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Blockchain Data Analytics: A Review

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Abstract:

Blockchain technology has emerged as a transformative force with widespread applications across various industries. In particular, the analysis of blockchain data has become crucial for crypto businesses and financial institutions seeking to protect transactions from illicit activities, minimize the risk of financial crimes, and ensure compliance with regulations. This paper presents a comprehensive review of blockchain data analytics, focusing on its significance in these domains. The paper examines the advancements and possibilities in blockchain data analytics, shedding light on their transformative potential. It provides an overview of the techniques and tools used for analyzing blockchain data, including transaction tracing, pattern recognition, and anomaly detection. Moreover, it explores the challenges and opportunities associated with blockchain data analytics, such as scalability, privacy concerns, and regulatory frameworks.

1. Introduction

The past decade has witnessed significant advancements in Blockchain technology, shaping its development and impact. The shared ledger Blockchain has been distributed which records transactions flanked by two parties without a stable central authority. Two individuals may perform an irreversible transaction on the Blockchain that is permanently registered on the public ledger [1]. The first use of the Blockchain was Bitcoin's cryptocurrency. The success of Bitcoin has given way to an age called Blockchain 1.0. Above 1000 chain-based cryptocurrencies known as “’alt-coins” are currently in place. These developments have created public interest in technology for the Blockchain[2]. Several new applications have emerged based on the Blockchain which includes identity systems (e.g. Hyper and Bitnation), copyright (e.g. Blockphase and LBRY) voting (e.g. Social Krona, FollowMyVote), and origin (such as chronicled and EverLedger).

Private blockchains have been built and only provide participants with the required permissions to read and write. In contrast, anonymous Blockchains, for instance, Bitcoin enables unrestricted network access to any block node without requiring permission. In all Block network nodes, all transactions can be detected. In this article, we concentrate on public Blockchains, where information is open to the public. While most Blockchain solutions adhere to a chain structure, it is worth noting that alternative data structures can also be employed. Analyzing this knowledge can yield fresh insights into emerging patterns, giving rise to numerous questions such as:

1) How will the data stored on Blockchains be interpreted and modeled?
2) What insights can be gleaned from shared Blockchain's transactions?
3) What are the cutting-edge computational, analytical tools, and techniques currently used for analyzing Blockchain data?

By providing a brief introduction to Blockchain analytics, we answer the above raised questions. First, we give a short history of shared blockchains. Following the examination of typical "data structure models" in Blockchain, this paper provides insights into essential analytical methods and tools utilized in the field. Finally, new research has been addressed using Blockchain cryptocurrency modelling, e-criminal identification, trade of human beings and illegal economic activity analytics.

2. Literature Review

Some of the developments we took for granted in their day were also revolutions. Remember about how much the way we live and operate on smartphones has changed. When people were out of the workplace, they went elsewhere, and they were connected to a location by telephone, not to an individual. Today, global nomads are beginning to create new companies directly on their phones. Smartphones were there just a decade ago. We are in the middle of yet another silent revolution: blockchain, a digital ledger with an ever-growing collection of documents or records called "blocks. Bitcoin, as the pioneering global blockchain innovation, initiated the digital currency experiment. Presently, the market capitalization of Bitcoin fluctuates between $10 and $20 billion, and it serves as a medium of exchange for millions of individuals, even within the vast and growing cash market.

The second invention was known as the blockchain, and was mostly the discovery that Bitcoin's code could be isolated from the money and used for all sorts of interorganisation. Current blockchain research is under way in almost every big financial institution in the world and 15 per cent of banks could use blockchain in 2017.

The third invention is known as the 'intelligent contract,' embodied in a blockchain system of the second generation called 'Ethera,' which explicitly includes small computational programs in blockchain that allow for the presentation of financial instruments such as loans and bonds instead of only cash tokens of bitcoin. The intelligent contract network currently has a market value of about $1 billion, with over hundred proposals on the market.

The fourth big breakthrough is the "proof of stake," which is now the bleeding edge of blockchain thinking. Current blockchains of the age are guaranteed with "job evidence," of which the party with the highest overall computational capacity decides. These groups are known as miners and run huge data centers in return for cryptocurrency payments to provide this protection. This data centers are replaced by modern structures, with a comparable or even higher level of safety, with sophisticated financial instruments. Proof-of-stake applications will live later this year.

Blockchain scaling is the fifth key breakthrough on the horizon. Right now, every device processing each transaction on the network in the blockchain world. It's sluggish. A scaled blockchain accelerates this mechanism by determining the number of computers needed to verify each transaction and division of work effectively without losing protection. It is a tough but not unpleasant challenge to handle this without losing the iconic safety and strength of blockchain. It is anticipated that a scaled blockchain would be fast enough to speed up the Internet of Things and lead the world's big payment mixers (VISA and SWIFT) [3].

It is only ten years after an elite group of informatics, encrypters and mathematicians worked for this landscape of creativity. When this breakthrough's full potential affects civilization, things will surely be a little strange. Blockchain technology enables payments for utilities like charging stations and landing pads to be more efficient and reliable. Transactions in international currencies, which can currently take anywhere from days to mere minutes, could be streamlined and made more dependable with this emerging system. All these changes and the other reforms are a major reduction in transaction costs. If the costs of transactions fall below invisible limits, aggregations and dislocations of current business models can be abrupt, drastic, and difficult to foresee. For instance, auctions were formerly small and local instead of universal and national, as they are now available on platforms such as eBay. The scheme suddenly changed as the costs of contacting people fell. As many of them as e-commerce has since been invented in the late 1990s, Blockchain is fairly supposed to trigger.

2.1. Blockchain

Blockchain looks complex and may certainly be complicated, but it has a very basic central definition. A ledger sort is a blockchain. It helps to get a first understanding of blockchain, what a ledger is really. A database is a knowledge set that is maintained on a file server electronically. Data, or data, is usually organized in table format in data base so that relevant information can be searched and filtered more easily. How does anyone use a Table to store information rather than a database? Spreadsheets intended for storage and retrieval information in limited quantities for an individual or a specific number of persons. In the other hand, a database contains much greater quantities of information that can be downloaded, filtered and exploited by a multitude of people efficiently and effectively. This is achieved by housing data on servers consisting of powerful machines in large databases. This servers can be installed with hundreds or thousands of processors, to allow multiple users to concurrently access the database through computing power and storage. Whilst any number of persons may have access to a spreadsheet or database, it is always maintained and run by a designated person, who is fully responsible for how it functions and the data in it.

2.2. Blockchain Storage Structure

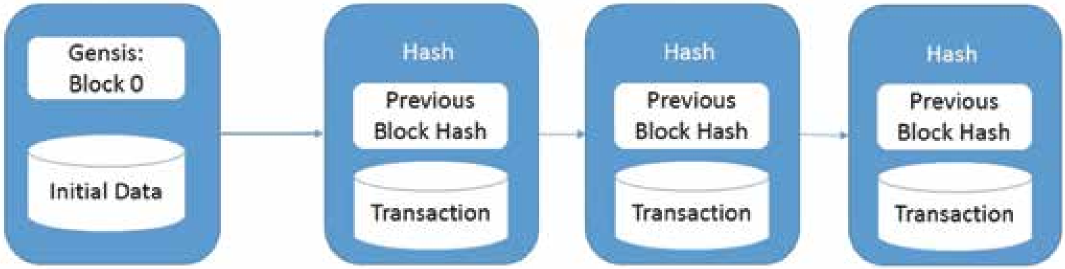
The data structure is a vital difference between a conventional and a blockchain databases. A blockchain collects information in groups containing information known as blocks. Blocks have these capabilities and the "block-chain" data chain is linked to the previously filled block until they are loaded. The new information after the recently inserted block is compiled and attached to the chain until it is done. A database organises its data into tables, whereas a blockchain organises its data into chunks, as its name implies, are chained together. It makes a blockchain database, but it's not all blockchain databases. This method also creates an inherently immutable decentralised data timeframe. When a block is filled, it becomes part of this schedule and is placed in stone. When attached to the chain, an exact time stamp is given to any block in the chain.

2.3. Blockchain Transaction Process

Blockchain is related list of the irreversible tamper-resistant blocks that has been stored at every node. A collection of transactions and related meta-data is recorded for each block. On the same ledger data deposited on each node, the transactions act Blockchain. First viewed as a peer-to-peer sharing mechanism by Satoshi Nakamoto[4]. Nakamoto referred to the transaction tokens traded as Bitcoins between customers in his scheme.

An immutable tamperproof block is the main element in every blockchain framework. A block in blockchain is encrypted data related to number of transactions in its simplest form. The fact that the block exists is a guarantor of the execution and verification of transactions. A current Blockchain is attached to a newly formed block. This Blockchain is mostly a related list that links one block to the other. The genesis block is the original block of such list. “Genesis Block” is a particular block which is numbered or labelled as zero. It is hard coded while programming the blockchain. Every other block has connections to an existing block. Thus, by adding new blocks to the current chains, a blockchain can expand[5].

Any OLTP transaction which operates on certain data shall be equivalent to a transaction in a blockchain environment. Traditional blockchain implementations (like Bitcoin) provide transactions representing money sharing between two individuals (or users). Any valid transaction is registered for efficiency in a block that may consist of several transactions. Immutability is accomplished by the use of solid cryptographic characteristics including hazing. A blockchain is in fact a connected sequence, as each block stores in its chain the hatch of the previous block. The hash of its contents within the block is also digitally signed by each block. These hazards have cryptographical integrity, since any opponent who wishes to amend a block often has to change all previous blocks in a series, making the attack cryptographically impossible. One main design approach is to build a Merkle tree to store and verify hazelnuts efficiently. Thus the Merkle tree root is stored by each block, as the root makes the immutability simple to check. Figure 1 shows basic blockchain transaction processing is shown in block diagram.



Blockchain transactions are similar to conventional equivalents in the database. The clients transmit those transactions to the blockchain system servers[6]. This transfers are based on the data saved on all the servers involved. The blockchain transaction in its vanilla form can be used on the replicated distributed database as a series of read or write operations carried out on any of the node in blockchain. Any blockchain implementation uses a consensus protocol to specify the ordering for all incoming transactions.

2.4. Data Models of Blockchain

Public blockchains can be categorized primarily into two types: those utilizing the "Unspent Transaction Output" model, also known as UTXO, and those that operate based on accounts (such as Bitcoin, Litecoin, Ethereum etc.). A block of the data contain limited number of the transactions in all types of blockchains, but transactions vary. Below, these two types of blockchain transaction data are briefly discussed.

2.5. Blockchain Data Based on Upsent Transaction Output

The unused blockchains (UTXO) are first and the most important blockchains in terms of market capitalization: Bitcoin itself ranges from 45 - 60% of the entire market capitalisation of cryptocurrency. Each block of data includes a (financial) transaction, which covers the transference of coins between several parties in UTXO blockchains. In each transaction, certain inputs are consumed and new outputs are produced (i.e. coins are directed to). There are three rules that emphasizes the shape of the data on the UTXO blockchain. This is because of Satoshi Nakamoto's design choices in Bitcoin[4].

2.5.1. Balance Rule

In the same transaction, all coins obtained from a single transaction shall be used. The transaction fee is any amount not sent to an output address and is collected by the miner who creates the block.The coin user will keep up the change by generating a new address (i.e. changing address) and submitting to this new address the balance remaining. Another alternative is to redirect the balance by the address of the user as one of the output addresses. This reprocess of donor address is discouraged. As a consequence, most of the nodes appear only twice, once when coins are received and again when they are spent. If a change address is generated, resulting in becoming new address of owner of the coin. Because of these principles, blockchains based on unspent transaction results should be considered as branching trees instead of networks. Non-transactional data are also stored in blockchains in UTXO. Nakamoto[4] Left the text message "The Times 3 January 2009 Chancellor on the verge of a second bailout for banks" was included in the first Bitcoin block. Metadata is disputed in Bitcoin transactions, and since 2014, every Bitcoin transaction has included an 80-byte (OP RETURN) field designed to store log information.

The blockchain was created in 2011 to store key-value pairs for a distributed namespace,enhancing the functionality of metadata. Namecoin data blocks are used to store ICANN-controlled registrations and updates for.bit domain names.[7].

2.5.2. Source Rule

Multiple transactions' input coins can be combined and consumed in single transaction, or they can be spent individually.

1.4.3. Mapping Rule

Payment of each coin must demonstrate proof of the funds through referring to a previous collection of outputs. While this helps us to track the past of payments, it is not always possible to pinpoint the origins of a particular coin. This is due to the fact that each transaction has its own set of inputs and outputs.

1.4.4. Blockchian Data-Based on Account

In the account-based blockchains, some of the coins are spent while retaining the rest. Ant transaction in blockchain has unerringly 1 input and 1 address While it is simple to create an address, most people use the same address for receiving and sending coins many times. Ethereum[8], is actually the most valuable account-based blockchain established in 2015. Including Bitcoin, Ethereum has its own currency: Ether. The Ethereum project's main goal is to store data and software code on a Blockchain. The code (a smart contract) is written in the Ethereum Virtual Machine's proprietary Solidity coding language, which is compiled and executed as bytecode. In both code and agreements, smart contracts are self-executing contracts. MYSQL snippets in a database are an example. Intelligent contracts, on the other hand, ensure the non-stop, deterministic execution of code that can be publicly regulated.

Externally controlled addresses (governed by users) and contract addresses are used in account-based blockchains (governed by smart contract code). In a blockchain system, the process of uploading smart contract code involves the initiation of a transaction by an externally owned address or a contract address. The transaction is broadcasted to the network and propagated to all participating nodes, where it is validated and included in a block during the consensus process. Once confirmed, the smart contract code becomes part of the blockchain's immutable ledger and is distributed to all nodes, ensuring decentralization, redundancy, and transparency. This shared infrastructure enables trustless and transparent interactions with the contract, as users can examine the code's functionality and expect consistent outcomes. To put it another way, uploading the contract forces the code to be stored locally on other nodes. Each Ethereum transaction comprises of an input data field, similar to the log field in UTXO blockchains, which is used to transfer messages to the smart contracts.

When executing smart contract code in the blockchain, the code is invoked by calling stored functions with specified parameters. This process takes place across all nodes worldwide, establishing Ethereum as the "World Computer." The contract formation cost is borne by the contract holder, while other users or contracts interact with the contract by creating transactions directed to its address. The operations performed by the contract, such as multiplication (e.g., 5) and addition (e.g., 3), accumulate a computational cost known as "gas," which is measured in ethers and charged to the address initiating the transaction. Ether serves as the digital currency, acting as the fuel for the Ethereum World Computer. The advent of smart contracts has given rise to smart contract-based tokens, representing units of data that can be traded. These tokens enable users to access real-world services provided by businesses. For instance, the Storj token allows storage of files on personal hard drives and compensates users with Ethereum-based fees. Tokens can be bought, sold, and function as stores of value within the global economy, with their exchange rates against fiat currencies viewable on platforms like coinmarket-cap.com.

There are two types of transactions in account-based blockchains. The first form of transaction involves sending a crypto-currency, such as Ether on Ethereum, from one address to another. A guided edge between the two addresses can be used to model this. Internal transactions, on the other hand, are made when smart contracts alter states associated with addresses.

1.5. Blockchain Data Analytics Tools and Methods

2.6.1. Tools

In blockchain systems, data blocks are typically stored in files on disk. For example, Ethereum utilizes levelDB files, while Bitcoin uses .dat files. However, the nature of storing data in this manner can result in time-consuming data querying processes. Although several blockchain query languages and analytics frameworks have emerged in recent years, their adoption remains relatively limited. [9]. In-house data querying and analysis tools have been developed by companies including Santiment.com and Chainalysis.com, but they are not yet available to the general public. Online explorers such as blockchain.com and etherscan.io provide limited access to analytics tools for the public. The BlockSci project [10] is a commonly used method in Bitcoin data analytics. Biva.1, a Bitcoin Network Visual Analytics application, is a related tool. In addition to transaction data related to financial interactions between addresses, the advent of Ethereum 2.0 and its inclusion of software code within blockchains has significantly contributed to the emergence of smart contract analysis as a vital path for data analytics. However, most of the existing research in this domain primarily focuses on static code analysis, which involves tasks like contract classification. Unfortunately, there is limited examination of the decisions made by the smart contracts under investigation. [11].

3. Methods

Early research works in the field of blockchain analysis have focused on analyzing UTXO data by constructing graphs using a single type of node, following established network analysis methodologies. Two prominent methods used in this context are the transaction graph and address graph approaches. The transaction graph method primarily considers transactions while ignoring addresses, forming edges between transaction nodes. It assumes that transactions are acyclic and prohibits the addition of new edges to a transaction node in the future. Conversely, the address graph method disregards transactions and connects address nodes with edges. However, the presence of the Mapping Rule, which links a transaction's inputs to all its output addresses[12], can result in the formation of large cliques when transactions involve a high number of addresses. It is important to note that employing single node approaches alone may not adequately capture the intricacies of blockchain data, including the relationships between transactions and addresses. Therefore, further advancements and methodologies are required to comprehensively understand and analyze the complexities of blockchain data.

The loss of knowledge regarding addresses or transactions can have a significant impact on predictive models. When crucial information about addresses or transactions is missing or not considered, it can lead to incomplete or inaccurate predictions. The predictive models heavily rely on historical data and patterns to make informed projections or forecasts. If there is a loss of knowledge, such as incomplete transaction records or missing address data, it can undermine the model's ability to accurately capture trends, patterns, and relationships within the blockchain data. As a result, the predictive models may produce less reliable or misleading outcomes, potentially hindering decision-making processes reliant on the model's predictions[13].

As Bitcoin gained popularity, numerous studies emerged with the objective of predicting its price by examining various network characteristics. For instance, researchers explored network features such as mean account balance, the number of new edges, and clustering coefficients in the blockchain network [13]. In contrast, [14]have used network flows and network temporal activity as alternative price predictors, respectively. K-chainlets provide a lossless network encoding technique for the blockchain, using subgraphs composed of nodes that can represent addresses or chainlets. This model leverages the local higher-order structures present in the blockchain graph, treating subgraphs as the building blocks for analysis instead of individual edges or nodes. These subgraphs, known as chainlets, are formed based on a single judgment, allowing them to be treated as a single data unit. Unlike social networks, where nodes' proximity is influenced by their neighbors' behavior, the inclusion of input and output nodes within a chainlet is fixed and cannot be modified due to the irreversible nature of blockchain transactions. Chainlets offer a powerful means of capturing complex relationships and patterns within the blockchain, enabling more comprehensive analysis and understanding of transaction flows. By considering subgraphs as cohesive units, the granularity of analysis increases, providing a higher level of abstraction for studying the blockchain's structure and dynamics. [15].

Blockchain Data Analytics' Applications

Since the seminal Bitcoin paper, cryptocurrencies have been the most widely used Blockchain technology [4] in 2008. While there has recently been interest in analysing Blockchain platform data, Blockchain Data Analytics has primarily focused on Bitcoin and a few other cryptocurrencies.. In general, studies look at the potential and weaknesses of coins in terms of providing a stable and open economic structure for all participants. Applications of the blockchain data analytics are described below:

4. Criminal Usage Detection

The utilization of Bitcoin in illicit activities, such as on SilkRoad.com, has been prevalent since its inception. While cryptocurrencies offer pseudonymity, as users are not required to disclose their identities to participate in the network, all transactions are visible on the public Blockchain. In order to maintain anonymity, criminals employ various tactics to separate their real-life and online identities. One such method is accessing the Blockchain network through privacy-enhancing distributed platforms like Tor. Additionally, criminals aim to make their activities on the Blockchain indistinguishable from those of regular users, attempting to create transactions that appear natural in terms of frequency, timing, and quantity. Cryptocurrencies are also utilized in illegal practices such as personal extortion, human trafficking, and ransomware payments. To combat these activities, law enforcement authorities may employ Blockchain Data Analytics software and algorithms to identify and analyze illegal behaviors [16-19]

5. Trade Finance

Companies have increasingly found traditional methods of commercial financing to be frustrating, as lengthy cycles often disrupt operations and create challenges in managing liquidity effectively. When it comes to cross-border trade, multiple variables need to be considered, including the country of origin and product details. Such transactions also generate a significant amount of paperwork. However, blockchain technology has the potential to revolutionize trade finance by simplifying transactions and enhancing cross-border management. It empowers companies to operate more efficiently across regions and overcome geographical boundaries, thus improving overall trade finance operations.

6. Money Laundering Protection

Blockchain technology, at its essence, offers immense value in the fight against money laundering. Its underlying technology provides strong support for the implementation of crucial mechanisms like 'Know Your Customer (KYC).' KYC enables businesses to uncover and verify the identities of their customers, serving as a vital tool in preventing money laundering activities. By leveraging the capabilities of blockchain encryption, organizations can enhance their safeguards against illicit financial transactions and bolster their overall money laundering protection measures.

7. Supply Chain Management

The inherent immutability of the blockchain ledger renders it highly suitable for various activities within supply chain management, including real-time product monitoring as goods move and change hands. Blockchain technology introduces numerous possibilities for businesses involved in shipping and logistics. By utilizing blockchain entries, events in the supply chain, such as the distribution of products across different containers until they reach their destination port, can be efficiently tracked and recorded. This empowers businesses with a modern and dynamic approach to organizing and leveraging tracking data, thereby enhancing overall supply chain management practices.

7.1. Real Estate

In the real estate industry, where homeowners typically sell their houses every five to seven years and individuals tend to move approximately 12 times in their lifetime, blockchain technology holds significant potential. With such high activity levels, blockchain can play a vital role in expediting domestic property sales by enabling swift monitoring of financial details. Additionally, it serves as a robust safeguard against encryption theft, ensuring the security of sensitive information. Moreover, blockchain brings transparency to the sales and procurement process, fostering trust and confidence among buyers, sellers, and other stakeholders in the real estate market.

8. Healthcare

Blockchain technology has great potential in the healthcare sector, particularly for storing and managing certain types of health information. General details such as age and sex, as well as basic medical data like immunization records or vital signs, can be effectively stored on a blockchain. These pieces of information, when isolated, do not reveal a patient's identity, thereby addressing privacy concerns. By utilizing a shared blockchain, accessible to a large number of authorized individuals, healthcare stakeholders can securely access and update relevant health information.

As connected medical devices gain popularity and become more integrated with patient records, blockchain can play a crucial role. It enables the seamless integration of specialized connected medical devices with individual health records. Data generated by these devices can be stored and added to personal medical records through the blockchain. Currently, the fragmentation of data from connected medical devices poses a significant challenge, but blockchain technology can serve as the bridge connecting these data silos. By leveraging blockchain, healthcare providers can enhance data interoperability and create a comprehensive view of a patient's health information, ultimately improving the quality and efficiency of healthcare delivery..

8.1. Insurance

Intelligent contracts represent a groundbreaking application of blockchain technology in the insurance industry. They offer a transparent and secure way for customers and insurers to handle claims effectively. By registering both the contracts and claims on the blockchain, the network can validate the authenticity of claims, reducing the occurrence of fraudulent or duplicate claims associated with the same incident. An illustrative example of this is openIDL, a network developed in collaboration with the American Insurance Association and built on the IBM Blockchain platform. This platform automates the reporting of insurance regulations and simplifies compliance requirements, streamlining the overall insurance process. With intelligent contracts and blockchain technology, the insurance sector is empowered to enhance efficiency, trust, and accuracy in claims management and regulatory compliance.

9. Price Prediction

One of the most urgent issues is how Bitcoin acts as a class of financial assets, particularly as regards whether the transaction chart is linked to price formation, liquidity or a market crash. The analysis of transactions and addresses and the price of Bitcoin has become a prominent analytic subject. It is becoming increasingly necessary to build mathematical models that can forecast and assign price changes to transactions and transaction graph properties. Although simple transactional Blockchain features such as the average transaction amount display mixed results for cryptocurrency price prediction, a number of recent studies have shown that the global graphical features are useful for predicting price[13]. For example, [20] looked at the effects of average balance, clustering coefficient, and the number of new edges on Bitcoin price prediction, and Blockchain chainlets as a predictor. In [21] recently proposed two network flow tests to calculate the Bitcoin transaction network's dynamics and evaluate the relationship between flow sophistication and Bitcoin market variables.

10. Conclusions

This article has shed light on the research topics that encompass the prevalent challenges faced in data management and analytics within real-world blockchain applications. By exploring these issues, we aim to lay the groundwork for future research endeavors focused on identifying viable solutions to these open problems. It is our hope that this study serves as a stepping stone towards addressing and resolving the key obstacles in the field, leading to advancements and innovations in blockchain technology.

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