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Designing and Evaluating a Structural Model for Conformance Checking Visualizations

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Abstract

Conformance checking is one of the main operations of process mining with which enterprises can analyse their business processes and consider whether their behaviour follows the desired one, or whether and where it deviates. In order to meaningfully present the results of this family of techniques, an appropriate and accessible visual interaction platform is necessary. However, existing work has focussed primarily on technical aspects, and less on user concerns. To this end, we combine visual analytics concepts with conformance checking. We derive a structural model from literature, which summarizes conformance checking applications, and helps in deriving descriptive models for concrete analyses. We implement our concept prototypically, and evaluate it in a user study, thereby showing the structural model's ability to help in creating accessible and appropriate visualizations for conformance checking.

CCS Concepts

• Human-centered computing* → *Visual analytics; • Information systems* → *Data mining; • Applied computing* → *Business process management;

1. Introduction

Conformance checking is a technique in the field of *business process management* (BPM) that helps organisations to assess and maintain compliance with rules, mitigate risks and avoid potential penalties or legal consequences [CVDSW18]. It is related to process mining and uses information from recorded behaviour of business processes in the form of *event logs*, to assess whether processes followed the desired behaviour, often represented in a process model, or whether they deviated [vdA16]. However, the visualization of conformance checking results can be challenging in the face of vast amounts of process execution data. To fruitfully apply conformance checking, it is essential to visualise its results appropriately and accessibly [RPGK23].

Many of the visual representations that are commonly used for conformance checking were created to convey research-related findings to a scholarly audience [PR21]. Further, many conformance checking approaches seem not to have grounded their visualisation decisions in comprehensive user studies that incorporate feedback from potential target users early in the process [Gsc17]. Typically, the feedback given by conformance checking techniques is a generalised fitness measure between the log and the model [DSMB19]. Such feedback may fall short in providing organisations with sufficient detail necessary to make informed conclusions about conformance issues [RPGK23]. Thus, we see a need to provide a concept with which meaningful conformance checking visualizations can be derived in a structured manner.

By integrating principles from *visual analytics* into the conformance checking domain, many of the current visualization-related limitations can be addressed. Visual analytics enables a transformation of data into visual representations, potentially streamlining the process for analysts to understand discrepancies between intended and actual processes, and to pinpoint underlying causes. Consequently, organisations can ensure both process conformance and continuous improvement, aligning their operations more closely with their objectives. Its application in the area of conformance checking thus holds potential for end users, such as business analysts, to take action based on conformance checking results in a more informed manner. Thus, the *objective* of this work is to provide a concept which helps in designing useful, i.e., *appropriate* and *accessible*, visualizations for conformance checking tasks. To this end, a concept for representing conformance checking results is designed and implemented according to visual analytics concepts in the following. Based on a *structural model*, describing and summarizing the aspects and relation of conformance checking applications present in literature and practice, we describe possible concrete visualizations and implement the concept prototypically. We demonstrate the *appropriateness* (i.e., it is consistent with the data,

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fit to the purpose, has sufficient scope, and is comprehensive; thus it should be useful for successfully solving conformance checking tasks [ALA*18]) and evaluate the *accessibility* (i.e., how well does it convey conformance checking results regardless of prior knowledge or background of users) of the concept. The remainder of this article is organized as follows: First, we present background information and related work. Then, we describe our research method, after which we present the results and their evaluation. Finally, the work is discussed, conclusions are drawn, and future work is presented.

2. Background and Related Work

2.1. Conformance Checking

Alongside *discovery* and *enhancement*, conformance checking is a central technique of *process mining*, focussing on the analysis of event data generated during process execution [vdA16]. The focus lies in comparing the actual behaviour of process instances recorded in event logs with the behaviour defined by a process model, identifying deviations and supporting alignment and improvement of processes [CVDSW18]. Considerations include whether process executions fit to a prescriptive process model, whether rule violations have been recorded, or whether a process model of a process sufficiently reflects its executions [CVDSW18, CvDW22]. Thus, business analysts are enabled to effectively assess business processes and properties of their execution behaviour [CVDSW18]. Notably, the focus of conformance checking research has been mainly on developing efficient algorithms, and less on visualization concerns [RPGK23].

2.2. Visual Analytics

Visual analytics represents the combination of data analysis and interactive visualisation techniques. Its core purpose lies in facilitating decision-making and extracting insights from large and complex data sets. Further, it integrates human judgment with computational capabilities, enabling efficient processing and analysis of data. By visually representing information, visual analytics empowers users to engage with data, explore patterns, draw conclusions, and ultimately make more informed decisions [CT05].

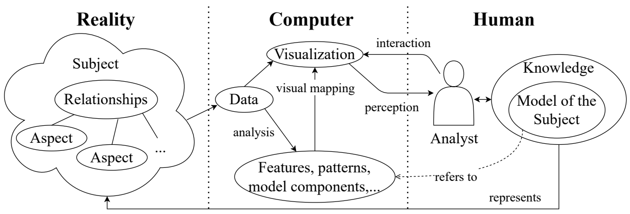

Figure 1: *Visual data exploration process, adapted from [ALA*18]*

[ALA*18] proposes a visual data exploration process that draws upon the concept of *reality*, which embodies the *subject* of analysis and multiple *aspects* that constitute this subject. It suggests that the data which is analysed is *derived* from reality, distinguishing between the real world and the data that represents it. A *structural model* explicitly describes relations between the subject's aspect and, is either provided as part of the analysis problem under consideration, or part of the analyst's prior knowledge. Together with data representing reality and concrete tasks to address, the structural model is the basis for an analyst to answer their tasks. Furthermore, the process illustrates the translation of data into knowledge of a subject. The aspects and relationships of the subject in reality are captured as data through *visual mapping*. Moreover, the process introduces the concept of *interaction*, emphasising that the human analyst plays an active role in the analysis. Through interaction, there is a *refinement* step, signifying iterative improvement.

2.3. Related Work

Several studies have investigated the combination of conformance checking and visual analytics, focussed on how conformance checking results are visualised in process mining tools and identifying the challenges and future research directions in presenting these results in a user-friendly manner. In [RPGK23], the authors analyse the visualisation capabilities of nine academic and seven commercial process mining tools. The study finds that the visualisation of conformance checking results has not been widely considered in research, and proposes a framework for future research on conformance checking visualisation, breaking down the *Why*, *What*, and *How* aspects of visualisation (see [BM13]). [KMW19] finds that results of conformance checking applications are usually represented via bar charts, tables or process models, and invites further research into conformance-checking-specific visualizations. Moreover, [GRM21] develops a visualization for constraints that span processes or instances, and finds that expert users find coloured representations for providing an overview, and text-based representations for providing detailed insights, particularly useful. Finally. [YM24] provides a comprehensive survey of different approaches for event sequence analysis and visualisation, specifically focusing on the integration of process mining and information visualisation. It explores various visualisation techniques and categories used in the analysis of event sequence data, providing valuable insights for the combination of conformance checking and visual analytics in the context of business process compliance. Overall, the related work highlights the need to visualise conformance checking results in an approachable and understandable manner for non-expert users. It emphasises the importance of understanding users' information needs and preferences, as well as developing and evaluating suitable visualisation idioms.

3. Method

To develop and evaluate a concept for conformance checking visualization, we utilize a *design science research* (DSR) approach [PTRC07, Wie14]. In DSR, the focus lies on creating and evaluating artefacts for solving explicit problems, and thereby acquiring knowledge [Rec13]. In doing so, we follow an *objective-centered* approach, in which, based on *defined solution objectives*, an artefact is iteratively *designed and developed*. The objective is concretely defined in Sec. 1. Based on this, the *artifact*, consisting of a concept for representing conformance checking applications and results, is designed and developed. For the *demonstration*, the conceptual visual representation models for conformance checking are implemented in a prototype. By translating the conceptual artefact into a tangible tool, we can *evaluate* it via a user study, following [KHI*03], to investigate the appropriateness and accessibility of the prototype, and thus, the usefulness of the artefact.

4. Results

4.1. Structural Model

First, we present a structural model in Fig. 2, following [ALA*18], which provides an overview of the domain of conformance checking, its aspect and relations, and thus potential tasks therein. Here, tasks are meant to represent any question that is assessable by conformance checking techniques, regardless of its purpose and domain. While some tasks may be visualized more appropriately given a specific purpose and setting, we focus on analyses that stem directly from the application of conformance checking, to limit the scope of our work. Further, the structural model was developed by identifying, based on conformance checking literature such as [CVDSW18, DSMB19], what aspects of conformance checking techniques serve as input and directly influence the output. This allows identifying what conformance checking visualization mechanisms need to take into account in terms of input. In making the structural model and interaction explicit, we provide a useful representation of prior knowledge an analyst would otherwise need to have in order to engage with conformance checking visualizations. As shown in Fig. 2, a *conformance checking application* has *input formats* (e.g., XES), uses conformance *techniques* (e.g., token-based or alignment-based [DSMB19]), has *process constraints* (e.g., the control flow of a prescriptive process model, or temporal constraints between activities) and *aggregation levels* (e.g., log-model, where an entire log is checked, or event-model, where the focus lies on individual events), and produces *conformance checking results*. These can either be *conformance measures* or *conformance diagnostics*, which both require visual representations.

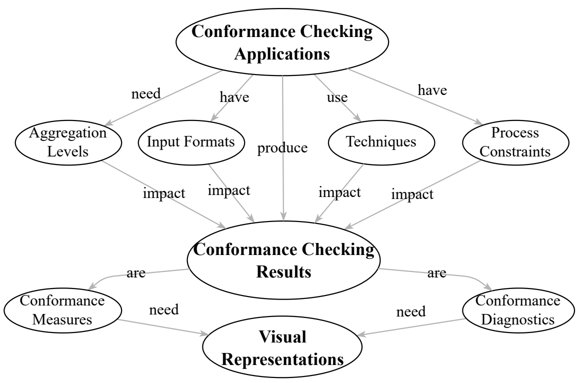

Figure 2: *Structural model of conformance checking applications. An extended version is available online [KKP24]*

Conformance measures provide high-level insights into the adherence of actual process executions to related process models or process constraints. These measures, such as quality metrics (e.g., fitness, precision, and generalisation) offer a numeric representation of how closely a process is executed in relation to its intended design. Other key metrics include the number of conformant versus non-conformant cases, the total number of deviations observed, and an overall conformance rate. Essentially, these measures give a quantitative overview of conformance at a high-level perspective [CVDSW18, ALH11]. *Conformance diagnostics*, on the other hand, aim at a lower level of analysis, focussing on concrete deviations in process executions. These diagnostics pinpoint specific deviation categories, often associated with particular conformance checking techniques, for instance ”log moves” or ”model moves” when using the alignment technique. They also may identify recurring deviation patterns, provide detailed insights, and can be used in finding root causes of deviations. These diagnostics are essential for understanding the specifics of where and how processes deviate from their intended behaviour [CVDSW18, ALH11].

4.2. Visualization Concept

The structural model represents the analysis subject and its aspects, being conformance checking applications. From this structural model, in conjunction with data and analytic tasks, *descriptive models* can be derived. These descriptive models provide descriptions and explanations of aspects of reality and their relation [ALA*18]. Here, we present descriptive models abstractly, based on common result types of conformance checking tasks. For both possible result types, being conformance measures and conformance diagnostics, we inductively identify possible *abstract* representations based on literature and existing visualization tools [CVDSW18, DSMB19, RPGK23]. Abstract representations, as opposed to concrete ones, are not *implemented* in the sense that a user could see them. Only in translating them into concrete representations, e.g. through implementing them in a dashboard and plugging in concrete data, can they transmit actual information. The relation between the structural and descriptive models is displayed in Fig. 3.

For *conformance measures*, we identify the following abstract representations:

- *Numeric representations* quantify conformance. These can be raw numbers, percentages of deviation, and provide a direct, numeric, sense of conformance, such as the quality metrics fitness, simplicity, precision, and generalization [DSMB19]
- *Support representations* encompass visualisations like charts, graphs, and plots that aid in understanding and interpreting conformance measures. They offer a visual summary and allow for comparison and identification of outliers.

For *conformance diagnostics*, we identify the following abstract representations:

- *Event log representations* represent the log's events, enhanced with information about conformance, in a structured format with the events as rows and their attributes as columns. This can be realised through a table or spreadsheet, usually following the event log's structured format [WSA*22]. They provide granular insights into each event, its attributes, conformance status and other related data, with the possibility to filter or sort the data.
- *Process model representations* capture graphical representations of the desired process flow, decorated with conformance information. By overlaying deviations onto the process model, areas of non-conformance become visible. This allows analysts to

gain an understanding of the process behaviour and its deviations [ALH11].

- *Sequence representations* show events in a log, sequenced in temporal order. Enhanced with textual overlays, they could provide context or highlight deviations, which is useful for identifying deviating behaviour [YM24, Yan19].
- *Helicopter representations* are two-dimensional plots that give a "top-down" view of conformance information across dimensions of interest (e.g., temporal or organizational). In literature, this is called a *helicopter view* [ALH11]. Typical representations are dotted charts, which can visualise events directly as coloured dots. These plots can give an overview of the specified dimensions, while at the same time allowing the user to drill down into each data point.

These abstract representations can be instantiated into *concrete representations* through implementation, e.g., by way of a dashboard, and thus, describe concrete aspects of reality. These concrete representations comprise end points in the overall concept, which end users perceive and through which they interact with the concrete representations.

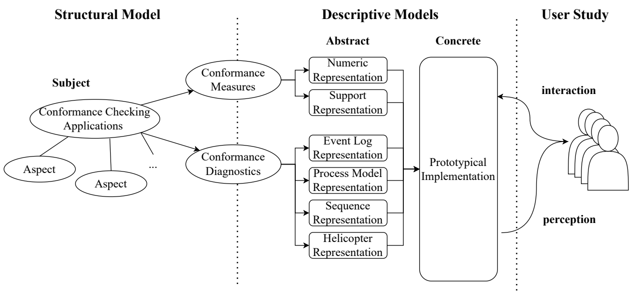

Figure 3: *Overview of the concept presented in this work, consisting of a structural model, abstract and concrete representations, a prototypical implementation, and its evaluation.*

4.3. Prototype

Based on the structural and descriptive models, and the identified abstract representations, we implemented a prototypical conformance checking toolkit, which instantiates abstract representations into concrete ones. To effectively conduct a user study, we opted for a web data dashboard, which allows access without any need for installation. We utilize *PM4PY* [BvS23], an open-source process mining platform, for a conformance checking implementation. We also employ the open-source web dashboard framework *Streamlit*, and *PyCharm* for visualization purposes. For each possible abstract representation, we aim to provide at least one concrete one.

The prototype provides the following capabilities along the structural model:

1. *.csv* event logs and process models in the form of *.pnml* petri nets can be uploaded. Consequently, our dashboard only supports control-flow related process constraints. Support for time, data, and resource constraints could be added in the future.
2. In terms of technique, alignment-based conformance checking is supported.
3. As for aggregation levels, we support *log-model*, *variant-model case-model* and *event-model*.
4. For conformance measures, we elicit fitness values, numbers of deviations, and numbers of conformant events.
5. For conformance diagnostics, we utilize log moves, model moves, and synchronous moves.

As for the descriptive models, the concrete visual representations implemented are (1) *metrics* and (2) *pie chart* (both conformance measures); (3) *alignment log*; (4) *alignment model*; (5) *variant table*; and (6) *alignment plot* (all conformance diagnostics). In terms of user interaction, the implementation provides multiple aggregation levels which influence the alignment plot, and the event log and alignment log can be filtered and sorted. Further, all concrete representations can be moved and re-sized according to user need. Due to space limitations, we provide screenshots of the concrete visualizations and the entire structural model as supplementary material online [KKP24].

4.4. Evaluation

Based on the proof-of-concept implementation, we conducted a user study to assess the visualizations' *appropriateness* and *accessibility* based on the user's perception of, and interaction with, our implementation. This allows us to show that the structural model contributes to providing useful and intuitive visualizations. Fig. 3 illustrates this further. The participants were provided with a structured online survey. First, they answered questions regarding prior knowledge of process mining and data visualization. Second, they were guided through the conformance checking dashboard by having to solve 10 different conformance checking tasks (such as identifying underlying patterns for deviating events) and determining their solution. Finally, the participants evaluated their experience and reported on the perceived appropriateness and accessibility of the visual representations. The full list of questions and tasks is available online as supplementary material [KKP24]. For *appropriateness*, we assessed 1.) the objective user performance across all tasks (in % of correct answers); and 2.) the perceived appropriateness of the concrete visualizations provided (i.e., whether users found the prototype useful for successfully solving conformance checking tasks, on a 6-step Likert scale, with 0.0 not appropriate – 1.0 very appropriate). For *accessibility*, we assessed 1.) the subjective perceived usability (on a 6-step Likert scale, with 0.0 not useable and 1.0 very useable); 2.) the perceived intuitiveness, also in comparison to other process mining tools (on a 6-step Likert scale, with 0.0 not intuitive and 1.0 very intuitive); and 3.), the reported use of concrete visualizations for solving tasks.

In total, the survey was completed in its entirety by $n = 21$ participants with varying degrees of prior knowledge and experience. According to [HS10], this comprises a sufficient sample size for a usability evaluation. Figure 4 provides a summary of the main measurements for objective task performance, subjective intuitiveness, and subjective usability. Note the small box of "intuitiveness" due to a prevalence of 0.8 ratings.

4.4.1. Appropriateness

We find that participants consistently solve conformance checking tasks with a high median performance of 0.9, but that, as expected,

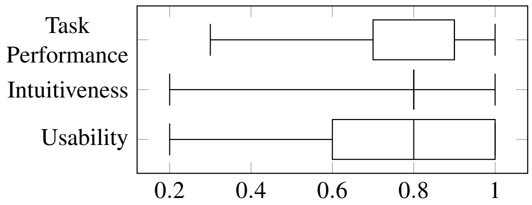

Figure 4: *Measured user performance, perceived intuitiveness, and perceived usability of the proof-of-concept implementation. The scale goes from very low (0.0) to very high (1.0).*

knowledge in the area of conformance checking contributes to better performance. In Table 4.4.1, the reported use and median perceived appropriateness of the concrete visual representations are displayed. Here, metrics, alignment log, variant table, and alignment plot appear to be appropriate visualizations for conformance checking tasks, with high uses for solving tasks successfully, and a relatively high reported appropriateness. On the other hand, the alignment model and pie chart were perceived as less appropriate and used less frequently.

Result Group	Visual Representation	Actual Usage	Median Appropriateness
Measures	Metrics	26	0.8
	Pie Chart	15	0.4
Diagnostics	Alignment Log	44	0.6
	Alignment Model	6	0.4
	Variant Table	42	0.8
	Alignment Plot	65	0.8

Table 1: *Reported uses and median appropriateness of concrete visualizations implemented in the prototype*

4.4.2. Accessibility

A high number of users reported the dashboard as usable, with a median of 0.8. As for intuitiveness, a majority (median 0.8) of the respondents found the prototype easy to engage with. It seemed to be feasible for users to operate it without extensive guidance. Additionally, in comparison to existing process mining tools, the dashboard was perceived as *more* intuitive (median 0.6, max. 1), with all users rating it as, to at least some degree, more intuitive. This suggests that the dashboard has potentially addressed several user concerns of existing process mining tools, presumably due to the use of multiple representations and result types, as well as the interactive nature of the dashboard itself.

5. Discussion

As we have seen, the user study has produced good results regarding a) task performance and perceived appropriateness; b) perceived usability and perceived intuitiveness. Hence, we conclude to have met the objectives of providing a mechanism for visualizing conformance checking applications that is both appropriate and accessible. This, we posit, is the contribution of having derived a structural model for conformance checking tasks, thus externalizing previously required expert knowledge, and deriving descriptive models and an implementation based on that. Hence, we have demonstrated and evaluated the utility of our artefact, being an approach for visualizing conformance checking applications and results, based on an explicit structural model. Further, some findings were particularly relevant for researchers and practitioners that further develop appropriate visualizations: Pie charts were particularly unpopular in our study and not perceived as appropriate for solving tasks, as was the alignment model. Log and variant representations, as well as alignment plots were, on the other hand, well-received. Thus, the context that a concrete representation provides, also w.r.t. the behaviour that led to individual violations, seems more important than process model or numeric representations.

Several threats remain to the validity of our research: First, the structural model might benefit from a validation iteration with conformance checking experts. Second, the prototype was limited in terms of functionality, and hence, is not provided as an artifact. Developing it further and conducting an evaluation with real tasks in real-world settings would allow us to further reason about the appropriateness and accessibility than an artificial study setting. Nonetheless, the results regarding our objectives seem promising, especially given the number of participants and their success in solving conformance checking tasks. Finally, the comparison of intuitiveness with existing process mining tools was done based on subjective reports, and would gain more rigour from an empirical investigation. Nonetheless, having all participants agree that our concept provided to at least some degree a more intuitive solution hints at the conformance checking structure model's potential in deriving accessible visualizations.

6. Conclusions and Future Work

In this work, we have drawn upon conformance checking literature and visual analytics concepts to derive a structural model of conformance checking applications. In developing a concept for creating conformance checking visualizations, we have utilized the structural model to create a prototypical implementation that comprises various instantiated descriptive models. An evaluation through a user study indicates that the prototype is perceived by users as appropriate and accessible, and therefore, underlines the contribution of the structural model provided herein. In the future, we plan to expand the analysis and evaluation, to include empirical comparisons with other process mining tools, instead of a subjective comparison based on user preference. We plan to develop the prototypical implementation, which has been met with positive user feedback, into a full-fledged artifact to be released to researchers and practitioners. Quantitative analyses could help us more concretely assess hypotheses about the concrete visualizations we implemented, and thereby help us understand better the overall concept. Finally, concretizing a structural model for a specific domain and use case could contribute to making the conceptualization of conformance checking tasks and the corresponding concrete representations more tangible.

Acknowledgements

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