Reviewing Conformance Checking Uses for Run-Time Regulatory Compliance*

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Abstract. Organizations manage numerous business processes to deliver their products and services to customers effectively while adhering to laws, industry standards, or guidelines, summarized here as regulations. Compliance checking involves verifying whether these processes align with the relevant regulations. There has been an increase in the availability of process execution data within IT systems that support these business processes. One valuable operation of process mining – *conformance checking* – enables a comparison between the actual execution behaviour, represented as event logs, and the desired behaviour outlined in a process model. As a result, conformance checking can be employed for run-time compliance checking, a concept that has been explored and enhanced through various research studies. This work presents a systematic literature review on regulatory compliance checking with conformance checking that offers insights into different domains, the operationalization of regulations, applied conformance checking techniques, and visualizations. Our analysis reveals that several steps are still performed manually, but we anticipate that future advancements in automation can significantly support the goals of run-time compliance checking.

Keywords: Conformance Checking · Regulations · Process Compliance · Literature Review.

1 Introduction

Organizations must effectively manage a diverse range of business processes in order to deliver their services and products to their customers [7]. A *business process* is a structured and repeatable set of activities designed to achieve specific business objectives [26]. Business processes are usually subject to a set of laws, industry standards, or guidelines [9], summarized here as *regulations*, stemming from their environment and governing their execution.

To guarantee organizational success, it is important for businesses to ensure that their processes comply with relevant regulations [14], e.g., to avoid legal

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and financial penalties or reputational damage. For this, organizations conduct compliance checking [11]. Compliance checking is an operation that can be conducted when the business processes are designed, at run-time [11], or after the fact [10]. In the area of business process management and *process mining*, the technique of *conformance checking* has been established [3], aiming at providing data-driven solutions for assessing the conformance of the real-world execution behaviour of a business process to a desired process behaviour.

Given the range of research that utilizes conformance checking for evidence-based compliance checking (e.g., case studies [13] or new approaches [14]), it seems to be a useful approach. However, there currently is no overview of works that apply conformance checking for run-time regulatory compliance checking. To this end, so that practitioners are aware of existing solutions and researchers of the potential for further contributions, this work conducts a systematic literature review to answer the following research questions:

RQ1: What are existing contributions that practically apply conformance checking techniques to business processes for regulatory compliance checking?
RQ2: What characterizes the concrete conformance checking mechanisms used in the contributions for regulatory compliance checking?
RQ3: What are, based on the characterization of existing works, potential areas of further investigation for the use of conformance checking for regulatory compliance checking?

In Sec. 2, we provide background on conformance and compliance checking, and related work. Section 3 presents the approach utilized for identifying and synthesizing relevant works. In Sec. 4, we analyse the synthesis and present results. Section 5 discusses our results and the contribution, which is finally concluded in Sec. 6, where we also present potential for future work.

2 Background and Related Work

2.1 Conformance Checking

Central to the execution of business processes are information systems, which capture information about the processes and their execution. These so-called *event logs* contain ordered records of individual process instances and the events that record what activity has happened when [24].

A common consideration is, whether the behaviour captured in the event log corresponds to normative, i.e., prescribed, behaviour given through a *prescriptive* process model [3,10]. Process models are – usually graphical – representations of business processes, describing the actives and their ordering [26]. The technique of *conformance checking* can be used to analyse the relation between recorded and prescribed process behaviour. Usually, the results of such an analysis are expressed in the form of fitness values, expressing the degree of conformance between event log and process model, and lists of deviations, i.e., recorded process instances that deviate from the process model. Different approaches exist to facilitate conformance checking, mainly differentiated by the type of prescriptive model used [8]. *Imperative* approaches use imperative models, such as BPMN or Petri nets, which describe only allowed behaviour. *Declarative* approaches apply declarative models, such as Declare, which only express constraints on process behaviour, instead of explicitly specifying it. Further, *hybrid* approaches use a mixture of imperative and declarative elements to prescribe the behaviour of business processes [6]. Prescriptive models formalize constraints towards one or more *process perspectives*, which are characteristics of processes relevant for conformance checking. These perspectives include the ordering of activities, temporal aspects, data and documents, and resources that execute the process [20].

2.2 Compliance Checking

As discussed above, it is necessary for businesses to assess whether their behaviour complies with the regulations to which they are subject. These regulations are usually available in the form of textual documents. Hence, for checking regulatory process compliance, an interpretation, or operationalization, becomes necessary to relate the regulation to the process under investigation.

This act of ensuring that business processes do not violate the regulations relevant for them is called *regulatory compliance checking* [10]. One existing approach, the so-called *run-time regulatory compliance checking*, aims at monitoring process executions to assess their compliance with regulations [10,2]. This contrasts with traditional *design-time regulatory compliance checking* [10], in which the process model itself is analysed for violations of and compliance with regulations. However, processes are usually executed in ways that differ from the process model, thus giving relevancy to run-time compliance checking [11].

In practice, conformance checking has been identified as a suitable technical approach for run-time regulatory compliance checking [3]. Here, regulations relevant for a business process are interpreted and operationalized into prescriptive models, which are then used to assess the regulatory compliance of recorded process executions in the form of event logs, with the help of conformance checking techniques. This is done either based on event logs (offline and ex-post, similar to auditing), or based on event streams (online, during run-time). According to [10], the main issue with using conformance checking for run-time regulatory compliance checking lies in the fact that the prescriptive model being used must *also* be proven to be regulatory compliant with regulatory compliance checking. However, given that that conformance checking *is* indeed applied for run-time regulatory compliance checking, a systematic investigation is warranted.

2.3 Related Work

Some contributions have already aimed at systematically assessing the capabilities of existing conformance checking approaches. In [8], conformance checking approaches are analysed for the modelling language and the type of algorithm being used, the kind of metric with which conformance is expressed, and the process perspective that is considered (e.g., the ordering of activities or temporal aspects). However, the work does not focus on compliance checking with regulations in particular, nor is the creation of the prescriptive models analysed. Further, in [16], approaches that exclusively assess clinical guidelines are investigated. Concretely, the guidelines that are used by existing works are analysed per disease, their complexity is assessed, as well as the prescriptive model in terms of e.g., nodes in the process model or number of declarative constraints. However, there is no further consideration of how these prescriptive models are created, nor what the results are or how the techniques are applied. Thus, we see a need for investigating how conformance checking approaches for run-time regulatory compliance checking utilize regulations in a practical sense, how they are applied, and what results they provide.

3 Research Method

To address the research questions above, we conduct a *systematic literature review* (SLR) to identify scientific works that apply conformance checking techniques for run-time regulatory compliance checking of business processes with *concrete* regulations. For this, we follow the eight-step method of Okoli [15]. These steps are: (1) purpose of the literature review, (2) protocol and training, (3) searching for the literature, (4) practical screen, (5) quality appraisal, (6) data extraction, (7) synthesis of studies, and finally (8) writing the review. Additionally, we use a concept matrix as a framework for presenting the results [25]. Figure 1 illustrates our search process.

The *purpose* of this SLR is stated above, and detailed upon in Sec. 1. For the *protocol and training* step, we set up a shared document in which we documented all identified articles and reasons for their inclusion, respective exclusion. The *search* is conducted using four scientific databases (ACM, IEEE Explore, Science Direct, Web of Science), up to and including December 2023. We explicitly include conformance checking as the technique for run-time regulatory compliance checking. Moreover, we include terms commonly associated with regulations. The complete search term (*"conformance checking" AND ("law", "guideline", "manual", "reference", "quality", "compliance", "regulation")*) is applied to the title, abstract, and keyword search, where applicable.

Aiming to investigate the scientific support for practical regulatory compliance checking with conformance checking (i.e., run-time checking, both online and offline), we exclude EX1) all works that assess this topic in an abstract manner, such as literature reviews, EX2) works that provide general techniques or metrics for conformance checking without application, and EX3) works where conformance checking is not applied to a *concrete* business process and regulation. We explicitly include IN1) works that apply conformance checking to business processes against specific guidelines, laws, regulations, manuals, etc., IN2) which are peer-reviewed and written in English. This constitutes the *practical screen*.

An initial search with the databases and search term described above produces, after deduplication, 215 candidates for analysis. Afterwards, we conduct the *quality appraisal* by deciding first based on the title and abstract, and then on the full text, whether the found works meet our criteria. In total, 41 remain after the title and abstract screening and 22 after the full-text screening. We add 8 papers through the authors' expert knowledge and identify 6 additional works via a "forward-backward-search" we conduct to find potentially missing works. This leads to 36 papers we consider relevant for our analysis.

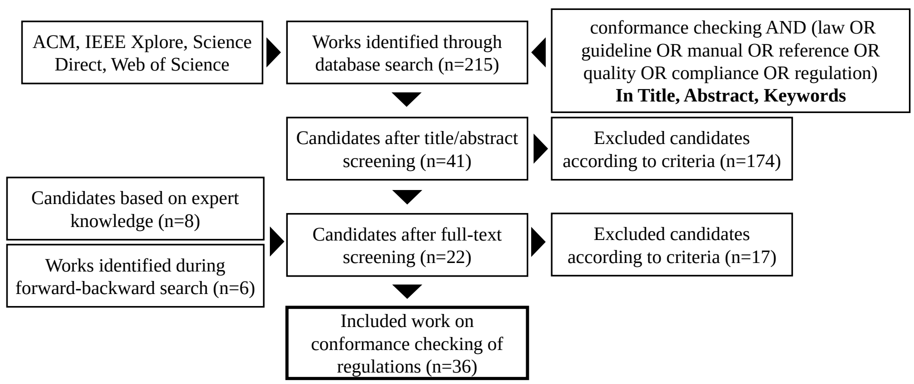

Fig. 1. Search process for relevant literature

After having identified 36 relevant works, we continue with *data extraction* and *synthesis* of the extracted information. In relation to our research questions, we define a set of categories and corresponding characteristics to capture the distinctions within the conformance checking approach of each work. We first extract highly detailed information as raw material for each category. Subsequently, we analyse the extracted information for similarities in their characteristics. Finally, as the synthesis step, we identify potential levels of abstraction that accurately reflect the essential information content while avoiding excessive specificity.

We identify characteristics in relation to the lifecycle model of conformance checking projects, as discussed in [3], which divides the application of conformance checking into three phases: *preparation* (where a prescriptive model is formalized, an event log created, and the two related), *action* (where a conformance checking algorithm is applied), and *reflection* (where results are interpreted and insights derived). An excerpt of these results, in the form of a concept matrix following [25], can be found in Table 1. For the preparation phase, we capture the process *domain*, the *goal* with which conformance checking is applied (to improve conformance checking techniques, to improve the business process compliance, or to demonstrate conformance checking techniques), as well as whether the prescriptive model is *created* manually or automatically, and whether it is explicitly *validated* through e.g., process experts or stakeholders. For the action phase, we identify whether *expert knowledge* is necessary for applying conformance checking techniques, whether imperative, declarative, or hybrid conformance checking *techniques* are used (see [3,5]), which *process perspectives* are assessed (control flow, temporal, data, or resource, see [20]), and whether the conformance checking techniques are *applied* manually, in a tool-supported manner, automatically, or in real-time (i.e., *online*). For the reflection phase, we capture the different *types of results* and their representation (i.e., whether conformance is *qualified*, *quantified*, *broken down and compared*, or *explained and diagnosed*, following a classification of representations identified from current process mining tools [17]).

All data extraction and synthesis steps are performed independently by one of three authors for a subset of the relevant works and validated by all three.

Table 1. Excerpt of a concept matrix [25] displaying the synthesis results. *PM* refers to *prescriptive model*; the domains and results are abbreviated.

	Preparation							Action												Reflection				
Work	Domain	Goal			PM Creation		PM validated	Exp. Knowl.	Technique			Process Perspective				Application				Results				
Reference	Domain	Technique Improv.	Process Improv.	Demonstration	manual	automated	yes	yes	Imperative	Declarative	Hybrid	Control Flow	Temporal	Data	Resources	Manual	Tool-supported	Automated	Real-Time	Qualify conf.	Quantify conf.	BD & Comp.	Loc. & Show	Expl. & Diagn.
[1]	Fin	•			•		•	•	•			•	•	•	•		•				•	•	•	•
[4]	PS	•			•					•		•					•			•		•		
[12]	HC	•	•		•		•	•		•		•	•	•	•			•	•	•				•
[13]	SW		•	•	•		•		•			•					•				•	•	•	•
[14]	Data	•			•		•	•		•		•	•			•				•				
[18]	HC			•	•			•	•			•	•				•				•	•	•	•
[22]	HC	•		•	•		•	•	•			•					•				•	•		
[23]	Man	•	•	•	•		•	•	•			•	•	•	•			•	•		•			•
[27]	HC	•		•	•		•	•		•		•	•	•	•		•				•		•	•

Due to limitations in length, we provide the entire concept matrix and a bibliography in a separate document online.[4] In the following, we analyse the resulting synthesis along its dimensions, thereby *writing the review*.

4 Results

After inductively coding and synthesizing the 36 relevant works, we analyse the resulting data, in order to characterize their conformance checking mechanisms.

[4] See https://doi.org/10.6084/m9.figshare.25118849 [Accessed: 03/04/2024]

This is done along the three phases of conformance checking projects, being preparation, action, and reflection [3].

4.1 Preparation

Domain. The majority of works focusses on the area of healthcare (17 works), with finance being second (6 works). Other areas, such as public services (4 works) or data processing (3 works), are also present. The prevalence of healthcare and finance seems to indicate that regulations in these areas are well-suited to be assessed with conformance checking.

Goals. Regarding the explicitly stated goals of the works for applying conformance checking, we see that those in the area of healthcare mainly aim to improve the conformance checking technique and its application (11 of 17) or to demonstrate the applicability of conformance checking (11 of 17), whereas only half of the works utilizing healthcare-related regulations aim to improve the process itself. Similarly, no finance-related contribution aims to provide actual process improvement, but all of them aim to improve conformance checking techniques, and two out of six explicitly intend to demonstrate them. This tendency is noticeably present across all domains we identified, with more than two thirds (25) aiming to improve techniques, more than half aiming to demonstrate them (19), and less than half of the works (14) aiming to investigate actual process improvement.

Prescriptive model creation. Considering how prescriptive models are created in the relevant works, we see that no contribution out of the 36 identified studies automatically creates them based on the relevant regulations. In fact, all works rely on manual input for creation of the required prescriptive model. Notably, the exact operationalization that led to the model is not described, and instead, only descriptions or visualizations of them are provided. For example, in [1], a BPMN model is created manually with and validated by process experts (in this case, bank managers), and further requirements are provided informally by bank managers and auditors, and manually translated into LTL formulae by the authors.

Prescriptive model validation. Additionally, we note that in less than half of the works (14 of 36), the prescriptive model is explicitly validated by the authors in conjunction with stakeholders or process experts.[5] Interestingly, half (7 out of 14) of those works in which a validation is reported are in the healthcare domain. We assume that this may be because of the need for expert involvement in healthcare settings to even operationalize the treatment guidelines, so that validation is a comparatively trivial addition.

4.2 Action

Technique. The techniques utilized in the investigated contributions, are largely imperative, with a third declarative and only three hybrid techniques. The largest

[5] The remaining works did not mention whether the prescriptive model was evaluated or not. Hence, we only capture whether an explicit evaluation took place.

share of declarative techniques is present in the healthcare domain (9 of 12), underlining that the nature of clinical guidelines may be especially suited for declarative techniques.

Process Perspective. As to the process perspective, we observe that control-flow constraints are always assessed. All other perspectives, being temporal (15 times), data (22 times), and resource (13 times), are used in various combinations in around half of the approaches, with a prevalence of data constraints. Notable is that all hybrid approaches assess both data and resource perspectives. Hence, relevant process perspectives seem to have some importance for the choice of technique.

Application. We identify that the majority of approaches are applied with tools, but not in an automated or real-time fashion. More concretely, we only note three approaches that are automated and two that are real-time. One of these real-time works proposes an automated approach, where clinical events created during patient treatment of unstable clinical angina are pre-processed using i.a. NLP techniques, constructed into traces, and checked against compliance rules describing the treatment process. Potential violations are sent directly as feedback to the clinical information system, allowing clinicians to react and remedy or accept compliance violations [12]. Only one approach is truly manual, where no tool is utilized to check for conformance, but instead a new technique is defined formally and applied for illustration purposes by manually considering the formal definitions [14]. Finally, all other approaches rely on tool support for conformance checking. For example, in [27] ProM is used for checking conformance to a Declare-based prescriptive model. From this, we conclude that existing tools, especially ProM, have been disseminated widely and reached acceptance in the scientific community. Notably, the automated/real-time approaches are limited to the healthcare and manufacturing domain, potentially due to the presence of information systems in hospitals and production chains allowing for detailed event log recording and automatic application of conformance checking techniques.

Expert Knowledge. Of all the contributions, around two thirds (25 of 36) explicitly reference the need for expert knowledge, either in operationalizing the regulations into a prescriptive model for conformance checking, in the application of conformance checking, or in interpreting the results.[6] For example, [27] relies on clinical experts for interpreting the conformance checking results. Further, how expert knowledge concretely contributes is often not mentioned in detail, but instead only the resulting prescriptive model or interpretation are presented (e.g., in [22], the use of expert knowledge in the form of a medical specialist for definition of the case study is mentioned, but the exact input of the expert and to what end remain not known). Notably, we see that 16 out of 17 approaches in healthcare and 4 out of 6 approaches in finance explicitly require expert knowledge throughout the application, a higher ratio than in any other application

[6] Similar to the model validation, the remaining works made no explicit reference to such a requirement; therefore we only differentiate between explicit needs for expert knowledge and no reference to such a need.

domain we identified. This might be explained by the difficulty of operationalizing these regulations and deriving prescriptive models for conformance checking compared to other domains. A potential reason might lie in the language and wording specific to these domains, or the implicit domain knowledge required for interpreting the regulations correctly.

4.3 Reflection

Finally, regarding the results and their visualization, we see that most contributions (28 of 36) use *quantitative measures*, i.e., numerical representations, to present the conformance checking results. One example for this is [19], where a table detailing the counts of conformance violations and fulfilments is provided.

Few works (8 in total) employ a *qualification*, such as [4], where a differentiation is made between strong compliance, conditional compliance, and non-compliance. Further, less than half of the works (i.e., 14) elaborate further on those measures by *break-down and comparison*, for example [13] compares the most frequent variants and their conformity. 15 of 36 works *localize and show* deviations or further results in, e.g., a process model. One example of this is [18], where individual traces and occurring violations are considered and related to the general fitness value. However, almost two thirds (i.e., 23) *explain and diagnose* the observed deviations in context and discuss potential causes and remedies, such as [23], where deviations are explained by confirmed measurement errors and a previously undetected collision of robotic arms in a manufacturing process. Additionally, it should be noted that works are not limited to one way of presenting the results, but usually use multiple representations throughout.

Moreover, we see that all the works relying on imperative techniques use quantitative measures for representing results and no qualification. In contrast, half of the declarative approaches employ qualitative measures, and the other half quantitative ones. Additionally, both imperative and declarative techniques (9 of 21, respective 5 of 12) localize and show deviations in, e.g., a process model less often. However, explanations and diagnoses appear to be relatively frequent (12 of 21, respective 9 of 12 times) in declarative approaches. As to hybrid approaches, it is notable that all types of results are covered, and a focus seems to lie on qualifying and explaining diagnoses. Thus, it appears that the conformance checking technique chosen in the approaches is related to the results and their contextualization by them, and therefore should be chosen with care.

5 Discussion

Following the analysis of the works that apply conformance checking techniques for run-time regulatory compliance checking, we discuss and contextualize our findings along our research questions.

5.1 RQ1 — Identification of Existing Contributions

The SLR has identified existing contributions that check business processes for their run-time regulatory compliance and has underlined that the majority of works are focused on the domain of healthcare, finance, and public services. Notably, we observe that a large share of works focuses on demonstrating and improving conformance checking techniques, especially in healthcare and finance.

5.2 RQ2 — Characteristics of Existing Contributions

Next, we look at the steps necessary for run-time regulatory compliance checking of business processes with conformance checking. As to the characteristics of the identified mechanisms, we have underlined that the operationalization of regulations into prescriptive models is, so far, a manual process, that often is in need of expert knowledge for interpreting the regulations. There also seems to be a lack of reporting regarding the validation of prescriptive models, either due to a lack of access to expert knowledge, or due to the general difficulty in deriving them from the relevant regulations in a sound way. This ties back to the point raised above, where, when using conformance checking techniques for run-time regulatory compliance checking, the prescriptive model must also be proven to be regulatory compliant [10], which is not reported upon in more than half of the approaches. Contributions that aim at automatically creating prescriptive models and incorporate expert knowledge in a more explicit manner could provide a benefit here, and some research in this direction has already been started [21]. We see, in contrast to the literature review by [8], a wide range of process perspectives being assessed together. This illustrates the importance placed on data, time, and resource perspectives for regulatory compliance checking with conformance checking. Further, a noticeable focus on imperative and declarative techniques exists in the investigated works, with only 3 out of 36 utilizing hybrid conformance checking approaches. Almost all approaches are tool-supported, meaning they employ established conformance checking tooling for the analysis of regulation conformance, and only three are applied in an automated or real-time fashion. Moreover, we see that the choice of the conformance checking technique seems to be related to the overall results and visualization of insights. However, there appears to be no general guidance or reasoning provided by the works on when to choose what technique, and why. Additionally, regarding the results offered by the primary studies, we observe a general focus on quantitative analyses and less often on explanations and qualifications in imperative approaches, with declarative approaches focussing additionally on qualitative analyses, as well as explanations and diagnoses. Localizations of deviations and break-downs are less common.

5.3 RQ3 — Research Opportunities

Analysing existing contributions, we see the following *research opportunities* (ROs) for future work, summarized in Table 2: First, the prevalent use of imperative and declarative techniques hints at a potential for further investigation of hybrid techniques and their utilization for run-time regulatory compliance checking (RO1). This is underlined by the fact that hybrid approaches produce a wide range of results, and utilize multiple process perspectives, which may prove advantageous. Second, in terms of automatization (RO2), we see a small number of contributions that go beyond utilizing existing conformance checking tooling. This illustrates a potential for further research in the area of truly automated or real-time regulatory compliance checking with conformance checking. We additionally expect to see a benefit for the creation and validation of prescriptive models. Third, we also determine potential for research of automated conformance checking for run-time regulatory compliance checking in other domains and processes beyond healthcare and manufacturing, which are not yet considered in great numbers by existing contributions (RO3). Moreover, we identify a need for approaches and techniques that help in deriving regulatory compliant prescriptive models for conformance checking, which are applicable across a wide range of domains (RO4).

Table 2. Research opportunities of conformance checking for run-time regulatory compliance checking identified

Research Opportunity	Description
RO1	Uses of hybrid conformance checking techniques for run-time regulatory compliance checking
RO2	Automated / real-time conformance checking tooling; Automated creation and validation of prescriptive models
RO3	Automated conformance checking in domains besides healthcare and manufacturing
RO4	Generalizable techniques for supporting the creation of regulatory compliant prescriptive models for conformance checking

Generally, we observe that the role of expert knowledge is under-illustrated and not detailed upon. To derive a clear procedure for a more automatic operationalization of regulations, including the creation and validation of prescriptive models, more details are needed. Existing works rather analyse and demonstrate the potential of conformance checking for regulatory compliance checking, and it is unclear from individual contributions where the actual challenges and tasks to solve are. To develop useful conformance checking tools for run-time regulatory compliance checking, we therefore suggest a structured requirement analysis of these.

5.4 Threats to Validity

Notably, our work underlies some limitations which pose threats to its validity. Arguably, the search terms and criteria for our SLR limit the relevant contributions we were able to identify. However, by incorporating a forward-backward search and adding works through prior knowledge, we sought to limit the influence of this on our findings. Moreover, the inductive coding we applied to the studies is subjective, due to the judgement and careful reading required of the authors. We addressed this threat by following a thorough protocol when analysing the works, by taking detailed notes during analysis, and by clarifying uncertainties through discussions.

6 Conclusion and Future Work

To conclude, we identified relevant contributions that practically apply conformance checking to business processes for run-time regulatory compliance checking. We investigated properties to characterize them, and noted that existing approaches are, generally, reliant on expert knowledge and largely only tool-assisted. This underlines a potential for research in approaches that aid in the knowledge-intense operationalization of regulations, assess their compliance in an automated fashion, and provide detailed results beyond numeric assessments. In the future, we plan to investigate novel ways of visualizing deviations in a way that is actionable and contextualizes deviations with the corresponding regulations. Based on the SLR, we observe that supporting experts in the derivation of prescriptive models from regulations is a valuable field for future research.

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