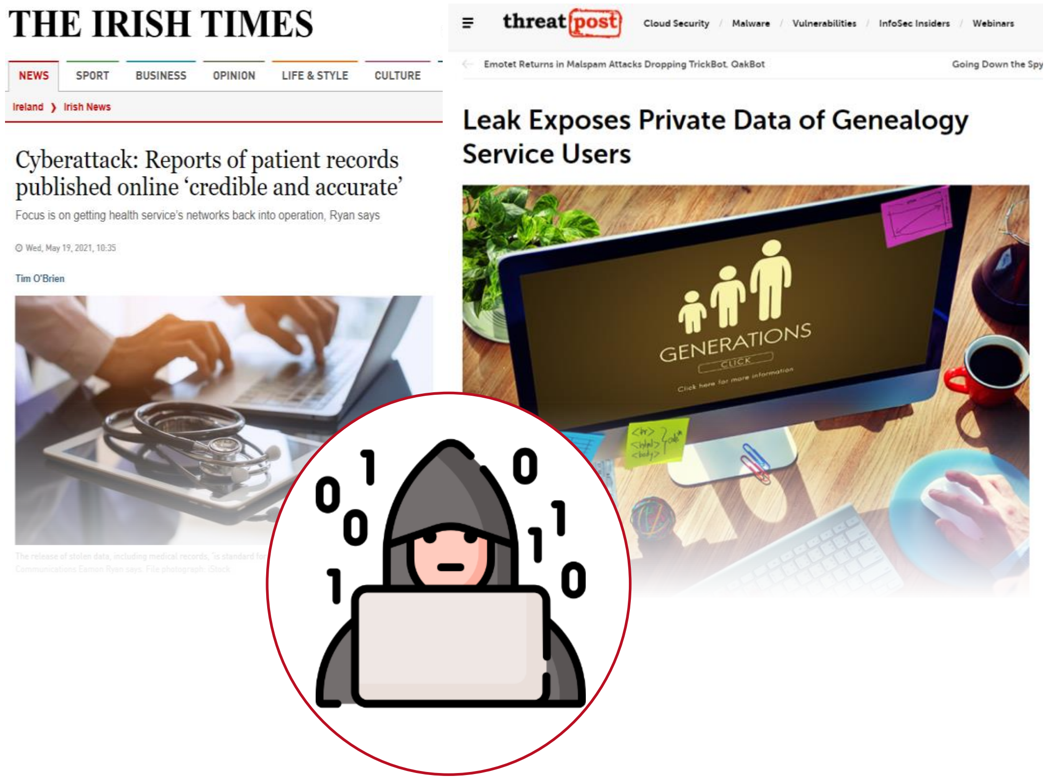
All About That Data: Towards a Practical Assessment Of Attacks on Encrypted Search

Seny Kamara, Abdelkarim Kati, Tarik Moataz, Thomas Schneider,
Amos Treiber, and Michael Yonli

TECHNISCHE UNIVERSITÄT DARMSTADT

ENCRYPTO CRYPTOGRAPHY AND PRIVACY ENGINEERING



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Cyberattack: Reports of patient records published online 'credible and accurate'

Focus is on getting health service's networks back into operation, Ryan says

Wed, May 19, 2021, 10:35

Tim O'Brien

The release of stolen data, including medical records, 'is standard for
Communications Eamon Ryan says. File photograph: iStock

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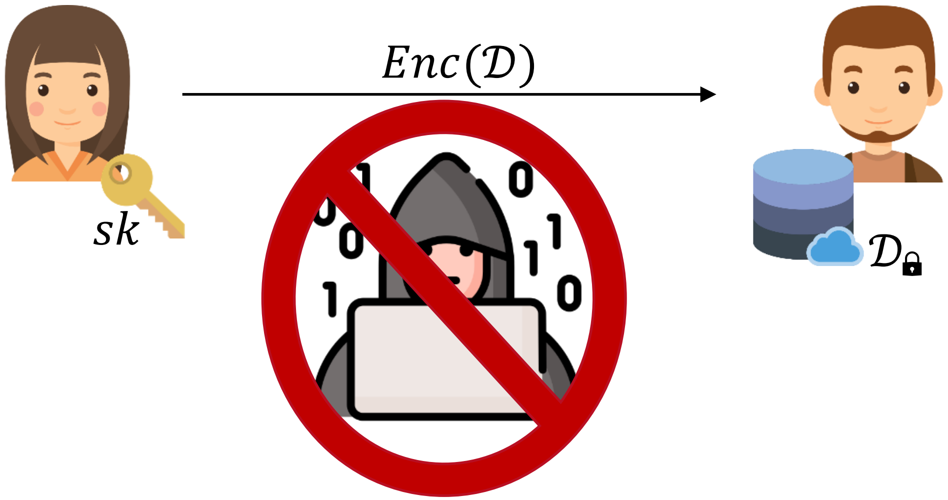
Emotet Returns in Malspam Attacks Dropping TrickBot, QakBot

Going Down the Spy

Leak Exposes Private Data of Genealogy Service Users



BROWN

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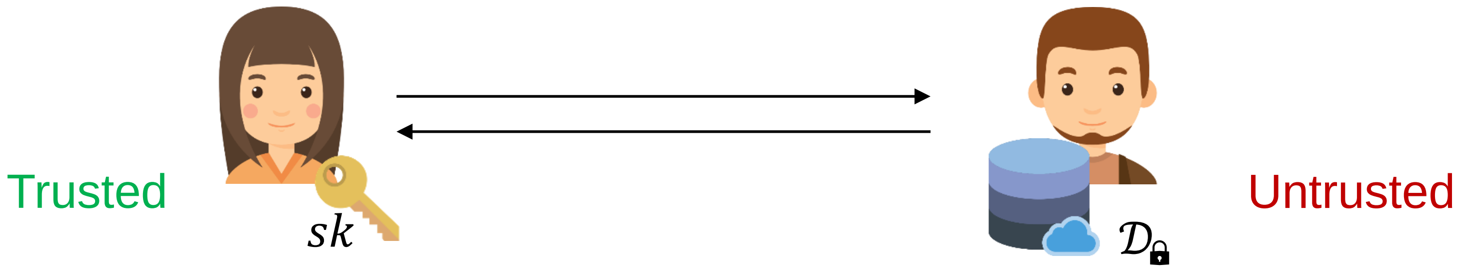
AROKI SYSTEMS

Encrypted Search Algorithms (ESAs)



Trusted

sk

$\mathcal{D}$

Untrusted

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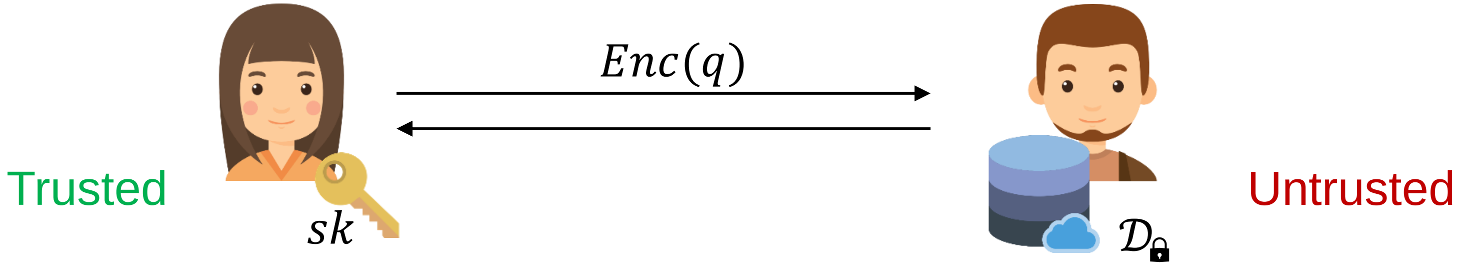

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$Enc(q)$

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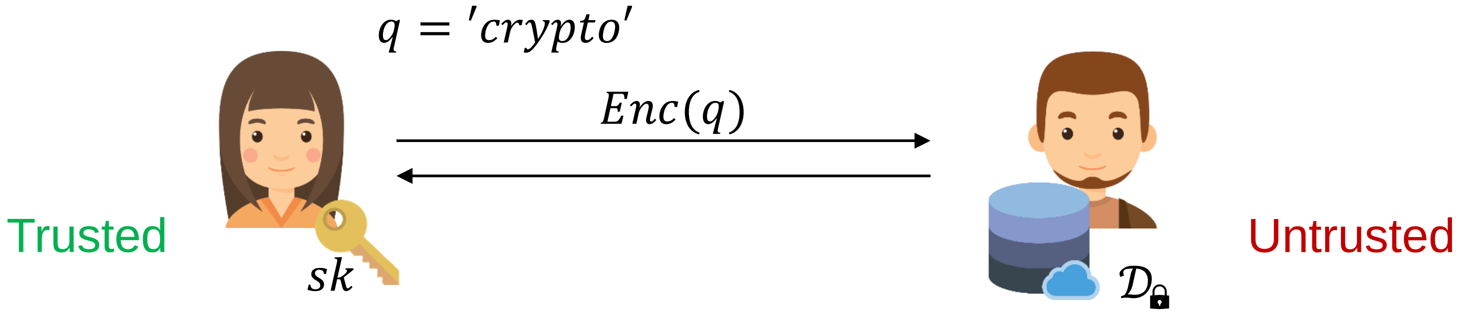

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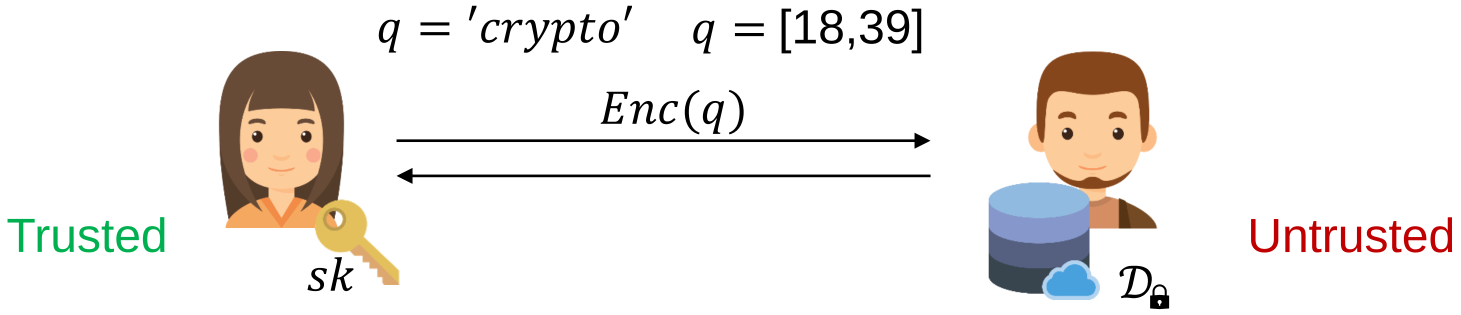

$q = \text{'}crypto\text{'}$ $q = [18,39]$

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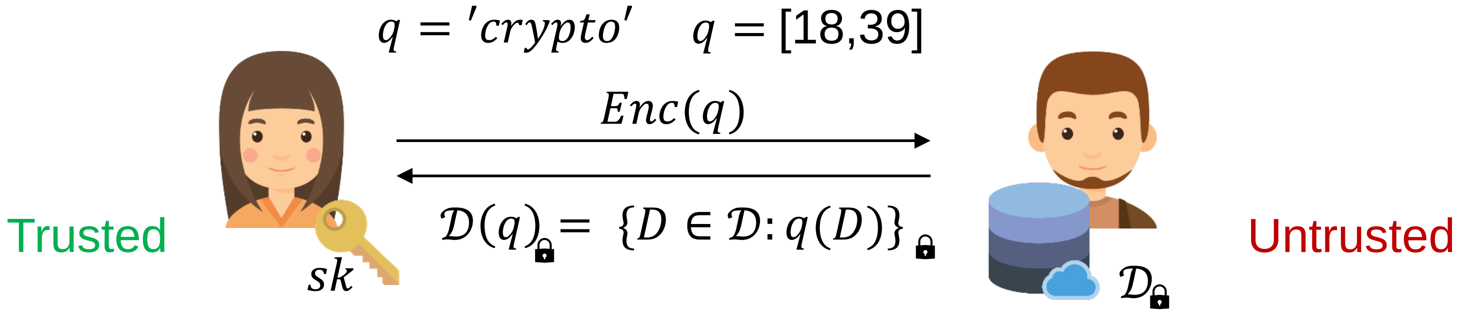

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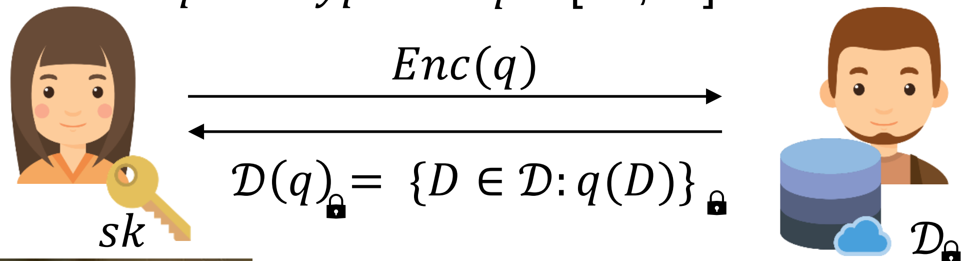

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Leakage

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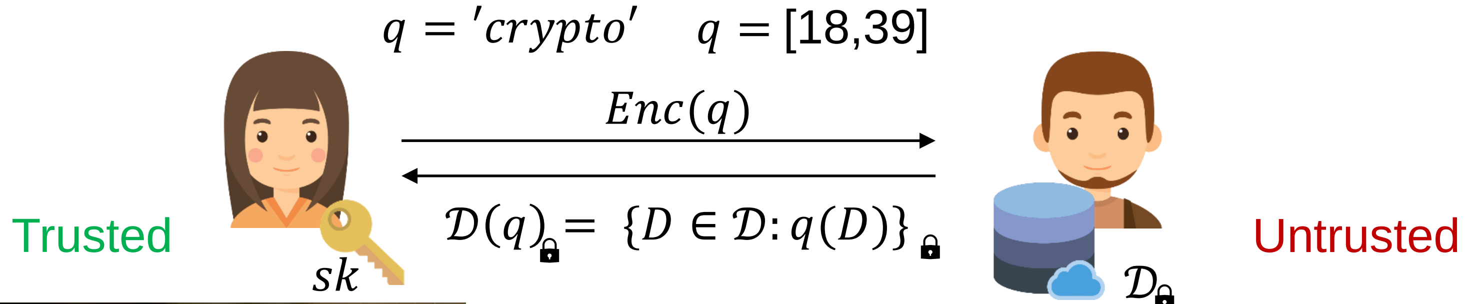

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Leakage

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- Structured Encryption (**STE**)
- Searchable Symmetric Encryption (**SSE**)
- Oblivious RAM (**ORAM**)

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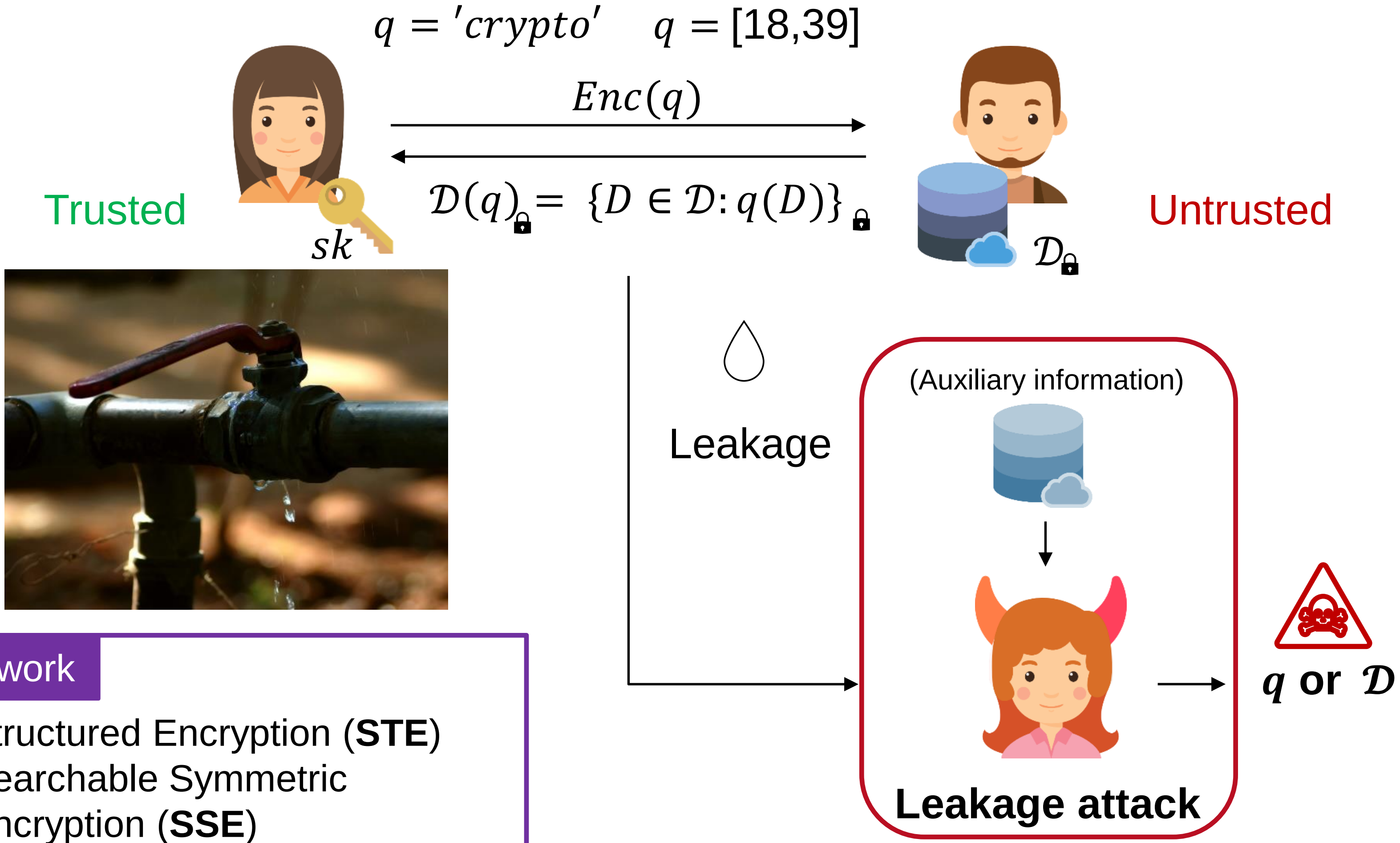

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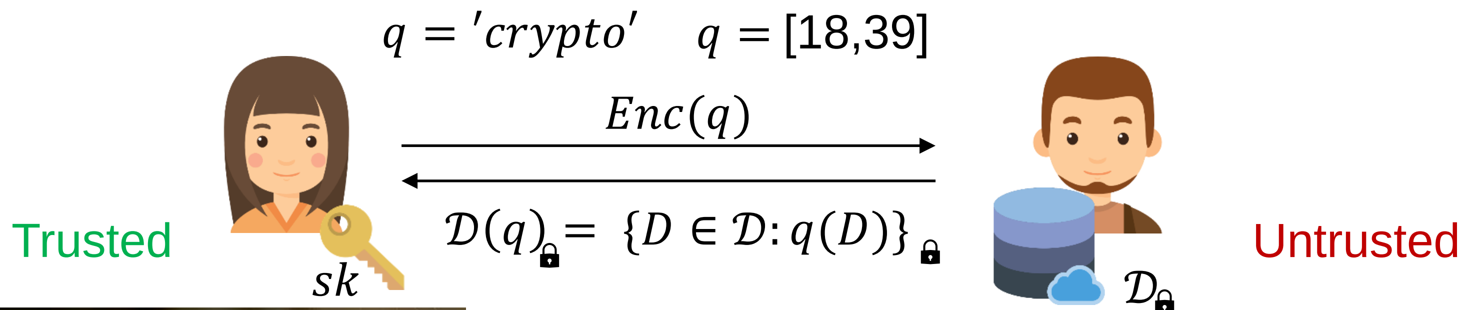

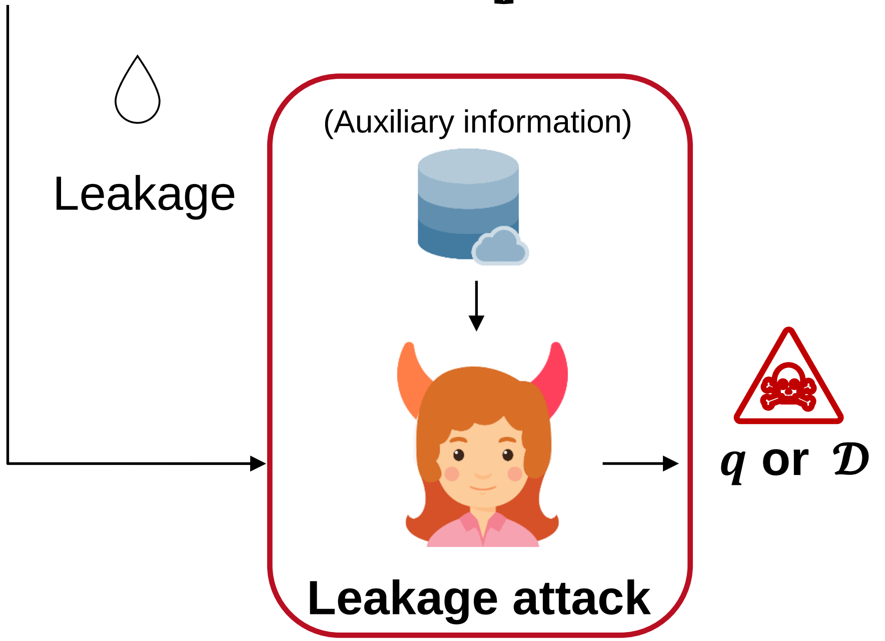

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Persistent & passive

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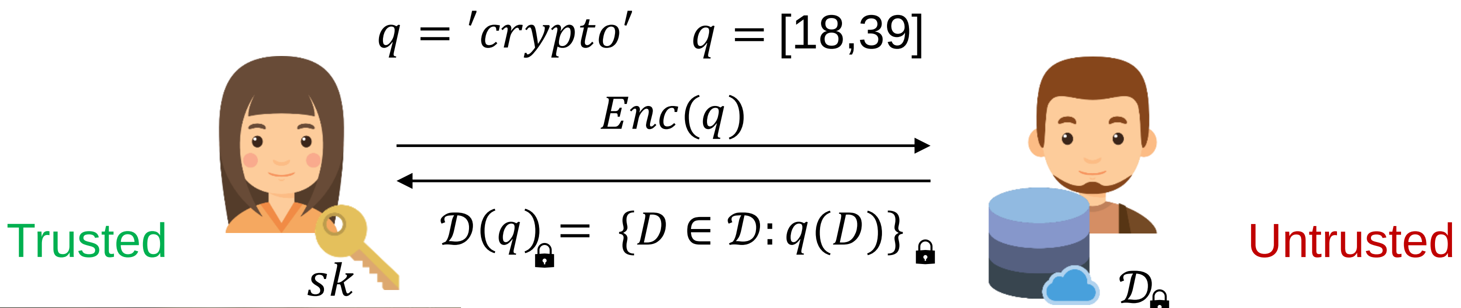

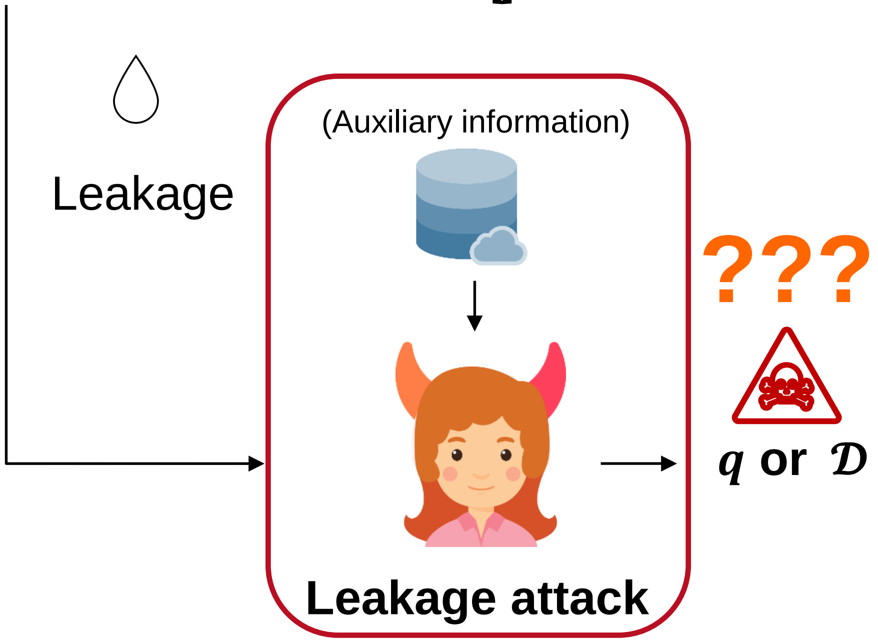

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Encrypted Search Algorithms (ESAs): Uncertainty Of Security

Constructions

Attacks & Countermeasures

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Attacks & Countermeasures

“Benign leakage”

“Common leakage”

“Standard leakage”

“Accepted leakage”

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“Leakages [...] are not exploitable via leakage-abuse attacks in practice”

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“Severe threat”

“Devastating results”

“[ESAs] are extremely vulnerable to [attacks]”

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“Our assumptions on background information are weak”

“With some prior knowledge [...] an honest-but-curious server can recover the underlying keywords”

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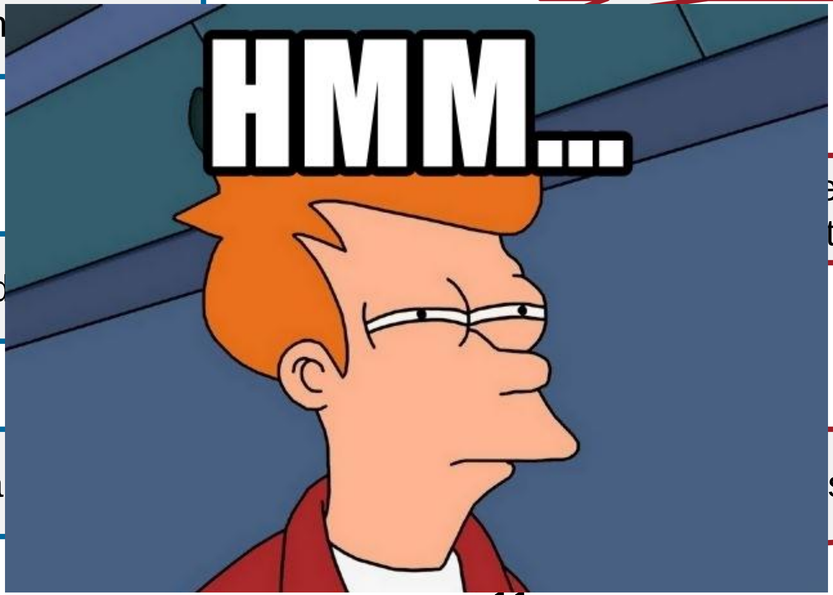

Previous Evaluations & Our Contributions

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Single use case

Few comparisons

Small/restricted data

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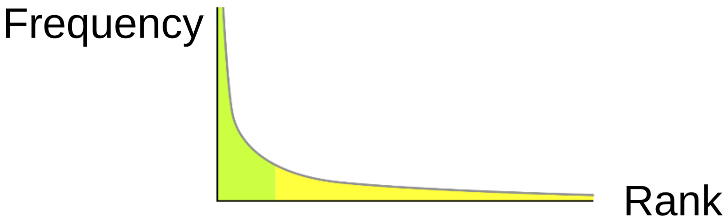
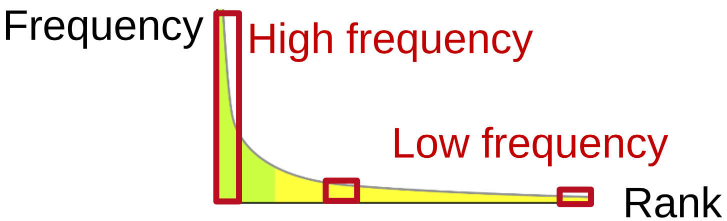


Artificial queries

Previous Evaluations & Our Contributions

Previous evaluations

- Closed-source code
- Single use case
- Few comparisons
- Small/restricted data



Artificial queries

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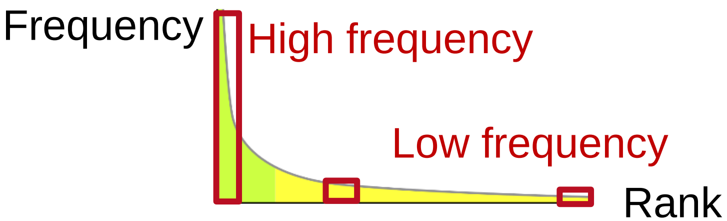

Artificial queries

This work

Open-source **framework**

Multiple use cases

Systematic re-evaluation

Large data

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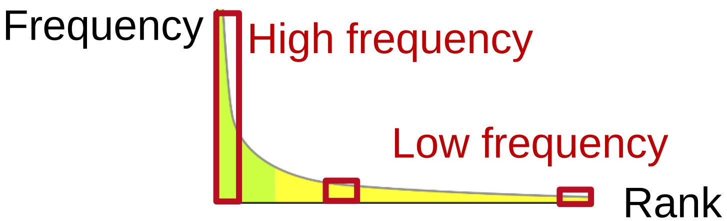


Artificial queries

This work

- Open-source **framework**
- Multiple use cases
- **Systematic re-evaluation**
- Large data

```
User,Query
216,'crypto'
216,'amsterdam'
106,'doctor'
216,'hotel'
```

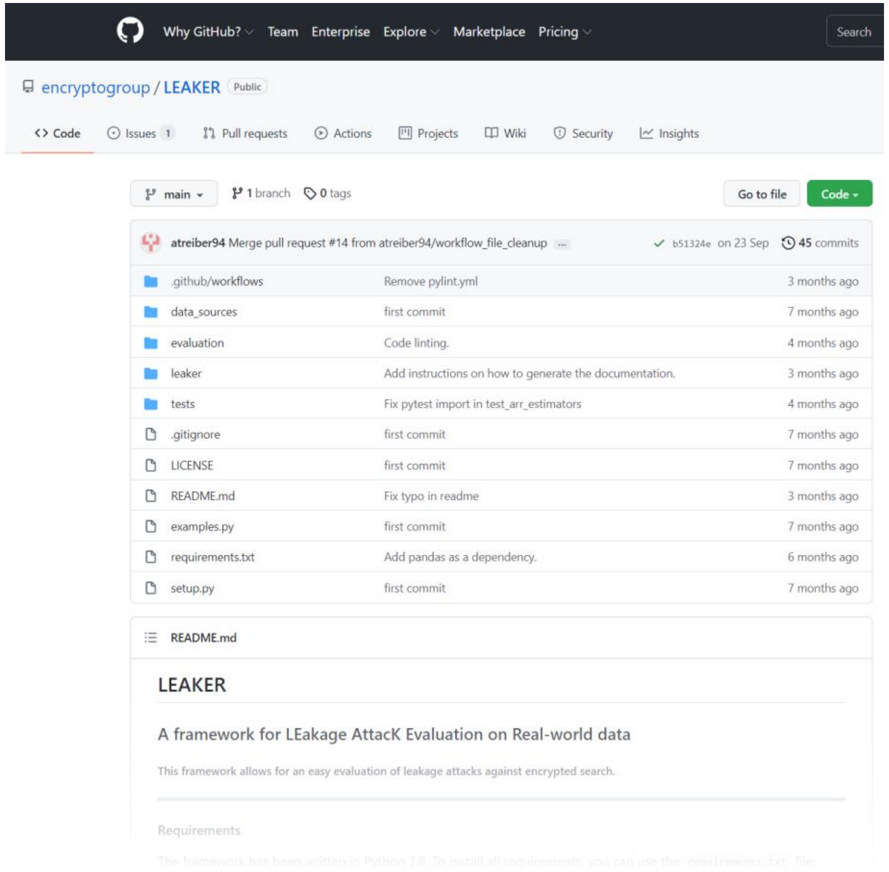
First real-world query logs

New Software: LEAKER

- Re-implementation of **17** major attacks in open-source framework

[IKK12,CGPR15,LMP18,GLMP18,GLMP19,GJW19, BKM20,KPT20,KPT21,RPH21]

https://encrypto.de/code/LEAKER



atreiber94 Merge pull request #14 from atreiber94/workflow_file_cleanup … ✓ b51324e on 23 Sep 45 commits

.github/workflows	Remove pylint.yml	3 months ago
data_sources	first commit	7 months ago
evaluation	Code linting.	4 months ago
leaker	Add instructions on how to generate the documentation.	3 months ago
tests	Fix pytest import in test_arr_estimators	4 months ago
.gitignore	first commit	7 months ago
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README.md

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This framework allows for an easy evaluation of leakage attacks against encrypted search.

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The framework has been written in Python 3.8. To install all requirements, you can use the `requirements.txt` file:

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[IKK12,CGPR15,LMP18,GLMP18,GLMP19,GJW19,
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- Modular design & interoperability
- Easy to implement new attacks & countermeasures
- Easy to pre-process & use new data

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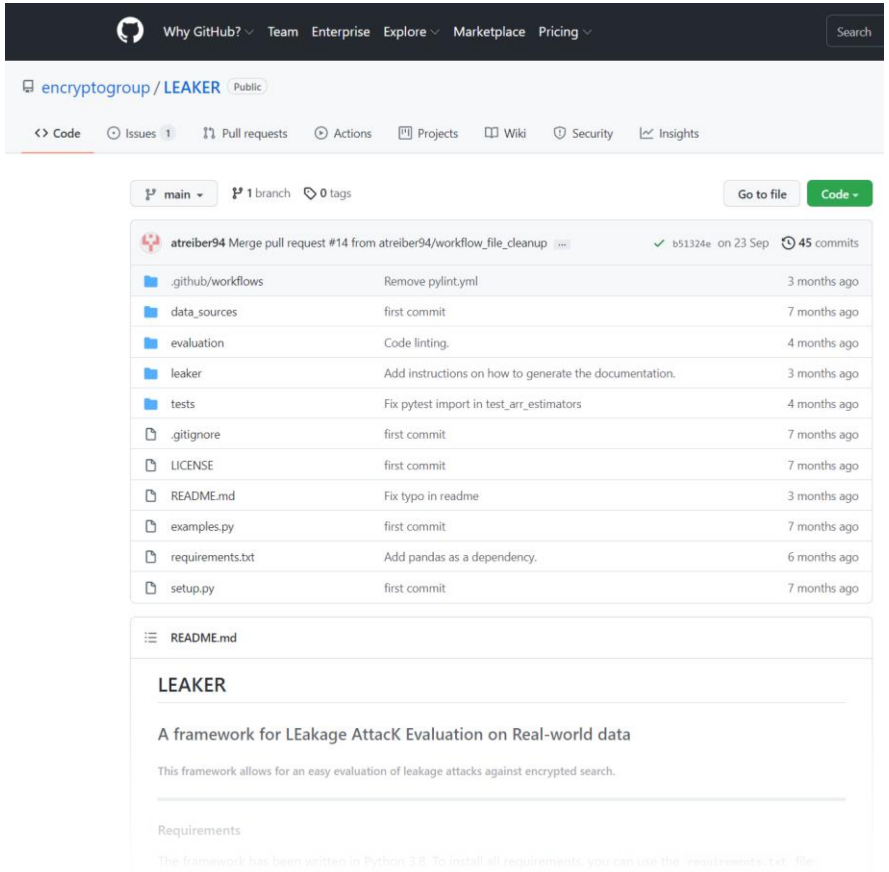

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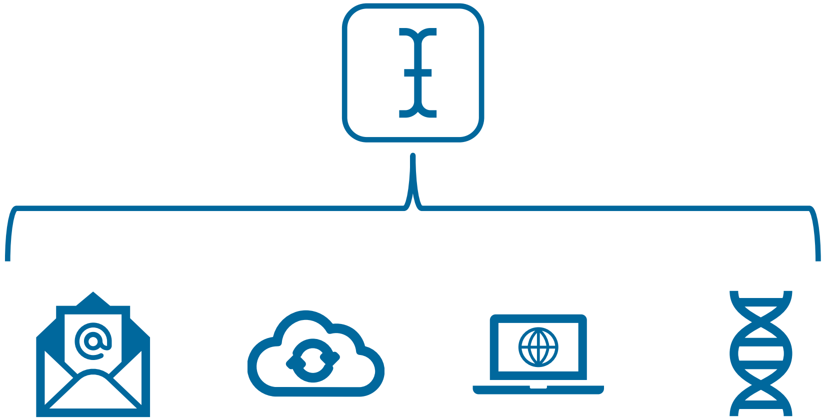

My Google activity
AOL
tair

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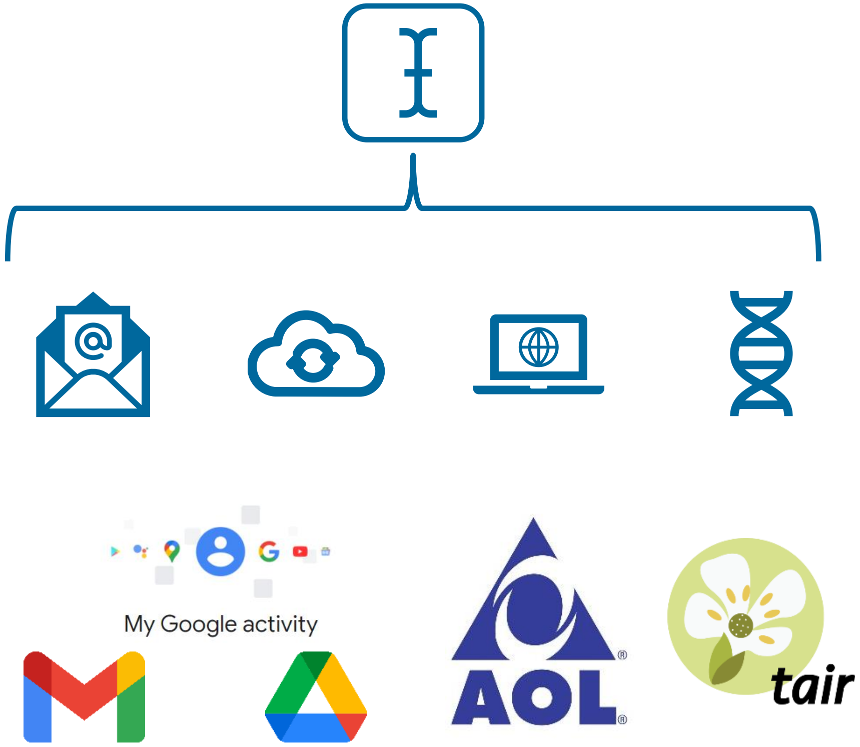
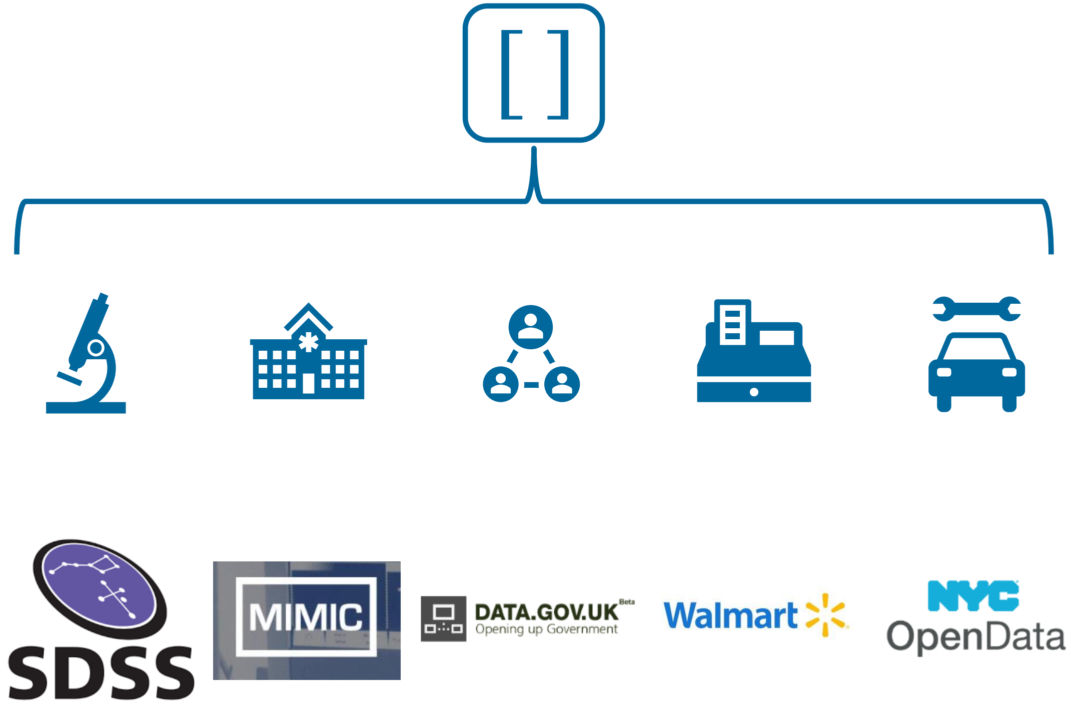


Range queries



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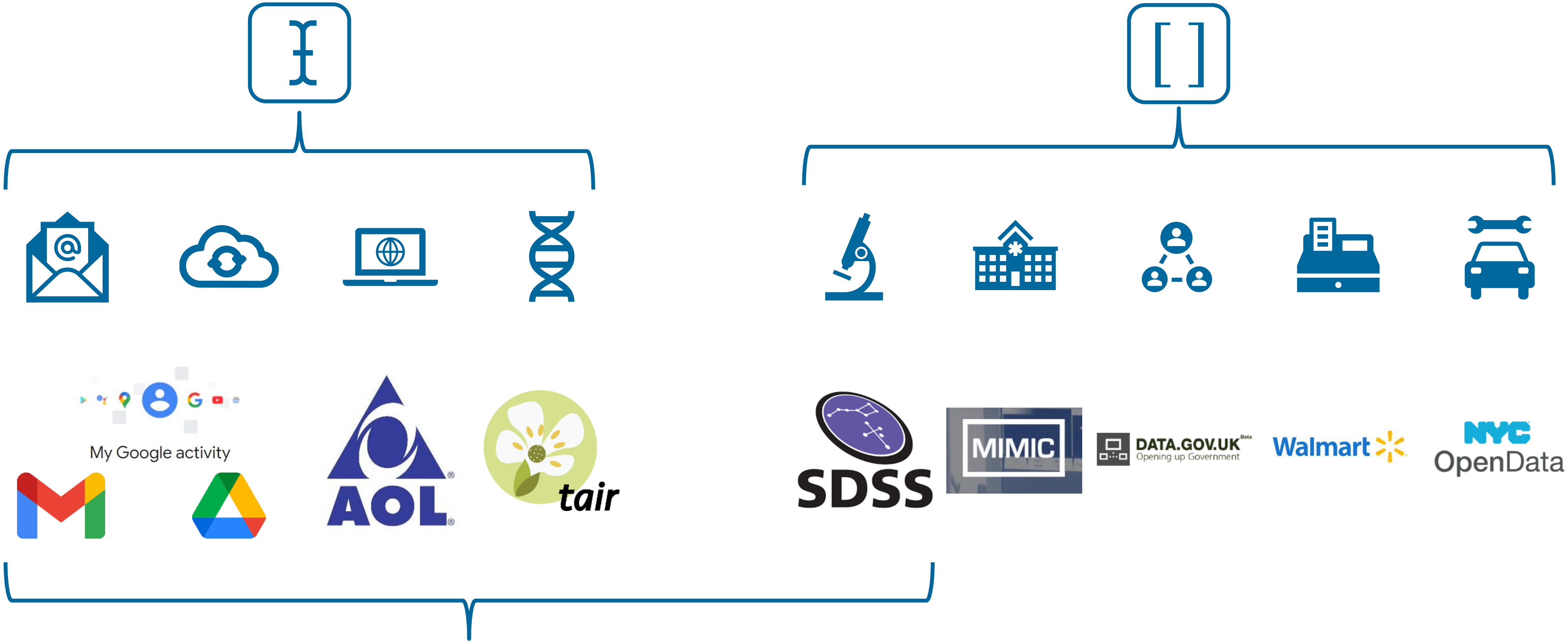

Have query logs

Evaluation: Summary – Keyword Search

(subjective)

Leakage	Attack Success	Risk
- Response length - Response volume	- High adversarial knowledge	Low
- Co-occurrence	- High adversarial knowledge	Low
- Response identifiers - Response volumes (of individual documents)	- Low adversarial knowledge	High

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=> Suppression of identifier and volume leakage of responses necessary!

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Subgraph attacks [BKM20]

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“ **None of the attacks worked against low-[frequency] keywords** ”

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“ Users are more likely **to search for a specific email** ”

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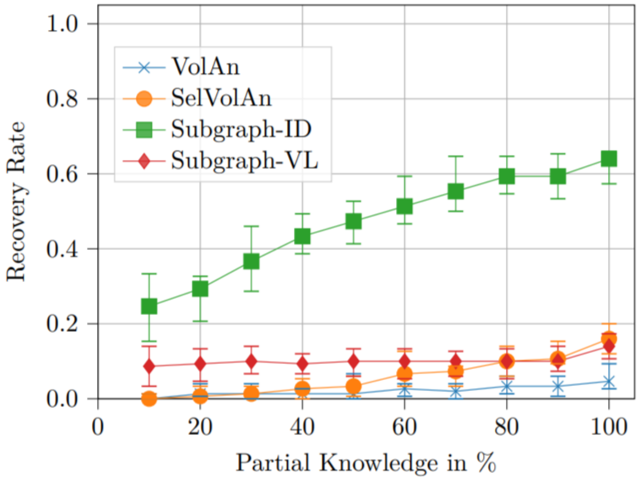

Mean frequency: 1.54!

(on TAIR)

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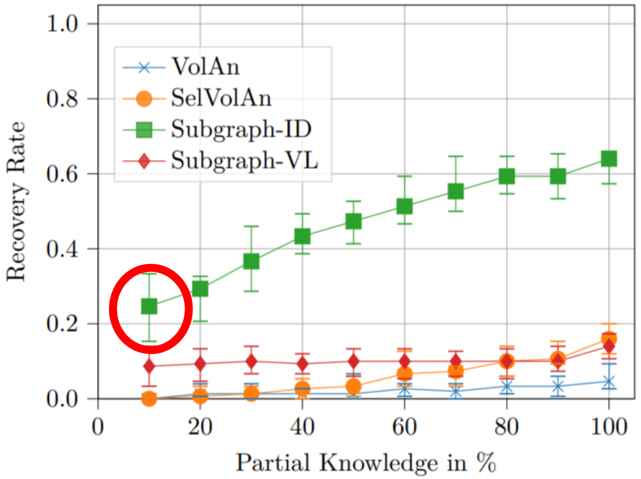

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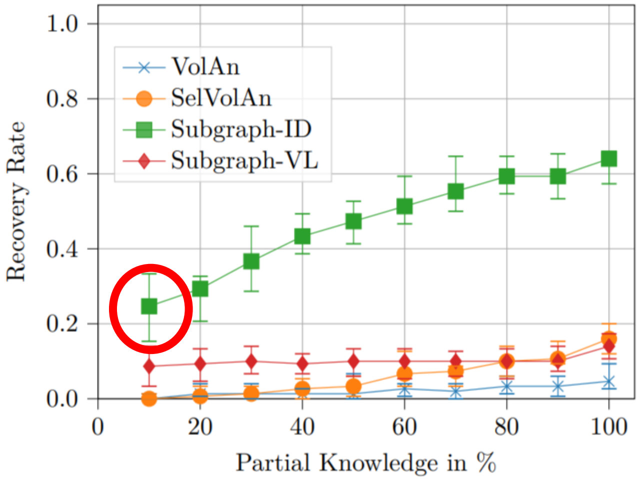

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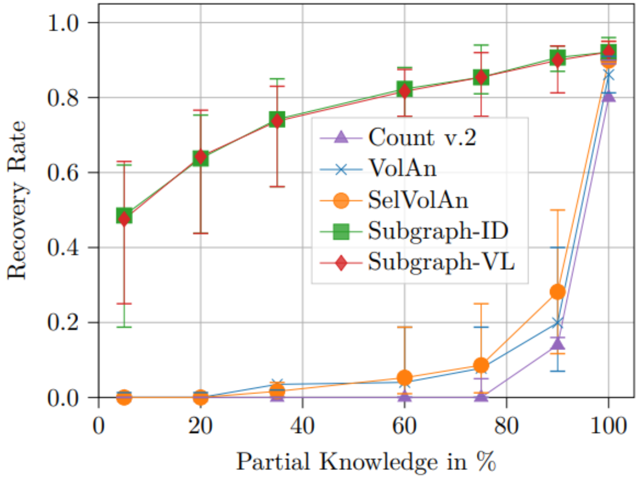

Mean frequency: 326!

(on GMail)

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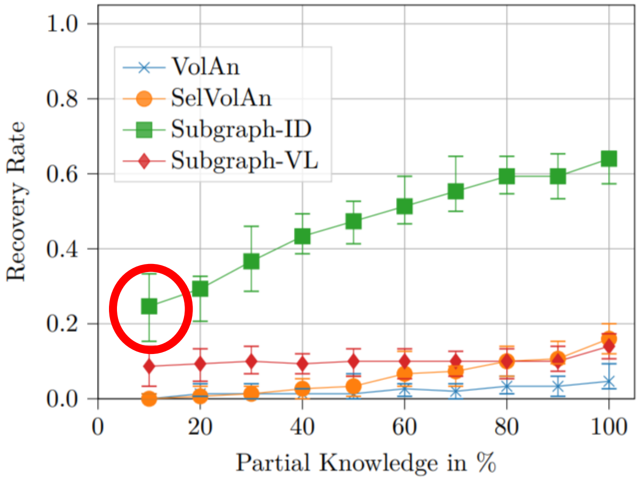

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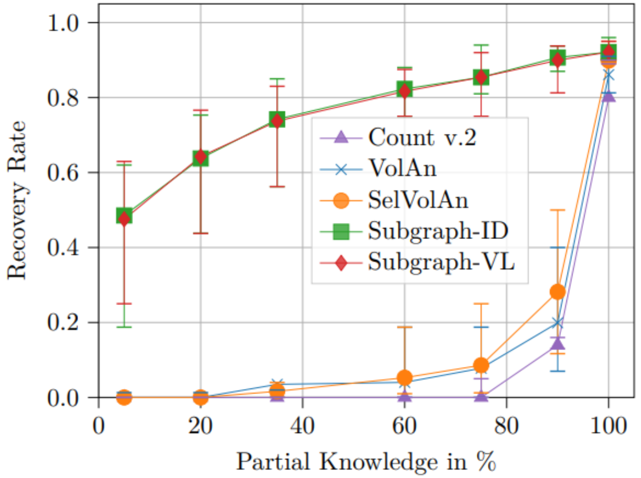
[RPH21]



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Evaluation: Summary – Range Search [ ]

(subjective)

Leakage	Attack Success	Risk
- Response length	- None	**Very low**
- Response length - Query equality	- Evenly distributed data	**Medium**
- Co-occurrence	- Large widths - Skewed values	**Medium**
- Co-occurrence - Order	- Most cases	**High**

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=> Leakage suppression for range case!

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- Extensible **open-source** framework LEAKER

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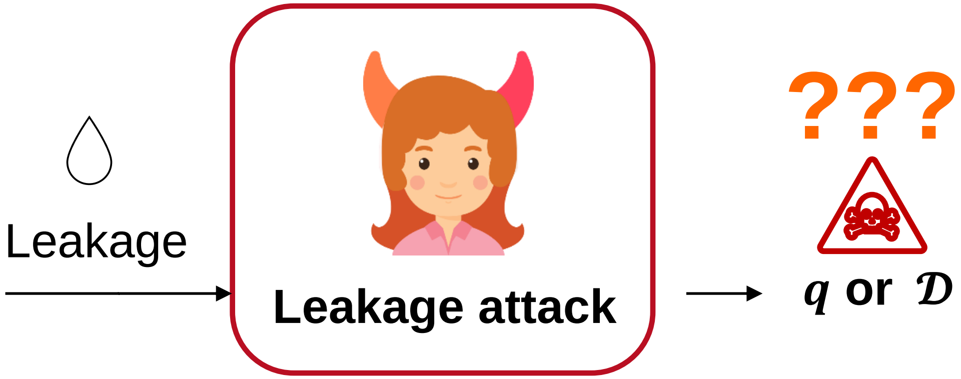

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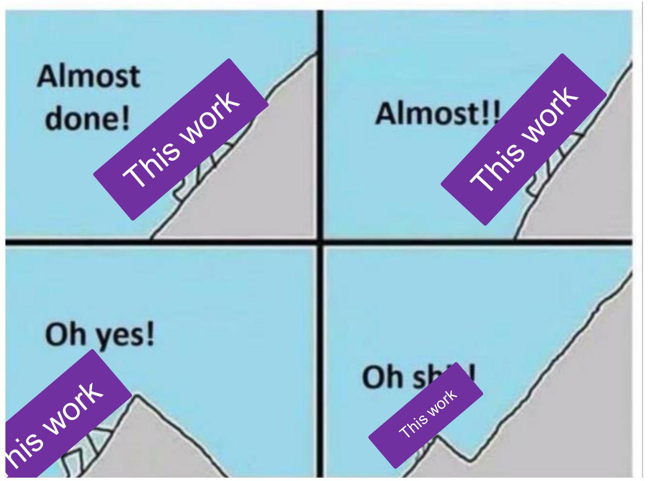
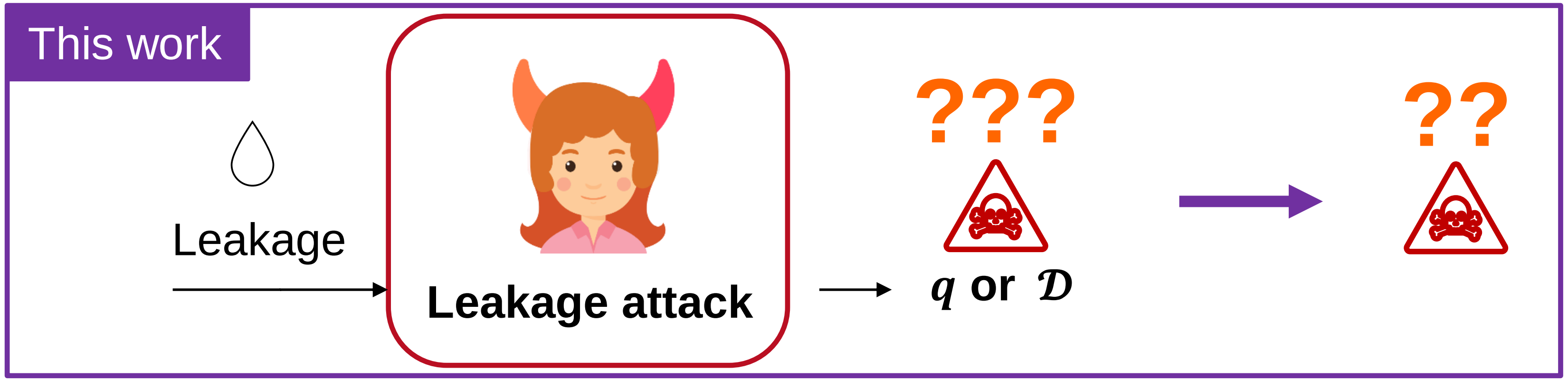
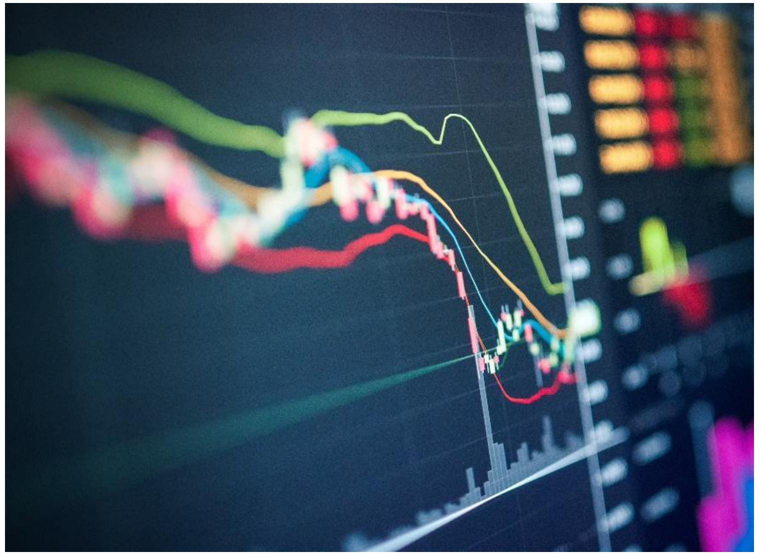




What needs to be done



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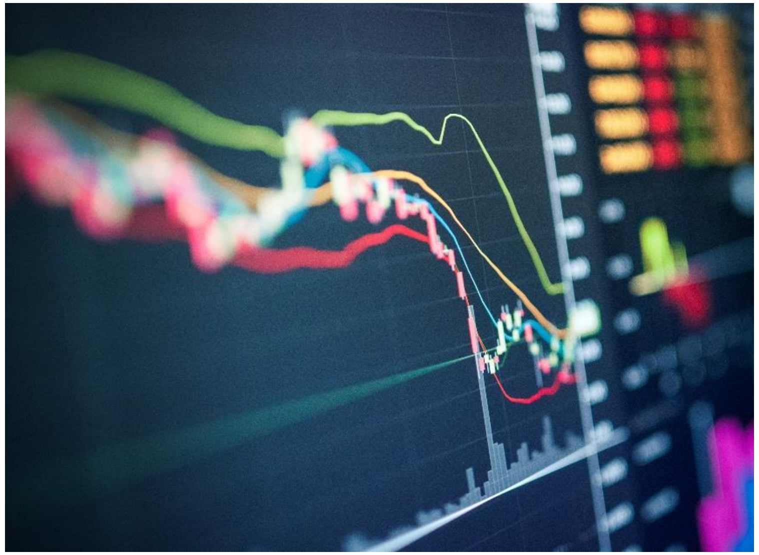

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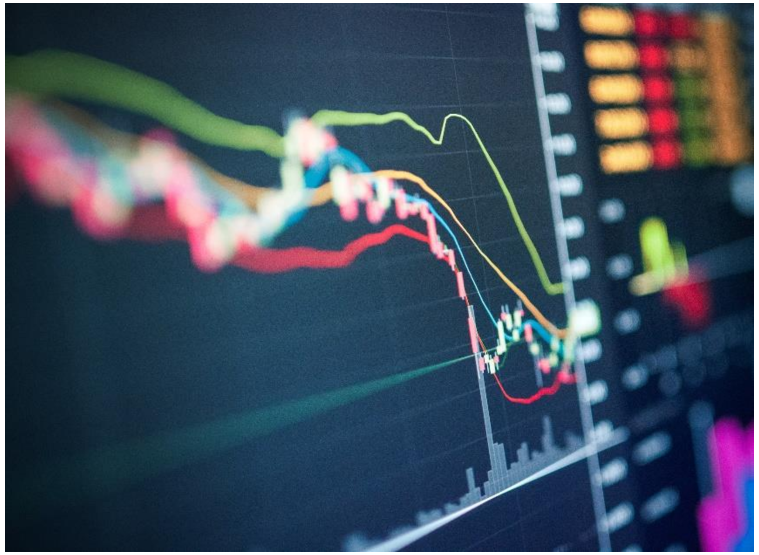

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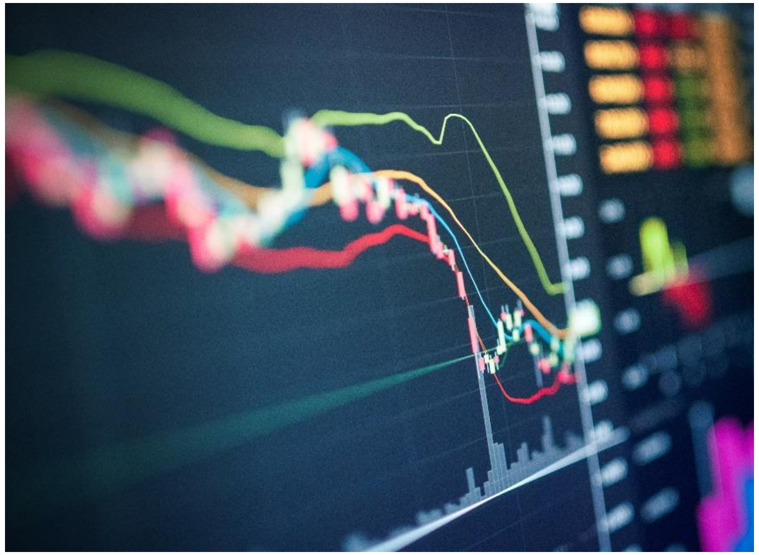

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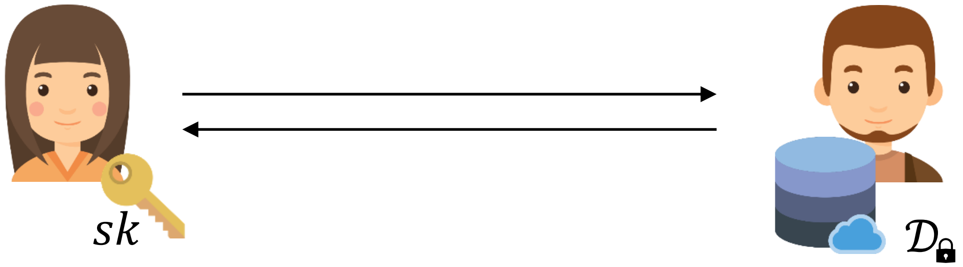

THANK YOU!

https://encrypto.de/treiber

More details:
https://ia.cr/2021/1035
(to appear at ***EuroS&P'22****)*

Leakage attack

Code:
https://encrypto.de/code/LEAKER

Resources

- Icons & pics by *Flaticons (FreePik, Becris, Darius Dan, Surang, Vectors Market, Becris), FreePNG, PNGItem, https://memegenerator.net/, Futurama - "The Lesser of Two Evils“, 2011 by 20th Television, Rawpixel.com / Shutterstock*
- [BKM20] Laura Blackstone, Seny Kamara, and Tarik Moataz. Revisiting leakage abuse attacks. In Network and Distributed System Security Symposium (NDSS), 2020
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Leakage Patterns

Leakage 💧	Information
Response Length	$\lvert D(q) \rvert$
Query Equality	$q_i = q_j$
Co-Occurrence	$\lvert D(q_i) \cap D(q_j) \rvert$
Response Identifiers	$\{i : D_i \in q(D)\}$
Response Volumes	$\{\lvert D_i \rvert_b : D_i \in q(D)\}$

(Simplified)

Leakage Attacks Types

Keyword (*point*) queries
[IKK12,CGPR15,BKM20,RPH21]

Keyword	Document IDs
‘real’	2,5,11,13,20,31
‘world’	3,5,10,11,13,25
‘crypto’	5,11,21,27

$$q = w$$
$$\mathcal{D}(q) = \{D \in \mathcal{D}: q \in D)\}$$
Recover q

$q = 'crypto'$

***Known-data**: Adversary knows subset of $\mathcal{D}$*

Range queries
[KKNO16,LMP18,GLMP18,
GLMP19,GJW19,KPT20,KPT21]

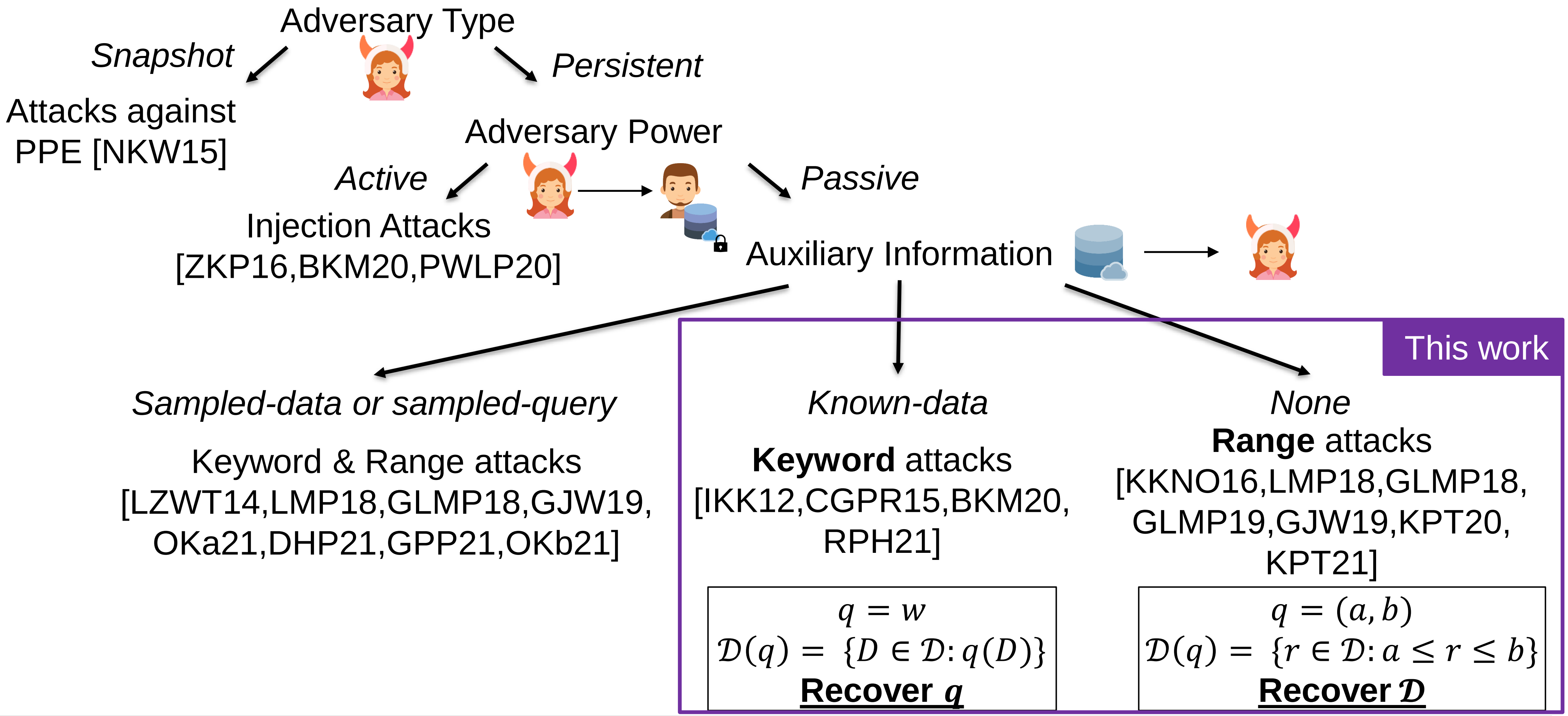
ID	Age
1	65
2	7
3	27

$$q = (a, b)$$
$$\mathcal{D}(q) = \{r \in \mathcal{D}: a \leq r \leq b\}$$
Recover $\mathcal{D}$

$q =$(18,39)

No auxiliary knowledge

Overview of Leakage Attacks on ESAs



Adversary Type

Snapshot

Attacks against
PPE [NKW15]

Persistent

Adversary Power

Active

Injection Attacks
[ZKP16,BKM20,PWLP20]

Passive

Auxiliary Information

Sampled-data or sampled-query

Keyword & Range attacks
[LZWT14,LMP18,GLMP18,GJW19,
OKa21,DHP21,GPP21,OKb21]

This work

Known-data

Keyword attacks
[IKK12,CGPR15,BKM20,
RPH21]

$q = w$

$\mathcal{D}(q) = \{D \in \mathcal{D}: q(D)\}$

Recover q

None

Range attacks
[KKNO16,LMP18,GLMP18,
GLMP19,GJW19,KPT20,
KPT21]

$q = (a, b)$

$\mathcal{D}(q) = \{r \in \mathcal{D}: a \leq r \leq b\}$

Recover $\mathcal{D}$

Overview of Techniques for ESAs (Extremely informal)

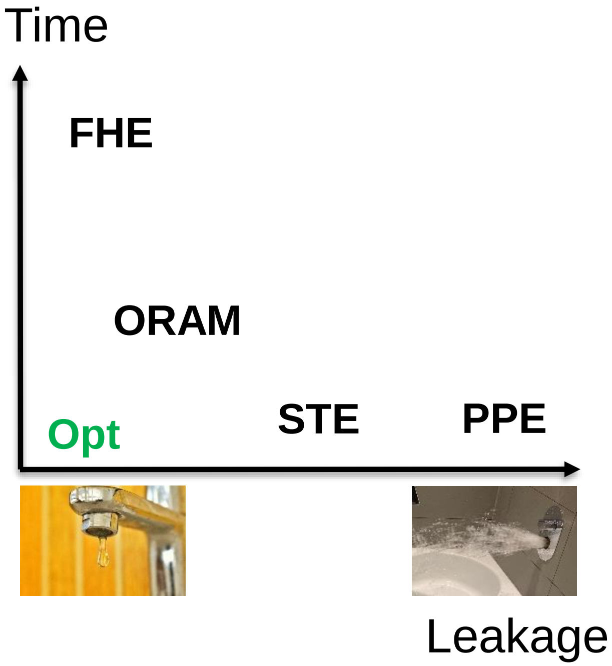
Technique	Leakage	Query Time
Fully Homomorphic Encryption (FHE)	• None	Linear
Oblivious RAM (ORAM)	• Response Length	Sublinear
Structured Encryption (STE)	• Query Equality • Responses' Equality	Optimal
Property-Preserving Encryption (PPE)	• Ciphertext Equality • Ciphertext Order	Optimal

FHE: Considered secure but inefficient

This work

ORAM, STE: Considered efficient and ???

PPE: Considered efficient but insecure [NKW15]



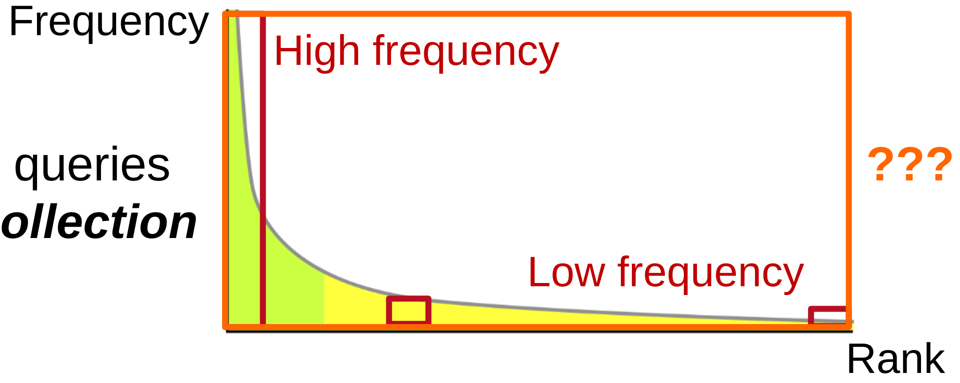
Previous Evaluations

- Usual evaluations for keyword attacks:

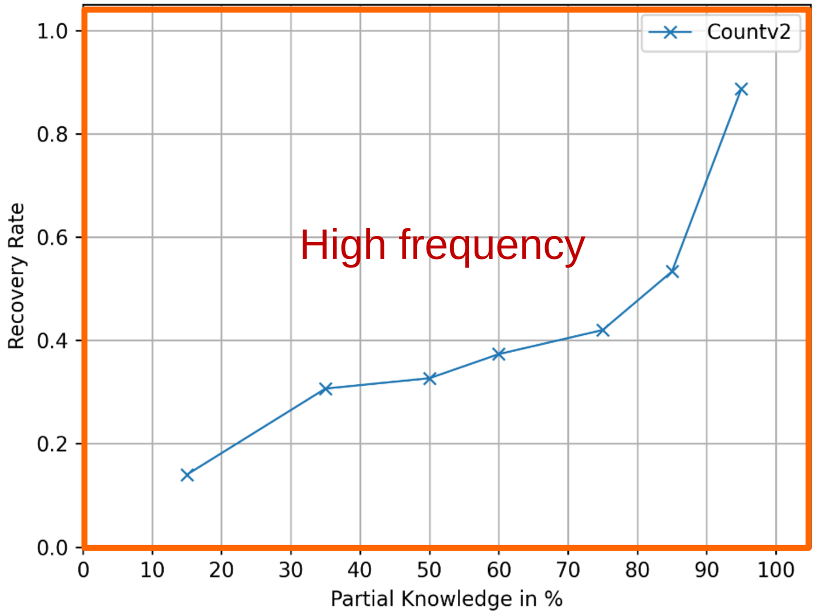
1. Enron (& Apache) email data collection

2. Restrict data to 500-3000 keywords

3. Draw 150 queries ***from data collection***

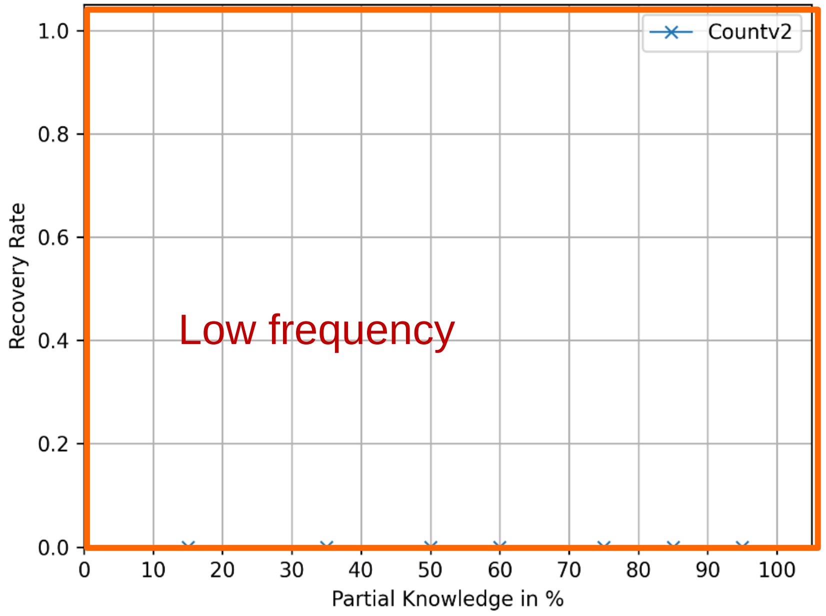


4. Evaluate on partial knowledge



or

???



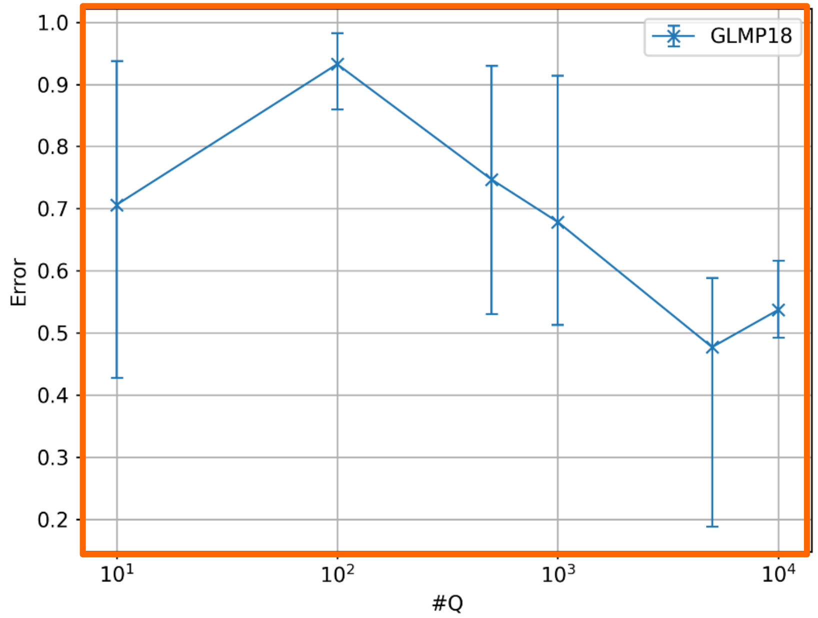
Previous Evaluations [ ]

- Usual evaluations for range attacks:

1. Subset of HCUP or artificial Data collection

2. Pick Artificial query distribution (Uniform/Zipf/…)

3. Evaluate for different amounts of queries



or

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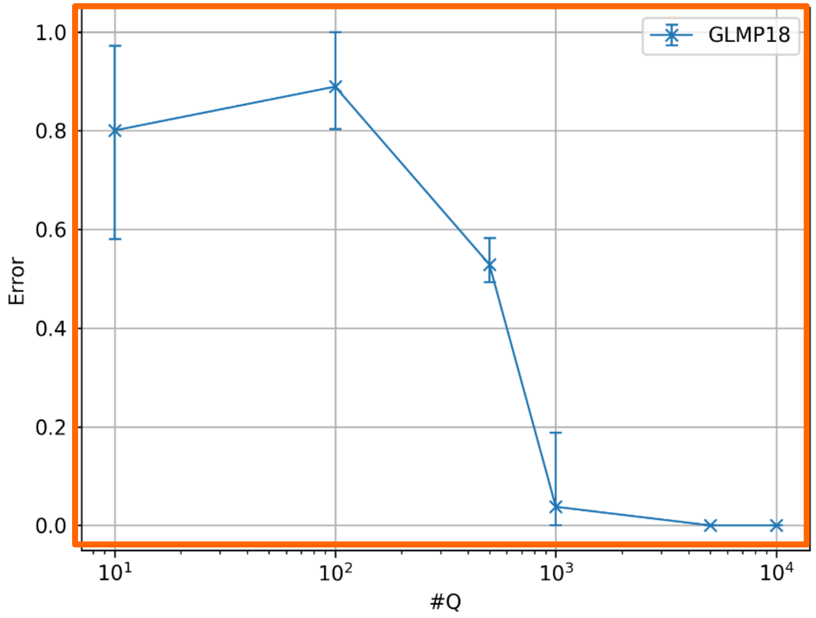
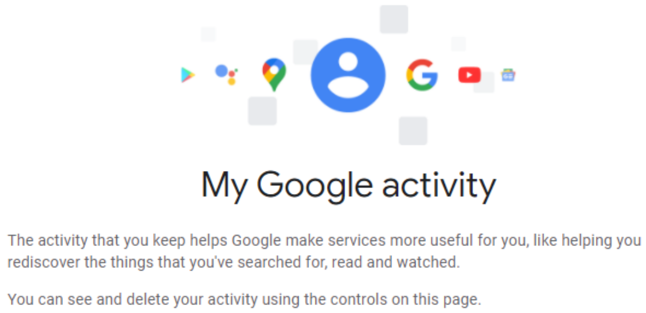


New Data

- **9** new data sources for more realistic evaluations
- Keyword setting:

Use Case:

Email/Cloud



My Google activity

The activity that you keep helps Google make services more useful for you, like helping you rediscover the things that you've searched for, read and watched.

You can see and delete your activity using the controls on this page.

GMail and Google Drive

- 7 Query Logs & Data Collections
- 7 Users
- 16-100 Queries
- 200-47k Documents
- 19k-895k Keywords

Web

AOL and Wikipedia

- 1 Query Log & 1 Data Collection
- 656k Users
- 2.9M Queries
- 151k Documents
- 268k Keywords

Genetic

The Arabidopsis Information Resource

- 1 Query Log & 1 Data Collection
- 1.3k Users
- 54k Queries
- 115k Documents
- 690k Keywords

New Data [ ]

- Range setting:

Scientific

Sloan Digital Sky Survey

- 3 Query Logs & 1 Data Collection
- 3 Users
- 215-8k Queries
- 5M Records
- Domain $N = 10k$
- Density 96%

Medical

Medical Information Mart for Intensive Care

- 3 Data Collections
- 2k-8k Records
- Domain $N = 73 - 10k$
- Density 3.3%-81%

Human Resources

Salaries of the UK Attorney General's Office junior civil servants

- 1 Data Collection
- 536 Records
- Domain $N = 395$
- Density 2.3%

Sales

Walmart Sales Data

- 1 Data Collection
- 143 Records
- Domain $N = 6.3k$
- Density 2.3%

Insurance

NYDT Insurance Claims

- 1 Data Collection
- 886 Records
- Domain $N = 25k$
- Density 1.2%

Evaluation: Highlights – Range Search

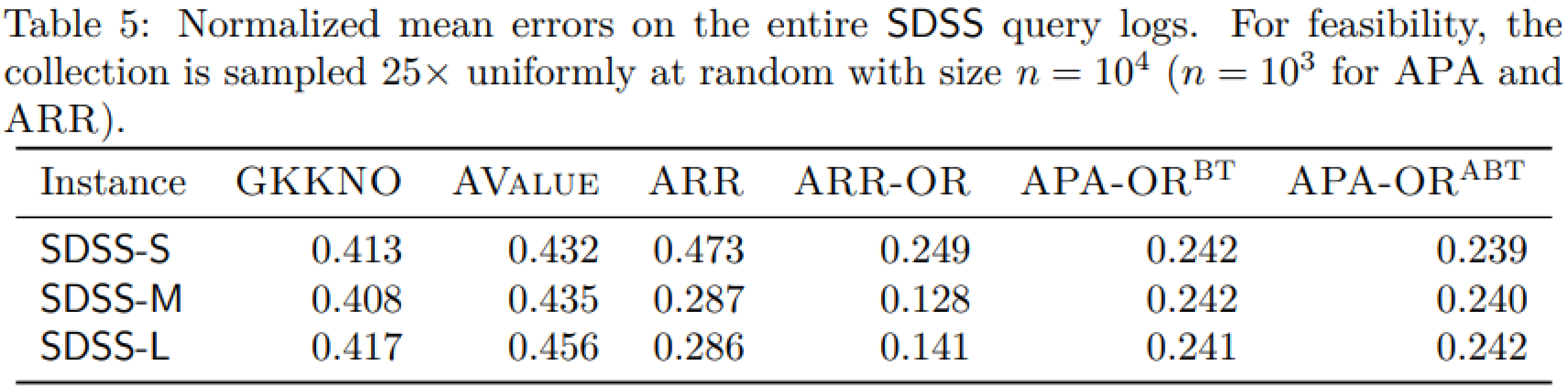


Table 5: Normalized mean errors on the entire SDSS query logs. For feasibility, the collection is sampled 25× uniformly at random with size $n = 10^4$ ($n = 10^3$ for APA and ARR).

Instance	GKKNO	AValue	ARR	ARR-OR	APA-OR$^{\mathrm{BT}}$	APA-OR$^{\mathrm{ABT}}$
SDSS-S	0.413	0.432	0.473	0.249	0.242	0.239
SDSS-M	0.408	0.435	0.287	0.128	0.242	0.240
SDSS-L	0.417	0.456	0.286	0.141	0.241	0.242