Research on the Blockchain-oriented Distributed Database

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Abstract. Blockchain has aroused wide attention from a wide variety of industries since its emergence for its decentralized characteristics. This technology has set off a "paradigm" model revolution where science, technology, and social governance overlap. Using blockchain technology, the degree of centralized control of information storage and sharing can be reduced, and distributed collaborative bookkeeping can be achieved among unfamiliar subjects, and the "Internet of Information" leaps to the "Internet of Value". Conventional centralized databases and distributed databases cannot ensure the security, high expansion, efficient sharing, and management of information data for their technical limitations. Accordingly, it is of vital importance to develop a novel database architecture that integrates the features of blockchain technology and the sharing and synchronization functions of distributed databases and applies to applications that conform to the requirements of high security and decentralization. Furthermore, the intrinsic mechanism should be clarified, and it is imperative to explore the way of avoiding the risks of its application, which takes on critical significance in determining the future refined development direction.

Keywords: blockchain, blockchain-oriented distributed database, intrinsic mechanism, risk prevention, future direction.

1. Introduction

Blockchain, as a special distributed computing system built on top of the Internet and directly oriented to the application of scenarios, is a revolutionary new technological structure that emerged after the development of information technology and digitization to a certain stage, with the characteristics of decentralization, removal of third-party trust and traceability. Its development has gone through "Blockchain 1.0" (virtual digital currency application represented by Bitcoin), and "Blockchain 2.0" (combination of digital currency and smart contract) to large-scale commercial applications beyond the scope of currency and finance. "Blockchain 3.0" stage. The traditional centralized database uses traditional computer technology to process information data, when the data is destroyed or tampered with, the system will automatically determine that the data is damaged and unprocessable, plus it is highly dependent on the network connection, data is stored in an integrated manner, there is only one central node, and if this node is attacked or fails, the whole information data system will be threatened or even collapse, which is difficult to meet the system's high scalability and high availability The traditional distributed database adopts the storage structure with data tables or data blocks that can be repeatedly modified as storage units, and records the historical state of data with additional mechanisms such as logs or snapshots, which can achieve high system expansion and high operational efficiency, but cannot guarantee the security of data.

To address the above dilemma, this paper intends to build a new database architecture based on the characteristics of blockchain technology and the sharing and synchronization functions of distributed database, which applies to applications requiring high security and decentralization - blockchain-oriented distributed database - from the design perspective, and reach the application risk prevention by analyzing its intrinsic mechanism. We also analyze its intrinsic mechanism to achieve the prevention of application risks and finally build its future refined development direction at the application scenario level to promote the remarkable role of blockchain-oriented distributed databases in the digital migration and digital transformation of information.

2. Overview of Blockchain

2.1 Definition of blockchain

Blockchain, as a distributed computing system built on top of the Internet and composed of a shared, misaligned distributed database and a multi-node network, is a new combination of technical structures that emerged after the development of information technology and digitalization to a certain stage. Blockchain uses P2P technology, consensus algorithm, elliptic encryption algorithm, public and private key system, digital signature and other cryptographic algorithms, as well as Merkle tree and other technologies to form a public chain, private chain, and alliance chain, which are three typical organizational forms in the Internet application. The unique features of a decentralized system, untamperable data forgery, equal status of nodes, traceable transactions, and third-party trust have brought about a change in the nature of Internet connection and realized the improvement of data, process, and system. It has been applied in the fields of the Internet of Things, Internet healthcare, cloud storage, security field, and Internet finance.

2.2 Features of blockchain

2.2.1 Decentralization and collective maintenance

Unlike the traditional Internet, the blockchain network system is "decentralized", and there is no institution for unified maintenance and centralized management of data. Blockchain uses Peer-to-Peer technology to guarantee the information interaction among network nodes in the system. At the same time, relying on the consensus mechanism of the blockchain itself, the nodes participating in the consensus on the "chain" jointly complete the task of guaranteeing the authenticity and stability of information, thus determining the consensus reached and maintained by all parties on the "chain", solving and guaranteeing the consistency and correctness of the deposited evidence in all nodes. In addition, the mechanism of data verification can enhance system security and reliability, and make the system network realize large-scale and efficient collaboration.

2.2.2 De-third-party trust and mutual supervision

In the blockchain network system, all nodes are equal in status. Blockchain uses distributed ledger mode to initiate data information at a single node through a consensus mechanism, and the subject on the "chain" can transmit and transfer information and data without knowing the identity of other participants, thus eliminating the basis of trust, i.e. "de-third-party trust". "This enables each node to record a complete account without any difference and equally, and to cross-supervise and audit the data[1] ,so that the data on the "chain" can be kept highly transparent and traceable, and ultimately avoid the problem of fraud to a greater extent, and bridge the trust gap, thus realizing In this way, we can achieve the leap from the Internet of information to the Internet of value under the "faith of unbelief".

2.2.3 Nearly tamper-proof, safe, and reliable

On the one hand, the activities of any node in the blockchain network system are supervised by the whole network, and the data and information storage of each node is distributed in the system servers of each subject on the "chain", and the blocks are interconnected with each other and the data chain generated is stored in a distributed manner and fixed with a time stamp. It is difficult for both individuals and organizations to control the operation of the whole network and change the data on the "chain"; on the other hand, the data obtained by the blockchain by consensus mechanism and the ability of the system to resist malicious attacks will be enhanced with the increase of the number of nodes on the "chain". In this case, the cost of tampering exceeds, or even far exceeds, its benefit, thus making tampering uneconomical and abandoned, and ultimately greatly increasing the difficulty of tampering and forgery, ensuring that the data is consistent, clear, and irreversible across the network. Both of these aspects ensure that the blockchain system is difficult to tamper with and secure and reliable.

2.3 The differences between blockchain and traditional distributed database

As of the birth of blockchain in 2008, database technology has been an important part of modern computer systems for decades. It was spawned from the need for data persistence and gradually evolved the function of data organization and management, playing an important cornerstone role in the computer field. The core requirements of blockchain and database are different, which brings about the difference in their architectural design brought by different design concepts: on the one hand, in terms of security, blockchain relies on a block-chain data storage structure with timestamped unmodifiable transactions as the storage unit, and each node keeps its copy of the stored data, and the consensus among distributed nodes and incentive mechanism realizes the near tamper-proof and unforgeable data storage (Figure 1). In contrast, traditional distributed databases tend to adopt a storage structure with data tables or data blocks that can be repeatedly modified as storage units, and the historical state of data needs to be recorded through additional mechanisms such as logs or snapshots[2] .On the other hand, in terms of efficiency, distributed databases unify the organization of data query and operation transactions through database management, making full use of the efficiency advantages brought by distributed architecture and ACID characteristics (atomicity, consistency, isolation, and durability), and distributed nodes are independent of each other to improve the distributed nodes are independent of each other, which improves the efficiency of database query and execution transactions through high concurrency, thus greatly improving the efficiency of the database. In contrast, in the blockchain network system, data operations need to be executed by consensus and organized in chronological order, which means that data operations need to be serially submitted on the blockchain and the nodes of the blockchain cannot be highly parallelized, which ultimately limits the efficiency of the blockchain network system operation.

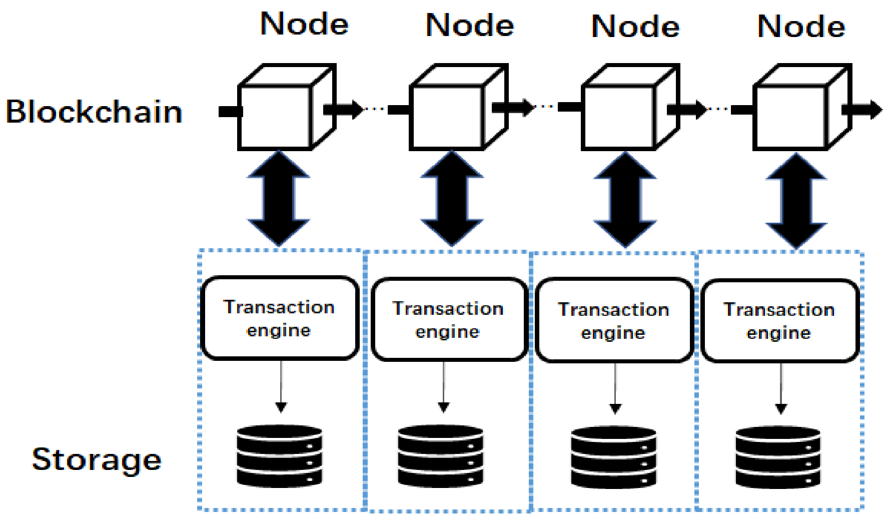

Figure 1 Blockchain Architecture

3. Overview of Blockchain-oriented Distributed Database

3.1 Definition of blockchain-oriented distributed database

A blockchain-oriented distributed database is a kind of distributed database built based on blockchain technology, which has the characteristics of being tamper-proof, decentralized, safe and reliable, transparency and privacy [3]. Unlike the traditional distributed database, the blockchain-oriented distributed database uses blockchain technology for data storage and transmission, and decentralizes the storage and verification of the database to multiple nodes in the network: each block contains a set of transaction records, which must be verified by nodes and consensus mechanism before being added to the block, and the block links the transaction data, and each node has the same authority and keeps the same The blocks are linked to the transaction data, each node has the same authority and keeps the same copy of the data, and the consensus algorithm is used to ensure the consistency and reliability of the data, and the database is jointly maintained and updated to form a tamper-evident distributed ledger system. This storage architecture enables distributed databases to achieve efficient data transfer through parallelism among nodes without the need for a centralized control point, thus improving the data transfer efficiency and processing speed [2]. Therefore, such databases are highly reliable and secure and are currently widely used in finance, logistics, and medical fields. The application of digital currencies such as Bitcoin is one of the most famous practices of blockchain-oriented distributed database technology [4], through which the security and reliability of monetary transactions are achieved.

3.2 Features of the blockchain-oriented distributed database

The blockchain-oriented distributed database relies on blockchain technology to build, so it has the unique advantages of blockchain technology in addition to the characteristics of the distributed database itself.

3.2.1 Decentralization

The decentralized characteristics of blockchain are inherited in the distributed database built based on blockchain. The traditional distributed database often adopts the centralized control node to manage the whole system, once this central node fails, the whole system will be paralyzed and the data will face the risk of loss. At the same time, the existence of the central node makes the performance of the whole system easy to become a bottleneck, especially in the case of high concurrency, the central node may become a bottleneck of performance, resulting in the performance of the whole system degradation. The blockchain-oriented distributed database adopts a decentralized architecture, so it is free from the centralized control point so that each data node has the same status and keeps the same copy of data, which can eliminate the failure at a faster speed when it encounters a single point of failure, thus guaranteeing the normal operation of the system and the security of data storage. In addition, it uses the distributed consensus algorithm of blockchain to ensure the consistency and reliability of data without the need for central nodes for control, which improves the performance and scalability of the system. Also, the nodes of this distributed database can interact directly with each other and have the ability to initiate data transfer directly without relying on intermediaries [5].

3.2.2 High transparency

The high transparency of the blockchain-oriented distributed database is reflected in two aspects: first, the blockchain-oriented distributed database is built based on blockchain technology, and the data of each node is open, transparent and traceable, and the node subjects can view and verify the stored and transported information, to guarantee the authenticity and integrity of the whole system operation, and thus has high transparency; second, the operation of each node subject in the blockchain-oriented distributed database is open and transparent, and the operation of each node subject in the blockchain-oriented distributed database is transparent. For example, when a node tries to modify some data in the database, the rest of the nodes can judge whether they need to stop the operation in time or according to the actual situation, so as to ensure the whole operation of the system is open and transparent, and thus guarantee the security, authenticity and integrity of information data.

3.2.3 High security and reliability

First, the blockchain-oriented distributed database uses a blockchain encryption algorithm to encrypt the information data in both data transmission and storage stages, which greatly improves the security of information data in its life cycle; second, the blockchain-oriented distributed database adopts multi-node distributed data storage and verifies the newly written data by consensus algorithm, which can be accessed only when most people agree. Third, the blockchain-oriented distributed database removes the trust mechanism of the traditional centralized database and stores data in multiple nodes, so that when a node is attacked, the remaining nodes can ensure the smooth operation of the system by eliminating the node, thus greatly improving the database's This will greatly improve the anti-interference property of the database and the possibility of malicious data writing, and finally guarantee the security and reliability of the database.

3.3 The difference between blockchain-oriented distributed database and blockchain-oriented database

There are many differences between blockchain-oriented distributed database and database-oriented blockchain due to different underlying technical architectures and design ideas: First, a blockchain-oriented distributed database is a distributed database built based on blockchain technology, which achieves efficient data transmission through parallelism between nodes and adopts consensus algorithm of blockchain to ensure data consistency and reliability, which makes the blockchain-oriented distributed database widely used in finance, medical, logistics and other fields; the database-oriented blockchain is based on database, which realizes data security by adding blockchain to the database and has an excellent performance in data insertion and update, etc. It is mainly applied in supply chain management, the Internet of things, games and other fields. Secondly, in terms of security and reliability, the blockchain-oriented distributed database adopts the security mechanism of blockchain and organically combines consensus mechanism, de-trust mechanism, anti-tampering mechanism, traceability, and co-regulatory mechanism, which usually has higher security and reliability compared with the database-oriented blockchain that relies more on traditional database security mechanism. Finally, it is worth noting that because the underlying architecture of the blockchain-oriented distributed database is in the blockchain, there may be certain performance bottlenecks in data insertion and update, etc., which may reduce the performance of the database compared with the database-oriented blockchain; while the database-oriented blockchain relies on the transaction processing mechanism of the database itself, compared with the blockchain-oriented distributed database, more attention is paid to Compared with the blockchain-oriented distributed database, it is more concerned about the efficiency and flexibility of the database and will have better performance in data insertion and update. From this point of view, when choosing the right blockchain technology to be applied to different scenarios, it is necessary to choose the right technical architecture and design ideas according to the actual situation to meet different needs.

4. Intrinsic mechanism and risk prevention of blockchain-oriented distributed database

4.1 The inherent mechanism of blockchain-oriented distributed database

The blockchain-oriented distributed database is based on the blockchain, and the functions of the database are added to the blockchain to realize [2]. As shown in Figure 2, the whole distributed database is divided into two parts, and the top-level database management system manages the whole database operation and performs related database operations; in each node of the distributed database, the blockchain-oriented distributed database abandons the original storage method and adopts the blockchain as the storage module instead, and a copy of the blockchain is kept in each node, so as to maintain the advantages of the blockchain in The advantages of blockchain in terms of data security are maintained while taking into account the efficient advantages of parallel operation of each node of the distributed database [2].

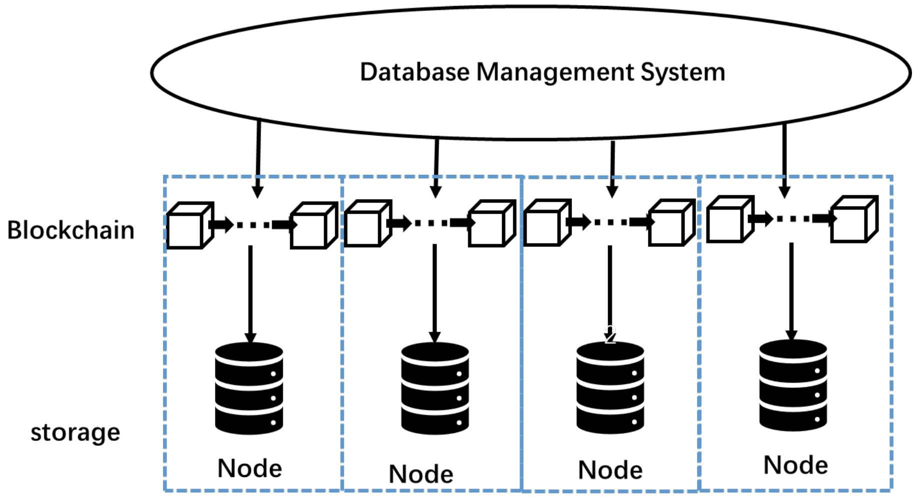

Figure 2 Blockchain-oriented Distributed Database Architecture

4.1.1 Consistency problem

The traditional distributed database uses a single central node for management and maintenance, each node is trusted to the database, and its consistency algorithm only needs to support Crash Fault-Tolerant (CFT) [6], so traditional distributed database generally uses Paxos [7-8] and Raft [9] algorithms to solve the distributed consistency problem. Blockchain has decentralized characteristics, the whole link is jointly managed and maintained by multiple parties, and any network node may be provided by any party, in this case, some nodes may not be trusted, thus, in the distributed database built by blockchain, the consistency algorithm needs to support Byzantine Fault- Tolerance (BFT) which is more complex than CFT. Tolerant (BFT), the current mainstream blockchain-based distributed database mostly adopts PBFT (Practical Byzantine Fault Tolerance) algorithm to deal with the Byzantine fault tolerance problem.

A blockchain-oriented distributed database also needs to consider the problem of Sybil attack (Sybil attack) [10] brought by the free access of nodes, which gives birth to the Proof of Work (PoW) mechanism, Proof of Stake (PoS) mechanism, Delegated Proof of Stake (DPOS) mechanism, etc. Stake (DPOS) mechanism, etc.

4.1.2 Security issues

While blockchain itself has the advantages of being tamper-proof, decentralization, and anonymity, it also inevitably has security risks such as double flower attacks, and the distributed database using blockchain will also face these security risks. Therefore, to improve the overall security of the database, various measures are usually taken to enhance risk resistance. Common security measures such as appropriate consensus mechanisms, digital signatures, cryptographic algorithms, smart contracts, privacy protection, and regulatory mechanisms are commonly used.

To prevent malicious nodes from tampering with the data, the blockchain-oriented distributed database generally adopts a suitable consensus mechanism to ensure that each node recognizes the modification. Since each transaction in blockchain uses digital signature technology to ensure the authenticity and integrity of the transaction, the blockchain-oriented distributed database also requires the modifier to provide the corresponding digital signature for each modification. In addition, such distributed databases use encryption algorithms to encrypt and protect data, which can not only prevent data leakage and data tampering by attackers already, but also effectively protect users' privacy with privacy protection technology. At the same time, blockchain's supervision mechanism also enables such databases to record detailed information about each operation step, and when security risks occur, database managers can quickly lock the source of risks through this operation information and deal with them in time.

4.2 Risk prevention for blockchain-oriented distributed databases

Blockchain, based on its technical limitations, is not a panacea and cannot solve all problems. For one, blockchain achieves consistent collaboration through the distribution of data by each node of the system to solve the problem of central node failure and information tampering, not to solve the problem of data and system security; second, blockchain technology has huge requirements for edge computing and storage, which also causes challenges such as high implementation cost and high energy consumption of blockchain-oriented distributed database built based on blockchain technology, while it cannot fully meet the real-time requirements of the network [11]. In response to the above dilemma, the following author mainly focuses on the two aspects of security and efficiency to propose measures for risk prevention applied to the blockchain-oriented distributed database.

4.2.1 Security

In blockchain networks, each node interacts anonymously on virtual interaction addresses through cryptographic methods such as symmetric keys and digital signatures to protect personal privacy. However, privacy is pseudo-anonymous, and attackers can analyze the overlay network of nodes based on the interaction records of nodes and link the addresses in the network with the actual addresses of nodes so that the privacy of nodes can be exposed. Based on this, the author believes that China should improve laws and regulations as soon as possible to regulate the risks that may be faced by blockchain system applications at the level of laws and regulations; at the same time, formulate corresponding technical standards, regulatory mechanisms, and build a technical system for blockchain systems and applications for pre-, in- and post-monitoring supervision and monitoring; group prevention and control, fully tap the potential power of decentralized operation and collective system maintenance mechanisms, and regularly Publish the list of platform technology applications to motivate all parties to jointly prevent the occurrence of risks.

4.2.2 High efficiency

Blockchain technology is not suitable for high concurrent task scenarios. Based on the security consensus mechanism of complex cryptography of blockchain and the network-wide data distribution of the system, the blockchain system is limited to bandwidth and storage, resulting in low transaction throughput and high confirmation delay, and applications with large data volumes are not suitable for direct processing with it. In response to the above dilemma, the author believes that we should adopt a hierarchical blockchain on top of the blockchain-oriented distributed data management architecture, so that different nodes can process transactions in parallel, and at the same time introduce the state evaluation mechanism of nodes to improve the internal throughput of the blockchain system and promote the solution of the consistency delay problem[12], thus improving the network efficiency of the system and solving the compatibility problem of a large number of chain node subjects running at the same time to realize the efficient operation of the system.

5. The future direction of building a blockchain-oriented distributed database

5.1 Data Service

The development of blockchain technology will play a tremendous role in data circulation and sharing. The blockchain-oriented distributed database is characterized by decentralization, and based on the unique tamper-evident and traceable mechanism of blockchain, it can greatly solve the defects of the traditional centralized data storage mode and meet the high requirements for data authenticity in large-scale data scenarios and is expected to become the preferred choice for data storage scenarios with high authenticity requirements. At the same time, the blockchain-oriented distributed database combines blockchain and distributed database, and the system is open to allow users to obtain data and carry out downstream processing at any time and any place under the premise of safeguarding data privacy, which has strong compatibility and is expected to solve the problem of "data silos" in the industrialization of big data. It is expected to solve the problem of "data silos" in the industrialization of big data and thus enhance the value of data circulation. With the continuous improvement and enhancement of blockchain technology performance, coupled with its closer connection with distributed databases, the blockchain-oriented distributed database will play a more significant role in the field of data services.

5.2 Internet of Things

Blockchain technology applied in the field of the Internet of Things will gramatically improve many of its existing problems. On the one hand, blockchain technology is decentralized, so large-scale IOT (Internet of Things) systems do not need to consider the expensive problem of deploying and maintaining central servers, which makes its operation and application economics greatly improved; on the other hand, privacy and anonymity are the core of future IOT development, however, the traditional data storage method does not give sufficient trust to these IOT vendors due to its closed source code. However, the traditional data storage method cannot give enough trust to these IOT manufacturers due to the closed source of code, but the blockchain technology itself is open source, with high openness and traceability, coupled with its anonymity and cross-platform advantages, it can compensate for the lack of trust caused by the closed source of traditional storage method, accelerate the data circulation, and help break the existing "information silo" in the IOT field in a large scale. "It will become the data storage solution for the next generation of the IOT. Additionally, relying on the traceability of blockchain technology combined with IoT technology can build an extensive and credible food traceability and anti-counterfeiting system, thus reducing the incidence of food safety accidents and thus improving food safety in China; at the same time, using blockchain technology to achieve transparent data transmission between doctors and patients, build a spatio-temporal multimedia that can support low latency, security, anonymity and always available in on-demand data sharing scenarios therapeutic data communication mechanism, design a multi-class collaborative activity monitoring and identification framework to provide therapeutic diagnosis [13], and use digital identity to achieve the corroboration and credible sharing, so as to eventually establish a extremely credible and complete continuous storage system for personal health data in the medical field, thereby advancing the construction of intelligent medical care and improving the level and efficiency of medical services in China.

5.3 Judicial Data Management and Electronic Evidence Storage

The natural virtual nature, vulnerability, tamperability and diversity of evidence inherent in electronic evidence lead to the difficulties of storage, forensics, and authentication in judicial applications. Blockchain, as a multi-node, distributed shared database, is decentralized, tamper-evident, and traceable, and provides effective technical support for the storage and sharing of electronic evidence by guaranteeing the openness and transparency of data through the sharing mechanism of its network system. The blockchain-oriented distributed database combines blockchain grassroots technology with a distributed database and is applied to judicial data management and electronic evidence storage scenarios to realize the separation of the two, which can not only solve the problem that the database is limited to on-chain storage of evidence and lacks attention to data privacy caused by the single technology of the current electronic evidence storage scheme, but also solve the problem caused by the single point of trust The dilemma of a huge amount of data on the chain, confusing and redundant data management, and inefficient evidence chain storage mechanism can be solved. At the same time, an effective solution should be proposed to make the judicial data and electronic evidence operations can be securely connected to achieve complete business logic[14].

6. Conclusion

In this paper, we propose to establish a new database architecture that combines the features of blockchain technology and the functions of distributed databases - blockchain-oriented distributed databases. We also outline and distinguish blockchain, traditional centralized database and distributed database for blockchain, and blockchain for database respectively, to highlight the unique performance of distributed database for blockchain. We also discuss the security and efficiency risks of blockchain-oriented distributed data and countermeasures to realize the excellent development of blockchain-oriented distributed data and balance the conflicts caused by the performance and risks of blockchain and distributed databases. Additionally, Additionally, we also put forward a preliminary framework concept for the future application scenarios of blockchain-oriented distributed data, intending to promote the magnificent role of blockchain-oriented distributed databases in the digital migration and digital transformation of information. There are still many issues concerning blockchain-oriented distributed databases that need to be studied in detail and in-depth, and we sincerely invite our readers to criticize and correct them.

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