LandLedger: Blockchain-powered Land Property Administration System

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***Abstract*—The current land administration system of many countries including India is plagued with incomplete and damaged records. Different departments pertaining to land administration system store their own copy of records, which lead to incomplete verification and document forgery. In this paper, we present a blockchain-powered land administration system, termed as LandLedger, which provides accountable, transparent, efficient, secure and scalable land property administration. The proposed architecture of LandLedger realizes property verification, registration and revocation using specially designed transactions on a permissioned blockchain, which is managed by various departments such as Registrar's office, The Income tax department, The Revenue department and so on. LandLedger uses Merkle Patricia Tree to implement ownership verification and property history checking efficiently. The implementation of LandLedger shows its practicality with enhanced features in comparison to the current practice used in many countries including India.**

***Index Terms*—Blockchain; Land management; Merkle Patricia tree; Smart contract.**

I. Introduction

Land administration system is typically aimed at registering land property transactions and maintaining their records. In a country like India, one of the biggest challenges that Government observes is forgery of documents [1] with respect to land property dealings that involve buyer, seller and intermediaries. Verification of land records for ownership is arduous, as many of these records are either incomplete, tampered or damaged. It takes months to register a land property and multiple departments execute the transaction for a particular land dealing relying on incomplete or fraudulent records without having an appropriate verification system that can stop multi-selling or forgery of land records. A major reform that Governments have tried in the past decade is to digitize all land records in the country and integrate textual and spatial records in a system of conclusive titling with title guarantee [2]. Although digitization of records can improve the efficiency of transaction registration, accession, and update, it does not address trust deficiency resulting from cumbersome methods and corrupt practices. Figure 1 depicts the steps involved in the current process of land property registration in India.

The records maintained by the authorities are primarily used for the purpose of collecting land revenue [3]. Therefore, the land titles are presumptive rather than conclusive [1], which means responsibility of checking the past ownership records is on the buyer and registrars do their job without checking its appropriateness in absence of counterclaims [1]. The following are the issues with the current system of land property transactions.

- **Accountability**: Land ownership is established through various documents such as registered sale deed, property tax receipts, survey documents, etc. However, these documents do not guarantee the ownership and is subject to challenge before the court.
- **Transparency**: Since the registration of land property is not mandatory for all transactions and cost of registering property is high, several property divisions are not recorded and thus, is not correctly reflected. In the current system, it is difficult to know the number of properties owned by a person.
- **Security**: A centralized database is subject to various threats such as data theft, loss and manipulation of records and it is not necessary that the process outlined for registration be followed judiciously because of general human negligence or malicious intent, that is, anyone can bribe an official to make them change the records.
- **Efficiency**: Land records are maintained across the various department and are updated slowly due to the massive size of records. Getting access to these records are time and cost consuming for public and other stakeholders, as it involves frequent visits and bribes to government agents. It also leads to formal channels of credit becoming inaccessible to small farmers as their property cannot be used as a collateral, which drives the increase in the interest rate for lending due to fear of NPAs making the credit expensive [3].

Blockchain technology [4] has found significant attention in recent times for its suitability in vast range of applications. Blockchain technology can address the problems associated with paper based as well as centralized land administration system such as accountability, efficiency, transparency and security. Blockchains are practically immutable which means property once registered on blockchain is immune to tampering, which is essential in establishing trust in the system. In addition to that, another feature of blockchain is irreplaceability, which solves the problem of *double spending*. Distributed ledger can enable relevant agencies to have access to same copy documents, in turn, helps in establishing authenticity of documents.

Several countries across the world like Georgia, Honduras and Sweden are exploring the blockchain approach to combat problems associated with traditional land administration system and most of the implementations are based on adding a logic layer called smart contracts upon the colored coins [5], which are designed to allow a digital code in a blockchain to represent an asset. These smart contracts allow credible transactions for escrow without involving third party [6] [7]. There have been instances in which adversaries exploited the security vulnerabilities associated with the smart contracts [8]. Another recent implementation uses Litecoin protocol to record transactions on mainchain and sidechain with the aim of providing conditional privacy [9].

Given the current scenario into consideration, a solution of blockchain-empowered land record administration will bring the features of transparency, accountability, ownership, security and scalability, which are lacking in existing solution space.

II. System Architecture

The proposed blockchain based land administration system, LandLedger, consists of the following entities.

Buyer: Buyer is the one who wants to buy a land property.

Seller: Seller is the current owner of the land property.

Sub-Registrar's Office: This entity is responsible for a sub-district and deals with verification of property transaction *PT* to detect fraud. It sends the *PT* to the revenue department and the income tax department for their approval.

Department of Land Resources: This department is mainly responsible for verifying the following:

1) The land and property transaction taxes are duly paid by parties involved.
2) The land is legally available for sale. For example, special care has to be taken if land is considered as agricultural land.
3) The land is currently not involved in a dispute.

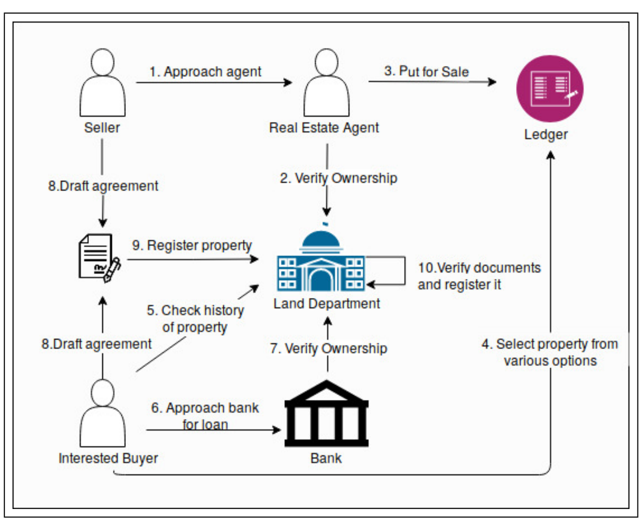

Fig. 1. Current Process of Land Registration

Income Tax Department: The Income Tax department is mainly responsible for verifying the following:

1) To verify the source of money to buy the property.
2) Parties involved are legitimate tax payers.
3) The buyer and seller are legally allowed to make transaction.

Registrar's Office: Registrar's office is responsible for final verification and upon successful verification, it adds the transaction *PT* to blockchain. Every district has at least one Registrar's office.

LandLedger architecture uses a permissioned blockchain, which is managed by Registrar and it is open to public to monitor its activities. Only Registrar has permission to write the *PT* in the blockchain. To ensure Registrar does not misuse its power, *PT* can only be approved by Registrar when sub-registrar, department of Land Resources and the Income Tax department duly verify and sign it. We use Proof-of-Authority [10] as the consensus mechanism in LandLedger. A Registrar, who is a Government official and whose identity is known to public will have the authority to approve the blocks. Each block consists of a block header and a fixed number of property transactions. Each block header consists of a hash of previous block header, a timestamp, a Merkle root computed from all the property transactions in the block and a Merkle-Patricia Trie (MPT) root, which is a cryptographically authenticated data structure used in Ethereum [11] to store all (key, value) pairs. MPT combines the advantages of Merkle tree and Patricia tree [12]. Like Patricia tree, it can perform efficient keyword search query and like Merkle tree, it can implement efficient keyword verification of data at leaf nodes. Ethereum uses public keys of accounts as keys and corresponding account balance as values in MPT. Likewise for a property with property ID *PID*, SHA256(*PID*) is used as keys, and block number containing the latest transaction of corresponding property as the value. In order to calculate the state root's hash, the MPT does not need to look at the entire state trie, but only needs to recalculate the edited branch's hash, which results in a quicker finding of the root hash. A lookup on Ethereum's MPT is sufficient to know the account balance at a particular time in history. However, this leads to humongous disk space utilization. To overcome this problem, we manage only one MPT and its root hash is always stored in the most recent block. MPT of older blocks can be purged to save space. Moreover, instead of storing the entire information about a property on MPT, LandLedger records the recent block number, which dealt with this particular property. This specially designed MPT helps in realizing efficient property history checking which is discussed in the subsequent sections.

Transaction. A property transaction in LandLedger is defined as follows:

$$
\begin{aligned}
PT = \{ & TX\_ID,\ PID,\ BNo_{old},\ Cre_B,\ Cre_S, \\
& Descp,\ SC,\ AD\,; \\
& Signatures: Sig_S,\ Sig_B,\ Sig_{ITD}, \\
& Sig_{LRD},\ Sig_{SR},\ Sig_R \}
\end{aligned} \tag{1}
$$

where *TX_ID* is the identity of a transaction, *PID* is the ID of property associated with the transaction, BNo_{old} is the block number of block which contains the preceding transaction corresponding to this property ID. Cre_B and Cre_S denote the credentials of the buyer and the seller, respectively. It consists of their public keys and other information like name, address for identification purpose. *Descp* is the description of the property for easy identification. *SC* is the sale consideration, that is, the amount of money paid by the buyer to buy the property. *AD* is the agreement details related to the whole transaction agreed upon by the parties involved.

III. Core protocols used in LandLedger

We describe the core procedures, initialization, verification, registration, and revocation phases, used in the proposed LandLedger.

A. Initialization Phase

This phase consists of the following procedures.

Key-Generation (1^λ): Each participating entity should generate a public-private key using RSA key generation algorithm which takes security parameter 1^λ as the input and outputs *(PK, SK)*, the public-private key pair.

Property-Identification(PID, Descp): Each property is allocated a unique property number of fixed length. A property can be identified using geospacial technology to properly define the boundary. Property description can further help to identify, describe, and locate property.

Genesis-Txn(PID, Cre_B, Descp, SC, AD): The current ownership of the property is recorded in the blockchain using the genesis transaction defined below. It is similar to *PT* except Cre_B will contain the credentials of the current owner of property and Cre_S will be $NULL$. Simultaneously, MPT is built by inserting new SHA256(*PID*) as the key and block number as the value.

$$
\begin{aligned}
GT = \{ & TX\_ID,\ PID,\ NULL,\ Cre_B,\ NULL, \\
& Descp,\ SC,\ AD\,; \\
& Signatures: Sig_S,\ Sig_B,\ Sig_{ITD}, \\
& Sig_{LRD},\ Sig_{SR},\ Sig_R \}
\end{aligned} \tag{2}
$$

B. Verification Phase

This phase enables a prospective buyer to verify the ownership of a property from the blockchain to prevent double-spending fraud. It also enables buyer to check the history of property for any disputes.

Ownership-Verification(PID): The aim of this function is to provide the interested buyer details of past transactions of the property. It takes property ID as input and finds its value in MPT using the sub-function MPT-Lookup(), which returns the leaf node of MPT as denoted by *traverse-node*. The value contained in leaf node points to the block containing the latest transaction associated with *PID*. We use the sub-function Extract-Txn() to extract the transaction corresponding to *PID* from the block. We use another function Insert-Txn() to insert this transaction in the list. Now this transaction contains the field BNo_{old} which points to the block containing the previous transaction associated with *PID* or the parent transaction. Similarly, parent transaction points to its own parent transaction and so on. We get the history of property in form of linked list of transactions.

Algorithm 1: Ownership-Verification

Input : *PID*
Output: List of PT_{PID}

```
function OVerify(PID)
    List L ⟵ ∅
    traverse-node ⟵ MPT-Lookup(PID)
    if traverse-node ≠ NULL then
        BNo ⟵ traverse-node.value
        while BNo ≠ Null do
            Txn ⟵ Extract-Txn(Bno, PID)
            L ⟵ Insert-Txn(L, Txn)
            BNo ⟵ Txn.BNo_old
        end
        return L
    else
        return NULL
    end
```

C. Registration Phase

Land property is registered in the blockchain when predetermined authorities approve it by signing a set of data containing public key of buyer and seller with their own private key. The registration phase shown in the Figure 2 consists of the following algorithms.

Request-Property(PID, Cre_B): Interested buyer *B* creates an unsigned version of the PT_{PID} (1) for property ID *PID* with his credentials Cre_B. Further, BNo_{old} is added to PT_{PID} after looking it up from MPT of the latest block. PT_{PID} is then sent to the seller *S* with the request to buy the property.

Algorithm 2: Request-Property

Input : *PID*, Cre_B
Output: PT_{PID}

```
function ReqProp (PID, Cre_B)
    Txn ⟵ new PT(PID, Cre_B)
    traverse-node ⟵ MPT-Lookup(PID)
    Txn.BNo_old ⟵ traverse-node.value
    return Txn
```

Property-Available(PT_{PID}, Cre_S, Descp, SC, AD): Upon receiving the request from the prospective buyer, seller S

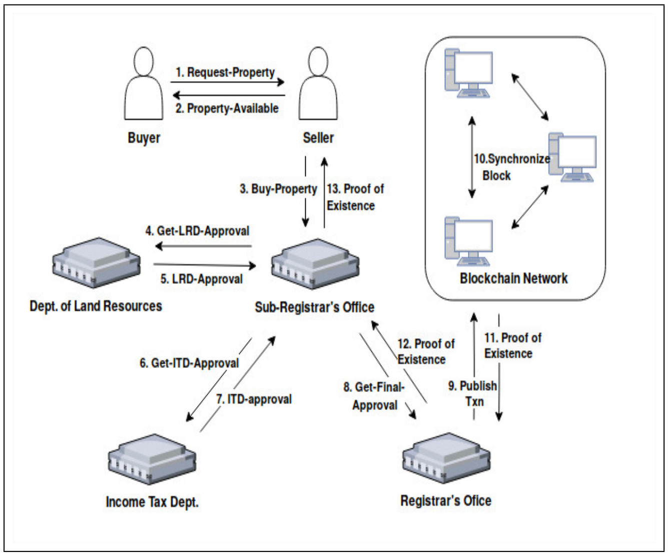

Fig. 2. Proposed Registration Process

updates PT_{PID} with sale consideration *SC* and other details of property agreement using the sub-function UPDATE-TXN(). Then *S* sends PT_{PID} back to *B* for approval after signing it with his private key SK_S.

Algorithm 3: Property-Available

Input : *old* PT_{PID}*,* Cre_S*, Descp, SC, AD*
Output: *updated* PT_{PID}

function PROPAVAIL (PT_{PID}, Cre_S, *Descp, SC, AD*)
  $PT_{PID} \longleftarrow$ UPDATE-TXN(PT_{PID}, Cre_S, *Descp, SC, AD*)
  $\text{Sig}_{SK_S}(\text{PT}_{PID})$
  return *Txn*

Buy-Property(PT_{PID}*)*: Upon receiving the updated PT_{PID}, buyer verifies the agreement and signs it with his secret key SK_B to confirm the that deal. To register this transaction, *B* sends PT_{PID} to sub-registrar's office for approval.

Algorithm 4: Buy-Property

Input : *old* PT_{PID}
Output: *updated* PT_{PID}

function BUYPROP (PT_{PID})
  if *(*PT_{PID} *== valid) && (S is owner)* **then**
    $Sig_{SK_S}(PT_{PID})$
    return PT_{PID}
  else
    return error;
  end

Get-LRD-Approval(PT_{PID}*)*: Sub-Registrar verifies the credentials of parties involved and the validity of transaction. If found satisfactory, sends PT_{PID} to Department of Land Resources *LRD* for further verification.

Algorithm 5: Get-LRD-Approval

Input : *old* PT_{PID}
Output: *updated* PT_{PID}

function GETLRDAPP (PT_{PID})
  if *(Signatures are valid) && (*PT_{PID} *is valid)* **then**
    return PT_{PID}
  else
    return error;
  end

LRD-Approval(PT_{PID}*)*: Department of Land Resources *LRD* checks the background of property. It makes sure that the laws of the region where property lies are followed before approval. For example, a land might belong to heritage property of region. *LRD* also ensures that property taxes are not due and property is not in dispute. After thorough checking *LRD* signs the transaction and PT_{PID} is sent back to Sub-Registrar's office *SR*.

Algorithm 6: LRD-Approval

Input : *old* PT_{PID}
Output: *updated* PT_{PID}

function LRDAPP (PT_{PID})
  if *(Property taxes are due)* **then**
    return error;
  end
  if *(Property is in dispute)* **then**
    return error;
  end
  if *(Property is not legally allowed to be sold)* **then**
    return error;
  end
  $Sig_{SK_{LRD}}(PT_{PID})$
  return PT_{PID}

Get-ITD-Approval(PT_{PID}*)*: Sub-Registrar verifies the signature of *LRD* and checks validity of *PT*. Next, the PT_{PID} is sent to Income Tax Department for their approval.

Algorithm 7: Get-ITD-Approval

Input : *old* PT_{PID}
Output: *updated* PT_{PID}

function GETITDAPP (PT_{PID})
  if *(Signatures == valid) && (*PT_{PID} *== valid)* **then**
    return PT_{PID}
  else
    return error;
  end

ITD-Approval(PT_{PID}*)*: *ITD* checks the history of the buyer and the seller to make sure they are legitimate tax payers and the money involved in the transaction is licit. It then signs PT_{PID} and sends it back to Sub-Registrar's office.

Algorithm 8: ITD-Approval

Input : *old* PT_{PID}
Output: *updated* PT_{PID}

function ITDAPP (PT_{PID})
  if *(B has taxes due) || (S has taxes due)* **then**
    return error;
  end
  $Sig_{SK_{ITD}}(PT_{PID})$
  return PT_{PID}

Request-Final-Approval(PT_{PID}): Upon receiving signed PT_{PID}, Sub-Registrar verifies the signature of *LRD* and checks validity of *PT*, signs it with SK_{SR} and sends it to Registrar for final approval.

Algorithm 9: Request-Final-Approval

Input : *old* PT_{PID}
Output: *updated* PT_{PID}

function FINALAPP (PT_{PID})
  if *(Signatures == valid) && (PT_{PID} == valid)* **then**
    $Sig_{SK_{SR}}(PT_{PID})$
    return PT_{PID}
  else
    return error
  end

Property-Txn-Approval(PT_{PID}): Registrar *R* verifies once again that *S* is indeed the current owner of property by checking MPT leaf node with key SHA256(*PID*). It is also necessary for *R* to verify that there are no other transactions related to PT_{PID} in the new candidate block waiting for confirmation to ensure double spending does not occur. Finally, *R* signs PT_{PID} with SK_R. PT_{PID} is added to the new block along with the other transactions using the sub-function ADD-TXN-TO-BLOCK(). After sufficient number of verified transactions are added to the new block, function ADD-NEW-BLOCK is invoked to form a valid block data structure with proper argument *blockData* which contains all the transactions. Further, sub-function UPDATE-MPT() is invoked to update the value of leaf nodes corresponding to the transactions of the new block. Member functions of *Block*, *compute-Merkle-Root()* and *compute-MPT-Root()* are invoked to compute Merkle root and MPT root for the block respectively. Finally the sub-function ADD-TO-BLOCKCHAIN() appends the new block to blockchain and returns the appropriate response which is then broadcasted in network using the sub-function BROADCAST(). Subsequently, everyone can check the blockchain to verify the transaction.

Existence-Proof(MerkleProof, Block Header): Finally, Registrar sends back a response to buyer through sub- registrar's office. This response includes the header of the block containing PT_{PID} and a Merkle Proof of PT_{PID} in the block. The Merkle Proof consists of the hash values on the Merkle Tree which can provide proof that PT_{PID} is on the Merkle Tree. If any of the departments find fraud at any point in the whole process, then process is cut-short and error message is displayed to buyer.

Algorithm 10: Property-Txn-Approval

Input : *old* PT_{PID}
Output: *updated* PT_{PID}

function PROPTXNAPP (PT_{PID})
  if *(Signatures == valid) && (PT_{PID} == valid) && (S is owner)* **then**
    $\mathrm{Sig}_{SK_R}(\mathrm{PT}_{PID})$
    ADD-TXN-TO-BLOCK(PT_{PID})
    return PT_{PID}
  else
    return error;
  end

Algorithm 11: Add-New-Block

Input : *blockData*
Output: *Response*

function ADDNEWBLOCK (*blockData*)
  Block $\longleftarrow$ *new Block(blockData)*
  UPDATE-MPT(*blockData, Block.blockNo*)
  Block.compute-Merkle-Root()
  Block.compute-MPT-Root()
  Response = ADD-TO-BLOCKCHAIN(BLOCK)
  BROADCAST(*Response*)
  return *Response*

D. Property Transaction Revocation Phase

Property transaction revocation is necessary when a property fraud occurs and court settles the matter. In this case, authorities can revoke the ownership based upon the court judgment. Legitimate owner invokes a Property Revocation PR transaction to revoke the current ownership and transfer it to himself. Property Revocation *PR* is defined as

$$\begin{aligned} PR = \{ & TX\_ID,\ PID,\ BNo_{old},\ Cre_B,\ Null, \\ & Court\text{-}Order,\ Descp,\ SC,\ AD\,; \\ & Signatures: Sig_B,\ Sig_{ITD},\ Sig_{LRD}, \\ & Sig_{SR},\ Sig_R \} \end{aligned} \tag{3}$$

where *Court-Order* refers to the legal document which revoked the property transaction. It will be useful for verification in future transactions related to this particular property.

IV. ANALYSIS

The proposed LandLedger provides the following features.

Immutability: The LandLedger system inherits one of the core properties of blockchain, which is to store data permanently. It records all the transactions that occur in Land property deal. The alteration of previously executed and captured transaction is practically difficult, as it requires to change all subsequent transactions which is not possible because of different parties involved in different transactions. In the LandLedger, SHA256 as cryptographic hash function and secure digital signature (e.g. ECDSA) [13] are being used for implementing a buyer-seller deal in the form of transaction and that has been captured in the blockchain. Therefore, changing records in blockchain is practically not feasible.

Ownership and Accountability: A buyer can verify the ownership of a property from the blockchain before buying it. This, in fact, instills confidence in the citizens regarding the legitimacy of the property transactions leading to a much needed accountable governance. The proposed system uses permissioned blockchain instead of public, because authorized stakeholder of the system requires to have a certain level of control to establish accountability. Therefore, the proposed system can provide who owns what and in which terms and conditions, which brings accountability into the system.

Prevention of Multi-Spending: One of the major problems in conventional land property dealing is multi-spending (or dubious ownership) of a land record. In the proposed LandLedger system, the multi-spending of land record is prevented. Suppose, a seller who is a legitimate owner tries to sell his/her property to buyer A and buyer B. Now after verifying the ownership of the property, both of the buyers apply for registration. Since in a particular block, there can not be two transactions related to a same property ID, one of the transactions is rejected by the Registrar.

Transparency and Efficiency: LandLedger employs Merkle Patricia Tree (MPT) to record the latest status of a property. Since each transaction is linked with its parent transaction, LandLedger system does not need to search entire blockchain to get the records associated with a particular property. Instead, we can get history as a linked list of transactions with time complexity $\mathcal{O}(n)$, where n is the number of records associated with the property. MPT records the current owners of all the properties recorded in the blockchain, which makes easier for Govt. to know the number of properties owned by a person.

Unforgeability of transaction: LandLedger inherits one important aspect of blockchain, trustworthy time-stamping. Since each block is generated after fixed interval of time, all the transactions present in that block acquire that timestamp. These timestamps help in establishing the proof of registration or revocation. Each block is linked with its previous block and each block contains Merkle root, which makes it difficult to forge the transaction.

V. Implementation

We have implemented the proposed LandLedger on Hyperledger Fabric Framework [14]. We consider the following three types of assets for LandLedger: (i) Property, (ii) Property Contract, and (iii)Property Transaction Status. Assets were defined in the business network using Hyperledger Composer Modeling Language. Figure 3 depicts the asset Property Transaction Status, which gets updated after every interaction between participants.


```
{
  "$class": "org.example.mynetwork.TransactionStatus",
  "tId": "T1",
  "txnStatus": "APPROVED",
  "currentDept": "resource:org.example.mynetwork.ROffice#R1",
  "contract": "resource:org.example.mynetwork.PropertyContract#PC1",
  "subRegistrar": "resource:org.example.mynetwork.SROffice#SR1",
  "registrar": "resource:org.example.mynetwork.ROffice#R1",
  "ITDept": "resource:org.example.mynetwork.IncomeTaxDept#ITD1",
  "LRDept": "resource:org.example.mynetwork.LandResourcesDept#LRD1",
  "approvedByLRD": true,
  "approvedByITD": true,
  "approvedBySR": true,
  "approvedByR": true
}
```


Fig. 3. Property Transaction Status

Participants in LandLedger are associated with a unique identity and interact with assets. These identities can be used to administer a certain amount of access control.

VI. Conclusion

A blockchain based land administration system, LandLedger, is proposed to address the inefficiencies of the conventional system and solving multi-spending of a land property. The design of LandLedger system is simple that can be easily integrated in the conventional system to register a property and the subsequent operations pertaining to land property dealing. LandLedger realizes efficient ownership verification and achieving other important features such as traceability, accountability and multi-spending.

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