Towards an Ontology Network in Finance and Economics

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Abstract. Finance and economics are wide domains, where ontologies are useful instruments for dealing with semantic interoperability and information integration problems, as well as improving communication and problem solving among people. In particular, reference ontologies have been widely recognized as powerful tools for representing a model of consensus within a community to support communication, meaning negotiation, consensus establishment, as well as semantic interoperability and information integration. In domains like economics and finance, which are too large and complex to be represented as a single, large and monolithic ontology, it is necessary to create an ontological framework, built incrementally and in an integrated way, as a network. Therefore, in this paper we introduce OntoFINE, an Ontology Network in Finance and Economics that organizes and integrates knowledge in the realm on finance and economics, serving as a basis to several applications. We discuss the development of OntoFINE and present some of its applications.

Key words: Ontology Network, Money, Value, Trust, Risk, Economic Exchanges

1 Introduction

In the last years, there has been a growing interest, within the financial sector, in the adoption of ontology-based conceptual models [44] to make the nature of the conceptualizations explicit, as well as to safely establish the correct relations between them, thereby supporting semantic interoperability. Naturally, having a clear understanding of the ontological nature of the concepts is fundamental not only to proper address semantic interoperability but also to understand the evolution of the economy before innovations in the financial industry, such as the introduction of cryptocurrencies and blockchain networks, the development of smart contracts, the release of stablecoins, the development of central bank digital currencies and the emergence of decentralized finance—the decentralized provision of financial products and services.

Reference ontologies have been widely recognized as a powerful tool for representing a model of consensus within a community. They are used for establishing a common conceptualization of the domain of interest to support communication, meaning negotiation, consensus establishment, as well as semantic interoperability and information integration. However, some domains are often too large and complex to be represented as a single, large and monolithic ontology. This is the case of *finance* and *economics*.

We believe that an integrated ontological framework, built incrementally and in an integrated way, as a network, can improve ontology-based applications in finance and economics, as well as improve communication among the different actors in these sectors.

This research aims at tackling these issues by investigating the conceptual foundations of some intertwined concepts in finance and economics, namely those of money, trust, value, risk and economic exchanges, to propose an Ontology Network in Finance and Economics (OntoFINE)[1], grounded in the Unified Foundational Ontology (UFO) [26], based on the literature review of the most relevant economic theories and considering recent innovations in the financial industry. The reason why we have chosen these subdomains is threefold. Firstly, because of their ubiquitous presence in the realm of finance and economics. Secondly because they are related to recent challenges faced by the financial industry, which involve new forms of money and trust, as well as new business models for digital exchanges. And finally, because they have been little explored by other initiatives in the same direction.

This paper is organized as follows. Section 2 provides an overview of our research baseline, including ontologies and their classifications, ontology networks and the Unified Foundational Ontology. Section 3 elaborates on the research method adopted. Section 4 presents OntoFINE and how it builds up from foundational to core and domain ontologies. Section 5 reports the application of OntoFINE in several initiatives. Section 6 discusses related works. Finally, Section 7 presents our final considerations.

2 Background

2.1 Ontologies and their Classifications

There are different classifications of ontologies in the literature. In the context of this research, we are interested in the ones that classify ontologies according to their generality levels and intended application. Regarding the generality level, ontologies can be classified into foundational, core and domain ontologies [43]. At the highest level of generality, there are the foundational ontologies. Foundational ontologies span across many fields and model the very basic and general concepts and relations that make up the world, such as object, event, parthood relation etc. [25, 15, 26]. Domain ontologies, in turn, describe the conceptualization related to a given domain, such as electrocardiogram in medicine [25]. With a level of generality between that of foundational and domain ontologies, there are core ontologies. Core ontologies provide a precise definition of structural knowledge in a specific field that spans across different application domains in this field. These ontologies are built based on foundational ontologies and provide a refinement to them by adding detailed concepts and relations in their specific field [43]. The different generality levels do not amount to a discrete classification, but to a continuum [3], ranging from foundational ontologies that are totally domain-independent (such as DOLCE [15] and UFO [26]), to domain ontologies, for a very

[1] The current specification of OntoFINE is available at `http://purl.org/krdb-core/ontofine`.

particular domain. Finally, core ontologies, despite being more general than domain ontologies, are also domain-dependent. Higher-level ontologies can be used to support the development of lower-level ontologies, e.g., foundational ontologies can be used as basis for building core and domain ontologies, and core ontologies can support the development of domain ontologies. In fact, considering the continuous nature of the aforementioned classification, some ontologies can be used for supporting the development of more specific ontologies even within the same level of generality. For example, UFO-A (an ontology of endurants) [26] and UFO-B (an ontology of events) [30], both of which are foundational ontologies, have been used as basis for building UFO-C (an ontology of social entities) [28]. The latter, albeit being more specific, is still considered to be a foundational ontology. ROME (a core reference ontology on money) [12] is grounded in UFO-C, while an electrocardiogram ontology in medicine is an example of domain ontology.

Another relevant classification criterion concerns the intended application of ontologies. Guizzardi [26] makes an important distinction between ontologies as conceptual models, known as reference ontologies, and ontologies as coding artifacts, called here operational ontologies. A reference domain ontology is constructed with the goal of making the best possible description of the domain in reality. It is a special kind of conceptual model, an engineering artifact with the additional requirement of representing a model of consensus within a community [26]. On the other hand, once users have already agreed on a common conceptualization, operational versions of a reference ontology can be created. Contrary to reference ontologies, operational ontologies are designed with the focus on guaranteeing desirable computational properties. In other words, when developing a reference ontology, the focus is on expressivity of the representation and truthfulness to the domain being represented (domain appropriateness), even at the expenses of computational characteristics such as tractability and decidability [27]. In summary, in the view employed here, a reference ontology is a particular kind of conceptual model, namely, a reference conceptual model capturing the shared consensus of a given community.

2.2 Ontology Networks

Ontologies have been widely recognized as a key enabling technology for knowledge management. They are used for establishing a common conceptualization of the domain of interest to support knowledge representation, integration, storage, search and communication [40]. However, some domains are often too large and complex to be represented as a single ontology. This is the case of finance and economics. If we try to represent the whole domain as a single ontology, we will achieve a large and monolithic ontology that is hard to manipulate, use, and maintain [46]. On the other hand, representing each subdomain separately would be too costly, fragmented, and again hard to handle.

D'Aquin and Gangemi [19] point out a set of characteristics that are presented in "beautiful ontologies", from which we detach the following ones: having a good domain coverage; being modular or embedded in a modular framework; being formally rigorous; capturing also non-taxonomic relations; and reusing foundational ontologies. We believe that an integrated ontological framework, built considering them, can improve ontology-based applications in finance and economics. In such integrated ontological framework, there must be ways for creating, integrating and evolving related ontologies. Thus, we advocate that these ontologies should be built incrementally and in an integrated way, as a network. An Ontology Network is a collection of ontologies related together through a variety of relationships, such as alignment, modularization, and dependency. A networked ontology, in turn, is an ontology included in such a network, sharing concepts and relations with other ontologies [46]. One of the most common ways for two ontologies to relate is to be dependent on each other. More precisely, it is often the case that in order to define its own model, an ontology refers to the definitions included in another ontology. Large, monolithic ontologies are hard to manipulate, use, and maintain. Modular ontologies on the contrary divide the ontological model in self-contained, interlinked components, which can be considered independently, while at the same time participate to the definition of a specific aspect of an ontology.

2.3 The Unified Foundational Ontology (UFO)

This research intends to provide conceptual foundations for modeling information in finance and economics, grounded on the Unified Foundational Ontology (UFO). UFO is an axiomatic domain independent formal theory developed based on a number of theories from Formal Ontology, Philosophical Logics, Philosophy of Language, Linguistics and Cognitive Psychology. Other examples of foundational ontologies include DOLCE [15] and GFO [32]. UFO, however, was created with the specific purpose of providing foundations for conceptual modeling. For example, unlike these other ontologies, UFO includes a rich ontology of relations [24], and an expressive system of formal distinctions among types of universals [29]. Furthermore, it provides an ontological treatment of higher-order domain types and the multi-level structures involving them [26]. Finally, again unlike DOLCE and GFO, UFO is formally connected to a set of engineering tools including a modeling language (OntoUML), as well as a number of methodological (e.g., patterns, anti-patterns) and computational tools [31].

UFO is divided into three incrementally layered compliance sets: UFO-A [26], an ontology of endurants (objects), UFO-B [30], an ontology of events (perdurants), and UFO-C [28], an ontology of social entities built on the top of UFO-A and UFO-B, which addresses terms related to the spheres of intentional and social things. For an in-depth discussion and formalization, one should refer to [26, 30]. UFO is the theoretical basis of OntoUML, a language for Ontology-driven Conceptual Modeling that has been successfully employed in a number of academic and industrial projects in several domains, such as services, value, petroleum and gas, media asset management, telecommunications, and government [31]. The “OntoUML Toolkit” contains a number set of tools to facilitate the ontology engineering process, such as ontological design patterns and anti-patterns, visual model simulation, and transformations for codification technologies [1]. UFO has a partial translation to OWL termed gUFO [1], which is suitable for knowledge graph applications. These gUFO/OWL concrete artifacts can contribute to semantic web related initiatives in finance [13], as well as to the goal of transparency of financial data exchange according to FAIR principles [35].

3 Methodological Aspects

For building OntoFINE, we followed some directions of the NeOn Methodology Framework [46]. NeOn provides guidance for engineering networked ontologies, making available detailed processes, guidelines and different scenarios for collaboratively building networked ontologies. In our work we have applied some of the NeOn methodological guidelines regarding ontology modularization, reusing and reengineering ontological resources.

In the development of each ontology we follow a customized version of the SABiO [2] methodology, suited to our particular context and needs. SABiO defines a process that starts with the development of a reference conceptual model, which is then used to develop a data model. We adhere to the general steps proposed in the methodology, up to the point of developing a reference ontology. These general steps are depicted in Fig. 1. The process starts with the specification of the purpose of the ontology and then enters an iterative loop of knowledge acquisition, ontology formalization, and ontology evaluation.

By combining NeOn Methodology's guidelines with a customized version of SABiO, we defined three flexible scenarios for building ontologies in the context of OntoFINE (Fig. 1). In the first scenario, the ontology is developed following just the customized version of SABiO. In the second and third scenarios, during the step "Ontology Formalization", defined in SABiO, we applied some methodological directions of Neon for reusing and reenginnering ontological resources, such as foundational and core ontologies, and ontology design patterns.

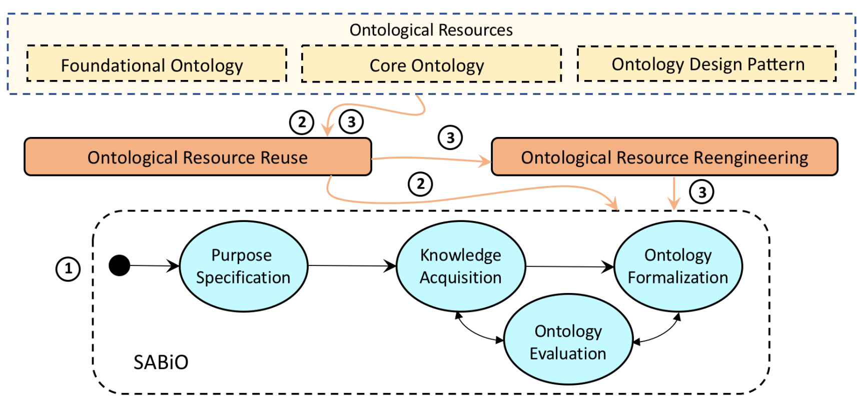

Fig. 1: Overview of the ontology development method (adapted from [46] and [2])

4 The Ontology Network in Finance and Economics (OntoFINE)

OntoFINE is part of a long term research program of providing a solid ontological foundation on finance and economics. It rises with three main premises: (i) being based on a well-founded grounding for ontology development; (ii) offering mechanisms to easy building and integrating new subdomain ontologies to the network; and (iii) promoting integration by keeping a consistent semantics for concepts and relations along the whole network. OntoFINE architecture is organized considering three ontology generality levels (Fig. 2):

Foundational Layer: The Unified Foundational Ontology lies in the foundational layer, providing the common grounding for all the networked ontologies. UFO's ontological distinctions are used for classifying OntoFINE concepts, e.g., as objects, events, commitments, agents, roles, goals and so on.

Core Layer. In the center of the ontology network, core reference ontologies are used to represent the general domain knowledge, being the basis for the subdomain networked ontologies. In its current version, OntoFINE includes four core reference ontologies:

- The Common Ontology of Value and Risk (COVER) [42];
- The Reference Ontology of Trust (ROT) [11], which reuses concepts from COVER;
- The Reference Ontology of Money and Virtual Currencies (ROME) [12], which reuses concepts from ROT; and
- The Core Ontology for Economic Exchanges (COEX) [41], which reuses concepts from COVER.

Domain-specific Layer. Over the foundational and core layers, OntoFINE places the domain ontologies. Each networked ontology is grounded in one or more core reference ontologies of the core layer and also in UFO, and encompasses a subdomain of OntoFINE. Currently, this layer contains the Reference Ontology of Trustworthines Requirements [5], which reuses concepts from ROT and COVER.

Figure 2 shows the current status of OntoFINE. Each circle represents an ontology. They are are described further in this Section. Arrowed lines denote dependencies between networked ontologies.

It is important to notice that, even adopting a layered architecture, OntoFINE is a network and each new added node contributes for the whole network. When a new ontology is added, it should reuse existing elements (from a higher or the same layer). Other ontologies, in turn, may be adapted to keep consistency and share the same semantics along the whole network. Even the core ontologies can evolve to adapt or incorporate new concepts or relations discovered when domain ontologies are created or integrated.

Being an ontology network, OntoFINE is like a living organism and is constantly evolving. It requires a continuous and long-term effort with ontologies being added and integrated incrementally. Therefore, we have been continuously working on OntoFINE. OntoFINE specifications are available at purl.org/krdb-core/ontofine, where machine processable lightweight versions of the ontologies implemented in gUFO/OWL are also available.

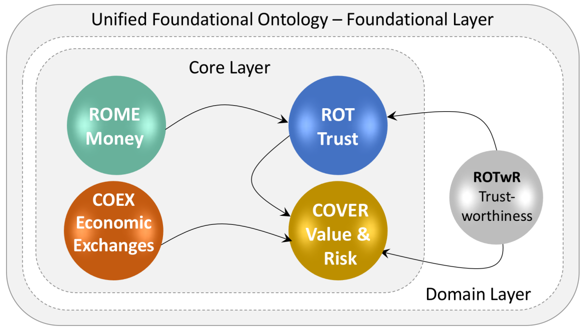

Fig. 2: OntoFINE: the network view

4.1 The Reference Ontology of Trust (ROT)

The Reference Ontology of Trust[2] (ROT) [11] is a UFO-based ontology that formally characterizes the concept of trust, clarifies the relation between trust and risk, and represents how risk emerges from trust relations. ROT makes the following ontological commitments about the nature of trust:

Trust is relative to a goal. An agent, the trustor, trusts someone or something, the trustee, only relative to a goal, for the achievement of which she counts upon the trustee.

Trust is a complex mental state of a trustor regarding a trustee and her behavior. It is composed of: (i) a trustor's intention, whose propositional content is a goal of the trustor; (ii) the belief that the trustee has the capability to perform the desired action or exhibit the desired behavior; and (iii) the belief that the trustee's vulnerabilities will not prevent her from performing the desired action or exhibiting the desired behavior. When the role of trustee is played by an agent, trust is also composed of the trustor's belief that the trustee has the intention to exhibit the desired behavior.

The trustor is necessarily an "intentional entity". Briefly put, the trustor is a cognitive agent, an agent endowed with goals and beliefs [18].

The trustee is not necessarily a cognitive system. The trustee is an entity capable of having a (hopefully positive) impact on a goal of the trustor by the outcome of its behavior [18]. A trustee may be a person, an animal, a car, a vaccine, etc.

Trust is context dependent. The trustor may trust the trustee for a given goal in a given context, but not do so for the same goal in a different context. We assume trust relations to be highly dynamic [18].

Trust implies risk. By trusting, the trustor accepts to become vulnerable to the trustee in terms of potential failure of the expected behavior and result, as the trustee may not exhibit the expected behavior or it may not have the desired result [37, p 21].

The reader interested in an in-depth description of the complete version of ROT is referred to [11, 8].

[2] The complete version of ROT in OntoUML and its implementation in OWL are available at `http://purl.org/krdb-core/trust-ontology`.

4.2 The Reference Ontology of Money and Virtual Currencies (ROME)

The Reference Ontology of Money and Virtual CurrEncies[3] (ROME) [12] is a reference model, grounded on the UFO, that formalizes the characterization of money, currency and virtual currencies, as well as its embedded concepts and relations. Some of ROME main ontological commitments on the nature of money are listed below:

Money depends on the collective acceptance or recognition of its status as money [45, 34, 36]. In contemporary society the status function of money is supported by law, which specifies both the currency and the objects that are considered money in a particular country or region. It also defines a structure for the currency value domain.

Monetary objects have a nominal value. This value is denominated in the currency defined in the law that describes its status function.

Physical monetary objects can be considered either valid or not valid. For example damaged banknotes fulfilling certain criteria defined in law are not considered valid. Obviously, only valid monetary objects can be exchanged for goods and services in the economy.

Money presupposes the existence of a credit/debt relation [34, 38]. Monetary objects establish this relation between the agent holding control of them and the central bank. As for central bank deposits and commercial bank deposits, they correspond to an electronic monetary credit denominated in a certain currency and represent a claim on the central bank or the issuing bank, respectively.

Monetary objects and electronic monetary credits have an associated exchange value. Agents holding control of monetary objects or owing electronic monetary credits are endowed with the capacity of making economic transactions in the amount corresponding to their exchange value. The exchange power resulting from the total of electronic monetary credits and monetary objects controlled by an agent stands for an aggregated exchange power that corresponds to the total value in economic transactions the agent is capable to carry out.

The aggregated exchange power of an agent has a correspondent purchasing power. Simply put, the purchasing power describes the quantity of goods an amount of money can buy. As the price of goods and services can change, the purchasing power of an agent can vary, but its aggregated exchange power remains the same.

Money depends on trust. A precondition for the functioning of any monetary system is trust that the monetary objects and credits will be generally accepted, as well as that both price and financial stability will be maintained.

The reader interested in an in-depth description of the complete version of ROME is referred to [12, 9].

[3] The complete version of ROME in OntoUML and its implementation in OWL are available at `http://purl.org/krdb-core/money-ontology`.

4.3 The Core Ontology for Economic Exchanges (COEX)

The Core Ontology for Economic Exchanges[4] (COEX) [41] is a well-founded reference ontology, specified in OntoUML, that formally characterizes the concept of economic exchanges based on the Action Theory of Economic Exchanges [39]. In this theory, an economic exchange is based on an agreement in which agents commit to performing certain reciprocal actions. This allows it to elegantly accommodate exchanges involving both products and services. The core assumption made by the Action Theory of Exchanges [39] is that, in any economic transaction, the "object" of the transaction is a pair of actions to be performed by the relevant agents involved in it. By viewing the object of transactions as actions, the ATE is capable of accounting for economic transactions about goods as well as services. In the case of services, the agreement is about the respective actions to be performed by the relevant parties. ATE's mechanism for explaining why economic transactions happen works by turning a conditional commitment into an unconditional commitment, under the suited conditions. For this reason, ATE also provides an explanation of why and under which circumstances an economic exchange happens.

The reader interested in an in-depth description of the complete version of COEX is referred to [41].

4.4 The Common Ontology of Value and Risk (COVER)

The Common Ontology of ValuE and Risk[5] (COVER) [42], a well-founded ontology that makes the deep connections between the concepts of value and risk explicit. COVER is grounded on several theories from marketing, service science, strategy and risk management. It is specified in OntoUML. COVER proposes an ontological analysis of notions such as value, risk, risk event (threat event, loss event) and vulnerability, among others. This ontology characterizes and integrates different perspectives of value and risk.

COVER makes the following ontological commitments on the nature of value:

Value emerges from impacts on goals: value emerges from events that affect the degree of satisfaction of one or more goals of an agent.

Value is relative: the same object or experience may be valuable to a person and of no value to another.

Value is experiential: even though value can be ascribed to objects, it is ultimately grounded on experiences. For instance, in order to explain the value of a smartphone, one must refer to the experiences enabled by it.

Value is contextual: the value of an object can vary depending on the context in which it is used.

As for risk, COVER makes the following ontological commitments:

[4] The complete version of COEX in OntoUML and its implementation in OWL are available at `http://purl.org/krdb-core/economic-exchanges-ontology`.

[5] The complete version of COVER in OntoUML and its implementation in OWL are available at `http://purl.org/krdb-core/value-and-risk-ontology`.

Risk is relative: this means that an event might be simultaneously considered as a risk by one agent and not as a risk by another (it may even be considered as an opportunity by such an agent).

A risk is perceived according to its impact on goals: n order to talk about risk, one needs to account for which goals are "at stake".

Risk is experiential: this means that we ultimately ascribe risk to events, not objects.

Risk is contextual: thus, the risk an object is exposed to may vary even if all its intrinsic properties (e.g. its vulnerabilities) are the same.

Risk is grounded on uncertainty about events and their outcomes.

The reader interested in an in-depth description of the complete version of COVER is referred to [42].

4.5 The Reference Ontology of Trustworthiness Requirements (ROTwR)

The Reference Ontology of Trustworthiness Requirements [6] (ROTwR) [5], is a reference domain ontology grounded on UFO [9], and based on the trust-related concepts defined in ROT. In ROTwR, trustworthiness requirements are defined as non-functional requirements, where the desired states-of-affairs are stakeholder mental states that include an attitude of trust towards the system-to-be. Trustworthiness requirements are related to an intention that is part of a trust relation between a stakeholder (the trustor) and the system- to-be (the trustee). According ROTwR, the system can emit trust-warranting signals to ensure trustworthy behavior. For example, information about how privacy and security measures are implemented could be provided as signals of the trustworthiness of a system. The reader interested in an in-depth description of the complete version of ROTwR is referred to [5].

5 OntoFINE Applications

In this section, we demonstrate the relevance of OntoFINE by presenting some of its applications (Fig. 3).

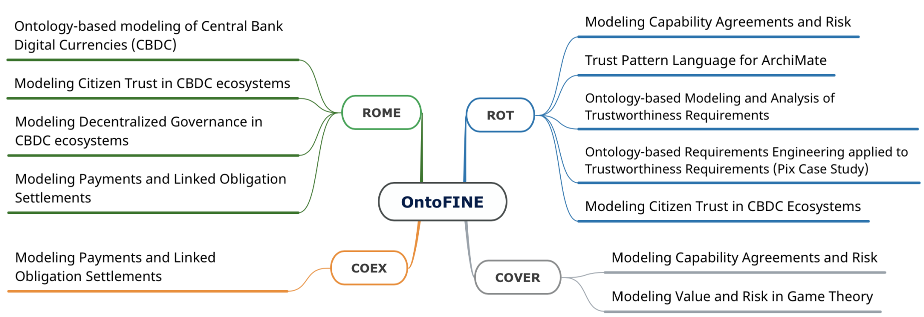

Fig. 3: OntoFINE Applications

[6] The complete version of ROTwR in OntoUML and its implementation in OWL are available at `http://purl.org/krdb-core/trustworthiness-requirements-ontology`.

Modeling capability agreements and risk [4, 11]: In this initiative, COVER and ROT were used to analyze the emergence of value and risk from trust, in delegation relations. Briefly speaking, the decision to delegate depends largely on the degree of trust. This decision may create value, as the trustor is endowed with new capabilities, but also implies some risk, as the trustor becomes dependent on the trustee, and consequently, more vulnerable. Having a clear understanding of the influence of these forces over delegation networks is fundamental both for the management of risks and for the awareness of the value created through the complex network of interdependencies.

Trust pattern language for ArchiMate [10]: Driven by the need to align the vision and strategic goals of enterprises with their business architectures, we specified a pattern language for trust modeling in ArchiMate, based on ROT and COVER, which can be used to model trust in the context of Enterprise Architecture (EA). The advantage of a pattern language [16] is that it offers a context in which related patterns can be combined, thus, reducing the space of design choices and design constraints [22]. In ROT, trust is modeled as a complex mental state of a trustor, composed of a set of beliefs about a trustee and her behavior. In the specification of the trust pattern language, we focused on the modeling and on the assessment of the beliefs that compose trust relations, in order to identify potential risks that can emerge from these relations. These models can be used, for example, in risk management to address the gap between trust concerns and the components that integrate the different layers of the enterprise architecture.

Ontology-based modeling and analysis of trustworthiness requirements [5]: We proposed a novel methodology for ontology-based requirements engineering, which applied ROT in a case illustration. In this work, we relied on ROT to define the class of trustworthiness requirements for software systems and their relation to concepts such as trust, capability, vulnerability and risk, among others.

Ontology-based Requirements Engineering applied to trustworthiness requirements (Pix Case Study) [6]: We conducted a real case study to verify if the ROT is capable of properly representing real world situations. In this study, ROT was applied to help with the elicitation of trustworthiness requirements of software systems by analyzing the case of Pix, the Brazilian Instant Payments Ecosystem created and managed by the Central Bank of Brazil.

Ontology-based modeling of Central Bank Digital Currencies [9]: We applied ROME to provide an ontological account for the concept of Central Bank Digital Currencies (CBDC) and represent its embedded concepts and relations.

Modeling value and risk in game theory [7]: We conducted an ontological analysis characterizing some basic concepts in game theory, which made clear the emergence of value and risks from game outcomes. We made use of the concepts and relations defined in COVER to analyze the payoffs of a game in terms of value and risk, as well as how they emerge from outcomes in game theory. We formalized our analysis by means of an ontologically well-founded model, specified in OntoUML. In addition, we applied these results to represent the emergence of value and risk from game outcomes in enterprise architecture models in ArchiMate.

Modeling payments and linked obligation settlements: We proposed and ontology-based approach for the modeling of payments and linked obligation settlement mechanisms, aiming at providing conceptual clarification and supporting semantic interoperability in decentralized finance ecosystems. Firstly, we created two domain-related ontology patterns by reusing pieces of knowledge extracted from COEX and ROME. Then, we systematically applied these patterns to model payments and linked obligations in OntoUML. Finally, we exported the models to OWL using gUFO.

Modeling decentralized governance in CBDC ecosystems: Currently, ROME is being applied to support an ontological approach for decentralized governance in CBDC ecosystems. In order to define a proper governance model for CBDCs it is necessary to make explicit the notion of CBDC and its associated concepts and relations, which is provided by ROME.

Modeling citizen trust in CBDC ecosystems: ROME and ROT are also being applied to support the modeling and analysis of citizens' trust in CBDC ecosystems.

6 Related Work

There exists in the literature a number of initiatives aiming at the creation of an unified view of the reality related to finance and economics. These works include vocabularies relevant to the financial sector, semi-structured data schemas and ontologies.

The Financial Industry Business Ontology (FIBO) [20] is an industry standard resource for the definition of business concepts in the financial services industry. It is developed and hosted by the Enterprise Data Management Council (EDMC) and is published in a number of formats for operational use and business definitions. It is also standardized through the Object Management Group (OMG). FIBO is developed as a series of ontologies and, in general, can be seen as a kind of ontology network. Despite presenting some definitions in the domains of money, FIBO is considerably less comprehensive than OntoFINE regarding this topic. For example, concepts related to digital currencies and cryptocurrencies are not present in this ontology. Furthermore, FIBO does not explore concepts related to trust.

The Financial Industry Regulatory Ontology (FIRO) [21] is an ontology model composed of relevant and interlinked ontologies in the financial industry regulatory domain. FIRO captures regulatory vocabularies, compliance imperatives and rules into the Description Logic-based Web-Ontology Language (OWL-DL). Basically, the objective of FIRO is to enable efficient access and smarter consumption of the wide and complex spectrum of legislation and regulatory rules governing the financial industry globally. It is focused on the legislation and regulation domains and does not address the notions of money, trust, value, risk and economic exchanges.

The Financial Regulation Ontologies (FRO) [47] are a set of linked ontologies to implement "semantic compliance" in the financial industry. Regulatory compliance combines the domains of legal and finance. Therefore, FRO imports the FIBO [20] and the Legal Knowledge Interchange Format [33], which represent information in the finance and in the legal domain, respectively. In addition, FRO integrates three operational ontologies, namely: the Bank Regulation Ontology, the Fund Regulation Ontology, the Hedge Fund Regulation Ontology and the Insurance Regulation Ontology. Although the purpose of FRO is strongly related to OntoFINE, it has a different objective, focusing on regulatory compliance aspects.

The Financial Industry Operational Risk Ontology (FiORO) [17] aims at enabling the systematic identification, assessment, management, mitigation and regulatory compliance reporting of operational risks in a financial services organization. It is expressed using in OWL. Although FiORO is focused on risks, it addresses only operational risks. It does not provide support for the modeling of other types of financial risk nor for the modeling of systemic risk.

In [23] Fischer-Pauzenberger and Schwaiger proposed the OntoREA Accounting and Finance Model, which constitutes an ontology-based conceptualization of the accounting and finance domain, grounded on the UFO. This proposal is similar to OntoFINE in the sense that it uses a well-founded language to represent concepts on economic exchanges, value and risk, however, it does not provide ontological distinctions for the concept of money and trust. Similarly, Blums and Weigand [14] proposed a Reference Ontology of Complex Economic Exchanges for accounting information systems, grounded on UFO, which covers concepts in the realm of economic exchanges, but does not provide ontological foundations neither on money nor on trust.

7 Final Considerations

Knowledge in economics and finance is diverse, interlinked and highly influenced by technology innovations. For dealing with richer scenarios, addressing several subdomains in finance and economics, we need integrated ontologies. An ontology network can provide such integrated solution. Some benefits of ontology networks are: (i) knowledge is organized and structured and can be used as needed: whole or extracts of it; (ii) it is easier to reuse and extend; (iii) it is easier to figure out the "big picture" and at the same time have an understanding of each subdomain separately.

Thus, in this paper, we presented OntoFINE, an Ontology Network in Finance and Economics. In its current version, OntoFINE includes core reference ontologies on money, value, trust, risk and economic exchanges. Diverse initiatives can benefit from the use of OntoFINE, especially the ones in which the focus is improving communication among different actors, semantic interoperability and information integration. We have experienced the benefits of ontology networks by using OntoFINE in applications as the ones mentioned in Section 5.

In the future, other core and domain ontologies in economics and finance should be developed and integrated to OntoFINE to enlarge its coverage. We also plan to use OntoFINE in new application scenarios, such as trust aspects in decentralized finance ecosystems and privacy issues in the context of open finance.

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