Searching Encrypted Data with Size-Locked Indexes

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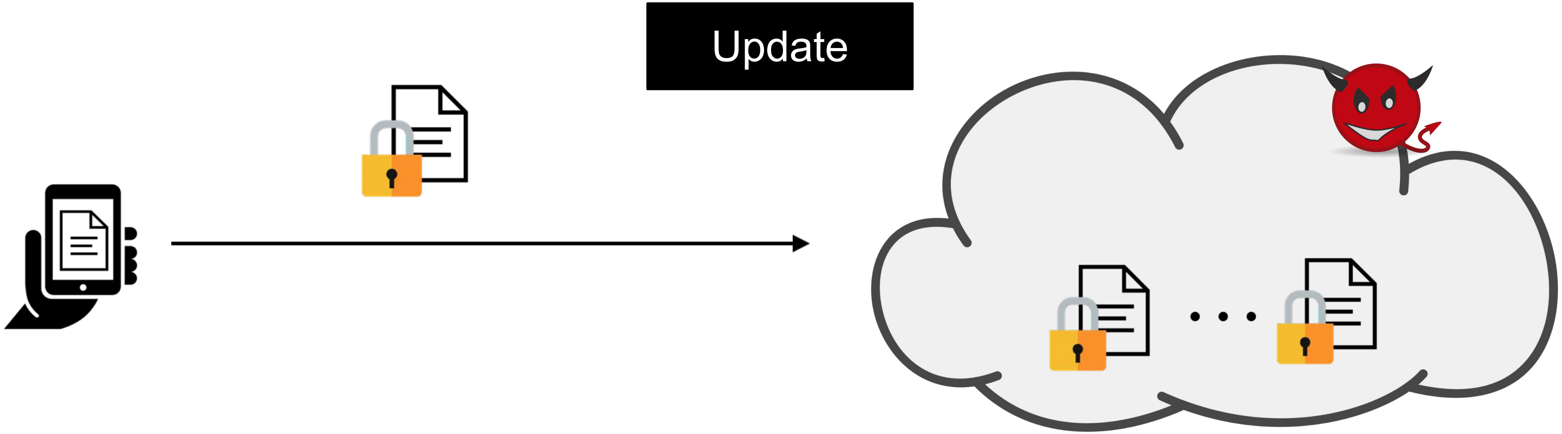
E2E Encrypted Keyword Search



- Users outsource documents to the cloud for cost-effective storage and convenient access
  - Limited amount of client-side storage capacity, via web/mobile interface
  - End-to-end encryption for full privacy

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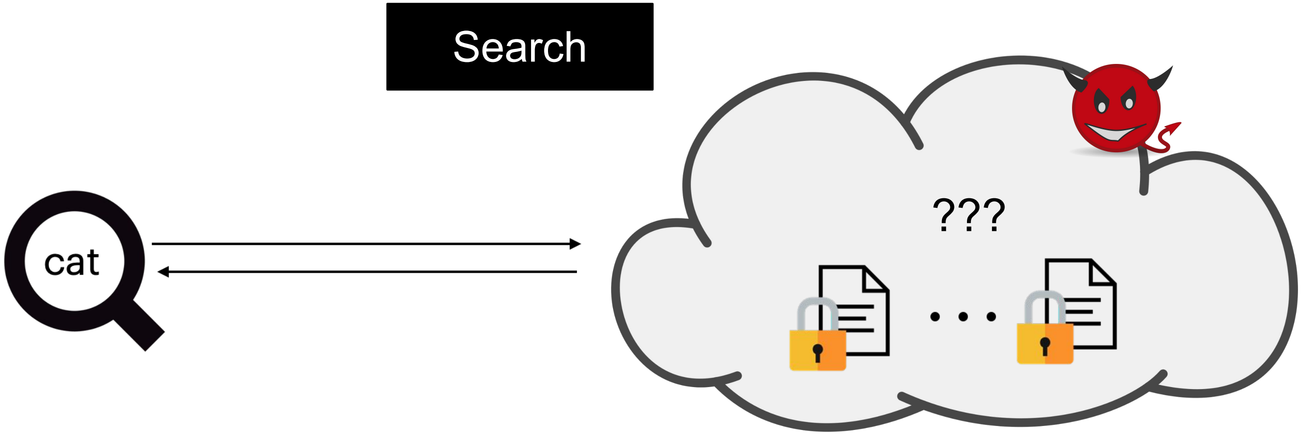
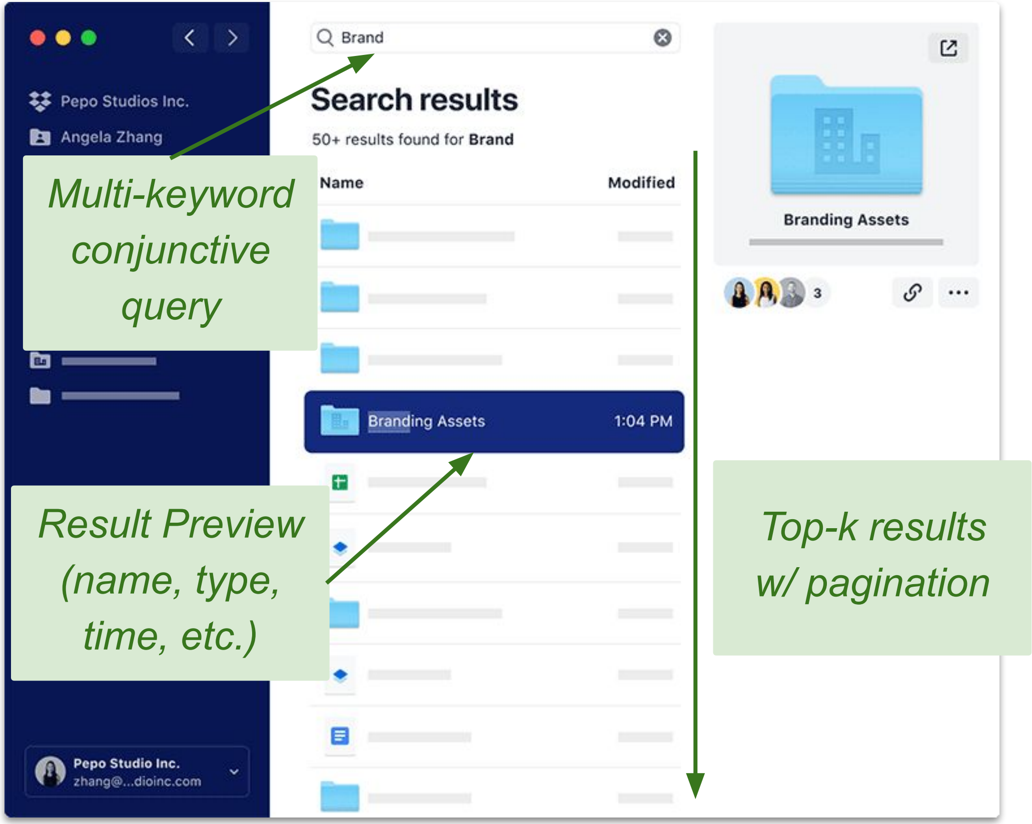
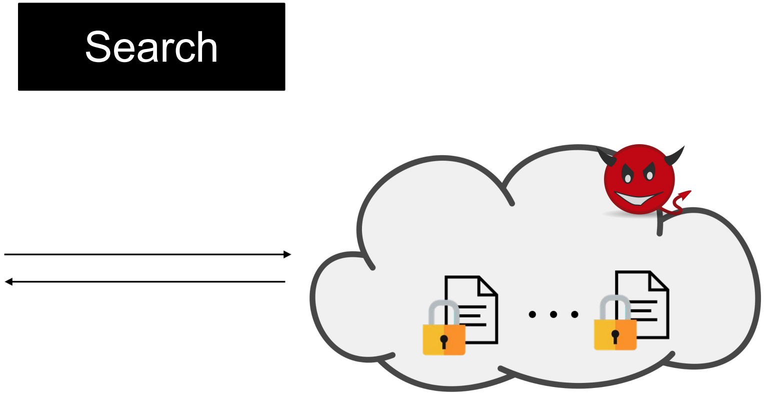


- Users outsource documents to the cloud for cost-effective storage and convenient access
  - Limited amount of client-side storage capacity, via web/mobile interface
  - End-to-end encryption for full privacy
- End-to-end encryption makes key service utilities difficult, if not impossible
  - Keyword search — find the uploaded documents most relevant to the user’s keywords

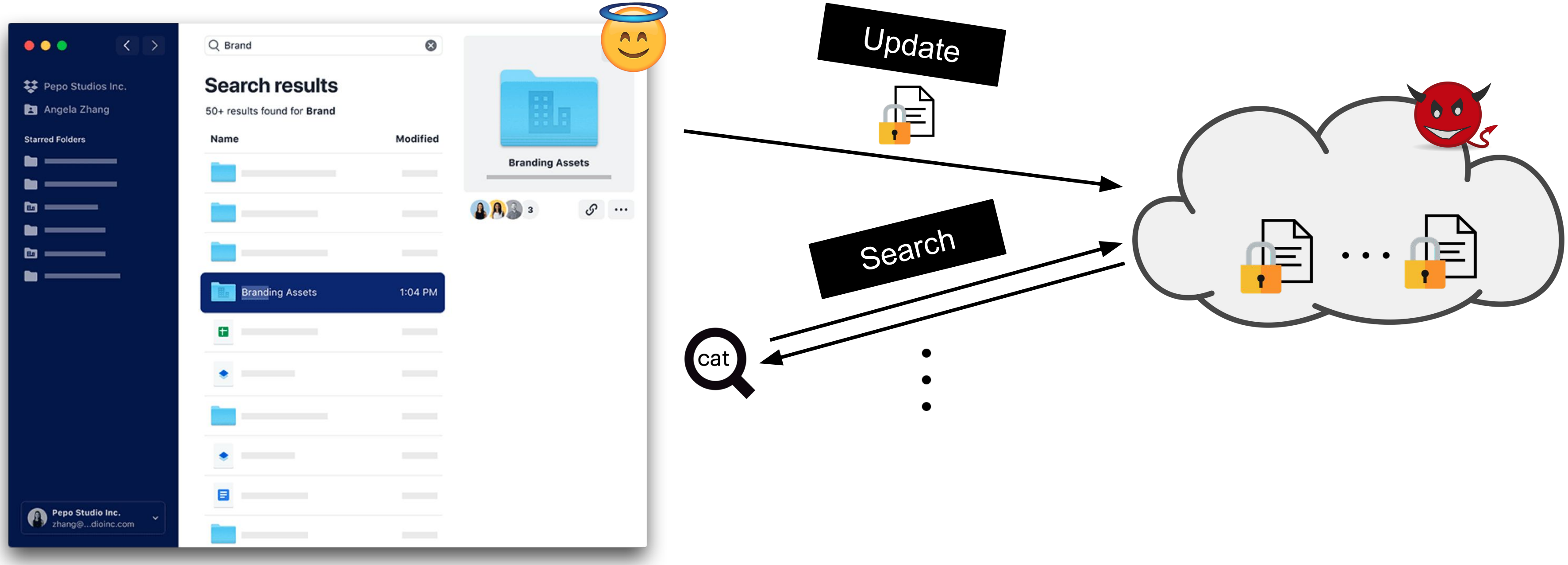
Our Target Search Interface





Similar interface is shared by Box, Google Drive, Microsoft OneDrive, etc.

Our Threat Model



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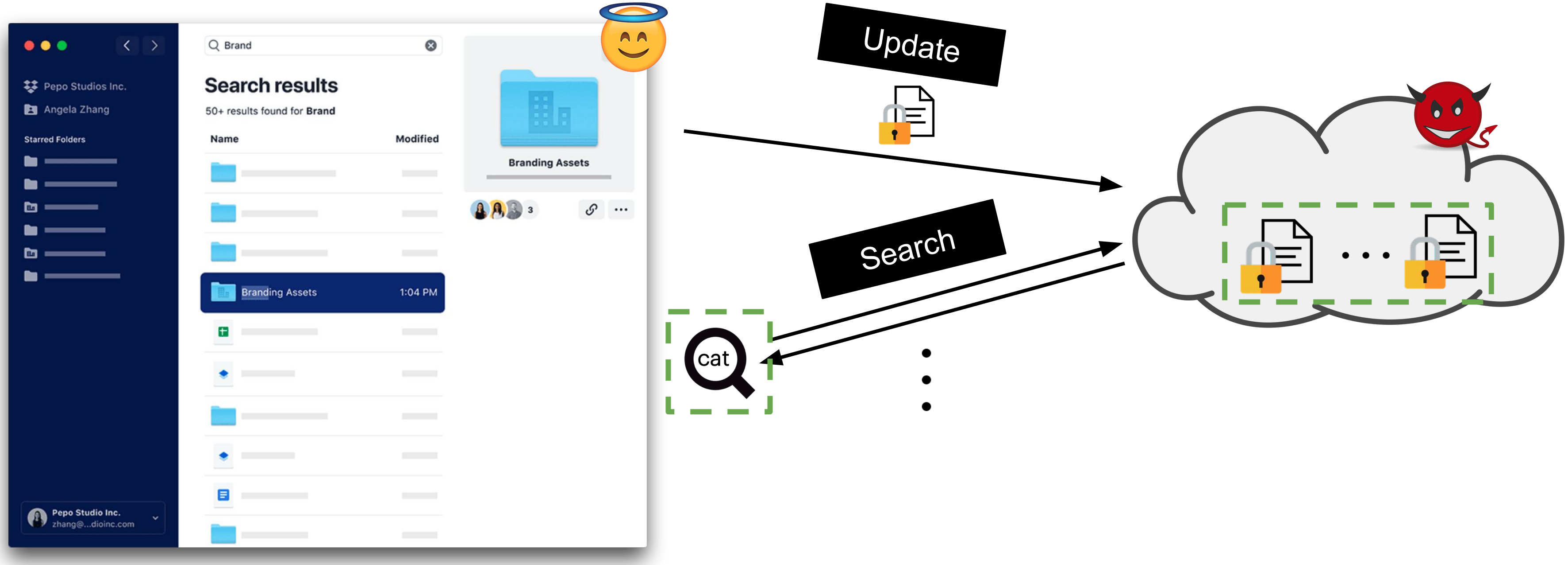

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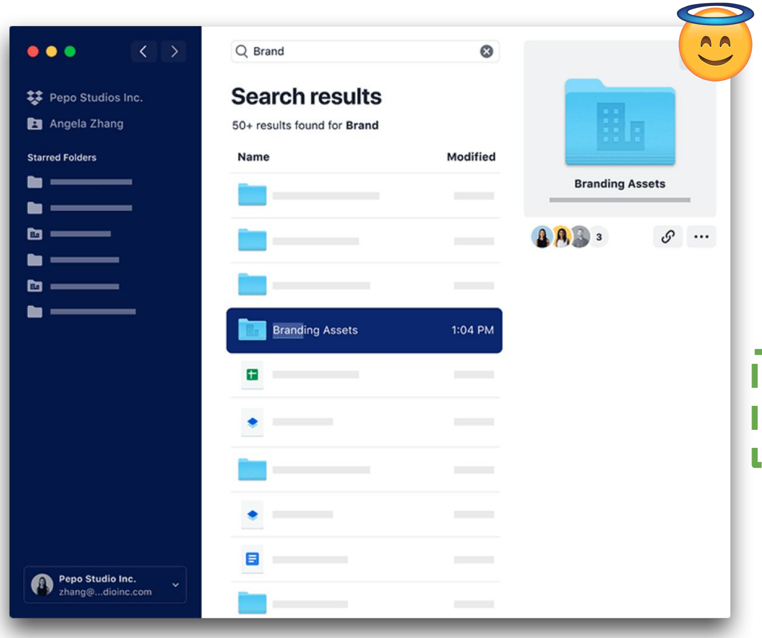
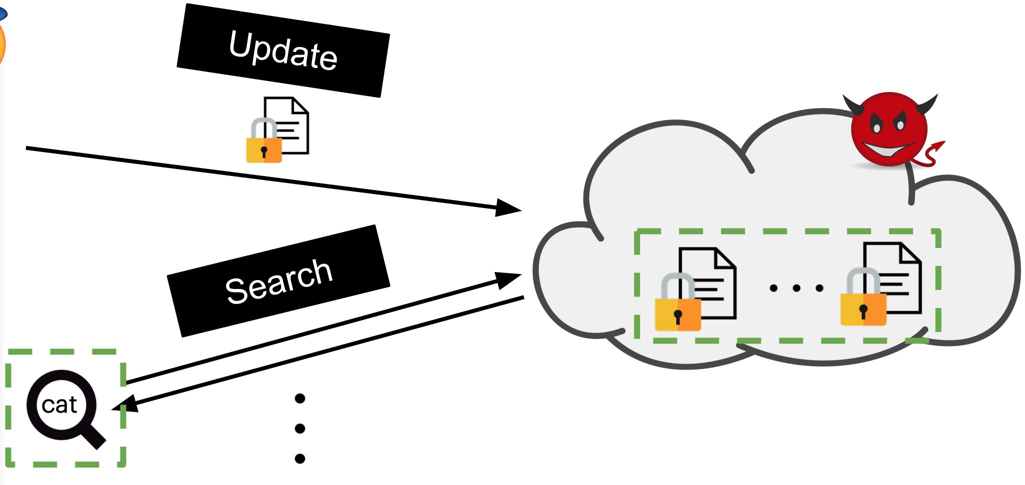
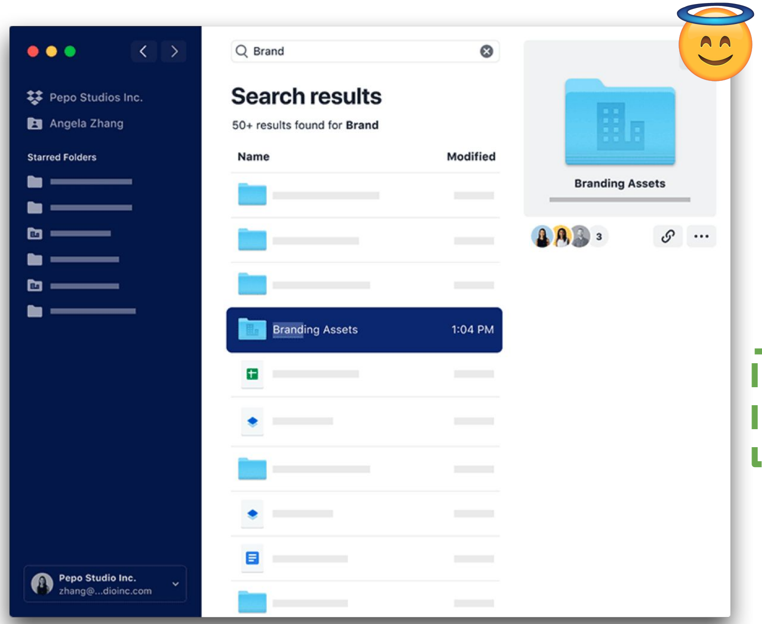


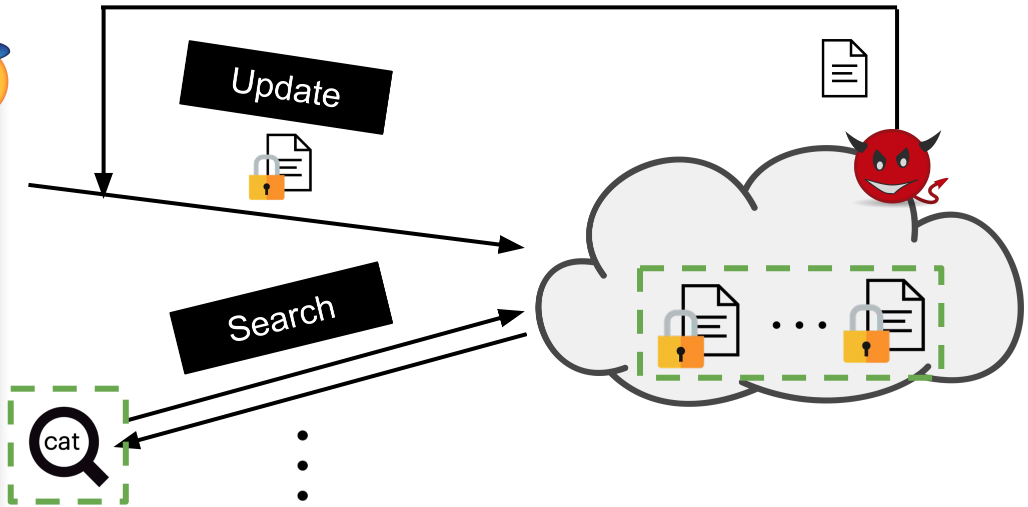


Persistent Active Adversary

- Full transcript of the update and search history

Our Threat Model





Persistent Active Adversary

- Full transcript of the update and search history
- *File-injection*: Adaptively inject documents of chosen words under user's key [CGPR15], [ZKP16]

Dynamic Searchable Symmetric Encryption (DSSE)

Time

Dynamic
[KPR'12]

- K, st; EDB $\leftarrow$ `setup`(λ)
- (K, st'; EDB') $\leftarrow$ `update`(K, st, op, (id, w); EDB)
- (DB(q);) $\leftarrow$ `search`(K, st, q; EDB)

Dynamic Searchable Symmetric Encryption (DSSE)

Leakage Profile $\Leftarrow$ Provably no more leaked

- **Result Pattern** the set of updates on the same keyword as the query
- **Volume** the number of documents containing the query keyword
- **Query Pattern** the set of queries on the same keyword

Time

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[KPR'12]

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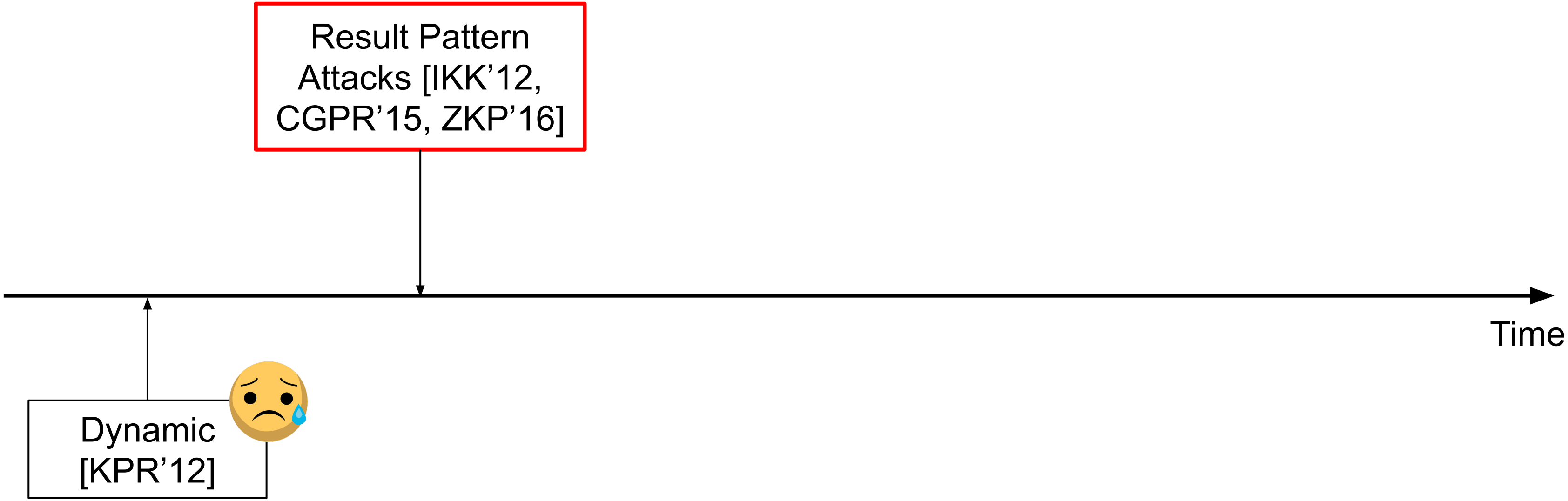
- Leakage profile are vulnerable to various *leakage-abuse attacks* (LAAs)
- Limited search functionality, i.e., no ranking or previewing

Dynamic Searchable Symmetric Encryption (DSSE)



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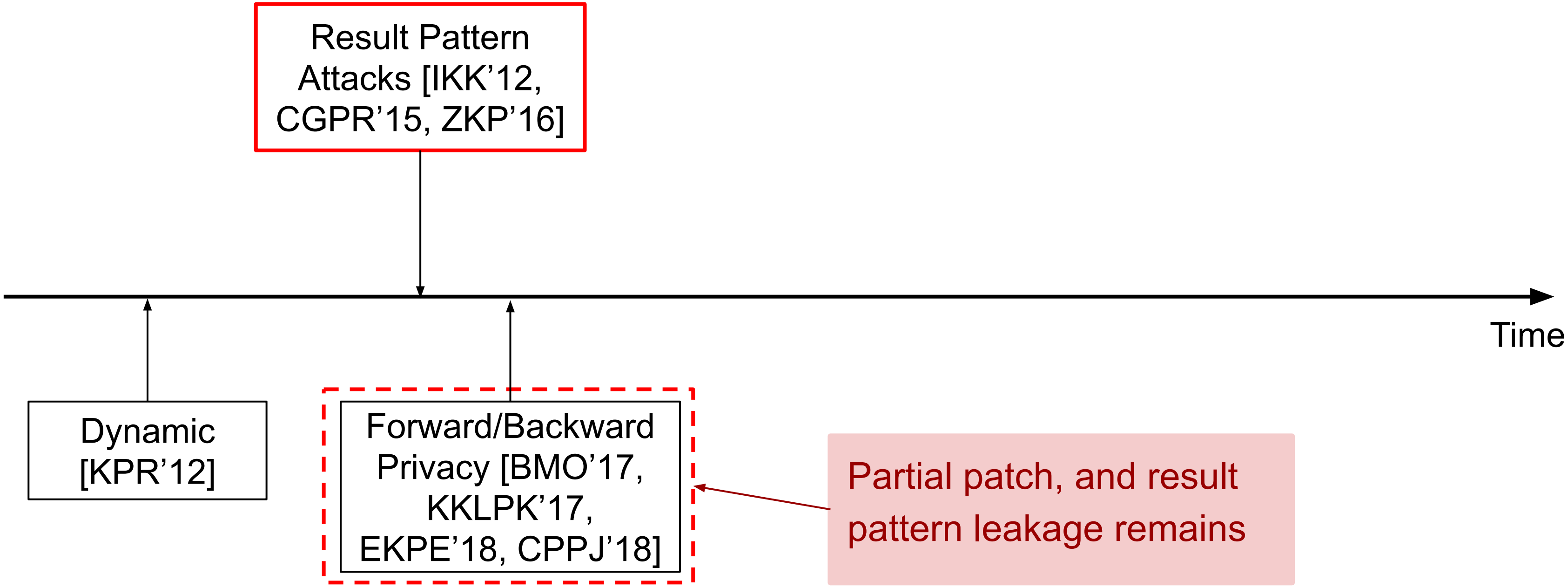

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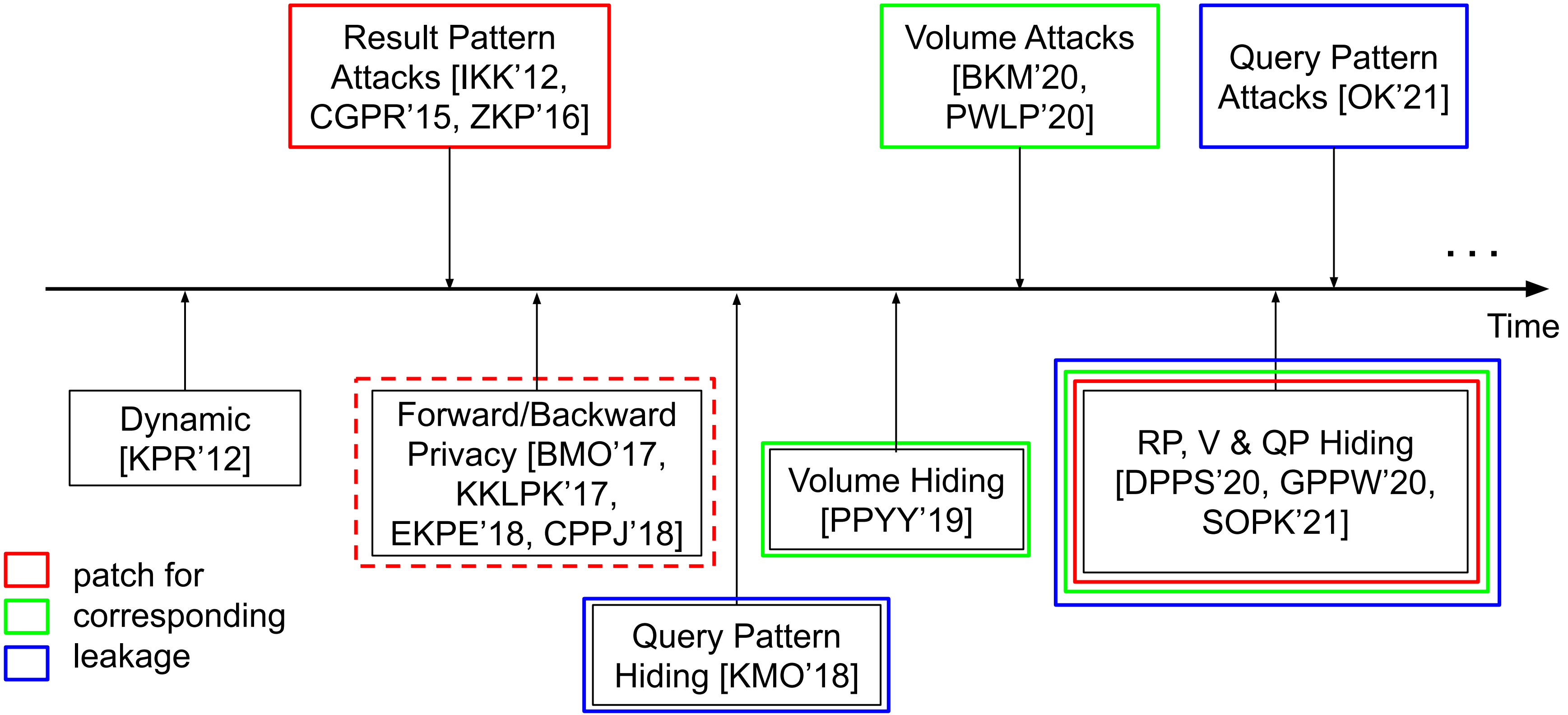

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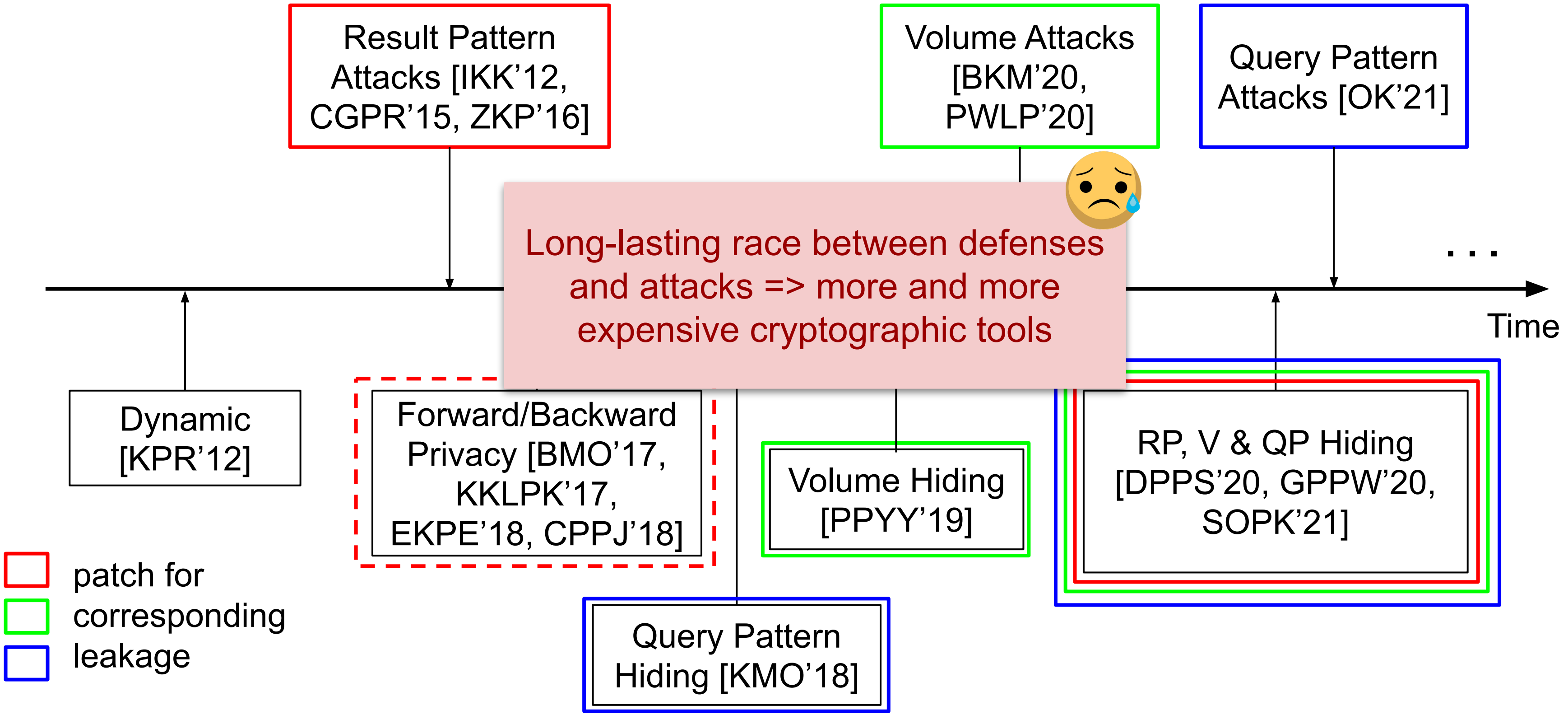

Our Approach - Download-then-Search-Locally

A Different Idea against File-Injection Attacks

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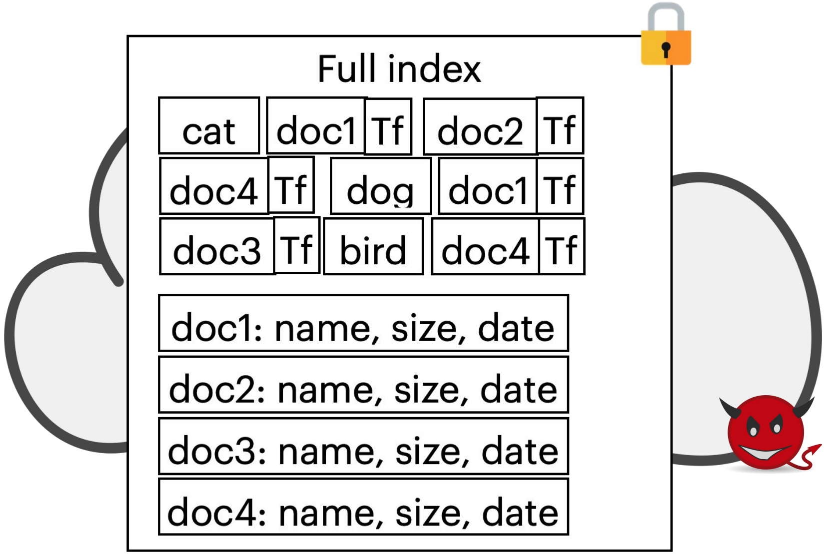

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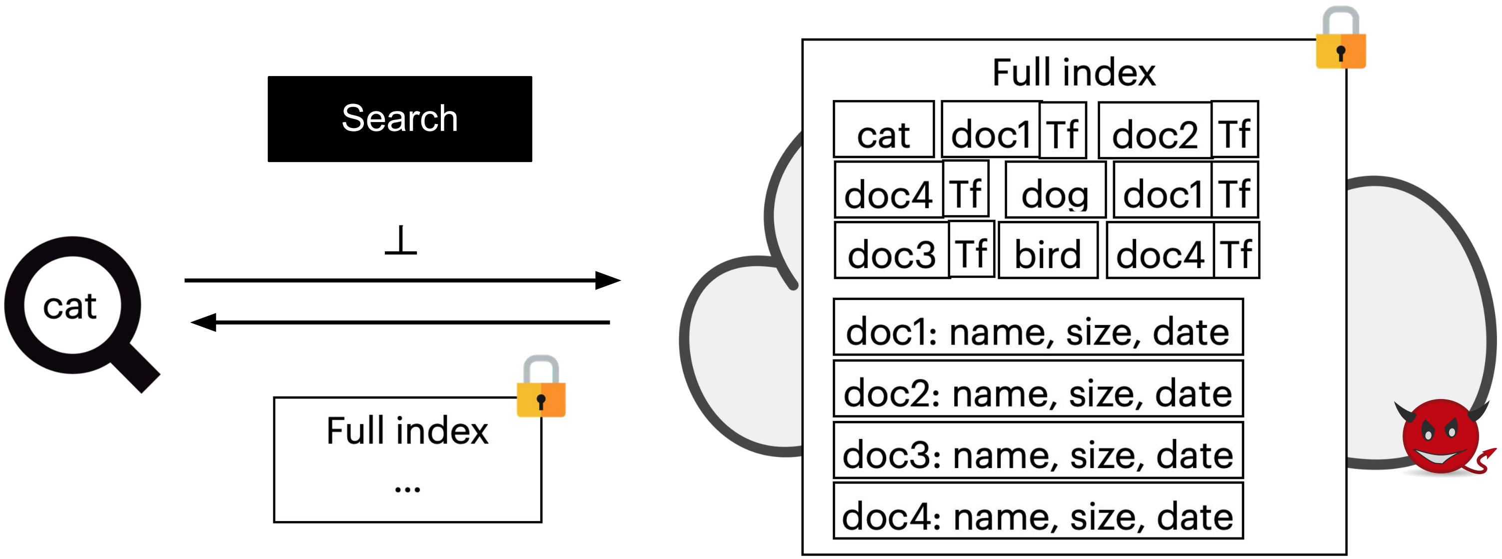

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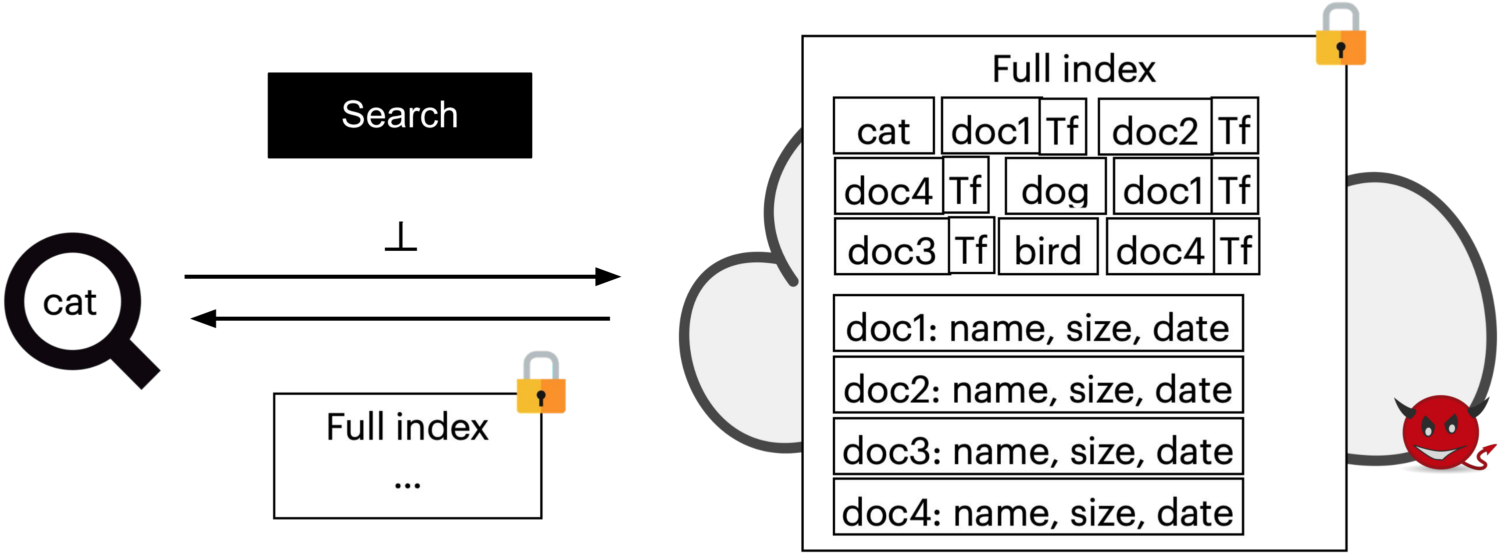

- No result pattern, volume or query pattern leakage whatsoever!

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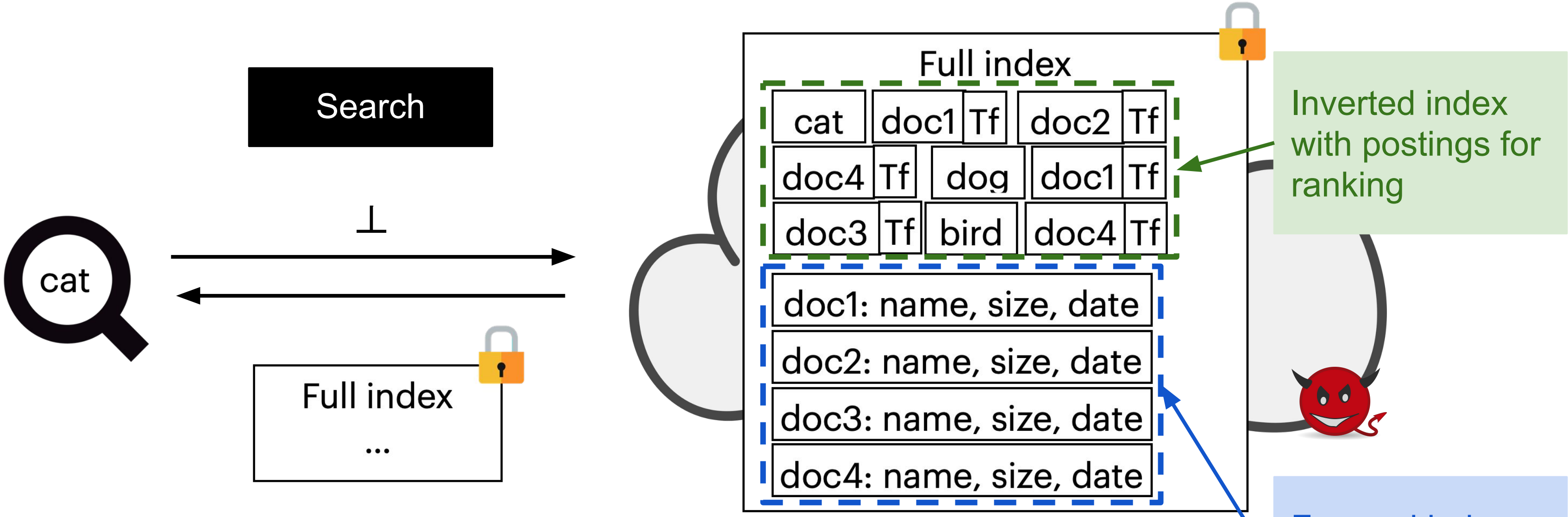
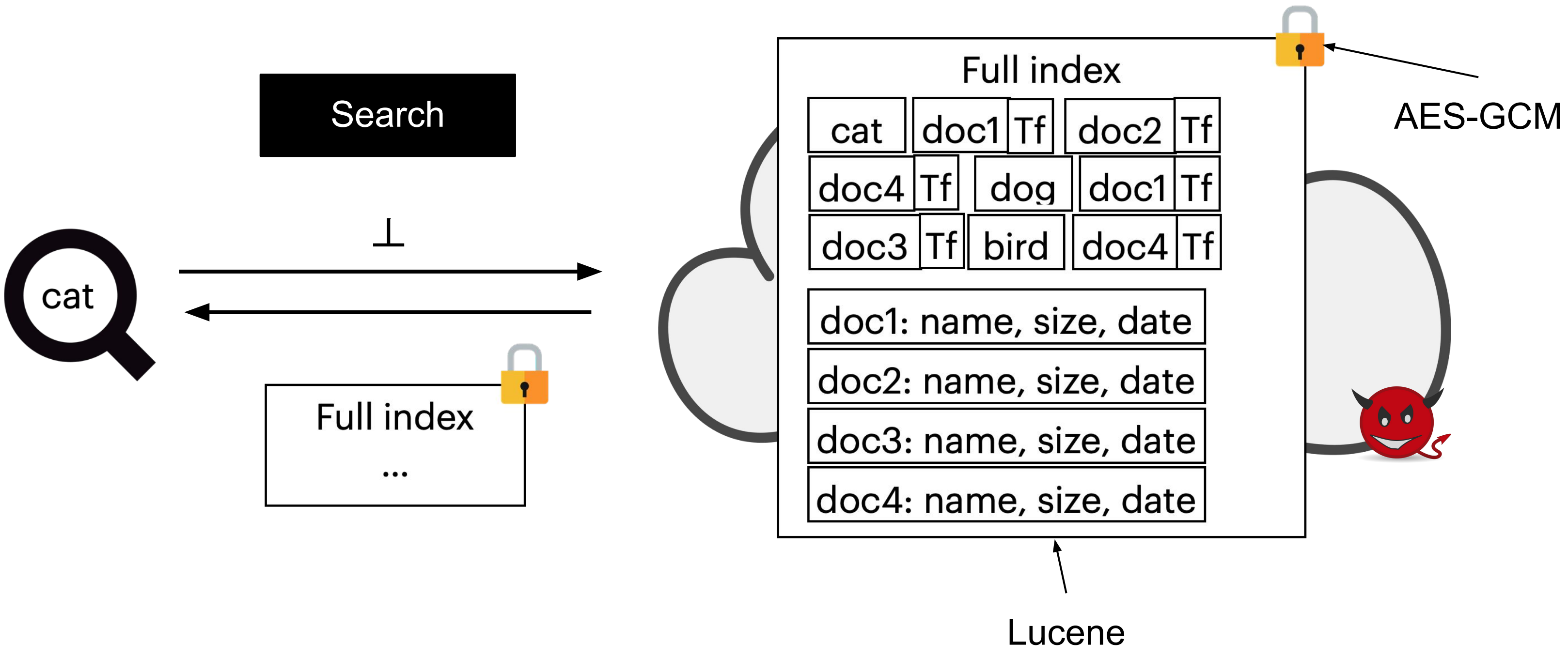


- ❏ No result pattern, volume or query pattern leakage whatsoever!
- ❏ Straightforward support for ranking and preview!

Our Contributions

- Develop previously under-treated technique: download-then-search-locally
- Identify attacks against naive construction and give solutions with security proofs
- New constructions for feature-rich, scalable search on E2E encrypted data
- Real-world prototype-based evaluation

Naïve Download-then-Search-Locally



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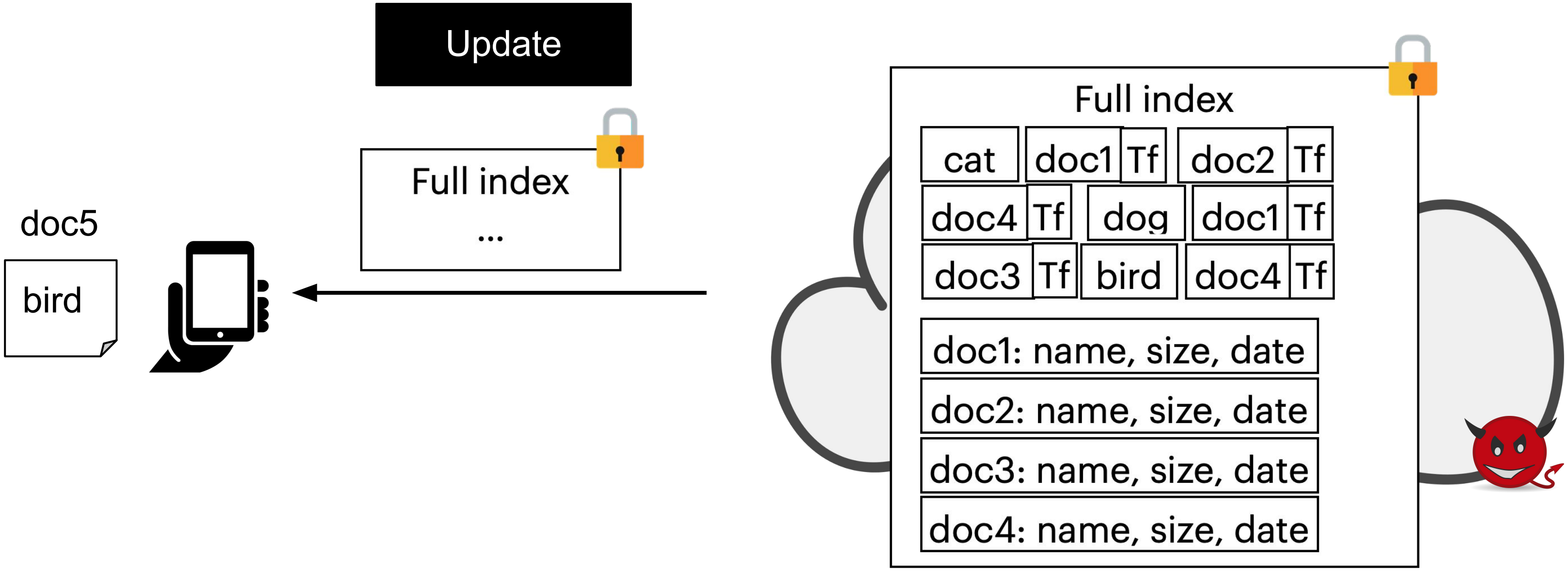

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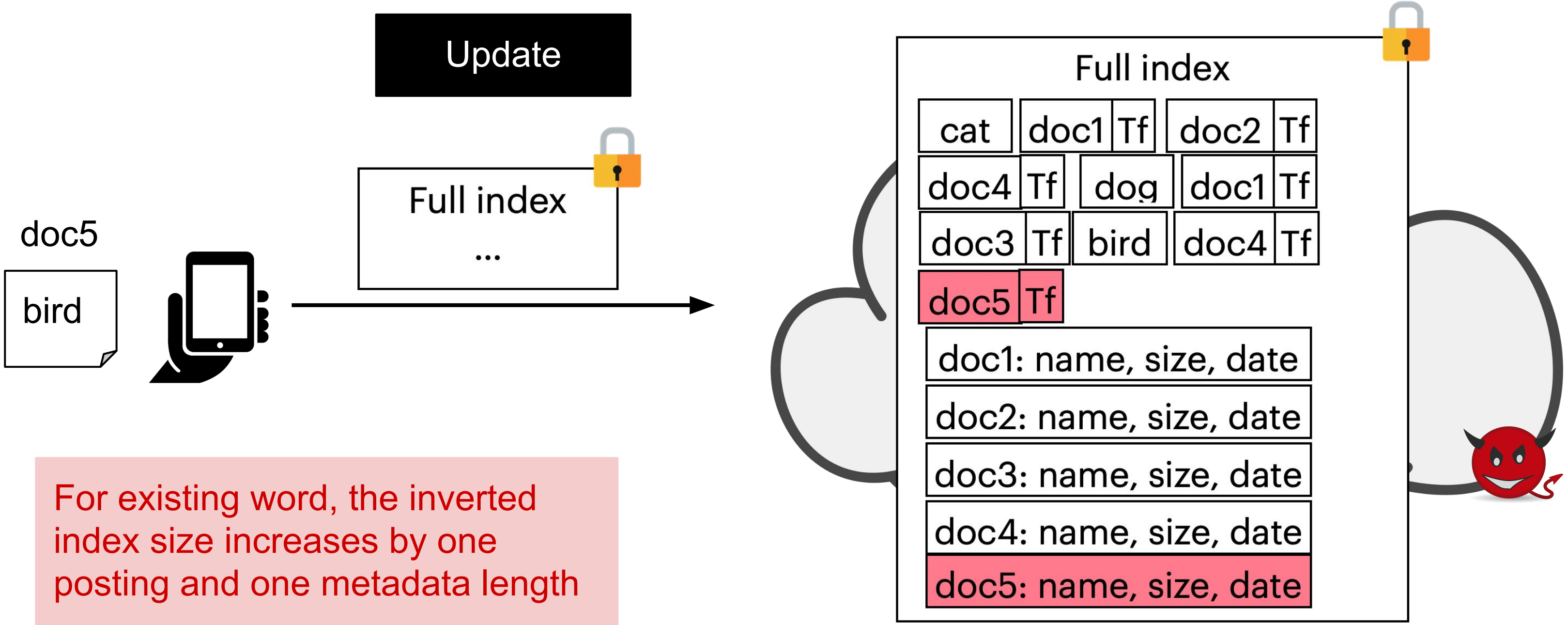

For existing word, the inverted index size increases by one posting and one metadata length

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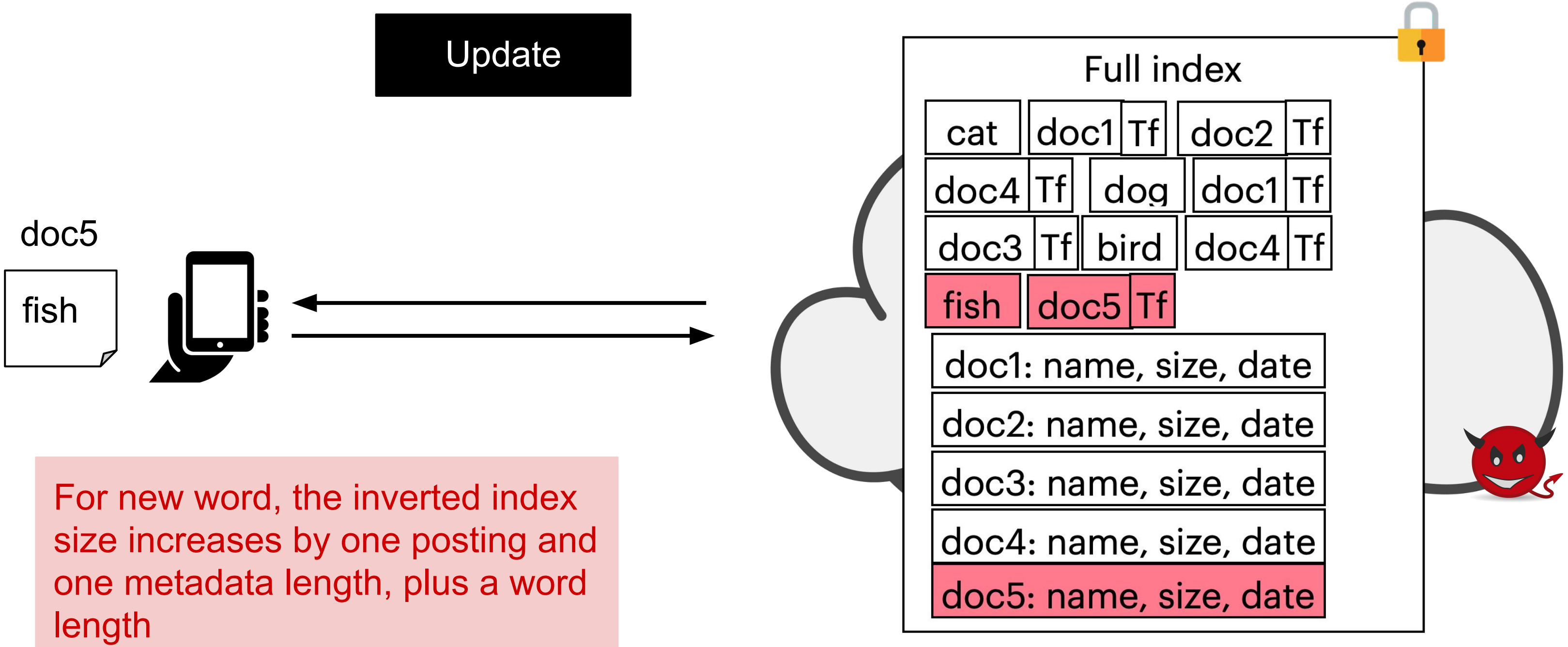
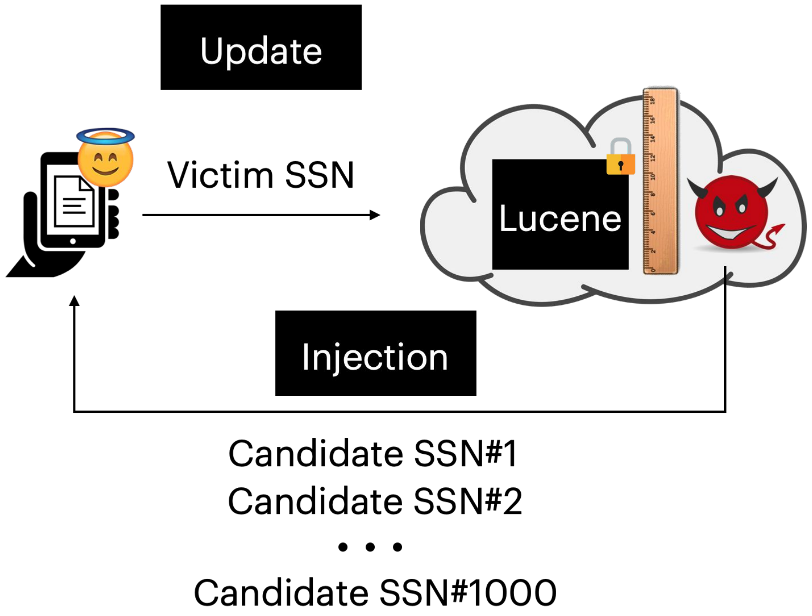


For new word, the inverted index size increases by one posting and one metadata length, plus a word length

LAAs w/ File-Injection



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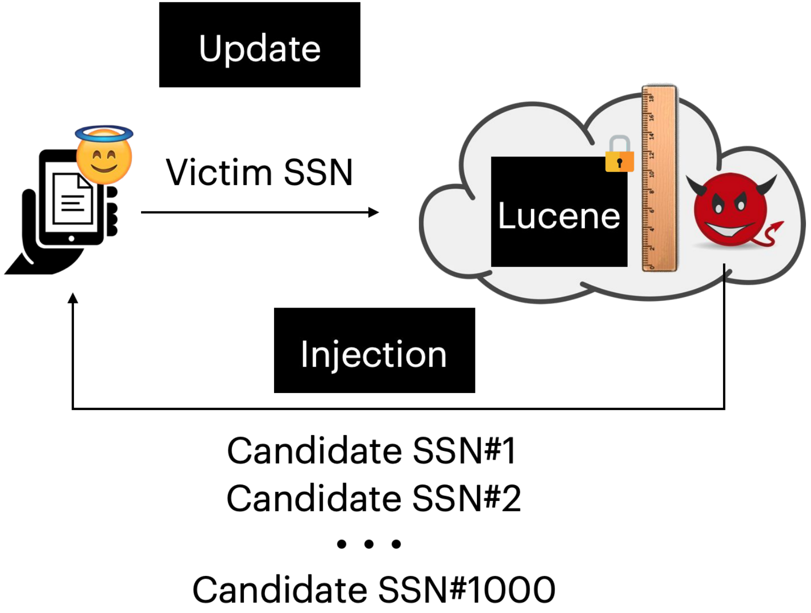

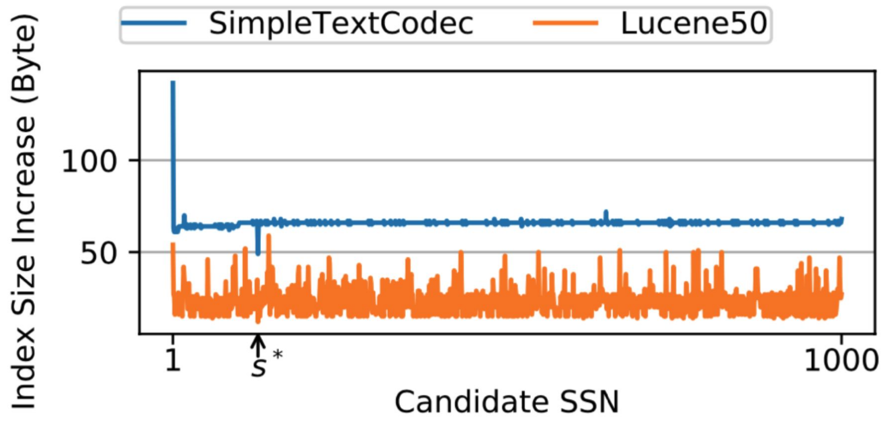

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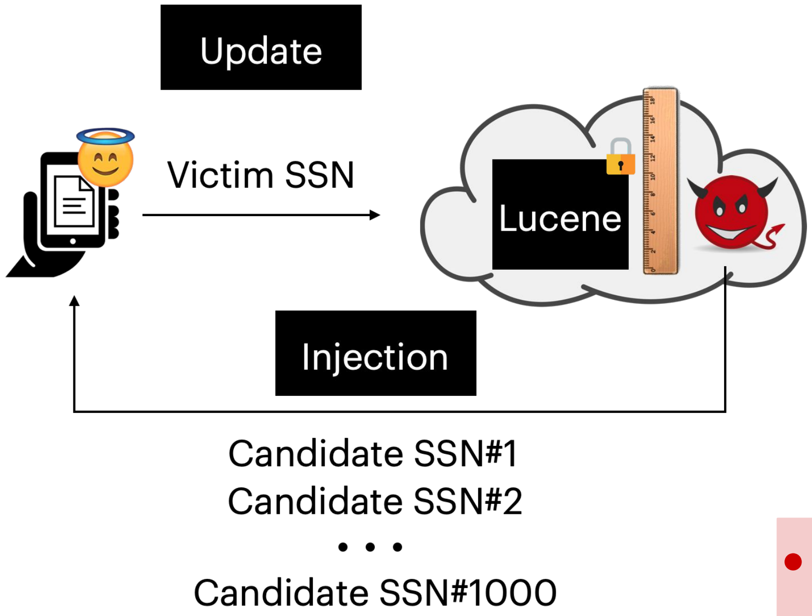

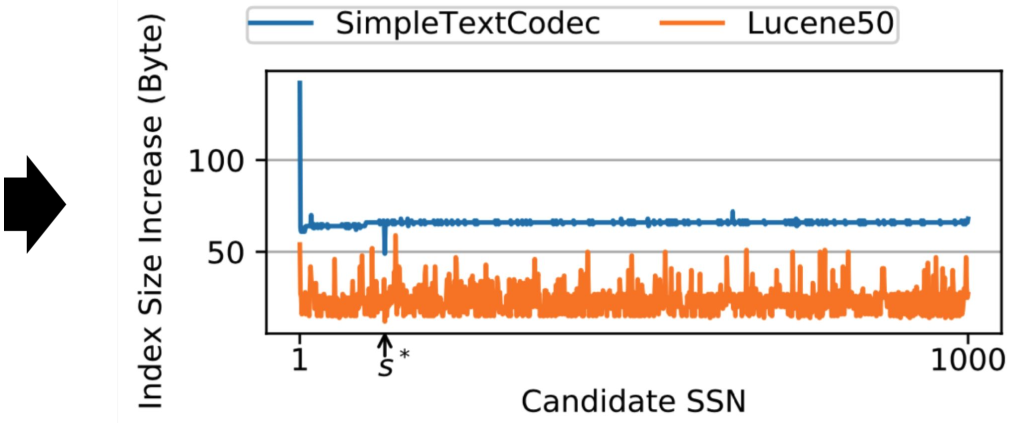

- Size of standard search index, encrypted using standard encryption, leaks sensitive information!
- File-injection is powerful to recover the data from the leakage!

Size-locked Indexing

- Size-locking - make the length of the index encoding a function of only the information we are willing to leak
  - ✓ N, the total number of postings
  - ✓ |D|, the total number of documents
  - X |W|, the total number of indexed keywords

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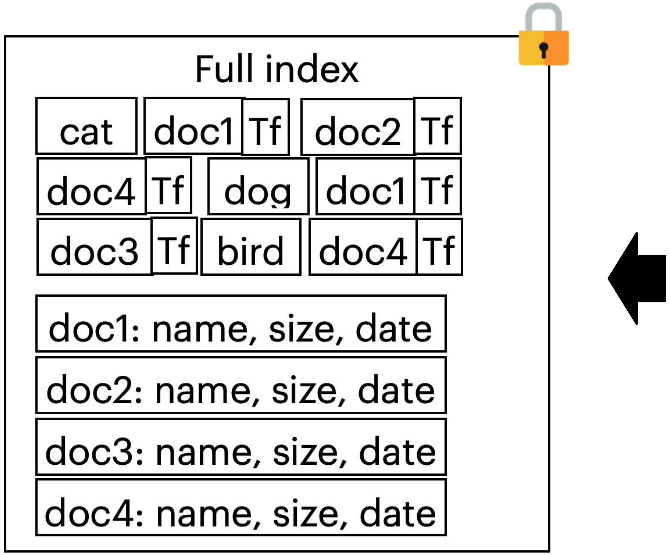

Lucene + AES-GCM has index size: **O(N+|W|+|D|)** ⇒ NOT size-locking

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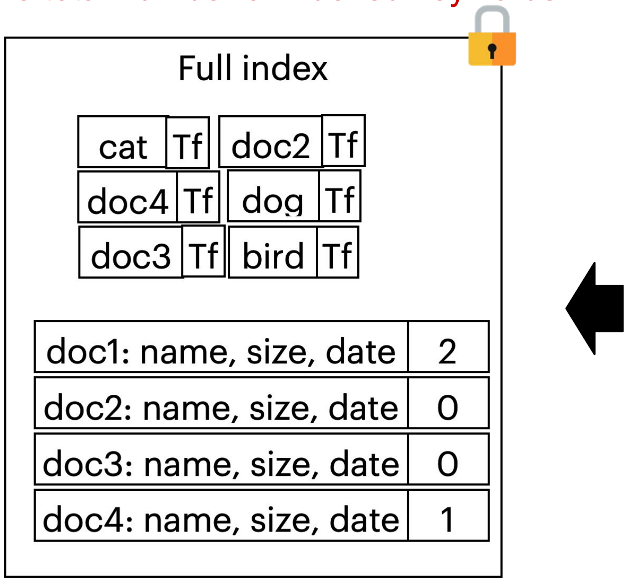
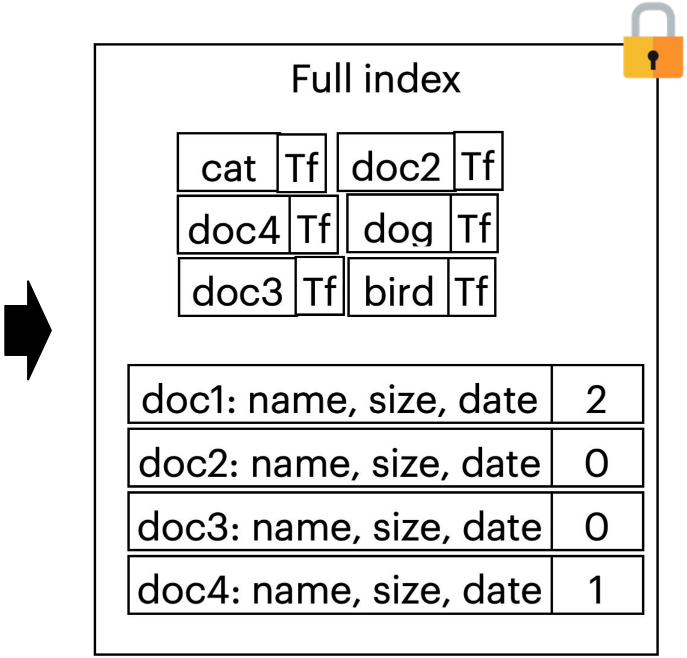


Our size-locked index:
O(N+|D|)

Scalability Challenge

For the entire Enron dataset, the full index gets as large as **228MB**! ⇒ Impractical to download for every search



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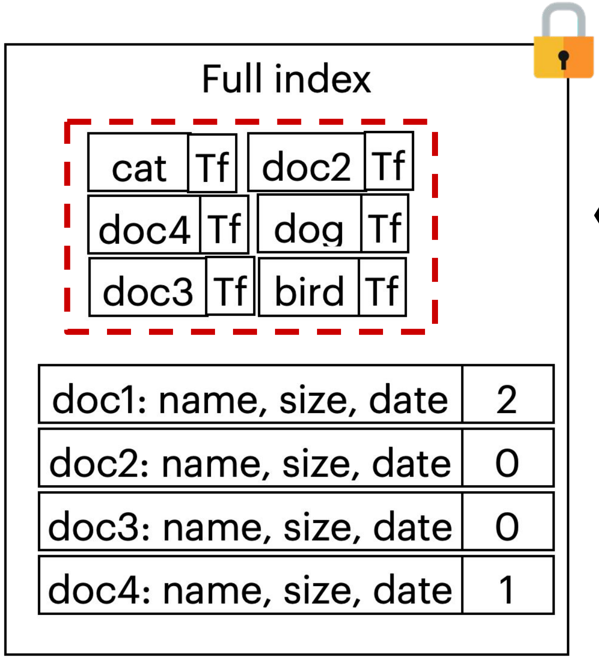

Out of the 228MB of index, **212MB** is the inverted index

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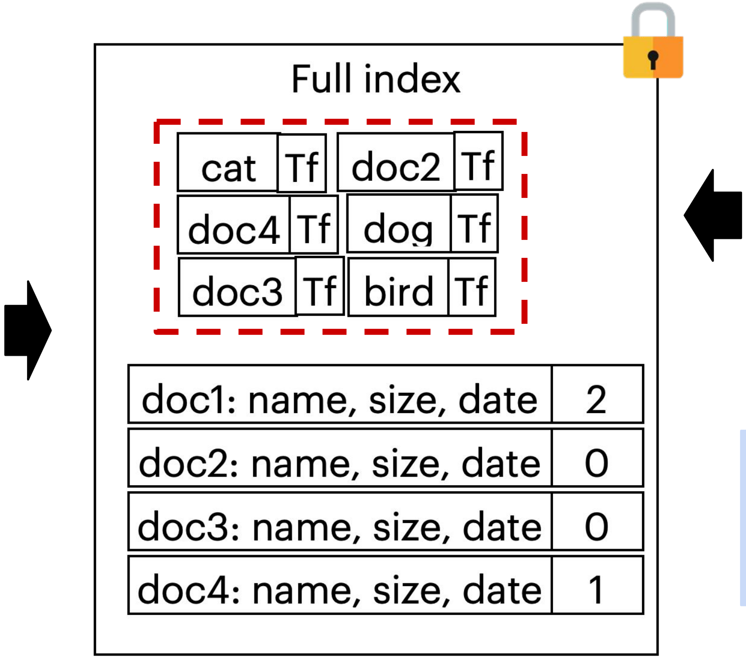
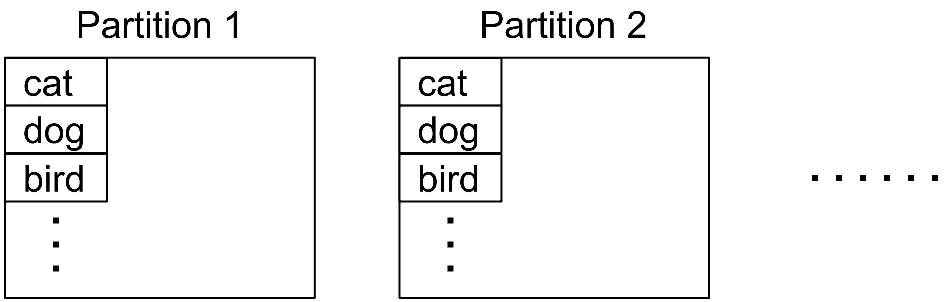


Out of the 228MB of index, **212MB** is the inverted index

Can we reduce the cost down to the necessary, top-relevant postings?

Secure Vertical Index Partitioning



- Partition index into blobs by relevance to the indexed keywords
  - Top relevant results all in the first partition

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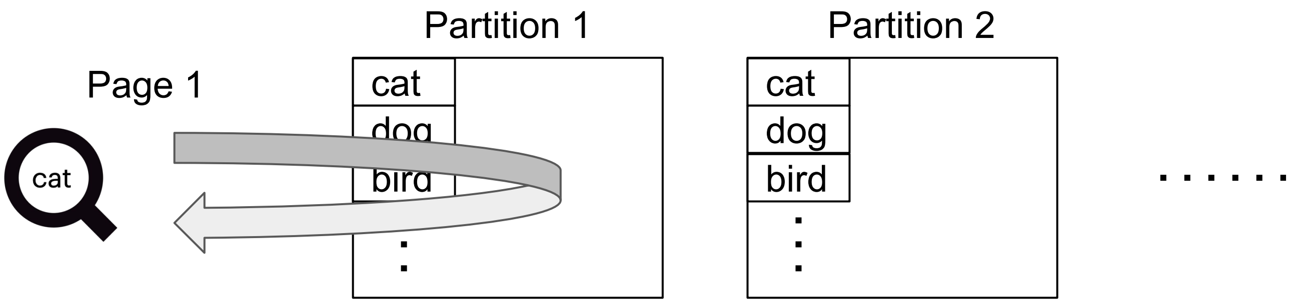

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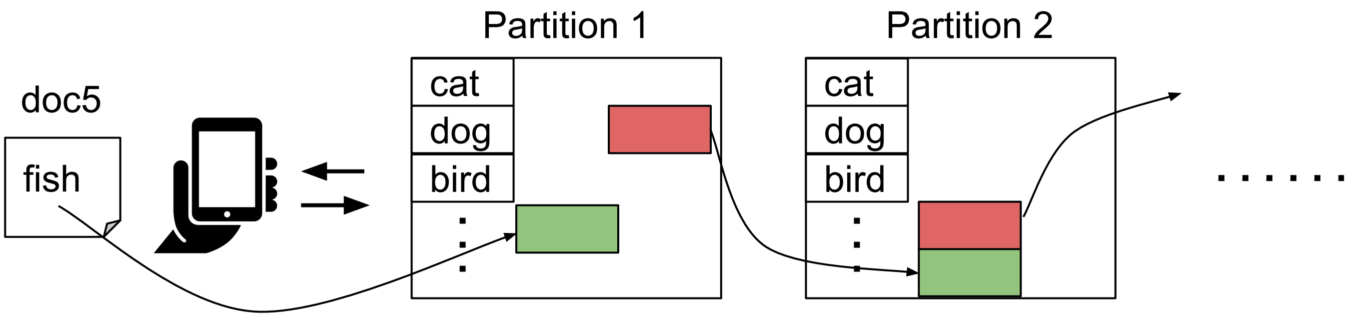

- Partition index into blobs by relevance to the indexed keywords
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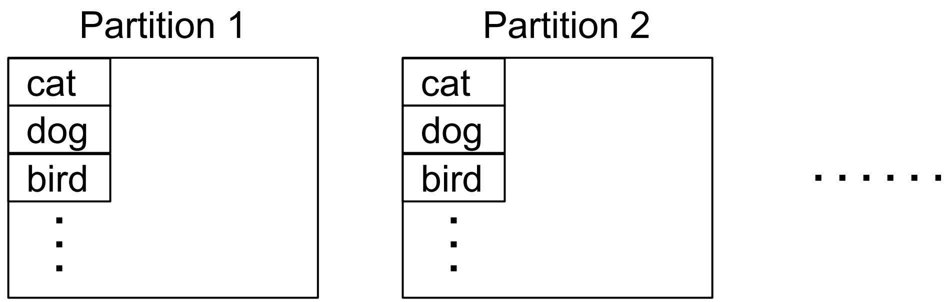
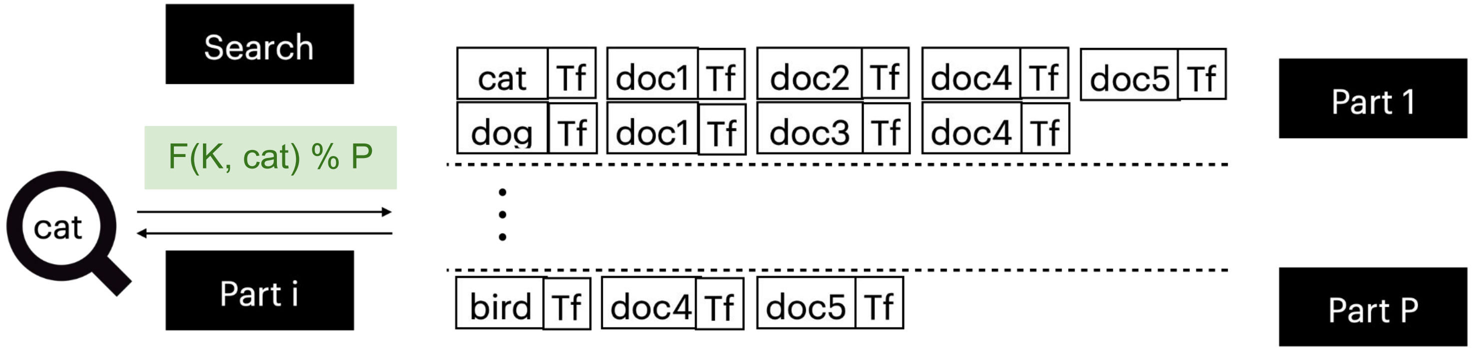


- ❑ Partition index into blobs by relevance to the indexed keywords
  - ❑ Top relevant results all in the first partition
- ❑ New postings from updates are merged, and less relevant ones are kicked to the subsequent partitions
  - ❑ When and how many postings to kick depend solely on the total number of postings, i.e., N
- ❑ No result pattern, volume or query pattern leakage

Secure Horizontal Index Partitioning



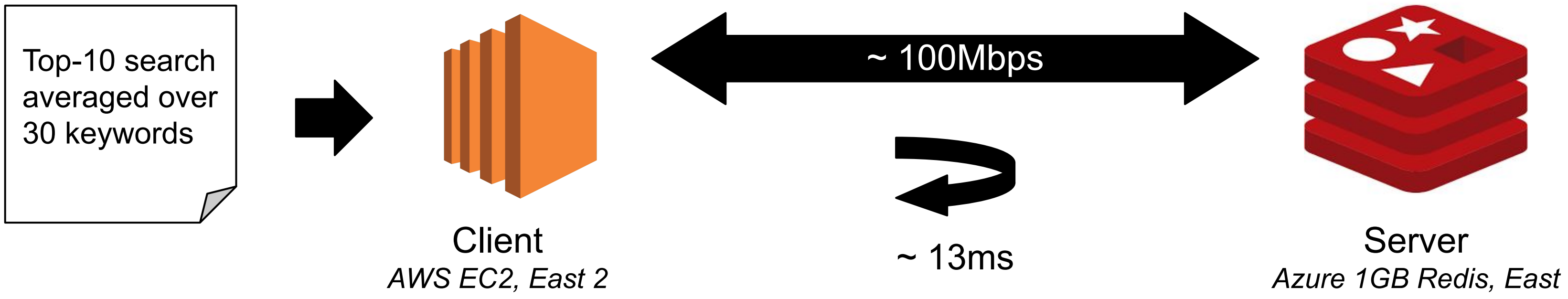
- ❏ Only 1 out of P partitions is needed for a single keyword query
- ❏ **Security Intuition** Randomly group words into buckets
  - ❏ Update leaks the # words of the update in each bucket
  - ❏ Search leaks the partition access pattern -> words in the same partition remain indistinguishable
- ❏ Can be combined with the vertical index partitioning for more efficiency

Performance Evaluations

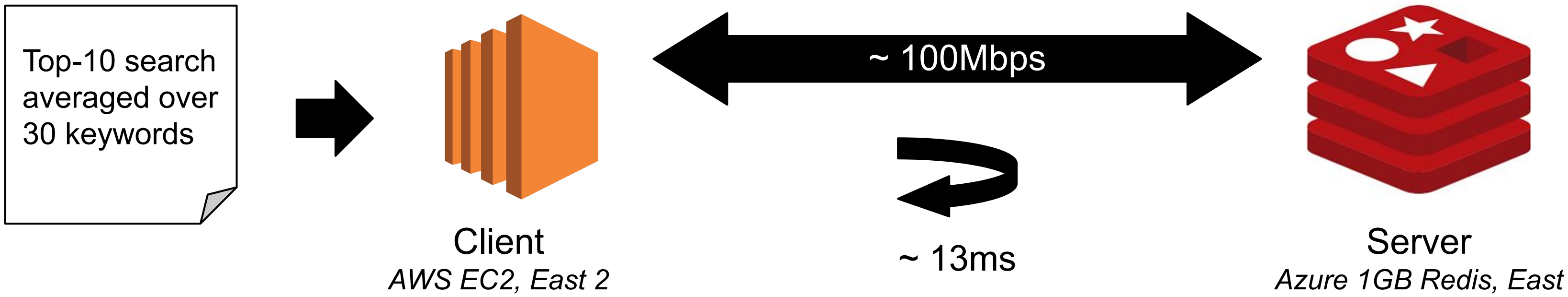
Dataset	Data Size	# Docs	# Keywords	# Postings
10% Enron	0.2 GB	51,731	131,903	4.3×10^6
50% Enron	0.8 GB	258,655	280,474	21.3×10^6
100% Enron	1.7 GB	517,310	338,913	42.5×10^6

- FULL: the basic size-locked download-then-search-locally
- VPart: the vertically partitioned size-locked download-then-search-locally
- VHPart-P: the vertically-and-horizontally partitioned size-locked download-then-search-locally with P horizontal partitions
- CTR-DSSE: the efficient forward private DSSE, named Diana from [BMO'17]

Search Performance

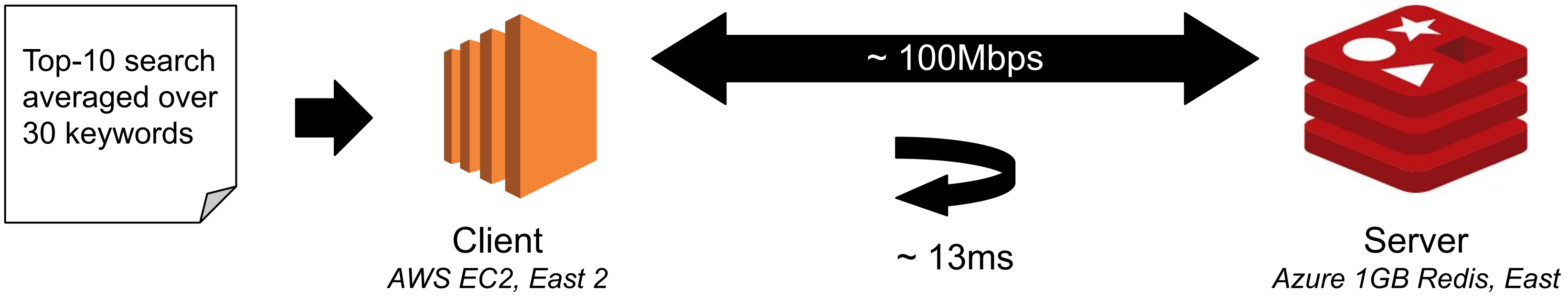


Search Performance - Bandwidth Cost



	Bandwidth (MB)			
	10% Enron	50% Enron	100% Enron	
Full	25.09	116.30	228.15	
VPart	6.72	16.68	25.38	9x
VHPart-10	1.17	4.16	7.51	30x

Search Performance - Bandwidth Cost



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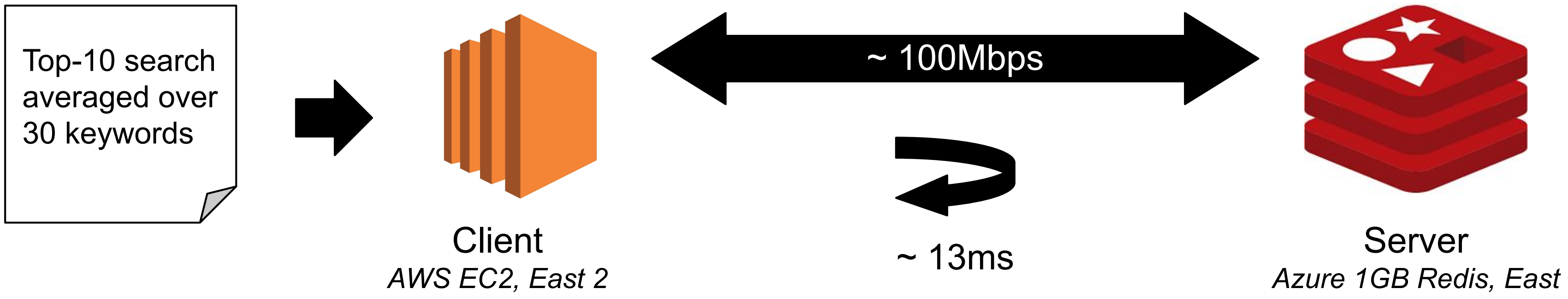
CTR-DSSE	1.48	4.35	--

- Cold start ⇒ O(|W|) counters downloaded for every search
- Download all matches

Search Performance - Latency



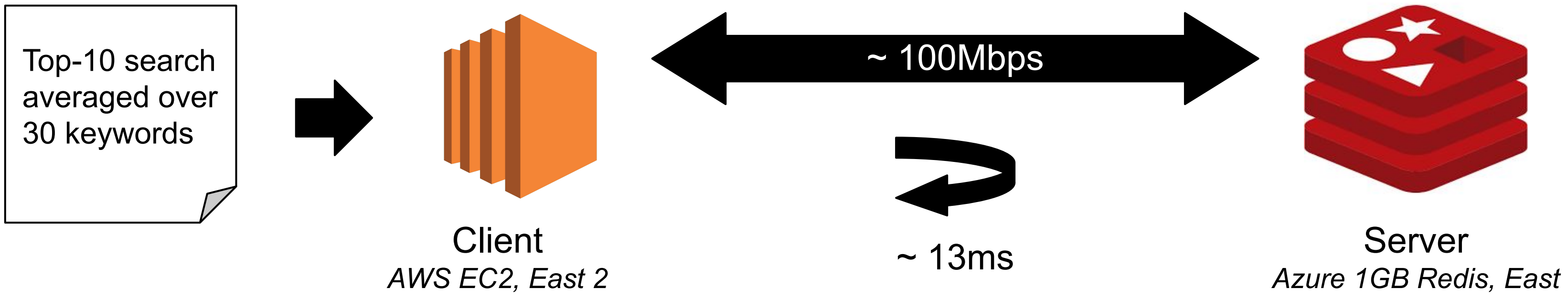
Latency (sec)

	10% Enron	50% Enron	100% Enron
Full	1.61	6.80	12.80
VPart	0.78	1.69	2.47
VHPart-10	0.16	0.33	0.46

5x

28x

Search Performance - Latency



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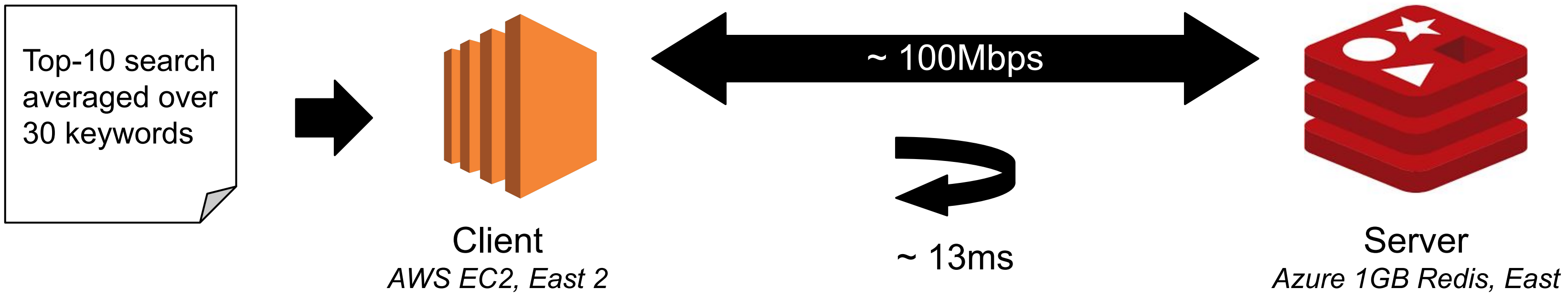
Sub-second Latency

Search Performance - Latency



Latency (sec)

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Full	1.61	6.80	12.80
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VHPart-10	0.16	0.33	0.46
CTR-DSSE	1.71	4.83	--

- Cold start ⇒ O(|W|) counters downloaded for every search
- Download all matches

Much more in the paper

- How to handle updates
- Progressive construction that transitions from Full to VPart, then from VPart to VHPart based on the number of postings
- More evaluation
  - Ubuntu and NYTimes datasets
  - Performance of search with index merge, update w/ and w/o index merge
  - Search quality based on the normalized discounted cumulative gain (NDCG)
  - End-to-end evaluation with synthetic workloads
- Formal security proofs
- Leakage-abuse analysis of the leakage

Thank you!

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References

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