State of Public and Private Blockchains: Myths and Reality

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ABSTRACT

It has been a decade since the concept of blockchain was invented as the underlying core data structure of the permissionless or public Bitcoin cryptocurrency network. Since then, several cryptocurrencies, tokens and ICOs have emerged. After much speculation and hype, significant number of them have become problematic or worthless! The public blockchain system Ethereum emerged by generalizing the use of blockchains to manage any kind of asset, be it physical or purely digital, with the introduction of Smart Contracts. Over the years, numerous myths have developed with respect to the purported utility and the need for public blockchains. The adoption and further adaptation of blockchains and smart contracts for use in the permissioned or private environments is what I consider to be useful and of practical consequence. Hence, the technical aspects of only private blockchain systems will be the focus of my SIGMOD 2019 keynote. Along the way, I will bust many myths associated with public blockchains. I will also compare traditional database technologies with blockchain systems' features and identify desirable future research topics.

CCS Concepts/ACM Classifiers

Trusted computing; data provenance; DBMS engine architectures; distributed database transactions; middleware business process managers; open source software; digital cash; secure online transactions; enterprise applications; pseudonymity, anonymity and untraceability; tamper-proof and tamper-resistant designs; peer-to-peer architectures; distributed systems organizing principles; privacy policies

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INTRODUCTION

Public/Permissionless Systems

More than a decade ago, the concept of blockchain (also called distributed ledger [36, 62]) was invented as the underlying technology of the *public or permissionless* Bitcoin cryptocurrency network [55]. Bitcoin's architecture combined in a novel way many ideas that had existed for decades [56]. By introducing the concept of Smart Contracts [32], the public blockchain system Ethereum emerged [16, 23], generalizing the use of blockchains to manage any kind of asset, be it physical or purely digital. Ethereum also introduced its own cryptocurrency called Ether and another entity called Gas for charging for resources consumed while executing blockchain transactions.

Anonymity or pseudonymity of the participants in a public blockchain system is an important attribute of such systems. All the information related to the transactions executed in such systems, as recorded in the blockchain data structure, are public to any interested party anywhere. Anyone in any part of the world is free to take part in such a system with no restrictions being placed on when users join or leave the system. These characteristics of public blockchain systems have led to scaling problems and incredibly bad performance compared to traditional transaction processing systems. They also make it very hard to control information sharing/visibility and obey privacy regulations like GDPR. Anonymity has also been exploited by many people to indulge in various types of illegal activities. Consensus protocols like Proof of Work (PoW) that were invented to deal with the fact that anonymous people with unknown backgrounds might exhibit *Byzantine behavior* cause incredible wastage of energy by demanding the solving of some mathematical problems ("mining").

PoW and variants of it [17] are also used to determine which participant in the network gets to add a new block of transactions to the existing blockchain. These algorithms don't guarantee that the blockchain will remain a linear chain always. They could cause branching of the chain to occur since more than one participant might be permitted to add conflicting blocks to the existing chain. Such branching leads to numerous correctness, usability and performance problems [58, 59].

Numerous issues associated with public blockchains have given rise to a cottage industry of esoteric research, business and regulatory explorations with associated algorithms, papers and startups [28, 63, 77].

The proliferation of numerous cryptocurrencies beyond Bitcoin and Ether, and the associated concept of Initial Coin Offerings (ICOs) has resulted in many scams and vast amounts of money being lost in speculative buying and selling of such assets. After much speculation and hype, significant number of them have become problematic or worthless! Fundamentally, new forms of money (cryptocurrencies) are being created with no underlying goods/services or intrinsic value, in contrast to in the case of fiat currencies like dollars, euros and rupees.

Private/Permissioned Systems

In contrast to a public blockchain system, when using a *private or permissioned* blockchain system, in a specific blockchain network only those people who are explicitly authorized by the current participants or administrators of that network are allowed to be a part of it. The real-world identities of the users of such systems are known and so the likelihood of Byzantine behavior being exhibited by them is significantly reduced. Hence, expensive consensus protocols like PoW aren't really needed. Security is much better and information sharing can be controlled very well. Performance and scalability are also far better. The protocols that are used in such private blockchain systems also ensure that there won't be any branching in the blockchain. The latter property gets rid of numerous correctness, usability and performance problems associated with public blockchains [58, 59].

Many big companies like IBM, Intel, Oracle, AWS, SAP, Alibaba, Tencent, Huawei and Baidu, a few smaller companies like MultiChain, and many key players in different vertical industry segments have recognized the applicability of blockchains in environments other than cryptocurrencies. IBM did some pioneering work by architecting and implementing the private blockchain system Fabric, and then open sourcing it. Since then Fabric has been enhanced as a project in the Hyperledger Consortium which IBM created under the auspices of the Linux Foundation [6, 7, 19, 40].

Currently, there is significant momentum behind Hyperledger Fabric throughout the world in terms of the number of vendors supporting it and the numerous solutions being built using it. Many vendors have released Blockchain-as-a-Service (BaaS) offerings based on Fabric – e.g., IBM Blockchain Platform (IBP) [43], Oracle Blockchain Platform [60], Amazon Managed Blockchain [3, 5], Microsoft Azure Blockchain Workbench [52], Alibaba Cloud BaaS [1, 2], Baidu Blockchain Engine (BBE) [8], JD Blockchain Open Platform [49], Huawei Blockchain Cloud Service (BCS) [37], Tencent TBaaS [70] and SAP Cloud Platform Blockchain [66].

Other significant private blockchain systems include Quorum [50, 51], Hyperledger Sawtooth [67], R3 Corda [14, 30, 35], Ripple [64, 68] and MultiChain [27, 33]. The Financial Blockchain Shenzhen Consortium (FISCO) of China has developed an open source system called FISCO BCOS [25]. Major Chinese companies like Huawei and Tencent are part of this effort. Some other recently announced systems are Baidu's XuperChain Super Chain [9, 18] and Ant Blockchain [2].

Some production deployments of the private blockchain systems Fabric and Sawtooth are described in [38]. Even though Intel initiated the Hyperledger Sawtooth project which competes with Hyperledger Fabric, recently it announced a verified, tested solution called Intel Select Solution for Blockchain: Hyperledger Fabric [47].

Hyperledger Fabric has had the benefit of numerous researchers across the world working on different aspects of that system as can be seen by the number of research-style papers/investigations that have been focused on it [6, 7, 13, 20, 21, 26, 34, 53, 54, 57, 72, 73, 76]. Other private blockchain systems haven't had the benefit of the same degree of such research-style attention being paid to their architectures, designs and performance characteristics. Future work along those lines is worthy of being pursued.

Oracle in its BaaS offering has incorporated a significant enhancement to the set of DBMSs supported by Hyperledger Fabric [60]. Oracle Blockchain Platform allows the use of SQL, instead of just NoSQL APIs like Get, Put and Delete, in smart contracts by supporting Oracle Berkeley DB as the state database. It creates relational tables in Berkeley DB based on the SQLite extension. These database enhancements to the Fabric haven't been open sourced by Oracle. The open source version of Fabric only supports LevelDB and CouchDB as the state database.

In my SIGMOD 2019 keynote, I will describe some private blockchain use-case scenarios, especially those in production deployment. I will also survey the landscape of private blockchain systems with respect to their architectures in general and their approaches to some specific technical areas. I will also discuss some of the innovation opportunities that exist and the challenges that need to be addressed. My extensive blockchain related collateral (references to papers, PPTs, videos of keynotes, panels, interviews, ...) can be found at http://bit.ly/CMbcDB

BLOCKCHAIN MYTHS

Over the years several myths have emerged with respect to private and public blockchains. Some of them are listed below. During my SIGMOD 2019 keynote, such myths will be busted. Due to lack of space they aren't being expanded on here. Interested readers can also find videos of my earlier talks and panels in which I have dealt with them [53].

- **Fiat** currencies are bad, and cryptocurrencies are good.
- Adoption of cryptocurrencies in place of fiat currencies would eliminate hyperinflation plaguing countries like Venezuela.
- **Bitcoin** will become the universal currency replacing all fiat currencies!
- Public blockchains provide trust in a **completely trustless** environment.
- Governments are bad and (pseudo) **anonymity** is good!
- Public blockchains are **completely decentralized.**
- Private blockchains are centralized or **centrally controlled.**
- Any participant (located anywhere in the world) in a public blockchain can **validate** any blockchain transaction.
- Public blockchains are **more secure** than private blockchains.
- **Off-chain** sensitive data storage in a traditional database system is better than **on-chain** storage of such data in the blockchain system itself.
- Technologists **creating "money"** with algorithms and energy wastage is better than well thought out and controlled printing of fiat currencies in a governmental system with checks and balances (e.g., economists taking into account money supply, inflation, real-world GDP based on goods/services).
- Worrying only about money transfers in Bitcoin networks is sufficient (i.e., without including in the blockchain system's purview the full cycle of receiving goods/services for which payments are being made).
- Initial Coin Offerings (**ICOs**) are better than **IPOs** since they enable crowdsourcing of capital.

Some technical and legal papers which relate to the above points are [28, 58, 59, 74, 75].

STANDARDS

Four decades ago when RDBMSs first emerged, while there was no database query language standard, at least the conceptual models of those systems were the same – namely, the relational model of data as defined by E.F. Codd. The IBM San Jose Research project System R developed the SQL language while the University of California at Berkeley Ingres project developed the QUEL language. In due course of time, IBM's SQL first became a de facto standard and then a formal standard of ANSI and ISO. Unfortunately, in the blockchain space, currently not only are the APIs of the different blockchain systems different but also are the underlying conceptual models! Only in the recent past, organizations like IEEE, ISO and W3C have begun to develop blockchain standards [46, 48]. These are very preliminary efforts focusing on narrow aspects of such systems. Some of the activities are focused on specific application areas like agriculture, clinical trials, connected and autonomous vehicles and IoT.

Since most of the private blockchain systems are being produced by consortiums consisting of different kinds of organizations, the number of such systems is very small. This situation is a good thing, especially in the absence of standards. This is in contrast to the situation with respect to NoSQL and big data systems where way too many such systems have proliferated since those systems have been mostly developed by small groups of individuals or organizations rather than by big consortiums!

Contrary to what one might imagine, the existence of a consortium doesn't mean that its goal is to let a single system be developed jointly by the members of the consortium. A case in point is Hyperledger which has multiple projects that are developing competing blockchain systems with different APIs and conceptual models (e.g., Hyperledger Fabric versus Hyperledger Sawtooth). Enterprise Ethereum Alliance (EEA), which came into existence after Hyperledger and which initially seemed to be following the operational model of the latter by supporting multiple projects, has more recently recast itself to be more of a standards development body for enterprise grade Ethereum [22]. In that mode of operation, EEA has released a couple of specifications relating to the client of a blockchain system and for off-chain trusted computation [10, 15].

In the absence of standards, SAP has chosen to develop a layer called Blockchain Application Enablement Service which insulates applications from the specifics of a few private blockchain systems like Fabric and MultiChain by providing a set of APIs which will get mapped to the specific blockchain system that the customer chooses to deploy [65]. The application, by using such a service, can remain unchanged even if the underlying blockchain system is changed from one to another one supported by SAP.

USE CASES AND PRODUCTION DEPLOYMENTS

Some of the application areas in which blockchain pilots are being carried out are: distributed energy, supply chain management, health data exchange, logistics, e-governance, unlisted securities, trade finance, bank guarantees, identity, insurance, food safety, Know Your Customer (KYC), derivatives processing and provenance management [61, 69]. Many production deployments have occurred [38]. Those include Northern Trust (private equity fund management), IBM Global Finance, Everledger (diamond provenance), IBM Food Trust (food safety) [39, 42], Chain-m (airline ticket processes), Cambio Coffee (coffee supply chain), JD.com (enterprise operations management), TradeLens (global supply chain) [44, 45]. Several production applications built using the system FISCO BCOS are described in [24]. MultiChain production deployments are presented in [29].

BENCHMARKS

One of the first efforts in the blockchain benchmarking space was the BLOCKBENCH project [20] at National University of Singapore (NUS). That project proposed workloads similar in flavor to those of the Transaction Processing Council (TPC) OLAP and OLTP benchmarks. Evaluations of an early version of Fabric and a couple of public blockchain systems were done using those workloads. Since then the Caliper project has been initiated in the Hyperledger consortium to develop blockchain benchmarks and associated tools [41]. An evaluation of Hyperledger Fabric based on a modified version of Hyperledger Caliper has been presented in [57].

DBMS RECOVERY LOGS AND BLOCKCHAINS

There are many similarities between a traditional DBMS recovery log and the blockchain data structure of a blockchain system. Both are append-only data structures, and both describe database/state updates performed by database/blockchain transactions. A significant difference is the fact that a database recovery log wasn't traditionally made tamper proof unlike the blockchain. Also, in the recovery log, the log records written by different transactions are interspersed whereas in the blockchain information about a given transaction is fully described before information related to another transaction is recorded. Additionally, in the case of Fabric, the blockchain includes information about data read as well as data modified by blockchain transactions (i.e., smart contracts) whereas a DBMS log describes typically only data modified by transactions.

There are several misconceptions about sensitive data being stored in the blockchain versus in a traditional ("off-chain") DBMS [31]. People generally claim that such data shouldn't be placed in the blockchain since it can never be removed from there. It is claimed that such data should be stored in an off-chain DBMS so that when it is deleted from the latter then it would disappear for good. People forget that the latter isn't true since the recovery log in the DBMS will continue to have that data even after it is deleted from the DBMS. This is no different from what will happen in the blockchain scenario also when such data is deleted from the state database of the blockchain system. Unless portions of the recovery log which describe the creation, modification and ultimate deletion of such an object is completely erased the situation is the same in both types of systems. For a variety of reasons, in the future there will be enhancements to the handling of the blockchain data structure which will introduce the ability to truncate or erase portions of the blockchain also, in spite of the often-emphasized immutability property of blockchains.

BLOCKCHAIN DATA ANALYTICS

Users of blockchain systems would like to be able to do analytics not only on the current states of the assets under management but also on the past states of such assets. Since, in a system like Hyperledger Fabric, the state database is a NoSQL system and it contains only the latest states of the assets, this makes it hard to do analytics, especially on the past states since the blockchain data structure is not ideally designed for such processing. So, users are forced to load the blockchain data into more traditional DBMSs to perform analytics. This is reminiscent of the traditional data warehousing approach. These days, the preferred approach, called Hybrid Transactional and Analytics Processing (HTAP), in the database world is to do in-place analytics in the OLTP database itself so that the analytics queries see the latest state of the data rather than the non-up-to-date data in the warehouse database.

A far better approach in the blockchain systems context would be to use an RDBMS as the state database and also to possibly store the historical states not only in the blockchain but also in the state database. The latter would permit *time walk* style queries, as is possible with temporal extensions to SQL [78].

DBMS VERSUS BLOCKCHAIN REPLICATION

Replication of DBMS data in a distributed context is a well-studied problem with numerous implementations in commercial RDBMSs like DB2, Oracle and SQL Server. There are significant differences between those systems' approaches and the approaches adopted by blockchain systems to create and maintain the replicated data. Typically, in the former, the updates of a transaction would first be performed and committed in one of the nodes of the distributed system (e.g., the primary copy) and then those updates would be replicated to the other copies using log records generated in the first node (e.g., by reapplying those log records or by generating SQL statements from those log records to regenerate those updates).

In a typical blockchain system like Fabric, the updates to be applied are determined simultaneously in multiple nodes (i.e., during *simulations* of a blockchain transaction's execution performed in parallel in multiple *endorsing* nodes). Once the required level of agreement is noticed to exist via such simulated executions, then the attempt is made to see if the updates of that blockchain transaction could be installed in parallel in all the relevant nodes, provided the underlying database state is still the same compared to the time of simulation (as in the *validation* phase of the *optimistic concurrency control* scheme in traditional database systems). This stylized transaction execution model of the blockchain system causes more resource consumption, delays and the failure of conflicting transactions that happened to be simulated in parallel. But this execution model brings with it a more collaborative approach to deciding which transactions can proceed forward. So, there is a cost benefit tradeoff to doing transaction executions in the blockchain way compared to the traditional transaction processing systems' way of executing transactions in a distributed, replicated context.

In some blockchain systems, identical results for the same blockchain transaction's executions in different nodes are guaranteed by disallowing non-deterministic constructs to be used in smart contracts (e.g., access to current time, random number generation) [6]. Traditional database replication methods can handle correctly such non-determinism (e.g., invoking random number functions, access to clocks) and so they are permitted in database transactions.

DBMS WITH BUILT-IN BLOCKCHAIN FEATURES

Traditional DBMSs could obviously be enhanced to have blockchain-like features. In this vein, Amazon has recently announced a system called Quantum Ledger Database (QLDB) [4]. QLDB is a managed ledger database which supports a SQL-like API, a document model and ACID transactions. It makes data's complete change history immutable and verifiable by leveraging cryptography and by writing data to an append-only journal. It should be noted that QLDB is not a distributed ledger but a centralized one. In other words, it does not support the concept of independent nodes that belong to different organizations that are creatable in a typical blockchain system like Fabric.

In contrast to QLDB, BigchainDB also starts out with a database system (MongoDB) and adds blockchain like features but it also supports a distributed environment [11, 12]. In doing this, it leverages Tendermint [71].

CONCLUSIONS

While great progress has been made in a short amount of time in building production-grade private blockchain systems with numerous features, much more work remains to be done to make these systems easy to use with appropriate tooling, standards and benchmarks to evaluate their performance. Mainstream database and distributed systems researchers and technologists need to get engaged in this space to ensure that their vast experiences are effectively leveraged to make these systems be even better along different dimensions.

With respect to various architectural features of the blockchain systems, the designers of these systems have made different choices. The rationale behind those choices are rarely well articulated and fully justified. Systematic comparisons of the different systems and their specific design choices remain to be performed. Many aspects of these systems could benefit from thorough and systematic investigations by researchers and deep technologists. Entrepreneurs could also find topics to work on to produce useful tools and methodologies to augment the existing blockchain systems. A useful analogy to keep in mind is that the state of blockchain systems today is like that of RDBMSs about 35 years ago when a few RDBMS products like DB2 and Oracle had just been released. Since that time, relational technology, products and users have benefitted tremendously from the work of researchers, and product-focused systems builders and entrepreneurs. Such a productive future awaits private blockchain systems and their users.

BIOGRAPHY

Dr. C. Mohan is currently an IBM Fellow at the IBM Almaden Research Center in Silicon Valley and a Distinguished Visiting Professor at Tsinghua University in China. He has been an IBM researcher for 37 years in the database and related areas, impacting numerous IBM and non-IBM products, the research and academic communities, and standards, especially with his invention of the well-known ARIES family of database locking and recovery algorithms, and the Presumed Abort distributed commit protocol. This IBM (1997), ACM (2002) and IEEE (2002) Fellow has also served as the IBM India Chief Scientist (2006-2009). In addition to receiving the ACM SIGMOD Innovations Award (1996), the VLDB 10 Year Best Paper Award (1999) and numerous IBM awards, Mohan was elected to the US and Indian National Academies of Engineering (2009) and named an IBM Master Inventor (1997). This Distinguished Alumnus of IIT

Madras (1977) received his PhD at the University of Texas at Austin (1981). He is an inventor of 50 patents. He is currently focused on Blockchain, Big Data and HTAP technologies (http://bit.ly/CMbcDB http://bit.ly/CMgMDS). For 2 years, he has been an evangelist for private blockchains and the myth buster of public blockchains. Since 2016, Mohan has been a Distinguished Visiting Professor of China's prestigious Tsinghua University. He has served on IEEE Spectrum's advisory board, and on many conference and journal boards. Mohan is a frequent speaker in USA, Europe and Asia, and has given talks in 40 countries. He is very active on social media and has a huge network of followers. More information can be found in the Wikipedia page at http://bit.ly/CMwIkP

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