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Understanding Granular Aspects of Ontology for Blockchain Databases

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Abstract

Blockchain technology first appeared a decade ago and is gaining momentum in recent years. The role of ontology to blockchain technology has drawn much attention from researchers. In this paper, we explore ontology in blockchain technology from a unique perspective: Since granular computing can be applied to ontology, it would be a good idea to explore granular aspects of ontology in blockchain technology. Continuing our previous examinations on granular aspects on databases, in this paper, we study granular aspects of ontology for blockchain databases. We provide our own observations, and analyse implications of recent research work related the nature of blockchain technology. As shown in our discussion, this kind of exploration not only helps a better understanding on the nature of blockchain technology, but could also advance the study of granular computing itself.

Keywords: Blockchain databases; Granular aspects; Ontology

1. Introduction

Blockchain technology offer decentralized environment and trustless consensus at cloud data storage era for Big data, which is characterized not just be volume, but also velocity, variety and veracity [8]. Note that although initially blockchain technology came with the invention of bitcoins [15], blockchain technology goes far beyond bitcoins and related applications, The theme of this paper is motivated from the following consideration: Since blockchain technology opens a new paradigm of thinking and practice, the philosophy behind it (particularly ontology) deserves much attention. Since granule computing can be applied to ontology, it would be a good idea to explore granular aspects in blockchain technology. In fact, understanding these aspects brings the potential of incorporating or applying granular computing tehcniques to enhance the study and practice of blockchain technology. Note this paper is not intended to be an introduction of blockchain technology or blockchain databases, nor a complete survey of blockchain technology.

We start with a quick review of important concepts in granular computing. A ***granule*** is a clump of elements drawn together by various criteria such as indisignuishability, equivalence, similarity, proximity or functionality. As such, a granule is an atom

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of uncertainty [13,14]. *Granular computing* is the general term referring any computing theory/technology involves elements and granules, with granule, granulated view, granularity, and hierarchy as its key concepts [3, 4]. Also we may note that in a more philosophical sense, granular computing can describe a way of thinking that relies on the human ability to perceive the real world under various levels of granularity (i.e., abstraction) in order to abstract and consider only those things that serve a specific interest and to switch among different granularities [24]. By focusing on granulations and granularities in an abstract manner, granular computing shares some common interest with database management systems (DBMSs), because DBMS is about storage and retrieval of structured data (at front end) and maintenance of such data (at backend) at various levels of granularities..) An examination of database management systems from a granular computing perspective can be found in [5]. Continuing this line of thinking, an examination of granular aspects of blockchain databases thus offers a unique opportunity to understand the nature of this new development.

The rest of this paper is organized as follows. We first provide a brief review on blockchain technology and its relationship with ontologies. We then examine granular aspects of blockchain databases from several perspectives. We also present a brief discussion on the interesting co-evolution of blockchain and granularity-focused ontology. Since blockchain technology is new and since the topic on granular aspects of blockchain technology is quite complex, in this paper we only provide some examples to illustrate the importance of this topic. This kind of study should enhance our understanding of blockchain technology and the nature/philosophical foundations of blockchain technology from a technical perspective.

2. Basics of blockchain technology and its ontological examination

In a nutshell, a blockchain is a linked list of blocks of data that can be thought as constituting a log of updates to data [21]. What makes blockchain technology interesting is that blockchains can be managed in a distributed manner in such a way that they are highly tamper resistant, and changes can be made only by appending digitally signed records to the blockchain. (A little more on basics of blockchain technology is presented in the next section.) As a decentralized environment as well as a trustless network, blockchain technology reveals a complete new paradigm, not only in specific techniques used, but also in its fundamental nature. As noted in [24], from a practical point of view, an ontological philosophy of blockchain would provide a concise definition of what the technology is, including its purpose, function, and dimensions. As a consequence, an examination on ontological philosophy of blockchain technology should benefit future research and practice of blockchain technology.

In order to study ontologies for blockchains, a reference architectural model is presented in [25,26] for blockchains and their possible configurations. Using a bottom-up approach and based on component-based design, the blockchain ontology decomposes the blockchains into individual functional or logical components and identifies any possible different layout. Seven components at the topmost level were identified. Studies like this are important, but mainly from application/enterprise perspectives. A study of ontology from a more technical perspective is still needed. Examination of granular aspects of blockchain databases could be a very important part of this kind of study, which help a better understanding on the nature of blockchain technology. In fact, reference [2] formally defines an Ontology as the quintuple O (I, C,R,F,A), where I is the set of individuals, C is the set of concepts, R is the set of relationships defined, F is the set of functions which define new concepts from existing concepts, A is a set of axioms which constrain the meaning of concepts, relationships and functions. Since concepts and individuals all refer to various kinds of granules, this definition implies the important role of studying ontology from a granular perspective. For convenience of discussion, we will refer the study of granular aspects of ontologies as *granularity-focused* ontologies. Below we will apply this idea to examine some basic features of blockchain databases.

3. Granular aspects of blockchain databases

3.1. Granular aspects of traditional databases: A quick review

When we examine granular aspects of databases, first of all, we should note that at the conceptual level of database design, entity-relationship (ER) model and certain constructs in United Modeling Language (UML) [21] capture real-world objects at various levels of granularity. (We will return to modelling-related issues a little later.) As for database implementation, as described in [4], we can identify s*tructural granularity*, o*perational granularity*, c*onstructed granularity*, as well as *interactions* of different kinds of granularities.

Since a granule is an atom of uncertainty [13,14], fuzzy set theory, rough set theory and other techniques have been applied to improve the computational complexity of granular computing, and an excellent discussion on data storage management for rough set theory implementation from Infobright can be found in [22].

3.2. Blockchain databases

Now we can turn our discussion to blockchain databases, a term used to refer to the structure where blockchains are viewed as a storage layer of databases [7,15,21]. The very basic structure of a blockchain database is shown in Figure 1, with the layer of blockchain storage appearing on the top, and h indicates the hash function, through which blocks are linked together. Each block contain a number of transactions, which are shown in the middle of the figure. These transactions, in turn, access contents stored in the database, shown at the bottom of the figure. Note as a very high level overview, some important concepts (such as smart contract) are not included.

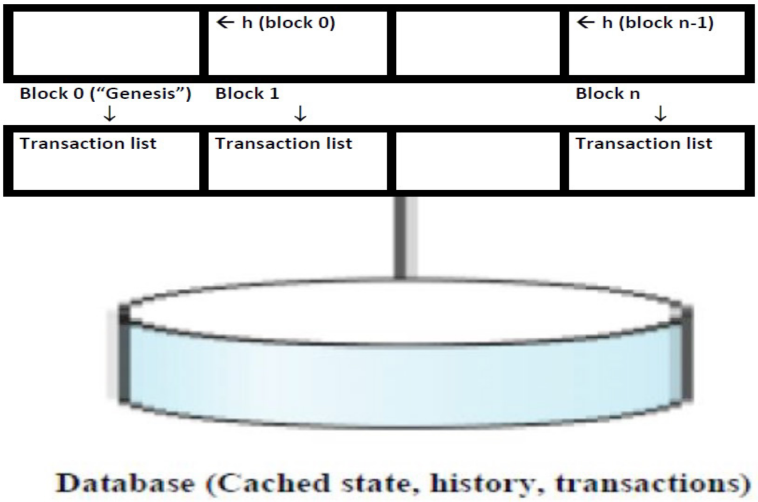

Figure 1. Basic structure of blckchain database

As noted in [21], in blockchain data structure, transactions are packed into blocks which are linked to previous blocks. A blockchain provides an alternative data format for storing a database, and its paradigm for transaction processing enables a high level of decentralization. Studying blockchains from a database perspective includes iidentifying ways in which blockchain databases differ from the traditional databases and show how these distinguishing features are implemented. A blockchain can be considered as a log of updates: At the most basic level, a blockchain is a linked list of blocks of data that can be thought as constituting a log of updates to data. Blockchains are managed in a distributed manner in such a way that they are highly tamper resistant, and cannot be easily modified or manipulated by any one participant, except by appending digitally signed records to the blockchain. Existing data items are not modified; instead, transactions add new information. Conflicts in transaction ordering are prevented. Dependencies of one transaction upon another are stated explicitly in a transaction and there is no explicit concurrency control. Much of the need for concurrency control is eliminated by the maintenance of a complete history and the direct sequencing of transactions. Thus, there is no contention for the current value of any database item [21]. Furthermore, there is a need to formally define lockchain database. For example, [5] defined a lockchain database D as a triple (R, I, T), where R is a set of relations, called the *current state,* I is a set of integrity constraints, such that R |= I, and T is a finite set of transactions for R, each of which is a set of tuples. Note this definition has an apparently flaw, because it is not specific to blockchains. So apparently more work is needed.

3.3. Granular aspects of ontology in bockchain databases

We can now provide a discussion on granular aspects of ontology in databases in two ways: directly from basic features of blockchain databases and (indirectly) from enterprise ontology identified by other authors (so this can be viewed as second order ontology). There are several aspects addressed in this section, and the organization of our presentation can be outlined as follows.

First, we present our own understanding of some basic granular aspects of blockchain databases. Next, we present a discussion on what we have learned from some recent research related to blockchains through a survey on several selected papers, including entity-relationship modeling for enterprise ontology, which leads to an examination related to granular computing and blockchain databases. We also examine unique features of uncertainty in blockchain databases. Although most part of this section is on the importance of ontologies for blockchains, we wrap up this section by examining the other direction of the relationship between ontologies and blockchains, namely, blockchains for ontologies.

3.3.1 Granular aspects of blockchain databases

A blockchain database includes a hierarchy of granules, such as transactions, blocks, blockchains, etc. Operations involving these granules include grouping, hierarchy, interoperation, etc. Below we examine some specific aspects related to granules, granularity and granulation in blockchain databases.

(a) *Transaction as a granule.* As in traditional databases, a transaction in a blockchain is an atomic unit containing a sequence of operations applied on some states, but the concurrency control mechanism is quite different. Every transaction can be considered as state-transition-function. A related concept is smart contract, which is a set of logic rules in the form of a coded script which can be embedded into the blockchain to govern a transaction. The contract is executed autonomously and is used to govern the transaction [7,20,21]. Interesting issues raise as transactions are grouped to form a block, as to be explained below.

(b) *Block as a granule consisting of transactions.* A blockchain is a linked list of blocks of data. A distinguished feature of the blockchain data structure is that the pointers in the linked list include not only the identifier of the next older block, but also a hash of that block. The initial block, block 0) is set up by the creator of the blockchain. Each time a block is added to the chain, it includes the pair of values in the form of (pointer to previous block, hash of previous block). This hash-validated pointer format in a blockchain makes tampering with a blockchain hard. These hash functions are quite different from those used as a means of indexing databases. Cryptographic hash functions need to have some specific mathematical properties such as the following: Given a data value x and a hash function h, it must be relatively easy to compute h(x) but virtually impossible to find a given h(x) [21]. How to decide a block should be accepted to a blockchain or not? This is concerned with a core topic in blockchain technology, referred to as consensus algorithms. As a critical property of a blockchain system, the nodes do not trust each other, meaning that some may behave in Byzantine manners, and the consensus protocol must thus tolerate Byzantine failures [7]. Therefore, although blocks are granules, relationships among blocks are much more complicated than relationships among granules as discussed in granular computing literature (which could be trivial). We can view this kind of relationship among blocks as a “value-added” feature of a granule in the domain of blockchains.

(c) *Blockchain as a granule.* As a higher-level granule, a blockchain is constructed from blocks through consensus algorithms. In addition to the mainchain, a blockchain may contain other structures such as sidechains (which includes those blocks cannot be accepted to the mainchain). Again this is a key area of study related to blockchains. A little more discussion is presented in next section when we talk about enterprise ontology.

(d) *Cross-chain transactions and interoperable blockchain systems.* At a level higher than individual blockchains, we should now consider cross-chain transactions [21]: If the system is controlled by multiple organizations, coordination could be difficult. The simplest solution is to use a trusted intermediary organization. There are two primary approaches to improve the performance of blockchain consensus, namely, sharding (distributing the task of mining new blocks to enable parallelism among nodes), or off-chain transaction processing. Note that in the latter approach, trusted systems process transactions internally without putting them on the blockchain, and these transactions are grouped into a single transaction that is then placed on the blockchain. This grouping, which forms a higher level granule, may occur with some agreed-upon periodicity or occur only at the termination of the agreement. This results in an interoperable blockchain architecture. According to NIST definition restated by [9], an interoperable blockchain architecture is a composition of distinguishable blockchain systems, each representing a unique distributed data ledger, where transaction execution may span multiple blockchain systems, and where data recorded in one blockchain is reachable, verifiable and referenceable by another possibly foreign transaction in a semantically compatible manner.

(e) In addition to those granules we have discussed above (which involves granularity at different levels of hierarchy), we should also consider *metadata* of blockchain databases, which can be viewed as a kind of *abstract,* or *meta-granule*. A discussion on such metadata can be found in [1].

In summary, we have seen various kinds of granules at different levels in blockchain databases. The advantage of examining these granule aspects is the potential of incorporating or applying granular computing techniques to the study blockchain databases. As noted in [29], granular computing not only offers philosophy of structured thinking, but also methodology of structured problem solving and mechanism of structured information processing. A study of blockchain databases from a granular computing perspective can enhance of our understanding on the nature of this new paradigm, and has the potential of offer new solutions. Note that this does not imply that granular computing itself will directly offer solutions to blockchain technology; instead, our point is that incorporating granular computing aspects to blockchain technology may hold the key for its future development.

3.3.2 Entity-relationship modeling for enterprise ontology

As noted in [12], ontology design only makes sense once the designer and audience have basic yet fundamental understanding about the subject of analysis, blockchain. Besides the information systems' perspective, the blockchain ontology should also relate to the business operation and processes of potential enterprise adopters. From one perspective, enterprise ontology provides a collection of relevant terms and natural language definitions, and distinguishes three basic human abilities, from which three ontological layers can be identified for blockchains: datalogical layer, infological layer and essential layer [12]. From this kind of description we can further examine granular aspects of ontology related to blockchains. For example, the datalogical domain taxonomy for the blockchain ecosystem can be represented through UML or entity-relationship (ER)-like diagram, in which entity sets such as chains, mainchains or sidechains are abstract granules. Entity sets from chain to mainchain to blockchain or alternative-chain form a hierarchy of granules. In addition, mainchain and sidechain in a blockchain system are associated together in a relationship set with "many to many" cardinality with total participation at the mainchain side. Similarly, infological ontology for a blockchain transaction can also be represented using another diagram, where entity sets are transactions, account, journals, object, ledgers, and so on, and these entity sets are associated together through relationship sets of various mapping cardinalities; for example, a transaction (as a granule) is associated through a "one to many" relationship "contains" to journal (another granule at different granularity level) with total participation at transaction side. In fact, entity-relationship modeling can play an important role of examining granular aspects in ontology, as to be briefly discussed in the next subsection.

3.3.3 Entity-relationship modeling, granular computing and blockchain

Since entity-relationship diagrams [21] can be used to capture the relationships between granules [28], its potential to capture the study of ontologies, and thus its potential contribution to the study of blockchains, should not be overlooked. For example, according to a recent study [6], in order to model, represent, and visualize knowledge profiles that show who in the organization knows what, a framework based on granular computing is proposed. The framework is aimed to capture, visualize, and analyze organizational knowledge by extracting granular, hierarchical entity-relationship models from unstructured text data that are mapped to individual users and organizational units. A granular knowledge cube (GKC) is a hierarchically granulated entity-relationship model of both user and organizational knowledge; it is extracted from user inputs in the form of unstructured data. Concepts and relationships are extracted from text to represent knowledge elements. In addition, dependencies among granules indicate inheritance and knowledge paths. The GKC is built using a three-step procedure using ontologies. A blockchain-based system is designed and implemented to demonstrate how such a system can increase transparency and automate interactions in the agricultural sector [20], in which an ER diagram is in traditional notation was first developed. It is also possible to develop blockchain-oriented software (BOS) that implements part of the business logic in the blockchain by using smart contracts, as shown in the work of [18], where three complementary modeling approaches (ER model, UML and Business Process Model and Notation (BPMN)) based on well-known software engineering models were described.

3.3.4 Blockchain for ontologies

In previous sbusections we have emphasized the importance of ontologies to blockchains. In order to show the close relationship between blockchain and ontologies, we show another way of their association, namely, how blockchains can have the potential of aiding the study related to ontologies. For example, according to [19], the Semantic Web of Things (SWoT) improves the Internet of Things power by increasing resource representation capabilities through knowledge management and reasoning technologies adapted from the Semantic Web. A blockchain framework was proposed for SWoT contexts settled as a Service-Oriented Architecture to redesign resource discovery, in which nodes can exploit smart contracts for registration, discovery and selection of annotated services/resources. In our view, granular computing should be able to play a significant role in this kind of study, because granular aspects are deeply rooted in both blockchain technology and ontologies, as we have discussed above.

We now summarize granular aspects examined in this section as follows. First, we provided our own analysis to identify various granules in blockchain databases. We then presented a brief review on selected research articles on ontologies in blockchain technology. This gives us a chance to explore granular aspects of blockchain databases through entity-relationship (ER) modelling, since these studies employed ER modelling techniques. We wrapped up this section through a brief examination on the other direction of relationship between blockchains and ontology, namely, how blockchain technology can aid the study of ontologies.

3.4. Dealing with uncertainty

Now we take a look at issues related to uncertainty in blockchain databases. As noted in [5], over time, a blockchain database evolves, by the addition of transactions to the current state. However, at any given point in time, it is not possible to know for certain which pending transactions will be permanently to the set of relations. Users usually do not know for certain which transactions issued earlier will or will not be appended to the current state. Another form of uncertainty takes the form of inconsistency. An interesting motivating example to illustrate the inconsistency was provided in [12], which shows that an exchange may have to pay the system twice, once with the original fee, and another one with the increased fee (after processing delay). In fact, all consensus algorithms are designed to deal with uncertainty in blockchain databases.

As indicated earlier, a granule is an atom of uncertainty [13]. However, uncertainty involved in blockchain databases as discussed above is very different from uncertainty discussed in traditional granular computing literature. So here comes a very interesting scenario: while fuzzy set theory or rough set theory is yet to be incorporated into blockchain technology (or blockchain databases) to assist handling of uncertainty and inconsistency, the latter also brings numerous research opportunities for the study of issues related to uncertainty in granular computing.

4. Co-evolution of blockchain and granularity-focused ontology

As noted in [10], the compelling rationale for ontology-based blockchains is that a modeling approach based on formal ontologies can aid in the development of smart contracts that execute on blockchains. An ontology-driven blockchain design for supply chain provenance was proposed to facilitate granular evaluation of provenance of physical goods. Encoding ontologies on the blockchain entails ontological commitment; i.e., blockchain developers would adopt some ontology terms as metadata. Based on this belief, a claim was made to state that blockchain and ontologies should co-evolve [11]. In this paper, we are not intended to explore the general issue of co-evolution of blockchain and ontologies; but we do agree on the mutual benefit of studying blockchain and granularity-focused ontology in that the study of one of them will benefit the other. In particular, we want to emphasize that the examination of granular aspects of blockchains actually inject momentum to the enrichment of granular computing research. In fact, this is already implied in discussion appeared in previous sections. Note that although we have adopted terms such as granule as they appear in granular computing literature, the use of these terms is *adapted* in blcochain context, with value-added features. For example, blocks are granules, but a block is connected to other blocks in a very restrictive way (through hash-validated pointer, as to be briefly explained below) rather than an un-specified way (as granules usually do). This is an example of mutual benefit of studying granular aspects of blockchain databases, because this not only helps better understanding on what blockchain database is, but also enriches the study of granular computing itself.

To make this point more explicit, below we present two examples.

(a) *Granule identification.* In "classical" granular computing, although formation of a granule (i.e., granulation process) may involve uncertainty, there is no uncertainty involved if we want to identify a granule after it is already formed. However, in the case of blockchains, each block is identified through a hash function, and if the hash function to the previous block is changed, all the following blocks in the blockchain will be affected. Note that identification of a granule is never a problem (i.e., always trivial) in the "classical" granular computing; but in the case of blockchains it is no longer trivial.

(b) *Membership through consensus.* Although a granule is an atom of uncertainty and granular computing applies fuzzy set theory or rough set theory as a means to handle uncertainty, blockchain technology introduces a new form of uncertainty never encountered before in granular computing: Inserting a new block (i.e., making a block as a new member) into a blockchain is not a simple task of adding a new granule; in fact, the acceptance of this block is never guaranteed. So in this sense, the membership becomes competitive, and the solution is offered through consensus algorithms. In our view, membership through consensus could be an interesting new topic for the study of uncertainty in the realm of granular computing.

5. Conclusion

In this paper we have examined blockchain technology from a database perspective, with an emphasis on granular aspects of ontology. As a new paradigm, blockchain technology not only present a whole range of new opportunities and challenges, but also opens the door of new ways of thinking. Examination from granular aspects contributes to the exploration on the ontology of blockchains. It is important to note that these granular aspects themselves do not bring blockchain technology to reality; rather, what we have emphasized is that in order to understand blockchain technology and to advance its techniques, we must respect these granular aspects. We have also seen the mutual benefit of studying granular aspects of blockchain databases, because this not only helps better understanding on what blockchain database is, but also enrich the study of granular computing itself. The observations and findings reported in this paper is still quite primitive, yet, we want to use this opportunity to call for attention of studying granular aspects of ontology for better understanding and mastering blockchain technology.

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