Percival: A Searchable Secret Split Datastore

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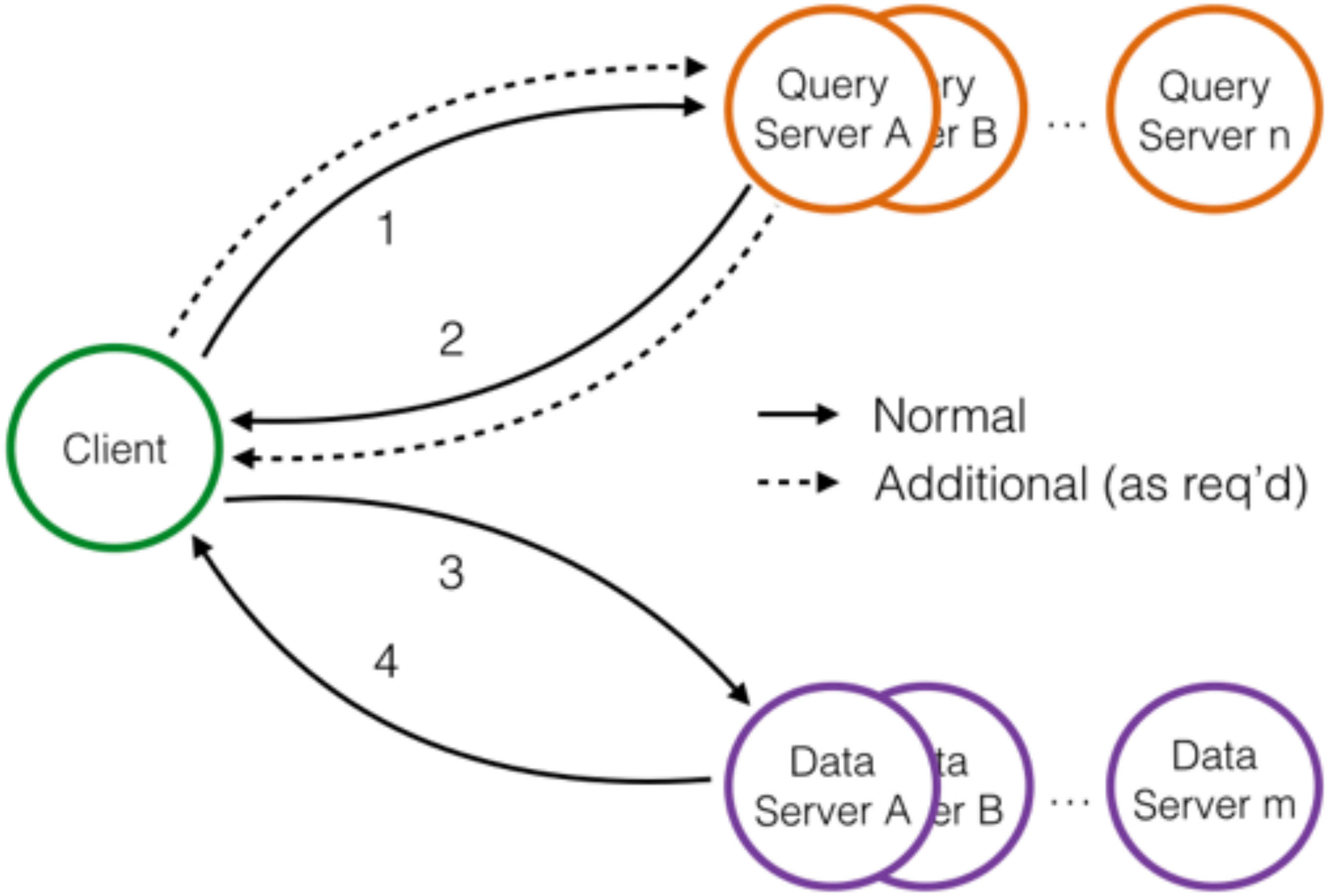
Untrusted Environment

- Distributed Datastore
- Main Concern: Information Privacy
- Trust the whole, not the individual
- Secret split the data
  - N pieces, each the size of the original
  - T pieces required for reassembly (1 < T ≦ N)
  - Minimizes insider threat
  - No single point of failure
- Information-theoretically secure, but…
  - Either can’t search it, or
  - Need to reassemble prior to searching
- Pre-index
  - Current methods rely on fixed-key encryption
  - Not well suited for long-term storage

Percival

- Goal: To enable searching without the need for reassembly
- Solution: Store secret split pre-generated queries (reverse indexes)
  - Query Servers: key, value store (hash :: secret-split reverse index)
  - Clients retrieve reverse index shares using a custom hash
  - Reassembled Query: maps search term to data share(s)
- Result
  - Secure and searchable data store
  - Aids in information sharing
  - Assumes insider threat
    - Single repository
    - No collusion between attackers



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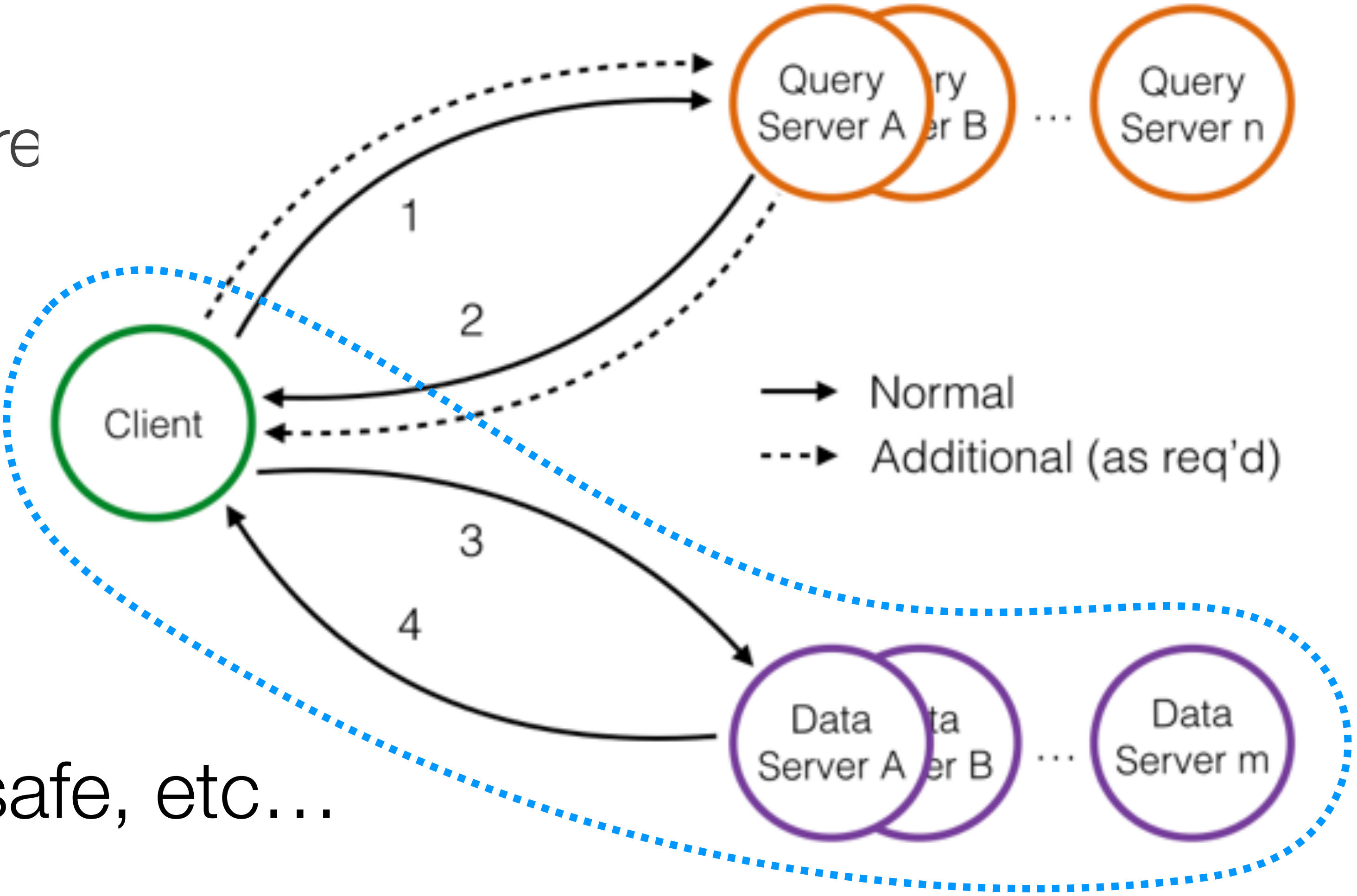

POTSHARDS, Cleversafe, etc…

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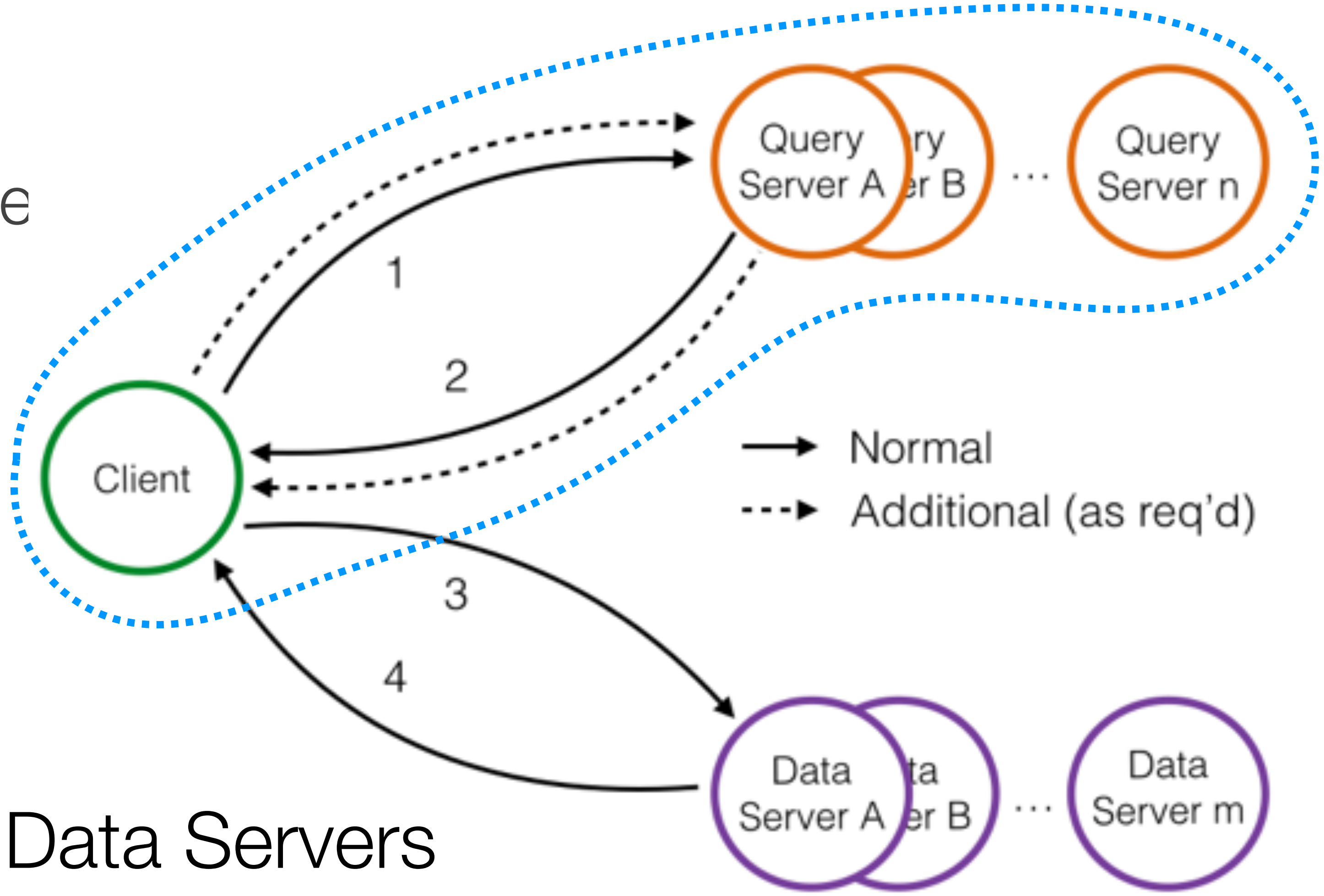
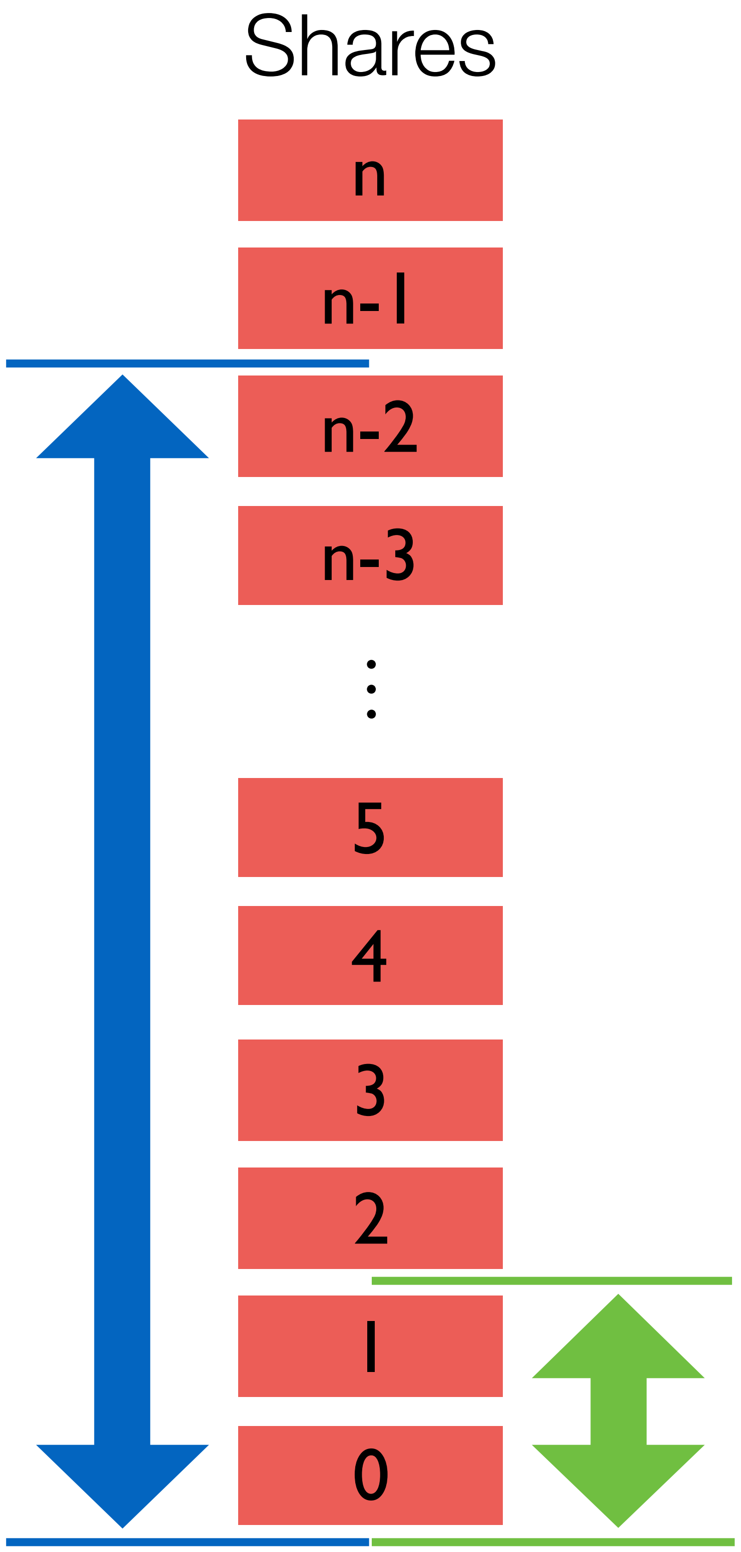


# of Query Servers ≠ # of Data Servers

Splitting Scheme Flexibility

High Threshold

- Example: (n - 2) shares
- More shares needed for reconstruction
- Higher barrier to compromise
- Denial of Service attack
- Ransomware

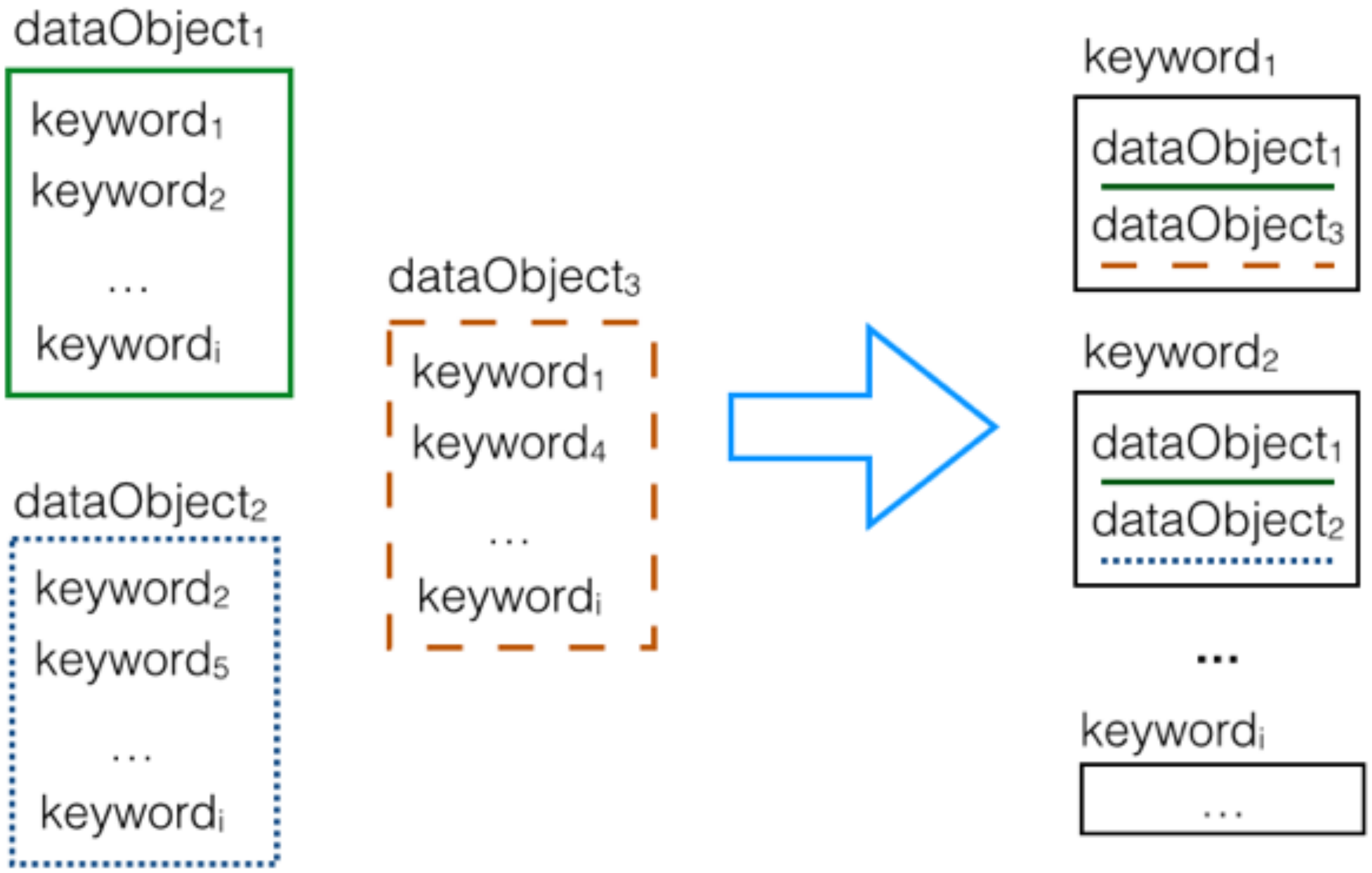


Low Threshold

- Example: 2 shares
- Fewer shares needed for reconstruction
- Lower barrier to compromise
- Improves data availability

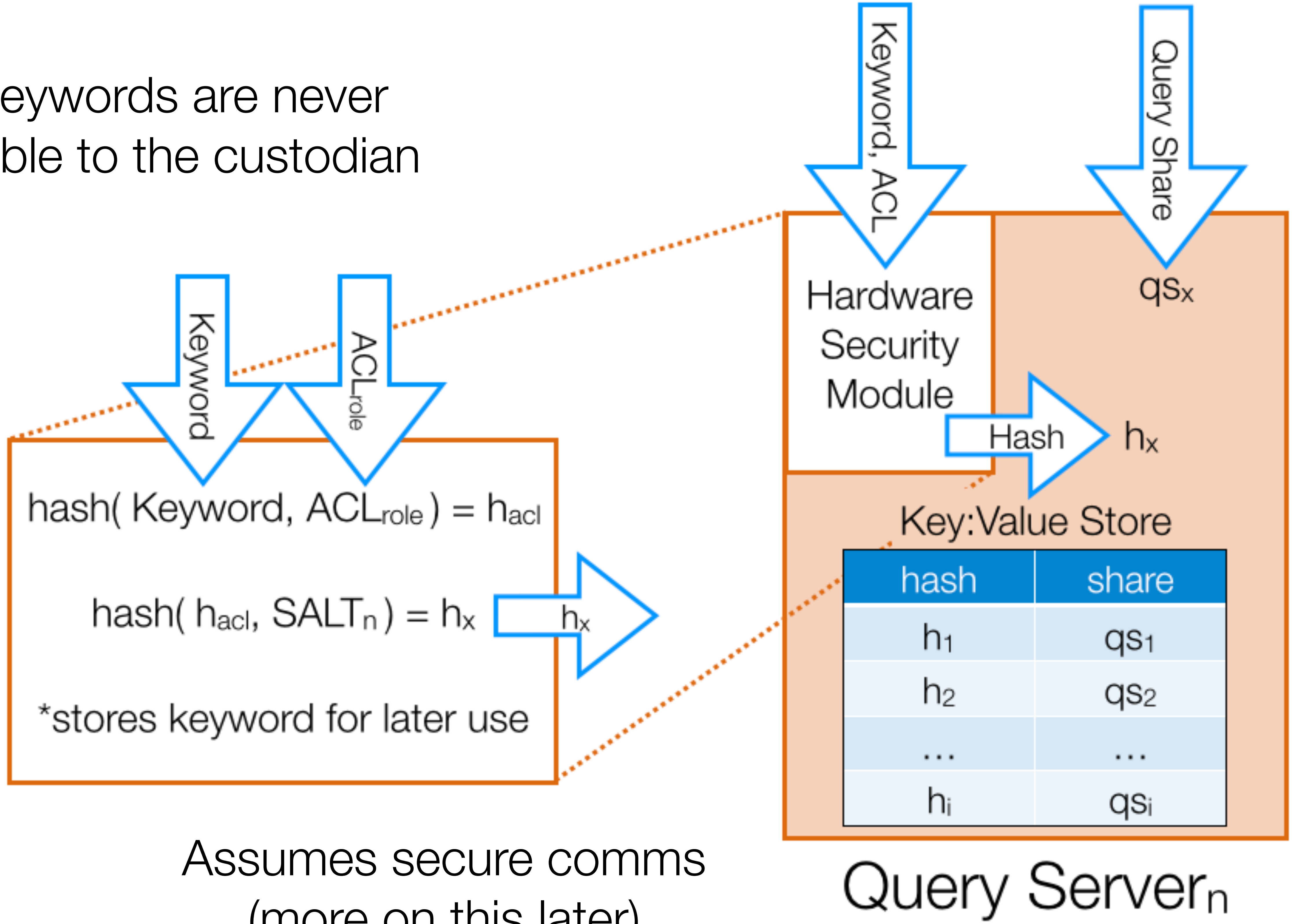
Ingestion: Reverse Indexes

- Identify the keywords for each piece of data
  - Choose top 10, 20, etc… keywords
  - Security is based on there being millions of files stored (more on that later)
- Generate reverse indexes: each reverse index is a query result
- Secret split each query



Ingestion: Query Server

Keywords are never visible to the custodian



hash(Keyword, ACL_{role}) = h_{acl}

hash(h_{acl}, $SALT_n$) = h_x

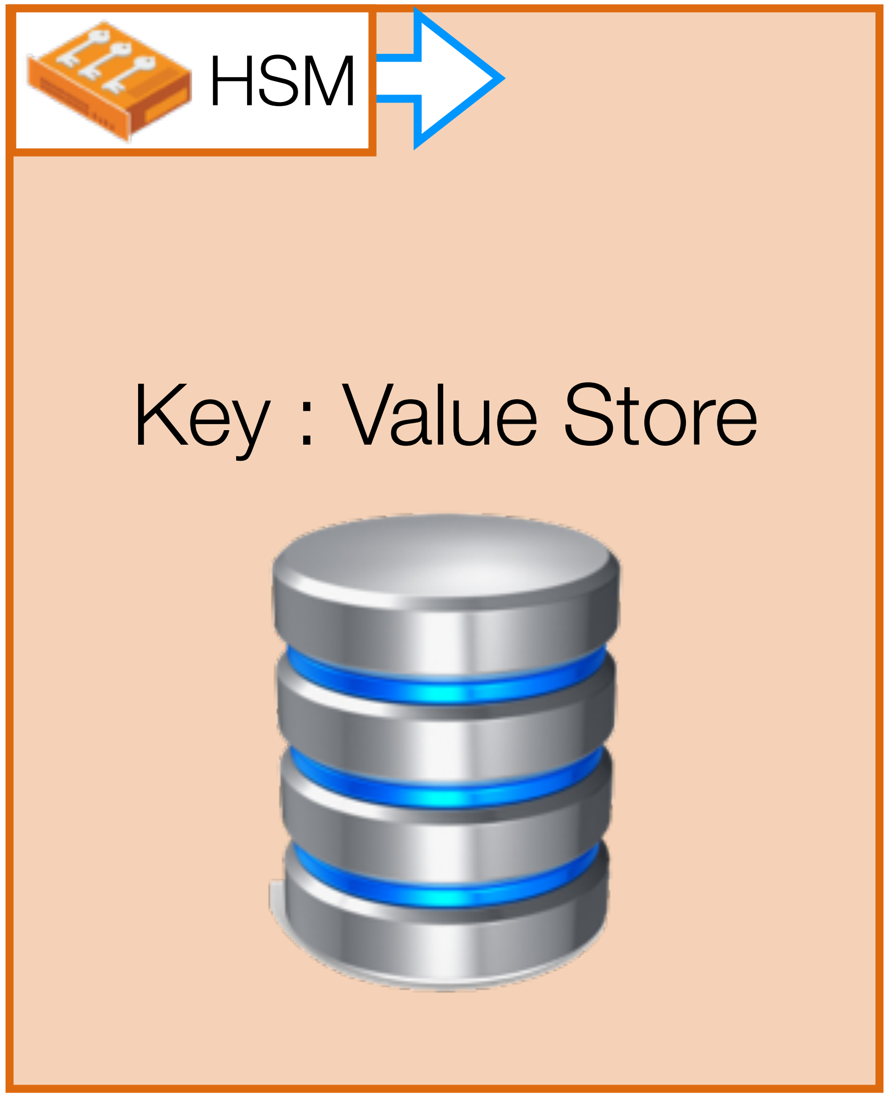
*stores keyword for later use

hash	share
h_1	qs_1
h_2	qs_2
…	…
h_i	qs_i

Assumes secure comms
(more on this later)

Hardware Security Module

- Physical device that:
  - Safeguards and manages keys
  - Provides crypto-processing
  - Has its own NIC
  - Can be a plug-in card or external device
- Provides tamper evidence and resistance
  - Logs suspected tamper attempts
  - Deletes its internal memory upon tampering
- Cost: Low bandwidth (~1.4MB/s)
- Easily parallelizable
- Secure channel between HSMs



Query Server$_n$

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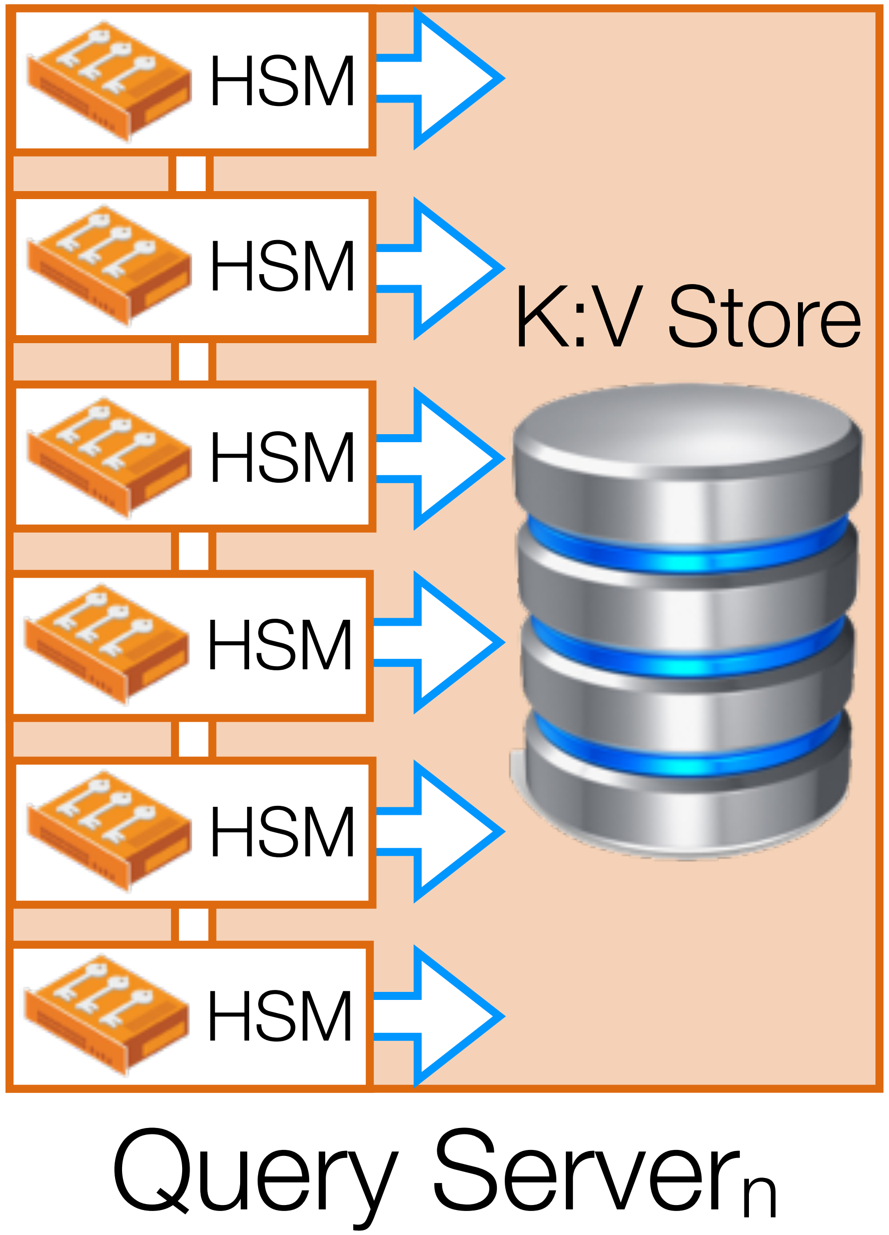
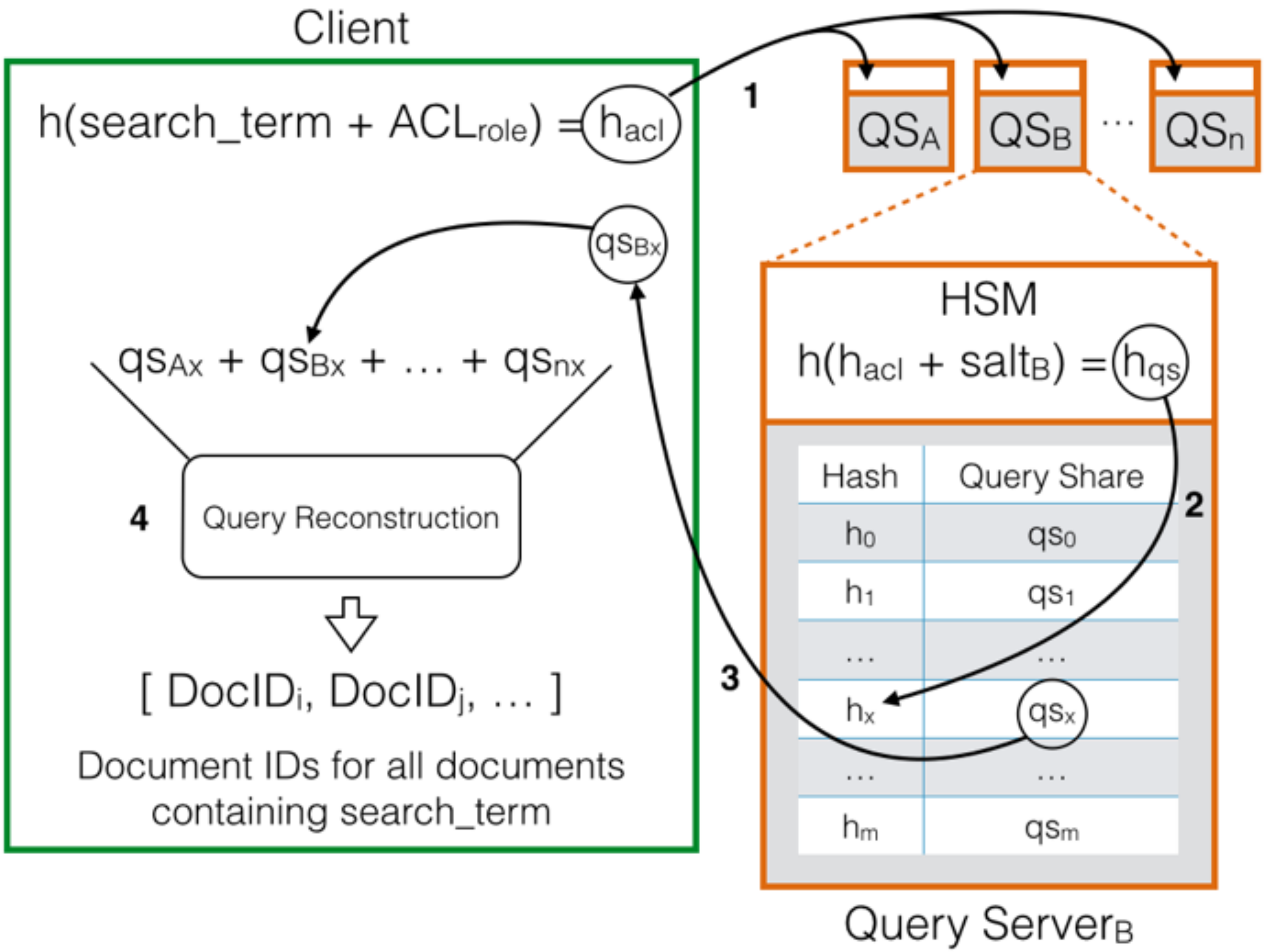


Secret Salt

- Each query server has a unique salt, that is:
- Each salt is:
  - Generated by its Hardware Security Module (HSM)
  - Never leaves the HSM
  - Write only. No interface to read the salt from the HSM
  - Ensures sibling query shares are stored with different hashes
- Targeted vs wholesale theft
- Theoretically possible to be brute forced, but…
  - Landauer limit: $L = kT \ln(2)$
  - 256 bit salt requires $8.9\text{x}10^{39}$ TWh
  - More on threat analysis later

Performing a Query

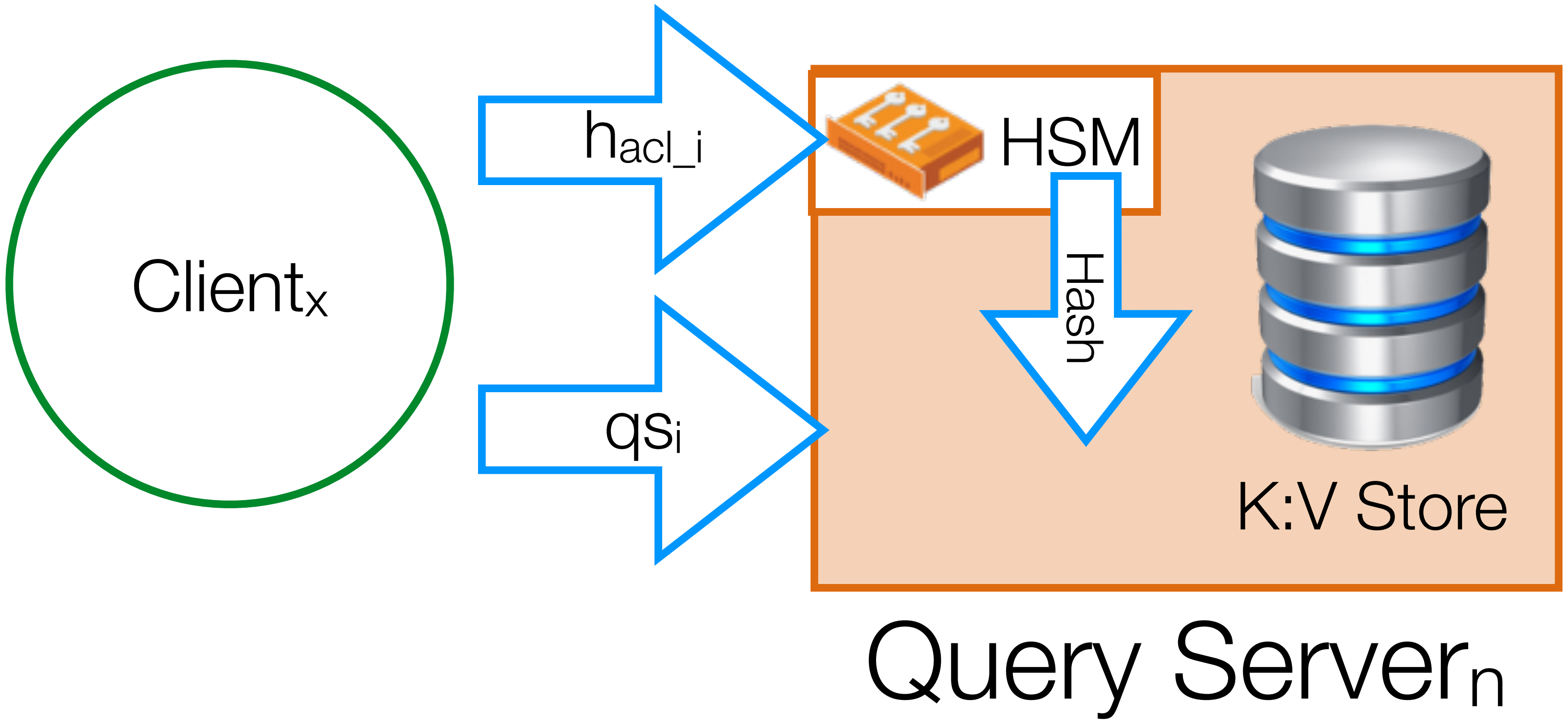
- Client reconstructs the reverse index
- Conjunctive search: intersection of queries


Client
$h(search\_term + ACL_{role}) = h_{acl}$
1
QS_A
QS_B
…
QS_n
qs_{Bx}
$qs_{Ax} + qs_{Bx} + \ldots + qs_{nx}$
4
Query Reconstruction
[$DocID_i$, $DocID_j$, …]
Document IDs for all documents containing search_term
HSM
$h(h_{acl} + salt_B) = h_{qs}$
2
3
qs_x
Query $Server_B$

Hash	Query Share
h_0	qs_0
h_1	qs_1
…	…
h_x	qs_x
…	…
h_m	qs_m

Adding new content

- Similar to ingestion process
- Identify keywords for new document
- Query for each of the existing reverse indexes
- Add the DOC ID to each reverse index
- Secret split them and push to each Query Server
- QS updates its key:value store with the new shares



Threat Analysis

- Goal: maintain information privacy in a distributed, untrusted environment

- At most (*threshold* - 1) query servers are compromised
- Able to read data sent to server (not the HSM)
- Potentially unlimited time to carry out attack
- Can run arbitrary code on a compromised server
- Targeted vs wholesale theft

- Numerous side channel attacks
  - Range from cold boot to social engineering
  - Not trying to solve
- Assume one or more clients <u>*will*</u> be compromised
- Access to client's RBAC credential
- Does not reveal salts or information not related to that role

Client$_x$

Threat Analysis

HSM

- High barrier for attackers to overcome
- Salt prevents targeted theft since all query servers differ
- If compromised, stored keywords are revealed
- Compromise does not lead to data release
- Recovery = rebuilding the server

K:V Store

- Most basic and probable attack vector
- Can detect ‘hot’ shares, search patterns, and client location
- Does not aid targeted theft

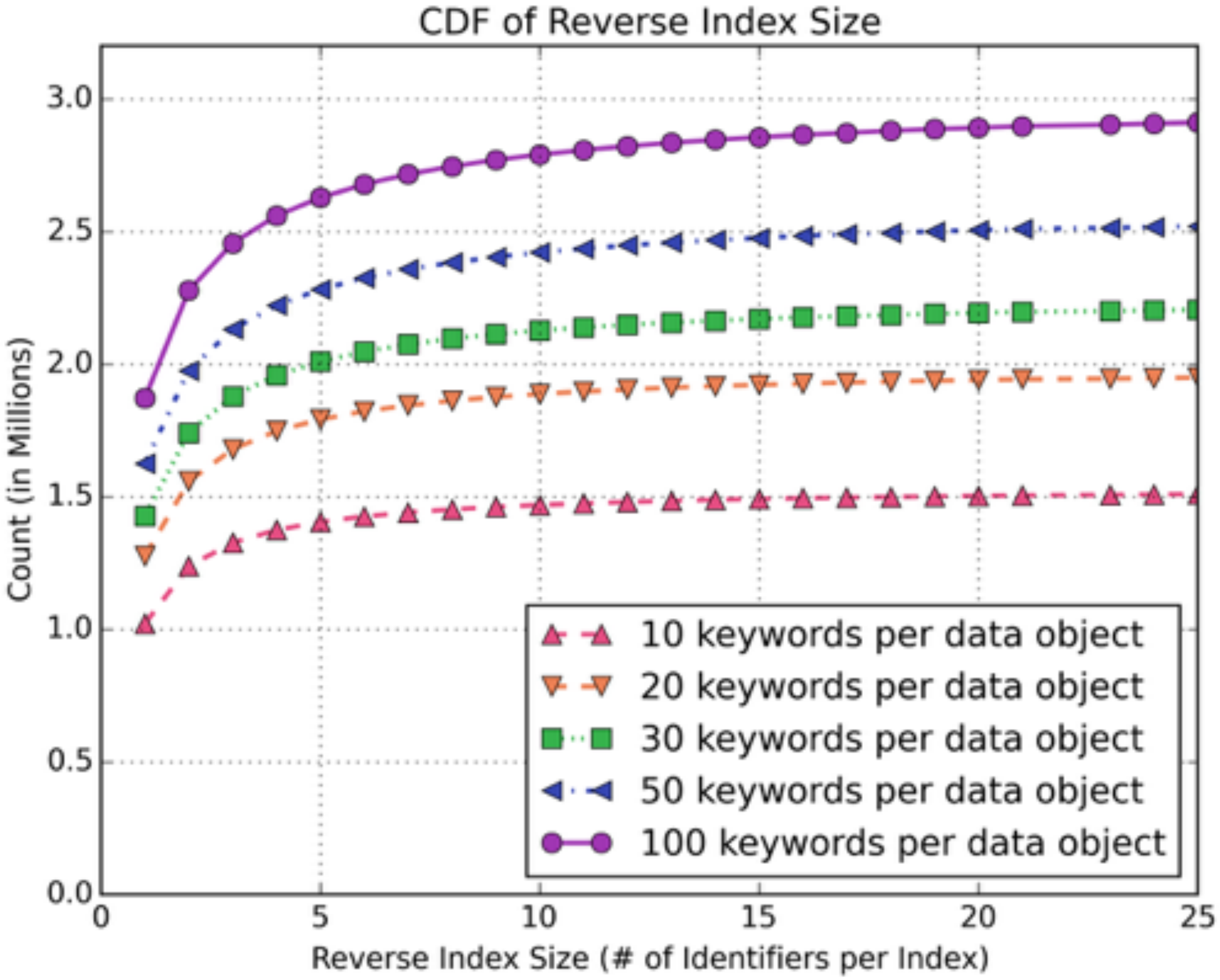
SSL

- Assume secure connections between client and servers
- SSL is not inviolate, just outside of Percival’s scope
- Unable to read contents of encrypted data stream
- Can get quantity of search requests, but not result

Performance: *Digital Corpora*

- 1 million files of various types (e.g. pdf, txt, html, etc…)
- Keywords found by a Stemmed TF-IDF
- 5 : 3 splitting scheme
- Ingest into a BerkeleyDB key:value store
- Very corpus dependent

64 bit Linux
4 core
24 GB
Intel 4764 HSM



- 80% contained < 3 Doc IDs
- All shares are of equal size
- Avg query completion time: < 1s
- Precision and recall: based on number and accuracy of keywords
- Salt rotation: < 2 min
- Query Server rebuild: 53 min
- 32B DocID with 100 keywords: 9.6GB

Future Work

- Support additional ACL methods (currently limited to RBAC)
- Hierarchical ACL support
- Keyword locality: a.k.a exact phrase matching
- Improve query server recovery time
- Evaluate performance using real search workload
- Disaster recovery

Thank You

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Backup Slides

Access Control

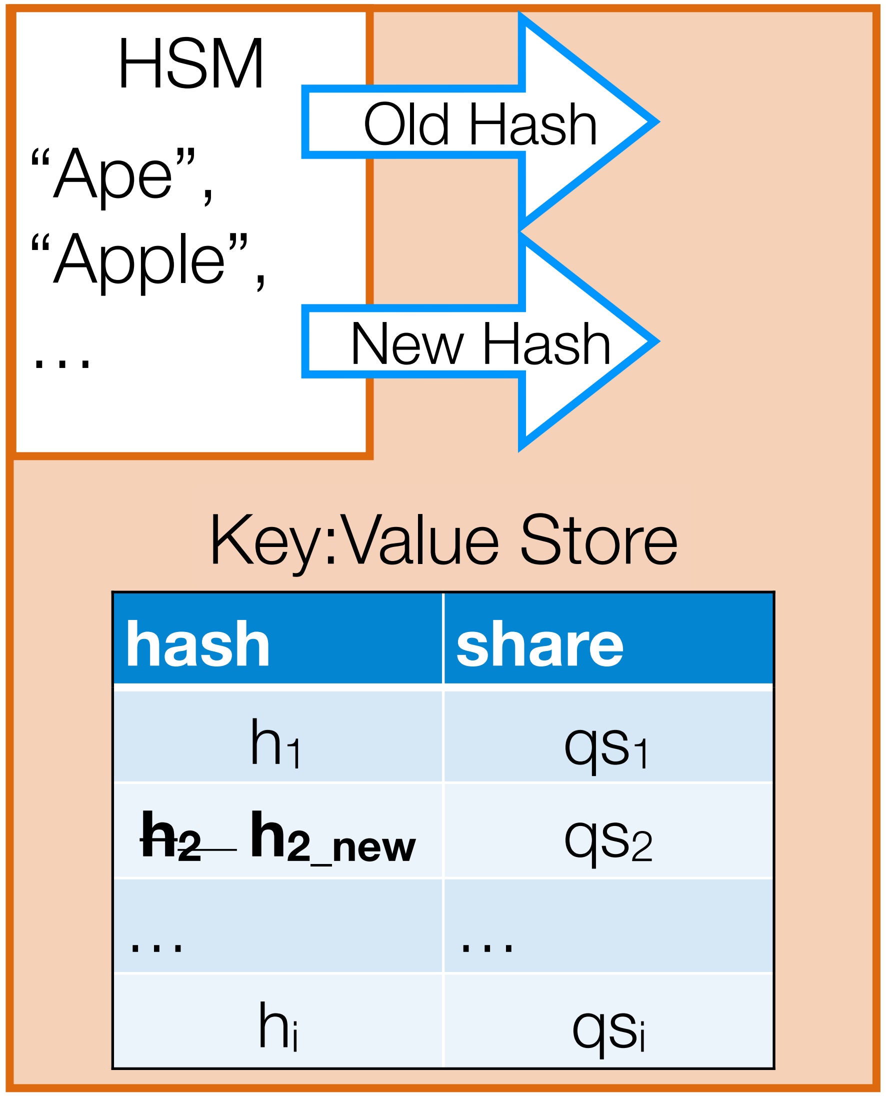
- Leverages a secure, external access control service
- Segregates the query servers to localize data loss
- Unique set of reverse indexes for each credential
    - Potentially large space overhead
    - Role-based access control (RBAC)
    - Organizations typically have ~20 defined roles

Concurrency Control

- Can potentially corrupt a set of reverse index shares
- Strong Strict Two-Phase Locking (SS2PL)
- Distributed Lock Manager (DLM)
- Operations that rely on the DLM:
  - Salt rotation
  - Performing a query
  - Adding new content

Salt Rotation

- New salt generated by the HSM
- Sent to other HSMs via secure channel
- HSM iterates over its stored keywords
- Does not help if already compromised



HSM

“Ape”,
“Apple”,
…

Key:Value Store

hash	**share**
h_1	qs_1
~~h_2~~ **h_{2_new}**	qs_2
…	…
h_i	qs_i

Query Server$_n$