Visualizations for Conformance Checking Tasks: An Empirical Assessment of Existing Visualization Idioms and User Preferences

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Abstract. Conformance checking is a sub-discipline of process mining that compares recorded process executions, captured in event logs, with the desired behavior, defined in process models. Thereby, it detects deviations whenever a trace diverges from the process model. Within conformance checking, there are many different tasks that can be of interest. These tasks have been investigated by recent work, leading to a taxonomy of conformance checking tasks. To answer these tasks, visualizations are essential. However, it is not yet identified whether the existing visualizations and their idioms, i.e., the visual element used, support these tasks. To investigate this, we focus on a subset of ten tasks from the recently developed taxonomy and answer two research questions. First, we analyze academic and commercial process mining tools to identify which visualization idioms are used to support specific tasks (RQ1). Second, we conduct a user study with 20 participants to evaluate which idioms are preferred for each task (RQ2). Our results offer a structured overview of the idioms currently applied in tools and reveal user preferences that sometimes diverge from the most frequently used idioms. These findings underscore the need for further research into task-specific visualizations.

Keywords: Conformance Checking · Visualizations · Tasks · Survey · User Preferences

1 Introduction

Conformance checking is a sub-discipline of process mining, which compares process executions, captured as traces recorded in an event log, to desired process behavior, captured in a process model [5]. Corresponding techniques detect deviations whenever a trace diverges from the process model [10]. Within conformance checking, there are multiple tasks that can be of interest. Such a task refers to a specific question to be answered within this context, e.g., "What is the overall degree of conformance between a log and a set of guidelines?". Recent work has investigated these tasks, leading to a taxonomy of them [22].

To solve these tasks, visualizations are essential to make the results of conformance checking accessible to users and allow them to answer these specific questions [7, 17, 19]. Although different conformance checking tasks are now defined and can be categorized with the recent taxonomy [22], the visualizations available to support these tasks have not yet been systematically identified. So far, no analysis has investigated how these tasks can be or are currently solved with the visualizations available in process mining tools. Thus, it is not established whether the visualizations used in existing tools with their visual elements, so-called visualization idioms, e.g., bar charts, adequately support conformance checking tasks and, if so, which visualizations are preferred by the users.

To address this gap, we systematically analyze conformance checking visualizations used in existing process mining tools with regard to specific conformance checking tasks and aim to answer two research questions.

RQ1: Which visualization idioms are used by existing academic and commercial process mining tools to visualize a set of conformance checking tasks?

RQ2: Which visualization idioms are preferred by users to solve these tasks?

For RQ1, we map the tasks to idioms currently supported by academic and commercial tools. This provides an overview of the used idioms for these tasks. For RQ2, we then conduct a survey with 20 participants to assess which of the used idioms are preferred by users. We find a preference for one idiom per task, not always aligning with the most commonly used idiom across the tools.

This paper is structured as follows. In Section 2, we provide the necessary background knowledge. Then, we discuss related work in Section 5. Section 3 elaborates on our research method. The results for RQ1 and RQ2 are presented in Section 4. Finally, we discuss our findings and conclude in Section 6.

2 Background

This section provides background on conformance checking, visual analytics, and their interplay in form of tasks in conformance checking.

Conformance Checking. Conformance checking is a sub-discipline of process mining, a family of techniques aimed to improve processes in a data-driven manner [1]. As input, conformance checking requires two objects: an *event log* and a *process model*. The event log contains recordings of process executions, so-called traces, each of them representing a sequence of events, with each event corresponding to the execution of a single activity. The process model formalizes the intended process behavior, described through a notation, being either imperative (i.e., defining the behavior that is allowed) or declarative (i.e., defining the behavior that is not allowed) [10]. By comparing actual to intended behavior, conformance checking can pinpoint deviations from the desired process [5]. Different techniques exist, such as rule checking, token-replay, or alignments. Most of them focus on the control-flow, i.e., the ordering of activities, whereas some are also able to consider data, resource, or time constraints [5]. For this paper, we focus solely on the results of the visualization, abstracting from algorithmic techniques to allow for a technology-agnostic view of conformance checking.

Visual Analytics. Visual analytics combines automated analysis techniques and interactive visualizations to enhance human understanding, reasoning, and decision-making for complex data sets [17]. The goal is to enable intuitive and useful data interpretation through visualizations and interactive capabilities [7, 17]. This allows users to see dynamics within the data, gain hidden insights, and adjust complexity to their needs [13, 20]. The focus is always on the underlying task that the user wants to perform with the visualization [17, 20]. Such a task can be defined as a "question concerning data that can be answered on the basis of the information contained in the data" [3, p. 646]. Thus, the visualization has to be suited to provide the answers for these tasks [17, 20]. Such visualizations contain one or many visualization idioms, also referred to as idioms, i.e., the visual element used [23]. Many different types of idioms exist, from simple bar charts to more complex ones like flow charts. An overview of common idioms can be found in the Data Visualization Catalogue [24].

Conformance Checking Tasks. Within conformance checking, there are multiple tasks that can be of interest. For these tasks, [22] developed a task taxonomy highlighting different tasks currently conducted in conformance checking based on case studies. The taxonomy consists of six dimensions:

1. *task goal*, i.e., why a user does this task (e.g., explore, confirm)
2. *task means*, i.e., how the task is carried out (e.g., discover, compare)
3. *data characteristics*, i.e., what facets of the data the task should reveal (e.g., process conformance, guideline violations)
4. *constraint type*, i.e., the perspective referred to (e.g., control-flow, data)
5. *data target*, i.e., the data on which the task is carried out (e.g., log, trace)
6. *data cardinality*, i.e., the cardinality of the data target (e.g., all, many)

In total, 102 tasks were found, some occuring more often than others.

3 Research Method

We followed a three-phase research model, shown in Figure 1. First, we selected the conformance checking tasks we wanted to analyze. In order to identify which idioms are used in existing tools for these tasks (RQ1), we developed a mapping of existing visualizations and the applied idioms for these tasks. This second step consisted of three sub-steps: (1) identifying task requirements, (2) assessing existing visualizations, (3) combining task requirements & existing idioms. Based on these results, we then conducted a survey to gain an understanding which idioms are preferred by users for these conformance checking tasks (RQ2).

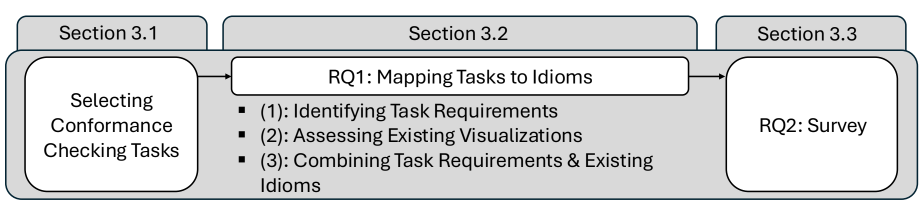

Fig. 1. Method Approach

3.1 Selecting Conformance Checking Tasks

First, we selected a set of conformance checking tasks to analyze next how existing visualizations address them. We built on the task taxonomy from [22], selecting the most frequently occurring tasks. This ensured that we captured relevant tasks likely to be incorporated by several tools. To obtain diverse tasks with a wide range of purposes, we abstracted from the dimensions *constraint type*, *data target*, and *data cardinality*, as these three dimensions do not change the purpose and are typically visualized similarly. This abstraction allows us to focus on the core of the task and ensures that visualizations are more likely to be found for each task. Consequently, we selected the ten most frequent realizations of the task dimensions 'task goal: task means, data characteristics', listed in Table 1. They account for 68 out of 102 identified conformance checking tasks.

Table 1. The 10 Conformance Checking Tasks

ID	Task Name	Task Dimensions	Question to be answered
1	Degree of Conformance	Describe: Derive, Process conformance	What is the overall degree of conformance between a (single) log and a set of guidelines?
2	Locations	Present: Present, Guideline violations	Where does the recorded behavior violate which guidelines?
3	Location Analysis	Explore: Identify, Guideline violations	Where exactly does the process execution differ from the guideline? What does alternative behavior look like?
4	Degree Comparison	Describe: Compare, Process conformance	How does the overall degree of conformance with a set of guidelines differ between multiple logs or traces?
5	Location Details	Describe: Identify, Guideline violations	How exactly does the process execution differ from the guidelines? What behavior was prescribed by the guidelines and what behavior was executed instead?
6	Patterns with Frequency	Explore: Summarize, Guideline violations	What type of guideline violation happened in different traces? How often do they happen?
7	Causes	Explain: Discover, Reasons for guideline violations	What control-flow, data, resource, or time attributes of events, traces, or logs lead to guideline violations?
8	Frequency	Describe: Present, Conformance distribution	How often did a specific guideline violation occur?
9	Distribution	Describe: Present, Conformance Distribution	Which percentage of traces in the log fall into which conformance category?
10	Outcome	Present: Compare, Impact of conformance on process outcome	Do cases with a higher degree of conformance lead to a higher probability of a positive process outcome?

3.2 Mapping Tasks to Idioms

To answer RQ1, we mapped the selected tasks to existing visualizations and their idioms in three sub-steps: (1) identifying task requirements, (2) assessing existing visualizations, (3) combining task requirements & existing idioms.

(1) Identifying Task Requirements. First, we aimed to gain insights on what requirements conformance checking tasks place on visualizations in order to understand what these visualizations must portray to fulfill the tasks. Unlike the characteristics in the taxonomy, these requirement are essential and task specific. To derive them, we used existing works that outline in what cases visualizations fulfill a task [22, 23]. As a result, we identified three task requirements:

(1) *Data scope:* The task requires visualizing input data with a specific scope, referring to constraint type, data granularity, or cardinality [22]. Although

we abstracted from these dimensions during task selection to focus on a diverse range of tasks, they are still a necessary requirement to determine what data is needed as an input for the task. For example, for task 1 the log is required for data granularity, as otherwise the task cannot be fulfilled.

(2) *Data object:* The task requires specific data objects to be presented as the output. We grouped the required data objects of the tasks according to the *What* categories of conformance checking visualization from [23], including, e.g., the conformance rate or the number of deviations. For example, for task 1 the conformance rate needs to be portrayed to fulfill the task.

(3) *Goal:* The task has a specific motivation defining the visualization's goal. We categorized the task's goal based on the four *Why* dimensions of conformance checking visualization from [23]: 1) quantify conformance, 2) break down & compare conformance, 3) localize & show deviations, and 4) explain & diagnose deviations. For example, for task 1 the goal is quantify conformance.

For each previously selected task, we defined the specifications of the three requirements. The result was an overview of requirements for each task that a visualization should fulfill to be applicable for the task, available online.[1]

(2) Assessing Existing Visualizations. In the next step, we wanted to gain an overview of what visualizations currently exist for conformance checking tasks. Thus, we selected all existing and accessible process mining tools supporting conformance checking [11,25]. The resulting selection consists of six commercial tools (Apromore, Aris PM, Celonis, SAP Signavio, Mindzie, IBM PM) and three academic tools (PMTK, ProM[2], PM4Py[3]). To achieve comparability between the visualizations within these tools, we applied them all to the same dataset. For that, we chose the road traffic fine management process due to its adequate size and complexity [8]. The corresponding process model was taken from [23].

Based on event log and process model, we examined the visualizations in all tools, thus only considering already existing ones. To abstract and generalize existing visualizations, we assigned each visualization to an idiom from the Data Visualization Catalogue [24], e.g., bar chart, scatterplot, or heat map. If a visualization could not be assigned to an idiom in the catalogue, we created a new idiom for it (i.e., tile metric and table were added). Further, some tools used idioms combined with tables, which we accounted for with combined idioms (e.g., flow charts & tables). Last, we subdivided the idiom flow chart into the two sub-categories flow chart (e.g., chevron diagrams, i.e., linear diagrams of single traces using v-shaped arrowheads) and flow chart+ (process model diagrams, such as BPMNs) as the difference of simple flow charts and process models should be reflected. The result was a list of 23 idioms used by the tools to represent conformance checking results, which can be found online.[4]

[1] Overview of Requirements for Tasks

[2] We used four ProM plug-ins: Multi-perspective Process Explorer, Replay a Log on Petri Net for Conformance, Mine with Inductive Visual Miner, Perform Predictions of Business Process Feature.

[3] We applied and visualized the implementation of alignments and token-replay [4].

[4] List of 23 Idioms and Exemplary Screenshots available upon request.

(3) Combining Task Requirements & Existing Idioms. Lastly, we combined the findings from the previous steps by assessing which of the currently used idioms are suitable for the tasks. For each task and idiom pair, we checked if the idiom fulfills the identified requirements of the task. An idiom was considered for the task if all task requirements were fulfilled. In several cases, elements of the data scope requirement refer to multiple possible scopes (e.g., both data and control-flow perspective or log and trace granularity). However, existing visualizations often tend to focus only on a single scope at once (e.g., only on control-flow or only on log level). To account for that, we counted the requirement *data scope* to be fulfilled if already one possible scope was visualized. Ten idioms were used as a visualization but not mapped to any of the ten tasks, meaning we removed them from our list, e.g., gantt chart. The result was a matrix of ten tasks by 13 idioms (Figure 2), where each task is mapped to the idioms that fulfill it. If an idiom is used for a specific task, the matrix entry corresponds to the number of tools that used this idiom for the task. Otherwise, it is empty as the selected idiom was not offered for the specific task.

3.3 Survey

After identifying what idioms currently exist for the different tasks, we now aimed to empirically assess which of these idioms are preferred by users for which task to answer RQ2. For that, we conducted a survey, of which screenshots can be found online.[5] After introducing the survey goal as well as conformance checking background and collecting consent, we presented the tasks one by one including all mapped idioms. Thereby, we reduced the ten tasks to six by aggregating those that were similar and employed identical idioms, differing only in the number of idioms used. In particular, task 1 and 4 were combined, as task 4 only extends task 1 by a comparison of the same visualizations as in task 1. Task 2, 3 and 5 all localize deviations, differing primarily in the analysis detail level, but using identical idioms. Thus, we grouped them together. The same applied to task 6 and 8, where the same set of idioms are provided by the tools. Tasks 7, 9, and 10 were not combined, as their requirements and the used idioms are sufficiently distinct. For each grouped task, we presented those idioms from the 13 identified ones that were used in the tools for this task. Then, participants were asked to rank the idioms according to their preference. The result was a task-specific ranking of all idioms, allowing us to infer which idioms are preferred over others.

Twenty participants took part in our survey, recruited from our university or professional network. Detailed knowledge of conformance checking was not required, as all necessary concepts were explained at the start. Only complete surveys were included, resulting in a final sample of 20 participants (11 female, 9 male), comprising 13 students, 4 practitioners, and 3 researchers with varying levels of process mining expertise (2 novice, 10 basic, 7 advanced, 2 expert).

[5] Screenshots of the Online Survey

4 Results

This section presents the two-folded results of our work. First, we answer RQ1 by providing an overview of the conformance checking tasks with the currently used idioms in Section 3.2. Second, we outline the insights from our survey on the user preference of the idioms for the specific tasks to answer RQ2 in Section 3.3.

4.1 RQ1: Mapping Task to Idioms

We identified 48 pairs of tasks and idioms, shown in Figure 2. For each task, there are two to seven idioms used. If an idiom is used for a specific task, the matrix entry corresponds to the number of tools that use this idiom for this task.

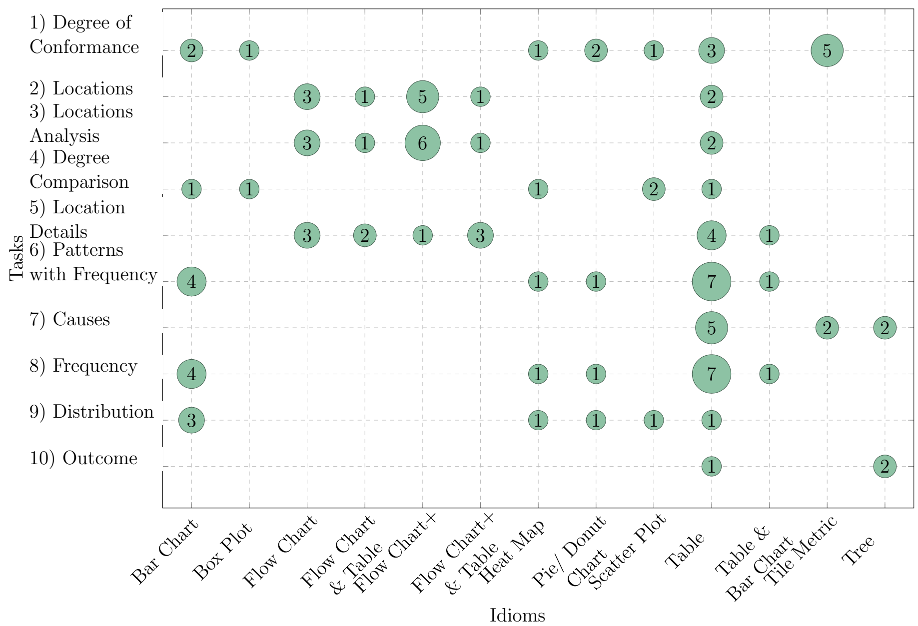

Fig. 2. Overview of Conformance Checking Task and Existing Visualization Idioms

When analyzing the results from an idiom perspective, the most common idiom across the tasks is a table, occurring for each task, followed by bar chart and heatmap, both used for five tasks. Trees, tile metrics, and box plots are used the least, occurring only for two tasks each. Some tasks are visualized through many different idioms, such as task 1 by seven idioms. In contrast, only two idioms are available for task 10. Flow charts are only used for three tasks (task 2, 3, and 5), as the violation location seems less relevant for the other tasks.

When analyzing the results from a task perspective, a clear focus on specific tasks and tendency of specific idioms for each task by the tools can be identified. Tasks 1, 2, 3, 6, 7, and 8 have at least one idiom offered by five or more tools.

Considering the tendency of specific idioms by the tools, for task 6 and 8 tables are used by seven tools, followed by bar charts, in four tools. For task 3, available in six tools, and task 2, available in five tools, flow chart+, i.e., BPMNs, DFGs or Petri Nets, are most often used. For task 7 and 5 tables and for task 1 tile metrics are most common, offered by four or more tools. Moreover, some tasks use identical idioms, such as tasks 2 and 3 or tasks 6 and 8, likely due to similar task requirements (e.g., task 3 is a more user-centered analysis of task 2).

4.2 RQ2: Users' Visualization Preferences for the Tasks

Our findings regarding the user preferences are outlined in Figure 3, which illustrate the mean rating values for the task-idiom pairs from our survey, thus answering RQ2. The rating scale depends on the number of idioms available for the tasks. For example, since the combination of task 1 and 4, has seven possible idioms, its ratings range from 1 to 7. A lower score indicates a higher user preference. The tile colors, normalized across the tasks, emphasize this as well, with dark green showing a high and dark red showing a low preference.

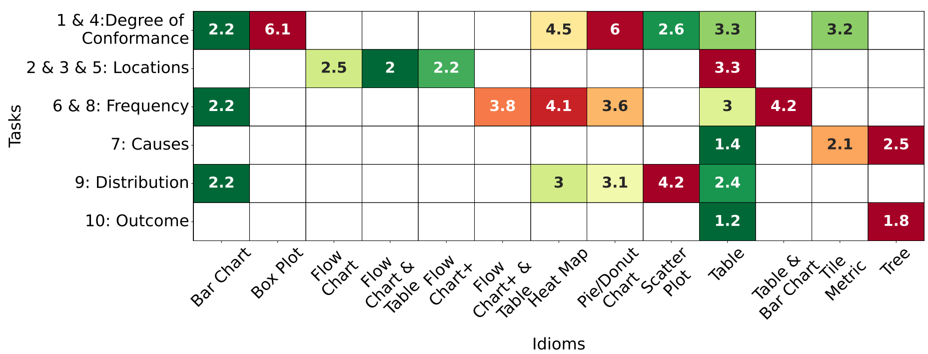

Fig. 3. User Preference Scores: Cells show mean rankings per idiom and task (lower is better), with colors (normalized) from green (most preferred) to red (least preferred).

The results show a preference for one idiom per task, not always aligning with the most commonly used idiom across the tools. Notably, users prefer tables and bar charts for most tasks, while less common idioms, such as boxplots and trees, tend to rank lower. For location tasks (task 2, 3, and 5), flow chart, flow chart & table, and flow chart+ receive high ratings, compared to tables. An example of a discrepancy between the most common idiom across the tools and the user preferences are tile metrics for task 1. In particular, for task 1, users prefer bar charts and scatterplots, with tile metrics coming third. In contrast, tile metrics are used by seven tools for this task, whereas only one tool uses a scatterplot and two use a bar chart. Another example is task 6 & 8, where users prefer bar charts followed by tables, but the tools use tables more often than bar charts.

Additionally, we analyzed the variance in the rankings, shown in Figure 4. Although some variance exists, we can identify a clear preference of idioms for

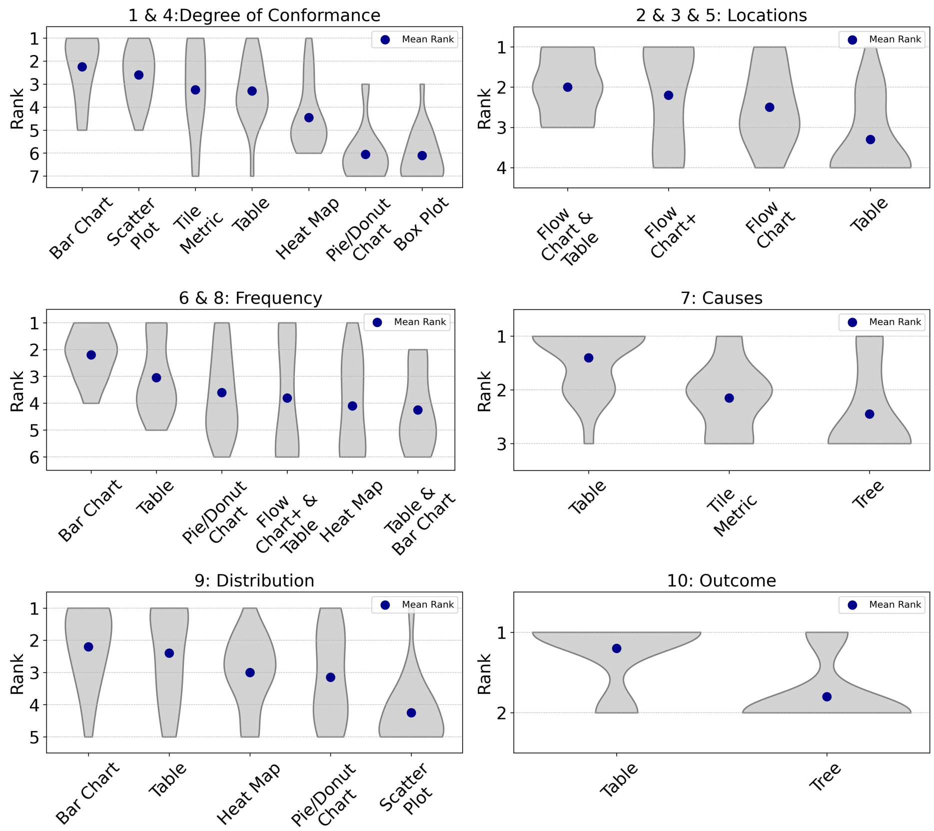

Fig. 4. Distribution of user-assigned ranks (y-axis) for each idiom (x-axis) per task

each task. For task 1 & 4, 6 & 8, and 9 users clearly prefer bar charts. For location tasks, flow chart & table, only with a slight advantage, followed by flow chart+, are preferred. For these tasks, the differences in rank between the idioms are rather small. For task 7 and 10, a clear preference for tables can be noted. Overall, the variance of the idiom-task combination differs. For example, boxplots and in the case of task 9 scatterplots show a consistently narrow distribution, forming a tube-like shape that indicates low variance in rankings. In contrast some idioms, such as flow chart+ & table for tasks 6 & 8 or pie/donut charts for task 9, are rated very ambiguously. They show a high variance, with some users ranking them as the best and others as the worst option for the specific task.

5 Related Work

In the following section, we elaborate on related work and our contribution.

Visual Analytics in Conformance Checking. The combination of visual analytics and process mining was first mentioned by van der Aalst et al. [2]. However, since then research had been limited, until it recently gained traction [9]. Combining both fields can help to better understand and optimize processes based on an improved user analysis supported by suitable visualizations [23]. In this light, research has analyzed and assessed process mining visualizations [13, 18, 19, 22] and improve them or develop new ones with visual analytics in mind [12, 14, 16]. Only few works looked at conformance checking visualization. First, [23] applied an analysis framework [20] to identify how conformance checking results are visualized in available academic and commercial tools. Second, [22] developed the conformance checking task taxonomy, which lays the foundation of our work. Last, [15] created a taxonomy for an overview of the information currently contained in existing conformance checking visualizations.

User Preference in Visual Analytics. In visual analytics user preference is one common criteria to assess and compare visualizations [21]. For example, [6] compared three different visualizations for weighted networks and asked the participants to rank them based on their preference. [26] also collected user preference as rankings of different two-dimensional visualizations for specific tasks.

Our Contribution. Compared to prior work on conformance checking visualization, we investigate how underlying tasks are currently visualized in existing tools and which of these visualizations users prefer. To our knowledge, no previous study has addressed either one of these aspects. Further, we show how user preference can be used in process mining to assess and compare visualizations, representing an initial step with considerable potential for future research.

6 Discussion & Conclusion

The aim of this paper was to identify which idioms are currently used by existing tools to visualize a set of conformance checking tasks (RQ1) and which of these idioms are preferred by users for these tasks (RQ2). By following a three-phase research method, we identified the idioms used in existing tools and gained first insights on the user preferences. Our results offer valuable new insights and follow the call by [22] to link visualizations to tasks. Moreover, our survey is one of the first to consider user preferences for conformance checking visualization.

Our work has practical and scientific implications. Researchers can deepen their understanding of users as well as user preferences of visualizations for conformance checking tasks. Practitioners can use our results to select idioms for a given task by treating all existing idioms as options and the most preferred idiom as a suggestion. For tool vendors, our results offer guidance on which idioms to implement for specific tasks to adhere to user preferences and increase the spectrum of supported tasks with the tool's idioms.

Our work is subject to multiple limitations. First, we were limited to the visualizations currently available in the accessible tools. Thus, important insights from the tools we did not have access to might have been missed. However, with the tools used in this paper the majority of the market for conformance checking is covered. Related to that, we cannot assure whether imperative or declarative conformance checking was used by most visualizations as especially commercial tools do not reveal this information. We do abstract from object-centric conformance checking approaches since they were rarely implemented in the tools and can differ significantly in the data and, thus, visualization. Although we might have missed visualizations due to this abstraction, it is necessary to achieve comparability between the visualizations across tools whereas rare object-centric visualizations would distort this comparability. Furthermore, we only used one dataset, which may have resulted in the omission of specific tool features and visualizations that were unavailable for this dataset, e.g., visualizations for specific attributes. Yet, it is a well-established dataset covering additional perspectives besides the control-flow perspective. Moreover, in our survey, we combined some of the tasks through which we may have missed some insights. Further, the strict ranking design forced participants to choose a preference and did not allow equal ratings, which limits comparability, yet it ensured definite choices and thereby eliminated ambiguity in the results. Also, using screenshots from different tools may have introduced bias due to familiarity or preference of tools, and although all visualizations conveyed sufficient information to complete the tasks, the varying levels of detail could have influenced their comparability. Regardless, it shows first insights on how visualizations are perceived. Lastly, while the number of participants is sufficient to gain initial insights of user preferences, more participants would strengthen these insights.

Despite these limitations, our work provides a valuable foundation and opportunities for future research. First, our work could be extended to more conformance checking tasks and could be conducted with tool-independent visualizations to reduce biases. Additionally, a novel survey, preferably with more participants, could analyze whether user preferences are driven by familiarity, data literacy, or other factors. Further, as preference is only one way to assess visualizations, other criteria for suitability should be considered, such as usability, accessibility, or understandability. Future experiments could also measure efficiency and effectiveness of the different idioms for each task. Last, the analysis of conformance checking tasks and suitable visualizations could be broadened beyond existing tools and implementations, e.g., through newly developed idioms.

In conclusion, our work builds on the task taxonomy by [22] and connects ten conformance checking tasks to currently existing visualizations in academic and commercial tools. Moreover, first insights on user preferences for these tasks are identified, showing that they do not always align with the most commonly used idiom in the tools. Thus, it contributes to research by bridging the gap between conformance checking and visual analytics, while offering future research paths.

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