An Ontological Representation of Money with a View Toward Economic Determinants of Health

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Abstract

Money plays a large role in people's access to healthcare and to health-related resources, such as food, education, and housing. Because of this and its association with mortality and various health outcomes, identifying risks due to financial instability are of key importance to researchers and clinicians. While biomedical ontologies are often used to build structured datasets to enable sharing and integration of health-related data, the semantic representation of money and income, as well as other economic determinants of health (EDH), are limited. As such, identifying and filling gaps in existing ontological representations of income are needed. In this paper, we describe our approach to representing a key aspect of income and other EDH— money. We reviewed existing representations of money and financial transactions in publicly available biomedical ontologies for potential reuse and identified their strengths and weaknesses. Since we did not find any classes that sufficiently represent money or financial transactions for general use, we extended the Ontology of Medically Related Social Entities (OMRSE) by creating 7 new classes and importing four classes to represent money, financial obligations, four of the essential types of processes money is used in, and currency. We explain why our approach to representing 'money' has the advantage of being broadly applicable to both modern and historic forms of money that exist as bank accounts, currency, or consist of objects that have a secondary use as money (e.g., cigarettes).

Keywords

money, social-determinants of health, economic-determinants of health, economics

1. Introduction

The relationship between money and health is complex. In countries without free or universal healthcare, like the United States, people need money to purchase healthcare services and medication. The amount of money they have therefore can affect greatly their ability to obtain necessary care. Additionally, having a higher income is associated with various other factors such as better schools, nutrition, recreational resources, and housing, all of which also have documented associations with health outcomes (1). Indeed, in regions with noticeable disparities in income, studies have shown a link between income distribution and rates of mortality (2,3).

The importance of income in healthcare has motivated some to develop tools that assess patient risk using social and economic determinants of health, such as the Protocol for Responding to and Assessing Patient Assets, Risks, and Experiences (PRAPARE) Screening Tool (4). The PRAPARE Screening Tool is a standardized assessment of patient risk that includes income- and money-related questions, like "What is your family's total combined income?" and "In the past year, have you or any family members you live with been unable to get [Food/Clothing/Utilities/Healthcare/Child Care/Phone/etc.] when it was really needed?".

Therefore, if biomedical ontologies are to be used to integrate health data with social and economic data for researchers and clinicians, they

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will need to be equipped with representations of income, and with it, money. However, representing the latter is not an easy task. Despite coming in various forms, such as cash or coins, money in the modern world is widely considered to be a social construct (5–8). In fact, according to modern theories, money is a type of debt (9,10) in the sense that it represents the good faith of another party to settle its debt. For example, a banknote that has been issued by the United States (US) Federal Reserve represents an obligation (an IOU, so to speak) the US government has to whoever possesses the banknote to recognize it as a means of paying for taxes, fines, or US securities. For the person who possesses the banknote, that piece of money will represent a claim that they have against the US government. Thus, each debt necessarily has an associated debtor and creditor. Indeed, such theories underly much of how modern monetary policy is conceptualized and conducted, and have been adopted by major financial institutions around the world, such as the US Federal Reserve and International Monetary Fund (11,12). As such, these institutions widely consider highly liquid assets like checking deposits and traveler's checks, in addition to currency, to be money. Due to technological innovation over time, they have also come to categorize slightly less liquid assets that can easily be converted into currency or moved to a checking account, such as a savings account and small time deposits, as money. Lastly, money in modern economics and finance is typically viewed as being created by both governments and commercial banks since the former can create and issue currency and the latter can issue loans that are then deposited into checking accounts.

Although each of these forms of money differ in substance (e.g., currency is something that is material, while checking deposit accounts are immaterial) and in how they're created, they are traditionally considered to have four "functions" (13). We note that the term "function of money" is an economic—not an ontological—term of art. From here on, when we talk about "functions" of money, we are borrowing the economic usage of the term until we develop an account of money and our ontological theory of these "functions". We note for now that these "functions" of money are not at all functions as defined by upper-level ontologies such as Basic Formal Ontology. The first function of money is as a medium of exchange, which is what allows money to be

exchanged for goods and services. Its second function is the measure of value function, which enables money to serve as a standard unit of measure when assessing a numeric value of a good or service. Third, money functions as a standard of deferred payment, which means that it is widely used to value and settle debts. The fourth and final function is the store of value function that provides a high level of assurance that money will retain its value over time after being stored for retrieval later.

With this knowledge in mind, we reviewed past attempts at representations of money in publicly available Web Ontology Language (OWL 2) ontologies, with the intention of reusing classes where possible and creating our own classes where needed in the Ontology of Medically Related Social Entities (OMRSE) (14). OMRSE is an appropriate home for these terms given that money and its functions are quintessential social entities and are highly medically relevant as a social determinant of health. Through the efforts described in this paper, anyone can reuse the classes that we developed to assert that any type of material entity is money or holds value (e.g., gold).

2. Methods

For this project, we extended OMRSE to include money-related classes that can be used to richly and expressively represent various EDH. OMRSE (14) is an open source, mid-level domain ontology for representing social entities that are relevant to health. It is developed and maintained using the OBO Ontology Development Kit (ODK) (15) and can be found at https://github.com/ufbmi/OMRSE. OMRSE is an OBO Foundry library ontology (16), and it imports the Basic Formal Ontology (BFO) (17) for its top level to enable interoperability with other BFO-aligned ontologies.

Our first steps were to identify and review any and all classes in existing OBO-aligned ontologies that are used to represent money and financial entities relevant to EDH. To accomplish this, we performed a search of three online databases for viewing and downloading the content of ontologies: the OBO Foundry's Ontobee (18), the European Bioinformatics Institute's (EMBL-EBI) Ontology Lookup Service (OLS) (19), and the National Center for

Biotechnology Information's (NCBI) BioPortal (20). For each database, we manually performed a keyword search for ontology classes using the following search terms: "money", "finance", "financial", and "transaction."

We reviewed any classes that were identified through each search if they had English label and definition annotations. In addition, we relied on our knowledge of other ontologies to identify further classes for reuse. In reviewing each identified class, we looked at the quality of its definition before deciding to import it. To assess the quality of each definition, we took into account whether they included the four traditional functions of money: medium of exchange, measure of value, standard of deferred payment, and store of value (13). We also looked at whether a definition was broad enough to include ancient and modern forms of commodity money, representation money, and fiat money. Our motivations for assessing the definitions along these criteria were to ensure that they are domain independent and accurate enough to capture the characteristics of money that make it such a vital social entity for everyday life. Any class that was determined to be of sufficient quality was imported using the ODK's custom imports template workflow, which uses a ROBOT filter based approach to import classes (21,22). Terms we did not find equivalent classes for in existing ontologies were defined according to the principles of ontological realism (23) and added to OMRSE using the Protégé ontology editing tool (24).

3. Results

Our review of existing representations of money in ontologies indexed in Ontobee, BioPortal, and OLS returned several potential candidates for reuse, however none of them met our quality criteria. We did, however, end up reusing three classes from the Document Acts Ontology (d-acts)—'social act', 'claimant role' and 'duty holder role'—in our representation of money and debt obligations. We also imported 'predicted data item' from the Ontology of Biomedical Investigations (OBI) (25). Because money and social entities related to it are within the scope of OMRSE, if we could not reuse an existing class, we created a new class in OMRSE with a distinct definition. In nearly every case, due to various deficiencies of existing classes, the

referent of the OMRSE class is distinct from the referent of a related, existing class (possibly with the same label), typically being more general (i.e., being more inclusive of a range of types of entities).

In total, we created 7 new classes in OMRSE and imported four classes from OBO ontologies to represent money, the functions of money, the processes through which those functions are utilized, debt obligations, and currency. We also created textual definitions for each of the 7 new OMRSE classes.

3.1. Review of Current OWL Representations of Money

Through our searches of Ontobee, BioPortal, and OLS, we identified several potential terms for reuse. After removing duplicates and classes with no textual definition, we were left with two classes representing 'money' and two classes representing 'financial transaction'. We also discovered two classes representing 'payment' and one class representing 'selling'.

The first class that represents 'money' that we identified comes from the Gender, Sex, and Sexual Orientation (GSSO) Ontology (26). This ontology was designed to support the annotation of data related to various social groups and identities that relate to gender, sex, and sexual orientation and uses BFO for its top-level hierarchy. GSSO defines 'money' as "Any item or verifiable record that is generally accepted as payment for goods and services and repayment of debts, such as taxes, in a particular country or socio-economic context." This definition captures many of the essential characteristics of money (in fact, it is the most comprehensive definition we found), however it fails to define money as a debt itself and in so doing fails to capture the associated claim that the owner of that money possesses. The definition also leaves out any mention of money being a standard of value or a store of value. GSSO also contains a class representing 'financial transaction', which it defines as "An agreement, or communication, carried out between a buyer and a seller to exchange an asset for payment." Some financial transactions, such as payments of debt, however, do not involve the exchange of an asset in return for a sum of money paid. Another example is the provision of services as opposed to an asset. We

therefore also deemed this definition as too narrow for our needs.

The second class we identified that represents 'money' comes from the National Cancer Institute Thesaurus (NCIt), which was originally developed by the National Cancer Institute to support the sharing and interoperability of data between each of its subdivisions and is now widely used by public and private organizations around the world (27). It contains a class labeled 'Money' (C88415) that is defined as "The official currency issued by a government or national bank." We deemed this definition to be too narrow to justify reusing it since it excludes forms of money not issued by a government entity that may be used by groups of people today, such as by various indigenous tribes throughout the world, or forms of money that predate modern governments and state entities, or even checking accounts. In fact, the class definition more closely resembles definitions in modern economics for 'currency' (6–8,12), and indeed 'Currency' is listed as an exact synonym. NCIt also contains a class for 'Payment' (C25371), which it circularly defines as "A sum of money paid." Unfortunately, this definition is uninformative as to what the class represents, so we did not reuse it.

Our search also led us to identify a class in the Informed Consent Ontology (ICO), labeled 'act of selling' (ICO:0000423). ICO is an ontology aligned with BFO that describes itself as an ontology for representing informed consent and related processes in medicine (28). Its definition of 'act of selling' is defined as "A planned process in which goods or services are exchanged for money." However, goods and services are not the only entities that one can sell—one can also sell various types of financial assets or liabilities that likely cannot be accurately described as being either a good or a service (e.g., debts are often sold to debt collectors). As such, we did not end up reusing this class.

Lastly, we found a class labeled 'monetary payment' in the Behaviour Change Intervention Ontology (BCIO), which aims to model interventions involving changes to human behavior and the various methods used to evaluate them (29). This class (BCIO:010131) is defined as "A payment of person source that is money, vouchers or valued objects given to the source for delivering the intervention." It is obvious from this definition that this class refers to only those

payments involved in medical care. As such, we did not import it due to its very narrow scope.

3.2. Development of Classes for Debt and Money

When we originally set out to define both 'debt' and 'money', we immediately ruled out 'occurrent' (BFO:0000003) as a possible parent class since neither debt nor money are things that can be divided into temporal parts. To distinguish money from other types of debt, our first inclination was to explicitly represent the four functions of money as BFO roles. In BFO, roles are defined as "A realizable entity that (1) exists because the bearer is in some special physical, social, or institutional set of circumstances in which the bearer does not have to be, and (2) is not such that, if this realizable entity ceases to exist, then the physical make-up of the bearer is thereby changed" (17). As such, it inherits from its parent class—'realizable entity' (BFO:0000017)—the characteristic of inhering in independent continuants that are not spatial regions. Since we would want to assert that money is any debt that is the bearer of all four roles, simultaneously, this limits the options in BFO for a parent class for both 'debt' and 'money' to the following: 'continuant fiat boundary' (BFO:0000140), 'site' (BFO:0000029), 'immaterial entity' (BFO:0000141), and 'material entity' (BFO:0000040). We immediately ruled out 'continuant fiat boundary' and 'site' as possible parent classes, as debt and money are obviously neither boundaries nor sites. From this, we also ruled out 'immaterial entity' as a parent class since it is defined as "An independent continuant that contains no material entities as parts. Immaterial entities divide into two major subgroups: (1) boundaries and sites, and (2) spatial regions" (17). Additionally, because money, and therefore debts, can exist as digital records in a commercial bank's databases (i.e., checking deposit accounts) without those databases or other hardware that are used to store records and process transactions ever being usable as money, we ruled out 'material entity' as a possible parent class.

Indeed, it is this fact that debts and money can exist both in multiple material and digital forms that led us to further rule out 'specifically dependent continuant' (BFO:0000020) and identify 'generically dependent continuant'

(BFO:0000031) as a possible parent class. Our decision to eliminate 'specifically dependent continuant' (SDC), which is defined as "A continuant entity that depends on precisely one independent continuant for its existence" (17), stems from the fact that the money in one's checking account can inhere in one database today and then after a bank acquisition be moved to a different database tomorrow. This left us with 'generically dependent continuant' (GDC), which BFO defines as "A continuant that is dependent on one or other independent continuants and can migrate from one bearer to another through a process of copying" (17). This aspect of being migratable made this class a promising candidate since multiple records of a particular debt or multiple copies of a particular denomination of currency can exist at once. BFO also describes GDCs as being concretized in an SDC that itself inheres in an independent continuant. An example of this is the instance of a Coca-Cola logo—itself a copyable pattern that can exist in multiple bearers, and thus is a GDC—being concretized as the patterns of ink—an SDC, or more specifically a quality (BFO:0000019)—on a plastic bottle.

However, there is more to be said about debts and money than just being copyable, although we note here that there are socially built-in constraints to restrict—and in the case of paper and coin-based currency, prohibit—creating unauthorized copies. For one, all debts involve at least one party to whom the debt is owed (i.e., the creditor) and at least one party that owes the debt (i.e., the debtor). Following from past work in the Document Acts Ontology (d-acts), we propose that a creditor can be represented as a human or organization that bears a claimant role (IAO:210013), which is defined as "A deontic role that inheres in an agent A, that mutually depends on the existence of a duty holder role borne by agent B, and that specifies B doing or abstaining from C, or providing or surrendering C to A." Similarly, we can represent a debtor as a human or organization that is the bearer of a duty holder role (IAO:210016), which d-acts defines as "A deontic role that inheres in an agent A, that mutually depends on the existence of a claimant role borne by agent B, and that specifies A doing or abstaining from some action C, or providing or surrendering C to B." Additionally, money is a type of debt that can be used as a medium of exchange, a standard of deferred payment, a store of value, and a standard of value. With this in

mind, we define 'debt obligation' and 'money' as follows:

- **debt obligation** $=_{\text{def.}}$ A directive information entity that prescribes that something will be transferred from some human or organization that is the bearer of a duty holder role to another human or organization that is the bearer of a claimant role.
- **money** $=_{\text{def.}}$ A debt obligation between two parties that has part a scalar value specification and whose concretizations indicate that their bearers can be used in a financial transaction or payment of debt, or as a measure of the value of some entity in a financial valuation process or prospective financial valuation process.

We identified 'directive information entity' (IAO:0000033), which IAO defines as "An information content entity whose concretizations indicate to their bearer how to realize them in a process," as the best parent class for 'debt obligation'. We justify this by nothing that concretizations of debt obligations, including money, indicate how the associated duty holder and claimant roles can be realized—a simple paper record of a debt will contain concretizations that explain how the debt is to be paid, a piece of currency concretizes an obligation the issuing government has to recognize it as payment for taxes or treasury bonds, and the online record of your checking deposit account as its appears on a computer screen concretizes an obligation a commercial bank has to provide you with funds upon request. For money, we state in the definition that its concretizations indicate that its bearer can be used in a financial transaction (i.e., as a medium of exchange) or a payment of debt (i.e., as a standard of deferred payment), or in a financial valuation process (i.e., as a standard of value) or prospective valuation process (i.e., as a store of value) as a measure of the value of some entity, such as another debt, a material object, or a service. These concretizations are instantiated as qualities, such as the patterns of ink that are printed on a US banknote or the shape, color, and size of material entities that are used as commodities (e.g., cigarettes in prisoners-of-war camps (30)). Lastly, we define 'money' as having a scalar value specification as a part, which the Ontology for Biomedical Investigations (OBI) defines as "A value specification that consists of two parts: a numeral and a unit label." Although it is easy to see how currency can have a scalar value

specification, in that the number printed on the coin or banknote represents that value specification, it is less obvious for commodities that are used as money, such as cigarettes. For this type of money, we believe that the scalar value specification will take a value of "1" to indicate that that instance of money represents one unit, or it will derive this value from other commodities of the same type (e.g., a hand-rolled cigarette might be worth two Red Cross cigarettes, and thus it will have a scalar value specification equal to two Red Cross cigarettes). We additionally define 'financial transaction', 'payment of debt', 'financial valuation process', and 'prospective financial valuation process' as follows:

- **financial transaction** $=_{def.}$ A planned process whereby one participant partly or completely fulfills an obligation to another participant by transferring ownership of some other debt obligation, which is typically money.
- **payment of debt** $=_{def.}$ A planned process whereby ownership of some entity of value is transferred by one participant to another to fulfill some obligation, on their behalf, after some service is performed or the ownership of some entity is exchanged.
- **financial valuation process** $=_{def.}$ A planned process that has as specified output some scalar measurement datum that is about an entity—such as a material good or a service—and is measured in terms of the quantity of some other material entity.
- **prospective financial valuation process** $=_{def.}$ A planned process that has as specified output some predicted value that is about an entity—such as a material good or a service—and is measured in terms of the quantity of some material entity at some point in the future.

For 'financial transaction', we do not say in the definition that some quantity of money is transferred from one participant to the other to allow for other types of things to be used in place of money. For example, credit cards are not considered money because the resulting credits are debt that the owner of the card owes to a credit card company. Similarly, payments of debt can be settled and things can be valued with items other than money, which is why we did not specify in our definitions of 'payment of debt', 'financial valuation process', and 'prospective financial valuation process' that only money may be used. In addition, although 'financial valuation process'

and 'prospective financial valuation process' are very similar processes—indeed, one might be led to think that the latter could be a subclass of the former—it is important to note that the data items that are output from them are a bit different. For 'financial valuation process', the data item that is referenced in the definition is the Information Artifact Ontology's (IAO) 'scalar measurement datum' (IAO:0000032) (31), whereas 'prospective financial valuation process' references OBI's 'predicted value' (OBI:0001934).

3.3. Defining Currency

Lastly, we define 'currency' since it is one of the most common forms of money in the modern era. Currency is commonly known as anything that has been declared to be an acceptable means of settling debts, including taxes, and an acceptable medium of exchange by a government entity (6–8,12). Currencies are physically made and issued by government or government sanctioned institutions, such as the United States Federal Reserve (11). As such, we define 'currency' as "A material entity that is the bearer of a concretization of money and is created by some governmental organization or on behalf of some governmental organization that has authorized its creation."

4. Discussion

There is a current need in biomedical ontologies to represent EDH due to an increased interest in their role in determining health outcomes and contributing to health disparities. In this paper, we reviewed several existing representations in OWL ontologies for money and financial transactions, but found none that were broadly reusable based on our needs. The most common reason, and one that was nearly ubiquitous for each class identified, was that the definition was too narrow in its scope. In the majority of cases, this was due to the definition omitting some aspect of what the term represents that would make it generally applicable. In one instance, (i.e., NCIt's 'Payment') the class definition was not informative.

To fill this gap in the representation of money- and finance-related entities, we created 7 new classes in OMRSE and imported an additional four. These four imported classes were

not identified through the ontology database search, but rather came from our familiarity with existing OBO Foundry ontologies, such as OBI and d-acts. We believe this highlights the value of multi-collaborative efforts, like the OBO Foundry, in developing ontologies that are interoperable and specialized for a well-defined domain. Of the 7 new classes, one represents money, one represents debt obligations, one represents currency, and four represent the processes in which money can be used as a medium of exchange, a payment of debt, or to value other things. Our definitions are intended to be domain-independent and are based on established definitions from within economics so that they are applicable to domains within and outside of biomedicine. Because OMRSE uses BFO for its top-level hierarchy, these classes can be easily reused within other BFO-aligned ontologies.

As we've stated, our motivation for this work stems from a broader need to represent EDH and the data that are collected on them, such as income, wealth, and the ability to pay for resources like food, utilities, clothing, and housing. Although explicitly representing this information and the non-money-related entities that they're about (e.g., clothing items or food) is future work, we believe the classes we've proposed are necessary prerequisites and thus a required starting point, to do so. For instance, we would use our 'money' class to define 'past year income data item' as "A data item that is about the sum of the value of monies that a person or household or organization acquired in a past year-long interval."

This work is not without limitations. Because we classify 'money' as a debt, in line with modern definitions of 'money' in finance and economics, it is possible that there are older monetary systems for which this definition does not apply. While a comprehensive review of monetary systems throughout history is beyond the scope of this paper, we do note that this definition is nevertheless consistent with many historic forms of money, such as Babylonian clay tablets, tally sticks, and cigarettes in World War II prison camps (9,30). We also did not represent various entities used as money, such as checks or bonds, or financial assets, such as stocks, that would be useful for more comprehensibly representing financial transactions and wealth, respectively. Such additions will be included as future work in OMRSE as needed by various use cases for representing EDH and possibly other medically-relevant social entities.

Additional future work to extend our representation of money and finances will aim to more completely represent other entities that are used as money, digital transactions, financial assets, and finance-related processes that are relevant to medicine. We also are developing classes in OMRSE to represent other EDH, such as occupation and education, as well as intimate partner violence.

5. Acknowledgements

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