OntoBacen: A Modular Ontology for Risk Management in the Brazilian Financial System

Filipe Polizel
Instituto de Matemática e Estatística
Universidade de São Paulo
fpolizel@ime.usp.br

Sara Casare
IBM do Brasil
sjcasare@uol.com.br

Jaime Sichman
Escola Politécnica
Universidade de São Paulo
jaime.sichman@poli.usp.br

Abstract

This paper presents a first semantic formalization of the Brazilian financial system risk management policies, called OntoBacen, that is based on a modularized approach. We show some partial results generated by a knowledge-based system that uses an ontology constructed to address some domain questions.

Episodes like global crisis undermine people's confidence in the financial system, but also provide lessons for the future. The 2007-2008 meltdown resulted in a significative advancement of governance policies followed by financial institutions worldwide, with some of them treating classic data management problems, as integrity and completeness. To enable the adoption of an integrated and robust global financial system, IT companies and financial institutions are joining efforts for the creation and adoption of a technological framework to better meet the industry needs.

The main goal of this work is to explore alternative approaches for the conceptualization and definition of business rules present in governance policies of the Brazilian financial system, more specifically those related to risk management. To this end, it proposes an ontology, called OntoBacen, that expresses the concepts (and their relationships) of this domain, and by using inference algorithms, can verify the compliance of hypothetical financial institutions with those policies.

For such a wide and complex domain, modularity must play a central role in the design of the proposed solution, to ensure that it results in an coherent, understandable and scalable knowledge-based system.

In the following section, the risk management setting of the Brazilian financial system is briefly introduced. We then present the main initiatives involving ontologies for the financial industry, followed by a description of OntoBacen by means of its properties and requirements. In the sequence, we show the modularization approach adopted by the proposed solution, followed by a section that details how OntoBacen has been developed and how it's meant to be used. Some test cases illustrate the use of the proposed ontology, followed by current conclusions and future development steps.

Financial Industry Risk Management

The main good practices for the governance of the global financial system were established and formalized by the Basel Committee on Banking Supervision (BCBS), forming part of the Bank for International Settlements (BIS), that in post-crisis periods identified the need for a robust data management framework. This must ensure that banks have the capacity to aggregate risk exposure data in an integrated manner, reaching all the corporation levels, in addition to standardized risk reporting practices (BIS 2013a), confering the degrees of assertiveness and timeliness required by institutional leaders for decision-making in times of stress.

Once established the core principles for banking supervision (BIS 1997; BIS 2012), central banks around the globe have taken them as basis for the establishment of their own regulatory norms. Moreover, they also considered the singularities of their domestic financial systems, what partially mitigated the level of heterogeneity of the global financial system risk management domain. However, this was not sufficient to achieve the goal of representing these domain concepts and their relationships in an integrated manner worldwide, which demands the use of highly integrable and logically grounded tools, such as the use of formal ontologies (Guarino 1995) in the Semantic Web (Berners-Lee, Handler, and Lassila 2001).

The policies and guidelines to be followed by the Brazilian financial institutions are created and maintained by the local monetary authorities, but mainly by the executive authority of the national financial system, the Brazil Central Bank, also known as BACEN. In order to align their governance policies with the Basel principles, the Brazilian monetary authorities created a series of norms, known as prudential regulation (BACEN 2014), to be followed by local banks and financial institutions. The main goal of the prudential regulation is to consolidate a national system for risk management and capital adequacy.

These regulations are arranged to take into account the main types of risk, described as follows:

Credit Risk Associated with the risk of default, the failure to comply with obligations and responsibilities.

Market Risk Related to the volatility of rates or prices over the time, such as currency exchange and interest rates, or prices of securities and commodities.

Operational Risk Associated with the probability of loss resulting from internal processes failures or deficiencies, including legal risks, such as damages to third parties arising from its activities, or violation of rules established in their jurisdiction.

This business division of the domain suggests that modularity should be taken into account (and exploited to the fullest) when dealing with risk management.

Ontologies for Financial Industry

In recent years, with the greater control over the financial systems by regulatory agencies, the need for information systems interoperability and data integration has increased, which strengthened initiatives related to finance on the Semantic Web; these initiatives, allied with the ontologies' semantic formalism, have gained their place and importance in this specific industry.

As an example, the Suggested Upper Merged Ontology (Niles and Pease 2001), also known as SUMO, has included its own finance domain ontology years ago, dealing with concepts related primarily to financial services, typical of commercial banks, such as bank accounts, payments, loans, etc. A more recent work (in progress at the time of writing), is the Financial Report Ontology[1] (FRO), which provides formal and structured meta-information about financial reports, such as balance-sheets; it is primarily based on a well-known XML schema for this application domain, XBRL (Engel et al. 2013), that stands for eXtensible Business Reporting Language.

Other relevant initiative is the Financial Industry Business Ontology[2] (FIBO), a series of standards being developed by the Enterprise Data Management Council (EDMC) and published following the technical governance process of the Object Management Group (OMG). FIBO currently provides a framework of conceptual definitions concerning the wide spectrum of financial applications, currently available for use in two modules.

The first module, FIBO foundations, defines high-level financial concepts such as currency or contracts, and even non-financial concepts such as autonomous agent or country, that are need for the definition of more specific financial concepts. The second module, FIBO Business Entities, defines concepts such as legal persons and corporations, entities that could incur legal obligations such as establishing business contracts with other entities.

There are also ontological initiatives concerning financial regulations, where lies the scope of this work. Abi-Lahoud et al. (2013) developed an ontology concerning the compliance with American anti-money-laundering regulations; later, Abi-Lahoud, OBrien, and Butler (2013) presented an experimental discussion about the adopted approach, an iterative process based on subject-matter expertise and on the use of structured natural language, more precisely based on SBVR (OMG 2008), that stands for Semantics of Business Vocabulary and Business Rules, a structured vocabulary founded in formal logic.

[1] See: http://xbrl.squarespace.com/financial-report-ontology/.

[2] See: http://www.omgwiki.org/OMG-FDTF/doku.php.

These initiatives are being conducted with the support of the Governance, Risk and Compliance Technology Centre[3] (GRCTC), also responsible for the development of the Financial Industry Regulatory Ontology (FIRO) and the Financial Governance, Risk and Compliance Ontology (FIGO).

OntoBacen Proposal

The final and main goal of this work is to create an ontology to represent the Brazilian financial system, by means of its risk management concepts, and to be implemented in the Web Ontology Language (OWL). In this sense, it is related to some of the ontologies mentioned in the previous section, while considering BACEN's governance policies, as published in its norms.

A Brazilian financial jargon says that BACEN's regulations are the "tropicalization of Basel". To exemplify this statement, when comparing BACEN and Basel standardized approaches to evaluate market risks, one can conclude that the BACEN approach has an additional component of risk for fixed interest rates denominated in the local currency (real), making it a conservative adaptation of the Basel approach (BIS 2013b).

The specification of OntoBacen, by means of its requirements, is given by a set of competence questions (Grüninger and Fox 1995), as shown in the following:

CQ1: What is the capital structure, by means of its components, of a financial institution that belongs to the Brazilian financial system?

CQ2: What are the maximum and minimum constraints for the capital components of a Brazilian financial institution?

CQ3: What are the cash amounts that represent each capital component of a Brazilian financial institution?

CQ4: Do the capital components of a Brazilian financial institution respect its constraints?

The definition of capital component used in this paper is that of a grouping of assets or liabilities, possibly weighted by some factor and represented by an amount of money.

Aditionally, for the development of the proposed ontology, a methodology partially based on the GRCTC methodology (adopted by FIRO and FIGO) will be used, as shown in the Construction and Usage section.

OntoBacen Modularization

The BACEN's prudential regulation is the starting point for the definition of OntoBacen. It was analyzed in a top-down approach, beginning with the most high-level view, represented by the notions related to the methodology for calculation of the Reference Capital, later reaching the lower-level related concepts. In this sense, by the interpretation of a series of BACEN documents, the lower level concepts were identified, introducing definitions related to several approaches for the measurement of different types of risk.

After this domain analysis, some core modules were identified for the development process, as shown in Figure 1.

[3] See: http://www.grctc.com/platform-research/.

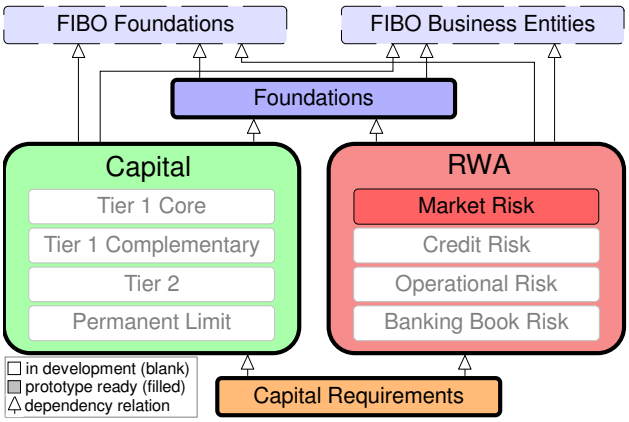

Figure 1: OntoBacen modules

Primarily, the FIBO Foundations and FIBO Business Entities ontologies were chosen to provide the highest level of semantics, such as the *has part* property, a whole-part relationship frequently used by OntoBacen, or even concepts common in finance, such as currency.

Some additional concepts not present in FIBO were defined to provide mid-level semantics, constituting the module Foundations, that is supposed to be used by other modules and ontologies of OntoBacen; it is composed by a set of ontologies described later in this section.

The lower level ontologies are then separated in two major disjoint groups: Capital and RWA. The first group addresses the definition of capital, that is represented in an accounting perspective by shareholder's equity, savings and other kinds of liabilities. The second group name is an acronym for Risk Weighted Assets, that also in an accounting perspective consists of the values of assets weighted by distinct types of risks according to the degree of risk exposure; these two groups encompass the concepts that must be defined for addressing CQ1.

To exemplify how RWA captures the notion of risk, one could think, for instance, in a market risk perspective, if you have a given amount of resources applied in the stock market and the same amount of resources applied in treasury bonds, it is expected that the weighting factor of the first group is higher than the second one's weighting factor, and consequently its RWA, because of the probability that the company which some stocks was acquired enter bankruptcy is higher than that of the government defaulting.

Each one of these groups were then divided in minor (and also disjoint) modules. Capital group takes into account BACEN major definitions to do these separation, being decomposed in Tier 1 Core, Tier 1 Complementary and Tier 2 ontologies. The same group also encompasses a Permanent Limit ontology, that is used to reduce the amount of capital used for requirements checking, in cases that permanent assets exceed a certain limit.

The RWA group considered the division for risk management mentioned in the first section, resulting in different ontologies for Market Risk, Credit Risk and Operational Risk. An additional ontology Banking Book Risk was added to treat the risk related to interest rates of banking book assets, i.e. those acquired and meant to be held until their maturity, because the risk exposure calculation method for these cases is different from the standard market risk for interest rates approach.

An additional reason to adopt such modularization is that these subdomains are commonly subject of distinct business areas in financial institutions (specially the big ones). In this sense, the compliance area is more willing to treat issues addressed by the Capital ontologies, the market risk management area to those of the Market Risk ontology, and so forth, in such a way that those areas could consult specific ontologies as semantics repositories or even use its inference capabilities to address their own issues.

Finally, an additional ontology, Capital Requirements, deals with the capital adequacy questions mentioned in the proposal section. It is related to concepts defined in both Capital and RWA ontologies, and contains the definitions of business rules necessary for addressing CQ2.

Currently, the Foundations, Market Risk and Capital Requirements ontologies are ready to be used, as detailed in the sequence. Consequently, the capital adequacy competence questions address only market risk exposure.

Foundations Module

This module is composed of four foundational ontologies, described as follows:

Common Relations Ontology that defines a set of data and object properties required by other ontologies, such as:

1. mathematical properties, to define product, minimum, maximum, and other derivation relationships;
2. time constraints properties, such as initial and ending date (*xsd:dateTime*), minimum and maximum duration (*xsd:duration*), needed for time intervals definition;
3. the *has reference date* property, needed for the definition of financial system governance contexts;
4. the *has decimal value* property, used to define factors;

BACEN Factors Ontology for the definition of constant or time dependant factors present in BACEN regulations. Time dependancy is defined by fixed *xsd:dateTime* intervals or fixed *xsd:duration* intervals relative to a specific date;

Financial Institutions Ontology encompassing concepts that define the Brazilian financial system agents, such as:

1. The financial institutions classification, specializing the concept for legal person from FIBO Business Entities. Examples are commercial banks, investiment banks, securities brokerages, etc.;
2. The concept of *monetary authority*, that also is a legal person, and used to define BACEN;
3. The concepts for classification of institutions into *compliant* or *not-compliant* to specific regulatory norms;

Contextualized Monetary Amount Ontology for the definition of a generic *context* concept, and also:

1. The *contextualized monetary amount* concept is a specialization of FIBO Foundations *monetary amount* concept, something that has a currency and an amount, and that additionally has a context (uses FIBO Foundations *has currency*, *has amount* and *has context* properties);
2. The *financial system governance context* concept, that specializes *context*, and also involves a monetary authority governing and constraining the behavior of a financial institution at a specific moment in time (uses FIBO Foundations *is governed by* and *constrains* properties).

The *contextualized monetary amount* concept is used to represent amounts of cash related someway to a *financial system governance context*, thus it is the major definition of OntoBacen for addressing CQ3.

Market Risk Ontology

The main goal of this ontology is to provide a way to evaluate the market risk exposure by using at least one of the approaches available. Its semantics translates the business rules needed to obtain the market risk RWA (risk weighted assets by market risk exposure).

Figure 2 shows its main concepts and their relationships using a notation similar to VOWL (Lohmann et al. 2014), where concepts are represented as circles (filling colors indicate modules), relationships (properties) as plain-line arrows and generalization relationships as dotted-line arrows.

The first important thing to note is that there are two possible appoaches to evaluate the market risk RWA, the standardized approach (called RWAMPAD) and the internal model approach (called RWAMINT). Both of these approaches have more specific concepts that are omitted here for a matter of simplicity.

In both cases, financial institutions must verify their market risk exposure by the standardized approach, because even the internal model approach depends on the standardized. In addition, they are not required to have (or to use) an internal model, but in the cases that both approaches are implemented, one of them must be chosen.

To opt for the internal approach, the institution must show to BACEN that the proposed model actually maps the market risk efficiently and that it is consistent with the regulations and norms. When opting for this model, things get a bit messy, because in this case, some conservative constraints for the evaluation of the RWA must be considered.

Firstly, a market risk model transition factor (defined as *Sm*) must be considered. This factor assumes the value of 90% in the first year of the transition, and 80% after that. This weighting factor is then applied to the standardized approach, producing an intermediate result, the standardized approach considering *Sm factor*. From the results obtained by both the application of the internal model approach and the standardized approach considering *Sm factor*, the greater of these is defined as the internal model RWA.

Independently of the values for the market risk RWA obtained by different approaches, institutions must choose one of them to report BACEN. OntoBacen's current implementation chooses, in cases where the two models are evaluated,

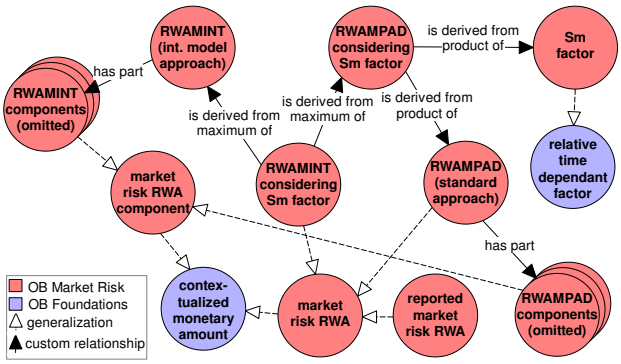

Figure 2: Market Risk Ontology

the smallest (by comparing the *has amount* data property); in the other cases, where there is only the standardized approach, this latter is the one to be reported.

The market risk ontology defines the concepts mentioned before as specializations of *contextualized monetary amount*. A general *market risk RWA* concept is defined, so that it encompasses any market risk evaluation approach, being naturally specialized by the two approaches previously mentioned, and by an additional concept for the approach that was chosen to be reported to BACEN.

The intermediate results used in the evaluation of the market risk RWA are conceptualized as specializations of an additional concept *market risk RWA component*. Finally, the *Sm factor* concept is classified as a specialization of *relative time dependant factor*, defined by Factors ontology and whose semantics define that its value is dependant of the amount of time elapsed from a specific date (in this case, the market risk model transition date).

Capital Requirements Ontology

There are different capital requirements specified by the BACEN regulations, such as minimum requirements for *tier 1 capital* and *reference capital*. The latter is the most general (and relevant) definition of capital, so that this requirements rules was chosen as the first to be implemented by the Capital Requirements ontology. For the implementation of capital requirements rules related to more specific concepts, such as *tier 1 capital*, some efforts will be needed in the construction of ontologies for the Capital module, described in the beginning of this section, and working in progress at the moment of writing.

The main idea of this ontology is to compare the risk weighted assets with some liabilities composition, defined in this case as *reference capital*, and that is mainly composed by reserves and shareholder's equity. To define the concept of *risk weighted assets*, it is necessary to consider all types of risk (such as the market risk mentioned before), aggregating these multiple risk types as a general and single concept. For that, all ontologies of the RWA module must be available; as already mentioned before, at this moment the capital requirements ontology is considering only market risk as a risk type.

The *minimum required reference capital* can be deter-

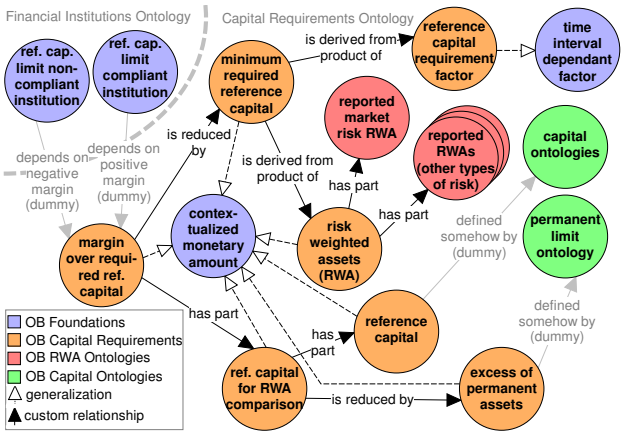

Figure 3: Capital Requirements Ontology

mined from the *risk weighted assets*, as depicted by the dependency relationship between these concepts in Figure 3. This minimum requirement amount is given by applying a numerical factor (*reference capital requirement factor*) to the RWA, whose value decreases yearly (11% before 2016, 9.875% at 2016, 9.25% at 2017, 8.625% at 2018 and 8% after 2018). This fixed time interval dependancy is represented as an specialization of the concept *time interval dependant factor* of the Factors ontology.

Before this comparison between the *reference capital* and its minimum requirement could be done, the excess of permanent assets must be discounted from the capital, resulting in an additional concept for comparison between capital and RWA: *reference capital for rwa comparation*. This excess is determined by additional business rules, omitted here, because they are in the scope of the Permanent Limit ontology, not yet constructed.

Another important concept definition is that of *margin over required reference capital*, which is given by the difference between the capital component, considering any necessary deductions such as the excess of permanent assets, and the minimum required capital. From the *margin over required reference capital*, one can determine if a financial institution is compliant with the capital requirements verifying if its value is non-negative, analogous analysis could be made to determine if the institution is non-compliant (negative margin).

Given these final considerations, concepts like *reference capital requirement compliant* and *reference capital requirement non-compliant* can be defined (shown as part of an external ontology in Figure 3), which indicate the compliance (or not) of some Brazilian financial institution to BACEN's prudential regulation at a specific time.

Construction and Usage

The nine steps for developing and using OntoBacen are shown in Figure 4. The six first steps are for the ontology construction, while the last three are for its usage. BACEN's prudential regulation is the input to this methodology, and is available as a set of .pdf files written in Portuguese, that are copied to an easily editable format, such as text files.

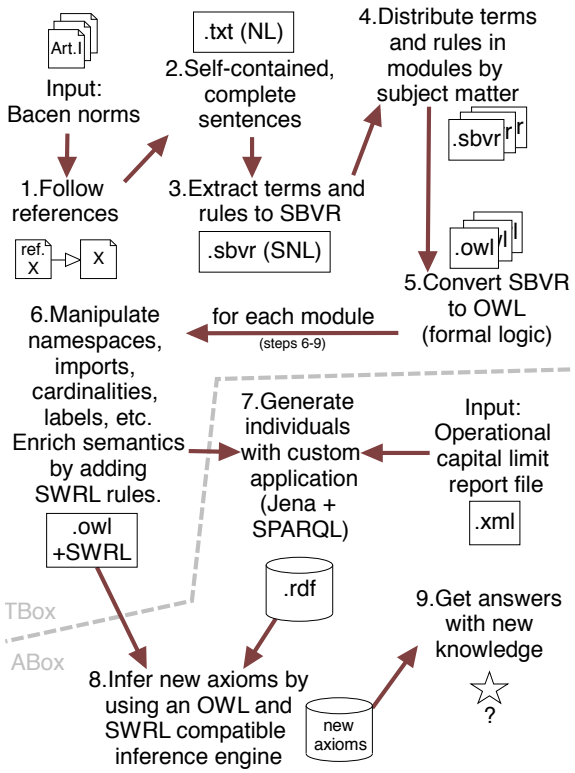

Figure 4: OntoBacen construction and usage steps

In the first step, it is needed to follow reference chains present in such norms, to construct, in a second step, semantically complete and self-contained sentences in natural language (Portuguese), by cutting and pasting portions of the original text.

After that, in the third step, the self-contained sentences are interpreted in order to achieve a first level of formality, identifying and representing its terms and rules with SBVR (structured natural language). Note that there isn't a SBVR structured vocabulary for Portuguese; in this sense, relationships and rules are translated to English so they can be based on SBVR-SE (SBVR Structured English), but terms (concepts) are kept in their original form.

Marinos, Gazzard, and Krause 2011 proposed the creation of a tool for the manipulation of SBVR vocabularies with auto-completion and highlighting features, work that later evoluted to SBVR Lab 2.0[4], a tool freely available on the Web; this tool was used to help achieving the goals of the third step.

The fourth step begins with the possession of the SBVR vocabulary; its terms and rules are distributed in a set of distinct vocabularies, mainly by considering their subject matter, what inevitably demands interpretation and expertise of the domain; secondly, we take into account technical considerations, in order to achieve, for instance, a higher degree of disjointness between vocabularies, and thus minimizing the number of relationships between terms of distinct sets. Other important issue involves the detection of core terms,

[4]See: http://www.sbvr.co/.

those that are extensively related to other terms, and should be organized in such a manner that could be easily shared between multiple modules.

All these initial steps involves human interpretation and manual activities to be accomplished; they demand familiarity with Brazilian legal writing, as the BACEN's norms are written similarly to any other Brazilian law document (legalese), and also require prior knowledge about its subject matter, since these norms aren't designed to be educational.

The fifth step is the conversion of these multiple SBVR vocabularies to OWL 2.0, generating the ontology modules. Some works in the literature address the conversion between these two languages without semantics loss, however a more detailed description is beyond the scope of this paper. Karpovic and Nemuraite 2011 worked in the field, resulting in the creation of a conversion tool freely available on the Web, called s2o[5]. The initial step for the creation of OntoBacen OWL files used this tool[6].

In the sixth step, the initial OWL files obtained from s2o are subjected to manipulations in order to complement and enrich their semantics. For that, the Protégé[7] software was used to:

- Add or update namepaces and ontology imports;
- Include some cardinality restrictions not captured in the SBVR vocabularies phase;
- Add labels and other annotation properties useable for documenting the ontology (in Portuguese and English);
- Create SWRL rules to allow the inference of additional axioms, including the use of its built-in functions for math and date operations.

At this point, each OWL file is the final version of an ontology, concluding the terminological component (TBox) of the system.

The main reason to adopt such approach is because manipulating a large vocabulary such as the BACEN's prudential regulation, is made quickly by just listing its terms and rules in text files than formalizing all them in ontology development tools. In this sense, for OntoBacen's initial development phase, described in this paper, only small subsets of the identified concepts were subjected to the formal ontology engineering process (step 6).

For the construction of the assertion component (ABox), the input artifact for the definition of instances of the ontology classes (individuals) is the DLO[8], a XML report file that Brazilian financial institutions must submit to BACEN, briefly depicted in Figure 5.

This file, containing the data required for the possible assertions which one can infer by the use of OntoBacen, is available in accordance with a XML Schema similar to accounting, where each structure is composed basically of

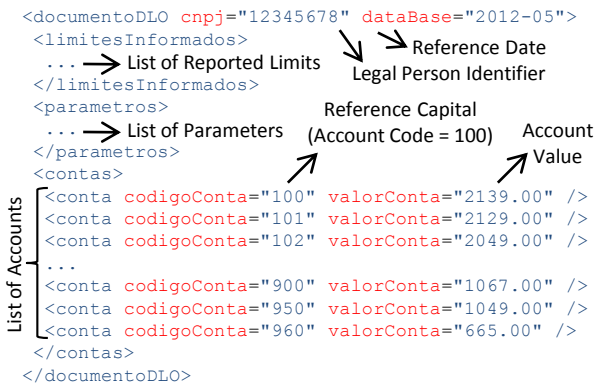

Figure 5: Example of limit report XML file (DLO)

a numerical identification code, and an amount of money (Brazilian reais).

A Java application was developed to do the XML deserialization, that also used Apache Jena framework (with some help of SPARQL queries), for the automatic instantiation of the individuals to be later used in conjunction with OntoBacen. The final result is a set of RDF files, following the same modularization approach used in the ontology creation phase.

From now on, all components required for the reasoning phase are ready. The reasoning can be done through a specific module, subsets of modules, or even all of them. In this phase, an inference engine compatible with SWRL rules must be used; for the test cases presented in this paper, Pellet (Sirin et al. 2007) was used for such a task.

Finally, by using the set of inferred axioms, one can get the answers to the proposed competence questions, for instance: a Brazilian financial institution complies to BACEN's prudential regulation in a determined context, if it is classified as *capital requirement compliant* in that context.

Notice that each module can answer some limited and specific questions, for instance: the Market Risk ontology can only determine the degree of exposure to market risk, and that isn't sufficient to verify the compliance or not to BACEN's prudential regulation; the presented competence questions have a higher level of complexity, and need some reasoning over all modules of the ontology so that they can be answered.

Test Cases

For testing the proposed knowledge system capabilities, a standard example of the DLO was used, as provided by BACEN. From there, three additional test cases were created by altering elements of the XML file, so that their instantiation could be automatically done by the custom application mentioned in the construction and usage section.

Table 1 shows the relevant input data of the four test cases, in millions of Brazilian reais, and for a matter of simplicity, the market risk RWA models were consolidated by its components, as it was shown in Figure 2.

According to the information shown in Table 1, OntoBacen can apply business rules by using an inference engine

[5]See: http://s2o.isd.ktu.lt/about.php.

[6]It was necessary to apply a simple syntax transformation algorithm in this step, whose details are beyond the scope of this paper.

[7]See: http://protege.stanford.edu.

[8]DLO is an acronym for *Demonstrativo de Limites Operacionais* in Portuguese, and stands for operational limit statement.

compliant with OWL and SWRL rules, in order to answer if the institutions in each case are compliant or not with BACEN's capital requirements regulations, considering their exposure to market risk.

Case	1	2	3	4
Reference Date	2015 Jan 1	2015 Jan 1	2016 Jan 1	2016 Jan 1
Mkt. Risk Model Transition Date	N/A	2014 Jul 1	2015 Jul 1	2014 Jan 1
Reference Capital	2139	1000	1000	1000
Excess of permanent assets	0	500	0	100
RWAMPAD	382	5000	5000	15000
RWAMINT	N/A	6000	4750	10000

Table 1: Test cases input data

Case	1	2	3	4
Sm Factor	N/A	90%	90%	80%
RWAMPAD (considering Sm)	N/A	4500	4500	12000
RWAMINT (considering Sm)	N/A	6000	4750	12000
Reported Market Risk RWA	RWA MPAD	RWA MPAD	RWA MINT	RWA MINT
Reported RWA	382	5000	4750	12000
Reference Capital Req. Factor	11%	11%	9.875%	9.875%
Min. Required Reference Capital	42	550	469	1185
Ref. Capital for RWA comparison	2139	500	1000	900
Margin over Req. Reference Capital	2097	-50	531	-285
CQ4: Ref. Capital Limit Compliant?	Yes	No	Yes	No

Table 2: Test cases inference steps and results

Case 1 is the default example provided by BACEN[9]. In this case, only the standardized market risk approach is used, so that it is necessarily the reported one, and the reference capital is more than five times higher than the reported RWA, with a highly positive margin over the required reference capital, resulting in the inference of such institution as compliant to the capital requirements.

In case number 2, both models are implemented, but the standardized model indicates a lower risk exposure than the internal model, and as OntoBacen is configured to choose the minimum exposure approach (this isn't obligatory), the standardized approach is chosen to be reported. This institution has a high amount of permanent assets, so that the reference capital is halved when reduced by the excess of permanent assets, making the minimum required reference capital higher in comparison with this amount, resulting in a negative margin over the required reference capital and therefore the conclusion that it is not adherent to the norms.

Case 3 has both models implemented too, but the internal approach indicates the lower risk exposure (being reported), not sufficiently low to break the barrier of the standardized approach weighted by the *Sm factor* (90% in this case because the model transition was done in less than a year). Additionally, the reference date is now at the year of 2016, when the reference capital requirement decreases from 11% to 9.875% of the RWA, and finally results in a handily positive margin over the required capital, concluding that this case is compliant.

In the last case, number 4, the market risk approaches differ greatly from one another, in such a manner that even the *Sm factor* being of 80% (since the model transition happened more than a year before the reference date), the internal model broke the barrier of the standardized approach weighted by *Sm*, so that the final RWA value by the internal model will be the same of the barrier. As in this case the internal model will assume 80% the value of the standardized approach, OntoBacen will choose it for being the lower one. The minimum required reference capital is then evaluated from the resulting RWA and compared with a minor value, which brings to a negative margin and the conclusion of non-compliance to BACEN's capital requirements regulations.

All test cases executed the mentioned inferences in few seconds, by using Pellet reasoner within Protégé, so that computational performance was adequate, since this isn't a real time problem. The time for loading required ontologies from the Web was approximately thirty seconds.

OntoBacen currently deals with very general and aggregated concepts, so that performance was not a great concern yet. However, as the level of detail (and data) increases, to deal with all data at once could be a performance issue, given the exponential nature of reasoning systems; this is another reason to consider modularity, alongside with distributed reasoning, as a primary design requirement for modeling this domain.

Conclusions

This paper presented an alternative technical approach for dealing with risk management: instead of the standard specialized systems, we propose to use ontology-based technologies together with a knowledge-based system.

Our proposal provides an open knowledge reference to address issues of this domain, freely available in the Semantic Web[10]; its semantics provides a formal representation of rules established by BACEN's prudential regulation, and also a computational artifact that along with automated reasoning can provide answers to the user.

By the use of such approach, any Brazilian financial institution that needs to report accounting and risk indicators to BACEN by using an XML operational limit statement (which has only syntactical and structural constraints, without formal semantics), could verify its semantic consistency before submission, or even generate semantically consistent

[9]The operational limit statement XML files are available at: http://www.bcb.gov.br/fis/pstaw10/leiaute_limitesDLO.asp.

[10]URI: http://lti.pcs.usp.br/~filipe.polizel/OntoBacen/.

content, avoiding mistakes and delays that can bring eventual penalties and losses.

Finally, for the effective success of such solution, modularity must play a central role in its design from the beginning to the end, allowing financial institutions to take advantage of computational features such as distributed computing and avoiding to handle massive amounts of knowledge at once, given the exponential computational complexity of logical reasoning algorithms.

Further Work

This work intends to further explore the BACEN regulations in order to define business rules for other risk types, such as credit and operational risk. Besides, the ontologies for capital definition will be created so that the *reference capital* concept can be decomposed in more detailed definitions. Therefore, the Capital Requirements ontology could be enriched in order to consider all possible types of risk, and capital requirements rules could be evaluated in additional levels, such as *tier 1 capital* requirements.

Other issue concerns the integration capabilities of the proposed ontology. In order to address that, additional semantic alignments can be done between OntoBacen and other ontologies, while the work on financial ontologies (FIBO, FIRO, etc) progresses. Another possible approach for this question would be consider additional ontologies as possible semantic foundations, such as a mathematics ontology to express some of the relations identified in OntoBacen (derivation of concepts by differences, maximums, etc).

As these goals are achieved, additional efforts can be done in such a way to deepen the concepts definition for each subdomain that composes the governance of a financial system risk management, increasing the proposed system granularity and thus allowing it to treat additional risk management questions (or even accounting). To this end, a lot of work in the interpretation of an extensive set of BACEN regulation documents should be done, and as the ontology evolve in depth of details, new modular considerations must be taken into account, such as those discussed in this paper.

After the construction of the modules proposed in the specification section, this work also aims to evaluate the approach using a more realistic case study, by applying OntoBacen rules with the data of a real Brazilian financial institution, that is publicly available via balance sheets and risk reports, or even by collecting more detailed data using the operational limit statement XML sent to BACEN by some institutions.

Acknowledgements

Jaime Sichman partially financed by CNPq, Brazil, proc. 303950/2013-7.

References

[Abi-Lahoud et al. 2013] Abi-Lahoud, E.; Butler, T.; Chapin, D.; and Hall, J. 2013. Interpreting regulations with sbvr. *In Proceedings of RuleML (2)'13*.

[Abi-Lahoud, OBrien, and Butler 2013] Abi-Lahoud, E.; OBrien, L.; and Butler, T. 2013. On the road to regulatory ontologies: Interpreting regulations with sbvr. *AICOL*.

[BACEN 2014] BACEN. 2014. Regulação prudencial. Retrieved from https://www.bcb.gov.br/?REGPRUDENCIAL, last access on 2015 Apr 12.

[Berners-Lee, Handler, and Lassila 2001] Berners-Lee, T.; Handler, J.; and Lassila, O. 2001. The semantic web. *Scientific American*.

[BIS 1997] BIS. 1997. Core principles for effective banking supervision. Retrieved from http://www.bis.org/publ/bcbs30a.pdf, last access on 2014 Aug 8.

[BIS 2012] BIS. 2012. Core principles for effective banking supervision. Retrieved from http://www.bis.org/publ/bcbs230.pdf, last access on 2014 Aug 8.

[BIS 2013a] BIS. 2013a. Principles for effective risk data aggregation and risk reporting.

[BIS 2013b] BIS. 2013b. Regulatory consistency assessment programme (rcap) assessment of basel iii regulations in brazil.

[Engel et al. 2013] Engel, P.; Hamscher, W.; Shuetrim, G.; vun Kannon, D.; and Wallis, H. 2013. Extensible business reporting language (xbrl) 2.1.

[Grüninger and Fox 1995] Grüninger, M., and Fox, M. S. 1995. Methodology for the design and evaluation of ontologies.

[Guarino 1995] Guarino, N. 1995. Formal ontology, conceptual analysis and knowledge representation. *International Journal of Human and Computer Studies* 43:625–640.

[Karpovic and Nemuraite 2011] Karpovic, J., and Nemuraite, L. 2011. Transforming sbvr business semantics into web ontology language owl2: Main concepts. In *Proceedings of the 17th international conference on Information and Software Technologies (IT 2011)*, 231–238.

[Lohmann et al. 2014] Lohmann, S.; Negru, S.; Haag, F.; and Ertl, T. 2014. Vowl 2: User-oriented visualization of ontologies. In *Proceedings of the 19th International Conference on Knowledge Engineering and Knowledge Management*, EKAW '14, 266–281. Springer.

[Marinos, Gazzard, and Krause 2011] Marinos, A.; Gazzard, P.; and Krause, P. 2011. An sbvr editor with highlighting and auto-completion.

[Niles and Pease 2001] Niles, I., and Pease, A. 2001. Towards a standard upper ontology. In *Proceedings of the 2nd International Conference on Formal Ontology in Information Systems (FOIS 2001)*. ACM. See also www.ontologyportal.org.

[OMG 2008] OMG. 2008. Semantics of business vocabulary and business rules (sbvr), v1.0.

[Sirin et al. 2007] Sirin, E.; Parsia, B.; Grau, B. C.; Kalyanpur, A.; and Katz, Y. 2007. Pellet: A practical owl-dl reasoner. *Web Semantics: Science, Services and Agents on the World Wide Web archive* 5:51–53.