Lightweight Authentication of Linear Algebraic Queries on Data Streams

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Problem Definition

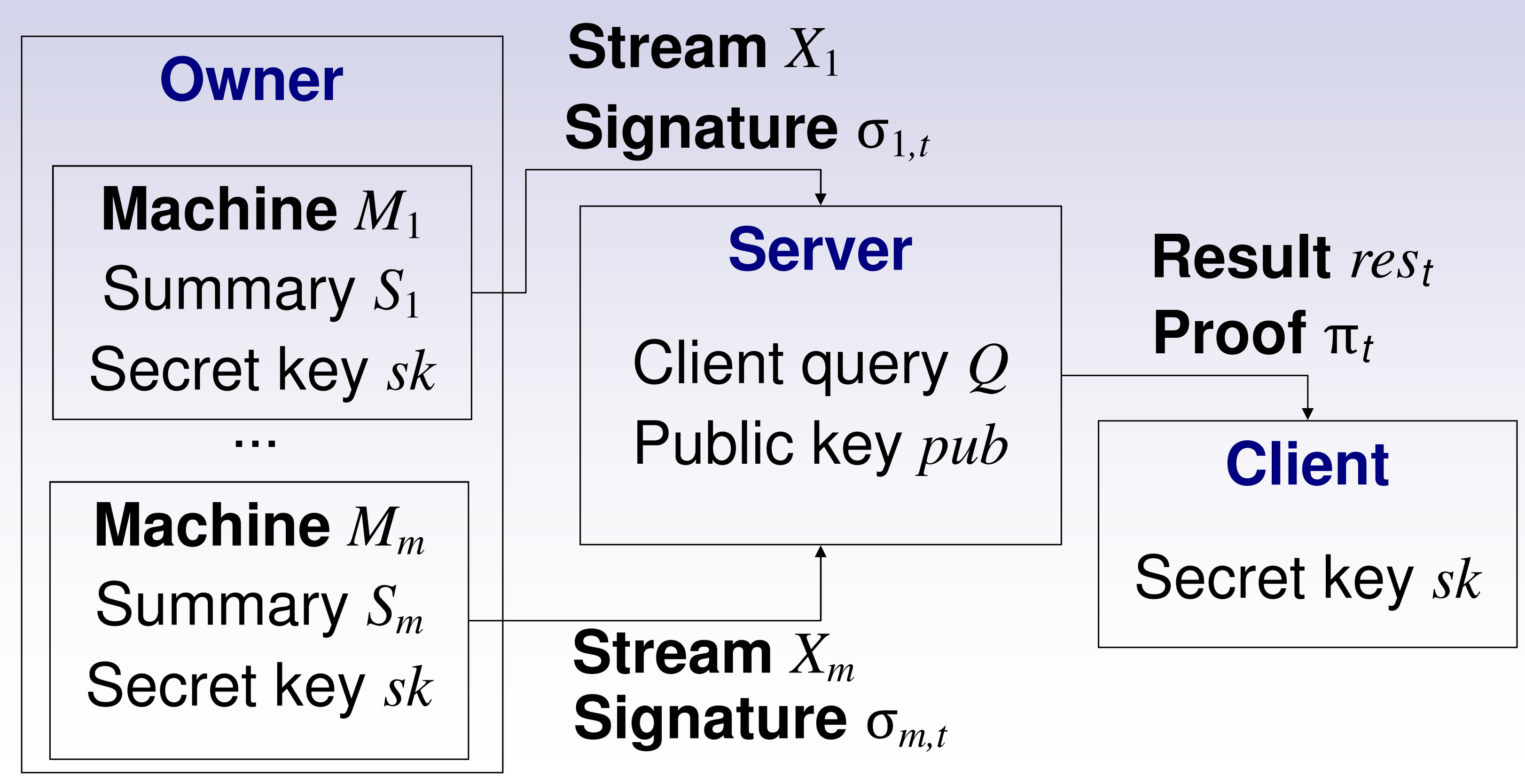
Motivation: A company may not possess the resources for deploying a DSMS

Solution: The company **outsources** its data stream storage and management to a third-party server

Challenge: The server may be **untrustworthy**: result **integrity** and **freshness** must be ensured to the clients

Result Summary: For 3 important functions (**vector sum**, **dot product**, **matrix product**) we show **secure** and **lightweight** schemes that allow the client to check the computation of the server

Architecture



Dynamic Vector Sum (DVS)

Setting

- There are m machines generating m streams
- Stream X_i updates an n-element vector $\mathbf{a}_i$ at M_i
- The query result is $\Sigma_{i\in[m]}\, \boldsymbol{a}_i$

Our Results:

- **O(1)** costs at M_i
- **O(m)** processing cost and **O(1)** space at the server
- **O(m+n)** verification cost at the client
- **O(1)** proof size (a few bytes)
- All operations are **lightweight** (order of a few μs)

Solution idea:

- M_i incrementally maintains summary $S_i = \Sigma_{j\in[n]}\, k_j \cdot \boldsymbol{a}_i[j]$ (in a finite field) where k_j are secret keys
- M_i signs S_i with a variant of one-time pad encryption
- All keys are produced from sk
- The server computes proof $\pi_t = \Sigma_{i\in[m]}\, \sigma_{i,t}$
- The client can verify π_t with the result and sk
- Security is based on the security of pseudorandom functions (PRFs)

Applications:

- Group by queries (e.g., for network analysis)
- Sum and count queries in sensor networks

Dynamic Matrix Product (DMP)

Setting

- Machines M_a, M_b generate streams X_a, X_b, resp.
- X_a (X_b) updates an n_a x n (n x n_b) matrix $\mathbf{A}$ ($\mathbf{B}$)
- The query result is n_a x n_b matrix $\mathbf{A} \cdot \mathbf{B}$

Our Results:

- **O(1)** update and **O(n)** space/comm. cost at M_a, M_b
- **O(n)** processing cost and **O(1)** space at the server
- **O($n_a \cdot n_b$)** verification cost at the client
- **O(1)** proof size
- All operations are **lightweight**

Solution idea:

- The matrix product is the summation of outer products between a column from $\mathbf{A}$ and a row from $\mathbf{B}$
- M_a (M_b) maintains summary $S_a[j]$ ($S_b[j]$) for each n-element column (row) j, similar to DVS
- $\Sigma_{j\in[n]}\, S_a[j] \cdot S_b[j]$ is an (unsigned) summary for $\mathbf{A} \cdot \mathbf{B}$
- A trick is needed to handle the one-time pad nonces
- Security is based on the security of PRFs

Applications:

- Event co-occurrence in monitoring applications
- Joint frequency distribution of attributes in joins

Dynamic Dot Product (DDP)

Setting

- Machines M_a, M_b generate streams X_a, X_b, resp.
- X_a (X_b) updates an n-element vector $\mathbf{a}$ ($\mathbf{b}$)
- The query result is the dot product $\mathbf{a} \cdot \mathbf{b}$

Our Results:

- **O(1)** costs at M_a, M_b
- **O(n log n)** process. and **O(n)** space at the server
- **O(1)** verification cost at the client
- **O(1)** proof size
- All operations at the client and M_a, M_b are **lightweight** (the server requires exponentiations)

Solution idea:

- The result is the trace of the outer product $\mathbf{a} \otimes \mathbf{b}$
- Create a signed summary for $\mathbf{a} \otimes \mathbf{b}$ similar to DMP, and assist the server to remove unnecessary terms
- To avoid giving key material to the server, we provide (offline and only once as public info pub) the key information in the exponent of a group generator—all computations move to the exponent
- Security is based on the security of PRFs and the Diffie Hellman Exponent (n-DHE) assumption

Applications:

- Joins
- Similarity queries