When Query Authentication Meets Fine-Grained Access Control: A Zero-Knowledge Approach

Cheng Xu[1], Jianliang Xu[1], Haibo Hu[2], and Man Ho Au[2]

[1]Hong Kong Baptist University
{chengxu, xujl}@comp.hkbu.edu.hk

[2]Hong Kong Polytechnic University
{haibo.hu@, csallen@comp.}polyu.edu.hk

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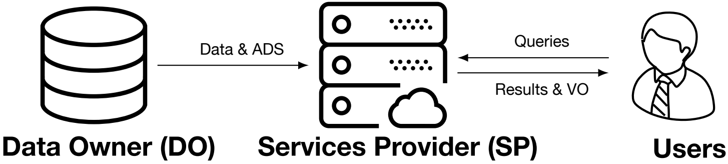
Background

- *Data-as-a-Service* (DaaS) and cloud computing are gaining popularity for big data analytics



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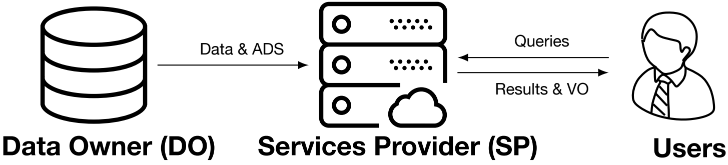

- Fine-Grained Access Control: enable big data sharing

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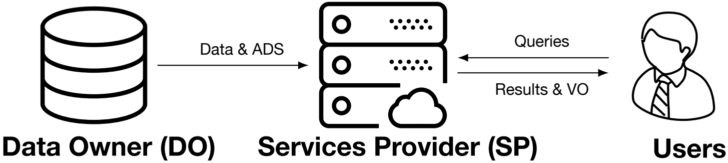
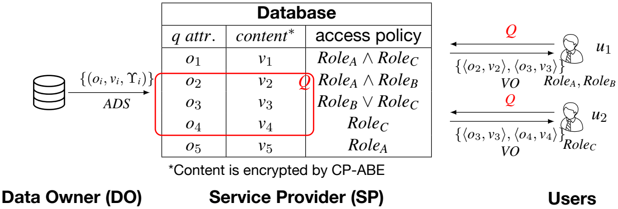


- Fine-Grained Access Control: enable big data sharing
- Security Threats:
  - Query result integrity not guaranteed
  - Leaking information beyond query result may breach privacy

Problem Model



$\{(o_i, v_i, \Upsilon_i)\}$

ADS

Database

$q\ attr.$	$content^*$	access policy
o_1	v_1	$Role_A \wedge Role_C$
o_2	v_2	$Role_A \wedge Role_B$
o_3	v_3	$Role_B \vee Role_C$
o_4	v_4	$Role_C$
o_5	v_5	$Role_A$

Q

*Content is encrypted by CP-ABE

Q

$\{\langle o_2, v_2\rangle, \langle o_3, v_3\rangle\}$

VO

u_1

$Role_A, Role_B$

Q

$\{\langle o_3, v_3\rangle, \langle o_4, v_4\rangle\}$

VO

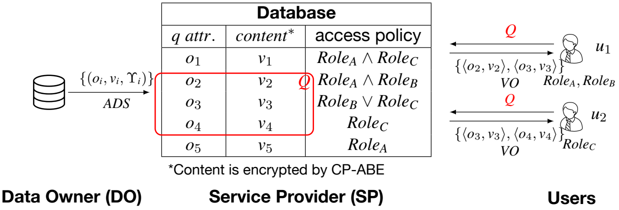
u_2

$Role_C$

Data Owner (DO) **Service Provider (SP)** **Users**

- Fine-grained access policy as monotone boolean function

Problem Model



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o_4	v_4	$Role_C$
o_5	v_5	$Role_A$

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$\{(o_i, v_i, \Upsilon_i)\}$
ADS
Q
Q
$\{\langle o_2, v_2\rangle, \langle o_3, v_3\rangle\}$
VO
u_1
$Role_A, Role_B$
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VO
u_2
$Role_C$
Data Owner (DO)
Service Provider (SP)
Users

- Fine-grained access policy as monotone boolean function
- Our solution:
  - Integrity: SP returns a *verification object* (VO) to prove
    - Soundness
    - Completeness
  - Zero-Knowledge Confidentiality:
    VO leaks no information beyond query results

Our Contributions

- Develop a novel ABS-based APP signature
  - Authenticate accessible records
  - Prove inaccessibility in zero-knowledge
- Supported query types:
  - Equality queries
  - Range queries
  - Join queries
- Optimization techniques to reduce verification cost

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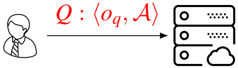
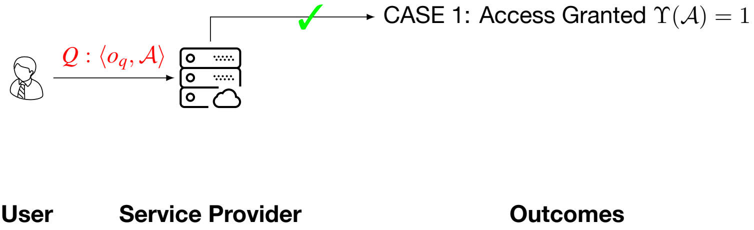
Equality Query



User **Service Provider**

- User submits a query key o_q and a role set $\mathcal{A}$

Equality Query



$Q : \langle o_q, \mathcal{A} \rangle$

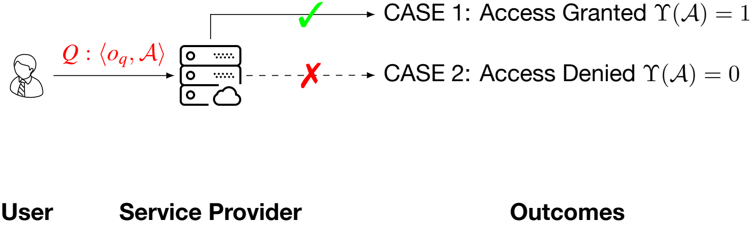
✓

CASE 1: Access Granted $\Upsilon(\mathcal{A}) = 1$

User **Service Provider** **Outcomes**

- User submits a query key o_q and a role set $\mathcal{A}$

Equality Query



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✓ CASE 1: Access Granted $\Upsilon(\mathcal{A}) = 1$

✗ CASE 2: Access Denied $\Upsilon(\mathcal{A}) = 0$

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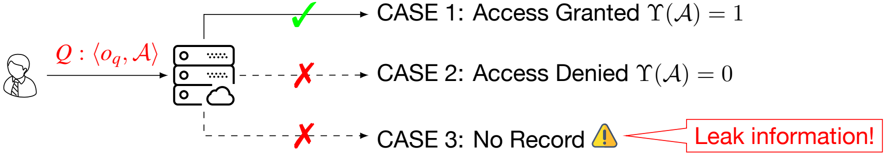

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✓ CASE 1: Access Granted $\Upsilon(\mathcal{A}) = 1$

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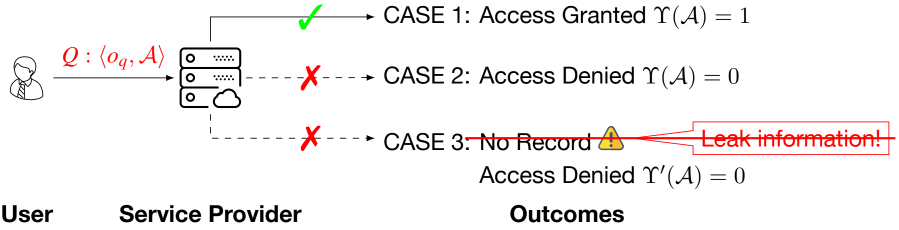
✗ CASE 3: No Record ⚠

Leak information!

User **Service Provider** **Outcomes**

- User submits a query key o_q and a role set $\mathcal{A}$
- Non-existent record will leak information

Equality Query



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✗ CASE 3: ~~No Record~~ ⚠ ~~Leak information!~~

Access Denied $\Upsilon'(\mathcal{A}) = 0$

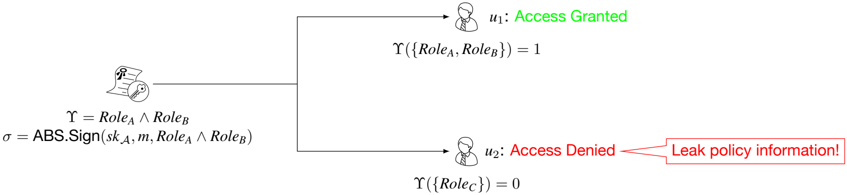
User **Service Provider** **Outcomes**

- User submits a query key o_q and a role set $\mathcal{A}$
- ~~Non-existent record will leak information~~
- Treat non-existent records as inaccessible by anyone
  i.e. $\Upsilon' = Role_{\emptyset}$

ABS with Predicate Relaxation

- Attribute Based Signature (ABS)

  It signs a message with a monotone boolean function predicate that is satisfied by the attributes obtained from the authority



$\Upsilon = Role_A \wedge Role_B$

$\sigma = \text{ABS.Sign}(sk_{\mathcal{A}}, m, Role_A \wedge Role_B)$

u_1: Access Granted

$\Upsilon(\{Role_A, Role_B\}) = 1$

u_2: Access Denied

$\Upsilon(\{Role_C\}) = 0$

Leak policy information!

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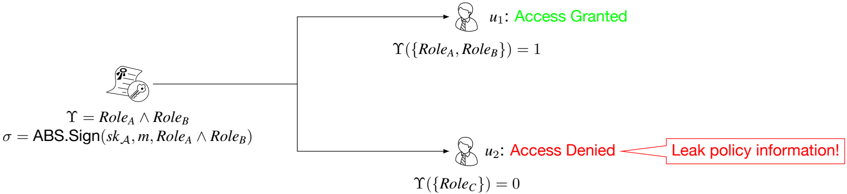

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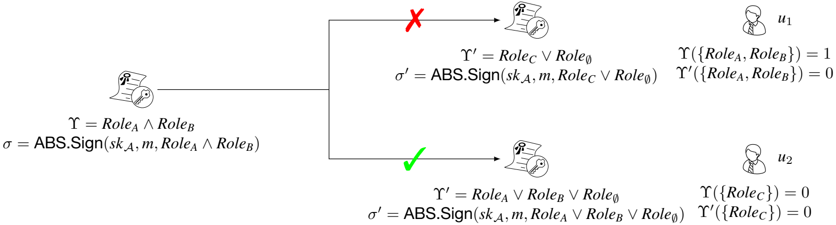
u_2: Access Denied

Leak policy information!

$\Upsilon(\{Role_C\}) = 0$

- Predicate Relaxation

  Derive a weaker ABS signature without knowing secret key



✗

$\Upsilon' = Role_C \vee Role_\emptyset$

$\sigma' = \text{ABS.Sign}(sk_{\mathcal{A}}, m, Role_C \vee Role_\emptyset)$

u_1

$\Upsilon(\{Role_A, Role_B\}) = 1$

$\Upsilon'(\{Role_A, Role_B\}) = 0$

$\Upsilon = Role_A \wedge Role_B$

$\sigma = \text{ABS.Sign}(sk_{\mathcal{A}}, m, Role_A \wedge Role_B)$

✓

$\Upsilon' = Role_A \vee Role_B \vee Role_\emptyset$

$\sigma' = \text{ABS.Sign}(sk_{\mathcal{A}}, m, Role_A \vee Role_B \vee Role_\emptyset)$

u_2

$\Upsilon(\{Role_C\}) = 0$

$\Upsilon'(\{Role_C\}) = 0$

Authenticated Data Structures (ADS)

- Access-Policy-Preserving (APP) signature
  - Signed by DO and used as ADS
  - It captures three parts of information: query attribute o_i, data content v_i, and access policy Υ_i

Example 1

$$\text{Record}_2 \leftarrow \langle o_2, v_2, \Upsilon_2 = Role_A \land Role_B \rangle$$

$$\sigma_2 \leftarrow \text{ABS.Sign}(sk_{\text{DO}}, hash(o_2)|hash(v_2), Role_A \land Role_B)$$

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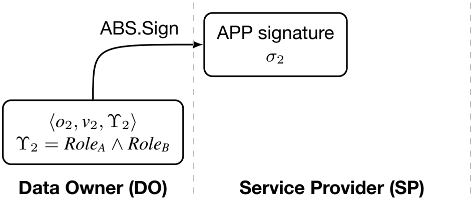
- Access-Policy-Stripped (APS) signature
  - Replace Υ_i to $\hat{\Upsilon}_{\mathcal{A}} = a_1 \vee a_2 \vee \cdots \vee a_n, a_i \in \mathbb{A} \backslash \mathcal{A}$
  - Be used to prove inaccessibility in zero-knowledge

Example 2

$$\mathbb{A} = \{Role_A, Role_B, Role_C, Role_\emptyset\}, \hat{\Upsilon}_{\{Role_C\}} = Role_A \vee Role_B \vee Role_\emptyset$$

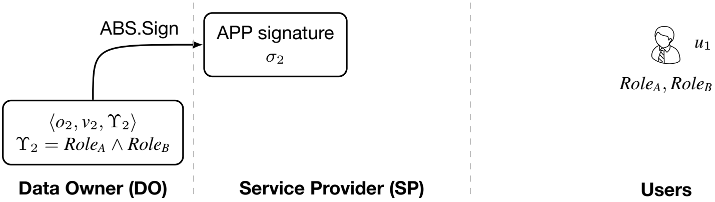
$$\hat{\sigma}_2 \leftarrow \text{ABS.Sign}(sk_{\text{DO}}, hash(o_2)|hash(v_2), Role_A \vee Role_B \vee Role_\emptyset)$$

Query Processing


ABS.Sign
APP signature
σ_2
$\langle o_2, v_2, \Upsilon_2 \rangle$
$\Upsilon_2 = Role_A \wedge Role_B$
Data Owner (DO)
Service Provider (SP)

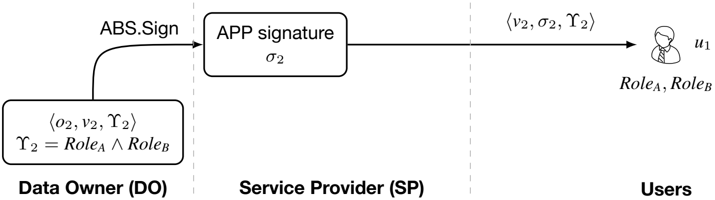
- DO generates ADS and sends to the SP

Query Processing



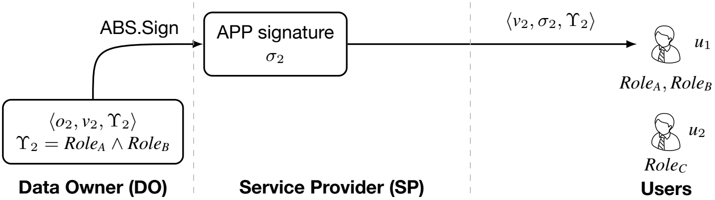
- DO generates ADS and sends to the SP
- u_1 can access the data,

Query Processing


ABS.Sign
APP signature
σ_2
$\langle v_2, \sigma_2, \Upsilon_2 \rangle$
u_1
$Role_A, Role_B$
$\langle o_2, v_2, \Upsilon_2 \rangle$
$\Upsilon_2 = Role_A \wedge Role_B$
Data Owner (DO)
Service Provider (SP)
Users

- DO generates ADS and sends to the SP
- u_1 can access the data, APP signature is the VO

Query Processing


ABS.Sign
APP signature
σ_2
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$\Upsilon_2 = Role_A \wedge Role_B$
u_2
$Role_C$
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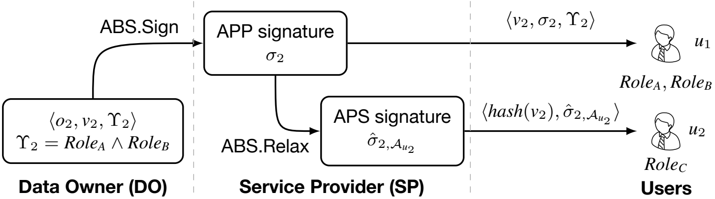
Service Provider (SP)
Users

- DO generates ADS and sends to the SP
- u_1 can access the data, APP signature is the VO
- u_2 cannot access the data,

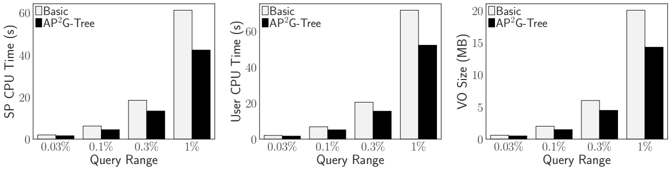
Query Processing


ABS.Sign
APP signature
σ_2
$\langle v_2, \sigma_2, \Upsilon_2 \rangle$
u_1
$Role_A, Role_B$
$\langle o_2, v_2, \Upsilon_2 \rangle$
$\Upsilon_2 = Role_A \wedge Role_B$
ABS.Relax
APS signature
$\hat{\sigma}_{2,\mathcal{A}_{u_2}}$
$\langle hash(v_2), \hat{\sigma}_{2,\mathcal{A}_{u_2}} \rangle$
u_2
$Role_C$
Data Owner (DO)
Service Provider (SP)
Users

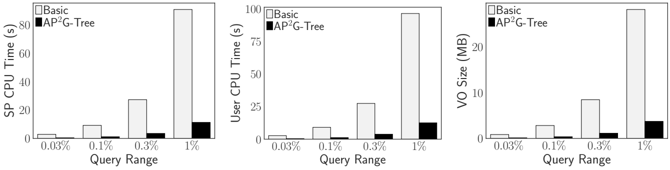
- DO generates ADS and sends to the SP
- u_1 can access the data, APP signature is the VO
- u_2 cannot access the data, SP generates an APS signature as VO

Performance Evaluation

- TPC-H dataset ($1\,800\,000$ records)
- 10 distinct policies (10 global roles, max policy length is 6)



Range Query Performance vs. Range



Join Query Performance vs. Range

Thanks

Q&A