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(54) **COMPRESSIBLE BLOCKCHAINS**

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(57)

**ABSTRACT**

A node in a blockchain network may invoke a process comprising receiving one or more operations for inclusion in a block, receiving a previous Merkle root created from previously determined account dispositions from a previous block, resolving the one or more operations based on the previous account dispositions to determine one or more current account dispositions, creating a current Merkle root for the one or more current account dispositions, and hashing current data for the current block, the data comprising the current Merkle root and the previous Merkle root to generate an account disposition block.

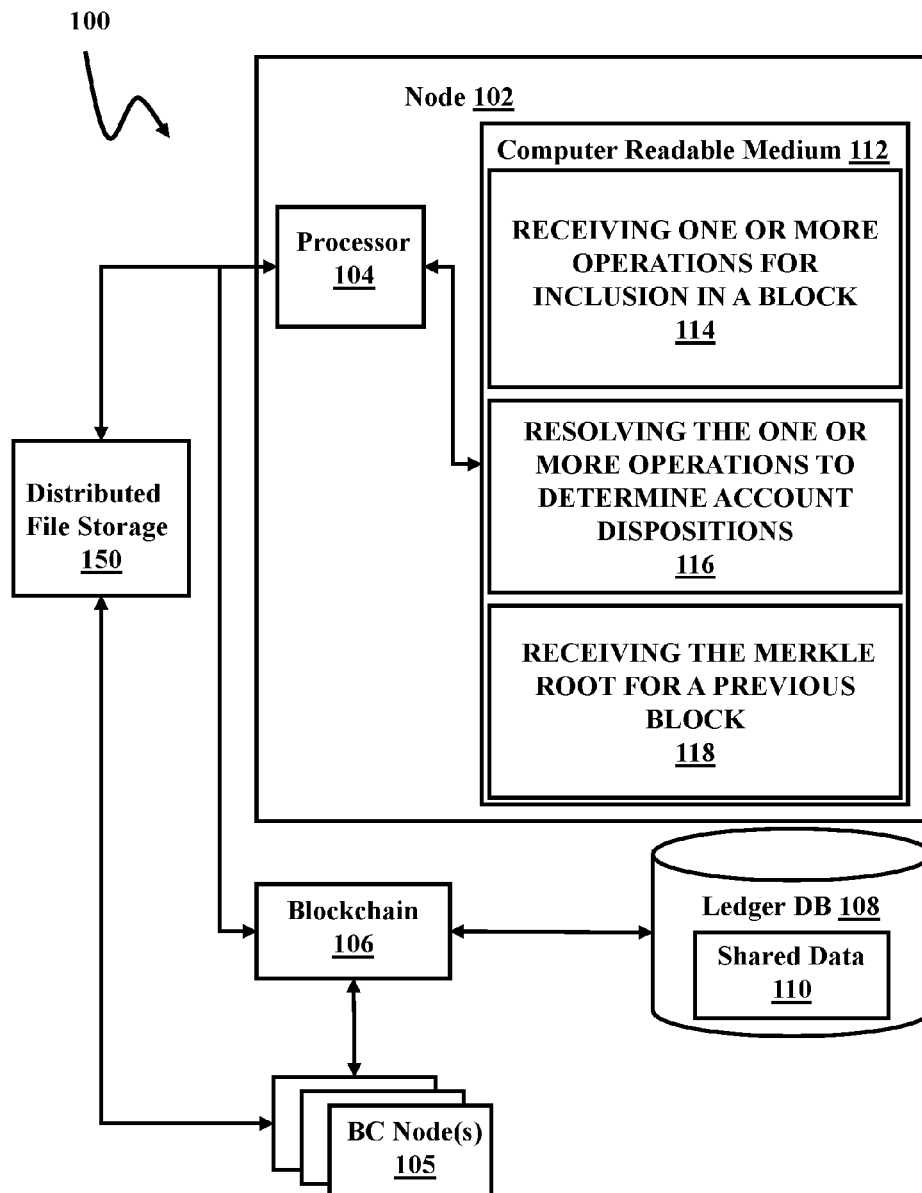
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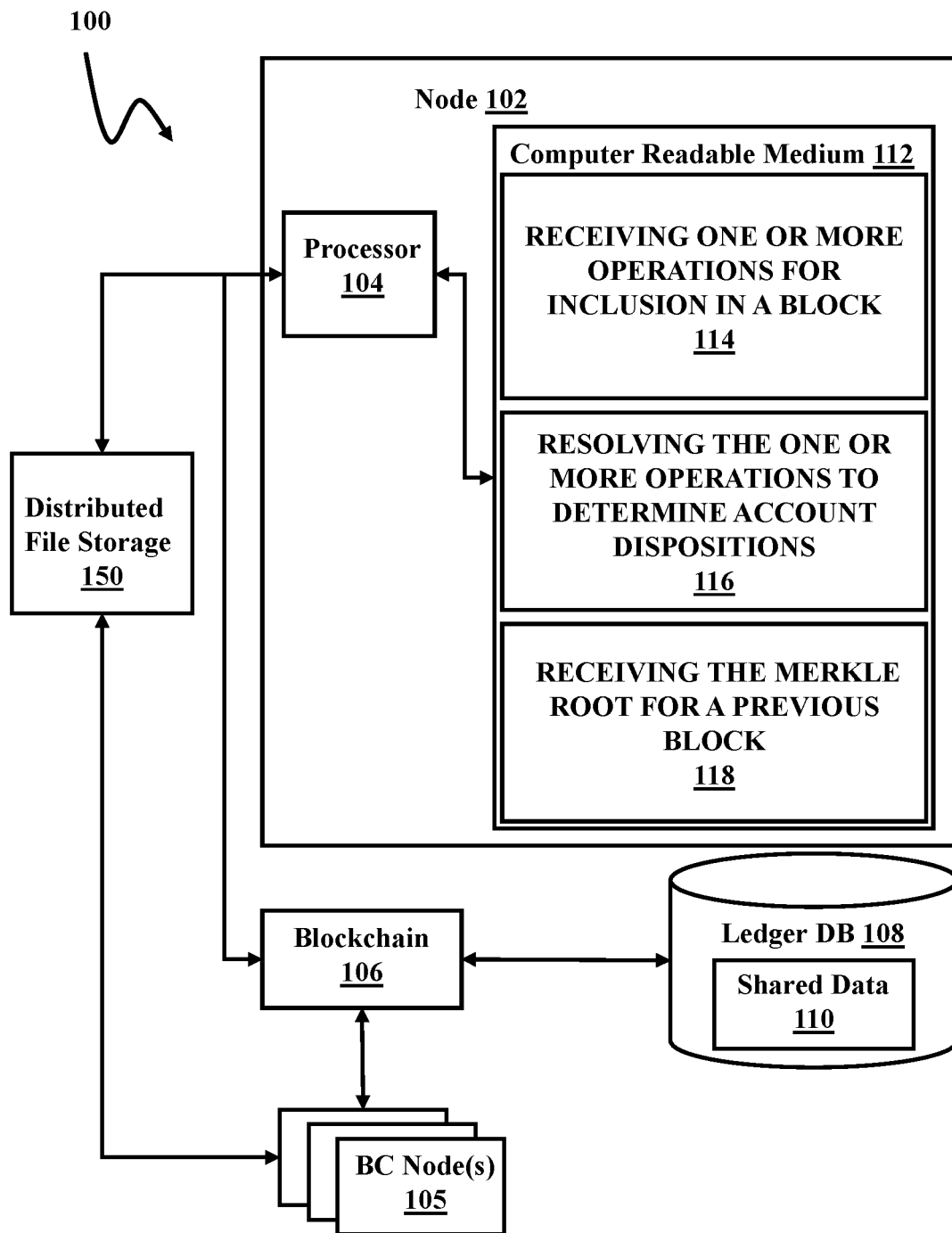
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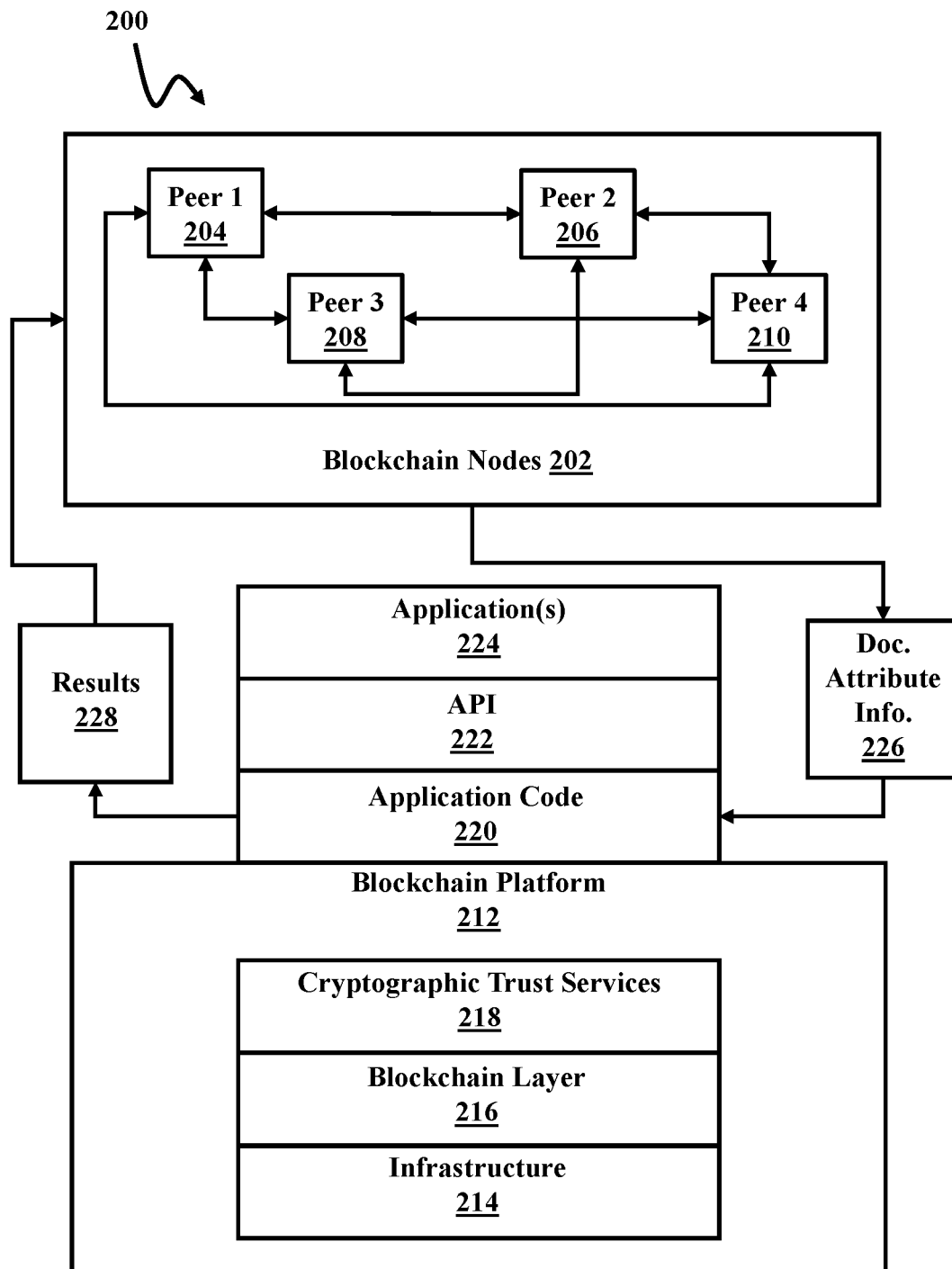
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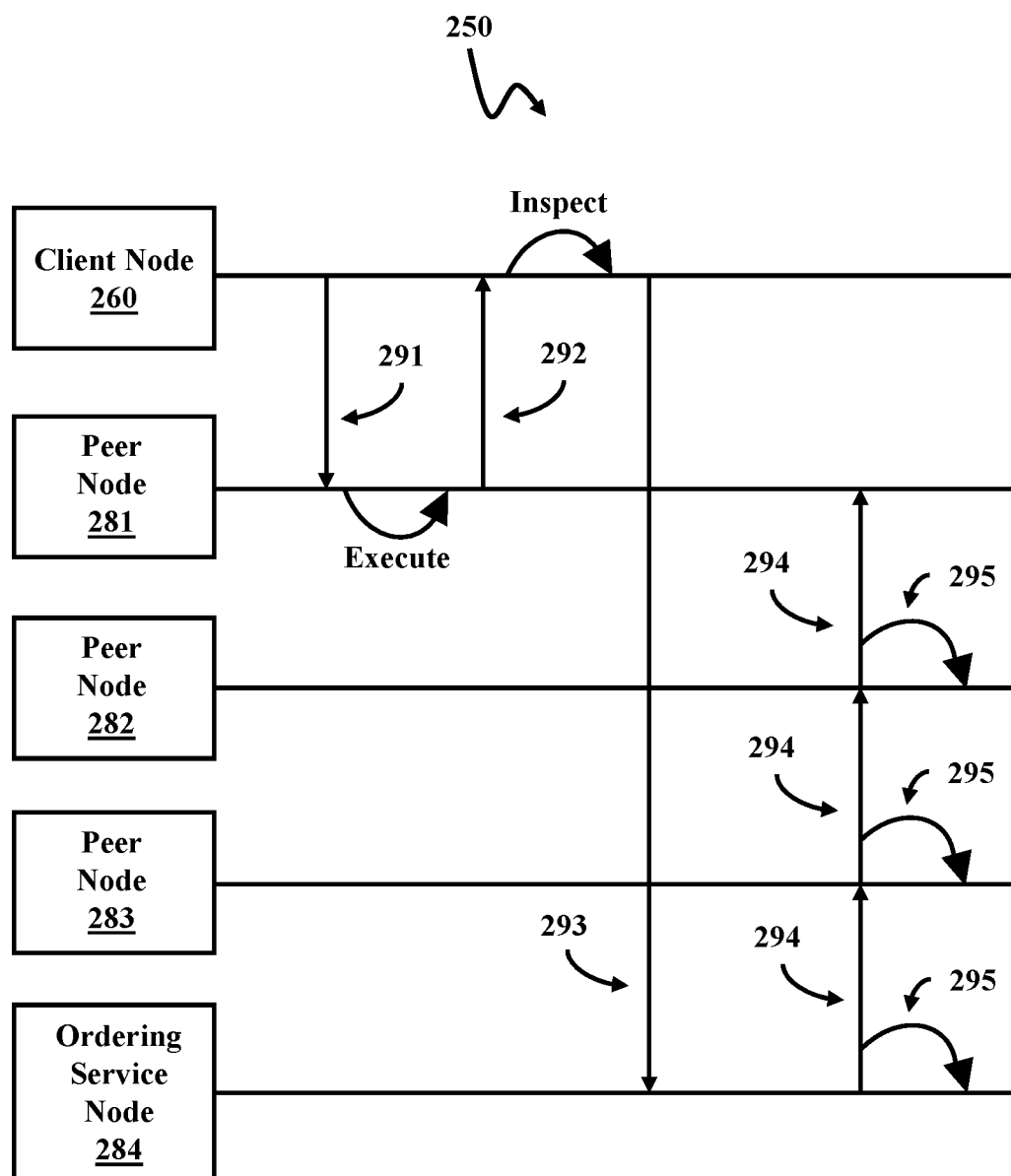




**FIG. 1**



**FIG. 2A**



**FIG. 2B**

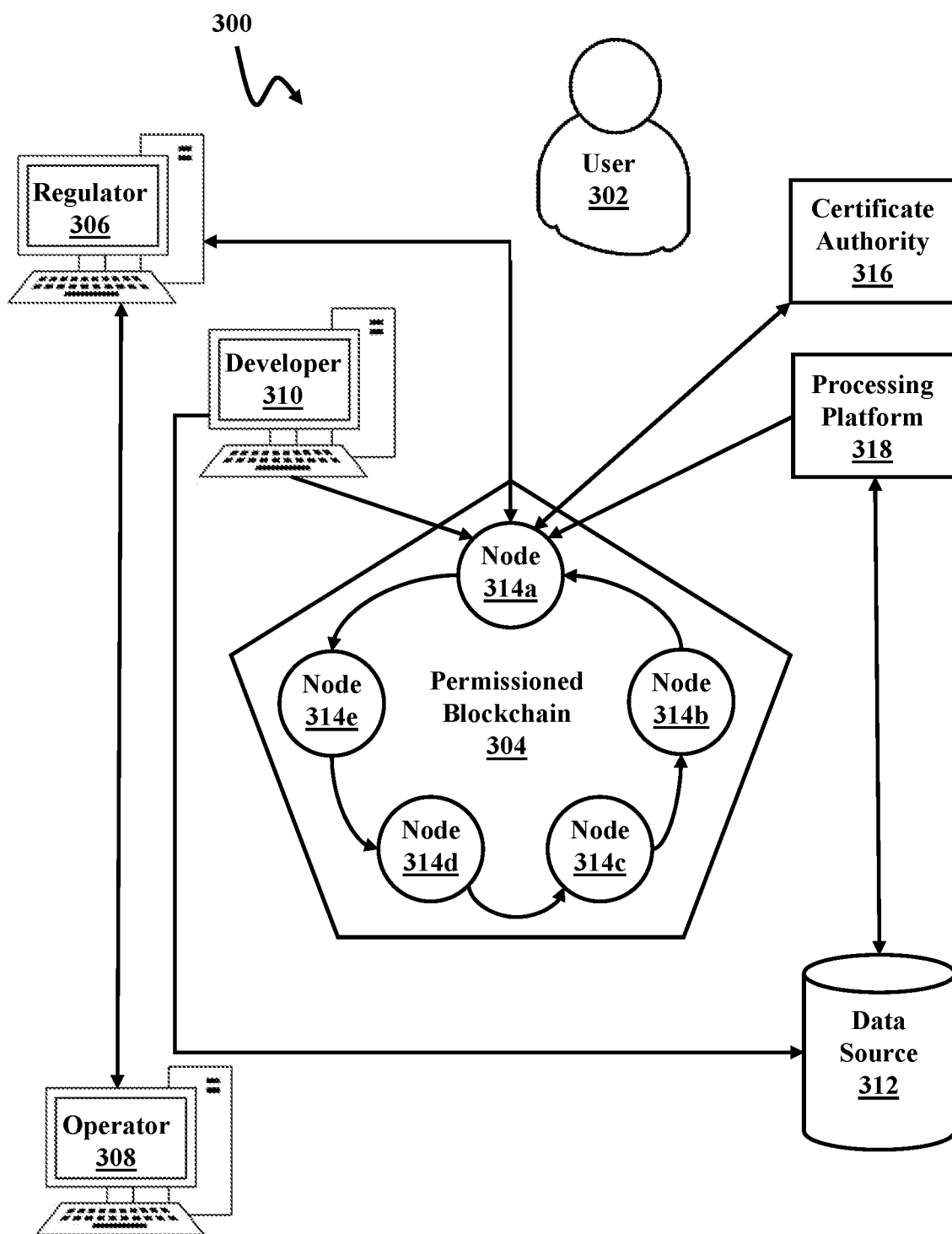
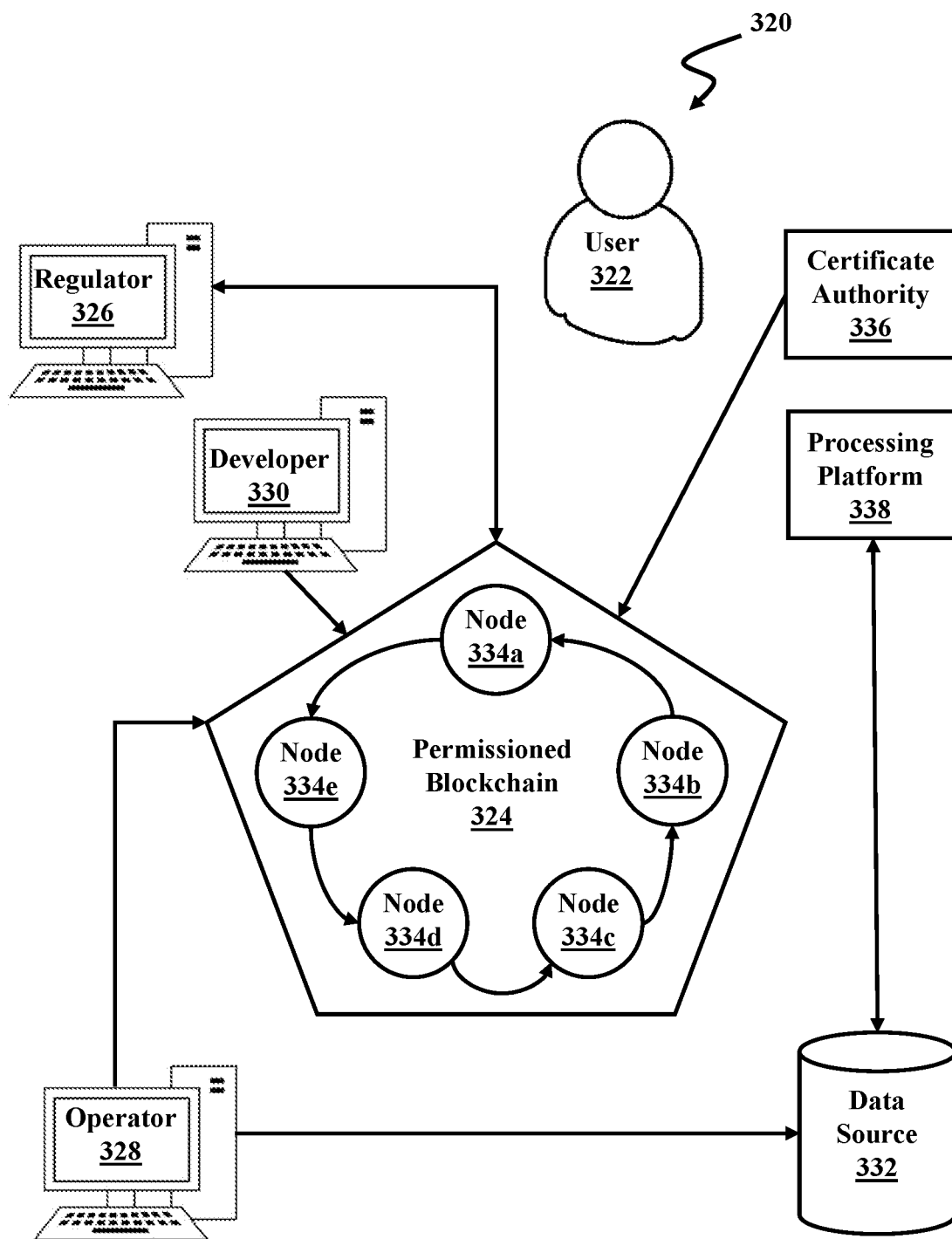
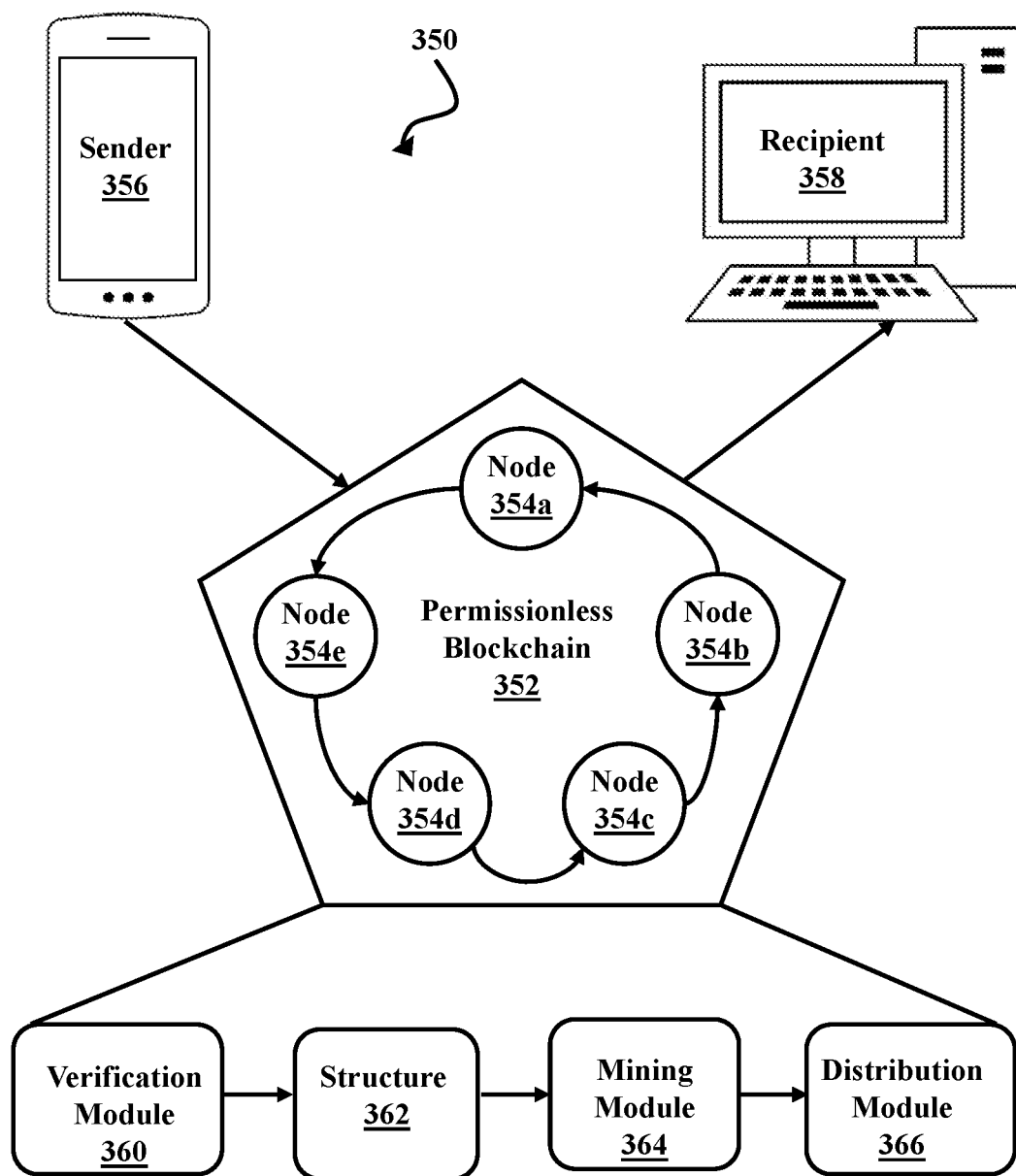


FIG. 3A



**FIG. 3B**



**FIG. 3C**

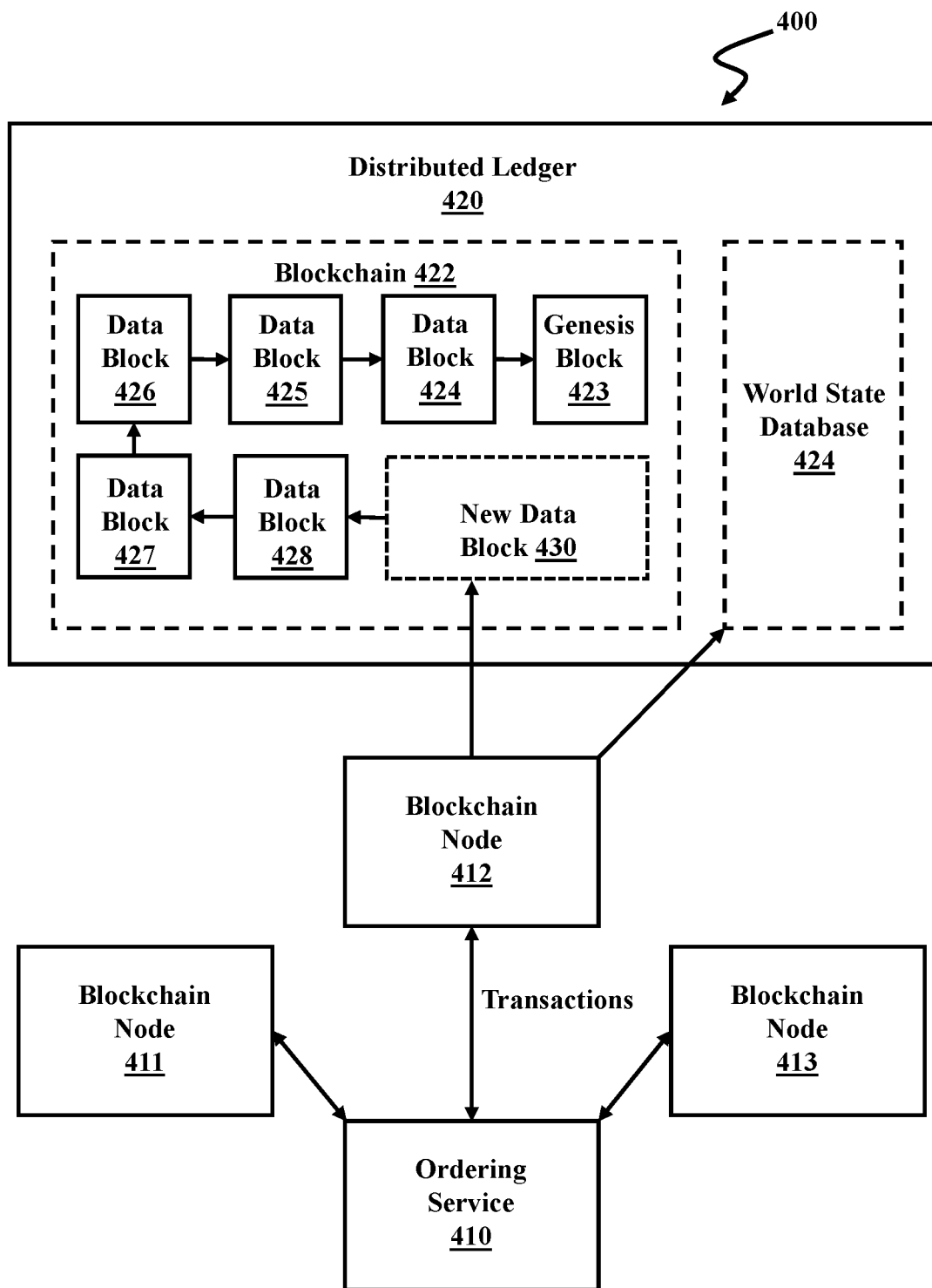


FIG. 4A



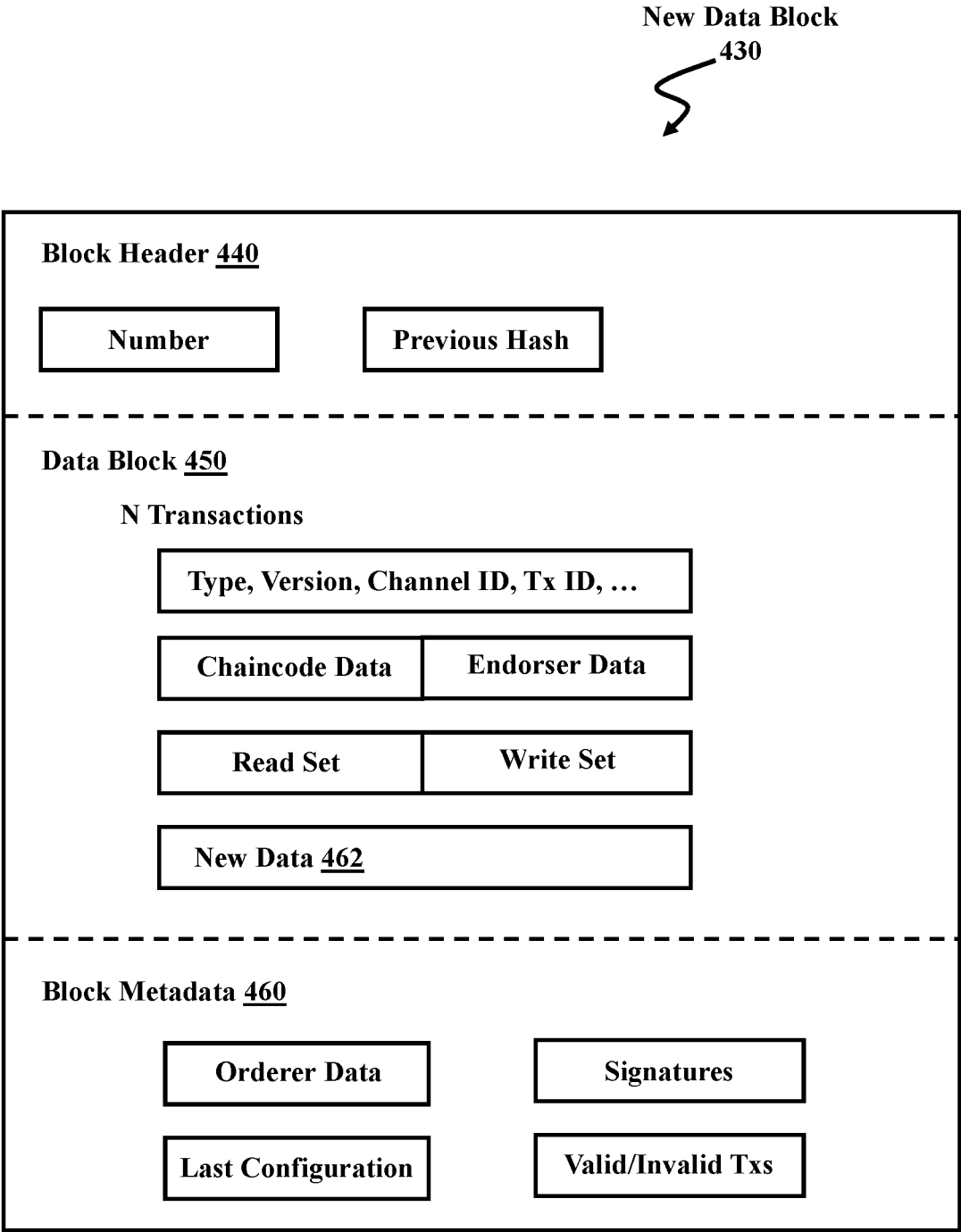


FIG. 4B

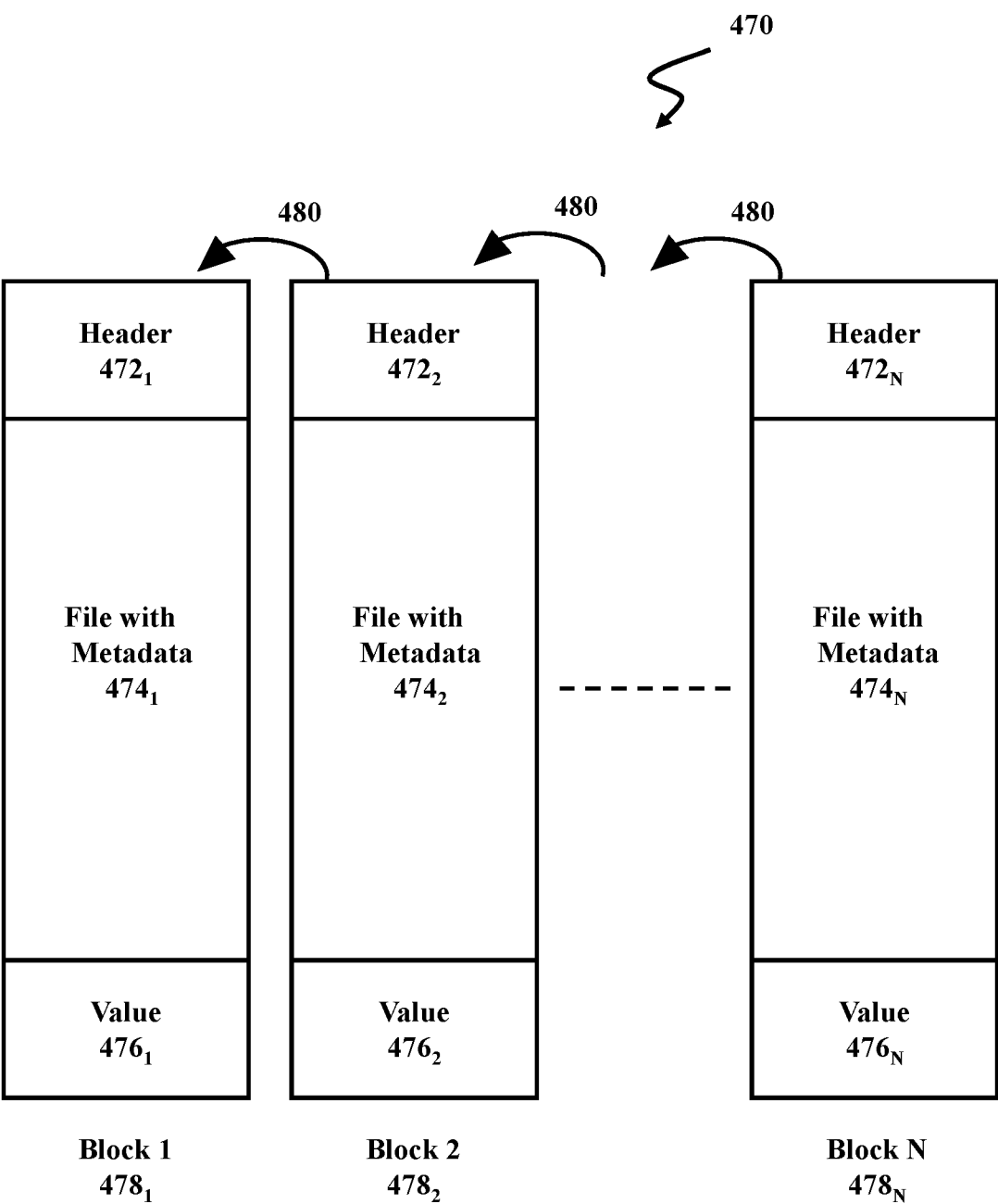


FIG. 4C

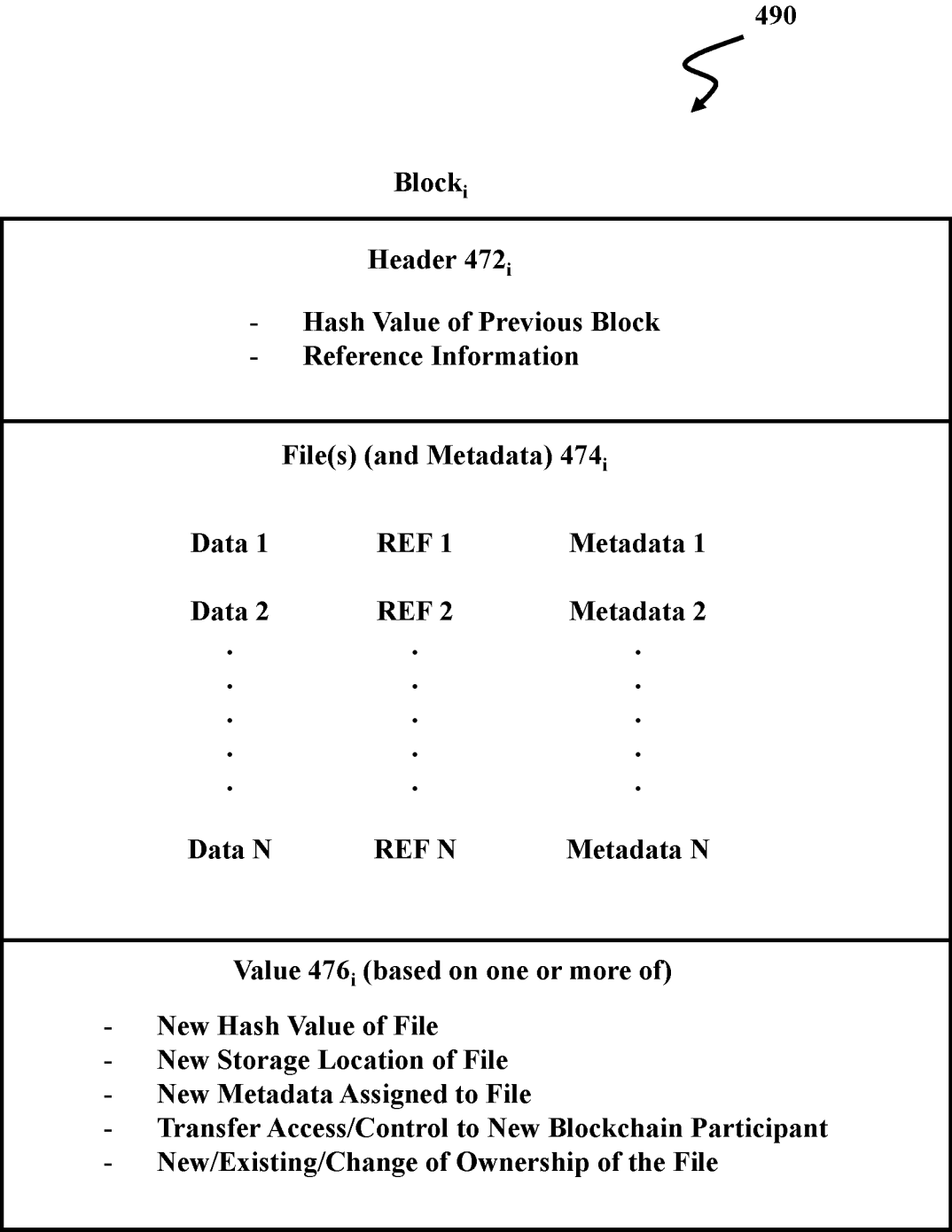
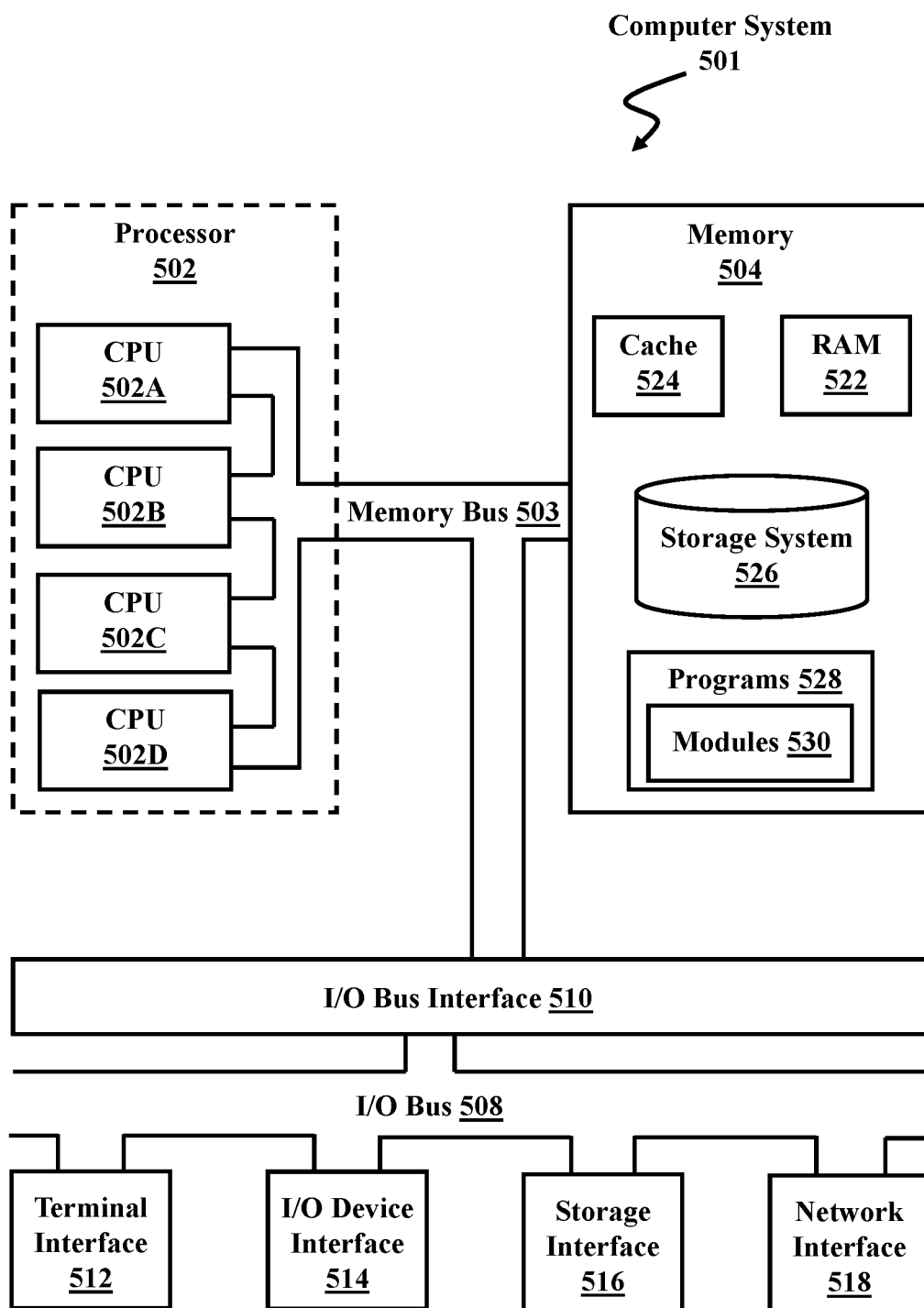


FIG. 4D



**FIG. 5**

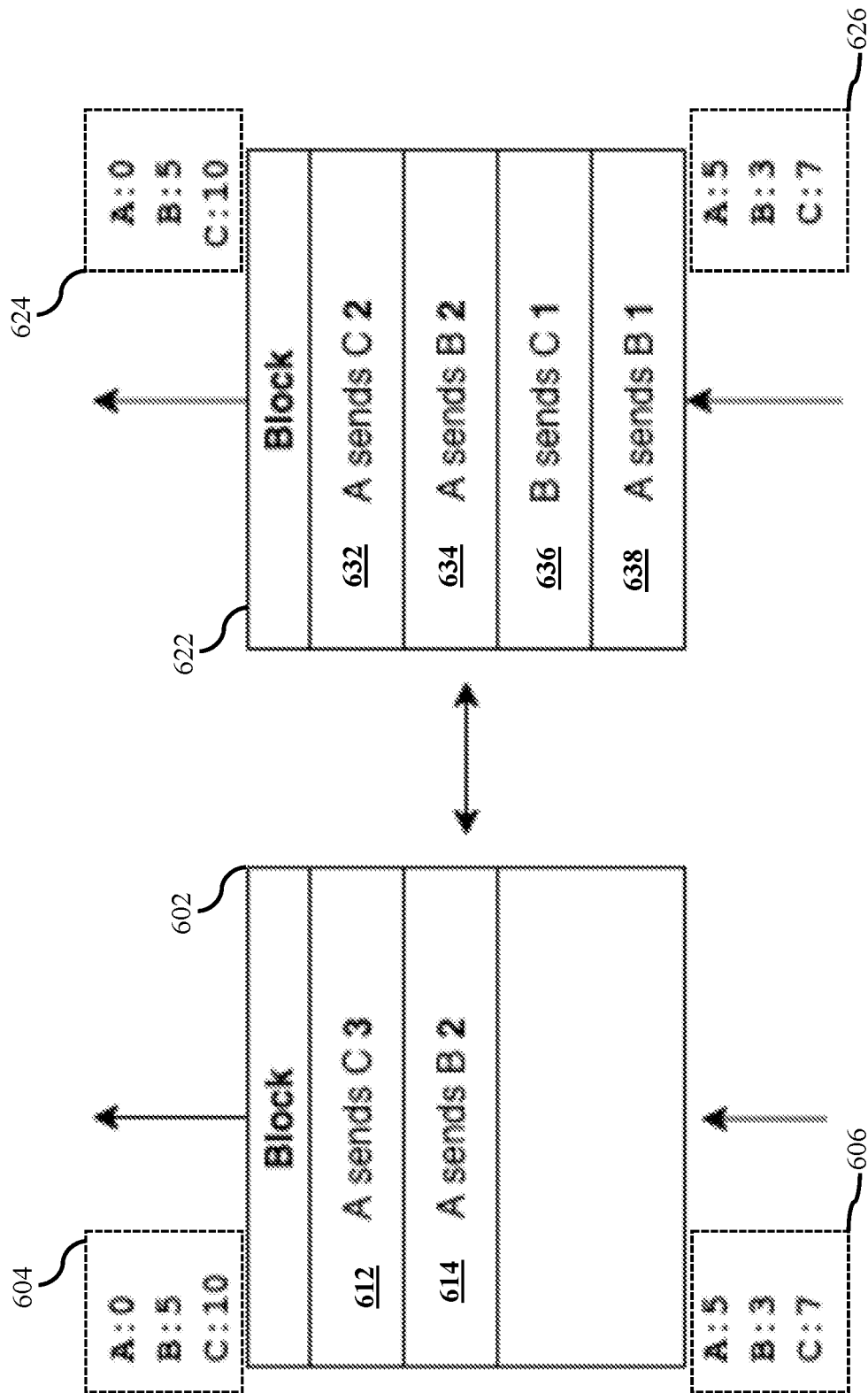


FIG. 6

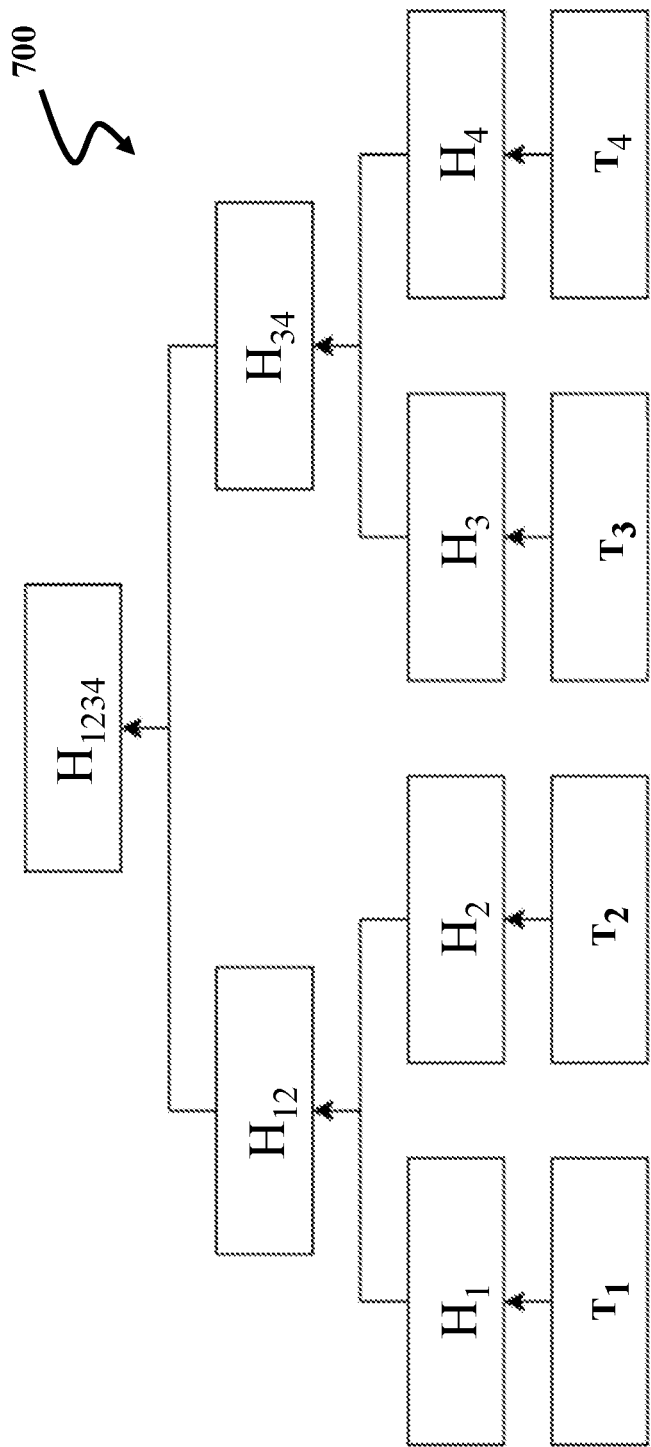


FIG. 7A

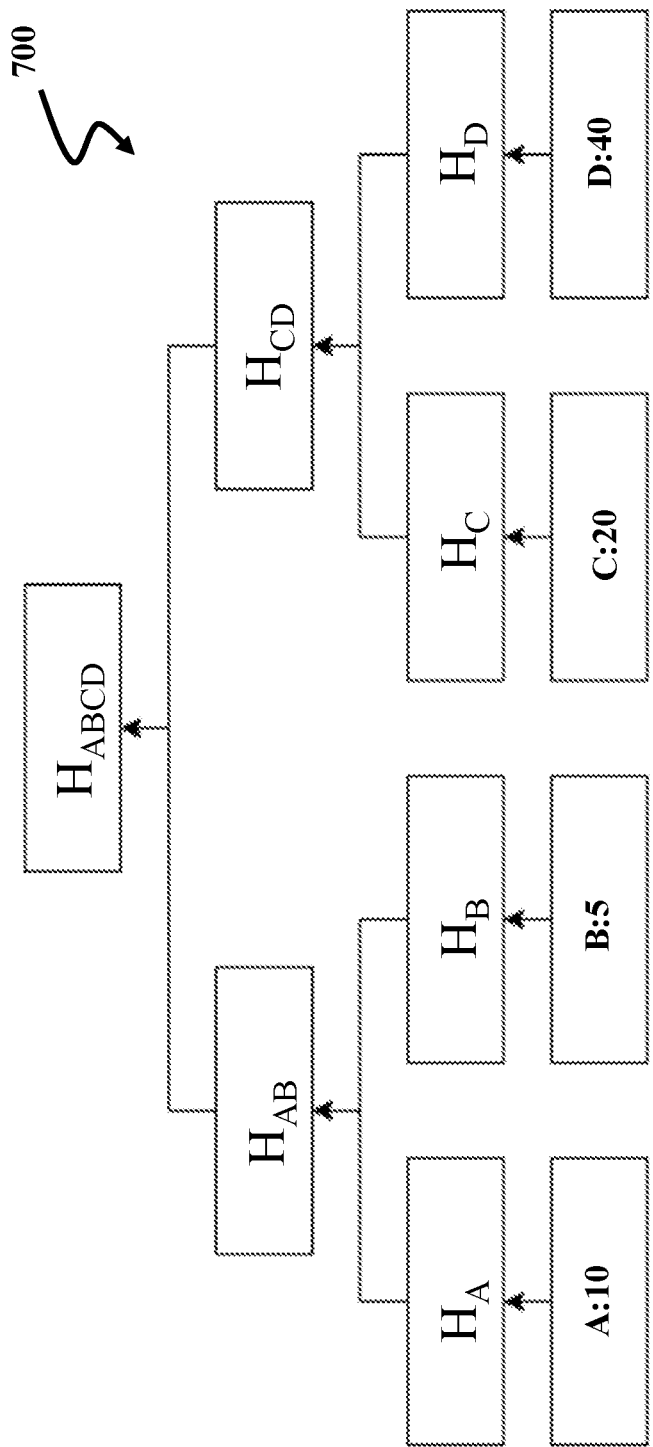
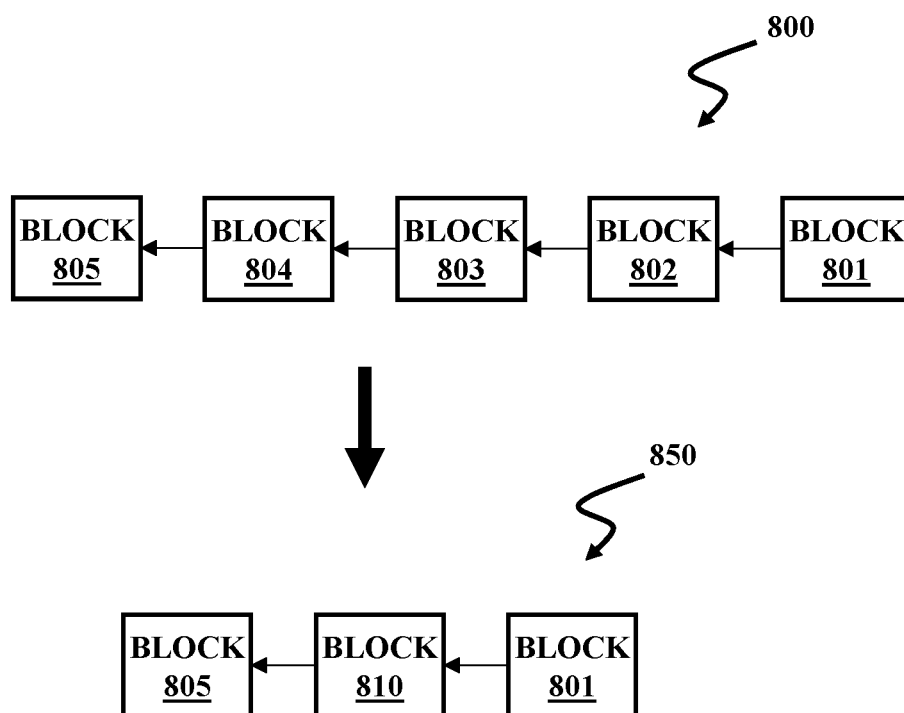
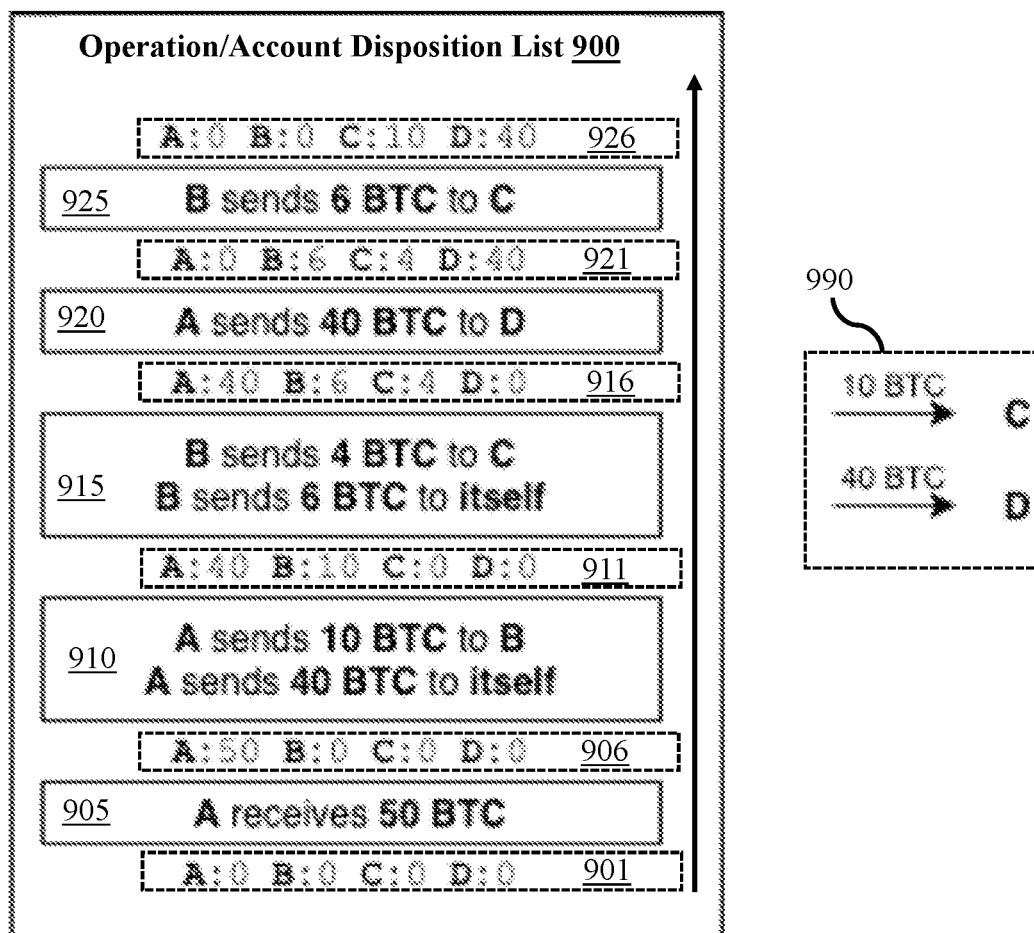


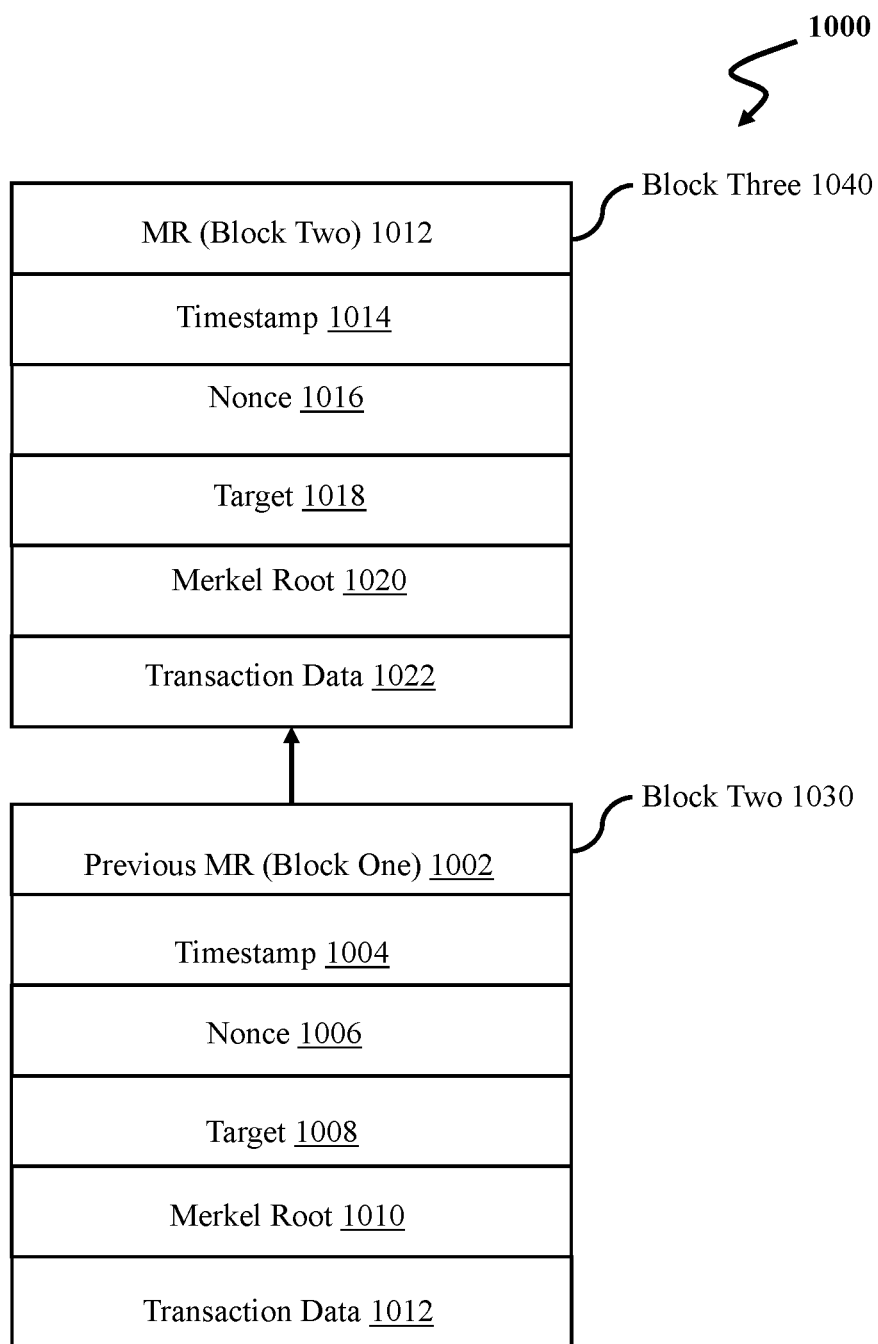
FIG. 7B

**FIG. 8**

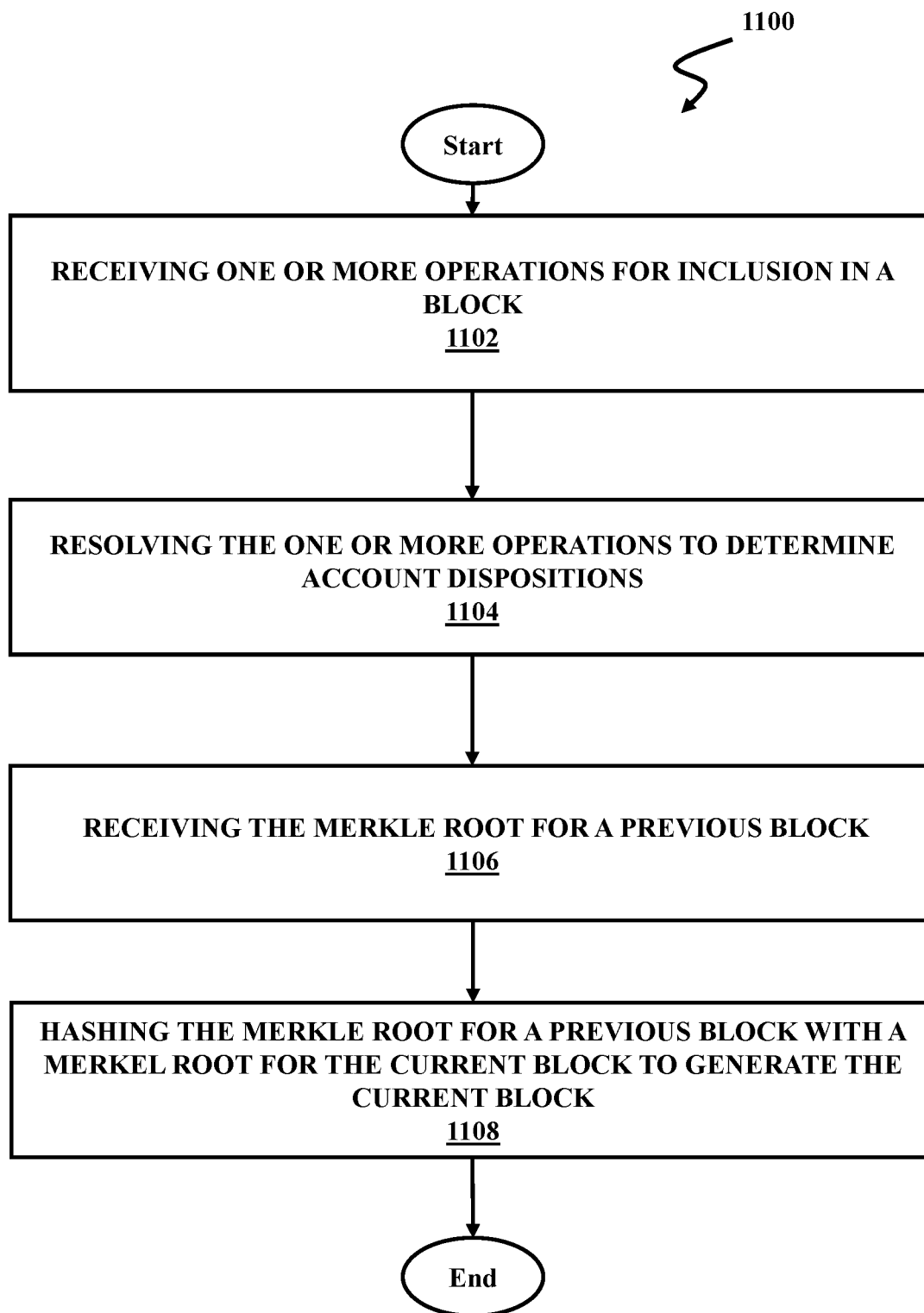


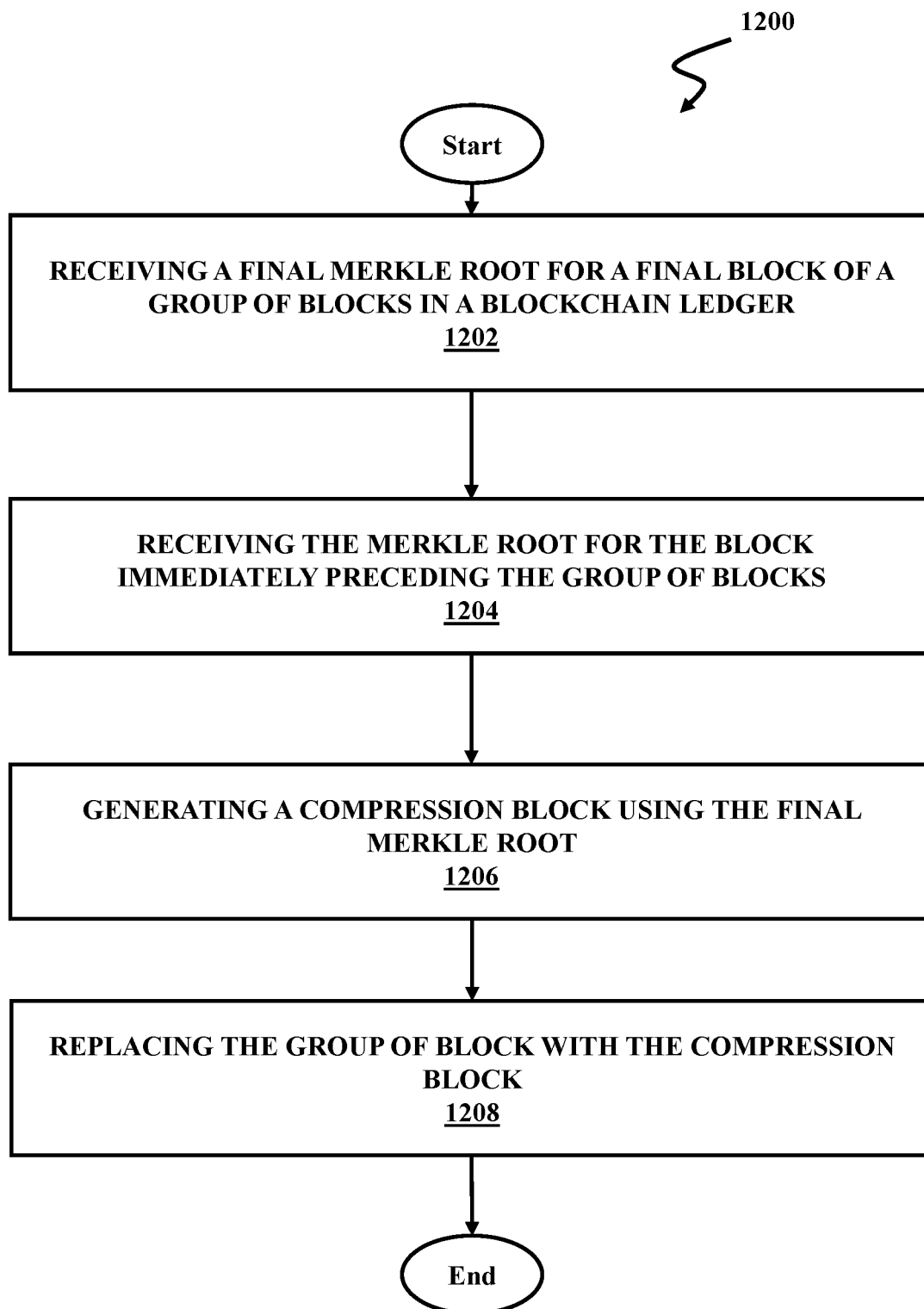


**FIG. 9**



**FIG. 10**

**FIG. 11**

**FIG. 12**

## COMPRESSIBLE BLOCKCHAINS

### BACKGROUND

[0001] The present disclosure relates to generating a blockchain network, and more specifically to compressible blockchains.

[0002] A blockchain is a list of cryptographically linked records, called blocks. Blockchain networks may be used to regulate different types of operations by a variety of parties.

### SUMMARY

[0003] Embodiments of the present disclosure include a system, method, and computer program product for compressible blockchains.

[0004] Embodiments of the present disclosure include a system comprising a memory, and a processor in communication with the memory, the processor being configured to perform operations comprising invoke a process comprising receiving one or more operations for inclusion in a block, receiving a previous Merkle root created from previously determined account dispositions from a previous block, resolving the one or more operations based on the previous account dispositions to determine one or more current account dispositions, creating a current Merkle root for the one or more current account dispositions, and hashing current data for the current block, the data comprising the current Merkle root and the previous Merkle root to generate an account disposition block.

[0005] Additional embodiments of the present disclosure include a method comprising invoke a process comprising receiving one or more operations for inclusion in a block, receiving a previous Merkle root created from previously determined account dispositions from a previous block, resolving the one or more operations based on the previous account dispositions to determine one or more current account dispositions, creating a current Merkle root for the one or more current account dispositions, and hashing current data for the current block, the data comprising the current Merkle root and the previous Merkle root to generate an account disposition block.

[0006] Further embodiments of the present disclosure include a computer program product comprising a computer readable storage medium having program instructions embodied therewith, the program instructions executable by a processor to cause the processors to perform a method, the method comprising invoke a process comprising receiving one or more operations for inclusion in a block, receiving a previous Merkle root created from previously determined account dispositions from a previous block, resolving the one or more operations based on the previous account dispositions to determine one or more current account dispositions, creating a current Merkle root for the one or more current account dispositions, and hashing current data for the current block, the data comprising the current Merkle root and the previous Merkle root to generate an account disposition block.

[0007] The above summary is not intended to describe each illustrated embodiment or every implementation of the present disclosure.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The drawings included in the present disclosure are incorporated into, and form part of, the specification. They

illustrate embodiments of the present disclosure and, along with the description, serve to explain the principles of the disclosure. The drawings are only illustrative of certain embodiments and do not limit the disclosure.

[0009] FIG. 1 illustrates a network diagram of a system including a database, according to example embodiments.

[0010] FIG. 2A illustrates an example blockchain architecture configuration, according to example embodiments.

[0011] FIG. 2B illustrates a blockchain transactional flow, according to example embodiments.

[0012] FIG. 3A illustrates a permissioned network, according to example embodiments.

[0013] FIG. 3B illustrates another permissioned network, according to example embodiments.

[0014] FIG. 3C illustrates a permissionless network, according to example embodiments.

[0015] FIG. 4A illustrates a process for a new block being added to a distributed ledger, according to example embodiments.

[0016] FIG. 4B illustrates contents of a new data block, according to example embodiments.

[0017] FIG. 4C illustrates a blockchain for digital content, according to example embodiments.

[0018] FIG. 4D illustrates a block which may represent the structure of blocks in the blockchain, according to example embodiments.

[0019] FIG. 5 illustrates a high-level block diagram of an example computer system that may be used in implementing one or more of the methods, tools, and modules, and any related functions, described herein, in accordance with embodiments of the present disclosure.

[0020] FIG. 6 illustrates a visual depiction two example blocks which may be considered equivalent, according to example embodiments.

[0021] FIG. 7A illustrates an example of calculating the Merkle root of a block with operations, according to example embodiments.

[0022] FIG. 7B illustrates an example of calculating the Merkle root of a block with the account dispositions after the block operations have been executed, according to example embodiments.

[0023] FIG. 8 depicts an example network before and after compression, according to example embodiments.

[0024] FIG. 9 depicts an operation/account disposition list of operations which must be resolved to yield the respective account balances, according to example embodiments.

[0025] FIG. 10 depicts two example account disposition blocks, according to example embodiments.

[0026] FIG. 11 illustrates a flowchart of an example method for using account dispositions blocks in a blockchain network, according to example embodiments.

[0027] FIG. 12 illustrates a flowchart of an example for using compression blocks in a blockchain network, according to example embodiments.

[0028] While the embodiments described herein are amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the particular embodiments described are not to be taken in a limiting sense. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure.

## DETAILED DESCRIPTION

[0029] Aspects of the present disclosure relate to processing of operations on a blockchain network, and more specifically to generating a compressible blockchain network.

[0030] It will be readily understood that the instant components, as generally described and illustrated in the figures herein, may be arranged and designed in a wide variety of different configurations. Accordingly, the following detailed description of the embodiments of at least one of a method, apparatus, non-transitory computer readable medium and system, as represented in the attached figures, is not intended to limit the scope of the application as claimed but is merely representative of selected embodiments.

[0031] The instant features, structures, or characteristics as described throughout this specification may be combined or removed in any suitable manner in one or more embodiments. For example, the usage of the phrases “example embodiments,” “some embodiments,” or other similar language, throughout this specification refers to the fact that a particular feature, structure, or characteristic described in connection with the embodiment may be included in at least one embodiment. Accordingly, appearances of the phrases “example embodiments,” “in some embodiments,” “in other embodiments,” or other similar language, throughout this specification do not necessarily all refer to the same group of embodiments, and the described features, structures, or characteristics may be combined or removed in any suitable manner in one or more embodiments. Further, in the FIGS., any connection between elements can permit one-way and/or two-way communication even if the depicted connection is a one-way or two-way arrow. Also, any device depicted in the drawings can be a different device. For example, if a mobile device is shown sending information, a wired device may also be used to send the information.

[0032] In addition, while the term “message” may have been used in the description of embodiments, the application may be applied to many types of networks and data. Furthermore, while certain types of connections, messages, and signaling may be depicted in exemplary embodiments, the application is not limited to a certain type of connection, message, and signaling.

[0033] In some embodiments, the method, system, and/or computer program product utilize a decentralized database (such as a blockchain) that is a distributed storage system, which includes multiple nodes that communicate with each other. The decentralized database includes an append-only immutable data structure resembling a distributed ledger capable of maintaining records between mutually untrusted parties. The untrusted parties are referred to herein as peers or peer nodes. Each peer maintains a copy of the database records, and no single peer can modify the database records without a consensus being reached among the distributed peers. For example, the peers may execute a consensus protocol to validate blockchain storage transactions, group the storage transactions into blocks, and build a hash chain over the blocks. This process forms the ledger by ordering the storage transactions, as is necessary, for consistency.

[0034] In various embodiments, a permissioned and/or a permission-less blockchain can be used. In a public or permission-less blockchain, anyone can participate without a specific identity (e.g., retaining anonymity). Public blockchains can involve native cryptocurrency and use consensus based on various protocols such as Proof of Work. On the other hand, a permissioned blockchain database provides

secure interactions among a group of entities which share a common goal but which do not fully trust one another, such as businesses that exchange funds, goods, information, and the like.

[0035] Further, in some embodiments, the method, system, and/or computer program product can utilize a blockchain that operates arbitrary, programmable logic, tailored to a decentralized storage scheme and referred to as “smart contracts” or “chaincodes.” In some cases, specialized chaincodes may exist for management functions and parameters which are referred to as system chaincode. The method, system, and/or computer program product can further utilize smart contracts that are trusted distributed applications which leverage tamper-proof properties of the blockchain database and an underlying agreement between nodes, which is referred to as an endorsement or endorsement policy. Blockchain transactions associated with this application can be “endorsed” before being committed to the blockchain, while transactions which are not endorsed are disregarded.

[0036] An endorsement policy allows chaincode to specify endorsers for a transaction in the form of a set of peer nodes that are necessary for endorsement. When a client sends the transaction to the peers specified in the endorsement policy, the transaction is executed to validate the transaction. After validation, the transactions enter an ordering phase in which a consensus protocol is used to produce an ordered sequence of endorsed transactions grouped into blocks.

[0037] In some embodiments, the method, system, and/or computer program product can utilize nodes that are the communication entities of the blockchain system. A “node” may perform a logical function in the sense that multiple nodes of different types can run on the same physical server. Nodes are grouped in trust domains and are associated with logical entities that control them in various ways. Nodes may include different types, such as a client or submitting-client node which submits a transaction-invocation to an endorser (e.g., peer) and broadcasts transaction-proposals to an ordering service (e.g., ordering node).

[0038] Another type of node is a peer node which can receive client submitted transactions, commit the transactions and maintain a state and a copy of the ledger of blockchain transactions. Peers can also have the role of an endorser, although it is not a requirement. An ordering-service-node or orderer is a node running the communication service for all nodes. In some instances, an ordering service node implements a delivery guarantee, such as a broadcast to each of the peer nodes in the system when committing/confirming transactions and modifying a world state of the blockchain. World state is another name for the initial blockchain transaction which normally includes control and setup information.

[0039] In some embodiments, the method, system, and/or computer program product can utilize a ledger that is a sequenced, tamper-resistant record of all state transitions of a blockchain. State transitions may result from chaincode invocations (e.g., transactions) submitted by participating parties (e.g., client nodes, ordering nodes, endorser nodes, peer nodes, etc.). Each participating party (such as a peer node) can maintain a copy of the ledger. In some embodiments, a participating party is a party (e.g., an organization with nodes on a blockchain network) that is involved in an operation. A transaction may result in a set of asset key-

value pairs being committed to the ledger as one or more operands, such as creates, updates, deletes, and the like. The ledger includes a blockchain (also referred to as a chain) which is used to store an immutable, sequenced record in blocks. The ledger also includes a state database which maintains a current state of the blockchain.

**[0040]** In some embodiments, the method, system, and/or computer program product described herein can utilize a chain that is a transaction log that is structured as hash-linked blocks, and each block contains a sequence of N transactions where N is equal to or greater than one. The block header includes a hash of the block's transactions, as well as a hash of the prior block's header. In this way, all transactions on the ledger may be sequenced and cryptographically linked together. Accordingly, it is not possible to tamper with the ledger data without breaking the hash links. A hash of a most recently added blockchain block represents every transaction on the chain that has come before it, making it possible to ensure that all peer nodes are in a consistent and trusted state. The chain may be stored on a peer node file system (e.g., local, attached storage, cloud, etc.), efficiently supporting the append-only nature of the blockchain workload.

**[0041]** The current state of the immutable ledger represents the latest values for all keys that are included in the chain transaction log. Since the current state represents the latest key values known to a channel, it is sometimes referred to as a world state. Chaincode invocations execute transactions against the current state data of the ledger. To make these chaincode interactions efficient, the latest values of the keys may be stored in a state database. The state database may be simply an indexed view into the chain's transaction log; it can therefore be regenerated from the chain at any time. The state database may automatically be recovered (or generated if needed) upon peer node startup and before transactions are accepted.

**[0042]** Blockchain is different from a traditional database in that blockchain is not a central storage, but rather a decentralized, immutable, and secure storage, where nodes may share in changes to records in the storage. Some properties that are inherent in blockchain and which help implement the blockchain include, but are not limited to, an immutable ledger, smart contracts, security, privacy, decentralization, consensus, endorsement, accessibility, and the like, which are further described herein.

**[0043]** In particular, the blockchain ledger data is immutable, and that provides for an efficient method for processing operations in blockchain networks. Also, use of the encryption in the blockchain provides security and builds trust. The smart contract manages the state of the asset to complete the life-cycle, thus specialized nodes may ensure that blockchain operations with anonymity requirements are able to securely submit operations to the blockchain network. The example blockchains are permission decentralized. Thus, each end user may have its own ledger copy to access. Multiple organizations (and peers) may be on-boarded on the blockchain network. The key organizations may serve as endorsing peers to validate the smart contract execution results, read-set and write-set. In other words, the blockchain inherent features provide for efficient implementation of processing a private transaction in a blockchain network.

**[0044]** One of the benefits of the example embodiments is that they improve the functionality of a computing system

by implementing a method for processing a private transaction in a blockchain network. Through the blockchain system described herein, a computing system (or a processor in the computing system) can perform functionality for private transaction processing utilizing blockchain networks by providing access to capabilities such as distributed ledger, peers, encryption technologies, MSP, event handling, etc. Also, the blockchain enables creating a business network and making any users or organizations to on-board for participation. As such, the blockchain is not just a database. The blockchain comes with capabilities to create a network of users and on-board/off-board organizations to collaborate and execute service processes in the form of smart contracts.

**[0045]** Meanwhile, a traditional database may not be useful to implement the example embodiments because a traditional database does not bring all parties on the network, a traditional database does not create trusted collaboration, and a traditional database does not provide for an efficient method of securely and efficiently submitting operations. The traditional database does not provide for a tamper proof storage and does not provide for guaranteed valid transactions. Accordingly, the example embodiments provide for a specific solution to a problem in the arts/field of anonymously submitting operations in a blockchain network.

**[0046]** FIG. 1 illustrates a logic network diagram 100 for smart data annotation in blockchain networks, according to example embodiments.

**[0047]** Referring to FIG. 1, the example network 100 includes a node 102 connected to other blockchain (BC) nodes 105 representing document-owner organizations. The node 102 may be connected to a blockchain 106 that has a ledger 108 for storing data to be shared 110 among the nodes 105. While this example describes in detail only one node 102, multiple such nodes may be connected to the blockchain 106. It should be understood that the node 102 may include additional components and that some of the components described herein may be removed and/or modified without departing from a scope of the node 102 disclosed herein. The node 102 may be a computing device or a server computer, or the like, and may include a processor 104, which may be a semiconductor-based microprocessor, a central processing unit (CPU), an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), and/or another hardware device. Although a single processor 104 is depicted, it should be understood that the node 102 may include multiple processors, multiple cores, or the like, without departing from the scope of the node 102 system. A distributed file storage 150 may be accessible to processor node 102 and other BC nodes 105. The distributed file storage 150 may be used to store documents identified in ledger 108.

**[0048]** The node 102 may also include a non-transitory computer readable medium 112 that may have stored thereon machine-readable instructions executable by the processor 104. Examples of the machine-readable instructions are shown as 114-118 and are further discussed below. Examples of the non-transitory computer readable medium 112 may include an electronic, magnetic, optical, or other physical storage device that contains or stores executable instructions. For example, the non-transitory computer readable medium 112 may be a Random Access memory (RAM), an Electrically Erasable Programmable Read-Only Memory (EEPROM), a hard disk, an optical disc, or other type of storage device.

[0049] The processor 104 may execute machine-readable instructions 114 of receiving one or more operations for inclusion in a block. As discussed above, the blockchain ledger 108 may store data to be shared 110 among the nodes 105. The blockchain 106 network may be configured to use one or more smart contracts that manage transactions for multiple participating nodes. Documents linked to the annotation information may be stored in distributed file storage 150. The processor 104 may execute machine-readable instructions 116 of resolving the one or more operations to determine account dispositions. The processor 104 may execute machine-readable instructions of receiving the Merkle root for a previous block.

[0050] FIG. 2A illustrates a blockchain architecture configuration 200, according to example embodiments. Referring to FIG. 2A, the blockchain architecture 200 may include certain blockchain elements, for example, a group of blockchain nodes 202. The blockchain nodes 202 may include one or more peer nodes 204, 206, 208 210 (these four nodes are depicted by example only). These nodes participate in a number of activities, such as blockchain transaction addition and validation processes (consensus). One or more of the blockchain nodes 204-210 may endorse transactions based on an endorsement policy and may provide an ordering service for all blockchain nodes 202 in the architecture 200. A blockchain node 204-210 may initiate a blockchain authentication and seek to write to a blockchain immutable ledger stored in blockchain layer 216, a copy of which may also be stored on an underpinning physical infrastructure 214. The blockchain configuration 200 may include one or more applications 224 which are linked to application programming interfaces (APIs) 222 to access and execute stored program/application code 220 (e.g., chaincode, smart contracts, etc.) which can be created according to a customized configuration sought by participants and can maintain the participant's own state, control the participant's own assets, and receive external information. This can be deployed as a transaction and installed, via appending to the distributed ledger, on all blockchain nodes 204-210.

[0051] A blockchain base or platform 212 may include various layers of blockchain data, services (e.g., cryptographic trust services, virtual execution environment, etc.), and underpinning physical computer infrastructure 214 that may be used to receive and store new transactions and provide access to auditors which are seeking to access data entries. The blockchain layer 216 may expose an interface that provides access to the virtual execution environment necessary to process the program code 220 and engage the physical infrastructure 214. Cryptographic trust services 218 may be used to verify transactions such as asset exchange transactions and keep information private.

[0052] The blockchain architecture configuration 200 of FIG. 2A may process and execute program/application code 220 via one or more interfaces exposed, and services provided, by blockchain platform 212. The code 220 may control blockchain assets. For example, the code 220 can store and transfer data, and may be executed by nodes 204-210 in the form of a smart contract and associated chaincode with conditions or other code elements subject to its execution. As a non-limiting example, smart contracts may be created to execute reminders, updates, and/or other notifications subject to the changes, updates, etc. The smart contracts can themselves be used to identify rules associated

with authorization and access requirements and usage of the ledger. For example, document attribute(s) information 226 may be processed by one or more processing entities (e.g., virtual machines) included in the blockchain layer 216. Results 228 of this processing may include a plurality of linked shared documents. The physical infrastructure 214 may be utilized to retrieve any of the data or information described herein.

[0053] A smart contract may be created via a high-level application and programming language, and then written to a block in the blockchain. The smart contract may include executable code which is registered, stored, and/or replicated with a blockchain (e.g., distributed network of blockchain peers). A transaction is an execution of the smart contract code which can be performed in response to conditions associated with the smart contract being satisfied. The executing of the smart contract may trigger a trusted modification(s) to a state of a digital blockchain ledger. The modification(s) to the blockchain ledger caused by the smart contract execution may be automatically replicated throughout the distributed network of blockchain peers through one or more consensus protocols.

[0054] The smart contract may write data to the blockchain in the format of key-value pairs. Furthermore, the smart contract code can read the values stored in a blockchain and use them in application operations. The smart contract code can write the output of various logic operations into the blockchain. The code may be used to create a temporary data structure in a virtual machine or other computing platform. Data written to the blockchain can be public and/or can be encrypted and maintained as private. The temporary data that is used/generated by the smart contract is held in memory by the supplied execution environment, then deleted once the data needed for the blockchain is identified.

[0055] A chaincode may include the code interpretation of a smart contract, with additional features. As described herein, the chaincode may be program code deployed on a computing network, where it is executed and validated by chain validators together during a consensus process. The chaincode receives a hash and retrieves from the blockchain a hash associated with the data template created by use of a previously stored feature extractor. If the hashes of the hash identifier and the hash created from the stored identifier template data match, then the chaincode sends an authorization key to the requested service. The chaincode may write to the blockchain data associated with the cryptographic details.

[0056] FIG. 2B illustrates an example of a blockchain transactional flow 250 between nodes of a blockchain (e.g., blockchain 106 illustrated in FIG. 1), in accordance with an example embodiment. Referring to FIG. 2B, a general description of the transactional flow 250 will be given followed by a more specific example. The transactional flow 250 may include a transaction proposal 291 sent by an application client node 260 to a first endorsing peer node 281. The first endorsing peer 281 may verify a client signature and execute a chaincode function to initiate the transaction. The output may include the chaincode results, a set of key/value versions that were read in the chaincode (read set), and the set of keys/values that were written in chaincode (write set). A proposal response 292 is sent back to the client 260 along with an endorsement signature, if approved. The client 260 assembles the endorsements into a



transaction payload **293** and broadcasts it to an ordering service (fourth peer) node **284**. The ordering service node **284** then delivers ordered transactions as blocks to all additional peers **281**, **282**, and **283** on the same channel. Before committal to the blockchain, each additional peer **281-283** may validate the transaction. For example, the peers **281-283** may check the endorsement policy to ensure that the correct allotment of the peers specified in transaction proposal **291** have signed the results and authenticated the signatures against the transaction payload **293**. In some embodiments, one or more of the peers may be manager nodes.

**[0057]** A more specific description of transactional flow **250** can be understood with a more specific example. To begin, the client node **260** initiates the transaction proposal **291** by constructing and sending a request to the first peer node **281**, which is an endorser. The client **260** may include an application leveraging a supported software development kit (SDK), which utilizes an available API to generate a transaction proposal. The proposal is a request to invoke a chaincode function so that data can be read and/or written to the ledger (i.e., write new key value pairs for the assets). The SDK may serve as a shim to package the transaction proposal into a properly architected format (e.g., protocol buffer over a remote procedure call (RPC)) and take the client's cryptographic credentials to produce a unique signature for the transaction proposal.

**[0058]** In response, the endorsing peer node **281** may verify (a) that the transaction proposal is well formed, (b) the transaction has not been submitted already in the past (replay-attack protection), (c) the signature is valid, and (d) that the submitter (client **260**, in the example) is properly authorized to perform the proposed operation on that channel. The endorsing peer node **281** may take the transaction proposal inputs as arguments to the invoked chaincode function. The chaincode is then executed against a current state database to produce transaction results including a response value, read set, and write set. However, no updates are made to the ledger at this point. The set of transaction results, along with the endorsing peer node's **281** signature is passed back as a proposal response **292** to the SDK of the client **260** which parses the payload for the application to consume.

**[0059]** In response, the application of the client **260** inspects/verifies the endorsing peer's **281** signature and compares the proposal response **292** to determine if the proposal response **292** is valid. If the chaincode only queried the ledger, the application would inspect the query response and would typically not submit the transaction to the ordering service node **284**. If the client application intends to submit the transaction to the ordering service node **284** to update the ledger, the application determines if the specified endorsement policy has been fulfilled before submitting (i.e., did all peer nodes necessary for the transaction endorse the transaction). Here, the client **260** may include only one of multiple parties to the transaction. In this case, each client may have their own endorsing node, and each endorsing node may need to endorse the transaction. The architecture is such that even if an application selects not to inspect responses or otherwise forwards an unendorsed transaction, the endorsement policy may still be enforced by peers and upheld at the commit validation phase.

**[0060]** After successful inspection, the client **260** assembles endorsements into a transaction **293** and broad-

casts the transaction proposal and response within a transaction message to the ordering node **284**. The transaction **293** may contain the read/write sets, the endorsing peer's signatures and a channel ID. The ordering node **284** does not need to inspect the entire content of a transaction in order to perform its operation. Instead, the ordering node **284** may simply receive transactions from all channels in the network, order them chronologically by channel, and create blocks of transactions per channel.

**[0061]** The blocks of the transaction **293** are delivered from the ordering node **284** to all other peer nodes **281-283** on the channel. Transactions **294** within the block are validated to ensure any endorsement policy is fulfilled and to ensure that there have been no changes to ledger state for read set variables since the read set was generated by the transaction execution. Transactions **294** in the block are tagged as being valid or invalid. Furthermore, in operation **295** each peer node **281-283** appends the block to the channel's chain, and for each valid transaction the write sets are committed to current state database. An event is emitted to notify the client application that the transaction (invocation) **293** has been immutably appended to the chain, as well as to notify whether the transaction **293** was validated or invalidated.

**[0062]** FIG. 3A illustrates an example of a permissioned blockchain network **300**, in accordance with an example embodiment, which features a distributed, decentralized peer-to-peer architecture. In this example, a blockchain user **302** may initiate a transaction to a permissioned blockchain **304**. In this example, the transaction can be a deploy, invoke, or query, and may be issued through a client-side application leveraging an SDK, directly through an API, etc. The network **300** may provide access to a regulator **306**, such as an auditor. A blockchain network operator **308** manages member permissions, such as enrolling the regulator **306** as an "auditor" and the blockchain user **302** as a "client." An auditor may be restricted only to querying the ledger whereas a client may be authorized to deploy, invoke, and query certain types of chaincode.

**[0063]** A blockchain developer **310** can write chaincode and client-side applications. The blockchain developer **310** can deploy chaincode directly to the network **300** through an interface. To include credentials from a traditional data source **312** in chaincode, the developer **310** may use an out-of-band connection to access the data. In this example, the blockchain user **302** connects to the permissioned blockchain **304** through one of peer nodes **314** (referring to any one of nodes **314a-e**). Before proceeding with any transactions, the peer node **314** (e.g., node **314a**) retrieves the user's **302** enrollment and transaction certificates from a certificate authority **316**, which manages user roles and permissions. In some cases, blockchain users must possess these digital certificates in order to transact on the permissioned blockchain **304**. Meanwhile, a user attempting to utilize chaincode may be required to verify their credentials on the traditional data source **312**. To confirm the user's **302** authorization, chaincode can use an out-of-band connection to this data through a traditional processing platform **318**.

**[0064]** FIG. 3B illustrates another example of a permissioned blockchain network **320**, in accordance with an example embodiment, which features a distributed, decentralized peer-to-peer architecture. In this example, a blockchain user **322** may submit a transaction to a permissioned blockchain **324**. In this example, the transaction can be a

deploy, invoke, or query, and may be issued through a client-side application leveraging an SDK, directly through an API, etc. Networks may provide access to a regulator 326, such as an auditor. A blockchain network operator 328 manages member permissions, such as enrolling the regulator 326 as an “auditor” and the blockchain user 322 as a “client.” An auditor may be restricted to only querying the ledger whereas a client may be authorized to deploy, invoke, and query certain types of chaincode.

**[0065]** A blockchain developer 330 writes chaincode and client-side applications. The blockchain developer 330 can deploy chaincode directly to the network through an interface. To include credentials from a traditional data source 332 in chaincode, the developer 330 may use an out-of-band connection to access the data. In this example, the blockchain user 322 connects to the network through a peer node 334 (referring to any one of nodes 334a-e). Before proceeding with any transactions, the peer node 334 (e.g., node 334a) retrieves the user’s enrollment and transaction certificates from a certificate authority 336. In some cases, blockchain users must possess these digital certificates in order to transact on the permissioned blockchain 324. Meanwhile, a user attempting to utilize chaincode may be required to verify their credentials on the traditional data source 332. To confirm the user’s authorization, chaincode can use an out-of-band connection to this data through a traditional processing platform 338.

**[0066]** In some embodiments of the present disclosure, a blockchain herein may be a permissionless blockchain. In contrast with permissioned blockchains (e.g., blockchains 304 and 324) which require permission to join, anyone can join a permissionless blockchain. For example, to join a permissionless blockchain a user may create a personal address and begin interacting with the network by submitting transactions, and hence adding entries to the ledger. Additionally, all parties have the choice of running a node on the system and employing the mining protocols to help verify transactions.

**[0067]** FIG. 3C illustrates a network 350 with a transaction being processed by a permissionless blockchain 352 including a plurality of nodes 354, in accordance with an example embodiment. A sender 356 desires to send payment or some other form of value (e.g., a deed, medical records, a contract, a good, a service, or any other asset that can be encapsulated in a digital record) to a recipient 358 via the permissionless blockchain 352. In some embodiments, each of the sender device 356 and the recipient device 358 may have digital wallets (associated with the blockchain 352) that provide user interface controls and a display of transaction parameters. In response, the transaction is broadcast throughout the blockchain 352 to the nodes 354 (referring to any one of nodes 354a-e).

**[0068]** Depending on the blockchain’s 352 network parameters the nodes use verification module 360 to verify the transaction based on rules (which may be pre-defined or dynamically allocated) established by the permissionless blockchain 352 creators. For example, this may include verifying identities of the parties involved, etc. The transaction may be verified immediately or it may be placed in a queue with other transactions and the nodes 354 determine if the transactions are valid based on a set of network rules.

**[0069]** In structure 362, valid transactions are formed into a block and sealed with a lock (hash). This process may be performed by mining nodes among the nodes 354. Mining

nodes may utilize additional software specifically for mining and creating blocks for the permissionless blockchain 352. Each block may be identified by a hash (e.g., 256 bit number, etc.) created using an algorithm agreed upon by the network 350. Each block may include a header, a pointer or reference to a hash of a previous block’s header in the chain, and a group of valid transactions. The reference to the previous block’s hash is associated with the creation of the secure independent chain of blocks.

**[0070]** Before blocks can be added to the blockchain 352, the blocks must be validated. Validation for the permissionless blockchain 352 may include a proof-of-work (PoW) which is a solution to a puzzle derived from the block’s header. Although not shown in the example of FIG. 3C, another process for validating a block is proof-of-stake. Unlike the proof-of-work, where the algorithm rewards miners who solve mathematical problems, with the proof of stake, a creator of a new block is chosen in a deterministic way, depending on its wealth, also defined as “stake.” Then, a similar proof is performed by the selected/chosen node.

**[0071]** With mining module 364, nodes try to solve the block by making incremental changes to one variable until the solution satisfies a network-wide target. This creates the PoW thereby ensuring correct answers. In other words, a potential solution must prove that computing resources were drained in solving the problem. In some types of permissionless blockchains, miners may be rewarded with value (e.g., coins, etc.) for correctly mining a block.

**[0072]** Here, the PoW process, alongside the chaining of blocks, makes modifications to the blockchain 352 extremely difficult, as an attacker must modify all subsequent blocks in order for the modifications to one block to be accepted. Furthermore, as new blocks are mined, the difficulty of modifying a block increases, and the number of subsequent blocks increases. With a distribution module 366, the successfully validated block is distributed through the permissionless blockchain 352 and all nodes 354 add the block to a majority chain which is the permissionless blockchain’s 352 auditable ledger. Furthermore, the value in the transaction submitted by the sender 356 is deposited or otherwise transferred to the digital wallet of the recipient device 358.

**[0073]** FIG. 4A illustrates a blockchain system performing process 400 of a new block being added to a distributed ledger 420, according to example embodiments, and FIG. 4B illustrates contents of a new data block structure 430 for blockchain, according to example embodiments. The new data block 430 may contain document linking data.

**[0074]** Referring to FIG. 4A, clients (not shown) may submit transactions to blockchain nodes 411, 412, and/or 413 in process 400. Clients may be instructions received from any source to enact activity on the blockchain 422. As an example, clients may be applications that act on behalf of a requester, such as a device, person or entity to propose transactions for the blockchain 422. The plurality of blockchain peers (e.g., blockchain nodes 411, 412, and 413) may maintain a state of the blockchain network and a copy of the distributed ledger 420. Different types of blockchain nodes/peers may be present in the blockchain network including endorsing peers which simulate and endorse transactions proposed by clients and committing peers which verify endorsements, validate transactions, and commit transactions to the distributed ledger 420. In this example, each of

blockchain nodes **411**, **412**, and **413** may perform a role of endorser node, committer node, or both.

[0075] The distributed ledger **420** includes a blockchain which stores immutable, sequenced records in blocks (e.g., data blocks **423**, **424**, **425**, **426**, **427**, **428**, **429**, and **430**), and a state database **424** (current world state) maintaining a current state of the blockchain **422**. One distributed ledger **420** may exist per channel and each peer maintains its own copy of the distributed ledger **420** for each channel of which they are a member. The blockchain **422** is a transaction log, structured as hash-linked blocks where each block contains a sequence of N transactions. Blocks may include various components such as shown in FIG. 4B. The linking (shown by arrows in FIG. 4A) of the blocks (e.g., data blocks **423-430**) may be generated by adding a hash of a prior block's header within a block header of a current block. In this way, all transactions on the blockchain **422** are sequenced and cryptographically linked together preventing tampering with blockchain data without breaking the hash links. Furthermore, because of the links, the latest block (e.g., data block **430**) in the blockchain **422** represents every transaction that has come before it. The blockchain **422** may be stored on a peer file system (local or attached storage), which supports an append-only blockchain workload.

[0076] The current state of the blockchain **422** and the distributed ledger **420** may be stored in the state database **424**. Here, the current state data represents the latest values for all keys ever included in the chain transaction log of the blockchain **422**. Chaincode invocations execute transactions against the current state in the state database **424**. To make these chaincode interactions extremely efficient, the latest values of all keys are stored in the state database **424**. The state database **424** may include an indexed view into the transaction log of the blockchain **422**. It can therefore be regenerated from the chain at any time. The state database **424** may automatically get recovered (or generated if needed) upon peer startup, before transactions are accepted.

[0077] Endorsing nodes (**411**, **412**, and/or **413**) receive transactions from clients and endorse the transaction based on simulated results. Endorsing nodes hold smart contracts which simulate the transaction proposals. When an endorsing node endorses a transaction, the endorsing node creates a transaction endorsement which is a signed response from the endorsing node to the client application indicating the endorsement of the simulated transaction. The method of endorsing a transaction depends on an endorsement policy which may be specified within chaincode. An example of an endorsement policy is "the majority of endorsing peers must endorse the transaction." Different channels may have different endorsement policies. Endorsed transactions are forward by the client application to ordering service **410**.

[0078] The ordering service **410** accepts endorsed transactions, orders them into a block, and delivers the blocks to the committing peers. For example, the ordering service **410** may initiate a new block when a threshold of transactions has been reached, a timer times out, or another condition. In the example of FIG. 4A, blockchain node **412** is a committing peer that has received a new data block **430** for storage on blockchain **422**. The first block **423** in the blockchain **422** may be referred to as a genesis block which includes information about the blockchain, its members, the data stored therein, etc.

[0079] The ordering service **410** may be made up of a cluster of orderers. The ordering service **410** does not

process transactions, smart contracts, or maintain the shared ledger. Rather, the ordering service **410** may accept the endorsed transactions and specifies the order in which those transactions are committed to the distributed ledger **420**. The architecture of the blockchain network may be designed such that the specific implementation of 'ordering' (e.g., Solo, Kafka, Byzantine fault-tolerant, etc.) becomes a plug-gable component.

[0080] Transactions are written to the distributed ledger **420** in a consistent order. The order of transactions is established to ensure that the updates to the state database **424** are valid when they are committed to the network. Unlike a cryptocurrency blockchain system (e.g., Bitcoin, etc.) where ordering occurs through the solving of a cryptographic puzzle, or mining, in this example the parties of the distributed ledger **420** may choose the ordering mechanism that best suits that network.

[0081] When the ordering service **410** initializes a new data block **430**, the new data block **430** may be broadcast to committing peers (e.g., blockchain nodes **411**, **412**, and **413**). In response, each committing peer validates the transaction within the new data block **430** by checking to make sure that the read set and the write set still match the current world state in the state database **424**. Specifically, the committing peer can determine whether the read data that existed when the endorsers simulated the transaction is identical to the current world state in the state database **424**. When the committing peer validates the transaction, the transaction is written to the blockchain **422** on the distributed ledger **420**, and the state database **424** is updated with the write data from the read-write set. If a transaction fails, that is, if the committing peer finds that the read-write set does not match the current world state in the state database **424**, the transaction ordered into a block may still be included in that block, but it may be marked as invalid, and the state database **424** may not be updated.

[0082] Referring to FIG. 4B, the new data block **430** (also referred to as a data block) that is stored on the blockchain **422** of the distributed ledger **420** may include multiple data segments such as a block header **440**, block data **450**, and block metadata **460**. It should be appreciated that the various depicted blocks and their contents, such as new data block **430** and its contents. Shown in FIG. 4B are merely examples and are not meant to limit the scope of the example embodiments. The new data block **430** may store transactional information of N transaction(s) (e.g., 1, 10, 100, 500, 1000, 2000, 3000, etc.) within the block data **450**. The new data block **430** may also include a link to a previous block (e.g., on the blockchain **422** in FIG. 4A) within the block header **440**. In particular, the block header **440** may include a hash of a previous block's header. The block header **440** may also include a unique block number (e.g., data block **423-430**), a hash of the block data **450** of the new data block **430**, and the like. The block number of the new data block **430** may be unique and assigned in various orders, such as an incremental/sequential order starting from zero.

[0083] The block data **450** may store transactional information of each transaction that is recorded within the new data block **430**. For example, the transaction data may include one or more of a type of the transaction, a version, a timestamp, a channel ID of the distributed ledger **420**, a transaction ID, an epoch, a payload visibility, a chaincode path (deploy transaction), a chaincode name, a chaincode version, input (chaincode and functions), a client (creator)

identify such as a public key and certificate, a signature of the client, identities of endorser, endorser signatures, a proposal hash, chaincode events, response status, namespace, a read set (list of key and version read by the transaction, etc.), a write set (list of key and value, etc.), a start key, an end key, a list of keys, a Merkle tree query summary, and the like. The transaction data may be stored for each of the N transactions.

**[0084]** In some embodiments, the block data **450** may also store new data **462** which adds additional information to the hash-linked chain of blocks in the blockchain **422**. The additional information includes one or more of the steps, features, processes and/or actions described or depicted herein. Accordingly, the new data **462** can be stored in an immutable log of blocks on the distributed ledger **420**. Some of the benefits of storing such new data **462** are reflected in the various embodiments disclosed and depicted herein. Although in FIG. **4B** the new data **462** is depicted in the block data **450**, it may also be located in the block header **440** or the block metadata **460**. The new data **462** may include a document composite key that is used for linking the documents within an organization.

**[0085]** The block metadata **460** may store multiple fields of metadata (e.g., as a byte array, etc.). Metadata fields may include signature on block creation, a reference to a last configuration block, a transaction filter identifying valid and invalid transactions within the block, last offset persisted of an ordering service that ordered the block, and the like. The signature, the last configuration block, and the orderer metadata may be added by the ordering service **410**. Meanwhile, a committer of the block (such as blockchain node **412**) may add validity/invalidity information based on an endorsement policy, verification of read/write sets, and the like. The transaction filter may include a byte array of a size equal to the number of transactions in the block data **450** and a validation code identifying whether a transaction was valid/invalid.

**[0086]** FIG. **4C** illustrates a blockchain **470** for digital content in accordance with some embodiments described herein. The digital content may include one or more files and associated information. The files may include media, images, video, audio, text, links, graphics, animations, web pages, documents, or other forms of digital content. The immutable, append-only aspects of the blockchain serve as a safeguard to protect the integrity, validity, and authenticity of the digital content, making it suitable for use in legal proceedings where admissibility rules apply or other settings where evidence is taken in to consideration or where the presentation and use of digital information is otherwise of interest. In this case, the digital content may be referred to as digital evidence.

**[0087]** The blockchain may be formed in various ways. In some embodiments, the digital content may be included in and accessed from the blockchain itself. For example, each block of the blockchain may store a hash value of reference information (e.g., header, value, etc.) along the associated digital content. The hash value and associated digital content may then be encrypted together. Thus, the digital content of each block may be accessed by decrypting each block in the blockchain, and the hash value of each block may be used as a basis to reference a previous block. This may be illustrated as follows:

Block 1	Block 2	...	Block N
Hash Value 1	Hash Value 2		Hash Value N
Digital Content 1	Digital Content 2		Digital Content N

**[0088]** In some embodiments, the digital content may be not included in the blockchain. For example, the blockchain may store the encrypted hashes of the content of each block without any of the digital content. The digital content may be stored in another storage area or memory address in association with the hash value of the original file. The other storage area may be the same storage device used to store the blockchain or may be a different storage area or even a separate relational database. The digital content of each block may be referenced or accessed by obtaining or querying the hash value of a block of interest and then looking up that has value in the storage area, which is stored in correspondence with the actual digital content. This operation may be performed, for example, a database gatekeeper. This may be illustrated as follows:

Blockchain	Storage Area
Block 1 Hash Value	Block 1 Hash Value . . . Content
.	.
.	.
Block N Hash Value	Block N Hash Value . . . Content

**[0089]** In the example embodiment of FIG. **4C**, the blockchain **470** includes a number of blocks **478<sub>1</sub>**, **478<sub>2</sub>**, . . . **478<sub>N</sub>** cryptographically linked in an ordered sequence, where  $N \geq 1$ . The encryption used to link the blocks **478<sub>1</sub>**, **478<sub>2</sub>**, . . . **478<sub>N</sub>** may be any of a number of keyed or un-keyed Hash functions. In some embodiments, the blocks **478<sub>1</sub>**, **478<sub>2</sub>**, . . . **478<sub>N</sub>** are subject to a hash function which produces n-bit alphanumeric outputs (where n is 256 or another number) from inputs that are based on information in the blocks. Examples of such a hash function include, but are not limited to, a SHA-type (SHA stands for Secured Hash Algorithm) algorithm, Merkle-Damgard algorithm, HAIFA algorithm, Merkle-tree algorithm, nonce-based algorithm, and a non-collision-resistant Pseudo Random Function (PRF). In another embodiment, the blocks **478<sub>1</sub>**, **478<sub>2</sub>**, . . . **478<sub>N</sub>** may be cryptographically linked by a function that is different from a hash function. For purposes of illustration, the following description is made with reference to a hash function, e.g., SHA-2.

**[0090]** Each of the blocks **478<sub>1</sub>**, **478<sub>2</sub>**, . . . **478<sub>N</sub>** in the blockchain includes a header, a version of the file, and a value. The header and the value are different for each block as a result of hashing in the blockchain. In some embodiments, the value may be included in the header. As described in greater detail below, the version of the file may be the original file or a different version of the original file.

**[0091]** The first block **478<sub>1</sub>** in the blockchain is referred to as the genesis block and includes a header **472<sub>1</sub>**, original file **474<sub>1</sub>**, and an initial value **476<sub>1</sub>**. The hashing scheme used for the genesis block, and indeed in all subsequent blocks, may vary. For example, all the information in the first block **478<sub>1</sub>** may be hashed together at one time, or a portion of the

information in the first block **478<sub>1</sub>** may be separately hashed and then a hash of the separately hashed portions may be performed.

**[0092]** The second header **472<sub>1</sub>** may include one or more initial parameters, which, for example, may include a version number, timestamp, nonce, root information, difficulty level, consensus protocol, duration, media format, source, descriptive keywords, and/or other information associated with original file **474<sub>1</sub>** and/or the blockchain. The first header **472<sub>1</sub>** may be generated automatically (e.g., by blockchain network managing software) or manually by a blockchain participant. Unlike the header in other blocks **478<sub>2</sub>** to **478<sub>N</sub>** in the blockchain, the header **472<sub>1</sub>** in the genesis block **478<sub>1</sub>** does not reference a previous block, simply because there is no previous block.

**[0093]** The original file **474<sub>1</sub>** in the genesis block may be, for example, data as captured by a device with or without processing prior to its inclusion in the blockchain. The original file **474<sub>1</sub>** is received through the interface of the system from the device, media source, or node. The original file **474<sub>1</sub>** is associated with metadata, which, for example, may be generated by a user, the device, and/or the system processor, either manually or automatically. The metadata may be included in the first block **478<sub>1</sub>** in association with the original file **474<sub>1</sub>**.

**[0094]** The value **476<sub>1</sub>** in the genesis block is an initial value generated based on one or more unique attributes of the original file **474<sub>1</sub>**. In some embodiments, the one or more unique attributes may include the hash value for the original file **474<sub>1</sub>**, metadata for the original file **474<sub>1</sub>**, and other information associated with the file. In one implementation, the initial value **476<sub>1</sub>** may be based on the following unique attributes:

- [0095]** 1) SHA-2 computed hash value for the original file
- [0096]** 2) originating device ID
- [0097]** 3) starting timestamp for the original file
- [0098]** 4) initial storage location of the original file
- [0099]** 5) blockchain network member ID for software to currently control the original file and associated metadata

**[0100]** The other blocks **478<sub>2</sub>** to **478<sub>N</sub>** in the blockchain also have headers, files, and values. However, unlike header **472<sub>1</sub>** the first block, each of the headers **472<sub>2</sub>** to **472<sub>N</sub>** in the other blocks includes the hash value of an immediately preceding block. The hash value of the immediately preceding block may be just the hash of the header of the previous block or may be the hash value of the entire previous block. By including the hash value of a preceding block in each of the remaining blocks, a trace can be performed from the Nth block back to the genesis block (and the associated original file) on a block-by-block basis, as indicated by arrows **480**, to establish an auditable and immutable chain-of-custody.

**[0101]** Each of the headers **472<sub>2</sub>** to **472<sub>N</sub>** in the other blocks may also include other information, e.g., version number, timestamp, nonce, root information, difficulty level, consensus protocol, and/or other parameters or information associated with the corresponding files and/or the blockchain in general.

**[0102]** The files **474<sub>2</sub>** to **474<sub>N</sub>** in the other blocks may be equal to the original file or may be modified versions of the original file in the genesis block depending, for example, on the type of processing performed. The type of processing performed may vary from block to block. The processing

may involve, for example, any modification of a file in a preceding block, such as redacting information or otherwise changing the content of, taking information away from, or adding or appending information to the files.

**[0103]** Additionally, or alternatively, the processing may involve merely copying the file from a preceding block, changing a storage location of the file, analyzing the file from one or more preceding blocks, moving the file from one storage or memory location to another, or performing action relative to the file of the blockchain and/or its associated metadata. Processing which involves analyzing a file may include, for example, appending, including, or otherwise associating various analytics, statistics, or other information associated with the file.

**[0104]** The values in each of the other blocks **476<sub>2</sub>** to **476<sub>N</sub>** in the other blocks are unique values and are all different as a result of the processing performed. For example, the value in any one block corresponds to an updated version of the value in the previous block. The update is reflected in the hash of the block to which the value is assigned. The values of the blocks therefore provide an indication of what processing was performed in the blocks and also permit a tracing through the blockchain back to the original file. This tracking confirms the chain-of-custody of the file throughout the entire blockchain.

**[0105]** For example, consider the case where portions of the file in a previous block are redacted, blocked out, or pixelated in order to protect the identity of a person shown in the file. In this case, the block including the redacted file may include metadata associated with the redacted file, e.g., how the redaction was performed, who performed the redaction, timestamps where the redaction(s) occurred, etc. The metadata may be hashed to form the value. Because the metadata for the block is different from the information that was hashed to form the value in the previous block, the values are different from one another and may be recovered when decrypted.

**[0106]** In some embodiments, the value of a previous block may be updated (e.g., a new hash value computed) to form the value of a current block when any one or more of the following occurs. The new hash value may be computed by hashing all or a portion of the information noted below, in this example embodiment.

- [0107]** a) new SHA-2 computed hash value if the file has been processed in any way (e.g., if the file was redacted, copied, altered, accessed, or some other action was taken)
- [0108]** b) new storage location for the file
- [0109]** c) new metadata identified associated with the file
- [0110]** d) transfer of access or control of the file from one blockchain participant to another blockchain participant

**[0111]** FIG. 4D illustrates a block **490** which may represent the structure of the blocks in the blockchain (e.g., **470**) in accordance with some embodiments. The block, e.g., Block<sub>i</sub>, includes a header **472<sub>i</sub>**, a file **474<sub>i</sub>**, and a value **476<sub>i</sub>**.

**[0112]** The header **472<sub>i</sub>** includes a hash value of a previous block Block<sub>i-1</sub> and additional reference information, which, for example, may be any of the types of information (e.g., header information including references, characteristics, parameters, etc.) discussed herein. All blocks reference the hash of a previous block except, of course, the genesis block. The hash value of the previous block may be just a hash of

the header in the previous block or a hash of all or a portion of the information in the previous block, including the file and metadata.

**[0113]** The file **474**, includes a plurality of data, such as Data 1, Data 2, . . . , Data N in sequence. The data are tagged with Metadata 1, Metadata 2, . . . , Metadata N which describe the content and/or characteristics associated with the data. For example, the metadata for each data may include information to indicate a timestamp for the data, process the data, keywords indicating the persons or other content depicted in the data, and/or other features that may be helpful to establish the validity and content of the file as a whole, and particularly its use as a digital evidence, for example, as described in connection with an embodiment discussed below. In addition to the metadata, each data may be tagged with reference REF 1, REF 2, . . . , REF N to a previous data to prevent tampering, gaps in the file, and sequential reference through the file.

**[0114]** Once the metadata is assigned to the data (e.g., through a smart contract), the metadata cannot be altered without the hash changing, which can easily be identified for invalidation. The metadata, thus, creates a data log of information that may be accessed for use by participants in the blockchain.

**[0115]** The value **476**, is a hash value or other value computed based on any of the types of information previously discussed. For example, for any given block, Block<sub>i</sub>, the value for that block may be updated to reflect the processing that was performed for that block, e.g., new hash value, new storage location, new metadata for the associated file, transfer of control or access, identifier, or other action or information to be added. Although the value in each block is shown to be separate from the metadata for the data of the file and header, the value may be based, in part or whole, on this metadata in another embodiment.

**[0116]** Once the block **490** is formed, at any point in time, the immutable chain-of-custody for the file may be obtained by querying the blockchain for the transaction history of the values across the blocks. This query, or tracking procedure, may begin with decrypting the value of the block that is most currently included (e.g., the last (N<sup>th</sup>) block), and then continuing to decrypt the value of the other blocks until the genesis block is reached and the original file is recovered. The decryption may involve decrypting the headers and files and associated metadata at each block, as well.

**[0117]** Decryption is performed based on the type of encryption that took place in each block. This may involve the use of private keys, public keys, or a public key-private key pair. For example, when asymmetric encryption is used, blockchain participants or a processor in the network may generate a public key and private key pair using a predetermined algorithm. The public key and private key are associated with each other through some mathematical relationship. The public key may be distributed publicly to serve as an address to receive messages from other users, e.g., an IP address or home address. The private key is kept secret and used to digitally sign messages sent to other blockchain participants. The signature is included in the message so that the recipient can verify using the public key of the sender. This way, the recipient can be sure that only the sender may have sent this message.

**[0118]** Generating a key pair may be analogous to creating an account on the blockchain, but without having to actually register anywhere. Also, every transaction that is executed

on the blockchain is digitally signed by the sender using their private key. This signature ensures that only the owner of the account can track and process (if within the scope of permission determined by a smart contract) the file of the blockchain.

**[0119]** As discussed in more detail herein, it is contemplated that some or all of the operations of some of the embodiments of methods described herein may be performed in alternative orders or may not be performed at all; furthermore, multiple operations may occur at the same time or as an internal part of a larger process.

**[0120]** FIG. 5, illustrated is a high-level block diagram of an example computer system **501** that may be used in implementing one or more of the methods, tools, and modules, and any related functions, described herein (e.g., using one or more processor circuits or computer processors of the computer), in accordance with embodiments of the present disclosure. In some embodiments, the major components of the computer system **501** may comprise one or more CPUs **502**, a memory subsystem **504**, a terminal interface **512**, a storage interface **516**, an I/O (Input/Output) device interface **514**, and a network interface **518**, all of which may be communicatively coupled, directly or indirectly, for inter-component communication via a memory bus **503**, an I/O bus **508**, and an I/O bus interface unit **510**.

**[0121]** The computer system **501** may contain one or more general-purpose programmable central processing units (CPUs) **502A**, **502B**, **502C**, and **502D**, herein generically referred to as the CPU **502**. In some embodiments, the computer system **501** may contain multiple processors typical of a relatively large system; however, in other embodiments the computer system **501** may alternatively be a single CPU system. Each CPU **502** may execute instructions stored in the memory subsystem **504** and may include one or more levels of on-board cache.

**[0122]** System memory **504** may include computer system readable media in the form of volatile memory, such as random access memory (RAM) **522** or cache memory **524**. Computer system **501** may further include other removable/non-removable, volatile/non-volatile computer system storage media. By way of example only, storage system **526** can be provided for reading from and writing to a non-removable, non-volatile magnetic media, such as a “hard drive.” Although not shown, a magnetic disk drive for reading from and writing to a removable, non-volatile magnetic disk (e.g., a “floppy disk”), or an optical disk drive for reading from or writing to a removable, non-volatile optical disc such as a CD-ROM, DVD-ROM or other optical media can be provided. In addition, memory **504** can include flash memory, e.g., a flash memory stick drive or a flash drive. Memory devices can be connected to memory bus **503** by one or more data media interfaces. The memory **504** may include at least one program product having a set (e.g., at least one) of program modules that are configured to carry out the functions of various embodiments.

**[0123]** One or more programs/utilities **528**, each having at least one set of program modules **530** may be stored in memory **504**. The programs/utilities **528** may include a hypervisor (also referred to as a virtual machine monitor), one or more operating systems, one or more application programs, other program modules, and program data. Each of the operating systems, one or more application programs, other program modules, and program data or some combination thereof, may include an implementation of a net-

working environment. Programs **528** and/or program modules **530** generally perform the functions or methodologies of various embodiments.

**[0124]** Although the memory bus **503** is shown in FIG. **5** as a single bus structure providing a direct communication path among the CPUs **502**, the memory subsystem **504**, and the I/O bus interface **510**, the memory bus **503** may, in some embodiments, include multiple different buses or communication paths, which may be arranged in any of various forms, such as point-to-point links in hierarchical, star or web configurations, multiple hierarchical buses, parallel and redundant paths, or any other appropriate type of configuration. Furthermore, while the I/O bus interface **510** and the I/O bus **508** are shown as single respective units, the computer system **501** may, in some embodiments, contain multiple I/O bus interface units **510**, multiple I/O buses **508**, or both. Further, while multiple I/O interface units are shown, which separate the I/O bus **508** from various communications paths running to the various **110** devices, in other embodiments some or all of the I/O devices may be connected directly to one or more system **110** buses.

**[0125]** In some embodiments, the computer system **501** may be a multi-user mainframe computer system, a single-user system, or a server computer or similar device that has little or no direct user interface, but receives requests from other computer systems (clients). Further, in some embodiments, the computer system **501** may be implemented as a desktop computer, portable computer, laptop or notebook computer, tablet computer, pocket computer, telephone, smartphone, network switches or routers, or any other appropriate type of electronic device.

**[0126]** It is noted that FIG. **5** is intended to depict the representative major components of an exemplary computer system **501**. In some embodiments, however, individual components may have greater or lesser complexity than as represented in FIG. **5**, components other than or in addition to those shown in FIG. **5** may be present, and the number, type, and configuration of such components may vary.

**[0127]** Essentially, blockchain may be described as a growing sequence of blocks where each block contains some data such as an operation (e.g., a transaction), a timestamp, and a unique hash of the previous block. By including the previous block's hash, each block is linked together and cannot be modified without breaking this link.

**[0128]** Blocks cannot be modified or removed once they are added to the chain. This means blockchains will grow substantially in size and can become very large over time. For example, the Bitcoin blockchain is over 330 gigabytes (GB) in size.

**[0129]** Blockchains are designed to run in a decentralized, trust-free manner. However, as the size of a blockchain increases, it can become too large to run on a single computer, which encourages the use of third parties to host the blockchain, increasing centralization and requiring trust to be placed in the third party.

**[0130]** Existing blockchain scaling solutions involve a process known as "sharding." Sharding is a technique traditionally used to horizontally scale databases. Sharding involves running multiple blockchains simultaneously. This solution allows more operations to be processed simultaneously but is at odds with one of the core ideas of blockchains—decentralization. Sharding makes it more difficult for an individual to run the entire blockchain locally because sharding doesn't reduce the resources required by the block-

chain. It creates more blockchains, and so the resource requirements are multiplied by the number of blockchains.

**[0131]** Blockchains are secured by hashing a previous block with the new information to form the next block. By adding additional shards, the hashing power is split between the shards which means each individual blockchain has less hashing power protecting it. Additionally, existing techniques for removing blocks from a blockchain only allow blocks to be removed from the start of the blockchain. The novel techniques described in this disclosure enable blocks to be removed regardless of their position in the blockchain.

**[0132]** Chameleon hashes are hash functions that are designed to allow two inputs to produce the same output hash. Chameleon hashes may enable blocks to be replaced, but chameleon hashes require trusted individuals to keep a private key for every block. Therefore, the techniques described in this disclosure reveal a novel approach to a trust-less method of removing and replacing blocks. In some embodiments, a new type of blockchain is proposed, which allows groups' blocks to be replaced with a single compressed block under specific circumstances in order to reduce the size of the blockchain without sacrificing the security blockchains were designed to provide.

**[0133]** This disclosure proposes two new techniques for building a blockchain network.

**[0134]** First, in some embodiments, a modified method is proposed for calculating each block's hash which takes account of the entire blockchain at a point in time, rather than calculating a block's hash in such a way that only accounts for simply the operation in an individual block as is done currently.

**[0135]** Second, in some embodiments, a second class of block is called a compression block. Current blockchains have only one kind of block. FIG. **1** shows two blocks containing the same operations but with completely different hashes. Currently, blockchains don't allow any blocks to be swapped for an equivalent block because even two blocks that contain the same operations can have completely different hashes. For example, two blocks may contain the same operations, but the hash of each block is different because the order of the operations is different in each block.

**[0136]** This disclosure proposes a novel technique of calculating a block's hash, which enables two equivalent blocks to share the same hash.

**[0137]** FIG. **6** depicts two example blocks that may be considered equivalent. Even though they contain different operations, the account balances are the same before and after each block. Using the novel approach to generating block hashes described in this disclosure, both blocks may have the same hash. Prior account balance ledger **604** is the account balances before execution of block **602** (i.e., the account balances from block one which is not depicted), and **606** is the post account balances after execution of block **602**. Block **602** includes operations **612** and **614**. Prior account balance ledger **624** is the account balances before execution of block **622**, and **626** represents the account balances after execution of block **622**. Block **622** includes operations **632**, **634**, **636**, and **638**. As depicted, both blocks **602** and **622** have equivalent prior account balances **604** and **624** and equivalent post account balances **606** and **626** even though each block contains different operations.

**[0138]** In some embodiments, to achieve block equivalency, each block in a blockchain has a unique identifier which is generated using a hashing function. A hashing

function is a function that can map data to a fixed-length character string. For a given input, a hashing function will always produce the same output. One example of a hashing function used in existing blockchains is called secure hash algorithm (SHA)-256.

[0139] Blockchains normally calculate each block's hash using three parameters: the hash of the previous block, the current block's data, and a timestamp. Further, blockchains have two features that ensure that their security blocks can only be added (i.e., never modified or removed), and to further ensure that to add a new block, a proof-of-work must be completed.

[0140] Adding a new block to a blockchain is done through a process known as 'mining.' Mining involves first collecting the operations/data for the next block and then racing all other miners to find a hash for the block with a certain pre-determined number of leading zeros.

[0141] In some instances, information is represented as a single number called a Merkle root. In some embodiments, rather than using operations to calculate the Merkle root, account numbers and account dispositions (e.g., account balances) are used. In existing blockchains, only the operations included in the block are used when calculating the Merkle root. Some examples of account dispositions may include account balances, account status (e.g., active, inactive, good standing, default, etc.), type of account, a function of an account, and/or grouping of an account, among others.

[0142] FIG. 7A depicts an example of calculating the Merkle root of a block with operations (e.g., operations T1, T2, T3, and T4).

[0143] FIG. 7A depicts a technique 700 of calculating the Merkle root, in which only the operations (e.g., operations T1, T2, T3, and T4) included in each block are used to calculate the Merkle root, and the order of the operations is allowed to be arbitrary. A change in the order of operations may change the calculated Merkle root. For example, hashing the operations in the order T1, T2, T3, and T4 produces a hash  $H_{1234}$ , but changing the order of the operations to T1, T3, T2, and T4 produces a completely different hash of  $H_{1324}$ . Thus, changing the order of hashing for a Merkle root changes the Merkle root.

[0144] FIG. 7B depicts an example of calculating the Merkle root of a block with the account dispositions after the block operations have been executed (e.g., account balances A, B, C, and D). In some embodiments, every account number and account disposition in the entire blockchain is used to calculate each block's Merkle root. In some embodiments, account numbers may be included in the Merkle tree in a consistent natural ordering (e.g., numerical order, alpha-numeric order, natural sort order, etc.) by account numbers, which may be set by the network. For example, account 1 is always set before account 2. To calculate a Merkle root from account dispositions, a Merkle tree is constructed as shown in FIG. 7B. HA, HB, HC, HD represent the hash of each account number (account numbers may be a combination of characters and not just digits) and account disposition (here account balances may be, e.g., 10 for A, 5 for B, 20 for C, and 40 for D). In this example, HAB and HCD are the hashes resulting from hashing HA+HB and HC+HD. The final hash (HABCD), called the Merkle root, is the hash of HAB+HCD and is a single number representing all accounts and account dispositions at a single point in time. Since the account

numbers do not change and are hashed in order as described above, the Merkle root is the same for all blocks with the same account dispositions.

[0145] In some embodiments, entire groups of blocks may be replaced with a single block when using the previously stated novel hashing technique. FIG. 8 depicts an example network before and after compression. An example blockchain network version 800, which may be formed of blocks 801, 802, 803, 804, and 805, may be modified to form blockchain version 850 where blocks 802, 803, and 804 may be replaced by a single compression block 810. In this example, block 804 and the compression block 810 have the same ending account balances. In some embodiments, compression blocks can be used to reduce the number of operations that must be stored in the blockchain. Thus, instead of storing blocks 802, 803, and 804, the entities holding the ledger may store block 810.

[0146] FIG. 9 shows an operation/account disposition list 900 of operations 905, 910, 915, 920, and 925 which must be resolved to yield the respective account balances 901, 906, 911, 916, 921, and 926 before a block may be created. For example, starting account disposition 901 shows that all the account balances are 0, and final disposition 926 shows the final account balances of A:0, B:0, C:10, and D:40. Typically, all operations are included in a Merkle root for the block, even though a simple set (e.g., the effective transfer depicted in operation list 990) of operations may replace multiple operations. In some embodiments, instead of including all the operational information in operation/account disposition list 900, a final account disposition 926 may be used to generate a Merkle root for inclusion in the block.

[0147] At the end of the chain of operations, as depicted in FIG. 9, only accounts C and D have unspent operation outputs. Therefore, all the information in Operation/Account Disposition List 900 can be summarized by operation list 990.

[0148] In existing blockchains removing operations would invalidate the block's hash. However, by creating Merkle roots from the account dispositions instead of the operations in a block operations, even entire blocks that have been resolved may be removed without invalidating the block's hash.

[0149] In a blockchain, a hash of a block depends upon the block's own data and the hash of the previous block. The hash of a block is calculated using the block header for the block. For example, a block header may be:

$$\text{Block\_Header} = \text{Previous\_Hash} + \text{Timestamp} + \text{Nonce} + \text{Target} + \text{Merkle\_Root}.$$

[0150] In some instances, Previous\_Hash is the hash of the block just before the current block, Timestamp can be the time of the creation or validation of the block, the nonce is incrementally changed when generating a new hash, and the Merkle root is described FIG. A. In some embodiments, the 'target' in a block header is a number which represents a ceiling for valid block hashes. For example, blockchains such as Bitcoin adjust the difficulty of finding new blocks by making all block hashes less than the 'target'. Increases in the network's hashing power decreases the 'target' value which makes finding new blocks more difficult, ensuring that new blocks are discovered on time (e.g., once per ten minutes on average). For example, if every hash is a 256 bit number between 0 and  $2^{256}$ , then when the target decreases the range of valid hashes shrinks so it becomes more difficult



to find one. Blockchains store the target in every block because changes to the target number are relative, such that the target is only allowed to increase or decrease by a small amount each time it's changed (e.g., new target=previous target\*1.02).

[0151] A block header may contain other elements than those listed, the list provided is merely an example of what a block header may contain.

[0152] In some embodiments, each block in a compressible blockchain may have two purposes; first, to verify the information in a block while proving that a block hasn't been tampered with, and second for miners to use in creating new blocks. Other information may be included in the block header depending on the particular use.

[0153] FIG. 10 depicts two example account disposition blocks. In some embodiments, account disposition blocks are linked together using a previous (block preceding the current block) block's Merkle roots of the account balances for the previous block. For example, block two 1030 contains the MR (Merkle root) for block one (not depicted) and block three 1040 contains the Merkle root 1012 for block two 1030. In some embodiments, by using the account dispositions to calculate the Merkle roots, the Merkle root is essentially a single number that represents the state of the entire Blockchain (i.e., the account dispositions) instead of the operations for a single block. For example, hashing of an account disposition block may be:

```
sha256(sha256(Previous_MR+Timestamp+Nonce+
Target+Merkle_Root)).
```

[0154] In this way, each block contains the traditional information of a block (e.g., transactional data for the block 1012 or 1022, Merkle Root for block two 1010, Target 1008 or 1018, Nonce 1006 or 1016, and a timestamp 1004 or 1014) as well as the previous state of the blockchain from the previous block (e.g., for block three, previous MR for block two 1002) and the current state of the blockchain (e.g., MR for block three 1020). The block hash is calculated by concatenating its five header fields (e.g., the five header fields depicted) and then double-hashing the result. A single sha256 hash may be sufficient but it may be more secure to double-hash, as it prevents length-extension attacks.

[0155] In some embodiments, the block hashes described here may be used in a different manner than in a traditional blockchain. Traditional blockchains use each block's hash to link the block together with the rest of the chain. In some embodiments, the described hash link blocks together using their Merkle root only, which means the timestamp, nonce or target may not be used when the blocks are linked together.

[0156] In some embodiments, the block's hash is for verifying the integrity of the block to ensure it hasn't been tampered with. Traditional blockchains use each block's hash to both link the block with subsequent blocks in the blockchain and to verify each block's data integrity.

[0157] Thus, in some embodiment, the following formula would be used when verifying the integrity of a specific block:

```
sha256(sha256(Previous_MR+Timestamp+Nonce+
Target+Merkle_Root))
```

[0158] But, for adding a new block to the blockchain the system would check if 'the Previous\_MR of the block that is about to be added equals the MR of the block currently at the top of the blockchain?' wherein if it did the system would add the new block.

[0159] In some embodiments, to swap out a single existing block for an equivalent one, the system would check if the two blocks have the same Previous\_MR and the same MR, if so the system can swap them for one another.

[0160] In some embodiments, in an account disposition blockchain a block's Merkle root doesn't represent the operation data in a single block, it represents the state of the entire Blockchain after the block is executed. For example, the state of the blockchain may be the account disposition for each account.

[0161] FIG. 11 illustrates a flowchart of an example method 1100 for using account dispositions blocks in a blockchain network.

[0162] FIG. 11 begins with step 1102 of receiving one or more operations for inclusion in a block. In some instances, operations are received from one or more nodes in a blockchain network.

[0163] FIG. 11 continues with step 1104 of resolving the one or more operations to determine account dispositions. In some embodiments, as described above, the operations are used to determine how account dispositions change from one block to another.

[0164] FIG. 11 continues with step 1106 of receiving the Merkle root for a previous block. In some embodiments, each block in the blockchain network has a Merkle root of the account dispositions (as described above).

[0165] FIG. 11 continues with step 1108 of hashing the Merkle root for a previous block with a Merkle root for the current block to generate the current block (in this manner, current is used to described the block that is being generated, previous blocks may come before the current block and there may be blocks generated in the future that depend on the operations performed in the current block). Since each block is validated by the network before inclusion in the ledger, the Merkle root of the account dispositions is all that is needed to prove the validity of any operations that were completed in the block.

[0166] The described method also facilitates the compression of groups of blocks into a single block.

[0167] FIG. 12 illustrates a flowchart of an example method 1200 for using compression blocks in a blockchain network to replace multiple blocks.

[0168] FIG. 12 begins with step 1202 of receiving a final Merkle root for a final block of a group of blocks in a blockchain ledger. In some embodiments, the final Merkle root is the Merkle root for the account balance of the final block of the group of blocks.

[0169] FIG. 12 continues with step 1204 of receiving the Merkle root (previous Merkle root herein) for the block (previous block herein) immediately preceding the group of blocks. In some embodiments, the previous Merkle root is the Merkle root for the account balance of the previous block.

[0170] FIG. 12 continues with step 1206 of generating a compression block using the final Merkle root. In some embodiments, the block may be generated in a manner similar to that depicted in FIG. 10, where the data included in the block (compression block data) is hashed to form a block. In some embodiments, the data may include the Merkle root of the account balances for the last block in the group, the Merkle root of the account balances for the immediately preceding block in the group, and other data that may be included in the block. For example, other data may include timestamp, nonce, and target. In some embodi-

ments, the compression block may only retain the unspent operation outputs (e.g., where an unspent operation outputs are the operations which have not been completed) and the account dispositions for the accounts in the blockchain network. In some embodiments, the compression block may or may not contain all of the operations from the group of blocks, depending on the requirements of the system. For example, since the compression block is validated by the network, the account dispositions in the compression block may still be trusted, and thus the operations would not be needed for trust purposes. However, in another example, for a blockchain built for compliance purposes, a list of operations may still be needed to prove compliance. In some embodiments, the group of blocks may be sequential. For example, sequential blocks may be a group of blocks that are listed in the ledger one after another without skipping any blocks.

**[0171]** FIG. 12 continues with step 1208 of replacing the group of blocks with the compression block. Since each block depends on the MR of the account balances for the previous block, the compression block is able to replace an entire group of blocks by recording the MR of the account balances for the final block since the subsequent block is built on that MR, and not an MR of operations in the group of blocks.

**[0172]** In some embodiment, to swap a group of blocks for a single block the system may check, Does the MR of the block at the beginning of the group equal the Previous\_MR in the compression block header? and does the MR in the compression block header equal the MR of the block at the end of the group? If so the system can conclude the group of blocks and the compression block are equivalent and can be swapped.

**[0173]** Thus, an existing blockchain network (such as bitcoin) has approximately 335 GB of data, approximately 76 million unspent operation outputs (operations that have not been completed), and somewhere around 836 million blocks in total. Theoretically, the existing Blockchain could be reduced to 9% of its current size ( $76/836 \times 100 = 9\%$ ) (By replacing all blocks with a single compression block).

**[0174]** As discussed in more detail herein, it is contemplated that some or all of the operations of some of the embodiments of methods described herein may be performed in alternative orders or may not be performed at all; furthermore, multiple operations may occur at the same time or as an internal part of a larger process.

**[0175]** The present invention may be a system, a method, and/or a computer program product at any possible technical detail level of integration. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention.

**[0176]** The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory

(ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. A computer readable storage medium, as used herein, is not to be construed as being transitory signals per se, such as radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

**[0177]** Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The network may comprise copper transmission cables, optical transmission fibers, wireless transmission, routers, firewalls, switches, gateway computers and/or edge servers. A network adapter card or network interface in each computing/processing device receives computer readable program instructions from the network and forwards the computer readable program instructions for storage in a computer readable storage medium within the respective computing/processing device.

**[0178]** Computer readable program instructions for carrying out operations of the present invention may be assembler instructions, instruction-set-architecture (ISA) instructions, machine instructions, machine dependent instructions, microcode, firmware instructions, state-setting data, configuration data for integrated circuitry, or either source code or object code written in any combination of one or more programming languages, including an object oriented programming language such as Smalltalk, C++, or the like, and procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program instructions may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). In some embodiments, electronic circuitry including, for example, programmable logic circuitry, field-programmable gate arrays (FPGA), or programmable logic arrays (PLA) may execute the computer readable program instructions by utilizing state information of the computer readable program instructions to personalize the electronic circuitry, in order to perform aspects of the present invention.

**[0179]** Aspects of the present invention are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of

blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

**[0180]** These computer readable program instructions may be provided to a processor of a computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a computer readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored therein comprises an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

**[0181]** The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

**[0182]** The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the blocks may occur out of the order noted in the Figures. For example, two blocks shown in succession may, in fact, be accomplished as one step, executed concurrently, substantially concurrently, in a partially or wholly temporally overlapping manner, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

**[0183]** The descriptions of the various embodiments of the present disclosure have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

**[0184]** Although the present disclosure has been described in terms of specific embodiments, it is anticipated that

alterations and modification thereof will become apparent to the skilled in the art. Therefore, it is intended that the following claims be interpreted as covering all such alterations and modifications as fall within the true spirit and scope of the disclosure.

What is claimed is:

1. A system in a blockchain network comprising:
  - a memory; and
  - a processor in communication with the memory, the processor being configured to perform processes comprising:
    - receiving one or more operations for inclusion in a block;
    - receiving a previous Merkle root created from previously determined account dispositions from a previous block;
    - resolving the one or more operations based on the previous account dispositions to determine one or more current account dispositions;
    - creating a current Merkle root for the one or more current account dispositions; and
    - hashing current data for the current block, the data comprising the current Merkle root and the previous Merkle root to generate an account disposition block.
2. The system of claim 1, wherein the process further comprises:
  - selecting a group of sequential blocks, wherein the account disposition block is a first block in the group;
  - receiving the Merkle root for a final block in the group; and
  - hashing compression block data to generate a compression block, the compression block data comprising the Merkle root for the final block and the previous Merkle root.
3. The system of claim 2, further comprising, replacing the group in a ledger for the blockchain network with the compression block.
4. The system of claim 2, wherein the compression block data further includes unspent operation outputs from the group of blocks.
5. The system of claim 1, wherein the current data further includes a timestamp and one or more operations.
6. The system of claim 1, wherein the current Merkle root for the one or more current account dispositions is performed with the current account dispositions ordered by natural ordering.
7. The system of claim 1, wherein the hashing is performed using secure hash algorithm (SHA)-256.
8. A method comprising:
  - receiving one or more operations for inclusion in a block in a blockchain network;
  - receiving a previous Merkle root created from previously determined account dispositions from a previous block;
  - resolving the one or more operations based on the previous account dispositions to determine one or more current account dispositions;
  - creating a current Merkle root for the one or more current account dispositions; and
  - hashing current data for the current block, the data comprising the current Merkle root and the previous Merkle root to generate an account disposition block.

9. The method of claim 8, wherein the method further comprises:

selecting a group of sequential blocks, wherein the account disposition block is a first block in the group; receiving the Merkle root for a final block in the group; and

hashing compression block data to generate a compression block, the compression block data comprising the Merkle root for the final block and the previous Merkle root.

10. The method of claim 9, further comprising, replacing the group in a ledger for the blockchain network with the compression block.

11. The method of claim 9, wherein the compression block data further includes unspent operation outputs from the group of blocks.

12. The method of claim 8, wherein the current data further includes a timestamp and one or more operations.

13. The method of claim 8, wherein the current Merkle root for the one or more current account dispositions is performed with the current account dispositions ordered by natural ordering.

14. The method of claim 8, wherein the hashing is performed using SHA256.

15. A computer program product comprising a computer readable storage medium having program instructions embodied therewith, the program instructions executable by a processor to cause the processors to perform a method, the method comprising:

receiving one or more operations for inclusion in a block of a blockchain network;

receiving a previous Merkle root created from previously determined account dispositions from a previous block; resolving the one or more operations based on the previous account dispositions to determine one or more current account dispositions;

creating a current Merkle root for the one or more current account dispositions; and

hashing current data for the current block, the data comprising the current Merkle root and the previous Merkle root to generate an account disposition block.

16. The computer program product of claim 15, wherein the method further comprises:

selecting a group of sequential blocks, wherein the account disposition block is a first block in the group; receiving the Merkle root for a final block in the group; and

hashing compression block data to generate a compression block, the compression block data comprising the Merkle root for the final block and the previous Merkle root.

17. The computer program product of claim 16, further comprising, replacing the group in a ledger for the blockchain network with the compression block.

18. The computer program product of claim 16, wherein the compression block data further includes unspent operation outputs from the group of blocks.

19. The computer program product of claim 15, wherein the current data further includes a timestamp and one or more operations.

20. The computer program product of claim 15, wherein the current Merkle root for the one or more current account dispositions is performed with the current account dispositions ordered by natural ordering.

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