Metadata Driven Data Management in Distributed Computing Environments with Partial or Complete Lack of Trust Between User Groups

A. Demichev, A. Kryukov and N. Prikhod’ko

SINP MSU

Supported by RSF grant No. 18-11-00075
Provenance Metadata (PMD)

- Metadata describing data, provide context and are vital for accurate interpretation and use of data
- One of the most important types of metadata is provenance metadata (PMD)
  - tracking the stages at which data were obtained
  - ensuring their correct storage, reproduction and interpreting
  - ensures the correctness of scientific results obtained on the basis of data
- The need for PMD is especially essential when large volume (big) data are jointly processed by several research teams
Multimessenger astronomy

Organizations participating in a large project integrate their local computing/storage resources into a unified distributed pool.
PMD MS Construction for Collaborative DCS

- distributed environment $\Rightarrow$ distributed registry for PMD
- conditions of incomplete trust or lack of trust between groups of users of the system
- $\Rightarrow$ blockchain = distributed registry + provides:
  - no records can inserted into the registry in hindsight
  - no entries were changed in the registry
  - the registry has never been damaged or branched
  - monitoring and restoring the complete history of data processing and analysis
PMD MS Construction: Which Blockchain

- **permissionless**: no restrictions on the transaction handlers
  - open (public) networks of participants (Bitcoin, etc.)
- **permissioned**: transaction processing by specified entities
  - the handlers must come to a consensus about the content and the order of the recorded transactions
  - form a more controlled and predictable environment
  - suitable for networks with naturally existing trusted parties
    - our case: storage providers, representatives of real organizations participating in the project,...
Transaction Handlers in Collaborative DCS
System State of DCS Recorded in the Blockchain: preview

- The state of the entire DCS = aggregated state of the set of files stored in it with their states at the moment
- The state of the files is determined by their metadata
  - global ID + attributes, including:
    - local file name in a storage: fileName;
    - storage identifier: storageID;
    - creator identifier: creatorID;
    - owner identifier: ownerID;
    - type: type=primary/secondary/replica
    - ...

Smart contracts

- Smart contracts along with the registry form the basis of a blockchain system
  - determines the executable logic that generates new states to be added to the registry
- Parties of a business process must define a common set of contracts covering common terms, data, rules, concept definitions and processes.
  - Taken together, these contracts define a business model that governs all interactions between transactional parties.
- A smart contract defines these rules between the parties in the form of executable code.
Permissioned Blockchain Platforms

<table>
<thead>
<tr>
<th>Platform</th>
<th>Consensus</th>
<th>Performance</th>
<th>Smart Contract</th>
<th>Virtual Machine</th>
<th>Data Encryption</th>
<th>Activity (GitHub)</th>
<th>Popularity</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperledger Fabric</td>
<td>PBFT</td>
<td>10k-100k/s</td>
<td>Yes</td>
<td>Chaincode</td>
<td>Yes</td>
<td>High</td>
<td>High</td>
<td>IBM</td>
</tr>
<tr>
<td>Multichain</td>
<td>Round robin</td>
<td>100-1000/s</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Medium</td>
<td>Medium</td>
<td>Coin Sciences</td>
</tr>
<tr>
<td>Quorum</td>
<td>Time and vote based</td>
<td>12-100/s</td>
<td>Yes</td>
<td>EVM</td>
<td>Yes</td>
<td>Medium</td>
<td>High</td>
<td>J.P. Morgan</td>
</tr>
<tr>
<td>OpenChain</td>
<td>Partitioned</td>
<td>Thousands/s</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Low</td>
<td>Medium</td>
<td>Coinprism</td>
</tr>
<tr>
<td>Chain Core</td>
<td>Federated consensus</td>
<td>N/A</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>High</td>
<td>High</td>
<td>Chain</td>
</tr>
<tr>
<td>Corda</td>
<td>BFT, etc.</td>
<td>N/A</td>
<td>Yes</td>
<td>JVM</td>
<td>Yes</td>
<td>High</td>
<td>Medium</td>
<td>R3</td>
</tr>
<tr>
<td>Monax</td>
<td>Tender-mint</td>
<td>10k/s</td>
<td>Yes</td>
<td>EVM</td>
<td>No</td>
<td>Medium</td>
<td>High</td>
<td>Monax</td>
</tr>
</tbody>
</table>

Analysis of existing platforms: the **Hyperledger Fabric** (hyperledger.org) is most suitable for the use case under consideration.
Hyperledger Fabric (HLF) → ProvHL

- ProvHL = Provenance HyperLedger
- operation of smart contracts (chaincodes)
  - adaptation of HLF for the business process of sharing storage resources
- provides a record of transactions & advanced query tools
- advanced means for managing access rights
  - access rights can be managed by network members within their competence
PMD driven data management

- two approaches are possible
  - data management systems (DMS) manage data and use a blockchain simply as a distributed log
    - data driven data management
  - metadata is written to the blockchain beforehand, and DMSs refer to the blockchain and performs the transactions recorded there
    - metadata driven data management
- ProvHL implements the second approach
Business process within HLF-platform

- **Assets** are tangible or intellectual resources, records of which are kept in registers
  - in our case, the assets are data files; their properties (attributes) are provenance metadata

- **Participants** are members of the business network.
  - they can own assets and make transaction requests
  - can have any properties if necessary

- **Transaction** is the mechanism of interaction of participants with assets

- **Events**: messages can be sent by transaction processors to inform external components of changes in the blockchain
HyperLedger Fabric → ProvHL

- Participants
  - Person
  - StorageProvider
- Assets
  - File/Directory
  - Storage
  - Operation
  - Group
  - GroupMembership

- Transactions
  - FileAccessGrant
  - FileAccessRevoke
  - OperationUploadCreate
  - OperationUploadSetState
  - ...

A. Demichev, A. Kryukov & N. Prikhod'ko
There exist MANY other classes and relationships, in particular: StorageProvider, OperationCopy,..., SetGroupMembershipAsAdmin, FileAccessRevoke,... "sticky rights", ...
ProvHL: Basic operations ⇒ transactions

- new file upload
- file download
- file deletion
- file copy within local storage
- file copy/transfer to another local storage
- file transformation by a special service ⇒ grid-like DCS
  - each operation comprises of a number of transactions
  - each valid transaction ⇒ update of some state attributes
    - for example, after the transaction "file download" the values of the keys change: "number of file downloads" and "users who downloaded the file".
ProvHL operation

- Operations with files comprise of at least two types of transactions recorded in the blockchain:
  - client requests,
  - server responses
- Operation states: \textit{STARTED, COMPLETED, ERROR, ...}
- Operation = asset ⇒
  - level of correspondence (history recorded in blockchain) ⇔ (real history of the data in the distributed storage) practically acceptable
  - delegation of rights: user/service → service
  - ...

Sequence Diagrams

Upload

1. Create OperationUploadAsset
   - create Hello object
   - generate random uuid for OperationUpload id
   - create OperationUploadCreate
     object initialized with Hello and operation id
     OperationUploadCreate transaction
   - create HTTPS request with operation-id field
   - starting HTTPS POST with operation-id in header

2. [bad cert CAObject]
   - bad cert CAObject

3. [peer cert does not match with operation requestor]
   operation-id invalid

4. [peer cert does not match with operation requestor]
   peer cert does not match with operation requestor

5. [authorized]
   - OperationUploadCreate transaction
     with PENDING state

6. Continuing HTTPS POST with file attachment
   - OperationUploadSetState transaction
     with COMPLETED state

7. [peer cert does not match with operation requestor]
   peer cert does not match with operation requestor

8. [authorized]
   - OperationDownloadCreate transaction
     with PENDING state

9. Starting HTTPS GET with operation-id in header

10. [bad cert CAObject]
    - bad cert CAObject

11. [peer cert does not match with operation requestor]
    operation-id invalid

12. [peer cert does not match with operation requestor]
    peer cert does not match with operation requestor

13. [authorized]
    - OperationDownloadSetState transaction
      with PENDING state

14. Return data to client

Download
Consensus in Hyperledger Fabric/ProvHL

- **Transaction endorsement**: endorses the transactions by simulating the transaction execution process

- **Ordering**: set of ordering services take endorsed transactions and decide on a sequence in which the transactions will be written to the ledger
  - Ordering Consensus Algorithms
    - SOLO, Raft, Kafka, BFT,...

- **Validation and commitment**: committing peers first validate the transactions received from the orderers and then commit that transaction to the ledger
Rights Delegation in ProvHL

- Usual proxy-based delegation in DCS: low level of security + central service = point of failure, intrusion and bottleneck
- Due to its distributed nature, the blockchain-based delegation proves to be fully adequate to distributed computing systems.
- The use of smart contracts, in turn, provides flexibility because they allow one to define various conditions for the delegation of rights in DCSs.
Performance Characterization of HLF & ProvHL

- **HLF**
  - for the input transaction rate up to 800 tx/sec, the transaction latency is \(\leq 1\) sec
  - transaction throughput is \(\sim 800\) tx/sec
- **ProvHL** (each file operation consists of 3 ÷ 7 transactions)
  - \(\Rightarrow\) matching results for the latency \(\sim 4 ÷ 7\) sec
  - throughput \(\sim 100\) ops/sec.
- quite acceptable for operations with files of sufficiently large volumes
  - typical for DCS for large scientific experiments
Conclusion (1/2)

- we have suggested the new approach to the PMD driven data management in DCSs based on the integration of
  - blockchain technology
  - smart contracts
  - metadata driven data management
  - consensus algorithms
- intended for operation in a distributed environment with administratively unrelated organizations participating in joint projects
  - conditions of incomplete trust or lack of trust between groups of users of the system
Conclusion (2/2)

- ProvHL system on the top of Hyperledger Fabric blockchain platform
  - completely distributed $\Rightarrow$ fault-tolerant
  - safe and secure PMD and data management system
  - well granular access control management
    - including delegation of rights
  - testbed performance characteristics are promising