Knowledge level modeling for systemic risk management in financial institutions

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A B S T R A C T
The current subprime mortgage crisis is a typical case for systemic risk in financial institutions. In order to further our understanding and communication about systemic risk management (SRM) in financial institutions, this paper proposes a knowledge level model (KLM) for systemic risk management in financial institutions. There are two parts considered in the proposed KLM: ontologies and problem solving method (PSM). Ontologies are adopted to represent a knowledge base of KLM, which integrates top level ontology and domain level ontologies. And then the problem solving method is given to show the reasoning process of this knowledge. The symbol level of KLM is also discussed which integrates OWL, SWRL and JESS. Further, the discussion about Lehman Brother's Minibonds case in 2008 is provided to illustrate how proposed KLM is used in practice. With these, first, they will enhance the interchange of information and knowledge sharing for SRM within a financial institution. Second, they will assist knowledge base development for SRM design, for which a prototype of financial systemic risk management decision support system is given in this study. Third, they will support coordination among different institutions by using standardized vocabularies. And finally, from the design science perspective, the whole proposed framework could be meaningful to models in other domains.

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1. Introduction
Systemic risk refers to the risk or probability of breakdown (losses) in the individual parts of components, and is evidenced by co-movements (correlation) among most or all parts (Kaufman, 2000). The current subprime mortgage crisis is a typical case for systemic risk in financial institutions. The subprime mortgage crisis was triggered by a dramatic rise in subprime mortgage defaults and related foreclosures in the United States, but has brought huge adverse effects to the banks and financial markets all around the world. Many banks, real estate investment trusts (REIT), and hedge funds have suffered significant losses as a result of mortgage payment defaults or mortgage asset devaluation. Many observers have commented that the turmoil in world financial markets has led to a severe and still unfolding economic downturn in most of the Western economies; as a result, the world has come to the brink of the “worst economic downturn” since the Second World War. Because of this crisis, governments and international organizations are calling for increased systemic risk management (SRM) in financial institutions. To repeat the Nobel laureate, Dr. A. Michael Spence, an important challenge going forward is to better understand these dynamics and complexities of SRM in financial institutions as the analytical underpinning of an early warning system with respect to financial instability (Spence, 2008).

In order to further our understanding and communication about SRM in financial institutions, a knowledge level model for SRM is proposed in this paper. Knowledge level was first proposed by Newell, which was used to distinguish it from the symbol level of information system (Newell, 1981). Knowledge level modeling is a kind of conceptual modeling method. As defined by Mylopoulos (1992), “Conceptual modeling is the activity of formally describing some aspects of the physical and social world around us for the purposes of understanding and communication”. Knowledge level modeling means capturing and representing knowledge without specific attention being paid to how it will be implemented (Uschold, 1998). It includes ontologies and the problem solving model (PSM), where ontologies are concerned with static knowledge needed for problem solving and PSM with the dynamic reasoning process with knowledge.

Ontologies aim at capturing knowledge in a generic way and provide a commonly agreed understanding of a domain, which may be reused and shared across applications and groups (Chandrasekaran, Josephson, & Benjamins, 1999). In this study, ontologies were designed at two levels: top level ontology and domain level ontology. Top level ontology represents the general world.
knowledge (Uschold, 1998), and in this study ontology from the CYC project is adopted which is an attempt to build a very large knowledge base to facilitate common-sense reasoning1 (Lenat, 1995; Lenat & Guha, 1989; Lenat, Prakash, & Shepherd, 1985). Domain level ontology represents knowledge in a specific domain. In this study a general framework of domain level ontology will be given which shows the key concepts and their relationships in the SRM domain.

Problem solving models (PSMs) specify which bodies of knowledge participate in problem solving and how they relate to each other (Uschold, 1998). Many models have been proposed in this area, such as role-limiting method (Marcus, 1988), CommonKADS (Schreiber, Wielinga, & Breuker, 1993), and so on. In this research, a hypothesis-test model is given to detect the systemic risk signal from external institutions which is based on Simon’s decision-making theory (Simon, 1996).

And in the symbol level, the proposed KLM is integrated within Ontology Web Language (OWL), Semantic Web Rule Language (SWRL) and JESS rules framework which will be very helpful to information system development.

The rest of this paper is organized as follows: Section 2 discusses the background of SRM in financial institutions and outlines the technique used in this research; the knowledge model for SRM is proposed in Section 3, which includes ontologies and PSM; a case of Lehman Brothers Minibonds is used to illustrate our approach in Section 4; the concept modeling quality of our proposed model is discussed in Section 5 and finally the paper ends with the conclusion in Section 6.

2. Related works

2.1. Systemic risk management in financial institutions

As the integration of financial markets progresses rapidly, regulators and supranational agencies have become increasingly worried about systemic risk in financial institutions (Lehar, 2005). The main concern is that the world’s financial system could collapse like a row of dominos and then could result in a severe economic crisis (Schwarcz, 2008). The most important characteristic for systemic risk is its contagion effect (YE, Wang, Yan, Wang, & Miu, 2009).

The most classic example of systemic risk is within the banking system, for which there are two major sources of systemic risk: first, banks might have correlated exposures with an adverse economic shock resulting in simultaneous multiple bank defaults; second, troubled banks may default on their interbank liabilities and hence cause other banks to default triggering a domino effect (Elsinger, Lehar, & Summer, 2006). With the data set provided by the Austrian Central Bank, researchers have reported that among the two driving sources of systemic risk, the correlation in exposures is far more important than financial linkages (Elsinger et al., 2006). Schwarcz has defined this kind of systemic risk as institutional systemic risk (Schwarcz, 2008).

Further, there is also systemic risk outside the banking system (Schwarcz, 2008). In the modern market, companies are able to obtain most of their financing through capital markets instead of the banking system. As a result, systemic risk can spread through capital market linkages, rather than merely through banking relationships. A typical case of this kind of systemic risk is the Long Term Capital Management (LTCM) event in 1998 (Jorion, 2000; Scholes, 2000). In the LTCM case, systemic risk existed not by reason of its intrinsic status as a hedge fund, but by the sheer size of its exposure to other institutions and market participants (Edwards, 1999).

And Schwarz defined it as market systemic risk which distinguished it from the institutional system risk (Schwarcz, 2008).

2.2. Conceptual modeling

A general definition of conceptual modeling has been proposed by Mylopoulos (1992): “Conceptual modeling is the activity of formally describing some aspects of the physical and social world around us for the purposes of understanding and communication”. A conceptual model serves four roles in developing domain understanding (Kung & Solvberg, 1986): (1) aiding a person’s own reasoning about a domain, (2) communicating domain details between stakeholders, (3) communicating domain details to systems designers, and (4) documenting the domain for future reference. Viewed from this perspective, conceptual modeling can be seen as a process whereby individuals reason and communicate about a domain in order to improve their common understanding of it (Gemino & Wand, 2004).

Various conceptual modeling methods have been proposed by researchers since the 1960s of the last century. Ross Quillian proposed semantic networks as a model of the structure of human memory in 1966 (Quillian, 1966). In 1967 Ole-John Dahl proposed SIMULA, which is an extension of the programming language ALGOL 60, for simulation applications which require some “world modeling” (Dahl & Nygaard, 1966). And then the Entity-Relationship model, which is more advanced than the logical data model, was proposed by Peter Chen in 1975 (Chen, 1976). Doug Ross proposed in the mid-70’s the Structured Analysis and Design Technique (SADT) as a “language for communicating ideas”, and this technique was used by Softech, a Boston-based company, in order to model requirements for software systems (Marca & McGowan, 1987).

Lindland et al., proposed a framework to evaluate a conceptual model from three aspects: syntactic quality, semantic quality, and pragmatic quality (Lindland, Sindre, & Solvberg, 1994). Siau and Tan summarized this framework as followings (Fig. 1) (Siau & Tan, 2005):

In this framework, three important linguistic concepts (syntax, semantics, and pragmatics) are applied to four aspects of modeling: Language, domain, model and audience participation. This work has served as the foundation of International Workshop on Conceptual Modeling Quality (IWCMQ), held in conjunction with the Requirements Engineering Conference.

3. A knowledge level model for systemic risk management in financial institutions

3.1. Knowledge level model framework

The proposed knowledge level model for SRM in financial institutions is given in Fig. 2. From this figure, first of all, there are two different levels in the framework: symbol level and knowledge level, which follows Newell’s model, as mentioned earlier (Newell, 1981). At the knowledge level, there are two parts: ontologies and problem solving method, where ontologies are concerned with the static knowledge needed for problem solving, and PSMs with the dynamic reasoning process with knowledge (Uschold, 1998).

The ontologies part includes domain level ontology and top level ontology. The domain level ontology defines the basic entities in financial markets and relationships among them, which are related to SRM in financial institutions. For example, it defines securities which include basic securities and derivatives. Mortgage backed securities (MBS) and collateralized debt obligations (CDO), which are most important securities for systemic risk in the ongoing subprime crisis case, are both subclasses of derivatives.

1 http://www.cyc.com/.
Top level ontology used in this study is from the CYC project, which is used to support common-sense reasoning under the support of a very huge knowledge base (Lenat, 1995; Lenat et al., 1985). The problem solving method (PSM) part gives the decision making model of the systemic risk signal detection, based on reasoning through ontologies part.

At the symbol level, representation of the proposed knowledge level model is discussed, which adopts OWL, SWRL, JESS and OpenCyc. First, all the domain level ontology will be represented by OWL. OWL DL supports those users who want the maximum expressiveness while retaining computational completeness and decidability. Thus, in this study, OWL DL is adopted for representing the variety types of classes and relationships in the ontology.\(^2\)

Second, for domain level ontology, some SWRL rules are added to support OWL because of its limitation.\(^3\) For CYC ontology, OpenCyc is the open source version of the CYC project, and in this study the OWL edition of OpenCyc is adopted, as it can easily be integrated with the domain level ontology.\(^4\) For PSMs, the rule based approach is adopted to represent the proposed model, and some meta rules are given to reason through the proposed ontologies. Finally, all of

\(^2\) http://www.w3c.org/2004/owl/.
\(^3\) http://www.w3.org/Submission/SWRL/.
\(^4\) http://www.cyc.com/cyc/opencyc.
OWL, SWRL and meta rules will be implemented with JESS rules in a knowledge base.\(^5\)

In the following section, the details of every part in this model will be discussed.

### 3.2. Ontologies

Ontologies discussed in this section include two parts: domain level ontology and top level ontology. Domain level ontology represents the focused knowledge related to systemic risk management domain, while the top level ontology represents the general knowledge which is used to support common sense based reasoning.

#### 3.2.1. Domain level ontology

In this section the key concepts in the domain level ontology (e.g., financial instrument) will be shown first. Second, the relationship among these concepts in systemic risk management will be discussed.

As shown in Fig. 3, there are three different levels in the domain ontology: meta level, class level and instance level. The details of these three levels are as following:

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\(^5\) http://www.jessrules.com/
3.2.1. Meta level. Four key concepts are shown in the meta level: *institution*, *financial instrument*, *individual* and *financial news* as they are the most basic concepts for systemic risk management. The arrows in the meta level show that these six concepts have complex relationships which are denoted by object properties. For example, *Institution* and *Financial instrument and Individual* are the report topics of *Financial news,* and thus all of them have an object property *reported-by* to *Financial news.* Regarding *Institution* and *Financial instrument,* there are relationships among their subclasses, so there are also arrows to them. Concerning *Financial news* and *Financial instrument,* there are some attributes which are shown as datatype properties, e.g., *report time.* However, the details of these relationships will be discussed in class level.

3.2.1.2. Class level. Class level gives the detailed classification of concepts and their relationships.

Take *institution* for example, many different kinds of institutions play different roles for systemic risk management. In the ongoing subprime mortgage crisis case, it is obvious that government policies contributed significantly to the crisis before it happened, and the government has taken various actions since it became apparent. So here *institution* is classified to *financial institution, government* and *other institution* which is also related to systemic risk. Additionally, *financial institution* is classified as *bank* which includes *investment bank* and *commercial bank,* *investment company* (e.g., *Investment fund,* *credit agency* and *insurance company*). However, the whole ontology in the bottom class level is so huge that what is shown here is only part of it.

The concepts in class level inherit the properties in meta level, and these properties are also discussed in sub-properties. For example, in the meta level, it shows *financial instrument* is an object property of *institution* denoted as *used-by.* In class level, *debt securities* is a subclass of *financial instrument,* and then *debt securities* is also an object property of *institution* denoted as *used-by.* Further, *investment bank* is a subclass of *institution,* *debt securities* is an object property of *Investment bank* which denoted as *dealed-by,* and *dealed-by* is a sub-property of *used-by.*

3.2.1.3. Instance level. Some instances, denoted by rectangles, are given in this level, and they inherit all the properties in the class level. For example, *Bear sterns stock* is an instance of *common stock,* which means that *Bear sterns stock* has all the properties of *common stock,* and they will have certain values.

3.2.2. Top level ontology

Top level ontology represents the general world knowledge (Uschold, 1998), and in this study ontology from the CYC project is adopted, which is an attempt to build a very large knowledge base to facilitate common-sense reasoning6 (Lenat, 1995; Lenat & Guha, 1989; Lenat et al., 1985). CYC is a bold attempt to assemble a massive knowledge base (on the order of 10 axioms) spanning human consensus knowledge (Lenat, 1995). OpenCyc is the open source version of the CYC project, and in this study the OWL edition of OpenCyc is adopted, as it will be easy to be integrated into the domain level ontology.7 The details of the integration are discussed in our previous paper (He, Lai, & Wang, 2009).

There are two ways that this top level ontology can be used. First of all, during the domain level ontology building, some ontology can be found in the CYC knowledge base, e.g., financial instrument classification, and then it will save much effort. Second, because the reasoning of systemic risk management sometimes needs emergent knowledge, the CYC knowledge base can support emergent knowledge querying. For example, financial news is an important source for systemic risk detection, but it is very complex to get relevant information from news report, as it needs a very large knowledge base on financial news. With the CYC knowledge base on news reports, it will be very convenient to use it. However, the discussion about top level ontology is not the main focus of this paper under the space limit.

3.3. Problem solving model

The problem solving model represents the reasoning process of the knowledge to solve the focused problem. PSM consists of three related parts: competence, operational specification and requirements/assumptions (Benjamins & Fensel, 1998). The competence of a PSM describes what it can achieve; the operational specification depicts how it has been done; and the requirements/assumptions shows what domain knowledge is needed to support the reasoning process. Herbert A. Simon has proposed the most famous model of the decision making process, which identifies the following four different phases:

- **Intelligence:** searching the environment for condition calling for decision.
- **Design:** inventing, developing and analyzing possible courses of action.
- **Choice:** choosing among courses of action.
- **Review:** evaluating past choice (Simon, 1996).

In this paper, a PSM for systemic risk signal detection is proposed which is based on Simon’s decision making process theory. As has been mentioned earlier, a PSM comprises three parts: what it is used for, what is needed and how it works. As is shown in Fig. 4, the proposed PSM is used for systemic risk signal detection, and it gives the reasoning process based on the ontologies discussed previously.

There are four phrases here:

- **Intelligence phrase:**
  - Step 1: Collect relevant financial news from different sources. The key point here is to decide which news is relevant to a certain financial institution. Domain level ontology is used here which replaces simple keyword searching. Take Bear stern is an instance of investment banking, and domain level ontology shows that investment banks profit from companies and governments by raising money through issuing and selling securities, e.g., bonds. Then all the financial news about securities, which is currently issued or sold by Bear stern, will be searched. Further, in order to analyze the relationships between news and financial instruments, causal map based approach will be adopted, please check the detail in our previous research as it is not the focus of this research (Wang, Zhang, Kang, Wang, & Chen, 2008).
  - Step 2: Gather systemic risk information from collected news. Common sense based reasoning is adopted at this step which is supported by the CYC ontology.

- **Design phrase:**
  - Step 3: Generate systemic risk signal hypotheses.
  - Step 4: Deduce possible result from the hypotheses.

- **Choice phrase:**
  - Step 5: Check the deduced result with the information gathered.
  - Step 6: Generate the systemic risk report.

- **Review phrase:**
  - Step 7: Get feedback.
  - Step 8: Refine the reasoning process through feedback.

6 http://www.cyc.com/
3.4. Implementation of Knowledge level modeling

As is shown in Fig. 5, the proposed knowledge level modeling can be implemented with Protégé and JESS, where it is transformed as an expert system. With Protégé and its plug in tabs, the ontology and problem solving method can be represented with OWL and SWRL.

In the instance level of knowledge base, it will generate JESS facts that are used for reasoning. For example, Microsoft stock is an instance of financial contract, and then every relationship of financial contact in ontology will be transformed to JESS facts immediately. So with the problem solving method, it will be easy to decide whether Microsoft will generate a crisis in the securities market.

4. Evaluation of Knowledge level modeling

4.1. Case introduction: the Lehman Brothers Minibond in Hong Kong

Lehman Brothers has been a leading global dealer in credit and interest rate products and securities. The 15 September 2008 bankruptcy filing of Lehman Brothers produced dramatic effects on individual investors, who bought “Minibonds” from 21 bank and securities dealer distributors in Hong Kong (Arner et al., 2009). Minibond is a kind of complex structured notes, which were unlisted debt securities arranged by Lehman Brothers. As is set out in the report from Securities and Futures Commission of Hong Kong (SFC), Pacific International Finance Limited (PIFL), a Cayman Islands incorporated issuer, issued approximately HK$14 billion issued structured (mainly unlisted credit-linked) notes marketed as “Minibonds” to retail investors in Hong Kong, via licensed banks and securities brokers and arranged by a Hong Kong subsidiary of Lehman Brothers Holdings. The Minibonds were linked to the credit of companies, including HSBC, Hutchison Whampoa, DBS, Swire Pacific, Sun Hung Kai Properties, Goldman Sachs and Morgan Stanley. When Lehman Brothers filed for bankruptcy, there remained Minibonds with a nominal value of HK$ 12.6 billion in the hands of approximately 34,000 or more investors. The present controversy is over the Minibonds: Lehman Brothers’ collapse triggered contractual provisions in the Minibond issues requiring unwinding of the underlying financial structure such that their value immediately fell phenomenally.

The seller of Lehman Brothers Minibond received censure from its customers and government because of the misleading and incomplete information in the sales. Sun Hung Kai Investment Services, a securities brokerage firm and one of the first of the distributors for the Lehman Brothers structured products, agreed with the SFC to refund in full the face value of the Minibonds to the investors who purchased the Minibonds through them (SFC, 2009). Obviously, this arrangement brought about a big loss in cash, but it was the best possible solution to retrieve its reputation – even though it insisted that it did not accept any liability or wrongdoing in regard to this offer.

The Lehman Brothers Minibond incident is a typical example showing systemic risk in financial institutions where the collapse of Lehman Brothers brought unexpected loss to banks and securities dealer distributors in Hong Kong through Minibonds. In the following section of this paper, knowledge level model for systemic risk management in this case will be elaborated upon. As discussed
earlier, there are two parts in the proposed knowledge level model: the ontologies part and PSM part, where ontologies part is concerned with static knowledge needed for problem solving and PSM with dynamic reasoning process with knowledge. These two parts will be discussed individually (Uschold, 1998).

4.2. Ontologies

The domain ontology part is shown in Fig. 6. Similar to the general domain ontology discussed earlier, there are three levels: meta level, class level and instance level.

Generally, ellipse represents the concept in ontology, and four different arrows means four kinds of relationships between concepts, e.g., is an object property of.

4.2.1. Meta level

Obviously, the concepts and their relationships in the meta level of this case have no difference with what has been discussed before.

4.2.2. Class level

The concepts are discussed in detail in the class level, as they are key concepts to the systemic risk management of SHKP in Lehman Brothers’ minibond incident. First of all, the issuing and sales process of minibond is shown in the proposed ontology. Based on information from the Securities and Future Commission (SFC) report as set out in the reports of the HKMA and the SFC, 131 of the Minibonds are credit linked notes (CLNs). CLNs are normally credit notes issued by banks using a medium term note issuance...
programme to fund their operations. There is much controversy about the marketing of what were, in effect, credit linked notes using the term “Minibond”, because the inclusion of the word “bond” misled investors into thinking that the notes were corporate bonds instead of complex structured credit instruments (Arner et al., 2009). So minibond is a subclass of CLN in the proposed ontology.

In this case, Lehman Brother minibond is issued by Pacific International Finance Limited (PIFL), which is a special financial institution in Cayman Islands called Special Purpose Vehicle (SPV). And this is seen through an object property denoted as institution in Cayman Islands: Special Purpose Vehicle (SPV). And this is seen through a object property denoted as in the ontology. Then the minibonds are sold to retail investors through bank and securities dealer distributors in Hong Kong, as seen with object property invested by and sold through in the ontology.

Second, the complex securitization process of minibond is seen in the proposed ontology. Actually, this is a channel to detect systemic risk in the Lehman Minibonds event. Minibonds, which are credit linked notes, are unlisted debt securities through investment of Collateralized Debt Obligation (CDO) or CDOs, and then CDO has a object property denoted as bought by in the ontology. CDO is a type of structured asset-backed securities whose value payment is derived from a portfolio of fixed income underlying assets. In this case, CDO, bought by SPV is from corporate bond issued some well-known bank or property companies in Hong Kong, such as The Hong Kong and Shanghai Bank Corporation (HSBC), Sun Hung Kai Properties (SHKP), and so on. And this is also shown in the proposed ontology with object property synthetic from and issued by. Choosing these corporate bonds is important because they are well rated by the credit rating agency, e.g., double A. This is shown through rated by in the figure.

The principal repayment of the notes is linked not only to the creditworthiness of the issuer, but also to third party referenced debt obligation or a basket of debt obligations via sale of Credit Default Swap (CDS) or CDSs. So the issuer of minibond SPV has an object property denoted as sold by to CDS. At the same time, in order to solve the HK$ payment problem in Hong Kong, PIFL, the issuer of Lehman Brother minibonds entered into a master swap agreement which included interest swap and currency swap, which is represented through the object property between the swap and SPV in the proposed ontology.

Most securities mentioned above, such as CDS, CDO and SWAP are all provided by the subsidiaries of Lehman Brothers, and this is the exactly the way in which Lehman Brothers could earn such big profits in the minibonds event. These relationships are denoted by the data property provided by in the ontology. However, when Lehman Brothers filed for bankruptcy, they were also the reason that the unwinding of the underlying financial structure was required, which caused the minibonds’ value to fall immediately to such a low fraction of the amount paid.

4.2.3. Instance level

Entities are denoted by rectangles at the instance level; in this case they are the certain entities which play the key roles. For example, Pacific International Finance Limited (PIFL) is an instance of SPV, which is the issuer of minibonds. PIFL is controlled by Lehman Brothers, which is an instance of investment bank.

4.3. Problem solving method

In the Lehman Brother Minibonds case, the bank and securities firm which sold Minibonds to retail investors had to take the blame from the public and government because of the misleading and incomplete information in the sales. Sun Hung Kai Investment Services (SHKF), a securities brokerage firm and one of the first of the distributors for the Lehman Brothers structured products, agreed with the SFC to refund in full the face value of the Minibonds to the investors who purchased the Minibonds through them (SFC, 2009). Obviously, this brought SHKF big losses as the market value shrank a great deal, but this was its best practice choice. Thus, this case has exemplified the big loss caused by systemic risk in financial institutions. In the next section, the details of the problem solving method to detect systemic risk signal for SHKF will be discussed.

As mentioned before, there are four phrases here:

**Intelligence phrase:**

- **Step 1:** Collect relevant financial news from different sources.
The key point here is to decide which news is relevant to a certain financial institution. Domain level ontology is used here which replaces simple keyword searching. From the proposed ontology, Minibonds, which are issued by PIFL, financial products are sold by SHKF. Further, PIFL is a SPV controlled by Lehman Brothers. So in this case all the financial news about Lehman will be observed. For example, the reports from “The New York Times” mentioned that Lehman reported a loss of $2.8 billion in the second fiscal quarter of 2008 and was forced to sell off $6 billion in assets (Anderson & Dash, 2008).

**Step 2:** Gather systemic risk information from collected news.
The financial news collected in step 1 is raw materials, so they will be transformed to machine readable event. Common sense based reasoning is adopted at this step which is supported by CYC ontology. Taking the news about Lehman’s big loss mentioned in step 1 as an example, this news report will be transformed to the following style: (Entity: Lehman Brothers; Event: Big loss; Time: 2008.08.29; News source: The New York Times).

**Design phrase:**

- **Step 3:** Generate systemic risk signal hypotheses.
At this step the systemic risk signal is deduced through the relationship analysis between the news event gathered above and SHKF. For example, from the proposed ontology, it is easy to find that Minibonds are the channels that connect SHKF and Lehman. So if Lehman had a big loss, then it would bring systemic risk to SHKF through Minibonds. However, systemic risk signal here is only hypothesizing what will need further support in the next step.

- **Step 4:** Deduce possible result from the hypotheses.
Based on the proposed ontology, Minibonds are CLN issues by PIFL which is controlled by Lehman. So if only Lehman is in trouble, it is ok. But if it collapses, these Minibonds will be sold at market value. At this step, the systemic risk signal is assumed first, and then from this hypothesis, it is induced that the key to make detected risk signal proven is the collapse of Lehman.

**Choice phrase:**

- **Step 5:** Check the deduced result with the information gathered.
This step is used to check whether there is a big probability of the collapse of Lehman. More financial news will be collected and analyzed.

**Step 6:** Generate systemic risk report.
However, more and more information implies that Lehman may face bankruptcy. So in this step, the systemic risk report will be generated immediately which reminds the managers to be cautious with Minibonds.

**Review phrase:**

- **Step 7:** Get feedback.
Step 8: Refine the reasoning process through feedback. In order to refine and improve the reasoning process of the proposed PSM, feedback from domain experts are gathered in the last phrase. For example, in Lehman Mini-bonds case, SFC played key roles to force SHKF to compensate the loss of Minibonds’ investors. This will be considered in the reasoning process in the next similar case.

The details of whole reasoning process are shown in Fig. 7. Each reasoning step is based on the ontologies mentioned before.

5. Discussions about the knowledge level modeling quality

The model discussed in this paper is knowledge level model, which is a special level of conceptual model. So in this section, the conceptual model quality framework mentioned before is adopted to discuss the quality of the proposed knowledge level model.

Most of the current modeling research about systemic risk management is mathematic model. So here we compare our proposed knowledge level model with traditional mathematic model in this domain. The whole comparison framework is shown in Fig. 8.

Same with general conceptual modeling quality framework, three important linguistic concepts (syntax, semantics, and pragmatics) are applied to four aspects of modeling: language, domain, model and audience participation (Lindland et al., 1994).

5.1. Syntactic quality

The more closely the model adheres to the language rules, the higher the syntactic quality. The goal of syntactic goal is syntactic correctness, which means that all statements in the model are according to the syntax. The proposed knowledge level model adopts OWL and SWRL as implementation language, so it also has acceptable syntactic quality, but not so good as mathematic model. This is because mathematic models follow very formal notations and has perfect restrictions to adhere the implementation formats.

5.2. Semantic quality

The more similar the model and domain is, the better the semantic quality; the different, the worse the quality. There are two semantic goals: validity and completeness. Validity means that all statements made by the model are correct and relevant to the problem, while completeness means that the model contains all the statements about the domain that are correct and relevant.

The proposed knowledge level model has much better semantic quality compared to mathematic models both in validity and
completeness. For every mathematic model, it always based on some assumptions which are used to simplify the problem, and sometimes these assumptions are not accepted by the practice. So the statements made by mathematic models are not correct in these conditions, and this means it have not so good validity. Furthermore, every mathematic model is only used to deal with some aspects of the problem in the domain e.g., systemic risk in banking system (Elsinger et al., 2006). So it also has not so good performance in completeness. While for the proposed knowledge level model, ontology approach is adopted. Ontologies means specification of what exists; various research communities commonly assume that ontologies are the appropriate modeling structure for representing knowledge. The statements from knowledge level model have the most similarities to the domain within human knowledge scope. So it has much better semantic quality both in validity and completeness.

5.3. Pragmatic quality

Pragmatic is related to how the audience will interpret them. The goal of pragmatic goal is comprehension. Comprehension means that all model projections have been understood by their relevant audience. Same as validity and completeness, the criterion used in practice is also feasible comprehension. There are two main concerned parties in this problem: technique experts and financial experts. With systemic risk management models, technique experts can develop real system to solve problem, while financial experts support systemic risk management models development with their domain knowledge. Thus with pragmatic quality, there are two kinds of audiences: finance audiences and IT audiences. For IT audience, there are no big differences between mathematic models and the knowledge level models. Mathematic models can be used to support system development conveniently as they have powerful reasoning abilities. The proposed knowledge level model is also suitable for system design. While for financial audience, the proposed knowledge level model is much better. This is because the mathematic models for systemic risk management are too complex to be understood by normal investors as they employ some abstruse mathematic theories. For knowledge level model, it adopts conceptual modeling approach. As mentioned by John Mylopoulos, conceptual modeling supports structuring and inferential facilities that are psychologically grounded (Mylopoulos, 1992). So the pragmatic quality to financial audience of knowledge level model is much better.

In conclusion, the quality comparison results are shown in following Table 1.

6. Conclusion

Knowledge level modeling means capturing and representing knowledge without specific attention being paid to how it will be implemented. The ongoing global financial crisis, which has been treated as the greatest threat to the world economy since the Great Depression in 1930s, reflects the needs and importance of systemic risk management (SRM). In this research, knowledge level modeling is introduced and applied in systemic risk management in financial institutions.

The contributions of this paper are as follows:

(1) A knowledge level model for SRM in financial institutions has been proposed which integrates domain level ontology, top level ontology and problem solving model.
- Domain level ontology is described to investigate the basic concepts and their relationships for SRM in financial institutions.
- Top level ontology, adopted from the CYC project in this study, is discussed to support domain level ontology with common-sense knowledge for SRM.
• A problem solving model is proposed to detect systemic risk signal based on reasoning through the domain level ontology and top level ontology. The discussion of Lehman Brother’s Minibonds incident in Hong Kong also gives proof to the usefulness of the proposed model in practice.

(2) The symbol level of the proposed knowledge level model has also been discussed. In detail, OWL, SWRL and JESS rules are adopted to successfully represent them with a formal format.

(3) The developed knowledge level model can benefit SRM in many ways.
- It will enhance interchange of information and knowledge sharing for SRM within a financial institution.
- It will assist knowledge base development for SRM design. Actually, a prototype of financial systemic risk management decision support system is given in this study.
- They will support coordination among different institutions by using standardized vocabularies, e.g., they will allow integration of different SRM systems.

However, this work is only the beginning of the KLM research for SRM in financial institutions. Much more work is needed in the future:

(1) The evaluation of KLM used case study which is an informal valuation method. A more solid evaluation, such as field experiment, could be done in a future study.

(2) The discussion about top level ontology is very limited and more details will be left to future work. For example, the top level ontology used here is from the CYC project, in order to integrate with domain level ontology which is represented with OWL and SWRL; what was done in this study was to download the OWL knowledge base from OpenCyc. However, it would also be possible to translate the domain level ontology with CYC knowledge representation language.

(3) The discussion of KLM application will be left to future work.

As mentioned previously, the proposed KLM will benefit to SRM in financial institutions in many ways, however the individual performance has not been discussed in this paper, and will be left to future work.

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