ESPADA: Efficient Security and Privacy Assurance for Database Access

IARPA SPAR Program Challenge

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Talk Outline

1. Private Database Access challenge of the IARPA SPAR program
   - IARPA = Intelligence Advanced Research Projects Activity
   (Research Grant Agency, like DARPA but for Intelligence)
   - SPAR = Security and Privacy Assurance Research (Program)
   ≈ Privacy Assurance in Database Access

2. ESPADA: UC Irvine and IBM proposal for IARPA SPAR Program
   a) Overview
   b) Some of our techniques and efficiency/privacy tradeoffs
   c) Related challenges

Private DB Access: Functionality

Server: Database
Input: **DB**, e.g. Border Crossings

Client: Agent
Input: **Q**, list of queries

Server gets <u>nothing</u>
about Agent's queries **Q**

Client learns **Q(DB)**, i.e.
those records in **DB** which
match queries in **Q**,
and <u>nothing</u> else about **DB**

Private DB Access: Functionality

Server: Database
Input: **DB**, e.g. Border Crossings

Client: Agent
Input: **Q**, list of queries

Attr.1 (first name)	Attr.2 (last name)	Attr.3 (SSN)	Attr.4 (driv.lic. #)	Attr.5 (date)	…	Attr.n (…)
Joe	Smith	712-28-8748	C5121090	2009-07-29	…	…
Joe	Kleinert	418-11-5109	M3109988	2009-07-29	…	…
…	…	…	…		…	…

Private DB Access: Functionality

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Input: **DB**, e.g. Border Crossings

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Joe	Smith	712-28-8748	C5121090	...	...
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...	…	...	...	...	...

Client: Agent

Input: **Q**, list of queries

q_1: (last nm = Kleinert)

q_2: (licence# = C5121090)

q_3: ...

Client learns those records in **Q(DB)** and nothing else about Server's **DB**

Server learns nothing about Agent's input **Q**

Private DB Access: Functionality

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...	...	...	...	...	...

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...	...	...	...	...	...

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Joe	Kleinert	418-11-5109	M3109988	...	...
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Client learns those records in **Q(DB)** and nothing else about Server's **DB**

Server learns nothing about Agent's input **Q**

Two phases of the SPAR program

"Baby SPAR": Client retrieves from DB all records matching his queries s.t.:

1. Client learns nothing about the remaining DB records
2. Server learns nothing about Client's queries
3. Simple query type: atomic (single attribute) queries
4. Simple matching function: exact match with specified value
5. Medium DB: 100,000 records, 100KB each
6. Modest efficiency goal: < 100x MySQL

SPAR: the above, extended as follows:

New 3: disjunctions, conjunctions, threshold conj.'s (t-out-of-n matching fields)

New 4: interval ranges, stemming, wildcards, substrings, "close-distance" match

New 5: Large DB: 100,000,000 records, 100KB each

New 6: Stringent efficiency goal: < 10x MySQL

7: dynamic DB (record add, delete, modify)

8: authorization enforcement (on Client's blinded query and credentials)

Private Database Access
General Problem Statement

Server: **DB**
set of records

Client:
query **q** = (at,v)

Server learns
nothing about **q**

Client gets **DB** records
which match query **q**
and nothing else
about **DB**

Fundamental Limitation of PIR:
O(n) work per query to
hide q from Server

Private Database Access
Model Relaxation in ESPADA Scheme

Server: **DB**
set of records

Client:
query **q** = (at,v)

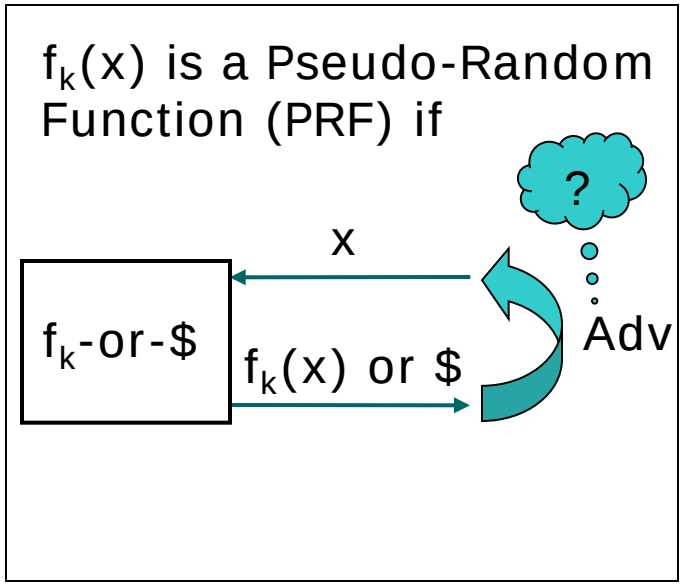
Split Server into two entities:
Server and Proxy

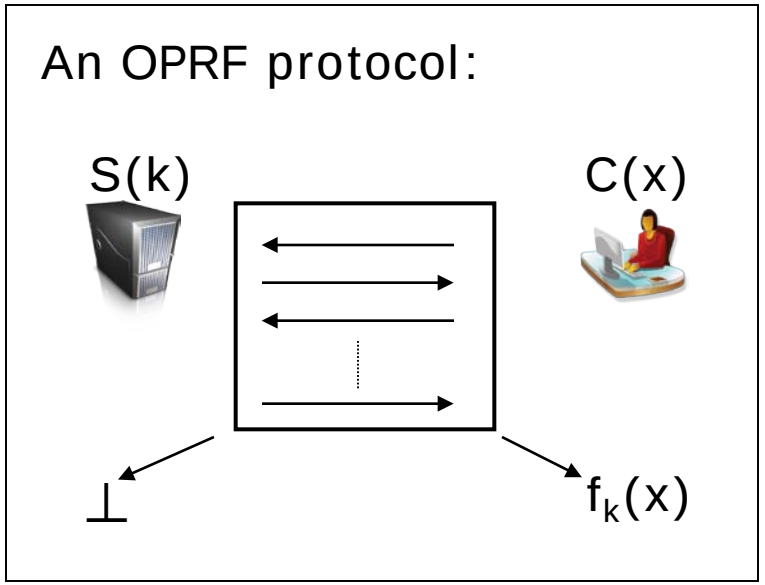
- ✓Server communicates with Proxy only at initialization, sending "Encrypted Database" (**EDB**)
- ✓Goal: O(n) work during initialization
- ✓Goal: O(1) work per query
- ✓Proxy can collude with Client
- ×Server and Proxy collusion breaks Client's privacy
- ×Proxy learns some access pattern information

EDB

Proxy

Main Tool: Oblivious PRF (OPRF) [NR'04,FIPR'05]





[Yao'82]:	$f_k(x)=AES_k(x)$	O(λ) exp.'s + O(|AES|) sym. ops.	2 msg	DDH *[λ: sec. Par.]*
[NR'04]:	$f_k(x)=g^{\{\Pi k_i \text{ s.t. } x_i=1\}}$	O(λ) exp.'s	2λ msg	DDH
[FIPR'05]:	(same)	O(λ) exp.'s	2 msg	DDH
[JL'09]:	$f_k(x)=g^{\{1/(k+x)\}}$	O(1) exp.'s	2 msg	q-DHI + DCR [Pailier]
[JL'10]:	$f_k(x)=(H[x])^k$	2 exp's	2 msg	"One More DH", ROM

Basic SPAR Solution [JT'09] (Exact Match, Atomic Queries)

I) Initialization: Creating Encrypted DB

Server: **DB**
key k of PRF F_k

Client:
query **q** = (at,v)

EDB: Each record *R* encrypted under $H_1(F_k(at,v))$ for all (at,v) in *R* and *tagged* by $H_2(F_k(at,v),ctr)$ where ctr incremented at each occurence of (at,v)

Proxy: **EDB**

|**EDB**| = |**DB**| + |Tag Table|

Basic SPAR Solution [JT'09] (Exact Match, Atomic Queries)

II) Servicing Client's Queries

Server: **DB**
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"Oblivious PRF": Oblivious Retrieval of $\sigma=F_k(\mathbf{q})$

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Server learns nothing about **q**

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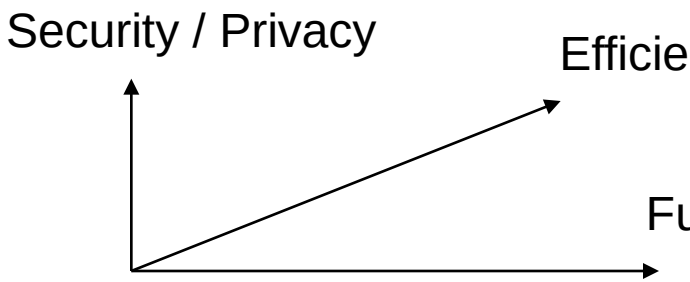
Look-up (and retrieval) of encrypted records by $H_2(F_k(\mathbf{q}),ctr)$ for ctr=1,2,...

Leaks no information to IB except # of hits (assuming Client caching)

Design Space and Tradeoffs



Provable Security:

Specify exact information leaked to each party

Functionality	Efficiency	Security/Privacy
query types atomic, disj.'s, conj.'s, thr-conj.'s match functions exact, stemming, interval ranges wildcards., substrs., close-dist. record creation static, dynamic (add, delete)	components initialization, retrieval, DB update, authorization resources computation, storage, bandwidth, latency	trust relations Client↔Prx, Server↔Prx fault types HBC, malicious, “covert” info. leakage sizes, access pattern, query type, match fnct., auth. type, DB leakage

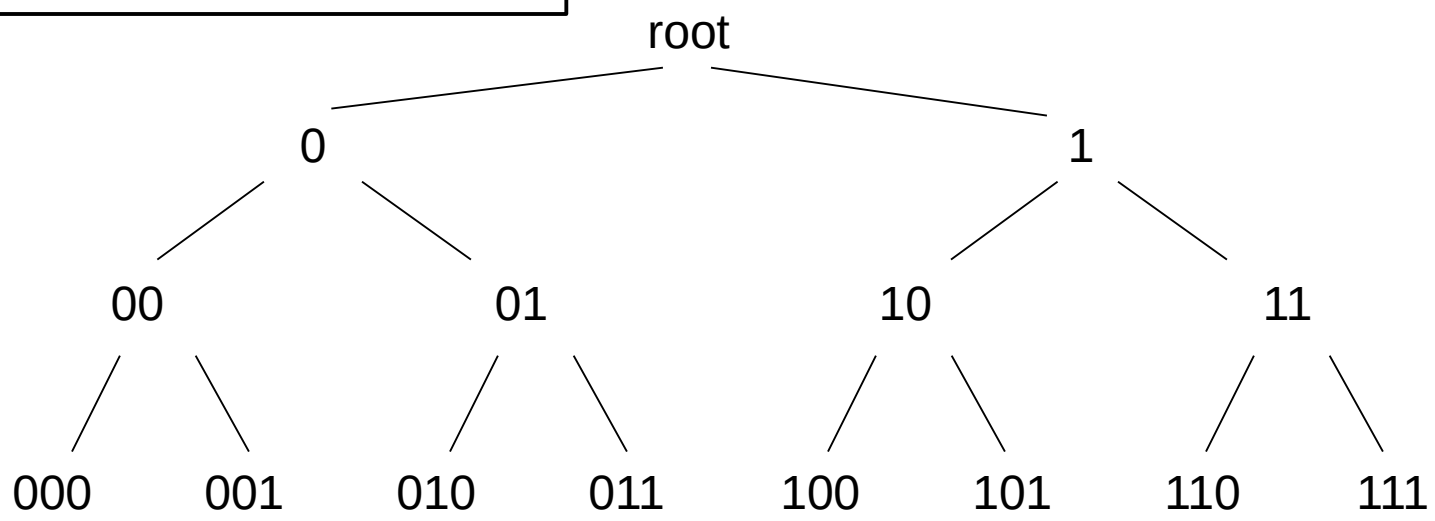
Techniques: (I) Complex Queries
Example: Interval Search

- Matching Function: M(v,q)=1 iff value v matches query q
- E_0,E_1: "expansion functions", mapping v's and q's onto sets of tokens

$$\text{s.t. } E_0(v) \cap E_1(q) = 1 \text{ iff } M(v,q)=1$$

- Initialization: Each R tagged with $F_k(v')$ for all v' in $E_0(v)$
- Retrieval: OPRF retrieves $F_k(q')$ for all q' in $E_1(q)$

values in range $[0,...,2^k)$, here k=3



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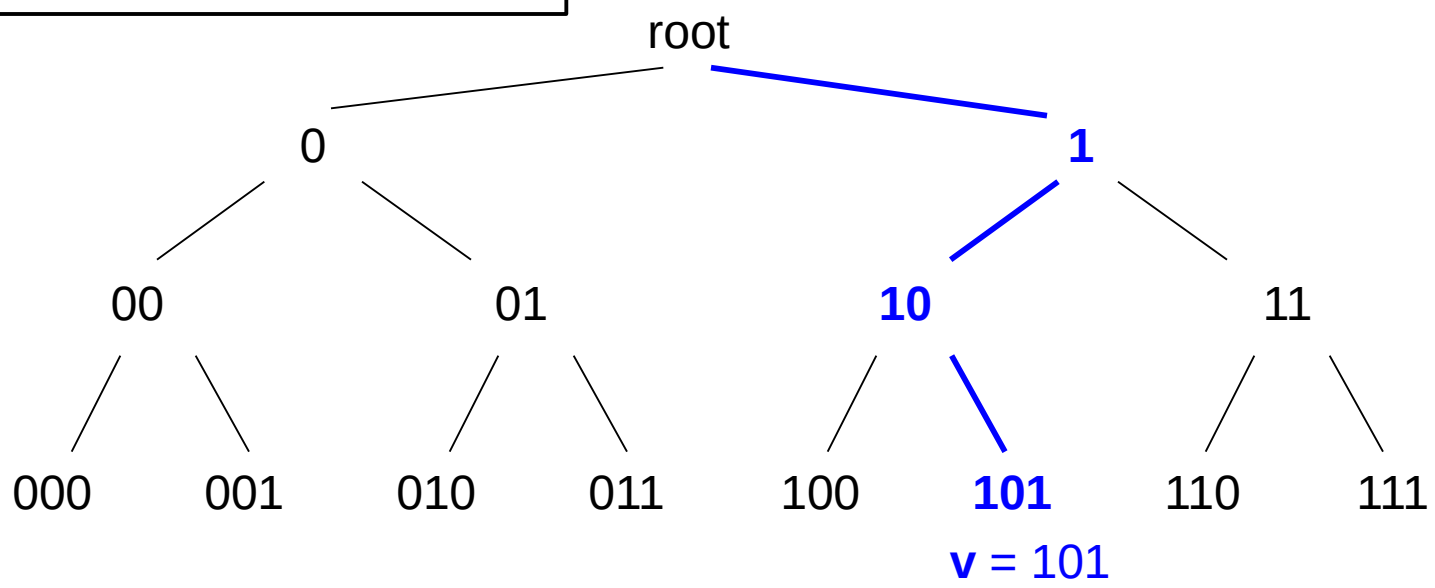
$E_0(v)$ = { *path from root to v* }



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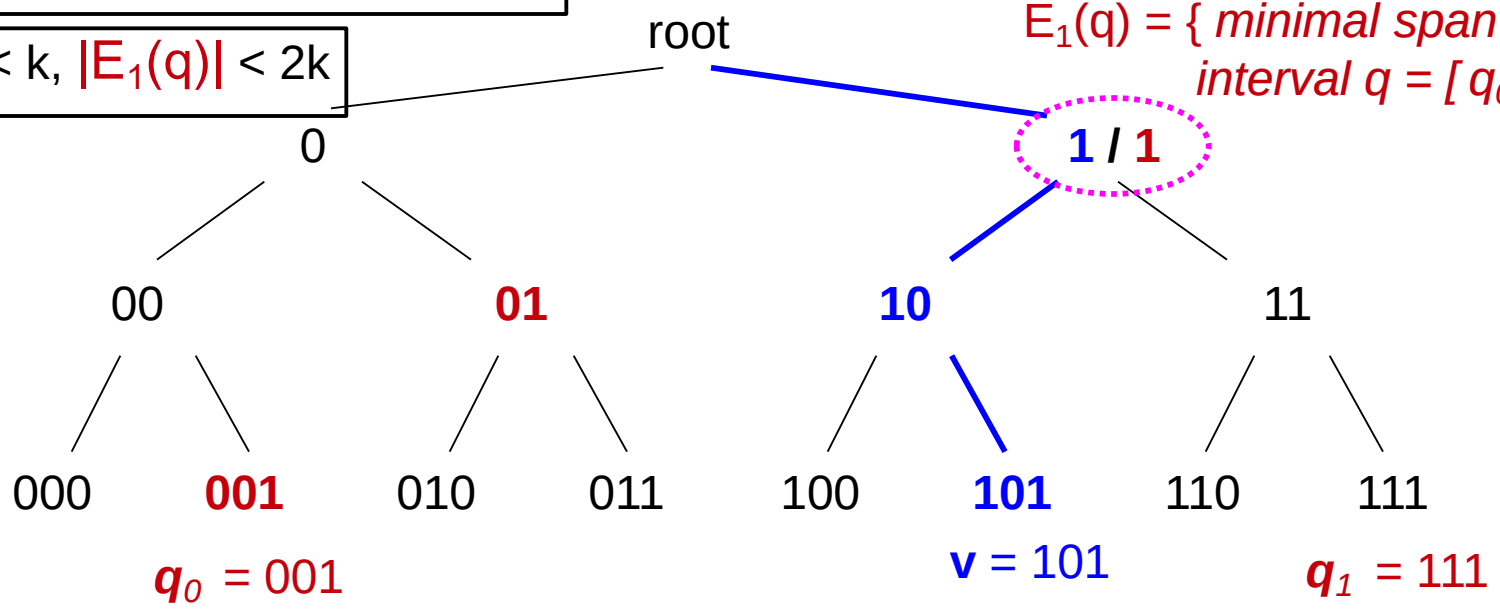
- Initialization: Each R tagged with **$F_k(v')$** for all **$v' \in E_0(v)$**
- Retrieval: OPRF retrieves **$F_k(q')$** for all **$q' \in E_1(q)$**

values in range $[0,...,2^k)$, here k=3

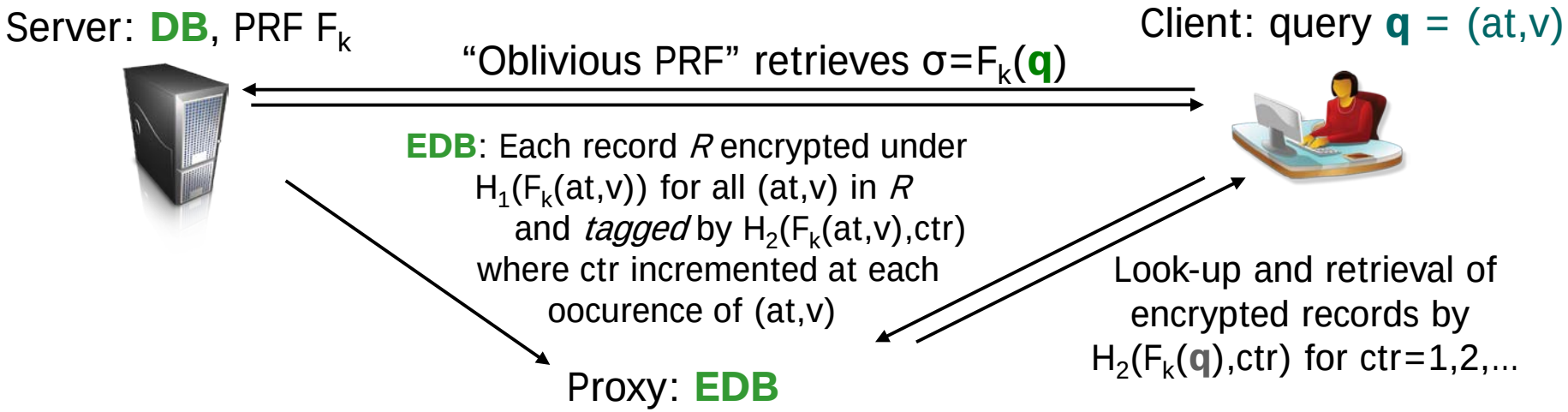
$|E_0(v)| < k$, $|E_1(q)| < 2k$

$E_0(v)$ = { *path from root to v* }

$E_1(q)$ = { *minimal span of interval* $q = [q_0, q_1]$ }



Techniques: (II) Authorizations



- Adding ZK Proof to OPRF:

  Client proves in ZK that it's query satisfies Server's access policy

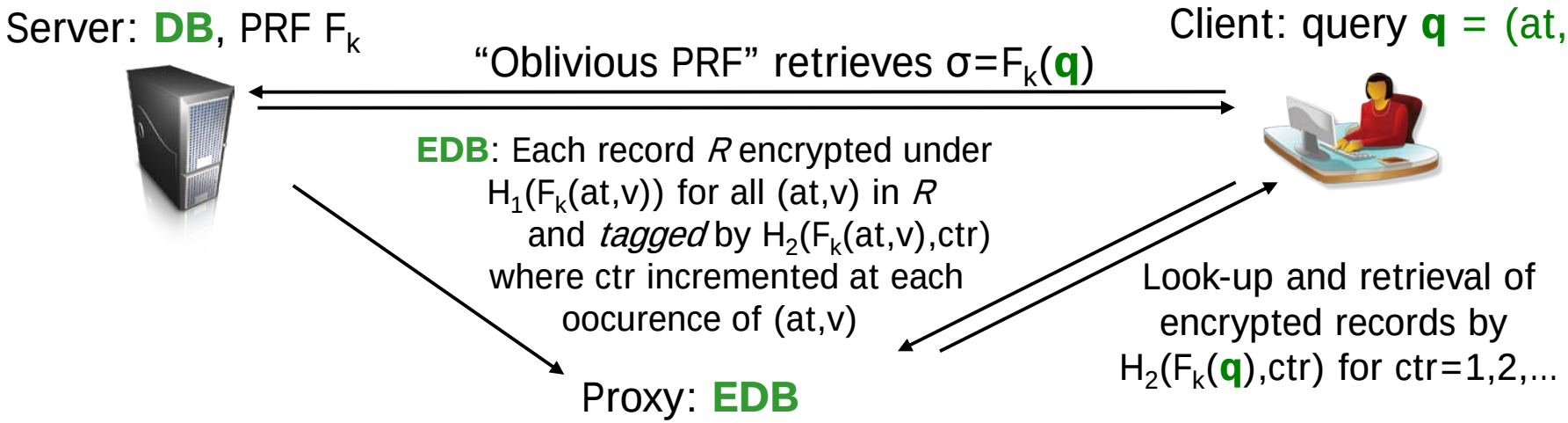
- Efficiency depends on access policy complexity:

  restrictions on attributes; query types; match functions; query values?

- Efficiency depends on Client's privacy protection:

  can Server learn query attribute, query type, match function ?

Techniques: (III) Conjunctions



Idea 1: Identify (encrypted) record sets matching each term and use MPC for Set Intersection on encrypted sets

O(|largest set|) public key ops; Proxy learns these (encrypted) sets

Idea 2: a) EDB stores mac's $F_k(R,(at,v))$ binding R to (at,v) pairs;

b) Proxy retrieves mac's binding same R to each query term;

c) Client obliviously exchanges these mac's for decryption of R.

O(|intersection|) p.k. ops; Proxy learns sets matching conjunctions of terms

Idea 3,4,...: Refinements for other efficiency/privacy trade-offs

Private Database Access
Some Research Challenges

- Many cryptographic protocol problems related to updates, authorizations, conjunction-handling, …
  - Partial List: OPRF, set intersection on encrypted items, escrow, malicious/covert security (overhead of ZK proofs)
- Privacy-Preserving Information Retrieval algorithms:
  IR algorithms that perform only equality tests? (cf. range queries)
- Can order-preserving encryption provide any gains?
- Use dedicated secure two-party computation, e.g. AES-OPRF?
- Use Oblivious RAM to hide patterns in queries and updates?
- Quantifying privacy leakage: differential privacy techniques?