evaluation

The preliminary evaluation used the user tasks and models of round 1 of the user study but this time the prototype solution was used. We interviewed 3 users from the previous group again, all with different backgrounds. Overall they were very positive regarding the improvements that were made towards the interpretability of process model. They did note that the LLM generated content should be accompanied by a warning attached to it. Presenting it as truth could potentially mislead users to think it is correct, whilst we cannot be certain of this. The selective highlighting and highlighting of partner gateways were very appreciated in creating more understanding of the model contents. In conjunction with the generated names users expressed more confidence in their understanding of the models and the underlying process. We acknowledge the limitation that, due to time constraints, this evaluation was performed with fewer users and on the same process models potentially biasing our results. It should also be noted that across the industry there are many different tools and our results may not generalize to them.

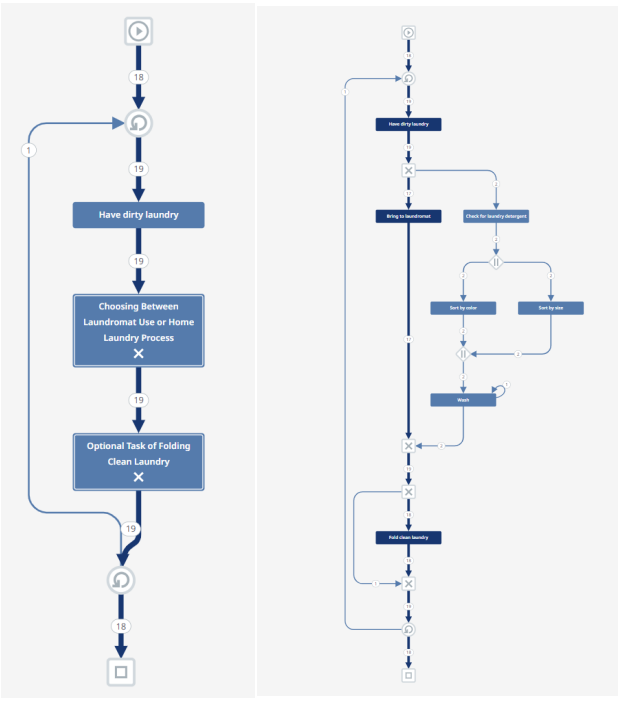

Figure 3: *The laundry model shown twice: (A) fully abstracted with sub-process nodes having generated names as well as being fully collapsed, and (B) the full model is opened without any abstraction or sub-processes showing.*

5. Conclusion

Our work clearly shows some of the possible issues with interpretability for discovered process models with additional alignment information. The main contribution of this work is a user study with users of different level of experience in the process mining field and the identification of requirements for visualization of discovered process models. The user study provides insights into what users find most detrimental towards the interpretability of these process models.

Users prefer clear and concise semantics, combined with providing more context on the general process and its steps. Having the ability to abstract the model without permanently removing any information provides users with a way to more easily navigate the model and still have the same context they had with the full model. Some of these requirements derived from the user study, were successfully addressed in a novel prototype visualization for discovered process models.

In future work, filtering out edges and activities to separate views should be further investigated. Separating certain filtered activities into a separate view, or even creating a separate view of a sub-process of the model could help users to keep track of previously noted anomalies within the process model.

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