Shortstack:
Distributed, Fault-tolerant, Oblivious Data Access



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Cornell University

Yale University

(First two authors contributed equally)

Oblivious Data Access

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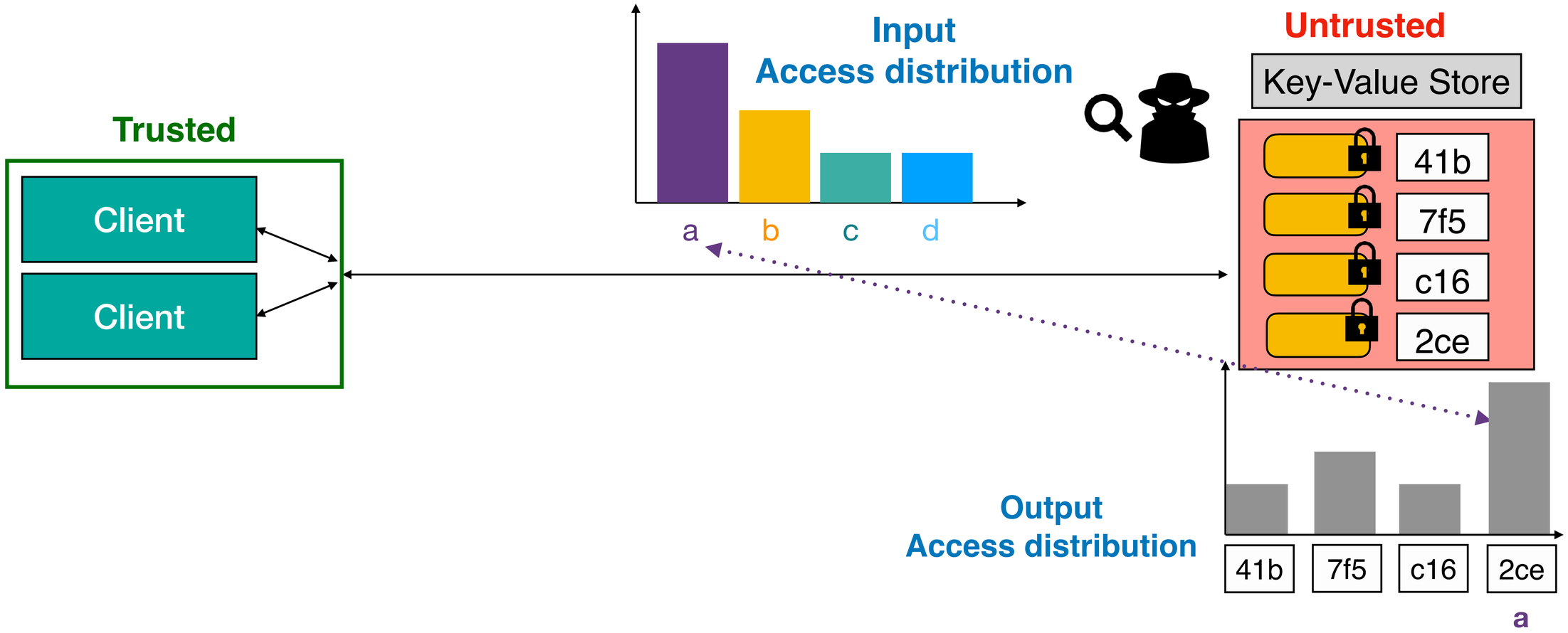

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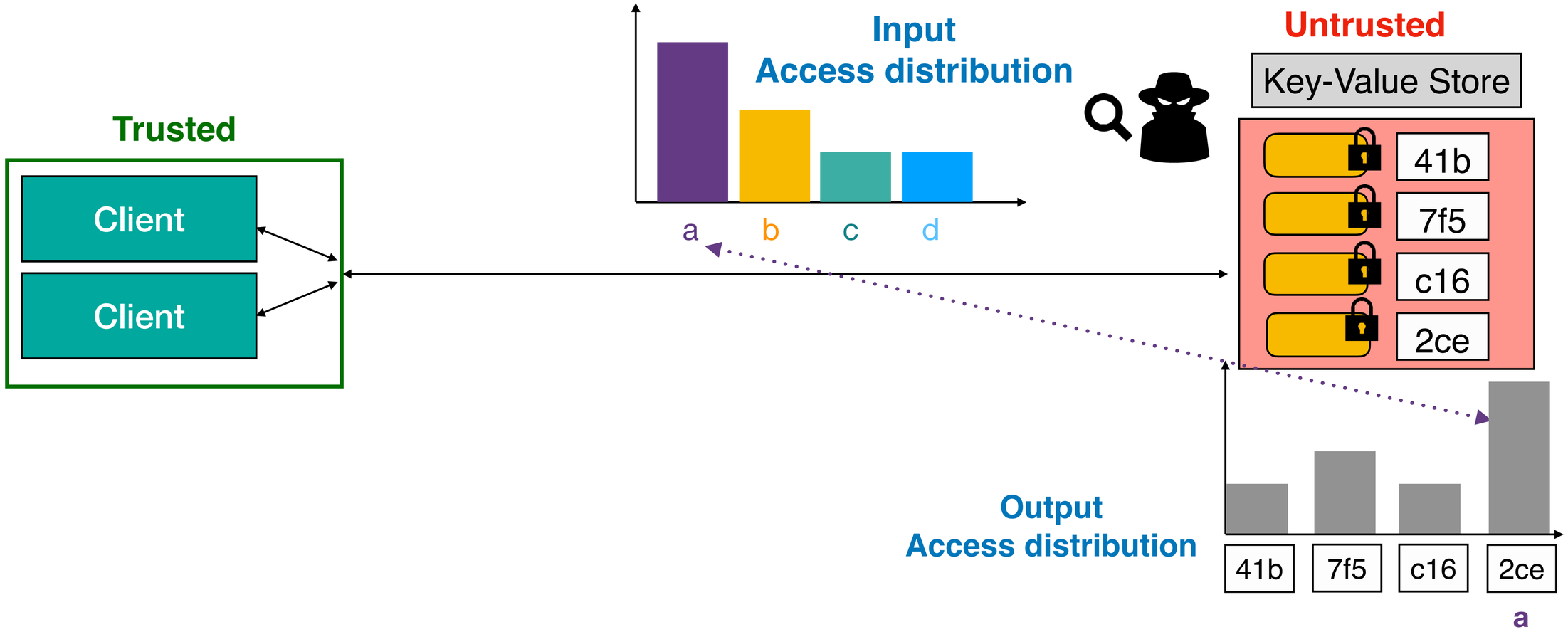

Encryption is not enough. Need to hide access patterns

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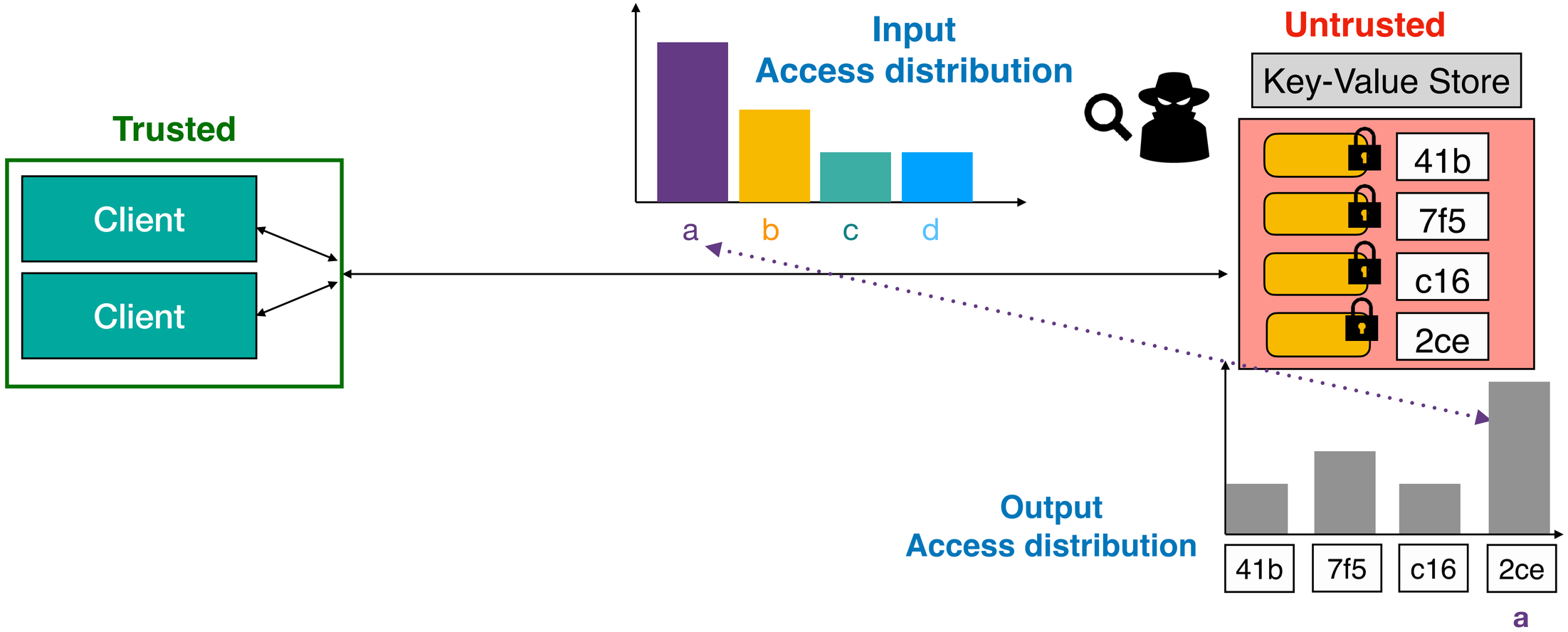

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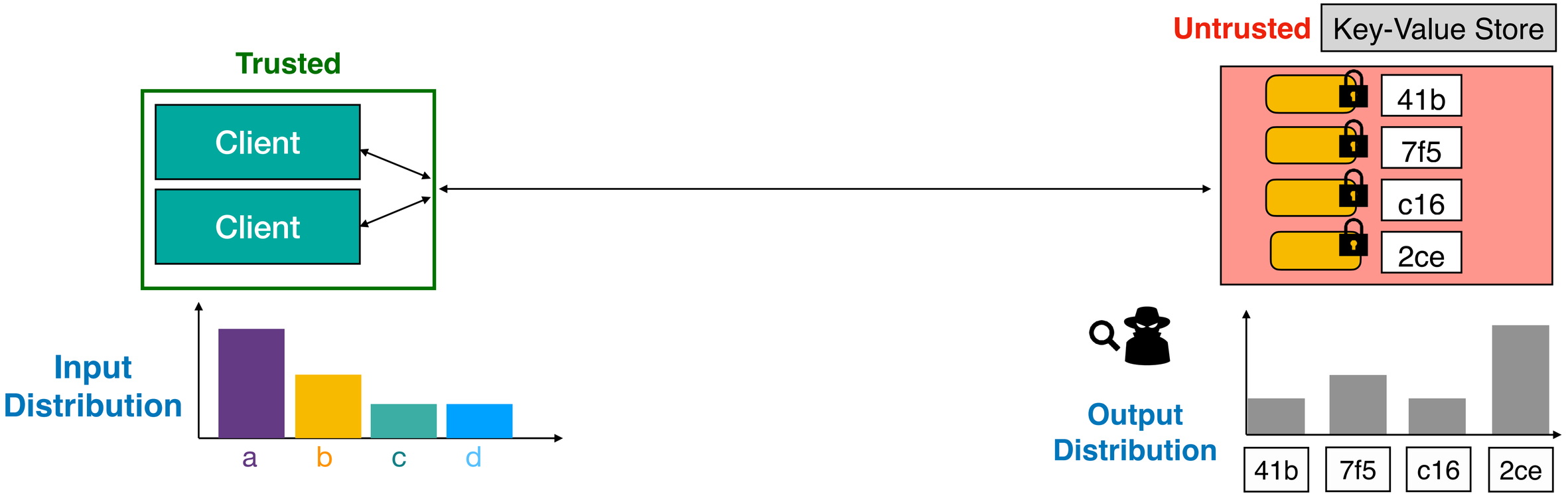
Oblivious Data Access: Output distribution independent of input distribution

Existing Oblivious Data Access Techniques



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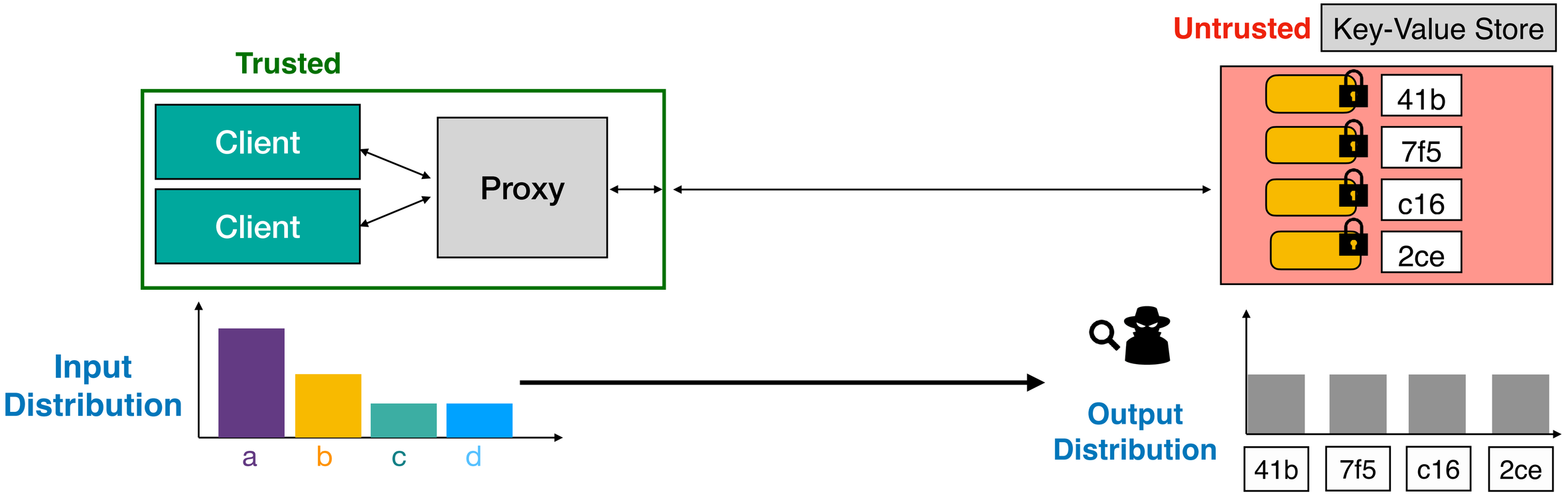

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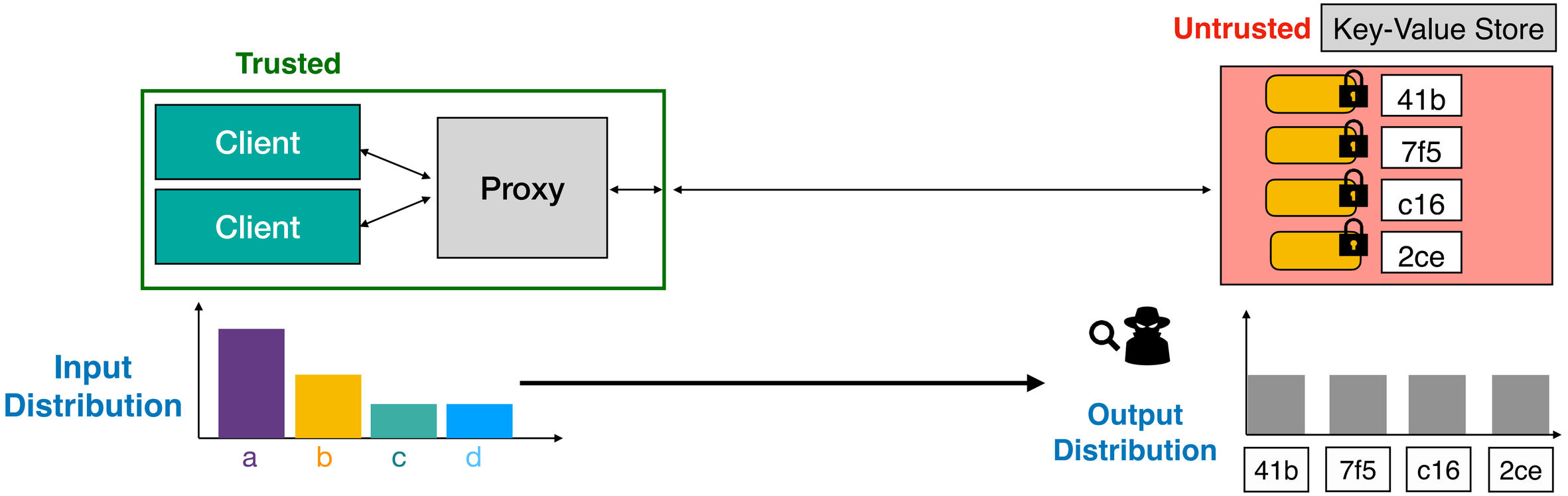

Existing techniques “flatten” input access distribution into **uniform** output distribution

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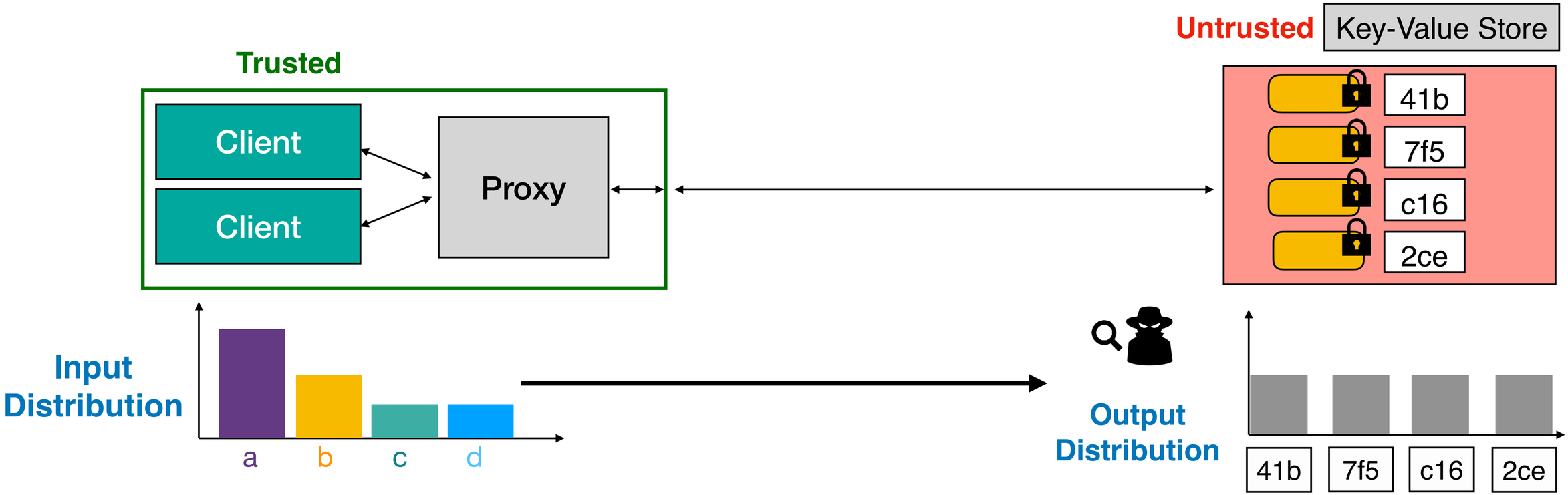

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Bandwidth Overhead	Large O(log n)
Adversarial Model	Active (Can inject queries)

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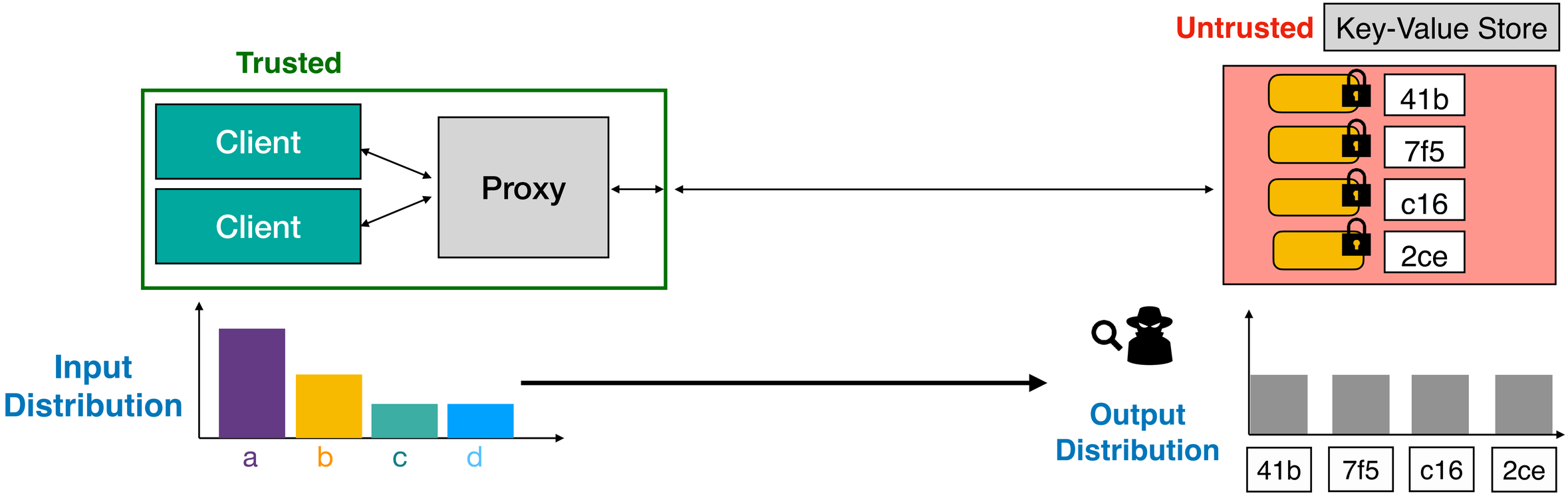

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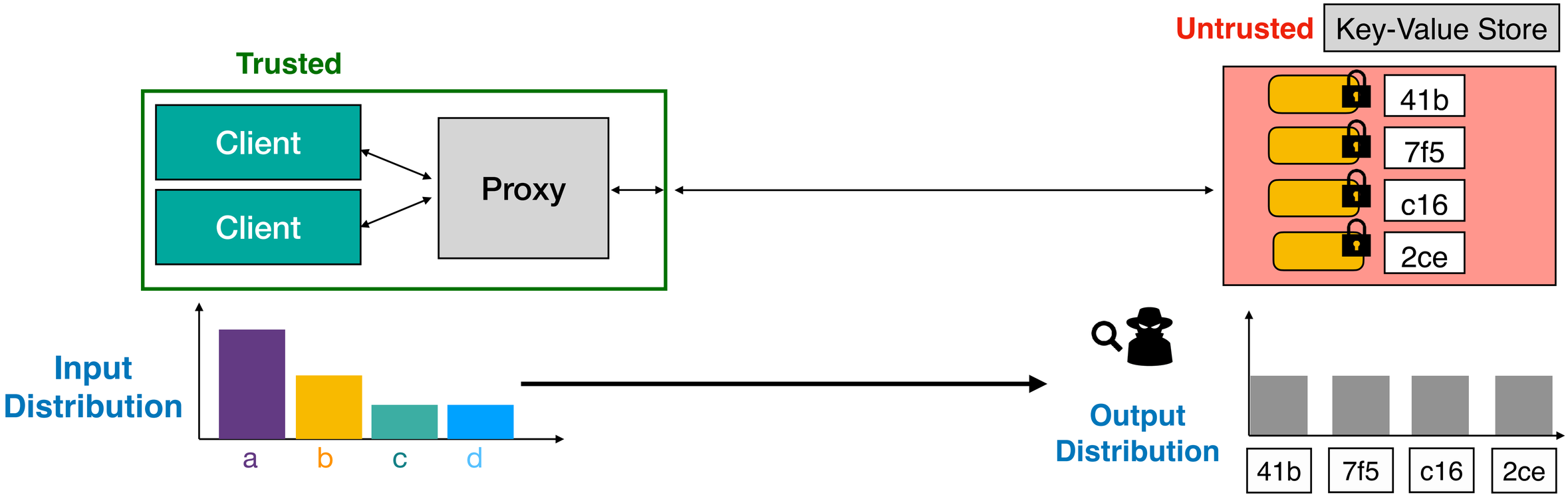

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All existing oblivious data access techniques use centralized (stateful) proxy

This work

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Challenges with Centralized Oblivious Data Access Systems

1. Insecure or unavailable during failures
2. Scalability bottleneck

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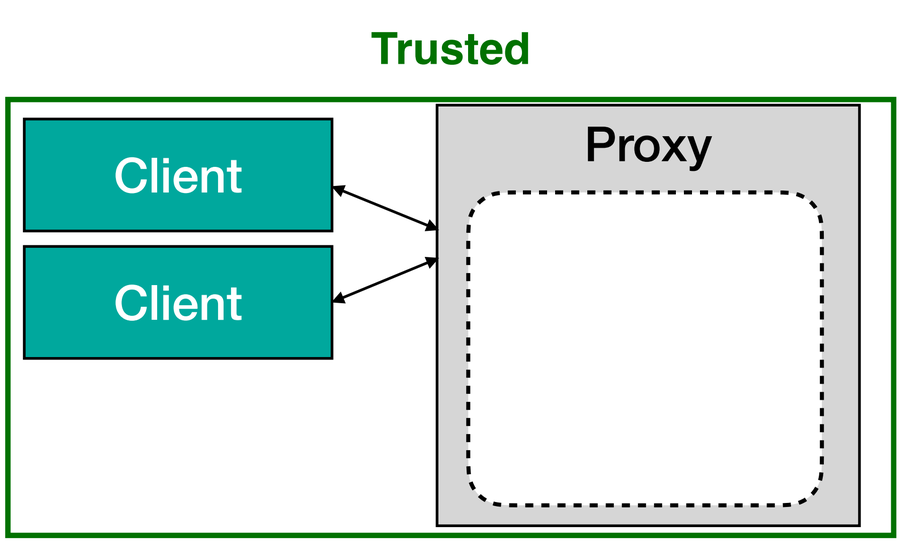

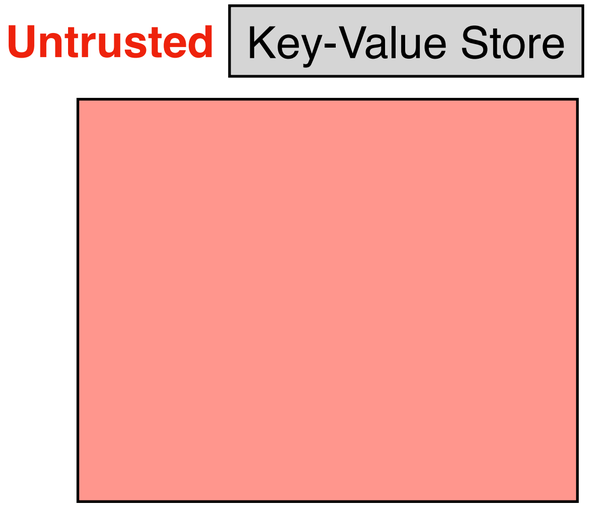

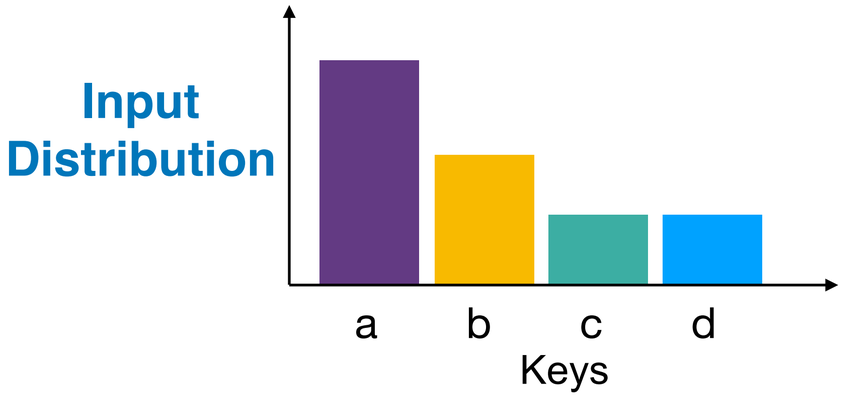

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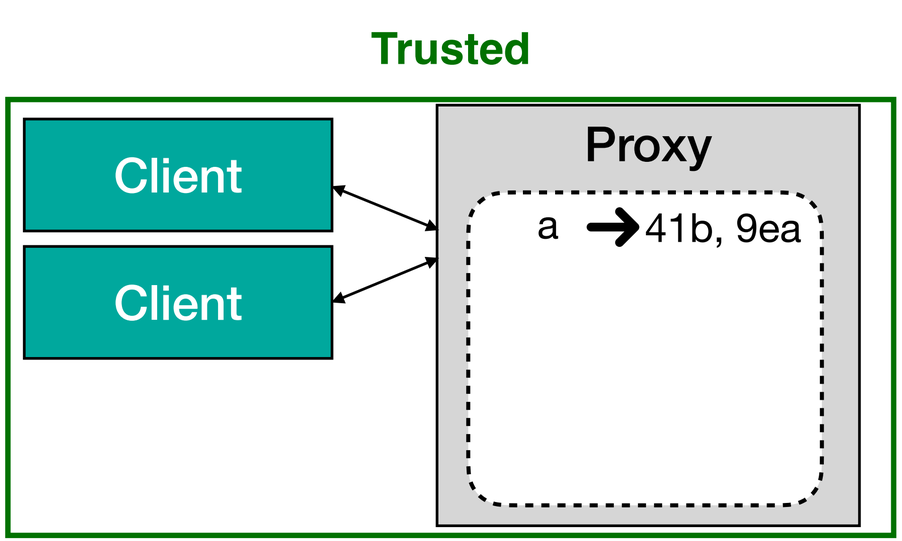

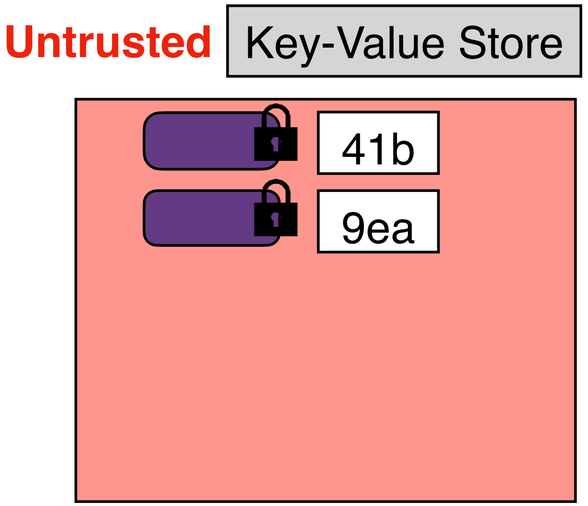

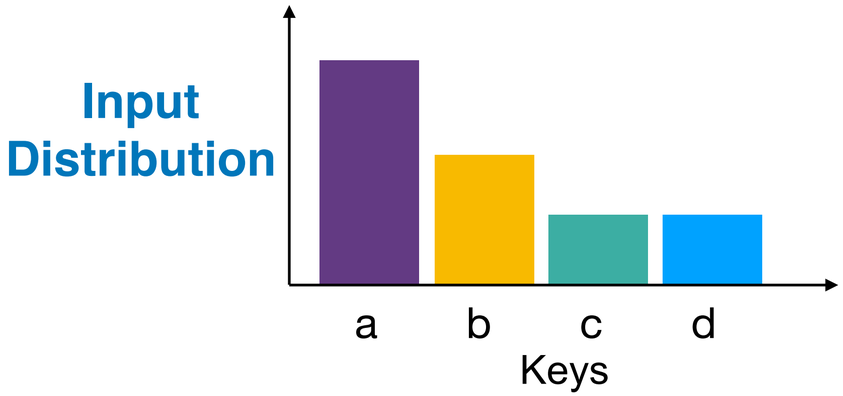

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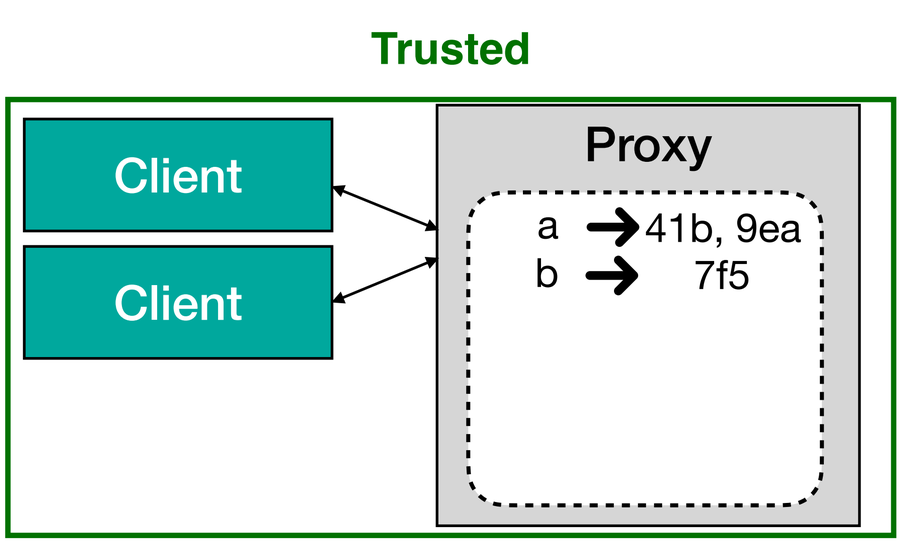

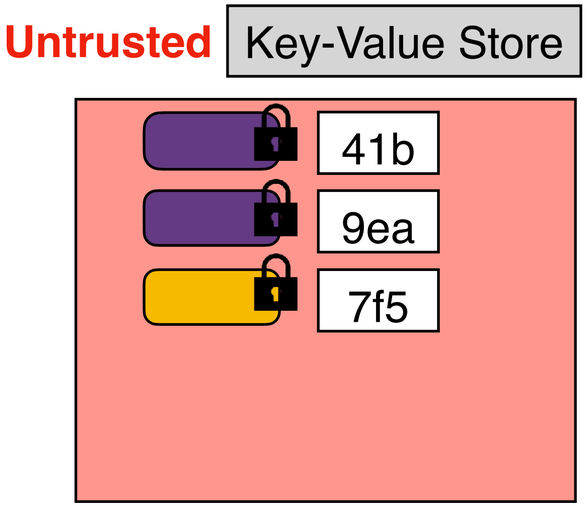

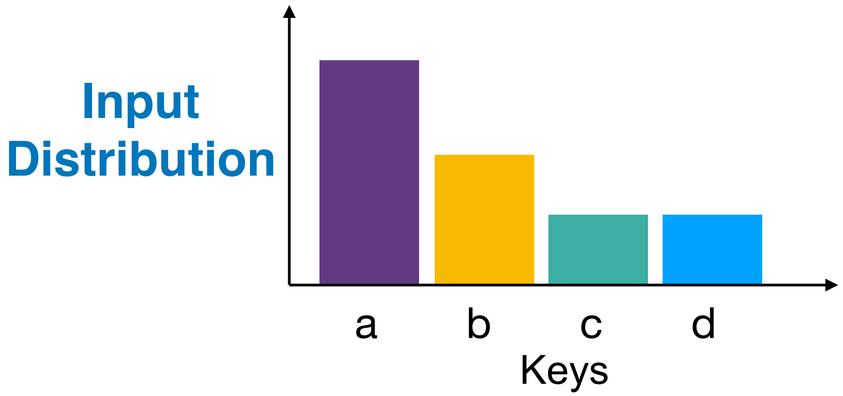

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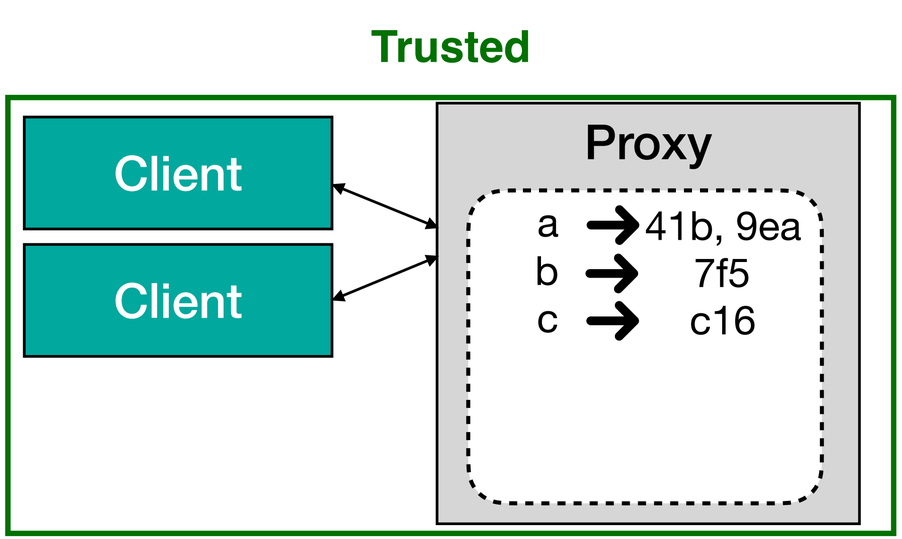

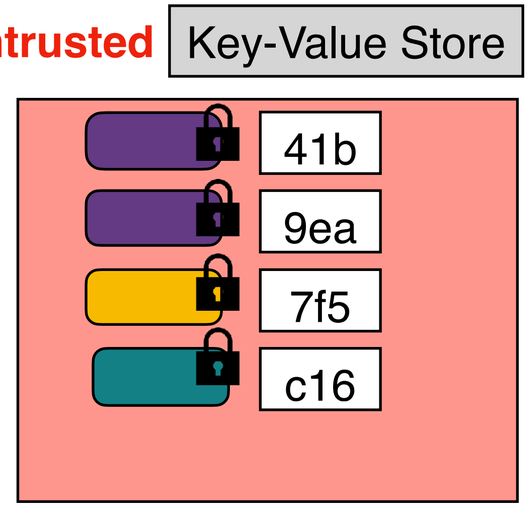

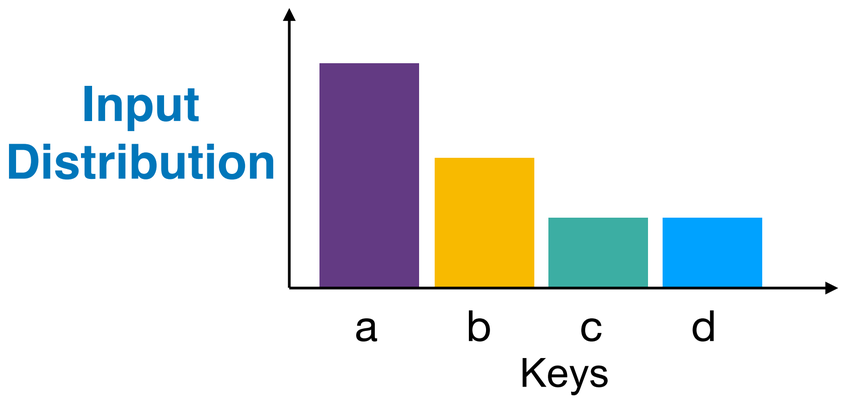

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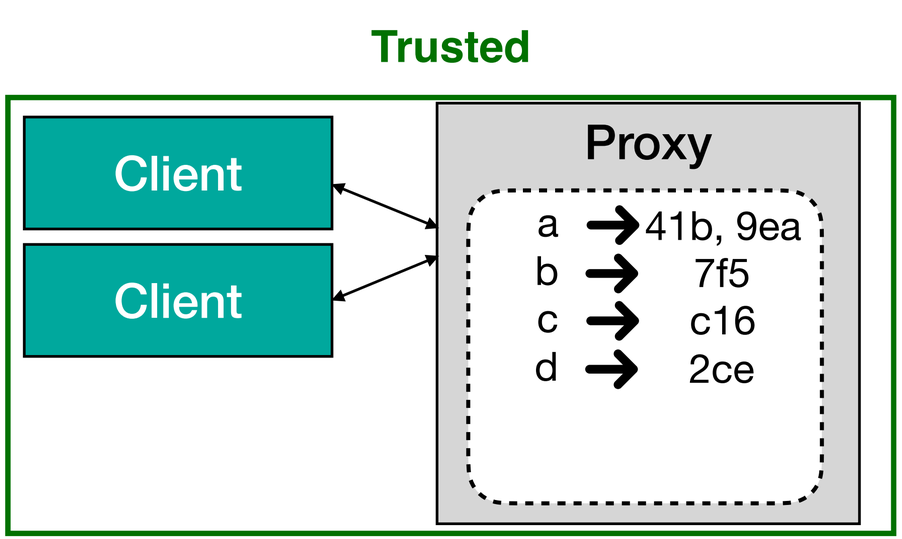

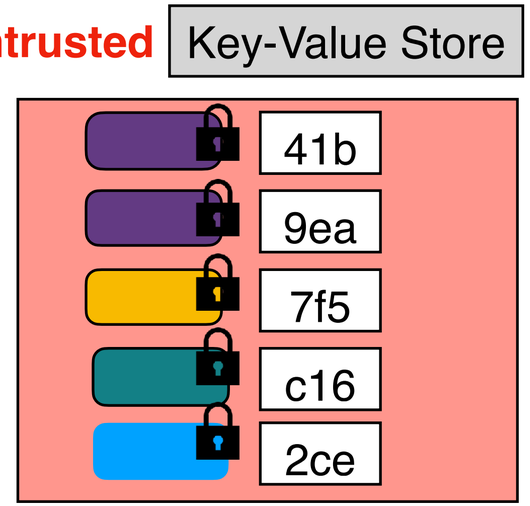

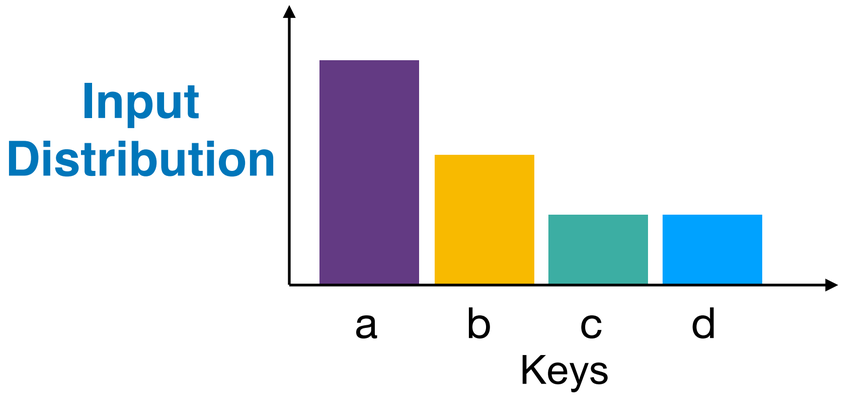

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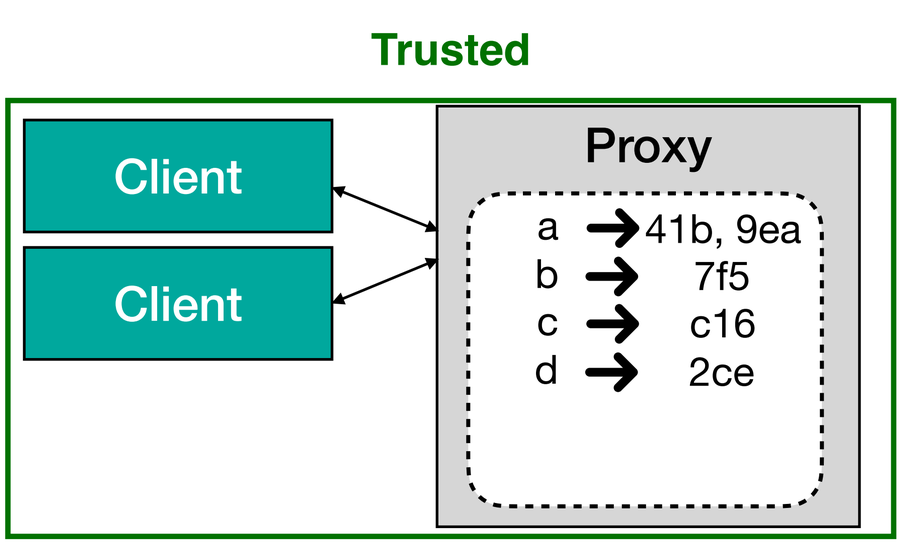

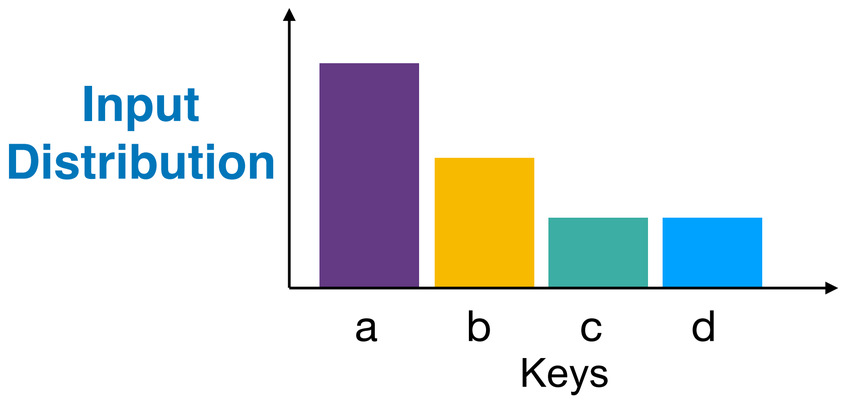

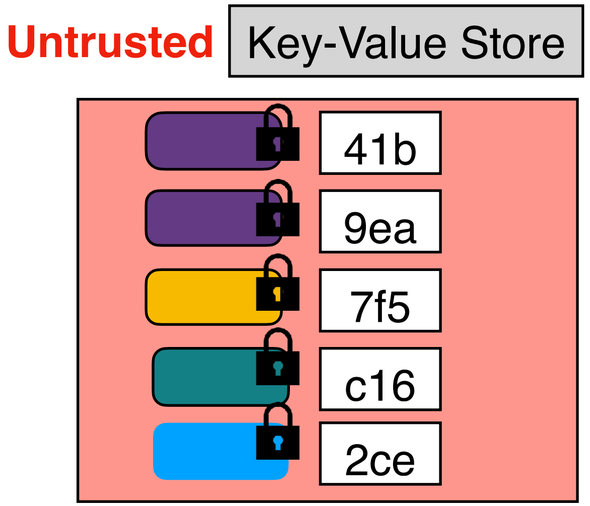

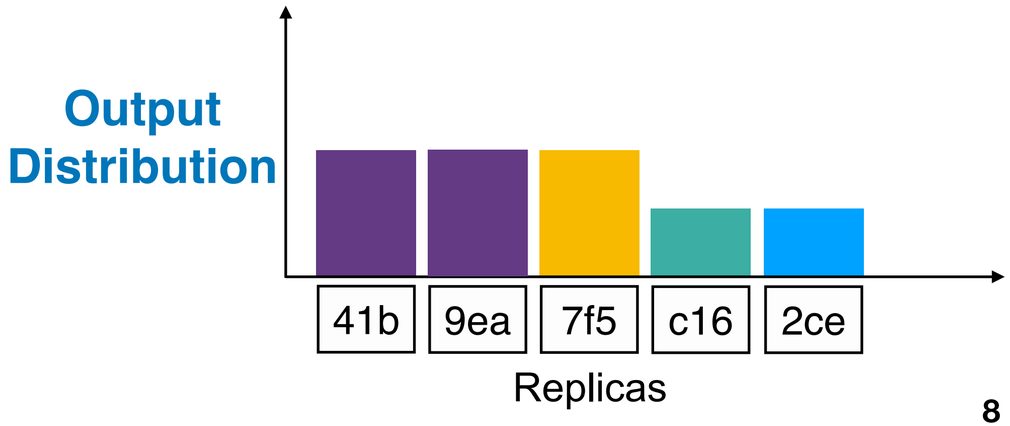

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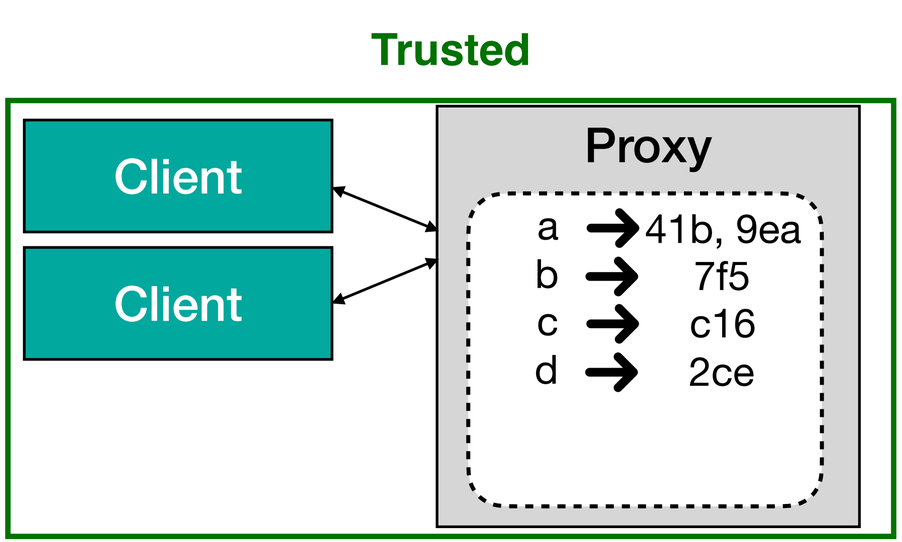

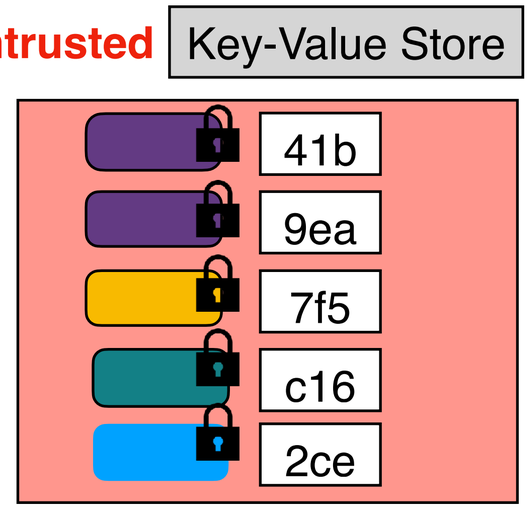

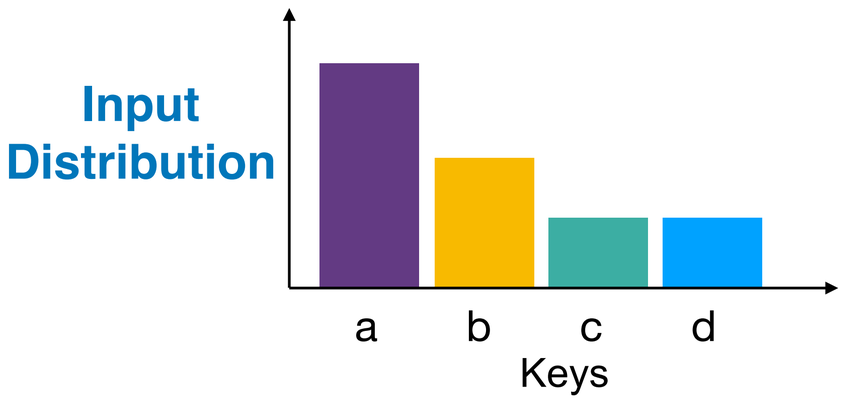

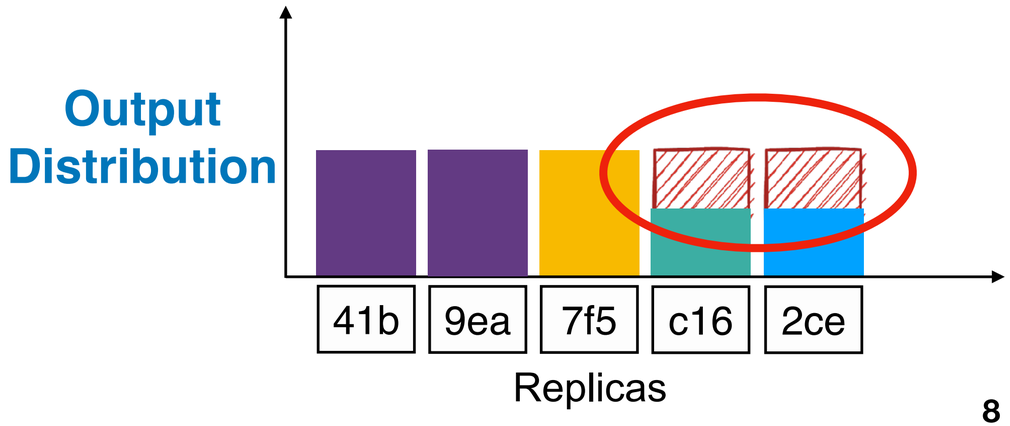

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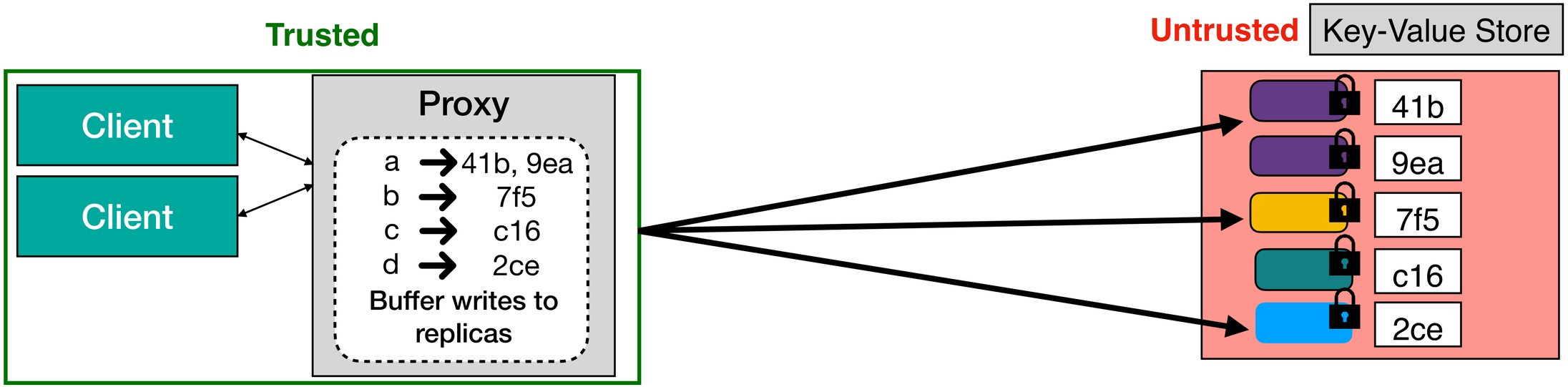

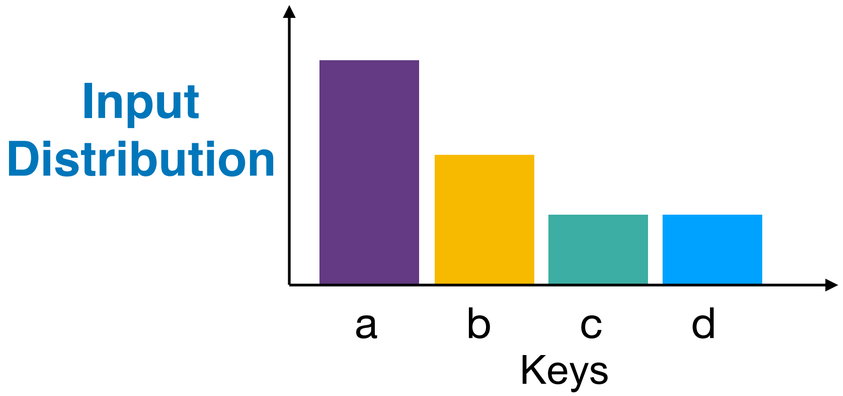

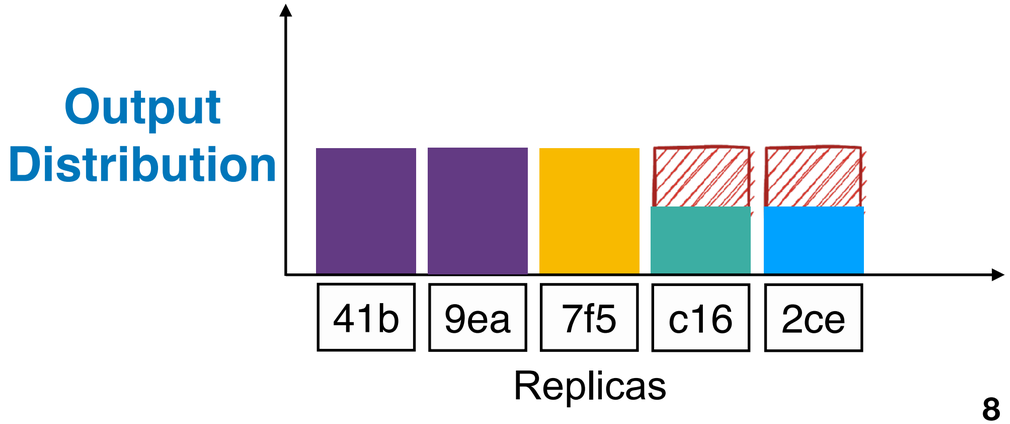

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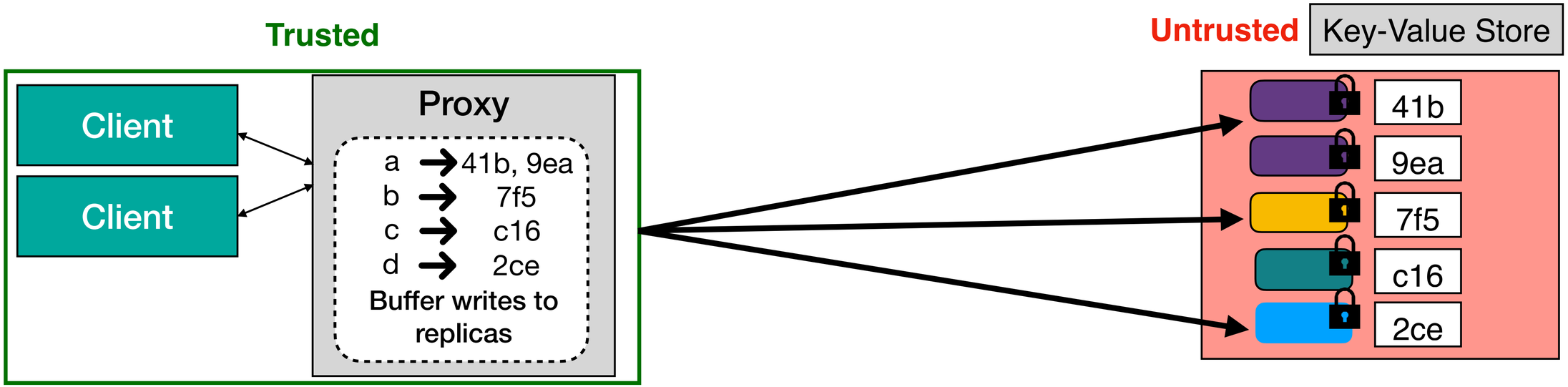
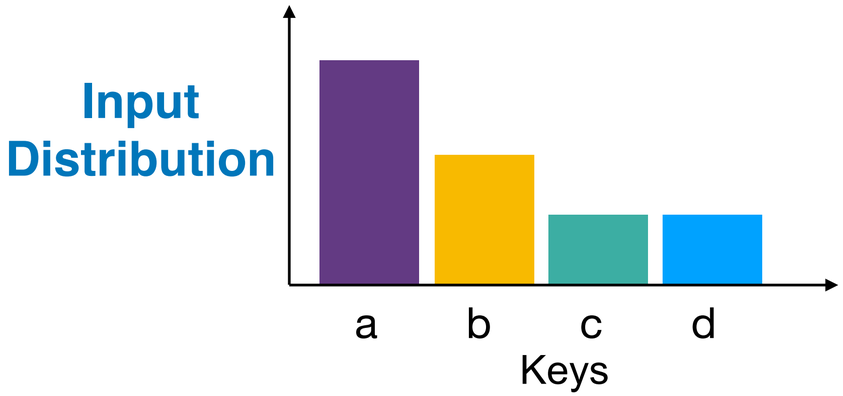
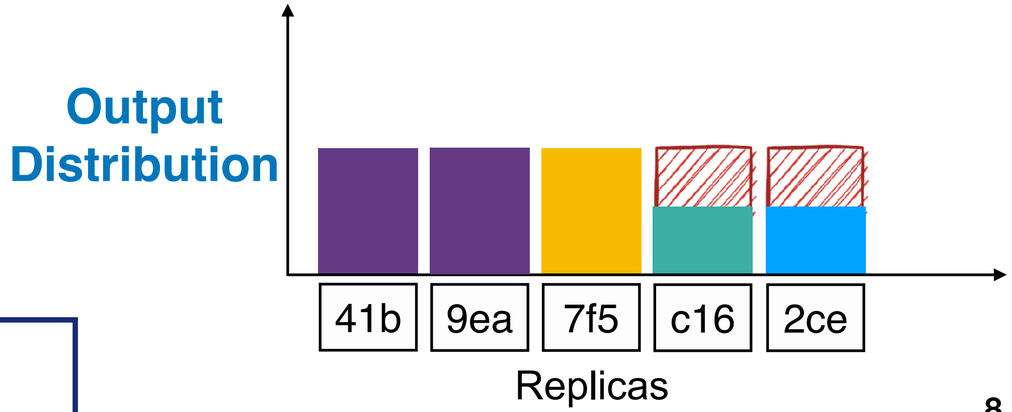




Proxy is stateful



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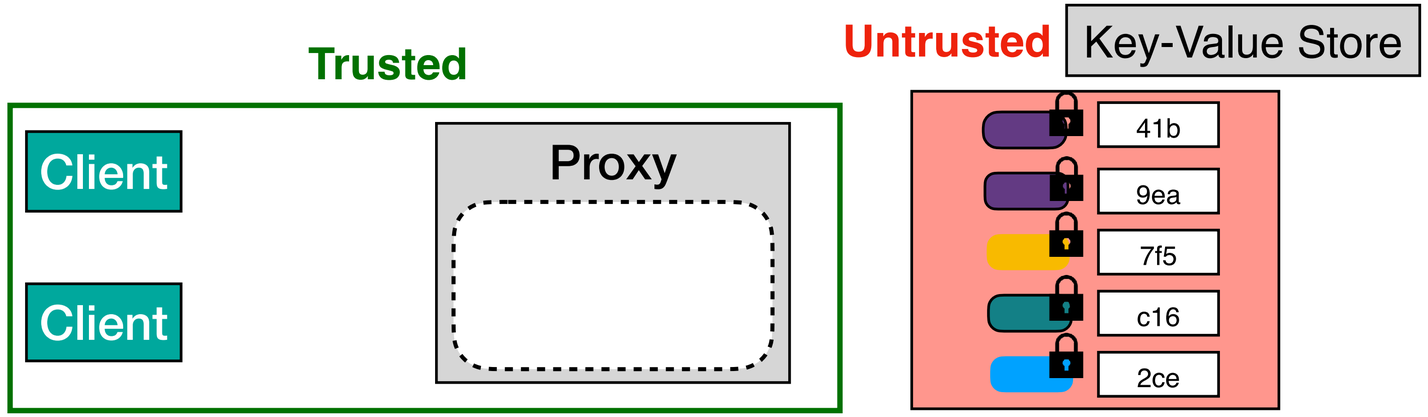

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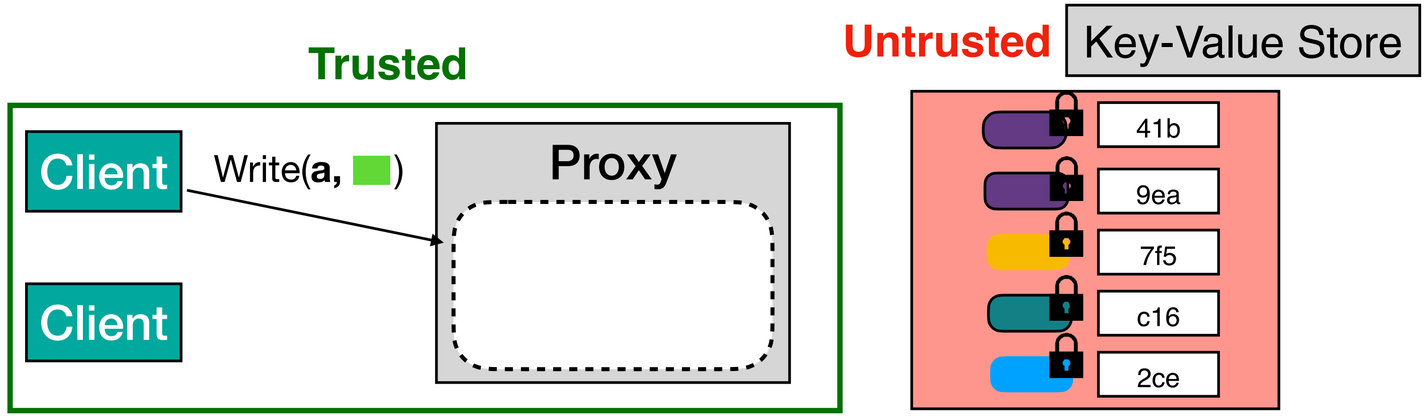

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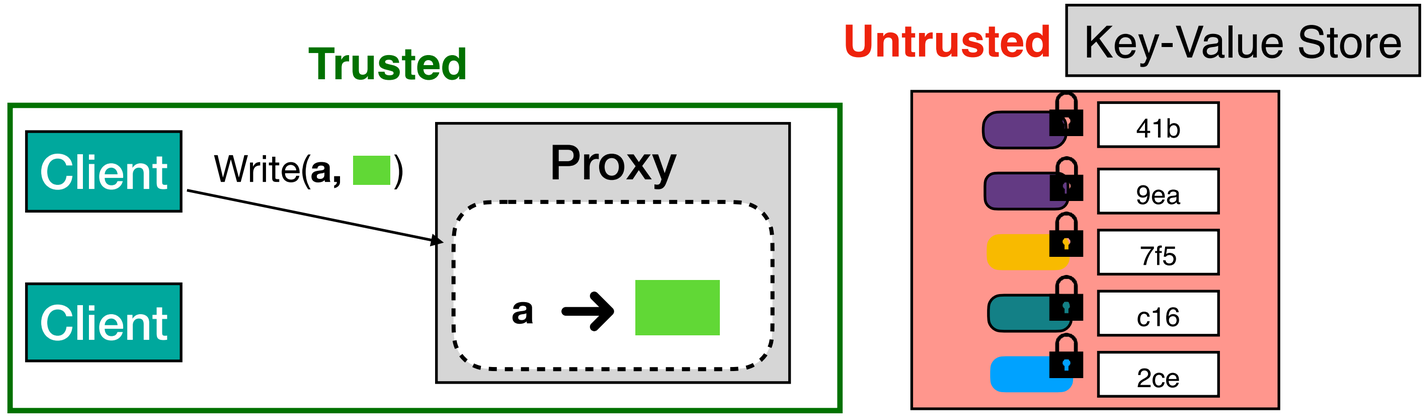

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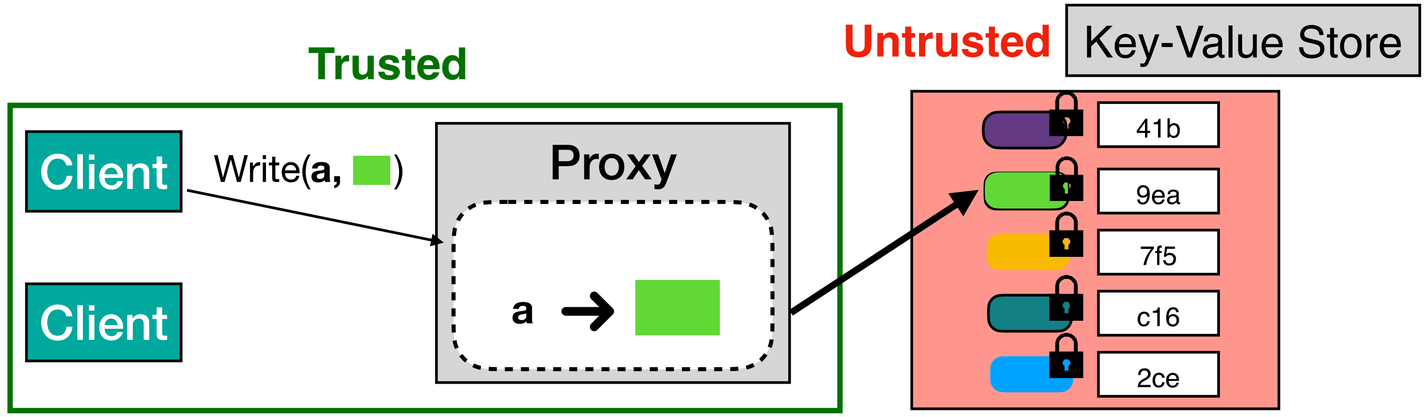

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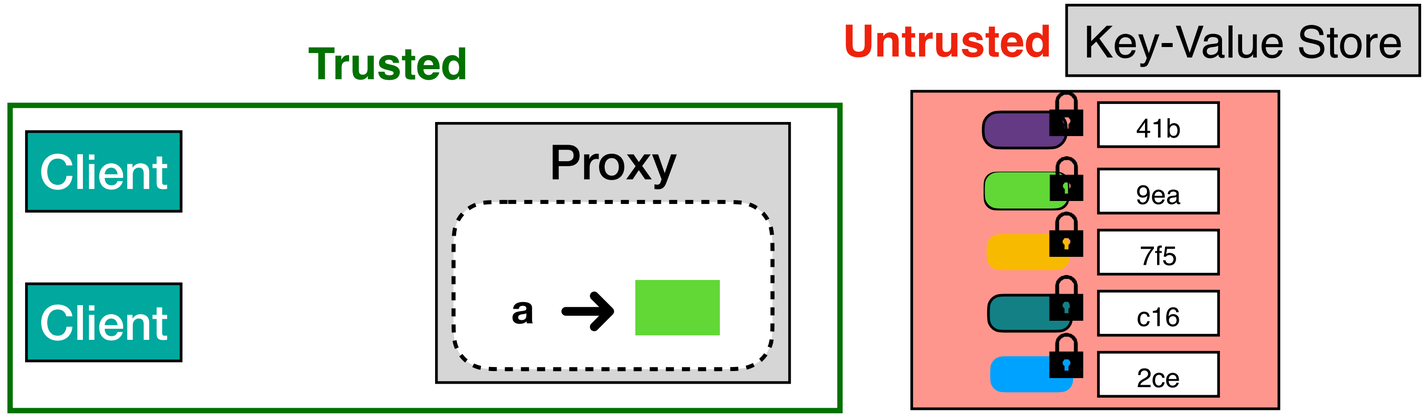

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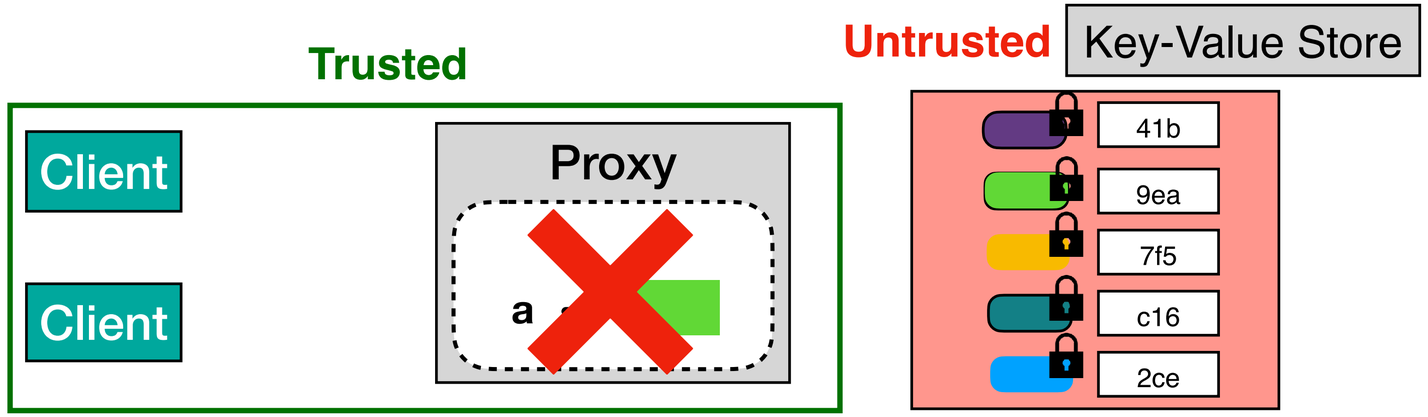

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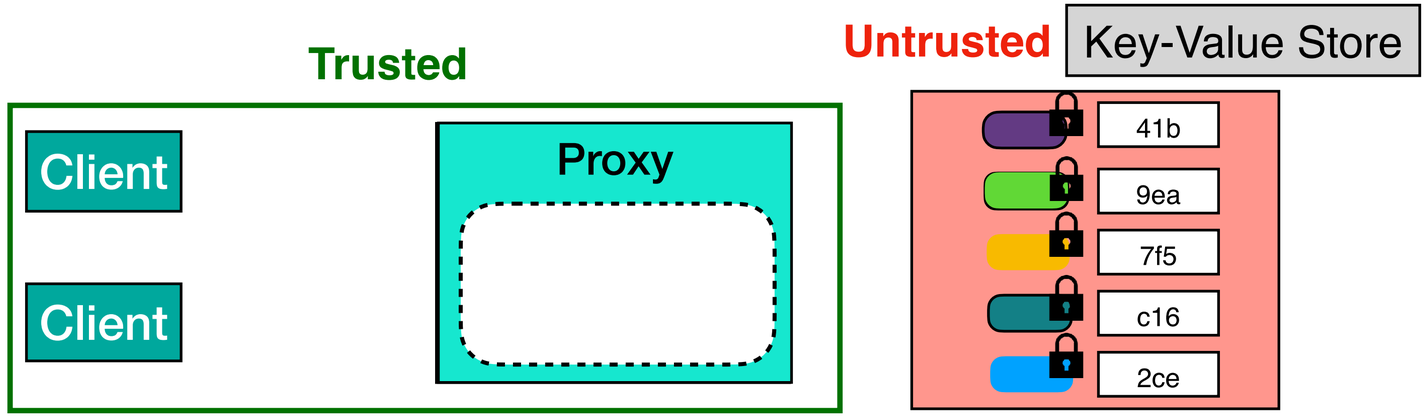

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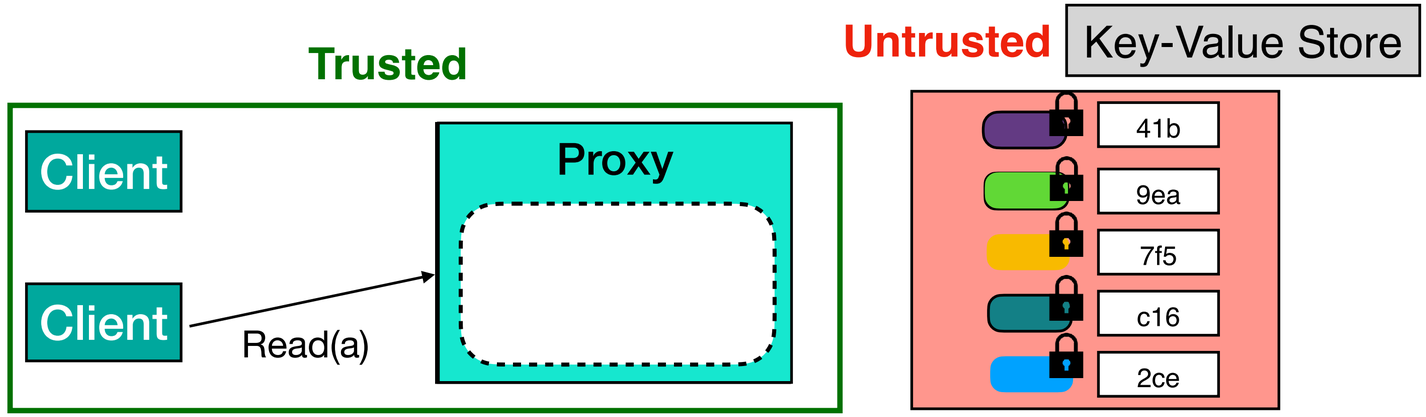

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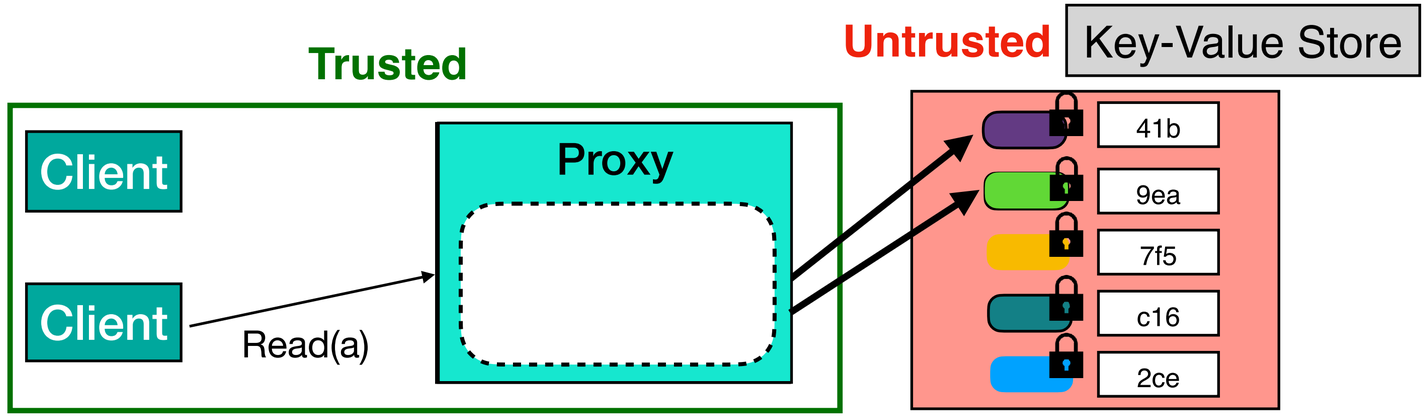

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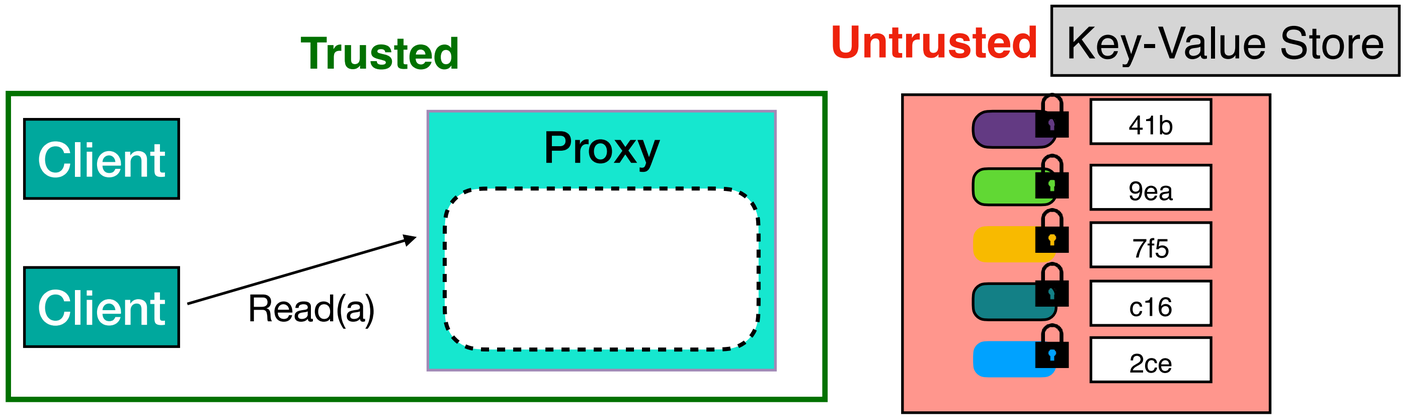

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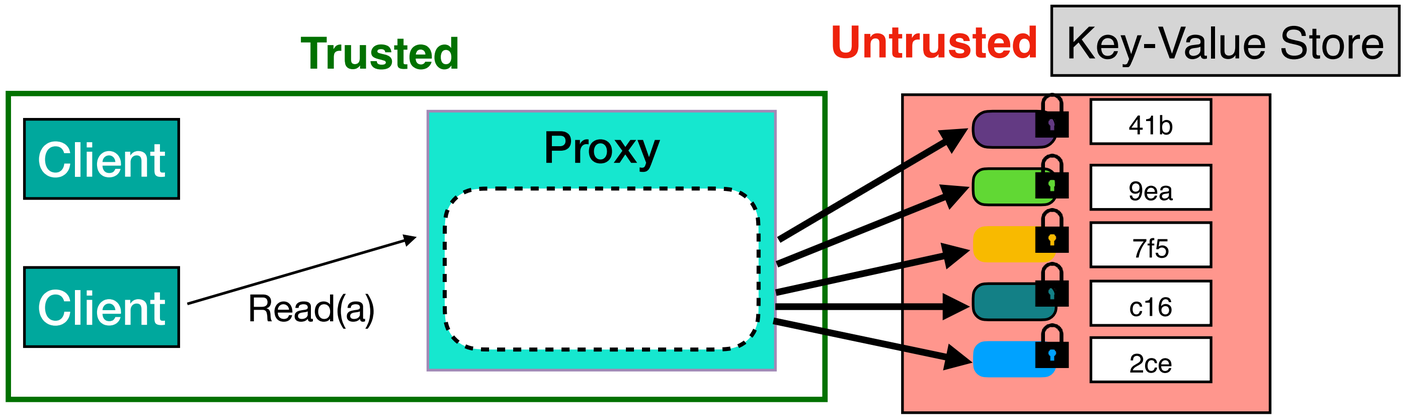

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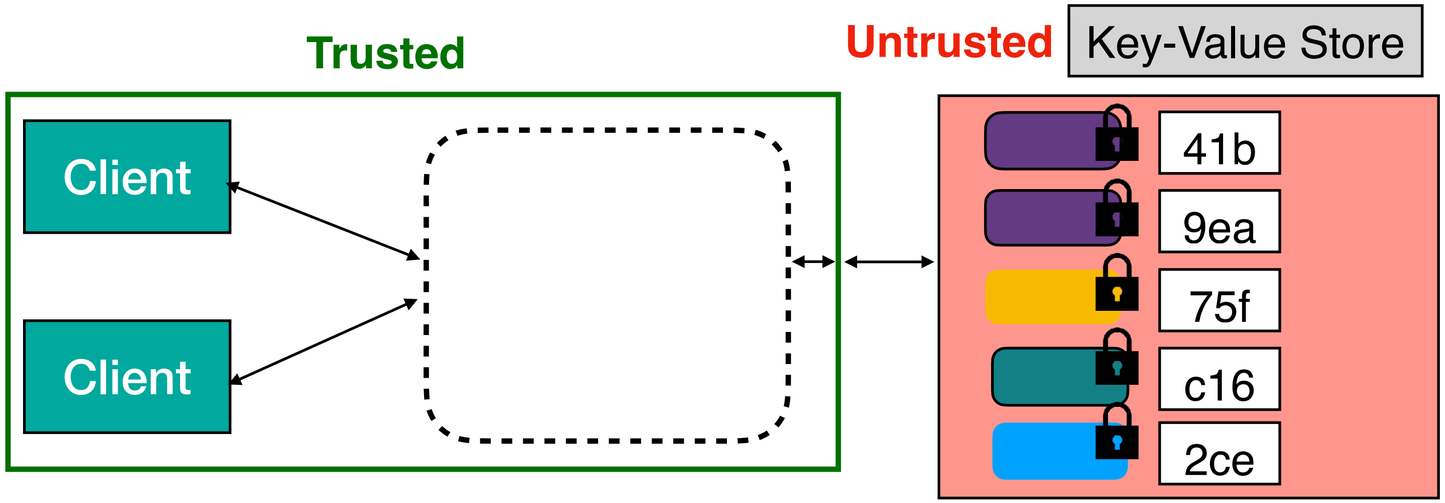

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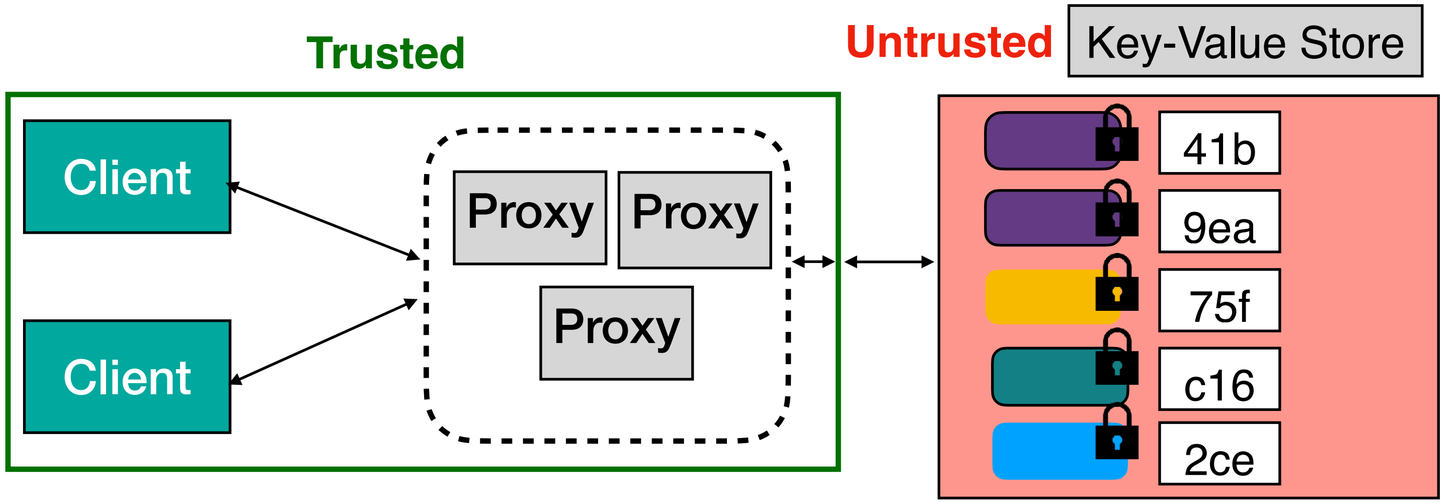

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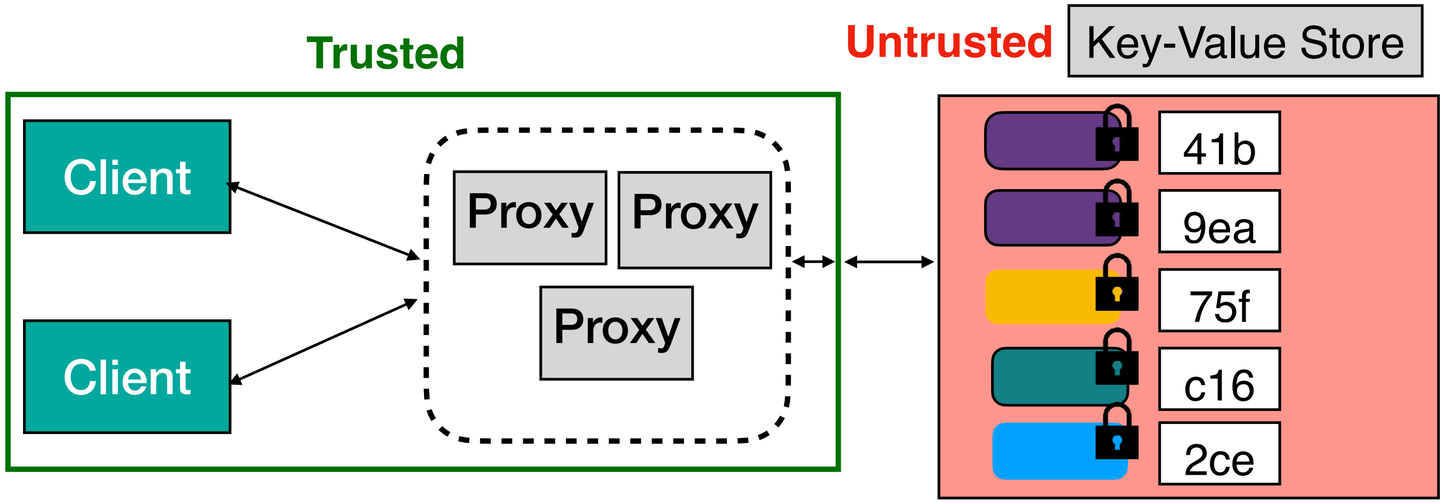

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   - Worst-case scenario : Arbitrary (bounded number of) failures at arbitrary times

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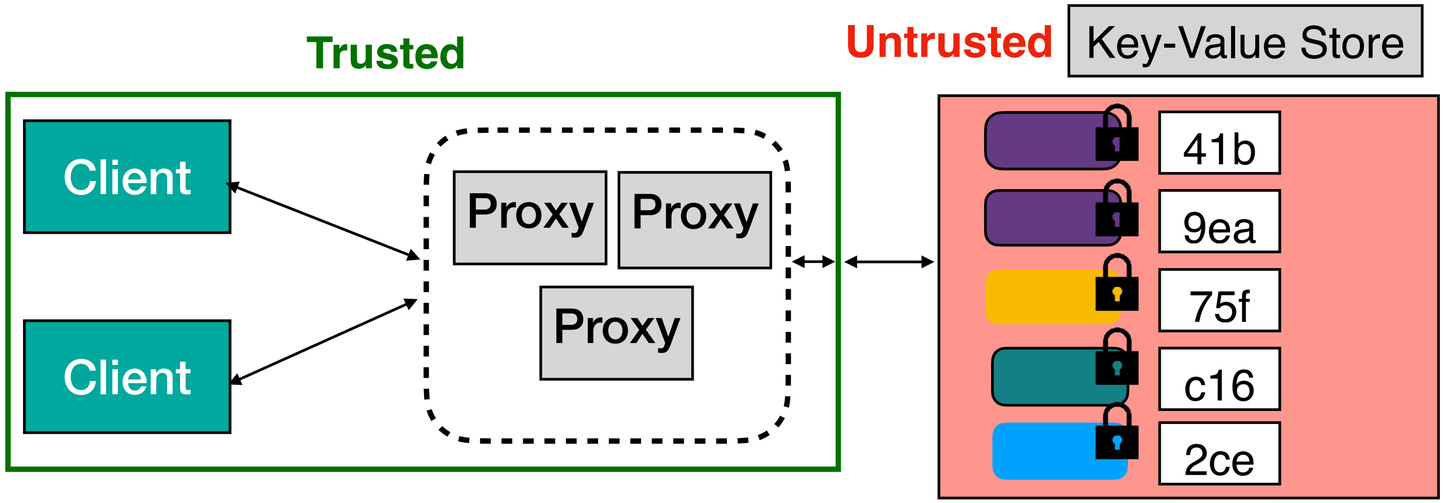

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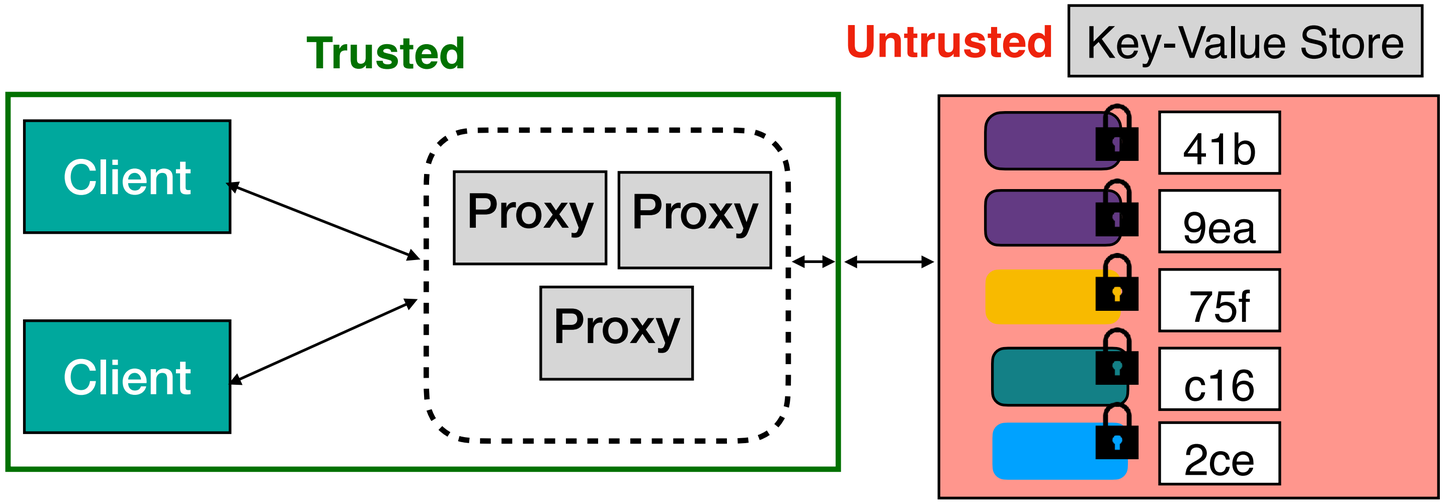

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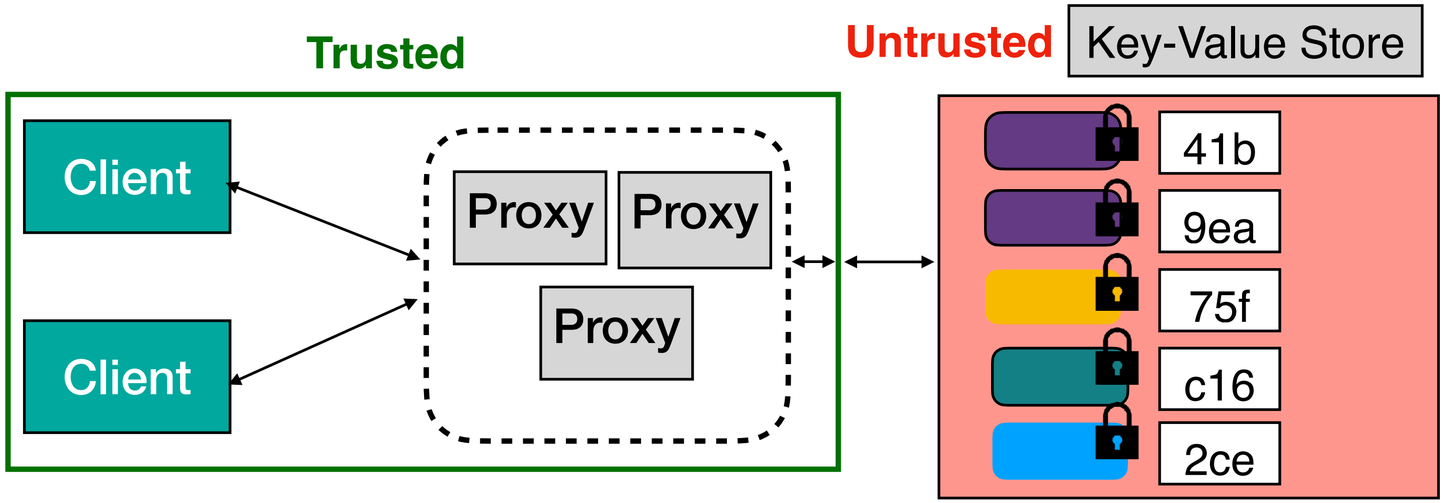

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Threat Model: Honest-but-curious Adversary (Or, Passive persistent adversary—The Pancake model)

Shortstack Key Insight

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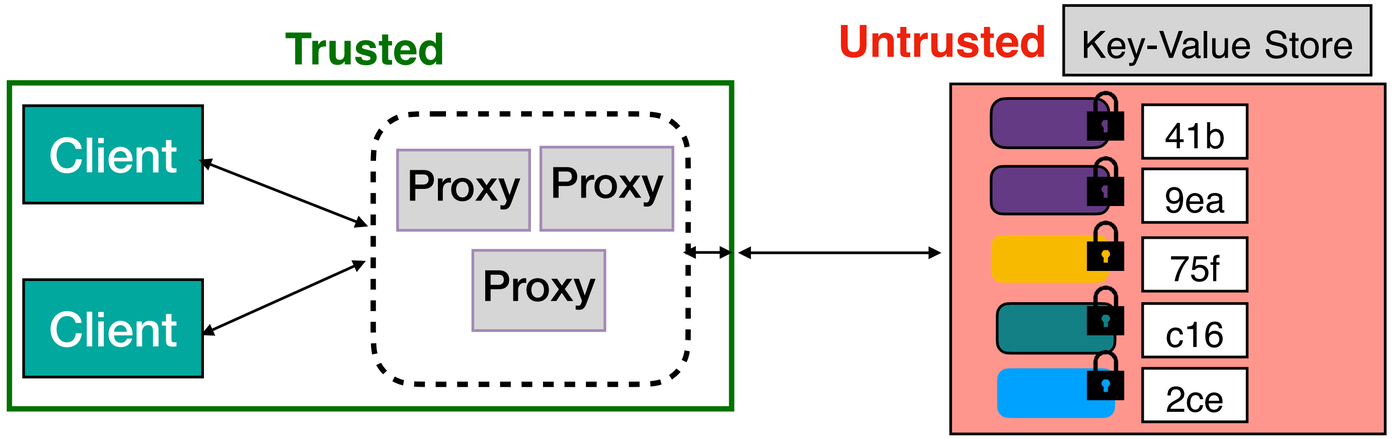

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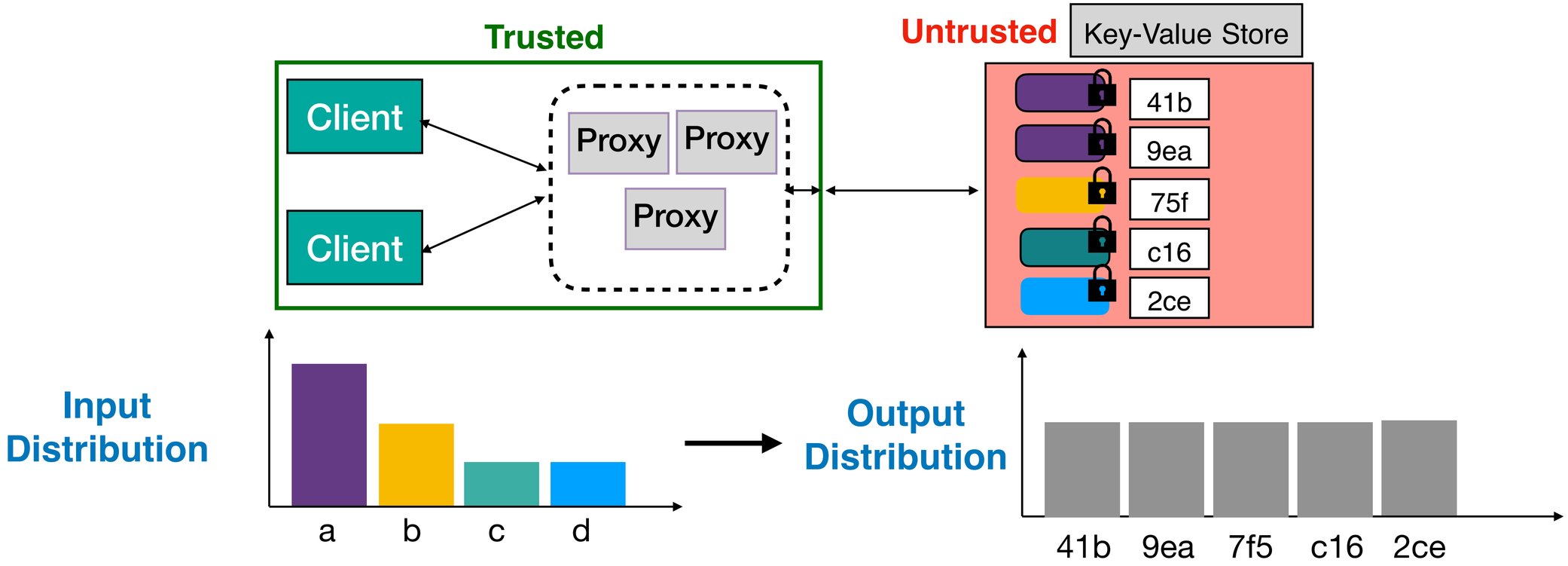

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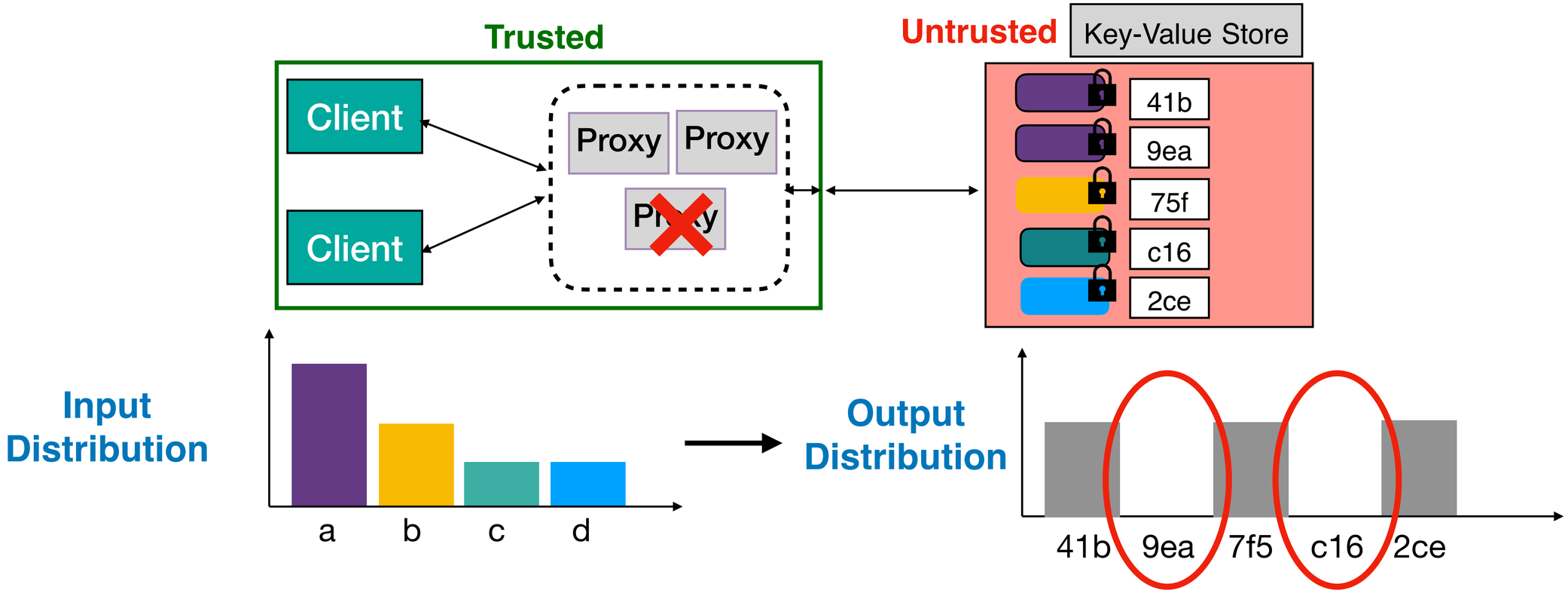

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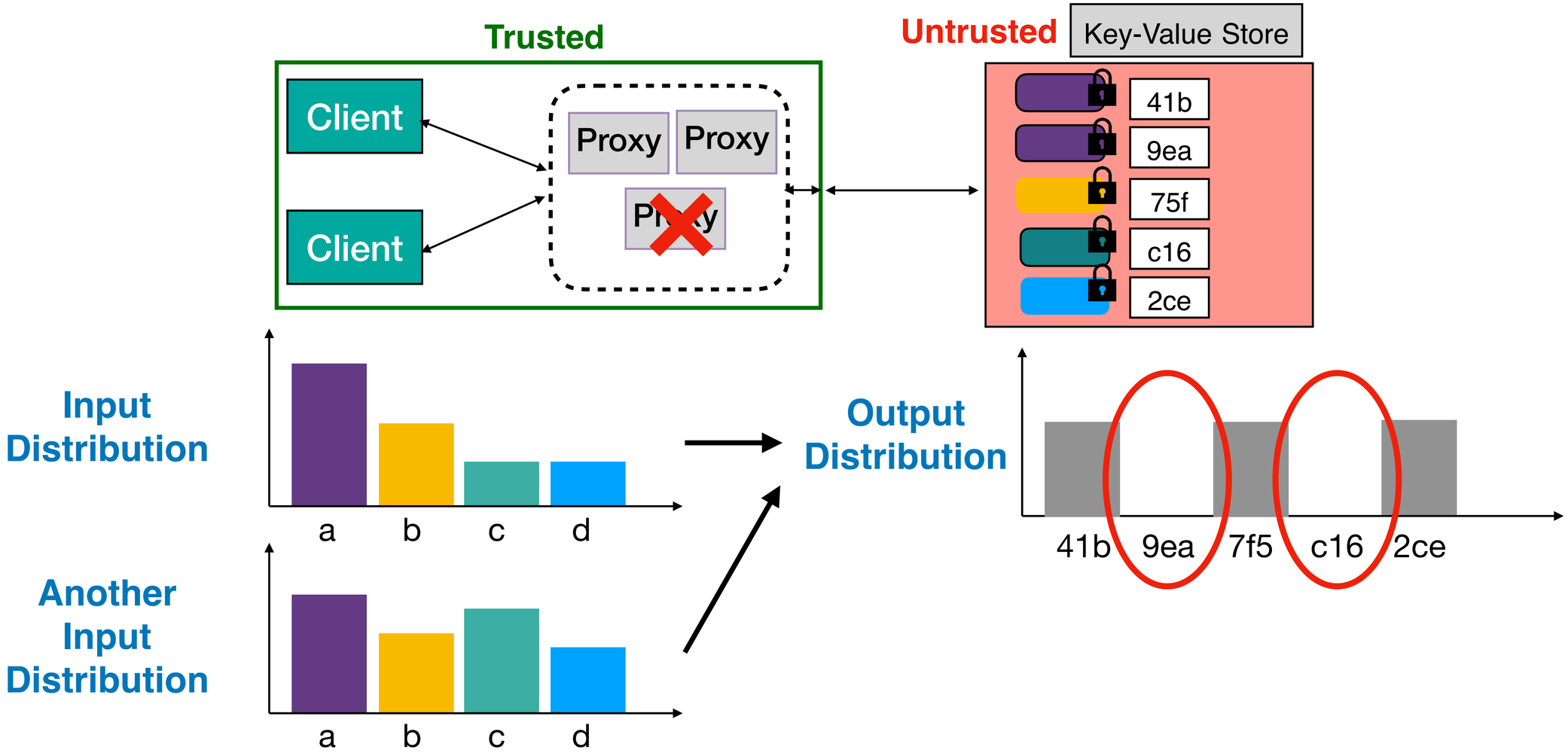

Shortstack Design Principle #1

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Partition query execution by Replicas

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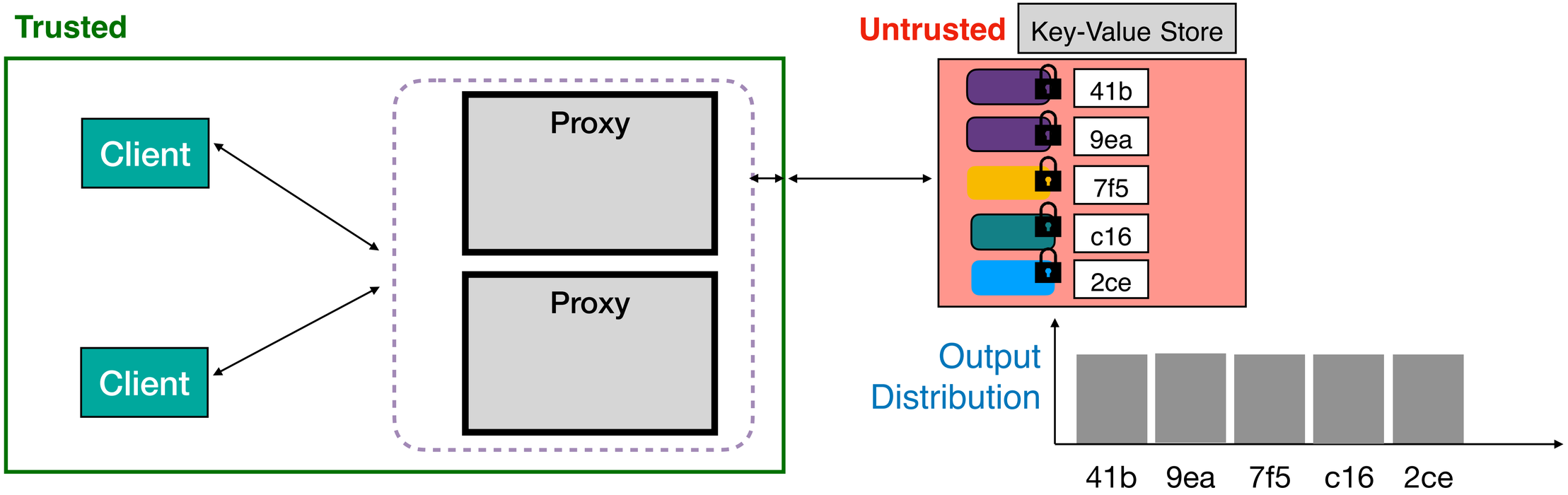

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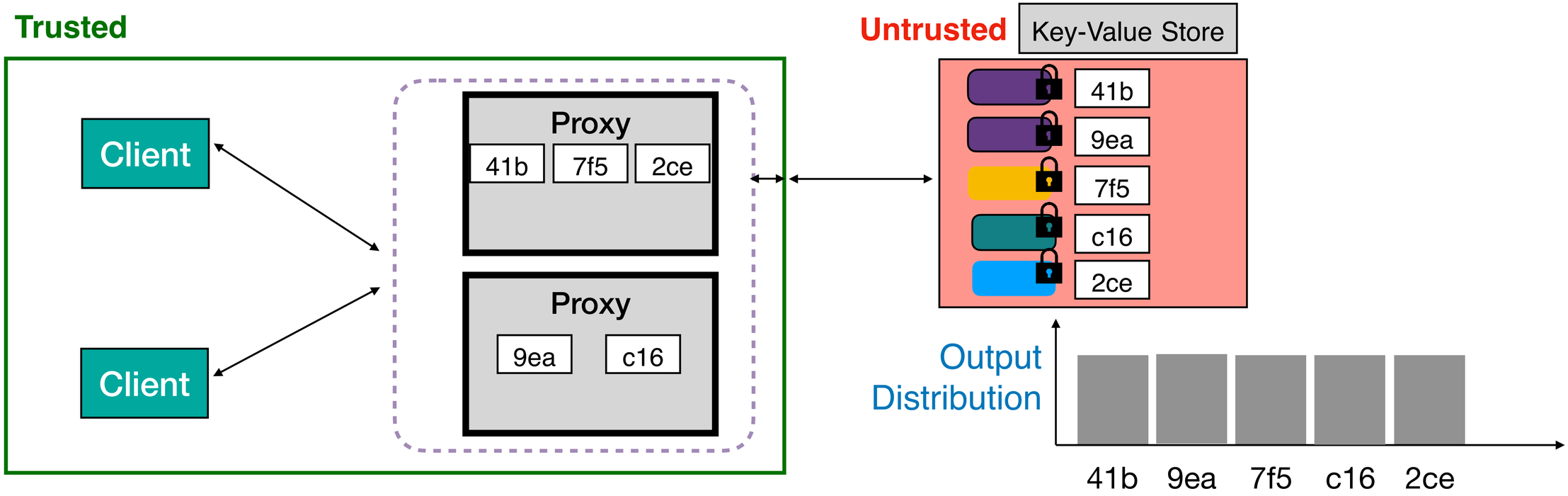

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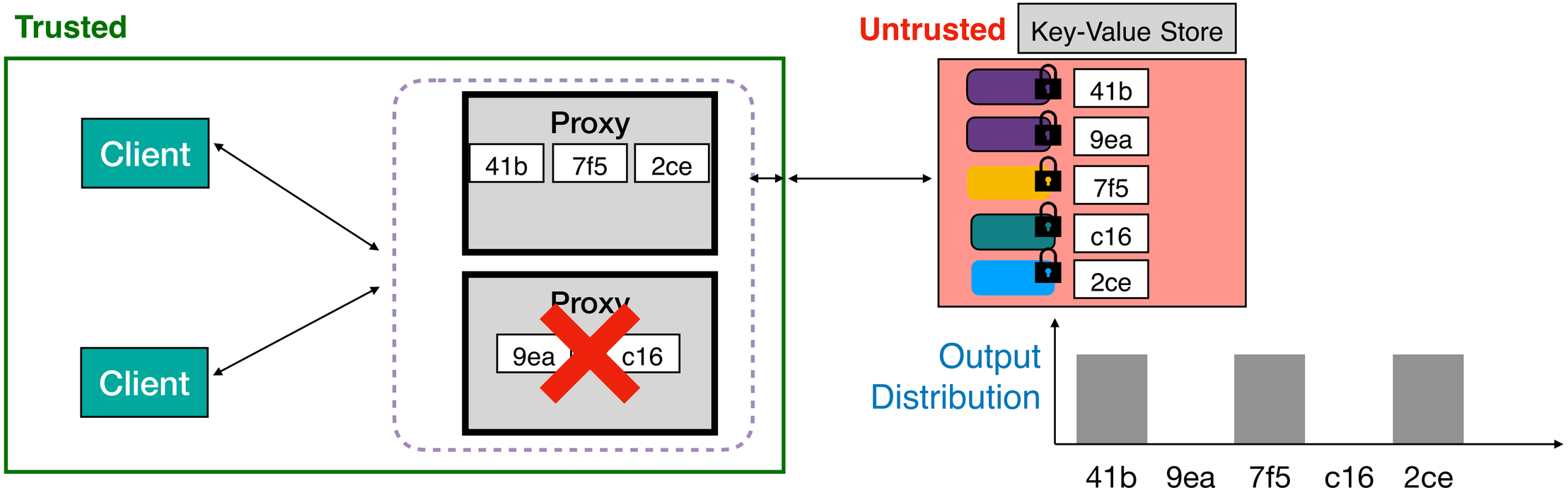
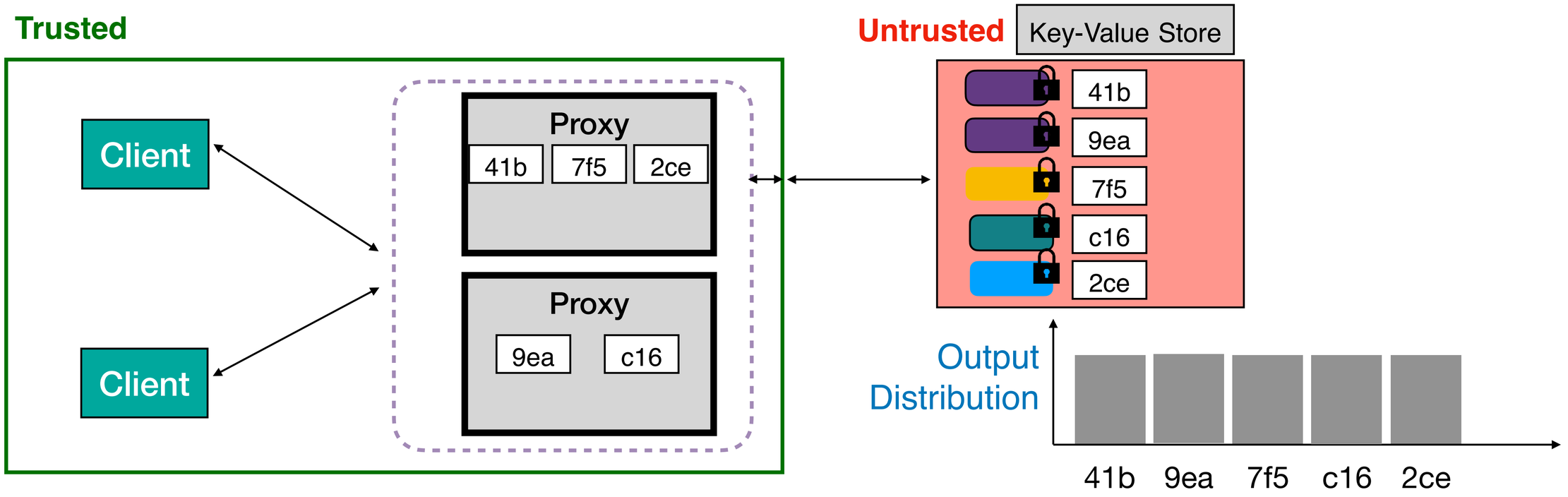


Upon failure, output distribution is uniform over a random subset of replicas

Output distribution is independent of input distribution (realizing our key insight)

Shortstack Design Principle #2

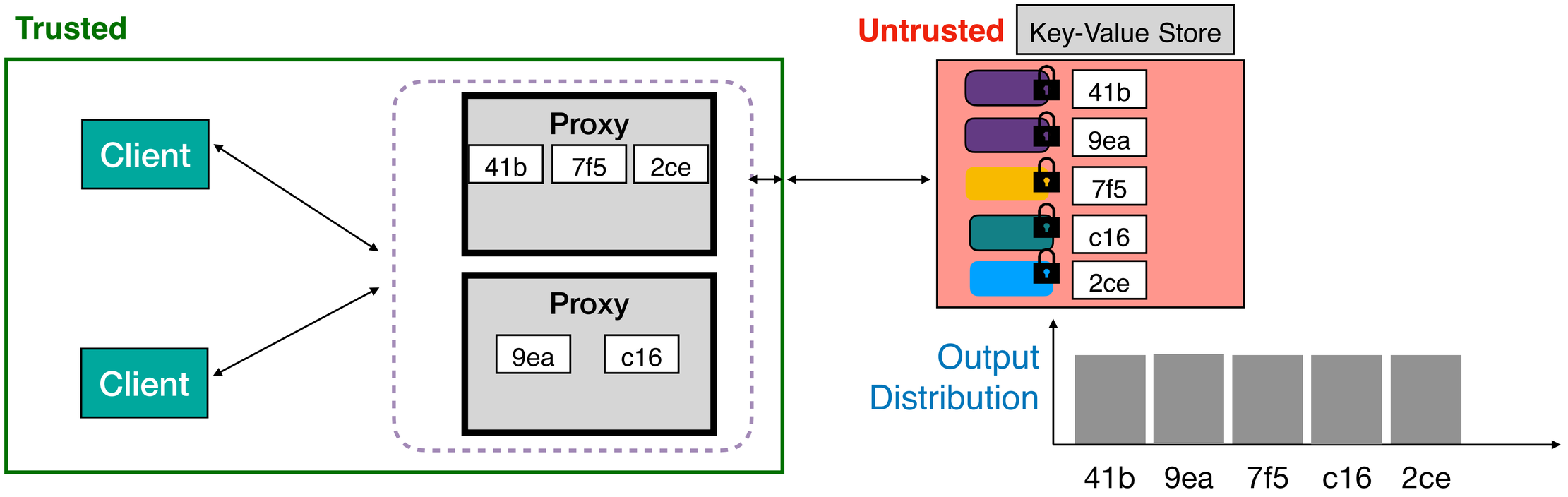


Shortstack Design Principle #2

Proxy State

a	41b, 9ea
b	7f5
c	c16
d	2ce

Partition Proxy state by Keys



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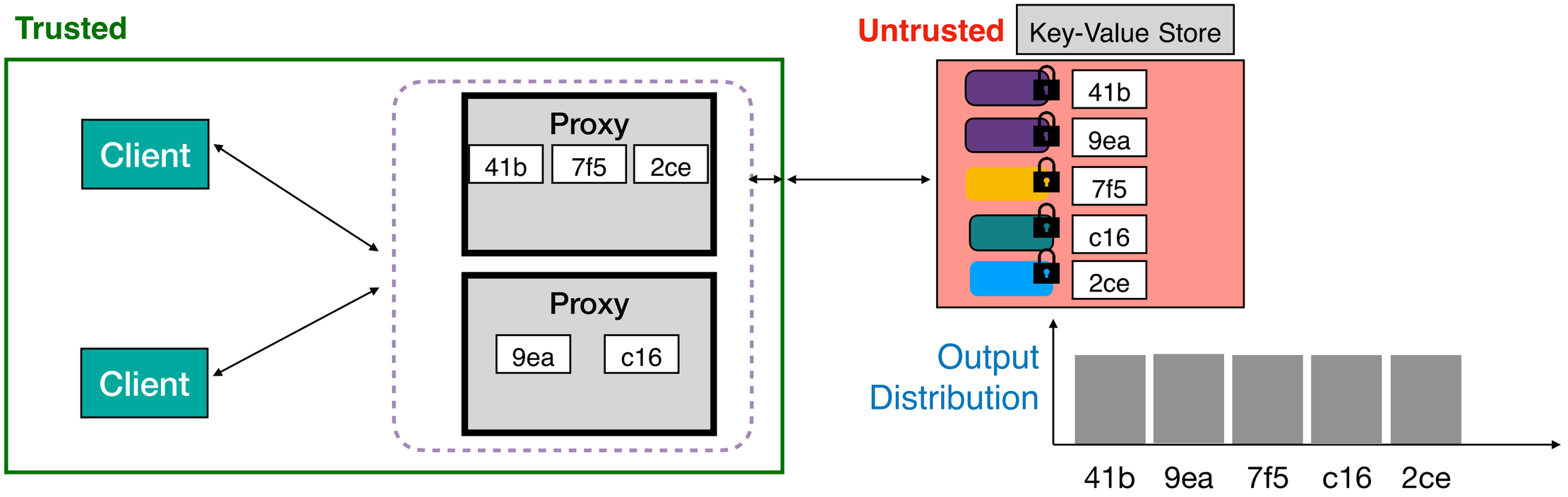

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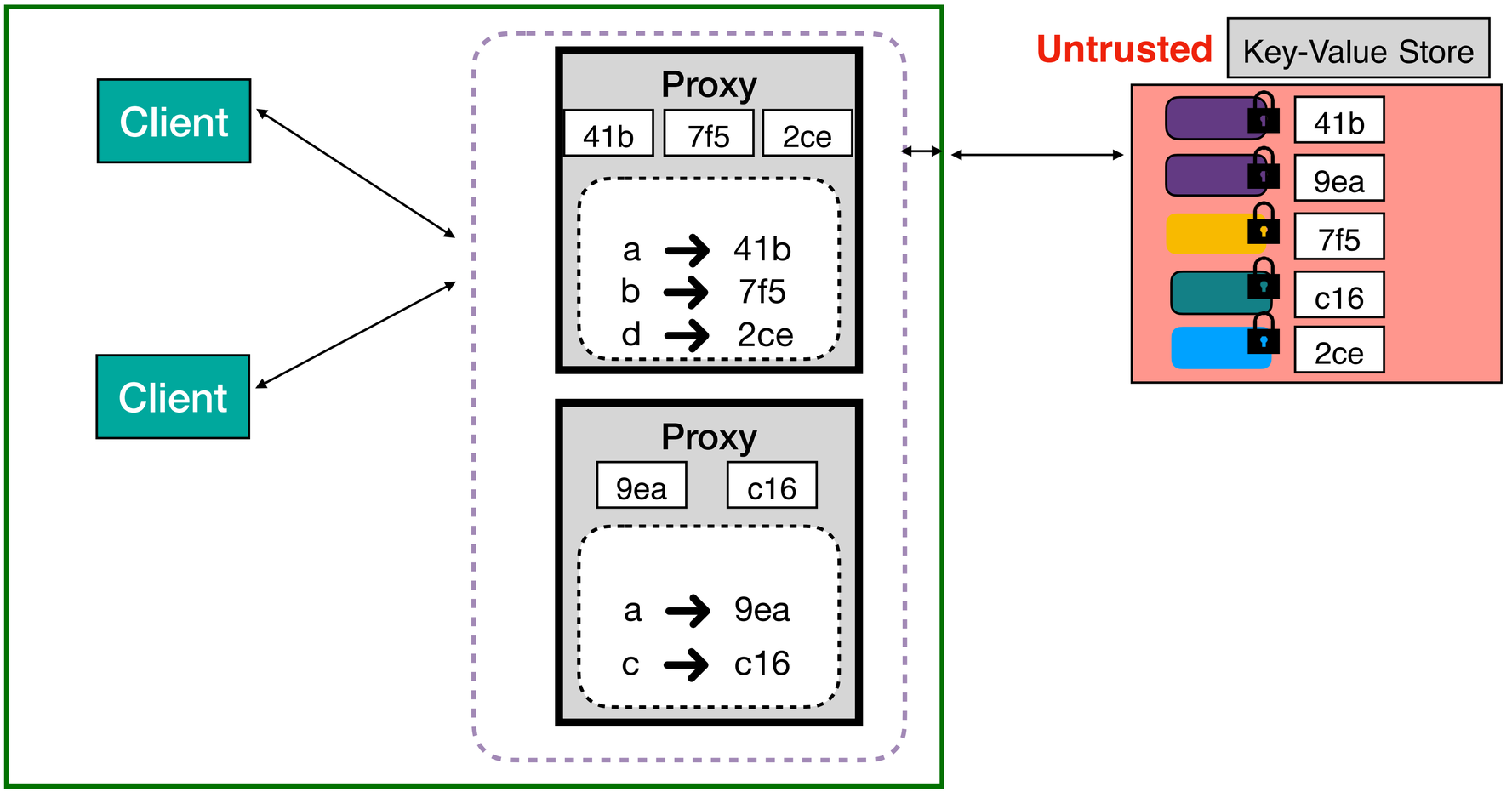

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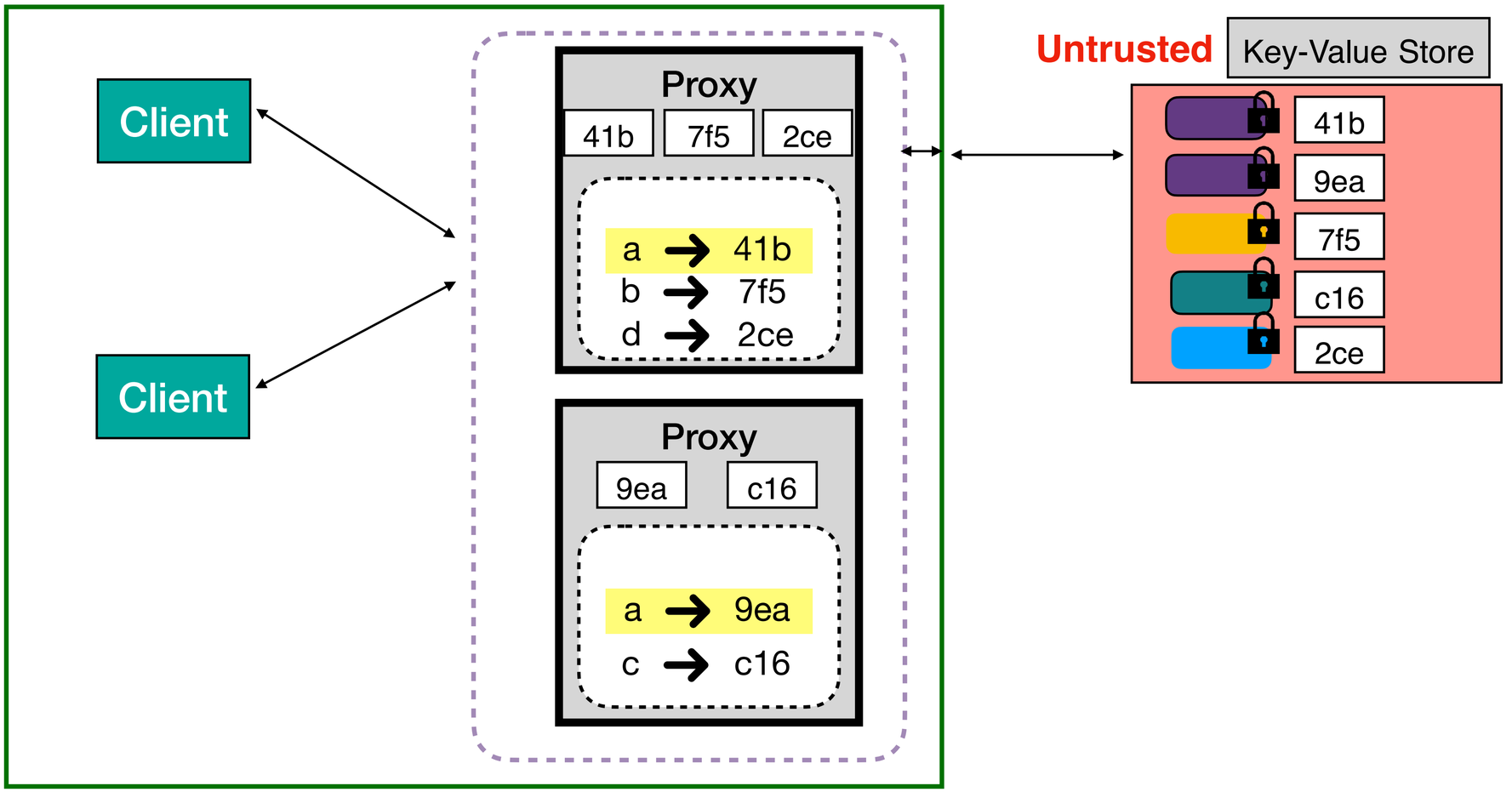

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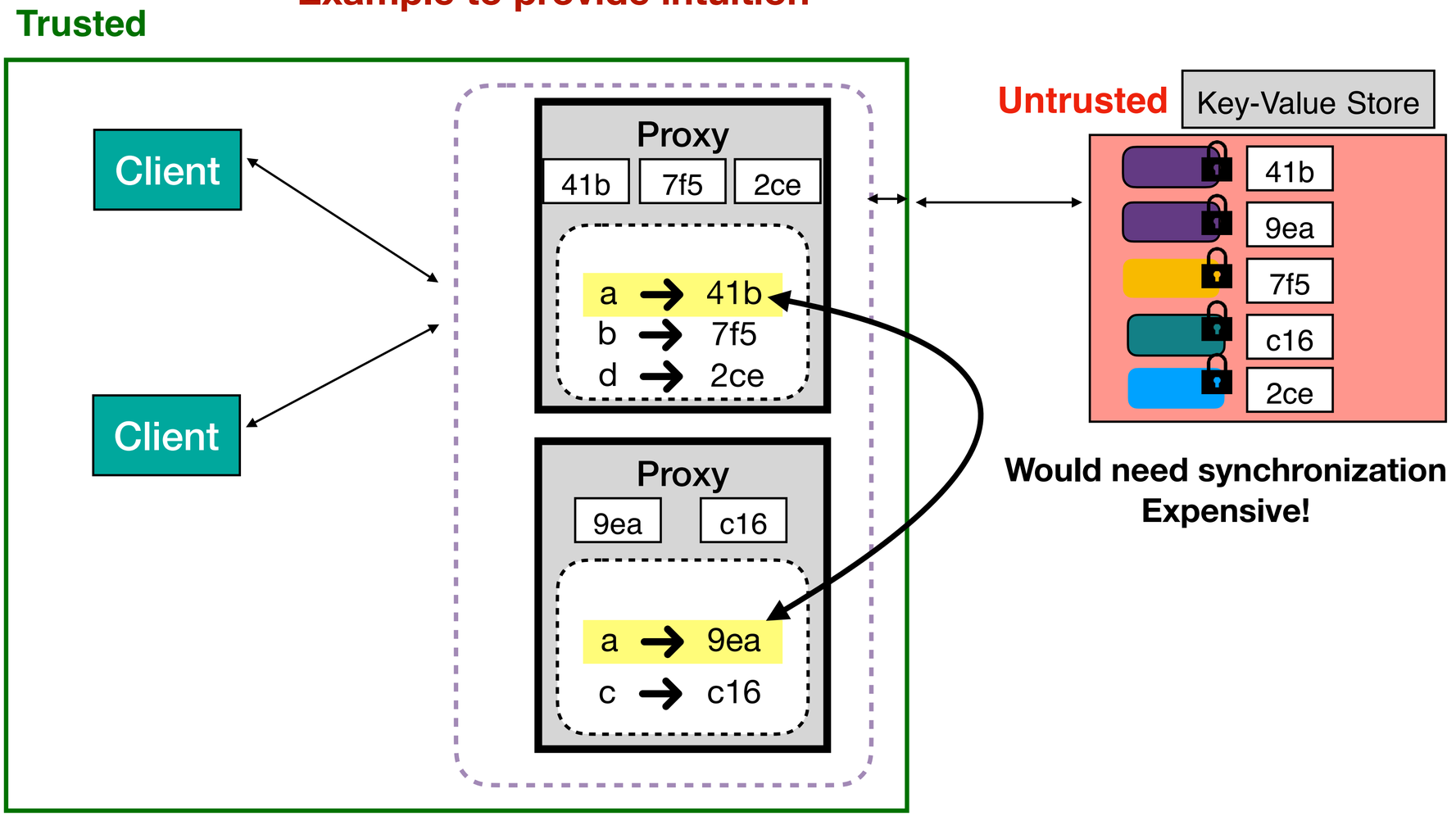

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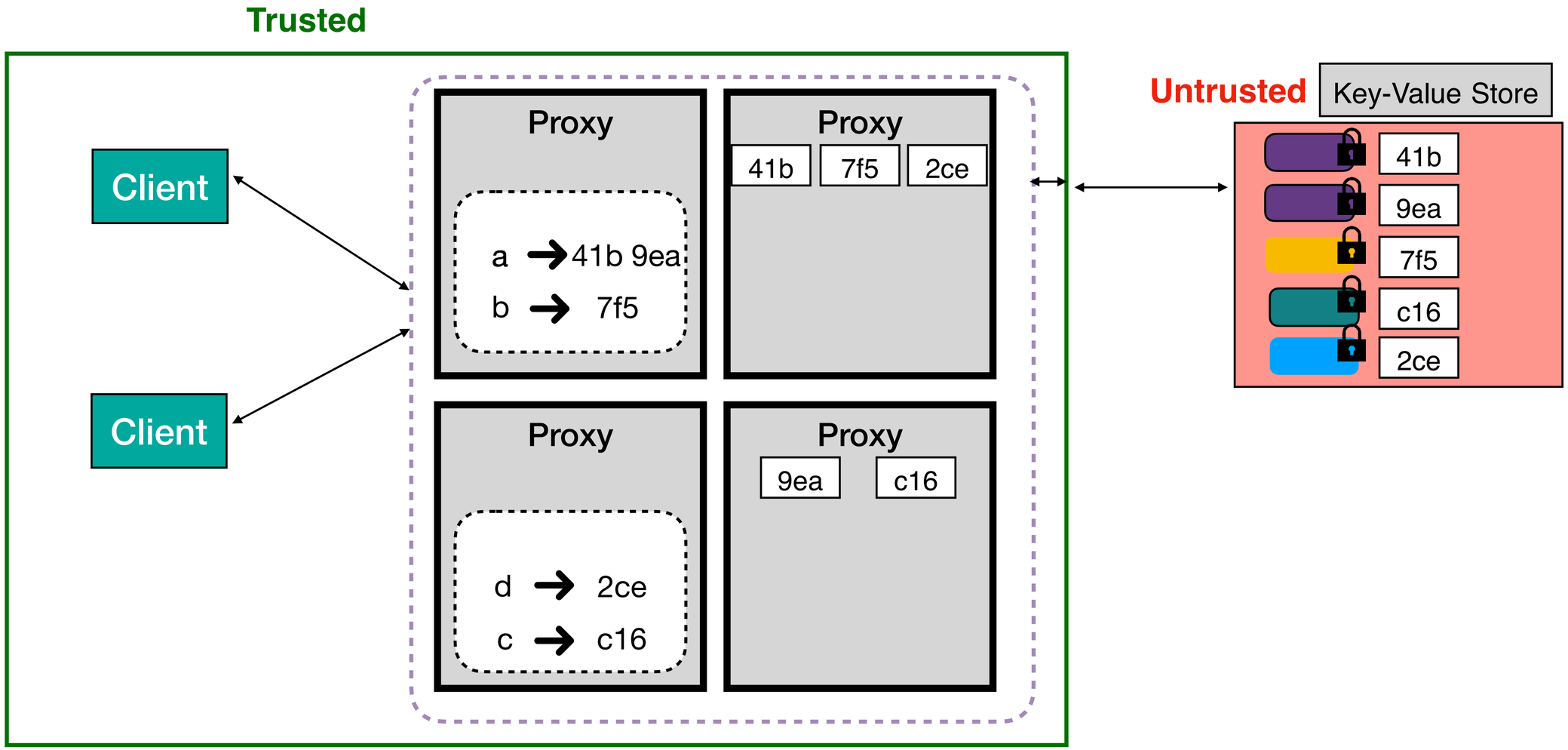

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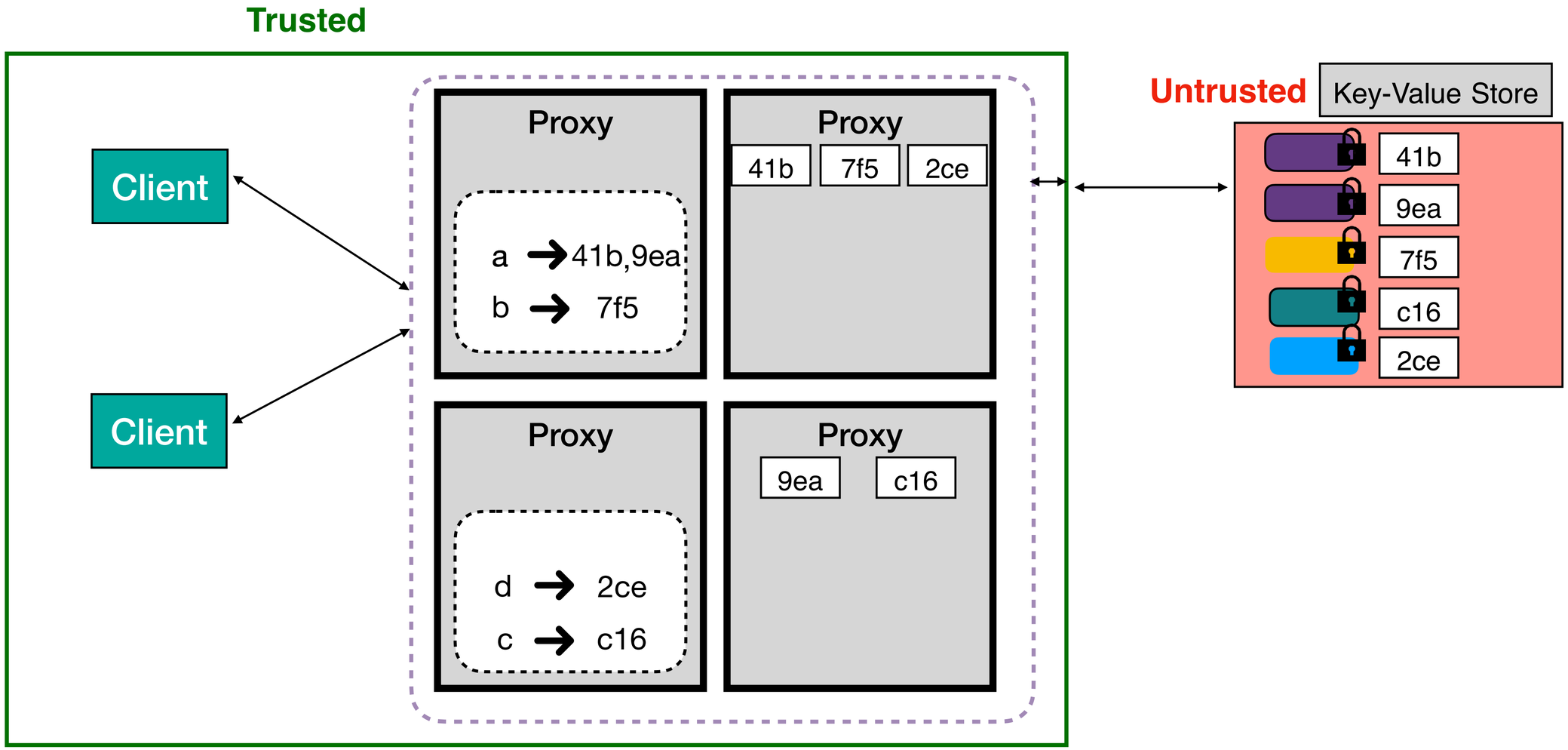

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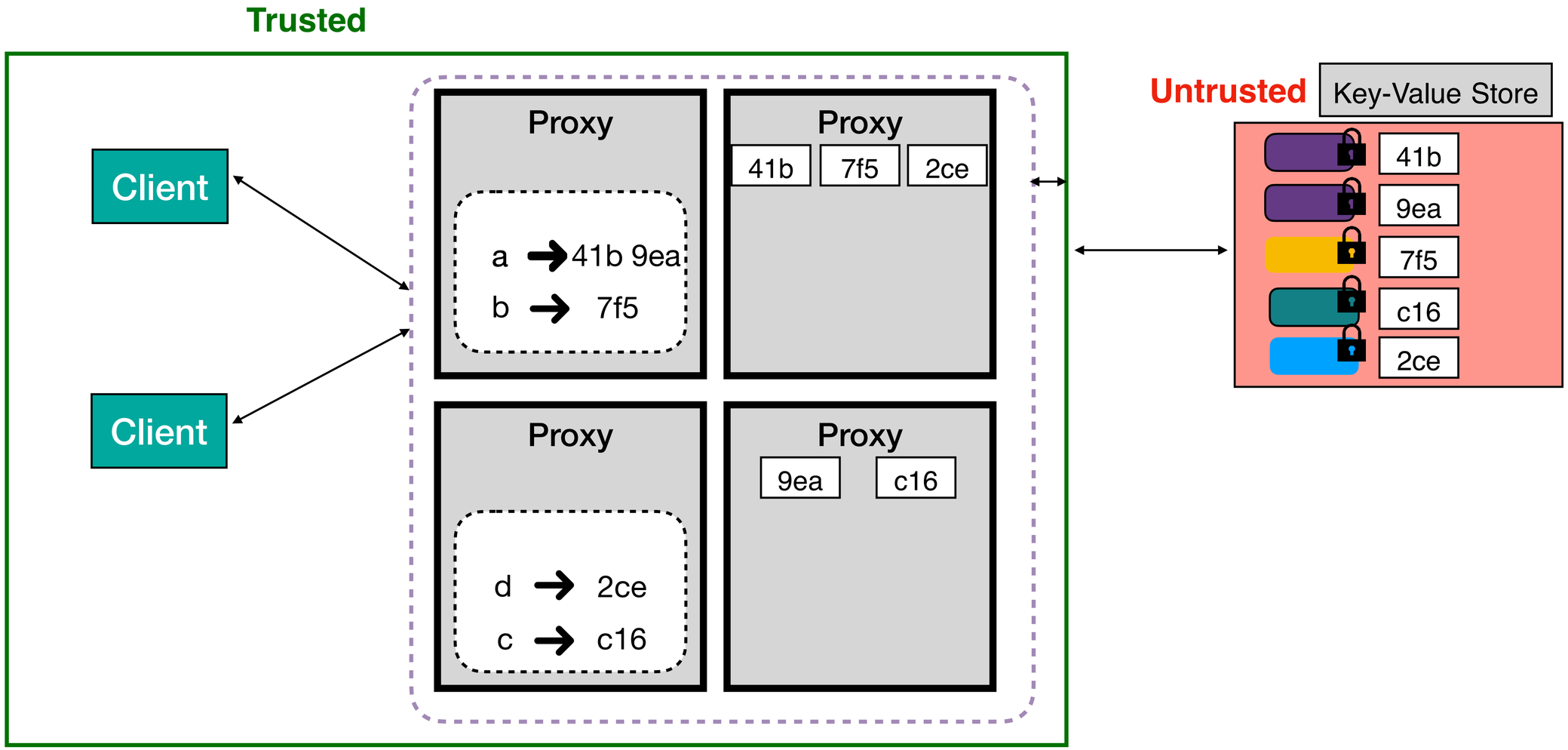
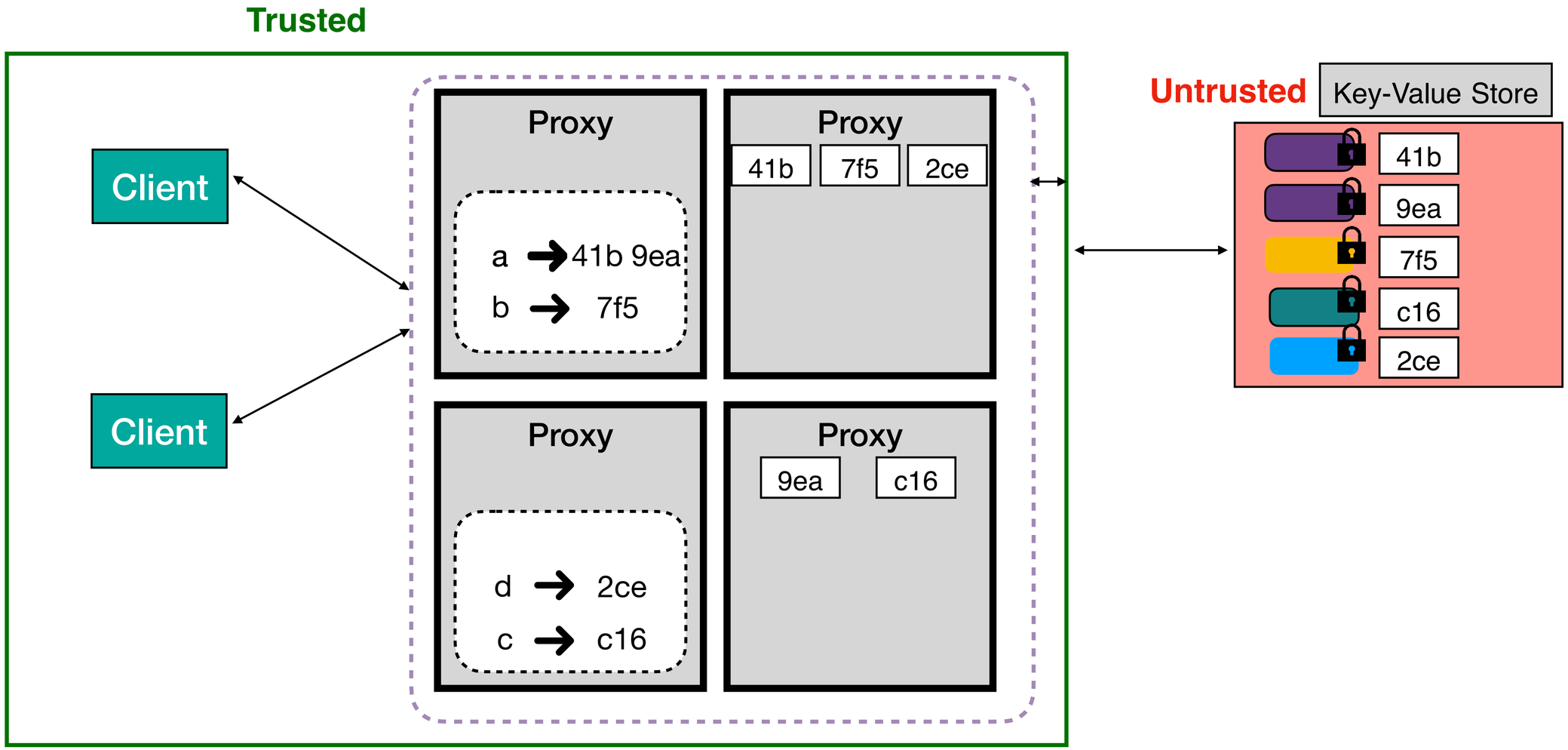


Shortstack Design Principle #3

Query Generation over all Keys



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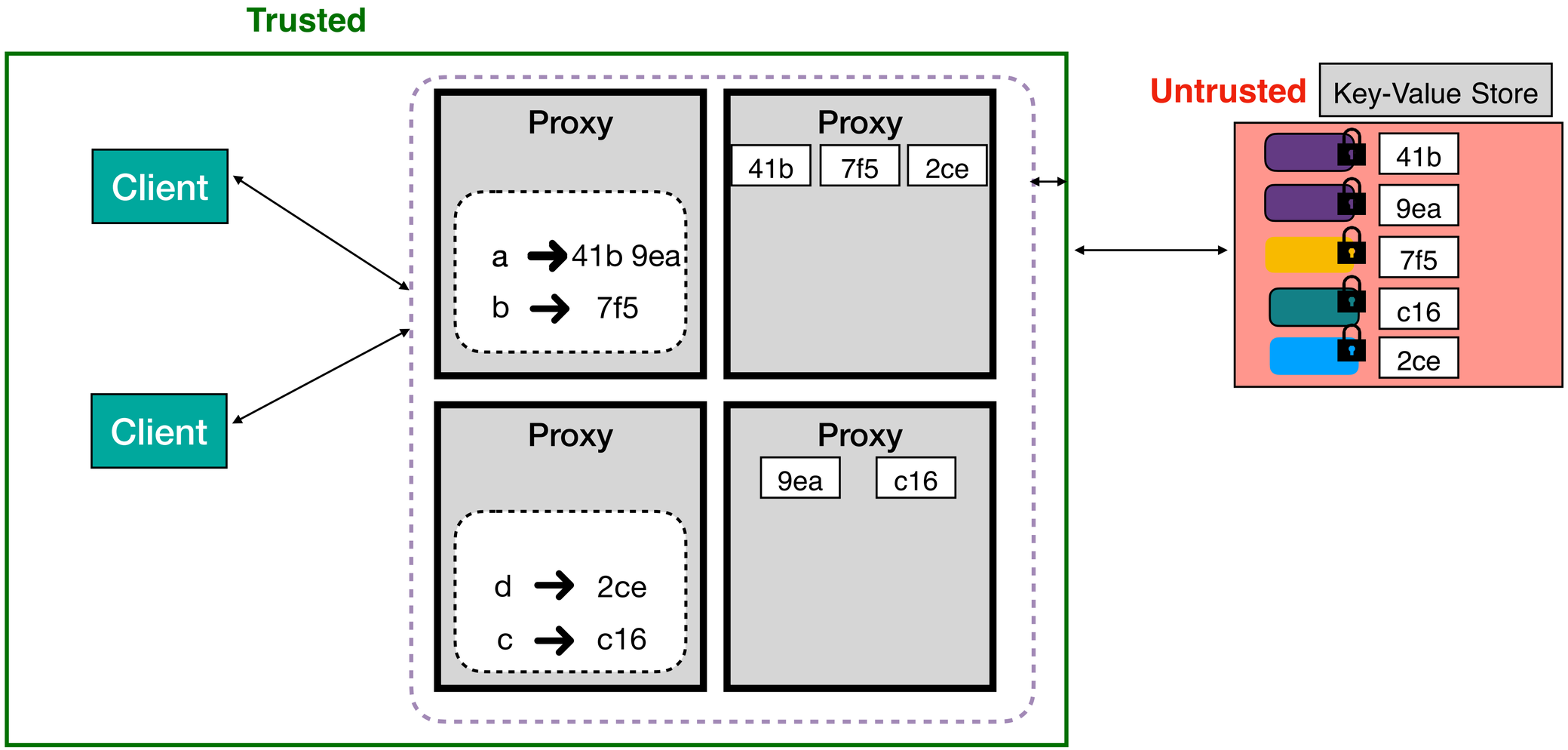

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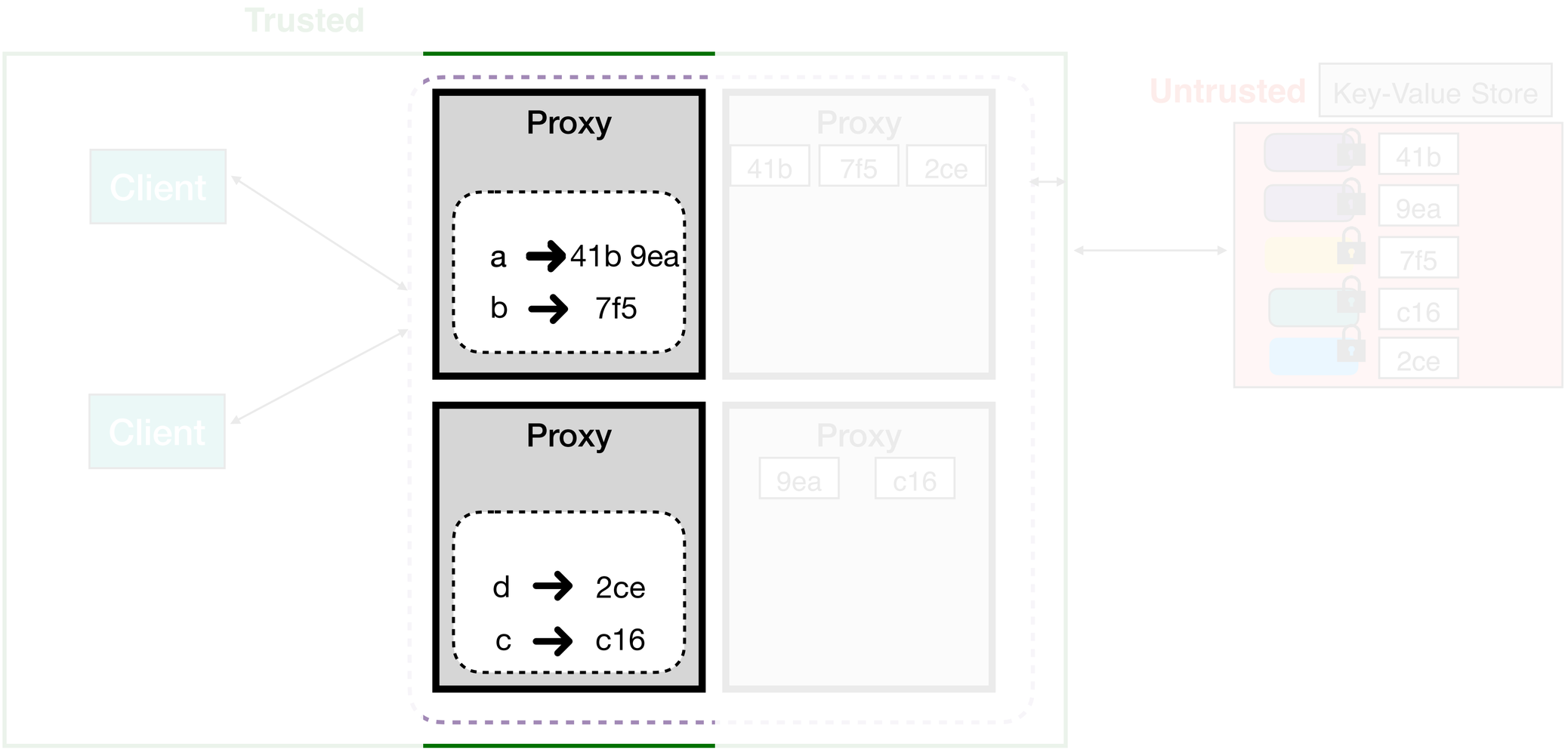

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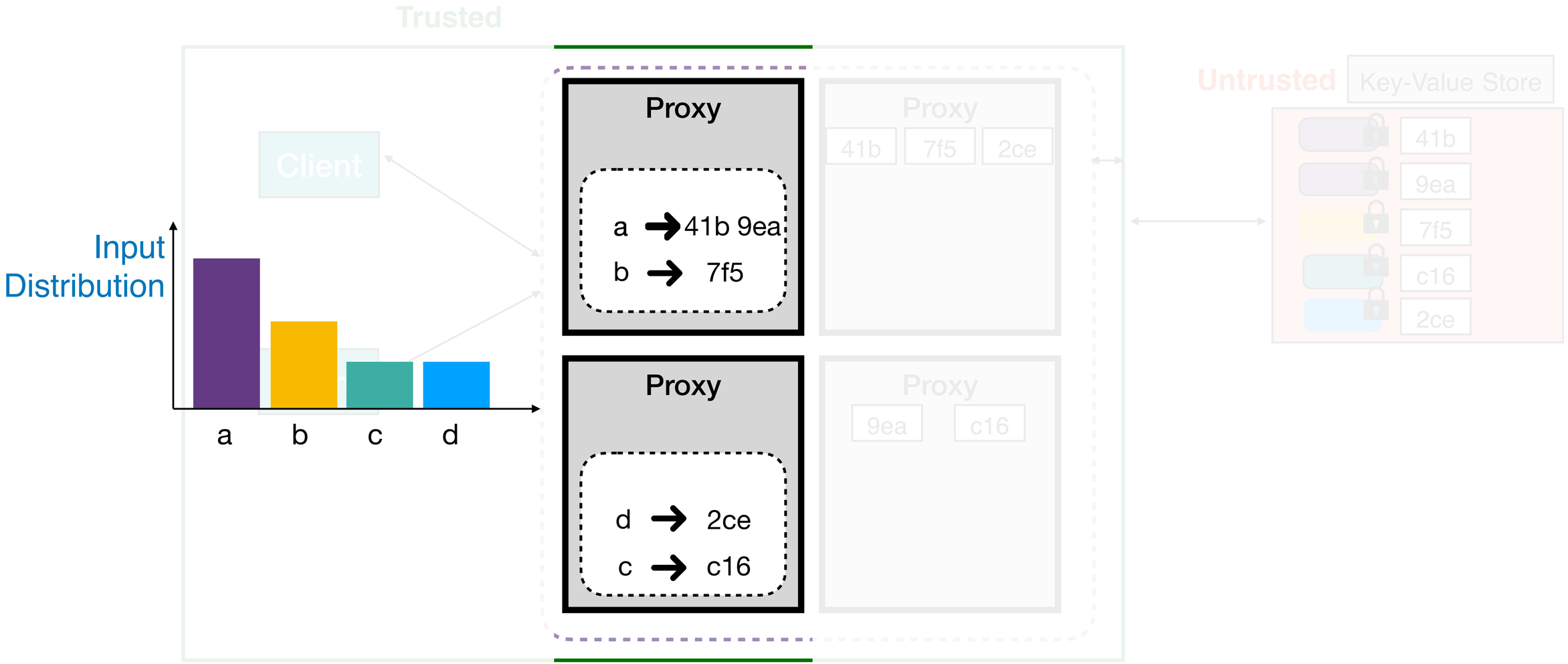

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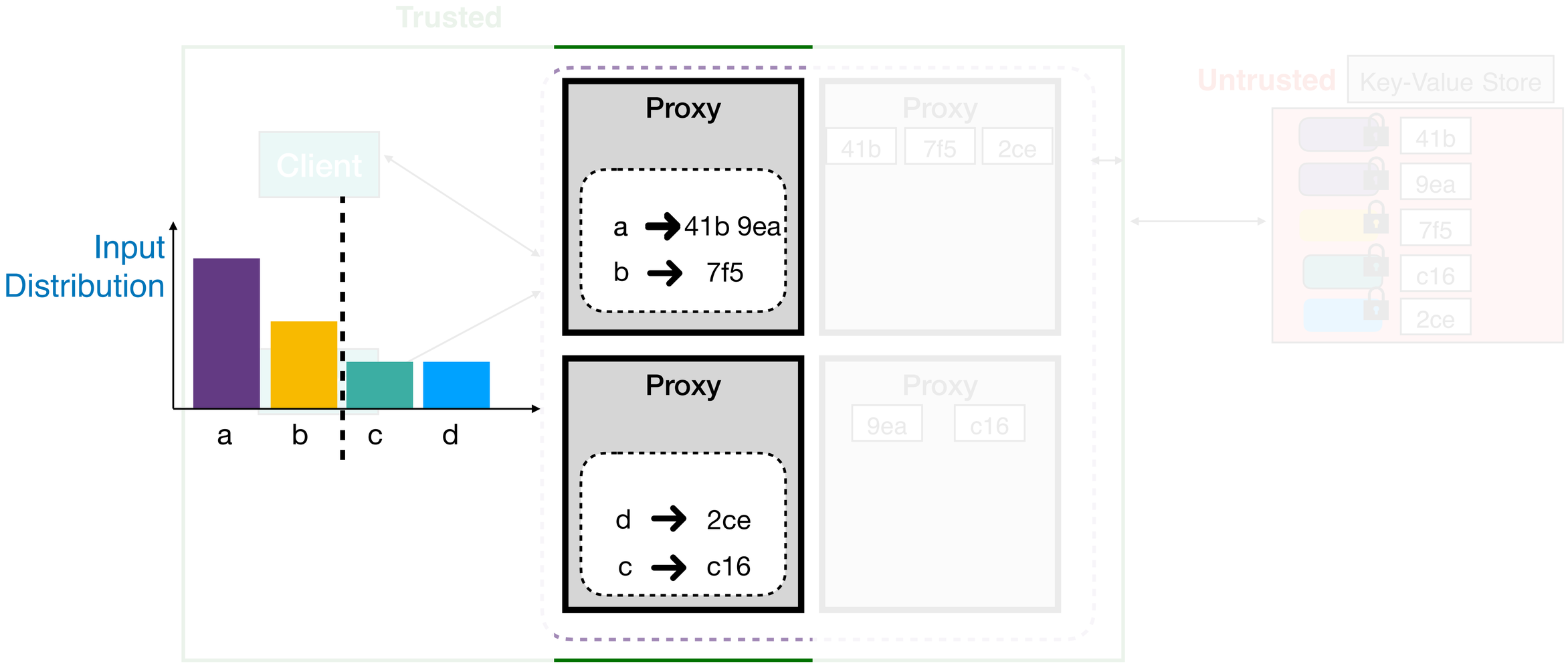

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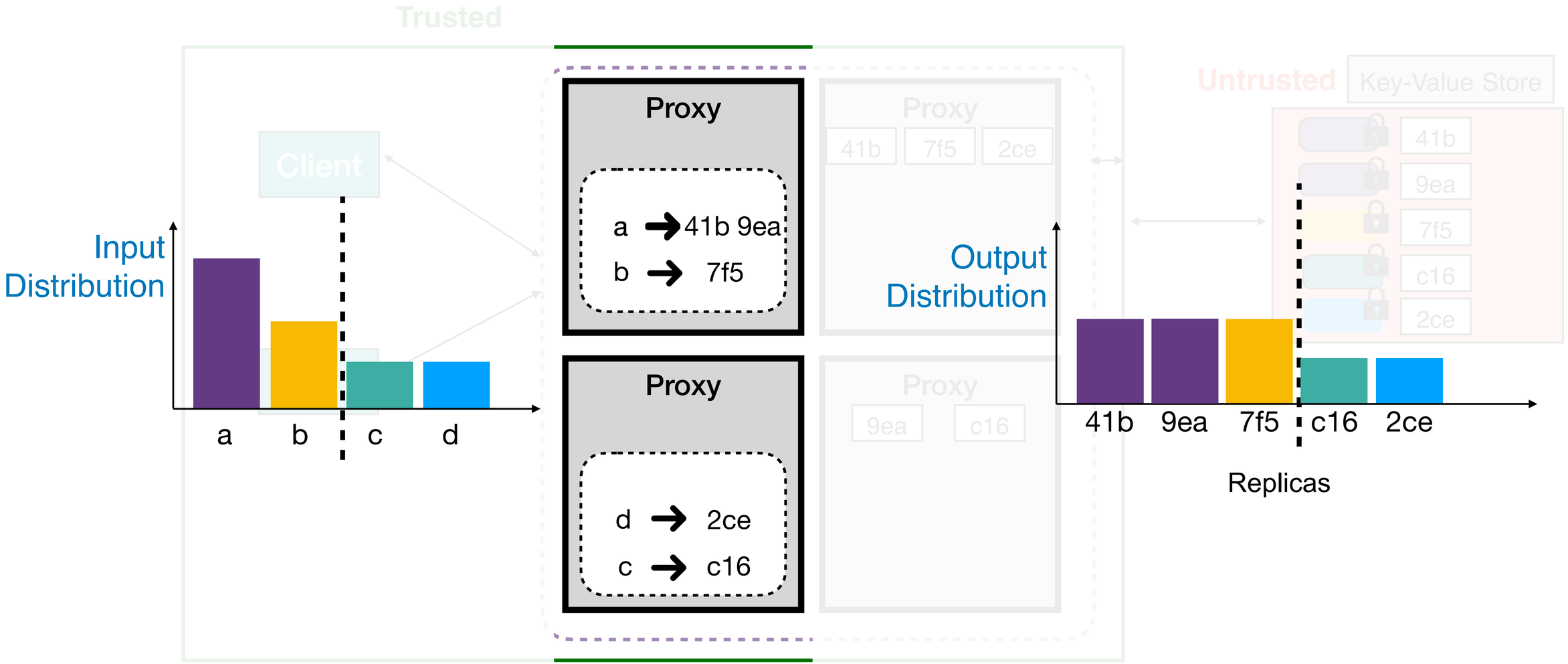

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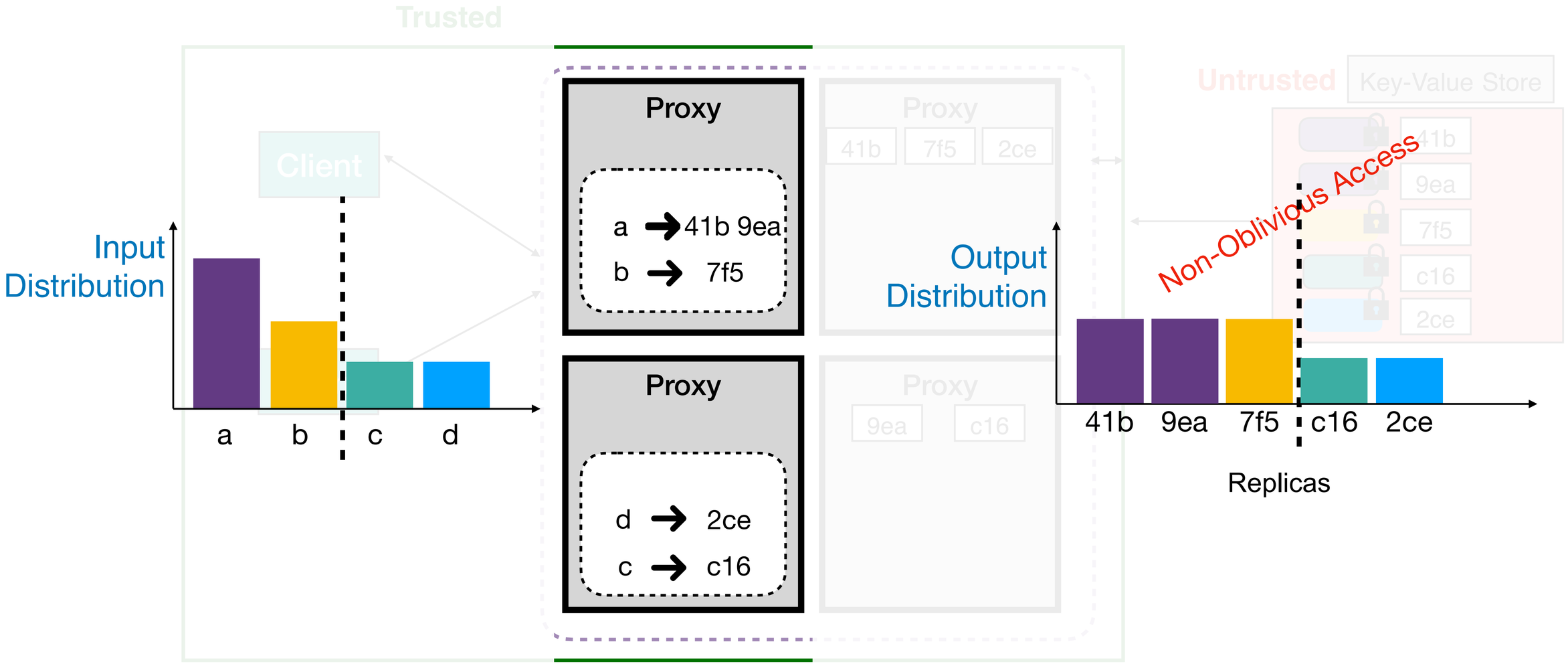

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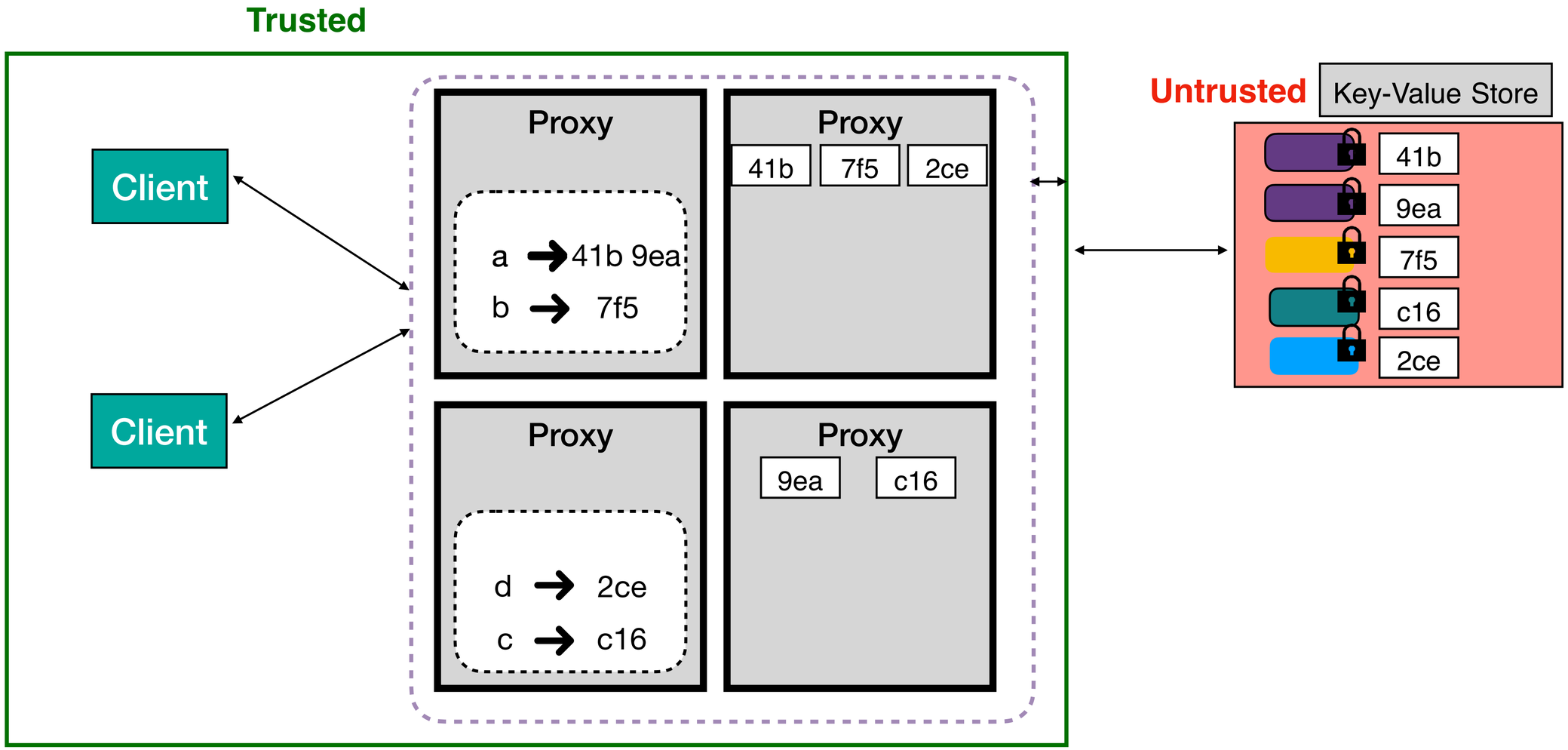

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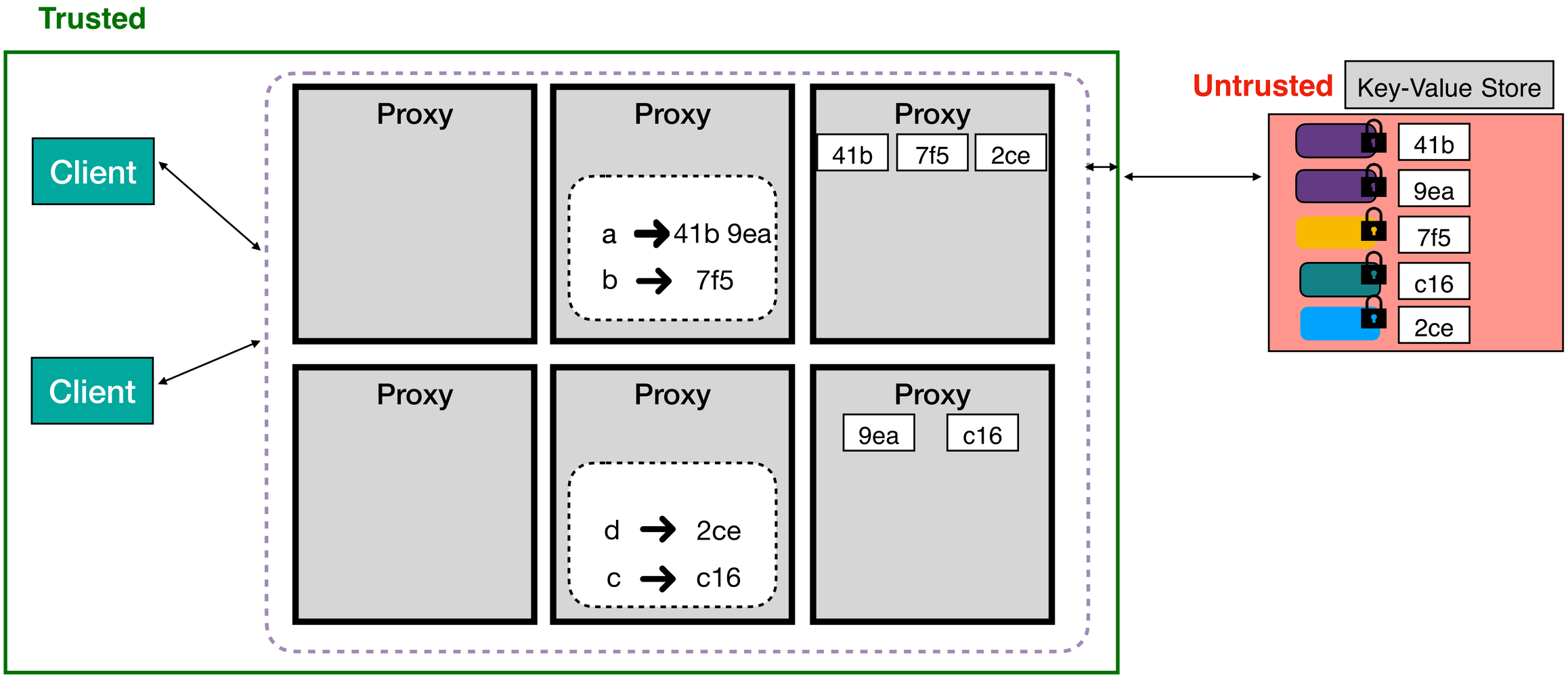

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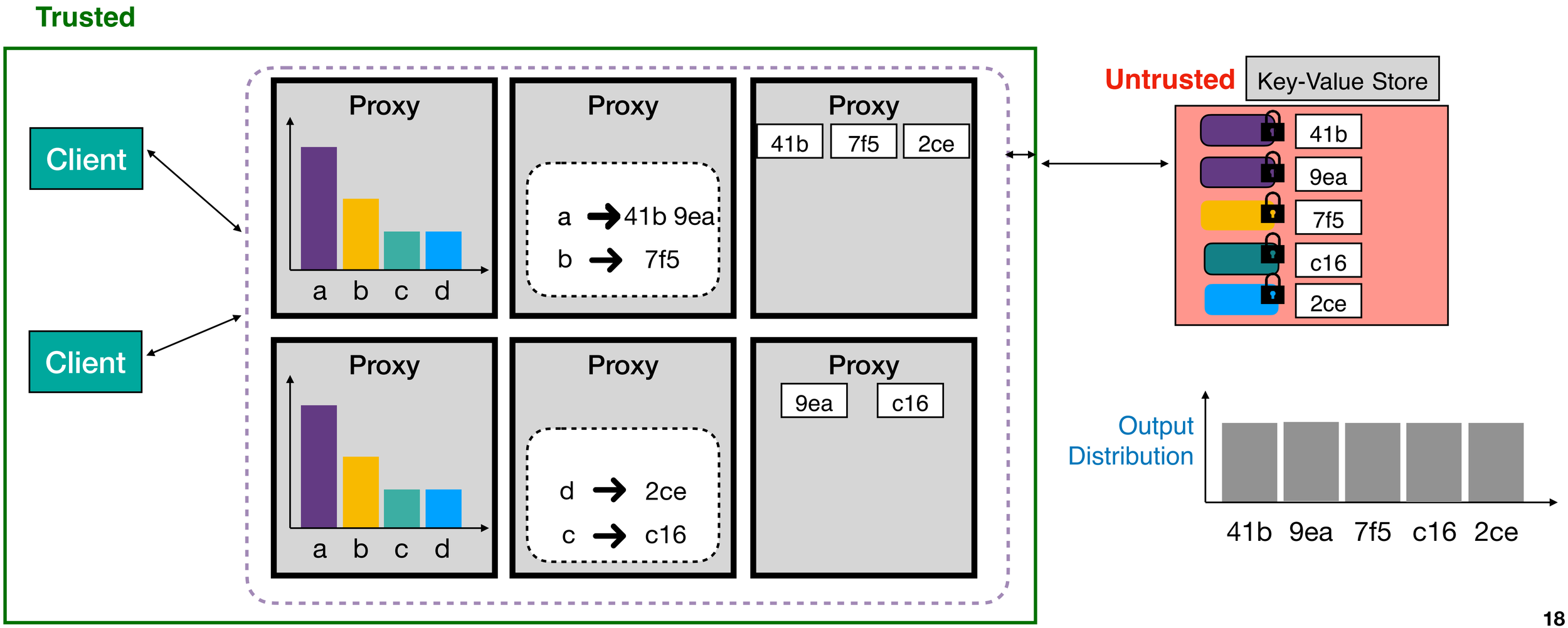
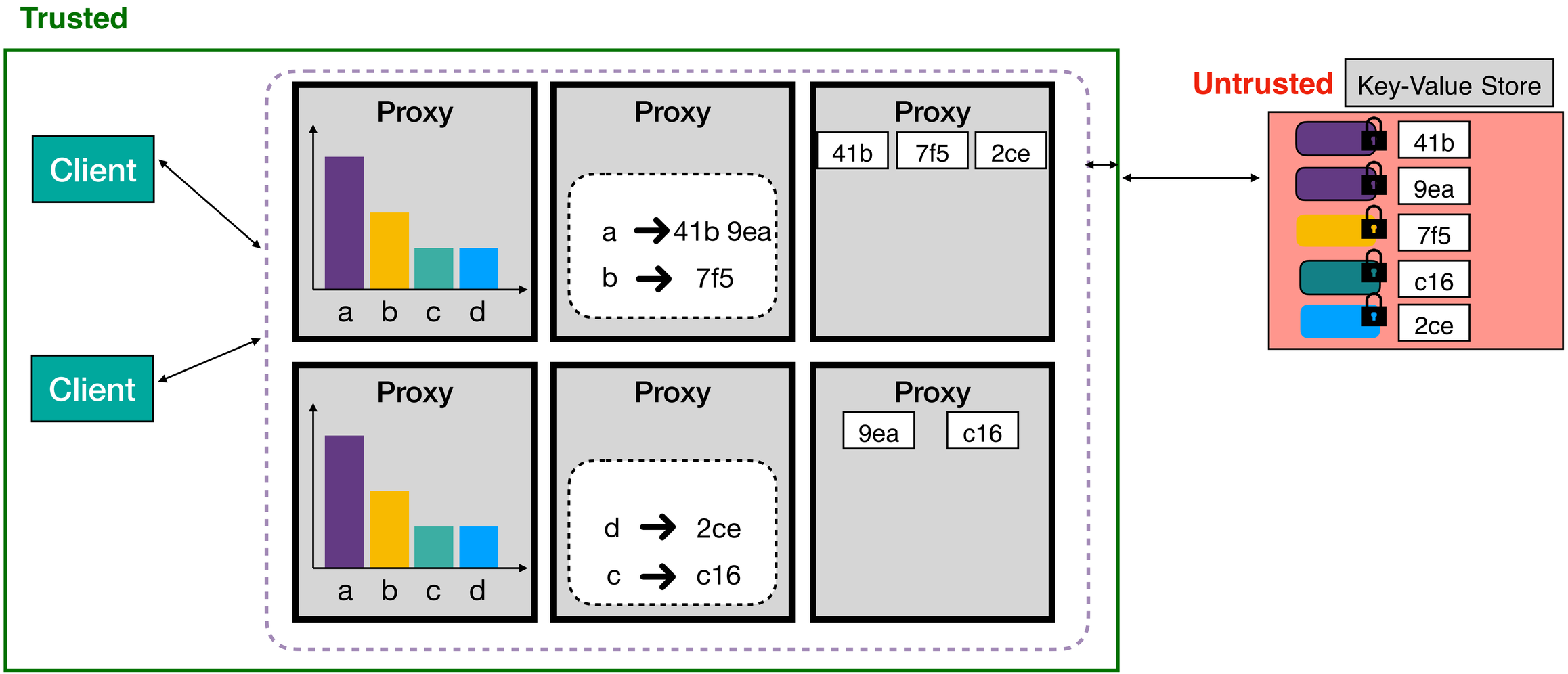


Shortstack Design Summary: Logical



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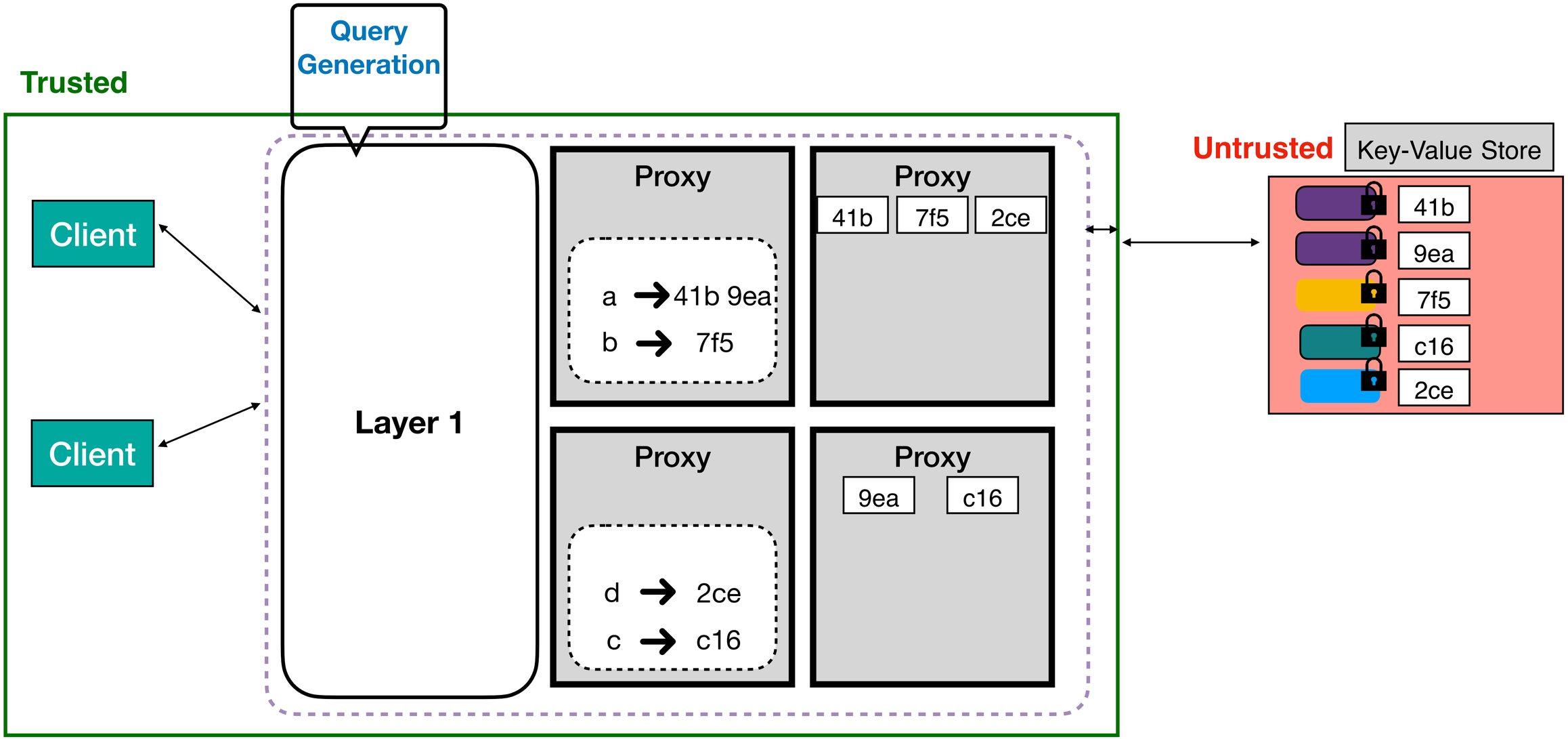

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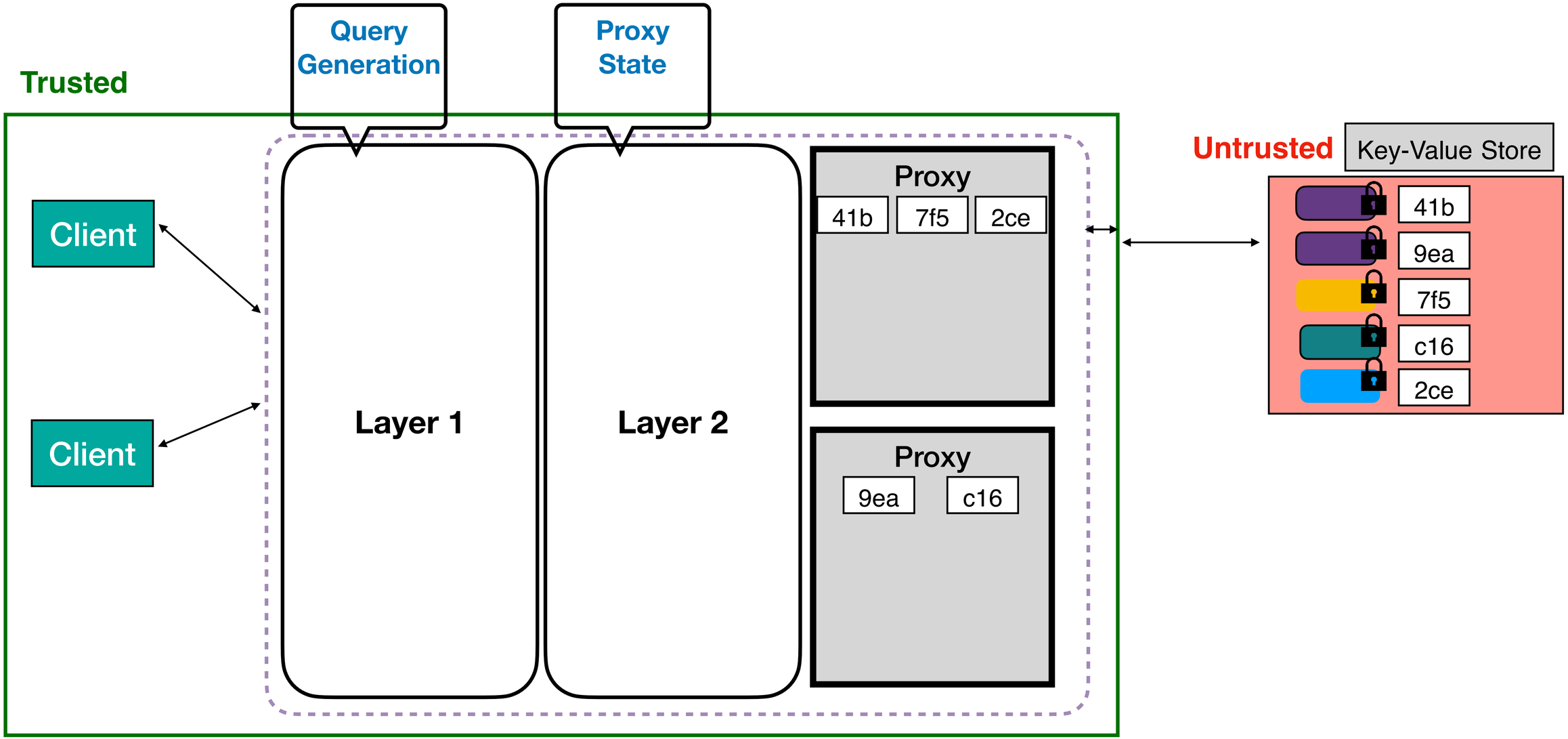

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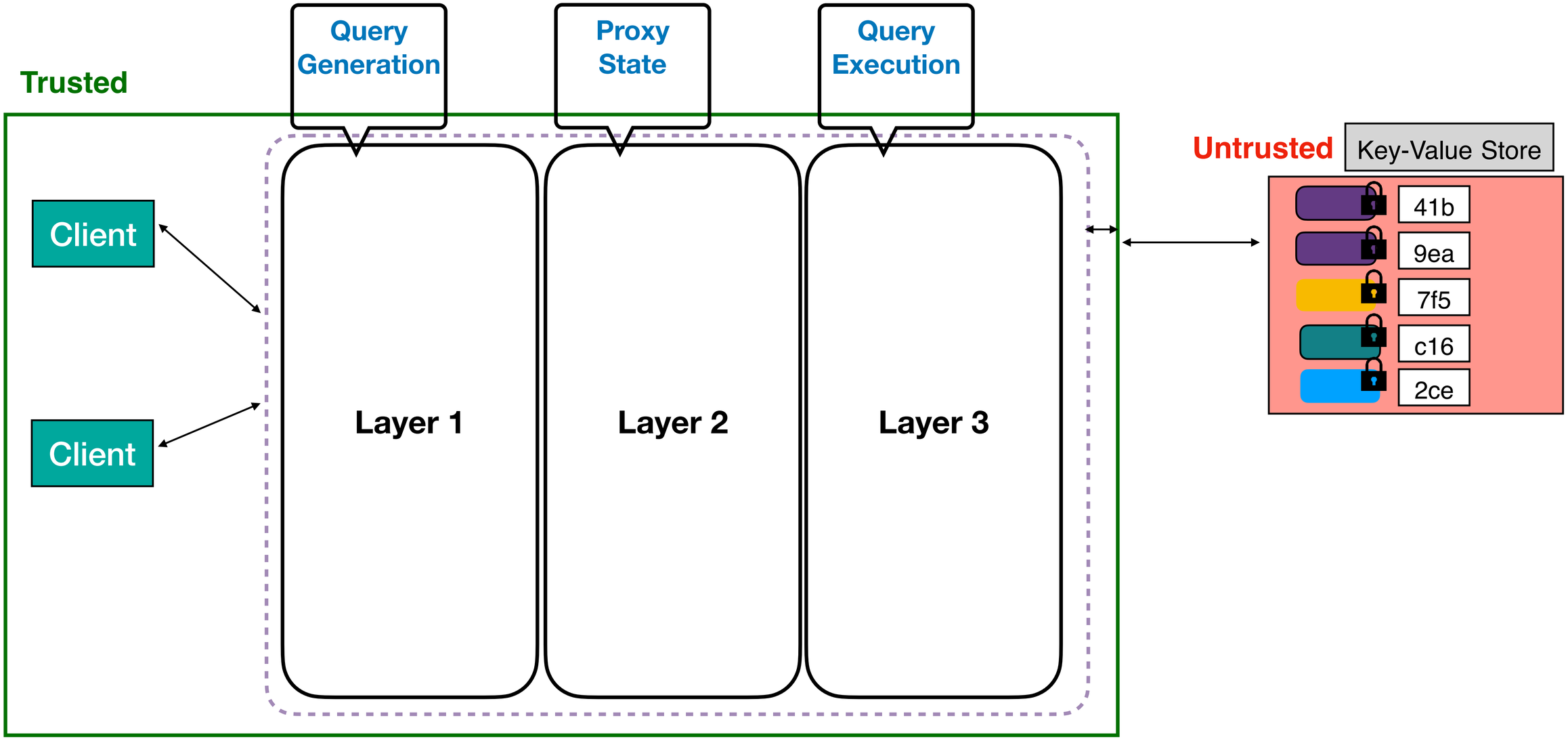

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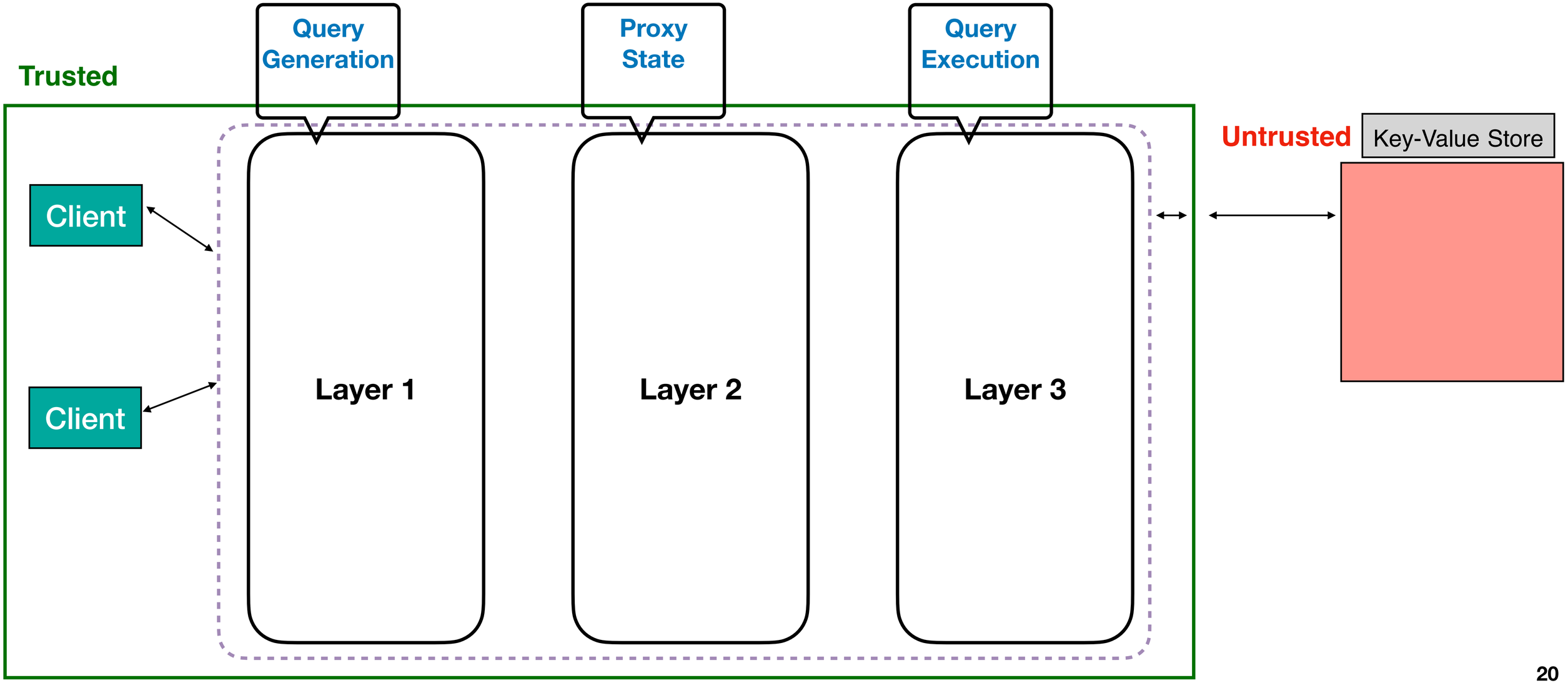

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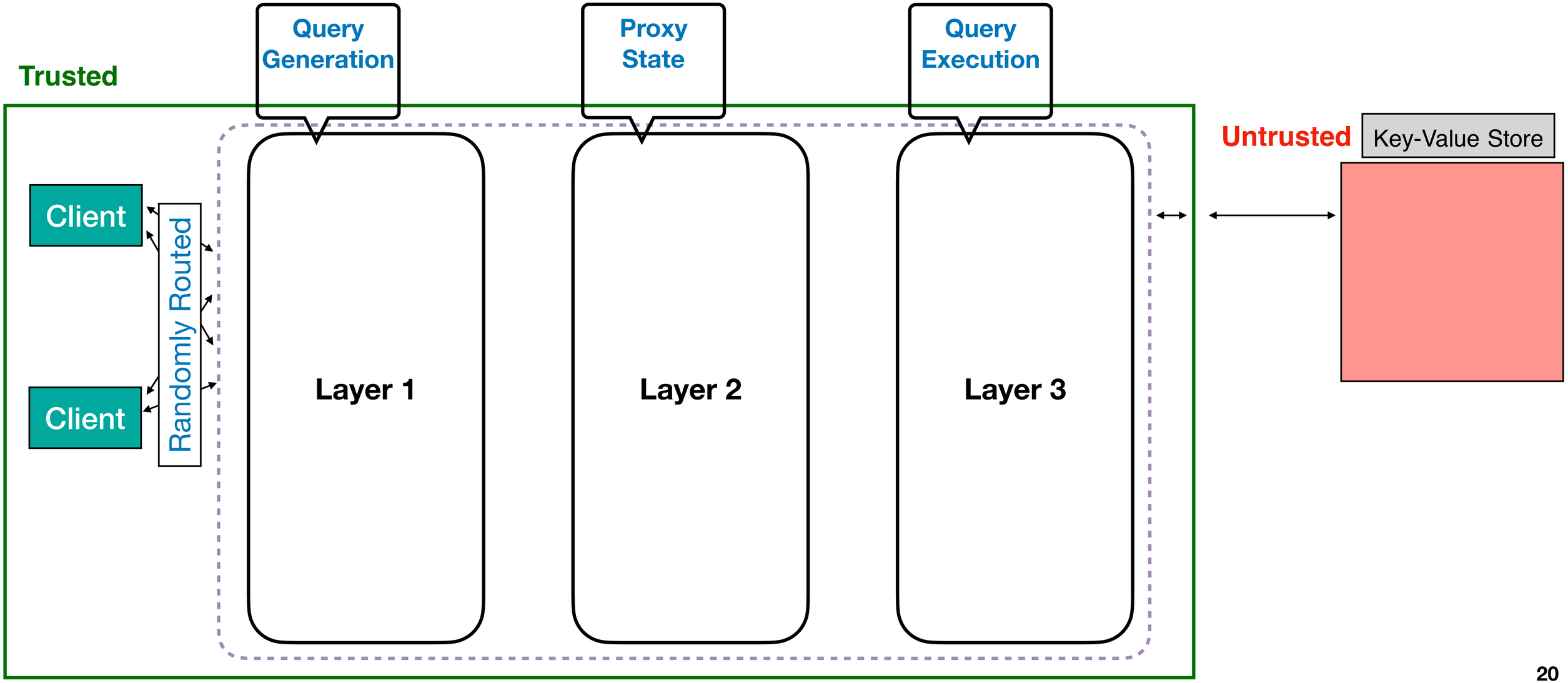

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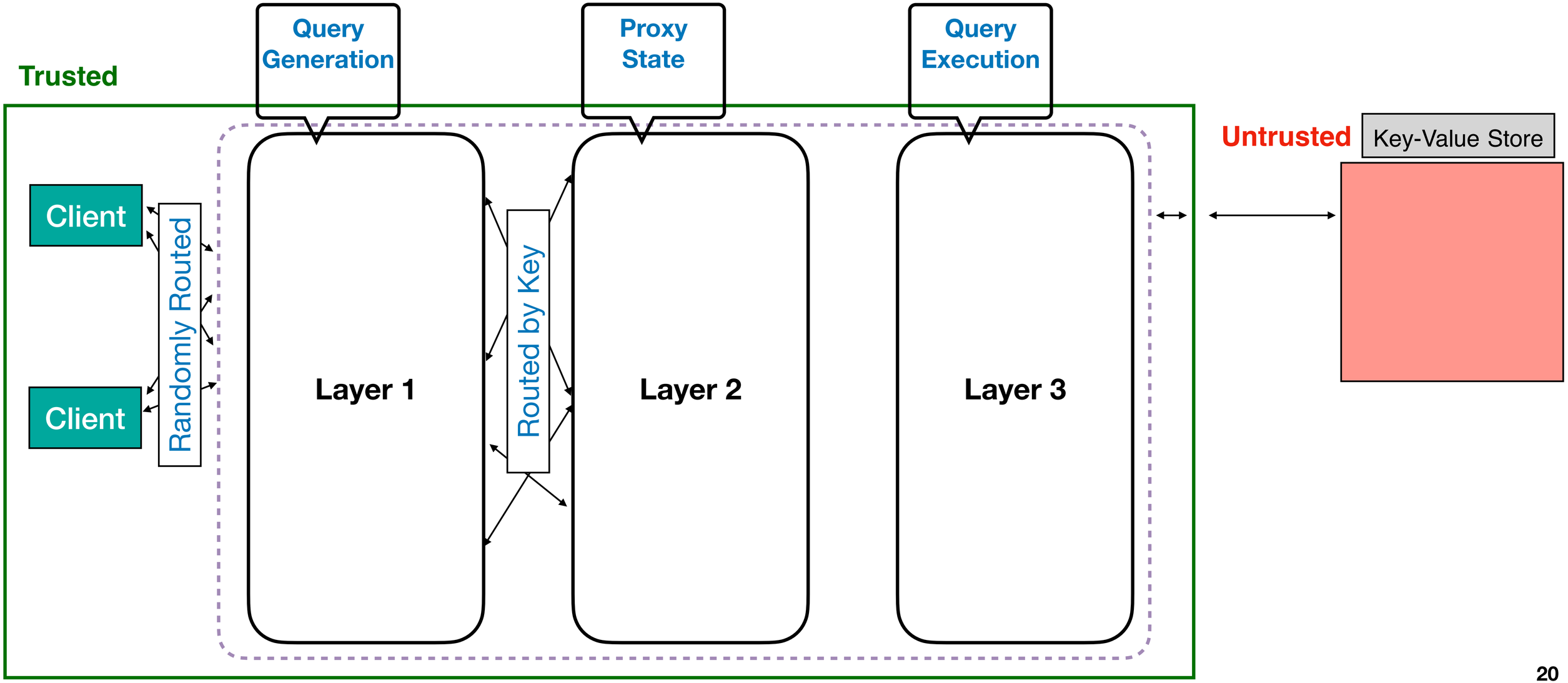

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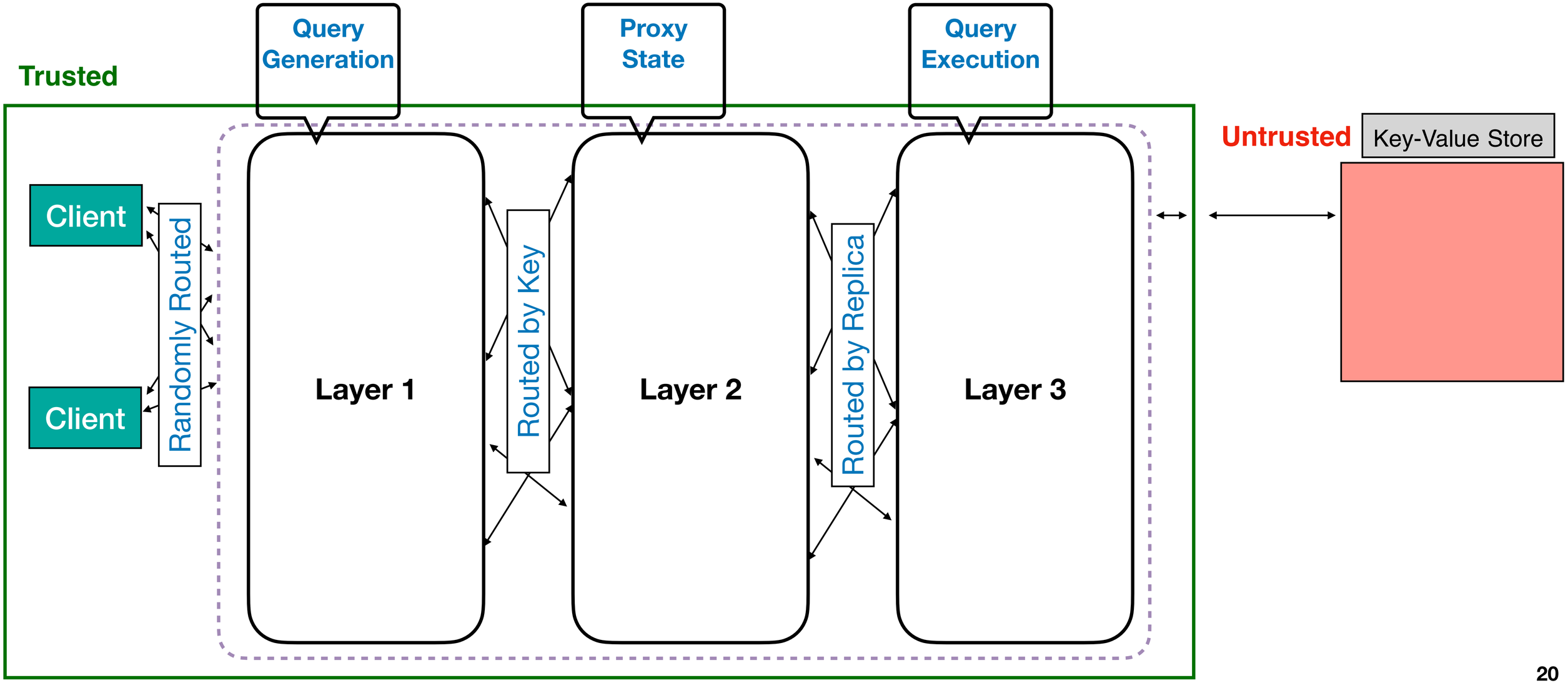
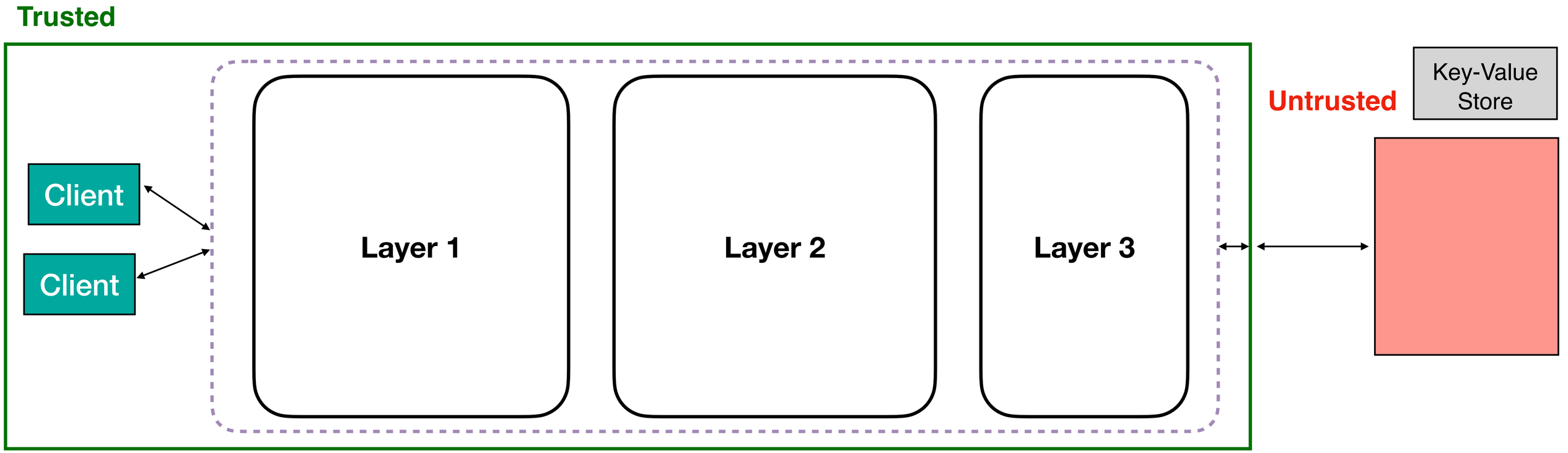


Shortstack Fault Tolerance



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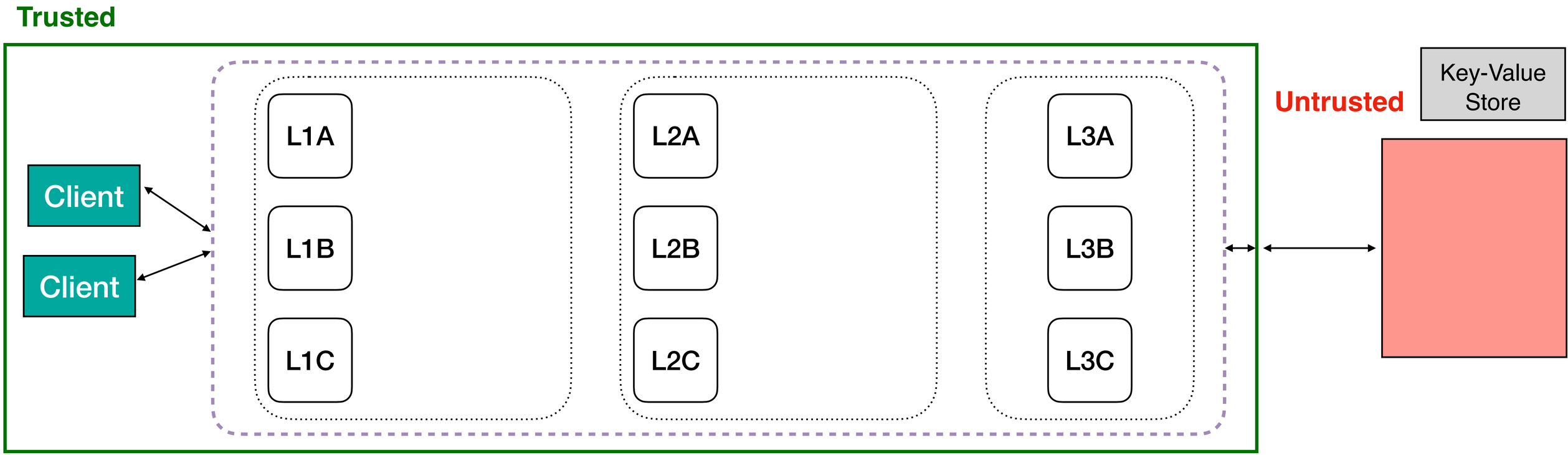

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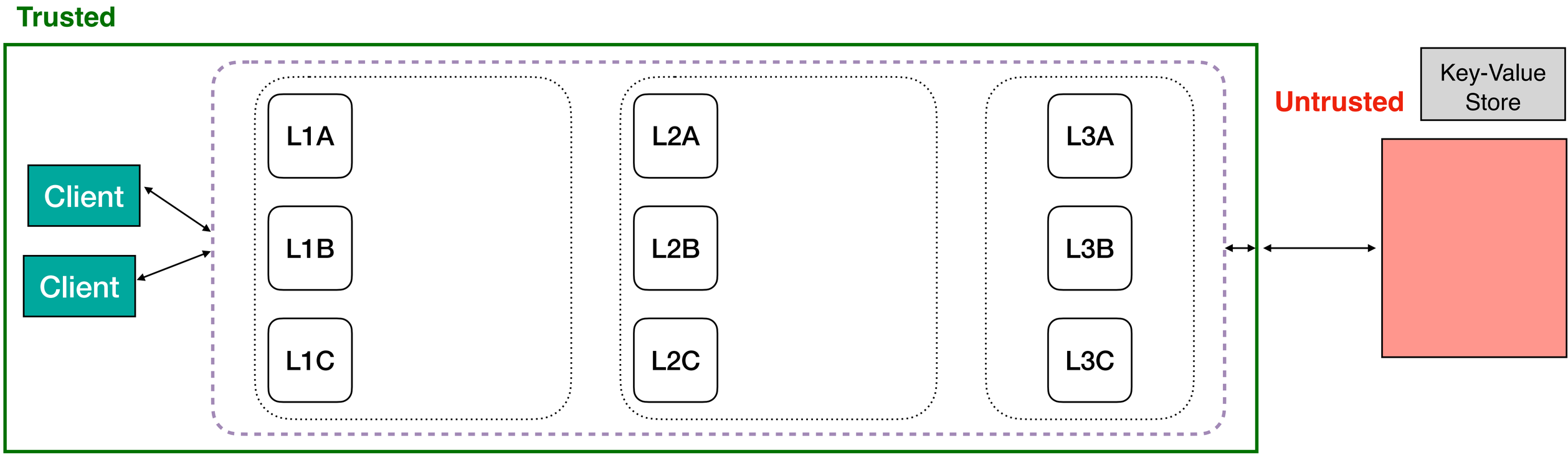
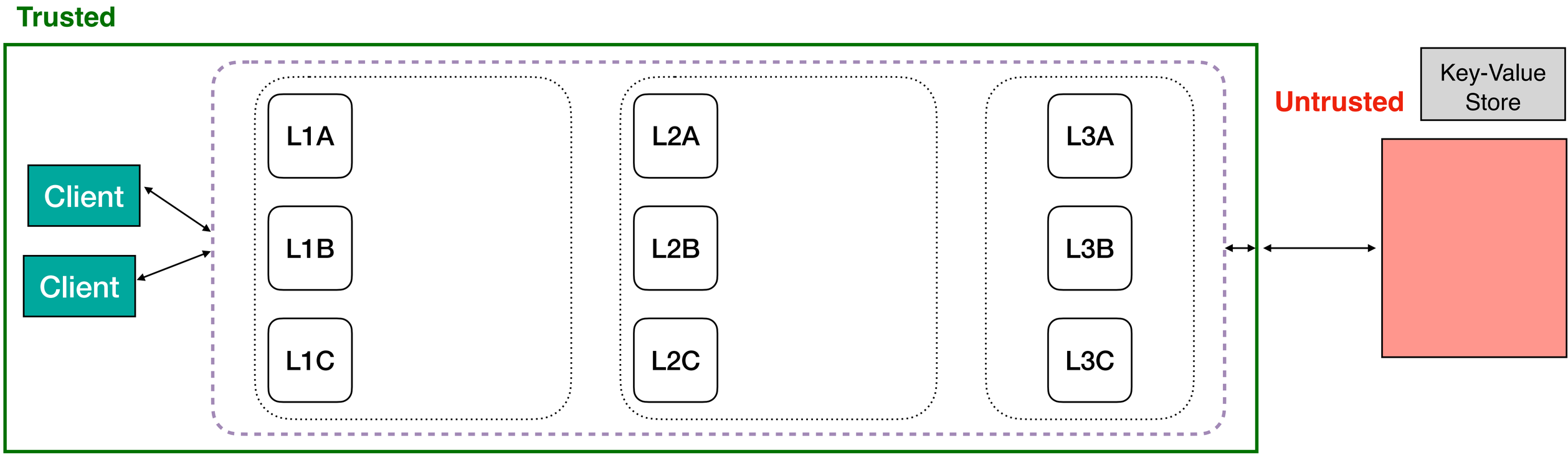


L3 failures: Redistribute requests across remaining servers

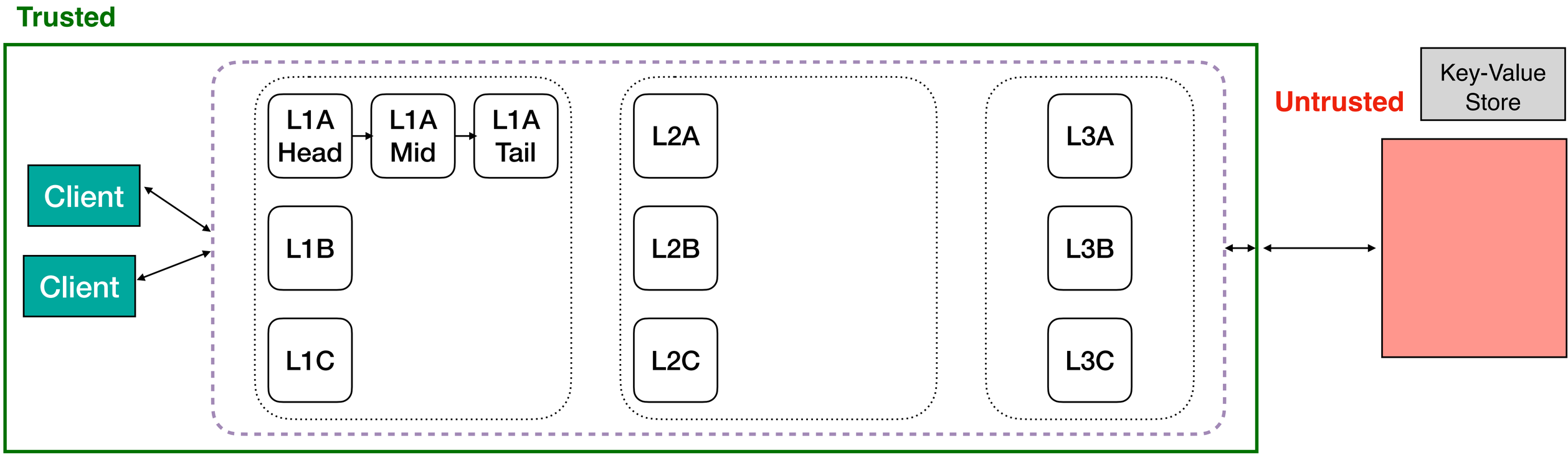
Shortstack Fault Tolerance



L3 failures: Redistribute requests across remaining servers

L1 and L2 failures handled through chain replication

Shortstack Fault Tolerance



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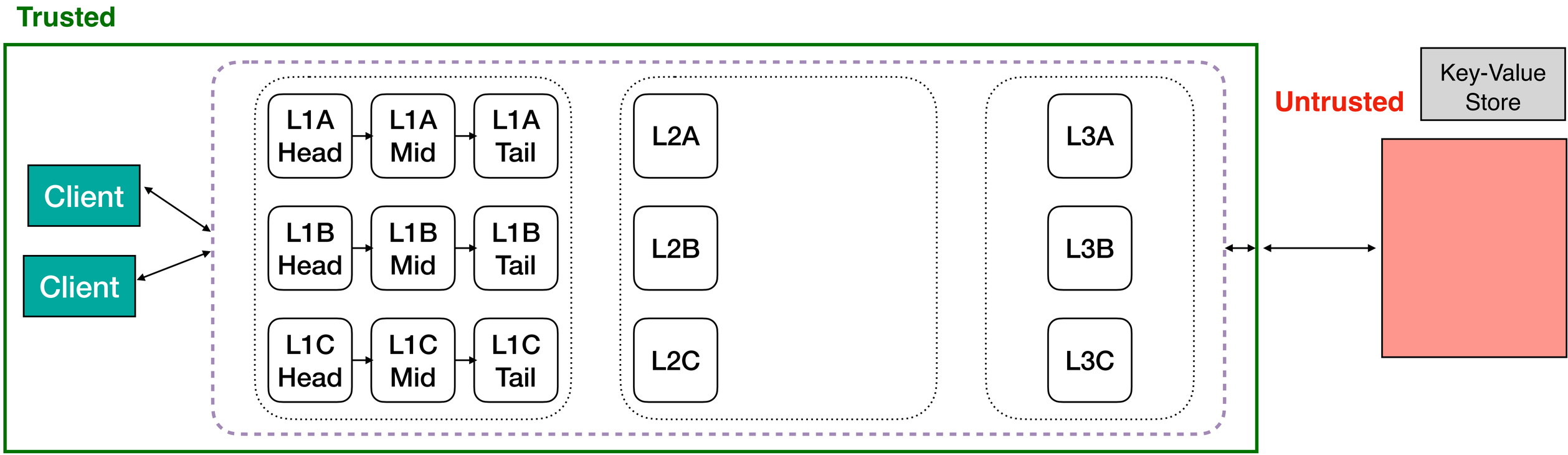

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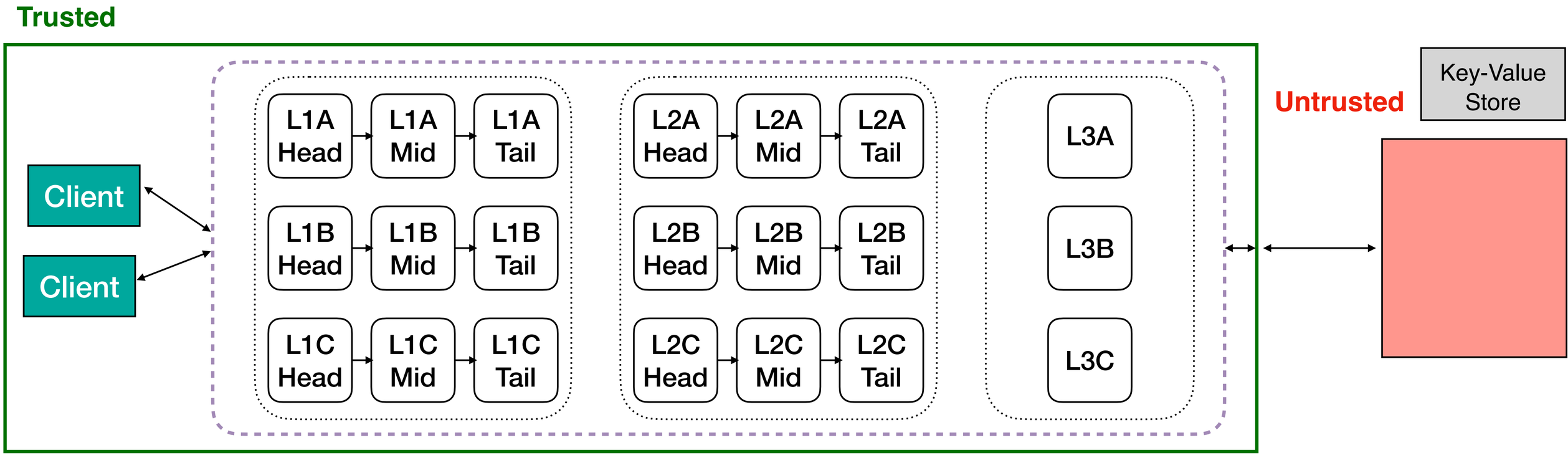

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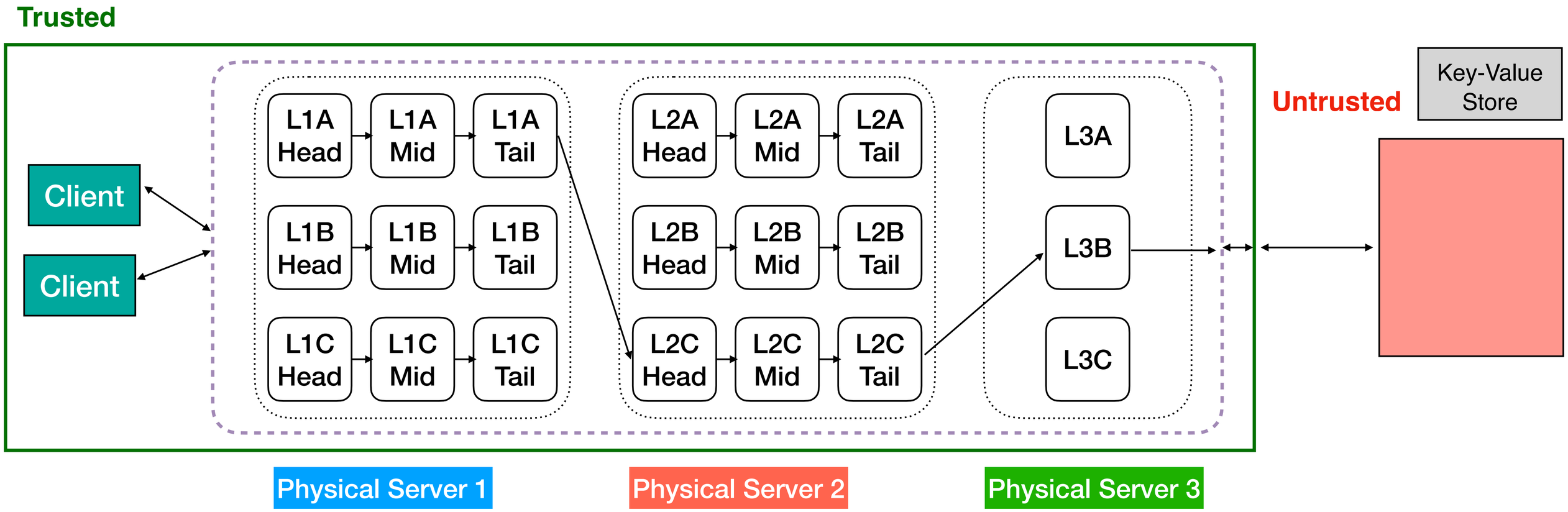
Logical→Physical Design



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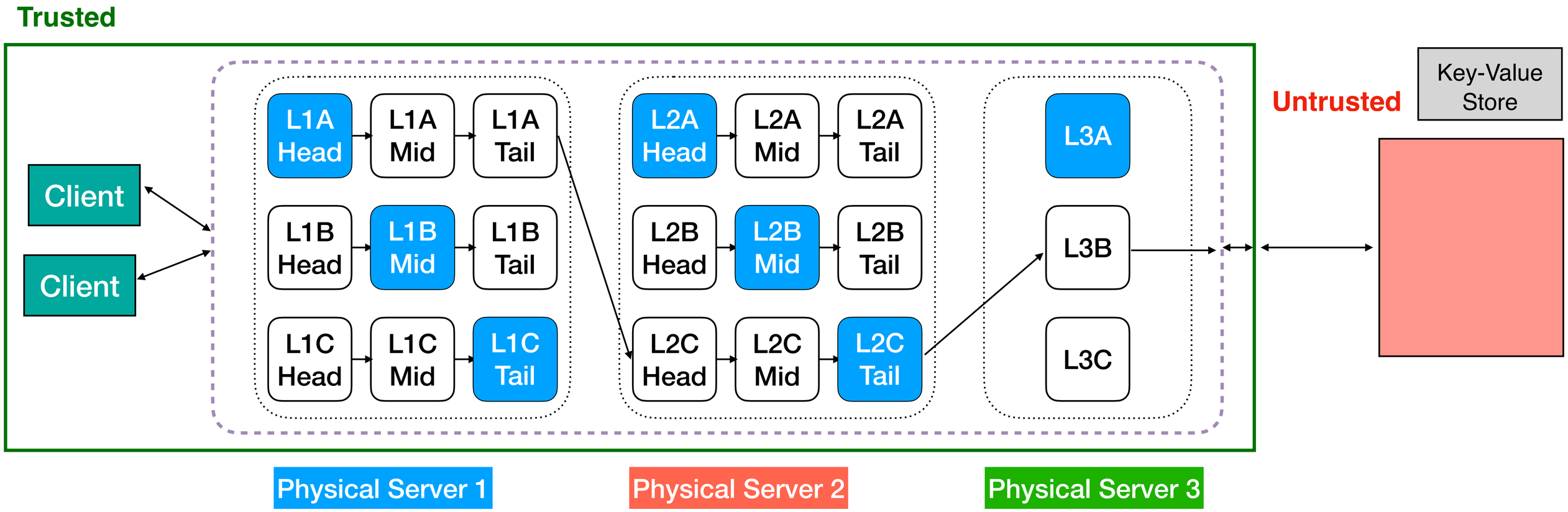

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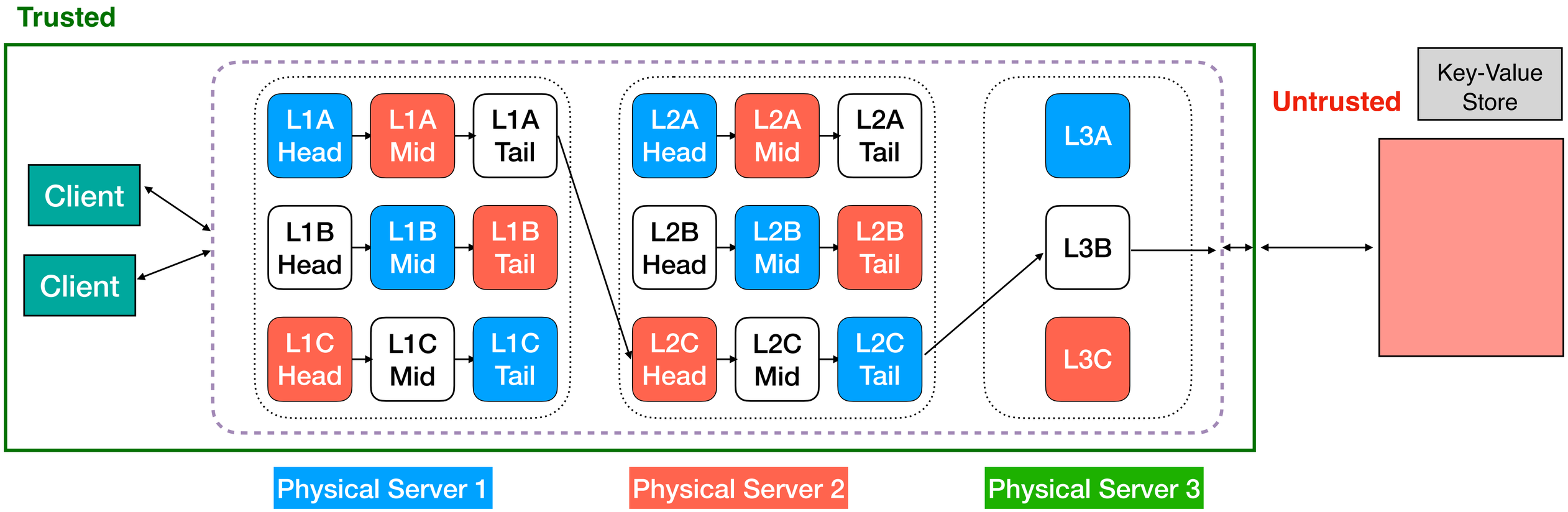

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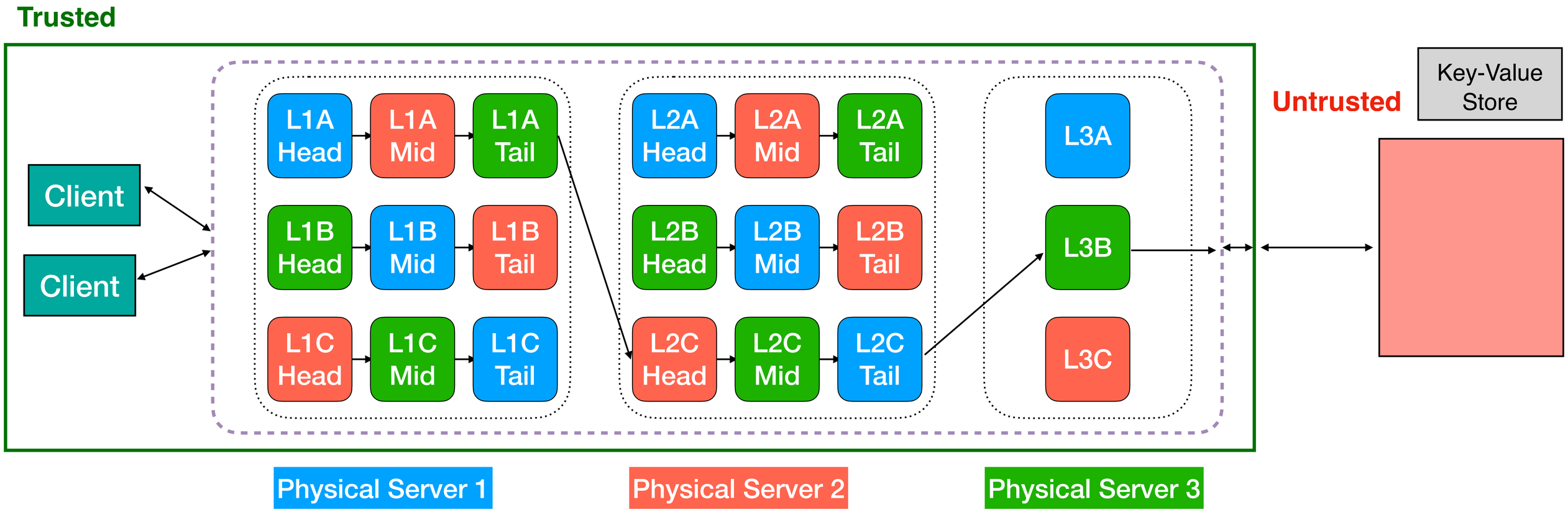

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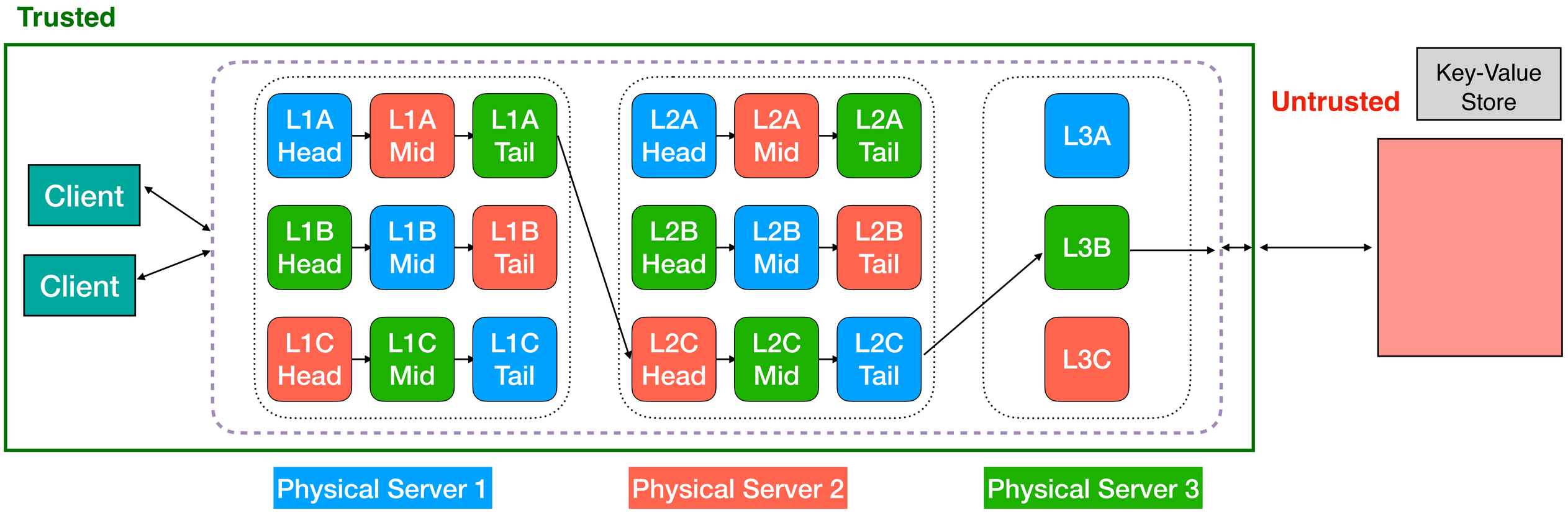
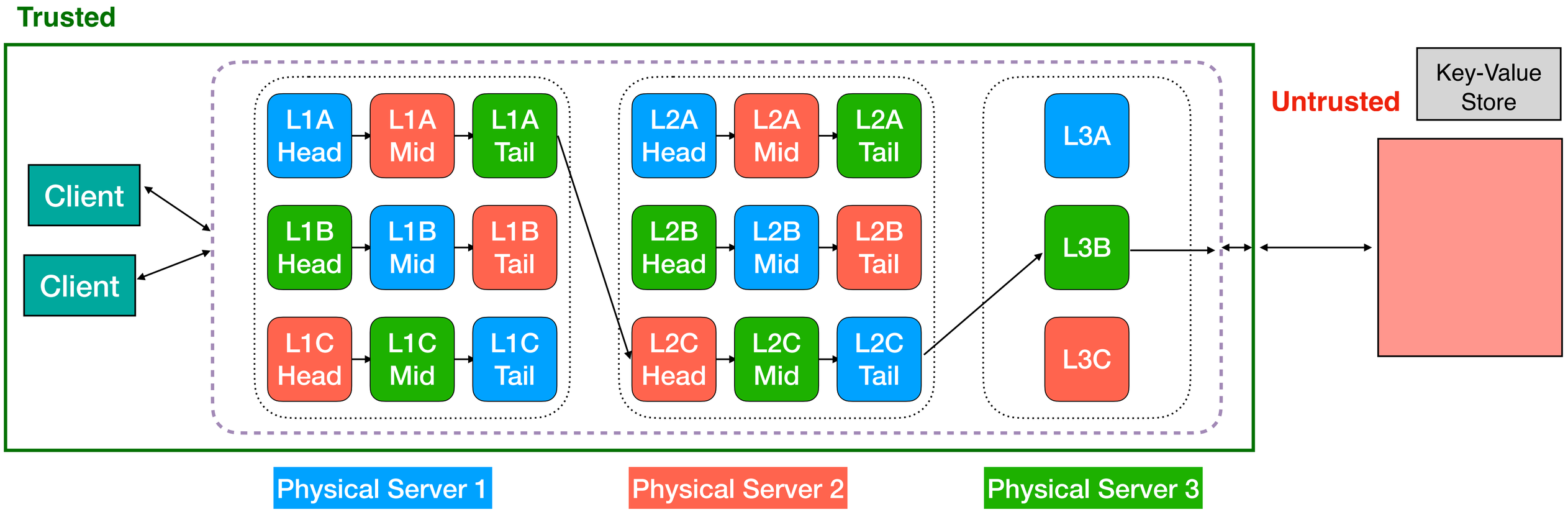


Shortstack needs 3 physical servers for handling 2 failures

Logical→Physical Design



Shortstack needs 3 physical servers for handling 2 failures

Shortstack needs *f+1* physical servers for handling *f* failures

This work

Challenges with Centralized Oblivious Data Access Systems
1. Insecure or unavailable during failures
2. Scalability bottleneck

Design of Shortstack:
Distributed, Fault-tolerant, Oblivious Data Access System

Security model:
Enables formal study of Distributed, Fault-tolerant, Oblivious Data Access systems

Security Model

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Existing security models do not capture failures

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New, General, Security Model

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Powerful adversary that cause
arbitrary failures (bounded number)
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Output distribution independent of input distribution (Oblivious data access guarantee)

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Output distribution independent of input distribution (Oblivious data access guarantee)

(Formal definitions and proof of Shortstack security in paper)

Evaluation

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    - Requires no modifications to the server side

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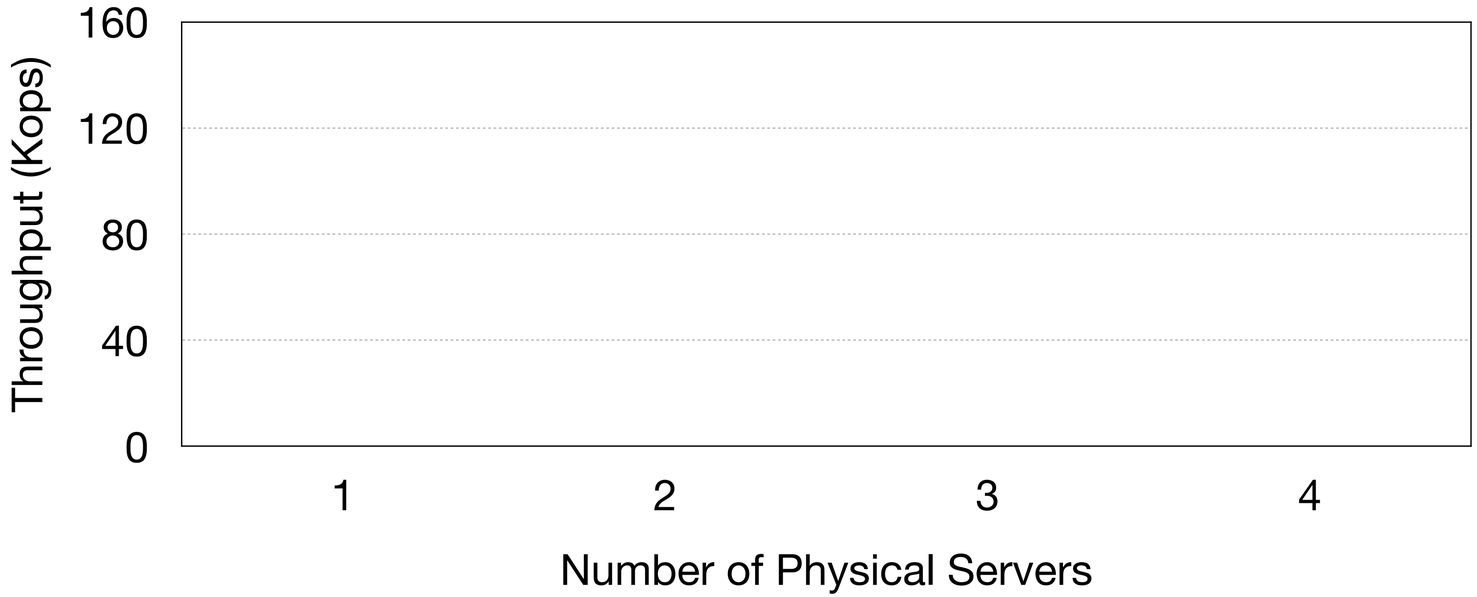

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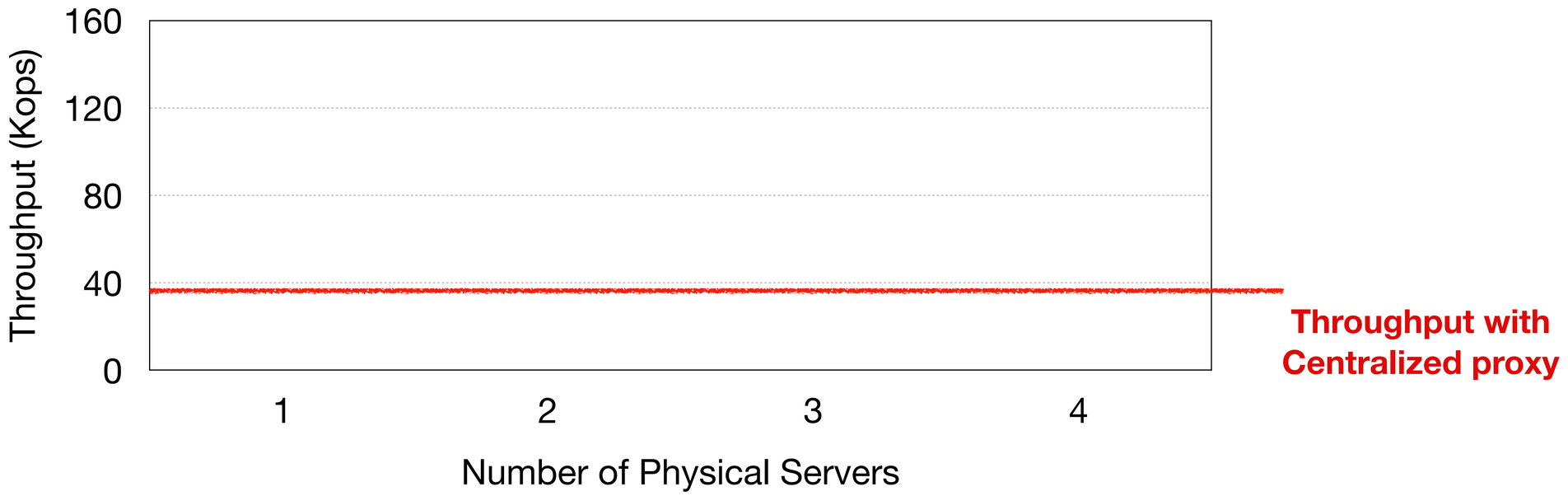

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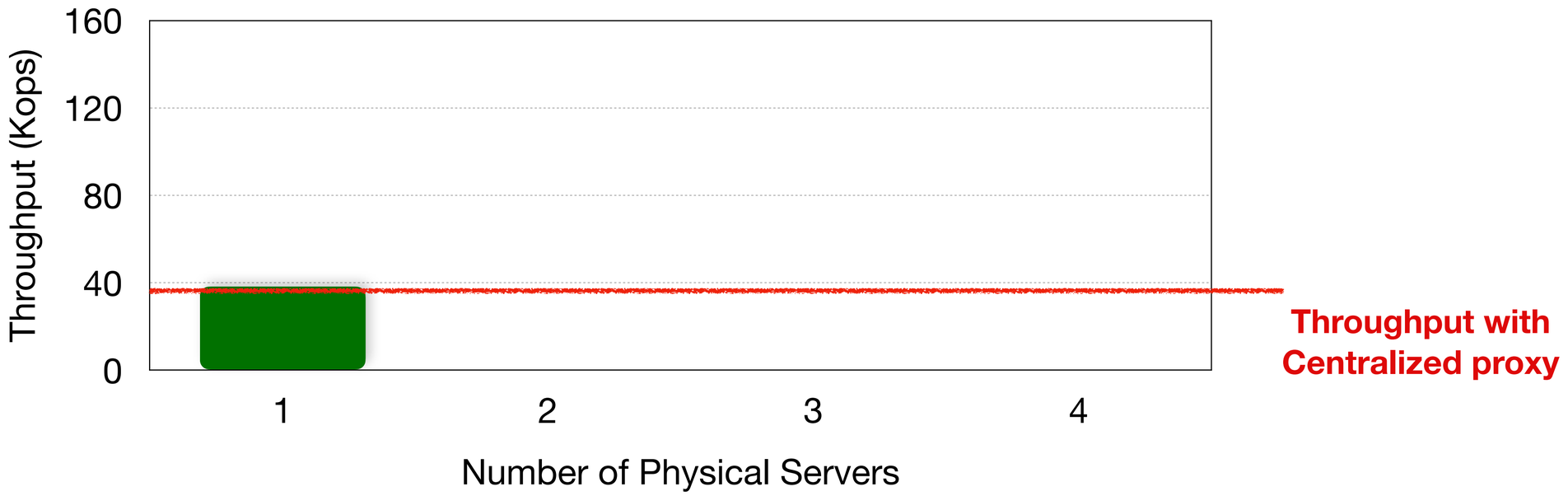

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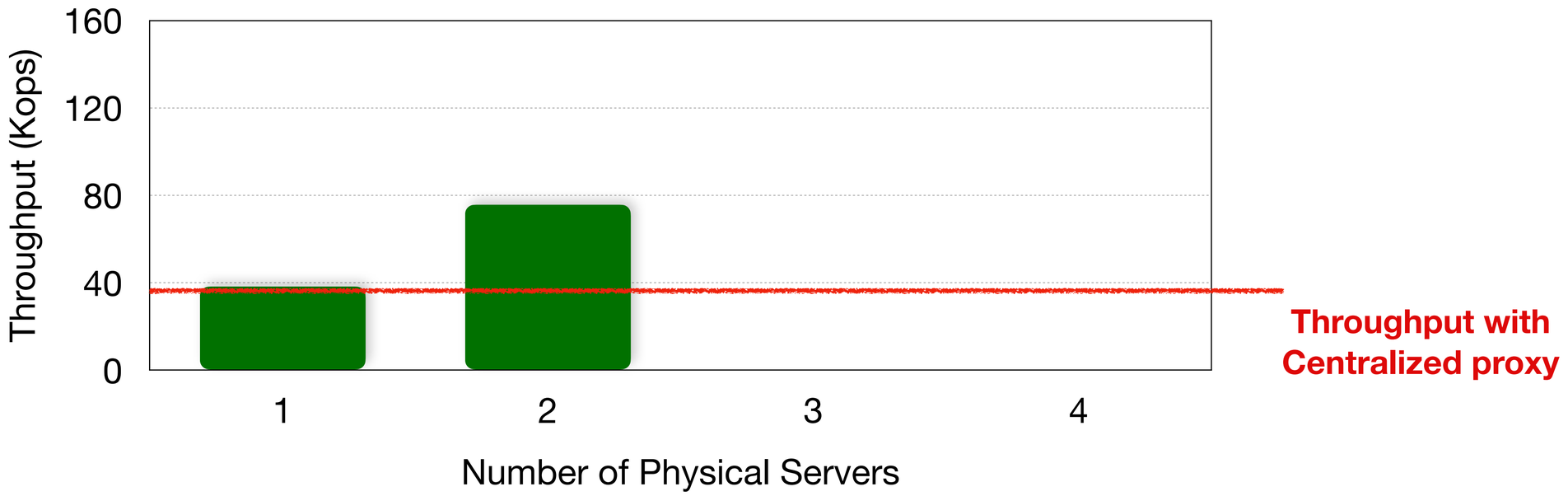

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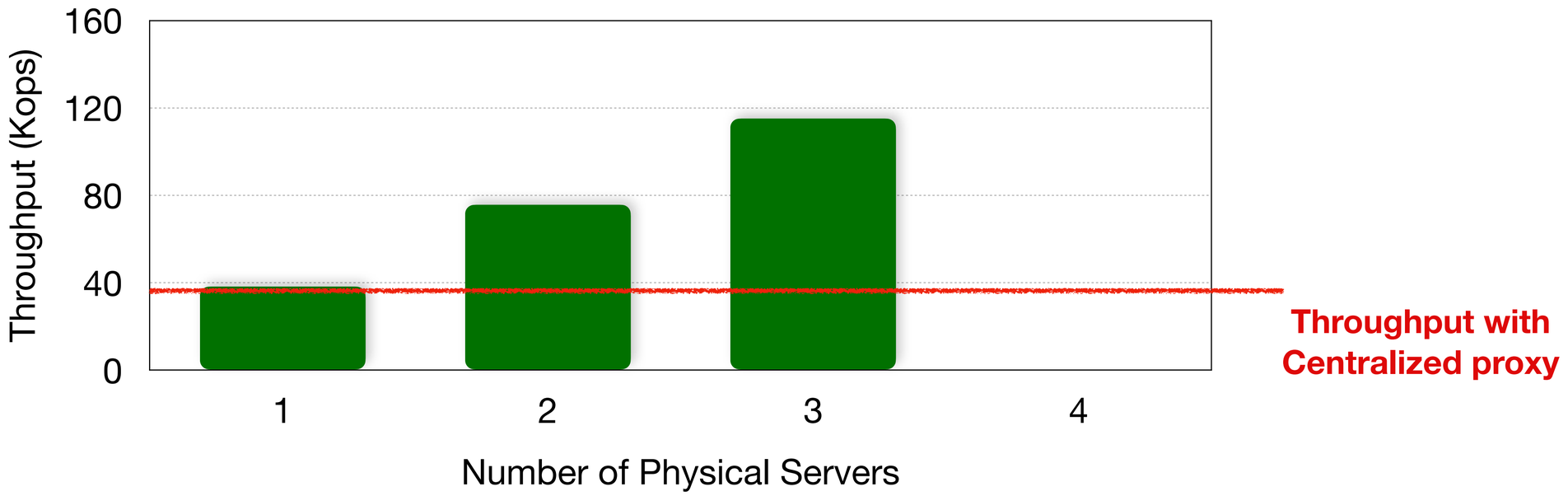

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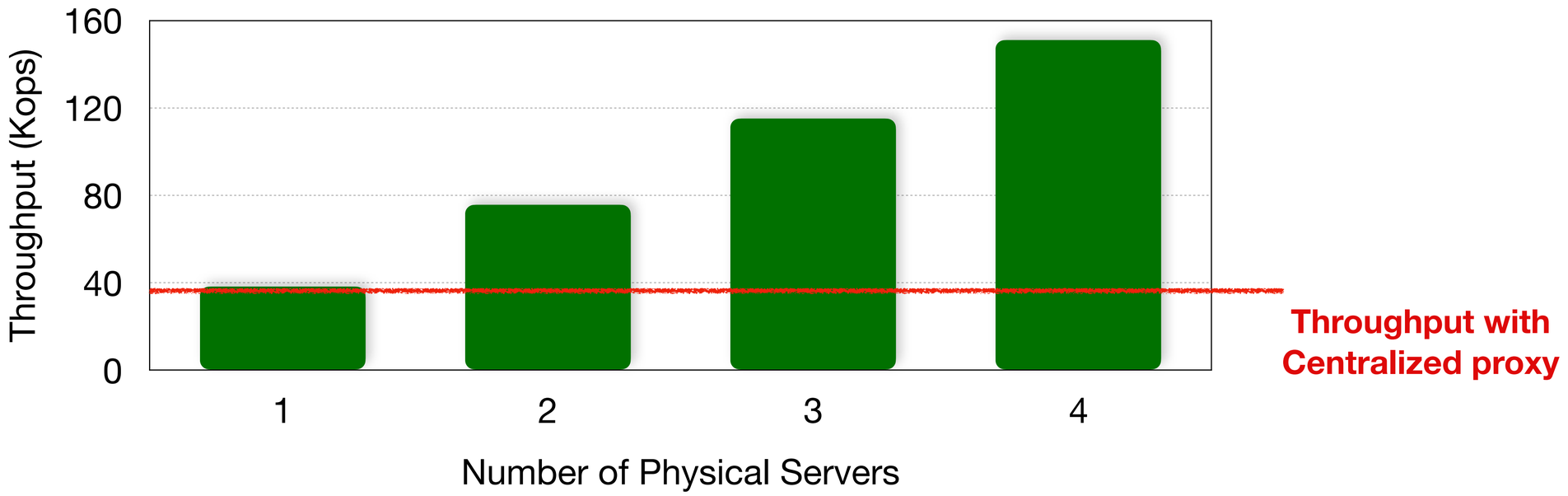

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- Many additional results in the Paper…
    1. System Scalability
    2. Fault Tolerance
    3. Latency
    4. Bottlenecks in each layer
    5. Skewed workloads

Conclusion

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https://github.com/pancake-security/shortstack