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Deploying Private Information Retrieval for Real Databases

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Private Information Retrieval (PIR)

Considers the cryptographic problem of retrieving data from **untrusted**, remote databases.

- ❏ Parties:
    - ❏ Client
    - ❏ Server (one or multiple)
- ❏ Steps:
    - ❏ Query
    - ❏ Response

Current outlook

❑ Very active research area

❑ Promising efficiency

❑ Variety of applications

Issues to discuss today

- ❑ Which performance criteria / applications matter?

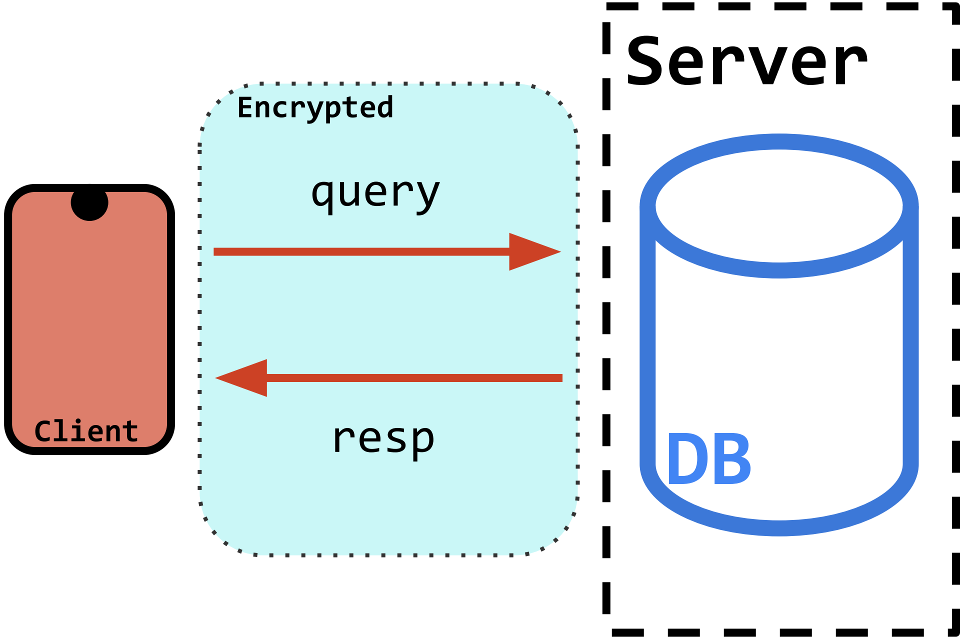
- ❑ What databases should be supported?

- ❑ How to unify PIR design for real-world?

Private Information Retrieval

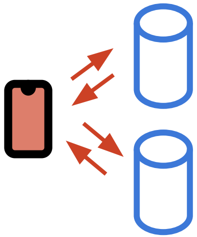
Base-case for this talk:

- ❑ Single (semi-honest) server
- ❑ query / resp =
  - ❑ DB.get(i)
  - ❑ DB.get(kw)
  - ❑ SELECT * FROM DB WHERE <condition>
  - ❑ …
- ❑ DB is assumed public
- ❑ May involve offline preprocessing



Why single-server?

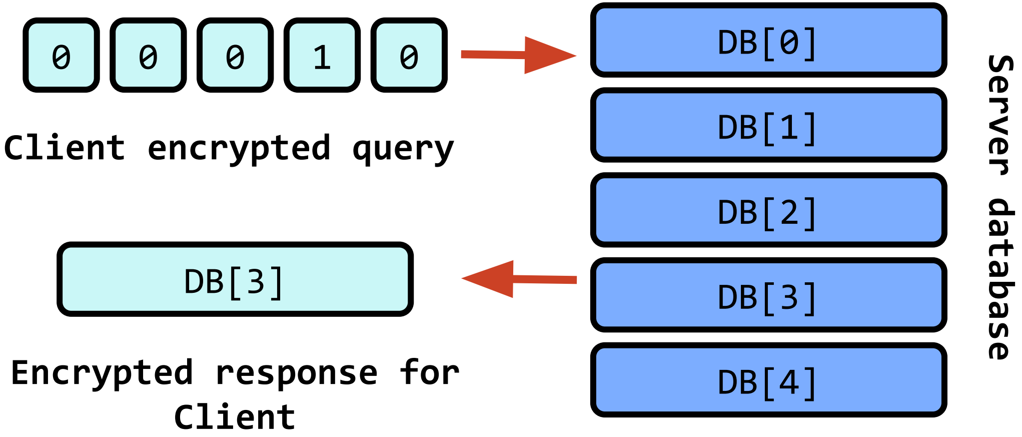
Multi-server PIR is more efficient and gives information-theoretic guarantees, but:



- No clear process (legal/practical) for finding independent, non-colluding partners
  - Co-deployment seems like a form of collusion
- Single-server efficiency is improving
- We already believe computational assumptions

Single-server constructions

Based on practical® constructions of homomorphic encryption from LWE or RLWE



- ❑ LWE-based (stateful) are simpler to implement, and process queries faster
- ❑ RLWE-based (stateless/stateful) include optimisations for amortisation, and are more flexible for higher-level applications

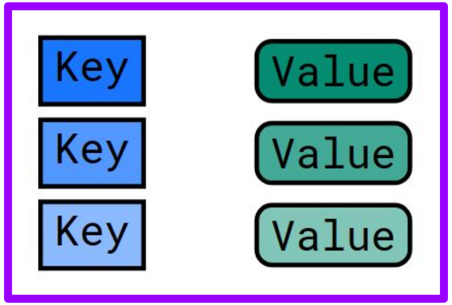
Current state of PIR

❏ High-throughput (<< 1 sec query, Θ(GBps))

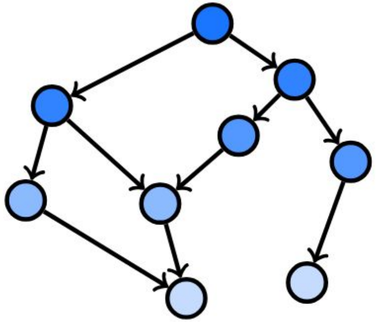
❏ High rate (|Enc(r)| ~ 3*|r|, Θ(KB))

❏ Practical queries for index or keywords

Real databases

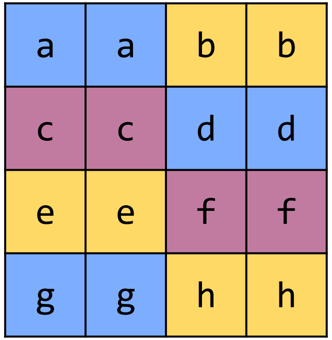


Key Value
Key Value
Key Value

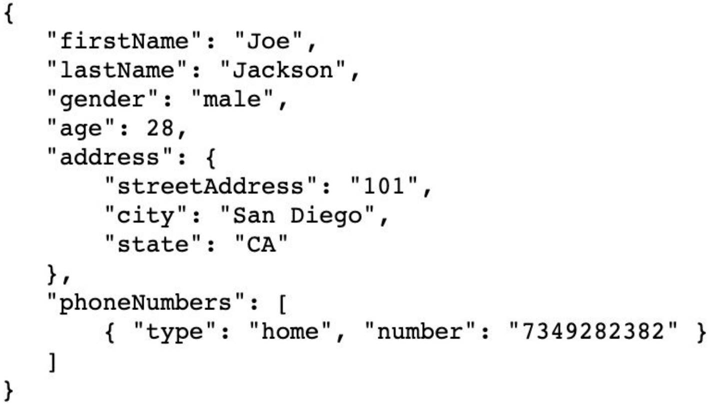


col_1	col_2	col_3
x_1	y_1	z_1
x_2	y_2	z_2
x_3	y_3	z_3

Issue #1: Non-uniform data

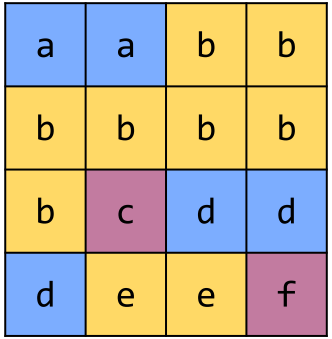


a	a	b	b
c	c	d	d
e	e	f	f
g	g	h	h



```
{
    "firstName": "Joe",
    "lastName": "Jackson",
    "gender": "male",
    "age": 28,
    "address": {
        "streetAddress": "101",
        "city": "San Diego",
        "state": "CA"
    },
    "phoneNumbers": [
        { "type": "home", "number": "7349282382" }
    ]
}
```

- ❑ Data-specific privacy?
- ❑ Efficiency for multi-layer keys?
- ❑ Client storage?



a	a	b	b
b	b	b	b
b	c	d	d
d	e	e	f

Goals:

Design PIR with real databases in mind.

*Security and performance modelling should take **database format** into account.*

Issue #2: Necessary Applications?

Some deployments / related technologies exist:

❑ Brave (compromised credential-checking, TBD)
❑ Blyss (https://github.com/blyssprivacy/sdk)
❑ Google (Device Enrollment)
❑ Microsoft (Password Monitor)

More complex use-cases (not deployed):

❑ Approximate nearest-neighbor: Brave News
❑ Private search: TipToe
❑ Oblivious document ranking: Coeus

***Open questions*:**

1. Build complex functions embedded directly into queries

2. Basic PIR used as part of higher-level application

Issue #3: Rapidly-updating databases

Differing update-cycles depending on application

- ❑ Slower cadence: contact discovery, compromised credentials
- ❑ Faster cadence: safe browsing, recommendation systems (*)

Stateful PIR: require state regeneration with every update

<u>Goals:</u>

1. *More benchmarking of stateful PIR with support for incremental updates*
2. *More efficient (and simpler®) stateless PIR*

Issue #4: Configurability

Different performance metrics matter to different people

- ❑ **Financial costs** may be more important than bandwidth for those without hardware
- ❑ **Server load** may be more important for CDNs, Google, etc.
- ❑ **Device load / bandwidth** for mobile devices

***Question**: Separate approaches for each criteria? Or support for simple re-parametrisation?*

Issue #5: Important security properties

- ❏ Does a semi-honest, public DB satisfy all applications?
  - ❏ **Probably not**: compromised credentials, contact-checking…

- ❏ Private DB + semi-honest seems important
  - ❏ Privacy measures are *ad-hoc* (OPRF, masking).
  - ❏ Implications: sub-optimal rounds, not post-quantum…

- ❏ Authenticated/verifiable/malicious PIR exists, is this what we should be using everywhere?

Issue #6: Simplicity®

- ❑ FHE-based PIR is very complex
  - ❑ Libraries are hard to audit/verify
  - ❑ Non-standard security parameters
  - ❑ Low-level optimisations required for PIR

- ❑ AHE-based is simpler and configurable
  - ❑ Restricted applications
  - ❑ Real-time databases require more complex RLWE

<u>Question</u>: *Do we want* ***widespread****, or* ***centralised*** *deployments?*

Conclusions

- PIR is a ***central*** cryptographic functionality
- However, not much evidence of real-world usage
- One-size-fits-all scheme seems **unlikely**
- New approaches need to consider and prioritise:
  - **Real** DB representations
  - **Real-time** updates
  - Enhanced **functionality** and **security** properties
  - More consideration of **higher-level** applications

Thank you!

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Our opinionated reading list

- Keyword-based PIR:
  - “Call Me By My Name: Simple, Practical Private Information Retrieval for Keyword Queries”: https://eprint.iacr.org/2024/092
  - “Don't be Dense: Efficient Keyword PIR for Sparse Databases”: https://eprint.iacr.org/2023/466
- Security properties:
  - “Fully Malicious Authenticated PIR”: https://eprint.iacr.org/2023/1804
  - “VeriSimplePIR: Verifiability in SimplePIR at No Online Cost for Honest Servers”: https://eprint.iacr.org/2024/341
- Complex queries:
  - “Private Web Search with Tiptoe”: https://eprint.iacr.org/2023/1438
  - “Coeus: A System for Oblivious Document Ranking and Retrieval”: https://eprint.iacr.org/2022/154