# A Systematic Review of Methods for Consistency Checking in SBVR-based Business Rules

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## ABSTRACT

Business enterprises in today's world have complex rules and process as their foundation. The rules and processes continuously change to reflect the enterprise's evolution and progress, market demands and regulations. This constant flux demands an automatic way to check these business rules for correctness and consistency. In the recent times, few methods were proposed for automated checks. In our literature review for this subject matter, however, we did not find a proper survey, which could present a consolidated picture of the properties, advantages and drawbacks of the different methods. The randomly scattered state of art for specifying business rules and analyzing them for inconsistencies is hindering the relevant research space. We conduct a systematic literature review of various solutions discussed in the field of consistency checking for business rules, especially rules in Semantics of Business Vocabularies and Rules (SBVR) format. We highlight the progress made in the field, aspects that can be developed further, and the current gaps in the methods so that future work can be channelized to address and close the gaps by proposing new or enhanced methods.

## Keywords

Business Rules; Rule Verification; SBVR; Consistency; Redundancy

## 1. INTRODUCTION

Business Rules are operational regulations, decision rules that a business organization follows to perform certain activities. The business rules are usually embodied in the system artefacts such as governing policies, guidelines, operating procedures, legacy source code, etc. Operationally, the business rules may be implemented in the source code of the running systems, and their parameters (if the rules are parametrized) are usually stored in a database or in datafiles or configuration files.

Both humans and information systems are involved in business operations, with the corresponding business rules spread across the enterprise in various forms (policy documents, operational procedures and in the source code of the information systems). Market conditions and external regulatory reasons are the causes behind changes to the business structure, policies, and strategies. Business transformation is a process of adjusting the business activities to accommodate the above changes. The ageing business information systems may also require changes in order to respond to changing business environment, i.e., competition and superior business products and services. Both IT transformation and business transformation force the enterprises to revisit their business rules, pushing forward the need for automatic testing of business rules.

Over the last few decades, in the field of business knowledge, a number of works have been proposed, dealing with extraction of business rules from information systems and gathering business information from text documents. Certain aspects of the domain, however, are still in need of answers. Among them, the following are the research topics based on mined business rules:

1. How complete and correct are the extracted business rules with respect to the source of the business rules?
2. Are the extracted or manually created business rules inconsistent with each other?
3. What can be the preferred notation for representing extracted knowledge or mined rules from multiple sources?

A few notable works [9, 10, 17, 3, 1] have been done to address (2) and (3). However, to the best of our knowledge, there is no proper literature review present, which reviews all the works addressing the above mentioned research problems. In this paper, we present a systematic literature review of works which aims to study the mappings of the knowledge represented in the form of business rules to a format which identify inconsistencies / redundancies among business rules. In this survey, we consider business rules which are represented in Semantics of Business Vocabularies and Rules (SBVR) [13]. The idea to go with only SBVR representation for this survey, is because of the immense popularity SBVR has garnered in recent years, and its strong theoretical foundation in formal logic [1].

A set of documents were published by OMG, grouped under the Business Modeling & Integration Domain Task Force (BEIDTF) project [12], as a solution to the representation to the business rules. The SBVR model has been presented as result of the request for proposal on Business Semantics of Business Rules (BSBR) made by OMG, which is a part of the business model layer in the Model Driven Architecture (MDA). The purpose of SBVR is to describe formally and without ambiguities the semantics of a business model, in turn benefiting business analysts and modelers, as well as business vocabulary and rules administrators and software tool developers. SBVR [13] works as a bridge between business and IT people, aiming to provide a way to express business knowledge (requirements, operational procedures etc.) to the IT people unambiguously using natural language. SBVR meta-model is used to represent business knowledge as:

1. Specifying business vocabularies.
2. Specifying business rules.

Organizations or communities specify the conduct of business using a cohesive set of interconnected concepts known as Business vocabulary. These concepts are entities represented through *name, term,* and *verb*. The fact is expressed as relation between these concepts. SBVR Structured English (SSE) is a popular textual representation of SBVR, providing the option to write business rules in plain English. The categorization of SBVR meta-model includes tokens and keywords. A token is a place holder for 'text' associated with name, term, and verb in the SBVR meta-model. The keywords are added to facts in order to create rules [13].

The rest of the paper is arranged as follows. In Section 2 we present the setup of the survey, which includes the Research Questions that form the structure of the survey, followed by the Study Quality Assessment metrics and the overview of the survey. Section 3 contains the summary of the works under review. Section 4 and 5 presents the Results & Discussions and Conclusion respectively.

# 2. SETUP OF THE SURVEY

In this section, we present the setup of the survey conducted. In order to follow a systematic approach, we identified few research questions that needed to be answered in a measured manner during this survey. At the end we also present the metrics that we have followed for the study quality assessment of the survey. We believe that the strong setup shall enable us to review the concerned literature in an organized and compact manner.

## 2.1 Research Questions

In order to undertake the systematic literature review, we frame the following research questions, based on the current status of the work done in the field of business rules represented using SBVR metamodel, after they have been extracted from the source code or specification documents.

**RQ1**: What are the analyzable model forms that SBVR-based business rules are converted into?

**RQ2**: How are the underlying theoretical foundations of SBVR utilized?

**RQ3**: What are the existing gaps in present solutions and possible opportunities for future research?

SBVR has a sound theoretical foundation of formal logic, underpinning both logical formulation and the structures of bodies of shared meanings. SBVR meta model has inherent support to First Order Logic (FOL). It is a Control Natural Language (CNL) with restricted user defined business vocabularies. The following are the key differences or additions to FOL to support SBVR:

- SBVR supports restricted quantification (*at most, at least*) while FOL is built on existential and universal quantification.
- SBVR supports modal logic (*deontic and alethic*), which FOL lacks.

The need to model SBVR into a knowledge representation, is because of the wide reach of FOL in the current research world, in terms of the number of solvers as well as their strength. Since the aim is to automatically infer from the business rules, the selection of knowledge base is an important step in the process.

The *Utilization* of represented knowledge form is varied as per the domain and company. Business institutions presently are demanding automatic consistency checks on their business rules and performing knowledge querying on the business rules. Automatic consistency checks on the business rules aims at identifying conflicts and/ or redundancies in the business rules (if any). Another popular aspect is Knowledge Querying, the process of retrieving desired information from the given business rules.

Our work aims to identify the present methods proposed for the problem of automatic consistency checking for business rules represented in SBVR format, assess their performance and their shortcomings. We define this as our *problem statement* throughout the paper. Through this, we aim to highlight the existing gaps between the proposed solutions and the desired solutions in the particular research area mentioned earlier and possible opportunities for future research.

## 2.2 Study Quality Assessment

Although there is no commonly agreed definition of study "quality", it could be assessed by constructing a check-list of factors that need to be evaluated for each study. To aid this, we mark a work based on the following three aspects:

(1) Evaluation of Proposed Approach.
(2) Automation level of the Proposed Approach.
(3) Definition of the Proposed Approach.

Figure 1 presents details of our study quality aspects. An approach is said to be *formal*, when it is enough to be reproduced. In a *semi-formal* approach, some steps can be reproduced, while a *vague* approach, is impossible to reproduce. The ultimate solution to our '*problem statement*' is an approach, which has a strong formal presentation, has complete automation and has results on an industrial case study.

## 2.3 Overview of the Survey

The study was conducted by first collecting the relevant works from various online repositories. The search string permuted on the major words pertaining to our problem statement, e.g., *SBVR, Business Rules, consistency, mappings, transformations, formalisation.* The search across the various repositories returned a number of results, whose abstracts and definitions were scanned to reduce the final basket of primary studies under review to *nine* categories.

We classify the primary studies according to their publication year and type. The results are presented in Table

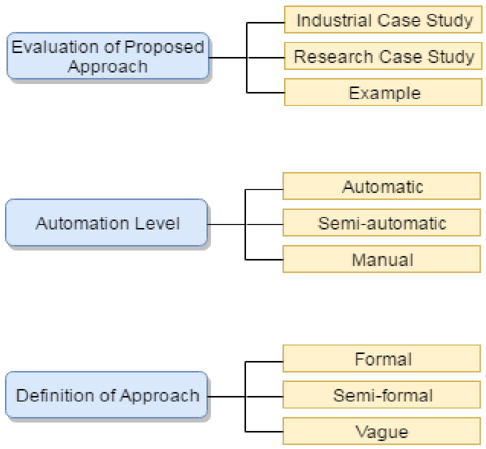


**Figure 1: Breakdown of the Study Quality Assessment metric**

1. We review each of the primary studies in regards to the research questions proposed in Section 2. In the following section, we summarize each primary study, highlighting their approaches, contribution and drawbacks.

## 3. SUMMARY OF THE PRIMARY STUDIES

The work of Ceravolo et al. [1] is one of the first works to represent business rules in a formal knowledge representation with the aim of using available reasoners to identify inconsistencies. The authors model SBVR rules to OWL Description Logic (DL). However, DL is not expressive enough, thus the rest of rules are modelled using Horn Rules expressed in the Semantic Web Rule Language (SWRL) formalism, with undecidability arising while reasoning with respect to Open World Assumption (OWA). The paper suggests a prototype application like Hoolet to reason about OWL+SWRL, or adopting Prolog-like languages to infer from knowledge represented as rules in Closed World Assumptions(CWA), with the drawback of of complex executions and loss of information. The paper falls short of clear and distinct mapping from SBVR to OWL DL, also lacking a concrete example showing consistency checking with the aid of the transformed formal knowledge bases, however creating a base for future works.

Denilson dos Santos Guimarães et al. [3] proposes a new approach by translating business rules into Alloy model [6]. Alloy is a language for describing structures and a tool for exploring them, supported by an Analyzer. The mentioned mappings of Business Rules into Alloy model are not described and shown in the paper, and that is a serious drawback. An initial Business Model is created in Alloy with the aid of a domain conceptual model created from the rule set, after which rules are added to the model one by one. After every addition, the analyzer tries to find a valid example for the model. If no such examples are found, then the model is said to be inconsistent. The conflicting rule is found by creating a test predicate containing the disjunction of the rule and the possibly conflicting rule, and then checking for consistency. If the model becomes consistent, then the rules are conflicting, highlighting lack of automation. Thus, if there are $n$ rules present in the model, addition of the $(n+1)th$ rule creates an inconsistency, in order to find the conflicting rule, we have to execute the same approach $n$ number of times in the worst case. The case where multiple rules create an inconsistency is not mentioned. The redundancy is handled in a near similar fashion, with a new assertion being created with the rule and the negation of the possibly redundant rule. If counterexamples are found, then the rule is proven to be redundant. This approach also suffers from the drawback of lack of automation mentioned earlier. This work remains one of the few to try to identify redundancies.

The following four publications are work of the same research group. The first paper Karpovic and Nemuraite [7] presents the groundwork for the complete work flow. It presents the basic concepts of the SBVR meta model, followed by the basic concepts of the OWL 2.0 meta model, aiming at drawing out the viability of the transformations. Transformations for four different SBVR concept types are presented, with graphical examples and explanations provided for all of them. Among the fact type roles, *N-ary* associative fact type role is mentioned to be needing special consideration as there is no direct mappings to OWL 2.0. The second paper [8] from the work flow, presents 23 different mappings from SBVR concepts to OWL2, with the aid of a running example, aiming to provide consistent ontologies. The paper presents requirements for SBVR Business Rules in order to produce consistent ontologies, effectively putting a few constraints on the expressibility of the Business rules. One such example of a constraint is that in order to have inverse properties in the OWL2 vocabulary, dedicated alethic SBVR rules needs to be explicitly defined. Another example is forcing business rules to be defined in a way that inferences should never result in making individual instances of several non-inferable concepts, by limiting each individual concept to be an instance of exactly one most specific self-standing primitive concept. Even though, it is mentioned that the transformations have been done aiming at reasoning and querying, the latter tasks are not shown. Thus, there is no metric to check the relevance or completeness of their transformations.

The presentation of [9] is similar to the previous paper, illustrating a number of mappings, with detailed explanation. This work, however focuses on describing reversible transformations between SBVR and OWL2, deviating from the earlier one way mappings of SBVR to OWL2. Once again some restrictions are highlighted out, e.g., *ObjectProperty* axioms must be simple properties, along with satisfying the restrictions on the property hierarchy for avoiding cyclic dependencies. We feel these constraints can affect the representation of SBVR vocabulary and rules in a real life scenario. Similar to [8], no application has been shown of the generated ontologies. The final paper [10] acts as a survey between all the works on transforming SBVR to OWL2, with results indicating that the work done by the group is the most complete and relevant transformations that have been proposed. The group claims that they have completed 69 different mappings, 51 of which have been implemented. They also point out which SBVR concepts have been mapped wrongly or have not been mapped in the other comparable works, followed by experimental results, which show, the relevancy of the transformations. This comparison shows the effectiveness of the SBVR extensions that have been proposed by the group and the viability of consistency check using the transformed ontologies. Nine different vocabulary and rules

Table 1: **Distribution of selected primary studies by year and publication type**

| **Year** | **Journals** | **Proceedings** | **Internal** Reports | Total |
|---|---|---|---|---|
| 2007 | 0 | 1 | 0 | 1 |
| 2011 | 0 | 1 | 0 | 1 |
| 2012 | 0 | 1 | 0 | 1 |
| 2014 | 2 | 1 | 1 | 4 |
| 2016 | 1 | 1 | 0 | 2 |
| **Total** | 3 | 5 | 1 | 9 |

are selected, two of them are in English and the rest are in Lithuanian The idea of *precision* and *recall* is used to represent the score in the results. The relevancy computation is not properly explained, i.e, the phrase *relevant transformations to OWL2 elements* raises the questions of what makes a transformation relevant and irrelevant among the executed transformations. Also, the strength of the proposed extensions is presented for only one of the English vocabulary and rule set, while the *Loan Vocabulary* did not use even one extension, even though it is more complex of the two.

Reynares et al.[15] presents the formal transformations from SBVR to OWL2, followed by examples for a few of them. The transformations appear a bit redundant, i.e, most of the transformations have been presented in the related works, with most of them covering the basic concepts of SBVR, lacking how to deal with complex SBVR rules. Some of the examples provided are unclear [15] and fails to explain the significance of *is_role_of* in the ontology, how it is to be identified, and the presence of two *SubObjectPropertyOf.* In the same example, the transformations for Universal Quantification and Existential Quantification are presented. However, the transformation criteria for both are given to be same, which is extremely confusing. There is a lack of clarity regarding the categorization and segmentation scheme. The example used for illustrating segmentation is presented as categorization with the introduction of *DisjointClasses.* The paper scores with presenting the *Ontology Quality Assessment* that is performed using *OQuaRE.* A case study is designed, where, a document specified in natural language is converted to SBVR and then transformed to OWL2, using the transformations provided before. The quality measurement is described in detail, following snapshots of a few transformations. The aim of this experiment is to show that the transformed ontologies has good quality and can be used for further computations. This quality measurement is one of the first work in this field, and is a novel presentation. However, the *Student Fellowship* rule set is very small, and covers only the basic SBVR cases. So the good quality measurement in the experiment is expected. However, as the authors mention, the experiment aims to justify the transformations provided and show that there is scope, rather than the efficiency. The other obvious drawback is that no work is shown, which deals with the efficiency of the transformed ontologies, in the field of consistency checking or query management of SBVR rules, keeping the question alive that how efficiently the generated ontologies can be used for knowledge management.

The work done by Kendall and Linehan [11] presents a set of transformations from SBVR to OWL2 elements and annotations, aiming to provide a different method for transferring SBVR among tools, than the traditional method of using the XMI based format. The focus of the transformations is on the representation of the ontologies rather than their utilization, thus the use of annotations, which makes the resulting ontologies not favorable for consistency checking. The transformations are however very limited, as many aspects of SBVR vocabularies are missing in the work, along with behavioral rules. Some notable examples are the categorization and segmentation parts of SBVR. The work makes some strong assumptions for their mappings, for example generating inverse verb property for all object properties, taking the presence of 'has' as property association. The assumptions can result in generating incorrect ontologies. We opine that, the work done by Kendall and Linehan is focused on a particular directive, and thus the transformations are limited for that utilization.

Chittimalli and Anand[2] is the latest work to be done in this field. The authors take a different approach than the existing preference towards OWL, and provide mappings to SMT-LIBv2. They propose a domain independent method of detecting inconsistencies in the business rules represented using SBVR underlying logical foundations, along with 40 different mappings that are currently implemented, with more expected to be provided in the future. Single sorted logic have been used to support term concepts hierarchies (specialization and synonyms), with primitive mappings defined for handling noun concept, term concept, and name concepts. Membership axioms have been defined to support these primitive mappings. They have used hierarchy axioms to support specialization of term, noun, name concepts and have mapped unary, binary, n-ary facts in SBVR into SMT-LIBv2 function with appropriate number of parameters. Their work support logical operators such as and, or, not, if then else using logical mappings. The quantification mappings are defined using SMT-LIBv2 *forall, exists* commands. The exactly-n, at least n, and at most n (restricted quantification) has been supported predicates and function calls. However they have not supported objectification and nominalization. The query and answer nominalization is generally used to find the consistent rules in the system. The complete work flow have been implemented in the form of a prototype tool BuRRiTo which executes these mappings.

One mentionable work that works with automatic consistency checking of business rules is the work done by Solomakhin et al. [17]. The work was not included in our review because the paper uses ORM2 representation instead of SBVR. Nevertheless, since SBVR and ORM2 are quite similar in their foundation and definition, the latter being more graphical oriented, we put in the summary of the paper in this section. Their idea is to present a first order deontic-alethic logic representation of business rules with sound and complete axiomatization which aims to capture the complete semantics of and interaction between business

Table 2: Summary of Methods for Consistency Checking of SBVR

| Study | Knowledge Form | Representation Form | Automation Level | Evaluation | Clarity |
|---|---|---|---|---|---|
| Ceravolo et al. [1] | SBVR 1.0 | OWL DL + SWRL | Manual | Example | Vague |
| Denilson dos Santos Guimarães et al. [3] | SBVR 1.2 | Alloy | Semi-automatic | Example | Vague |
| Karpovic and Nemuraite[7] | SBVR 1.0 | OWL 2.0 | Semi-Automatic using prototype tool | Example | Semi-formal |
| Karpovic et al.[8] | SBVR 1.0 | OWL 2.0 | Semi-Automatic using prototype tool | Running Example | Semi-formal |
| Karpovič et al.[9] | SBVR 1.2 | OWL 2.0 | Semi-Automatic using prototype tool | Running Example | Semi-formal |
| Karpovic et al.[8] | SBVR 1.2 | OWL 2.0 | Semi-Automatic using prototype tool | Research Case Study | Semi-formal |
| Reynares et al.[15] | SBVR 1.0 | OWL 2.0 | Semi-Automatic | Example | Formal |
| Kendall and Linehan [11] | SBVR 1.2 | OWL 2.0 + Annotations | Manual | Example | Semi-formal |
| Chittimalli and Anand [2] | SBVR 1.2 | SMT-LIBv2 | Automatic | Research Case Studies | Formal |

rules. A tool is proposed where ORM2 Formal Syntax is translated to less expressible *ALCQI*, which is a fragment of OWL2, and then checked for consistency. The approach is to reduce the consistency check to a *ALCQI* satisfiability, which in turn can be termed as unsatisfiability check in resulting OWL2 ontologies. The introduction of First Order Deontic and Alethic Logic (FODAL) has a strong theoretical background, and the approach behind the tool is well charted out. The aim is to map business rules to a usable First Order Logic Format, rather than directly to ontologies, providing users with the option of using the interactions between the business rules. The use of ORM2 to represent business rules is rather debatable, as the representation of the business model will be open to interpretation. The use of *ALCQI* causes the tool not to consider rules which are deontic in nature. Since *ALCQI* has less expressive power than ORM2, many concepts of SBVR are not considered by the tool, such as, *frequency constraints on multiple roles and ring constraints (which deals with n-ary relations)*. Major business rules set will have multiple cardinalities and relationships which are subsets or exclusions of each other, highlighting the above limitations.

# 4. RESULTS AND DISCUSSIONS

From the summary of each of the primary studies, we highlight the major points, including the approach, intention, implementation and drawbacks. The results are presented in Table 2, where we classify each of the work according to the properties for Study Quality Assessment presented in Figure 1.

In order to see which representation is preferred by the majority we bucket the primary studies according to the representation they are mapped to. It is clear that Web Ontology Language OWL2 is the most preferred form of knowledge representation, as OWL2 has capabilities for reasoning and querying semantic specifications. OWL2 also boasts of a number of reasoners which aid in consistency checking, like [4, 16, 18].

OWL2 plays a very important role in knowledge querying, with the help of ontology query language SPARQL [14]. SBVR questions are formulated and transformed into SPARQL for immediate access to business data from various sources. In terms of consistency checking however, OWL2 has some drawbacks. Complete SBVR transformation has not yet been done, the reason being that OWL2 is suitable for knowledge representation, rather than assertion enforcing. SBVR vocabulary with *concepts* and *facts* have direct transformations to OWL2, being knowledge representation, however SBVR rules, which are assertions to be enforced have no direct mappings. That is the reason why in all the mappings presented in the reviewed works, modality of SBVR is not preserved in the transformations. Another strong reason to discourage OWL2 is that Automatic Test Case Generation is not possible when mapped to OWL2, as no constraint checking is possible presently.

The automation level for most of the works that we reviewed are semi-automated. The work from [9, 7, 8, 10] has a prototype converter, which provides transformed ontologies, in which the objects need to be defined manually, for consistency checking in any of the reasoners. The method in [3] involves manually changing the status of each rule in order to find the source of inconsistency or redundancy, which is clearly not a judicious approach. [2] has implemented a framework, which is completely automated. The rest of the methods present basic mappings without any tool or transformation medium. [15] is marked as semi-automatic in Table 2 as the transformations are formal enough to be automated.

We find the aim of most of the reviewed works as representation of SBVR to a knowledge form, rather than any definite goal to be achieved with the knowledge form. To be more definite, most of the works do not aim for consistency checking, rather they aim for representation in OWL2 ontology, which they claim can be used for consistency checking, due to the presence of supported reasoners [4, 16, 18]. [3] and [2] are the works which aims for consistency or redundancy checking, while [10] publishes its performance for consistency checking, but as mentioned earlier, the results are not clear.

Most of the reviewed works, make the use of running examples, with the exception of [10, 9] which uses a research case study, *Photo Equipment* and [2] which uses *EU_Rent* [5]. The lack of a proper case study is extremely startling, and a major gap in this research area. The approach is semi-formal in majority of the cases, with the trend being to present a certain case followed by a transformation of an example. No general representation is presented most of the time, which makes it difficult for others to use the same mappings for complex rules. [15] aims to present a formal approach, but as mentioned its coverage of SBVR aspects is extremely limited. [2] tries to remove this deficiency, by presenting mappings based on general representation rather than examples.

The work from [17], presents a tool, which automatically identifies inconsistencies, and the sources behind the inconsistencies. However, the coverage of the particular tool is limited, and the debatable use of ORM2 instead of SBVR is a drawback, as the representation becomes to open to interpretation.

So far, we have identified a few gaps in the solutions proposed for our *problem statement*, which are listed below,

1. The mappings between SBVR rules and OWL2 are not complete.
2. A stronger knowledge representation is needed, which

will be able to cover all aspects of SBVR for inconsistency checks. Present ontologies are unable to provide complete coverage.
3. Need for complete case studies, which covers all form of inconsistencies and redundancies.
4. There is a lack of automation in the work flow.

Future research should be directed at closing the above mentioned gaps. If OWL2 is the decided knowledge base for SBVR representation, then the strength and coverage of the former needs to be increased. A complete list of possible inconsistencies and redundancies that can exist in SBVR needs to be verified and published. If ontologies fall short for the above requirements, other knowledge representation forms needs to be explored with a merger between different knowledge representations becoming a major possibility. The need of the hour is a complete case study which covers all the complexities that exist in this research problem. The presence of a case study, which has all the possible inconsistencies, will make it possible for a tool to be declared a complete inconsistency checker for business rules. The selection of knowledge representation should also consider the idea of automation, which means that the rules that causes inconsistencies or redundancies, should automatically be identified, without any manual effort from the user's side.

# 5. CONCLUSION

We observed that much of the prior work for consistency checking of SBVR business rules is directed towards converting SBVR to OWL2, aiming to exploit the querying capability available for OWL2 representation. Due to limitations of OWL2 reasoners to enforce assertions and check constraints, exploiting the OWL2 reasoners is not the primary objective of the conversions. Unfortunately, the mappings from SBVR to OWL2 are not complete, primarily due to few constructs of SBVR that have no direct equivalents in OWL2. Due to the absence of specific purpose-driven transformations of SBVR to OWL2, there are multiple mappings, leading to only semi-automated transformations.

We see the need to effectively extend OWL2 to enhance its strength and coverage. A benchmark to establish a common minimum set of anomalies for SBVR will go a long way for making it an effective representation, or evolving another useful representation. Suitability of knowledge representation for querying and automated checking for anomalies needs to be primary criteria for selecting and evolving standards.

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