VERIFIABLE SYMMETRIC SEARCHABLE ENCRYPTION

DATE 09/03/2016

SÉMINAIRE EMSEC - RAPHAEL BOST

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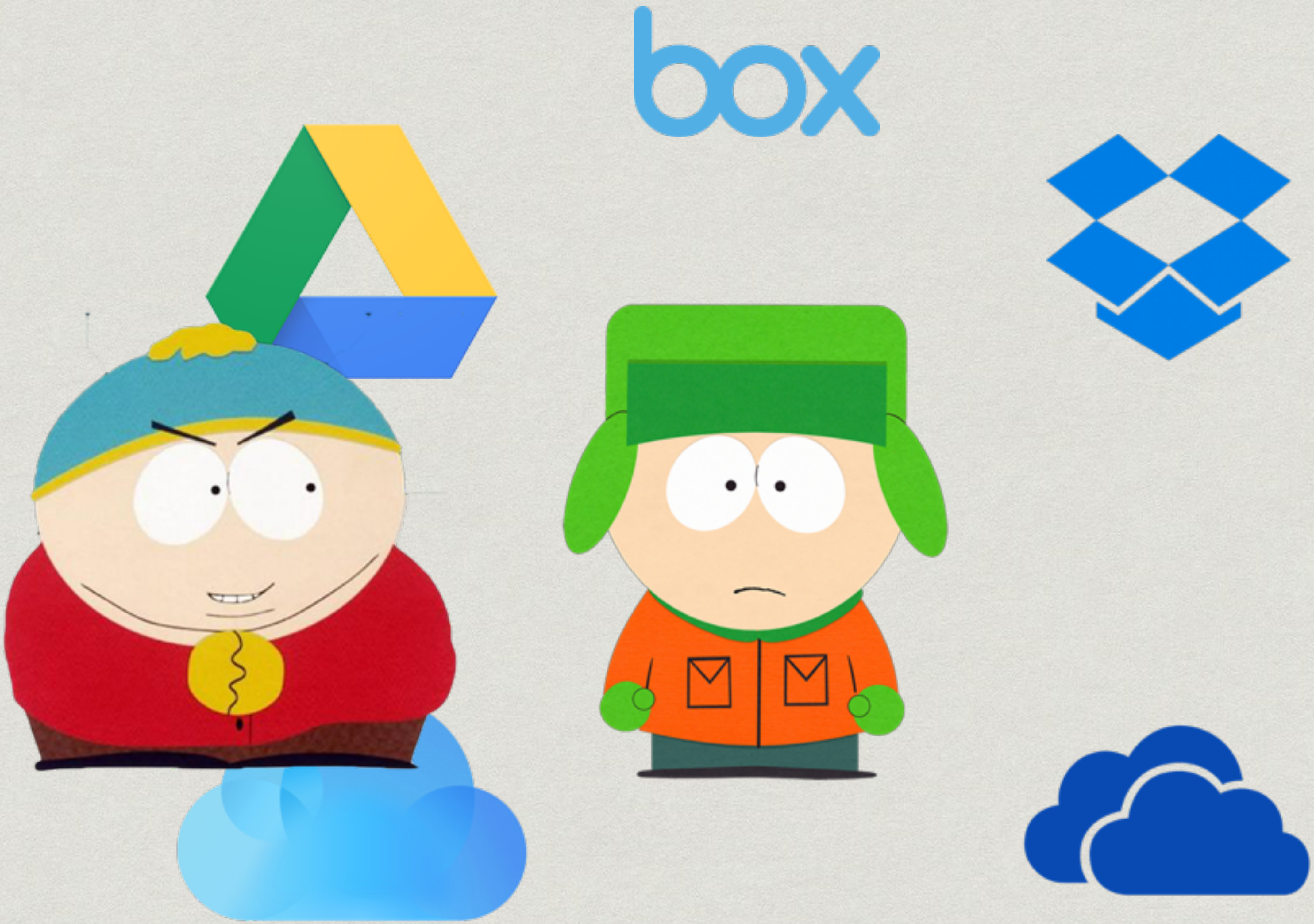
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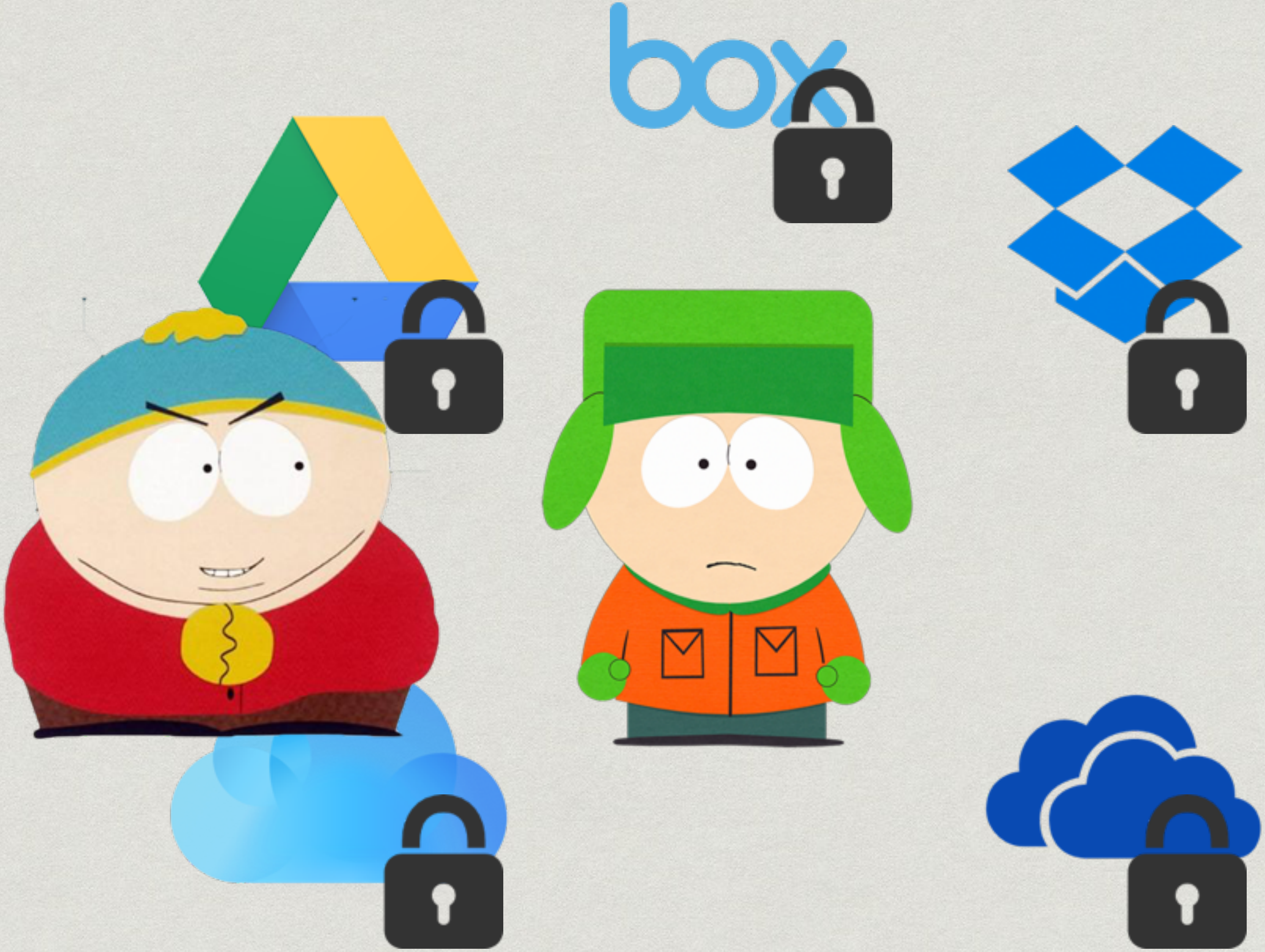
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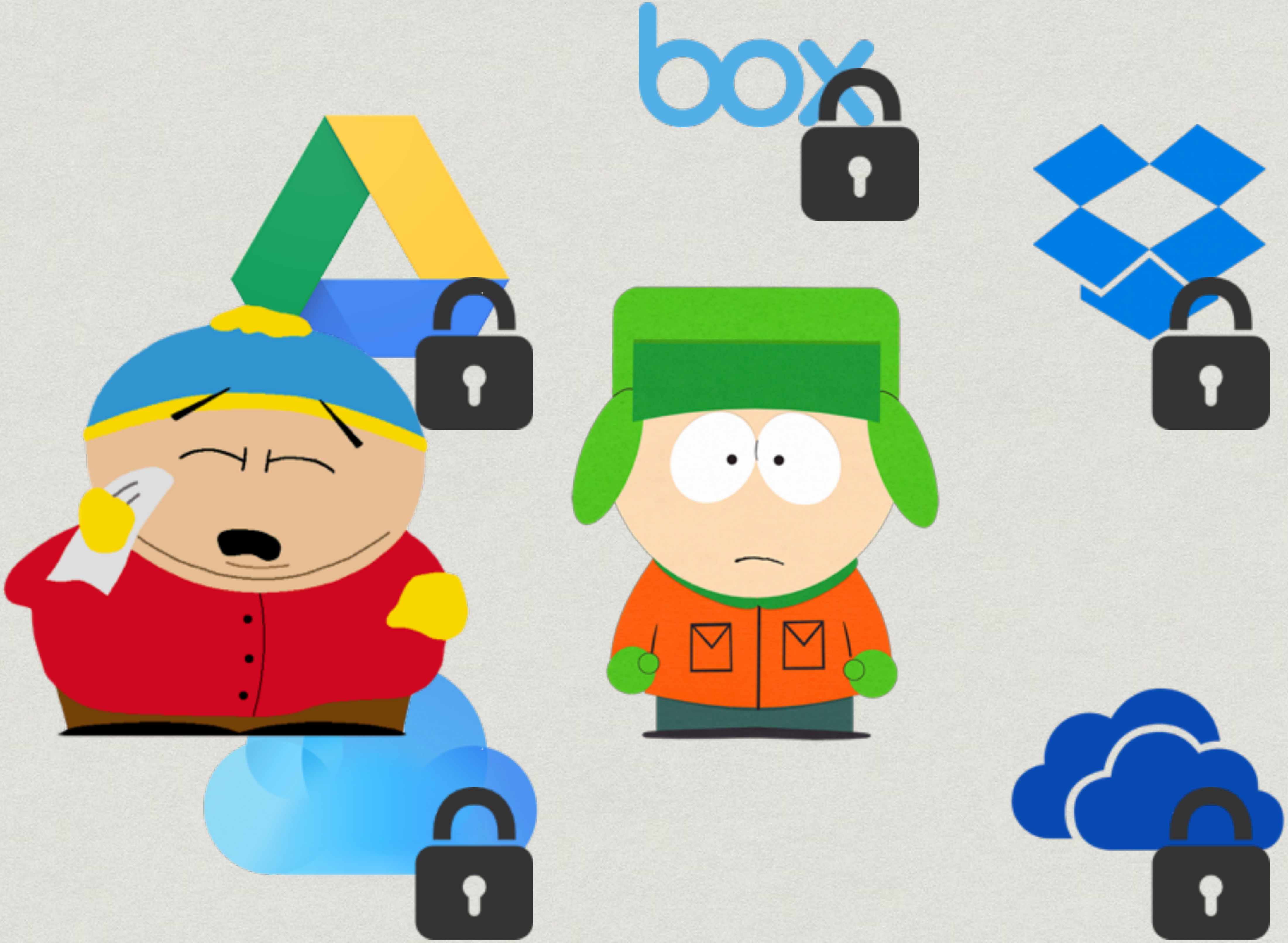
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Searchable Encryption

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

Generic Solutions

We can use generic tools to solve this problem:

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    Complexity linear in the DB size

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* 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

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Security/performance tradeoff

Security of SSE

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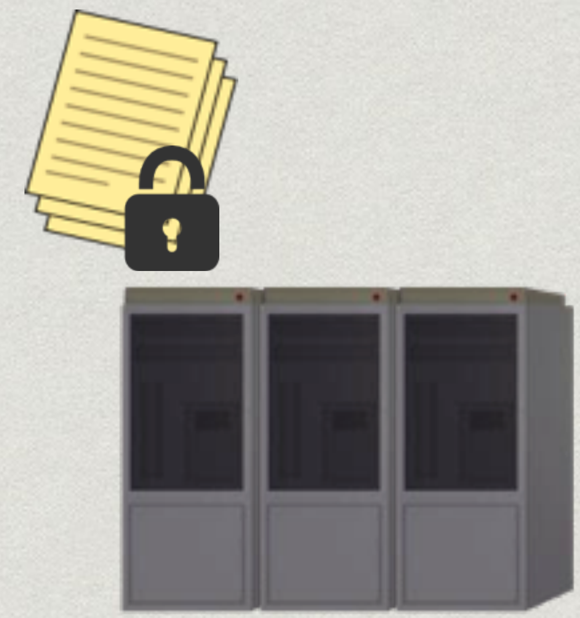

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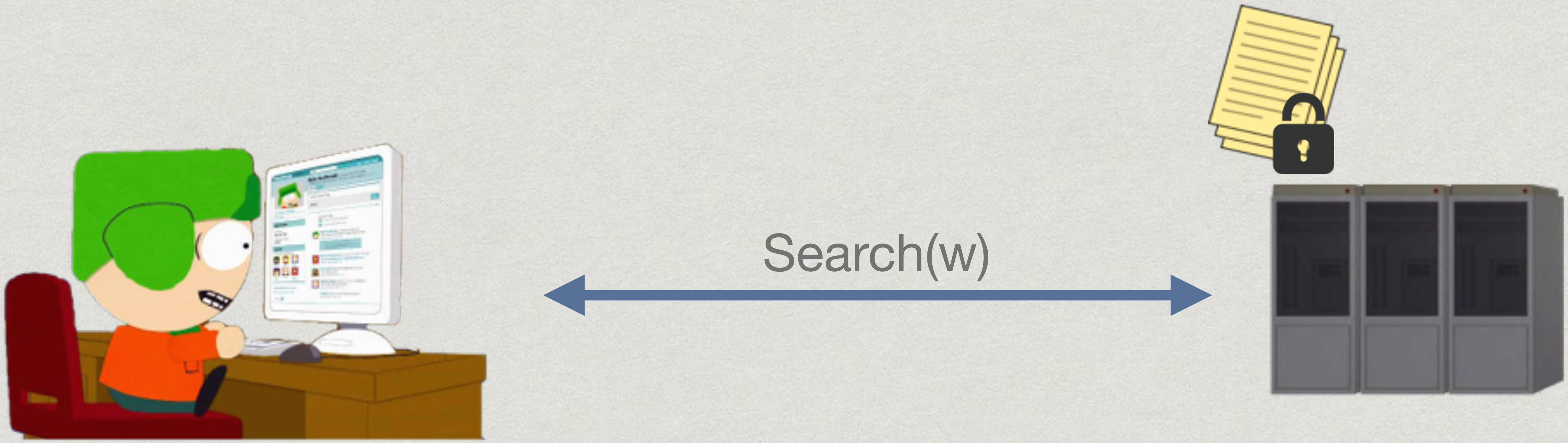

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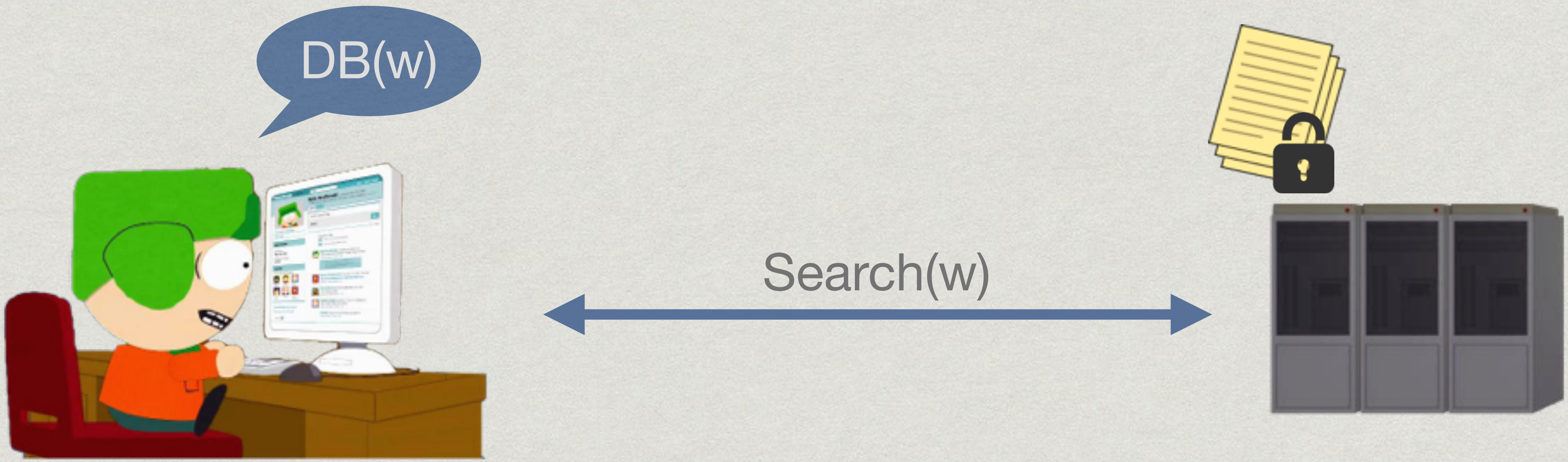

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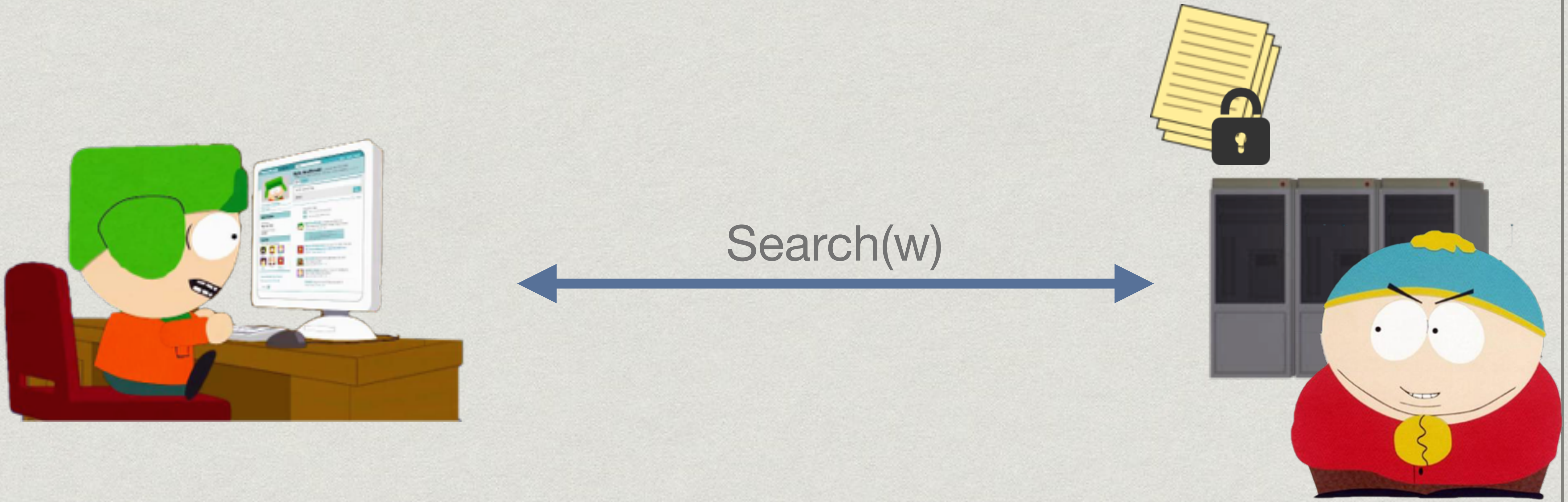

Security of SSE

Search(w)

Everything the server learns, he can compute from the leakage

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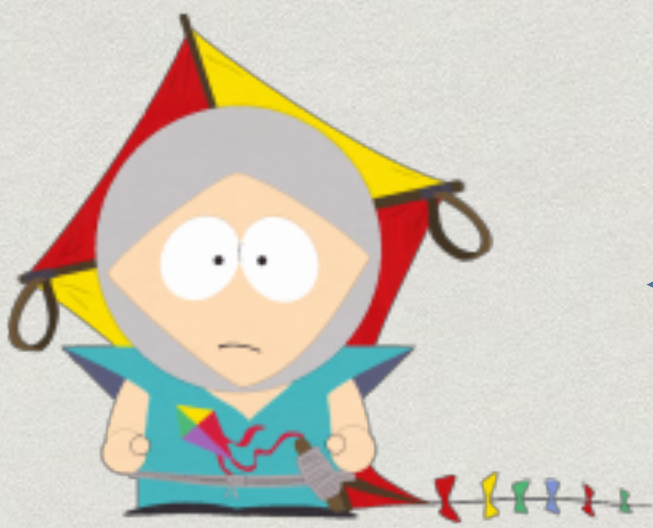

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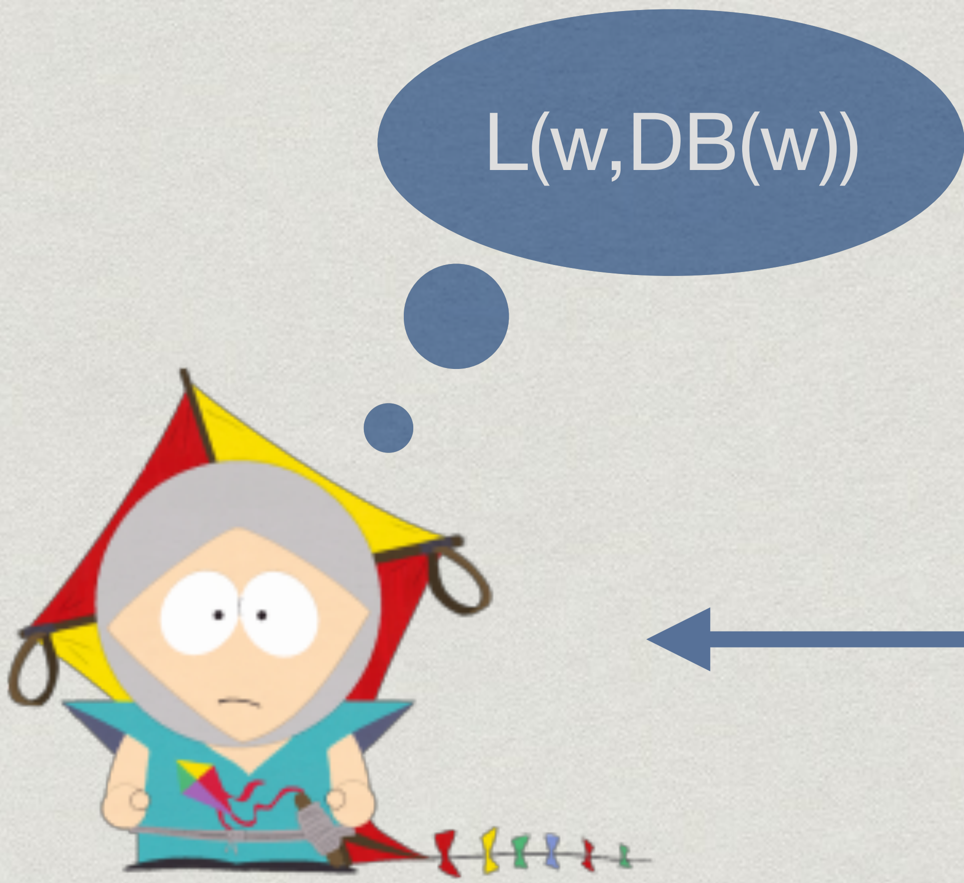

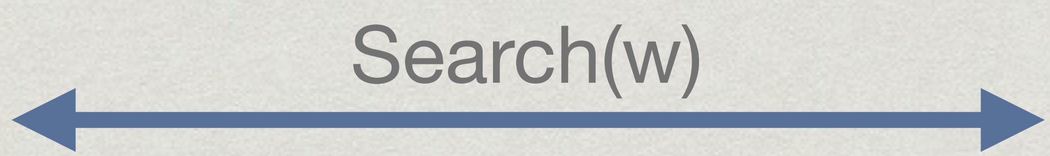

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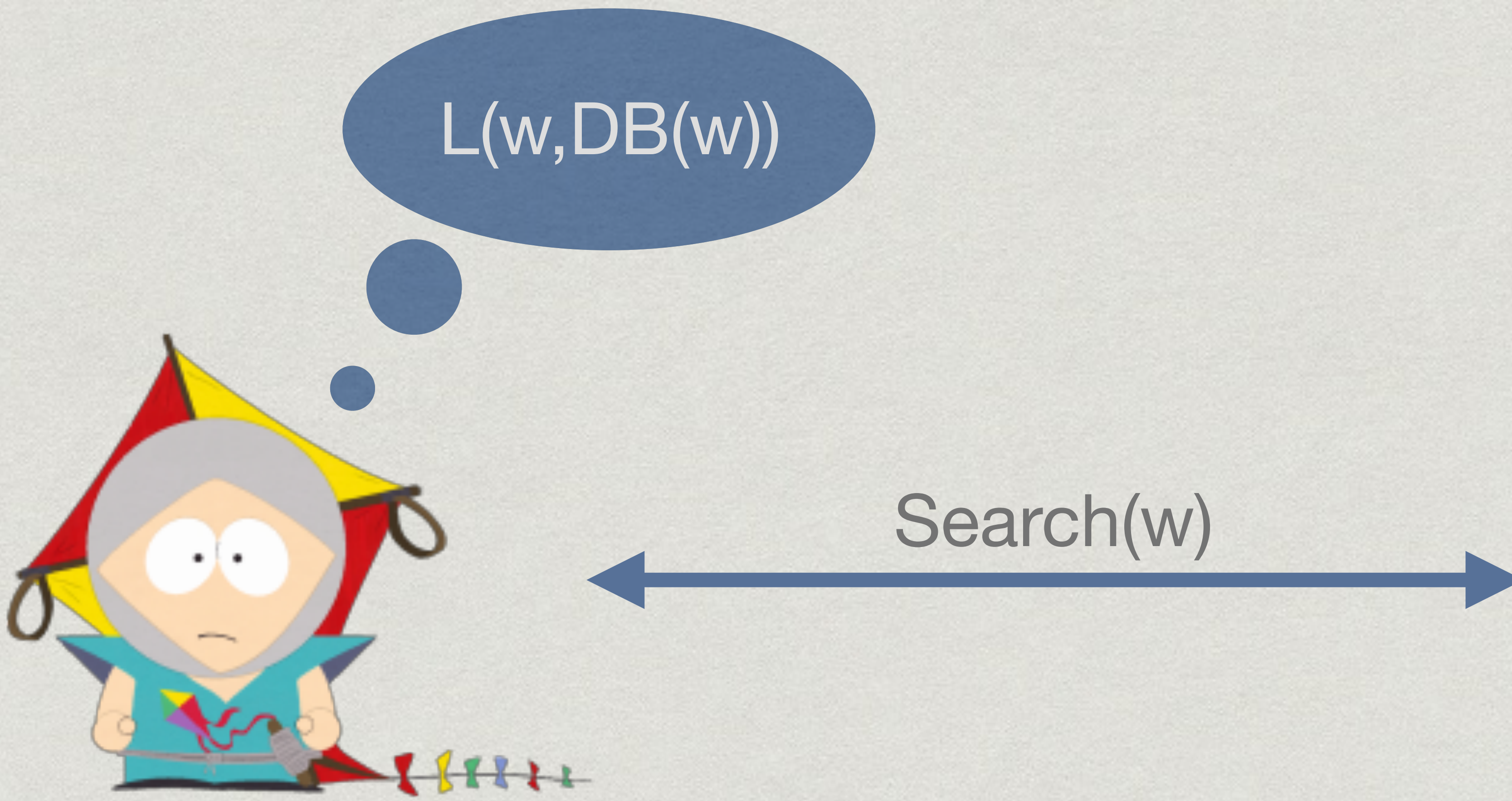

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The search protocol can be simulated from the leakage

Leakage

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- Search leakage :
  - repetition of queries
  - results

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  - results
- Update leakage:
  - updated documents
  - updated keywords
  - ...

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Verifiable SSE

First try

- We encrypt the reversed index: we consider $\{(w, ind) \mid w \in D_{ind}\}$
- MAC each pair: $\{(w, ind \| F(w, ind)) \mid w \in D_{ind}\}$
- If the MAC is unforgeable, the server will not be able to add a false result
- Yet he still is able to remove one result …
- MAC DB(w) and return it for each search query

Dynamic scheme

Let us consider the following operations:

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MACs are ineffective against replay attacks

Memory Checking

- A user with limited storage abilities wants to maintain a large DB on a remote untrusted server
- How many queries does the client have to make to the untrusted server per request
- Lower bound: $\Omega(\log n / \log \log n)$ (for n blocks)

Lower Bound on VSSE

- We can write a reduction from memory checkers to VSSE
  - Encode each block as a document index, each block address as a keyword
  - Block access: Search
  - Block update: Delete old index, add new index

Lower bound: $\Omega(\log |W| / \log \log |W|)$

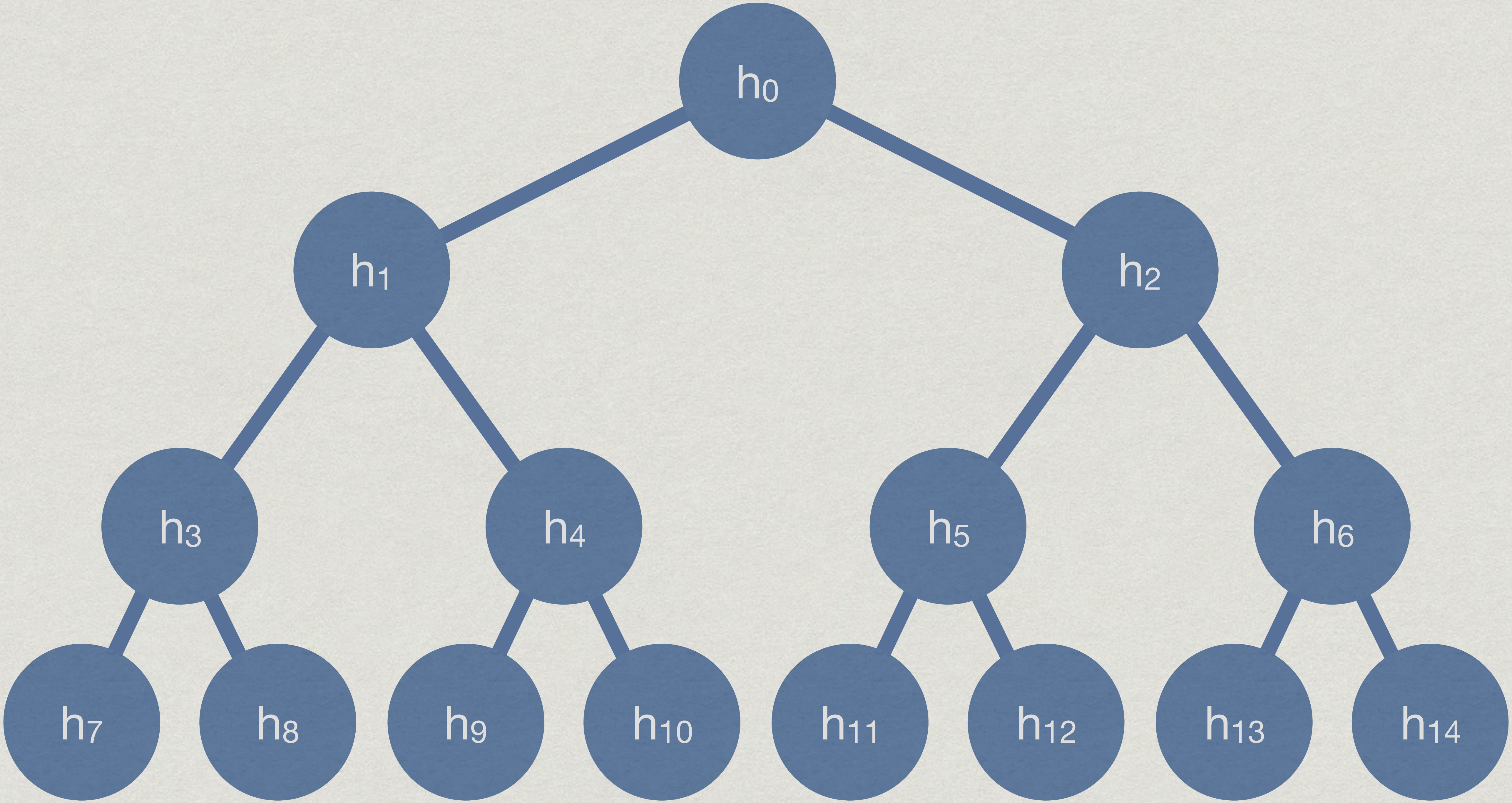
Verifiable Map

Outsource a map data structure.
Two types of constructions

- Hash based: Merkle Hash tree
  Query and updates in log(n) (optimal)

- Accumulator based
  Query in O(1), Updates in $O(n^{\varepsilon})$ or
  Query in $O(n^{\varepsilon})$, Updates in O(1)

Merkle Hash Tree



$$h_i = H(h_{2i+1} \,||\, h_{2i+2})$$

Cryptographic Accumulator

- Short membership proof
- E.g. $E = \{r_1, \ldots, r_n\}$ set of k bits primes
  $f(E) = g^{r_1 \cdots r_n} \bmod N$ where $g \in QR_N$ and N $k' > k$ bits RSA modulus
- Can be built from other assumptions (DHE, BM)

Where are we now?

- For each $w \in W$, Kyle stores MAC(DB(w))
- This map is outsourced using a verifiable map
- How to update?
  - Recompute MAC(DB(w)) every time it is modified
  - Incremental MAC/Hash

(Multi)Set Hashing

- Input: (multi)set, output: a string whose value is independent of the elements' order
- Incremental: $H(M \cup M') = H(M) \diamond H(M')$ for some $\diamond$
- Collision resistance: hard to construct $M_1 \neq M_2$ s.t. $H(M_1) = H(M_2)$

Set Hashing Constructions

- General idea: let G be a group with generator g
- $H(M) = \prod_{a \in M} g^{m(a)h(a)}$
- Examples for G: $(Z_N, \times)$, $(Z_N, +)$, EC

Our generic construction

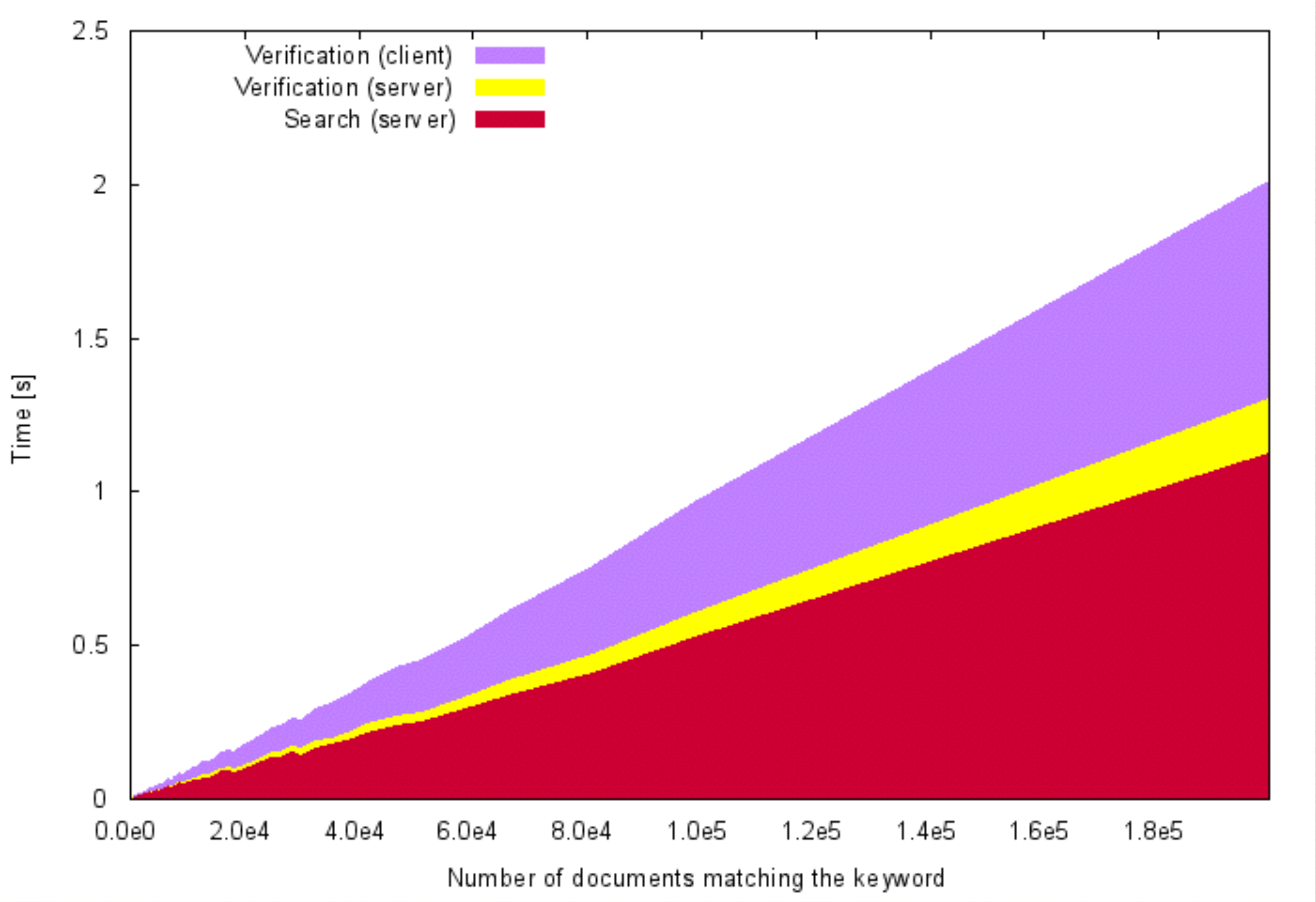
- Set hash DB(w) for all w
- Put the results in a verifiable map
- When searching, get the hash from the VM, check it matches the awaited value
- When updating, incrementally update the hash of DB(w) in the map

Complexity

- Hash-based map:
  Search: $O(\log |W| + m)$, Update: $O(\log |W|)$
- Accumulator-based map v1:
  Search: $O(m)$, Update: $O(|W|^{\varepsilon})$
- Accumulator-based map v2:
  Search: $O(m + |W|^{\varepsilon})$, Update: $O(1)$

Optimal with 3 different meanings

Implementation



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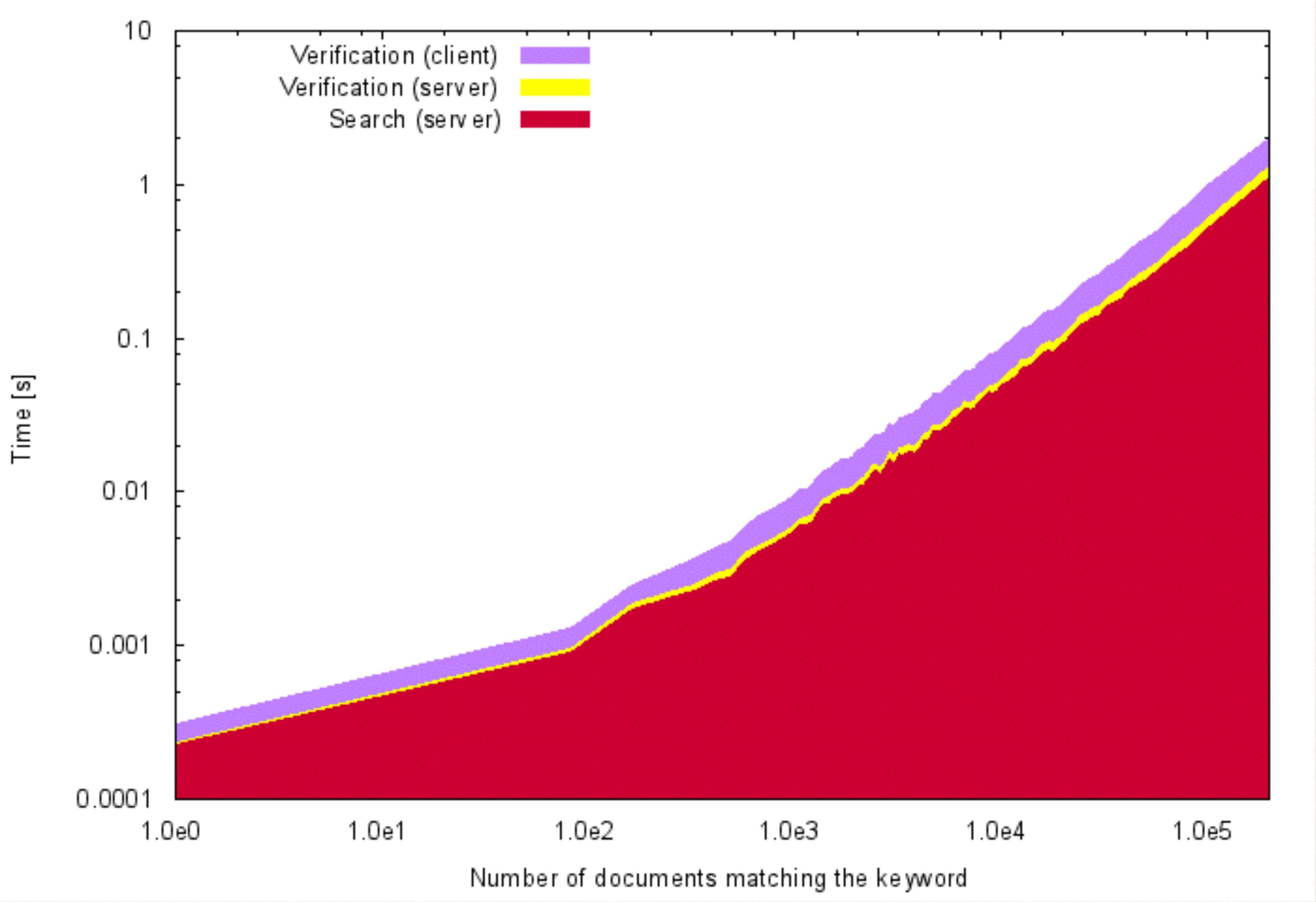

Multiple Keywords

- Cash et al., CRYPTO'13: search $DB(s \wedge x)$
  Generate DB(s), and for all ind $\in$ DB(s), look if $x \in D_{ind}$
- To verify, first verify DB(s), then generate proofs for the proposition $x \in D_{ind}$ (or $x \notin D_{ind}$)

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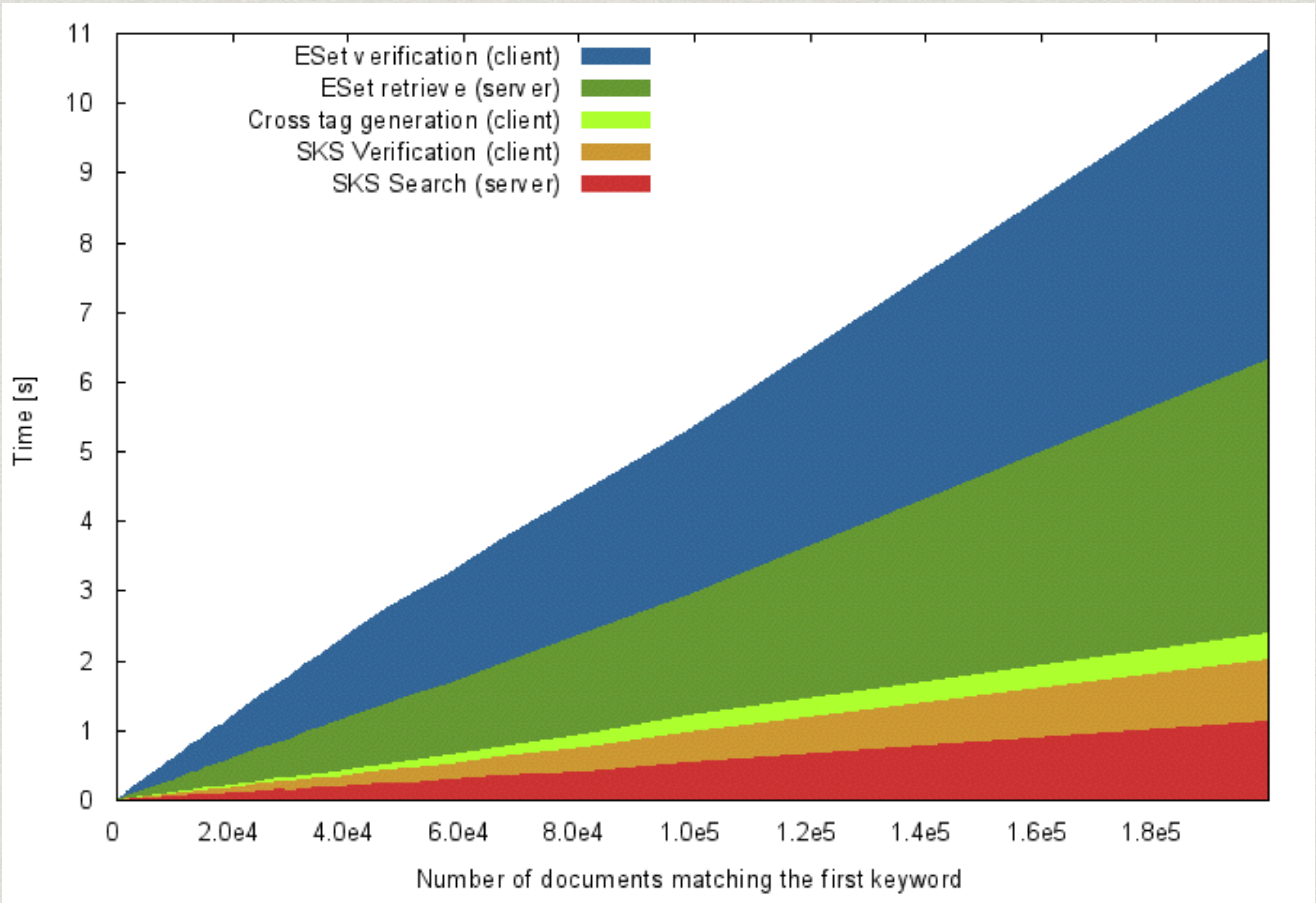

Next challenges

- Improve multiple keywords verification (batch verifications ??)
- Forward privacy
- Better understanding of leakage, avoid leakage abuse attacks