A Reference Ontology of Money and Virtual Currencies

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A Reference Ontology of Money and Virtual Currencies

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Abstract. In recent years, there has been a growing interest, within the financial sector, in the adoption of ontology-based conceptual models to make the nature of conceptualizations explicit, as well as to safely establish the correct relations between them, thereby supporting semantic interoperability. Despite the wide number of efforts to create a unified view of the reality related to economic and financial domains, no comprehensive enough formal model has been developed to, on one hand, accurately describe the semantics regarding the world of money and currencies and, on the other hand, differentiate them from virtual currencies - of which cryptocurrencies are the most significant representative. This research aims at tackling these questions by conducting an ontological analysis of money and related concepts, grounded in the Unified Foundational Ontology, based on a literature review of the most relevant economic theories, and considering recent innovations in the financial industry.

Key words: Money, Currency, Virtual Currency, Ontology, UFO, OntoUML

1 Introduction

It is a curious paradox that some entities are so ever-present in our daily life that we tend to be oblivious to the importance of the mechanisms that support their operation, as well as to the vital role they play in our lives. One example is breathing. We breathe all the time without even thinking about it, but when unexpected events occur, like the recent worldwide spread of a virus with the potential to threaten our respiratory capacity, we realize the importance of ensuring the proper functioning of our respiratory system.

The same goes for money. Money permeates most aspects of life in modern societies, however, the infrastructures that support the monetary system "remain invisible as long as they operate and fulfill their functions. In case of accident, disruption or crisis, their breakdown makes them visible and raises concerns and questions about their operation" [31, p. 6]. The financial crisis of 2007-2008 was an urgent reminder about the importance of money and finance. On that occasion, many banks could not aggregate risk exposures quickly and accurately, which "had severe consequences to the banks themselves and to the stability of the financial system as a whole" [4, p. 1].

Making sense of a plethora of information in a dynamic and complex environment is paramount not only in the aforementioned example, but also in many other activities realized to ensure the proper functioning of the financial system, such as the formulation of monetary policy, the safeguarding of financial stability, and the maintenance of *trust* in the monetary system. Moreover, having a clear understanding of the ontological nature of these concepts is fundamental to understand the evolution of the economy before innovations in the finance industry. This can be seen in the case of the advent of cryptocurrencies [13]. Despite their increasing popularization and the impacts they may have on the wider economy, research on this subject still lacks conceptual and semantic rigor, and the definition of a formal concept of cryptocurrencies and their relationship with money is still an open issue. Semantic interoperability is a fundamental aspect for a number of applications in this context in which, for example, values referred to in cryptocurrencies need to be integrated with values referred to in legal tender currencies. For example, in applications such as for anti-money laundering, one must analyze information from multiple and heterogeneous sources to detect unusual patterns, such as large amounts of cash flow at certain periods, by particular groups of agents.

Despite several efforts to create a unified view of our economic and financial reality [5, 12, 15], no formal model, comprehensive enough, has been developed to accurately describe the semantics of money and currencies. In a previous work [3] we have introduced an initial proposal for a money ontology, focusing on monetary objects and currencies. In this paper, we extend this ontology to consider monetary credit-related concepts, including electronic monetary credit, and improve the considerations on both exchange and purchasing power. In addition, we characterize the concept of virtual currencies and differentiate them from legal tender money. As a result, we propose a concrete artifact, namely, a Reference Conceptual Model (Reference Ontology) of Money and Virtual Currencies, which is specified in OntoUML [17] and thus, compliant with the ontological commitments of the Unified Foundational Ontology (UFO) [17].

The remainder of this paper is organized as follows. First, in Section 2, we briefly introduce the reader to UFO and OntoUML. Then, in Section 3, we present some characteristics of money and virtual currencies, as discussed in the literature. In Section 4, we analyze the nature of money, currencies, and virtual currencies and present our proposal, the Reference Ontology of Money and Virtual Currencies. We then conclude the paper with some final remarks in Section 5.

2 The Unified Foundational Ontology (UFO)

The Unified Foundational Ontology is an axiomatic domain-independent formal theory, developed by consistently putting together a number of theories originating from areas such as Formal Ontology in philosophy, cognitive science, linguistics, and philosophical logic. Other examples of foundational ontologies include DOLCE [6] and GFO [22]. 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 [16], and an expressive system of formal distinctions among types of universals [19]. Furthermore, it provides an ontological treatment of higher-order domain types and the multi-level structures involving them [17]. As we shall see, all these

aspects are needed for properly dealing with the topic of this paper. 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 [20].

UFO consists of three main parts: UFO-A [17], an ontology of endurants (roughly, objects), UFO-B [21], an ontology of perdurants (roughly, events and processes), and UFO-C [18], an ontology of social entities built on the top of UFO-A and UFO-B. For an in-depth discussion and formalization, one should refer to [17, 21, 20]. In our proposal of a Reference Ontology of Money and Virtual Currencies, we rely mainly on some concepts defined in UFO-C. For this reason, in the remainder of this section, we focus our discussion on this ontology, briefly explaining a subset of its ontological distinctions that are relevant for our analysis.

A basic distinction in UFO-C is that between *agents* and (non-agentive) *objects*. An *agent* is a specialization of a *substantial individual* (existentially independent objects) that can be classified as physical (e.g., a person) or social (e.g., an organization, a society). *Objects* are *non-agentive substantial individuals* that can be further specialized in physical (e.g., a book) and social objects (e.g., language). UFO-C defines a *normative description* as a *social object* that may define rules/norms recognized by at least one social *agent* as well as *social intrinsic and relational properties* (e.g., social commitment types), *social objects* (e.g., the crown of the King of Spain) and *social roles* (e.g., president, or pedestrian). Examples of normative descriptions include the Italian Constitution and a set of directives on how to perform some actions within an organization. In the finance domain, the Treaty on the Functioning of the European Union [38] is an example of *normative description*, which defines euro banknotes and coins as legal tender money in the countries of the euro area.

Over the years, UFO has been applied to analyze and (re)design a multitude of modelling languages and standards. One of these applications, however, stands out, namely the conceptual modelling language OntoUML [17, 20]. OntoUML is a version of UML class diagrams that has been designed such that its modelling primitives reflect the ontological distinctions put forth by UFO, and its grammatical constraints follow UFO axiomatization. We here employ OntoUML to model our proposed ontology [20].

3 On Money and Virtual Currencies

3.1 The Origins of Money

Different theories about the origin of money are reported in the literature and until today this topic is a matter for debate. Regarding the emergence of money in society, two leading schools of thought present fundamentally different arguments on its origins. A classic theory, known as the *commodity theory of money* or the *catallactic theory* [39], was defended by many classical economists like Carl Menger [29], Georg Simmel [36] and Ludwig von Mises [39]. They claim that money is an institution that spontaneously evolved in society, from some commodities (such as tobacco [36], salt [36] and cattle [36, 9]) until the current stage of fiat money that stands for any legal tender designated and issued by a central authority [34], which cannot be redeemed for a commodity [41].

Alternatively, there are those who argue that money is a social construction [10, 23, 25, 26, 28], "an instrument representative of a debt owed by the state or even a token created and accepted by it as an instrument to pay taxes" [41, p 12]. This view is known as *chartalism* or the *state theory of money* [26]. According to the chartalist school, money is what is stated in law [41].

In line with the state theory's argument that money represents a debt owed by the state, is the position defended by the *credit theory of money*, (a.k.a. *debt theory of money*), which states that money is merely a token of a credit/debt relationship [23, 27].

Questions about the commodity theory versus the state theory of money have been the subject of intense debate in the literature. In the current state of research, the state theory view seems to have stronger arguments than the commodity theory [9]. One of these arguments is that the value of the first metal coined money was too high for everyday consumption, so it is not plausible to think that it was intended to be used in exchanges between private individuals, while it makes sense to conclude that it was issued by city-states for administrative purposes [41]. Another noticeable argument of the state theorists is the difficulty the commodity theorists have in explaining the decreasing value of money over time (simply put, inflation) [10].

3.2 The Multiple Functions of Money

Although the format of money has changed considerably over time, its functions remain unchanged. From the wide number of definitions proposed in the literature on economics, it is possible to deduce a consensus about three main functions, namely:

- **medium of exchange**: a means of payment with a value that everyone trusts. For example, the statement "I bought this shirt for 20 euros" (from [34]) refers to this function. Note that here is also included the ability to make payments that have nothing to do with buying anything, like taxes and donations.
- **a unit of account**: money acts as a standard numerical unit for the measurement of prices and costs of goods, services, assets and liabilities. For example, the statement "My car is worth 10,000 euros" (from [34]) refers to this function.
- **a store of value**: "money can be saved and retrieved in the future" [13, p. 10]. For example, the statement "I have 1,000 euros in my bank account" (again from [34]) refers to this function.

It is generally accepted in the literature that money performs its functions in virtue of the collective recognition of a certain status that makes it valuable and guarantees its acceptability [35, 31, 10, 23, 25, 26, 28]. When this status is recognized for a certain object, it acquires a function known as *status function*, which "is not performed in virtue of the physical features of the person or object, but in virtue of the fact that a certain status has been assigned to the person or object" [34, p. 1457]. This function can be performed only in virtue of the collective acceptance or recognition of that status in the community in question. Status functions are created by a certain type of speech act that Searle [34, 35] terms *declaration*, where "you make something the case by declaring it to be the case" [34, p. 1458]. According to Searle [34, p. 1455] "money always requires a *declaration* whereby some representation makes it the case that it is money".

Currently, the status function of money is defined by law. The term legal tender refers to anything recognized by law that can be used to pay contractual debts. For example, a twenty-euros banknote fits this definition because it does have a definite status of being a twenty-euros banknote in Europe, as defined in the Treaty on the Functioning of the European Union [38]. People are willing to accept it in exchange for goods and services because they *trust* the monetary system that supports this status function. In [7], Castelfranchi and Falcone state that trust is the presupposition of money: originally money relies on the trust of the individuals accepting a monetary item as an instrument to indirectly acquire a certain amount of desirable goods [41]. Trust is therefore a crucial element of every monetary system.

3.3 Currency

The Oxford Dictionary [1] defines *currency* as "the system of money that a country uses". Generally, the national government is the only party authorized to produce and distribute physical currency in its geographical area of control. The government also regulates the production of non-physical currency by banks through its monetary policy, usually implemented via the central bank. In some countries, alternate currencies are permissible (e.g., Ethiopian Birr and US dollar in Ethiopia), but only the nationally sponsored currency has the status of legal tender. And in still other countries a foreign produced currency is both acceptable currency and legal tender (e.g. US dollar in Ecuador). For example, in the countries of the euro area, only euro banknotes and coins are legal tender and therefore, by law, they must be accepted as payment for a debt within those countries. According to the Article 128 of the Treaty on the Functioning of the European Union [38]: "The European Central Bank (ECB) shall have the exclusive right to authorise the issue of banknotes within the Union. The ECB and the national central banks may issue such notes. The banknotes issued by the ECB and the national central banks shall be the only such notes to have the status of legal tender within the Union".

3.4 Virtual Currencies (VC)

The ECB defines virtual currency as "a digital representation of value, not issued by a central bank, credit institution or e-money institution, which in some circumstances can be used as an alternative to money" [14, p. 4]. We could go a little bit further and include non-digital forms of virtual currencies in this definition such as tokens used in casinos.

From the point of view of central banks and regulatory authorities, virtual currencies cannot be regarded as full forms of money at the moment [14]. Also from a legal perspective, they are not considered money: so far no virtual currency has been declared the official currency of a state, nor have a legal tender capacity backed by law. From an economic perspective, the virtual currencies currently known do not fully meet all three functions of money defined in economic literature [14]. In some cases they "have a limited function as a medium of exchange because they have a very low level of acceptance among the general public" [14, p. 23]. In addition, due to the high volatility of

their exchange rates to currencies, they are not considered suitable to be used as store of value. Lastly, "both the low level of acceptance and the high volatility of their exchange rates and thus purchasing power make them unsuitable as a unit of account" [14, p. 24].

However, virtual currencies are similar to money within their user community. They necessarily have their own rules and processes enabling the transfer of value, as well as their payment systems [14]. These systems of rules and processes are called *virtual currency schemes*, and are organized into three categories:

1. **closed virtual currencies**, which have almost no link to the real economy, as they can only be spent by purchasing virtual goods and services offered within the virtual community and, at least in theory, they cannot be traded outside it.
2. **virtual currencies with unidirectional flows**, in which "units can be purchased using real money at a specific exchange rate but cannot be exchanged back to the original currency" [14, p. 6], and trading with other users is not allowed. Examples are loyalty programmes like airlines' points programmes and the Pokemon Go's PokeCoins [37] (which can be bought using real money and can be exchanged with in-game items).
3. **virtual currencies with bi-directional flows**, in which units can be bought and sold according to (floating) exchange rates. Examples include cryptocurrencies [30], such as Bitcoin and Ethereum, to name but a few.

4 The Ontology of Money and Virtual Currencies

4.1 Analysing Money, Currency and Related Concepts

In general, we are in line with the widespread position defended by some authors in the literature, which assume that money depends on the collective acceptance or recognition of its status as money [35, 31, 10, 23, 25, 26, 28]. This dependence is straightforward in the case of fiat money, but is also true for commodity money, as it requires a status function "precisely to the extent that it is collectively recognized as money and not just as a commodity" [34, p. 1460]. In contemporary society the status function of money is constituted as legal tender by the law that creates it. For example, in Europe, the Treaty on the Functioning of the European Union [38] describes the status function that defines euro banknotes and coins as legal tender money in the countries of the euro area. Note that the law specifies both the currency and the objects that are considered legal tender in a particular country or region. It also defines a structure for the currency value domain. Examples of structures are: one-dimensional structure of numbers with two decimal places defined for euros, and one-dimensional structure of integers defined for Paraguay's Guarani [24].

According to the literature on the history of money, different types of objects have been used as money in all its manifestations, such as (i) tobacco and salt, used as *commodity money*; (ii) banknotes and paper certificates, used as *commodity backed money*; and (iii) banknotes, coins and bank deposits in electronic format, used as *fiat money*. In our analysis we are focusing on the objects currently used as fiat money, such as banknotes and coins. We shall refer to these objects as *monetary objects* henceforth.

Every monetary object has a nominal value (also known as face value) denominated in the currency defined in the law that describes its status function. Only in exceptional cases in history (generally in times of crisis) there has been temporary reutilization of banknotes, "overstamped" with a nominal value different from the original one. For example, in 1986, in Brazil, the prevailing currency Cruzeiro was replaced by an new currency, named Cruzado, at a rate of 1 Cruzado to 1000 Cruzeiros. For a short period of time, some denominations of Cruzeiro banknotes were "overstamped" with the equivalent nominal value denominated in Cruzados [8].

During their life cycle, monetary objects can be considered either valid or not valid. For example, new banknotes are not considered valid until they are released and put into public circulation. Likewise, damaged banknotes fulfilling certain criteria defined in law are not considered valid (for example, an euro banknote is not considered valid if 50% or less of the banknote is presented and there are no proofs that the missing parts have been destroyed [11]). Obviously, only valid monetary objects can be exchanged for goods and services in the economy. In modern economies, money emerges a standard unit of account in which all other commodities express their exchange values. A valid monetary object has an exchange value that is equal to its nominal value; and an agent holding control of it is endowed with the capacity of making economic transactions in the amount corresponding to its exchange value. For example, a twenty-euros banknote has an exchange value of twenty euros. If the price of a Big Mac is five euros, an agent holding control of a valid twenty-euros banknote is capable of exchanging it for four Big Macs.

Money also presupposes the existence of a credit/debt relation [23, 27]. Monetary objects establish this relation between the agent holding control of them and the monetary authority (e.g. central bank), which ultimately represents the State. As for bank deposits, they correspond to an electronic monetary credit denominated in a certain currency. In this case, the credit/debt relation involves also the financial institution in charge of the bank account, as intermediary.

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 the exchange value of the monetary object or the electronic monetary credit value, respectively. This capacity is closely related to the *media of exchange* function of money. In this paper we name it exchange power. Moving in this direction, if we consider the exchange power resulting from the total of electronic monetary credits and monetary objects controlled by an agent, we obtain a kind of aggregated exchange power that corresponds to the total value in economic transactions the agent is capable to carry out.

As previously mentioned, goods and services have their prices expressed in terms of currencies. As the price of goods and services can change, influenced by the economic environment and the dynamic of the system of prices, the purchasing power associated with these aggregated exchange powers also changes. The purchasing power describes the quantity of goods an amount of money can buy. It is related to the concepts of inflation and price indexes. The inflation rate means an increase in general price level, measured by the variation in a price index during a period. When there is inflation, the purchasing power decreases. It means that the exchange value of the transactions

that the agent manages to carry out remains the same (and is equal to the aggregate exchange value), however, the quantity of goods and services that he manages to get with that value will vary, depending on the price of the commodities.

Let us consider an example in which an agent named Mary has twenty euros in her bank account and a ten-euros banknote in her wallet. In this case, she has an aggregated exchange power of thirty euros and is able to carry out economic transactions in the amount corresponding to this value. Considering that the price of a Big Mac is five euros, the purchasing power of Mary is equivalent to six Big Macs. If the Big Mac's price rises to six euros, Mary's aggregated exchange power remains the same, but her purchasing power is no longer the same because now she's able to buy only five Big Macs.

It is worth mentioning that monetary objects can also be traded in the economy as regular commodities, like collectible items. For example, some rare banknotes are traded by banknote collectors at far more than their nominal (or face) value. Even valid banknotes in circulation can be traded as collectible items at a value above their face value. However, for the acquisition of goods and services in the economy, a banknote functions as a means of exchange and will always be worth its face value.

Finally, another important aspect is money's dependence on trust [2]. It is clearly recognized in the literature that trust is a crucial element for the well functioning of any monetary system [7, 31, 34, 41]. A precondition for the system to work is trust that the monetary objects and credits will be generally accepted, as well as that both price and financial stability will be maintained. Even in this day and age, in which the legal tender status of money is enforced by law, money depends on the trust of society in the monetary system, which guarantees that mechanisms, infrastructures and protective structures (such as law, regulations, processes, procedures and government enforcement bodies) are in place to ensure that money is widely accepted, transactions take place, contracts are fulfilled and, above all, agents can count on that happening.

Nonetheless, as trust relations are highly dynamic [2], the decreasing level of trust in a particular monetary system can lead money to gradually lose its functions. When inflation rates are very high, money does not function as an effective store of value and people tend to spend it immediately rather than hold it [40]. Also, as prices start to rise rapidly, the function of money as unit of account diminishes. Finally, inflation reduces the function of money as a medium of exchange. In situations of hyperinflation, people may abandon the use of one currency for a more stable one [40]. For example, in 2007, hyperinflation was so problematic in Zimbabue that "people abandoned the Zimbabwean dollar, preferring to conduct transactions in U.S. dollars or South African rands. The Zimbabwean currency became nearly useless as money and was removed from circulation in 2009" [40, p 2].

4.2 Similarities and Differences between Money and VC

Virtual currencies have been the subject of intense policy debates, however there is currently no international agreement on how they should be defined. In this section, we elaborate on evidences that motivate us to advocate the position put forth by the European Central Bank [14], according to which virtual currencies are neither money

nor legal tender currencies. In particular, we explore the roles of status function, legal tender status and trust, in the conceptualization of both VC and money.

Status Function. Virtual currencies are similar to money in the sense that both have their value grounded on a collective recognition of a certain status that makes them valuable. In the case of money this status function is defined by law. As for virtual currencies, it is part of their specification and dedicated retail payment systems, also known as *virtual currency schemes*.

Legal Tender Status. According to the ECB [13, p 5] "virtual currency schemes differ from electronic money schemes insofar as the currency being used as the unit of account has no physical counterpart with legal tender status". In a virtual currency scheme, all digital representations of value map to "tokenised" representations of virtual currencies, which are not regulated by law. The lack of a legal framework leads to problems for redeeming funds, as the link between virtual currencies and currencies with legal tender status is not regulated by law [13].

Trust. Another similarity between money and virtual currencies is that both are dependent on trust. A precondition for the proper functioning of both the monetary and the VC system is trust that money and virtual currencies will be accepted, respectively. While in the case of money this acceptance comprises the whole society and trust includes the belief that both price and financial stability will be maintained, virtual currencies still have a limited level of acceptance among the general public, probably due to the high volatility of their exchange rates to currencies and to the "lack of a proper legal basis for virtual currency schemes" [13, p 42]. As currently virtual currencies do not have a legal tender capacity nor are backed by law, "users do not benefit from legal protection such as redeemability or a deposit guaranty scheme, and are more exposed to the various risks that regulation usually mitigates" [14, p 21].

4.3 Representing the Ontology of Money in OntoUML

In this section, we present a well-founded ontology that formalizes the characterization of money and currency, as well as its embedded concepts and relations. In the OntoUML diagrams depicting this ontology, we adopt the following color coding: types are represented in purple, objects in pink, qualities and modes in blue, relators in green, and datatypes in white.

Fig.1 depicts the concept of Money Status Function Description as a type of Normative Description (concept from UFO-C). The Money Status Function Description defines a Currency and the Monetary Object Types that have the status of money. For example, the "Treaty on the Functioning of the European Union" [38] is an example of Money Status Function Description, which defines euro banknotes and coins as legal tender money in the countries of the euro area. In this case, "euro" is the Currency, while "euro banknote" and "euro coin" are Monetary Object Types. The Money Status Function Description also defines a Currency Quality Space Structure for the Currency Quality Space. The former corresponds to a Social Object (concept from UFO-C) that prescribes a structure for the domain of values (eg. number with two decimal places), while the latter corresponds to the value domain itself (see [17] for *quality spaces*).

In the ontology, Monetary Objects represent instances of Monetary Object Types. For example, a "twenty-euros banknote" is a Monetary Object and corresponds to an instance of the "euro banknote" Monetary Object Type, defined in the "Treaty on the Functioning of the European Union" [38]. The nominal_value property corresponds to the nominal value stamped on the Monetary Object by the issuing authority.

Valid Monetary Object and Not Valid Monetary Object represent two different phases of the Monetary Object's life cycle. The distinction between "valid" and "not valid" allows for the representation of the life cycle of a monetary object. It is particularly important in the context of central banks, because they need to control the movement of monetary objects, such as banknotes, since they are printed until their destruction. For example, new banknotes are not considered valid until they are released and put into public circulation.

The property exchange_value is specific to Valid Monetary Objects as only they can be exchanged for goods and services in the economy. The exchange value of a Valid Monetary Object is equal to its nominal value. In UFO, properties can be directly evaluated (projected) into certain value spaces [17]. Both the exchange value and the nominal value of a Monetary Object are modeled as properties that have a value in a Currency Quality Space, which is structured according to a particular Currency Quality Space Structure. For example, euro has a measurable value in one-dimensional structure of numbers with two decimal places [24].

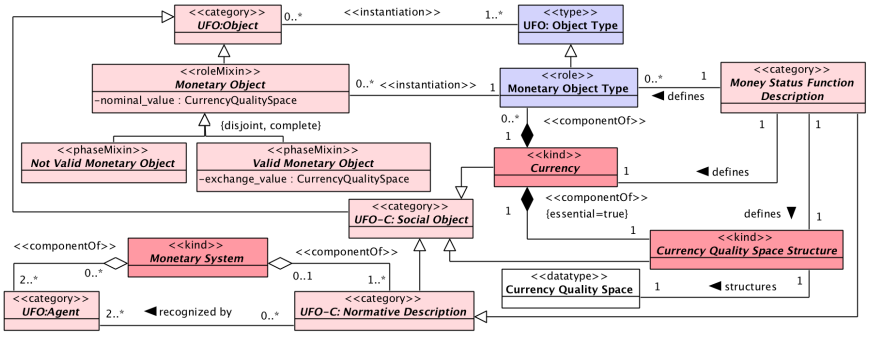

Fig. 1: Money and Status Function

Fig.2 depicts monetary objects and electronic monetary credit related concepts. As previously mentioned, money represents a credit/debt relation between the State (Monetary Authority) and an agent (Agent) either owing an Electronic Monetary Credit or holding control of a Monetary Object. Monetary Credit/Debt relations are composed of the Monetary Credit and the Monetary Debt, which have a value projected in a particular Currency Quality Space, and inhere both in the Agent (creditor) and in the Monetary Authority (debtor), respectively. In the ontology, the Monetary Credit/Debt Relation is specialized into Physical Monetary Credit/Debt and Electronic Monetary Credit/Debt. The former represents the credit/debit relation that a Valid Monetary Object establishes between the Agent that holds Control of it and the Monetary Authority (e.g. central banks). As for the Electronic Monetary Credit/Debt

relation, it represents bank deposits and, consequently, involves the Financial Institution in charge of the bank account, as intermediary.

As previously argued, when an Agent holds control of a Valid Monetary Object, she is endowed with the power to make economic transactions in the amount corresponding to its exchange value. In Fig.3, we capture it by means of the objectified relationship labeled Control, between Valid Monetary Object and Agent. The Exchange Power to carry out economic transactions inheres in the Agent and is grounded either on a Control relationship or in an Electronic Monetary Credit/Debt relation in which the Agent is the creditor. The Exchange Power's property exchange_power_value assumes a value in a Currency Quality Space, which is equal to either the exchange value of the Valid Monetary Object or the value of the Electronic Monetary Credit/Debt. We model the exchange power resulting from the sum of electronic monetary credits and monetary objects controlled by an Agent by means of the entity Aggregated Exchange Power, which is represented as a kind of capability inhering in the Agent. Finally, the Aggregated Exchange Power has an underlying Purchasing Power that corresponds to the quantity of goods and services the Agent manages to get with this Aggregated Exchange Power. As previously discussed, the Purchasing Power depends on the Price of goods and services. We model Price as a quality value that is "attached" to an Object, as a result of an assessment made by an Agent. The relationship Pricing represents this assessment. We are aware that the current ontology does not provide a deep analysis of pricing. This analysis fall outside the scope of this paper, as our focus is the modeling of the relationship between money and prices.

We make use here of the concepts and relations defined in the Reference Ontology of Trust (ROT) [2] to model the relation between money and trust, presented in Fig.4. ROT formalizes the general concept of trust and distinguishes between two types of trust, namely, social trust and institution-based trust. The latter builds upon the existence of shared rules, regularities, conventional practices, etc. and is related to social systems [2], like the Monetary System. According to ROT, Institution-based Trust is a specialization of Trust in which the Trustee is a social system. In our ontology the entity Institution-Based Trust represents the Trust of the society (a social Agent) in the Monetary System.

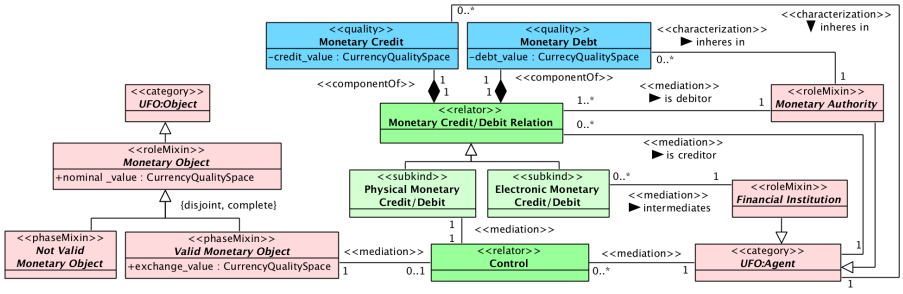

Fig. 2: Monetary Objects and Electronic Monetary Credit

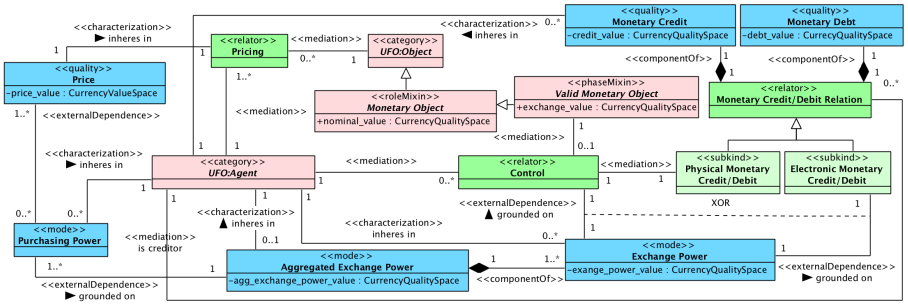

Fig. 3: Money, Exchange Power and Purchasing Power

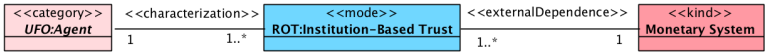

Fig. 4: Money and Trust (instantiating a fragment of ROT [2])

4.4 Modeling Virtual Currencies in OntoUML

Similar to money, virtual currencies have their value grounded on a status function, which is defined in their underlying virtual currency scheme. In Fig 5, the entity Virtual Currency Scheme Description, which defines the Virtual Currency and the Virtual Currency Token Type, represents this concept. As well as for money, the Virtual Currency Scheme Description also defines a Virtual Currency Quality Space Structure for the Virtual Currency Quality Space. Frequent flyer program points and cryptocurrencies, such as Bitcoin and Ethereum are examples of Virtual Currencies.

In the ontology, Virtual Currency Token represents instances of Virtual Currency Token Type. The property vc_token_value represents the token value and is projected in a Virtual Currency Quality Space.

As aforementioned, virtual currencies are similar to money regarding the role played by trust. As we did for money, we made use of the concepts defined in the Reference Ontology of Trust (ROT) [2] to model the relation between virtual currencies and trust. Therefore, in Fig. 5, the entity Institution-Based Trust represents the Trust of Agents in the Virtual Currency System.

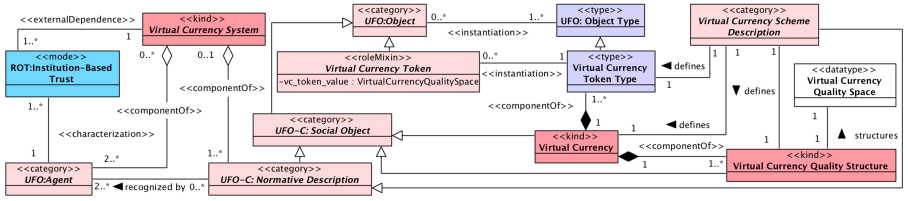

Fig. 5: Virtual Currency

Following the categorization proposed by the ECB [14], in Fig. 6 we distinguish Virtual Currency Token into Closed VC Token and Purchasable VC Token. Closed

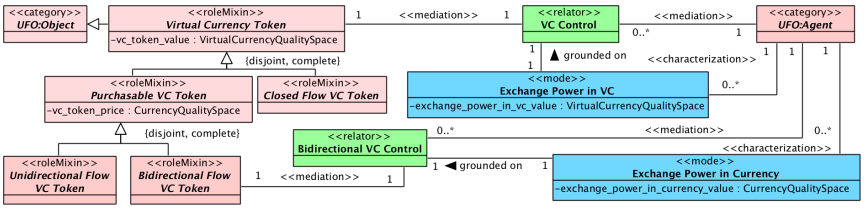

Fig. 6: Virtual Currency and Exchange Power

VC Tokens cannot be purchased nor converted to legal tender currencies. Differently, Purchasable VC Tokens can be purchased using legal tender currencies at a specific exchange rate. For this reason, they have an associated price value that is represented by means of the property vc_token_price, which takes a value in a Currency Quality Space. Within the category of Purchasable VC Token we can further distinguish into Unidirectional Flow VC Token and Bidirectional Flow VC Token. The difference between then is that only Bidirectional Flow VC Tokens can be exchanged to legal tender currencies. Therefore, Agents holding control of Bidirectional Flow VC Tokens have the power to exchange it to legal tender currencies, as well as to real goods and services. We model this capacity by means of the entity Exchange Power in Currency, which inheres in the Agent and is grounded on the control relation Bidirectional VC Control, between the Agent and Bidirectional Flow VC Token. Finally, every Agent holding control of a Virtual Currency Token has an exchange power to carry out economic transactions denominated in that particular virtual currency in the amount correspondent to the value of the Virtual Currency Token. The entity Exchange Power in VC represents this capacity.

5 Final Remarks

Despite the financial sector's interest in the adoption of ontology-based conceptual models to make the nature of the conceptualizations explicit [12, 33, 15, 32], to the best of our knowledge, no formal model, comprehensive enough, has been developed to accurately describe the semantics regarding the world of money and currencies. An initiative on this direction is the Financial Industry Business Ontology (FIBO), "an industry standard resource for the definition of business concepts in the financial services industry" [12]. Although FIBO includes a Currency Amount Ontology, it is not comprehensive and only marginally touches the notions of money and currency. For example, concepts related to money functions, types of money, legal aspects and trust are not explored in this ontology.

Our analysis allows us to formally characterize money and related concepts, as well as virtual currencies. The ontology presented here can serve as a basis for future business ontologies and as a conceptual foundation for several types of information analysis and data integration.

We conducted a preliminary evaluation of the ontology by means of interactions with experts in the field of economics and finance, including real practitioners directly

working on monetary policy in the context of central banks. In addition, as the ontology was specified in OntoUML, it is compliant with the ontological distintions put forth by UFO, thus preserving ontological consistency by design. As a next direction, we plan to apply our ontology to improve analytical data integration in the finance domain, as well as to support semantic interoperability across multiple cryptocurrencies blockchain networks. We also plan to integrate it to well-known ontologies in the finance domain (e.g. FIBO).

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