Blockchain

For other uses, see Block chain (disambiguation).

A **blockchain**[1][2][3] – originally **block chain**[4][5] – is a continuously growing list of records, called *blocks*, which are linked and secured using cryptography.[1][6] Each block typically contains a hash pointer as a link to a previous block,[6] a timestamp and transaction data.[7] By design, blockchains are inherently resistant to modification of the data. A blockchain can serve as "an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way."[8] For use as a distributed ledger a blockchain is typically managed by a peer-to-peer network collectively adhering to a protocol for validating new blocks. Once recorded, the data in any given block cannot be altered retroactively without the alteration of all subsequent blocks, which needs a collusion of the network majority.

Blockchains are secure by design and are an example of a distributed computing system with high Byzantine fault tolerance. Decentralized consensus has therefore been achieved with a blockchain.[9] This makes blockchains potentially suitable for the recording of events, medical records,[10][11] and other records management activities, such as identity management,[12][13][14] transaction processing, documenting provenance, or food traceability.[15]

The first distributed blockchain was conceptualised by Satoshi Nakamoto in 2008 and implemented the following year as a core component of the digital currency bitcoin, where it serves as the public ledger for all transactions.[1] The invention of the blockchain for bitcoin made it the first digital currency to solve the double spending problem, without the use of a trusted authority or central server. The bitcoin design has been the inspiration for other applications.[1][3]

1 History

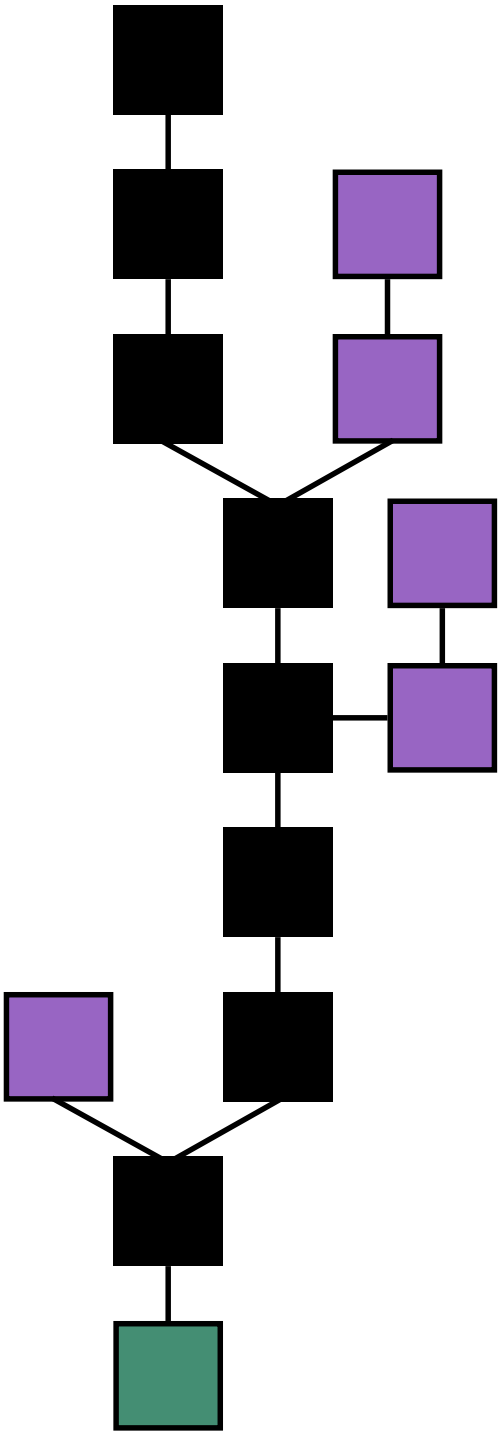
The first work on a cryptographically secured chain of blocks was described in 1991 by Stuart Haber and W. Scott Stornetta.[16] In 1992, Bayer, Haber and Stornetta incorporated Merkle trees to the blockchain as an efficiency improvement to be able to collect several documents into one block.[17][6]

The first distributed blockchain was then conceptualised by Satoshi Nakamoto in 2008 and implemented the following year as a core component of the digital currency bitcoin, where it serves as the public ledger for all transactions.[1] Through the use of a peer-to-peer network and a distributed timestamping server, a blockchain database is managed autonomously. The use of the blockchain for bitcoin made it the first digital currency to solve the double spending problem without requiring a trusted administrator.[4] The bitcoin design has been the inspiration for other applications.[1][3]

The words *block* and *chain* were used separately in Satoshi Nakamoto's original paper in October 2008,[18] and when the term moved into wider use it was originally *block chain,*[4][5] before becoming a single word, *blockchain,* by 2016. In August 2014, the bitcoin blockchain file size reached 20 gigabytes.[19] In January 2015, the size had grown to almost 30 gigabytes, and from January 2016 to January 2017, the bitcoin blockchain grew from 50 gigabytes to 100 gigabytes in size.[20]

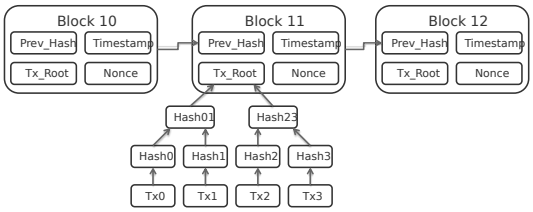
By 2014, "Blockchain 2.0" was a term referring to new applications of the distributed blockchain database.[21] *The Economist* described one implementation of this second-generation programmable blockchain as coming with "a programming language that allows users to write more sophisticated smart contracts, thus creating invoices that pay themselves when a shipment arrives or share certificates which automatically send their owners dividends if profits reach a certain level."[1] Blockchain 2.0 technologies go beyond transactions and enable "exchange of value without powerful intermediaries acting as arbiters of money and information". They are expected to enable excluded people to enter the global economy, enable the protection of privacy and people to "monetize their own information", and provide the capability to ensure creators are compensated for their intellectual property. Second-generation blockchain technology makes it possible to store an individual's "persistent digital ID and persona" and are providing an avenue to help solve the problem of social inequality by "[potentially changing] the way wealth is distributed."[22]:14–15 As of 2016, Blockchain 2.0 implementations continue to require an off-chain oracle to access any "external data or events based on time or market conditions [that need] to interact with the blockchain."[23]

In 2016, the central securities depository of the Russian Federation (NSD) announced a pilot project based on the Nxt Blockchain 2.0 platform that would explore the use of blockchain-based automated voting systems.[24] Various regulatory bodies in the music industry have started testing models that use blockchain technology for royalty collection and management of copyrights around the world.[25] IBM opened a blockchain innovation research

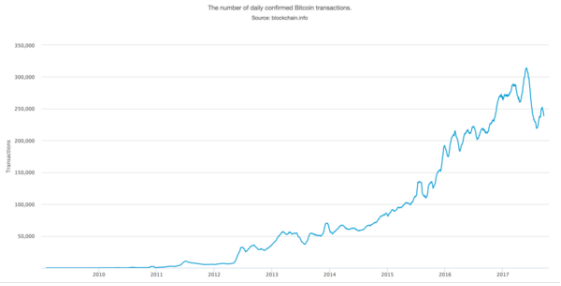


Blockchain formation. The main chain (black) consists of the longest series of blocks from the genesis block (green) to the current block. Orphan blocks (purple) exist outside of the main chain.

centre in Singapore in July 2016.[26] A working group for the World Economic Forum met in November 2016 to discuss the development of governance models related to blockchain.[27] According to Accenture, an application of the diffusion of innovations theory suggests that in



Bitcoin network data



Bitcoin transactions (January 2009 – September 2017)

2016 blockchains attained a 13.5% adoption rate within financial services, therefore reaching the early adopters phase.[28] In 2016, industry trade groups joined to create the Global Blockchain Forum, an initiative of the Chamber of Digital Commerce.[29]

In early 2017, the *Harvard Business Review* suggested that blockchain is a foundational technology and thus "has the potential to create new foundations for our economic and social systems." It further observed that while foundational innovations can have enormous impact, "It will take decades for blockchain to seep into our economic and social infrastructure."[8]

2 Description

A blockchain facilitates secure online transactions.[30] A blockchain is a decentralized and distributed digital ledger that is used to record transactions across many computers so that the record cannot be altered retroactively without the alteration of all subsequent blocks and the collusion of the network.[31][1] This allows the participants to verify and audit transactions inexpensively.[32] They are authenticated by mass collaboration powered by collective self-interests.[33] The result is a robust workflow where participants' uncertainty regarding data security is marginal. The use of a blockchain removes the characteristic of infinite reproducibility from a digital asset. It confirms that each unit of value was trans-

ferred only once, solving the long-standing problem of double spending. Blockchains have been described as a value-exchange protocol.[21] This blockchain-based exchange of value can be completed more quickly, more safely and more cheaply than with traditional systems.[34] A blockchain can assign title rights because it provides a record that compels offer and acceptance.[1]

A blockchain database consists of two kinds of records: transactions and blocks.[1] Blocks hold batches of valid transactions that are hashed and encoded into a Merkle tree.[1] Each block includes the hash of the prior block in the blockchain, linking the two. Variants of this format were used previously, for example in Git. The format is not by itself sufficient to qualify as a blockchain.[35] The linked blocks form a chain.[1] This iterative process confirms the integrity of the previous block, all the way back to the original genesis block.[36] Some blockchains create a new block as frequently as every five seconds.[37] As blockchains age they are said to grow in height.

Sometimes separate blocks can be produced concurrently, creating a temporary fork. In addition to a secure hash based history, any blockchain has a specified algorithm for scoring different versions of the history so that one with a higher value can be selected over others. Blocks not selected for inclusion in the chain are called orphan blocks.[36] Peers supporting the database have different versions of the history from time to time. They only keep the highest scoring version of the database known to them. Whenever a peer receives a higher scoring version (usually the old version with a single new block added) they extend or overwrite their own database and retransmit the improvement to their peers. There is never an absolute guarantee that any particular entry will remain in the best version of the history forever. Because blockchains are typically built to add the score of new blocks onto old blocks and because there are incentives to work only on extending with new blocks rather than overwriting old blocks, the probability of an entry becoming superseded goes down exponentially[38] as more blocks are built on top of it, eventually becoming very low.[1][39]:ch. 08[40] For example, in a blockchain using the proof-of-work system, the chain with the most cumulative proof-of-work is always considered the valid one by the network. There are a number of methods that can be used to demonstrate a sufficient level of computation. Within a blockchain the computation is carried out redundantly rather than in the traditional segregated and parallel manner.[41]

2.1 Decentralization

By storing data across its network, the blockchain eliminates the risks that come with data being held centrally.[1] The decentralised blockchain may use ad-hoc message passing and distributed networking. Its network lacks centralized points of vulnerability that computer crackers can exploit; likewise, it has no central point of failure. Blockchain security methods include the use of public-key cryptography.[4]:5 A *public key* (a long, random-looking string of numbers) is an address on the blockchain. Value tokens sent across the network are recorded as belonging to that address. A *private key* is like a password that gives its owner access to their digital assets or otherwise interact with the various capabilities that blockchains now support. Data stored on the blockchain is generally considered incorruptible.[1]

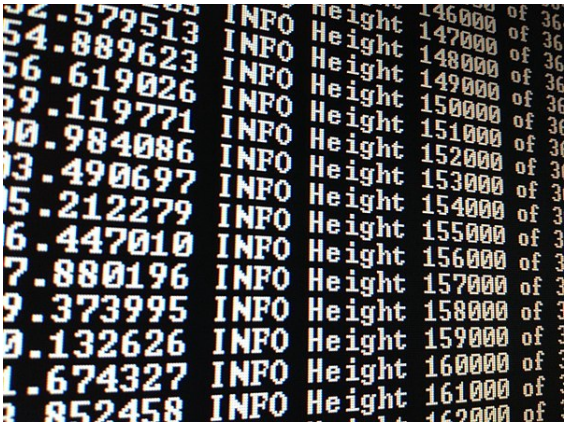
Every node or miner in a decentralized system has a copy of the blockchain. Data quality is maintained by massive database replication[9] and computational trust. No centralized "official" copy exists and no user is "trusted" more than any other.[4] Transactions are broadcast to the network using software. Messages are delivered on a best effort basis. Mining nodes validate transactions,[36] add them to the block they are building, and then broadcast the completed block to other nodes.[39]:ch. 08 Blockchains use various time-stamping schemes, such as proof-of-work, to serialize changes.[42] Alternate consensus methods include proof-of-stake and proof-of-burn.[36] Growth of a decentralized blockchain is accompanied by the risk of node centralization because computer resources required to operate bigger data become more expensive.[43]

2.2 Hard forks

As per *Investopedia*, a *hard fork* term refers to a situation when a blockchain splits into two separate chains in consequence of the use of two distinct sets of rules trying to govern the system.[44] For example, Ethereum has hard-forked to "make whole" the investors in The DAO, which had been hacked by exploiting a vulnerability in its code.[45] In 2014 the Nxt community was asked to consider a hard fork that would have led to a rollback of the blockchain records to mitigate the effects of a theft of 50 million NXT from a major cryptocurrency exchange. The hard fork proposal was rejected, and the majority of the funds were recovered after negotiations.[46]

2.3 Openness

Open blockchains are more user friendly than some traditional ownership records, which, while open to the public, still require physical access to view. Because all early blockchains were permissionless, controversy has arisen over the blockchain definition. An issue in this ongoing debate is whether a private system with verifiers tasked and authorized (permissioned) by a central authority should be considered a blockchain.[47][48][49][50][51] Proponents of permissioned or private chains argue that the term "blockchain" may be applied to any data structure that batches data into time-stamped blocks. These blockchains serve as a distributed version of multiversion concurrency control (MVCC) in databases.[52] Just as MVCC prevents two transactions from concurrently



Blockchain data

modifying a single object in a database, blockchains prevent two transactions from spending the same single output in a blockchain.[22]:30–31 Opponents say that permissioned systems resemble traditional corporate databases, not supporting decentralized data verification, and that such systems are not hardened against operator tampering and revision.[47][49] *Computerworld* claims that "many in-house blockchain solutions will be nothing more than cumbersome databases."[53] The *Harvard Business Review* defines blockchain as a distributed ledger or database open to anyone.[54]

2.3.1 Permissionless

The great advantage to an open, permissionless, or public, blockchain network is that guarding against bad actors is not required and no access control is needed.[38] This means that applications can be added to the network without the approval or trust of others, using the blockchain as a transport layer.[38]

Bitcoin and other cryptocurrencies currently secure their blockchain by requiring new entries including a proof of work. To prolong the blockchain, bitcoin uses Hashcash puzzles developed by Adam Back in the 1990s.[55]

Financial companies have not prioritised decentralized blockchains.[56] In 2016, venture capital investment for blockchain related projects was weakening in the USA but increasing in China.[57] Bitcoin and many other cryptocurrencies use open (public) blockchains. As of September 2017, bitcoin has the highest market capitalization.

2.3.2 Permissioned (private) blockchain

Main article: Distributed ledger

Permissioned blockchains are emerging as open source protocols where openness and collaboration are encouraged.[58] These always have the ability to restrict who can participate in the consensus processes as well as who can transact.[41] These private blockchains lack transparency.

The *New York Times* noted in both 2016 and 2017 that many corporations are using blockchain networks "with private blockchains, independent of the public system."[59][60]

In contrast to public blockchain networks, validators on private blockchain networks are vetted by the network owner. They do not rely on anonymous nodes to validate transactions nor do they benefit from the network effect.[61]

2.3.3 Disadvantages

Nikolai Hampton pointed out in *Computerworld* that "There is also no need for a '51 percent' attack on a private blockchain, as the private blockchain (most likely) already controls 100 percent of all block creation resources. If you could attack or damage the blockchain creation tools on a private corporate server, you could effectively control 100 percent of their network and alter transactions however you wished."[53] This has a set of particularly profound adverse implications during a financial crisis or debt crisis like the financial crisis of 2007–08, where politically powerful actors may make decisions that favor some groups at the expense of others. and "the bitcoin blockchain is protected by the massive group mining effort. It's unlikely that any private blockchain will try to protect records using gigawatts of computing power — it's time consuming and expensive."[53] He also said, "Within a private blockchain there is also no 'race'; there's no incentive to use more power or discover blocks faster than competitors. This means that many in-house blockchain solutions will be nothing more than cumbersome databases."[53]

2.4 Applications

Blockchain technology has a large potential to transform business operating models in the long term. Blockchain distributed ledger technology is more a foundational technology—with the potential to create new foundations for global economic and social systems—than a disruptive technology, which typically "attack a traditional business model with a lower-cost solution and overtake incumbent firms quickly."[8] Even so, there are a few operational products maturing from proof of concept by late 2016.[57] The use of blockchains promises to bring significant efficiencies to global supply chains, financial transactions, asset ledgers and decentralized social networking.[8]

As of 2016, some observers remain skeptical. Steve Wilson, of Constellation Research, believes the technology has been hyped with unrealistic claims.[62] To mitigate risk businesses are reluctant to place blockchain at the core of the business structure.[63]

Blockchain technology can be integrated into multiple areas. This means specific blockchain applications may be a disruptive innovation, because substantially lower-cost solutions can be instantiated, which can disrupt existing business models.[8] Blockchain protocols facilitate businesses to use new methods of processing digital transactions.[64] Examples include a payment system and digital currency, facilitating crowdsales, or implementing prediction markets and generic governance tools.[65]

Blockchains can be thought of as an automatically notarised ledger. They alleviate the need for a trust service provider and are predicted to result in less capital being tied up in disputes. Blockchains have the potential to reduce systemic risk and financial fraud. They automate processes that were previously time-consuming and done manually, such as the incorporation of businesses.[66] In theory, it would be possible to collect taxes, conduct conveyancing and provide risk management with blockchains.

Major applications of blockchain include cryptocurrencies—including bitcoin, BlackCoin, Dash, and Nxt—and blockchain platforms such as Factom as a distributed registry, Gems for decentralized messaging, MaidSafe for decentralized applications, Storj and Sia for distributed cloud storage, and Tezos for decentralized voting.[22]:94 Frameworks and trials such as the one at the Sweden Land Registry aim to demonstrate the effectiveness of the blockchain at speeding land sale deals.[67] The Republic of Georgia is piloting a blockchain-based property registry.[68] The Ethical and Fair Creators Association uses blockchain to help startups protect their authentic ideas.[69]

New distribution methods are available for the insurance industry such as peer-to-peer insurance, parametric insurance and microinsurance following the adoption of blockchain.[64] Banks are interested in this technology because it has potential to speed up back office settlement systems.[70] The sharing economy and IoT are also set to benefit from blockchains because they involve many collaborating peers.[71] Online voting is another application of the blockchain.[72] Blockchains are being used to develop information systems for medical records, which increases interoperability. In theory, legacy disparate systems can be completely replaced by blockchains.[73] Blockchains are being developed for data storage, publishing texts and identifying the origin of digital art.

Banks such as UBS are opening new research labs dedicated to blockchain technology in order to explore how blockchain can be used in financial services to increase efficiency and reduce costs.[74][75]

2.4.1 The Big Four

Each of the Big Four accounting firms is testing blockchain technologies in various formats. Ernst and Young has provided cryptocurrency wallets to all (Swiss) employees,[76] has installed a bitcoin ATM in their office in Switzerland, and accepts bitcoin as payment for all its consulting services.[77] Marcel Stalder, CEO of Ernst and Young Switzerland stated "We don't only want to talk about digitalization, but also actively drive this process together with our employees and our clients. It is important to us that everybody gets on board and prepares themselves for the revolution set to take place in the business world through blockchains, [to] smart contracts and digital currencies."[77] PwC, Deloitte, and KPMG have taken a different path from Ernst & Young and are all testing private blockchains.[77]

2.4.2 Smart contracts

Blockchain-based smart contracts are contracts that can be partially or fully executed or enforced without human interaction.[78] One of the main objectives of a smart contract is automated escrow. The IMF believes blockchains could reduce moral hazards and optimize the use of contracts in general.[79] Due to the lack of widespread use their legal status is unclear.[79]

Some blockchain implementations could enable the coding of contracts that will execute when specified conditions are met. A blockchain smart contract would be enabled by extensible programming instructions that define and execute an agreement.[80] For example, Ethereum Solidity is an open source blockchain project that was built specifically to realize this possibility by implementing a Turing-complete programming language capability to implement such contracts.[22]:ch. 11

Another example of smart contract utilization is in the music industry. In 2017, DJ Deadly Buda released the first DJ mix, "Rock the Blockchain" that pays the tracks and their artists contained within it via a cryptocurrency blockchain, Musicoin. Every time the dj mix is played, the smart contracts attached to the dj mix pays the artists almost instantly.[81]

An application has been suggested for securing the spectrum sharing for wireless networks.[82]

A January 2017 World Economic Forum report predicted that by 2025 ten percent of global GDP will be stored on blockchains or blockchain-related technology.[83]

2.5 Alternative blockchains

Alternative blockchains, also known as altchains, are based on bitcoin technology in concept and/or code.[7] The term encompasses all blockchains but bitcoin's main chain. Compared to bitcoin, these designs generally add functionality to the blockchain design. Altchains can provide solutions, including other digital currencies, though tokens in these designs are not always considered as such. Altchains target performance, anonymity, storage and applications such as smart contracts.[84] Starting with a

strong focus on financial applications, blockchain technology is extending to activities including decentralized applications and collaborative organizations that eliminate a middleman.[85]

Notable non-cryptocurrency designs include:

- LaZooz — decentralized real-time ride sharing[86]
- Swarm and Koinify — decentralized crowdfunding[87]
- Synereo — synchronous and asynchronous communication[88]
- Gem[89] — Blockchain Platform for healthcare and supply chain
- Steemit combines a blogging site/social networking website and a cryptocurrency
- DECENT Network content distribution platform
- Hyperledger — cross-industry collaborative effort from the Linux Foundation to support blockchain-based distributed ledgers.
- Counterparty — open source financial platform for creating peer-to-peer financial applications on the bitcoin blockchain
- Bitcache
- Bitnation is the world's first operational Decentralized Borderless Voluntary Nation, a Blockchain Powered Jurisdiction.
- JPMorgan Chase's Quorum permissionable private blockchain with private store for smart contracts[90]
- Ethereum is a Blockchain, with a Turing complete scripting language that enables the processing of smart-contracts on the Blockchain.
- æternity is being developed as the only Blockchain that can by its core design sustain throughput of mainstream world use cases thanks to state channels, while providing real-world interfaces within its Blockchain through Decentralised Oracles.[91]

For a list of cryptocurrencies, see *List of cryptocurrencies*.

2.6 Other uses

Blockchain technology can be used to create a permanent, public, transparent ledger system for compiling data on sales, storing rights data by authenticating copyright registration,[92] and tracking digital use and payments to content creators, such as musicians.[93] In 2017, IBM partnered with ASCAP and PRS for Music to adopt blockchain technology in music distribution.[94] Imogen Heap's Mycelia[95] service, which allows managers to use a blockchain for tracking high-value parts moving through a supply chain, was launched as a concept in July 2016. Everledger is one of the inaugural clients of IBM's blockchain-based tracking service.[96]

CLS Group is using blockchain technology to expand the number of currency trade deals it can settle.[63]

2.6.1 Commercial offerings

Distributed ledgers and other blockchain-inspired software are being developed by commercial organizations for various applications:

- Deloitte and ConsenSys announced plans in 2016 to create a digital bank called Project ConsenSys.[97]
- R3 connects 42 banks to distributed ledgers built by Ethereum, Chain.com, Intel, IBM and Monax.[98]
- Microsoft Visual Studio is making the Ethereum Solidity language available to application developers.[99]
- SafeShare Insurance offers blockchain-based insurance for the sharing economy, underwritten by Lloyd's of London.[100]
- A Swiss industry consortium, including Swisscom, the Zurich Cantonal Bank and the Swiss stock exchange, is prototyping over-the-counter asset trading on a blockchain-based Ethereum technology.[101]
- IBM offers a cloud Blockchain service based on the open source Hyperledger Fabric project[102][103]

In August 2016 a research team at the Technical University of Munich published a research document about how blockchains may disrupt industries. They analyzed the venture funding that went into blockchain ventures. Their research shows that $1.55 billion went into startups with an industry focus on finance and insurance, information and communication, and professional services. High startup density was found in the USA, UK and Canada.[104]

ABN Amro announced a project in real estate to facilitate the sharing and recording of real estate transactions, and a second project in partnership with the Port of Rotterdam to develop logistics tools.[105]

3 National currencies

The following countries have adopted the technology for currency issue:

- e-Dinar, Tunisia's national currency, was the first state currency using blockchain technology.[106]

- eCFA is Senegal's blockchain-based national digital currency.[107]

4 Academic research

Blockchain panel discussion at the first IEEE Computer Society TechIgnite conference

4.1 Journals

Main article: Ledger (journal)

In September 2015, the first peer-reviewed academic journal dedicated to cryptocurrency and blockchain technology research, *Ledger*, was announced. The inaugural issue was published in December 2016.[108][109] The journal covers aspects of mathematics, computer science, engineering, law, economics and philosophy that relate to cryptocurrencies such as bitcoin.[110][111]

The journal encourages authors to digitally sign a file hash of submitted papers, which will then be timestamped into the bitcoin blockchain. Authors are also asked to include a personal bitcoin address in the first page of their papers.[112]

5 Projects

5.1 Nonprofit organizations

- Level One Project from the Bill & Melinda Gates Foundation aims to use blockchain technology to help the two billion people worldwide who lack bank accounts.[113][114]

- Building Blocks project from The U.N.'s World Food Programme (WFP) aims to make WFP's growing cash-based transfer operations faster, cheaper, and more secure. Building Blocks commenced field pilots in Pakistan in January 2017 that will continue throughout Spring.[115][116]

5.2 Decentralized networks

- Backfeed project develops a distributed governance system for blockchain-based applications allowing for the collaborative creation and distribution of value in spontaneously emerging networks of peers.[117][118]

- The Alexandria project is a blockchain-based Decentralized Library.[119][120]

- Tezos is a blockchain project that governs itself by voting of its token holders.[121][122][123] Bitcoin blockchain performs as a cryptocurrency and payment system. Ethereum blockchain added smart contract system on top of a blockchain. Tezos blockchain will add an autonomy system - a decentralized code Development function on top of both Bitcoin and Ethereum blockchains.[124]

6 See also

- Changelog a record of all notable changes made to a project
- Checklist an informational aid used to reduce failure
- Economics of digitization
- Ledger (journal) academic journal on blockchains
- List of cryptocurrencies currency based blockchains
- List of emerging technologies

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