Query-private DB Query Processing Technique

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1차워크샵@암호연구회, May 20, 2016

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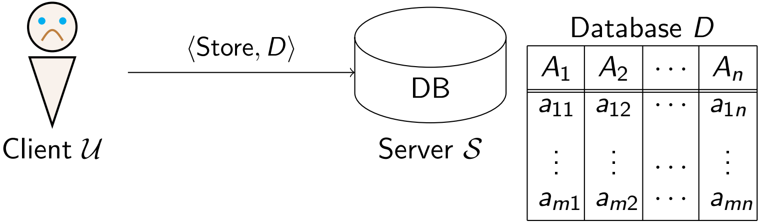
System model

- **Outsourced** Database: Naïve model
  - ∗ Client $\mathcal{U}$: DB D를 Server $\mathcal{S}$에 저장
  - ∗ Privacy issue: S learns all tuples in D



Database D

A_1	A_2	$\cdots$	A_n
a_{11}	a_{12}	$\cdots$	a_{1n}
$\vdots$	$\vdots$	$\cdots$	$\vdots$
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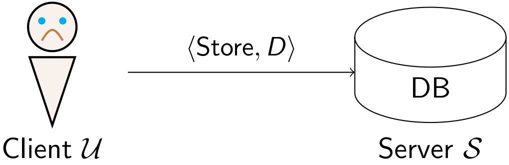

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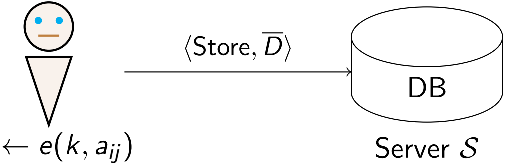

$\overline{a}_{ij} \leftarrow e(k, a_{ij})$

($e(,)$ is an enc. ftn)

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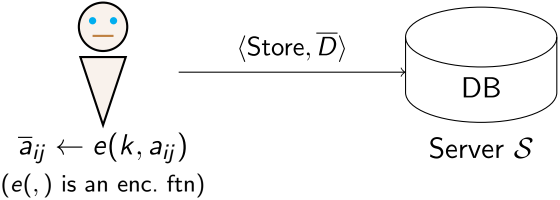
$\langle \text{Store}, \overline{D} \rangle$
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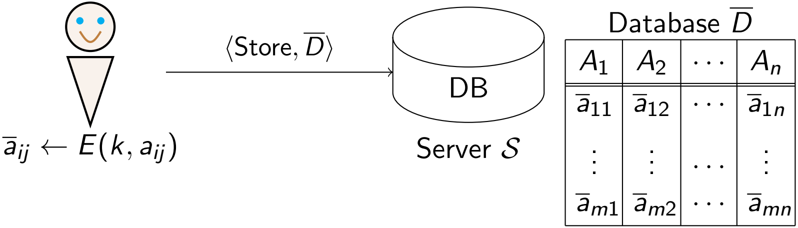
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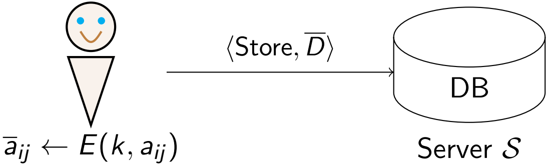
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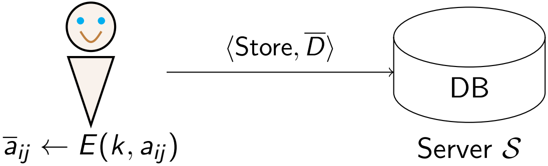
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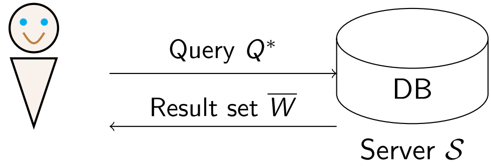

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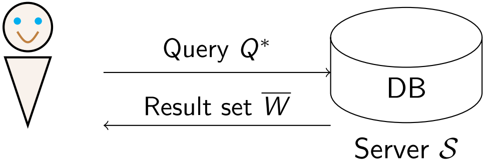

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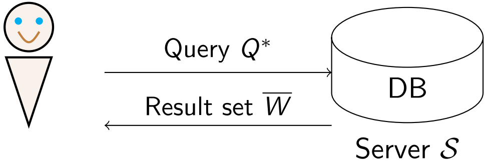

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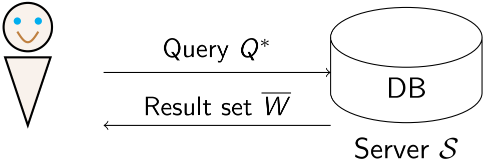

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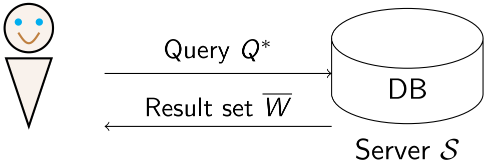

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  - An example
    - Q = SELECT Name FROM STUDENT WHERE Grd='A' AND Sex='M';
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Problem statement

Why "No"?

- $\mathcal{S}$ can learn the logical operators (e.g., `and`/`or`) from Q^*
- Our problem

How to hide the operators from the suspicious server?

An Example

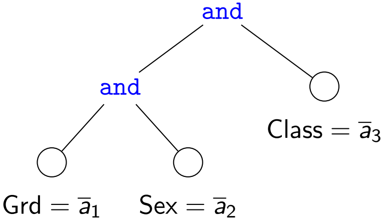

Figure 1: A Query Tree

```
SELECT  Name, Depart, Address
  FROM  STUDENT
 WHERE  Grd = ā1
   AND  Sex = ā2
   AND  Class = ā3;
```

Figure 2: An SQL Statement

Idea sketch

Our goals

1. Hide the select_condition clause
   ⇒ Protect private constants & logical operators
2. Harmonize security and performance
   ⇐ Reveal the `select`-statement & the `from`-statement
   ⇐ SIMD, Automorphism, Dynamic programming, Heuristics

Our assumptions

1. Underlying encryption: (leveled) Fully homomorphic encryption
2. Primitive: `EQ` circuit
   - $\mathrm{depth}(\mathtt{EQ}) = \lceil \log n \rceil$ for two n-bit inputs
3. Conjunctive, Disjunctive and Threshold Conjunctive queries

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- Express all of target queries as the **same structure** of circuits

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1. Hide the select_condition clause

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2. Harmonize security and performance

   $\Leftarrow$ Reveal the `select`-statement & the `from`-statement

   $\Leftarrow$ SIMD, Automorphism, Dynamic programming, Heuristics

Our assumptions

1. Underlying encryption: (leveled) Fully homomorphic encryption
2. Primitive: `EQ` circuit
   - $\ast$ $\mathrm{depth}(\mathtt{EQ}) = \lceil \log n \rceil$ for two n-bit inputs
3. Conjunctive, Disjunctive and Threshold Conjunctive queries

Our idea

- Express all of target queries as the **same structure** of circuits

Idea sketch

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Main observations

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   - $\mathbb{F}_{2^\ell}$: the plaintext domain
   - $a_i, b, c, d \in \mathbb{F}_{2^\ell}$ and $A_i \in \mathbb{F}_{2^\ell}$
   - Circuit $C^\star$ defined by

$$C^\star = \overline{d} + \prod_{i=1}^{n} \left(\overline{b} + \mathtt{EQ}\left(\overline{A}_i, \overline{a}_i\right) \cdot \overline{c}\right)$$

2. Evaluation table

Query type	b	c	d	Result of $C^\star$
Conjunction	0	1	0	0/1
Disjunction	1	1	1	0/1
Threshold Conjunction	1	$1+t$	0	t^κ

$t \in \mathbb{F}^*_{2^\ell}$ and κ: # of threshold conditions

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Main observations–continued

- A little bit problem: the results for threshold queries are still $\overline{t^i}$
  $\Rightarrow$ Modify the results into $\overline{0}$ or $\overline{1}$
- Our technique
  - $\mathcal{S}$ is required to evaluate an encrypted polynomial $\overline{g}(X)$ regardless of query types

$$g(X) = \begin{cases} h(X) & \text{if threshold queries} \\ X & \text{otherwise} \end{cases}$$

where $h(t^\kappa) = 1$ if $\kappa > T$ for a threshold $T \in \mathbb{N}$; $h(t^\kappa) = 0$ otherwise

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On-going works

- Complete our protocol
- Security modeling
  - Security definition
  - Security proof
- Proof-of-concept implementation
  - HElib [HElib] library for the BGV encryption scheme [BGV12], NTL library [NTL]
  - A sample DB generated by a script

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References

[BGV12] Zvika Brakerski, Craig Gentry, and Vinod Vaikuntanathan: *(Leveled) fully homomorphic encryption without bootstrapping*. ITCS2012:309-325.

[HElib] Shai Halevi and Victor Shoup: *Algorithms in HElib*, Eurocrypt 2014.

[NTL] NTL: A Library for doing Number Theory, `http://http://www.shoup.net/ntl/`.