FORWARD PRIVATE SEARCHABLE ENCRYPTION

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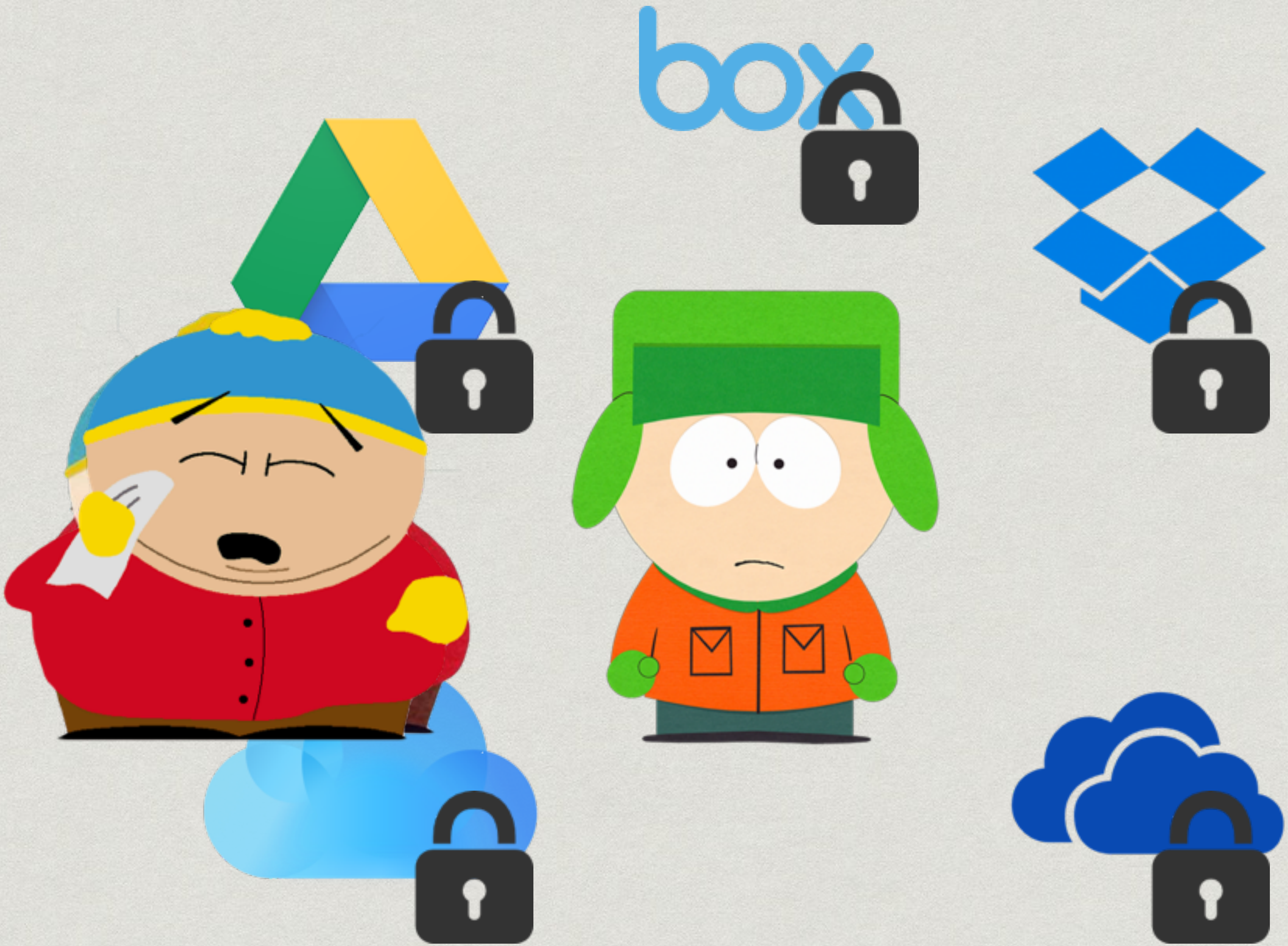

box

Searchable Encryption

- Outsource data …
- … securely
- … keep search functionalities

Generic Solutions

We can use generic tools to solve this problem:

- Fully Homomorphic encryption
  - Run all computations on the server
    Complexity linear in the DB size
- Oblivious RAM
  - Hide access pattern but…
    ORAM lower bound (logarithmic)

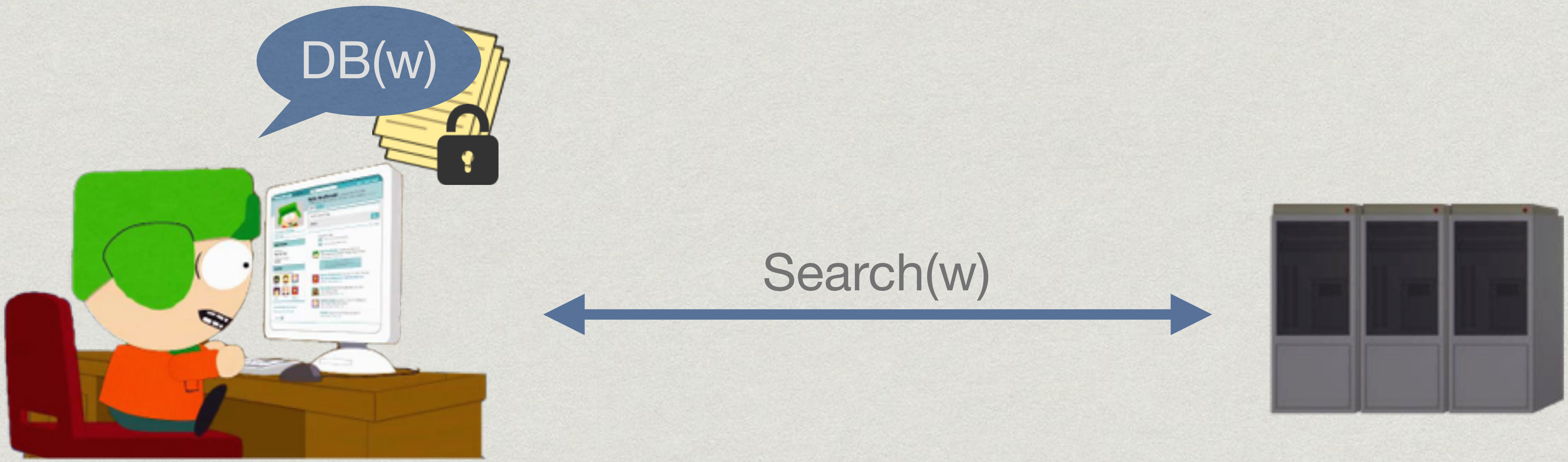
Ad-hoc Constructions

Can we get more efficient solutions?

- Yes, but …
- … we have to leak some information

Security/performance tradeoff

Security of SE



Security of SE

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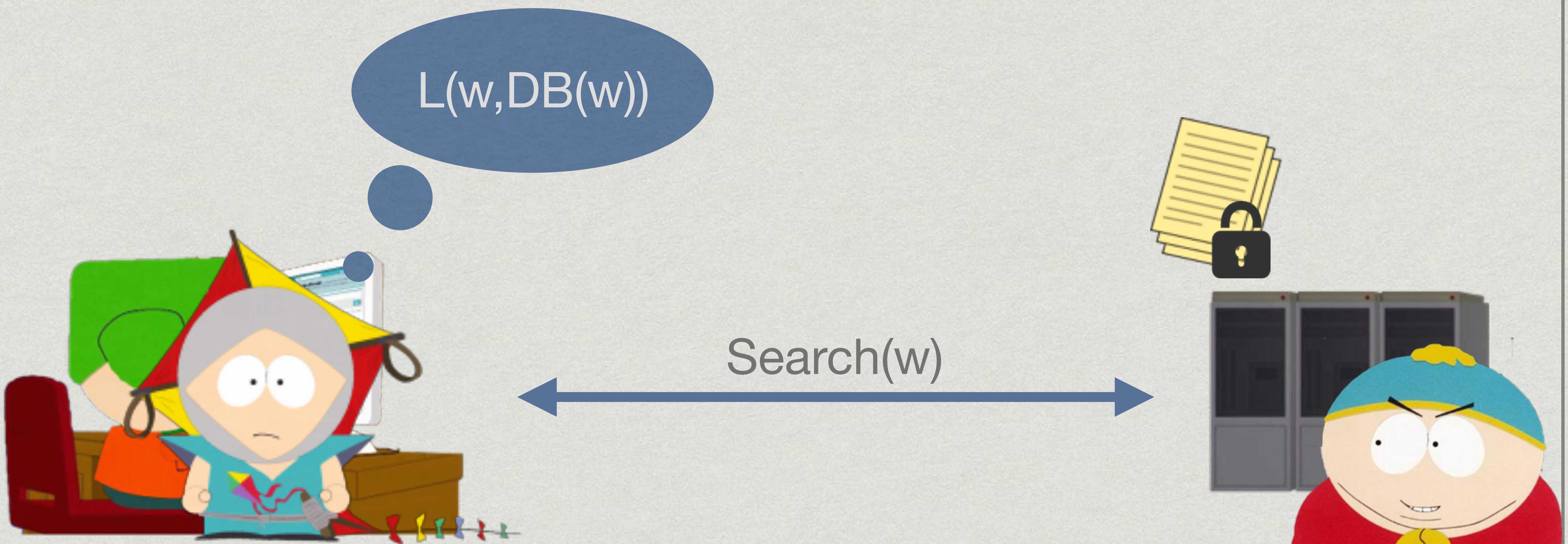


Everything the server learns, he can compute from the leakage

The search protocol can be simulated from the leakage

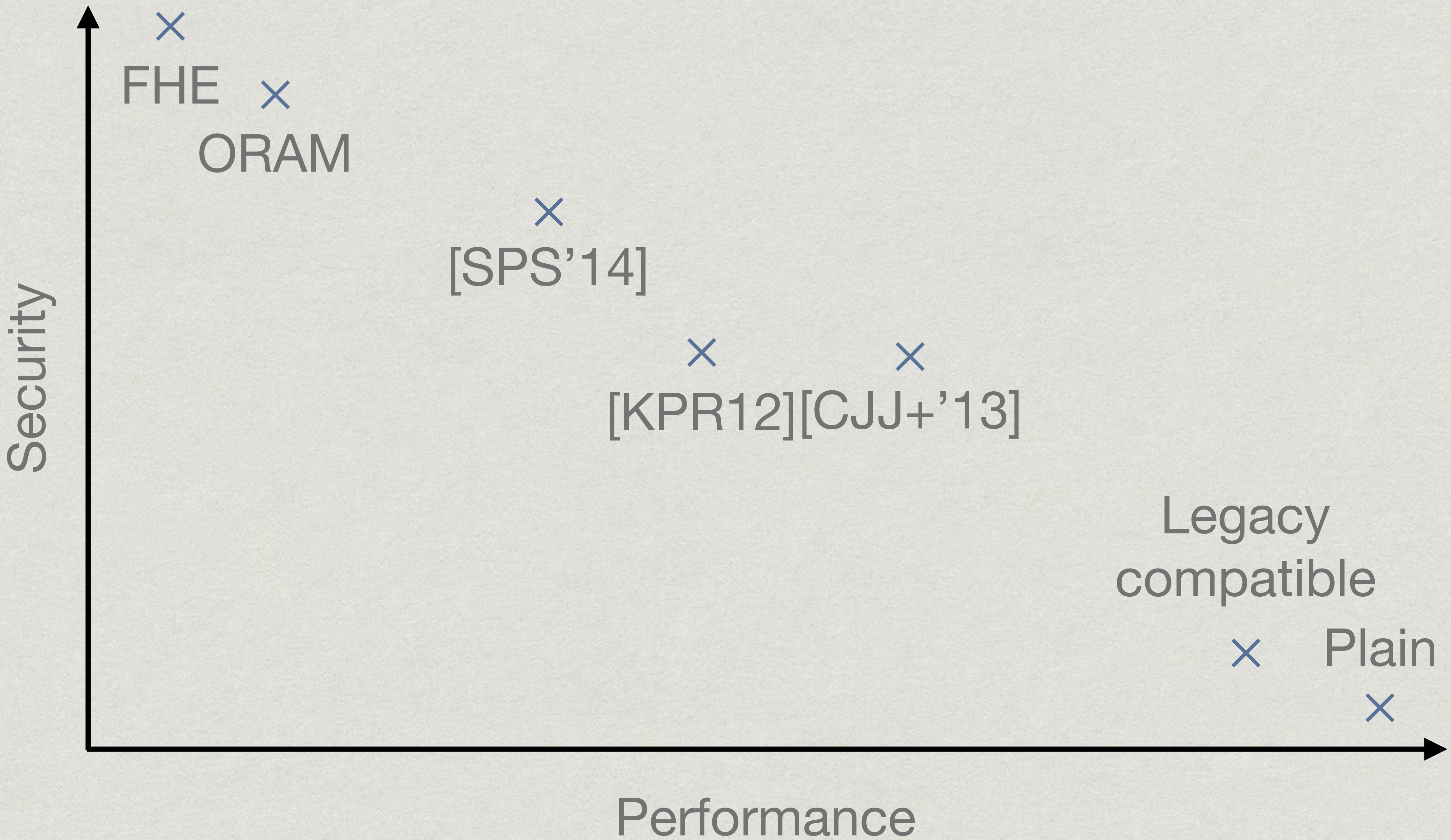
Common Leakage

* Search leakage :
  * repetition of queries (aka. search pattern)
  * results
* Update leakage:
  * updated documents
  * repetition of updated keywords
  * ...

Previous Results

- First constructions [SWP00]
- Formalization of the security model [CGKO06]
- Efficient dynamic constructions [KPR12]
- Boolean queries & scalability [CJJKRS13]
  - ↳ various extensions (dynamisms, wildcards, range queries, …)
- Reduced update leakage [SPS14]
- …

Security-Performance Tradeoff



Leakage-Abuse Attacks

- ‘Everything the server learns, he can compute from the leakage’
    - ➡ What can be computed from the leakage?
- Recover the queried keywords from the leakage

‘Passive’ Attacks

- [IKK’12]: Using a co-occurrence probability matrix, the attacker can recover from 100% to 65% of the queries
- [CGPR’15]: Improvement of the IKK attack, 100% recovery
    - ➡ Use padding as a countermeasure

‘Active’ Attacks

- [ZKP’16]: Non-adaptive file injection attacks
  - Insert purposely crafted documents in the DB. Use binary search to recover the query

D_1	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8
D_2	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8
D_3	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8

log K injected documents

‘Active’ Attacks

- [ZKP’16]: Non-adaptive file injection attacks
  - Insert purposely crafted documents in the DB. Use binary search to recover the query
  - Counter measure: no more than T kw./doc.

(K/T) · log T injected documents

  - Adaptive version of the attack

(K/T) + log T injected documents

‘Active’ Adaptive Attacks

- [ZKP’16]: File injection attacks
  - Adaptive version of the attack

(K/T) + log T injected documents

  - If the attacker has prior knowledge about the database (e.g. frequency distribution)

log T injected documents

'Active' Adaptive Attacks

- All these adaptive attacks use the update leakage:
  - For an update, most SE schemes leak if the inserted document matches a previous query
  - We need SE schemes with oblivious updates

Forward Privacy

Forward Privacy

- An SE scheme is forward private if its update protocol does not leak any information about the updated keywords

$$L(op,w,ind) = L'(op, ind)$$

- Important feature: secure online build of the EDB

- Only one existing scheme so far [SPS'14]

  ➡ Very close to ORAM (logarithmic updates)

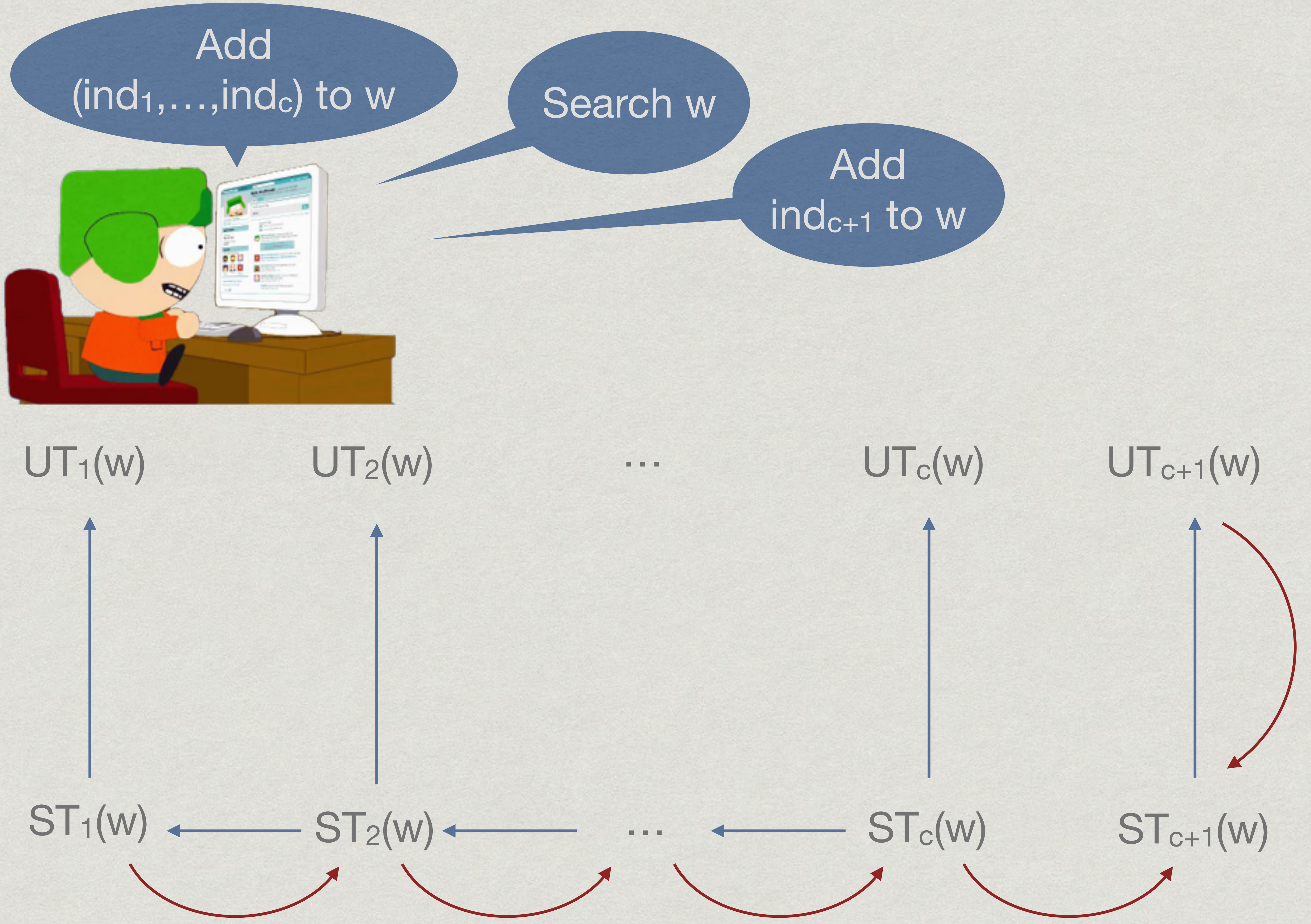
Add
$(ind_1, \ldots, ind_c)$ to w

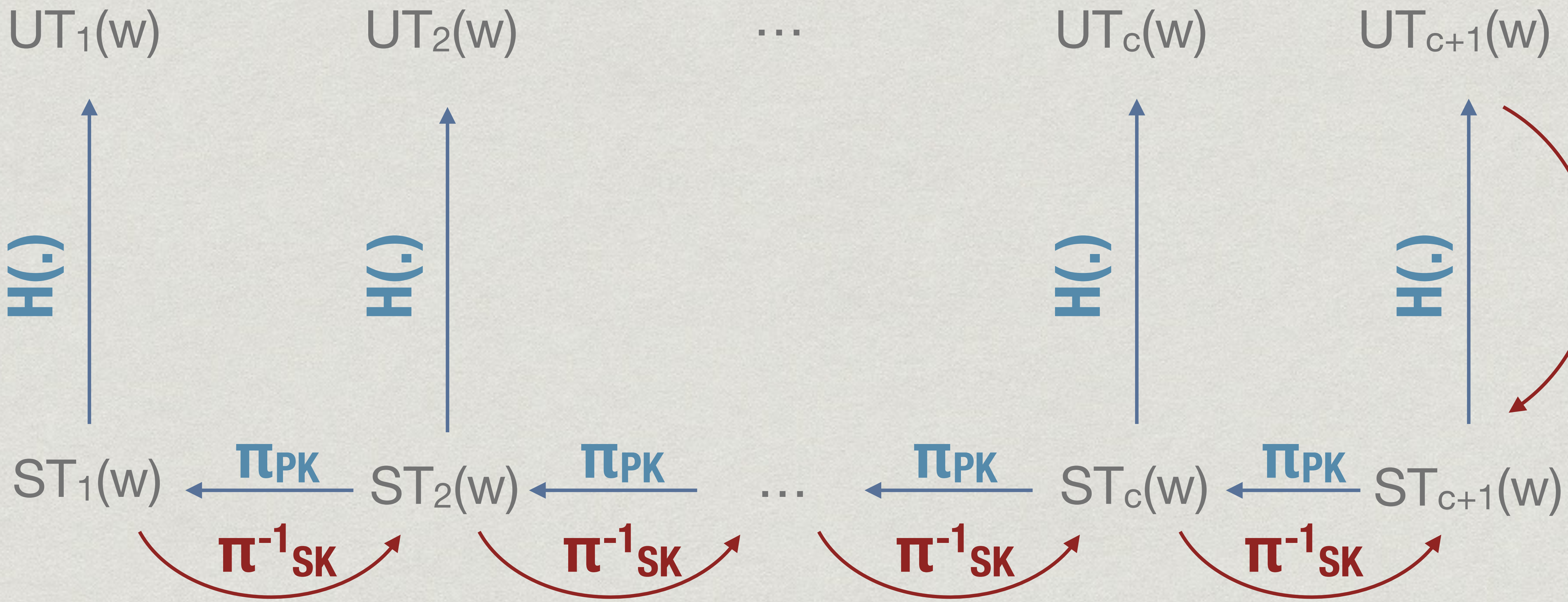
Search w

$UT_1(w)$ $UT_2(w)$ … $UT_c(w)$

…

$ST(w)$


Add
(ind$_1$,…,ind$_c$) to w
Search w
Add
ind$_{c+1}$ to w
UT$_1$(w)
UT$_2$(w)
…
UT$_c$(w)
UT$_{c+1}$(w)
ST$_1$(w)
ST$_2$(w)
…
ST$_c$(w)
ST$_{c+1}$(w)



- Naïve solution: $ST_i(w) = F(K_w, i)$
  - ✗ Client needs to send c tokens
  - ✗ Sending only K_w is not forward private
- Use a trapdoor permutation

Σοφος - Complexity

- Search(w): **Optimal**
  Client: O(1)
  Server: O(|DB(w)|)
- Update(+,w, ind): **Optimal**
  Client: O(1)
  Server: O(1)
- Storage:
  Client: O(K)
  Server: O(N) **Optimal**

Σοφος

- TDP π? RSA or Rabin
    - ✗ Elements (STs) are large (2048 bits).
    - ✗ Client storage is impractical
- Pseudo-randomly generate $ST_0(w)$, and compute $ST_c(w)$ on the fly (only c is stored by the client)
    - ✓ Efficient (non-iterative) using RSA
- Search is embarrassingly parallelizable

$$x^{d^{\cdot^{\cdot^{\cdot^{d}}}}} = x^{(d^c \bmod \phi(N))} \bmod N$$

Σοφος - Security

- Update leakage: nothing

Forward private

- Search leakage:
  - search pattern
  - ‘history’ of w: the timestamped list of updates of keyword w

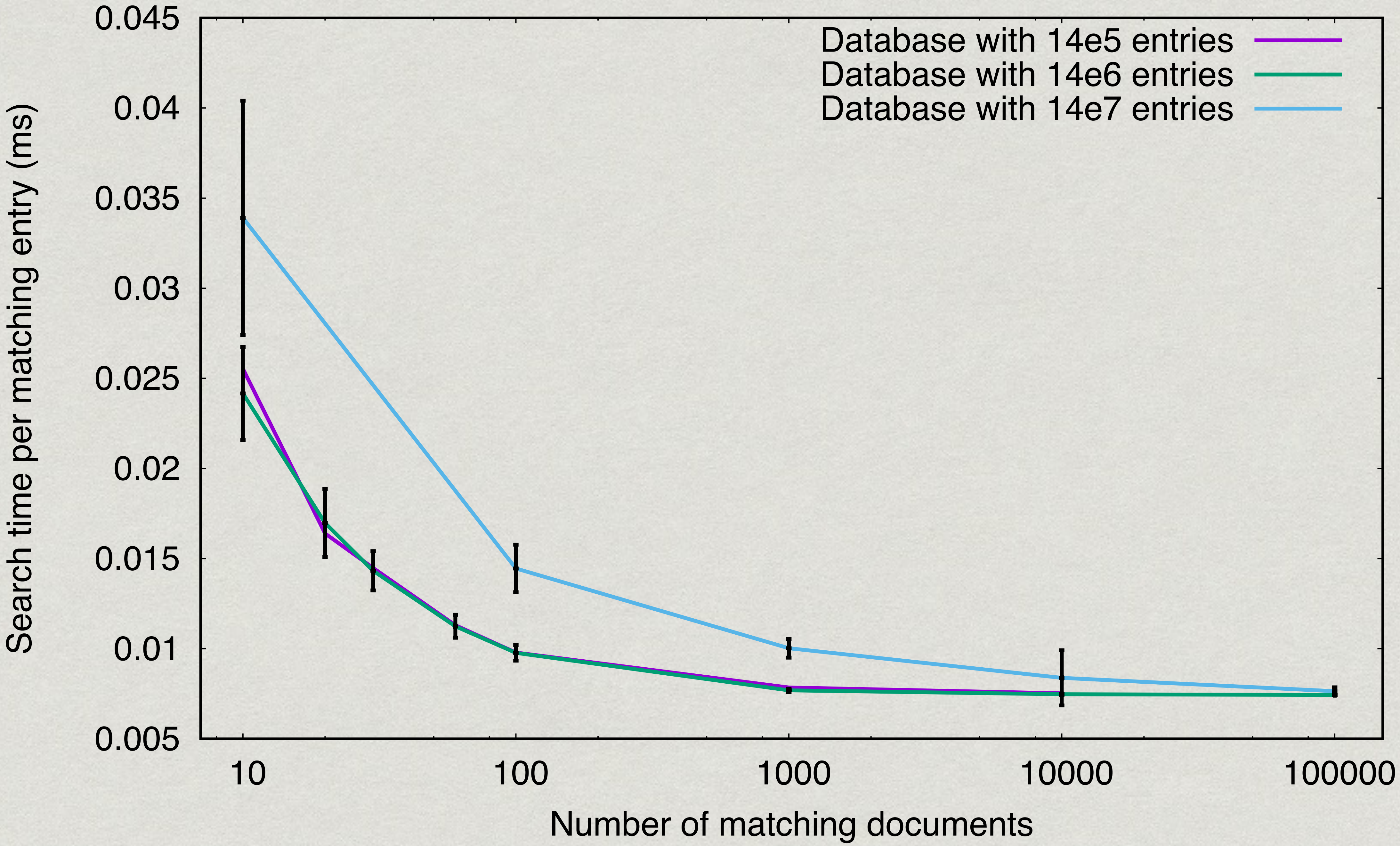
Adaptive security (ROM)

Σοφος - Evaluation

- C/C++ full fledged implementation
- Server KVS: RockDB
- Evaluated on a desktop computer
  4 GHz Core i7 CPU, 8GB RAM, SSD

https://gitlab.com/sse/sophos

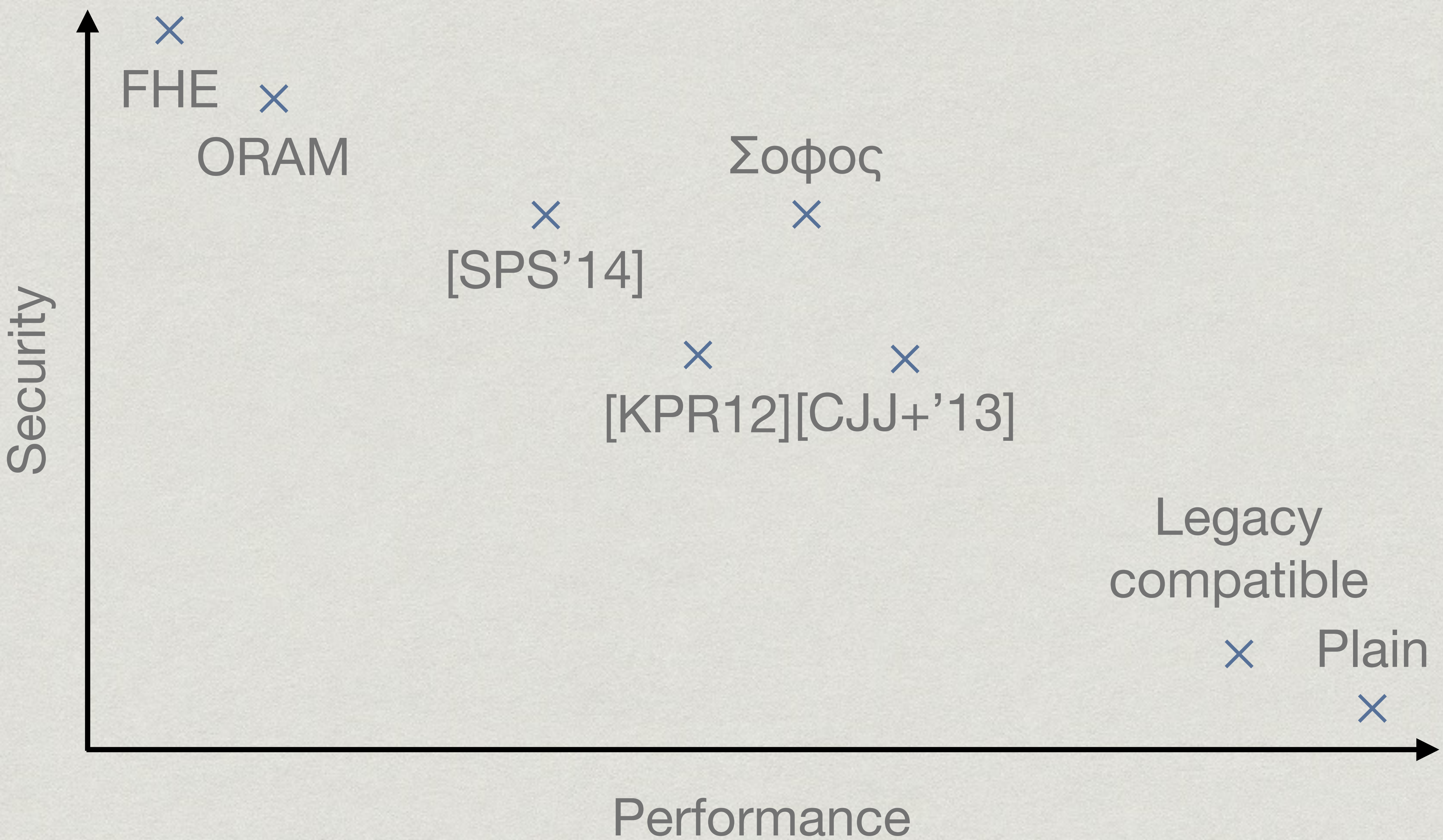
Σοφος - Evaluation



Σοφος

* Provable forward privacy
* Efficient search
* Asymptotically efficient update (optimal)
* In practice, very low update throughput (4300 p/s - 20x slower than other work)

Security-Performance Tradeoff



Ongoing/future work

* Improve the update throughput (get rid of RSA)
* Dynamic padding
* Thwart (non-adaptive) file injection attacks

THANKS!