Pancake: Frequency Smoothing for Encrypted Data Stores

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Cloud Data Stores

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Transition to cloud hosted data stores for **ease-of-management**, **scalability** & **cost-efficiency**

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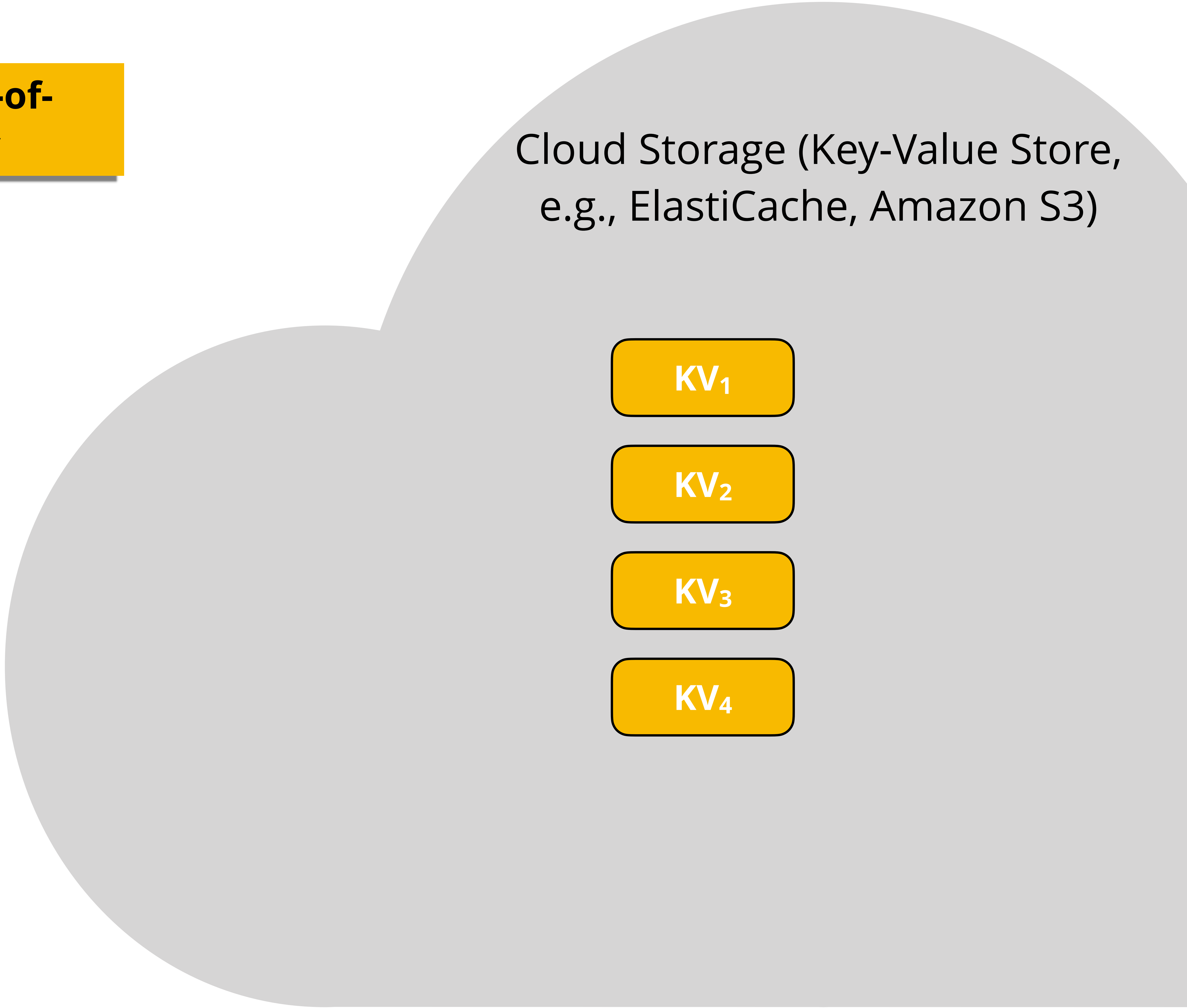

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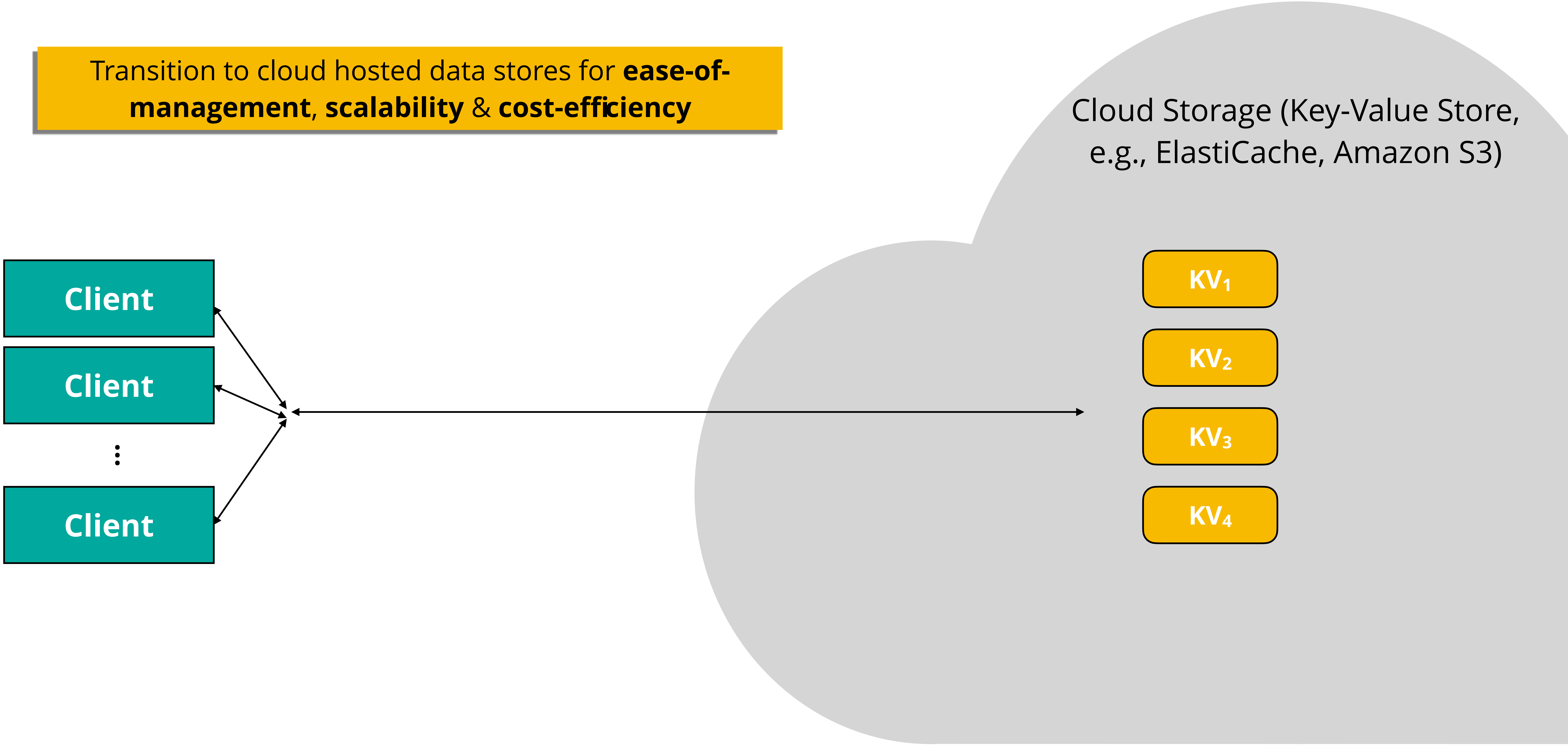

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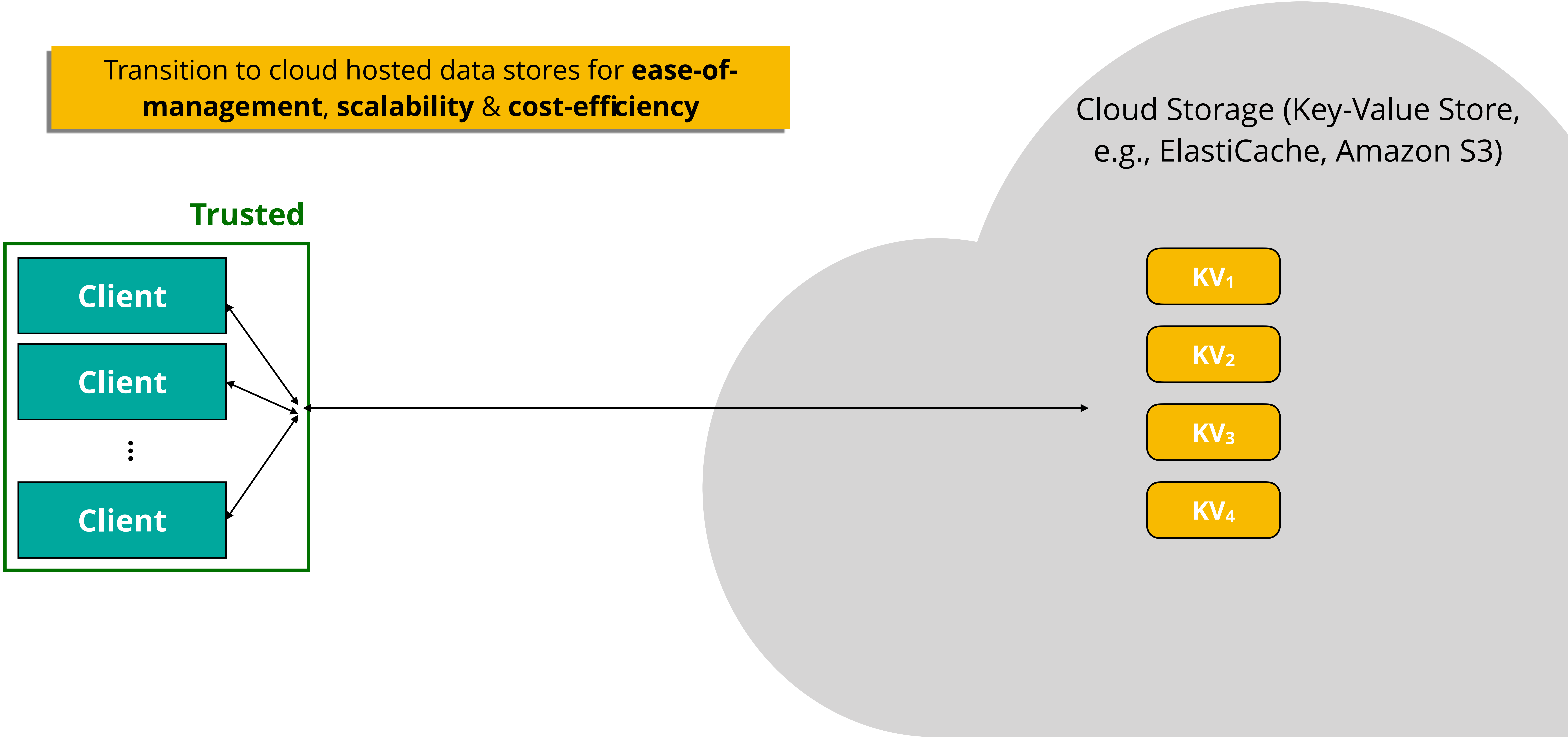

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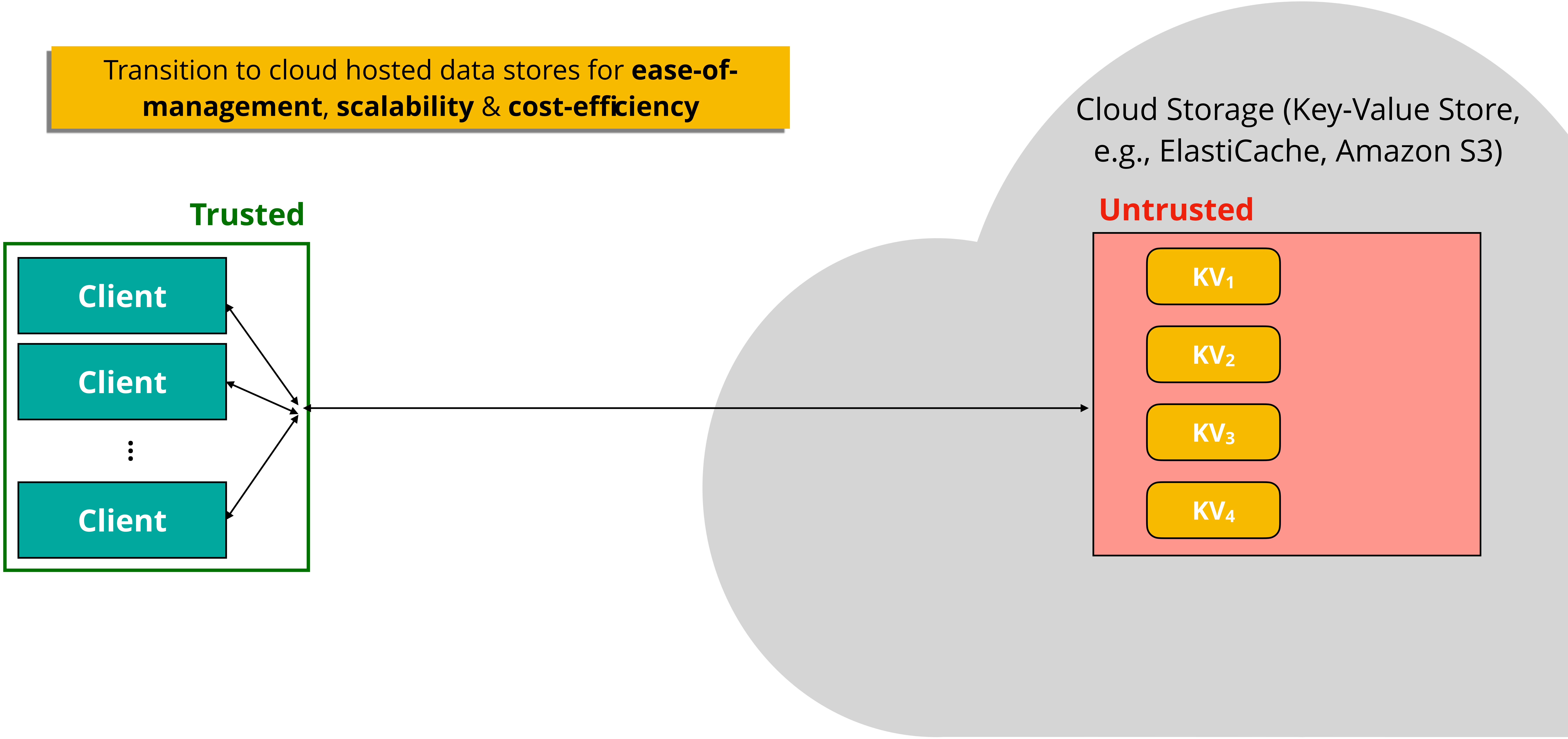

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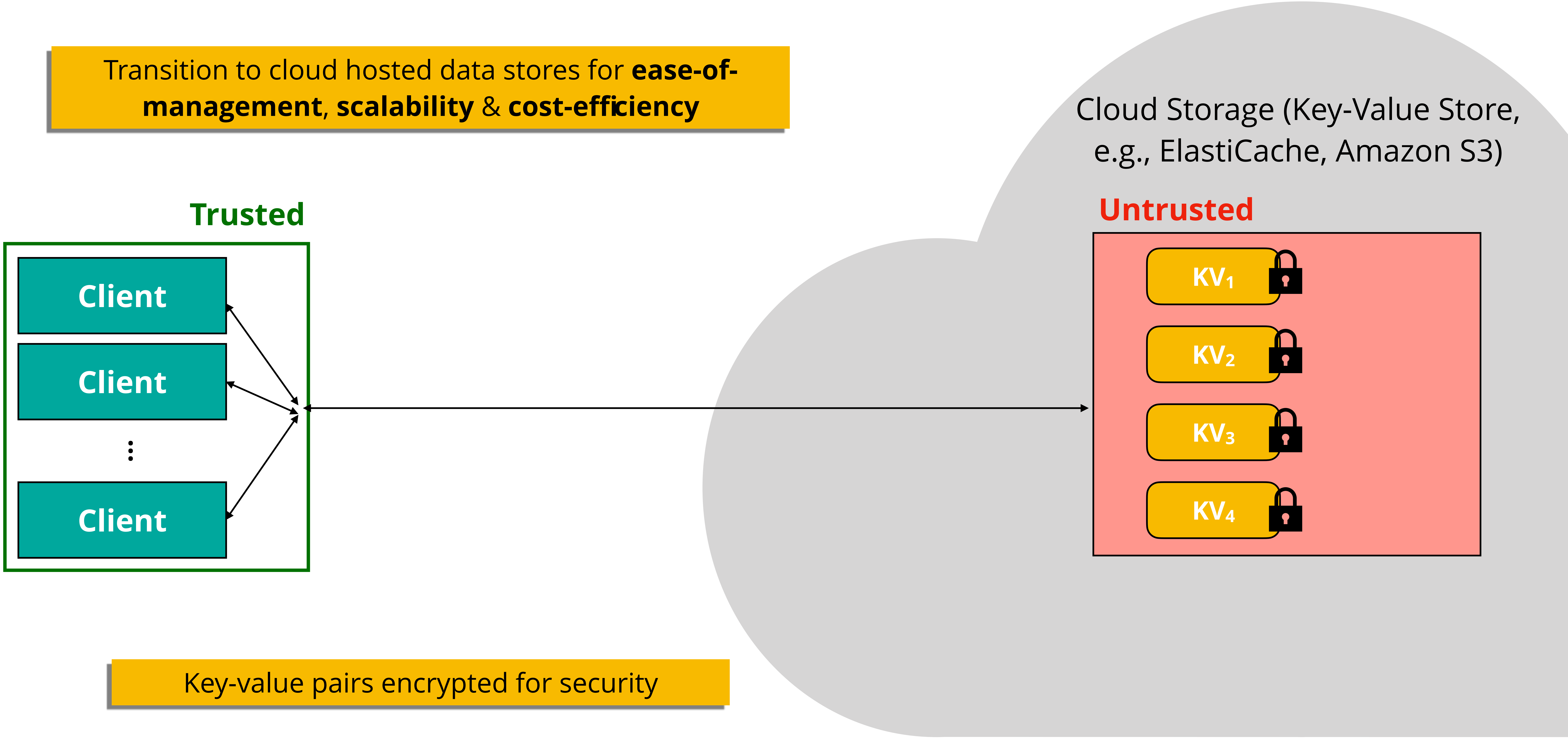
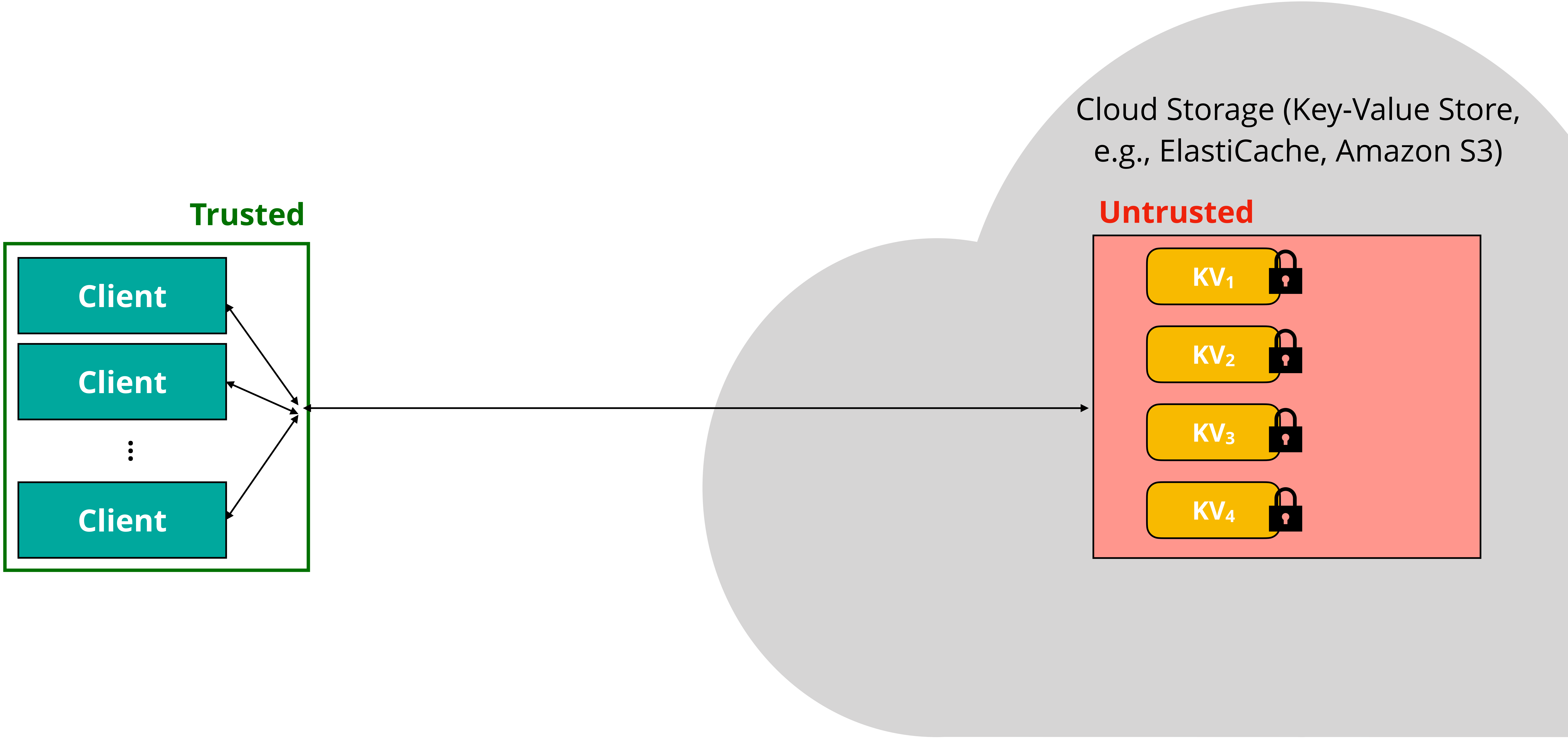


Key-value pairs encrypted for security

Access Pattern Attacks



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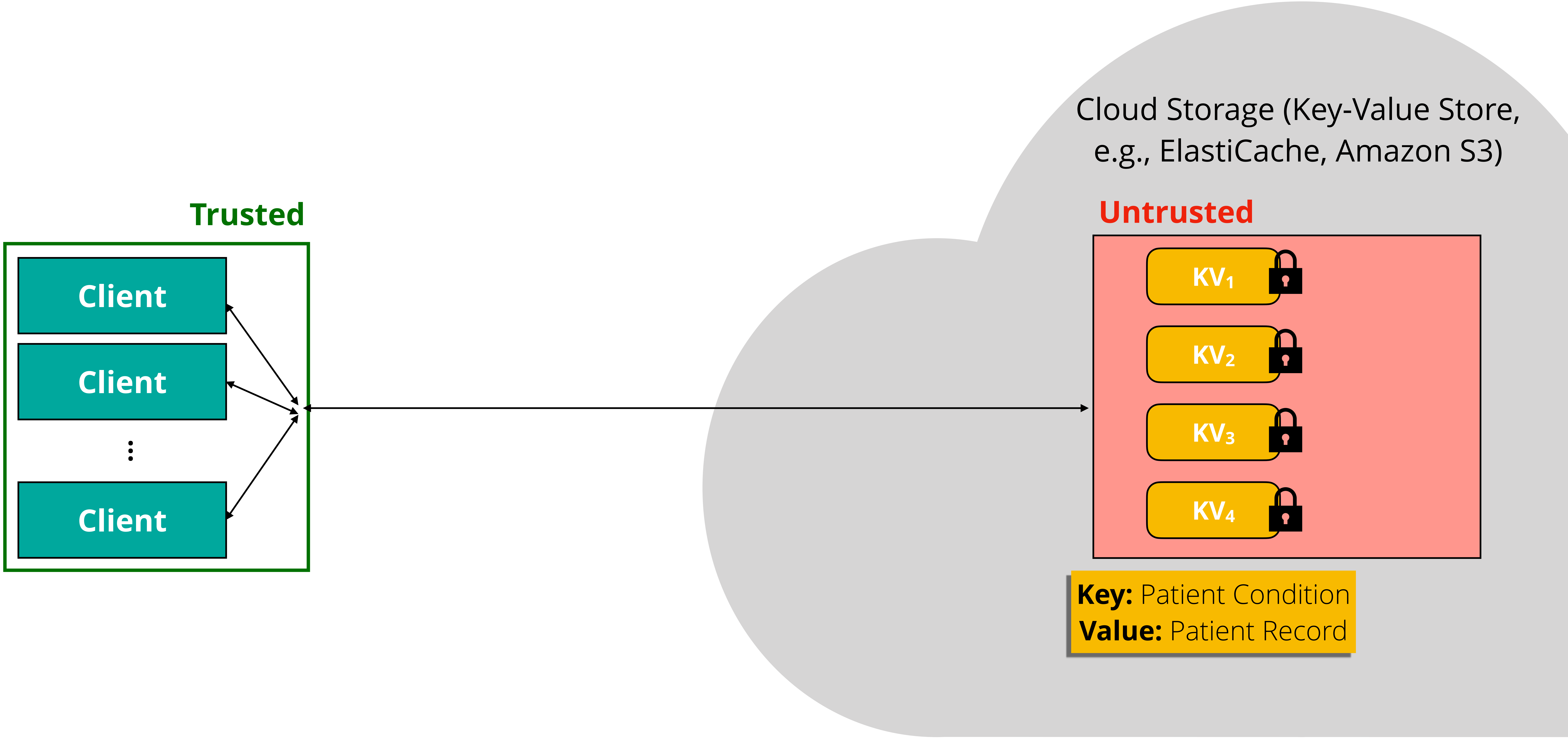

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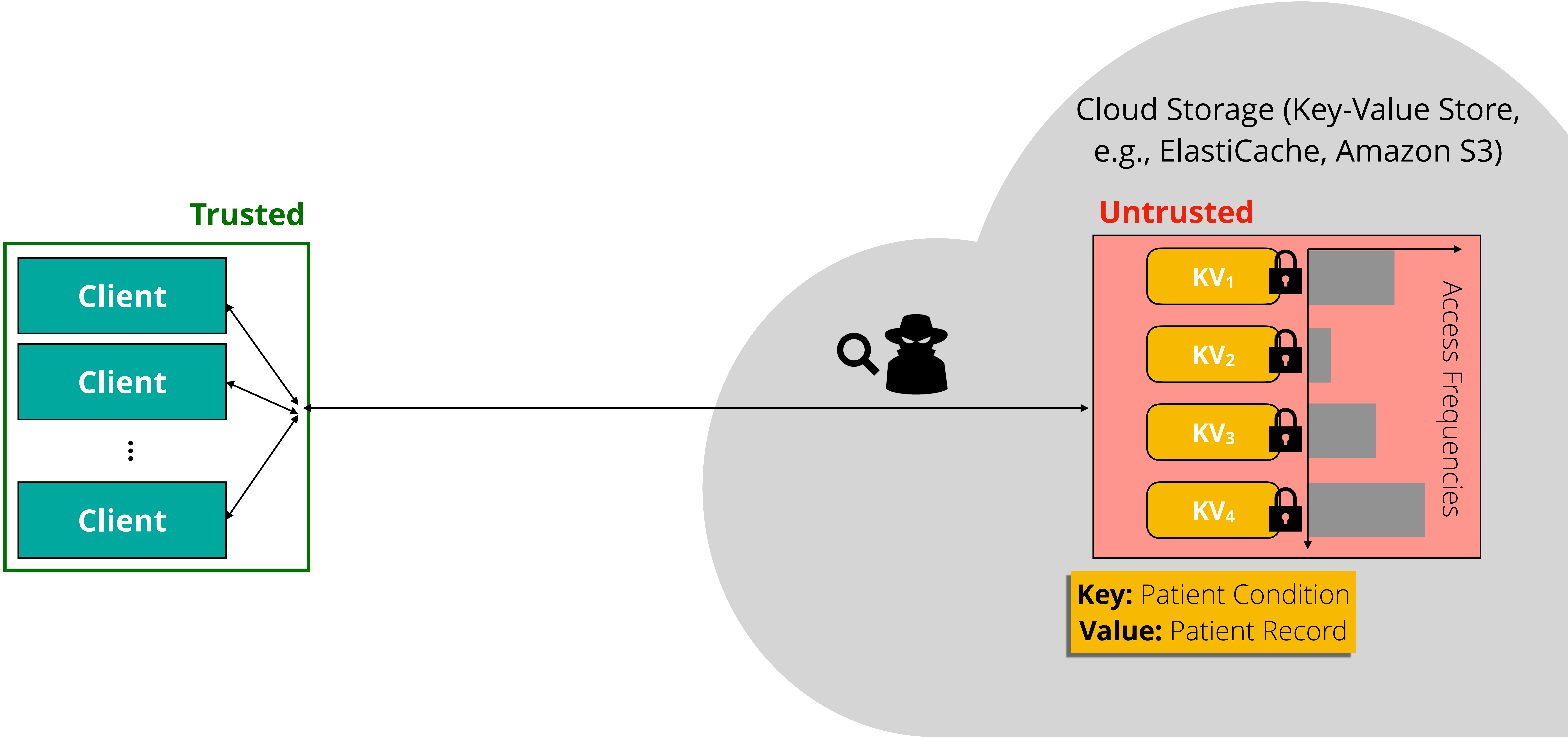

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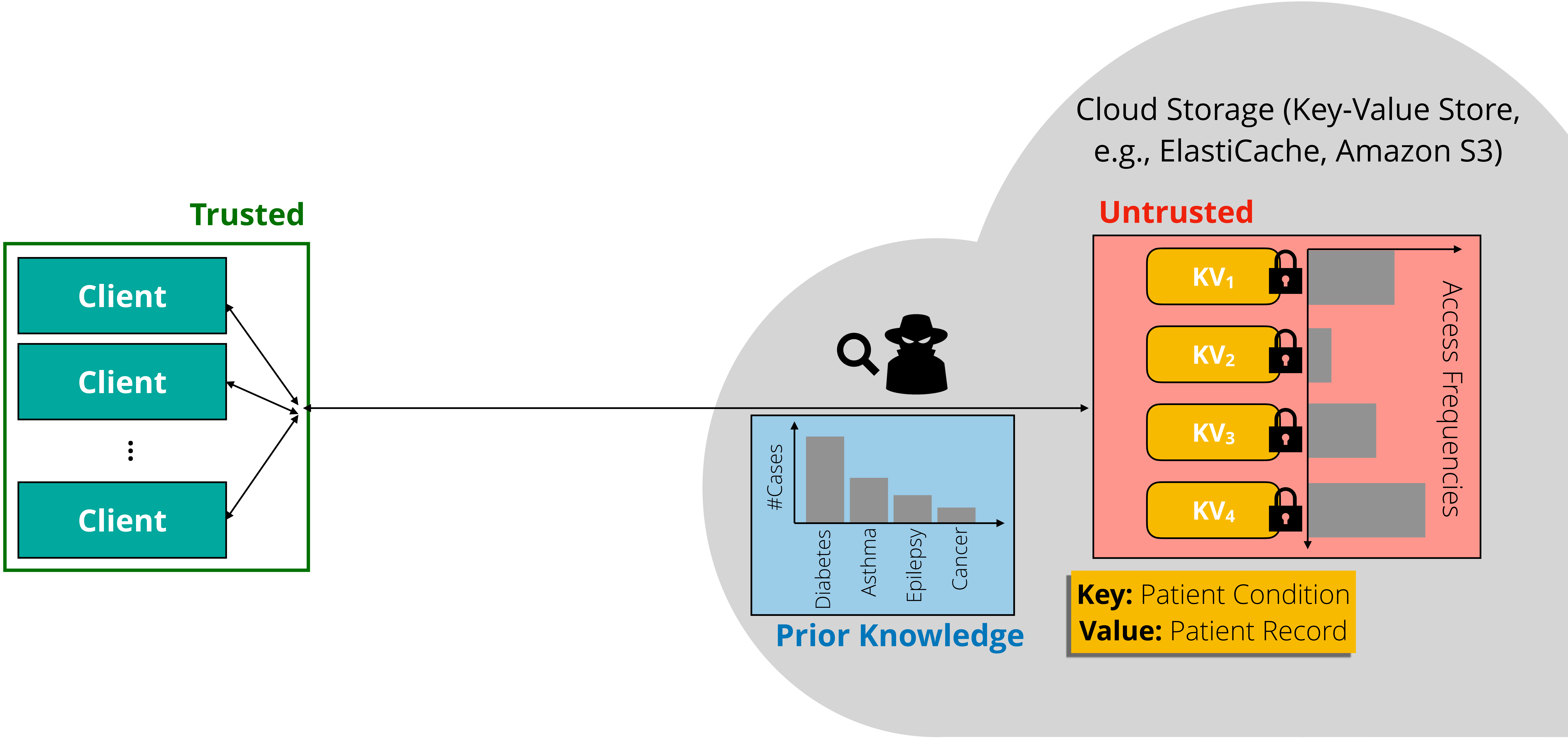

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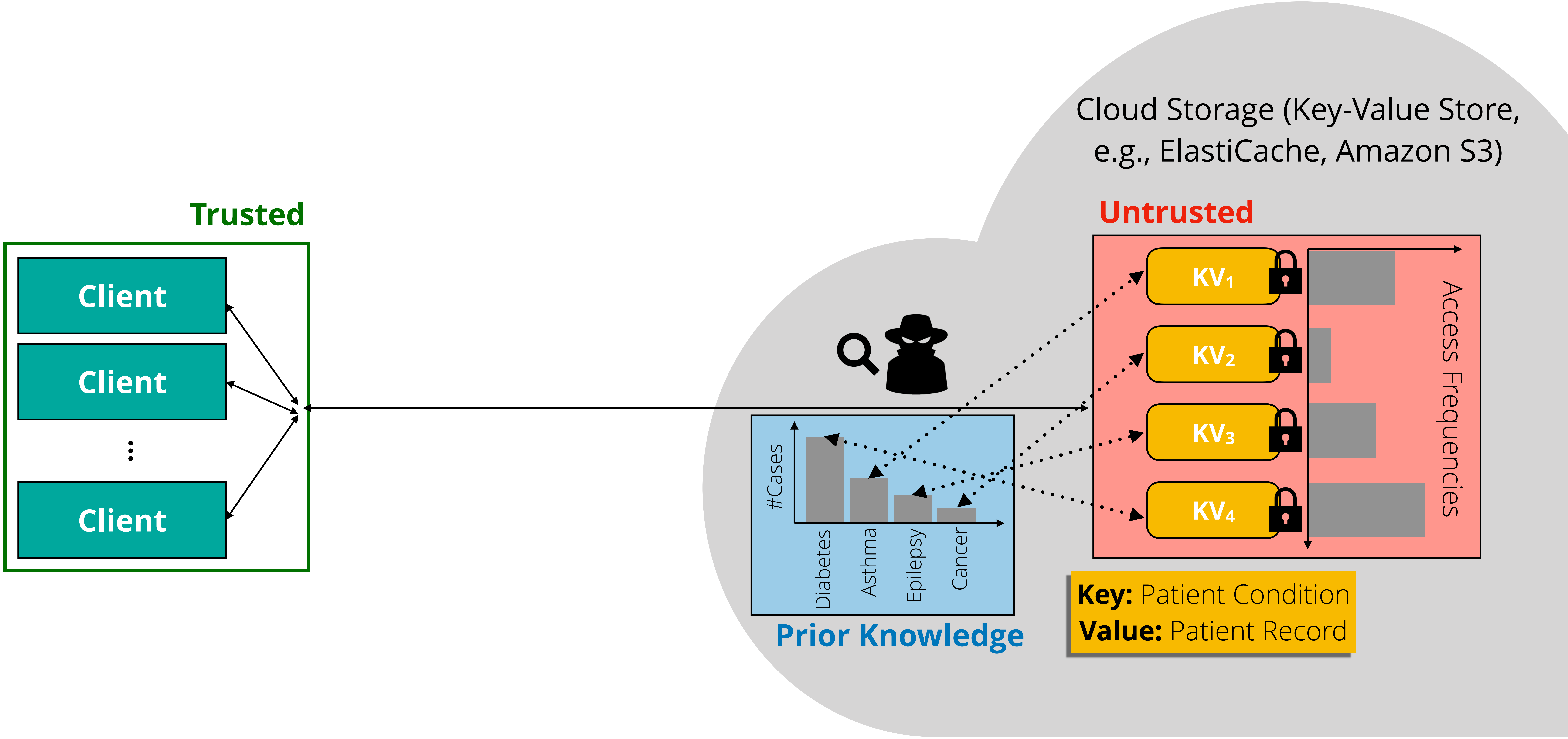

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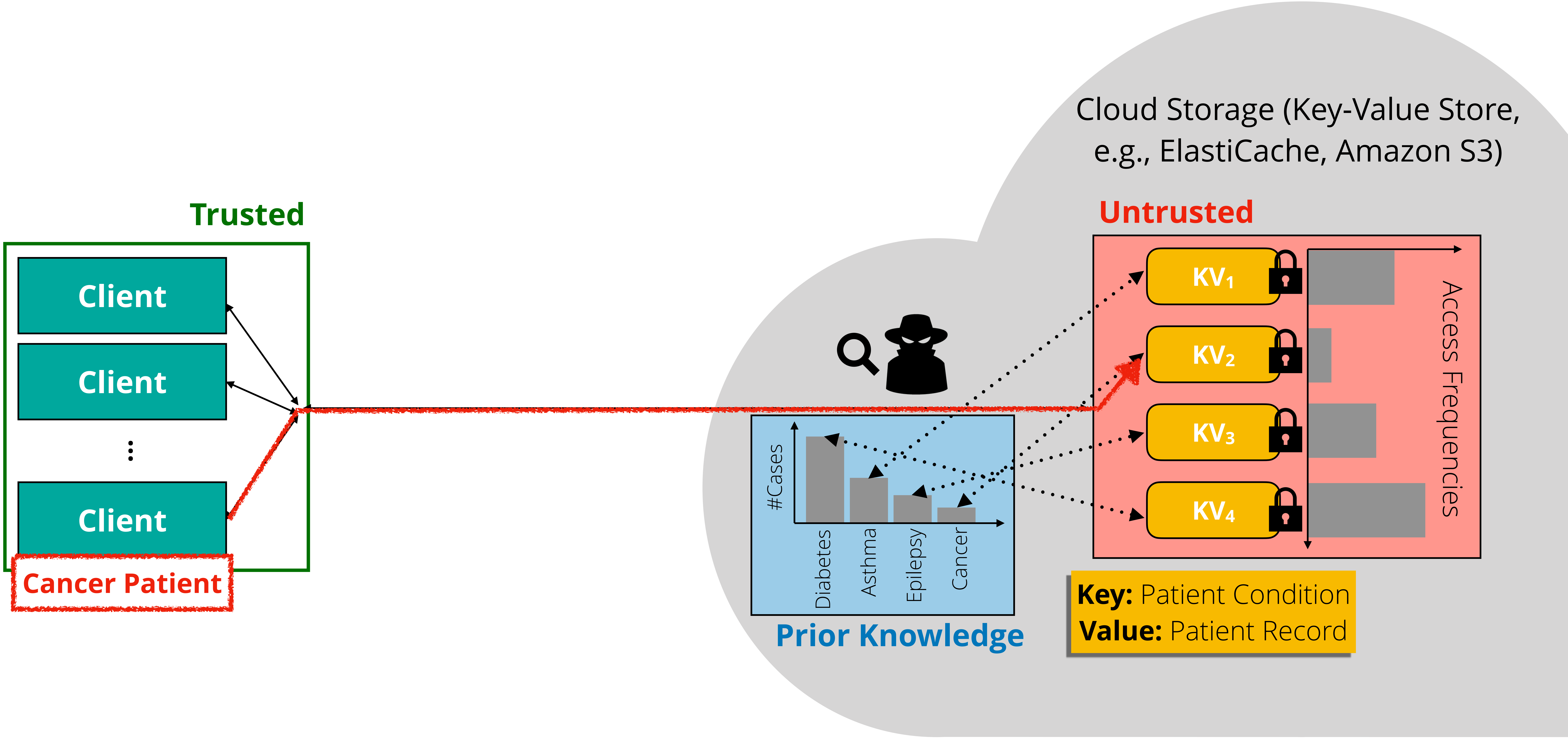

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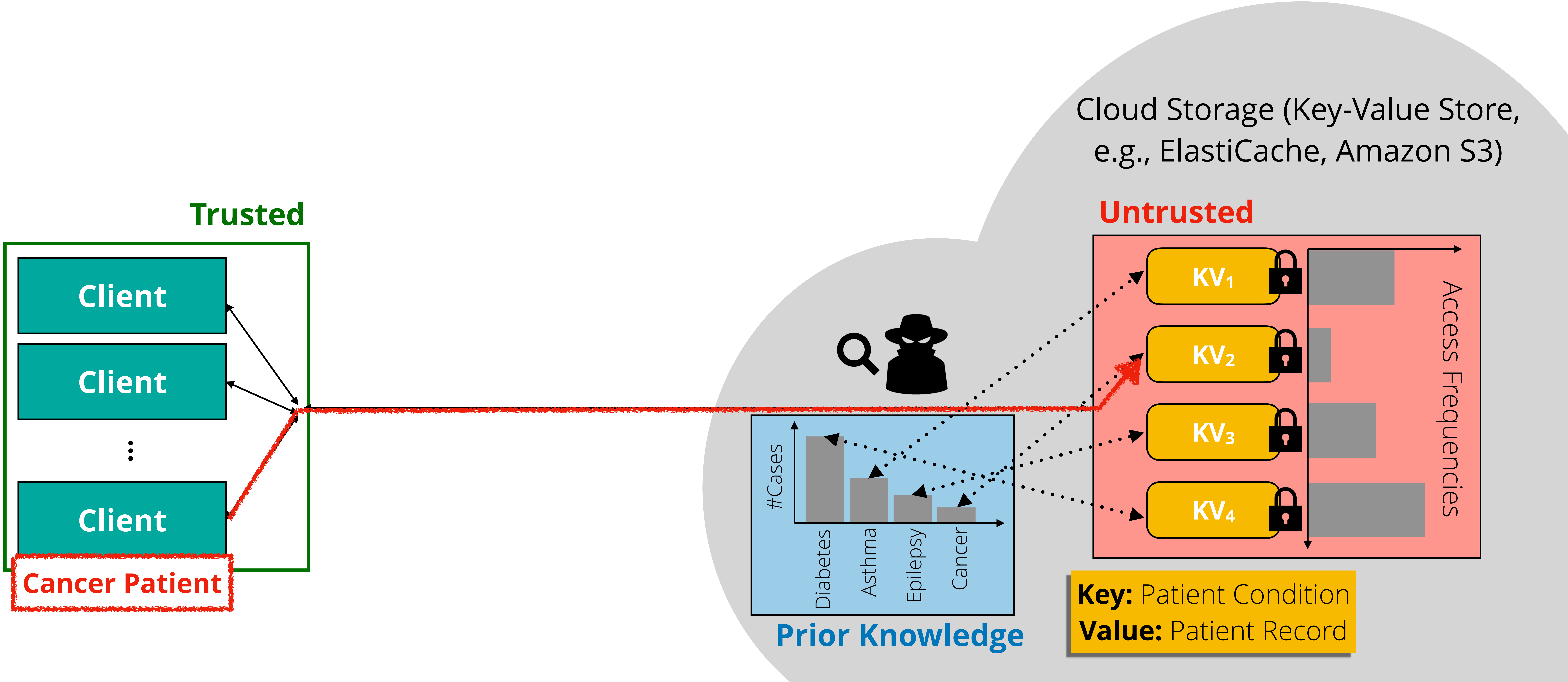
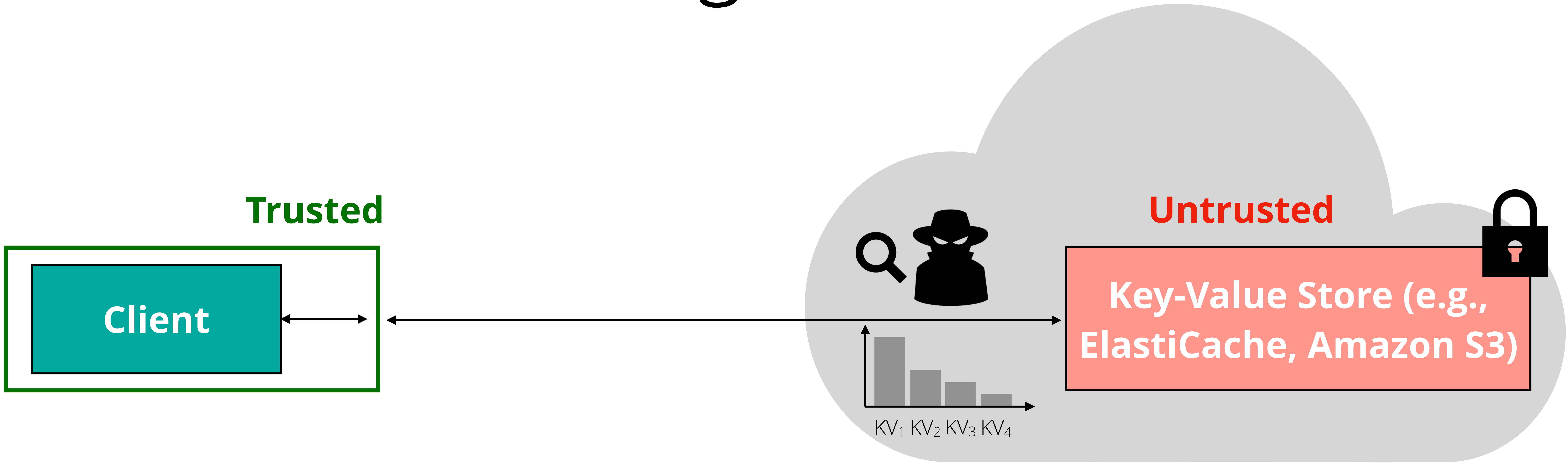


Many practical attacks: [IKK NDSS'12], [CGPR CCS'15], [KKNO CCS'16], [GLMP S&P'19], [KPT S&P'19]

Existing Solutions



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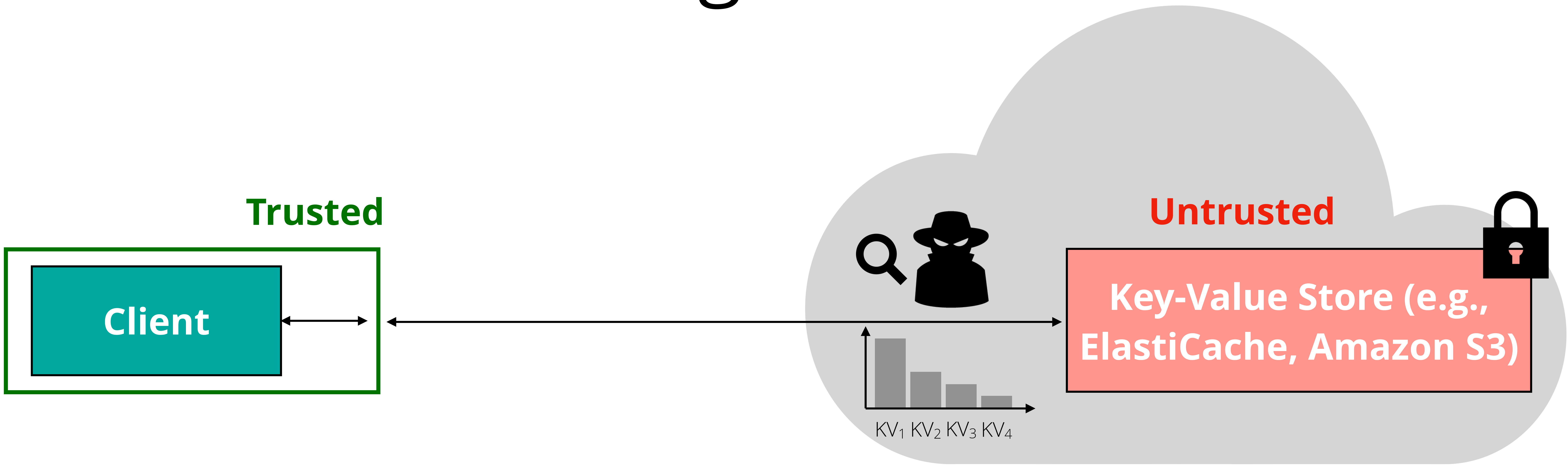

Threat model	Active Adversary
Approach	ORAM, PIR

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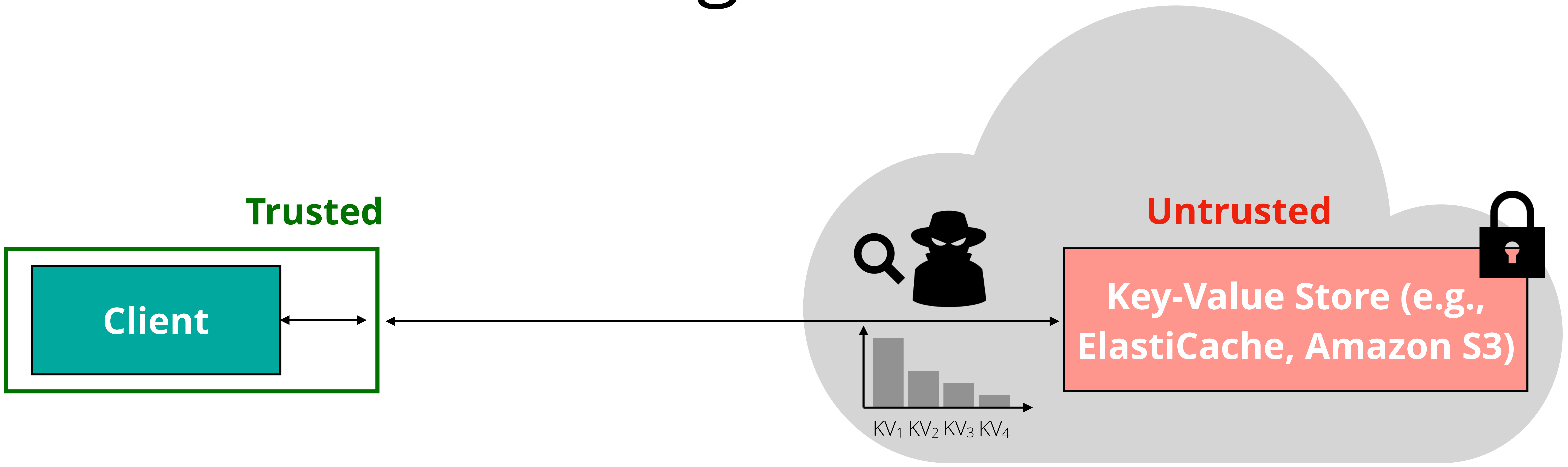

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Performance	Poor

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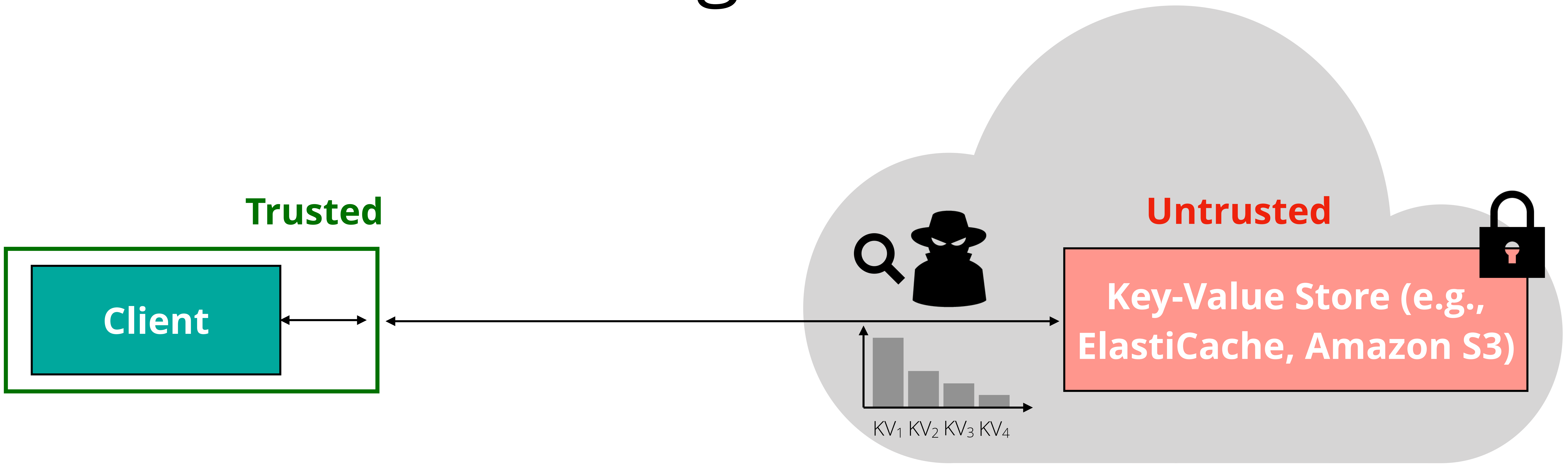

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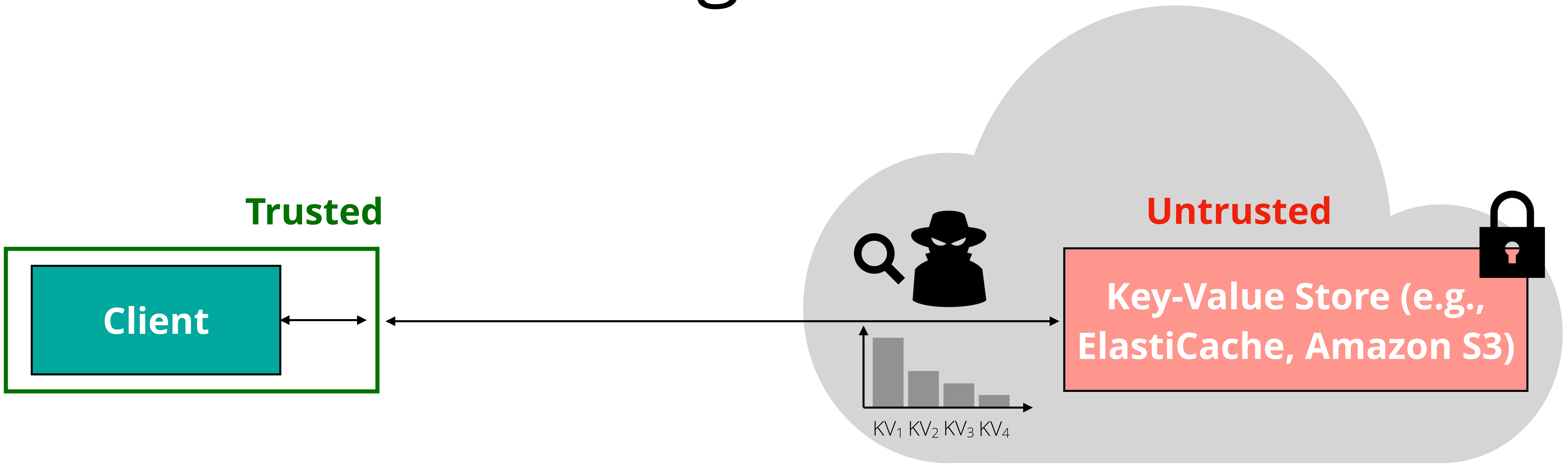
O(log n) bandwidth lower bound [BN ITCS'16, LN CRYPTO'19, …]
8x storage & 1600x bandwidth for real workloads!

Existing Solutions



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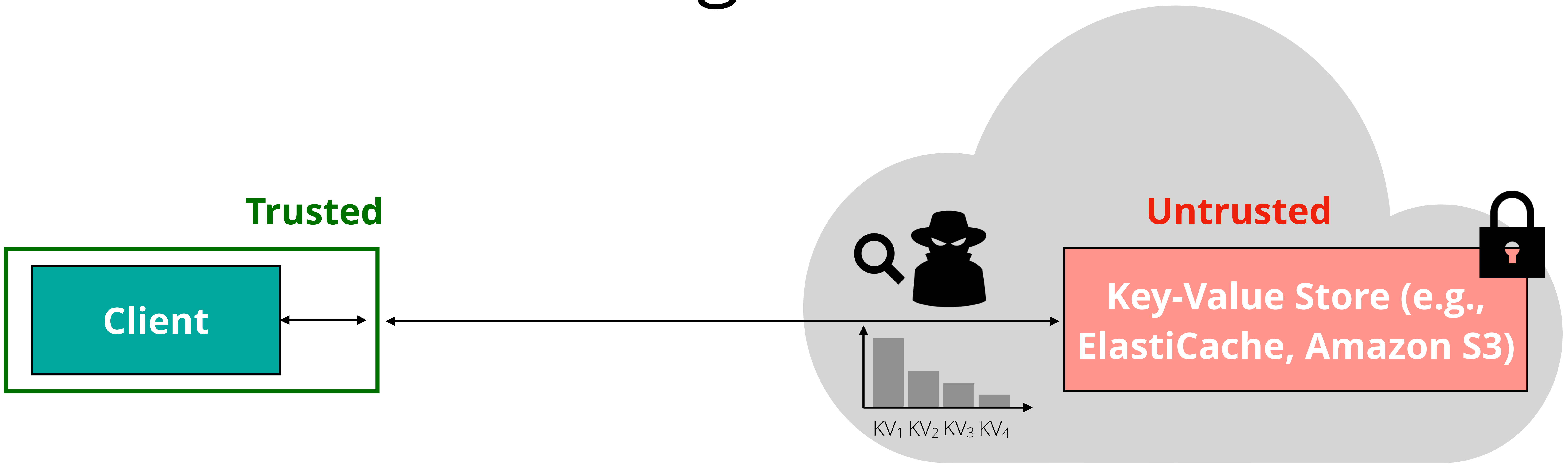

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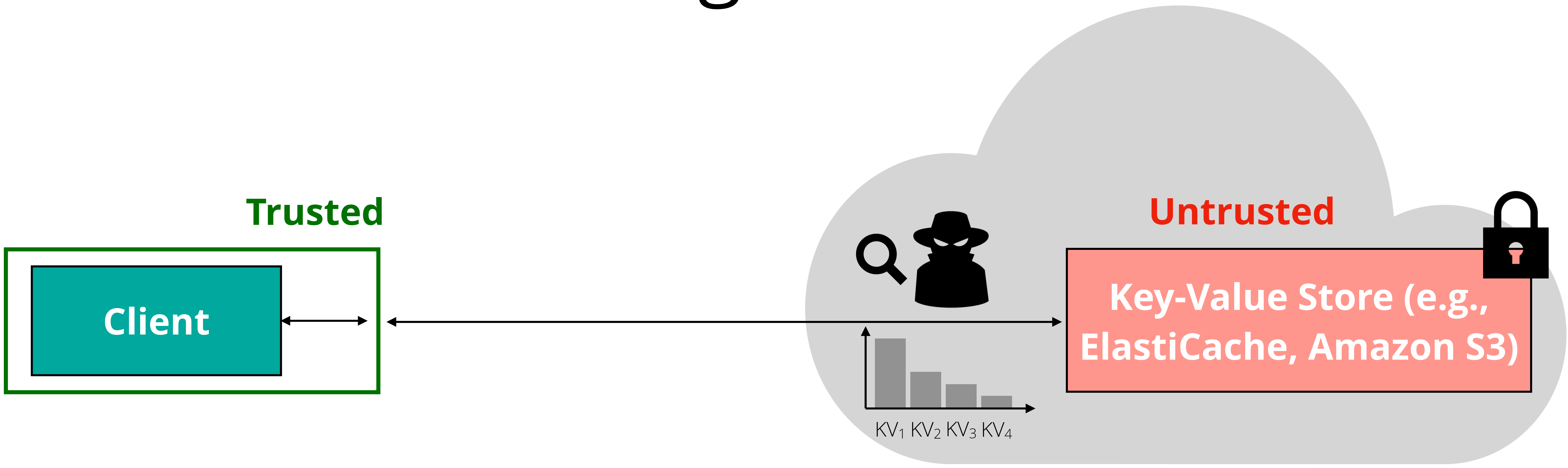

Threat model	Active Adversary		Snapshot Adversary
Approach	ORAM, PIR		SSE
Security	Strong	Unrealistic threat model [GRS HotOS'17]	Weak
Performance	Poor		High

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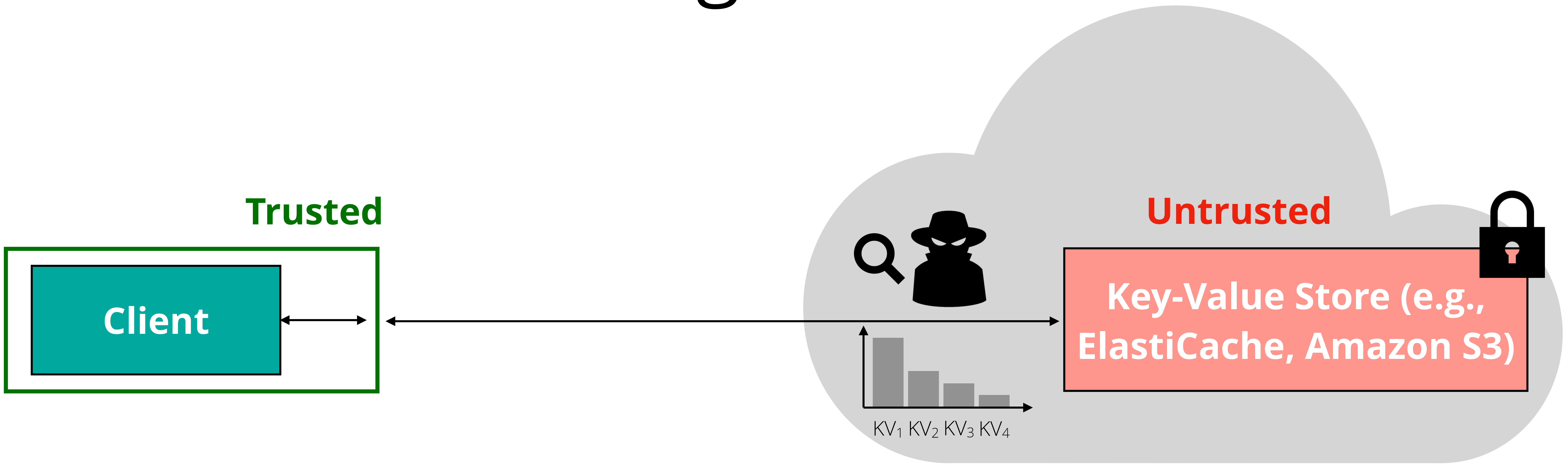

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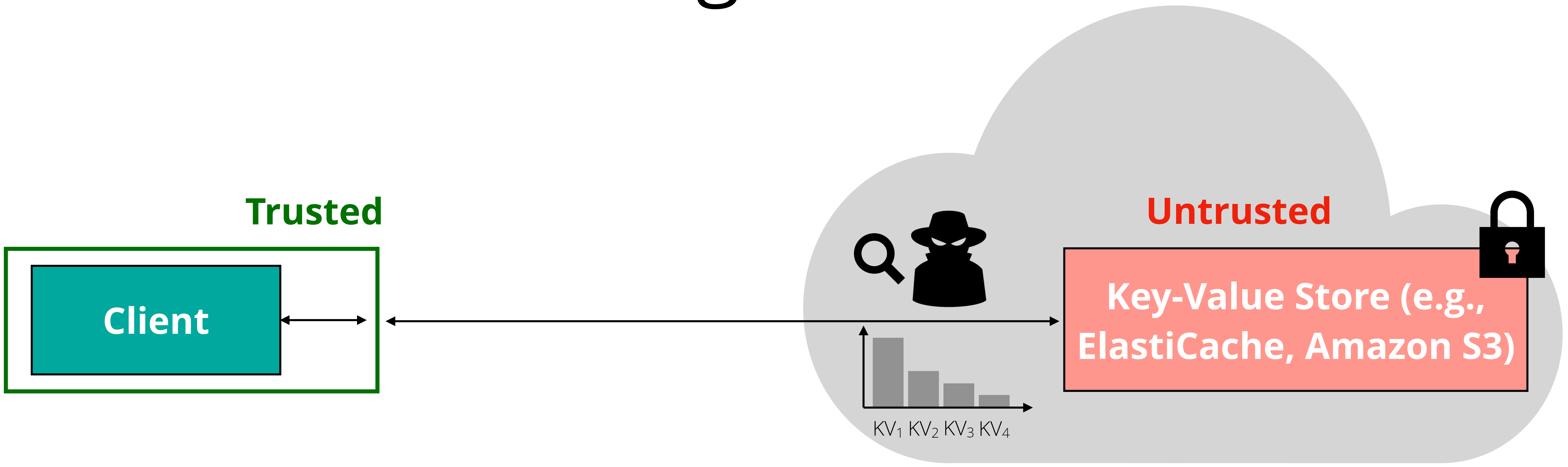

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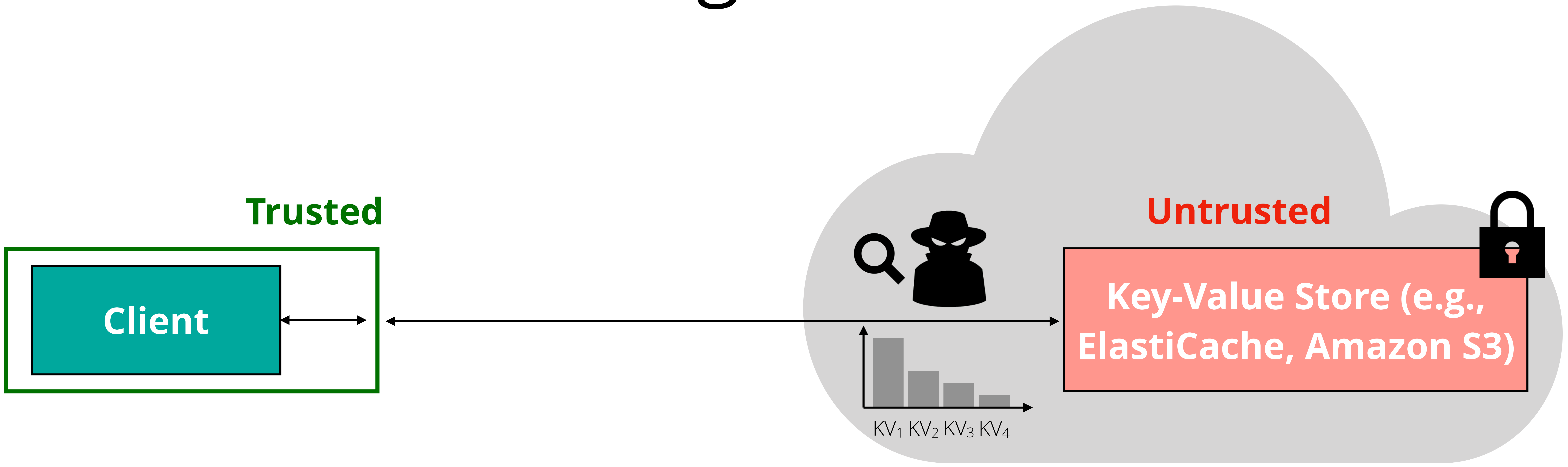

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Performance	Poor	Can we achieve low performance overheads?	High

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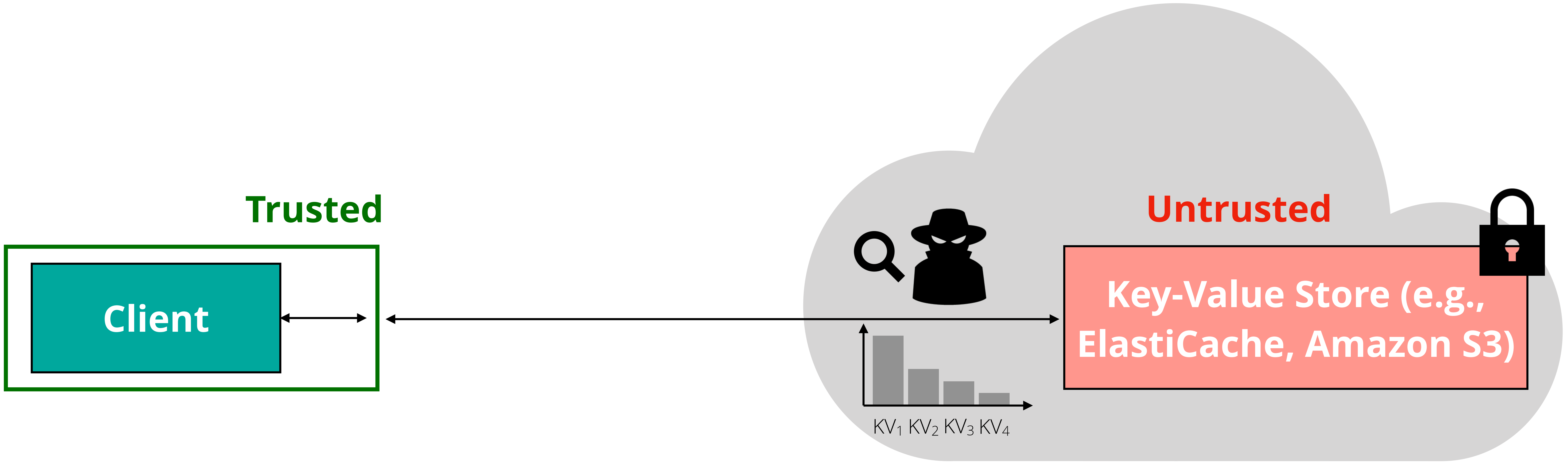

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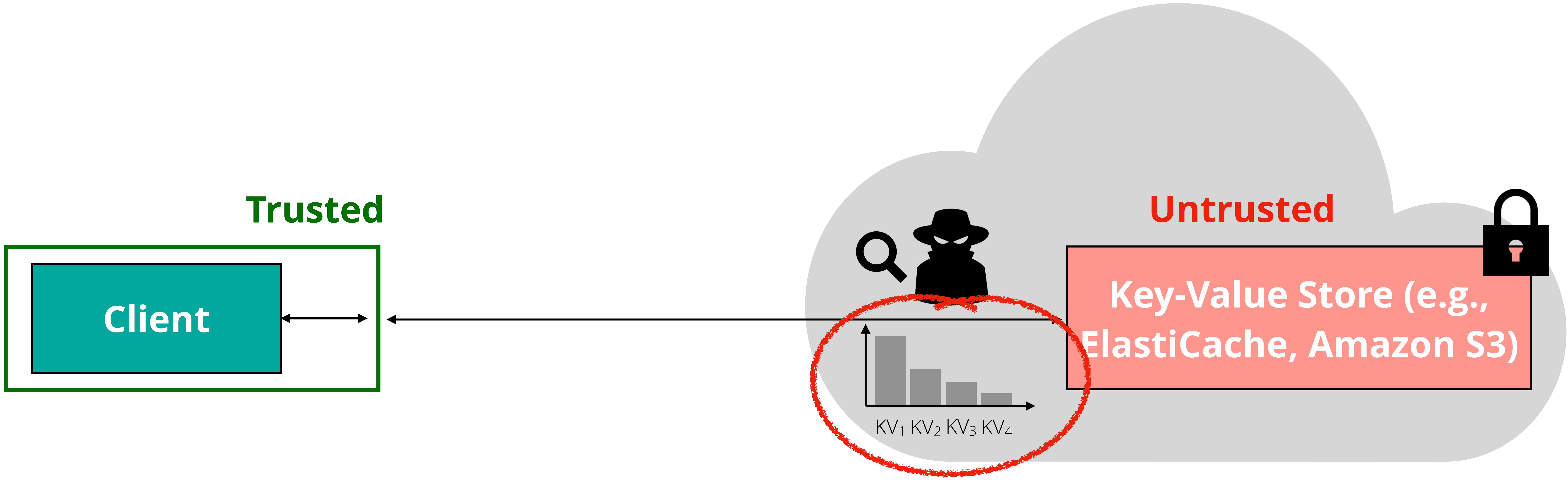

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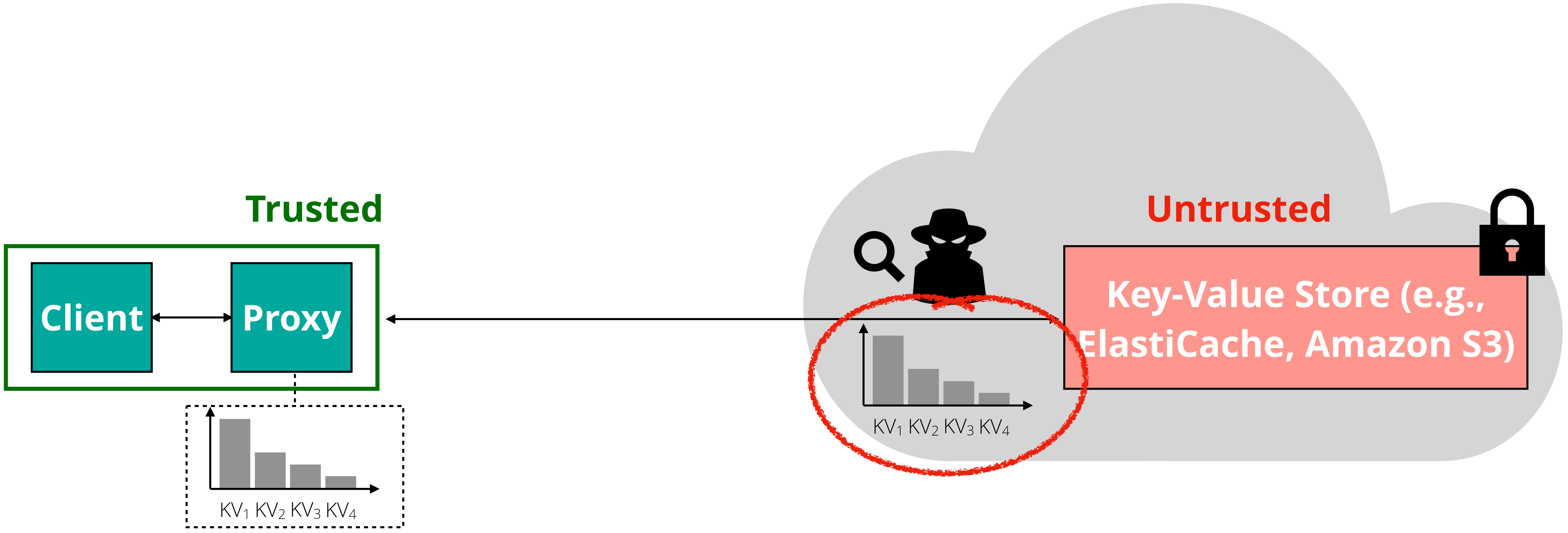
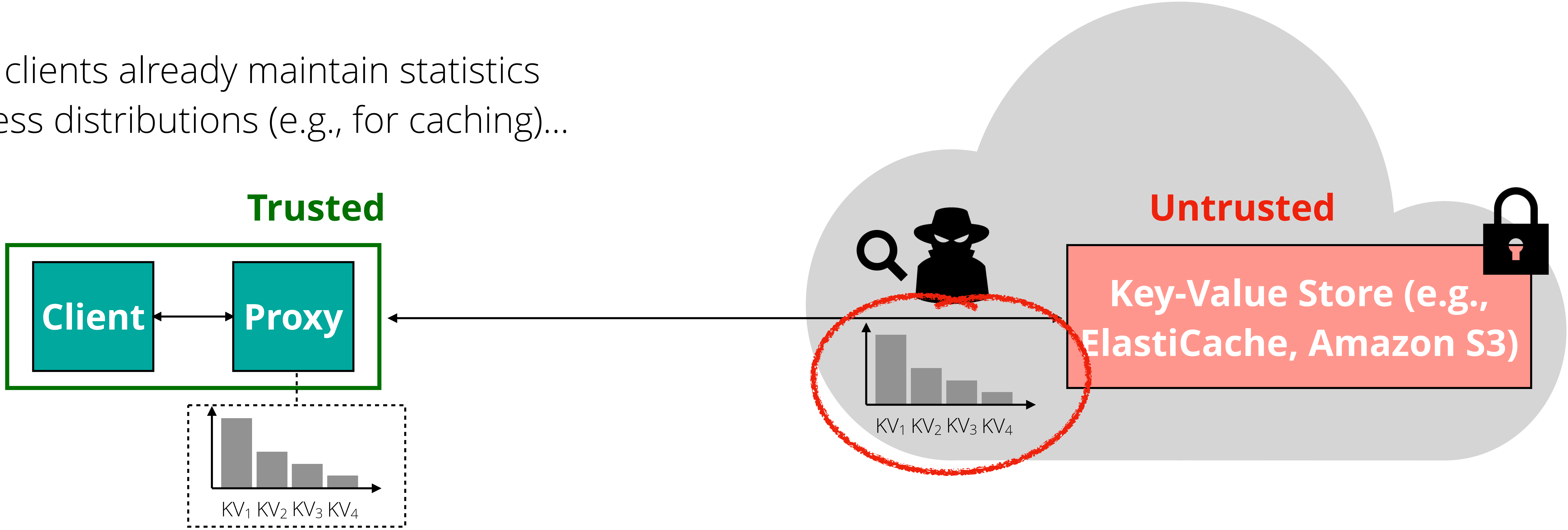


Can we do better?

KV store clients already maintain statistics about access distributions (e.g., for caching)...



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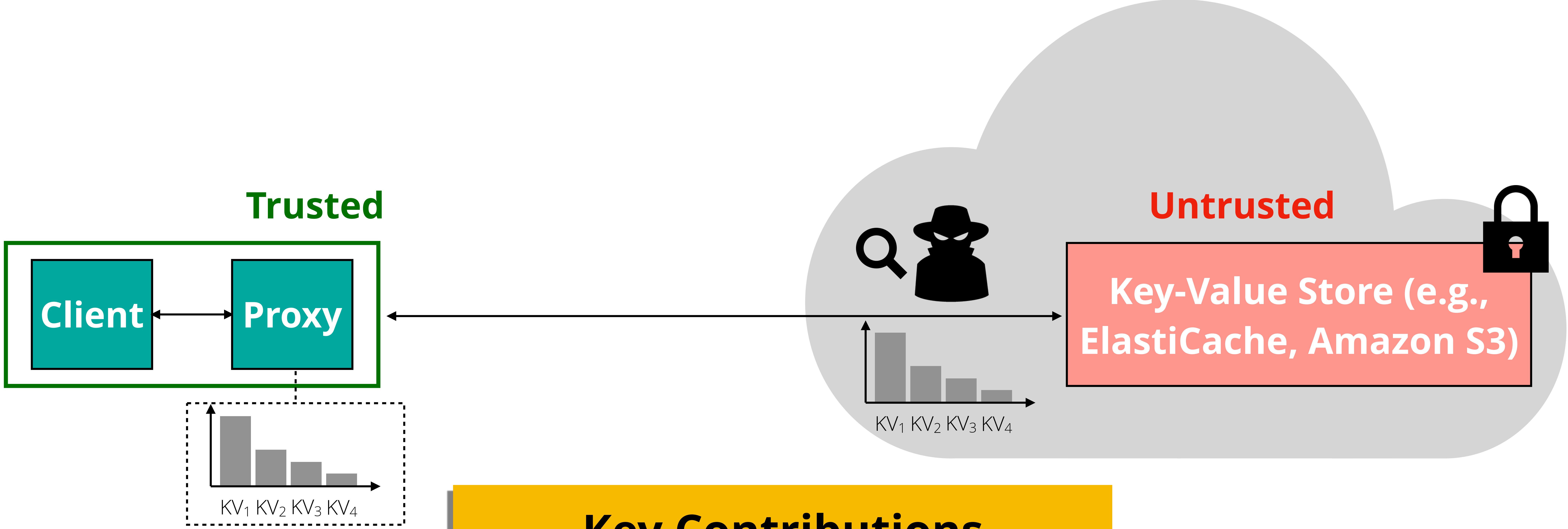

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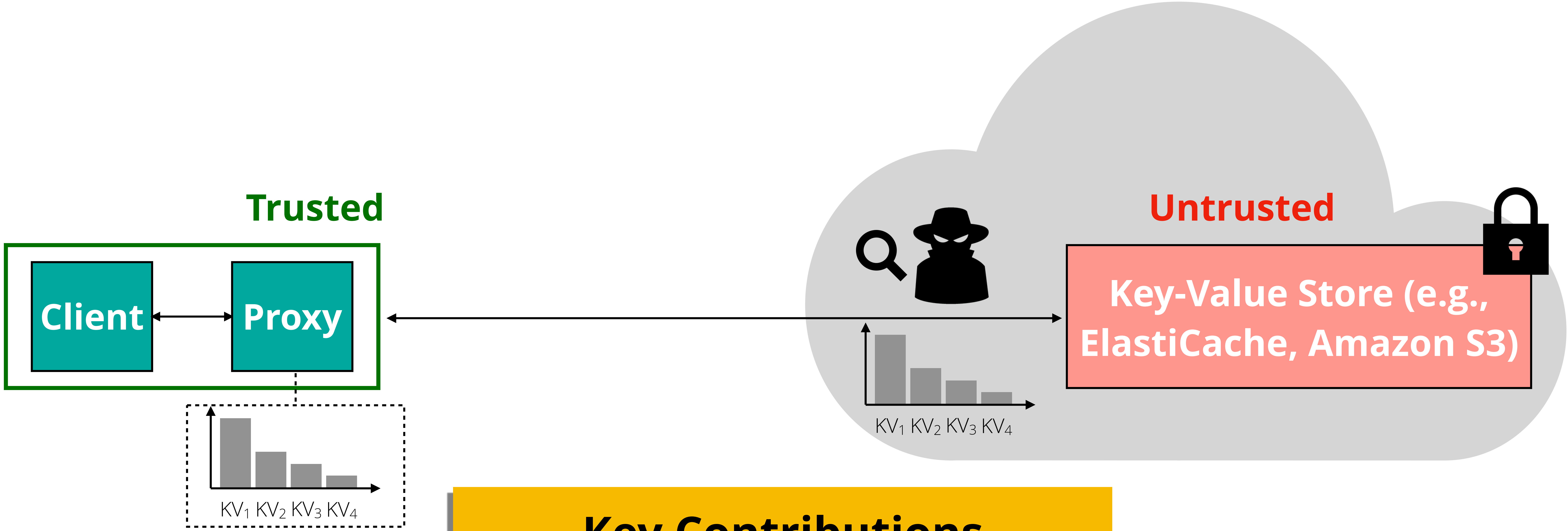

Key Contributions

- **Pancake:** use **frequency smoothing** over known access distribution to provide security against access pattern attacks with **constant server storage & bandwidth overheads**

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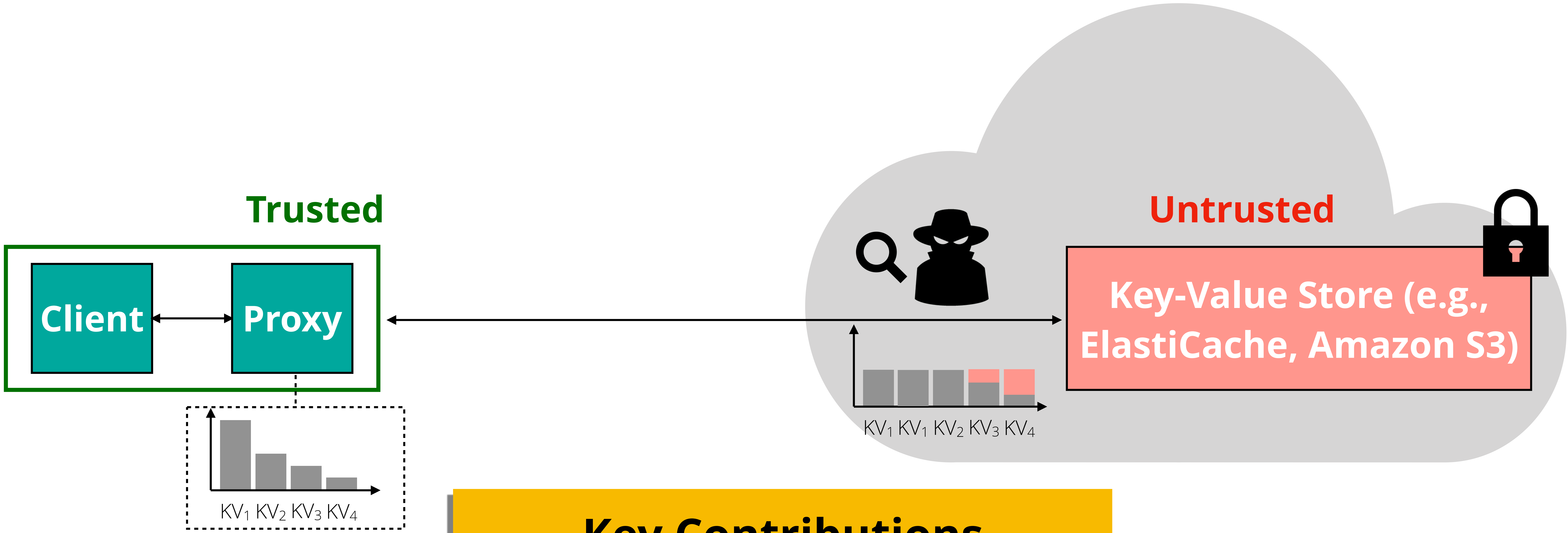

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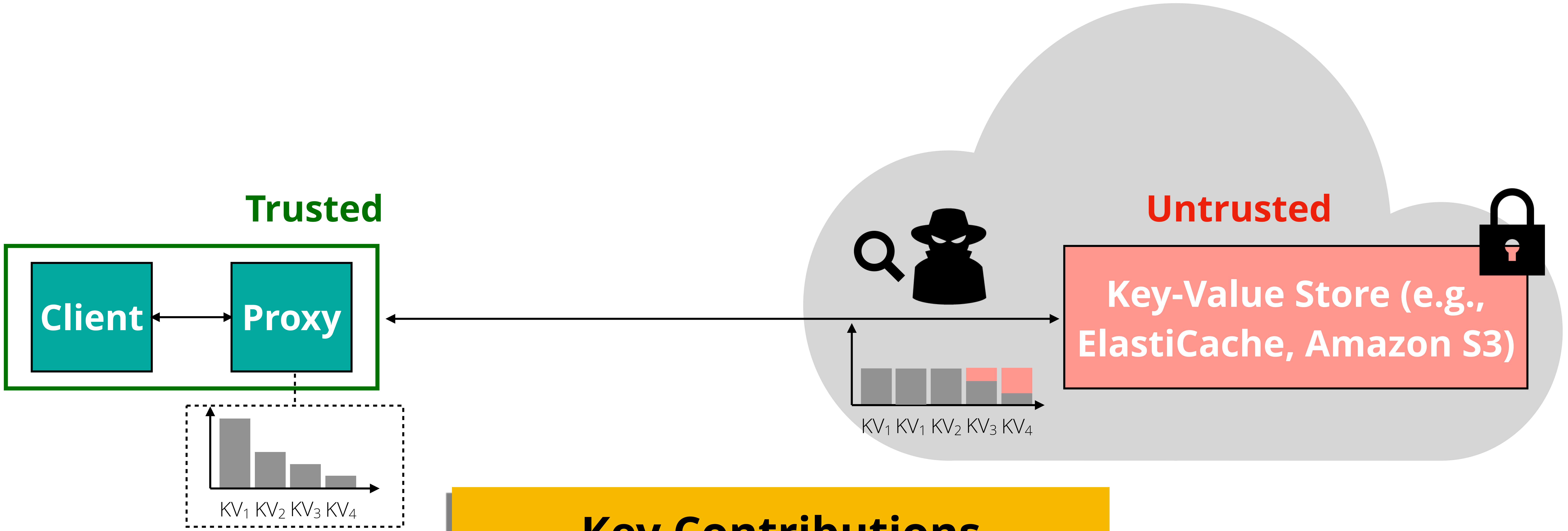

Key Contributions

- **Pancake:** use **frequency smoothing** over known access distribution to provide security against access pattern attacks with **constant server storage & bandwidth overheads**
- **Formal security analysis** showing passive persistent security
- Comprehensive evaluation shows throughput **> 2 orders of magnitude higher than state-of-the art** (PathORAM)!

Frequency Smoothing

Model: Queries drawn from **distribution** π over keys, known to both system & adversary

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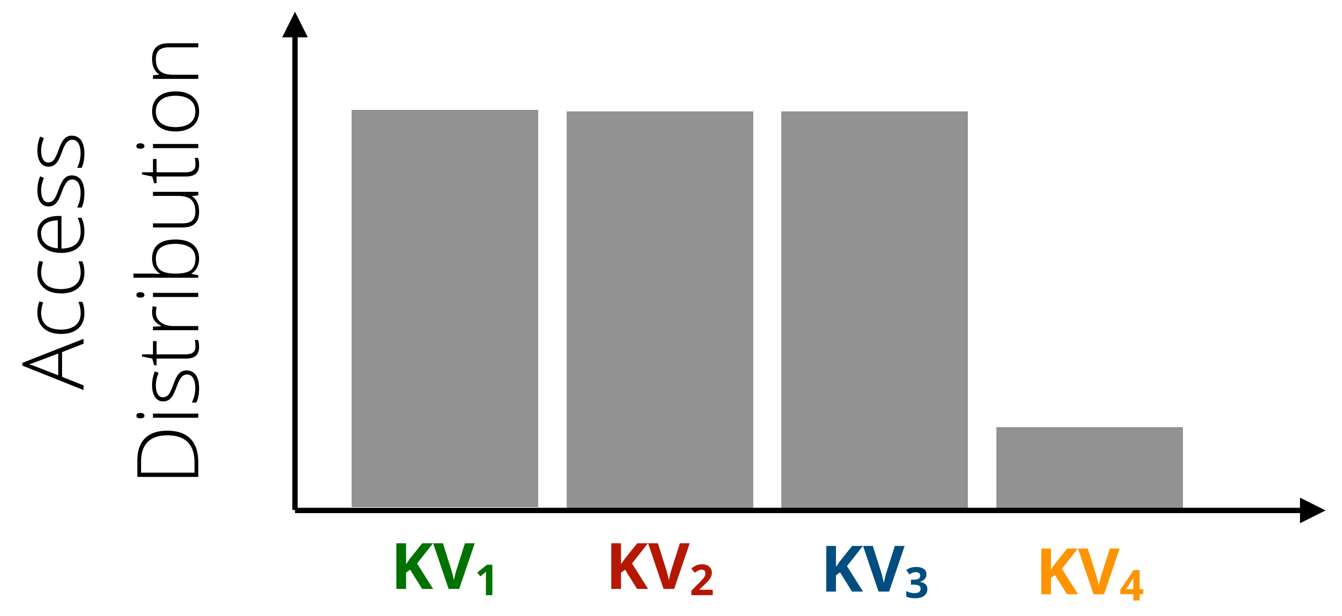

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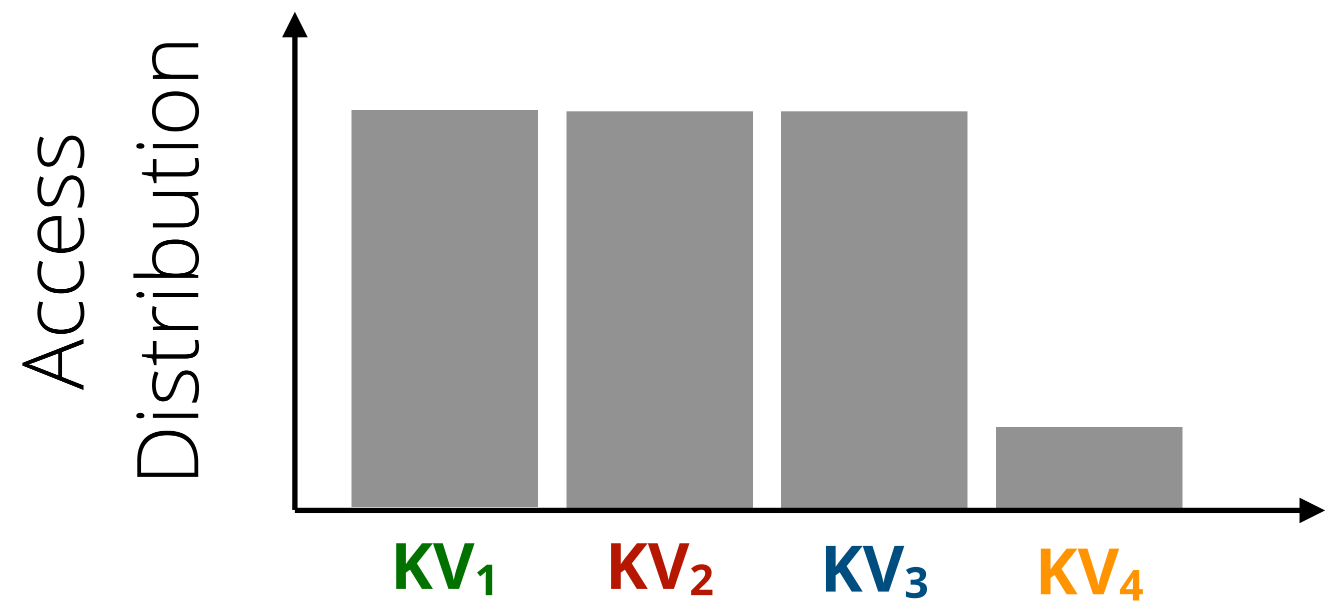

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Replicate popular items → uniform distribution across replicas

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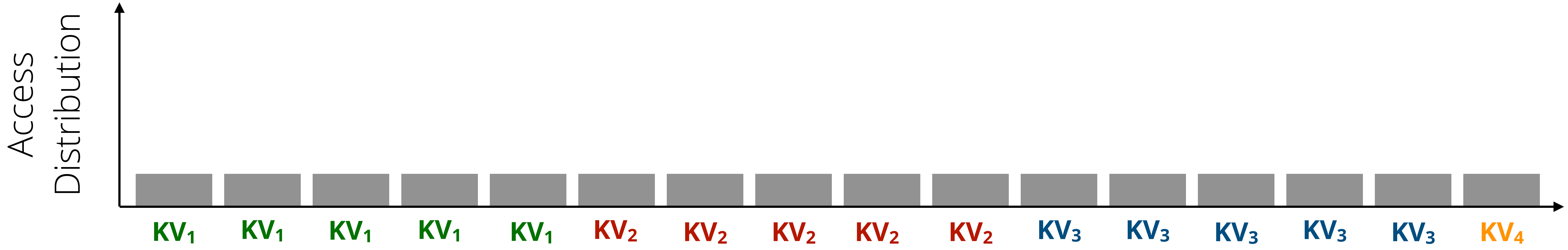

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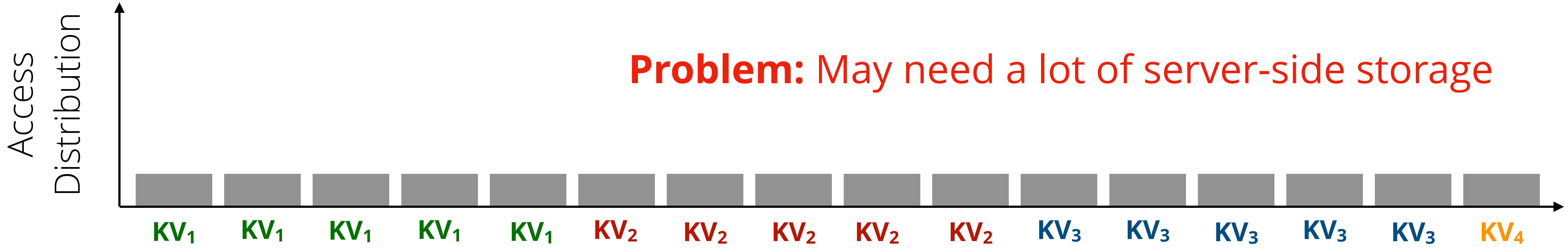

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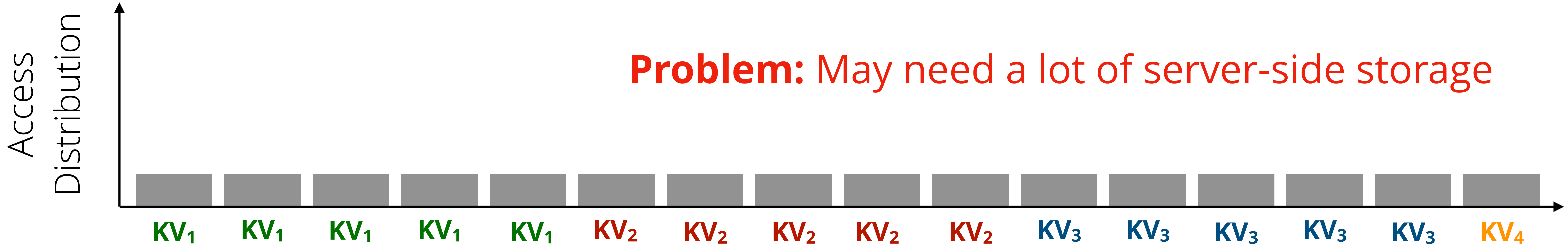

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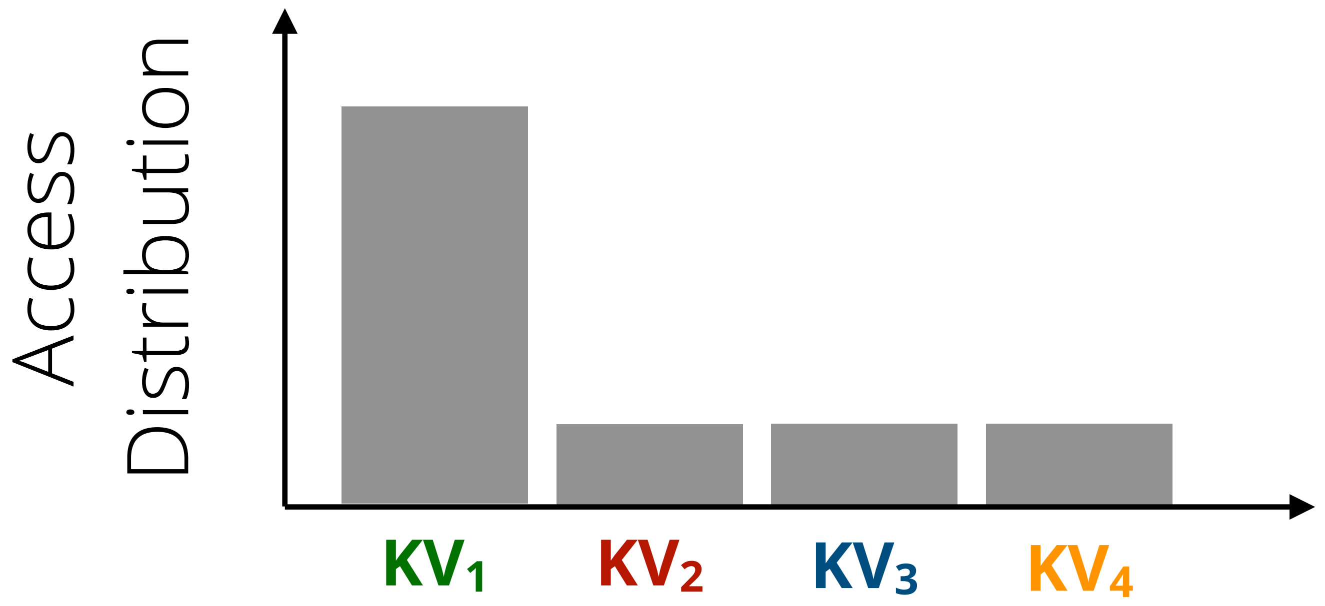

Idea#2: Fake Accesses

Fake accesses to unpopular items → uniform distribution across items

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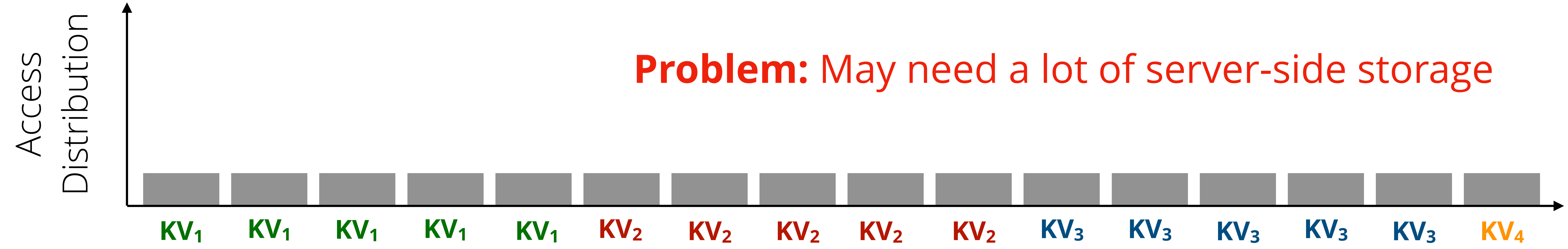

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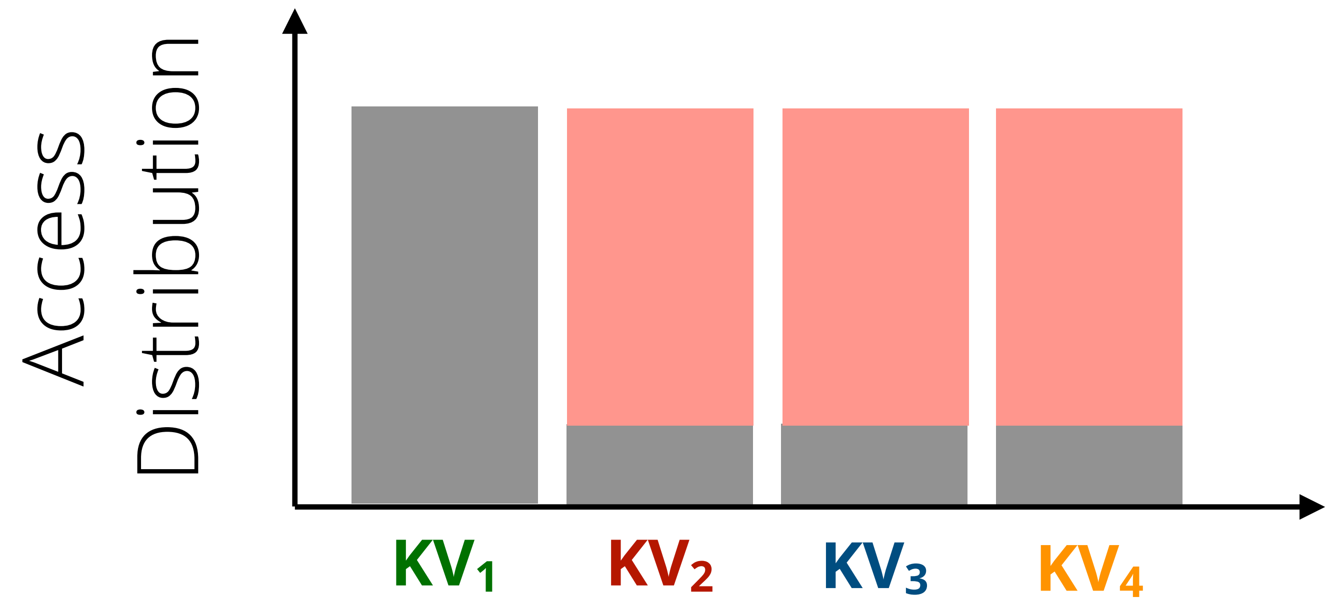

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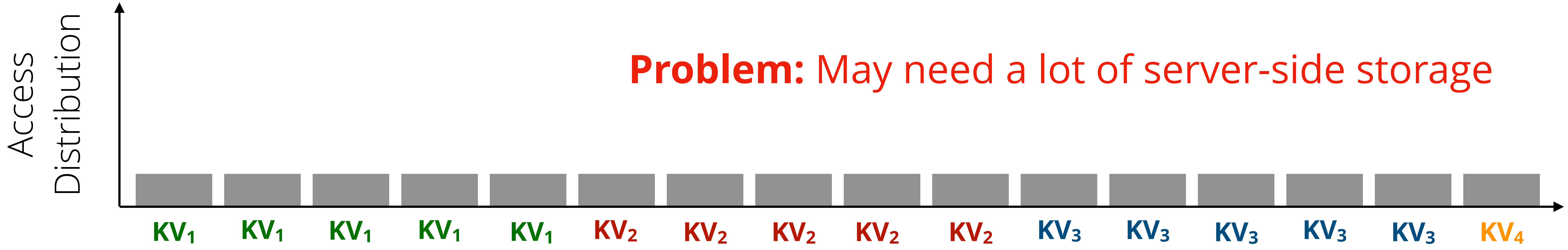

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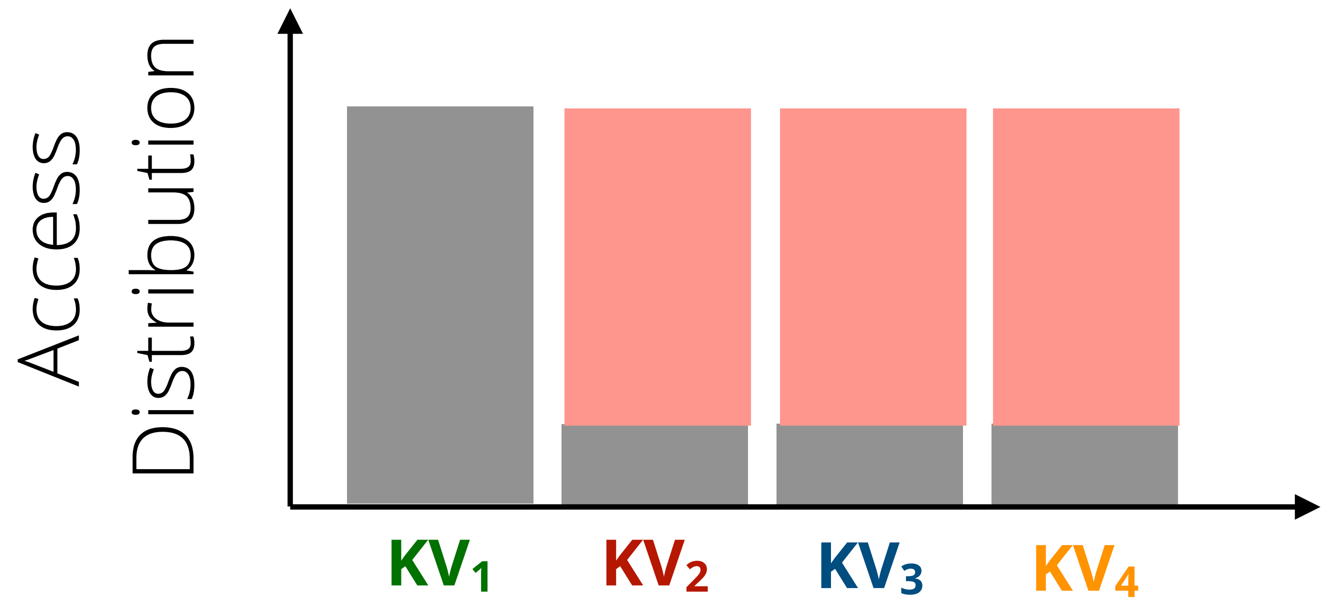

Problem: May add a lot of bandwidth overheads

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Pancake

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Combine replication and fake accesses!

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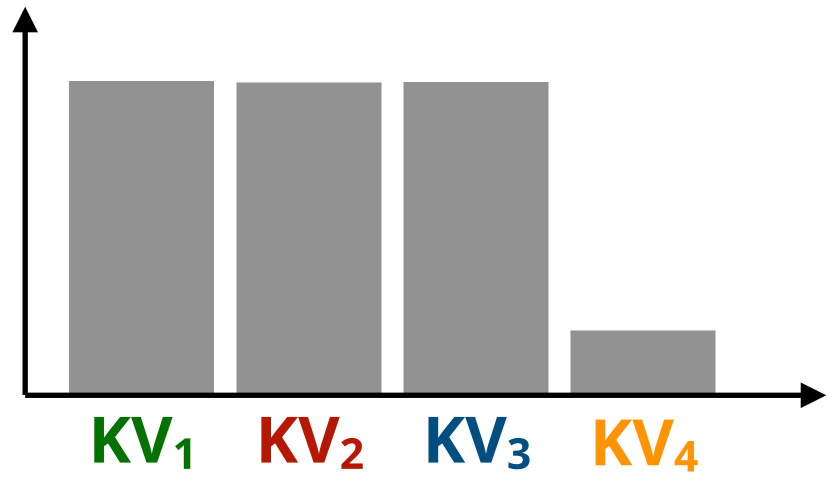

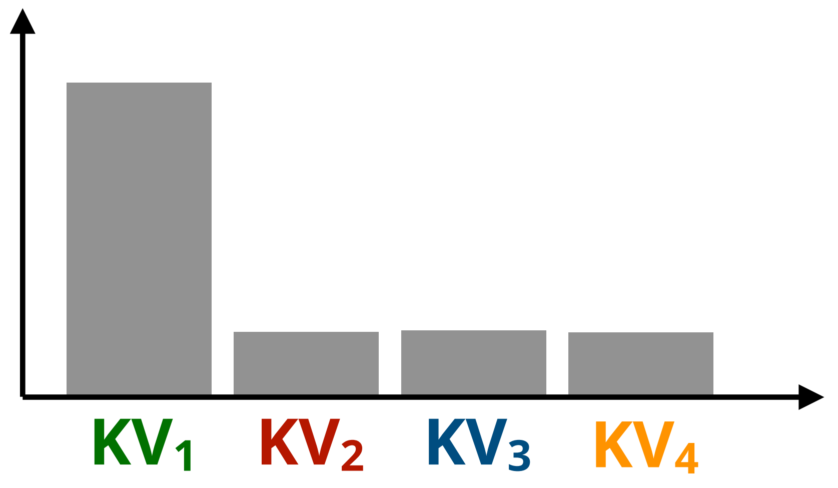

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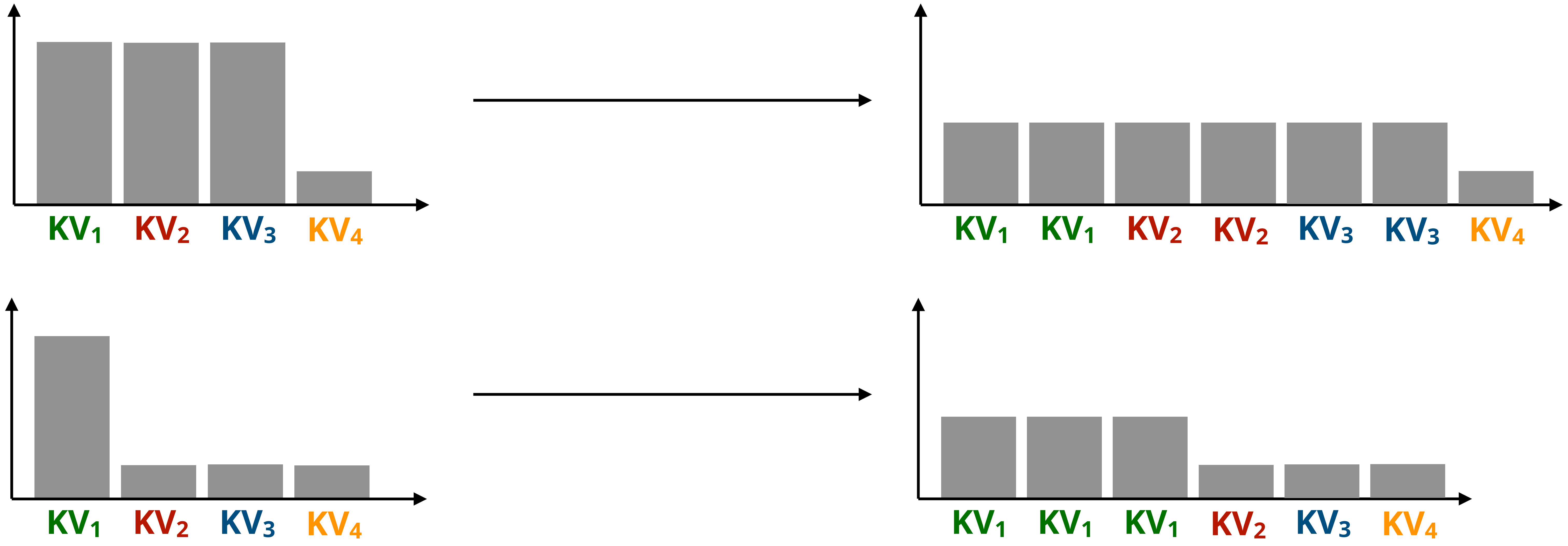

Step 1: Replication - Create "just enough" replicas to *partially* smooth out distribution π with bounded storage

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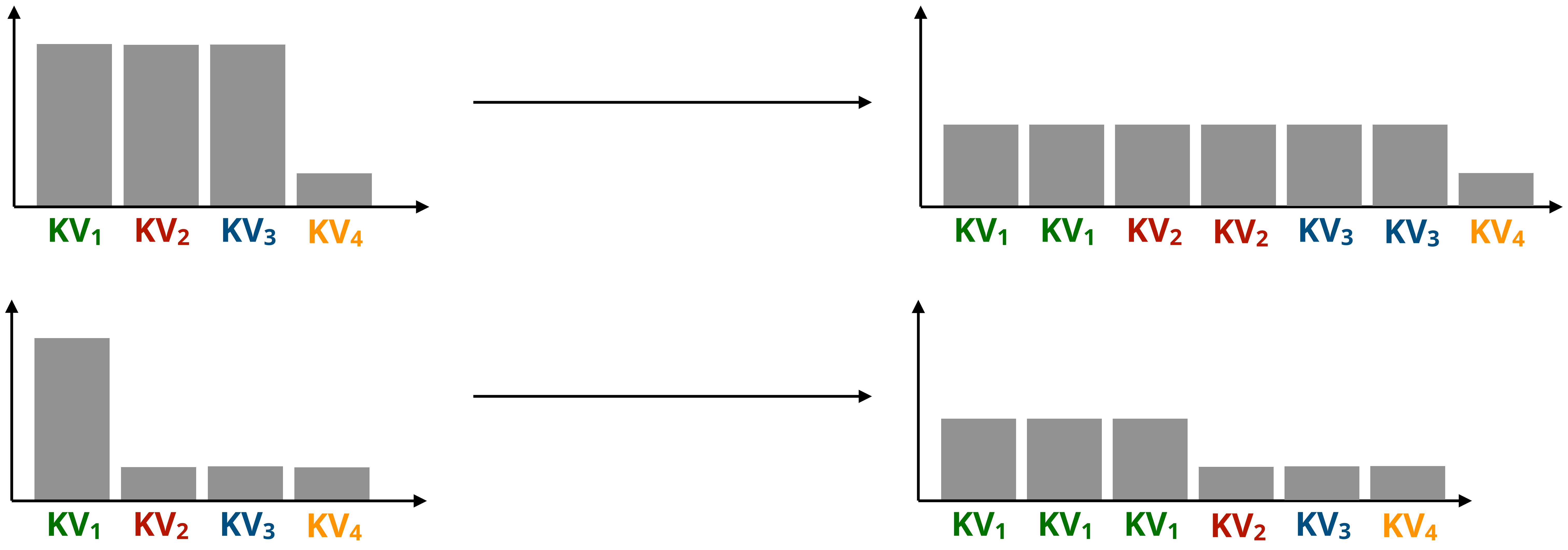

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At most 2x total KV pairs

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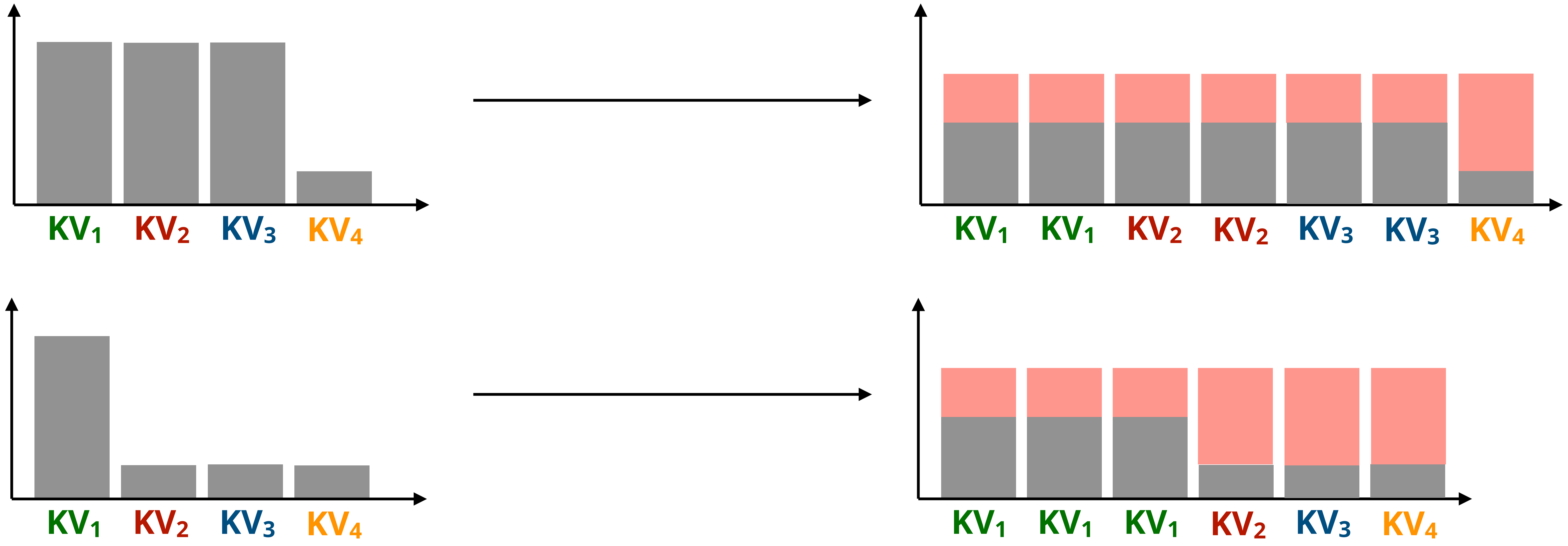

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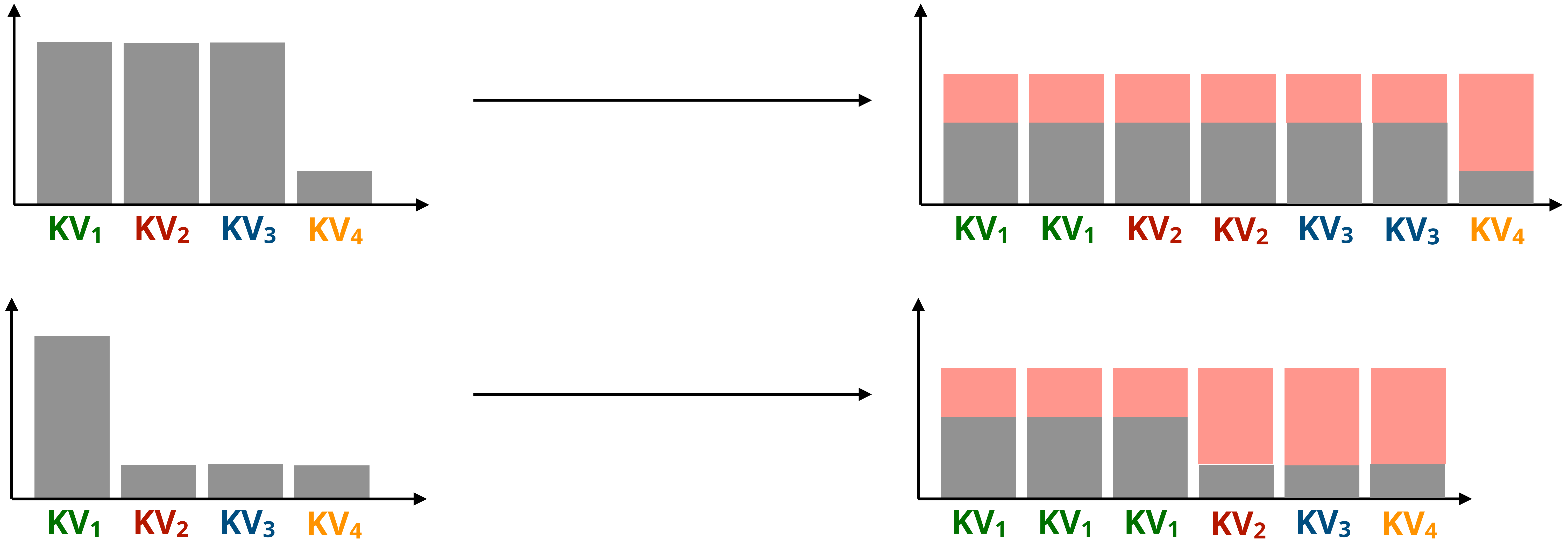

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At most one fake access (from π_f) per real access (from π)

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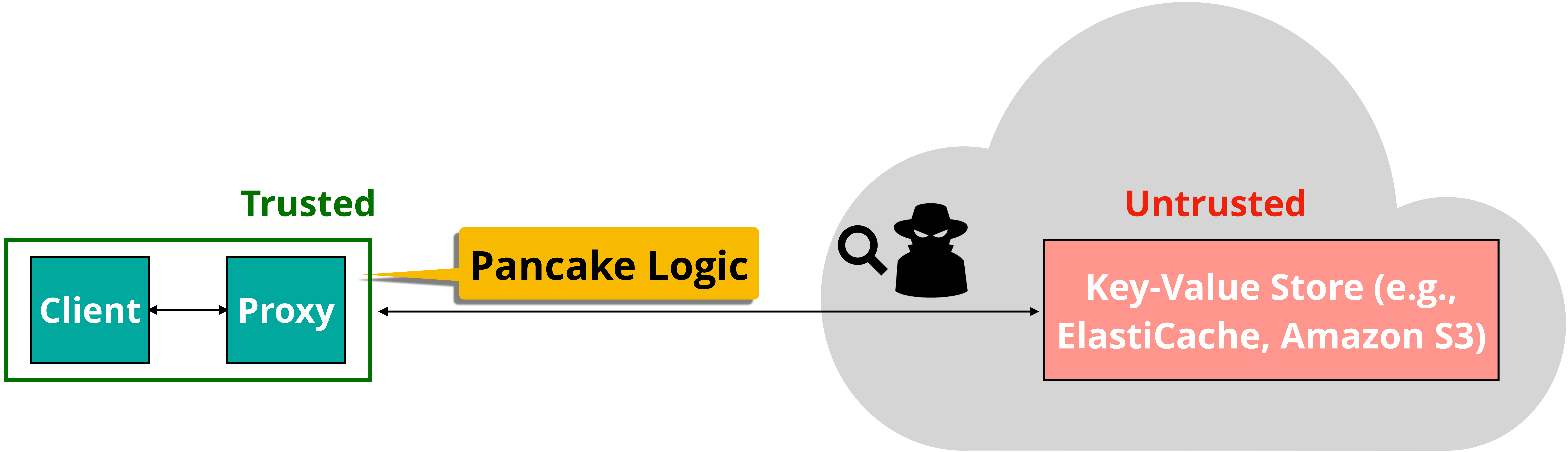

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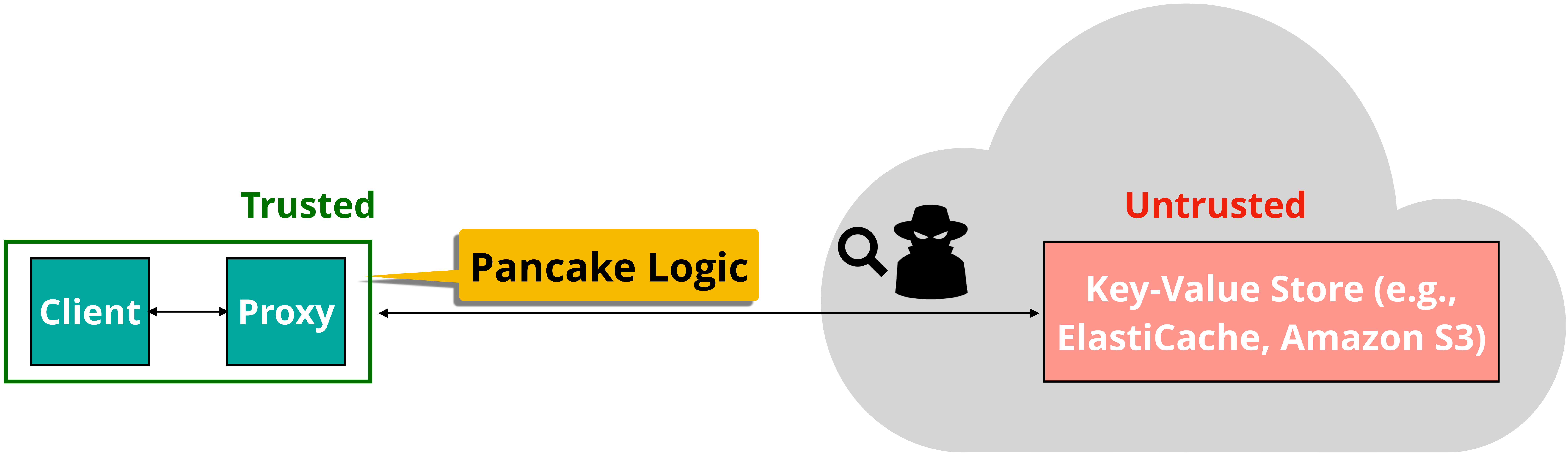

Challenge: How to issue fake+real accesses without revealing which is which?

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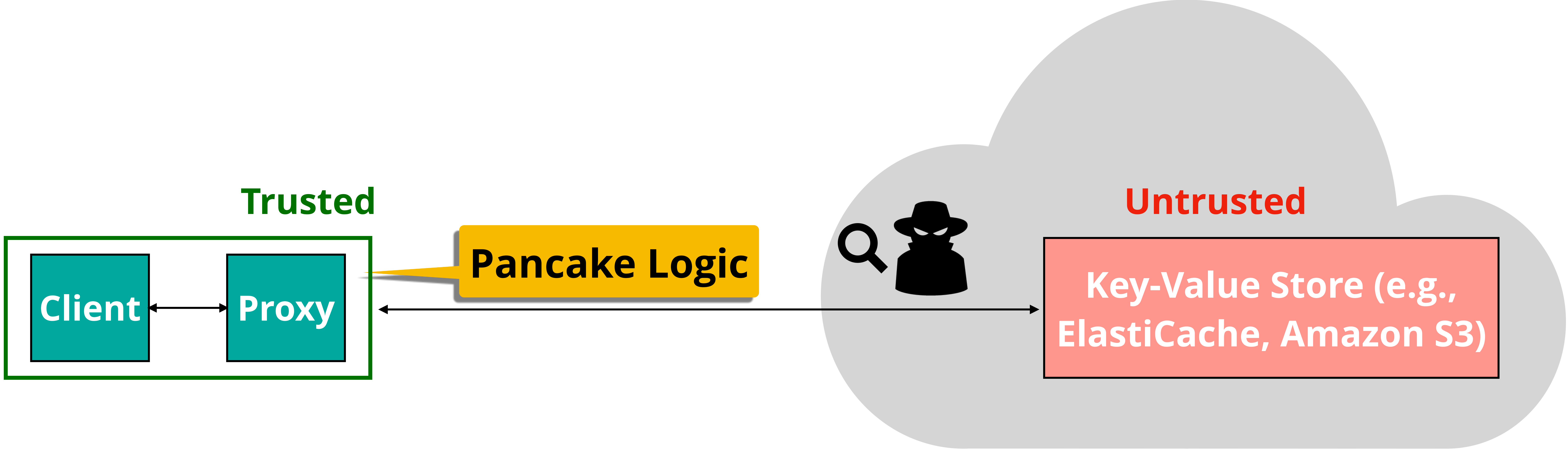

Challenge: How to issue fake+real accesses without revealing which is which?

Approach: Send fixed-size batches of real+fake accesses per query

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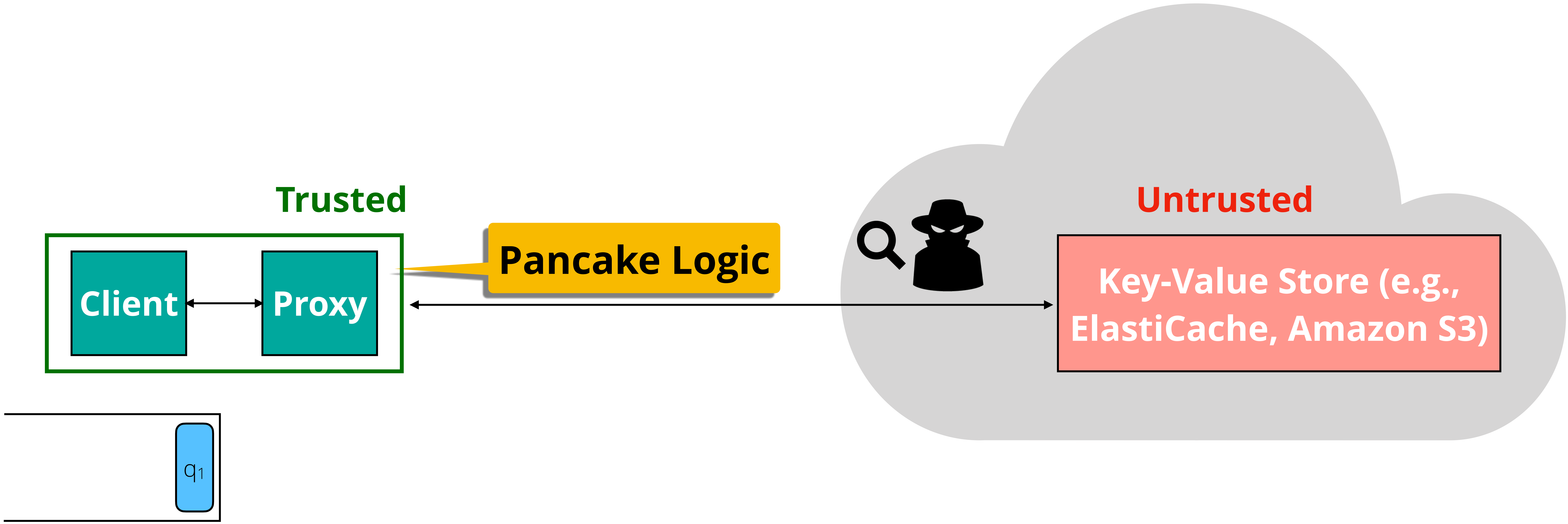

Every time a new query arrives, enqueue it

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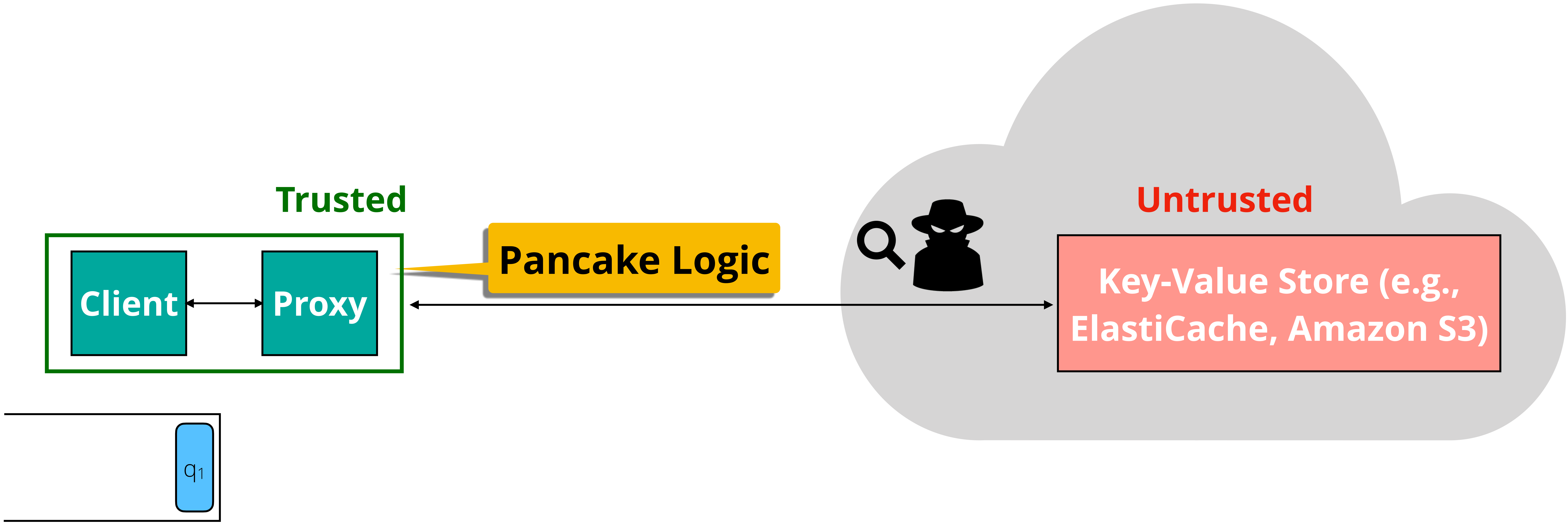

Every time a new query arrives, enqueue it and flip B coins

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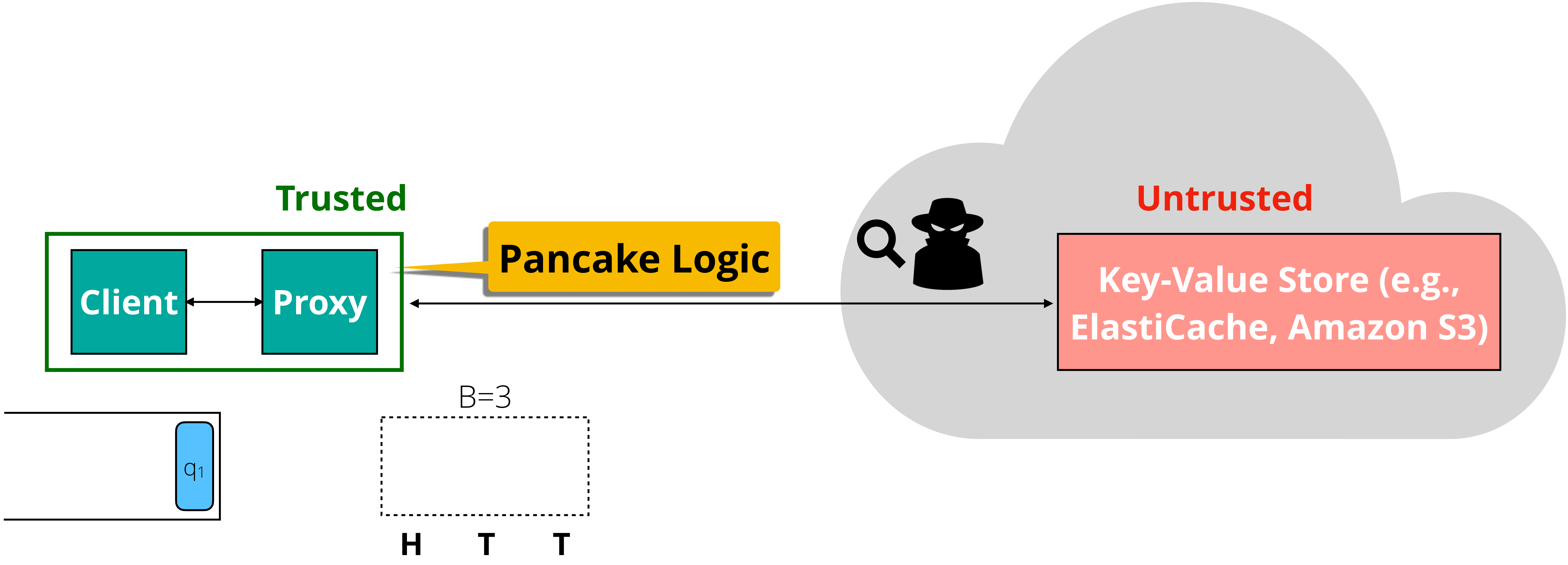

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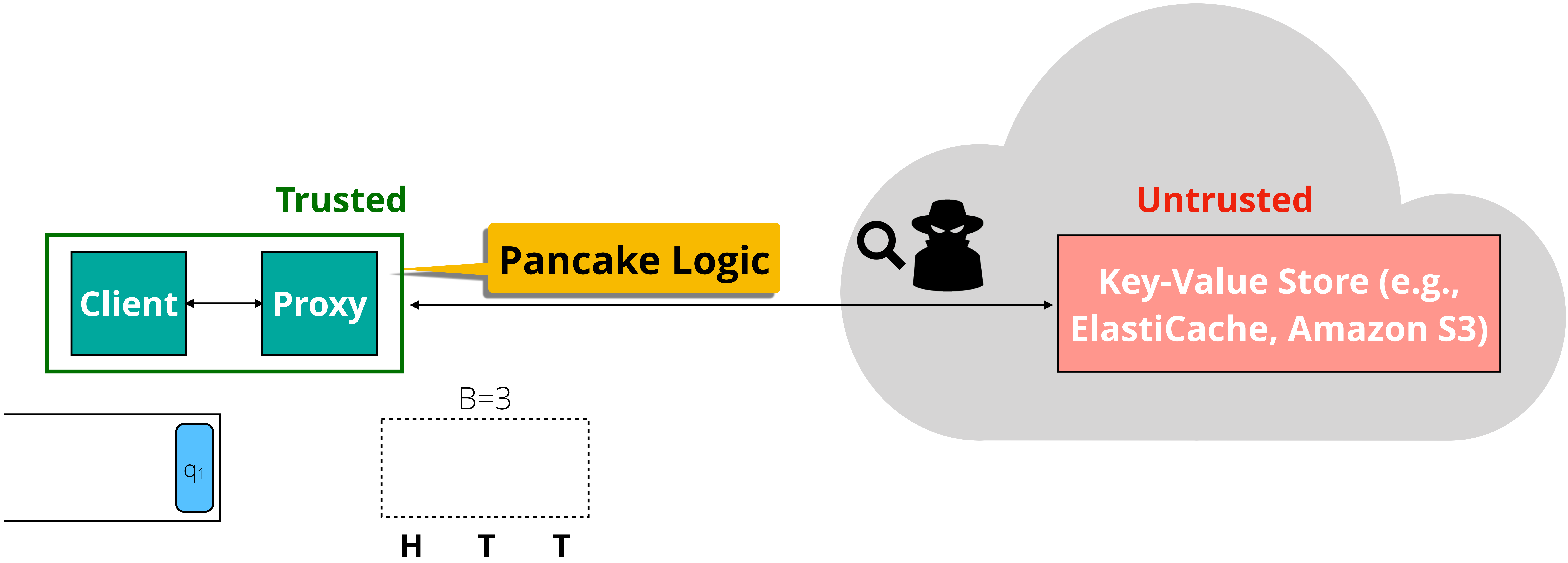

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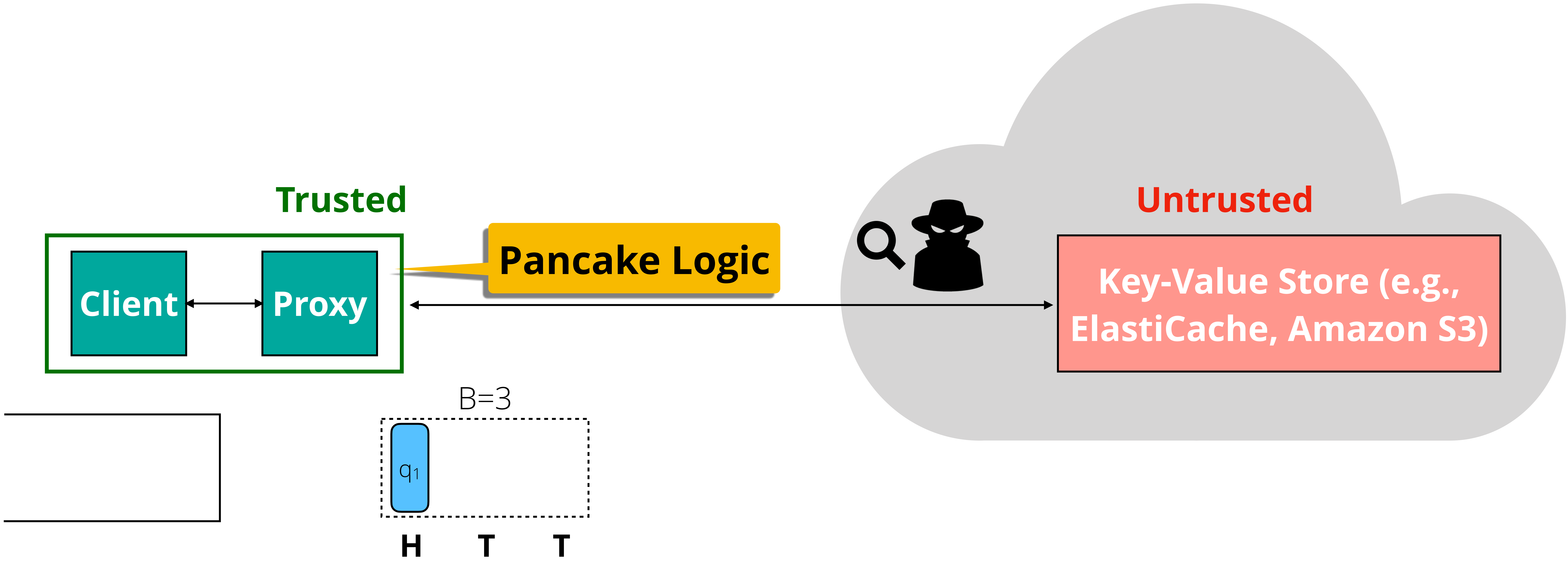

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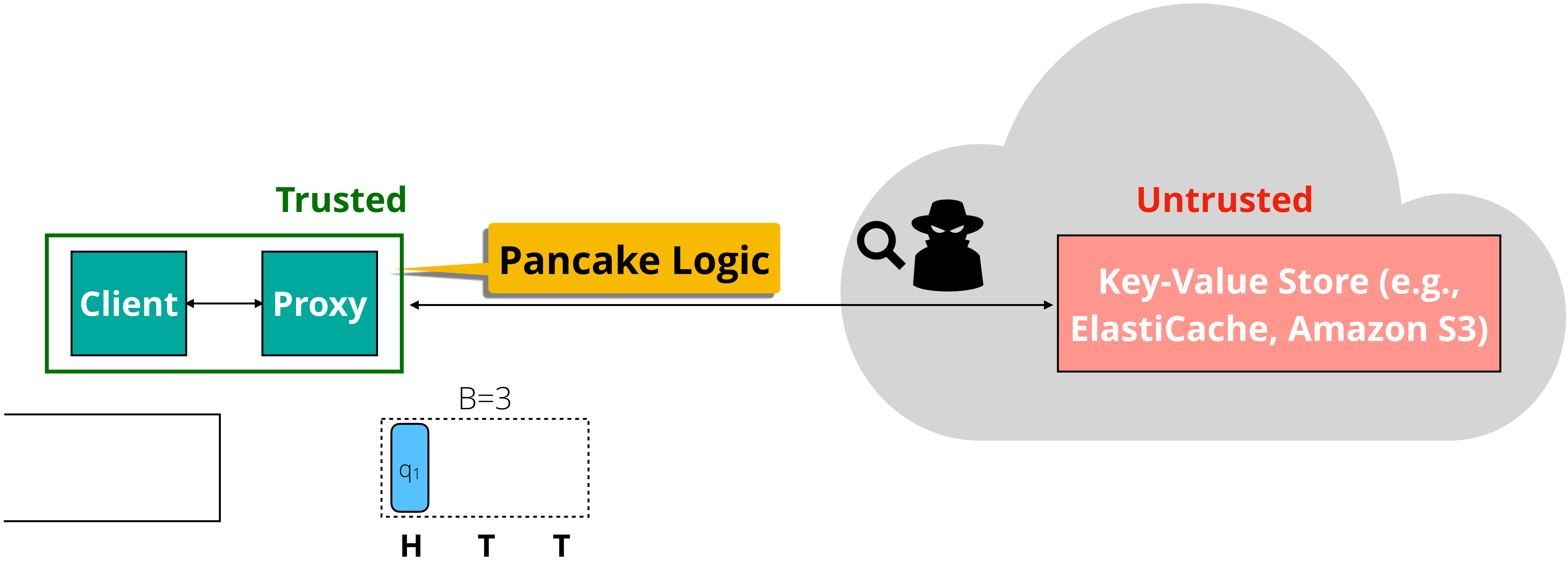

Every time a new query arrives, enqueue it and flip B coins

- If heads, dequeue a real query (or draw from π)
- Else, draw a fake access from π_f

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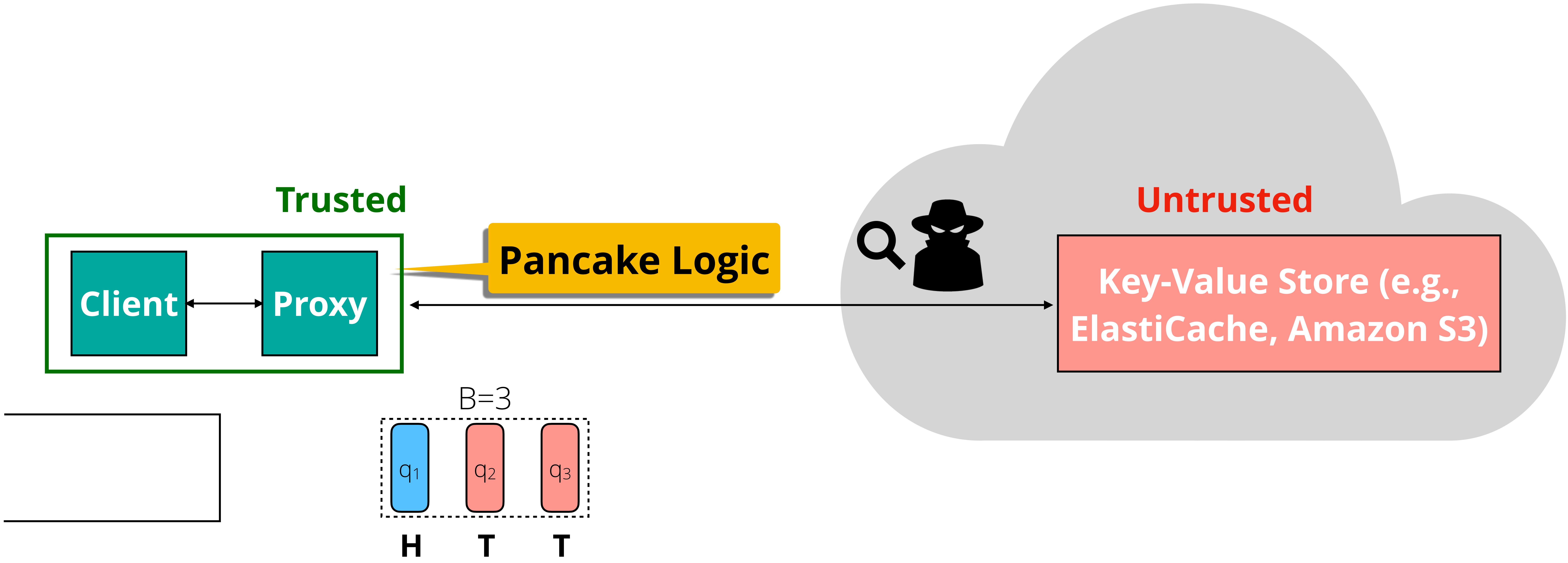

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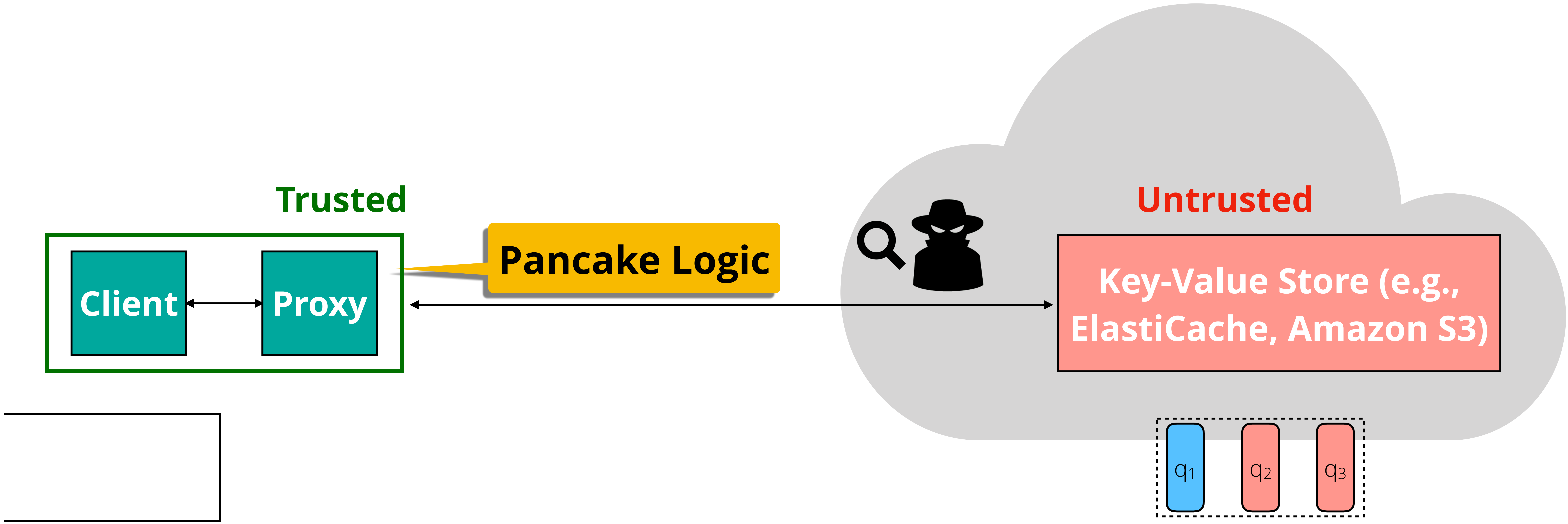

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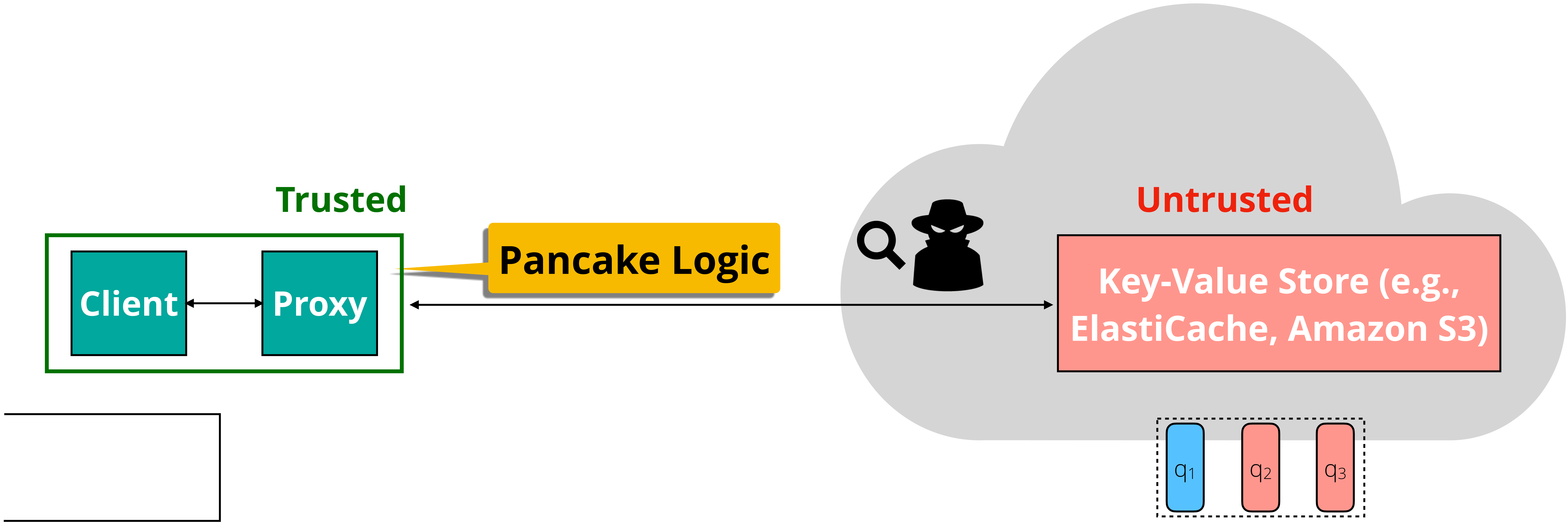

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$3\times$ **bandwidth overhead,** $\leq 2\times$ **storage overhead**

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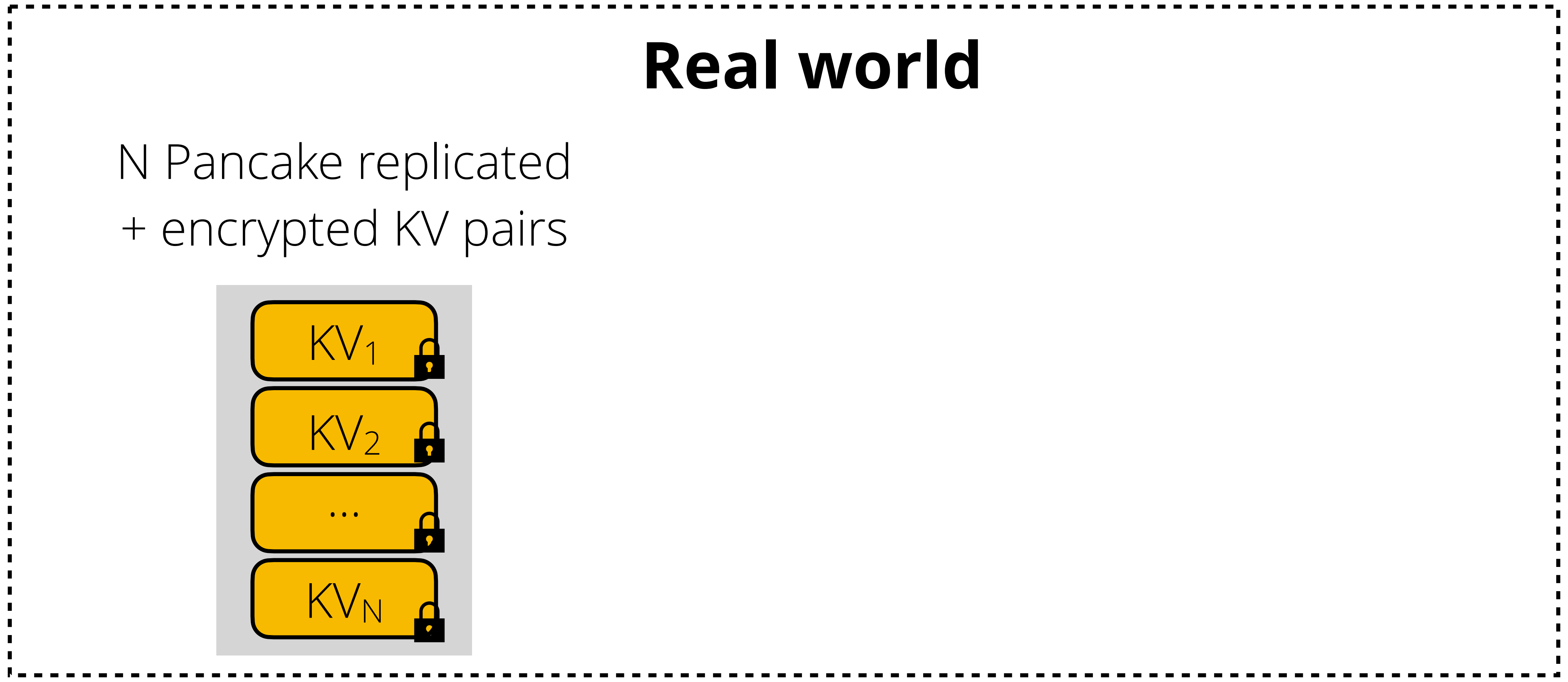

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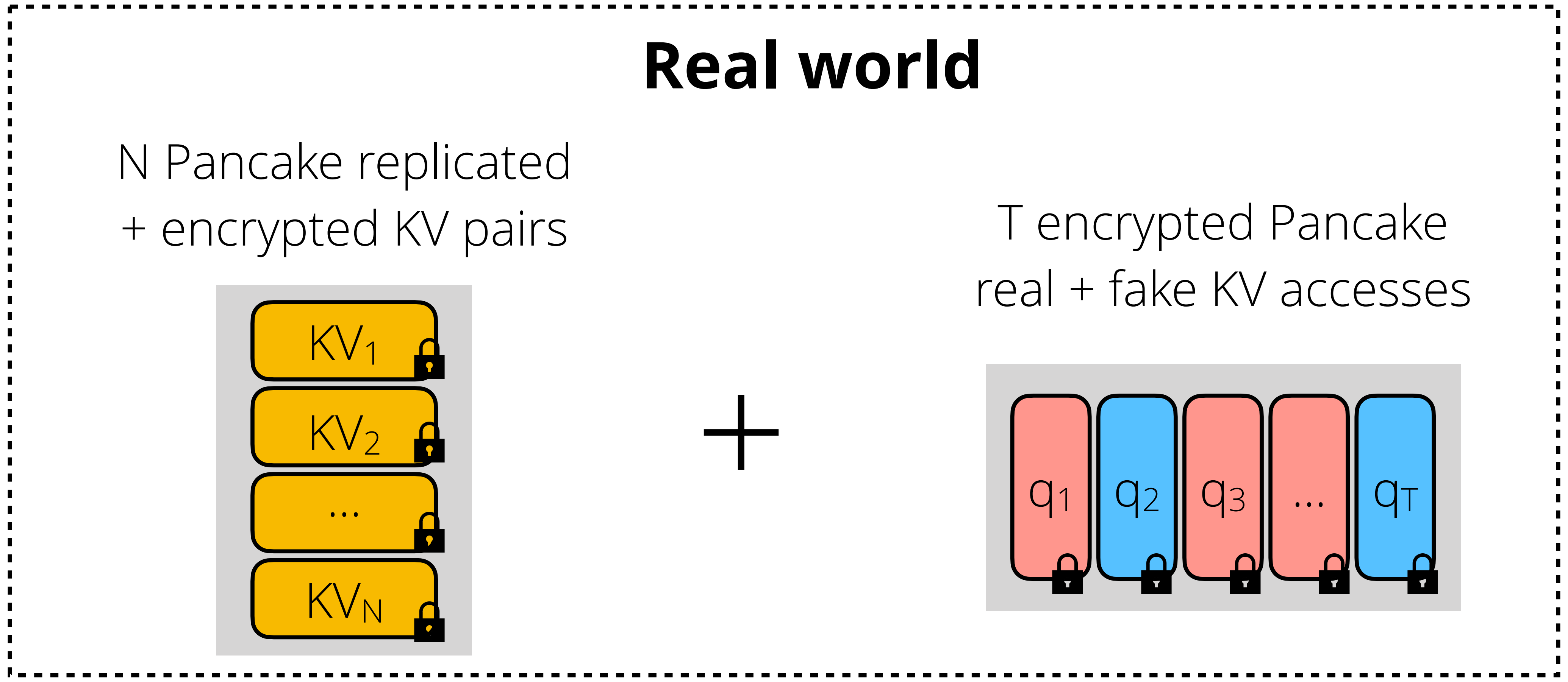

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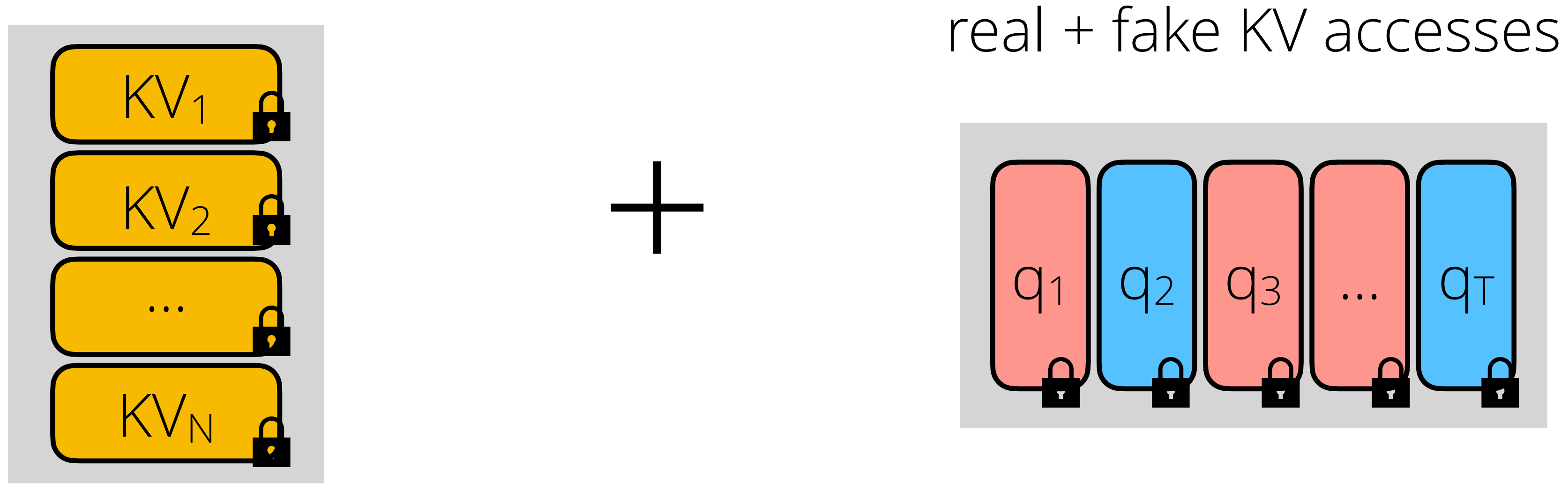
Real world

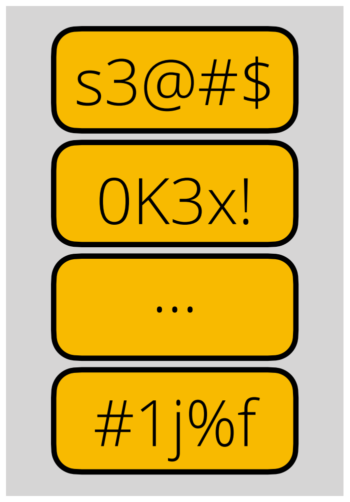
N Pancake replicated + encrypted KV pairs

T encrypted Pancake real + fake KV accesses



Ideal world

N random bit strings



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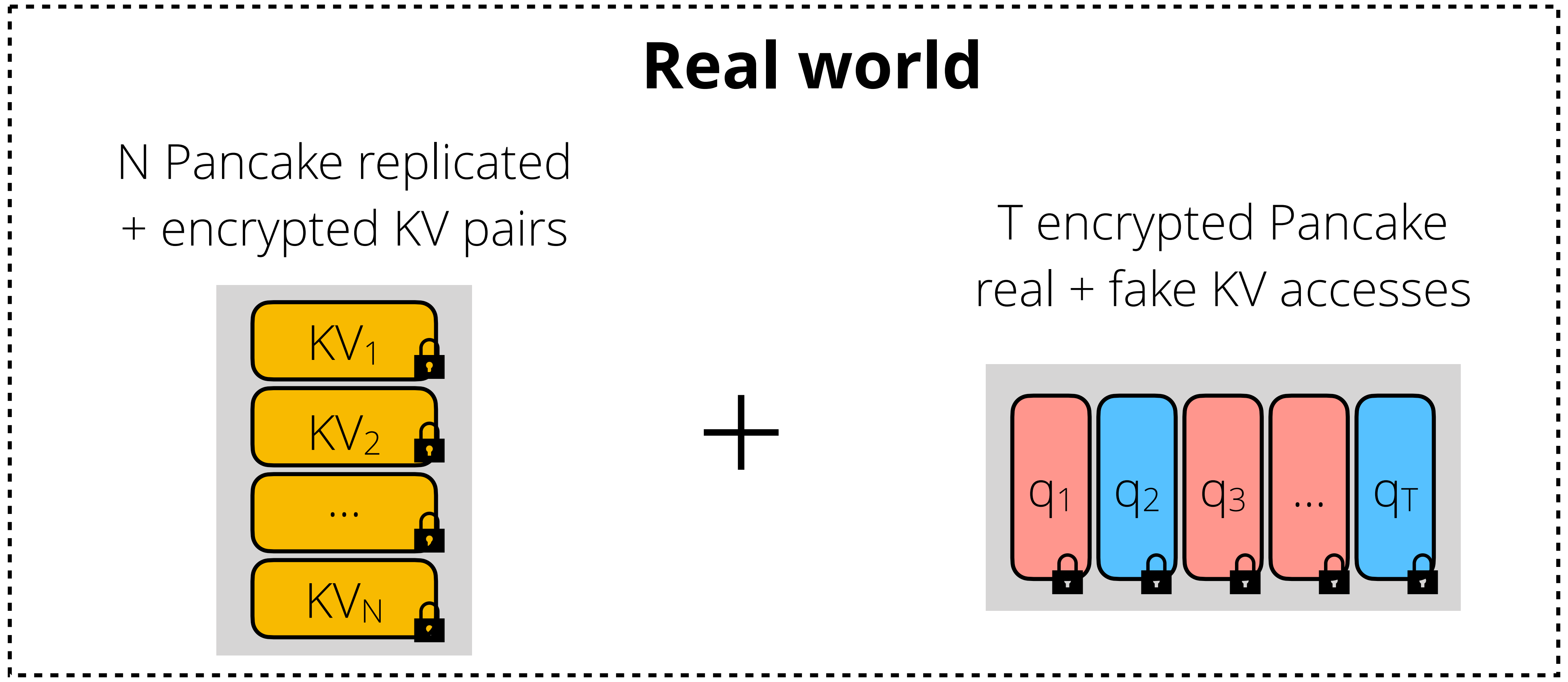

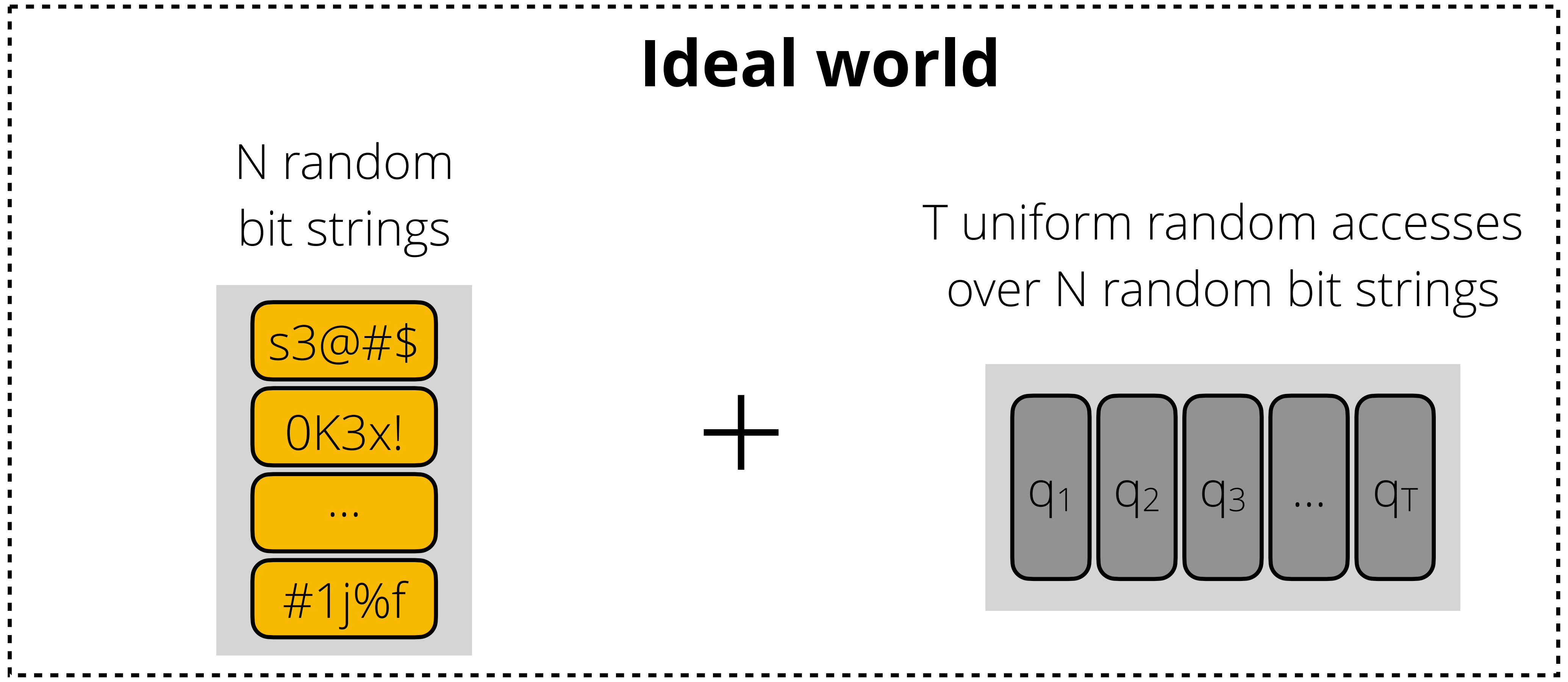

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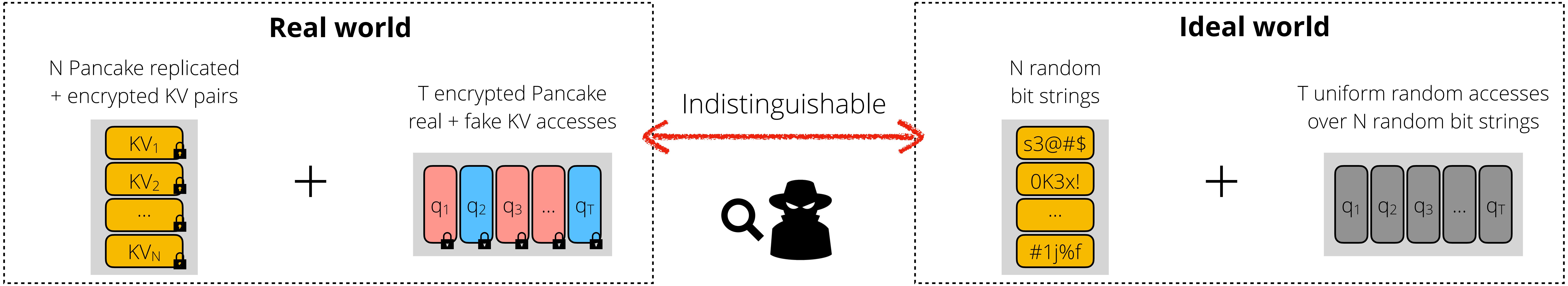

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Details in the paper!

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Many more results in the paper!

Summary

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Thank You!

Questions?