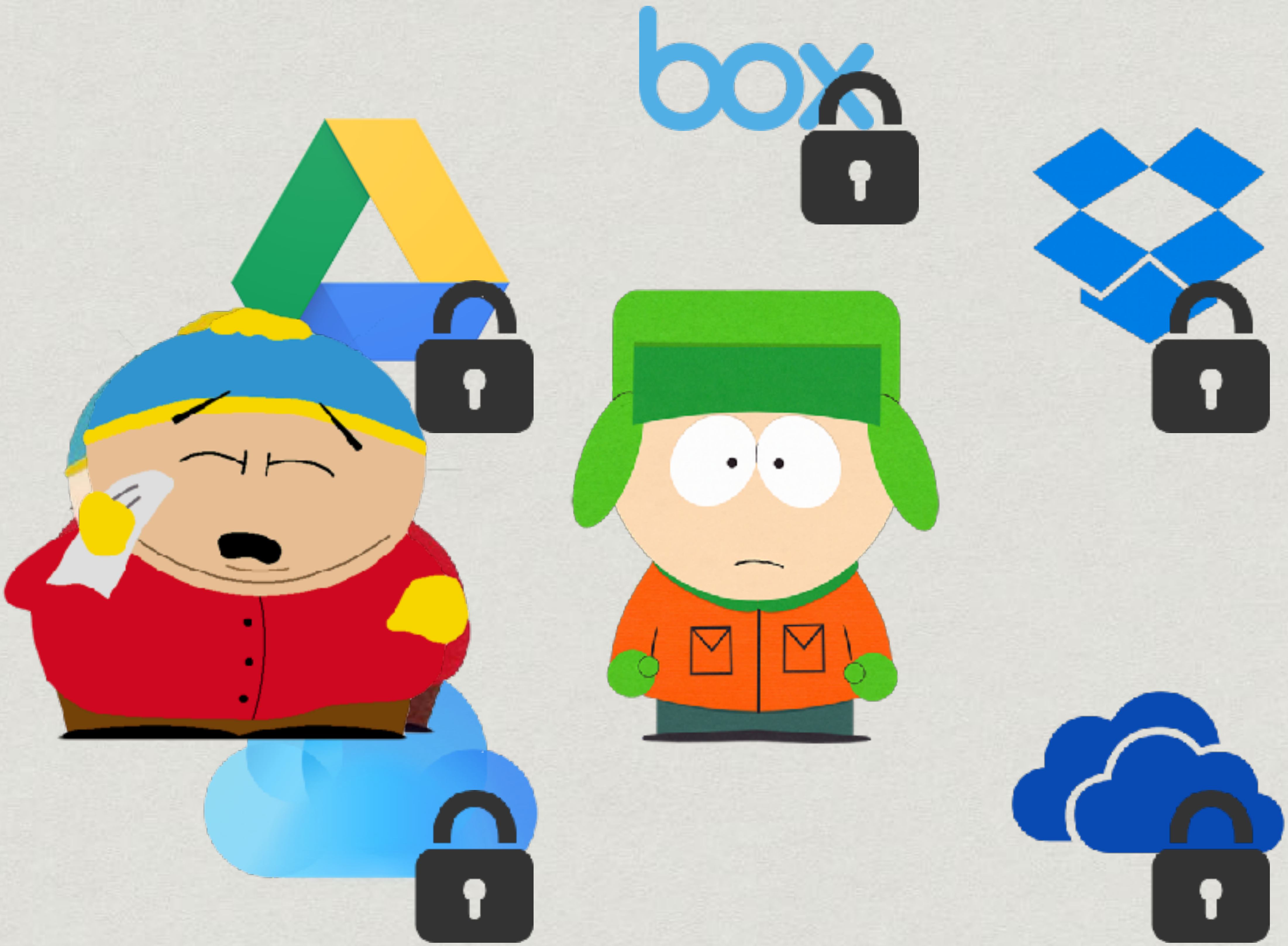
FORWARD PRIVATE SEARCHABLE ENCRYPTION & BEYOND

DATE 22/02/2017

MIT - RAPHAEL BOST

box


box

Searchable Encryption

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

Generic Solutions

Fully Homomorphic Encryption, MPC, ORAM

- ✓ Perfect security
- ✗ Large overhead (computation, communication)

Ad-hoc Constructions

Can we get more efficient solutions?

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

Security/performance tradeoff

Property Preserving Encryption

Deterministic Encryption, OPE, ORE

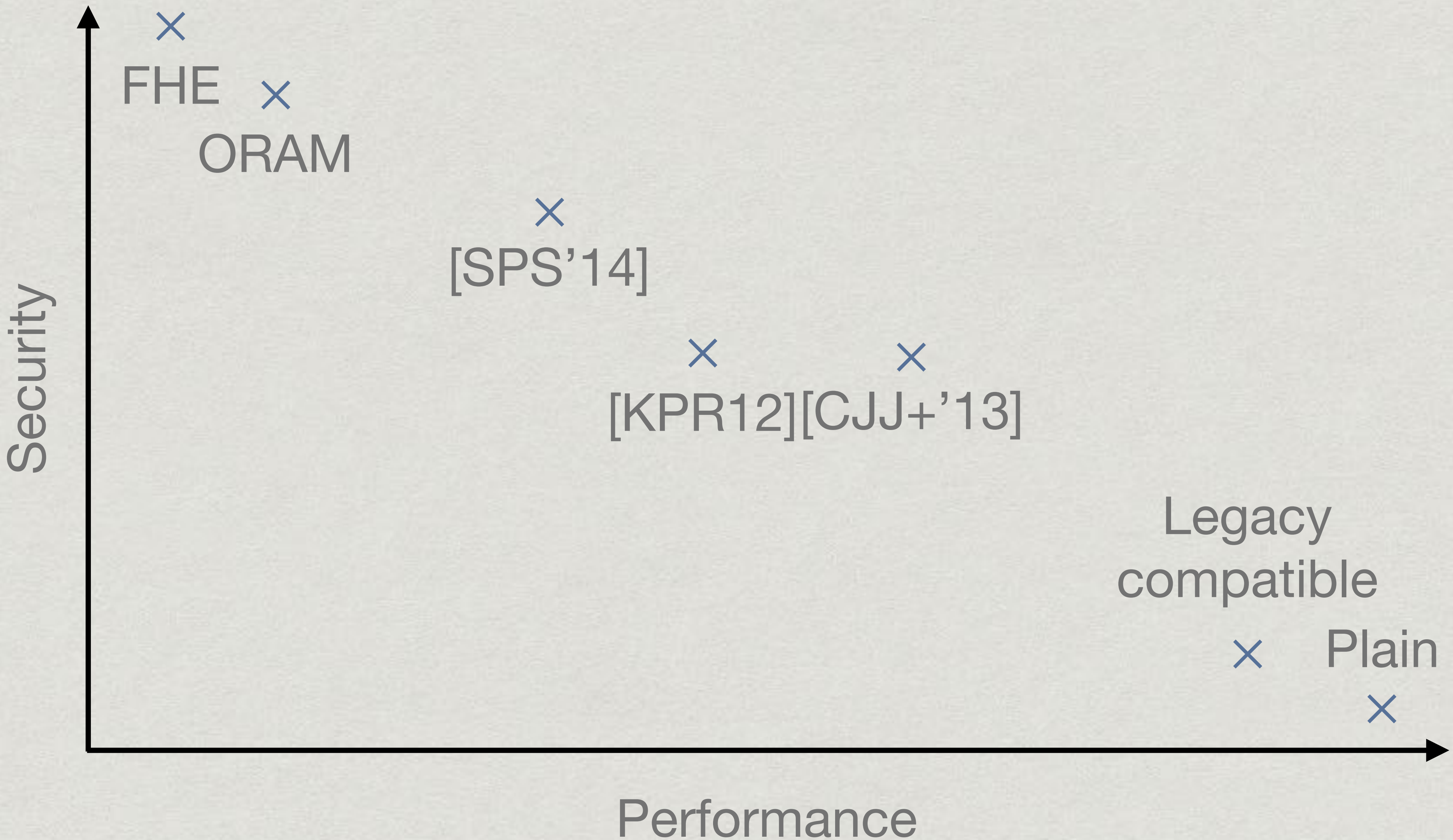
- ✓ Legacy compatible
- ✓ Very Efficient
- ✗ Not secure in practice (*e.g.* attacks on CryptDB)

Index-Based SE [CGKO'06]

Structured encryption of the reversed index: search queries allow partial decryption

- Search leakage :
  - repetition of queries (search pattern)
- Update leakage:
  - updated documents
  - <u>repetition of updated keywords</u>

Security-Performance Tradeoff



‘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

File Injection 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 <u>previous</u> query
  - We need SE schemes with oblivious updates

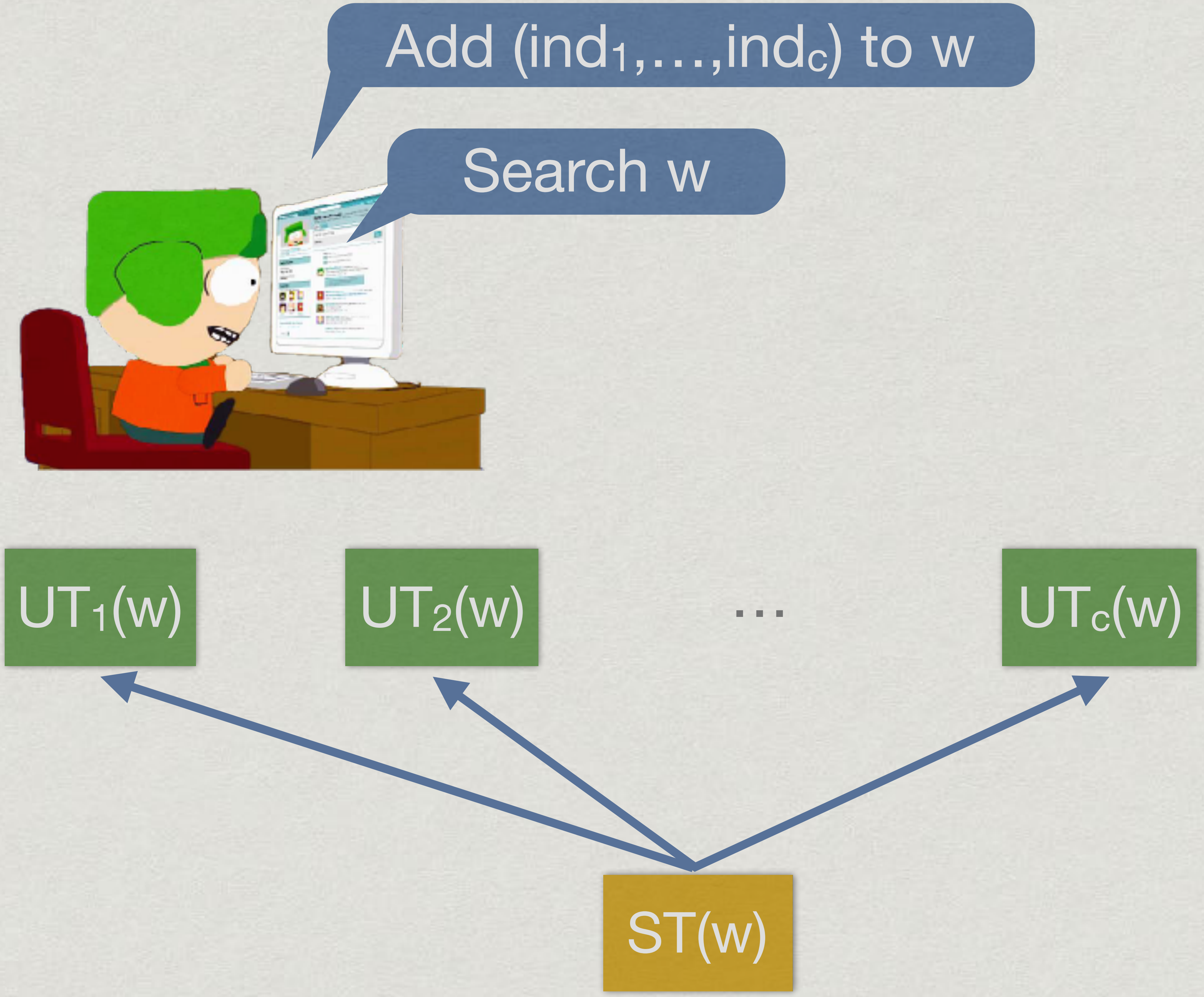
Forward Privacy

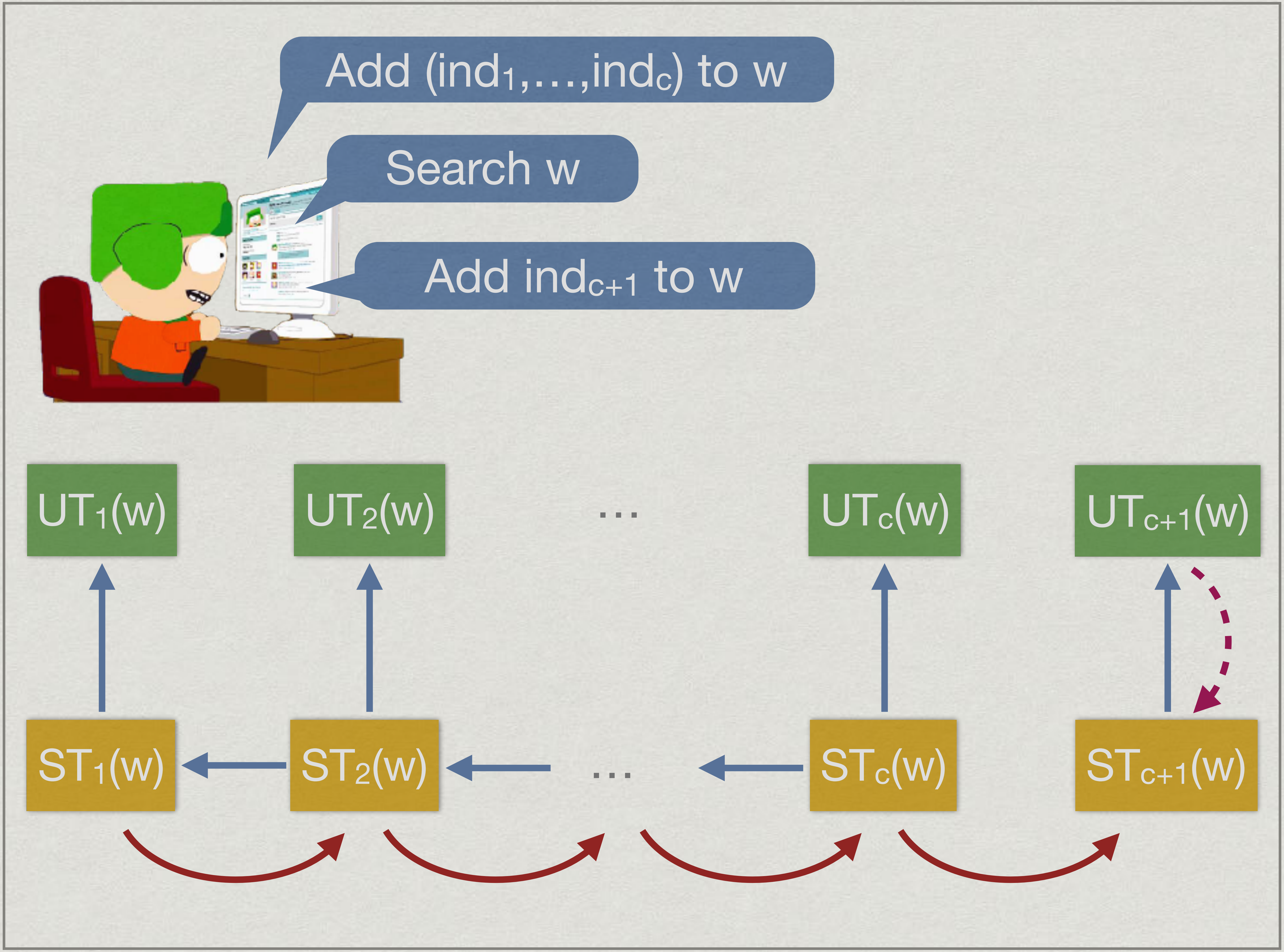
Forward Privacy

- Forward private: an update does not leak any information on the updated keywords
- Secure online build of the EDB
- Only one existing scheme so far [SPS'14]
    - ➡ ORAM-like construction
    - ✗ Inefficient updates
    - ✗ Large client storage

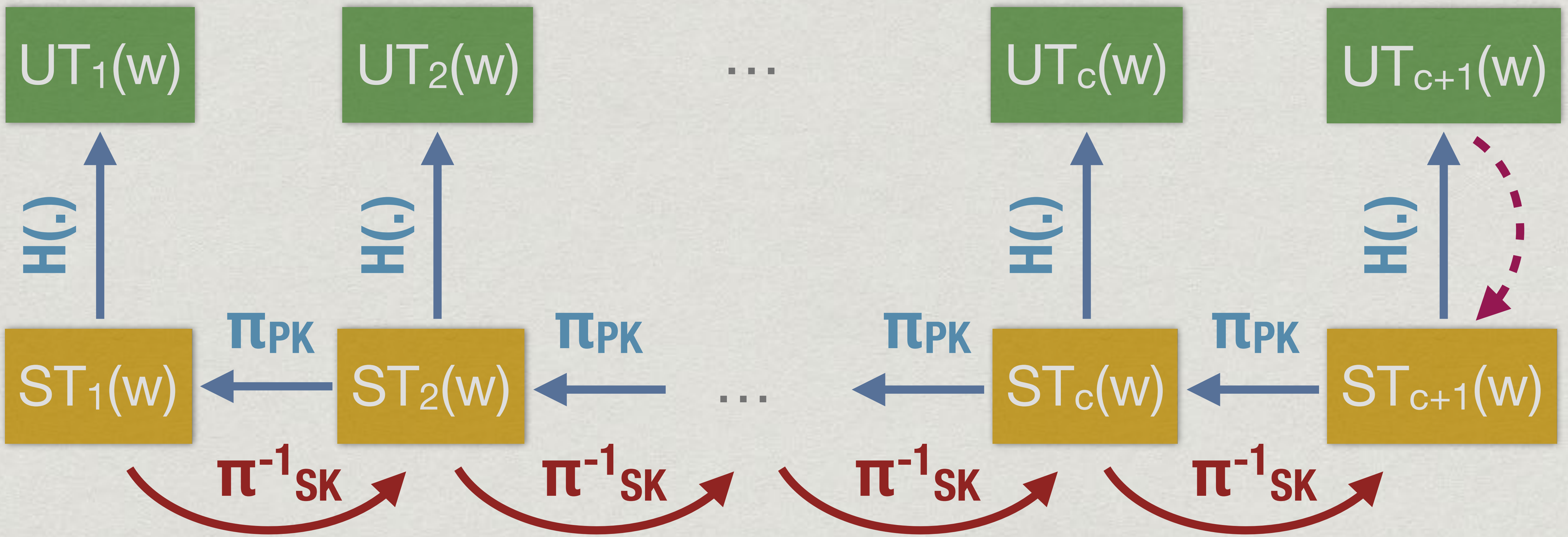
Σοφος

* Forward private index-based scheme
* Low search and update overhead
* A lot simpler than [SPS'14]

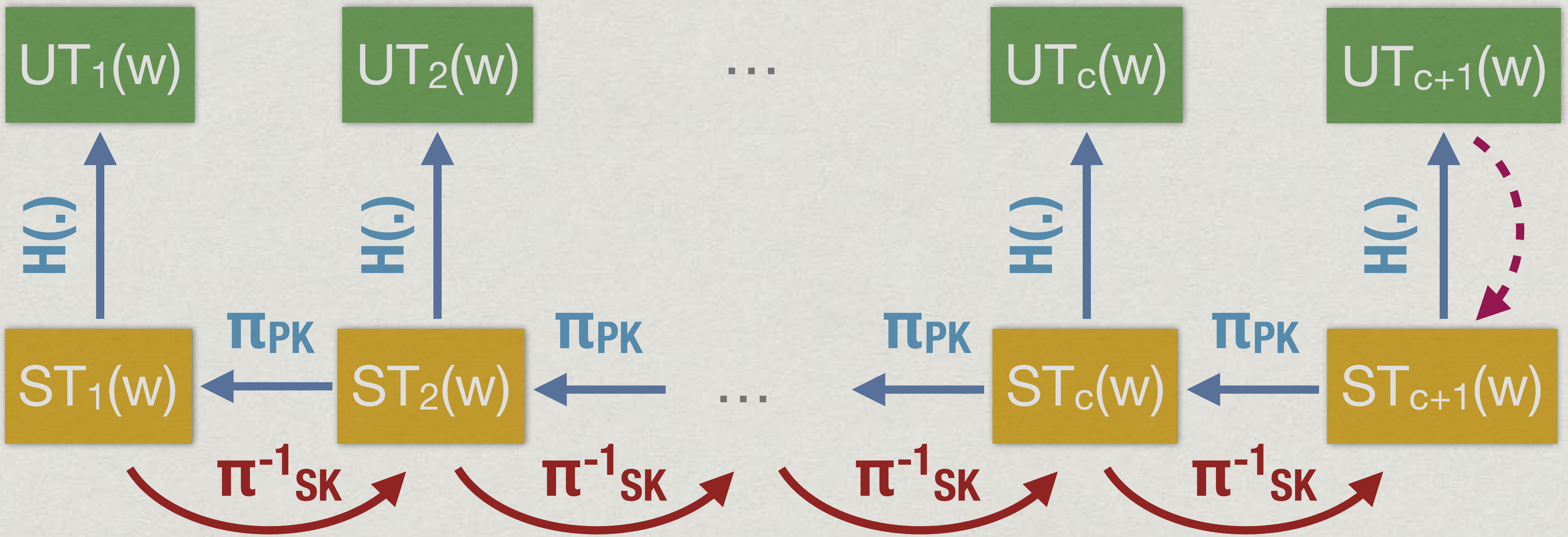

Add (ind1,…,indc) to w
Search w
UT1(w)
UT2(w)
…
UTc(w)
ST(w)



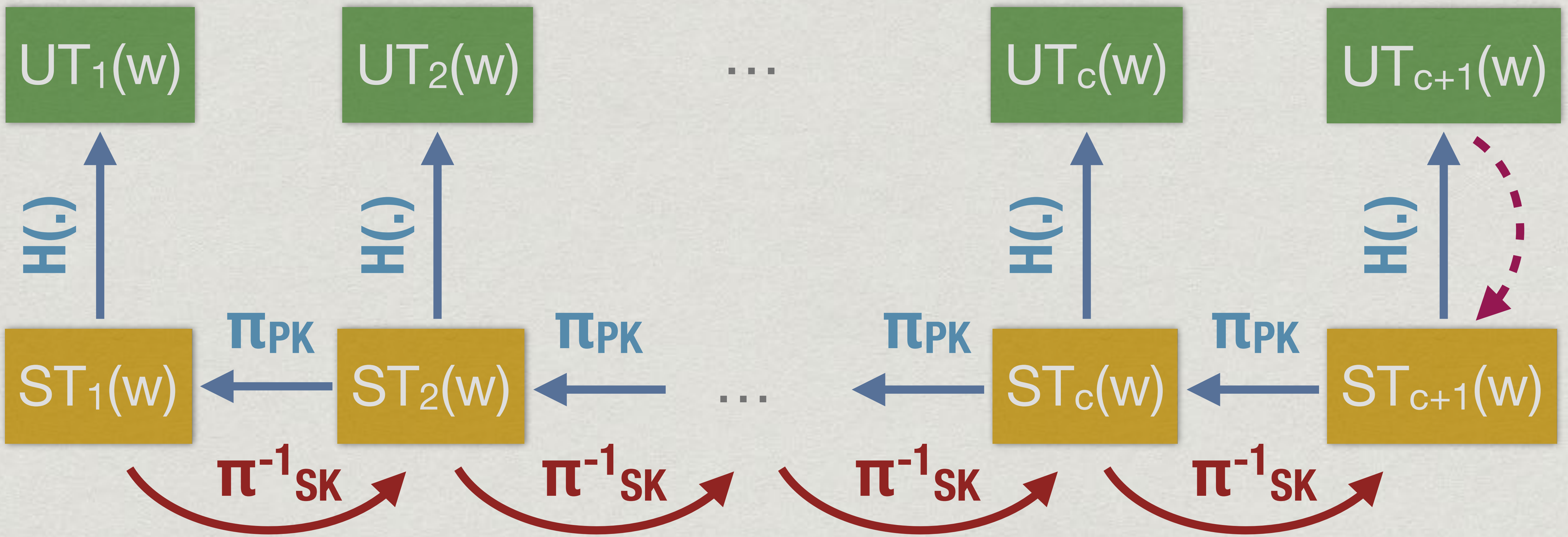
Add (ind1,…,indc) to w
Search w
Add indc+1 to w
UT1(w)
UT2(w)
…
UTc(w)
UTc+1(w)
ST1(w)
ST2(w)
…
STc(w)
STc+1(w)



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



- Client stores $W[w] := ST_c(w)$
- Search w: send $ST_c(w)$
- Update: $W[w] := \pi^{-1}_{SK}(ST_c(w))$



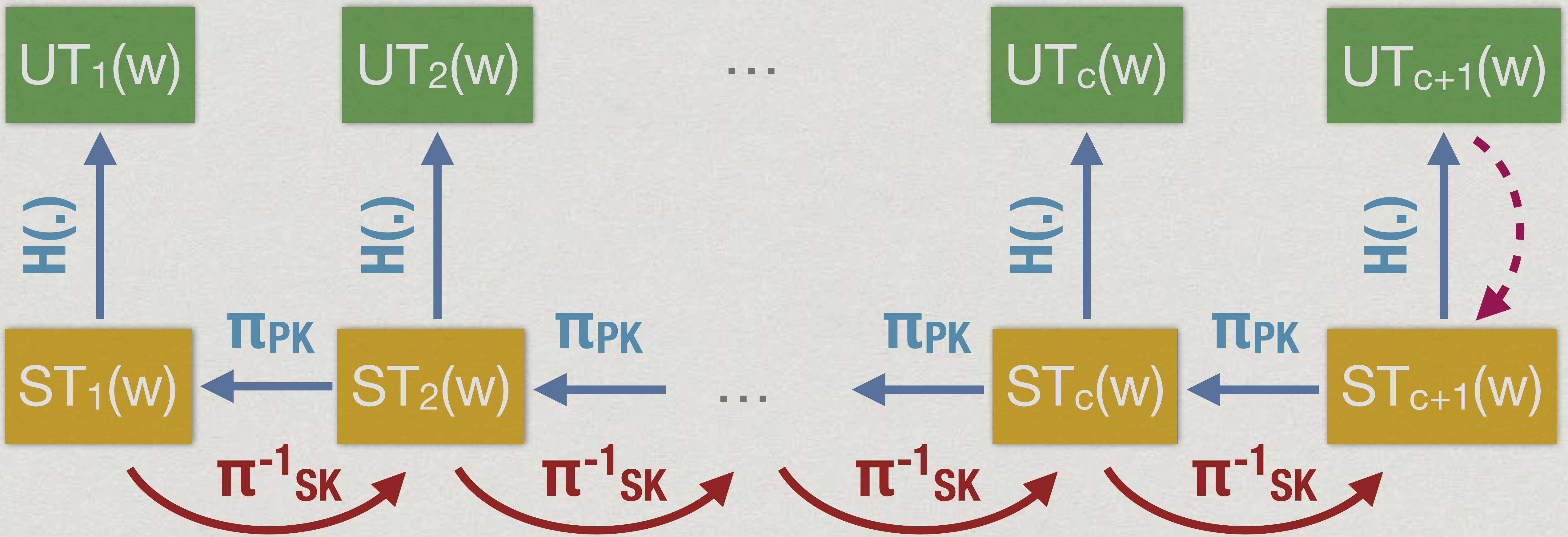
Search:

- Client: constant
- Server: O(|DB(w)|)

Update:

- Client: constant
- Server: constant

Optimal



Storage:

- Client: $O(K)$
- Server: $O(|DB|)$

Σοφος

- TDP π? RSA or Rabin
  - ✗ Elements (STs) are large (2048 bits).
  - ✗ Client storage is impractical
- Client only stores *c*, pseudo-randomly generates $ST_1(w)$, computes $ST_c(w)$ on the fly
  - ✓ 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

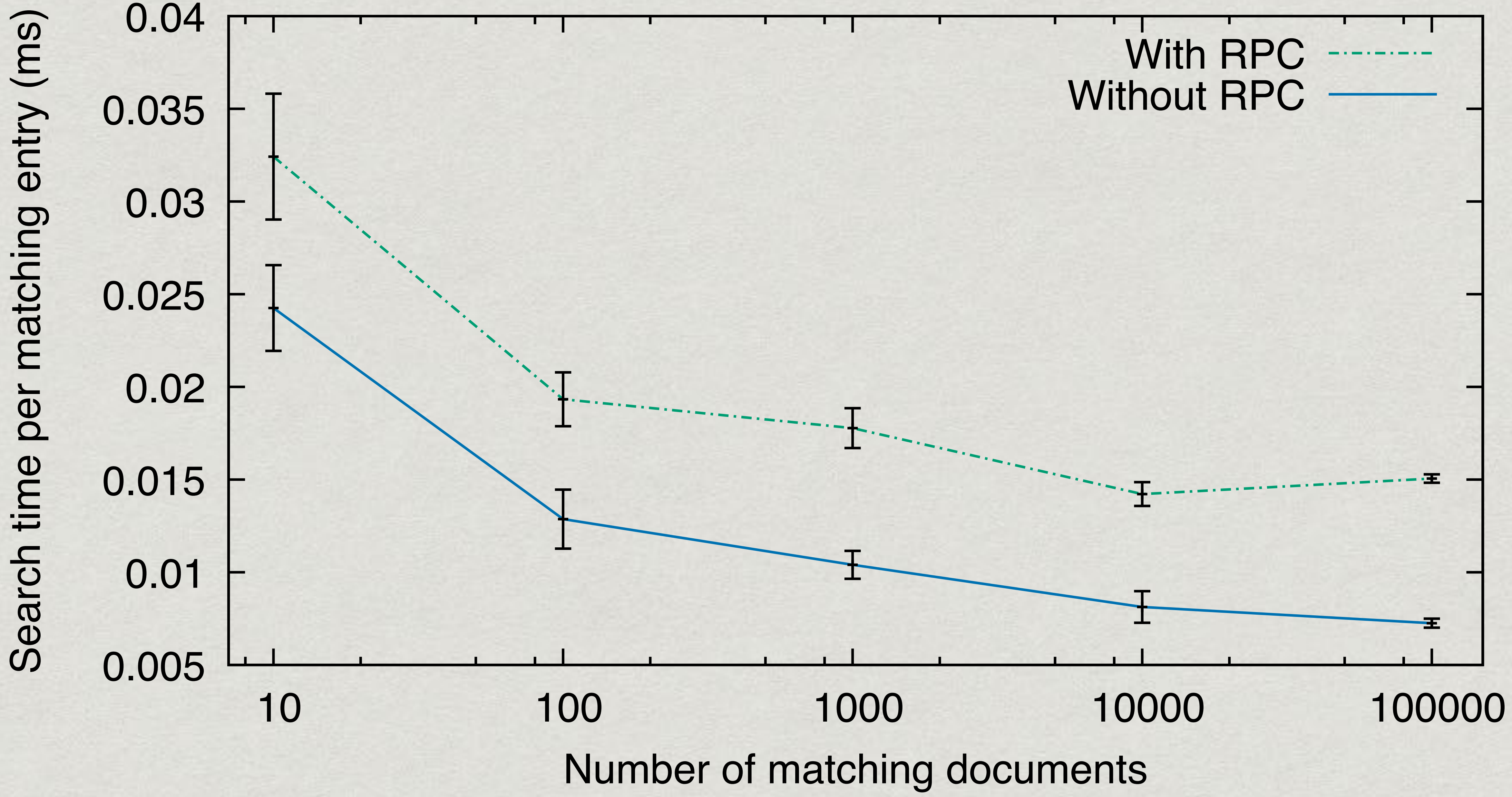
- C/C++ full fledged implementation
- Server KVS: RocksDB
- Evaluated on a desktop computer
  4 GHz Core i7 CPU (16 cores), 16GB RAM, SSD

https://gitlab.com/sse/sophos

Σοφος - Evaluation

2M keywords, 140M entries

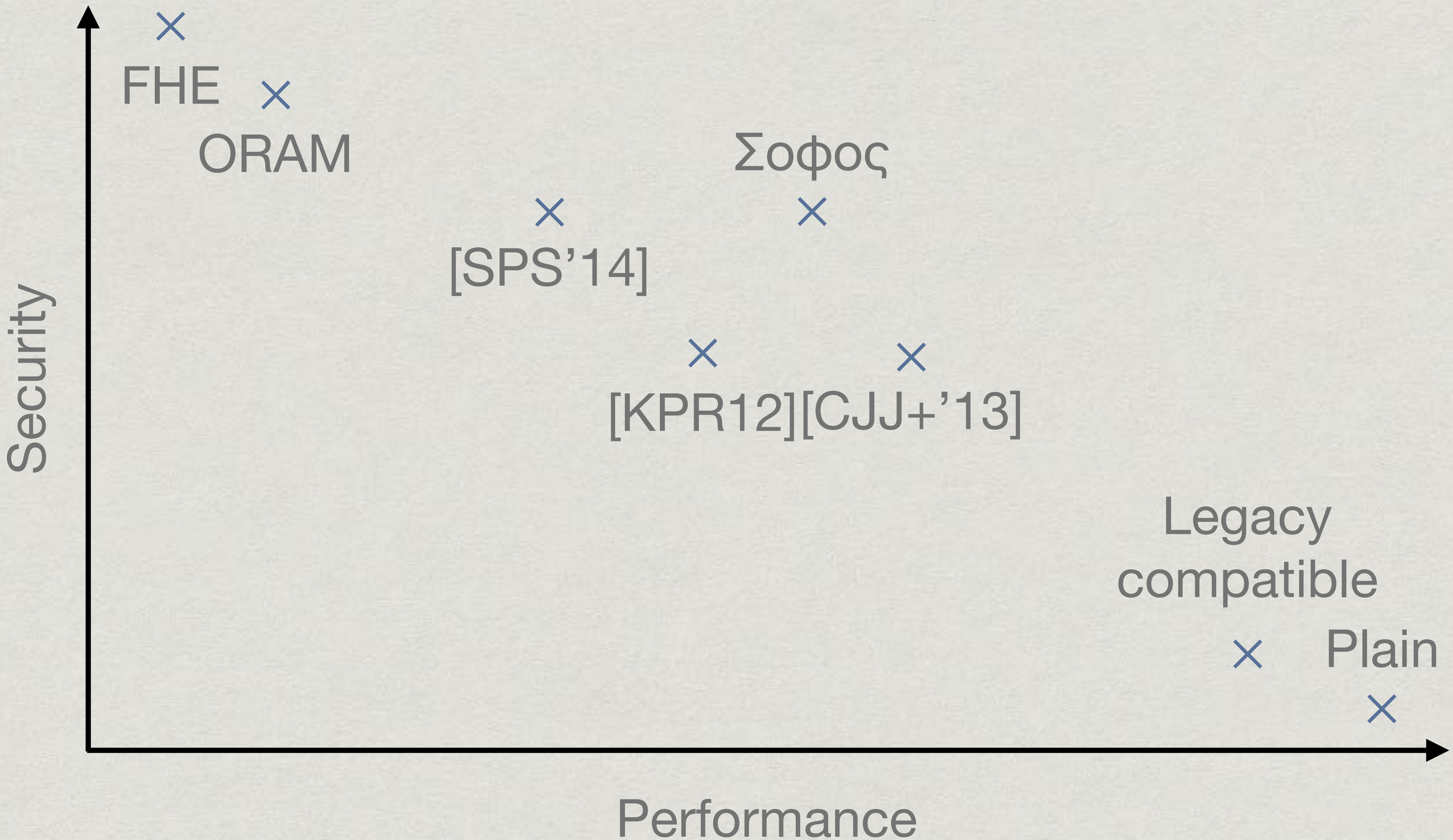
5.25GB server storage, 64.2 MB Client storage



Σοφος

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

Security-Performance Tradeoff



BEYOND FORWARD PRIVACY

PRACTICAL ISSUES WITH SEARCHABLE ENCRYPTION AND OPEN PROBLEMS

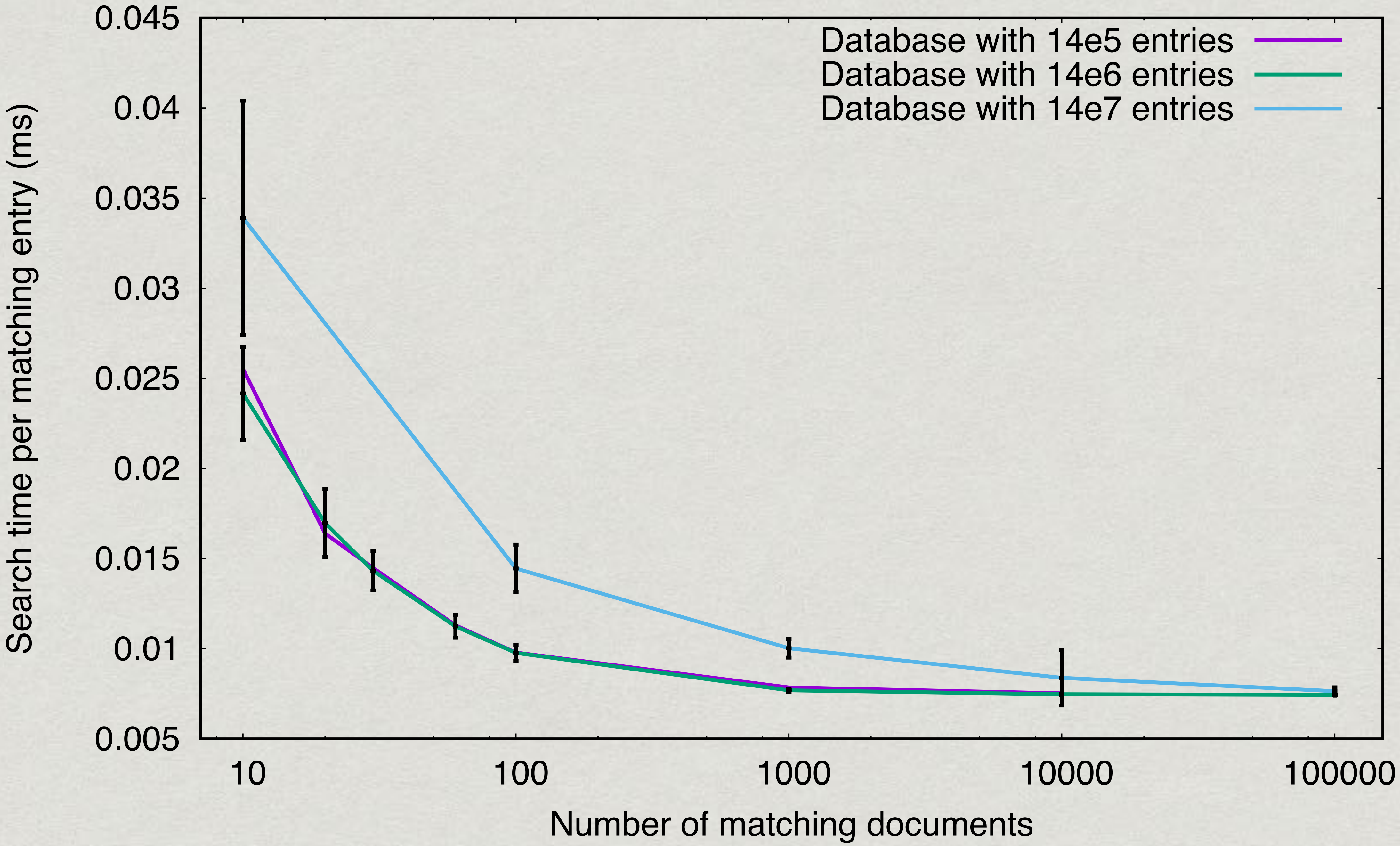
Thwarting File Injections

- Σοφος only thwarts the adaptive file injection attacks
- Idea: randomly delay the insertion of entries in the the database
- How to define the security of such counter-measures?

Locality

- Σοφος makes 1 random access/match
  - Even with SSDs, random disk accesses are <u>very</u> expensive
- One cannot construct a (static) SE scheme with optimal locality, linear storage, or optimal search complexity [CT'14]
- [ANSS'16] built a scheme with optimal loc., linear storage, and high read efficiency (log log N)

Σοφος - Locality



Locality and Forward Priv.

* The [ANSS'16] solution is inherently static. What about dynamic schemes?
* Locality goes <u>against</u> forward privacy
  Locality: put entries with the same kw. close
  F.P.: entries matching the same kw. are unrelated
* I think there is a (complicated) lower bound involving locality, comm. complexity, DB size and read efficiency

Open Problem

Locality in practice

* Regroup entries matching the same keyword by (large) blocks
* [MM'17] combine this idea with ORAM to save 80% of the IOs during search
* Other proposal: cache search results

Other adversaries

- The literature only focuses on persistent adversaries. Could we have better guarantees against weaker ones?
- Snapshot adversaries, ‘late’ persistent adversaries
- Might be important in practice: e.g. when caching previous queries’ results

Backward Privacy

- Queries should not be executed over deleted documents (*cf.* secure deletion)
- Only interesting against ‘late’ persistent adversaries
- Achieved by ORAM. Looks hard to achieve efficiently (single interaction, low comm. complexity)

THANKS!

Paper: http://ia.cr/2016/728
Code: https://gitlab.com/sse/sophos