Visual Modeling of Business Process Compliance Rules with the Support of Multiple Perspectives*

David Knuplesch[1], Manfred Reichert[1], Linh Thao Ly[1], Akhil Kumar[2], and Stefanie Rinderle-Ma[3]

[1] Institute of Databases and Information Systems, Ulm University, Germany
david.knuplesch,manfred.reichert,thao.ly@uni-ulm.de
[2] Smeal College of Business, Pennsylvania State University, PA, USA
akhilkumar@psu.edu
[3] Faculty of Computer Science, University of Vienna, Austria
stefanie.rinderle-ma@univie.ac.at

Abstract. A fundamental challenge for any process-aware information system is to ensure compliance of modeled and executed business processes with imposed compliance rules stemming from guidelines, standards and laws. Such compliance rules usually refer to multiple process perspectives including control flow, time, resources, data, and interactions with business partners. On one hand, compliance rules should be comprehensible for domain experts who must define and apply them. On the other, they should have a precise semantics such that they can be automatically processed. In this context, providing a visual compliance rule language seems promising as it allows hiding formal details and offers an intuitive way of modeling. So far, visual compliance rule languages have focused on the control flow perspective, but lack adequate support for the other perspectives. To remedy this drawback, this paper provides an approach that extends visual compliance rule languages with the ability to consider data, time, resources, and partner interactions when modeling business process compliance rules. Overall, this extension will foster business process compliance support in practice.

Keywords: business process compliance, compliance rule graphs, business process modeling, business intelligence

1 Introduction

During the last decade, numerous approaches for ensuring the correctness of business processes have been discussed [1, 2]. Most of them focus on syntactical correctness and process model soundness (e.g., absence of deadlocks and lifelocks). However, business processes must also comply with semantic rules stemming from domain-specific requirements such as corporate standards or legal regulations [3]. Summarized under the notion of *business process compliance*, existing

* This work was done within the research project C^3Pro funded by the German Research Foundation (DFG), Project number: RE 1402/2-1, and the Austrian Science Fund (FWF) under project number: I743.

approaches have mostly considered compliance issues related to the control flow perspective of single processes. By contrast, cross-organizational scenarios characterized by interacting and collaborating business processes of various parties have not been properly considered so far [4]. Furthermore, compliance requirements for both local and global process scenarios do not only concern control flow and interactions between business partners (i.e. messages exchanged), but also refer to time, resources, and data [5–8]. As examples, consider the compliance rules in Tab. 1, which are imposed on a cross-organizational process scenario involving the two business partners *reseller* and *manufacturer*. In particular, as shown by the highlighted terms in Tab. 1, the rules that arise in practice should be able to describe aspects of interaction, time, resource and data as they relate to a business process. Hence, these various perspectives of a business process should be modeled to support compliance.

Compliance rule c_1 considers a pair of interactions between a reseller and manufacturer (*request* and *reply*) after a particular point in time (*3rd January, 2013*) as well as the maximum time delay between them (*within three days*). The data perspective of compliance rules is emphasized by compliance rule c_2 of the manufacturer. It forbids changing an *order* after having started the corresponding *production* task. Compliance rule c_3 in turn, combines the interaction, time, and data perspectives. Finally, compliance rule c_4 introduces the resource perspective (*member of the order processing department* and *another member of the same department with supervisor status*). In addition, c_4 considers the data perspective (e.g. *new customer* and *total amount greater than €5,000*) and the time perspective (*at most three days*). Particularly c_4 shows that the different perspectives might be relevant for the same rule and hence cannot be considered in an isolated manner.
Comparing c_4 and c_2 with c_1 and c_3, one can further notice two different viewpoints: c_4 and c_2 are expressed from the viewpoint of the manufacturer (i.e., local view), while c_1 and c_3 reflect a global view. Note that such distinction between local and global views is common to cross-organizational collaboration scenarios not only in the context of process compliance. For example, BPMN 2.0 provides collaboration and choreography diagrams to express these different viewpoints.

Table 1: Examples of compliance rules for order-to-delivery processes

c_1	Any *request* sent from the reseller to the manufacturer *after January 3rd, 2013* should be *replied* by the manufacturer *within three days*.
c_2	After starting the production related to a particular *order*, the latter must not be changed anymore.
c_3	When the manufacturer *sends a bill* with an *amount lower than €5,000* to the reseller, the latter must make the payment *within 7 days*.
c_4	After receiving a production request message from the reseller, which refers to a *new customer* and has a *total amount greater than €5,000*, the solvency of this customer must be checked by a *member of the order processing department*. Based on the result of this check, *another member of the same department with supervisor status* must approve the request. Finally, the approval result must be sent to the reseller *at most three days* after receiving the original request.

Several approaches for formally capturing compliance requirements at different abstraction levels (e.g., temporal logics [9]) exist to enable the automatic verification of compliance of business processes with such rules. As the use of formal languages for compliance rule specifying might become too intricate, rule patterns [6, 8], which hide formal detail from rule modelers, have been proposed. Furthermore, a few approaches also consider more advanced issues like, e.g., the use of data conditions in the context of compliance requirements. However, existing approaches are usually restricted to a specific subset of rule patterns. In this context, rule languages, employing visual notations like the compliance rule graph approach [10] or BPSL [11], provide an alternative as they combine an intuitive notation with the advantages of a formal language. However, our meta-analyses and case studies, we conducted in domains like higher education, medicine and automotive engineering, have revealed that these visual compliance rule languages still lack support for the time, data, and resource perspective of business processes. Our analyses have further shown that existing compliance rule notations do not consider cross-organizational scenarios with interacting partners [4]. Overall, in our meta-analyses and case studies, we elicited the following fundamental requirements for visual compliance rule languages:

- In addition to the control flow perspective, the data, resource and time perspectives of compliance requirements must be properly captured.
- To not only consider process orchestrations, but cross-organizational scenarios as well, it becomes necessary to express the interaction perspective with compliance rule languages.
- To provide tool support for both the modeling and verification of compliance rules, their syntax as well as semantics must be formalized.

To cope with the shortcomings discussed above, we introduce extensions for visual compliance rule modeling supporting the data, time, and resource perspectives of business processes. More precisely these extensions are proposed for the compliance rule graph (CRG) language we developed in earlier work [10, 12]. However, the major concepts we propose may be applied to other compliance rule languages as well. Another fundamental contribution is the ability of our *extended compliance rule graph language* to specify compliance requirements for cross-organizational scenarios (i.e. processes choreographies) as well. For this purpose, we additionally introduce concepts that allow defining compliance rules in respect to message flows and partner interactions. Altogether, the visual compliance rule language developed in this paper allows capturing compliance requirements at an abstract level, while at the same time it enables the specification of verifiable compliance rules in the context of cross-organizational scenarios.

The remainder of this paper is structured as follows: Sect. 2 discusses related work. In Sect. 3, we introduce the data, time, resource, and interaction perspective of compliance rules. Our extensions of the CRG language regarding the support of these perspectives, the *extended compliance rule graphs* (eCRG), are described in Sect. 4. To validate our approach, we present a proof-of-concept prototype and outline the results of a pattern-based evaluation in Sect. 5. Sect. 6 concludes the paper and provides an outlook on future research.

2 Related Work

Recently modeling issues related to the interaction, time, resource, and data perspectives of business processes have been addressed in addition to the control flow perspective (e.g., [13–19]).

The integration of business process compliance throughout the entire process lifecycle has been discussed in [12, 20–22]; [23] examined compliance issues in the context of cross-organizational processes developing a logic-based formalism for describing both the semantics of normative specifications and compliance checking procedures. This approach allows modeling business obligations and regulating the execution of business processes. In turn, [24] introduced a semantic layer that interprets process instances according to an independently designed set of internal controls. Furthermore, there exist approaches using semantic annotations to ensure compliance [25]. An approach checking the compliance of process models against semantic constraints as well as ensuring the validity of process change operations based on Mixed-Integer Programming formulation is proposed in [26]. It introduces the notions of *degree of compliance*, *validity of change operations*, and *compliance by compensation.* [6] uses alignments to detect compliance violations in process logs. To verify whether compliance rules are fulfilled by process models at design time, many approaches apply model checking techniques [9, 11, 27–29]; some of them address the data and time perspectives as well. Further approaches for verifying compliance apply the notion of *semantic congruence* [30] or use *petri-nets* [31] and consider the data and time perspectives as well.

The approach described in [27, 32] for visually modeling compliance considers the control flow and data perspectives. It is based on linear temporal logic (LTL), which allows modeling the control flow perspective based on operators like *next*, *eventually*, *always*, and *until.* Finally, visual approaches for compliance rule modeling exist [11, 10, 33]. However, they focus on control flow and partly the data perspective, but ignore the other perspectives mentioned.

3 Compliance Perspectives

As noted above, compliance rules cannot be expressed completely by referring only to the control flow perspective of a business process. In [5–8], the importance of the time, resources, and data perspectives are emphasized. The need for ensuring compliance in the context cross-organizational scenarios is raised in [4]. Before introducing the visual notation of the eCRG language, we describe the compliance perspectives as well as related language concepts in more detail. The latter have been elicited through our analyses and case studies. Fig. 1 provides an overview of the perspectives we consider and characterizes their main features.

Process Perspective. The process (i.e. control flow) perspective of compliance rules is the most fundamental one. It comprises elements for expressing both the occurrence and presence (i.e., *exclusive*, *alternative*) of *tasks* as well as their ordering (i.e., *sequence flow*, *parallel flow*).

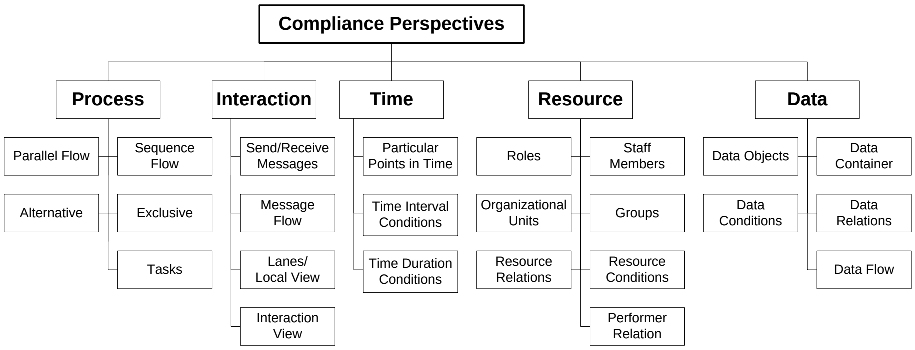

Fig. 1: Compliance perspectives

Interaction Perspective. In cross-organizational scenarios, compliance rules require particular elements for sending and receiving *messages*. *Message flows* correlate the sending and receiving of messages. Further, *lanes* express *local views* of the different partners on the different tasks to be performed. In turn, the *interaction view* focuses on the global sequence of interactions (i.e., messages exchanged). Compared to BPMN 2.0, *local views* correspond to *collaboration diagrams* and *interaction views* to *choreography diagrams*.

Time Perspective. Time support for compliance rules is tripartite: First, particular points in time may have to be expressed (e.g. *Monday, 3rd January 2013*). Second, conditions on the time intervals between events, tasks and points in time require support. Third, the duration of tasks may have to be constrained.

Resource Perspective. The resource perspective requires concepts for expressing constraints on *resources*. We select *staff member*, *group*, *organizational unit*, and *roles* as common concepts of organizational models. However, this list can be extended easily. The *performer relation* constrains the performer of a particular task. In turn, *resource conditions* and *relations* may be used to specify and constrain resources on a finegrained level.

Data Perspective. The data perspective comprises concepts for expressing data-aware compliance rules. Thereby, *data containers* refer to process data elements or global data stores. By contrast, *data objects* refer to particular data values and object instances. *Data flow* defines which process tasks read or write which data objects or data container. To constrain data container, data objects, and data flow, *data conditions* and *data relations* may be used.

In the following, required language extensions are presented taking the compliance rule graph (CRG) language as basis (cf. Sec. 4.1). However, these extensions may be applied to other compliance rule languages as well, since they are independent from particular properties of CRGs.

4 Extended Compliance Rule Graphs

This section introduces *extended Compliance Rule Graphs (eCRG)* - a visual notation for compliance rule modeling covering the process, interaction, time, resource, and data perspectives (cf. Section 3). Sect. 4.1 introduces fundamentals of CRGs, while its extensions are subsequently introduced step-by-step.

4.1 Fundamentals of Compliance Rule Graphs

The compliance rule graph (CRG) language [10, 12] allows visually modeling compliance rules whose semantics is defined over event traces. More precisely, a CRG is an acyclic graph consisting of an *antecedence pattern* as well as at least one related *consequence pattern*. Both patterns are modeled using *occurrence* and *absence nodes*, which indicate the occurrence or absence of events (e.g., related of the execution of a particular task). Edges between such nodes indicate control flow dependencies. As illustrated in Fig. 2, a trace is considered as compliant with a CRG iff for each match of the antecedence pattern there is at least one corresponding match of every consequence pattern. Further, a trace is considered as *trivially compliant* iff there is no match of the antecedence pattern. For example, the CRG from Fig. 2 expresses that for each B not preceded by an A, there must occur a D, which is not preceded by any C also preceding the respective B.

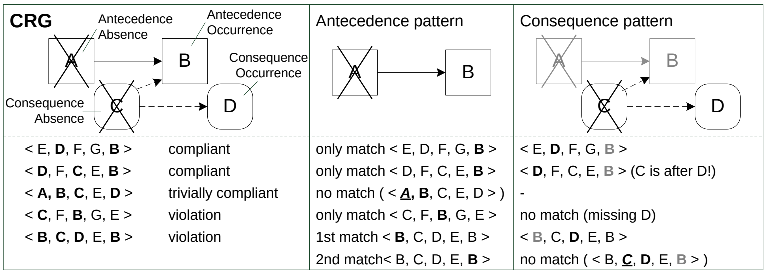

Fig. 2: CRG example and semantics over execution traces

In the following, we introduce the eCRG language, which is based on CRGs. Note that in addition to nodes and connectors (i.e., edges) as fundamental elements of graphs, eCRGs further support *attachments*. Attachments represent constraints to the nodes or edges they are attached to. Further, eCRGs may contain *instance nodes* representing particular instances, which exist independently from the respective rule (e.g. a particular employee *Mr. Smith*, date *3rd January 2013*, or role *supervisor*). Hence instance nodes are neither part of the antecedence nor the consequence pattern.

4.2 Process Perspective

The eCRG elements for modeling the process (i.e. control flow) perspective of compliance rules are introduced in Fig. 3. Since the extensions are based on the CRG language, there are four different task elements, i.e., *antecedence occurrence*, *antecedence absence*, *consequence occurrence*, and *consequence absence task*. These allow expressing whether or not particular tasks must be executed.

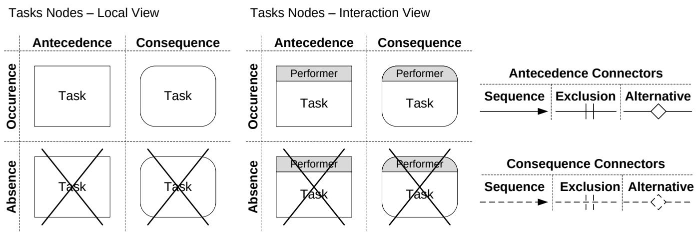

Fig. 3: eCRG elements of the process perspective

In addition, two different kinds of *sequence flow connectors* are provided that may be used to constrain the execution sequence of tasks. Note that the absence of sequence flow indicates parallel flow. To clearly distinguish between *start-start*, *start-end*, *end-start*, and *end-end* constraints on the execution sequence of tasks, sequence flow edges are either connected to the right or left border of a task node. Furthermore, *exclusive connectors* denote mutual exclusion of tasks. *Alternative connectors* express that at least one of the connected tasks must occur. Note that exclusive as well as alternative connectors may only connect nodes that are both part of either the antecedence or consequence pattern.

Fig. 5A shows an example of a start-start constraint on the execution sequence of tasks. It depicts the process perspective of compliance rule c_2 from Tab. 1. Note that this visual compliance rule disallows executing task *change order* after the start of task *production*.

4.3 Interaction Perspective

The interaction perspective covers constraints on the messages exchanged and the *interaction view* of the eCRG meta-model. Message exchanges are expressed in terms of particular nodes that reflect the events of *sending* and *receiving a message*. In turn, a *message flow* denotes the dependency between the events representing the sending and receiving of a particular message (cf. Fig. 4).

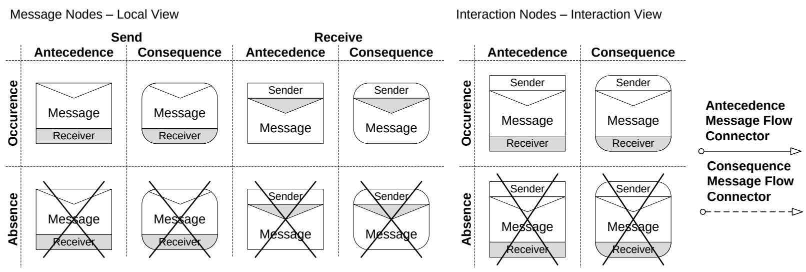

Fig. 4: eCRG elements of the interaction perspective

In Fig. 5B, the elements from Fig. 4 are used to model the process and interaction perspective of compliance rule c_4. This rule requires that after receiving message *request* from a reseller, a *solvency check* must be performed first. Then, a decision about *approval* has to be made before replying the request. Although the rule modeled in Fig. 5B considers the interaction perspective, using the two message nodes *request* and *reply*, it still represents the view of a particular business partner on its local business processes. We refer to this traditional point of view as the *local view* of a compliance rule. However, when considering the choreography diagram of BPMN 2.0 or compliance rules c_1 and c_3 from Tab. 1, one can easily discover a global point of view on cross-organizational processes and related interactions (i.e., the messages exchanged). In this *interaction view*, interaction nodes (cf. Fig. 4) are used to denote the exchange of a message between two business partners. Since the interaction view spans multiple business partners, task nodes may be annotated with the executing business partner if required (cf. Fig. 3).

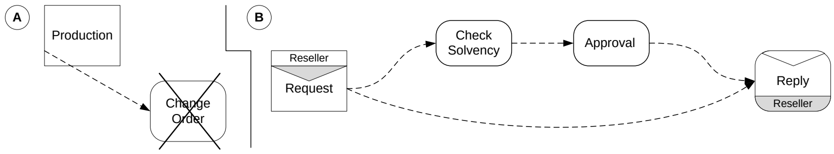

Fig. 5: Local view on c_2 and c_4 with process and interaction perspectives

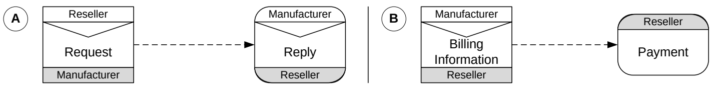

Fig. 6: Interaction view on c_1 and c_3 with process and interaction perspectives

Fig. 6A provides an interaction view on compliance rule c_1 from Tab. 1: After the reseller sends a *request* to the manufacturer, eventually, the manufacturer must *reply*. Further, Fig. 6B provides an interaction view on compliance rule c_3 from Tab. 1. This rule requires that the reseller must perform task *payment* after having received *billing information* from the manufacturer.

4.4 Time Perspective

Having a closer look on the original definition of compliance rules c_1 and c_3 from Tab. 1, it becomes clear that Figs. 6A and 6B do not fully cover them yet. In particular, the distance in time between the interactions and tasks have not been considered. Fig. 7 provides elements for modeling *points in time* and *time conditions* in compliance rules. The latter may be attached to task nodes as well as sequence or message flow connectors to either constrain the duration of a task or the time distance between tasks, messages, and points in time. Additionally, *time distance connectors* are introduced that must be attached with a time condition. Respective time distance connectors and related time conditions then allow constraining the time distance between tasks, messages, and points in time without implying a particular sequence.

Fig. 8A combines the interaction and time perspectives of compliance rule c_1. This visual representation of c_1 covers exactly the semantics of the compliance

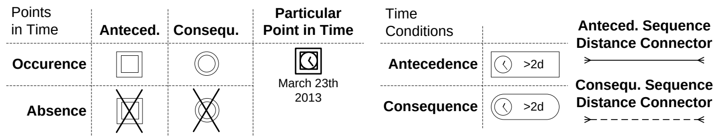

Fig. 7: eCRG elements of the time perspective

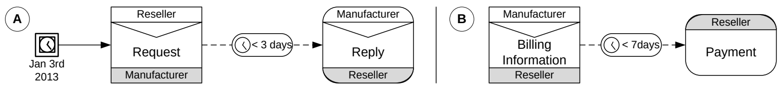

Fig. 8: Interaction view on c_1 and c_3 with process, interaction, and time perspectives

rule described in Tab. 1. In Fig. 8B, the interaction and time perspectives of c_3 are provided. This compliance rule requires that at most seven days after the manufacturer sends *billing information* to the reseller, the latter must perform task *payment*.

4.5 Resource Perspective

The resource perspective covers the different kinds of human resources as well as their inter-relations, and it allows constraining the assignment of resources to tasks. In particular, we consider resources like *staff member*, *role*, *group*, and *organizational unit*, and their relation to tasks. Furthermore, we support *resource conditions* and *relations* among resources (cf. Fig. 9). Similar to task nodes, *resource nodes* may be part of the antecedence or consequence pattern. Alternatively, they may represent a particular resource instance (e.g. staff member *Mr. Smith*, or role *supervisor*). In turn, *resource conditions* may constrain resource nodes. Further, the *performing relation* indicates the performer of a task. Finally, *resource relation connectors* express relations between resources. Note that the resource perspective can be easily extended with other kinds of resources if required.

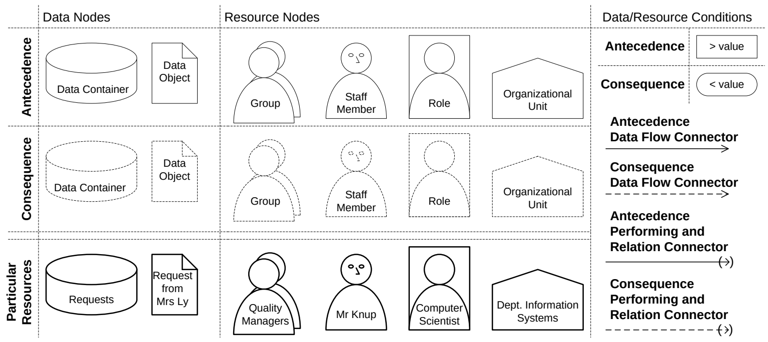

Fig. 9: eCRG elements of the resource and data perspectives

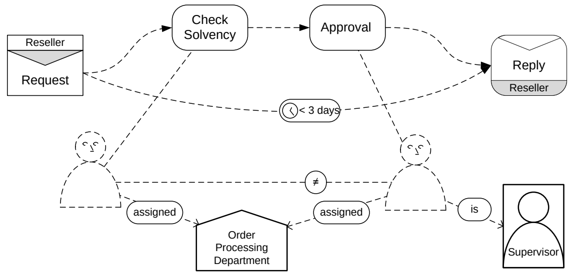

Fig. 10: Local view on c_4 with process, interaction, time, and resource perspectives

Fig. 10 combines the process, interaction, time, and resource perspectives of compliance rule c_4. This rule requires that at least three days after receiving a *request* of the reseller, a *replay* must be sent to him. Before sending this reply, first of all, task *solvency check* must be performed by a staff member assigned to the particular organizational unit *order processing department*. Following this task, another staff member of the same department with *supervisor* status (i.e., role) must decide whether or not to grant approval before sending the *reply*.

4.6 Data Perspective

Fig. 9 introduces elements for modeling data containers and data objects as well as connectors representing data flow. Thereby, *data containers* refer to process data elements or global data stores. By contrast, *data objects* refer to particular data values and object instances. Similar to resource nodes, *data nodes* may be part of the antecedence or consequence pattern, or represent a particular data container or data object (e.g., data container *student credit points*, document *1st order from Mr. Smith*). Further, *data flow* defines which process tasks read or write which data objects or data container. To constrain data container, data objects, and data flow, *data conditions* may be attached. Finally, *data relation connectors* may be used either to compare different data objects or to constrain the value of data containers at particular points in time.

Figs. 11A, 11B, and 11C show the visual modeling of compliance rules c_2, c_3, and c_4 covering the data perspective as well as the other perspectives discussed. Each of the depicted eCRGs covers the informal semantics described in Tab. 1.

5 Discussion and Validation

Sect. 4 introduced the eCRG language, which comprises various elements for modeling the process, interaction, time, resource, and data perspectives of compliance rules. However, note that the introduced elements must not be arbitrarily combined, but should follow syntactic constraints. First, any eCRG must be acyclic. Second, antecedence and consequence connectors must be applied in a reasonable way, e.g., any sequence flow between an antecedence absence and a

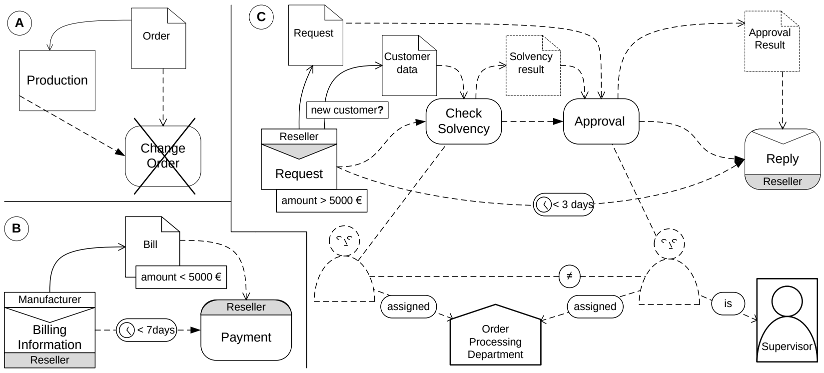

Fig. 11: Local view on c_2 and interaction view on c_3 and c_4, considering process, interaction, time, resource, and data perspectives

consequence absence node does not make sense, and hence is forbidden. Third, the use of attachments is restricted in a similar way. Finally, exclusive and alternative connectors must only connect tasks, messages, or interaction nodes of the same pattern. Fig. 13 summarizes valid and invalid use cases of connectors and attachments.

To the best of our knowledge, our approach is the first one that allows modeling compliance rules visually considering the interaction, time, resource, and data perspectives. Note that there exist pattern-based approaches that model compliance rules supporting at least the time, resource, and data perspectives [6, 8, 34]. These patterns resulted from literature and case studies, and thus constitute a suitable empirical basis for evaluating the appropriateness of our approach. Therefore, we modeled the compliance patterns introduced in [6, 8, 34] with our visual notation in [35]. Overall, we were able to fully model 26 out of the 27 business process control patterns from [8], including 5 time patterns and 7 resource patterns as well. Only the multi-segregation pattern cannot be modeled as eCRG [35]. Further, eCRGs allow modeling each of the 15 control flow compliance rules as well as the data flow restrictions and organizational aspects (i.e., separation of duty) from [6]. Finally, the time-patterns introduced in [16] can also be covered with eCRGs [35]. Note that the proposed visual notation (i.e., eCRG) is not restricted to these patterns (e.g., c_4 cannot be modeled by the use of compliance patterns).

Any syntactically correct eCRG can be converted into a corresponding FOL formula. The FOL formula, in turn, can be evaluated over process traces, including the process, interaction, time, resource, and data perspectives. Furthermore, the internal consistency (i.e., absence of conflicts) of a set of compliance rules can be verified. We provide details on the transformation of eCRG into FOL formula (i.e., the formal semantics of eCRGs) and the subsequent verification over process traces in [35]. We have demonstrated the feasibility of our modeling approach by implementing a proof-of-concept prototype of a modeling environment for eCRGs, which we then used to model compliance rules from a variety

Turetken et al.			
Precedes	++	USegregatedFrom	++
LeadsTo	++	BondedWith	++
XLeadsTo	+	RBondedWith	++
PLeadsTo	++	Multi-Segregated	-
ChainLeadsTo	++	Multi-Bonded	++
Chain Precedes	++	Within k	++
LeadsTo - Else	++	After k	++
Exists	++	ExactlyAt k	++
Absent	++	Exists Max/Min	+
Universal	+	Exists Every k	+
CoExists	++		
CoAbsent	++		
Exclusive	++		
CoRequisite	++		
MutexChoice	++		
PerformedBy	++		
SegregatedFrom	++		

Ramezani et al.	
Existence	++
Bounded Existence	+
Bounded Sequence	+
Parallel	++
Precedence	++
Chain Precedence	++
Response	++
Chain Response	++
Between	+
Exclusive	++
Mutual Exclusive	++
Inclusive	++
Prequisite	++
Substitute	++
Corequisite	++
Restricted data values	++
Separation of Duty	++

Lanz et al.	
Time Lags between Activities	++
Durations	++
Time Lags between Events	++
Fixed Date Elements	++
Schedule Restricted Elements	++
Time-based Restrictions	+
Validity Period	++
Time-dependend Variability	+
Cyclic Elements	++
Periodicity	++

++ full support, + inconvenient support, 0 partial support, - minor support, -- no support

Fig. 12: Support of compliance patterns with eCRGs

antecedence connector sequence flow

	AO	AA
AO	ok	ok
AA	ok	X

AO antecedence occurrence node
AA antecedence absence node
CO consequence occurrence node
CA consequence absence node

consequence connector sequence flow

	AO	AA	CO	CA
AO	ok	X	ok	ok
AA	X	X	X	X
CO	ok	X	ok	ok
CA	ok	X	ok	X

antecedence attachments

AO	AA	CO	CA
ok	ok	X	X

consequence attachments

AO	AA	CO	CA
ok	X	ok	ok

exclusive / alternative connectors

	AO	AA	CO	CA
AO	ok	ok	X	X
AA	ok	ok	X	X
CO	X	X	ok	ok
CA	X	X	ok	ok

Fig. 13: Valid Use of eCRG elements

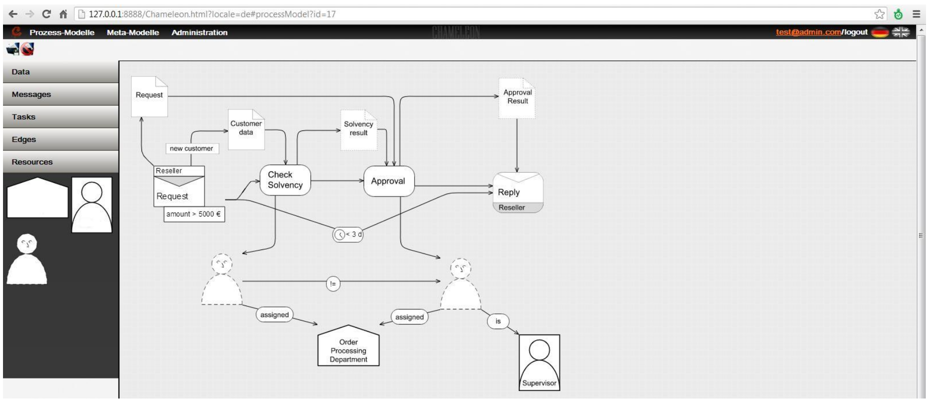

Fig. 14: Proof-of-concept implementation

of domains including higher education, medicine and automotive engineering. In particular, domain experts have been able to define and understand the visual notation we used. We are currently preparing user experiments to check how end users deal with large sets of visual compliance rules. Fig. 14 provides a screenshot of our prototype.

6 Summary and Outlook

While compliance rule modeling has been introduced by a plethora of approaches, the data, time, and resource perspectives of compliance rules have not been sufficiently addressed yet [5–8]. This paper introduces extensions for visual compliance rule languages to support these perspectives. In particular theses extensions are introduced as part of *extended compliance rule graphs (eCRG)*, which are based on the *compliance rule graph (CRG) language* [10, 12]. However, the modeling elements described may be applied to other compliance rule languages as well. Besides the data, time, and resource perspectives, we further suggest elements for modeling the interaction perspective of compliance rules. To provide tool support for both the modeling and verification of compliance rules, we formalize the syntax and semantics of eCRGs in a technical report [35]. Finally, pattern-based analysis has shown that eCRGs have sufficient expessiveness. Our next step will be an experiment to evaluate the usability and scalability of eCRGs. Further, we will apply the proposed extensions to other compliance rule languages. Finally, we will develop techniques for verifying compliance of business processes and process choreographies with such rules.

References

1. Reichert, M., Weber, B.: Enabling Flexibility in Process-Aware Information Systems. Springer (2012)
2. van der Aalst, W.M.P.: Verification of workflow nets. Application and Theory of Petri Nets (1997) 407–426
3. Sadiq, S., Governatori, G., Naimiri, K.: Modeling control objectives for business process compliance. In: BPM'07. (2007)
4. Knuplesch, D., et al.: Towards compliance of cross-organizational processes and their changes. In: Proc SBP'12, Springer (2012)
5. Cabanillas, C., Resinas, M., Ruiz-Cortés, A.: Hints on how to face business process compliance. In: JISBD'10. (2010)
6. Ramezani, E., Fahland, D., van der Aalst, W.M.: Diagnostic information in compliance checking. In: BPM'12, Springer (2012)
7. Mangler, J., Rinderle-Ma, S.: Iupc: Identification and unification of process constraints. arXiv. org (2011)
8. Turetken, O., Elgammal, A., van den Heuvel, W.J., Papazoglou, M.: Capturing compliance requirements: A pattern-based approach. IEEE Soft (2012) 29–36
9. Ghose, A.K., Koliadis, G.: Auditing business process compliance. In: ICSOC'07. (2007) 169–180
10. Ly, L.T., et al.: Design and verification of instantiable compliance rule graphs in process-aware information systems. In: CAiSE'10. (2010) 9–23

11. Liu, Y., Müller, S., Xu, K.: A static compliance-checking framework for business process models. IBM Systems Journal **46**(2) (2007) 335–261
12. Knuplesch, D., Reichert, M.: Ensuring business process compliance along the process life cycle. Technical Report 2011-06, Ulm University (2011)
13. Russell, N., et al.: Workflow resource patterns: Identification, representation and tool support. In: CAiSE'05, Springer (2005) 216–232
14. Kumar, A., Wang, J.: A framework for document-driven workflow systems. In: Int'l Handbook on Business Process Management. Springer (2010) 419–440
15. Eder, J., Tahamtan, A.: Temporal conformance of federated choreographies. In: DEXA'08. (2008) 668–675
16. Lanz, A., Weber, B., Reichert, M.: Time patterns for process-aware information systems. Requirements Engineering (2012)
17. Decker, G., Weske, M.: Interaction-centric modeling of process choreographies. Inf Sys **35**(8) (2010)
18. Barros, A., Dumas, M., ter Hofstede, A.: Service interaction patterns. In: BPM'05. (2005) 302–318
19. Knuplesch, D., et al.: Data-aware interaction in distributed and collaborative workflows: Modeling, semantics, correctness. In: CollaborateCom'12. (2012) 223–232
20. Ly, L.T., et al.: Integration and verification of semantic constraints in adaptive process management systems. Data & Knowl Eng **64**(1) (2008) 3–23
21. Ly, L.T., et al.: On enabling integrated process compliance with semantic constraints in process management systems. Inf Sys Front **14**(2) (2012) 195–219
22. Ramezani, E., et al.: Separating compliance management and business process management. In: BPM Workshops, Springer (2012) 459–464
23. Governatori, G., Sadiq, S.: The journey to business process compliance. In: Handbook of Research on BPM. IGI Global (2009) 426–454
24. Namiri, K., Stojanovic, N.: Pattern-Based design and validation of business process compliance. In: CoopIS'07. (2007) 59–76
25. Governatori, G., et al.: Detecting regulatory compliance for business process models through semantic annotations. In: BPM Workshops, Springer (2009) 5–17
26. Kumar, A., Yao, W., Chu, C.: Flexible process compliance with semantic constraints using mixed-integer programming. INFORMS J on Comp (2012)
27. Awad, A., Weidlich, M., Weske, M.: Specification, verification and explanation of violation for data aware compliance rules. In: ICSOC'09. (2009) 500–515
28. Knuplesch, D., Ly, L.T., Rinderle-Ma, S., Pfeifer, H., Dadam, P.: On enabling data-aware compliance checking of business process models. In: ER'2010. (2010)
29. Kokash, N., Krause, C., de Vink, E.: Time and data aware analysis of graphical service models. In: SEFM'10. (2010)
30. Höhn, S.: Model-based reasoning on the achievement of business goals. In: SAC '09, New York, NY, USA, ACM (2009) 1589–1593
31. Accorsi, R., Lowis, L., Sato, Y.: Automated certification for compliant cloud-based business processes. Business & Inf Sys Engineering **3**(3) (2011) 145–154
32. Awad, A., Weidlich, M., Weske, M.: Visually specifying compliance rules and explaining their violations for business processes. Vis Lang Comp **22**(1) (2011) 30–55
33. Feja, S., Speck, A., Witt, S., Schulz, M.: Checkable graphical business process representation. In: ADBIS'11, Springer (2011) 176–189
34. Dwyer, M.B., Avrunin, G.S., Corbett, J.C.: Property specification patterns for finite-state verification. In: FMSP'98. (1998)
35. Knuplesch, D., et al.: On the formal semantics of the extended compliance rule graph. Technical Report 2013-05, Ulm University (2013)