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A Data Integration Platform with Identifiable Falsification Detection and its Evaluation in Automotive Parts Manufacturing

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Outline

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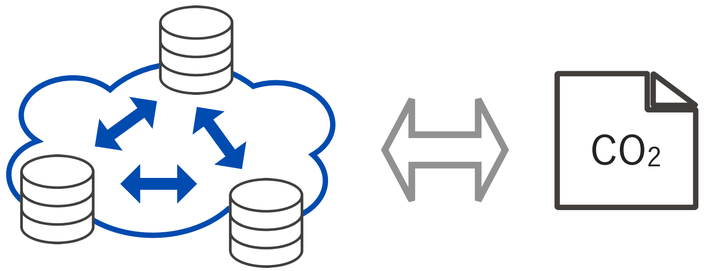
Introduction

Growing Importance of **Supply Chain CFP (Carbon Footprint of Products) Management** toward Decarbonization

- A key to identifying hotspots and selecting green products
- Increasing regulatory pressure in the automotive sector

Implementation Challenges

- **Data Falsification**
  Risk of fraud due to compliance pressure
- **Ensuring Traceability and Trust**
  Secure data integration across multiple enterprises in distributed systems



A distributed system
connecting each company

Introduction

Previous Work & Challenges

A study of blockchain-based metadata management and its use for data verification (Hori, Oguchi, the 12th International Symposium on Computing and Networking Workshops, 2024)

Realized a system to calculate, store, and verify CFP data using smart contracts.

Problem

- **Unidentifiable Falsification Location:** Can detect the *existence* of falsification, but cannot pinpoint the specific source.
- **Insufficient Security:** CFP data is processed and stored in plaintext.

Our Approach

- **Proposal: Hashed Component Tree**
  - A tree structure that integrates hash values using **XOR operations**.
  - **Leveraging XOR Properties**
    - Eliminates order information in integration.
    - Enables identification of the falsified location.
  - Handling **Duplicate parts**
- **System Design:** Modeled on the automotive parts manufacturing industry.

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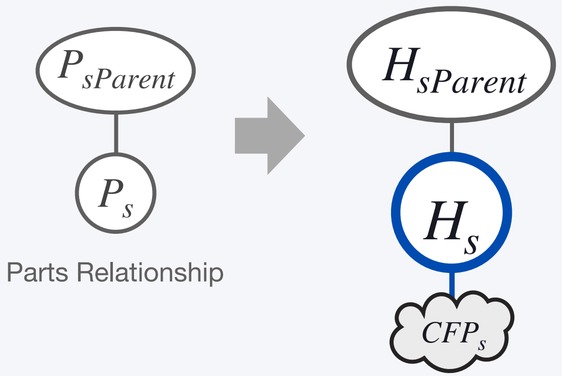
Definition: Hashed Component Tree

Determine a single hash value for each part by XORing hashed CFPs.

Single part

Hash value of its own CFP.

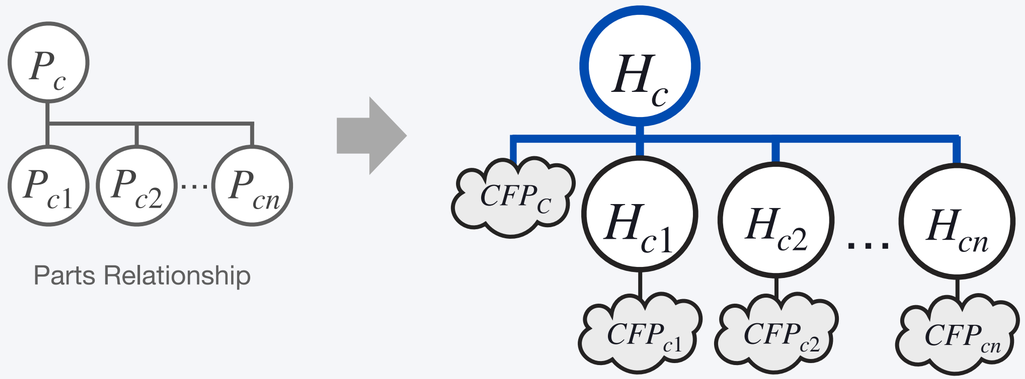
$$H_s = Hash(CFP_s)$$



Composite part

XOR combination of its own CFP and hash values of child parts.

$$H_c = Hash(CFP_c) \oplus H_{c1} \oplus H_{c2} \oplus \cdots \oplus H_{cn}$$



Root part is an automobile that contains CFP of **all** parts via XOR aggregation

6 Key Feature 1: XOR Properties

Advantages 1) Commutativity

Elimination of Order Information

$$a \oplus b = b \oplus a$$

- **No inherent ordering** among parts in this scenario.
- Parent hash remains unchanged even if the input order varies.

Advantages 2) Self-Inverse

Identification of Falsification

$$a \oplus a = 0$$

- Impact of falsification propagates toward the root part.
- **Clearly distinguishes** between the source of falsification and the affected parent nodes.

Key Feature 2: Handling Duplicate Parts

Issue Disappearance due to Self-Inverse Property

- Simple XOR causes **cancellation** in higher-level parts.
  → Loss of information for duplicated components.

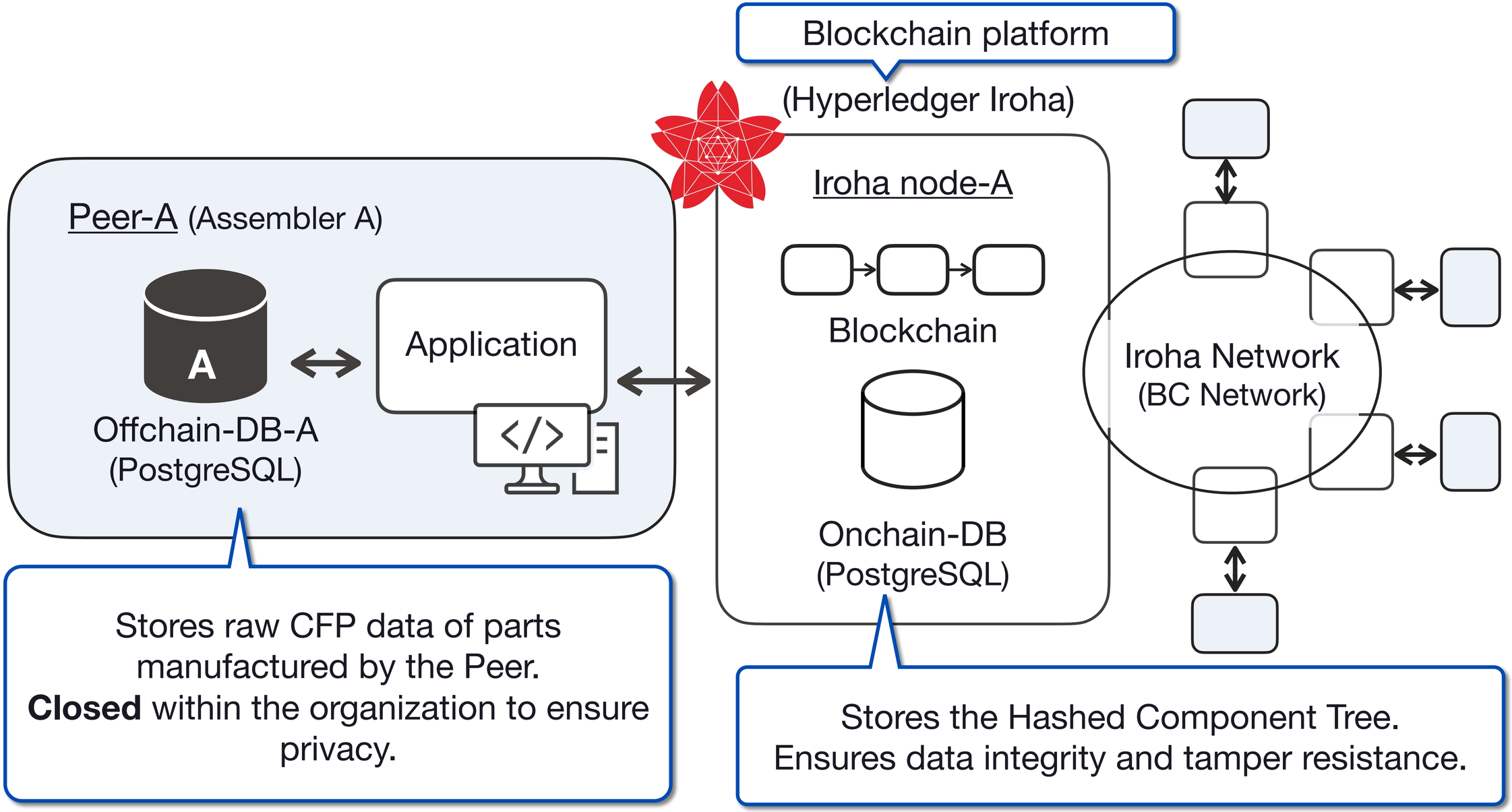
Solution

For a duplicate part H_{cd}, **concatenate the path to the root before hashing**.

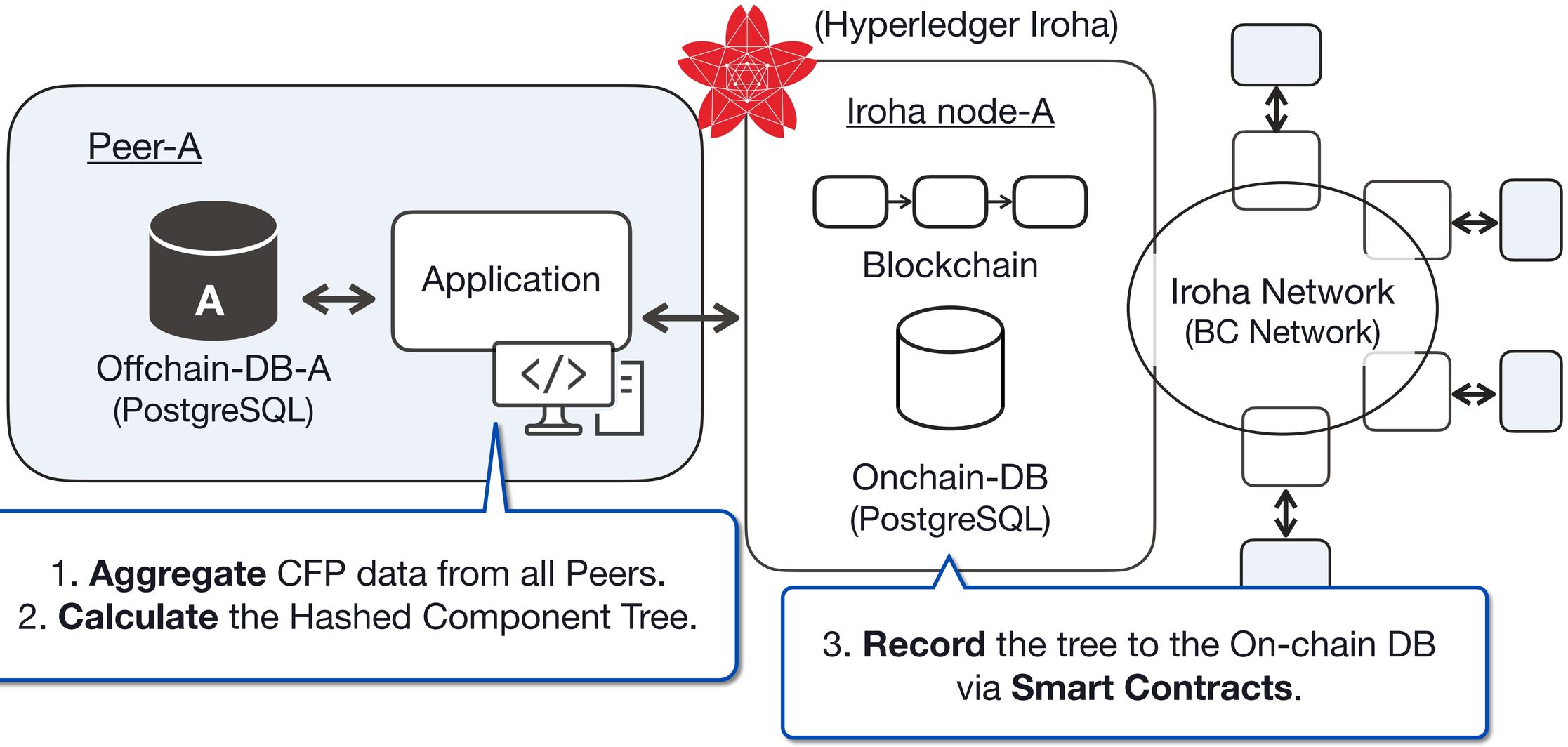
$$H_c = Hash(CFP_c) \oplus H_{c1} \oplus \cdots \oplus Hash(H_{cd} || Path(P_c, Root)) \oplus \cdots \oplus H_{cn}$$

- $Path(A, B)$: The specific path from node *A* to node *B*.
- **Benefit**: Ensures all hash values are unique, preventing cancellation caused by the self-inverse property.

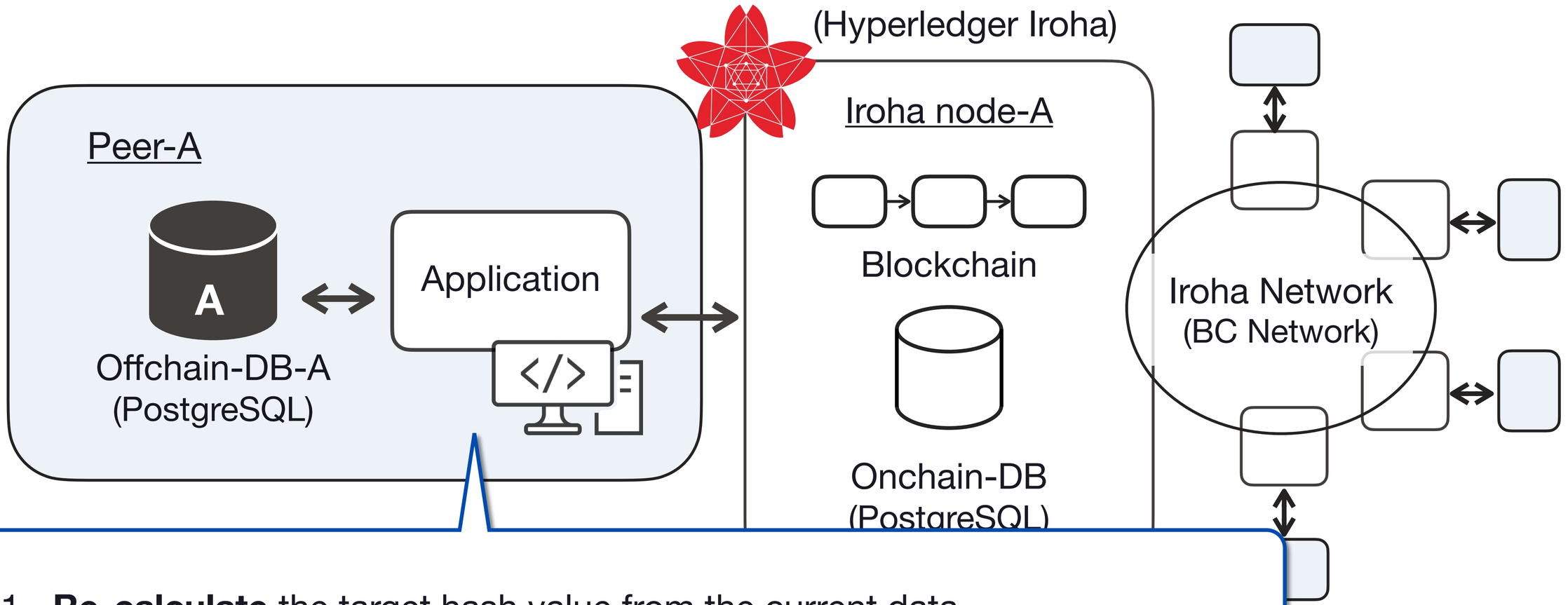
8 System Design



The Hashed Component Tree Generation Process



10 The Verification Process



1. **Re-calculate** the target hash value from the current data.
2. **Compare** it with the reference hash stored in the On-chain DB.
   → If a mismatch occurs, proceed to the Falsification Identification Process.

Falsification Localization Process

Purpose Verify if the part is the **actual source** of falsification using XOR's self-inverse property.

Process

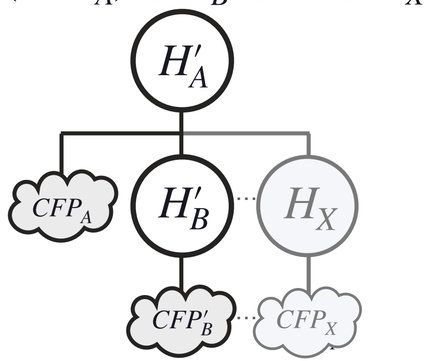
1. Search for hash discrepancies starting from the verification part (Root).
2. Difference Removal
3. Falsification Judgment

2. Calculation Method

Remove the child's influence (H'_B) from the parent (H'_A), and XOR with the correct child value retrieved from the On-chain DB.

$$Check = H'_A \oplus (H'_B \oplus H_B)$$

$$H'_A = Hash(CFP_A) \oplus H'_B \oplus \cdots \oplus H_X$$



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Falsification Localization Process

Purpose Verify if the part is the **actual source** of falsification using XOR's self-inverse property.

Process

1. Search for hash discrepancies starting from the verification part (Root).
2. Difference Removal
3. Falsification Judgment

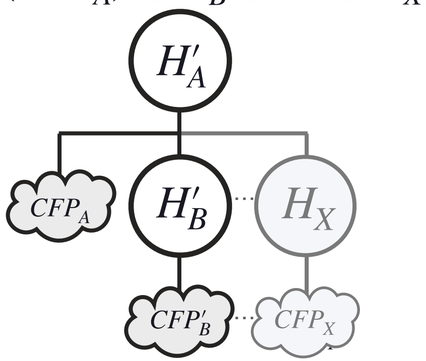
3. Judgement Logic

Does the calculated $Check$ value match the original correct hash (H_B)?

Match: Parent is **NOT** falsified (only affected by the child).

Mismatch: Parent **ITSELF** is falsified.

$$H'_A = Hash(CFP_A) \oplus H'_B \oplus \cdots \oplus H_X$$



13 Evaluation Setup

Investigated execution time, CPU usage, and memory usage verification process.

Build Environment

Ubuntu Container		PostgreSQL Container	
Blockchain Platform	Application	Onchain-DB	Offchain-DB
Hyperledger Iroha ver. 1	Python	PostgreSQL ver.16.3	
Virtual Environment	Docker		
OS	Ubuntu20.04LTS		
Physical Server	CPU : Intel(R) Xeon(R) Silver 4314 CPU @ 2.40GHz MEMORY : 192GB, CORE : 16, THEAD : 32		

Evaluation Parameters

- Total number of parts : 300 / 3,000 / **30,000**
- Duplication rate of parts : 0 / 10 / 20 / 30 / 40 (%)
- Falsification rate of parts : 0 / 1 / 5 / 10 / 15 (%)

Equivalent to the total number of parts in a single vehicle.

14 Summary of Evaluation Results

	Execution Time	CPU Usage	Memory Usage
Total number of parts	30,000 parts: 2.9 times the number of previous work Linear increase		
Duplication rate of parts	Lower is faster	largely unaffected	
Falsification rate of parts	Lower is faster		

We achieved a 100% falsification identification rate, albeit with increased overhead.

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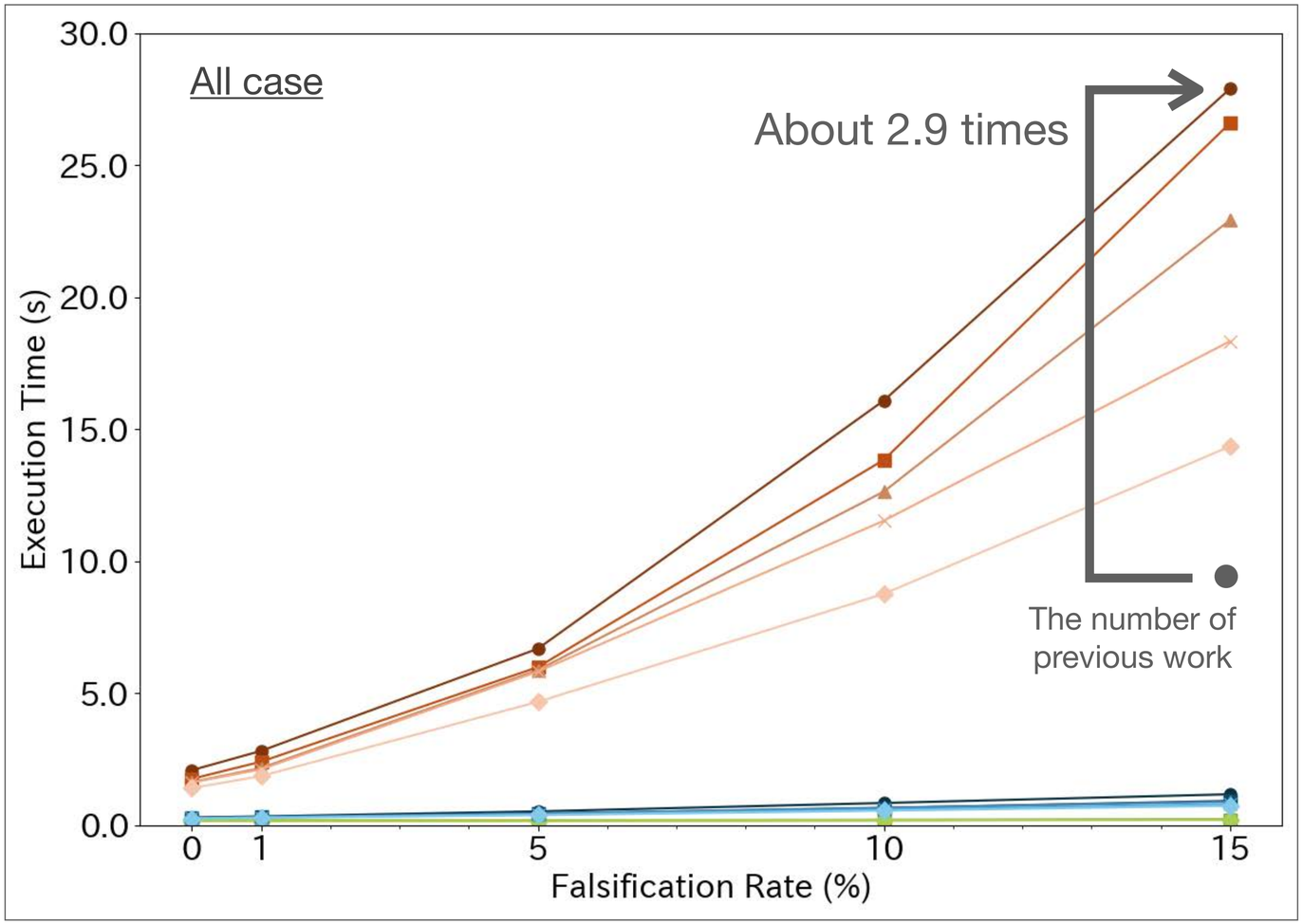
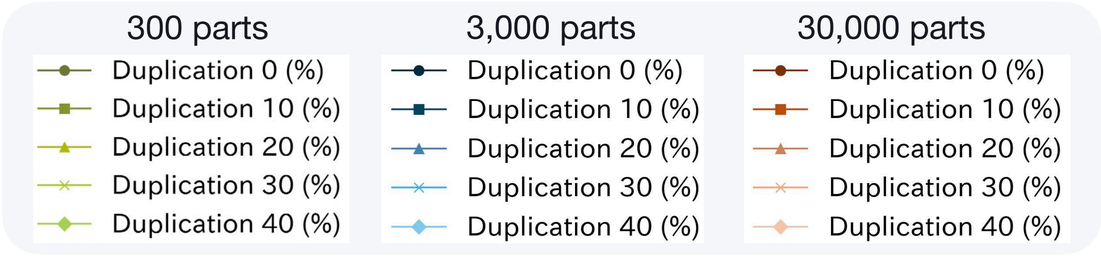
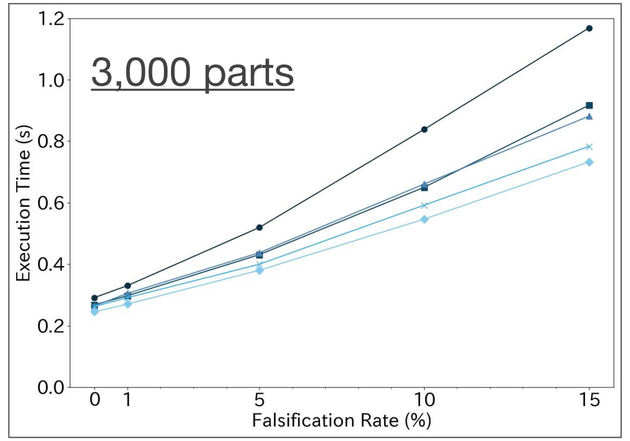
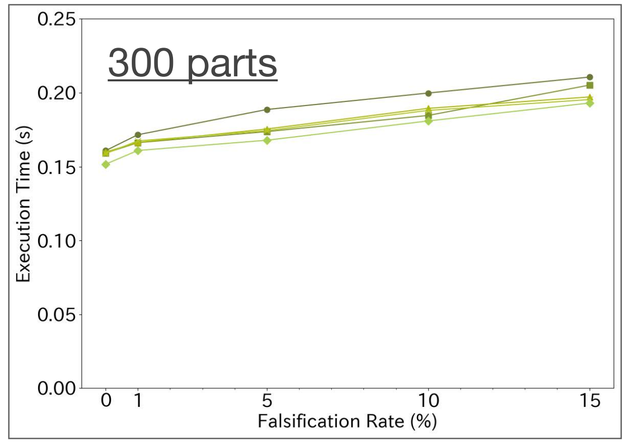
Results of Execution Time









Total number of parts

Linear increase

Duplication rate of parts

Lower is faster

Falsification rate of parts

Lower is faster

Conclusion

Conclusion

- Proposed a distributed CFP data integration platform for automotive parts manufacturing.
- **Developed a verification method** using Hashed Component Trees based on XOR properties:
  - **Commutativity Property:** Eliminates the need for component order information.
  - **Self-Inverse Property:** Identifies the specific location of falsification.
  - Handling duplication parts
- **Achieved a 100% identification rate** in evaluation experiments, confirming the system's expected behavior.

Future Work

- **Implement a data correction mechanism** for the identified falsified components.

Thank you for your attention.