Forward & Backward Private Searchable Encryption from Constrained Cryptographic Primitives

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Searchable Encryption

Outsource data

- Securely
- Keep search functionalities
- Aimed at efficiency
- … we have to leak some information …
- … and this can lead to devastating attacks

TL;DR

- We want to reduce the leakage due to insertions and deletions in the DB
- We introduce new definitions to formalize the reduction of leakage
- We use constrained cryptographic primitives (constrained PRFs, puncturable encryption) for provably secure fine-grained access control
- We implement the new schemes

Forward Privacy

- Forward-private: an update does not leak any information on the updated keywords (often, no information at all)
- Thwart adaptive file injection attacks [ZKP16]
- Few existing constructions
    - [SPS14]: ORAM-based, expensive updates
    - [B16]: Asymptotically optimal, (very) low update throughput in practice

A Simple Dynamic Scheme

- In regular index-based schemes: suppose w matches $DB(w) = (ind_1, \dots , ind_n)$.

  $K_w || K'_w \leftarrow H(K,w)$

  $\forall 1 \leq i \leq n_w,\ t_i \leftarrow F(K_w,i),\ EDB[t_i] \leftarrow F(K'_w,i) \oplus ind_i$

  $Search(w)$: the client sends (K_w,K'_w) to the server

- $Update(add,w,ind)$: Client computes $t_{n+1} \leftarrow F(K_w,n_w+1),\ c \leftarrow F(K'_w,n_w+1) \oplus ind_i$, sends (t_{n+1},c)

- Not forward-private: the server can compute t_{n+1} from K_w

Constrained PRF

- Can we restrict the evaluation of $F(K_w,.)$ on $[1,n]$?
- PRF: Setup ⟶ K $Eval(K,x) \longrightarrow F(K,x)$
- CPRF: $Constrain(K,C) \longrightarrow K_C$ $Eval(K_C,x) \longrightarrow F(K,x)$ if $C(x) = 1$, $\perp$ otherwise
- $F(K,x)$ is indistinguishable from random as long as no K_C with $C(x)=1$ has been released
- Introduced in [BW13], [KPTZ13], and [BGI14]
  Many applications (e.g. broadcast encryption)

Range-Constrained PRF

- Consider the circuits $C_n(x) = 1$ if and only if $1 \leq x \leq n$ (range circuits)
- $K^n = Constrain(K,n)$ can only be used to evaluate F on $[1,n]$

Generic FP from Range-Constrained PRF (FS-RCPRF)

- $K_w || K'_w \leftarrow H(K,w)$
  $\forall 1 \leq i \leq n,\ t_i \leftarrow F(K_w,i),\ EDB[t_i] \leftarrow F(K'_w,i) \oplus ind_i$ (as before)

- *Update(add,w,ind)*: Client sends
  $(t_{n+1},c) \leftarrow (\ F(K_w,n+1),\ F(K'_w,n) \oplus ind\ )$ (as before)

- *Search(w)*: the client sends $K^n_w \leftarrow Constrain(K_w,n)$ to the server. The server calls $Eval(K^n_w,\ x)$ on $1 \leq x \leq n$

- The server cannot use K^n_w to track future updates ➡ Forward privacy

Diana: GGM instantiation of FS-RCPRF

- Instantiate *F* with the tree-based PRF construction of GGM
- Asymptotically less efficient than Σοφος
- In practice, a lot better. Always IO bounded (for both searches and updates)
- Search: <1µs per match (on RAM)
  Update: 174 000 entries per second (4300 for Σοφος)


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Deletions

How to delete entries in an encrypted database?

- Existing schemes use a ‘revocation list’
- Pb: the deleted information is still revealed to the server
- Backward privacy: ‘nothing’ is leaked about the deleted documents

Backward privacy

We define three flavors of backward privacy:

I. Backward privacy with insertion pattern
II. Backward privacy with update pattern
III. Weak backward privacy

Backward privacy with insertion pattern

Leaks:

- The documents currently matching w,
- When they were inserted
- The total number of updates on w

Backward privacy with update pattern

Leaks:

- The documents currently matching w,
- When they were inserted
- When all the updates (add & del) on w happened

Weak backward privacy

Leaks:

- The documents currently matching w,
- When they were inserted
- When all the updates (add & del) on w happened
- Which deletion update canceled which insertion update

Example of the differences

Consider the sequence of updates

$$(+, ind_1, \{w_1, w_2\})\ ;\ (+, ind_2, \{w_1\})\ ;\ (-, ind_1, \{w_1\})\ ;\ (+, ind_3, \{w_2\})$$

Search(w_1) leaks:

I. ind_2 and that it was added at time 2.

II. Leakage for I. + w_1 updated at times 1, 2, and 3.

III. Leakage for II. + the entry inserted at time 1 was deleted at time 3.

A baseline construction

Baseline: the client fetches the encrypted lists of inserted and deleted documents, locally decrypts and retrieves the documents.

The encrypted lists are implemented using forward-private SSE.

✗ 2 interactions & $O(a_w)$ communication complexity

Moneta & Fides

- Moneta: baseline construction with ORAM-based SSE
  - Backward privacy with insertion pattern
  - Very high computational and communicational cost
- Fides: baseline construction using Diana/Σοφος
  - Backward privacy with update pattern
  - Reduced cost compared to Moneta

Backward privacy with optimal updates & communication

Could we prevent the server from decrypting some entries?

- Puncturable Encryption [GM'15]: Revocation of decryption capabilities for specific messages
- Encrypt a message with a tag. Revoke the ability to decrypt a set of tags: puncture the secret key
- Based on non-monotonic ABE [OSW'07]

Backward privacy from Puncturable Encryption

- Insert *(w, ind)*: encrypt *(w, ind)* with tag $t = H(w,ind)$, and add it to a (possibly forward-private) SE scheme Σ
- Delete: puncture the decryption key SK on tag $t = H(w,ind)$
- Search *w*: search for *w* in Σ and give the punctured SK to the server. Server decrypts the non-deleted results.

Backward privacy from Puncturable Encryption

Pb: the punctured SK size grows linearly (# deletions). One additional key element per deletion.

- Outsource the storage: put the SK elements in a new SSE instance on the server
- Requires an incremental PE scheme (as [GM'15])
  The puncture alg. only needs a constant fraction of SK

$$SK = (sk_0, sk_1, \ldots, sk_{d-1})$$
$$Puncture(SK, t) = IncPunct(sk_0, t, d) = (sk'_0, sk_d)$$

- sk_0 is stored locally by the client

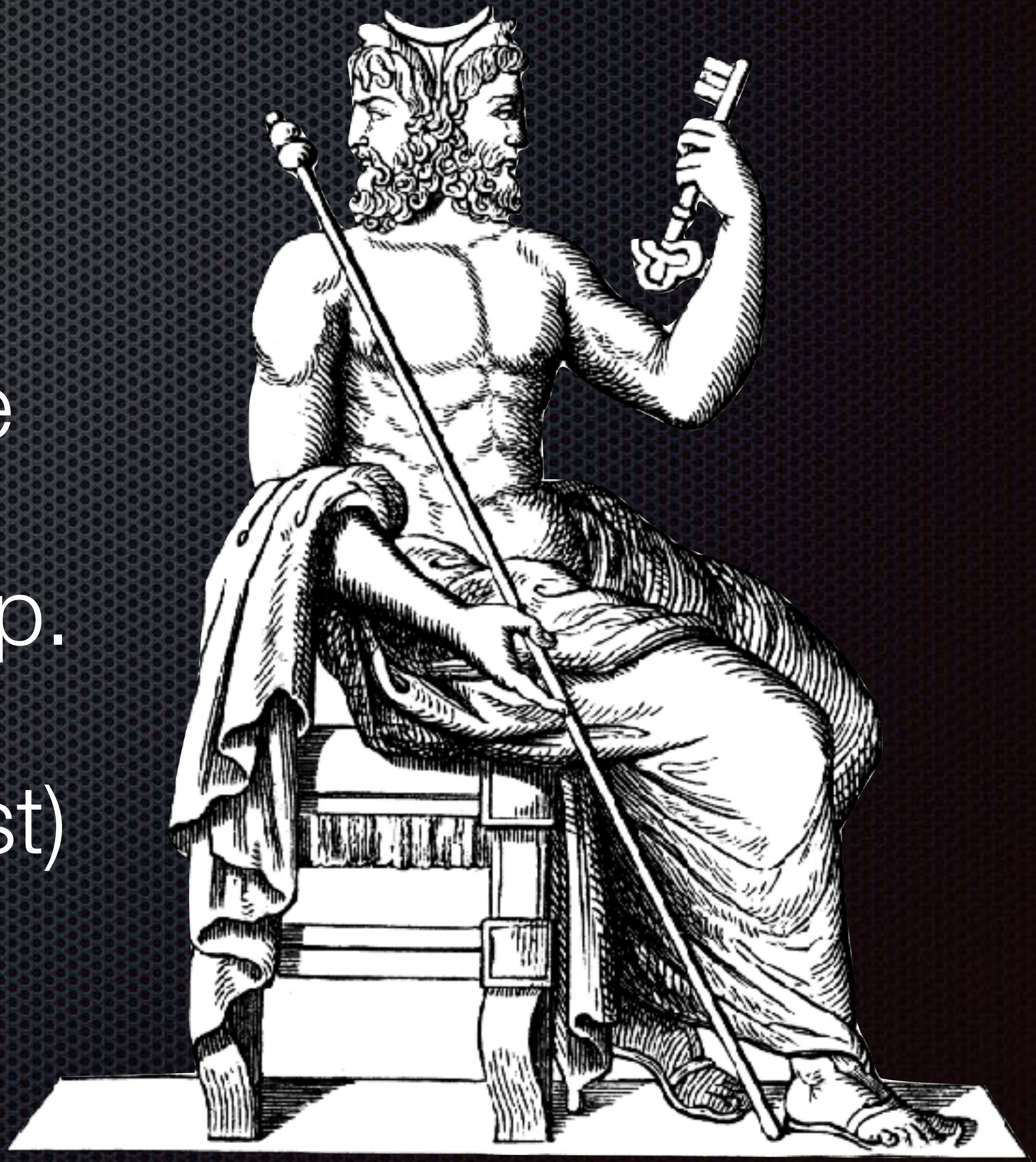
Janus

Good:

- ✓ Forward & backward-private
- ✓ Optimal update complexity
- ✓ Optimal communication

Not so good:

- ✗ $O(\ |W|\ )$ client storage
- ✗ $O(n_w.d_w)$ search comp.
- ✗ Uses pairings (not fast)



Conclusion

- Leakage during updates is a real security issue: forward & backward privacy
- New way to construct forward-private schemes from constrained PRFs
  - Diana: super efficient construction made possible from CPRFs
- Definition and constructions of backward privacy offering different tradeoffs
  - Janus: the first single roundtrip backward private construction, based on a (very) cool cryptographic tool — puncturable encryption

Questions?

[ia.cr/2017/805](ia.cr/2017/805)

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