A Taxonomy of Business Rule Organizing Approaches in Regard to Business Process Compliance

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Abstract. *In the scope of Business Process Compliance (BPC), business rules are used as a central means to represent regulatory policies and consequently to (automatically) verify, whether business process models abide by respective rules. While there has been a plethora of works regarding this actual verification of process models relative to business rules, we see a strong lack of works regarding the actual creation and maintenance of business rules. More precisely, many works assume sound sets of business rules as a basis for subsequent techniques. However, recent works suggest this assumption cannot be made in practice, and companies actually need to be supported in the scope of managing and organizing business rules, e. g. to remove redundant or contradictory rules. Otherwise, errors in business rules make these rule bases unusable and impede a subsequent verification of process compliance. Yet, the understanding on business rule organization is sparse - especially its relation to BPC. To address this issue on a conceptual level, we develop a taxonomy for business rule organizing approaches. Furthermore, we identify rule organizing approaches from literature based on a systematic literature review and classify these works in the scope of the developed taxonomy. Based on the identified literature, we also identify research gaps and propose a corresponding research agenda.*

Keywords. Business Rule Management • Business Process Compliance • Business Rule Lifecycle

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1 Introduction

Business process compliance (BPC) comprises methods and techniques concerned with ensuring the regulatory compliance of company processes (Sackmann et al. 2018). With an increasing amount of laws and regulations that directly affect how a company is allowed to conduct activities, ensuring the regulatory compliance of company processes is an important challenge. Violating policies can otherwise lead to sensitive financial fines, or even criminal prosecution (Hashmi et al. 2018).

Within BPC, business rules are a central artifact used to *represent* regulatory policies. Here, a business rule can be defined as a declarative statement, which guides or constraints company activities (Linden et al. 2019; Weiden et al. 2002). Business rules are used to verify whether company processes, i. e. company activities, are compliant, usually by means such as model query. Here, methods and techniques for this actual verification have been broadly studied, cf. e. g. (Hashmi et al. 2018; Sackmann et al. 2018) for some recent surveys. However, in this paper we want to take a needed step back.

While approaches for business process compliance verification are impressively advancing, they commonly share a central assumption, namely that a sound set of business rules exists, which can be used for these approaches. However, numerous

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recent works on business rules have suggested that this cannot simply be assumed in practice (Batoulis et al. 2017; Batoulis and Weske 2018; Calvanese et al. 2018; Corea and Delfmann 2018b; Di Ciccio et al. 2017; Sadiq and Governatori 2015).

A core problem for companies is a phase underlying BPC, namely that of *business rules management*. Business rules management is the discipline of creating and maintaining business rules. Here, relevant rules first need to be identified and then formally authored. Unfortunately, as the authoring process is usually a manual, collaborative and incremental process (Nelson et al. 2008; Sadiq and Governatori 2015), errors can occur frequently (Sadiq and Governatori 2015). Modellers might accidentally make mistakes, or model redundant rules due to a lack of oversight. Worse, modellers with different understandings on the same domain of interest might model business rules in a contradictory manner. As a recent example, Batoulis et al. (2017) reported on a case-study with a large insurance company, where those authors found that 27% of analyzed business rules contained modelling errors. Thus, rules must be assessed after authoring to ensure correctness, denoted as *rule organizing*. In this work, we define business rule organizing as understanding, clustering and selecting rules, with the goal to warrant a sound set of business rules, e. g. free of problems such as redundancies or inconsistencies. That is, rule organizing aims to ensure error-freeness *within* a set of business rules.

Despite the importance of rule organizing, this aspect is not represented in many proposed business rule lifecycle approaches, or even recent BPC surveys, e. g. (Hashmi et al. 2018; Ramezani et al. 2011; Sackmann et al. 2018). Rather, rule organizing is often described as an activity which should be performed by domain experts, cf. e. g. (Nelson et al. 2008). This is unsatisfactory from both an academic as well as a practical perspective. In light of new challenges imposed by an increasing amount, complexity and interdependence of regulations, companies need to be supported with (semi-)automated means in business rule organization in order to implement a sufficient quality management (Sackmann et al. 2018; Smit et al. 2017). Unfortunately, research on specific approaches to support companies in rule organizing is sparse – especially their relation to BPC. Following works such as (Smit et al. 2017), there is consequently a need for an overview of rule organization approaches. In this work, we therefore investigate general characteristics of rule organizing approaches and how they can be classified. To this aim, we present a taxonomy of business rule organizing approaches, which conceptualizes important characteristics and allows to classify rule organizing approaches. The actual taxonomy development is conducted based on the approach by Nickerson et al. (2013) and is grounded in a structured literature review as proposed by Brocke et al. (2009). Next to the taxonomy development, we also classify the works identified in our literature review using the proposed taxonomy, which provides researchers and practitioners a needed overview of the current state-of-the-art in business rule organizing approaches. Based on our analysis, we also propose a research agenda in order to leverage research on this important pre-phase of BPC.

The remainder of this work is structured as follows. In Sect. 2, we provide background knowledge on aligning rule organizing with BPC. Sect. 3 presents our research methodology, including the taxonomy development process and a documentation of our literature research. Then, Sect. 4 presents an overview of identified rule organizing approaches in the scope of the presented taxonomy. Here, we also distill a research agenda based on our findings. Last, we conclude in Sect. 5.

2 Background

This section provides preliminary knowledge on business rules, BPC and business rule organizing.

2.1 Business Rules and their Relation to BPC

Following Graham (2007, p. 7), a business rule is a *"declarative statement about an aspect of a business"*, which specifies obligations, permissions and restrictions that constrain how company activities should be performed. Business rules are usually divided into structural business rules (which describe constraints in data), and behavioral business rules (which describe how company activities should be conducted) (Graham 2007; Weiden et al. 2002). In this work, we focus on the latter type of behavioral business rules. Behavioral rules are of the general form

$$\textit{if } A_1, ..., A_n \textit{ then } B$$

where $A_1, ..., A_n$ represents the premise of the rule (condition), and the conclusion B can be entailed, if the premise holds. This representation of conditions and behavioral conclusions allows to model business rules as a basis for BPC.

Example 1 *Numerous regulations such as Sarbanes-Oxley, Basel II or AML/CTF have been introduced to regulate allowed company behavior (Sadiq and Governatori 2015). As an example, a real-life business rule from the Anti-Money Laundering and Counter-Terrorism Financing Act 2006 (AML/CTF) imposes that it is obligatory to check new customers against a company blacklist before accepting the customer application. Process models must adhere to this rule, otherwise compliance breaches could be committed, which in turn could result in sensitive financial fines. Based on the general business rule form above, this rule could be authored with the Formal Contract Language, which is a rule standard to represent deontic constraints, as follows:*

$$NewCustomer \rightarrow O[CheckAgainstBlacklist]$$

This exemplary FCL rule encodes that if *a new customer is registered,* then *an obligation (O) arises to check this customer against a blacklist. Subsequently, the following exemplary process model could be verified against this business rule. Here, results from model query can successfully be applied to ensure that the process model in Fig. 1 adheres to the provided business rule in the scope of Business Process Compliance.*

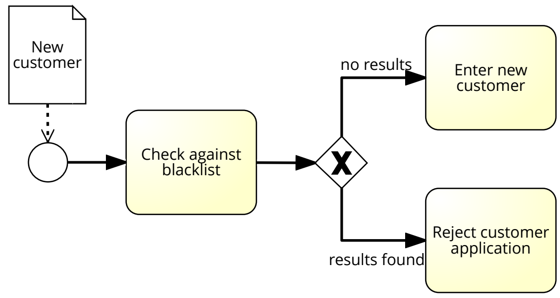

Figure 1: Exemplary customer application process.

Regarding BPC, companies can implement their compliance efforts using different so-called compliance strategies, usually divided into *design-time compliance*, *run-time compliance* and *post-execution compliance* (Hashmi et al. 2018).[1] Following Hashmi et al. (2018), design-time compliance can be defined as a preventative strategy, with the goal of facilitating compliant-by-design process models. To this aim, results from model checking or model query can be used to verify the compliance of process models against a set of business rules as in the above example. Checking models against business rules at design-time is important for companies, as otherwise illegal (sequences of) activities could be performed following such models. Thus, a sound set of business rules is a mandatory prerequisite for design-time model checking, as otherwise, model checking might not be possible or not correct.

In run-time compliance management, compliance is managed during process execution (Hashmi et al. 2018). To this aim, business rules can be used to govern the compliant execution of company processes. Especially in (semi-) automated process execution, e. g. via workflow management systems, systems and employees rely on business rules as a basis for decision-making. That is, case-dependent information is validated against the set of business rules in order to determine how to proceed with the process. Here, such decision-making also relies on a sound set

[1] We acknowledge that there are hybrid approaches which combine different strategies but continue to discuss these three basic strategies for simplicity.

of business rules. Otherwise, the (automated) decision-making might be flawed, which again can result in non-compliant process execution. Hence, ensuring an error-free set of business rules in the scope of business rule management is a prerequisite for run-time compliance management.

Last, post-execution compliance focuses on the analysis of company activities by domain experts after process execution (Hashmi et al. 2018). Here, the actually observed behavior, e. g. the company activities recorded in event logs during process execution, can be verified for compliance. Again, a sound set of business rules is needed to assess the compliance of observed behavior, as otherwise it might not be possible to detect compliance breaches. Thus, business rules management can be seen as a prerequisite for post-execution compliance.

Regarding which strategy is best, there are intuitively advantages to all approaches. Following Hashmi, *"the increased pressure and threat of possible criminal prosecutions [...] make the auditing method a less attractive compliance reporting strategy"* (Hashmi et al. 2018, p. 83), which advocates an emphasis on design-time compliance management. Unarguably, compliant-by-design processes are desirable for companies. In this context, works such as (Corea and Delfmann 2018b; Maggi et al. 2011a,b) however point out that some compliance violations might not be detectable a priori, as they might be dependent on case-specific contexts. A further factor to also consider here is that human behavior might not fully be predictable or controllable. Thus, run-time compliance management might be necessary, despite design-time compliance management efforts. Last, companies can benefit from post-execution compliance by the means of a retrospective compliance analysis from a global perspective. This could for example be used to create value through innovation, e. g. streamlining business processes or improving operations.

Regardless of the BPC strategy, we can observe that a sound set of business rules is a necessary prerequisite in all cases and therefore needs to be addressed by companies. Here, ensuring such a sound set of rules is a central goal of business rule organizing, which is embedded in business rule management as follows.

2.2 Business Rule Organizing Capabilities

As a counterpart to business process management and BPC, business rules management is geared towards the creation and long-term maintenance of business rule repositories. In essence, business rule management can be defined as a systematic and controlled approach to support the capturing, authoring and organization of business rules, as well as aligning and implementing rule management within the companies' socio-technical environment (Linden et al. 2019; Schlosser et al. 2014). Adapted from Nelson and Sen (2014), we define a business rule management lifecycle as shown in Fig. 2, containing the components of *strategic alignment*, *creation & maintenance* and *implementation*. In this report, we focus on the creation & maintenance aspect, which contains the phases of *capturing, authoring* and *organizing*.

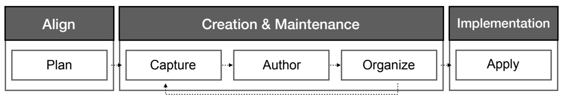

Figure 2: Proposed Business Rule Management lifecycle, adapted from Nelson and Sen (2014) and Schlosser et al. (2014).

In rule capturing, relevant business rules need to be identified. This is often performed by legal experts or using results from rule mining. This is an important step, as companies need to ensure they identify all relevant regulations that affect their domain.

Next, identified rules need to be formalized in the authoring phase. This relates to representing the identified rules in standards and rule languages, such that systems can access business rules. Authoring is usually a manual, collaborative and incremental process. In this setting, errors can occur frequently. For example, modellers might accidentally make mistakes, or model redundant rules due to a lack of oversight. Worse, modellers with different understandings on the same domain of interest might model business rules in a contradictory manner. Thus, the authored rules must be assessed and organized, in order to ensure error-freeness within the set of business rules. Even in cases where business rules are authored automatedly, e. g. in the scope of rule mining or declarative process discovery, recent works such as (Corea et al. 2019b; Di Ciccio et al. 2015, 2017) show that state-of-the-art algorithms can still yield erroneous rule sets, and thus such results should still be assessed in an organization phase.

Definition 1 (Rule Organizing) In this work, we define business rule organizing as understanding, clustering and selecting rules, with the goal to warrant a sound set of business rules, e. g. free of problems such as redundancies or inconsistencies.

While standards for authoring business rules and means to apply the authored rules have much matured, a wealth of recent research shows that the *organizing* phase still has to be evolved (Batoulis et al. 2017; Calvanese et al. 2016; Corea and Delfmann 2018b; Di Ciccio et al. 2017; Janssens et al. 2016; Lu et al. 2008; Sadiq and Governatori 2015; Weidlich et al. 2011). Despite these recent calls in literature, the understanding on this topicality is still at an early stage. A foundation for understanding and analyzing this domain is therefore needed. In order to address this issue, our research aim is therefore to investigate a classification of rule organizing approaches, explained in the following.

3 Research Approach

3.1 Research Aim and Scope

Our central research aim is to investigate a classification of rule organizing approaches, by means of taxonomy development. Following Nickerson et al. (2013), a taxonomy is a useful artifact to *"provide structure to the knowledge of a field"*, thus allowing researchers and practitioners to study the relationships among concepts.

Furthermore, from qualitative research such as (Smit et al. 2017), we see evidence that companies are currently seeking means to organize business rules, as they recognize this business rule management phase as a current challenge (Corea and Delfmann 2018b; Sadiq and Governatori 2015; Smit et al. 2017). To the best of our knowledge, there however currently exists no overview on existing approaches, making it hard for practitioners to grasp the available state-of-the-art. Therefore, our second research aim is to provide an initial overview on this matter. To this aim, we identify state-of-the-art approaches based on a systematic literature review and analyze these approaches using the developed taxonomy. This provides companies and scholars an overview of current approaches based on the proposed classification. Such an overview could for example be used by practitioners to gain a better understanding on existing approaches, or as a basis to make an informed decision on selecting suitable approaches. Here, we also aim to identify research gaps for current BRO approaches in order to distill a research agenda for using BRO approaches for BPC.

In the following, we present our taxonomy development approach, including a systematic literature review. Then, we present an analysis of the identified works in the scope of our novel taxonomy.

3.2 Taxonomy Development Approach

Following Nickerson et al. (2013), a taxonomy can be described as a system for grouping objects of interest in a domain based on common characteristics. Here, a taxonomy T is defined as a set of n dimensions, each consisting of a set of k characteristics. Based on our research aim, we apply the conceptual-to-empirical taxonomy development approach as proposed by Nickerson et al. (2013), shown in Fig. 3. In the following, we describe our individual research steps.

The first step in the taxonomy development approach is the definition of meta-characteristics. These meta-characteristics are the most comprehensive characteristics and should be aligned with the purpose of the taxonomy (Nickerson et al. 2013). Based on our research aim, we consequently decided to focus on the following aspects: First, to harmonize company efforts in business

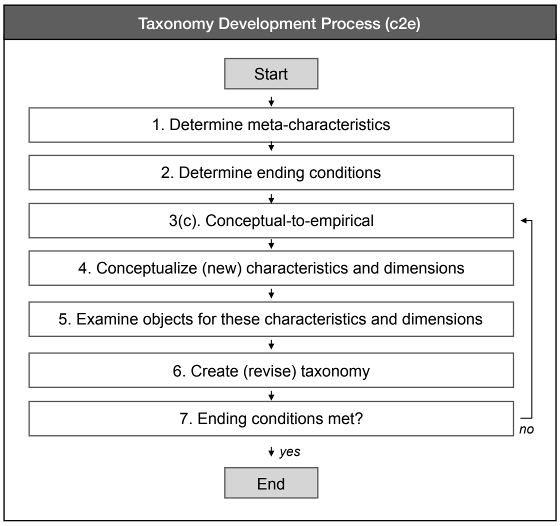

Figure 3: High level overview of the taxonomy development process (conceptual-to-empirical) as proposed by Nickerson et al. (2013)

rule organizing and BPC, we investigate how rule organizing approaches and compliance management strategies are aligned. Also, we investigate the specific capabilities offered by business rule organizing approaches, as well as tool-support, applicability and maturity of solutions. This yields the following meta-characteristics as a basis for our taxonomy:

- *(MC1) BPC Phase.* What are important compliance management phases that need to be addressed by rule organizing approaches?
- *(MC2) Capabilities.* What are important capabilities that need to be addressed by approaches for business rule organizing?
- *(MC3) Applicability.* What are important characteristics impacting the applicability of rule organizing approaches?
- *(MC4) Evaluation.* What are important strategies for evaluating rule organizing approaches?

As a second step in the applied taxonomy development approach, ending conditions need to be defined (Nickerson et al. 2013). This is necessary to assess whether the incremental development process can be ended. Nickerson et al. (2013) provide a series of objective ending requirements which impose formal requirements, e. g., there are no duplicate dimensions in the taxonomy, which were applied in our development process. Furthermore, based on the suggestions by Nickerson et al. (2013), we defined the following subjective ending conditions: The (number of) dimensions of the taxonomy should be *concise* and *comprehensive* as defined in (Nickerson et al. 2013), i. e., it should allow to classify all objects within a domain of interest. Here, this classification should also be *explanatory* as suggested in (Nickerson et al. 2013). Also, the dimensions as well as the characteristics need to be suitable to provide a differentiation between objects (*robustness*). Also, the finished taxonomy should be easily *extendable*, e. g., in future research.

Based on the defined meta-characteristics and ending conditions, we proceeded with the development process. In this work, we follow the conceptual-to-empirical approach as proposed by Nickerson et al. (2013), as it allows to conceptualize dimensions based on (domain) knowledge. This approach was iteratively performed in three cycles to refine the taxonomy. As a basis for our conceptualization, we conducted a structured literature review to consider a larger body of literature as a grounding for the development process. Here, we applied the structured literature review approach as proposed by Brocke et al. (2009), which consists of the five phases of *defining the review scope, conceptualizing the topic, the literature search, a literature analysis and synthesis* and a subsequent *discussion & agenda*. In the following, we provide details on our literature review as it is a central basis for the conceptualization of our taxonomy dimensions and characteristics.

To define our literature review scope, we use the taxonomy by Cooper (1988) as suggested by Brocke et al. (2009). As we aim to identify business rule organizing (BRO) approaches that can aid BPC, our *focus* is the research outcomes and applications of the reviewed works. To align our review with our research aim, the *goal* of our literature review is the integration of central issues. The *organization* of our research result is conceptual, as it is meant as a basis for taxonomy development. To the best of our ability, our results are *presented* in a neutral way. The *audience* of our review and our taxonomy are scholars and practitioners seeking to gain insights of BRO approaches capable of supporting individual company needs. Last, our *coverage* is exhaustive and selective, as our intention is a comprehensive overview of relevant literature by the means of a literature search in established databases, and reviewed works are discussed based on a literature analysis and taxonomy dimensions/characteristics, as opposed to a discussion of all works individually.

For our literature search, we followed the process proposed by Brocke et al. (2009), shown in Fig. 4.

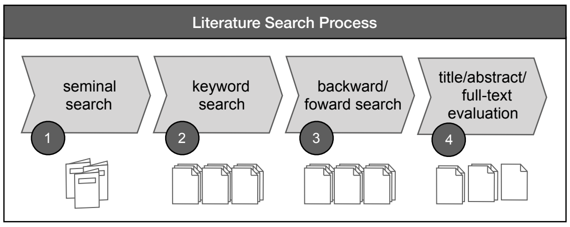

Figure 4: High Level overview of the search process as proposed by Brocke et al. (2009).

At first, we conducted brief searches as proposed as a good starting point by Brocke et al. (2009) and Rowley and Slack (2004) and found some initial surveys (Gadi 2015; Hashmi et al. 2018; Imgrund et al. 2017; Sackmann et al. 2018). We worked through these surveys to gain an initial overview of the topic. Then, we applied concept mapping techniques for a topic conceptualization as proposed by Rowley and Slack (2004) and Webster and Watson (2002). This conceptualization was used as a basis to derive suitable keywords. Our concept mapping revealed that the word “maintenance” was often used as a synonym to “organizing” or “long term management”. Through iterative tests, we found that the keywords “business rule(s) maintenance” resulted in a good balance between a feasible amount of results. It is noteworthy that the keyword “business rule(s) management” was not feasible, as this term refers not only to the scope of rule organizing but also to the other phases of the presented business rule management lifecycle. In result, this keyword resulted in too many results which were in many cases also not aligned with the scope of this work. Also, note that the keyword “business rule(s) organizing” returned too little results (the latter results were also subsumed by the selected keyword).

The keyword-based search was then conducted as follows: To warrant for a broad view on the research topicality, we queried 6 pertinent literature databases with the derived keywords, in particular ACM digital library,[2] Springer Link,[3] Emerald Insight,[4] AISel electronic library,[5] Science Direct[6] and IEEE Xplore,[7] respectively. In the scope of the mentioned balance between feasibility and coverage, the query was defined such that the title had to contain the phrase *“business rule(s)”* and any other field had to contain the word *“maintenance”*. In result, our keyword-based search yielded a total of 209 results. Fig. 5 shows the searched databases as well as an overview of the selection process, following the standard systematic literature review phases of *identification, screening, eligibility* and *inclusion* (Moher et al. 2009).

Based on the identified search results, we conducted a first review phase (Review Phase I). Here, we removed duplicates. Then, we read the abstracts of the considered search results and determined the potential relevance of the individual works, as suggested by Brocke et al. (2009, 2015). In result, we reduced the search results to 52 works.

Then, we conducted a second review phase (Review Phase II). All 52 works were read in full, to determine whether they were relevant in the scope of our research aim. Here, we defined a paper to be relevant if it met the following criteria:

[2] https://dl.acm.org/
[3] https://link.springer.com/
[4] https://www.emeraldinsight.com/
[5] https://aisel.aisnet.org/
[6] https://www.sciencedirect.com/
[7] https://ieeexplore.ieee.org/

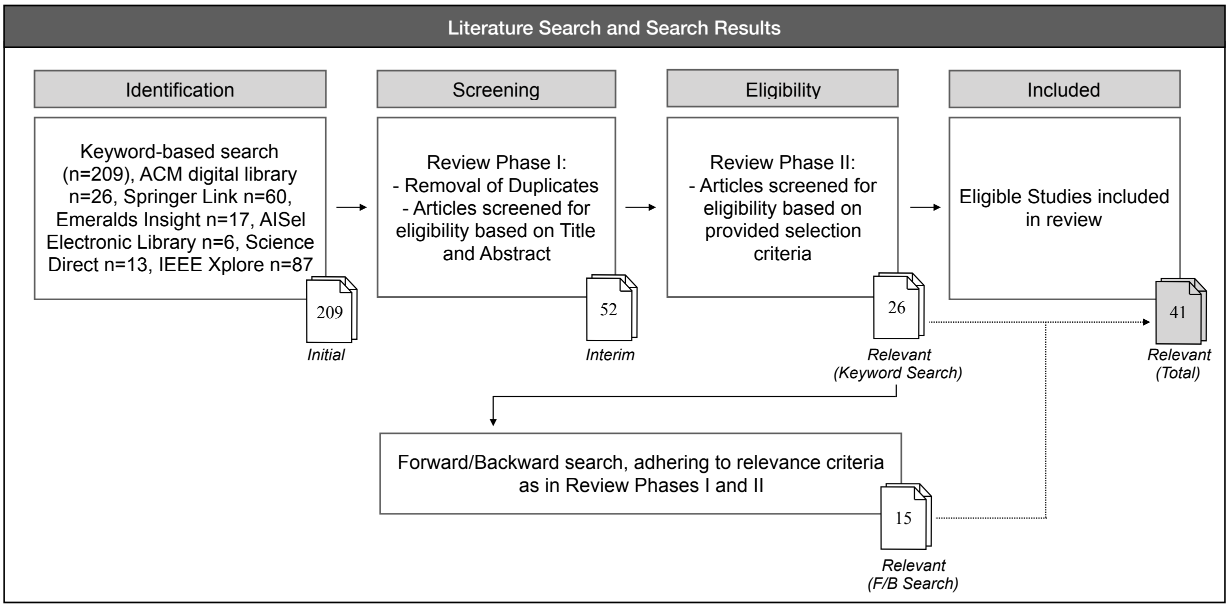

Figure 5: Selection process, including search results of the performed keyword search, backward search and forward search.

1. *Focus on Rule Organizing.* A paper was deemed relevant if its focus was an approach for business rule organizing. That is, following our research aim, the focus had to be on how to understand, cluster and select business rules to ensure the (long-term) error-freeness within a set of business rules.

2. *Focus on Business Rules.* A paper was deemed relevant if its focus was on business rules. That is, following our review scope, the focus had to be on rule formalisms which were applied in an enterprise context, in order to ensure that the identified approaches are applicable to aid companies.

In result, we obtained 26 relevant papers, in the following denoted as relevant (search) results.

As shown in Fig. 5, we then used the relevant results as a basis to retrieve more relevant works via a forward and backward search as proposed by Brocke et al. (2009) and Levy and Ellis (2006). For backward search, we conducted a backward search by references, where we regarded all the sources referenced by the initially found relevant results. Then, we conducted a forward search via Web of Science[8] to identify works that cited the relevant results.

To determine the relevance of the works found via forward- or backward search, we applied the same criteria as stated in the description of Review Phases I and II. Here, we identified 15 additional relevant works. To conclude, we identified a total number of 41 relevant results (26 KW + 15 F/B) by the means of our literature search. The literature search contains results up to January 31^{st} of 2020.

One design-choice we would like to address is that we decided to only include works published from 2000. In our initial seminal search, we had noticed there were many recent publications, rarely any around the 2000s, and then again, some publications dating back to the late 1980s to early 1990s. Here, one observation made was that earlier research often did not focus on currently used rule formalisms, as of course some of these standards were not even existant in the 1980s. Therefore, it would require more expertise to apply these results in an enterprise context, as they would need to be adapted to current standards.

[8] https://apps.webofknowledge.com/

Also, many recent works explicitly reference limitations of older works and therefore propose how to extend or adapt these results, e. g. (Calvanese et al. 2016). Therefore, we decided to make a cut at the 2000 mark, as many of recent works reference and extend older works, thus information on older works is still incorporated in our review, and the considered works are more accessible to companies based on using recent rule standards.

After our initial literature review, grounded in this body of literature and the acquired domain knowledge, the taxonomy development was iteratively conducted, as mentioned based on the conceptual-to-empirical approach as proposed in (Nickerson et al. 2013). For readability, we will introduce the developed taxonomy at this point and continue to discuss the development of the individual dimensions, respectively characteristics.

3.3 A Taxonomy for Business Rule Organizing Approaches

Fig. 6 shows the developed taxonomy for business rule organizing approaches. The shown dimensions and characteristics are defined as follows.

In regard to the meta-characteristic of the BPC phase, we introduced the dimension of a compliance management phase and were able to identify individual characteristics for this dimension. Following works such as (Hashmi et al. 2018; Sackmann et al. 2018), we identified the characteristics of design-time, run-time, and post-execution compliance management,[9] explained as follows:

- *Design-Time Compliance.* Approaches allowing to organize business rules at design-time, i. e. considering a set of business rules during modelling.
- *Run-Time Compliance.* Approaches supporting business rule organization during run-time. Here, these approaches must consider not only the business rules but also instance-dependent facts (Corea and Delfmann 2018b).
- *Post-Execution Compliance.* Approaches that enable to organize business rules in the scope of audits. Here, instance-dependent facts and/or observed process executions should be considered as well.

An important aspect is that rule organizing should ideally be conducted in regard to all three compliance management strategies: During design-time, run-time and post-execution compliance management, the information which can be used as a basis for rule organizing is highly different, and rule organizing has different goals during these perspectives. First, during design-time, only the business rules are known (but not the case-dependent facts that will be evaluated against the set of rules later during run-time). This means, that rule organizing at design-time focuses on finding logical contradictions or flaws *only* within the set of business rules. Eliminating such errors is a minimal prerequisite for deploying the rule set. Then, during run-time, case-dependent facts are known. The specific facts at run-time can yield novel errors in combination with rules (e. g. due to unexpected fact occurrences), which could not be detected at design-time (as it may not be possible to anticipate all possible fact combinations that can occur during run-time). Thus, despite design-time rule organizing, monitoring case-specific facts and organizing business rules during run-time (in regard to the facts) is also important to ensure that the modelled business rules are correctly aligned with reality. Then, during post-execution auditing, errors cannot only be investigated from an individual case perspective, but the interrelations of errors which occurred in different cases can also be used to further understand or prioritize issues in the rule base pertaining to individual cases. Thus, although a business rule and its representation remain the same at design-time, run-time and auditing, these perspectives yield different insights and allow to identify errors which are not detectable from the scope of the other strategies. In result, rule organizing approaches need to address all compliance management strategies.

[9] We decided to allow for objects in the taxonomy to be non-mutually exclusive in favor of conciseness (i. e., instead of specifying all possible combinations) based on the suggestion in (Nickerson et al. 2013).

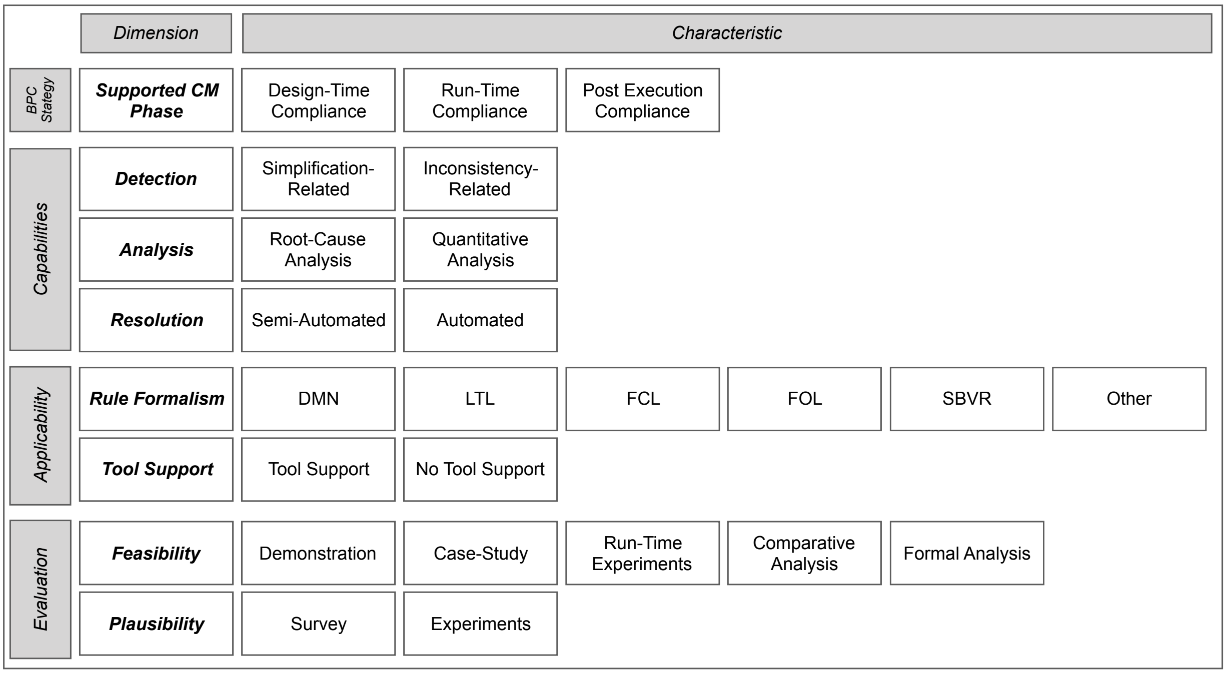

Figure 6: Proposed taxonomy for BRO approaches in regard to BPC.

Next, we conceptualized different dimensions for the meta-characteristic of capabilities. Following Corea and Delfmann (2018b), rule organizing can be divided into three general components, namely the *detection* of errors, the *assessment* of errors and the *resolution* of errors.

As a basis for rule organizing, detection comprises capabilities that allow to identify errors within a set of business rules. A detection of errors is the foundation for other capabilities. Here, many different types of errors in business rules can be defined and detected (we will discuss these error types below as characteristics). Following a detection of errors, recent works have advocated the importance of a (quantitative) analysis of the detected errors (Lu et al. 2008; Nagel et al. 2019; Sadiq and Governatori 2015). This analysis, mostly in the form of a quantitative assessment, can be presented to modellers in order to a) assess the *severity* of the detected errors, and b) provide a *prioritization* in which order rules should be attended to in the scope of re-modelling. A recent study by Nagel et al. (2019) shows that quantitative insights are associated with better understanding accuracy, better understanding efficiency and less mental effort needed for understanding problems in the scope of business rule organizing, as opposed to a manual analysis of errors. As shown in (Corea and Delfmann 2018b), a quantitative assessment can also be used as a driver for an informed re-modelling strategy. Finally, in the scope of ensuring error-freeness within a set of business rules, rule organizing can also include means for the actual resolution of the detected (and analyzed) problems. This can range from semi-automated resolution by the means of recommendation systems to fully automated resolution algorithms.

We subsequently introduced the dimensions of detection, analysis and resolution under the meta-characteristic "capabilities".

- *Detection.* Approaches allowing to detect, i. e. identify, errors within a set of business rules.
- *Analysis.* Approaches offering a detailed (quantitative) assessment of the detected errors, e. g. in order to foster an understanding and prioritization of specific errors.

- *Resolution.* Approaches fostering a (semi-) automated resolution of the detected errors, thus resulting in a sound set of business rules.

For these dimensions, we were able to identify several characteristics.

Especially for detection, it is important for companies to have a detailed overview of which types of errors can actually be detected. In this context, many different error classifications have been proposed. For example, Smit et al. (2017) recently proposed the BRM verification capability framework, which defines capabilities needed for business rule organizing. These capabilities include for example identical rules verification (checking if there are duplicate rules), subsumed rule verification (checking whether a rule is irrelevant), or interdeterminism verification (checking whether there are rules that yield contradictory conclusions). While those authors present a comprehensive framework, there exist too many different capabilities to identify a concise set of taxonomy characteristics.

We therefore propose to generally group error types in business rules and the corresponding detection capabilities into two main groups, namely *simplification-related* error types and *inconsistency-related* error types.

Simplification-related errors refer to multiple business rules which should be merged or reduced. For example, if one would detect that two rules are identical, one can simply delete one of the two. Hence, for all simplification approaches, the resolution of the error is trivial, or at least undisputed.

Inconsistency-related errors are generally defined as business rules that yield logically contradictory conclusions. Here, handling inconsistency-related errors is not trivial. For example, two modelers with different views on the same domain of interest might have entered two contradictory rules, such as the conclusions *creditWorthy* and *not creditWorthy* for the same condition. In this case, it is not clear how to resolve the issue, as two contradictory pieces of information exist, which requires careful analysis by experts.

Not only is inconsistency in business rules more difficult to resolve, but it can also have much more dramatic impact on business process compliance. Consider again the example of a rule base containing two identical rules. While this is unarguably undesirable and can lead to problems in data maintenance, two identical rules do not necessarily impose a problem with regard to business process compliance (e. g., the worst case is that a compliance check would be conducted twice). However, in case of inconsistent business rules, the inconsistency makes it *impossible* to use the business rules for their intended purpose of governing compliant business process execution. Hence, while simplification should not be neglected, handling inconsistencies in business rules is an important challenge to address for companies. Consequently, we identify these two general error groups as characteristics for our taxonomy.

Regarding the dimension of analysis, the characteristics of root-cause analysis and quantitative analysis were identified.

- *Root-cause Analysis.* Means to identify the exact causes of the detected problems, e. g., pin-pointing specific rules which are highly problematic.
- *Quantitative Analysis.* Means to assess the severity of problems, e. g., by providing a quantitative assessment, such as numerical values, indicating the degree of the problem.

Last, for the dimension of resolution, we identify the characteristics of semi-automated resolution, e. g. by the means of recommendations, and fully automated resolution, e. g. algorithms to automatedly resolve errors within sets of business rules based on our findings.

Continuing, the third meta-characteristic of applicability is aimed to capture characteristics impacting the adaptation or usage of methods and techniques, e. g. in an enterprise context. From our literature review, we observed that there was no clear consensus on which rule formalism to use. If a company has already invested efforts into modelling business rules, the support of specific rule standards may be a constraint for adaptation. Therefore, we introduced the dimension of "rule formalism". Based on our literature review, we could also identify some seminal rule standards, shown as characteristics in Fig. 6. We explicitly included a characteristic "other" as a design choice to warrant a higher flexibility of our taxonomy. Furthermore, regarding the applicability of individual approaches, it might be an important factor whether there exists an implementation that can be used "out-of-the-box", as opposed to having to invest efforts into implementing an approach. We therefore introduced the dimension "tool support".

Finally, the meta-characteristic of "evaluation" is meant to capture indicators for the maturity of approaches. Here, we distinguish between the evaluation dimensions of performance and plausibility. Performance evaluation is geared to show the general feasibility of the developed tools. Plausibility analysis refers to an analysis of approaches in the scope of surveys or experiments with human participants. In the identified literature, a multitude of different evaluation strategies were applied, and added to the taxonomy as characteristics. Please see Sect. 4.1.4 for a further discussion.

After three iterations, the applied taxonomy development approach was concluded. Next to the objective ending conditions, all subjective ending conditions were met. The taxonomy has 8 dimensions with a maximum of 6 characteristics and is therefore concise and robust. By applying the conceptual-to-empirical approach following Nickerson et al. (2013), as well as the literature review following Brocke et al. (2009), the resulting taxonomy can be seen as comprehensive. It can be easily extended in future work, e. g. by adding more characteristics such as detection capabilities. Additionally, the taxonomy is explanatory, which will be further discussed in the next section.

The proposed taxonomy extends the descriptive knowledge on business rule management and allows researchers and practitioners to classify rule organizing approaches. Intuitively, a limitation of our proposed taxonomy is the conceptualization by the researcher as dictated by the applied conceptual-to-empirical approach. This is however completely in line with the goal of developing taxonomies as defined by Nickerson et al. (2013), which is to provide a "useful" taxonomy, as opposed to the "best" or "correct" one (the latter of which is often intractible). As Iivari puts it: *"Conceptual knowledge, including taxonomies, does not have a truth value but is relevant input for the development of theories representing forms of descriptive knowledge"* (Iivari 2007, p. 5). Here, our taxonomy provides a useful foundation for theory building and can guide future research.

Next to our research aim of developing such an initial taxonomy, based on calls in academia that an overview of specific rule organizing approaches is missing as well, our second main research aim is to provide such a needed overview. This is important for scholars and practitioners in order to gain insights into the state-of-the-art, and further allows to identify research gaps. In the following, we classify the works identified in our literature review using the proposed taxonomy in order to provide an overview of business rule organizing approaches.

4 An Overview of Business Rule Organizing Approaches

Based on the presented taxonomy, Tab. 1 shows a classification of rule organizing approaches identified in our literature search. Note that the characteristics regarding error detection are shown in Tab. 2 following the framework by Smit et al. (2017).[10]

4.1 Discussion

Our results provide an overview of 41 business rule organizing approaches. Fig. 7 shows the number of identified approaches per year. As can be seen, there is an increase in works since 2013, and especially since 2016.

[10] Interdeterminsm relates to the characteristic of inconsistency-related errors as defined in the proposed taxonomy. Tab. 2 is simply meant as a more detailed view, as "detection" is the most researched dimension.

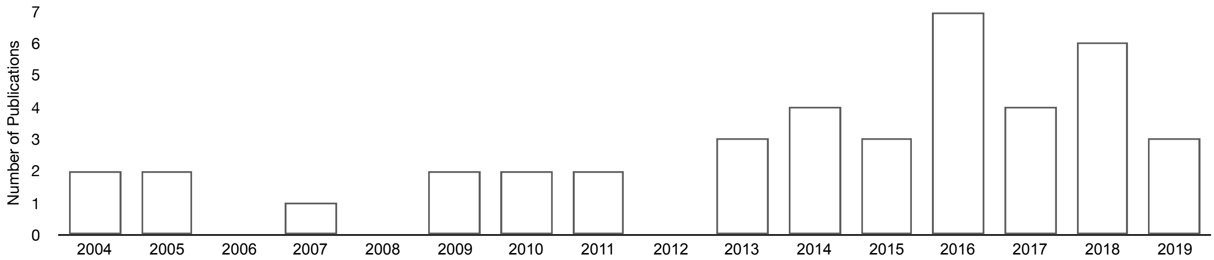

Figure 7: Distribution of approaches per year.

In the following, we discuss our results divided into the individual meta-characteristics, and then provide implications for practice and future research.

4.1.1 MC1: Supported Compliance Strategies

Fig. 8 shows the distribution of works supporting the individual BPC strategies. The majority of works (81%) are geared towards design-time compliance. This is in line with works such as (Hashmi et al. 2018; Olivieri et al. 2017; Sadiq and Governatori 2015), which strongly advocate the so-called compliance-by-design principle. In turn, there is a variety of approaches that can be used to organize business rules at design-time. Only a few approaches support run-time compliance - even fewer support post-execution compliance. However, as pointed out in (Corea and Delfmann 2018b) or (Maggi et al. 2011a,b), instance dependent case input can reveal errors in the decision logic that cannot be identified at design-time. An inadequacy of rules might also only be observable considering the actual activities at run-time, due to unexpected or unpredicted behavior. Therefore, it is necessary to conduct run-time compliance management in order to detect potential inconsistencies in decisions during run-time, cf. e. g. (Corea and Delfmann 2018a) or (Maggi et al. 2011b). Furthermore, a holistic a posteriori analysis of business rules in the context of the observed behavior, e. g. event logs, can also provide valuable insights that cannot be inferred during design-time (Burattin et al. 2012). Therefore, future work is needed on BRO approaches that support run-time and post-execution compliance. Due to the complementary effects of using multiple compliance management strategies as described in (Hashmi et al. 2018), it would also be desirable to have holistic approaches covering e. g. both design-time compliance and run-time compliance, as there are currently no holistic approaches that can be used during all compliance stages.

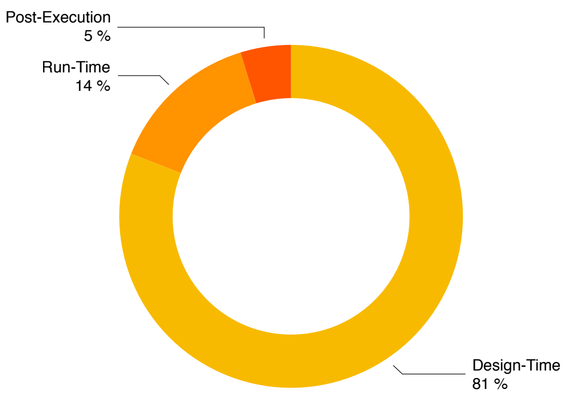

Figure 8: Distribution of BPC strategies supported by the individual approaches.

While it would theoretically be possible to combine multiple techniques (that each only address one BPC strategy) in order to gain coverage, a unified solution might be more beneficial due to the additional insights that can be gained by not only considering phases individually, but from a holistic perspective. Also, trying to combine different techniques is currently limited by the existing approaches and tools: There exist no sufficient means for rule-organizing during post-execution compliance.

	BPC Strategy			*Capabilities*			*Applicability*		*Evaluation*	
Literature	Design-Time Compliance	Run-time Compliance	Post-Execution Compliance	Detection*	Quantitative Analysis	Resolution	Rule Formalism	Tool	Performance	Plausibility
Kardasis and Loucopoulos (2004)	X						Text			
Fu et al. (2004)	X			X			n/a	X	run-time (syn), complexity	
Lin et al. (2005)	X						FOL		case-study	
Bajec and Krisper (2005)	X						Text	X	case-study	
Hicks (2007)	X			X			Text	X		
Cheng and Huang (2009)	X			X			n/a		run-time (syn)	
Governatori and Sadiq (2009)	X			X		A	FCL			
Governatori and Rotolo (2010)	X			X		A	FCL			
Lévy et al. (2010)	X			X			RIF	X		
Maggi et al. (2011b)		X		X	X		LTL		case-study	
Maggi et al. (2011a)		X		X	X		LTL		demonstration	
Decker and Muñoz-Escoı (2013)	X			X	X		FOL			
Silva et al. (2012)	X						DRL	X	case-study	
Maggi et al. (2013)	X			X		A	LTL	X	run-time (r)	
Berstel-Da Silva (2014)	X			X		A	FOL			
Cuzzocrea et al. (2014)	X			X	X		FOL		formal analysis (p)	
Guimaraes et al. (2014)	X			X		A	SBVR	X		
Zhang et al. (2014)	X			X		A	n/a	X	run-time (syn), comparative	
Cemus et al. (2015)	X						n/a			
Gómez-López et al. (2016)		X		X			n/a			
Olivieri et al. (2017)	X			X		A	FCL			
Agli et al. (2016)	X			X		A	ILOG	X	Demonstration	
Burgstaller et al. (2016)	X						SBVR			
Calvanese et al. (2016)	X			X			DMN	X	run-time (r)	
De Smedt et al. (2016)	X			X			LTL		Demonstration	N=95, M=(UA, Q)
Di Ciccio et al. (2015)	X			X		A	LTL	X	run-time (r)	
Gómez-López et al. (2016)		X		X			n/a	X	Demonstration	
Houari and Taghezout (2016)	X			X			n/a	X	run-time (syn)	N=10, M=Q)
Batoulis and Weske (2017)	X			X			DMN		Demonstration, Case-Study	
Calvanese et al. (2017)	X			X			DMN			
Di Ciccio et al. (2017)	X			X		A	LTL	X	run-time(r), complexity analysis	
Anand et al. (2018)	X			X			SBVR	X	Case-Study	
Batoulis and Weske (2018)	X			X		A	DMN	X	run-time(syn)	
Calvanese et al. (2018)	X			X		A	DMN	X	run-time, comparative	
Corea and Delfmann (2018b)		X	o	X	X	SA	FCL			
Corea and Delfmann (2018a)		X	o	X	X	SA	DMN	X	Demonstration	N=37, M=(UA, UE, OME, Q)
De Smedt et al. (2018)	X			X			LTL		Demonstration	N=146, M=(UA, UE, Q)
Ezekiel et al. (2019)	X			X			DRL	X	Demonstration	
Corea et al. (2019b)	X			X	X	A	LTL	X	run-time (r)	
Corea et al. (2019a)	X			X			DMN	X	run-time (syn)	
Corea and Delfmann (2019)	X			X	X		LTL	X	run-time (r)	

*Detection**:* Please refer to Tab. 2 for an overview of sub-capabilities.
Resolution: SA (Semi-Automated), A (Automated).
Rule Formalisms: TEXT (textual description/natural language), N/A (Non-standard or individual rule formalisms, e. g. if-then-structures), FOL (First-order logic), FCL (Formal Contract Language), RIF (Rule Interchange Format), DRL (Drools Rule Language), LTL (Linear Temporal Logic, respectively DECLARE), SBVR (Semantics of Business Vocabulary and Business Rules), ILOG (IBM Ilog), DMN (Decision Model and Notation).
Performance Evaluation: cf. the description of evaluation techniques. r (Real-Life dataset), syn (Synthetic dataset).
Plausibility Evaluation: N (number of participants), M (measures used), UA (understanding *a*ccuracy), UE (understanding *e*fficiency), OME (*o*bjective *m*ental *e*ffort), Q (*q*uestionnaire)

Table 1: Overview of approaches for Business Rule Organizing, classified into the dimensions of BPC Strategy, Capabilities, Applicability and Evaluation.

4.1.2 MC2: Capabilities

Tab. 1 classifies the capabilities of the considered approaches into the dimensions of detection, analysis and resolution. Fig. 9 shows the number of works that support these different high-level capabilities.

Detection Capabilities. In regard to the considered business rule management lifecycle, error detection within the organizing phase is usually performed *after* the rule authoring phase. That is, a given set of business rules needs to be analyzed in order to detect errors. As shown in Tab. 1, 84% of all works fall into this traditional use-case of rule organizing and can be used to detect some

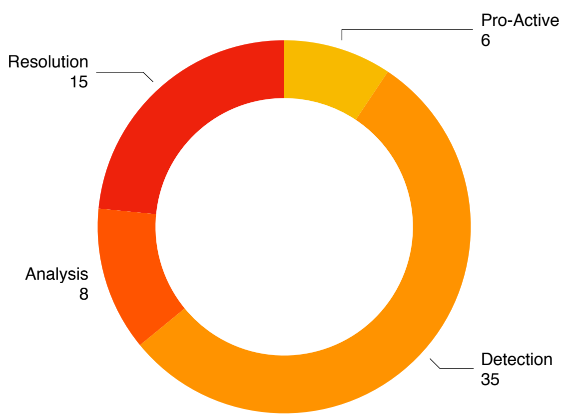

Figure 9: Number of approaches supporting the individual dimensions.

	Detection capabilities (detailed view)						
Literature	Identical Rules	Equivalent Rules	Subsumed Rules	Unnecessary Facts	Contradicting Conclusions	Overlapping Conditions	Missing Rules
Fu et al. (2004)	X		X			X	
Hicks (2007)					X		X
Cheng and Huang (2009)	X		X		X		X
Governatori and Sadiq (2009)	X		X			X	
Governatori and Rotolo (2010)	X		X			X	
Lévy et al. (2010)	X	X		X			
Maggi et al. (2011a)					X		
Maggi et al. (2011b)					X		
Decker and Muñoz-Escoı (2013)					X		
Maggi et al. (2013)			X			X	
Berstel-Da Silva (2014)					X	X	X
Cuzzocrea et al. (2014)					X		
Guimaraes et al. (2014)	X		X		X	X	
Zhang et al. (2014)					X		
Gómez-López et al. (2016)				X		X	X
Olivieri et al. (2017)	X		X			X	
Agli et al. (2016)					X		
Calvanese et al. (2016)	X		X			X	X
De Smedt et al. (2016)					X		
Di Ciccio et al. (2015)	X		X		X	X	
Gómez-López et al. (2016)				X		X	X
Houari and Taghezout (2016)	X		X	X	X	X	
Batoulis et al. (2017)	X		X			X	X
Batoulis and Weske (2017)	X		X			X	X
Calvanese et al. (2017)	X		X			X	X
Di Ciccio et al. (2017)	X		X		X	X	
Anand et al. (2018)	X	X			X		
Batoulis and Weske (2018)	X		X			X	
Calvanese et al. (2018)	X		X			X	X
Corea and Delfmann (2018b)	X				X	X	
Corea and Delfmann (2018a)	X				X	X	
De Smedt et al. (2018)					X		
Ezekiel et al. (2019)			X			X	
Corea et al. (2019b)	X				X	X	
Corea and Delfmann (2019)	X				X	X	
Corea et al. (2019a)	X	X	X	X	X	X	X

Table 2: Detailed view of which types of errors can be detected by the individual approaches, following the capability classification by Smit et al. (2017).

form of error within a given set of business rules. Interestingly, there are a few approaches which did not focus on the detection of errors, but instead on preventing errors during modelling. To clarify, such approaches are closely intertwined with the rule authoring phase and aim to provide means to author business rules in such a way, that errors are proactively counteracted. Most prominently, this is performed by linking business rules to predefined rule schemas (Guimaraes et al. 2014; Kardasis and Loucopoulos 2004; Lin et al. 2005; Silva et al. 2012), meta-models (Bajec and Krisper 2005; Burgstaller et al. 2016) or semantic annotations (Ezekiel et al. 2019; Lévy et al. 2010) during rule authoring. In result, advanced reasoning capabilities can be used to support modellers in creating sound sets of business rules. Houari and Taghezout (2016) even propose a procedure model, i. e. an actual guideline for modelers how to create business rules.

Yet, as mentioned the majority of approaches follow the more sequential business rule lifecycle model, i. e. a given set of business rules is assessed. Tab. 2 provides a detailed overview of the specific decision logic level verification capabilities offered by the individual approaches, outlined in the following. Note that “interdeterminism” as defined by those authors relates to inconsistency-related errors as defined in this work, and all other capabilities relate to simplification-related errors.

Simplification of business rules. A baseline approach is to simplify a set of business rules, e. g. by identifying identical rules, subsumed rules or overlapping conditions. When such errors are detected, they can be removed to reduce the size and complexity of the rule set. There are a substantial number of approaches geared towards this goal, available for various rule standards such as the Formal Contract Language (Governatori 2010; Governatori and Rotolo 2010), the Semantics of Business Vocabulary and Business rules (Anand et al. 2018), the Decision Model and Notation (Batoulis and Weske 2018; Calvanese et al. 2016, 2018, 2017; Corea et al. 2019a), or Declare (Di Ciccio et al. 2017; Maggi et al. 2013). All these approaches present some form of algorithm geared towards identifying different errors within a set of business rules as shown in Tab. 2. Regarding these simplification approaches, there are only a few which support the detection of equivalent rules, e. g. logically equivalent rules (Anand et al. 2018; Calvanese et al. 2017) or a semantically equivalent rule vocabulary (Corea et al. 2019a). Contrary to a simplification of rule sets, some approaches are also geared towards enhancing the rule set by identifying missing rules, e. g. gaps in rule conditions (Calvanese et al. 2016, 2017) or inadequacy of rules relative to business processes (Batoulis and Weske 2017).

On the concept of contradictory rules. A second interesting line of detection approaches are those concerned with contradictory rules. In essence, these approaches try to detect sets of rules that are logically contradictory or inconsistent. Other than with simplification or with missing rules, it is often not clear how to resolve this type of errors, as multiple, contradictory pieces of information exist and need to be resolved by experts. Regarding the concept of contradictory business rules, it is noteworthy that this notion is used very differently and not easily characterizable.

Di Ciccio et al. (2015, 2017) utilize automata representations of business rules in order to find inconsistent (sub)sets of business rules. Here, inconsistency is defined as a set of rules that cannot be satisfied, e. g. there cannot exist a sequence of activities that satisfies the set of constraints – hence the automata product is empty. Corea and Delfmann (2019) extend this concept and introduce the notion of quasi-inconsistency, which relates to cases where a set of rules *can* become inconsistent, *should* certain rules be activated together. In such cases, there can in fact exist activity sequences that satisfy the rule set – however some particular sequences will render the model inconsistent. The approach by Corea and Delfmann (2019) can thus be used to detect those activities that yield an inconsistency. Interestingly, De Smedt et al. (2016, 2018) propose a similar notion of hidden dependencies, which describes hidden relations of activities that can block each other in case of certain sequences of activities. For example, the occurrence of certain activities might block the execution of certain rules (however this is not made explicit from the rule set, hence the term hidden dependency). The approach by De Smedt et al. (2016, 2018) is similar to that in (Corea and Delfmann 2019), however where the former focuses more on possible (executable) sequences of activities, the latter focuses more on contradictions in business rules that can arise from particular activities.

Next to these mentioned approaches to detect contradictions at design-time, there are works geared towards detecting contradictions during run-time, e. g. inconsistent rule conclusions made during different points in time of running processes (Corea and Delfmann 2018a,b), inconsistencies in fact values during run-time (Gómez-López et al. 2016), or contradictions in business rules relative to observed (unexpected) behavior (Maggi et al. 2011a,b). Almost all works on run-time approaches provide examples where run-time errors occurred that could not be detected at design-time. This strongly advocates implementing multiple compliance management strategies.

Last, we can observe that there exist virtually no approaches supporting business rule organizing during post-execution compliance. The approach by Corea and Delfmann (2018b) can be used to analyze rules and facts that occured in a process *after* the actual process runtime, however this approach does not consider the interrelations of different process executions, i. e. no process log traces are analyzed or compared. Due to the increased availability of event logs (Burattin et al. 2012), future works should therefore focus on developing new means for a posteriori business rule organizations, as considering the relations of different traces could reveal even new problems which cannot be understood from a local run-time (i. e. individual process instance) perspective.

To summarize, regarding detection capabilities, we can identify four main capabilities which are commonly supported, namely *identifying identical rules, identifying redundant rules, identifying contradictions and inconsistencies*, and *identifying missing rules*. Only a few works support the *identification of semantically equivalent rules* or *unnecessary facts*. Detecting contradictions is supported by some works, though this area is still under development and the notion of contradiction and inconsistency are not yet clearly defined in literature. However, as contradictions in business rules are harder to solve than for example redundancies (as the former type of errors usually needs to be resolved by domain experts and it is not trivial how to resolve the problem), future work should continue to investigate the notion of inconsistency and contradiction in business rules.

Some approaches go beyond error detection. For example, some of the run-time approaches also allow companies to continue monitoring even after some inconsistencies were encountered during run-time (Maggi et al. 2011a), or support companies by automatically stopping process execution in the case inconsistencies were found, so that no compliance violations are committed (Corea and Delfmann 2018a). Also, we see some initial works aiming to apply results from knowledge representation such as inconsistency-tolerant reasoning (Agli et al. 2016; Cheng and Huang 2009; Cuzzocrea et al. 2014; Decker and Muñoz-Escoı 2013) or inconsistency measurement (Corea et al. 2019b; Corea and Delfmann 2018b, 2019; Cuzzocrea et al. 2014) to business rule organizing. This line of investigation should be continued in future work due to the strong alignment of goals.

What can be observed is that there is virtually no approach which covers all capabilities, except one approach for DMN decision tables (Corea et al. 2019a). Here, future work needs to be directed towards developing new approaches that support a broader variety of detection capabilities for other standards. Also, more approaches for post-execution should be investigated, as this could yield a further understanding of errors that cannot be detected during design-time or run-time.

Analysis Capabilities. Regarding the dimension of analysis, only very few approaches (13%) offer any form of quantitative insight. In general, quantitative insights for business rule organizing were divided into an overall assessment of the entire rule base, and the assessment of individual business rules.

Regarding *overall* rule base assessment, results from inconsistency measurement were primarily used to quantify the degree of inconsistency in business rule bases (Corea and Delfmann 2019; Cuzzocrea et al. 2014; Decker and Muñoz-Escoı 2013). These results allow companies to understand the severity of overall problems in their rule bases. Future work should investigate further metrics for other error types in sets of business rules, see e. g. Hasic et al. (2017) for a recent work in this direction.

Regarding the assessment of *individual* business rules, Corea and Delfmann (2018b, 2019) investigate culpability measures, which are quantitative measures which assign a numerical value to *individual* business rules. The intuition is that a higher value reflects a higher degree of blame, that an individual business rule carries in the overall context of inconsistency. In this way, highly problematic business rules can be pin pointed. Furthermore, the modeler can be presented with a prioritization as a basis for an informed decision regarding a re-modelling strategy. Following Lu et al. (2008) and Sadiq and Governatori (2015), such a prioritization of individual rules can be an important driver for experts during error resolution, as a resolution based on a “simple” detection might be unfeasible in practice. Also, in a recent study, Nagel et al. (2019) could in fact show the positive cognitive effects of such quantitative insights on understanding errors in business rules, where those authors found that culpability measures are associated with better understanding accuracy, better understanding efficiency and less mental effort needed for understanding contradictions in business rules. Subsequently, future work should focus on approaches which allow to assess individual business rules, to help companies to understand and prioritize errors.

Resolution Capabilities. Regarding the dimension of resolution, we see that a decent amount of approaches (40%) offer means for a (semi-) automated resolution. The high density of recent works which offer resolution mechanisms can be seen as positive because companies can be aided in efficiently resolving detected errors.

As discussed, the detection capabilities can be roughly divided into those who investigate a simplification of business rules, and those who investigate contradictory subsets of business rules. For the former, resolution is usually undisputed, e. g. redundant rules can be removed, or missing rules can be added. Consequently, many approaches that detect such errors also offer algorithms or fully automated means to resolve such errors (Calvanese et al. 2018; Di Ciccio et al. 2015, 2017; Governatori 2010; Governatori and Rotolo 2010; Maggi et al. 2013), or even for restructuring/improving the set of business rules (Batoulis and Weske 2018; Calvanese et al. 2016, 2018; Corea et al. 2019a). For the latter type of approaches that detect contradictory sets of business rules, a resolution is not trivial and can depend on an assessment by domain experts. Di Ciccio et al. (2015, 2017) provide means for a fully automated resolution, however those authors state that there might be a chance certain information is deleted by the algorithm due to a trade-off between efficiency and considering only local optima. As deleting information may be a task which should be strongly supervised by domain experts, semi-automated approaches such as recommender systems should also be investigated in order to guide modelers in resolving errors in a step-by-step manner, see e. g. (Corea et al. 2019b) for a recent work in this direction.

4.1.3 MC3: Applicability

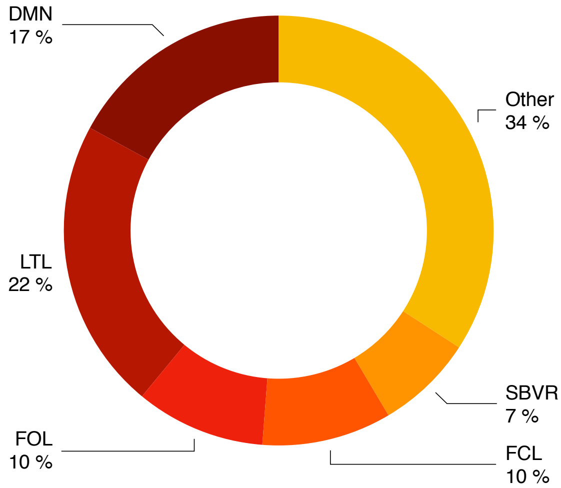

Figure 10: Distribution of rule formalisms supported by the identified approaches.

As companies might have already invested efforts in business rules elicitation and authoring, the rule formalism of approaches is an important criterion for the applicability in a company context, as business rules and the approach have to be compatible. Fig. 10 shows the percental distribution of which rule formalisms are used in the surveyed approaches. Declare is supported by the highest number of approaches, followed by the Decision Model and Notation. As can be seen in Fig. 7, there has been an increase in approaches since 2013. To gain a better understanding of recent approaches and relevant rule formalisms, we therefore investigated the development of rule formalisms support since 2013. Fig. 11 shows the percental distribution of formalisms supported by the respective approaches over time since 2013. As can be seen, from 2013-2015, there were a lot of approaches that used some non-standard formalisms or only supported business rules that followed a simple “if-then”-structure. Since around

2016, the evolution of standards is reflected in the proposed approaches, as approaches increasingly support maturing standards such as the Decision Model and Notation. Although it is interesting to see that these recent standards are being adapted in approaches, future work has to conclude the discussion on rule standards, such that there is a shared consensus and thus the approaches can be better aligned to support companies.

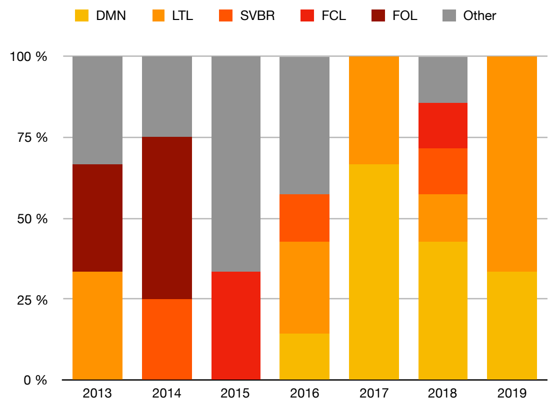

Figure 11: Percental distribution of supported rule formalisms over time.

4.1.4 MC4: Evaluation of current approaches

The evaluation of proposed approaches is an essential component of design science research, allowing companies and scholars to assess and compare the maturity and quality of respective approaches. While the evaluation overview provided in Tab. 1 provides an indication towards feasibility and plausibility of approaches, a definite comparison of approaches is difficult at this point. In the following, we discuss the evaluation for those 26 out of 41 approaches that have been implemented (denoted as "tools"), as the evaluation of unimplemented approaches did not go beyond simple demonstrations.

Fig. 12 shows an overview of evaluation techniques performed in the considered implemented tools. For the 26 (out of 41) implemented approaches, many authors only provide a demonstration, i. e. a short exemplary application of

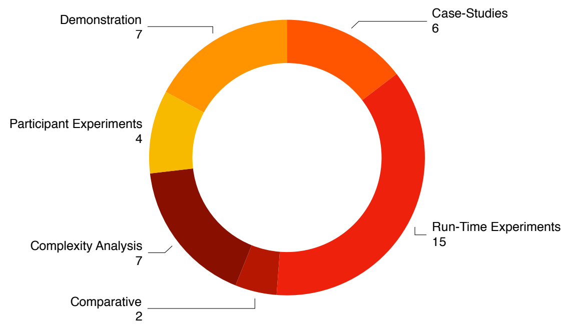

Figure 12: Number of works performing the individual evaluation techniques.

the proposed approach. While this is good for comprehension, the external validity of such toy examples is questionable. Here, roughly 20% of implemented works report on some case-studies, e. g. studies conducted with the tool and industrial partners. Such case-studies showcase the general feasibility of the proposed tools and make interesting cases for business rule organizing. More case-studies should be conducted to further motivate the need for BRO approaches in relation to BPC, or to investigate the adoption of specific approaches. Furthermore, out of the 26 tools, 13 works presented some form of run-time evaluation. This can be seen as positive, as run-time experiments can showcase the feasibility for the approaches on synthetic or real-life data. What we would like to point out, is that it is still difficult to compare run-times, as often different logs were used. Future works should focus more on comparing own results to other works, such as in (Calvanese et al. 2018; Zhang et al. 2014), or in general comparative meta-studies, e. g. as in (Cemus et al. 2015; Olivieri et al. 2017). Ideally, (real-life) data sets or data generators should be made available. A BRO competition for certain verification capabilities could also be fruitful. Next to a feasibility analysis by the means of run-time experiments, an evaluation aspect which needs to be investigated further is the formal analysis of proposed algorithms and approaches. We found only two works who provide a complexity analysis of the proposed algorithms. As complexity analysis allows to abstract compared to run-time experiments, a formal analysis should be emphasized more in future work.

Next, some authors also investigate the plausibility of their approaches. That is, such works investigate the usability of their approaches, and whether their proposed approaches can actually have positive (cognitive) effects for business rule organizing. As a baseline approach, new approaches can be shown to participants, who can then try the tool and provide feedback on usability, as in (De Smedt et al. 2016, 2018; Houari and Taghezout 2016; Nagel et al. 2019). Moreover, De Smedt et al. (2016, 2018) and Nagel et al. (2019) also performed controlled experiments to assess the cognitive effects of their approaches. To this aim, those authors applied between-subject design experiments, where participants where split into groups – some groups of which had access to an individual tool, and some groups of which did not. Then, those authors asked participants to solve general BRO tasks – as mentioned some groups with tool support. Then, different objective metrics were measured in order to identify significant (cognitive) effects of the proposed tools. Regarding these metrics, two baseline metrics seem to be understanding accuracy, i. e. the number of correct answers, and understanding efficiency, i. e. the speed in which the tasks were solved. Furthermore, Nagel et al. (2019) also used eye fixation duration using eye-tracking in order to measure the objective mental effort. As pointed out by those authors, instruments for neuro-physiological measurement such as eye-trackers or heart rate monitors are becoming more attainable, thus future works should consider to utilize these instruments in order to measure cognitive load and objective mental effort. Also, the evaluation of plausibility should in general be emphasized more in future works.

Interim Result 1 (Guideline for evaluation)
As an interim result, we propose the following guideline for rigorous evaluation of BRO approaches, based on the state-of-the-art evaluation techniques identified in our literature review.

- *Demonstration.* A demonstration of proposed approaches, e. g. by the means of examples, should be viewed as a minimum requirement.
- *Case-Studies.* If possible, approaches should be applied in (industrial) case-studies, to show general feasibility and make the case for BRO approaches.
- *Run-time Experiments.* Implemented approaches should be comprehensibly tested in run-time experiments. Ideally, datasets should be made available and re-used by other others if applicable.
- *Comparison.* Proposed approaches should be compared to other approaches based on objective measures, e. g. run-times.
- *Complexity Analysis.* Next to run-time experiments, complexity of proposed algorithms should be formally analyzed.
- *Plausibility/Experiments.* The usability of proposed tools should be investigated. As a baseline approach, participants can use the tool and provide qualitative feedback. Furthermore, experiment design research should ideally be applied to measure significant effects of proposed approaches in terms of improved usability or understandability. Also, cognitive effects should be measured.

4.1.5 Summary

Our distilled overview shown in Tab. 1 compares and classifies existing business rule organizing approaches using our developed taxonomy. Here, our discussion illustrates the state-of-the-art and can be used to derive research gaps. Our overview consequently reveals two results regarding a novel overview of BRO approaches and needed future research.

Result 1 (Overview)
The distilled results in Tab. 1 extend the current

body of knowledge in business rule management research. Here, existing approaches are classified relatively to the considered meta-characteristics of their compliance phase, capabilities, applicability and evaluation. This overview can be used by scholars and practitioners to gain insights about the current state-of-the-art. In a company context, our results can be used as a basis for informed decisions: Here, we envisage two scenarios, a) a company already has a business rule base and is seeking for rule organizing means, or b) a company is seeking to newly implement the business rules management approach (and rule organizing as a part of it).

For the first case, we argue it is essential that rule organizing approaches fit the existing rule management environment of the company, in order to allow for a seamless integration. Here, our results can be used to verify if there are suitable approaches from a company's perspective. For example, if a company verifies the compliance of their process models via model query at design-time, a corresponding BRO approach should be aligned to this phase, hence the company can verify this in the presented overview (e. g. column 1). Moreover, Tab. 2 provides detailed insights into the actual errors which can be detected. A company can thus utilize the overview to ensure that certain error types are analyzed. Also, information about tool support and maturity (evaluation) can be used as a basis for an informed decision as to which approach to adapt. Here, especially the information on supported rule formalisms helps to identify approaches that fit the rule standard applied by the company.

For the second case (a company is starting to implement business rules management), the presented state-of-the-art as well as the presented taxonomy allow to derive some preliminary guidelines:

- *Embracing rule organizing.* In the field of rule management, it is often assumed that a sound set of business rules exist. Much efforts are therefore directed towards rule standards or elicitation techniques, neglecting the organizing phase. However, we see recent evidence from the field that companies are having problems in the rule authoring phase. Therefore, instead of putting pressure on modelers, companies should embrace the chances of implementing a rule organizing phase as part of their business rule management lifecycle. Time and resources should be dedicated to this task, in order to iteratively improve business rules and foster sustainable business rule management.

- *Taking a holistic perspective.* Rule organizing research has predominantly focused on design-time approaches. However, we see evidence that certain errors cannot be detected a priori, as they may arise due to case-dependent facts. Here, next to striving for compliant-by-design rule bases, companies should invest efforts into implementing compliance monitoring and reporting. This allows to react to rule errors occurring at run-time and allows to further analyze errors in the scope of auditing. Ideally, this process should also be iterative, i. e., results from auditing should be considered in new design phases and so forth.

- *Current support of rule standards.* The choice of the actual rule formalism is important, as this strongly affects how legal regulations can be encoded and used. While there are many different types of business rules (Linden et al. 2019), some rule standards have evolved that can all be broadly used within BPC. Still, there are some factors that should be considered in the selection. First, companies should carefully consider the skillset of the experts involved in rule management or BPC. That is, while some formalisms such as FCL may allow for a higher expressiveness, the complexity might be overwhelming in such cases. Here, the DMN standard which uses graphical representation seems to be evolving into a highly acknowledged standard with a good balance between complexity and expressiveness, as well as a well-defined semantics (Calvanese et al. 2016). Second, the actual formalisms that are supported by rule organizing approaches might also be interesting to consider. Here, we see that the three rule standards of Declare, FCL and DMN have a good tool support.

Dimension	*Research needed on...*
1 - *(CM Phase)*	• Approaches supporting run-time and post-execution compliance • Holistic BRO approaches addressing multiple phases
2 - *(Detection)*	• Pro-active procedure models to guide business rules authoring • Further research on error verification capabilities
3 - *(Analysis & Resolution)*	• More approaches facilitating quantitative assessment • Foundations of how to quantify inconsistencies or errors, including postulates/properties for quantitative measures • Means to guide modelers in remodeling (Recommendations) • Means to anticipate possible case-data and corresponding errors in business rules at design-time (Preemptive Diagnostics)
4 - *(Other)*	• More case-studies to motivate BRO • Identification of company needs to further extend the presented taxonomy • Strong need for comparative studies • More rigorous evaluation, including plausibility analysis (cf. Interim Result 1) • Further conclusion on rule standards (part of a much higher scope)

Table 3: Research Agenda: Overview of potential research avenues for future research on business rule organizing.

Result 2 (Research Agenda)
Our literature analysis also identified research gaps, cf. also the above discussion.

What stands out is that there currently exists no approach which supports all three compliance management phases. While works such as (Hashmi et al. 2018) strongly advocate using multiple compliance strategies, there are only very few approaches for run-time and post-execution compliance (and as mentioned no approach allowing for a holistic support of all phases). The key focus of future research should therefore be to understand the interconnections of these three phases in relationship to business rule organizing, in order to develop suitable approaches.

Furthermore, the supported detection capabilities are rather scattered. Future works should seek to combine different verification capabilities in order to provide companies with unified solutions, as opposed to companies having to use multiple tools. In this context, procedure models for guiding business rule authoring should also be investigated in order to guide modelers and proactively counteract potential problems in collaborative rule modelling.

Future works should also focus on a quantification of detected errors in order to provide quantitative insights for companies. Recent studies (Nagel et al. 2019) show that metrics on errors in business rules help employees to resolve cases with a better accuracy, in a smaller amount of time, and with less mental effort needed. Prioritizing errors in the form of recommender systems can thus create value for companies by facilitating innovation, e. g. speeding up re-modelling.

On a meta-level, more case-studies or research on maturity models would be beneficial to further motivate the case for BRO and study the adoption of BRO approaches. Also, the evaluation of BRO approaches could be more extensive and comparative, in order to better understand the advantages of newly proposed means.

5 Conclusion

The pressure on business process compliance has increased in recent years. While approaches to verify the compliance of process models relative to business rules have advanced rapidly, research on the preceding question on how to ensure a sound set of business rules as a valid input for such approaches has been neglected. Here, organizing business rules is a mandatory prerequisite to BPC and must therefore be implemented by companies. In this work, we presented a taxonomy for rule organizing approaches. Furthermore, we provided an overview of current rule organizing approaches based on a systematic literature review. Our results support scholars and organizations in classifying (existing) rule organizing approaches. Also, we identified challenges and points of interest, which should be addressed in future work to support companies in business rules management.

Intuitively, a limitation of our research approach is that the presented artifacts are based on the conceptualization by the researcher. Here, we applied well-established procedural approaches and suggestions by works such as (Brocke et al. 2009, 2015; Moher et al. 2009; Nickerson et al. 2013; Webster and Watson 2002) to warrant a rigorous research process.

Our results show that BRO approaches supporting the design-time phase are dominant, and holistic approaches aligned with all BPC phases need to be addressed. Also, our results indicate that error detection capabilities need to be unified in order to counteract the current fragmented landscape of verification capabilities.

We see a strong need for future research regarding the following two aspects. First, the interrelation of rule authoring and rule organizing should be studied more closely. Here, an understanding of how errors occur in business rules authoring could foster the development of pro-active approaches. Second, research on recommender systems that are able to guide modelers in error resolution should be investigated. Providing prioritization or quantitative insights could help to support modelers in understanding problems. Investigating preemptive diagnostics, e. g. anticipating potential run-time problems based on possible case-data during business rule design, could also be beneficial to uncover unexpected behavior and unveil further hidden relationships between business rules that were unintended by the modeler. In future work, our taxonomy should also be extended by conducting qualitative research with key practitioners in order to refine the taxonomy dimensions and characteristics.

The motivation of this work is to raise awareness for the need of business rule organizing as a prerequisite to BPC, as well as the challenges related to business rule organizing. Many approaches embedded in later phases of business rule management or business process compliance assume a correct set of business rules as an input. However, we actually see evidence that this can currently not be sufficiently ensured in practice (Batoulis et al. 2017; Calvanese et al. 2018; Corea and Delfmann 2018b; Di Ciccio et al. 2017; Sadiq and Governatori 2015; Smit et al. 2017). Companies thus need to be supported with means for business rules organizing. Here, our work contributes a needed foundation for future work on business rule organizing.

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