A Quick Intro to Searchable Encryption

Theory & Practice - Constructions & Attacks

R. Bost - 21/04/2021

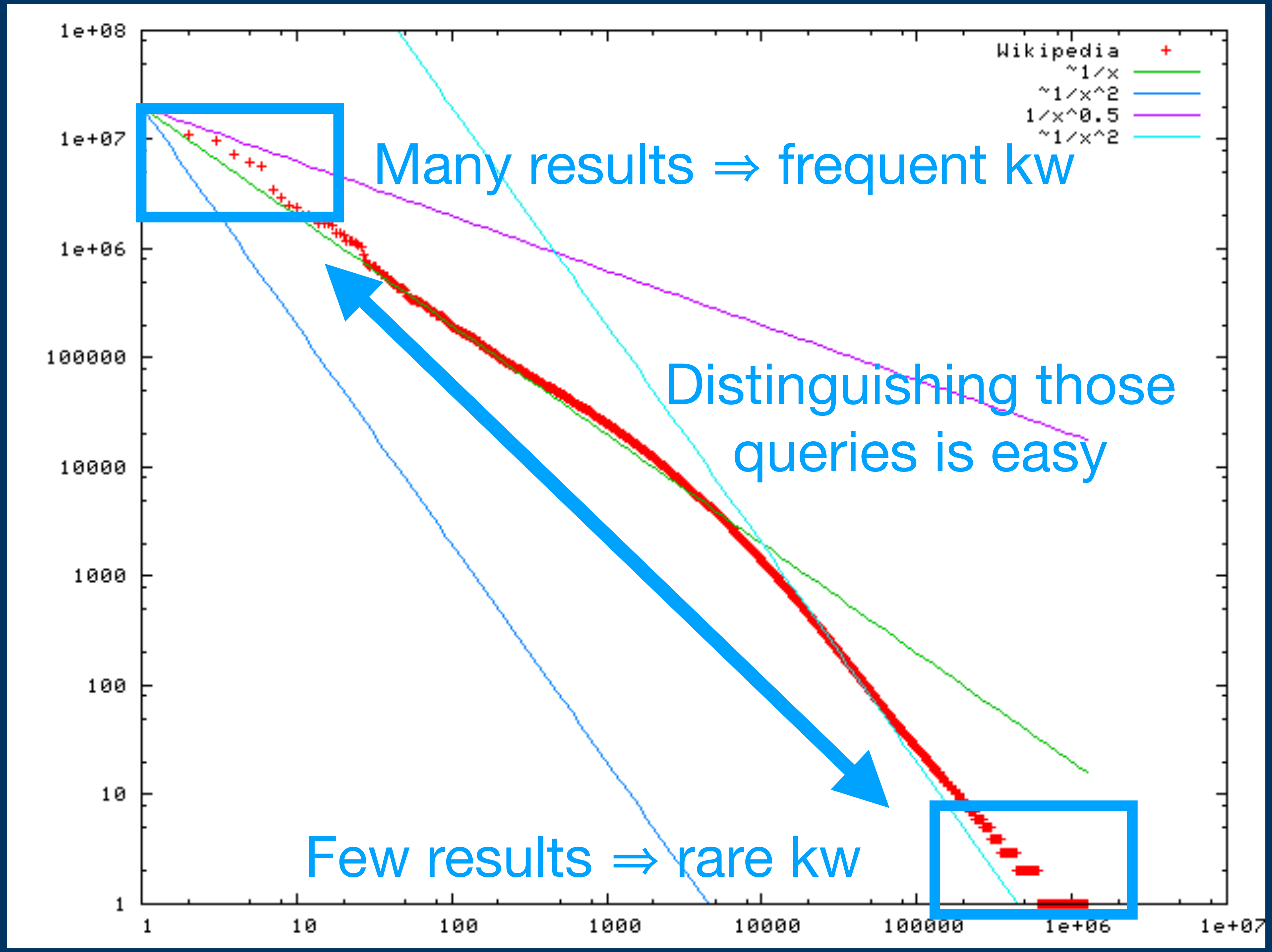
Searchable Encryption

Outsource data

- Securely
- Keep search functionalities
- Aimed at efficiency
- … we have to leak some information …
- … and this can lead to devastating attacks

Searchable Encryption

- We want to protect both data & queries from the server
  - Query only: PIR
  - Data only: does not really make sense
  - In practice, the docs are stored separately from the index, and the index is ‘encrypted’
- Example of leakage vs efficiency: keyword frequency
  - Padding or ~~O(N) comp./comm.~~



Property Preserving Encryption

Deterministic encryption, Order Preserving Encryption

✓ Legacy compatible (works on top of unencrypted DB)

✓ Very efficient

✗ Not secure in practice (frequency analysis)

FHE & ORAM

Fully Homomorphic Encryption

✓ Support arbitrary queries

✓ Fully secure

✗ Not efficient at all

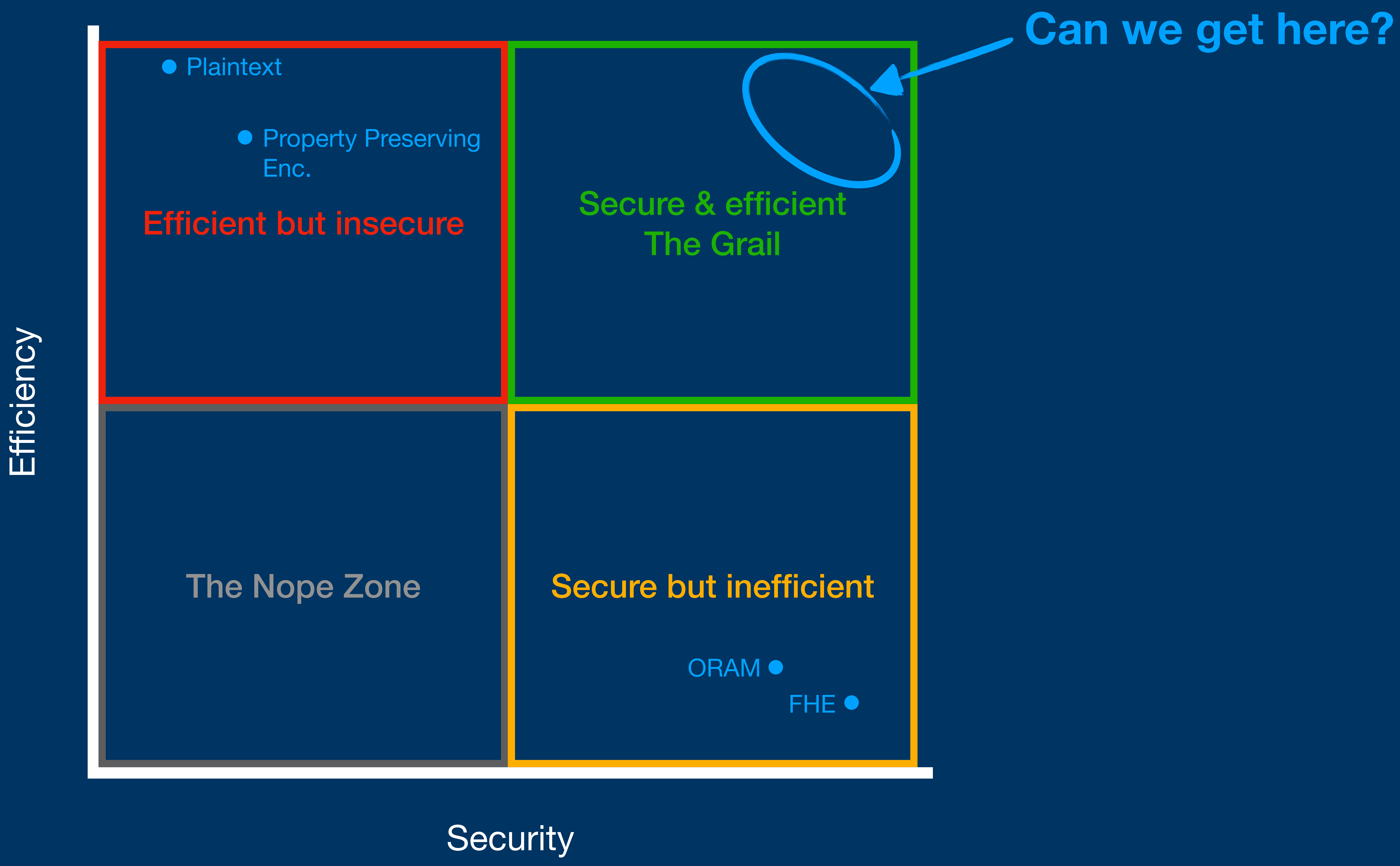
Oblivious RAM

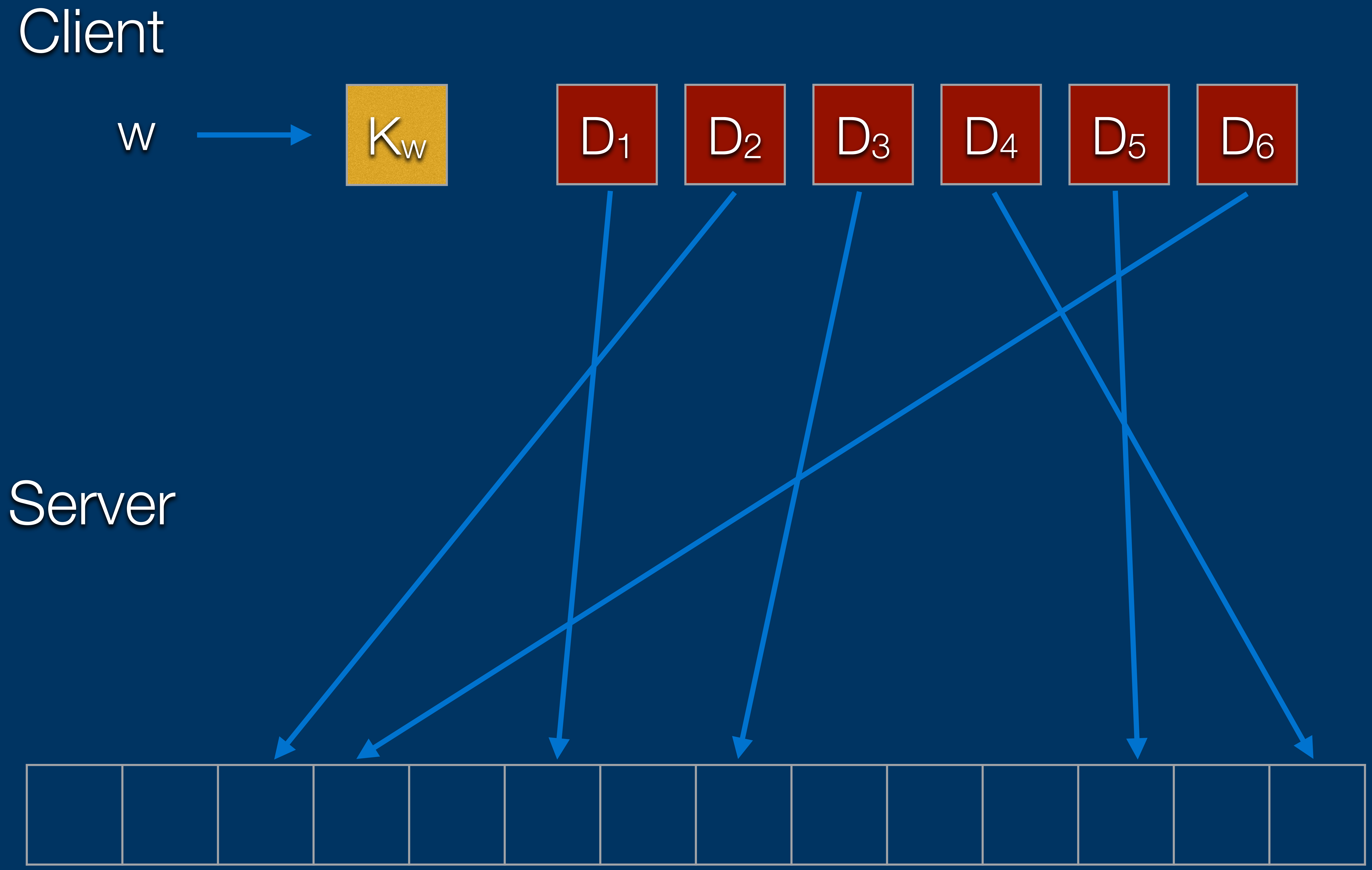
✓ Support arbitrary queries

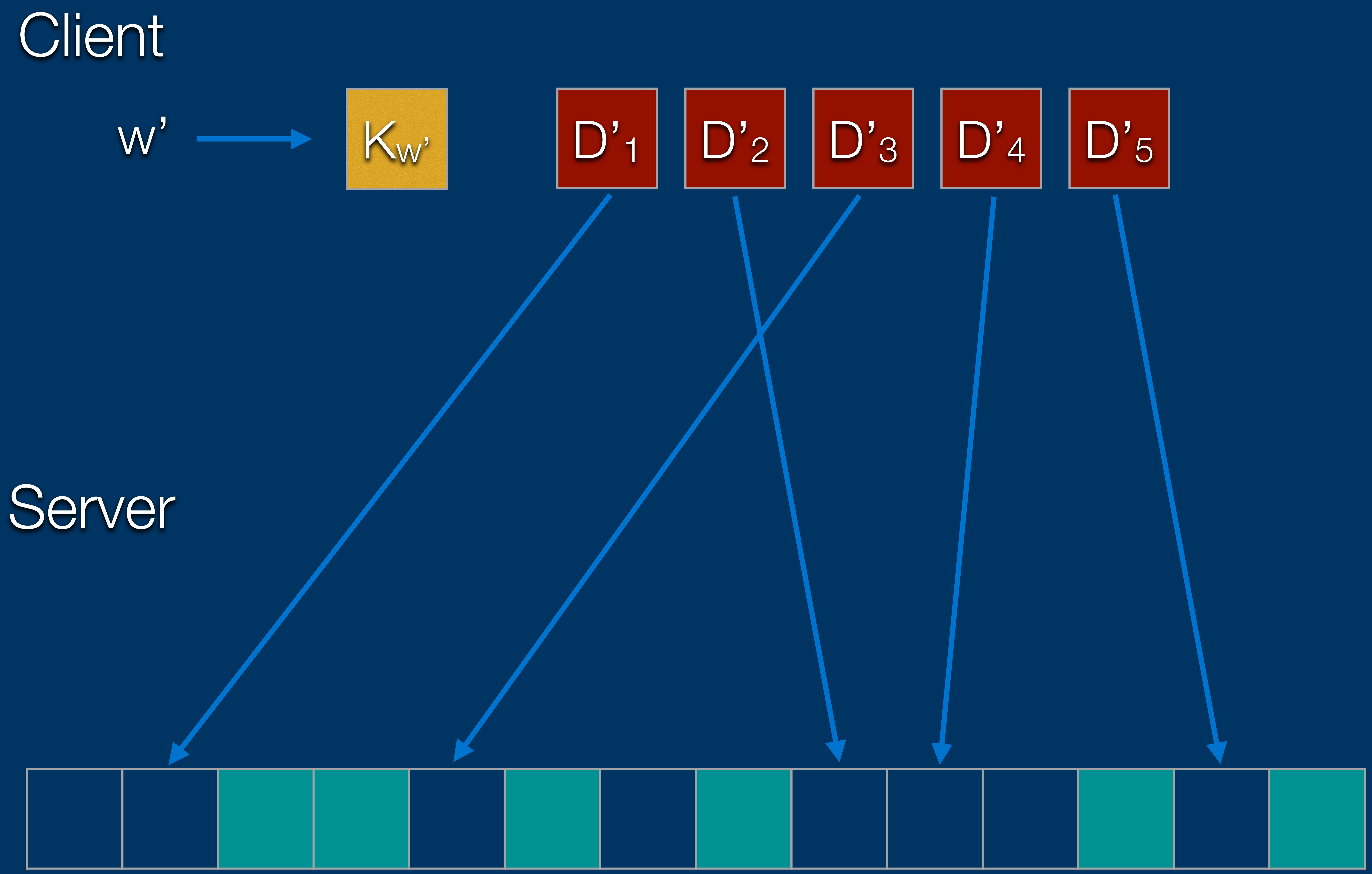
✓ Reveals the results count

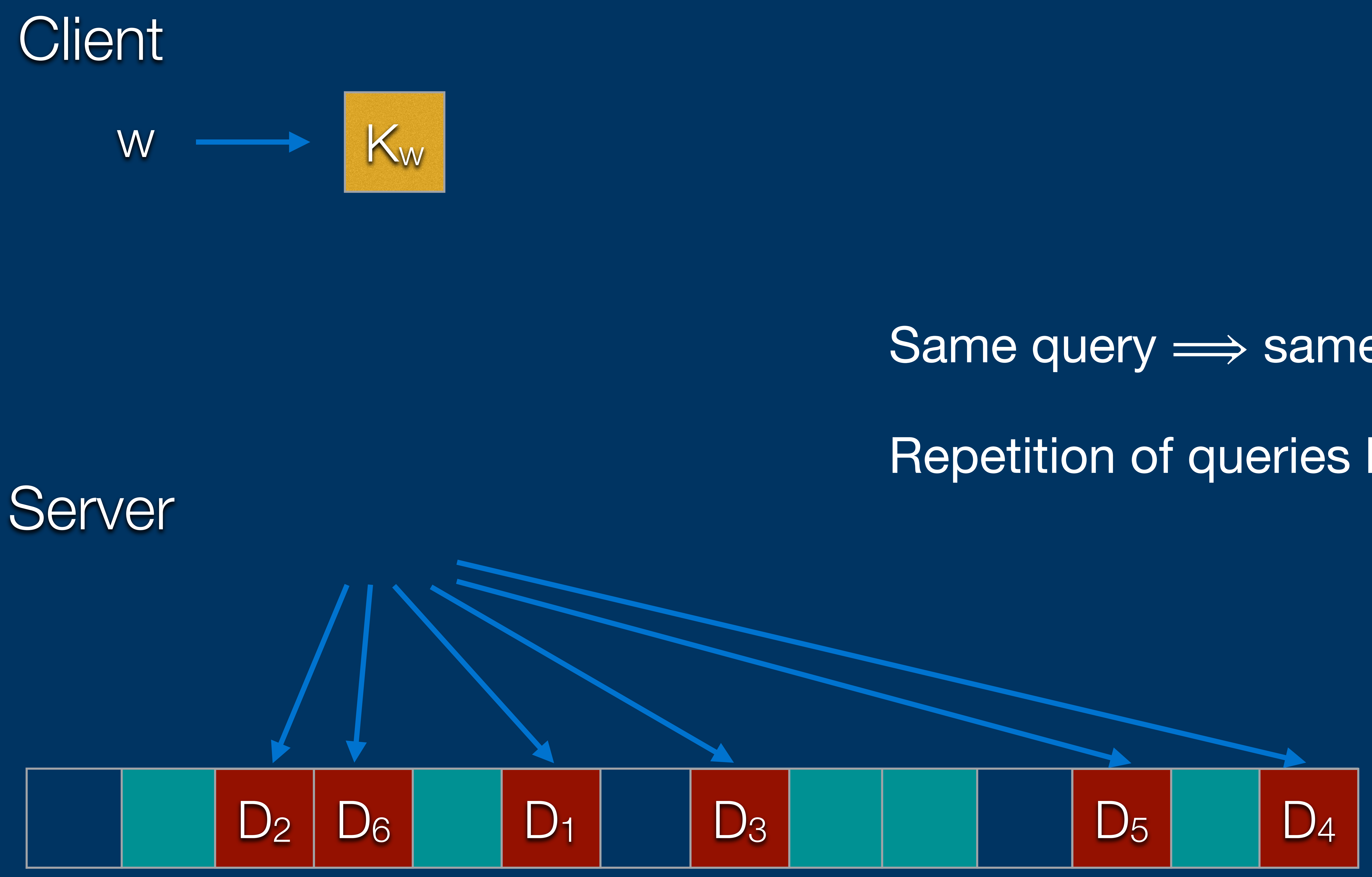
✗ Large communication overhead

Make compromise!


Can we get here?
Plaintext
Property Preserving Enc.
Efficient but insecure
Secure & efficient
The Grail
The Nope Zone
Secure but inefficient
ORAM
FHE
Efficiency
Security


Client
w
Kw
D1
D2
D3
D4
D5
D6
Server


Client
w'
$K_{w'}$
D'_1
D'_2
D'_3
D'_4
D'_5
Server



Same query $\Longrightarrow$ same accesses

Repetition of queries leaks

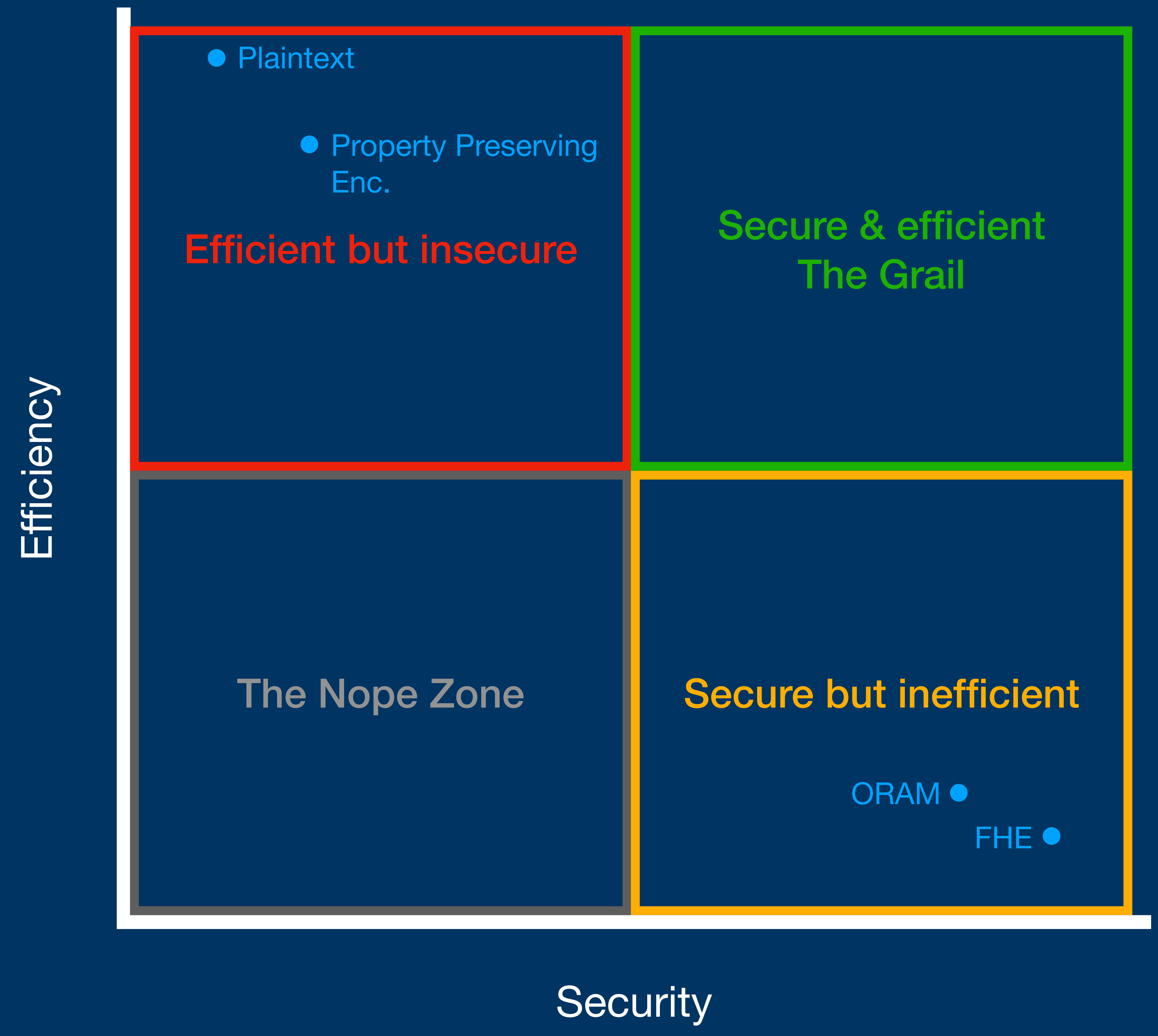
Lower bounds

- Oblivious RAM lower bound: if one wants to hide the access pattern to a memory of size N, the computational overhead is

$$\Omega\left(\frac{\log N}{\log \sigma}\right)$$

- A similar lower bound exists for searchable encryption: a search pattern-hiding SE incurs a search overhead of

$$\Omega\left(\frac{\log \binom{|DB|}{n_w}}{\log \sigma}\right)$$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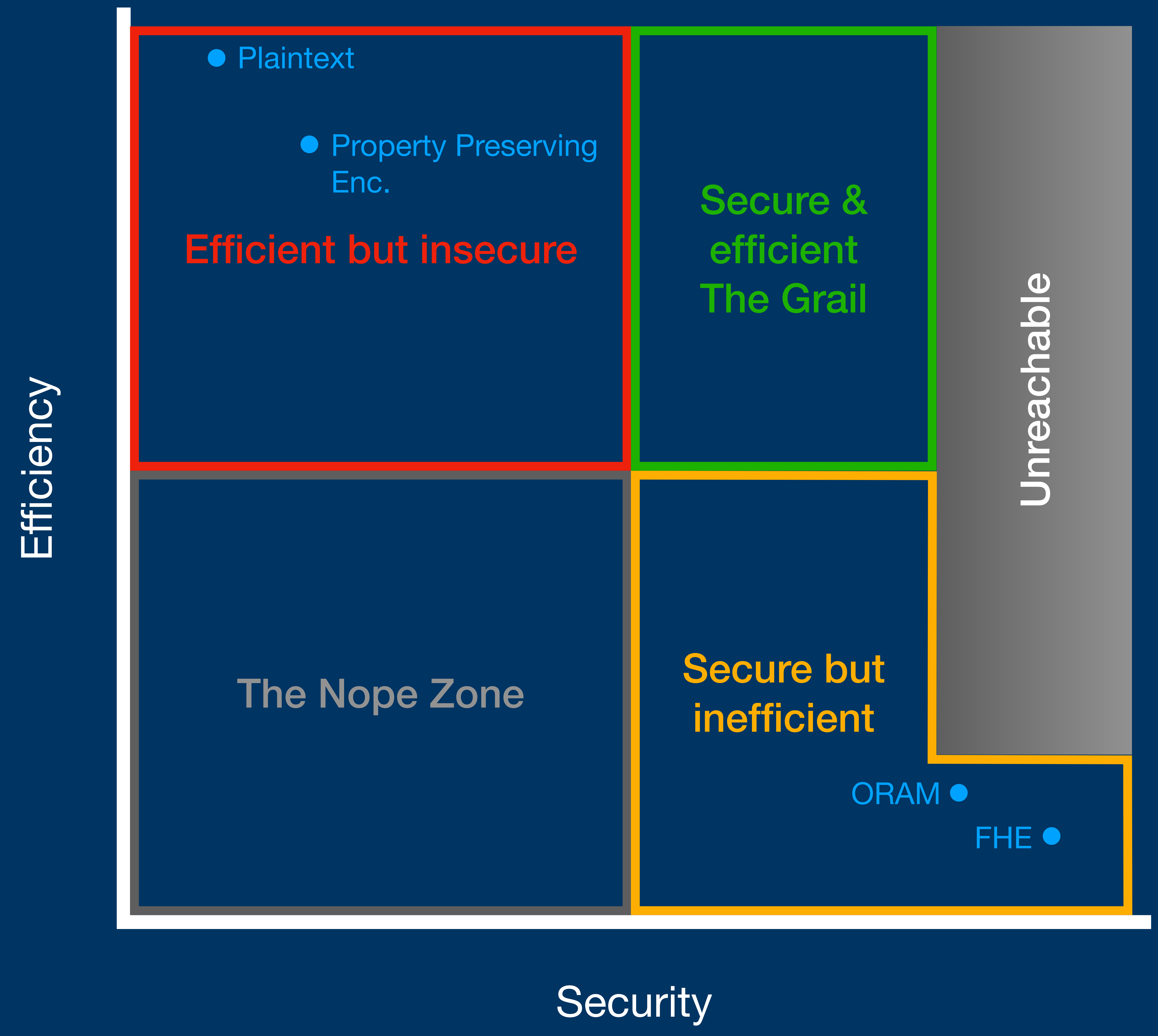
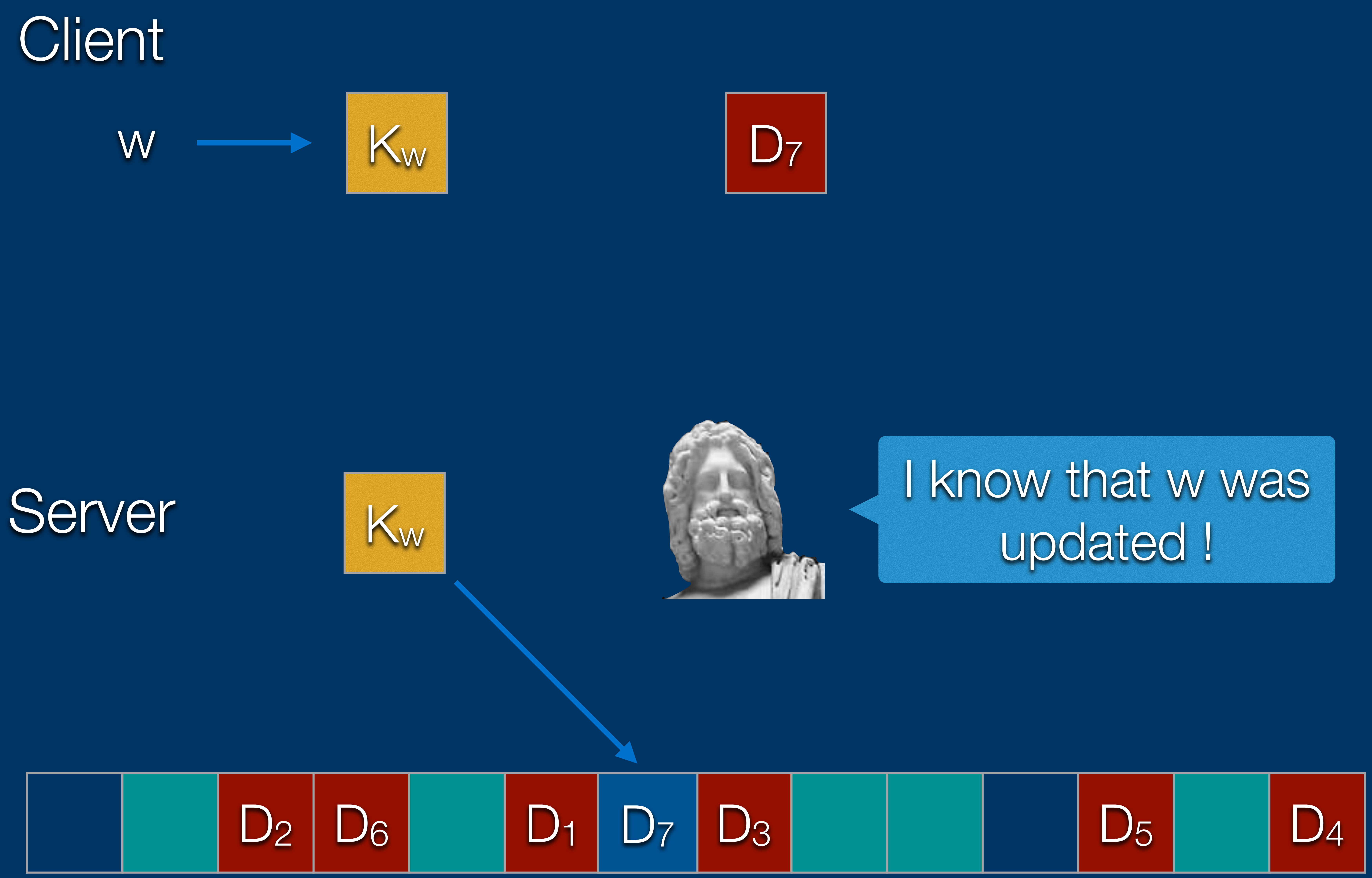
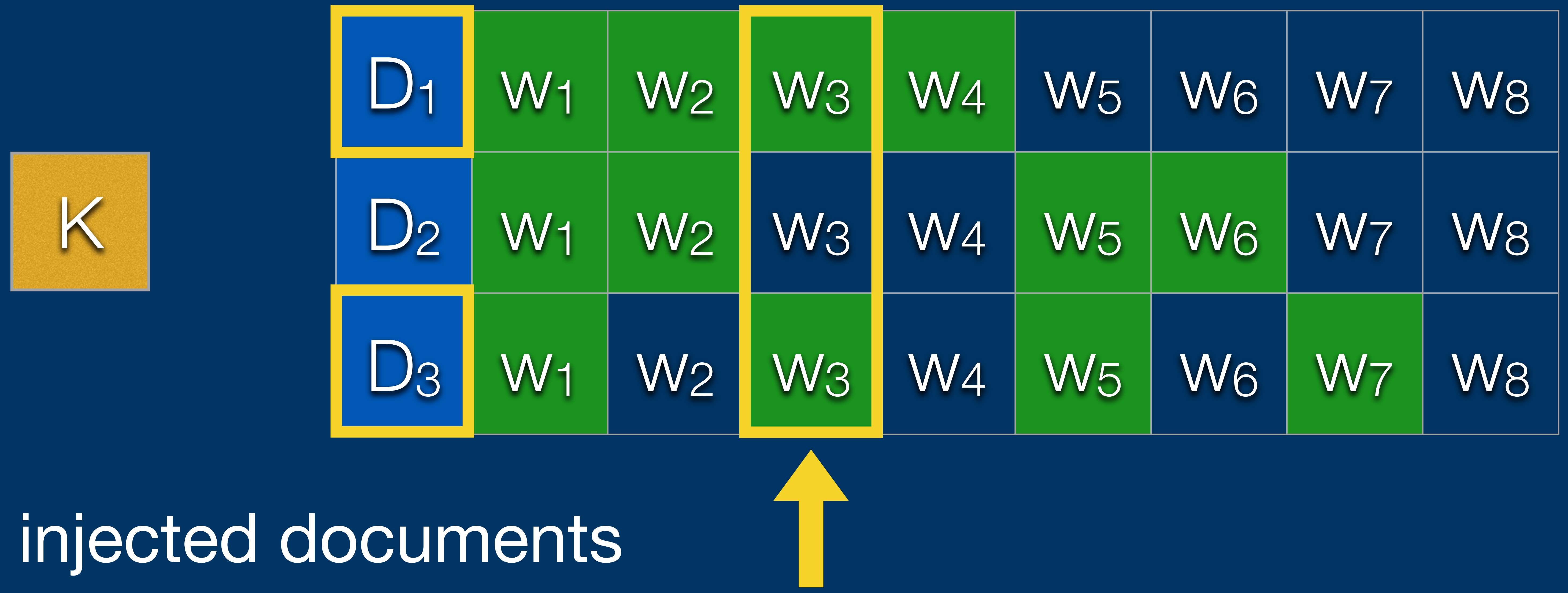
Efficient but insecure
Secure & efficient
The Grail
The Nope Zone
Secure but inefficient
ORAM
FHE
Efficiency
Security


Plaintext
Property Preserving Enc.
Efficient but insecure
Secure & efficient
The Grail
Unreachable
The Nope Zone
Secure but inefficient
ORAM
FHE
Efficiency
Security


Client
w
K_w
D_7
Server
K_w
I know that w was updated !
D_2
D_6
D_1
D_7
D_3
D_5
D_4

File injection attacks [ZKP'16]

- Insert purposely crafted documents in the DB (*e.g.* spam for encrypted emails)



log |W| injected documents

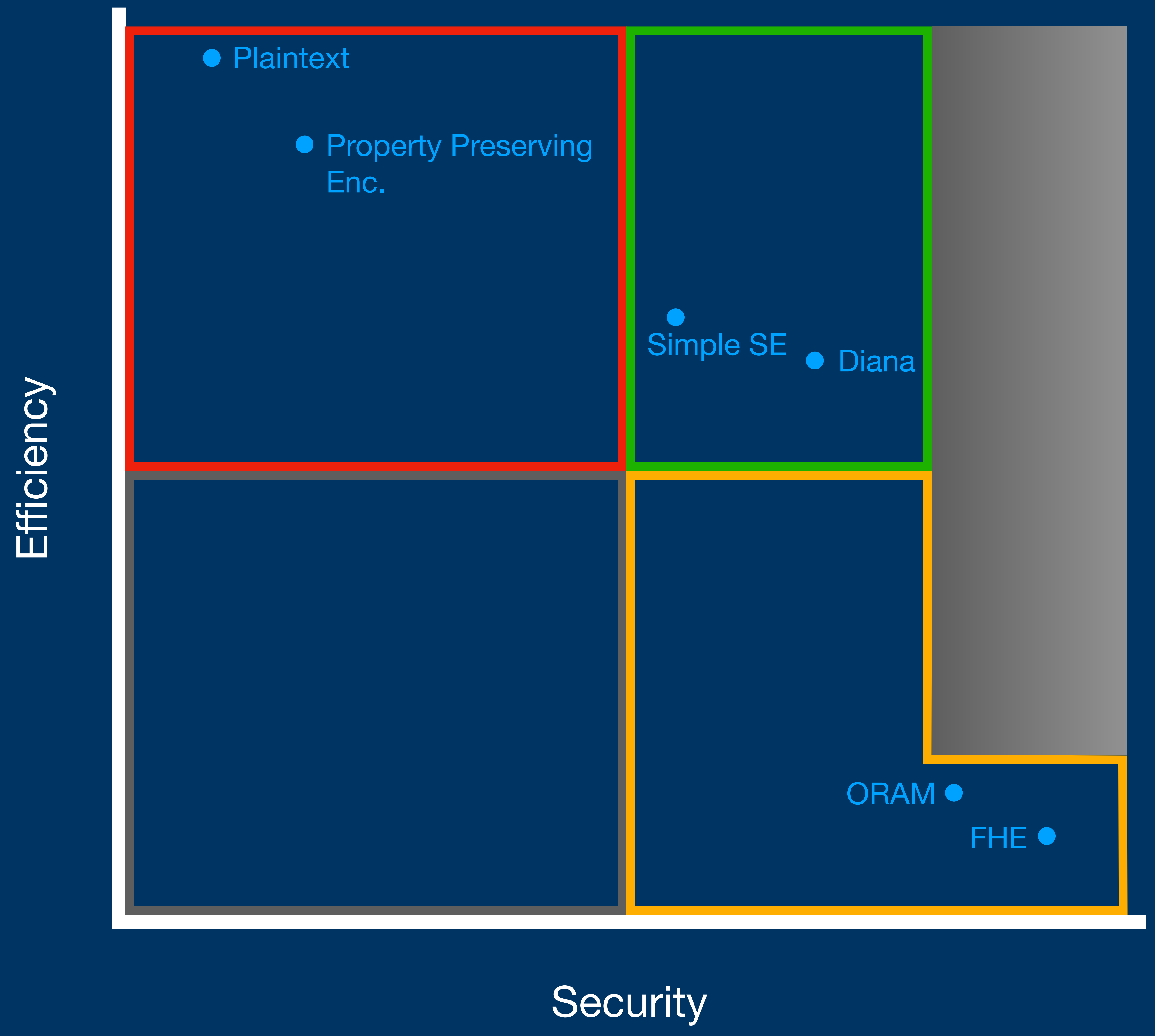
Active adaptive attacks

- These adaptive attacks use the update leakage
- We need SE schemes with oblivious updates

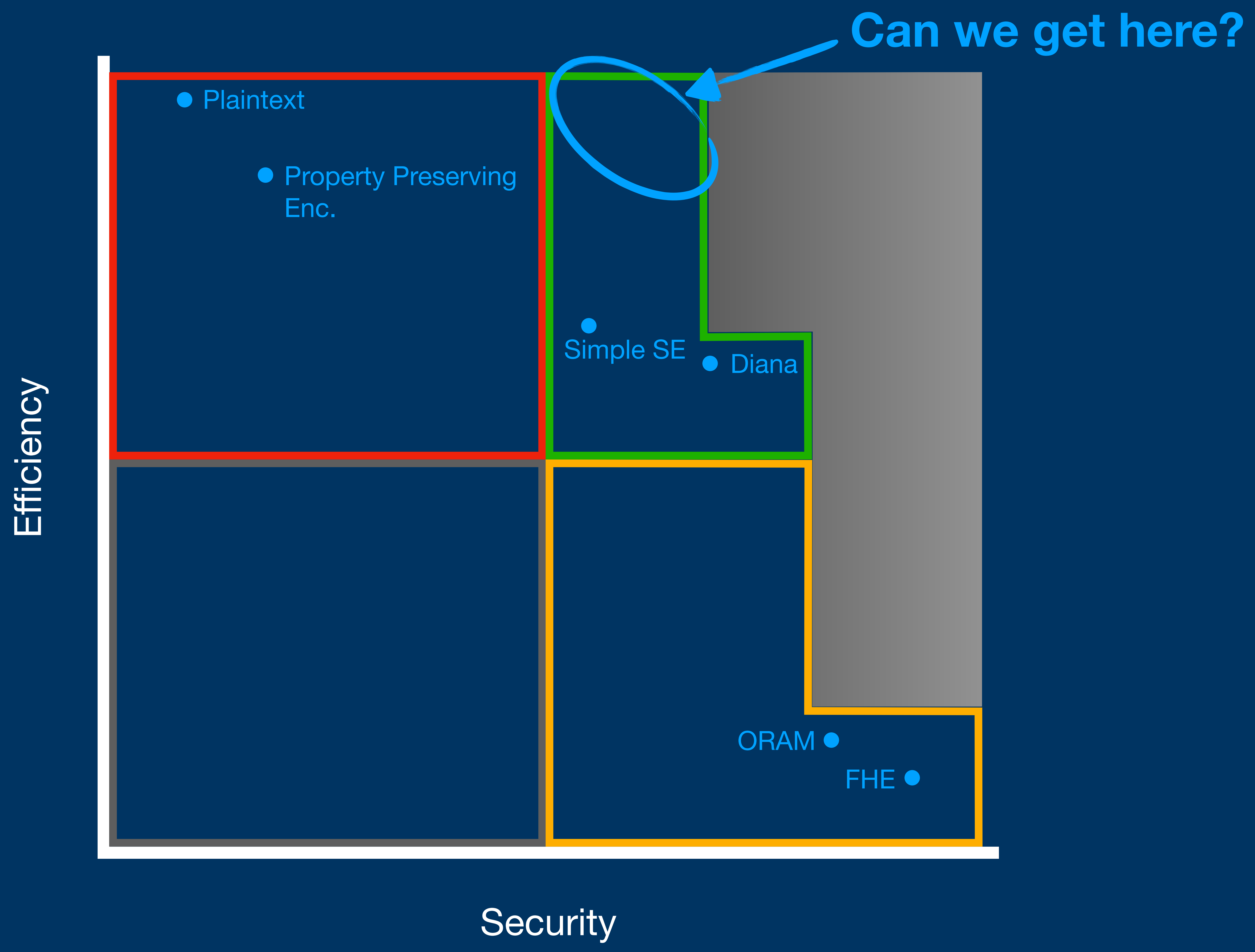
Forward Privacy

- Good news: we know how to do it at a small cost (see Σοφος or Diana)

  ⚠️ but there is also a lower bound on the efficiency of such schemes



Efficiency
Plaintext
Property Preserving Enc.
Simple SE
Diana
ORAM
FHE
Security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Practical Efficiency

- We mostly focused on the asymptotical complexity (comp. & comm.), but this is not enough.
- On hard drives, locality of accesses is important.

Cleartext DB

One (random) access

Simple SSE

n_w random accesses

Practical Efficiency

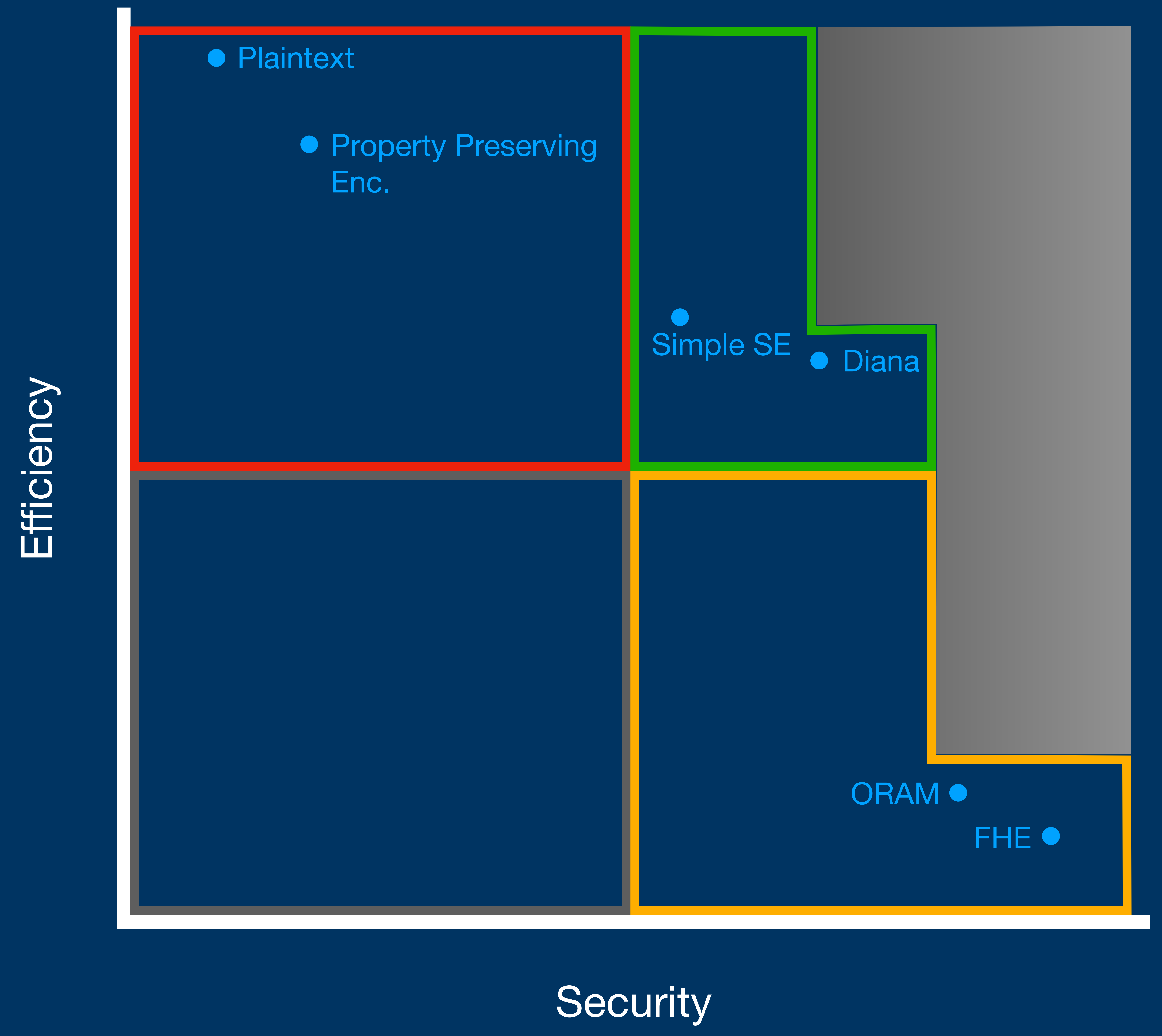
Locality

- Making many accesses is **very** costly

Action	Latency
4kB read (HDD)	6 ms
RSA SK Operation	1 ms
RSA PK Operation	0.05 ms
ECC exponentiation	0.2 ms
PRF Evaluation	300 ns

- It is worth reading more than necessary to avoid some accesses: reading once $O(\log N)$ bytes is better than reading $O(\log \log N)$ times $O(1)$ bytes.

- No free lunch ☹️ :
  [CT'14] Constant locality & constant read efficiency implies $\omega(N)$ storage.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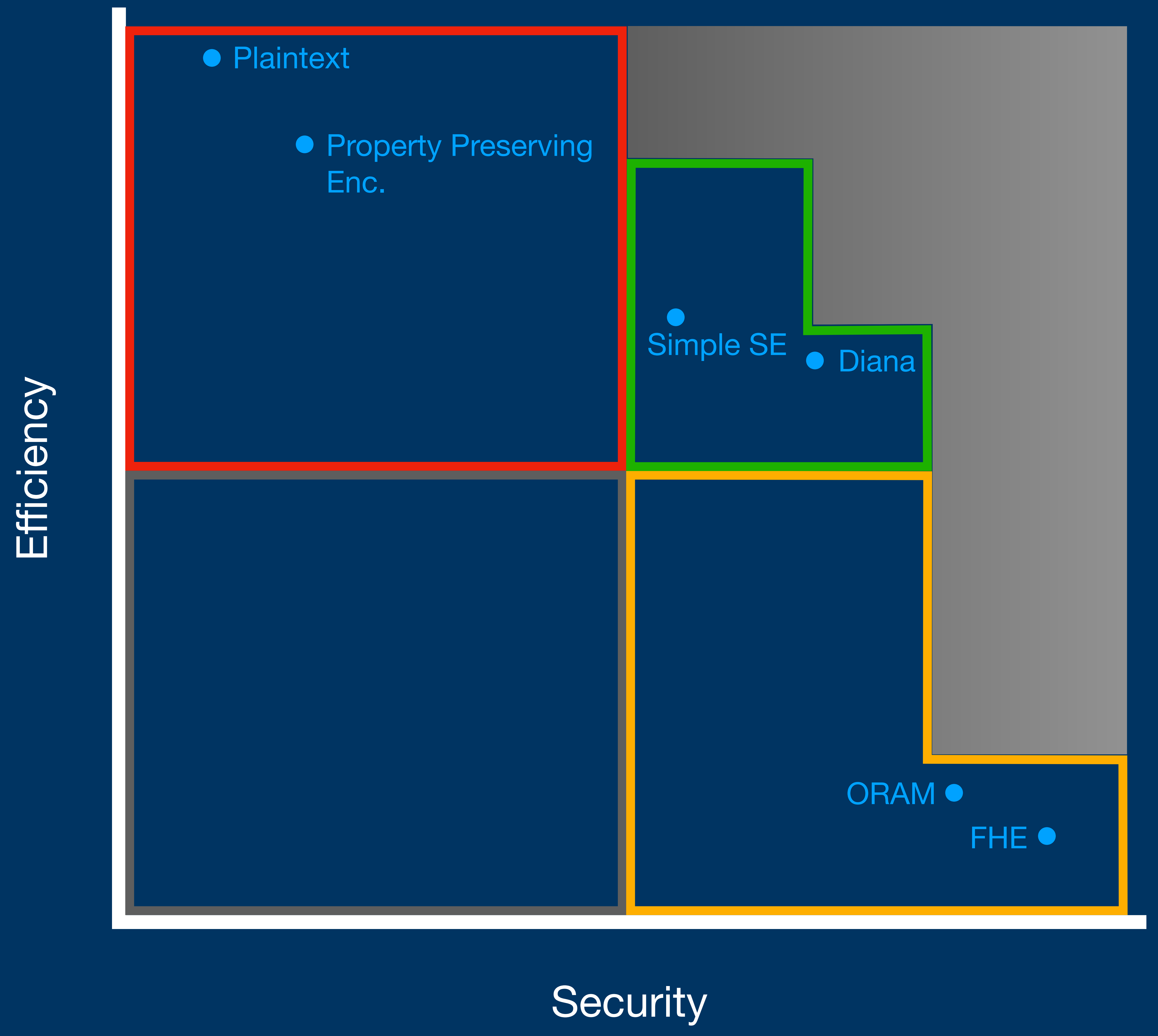
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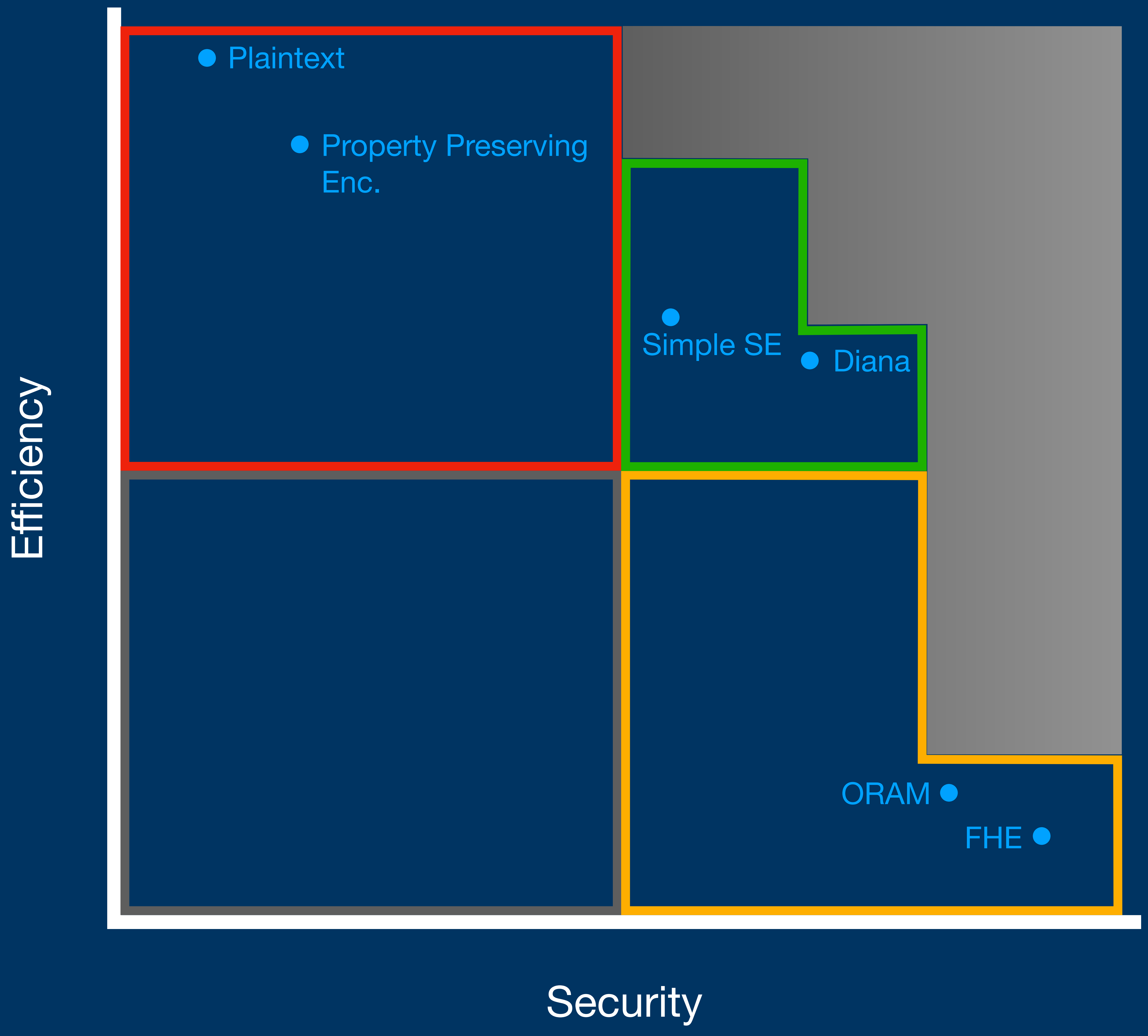
Practical Efficiency

SSDs

- Cool guys use flash memory now!

Action	Latency
4kB read (SSD)	0.1 ms
RSA SK Operation	1 ms
RSA PK Operation	0.05 ms
ECC exponentiation	0.2 ms
PRF Evaluation	300 ns

- SSDs are not local at all! There is built-in parallelism.
- Locality is no longer the right metric. Focus on the # of read pages.
- The previous lower bound no longer applies 😀



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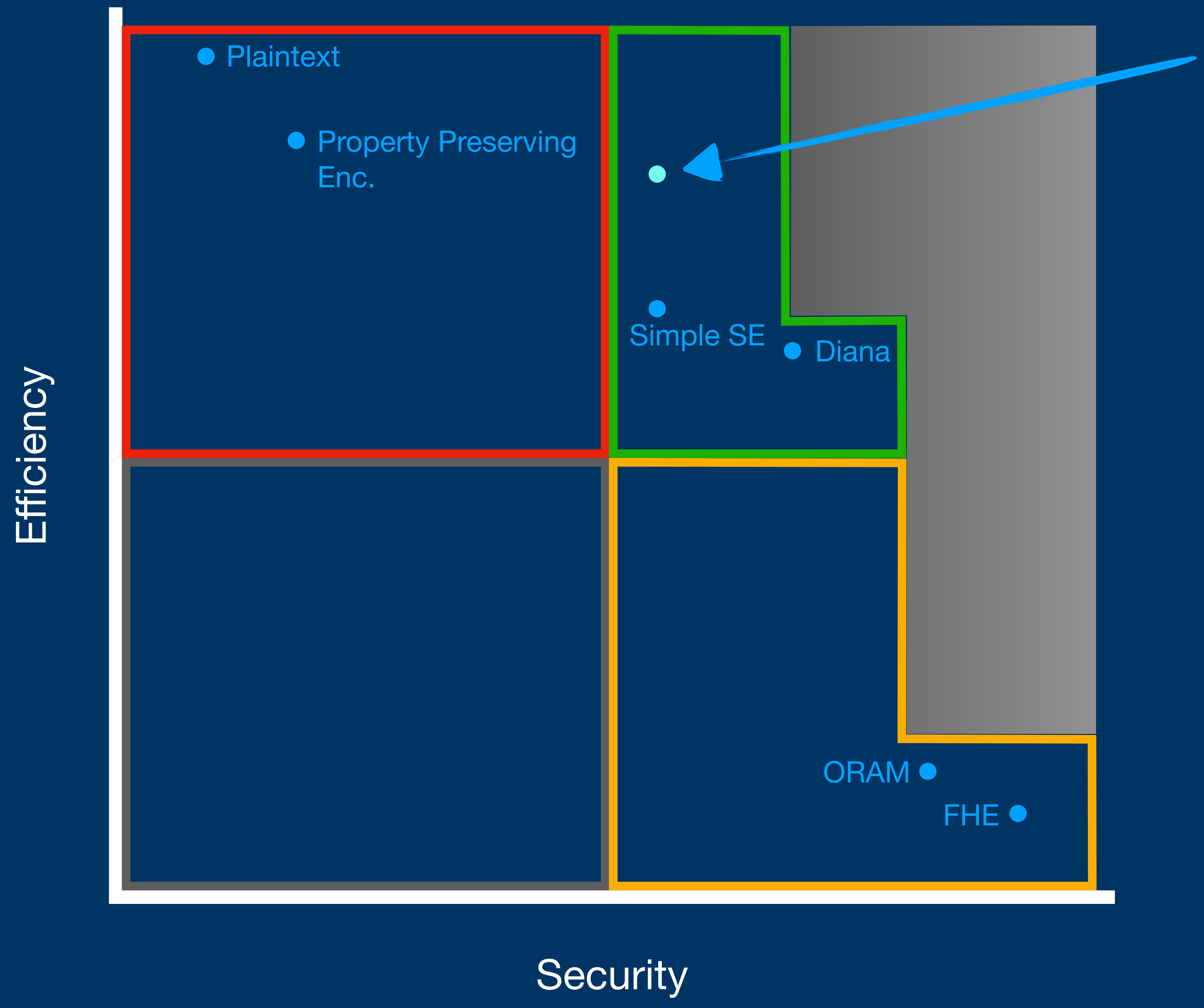

Under submission

Throughput half a raw read of the results (on a SSD)

Recipe:

- mix a systems-oriented approach, …
- a pinch of cryptography, …
- a lot of algorithmic, …
- a spoon of statistics, …
- shake everything, …
- and implement the result in your favorite language (C/C++/Rust)

Conclusion

- It is hard (sometimes impossible) to combine efficiency, features and security
- A lot of improvements have been made in the knowledge of SE:
  - Better security models and constructions
  - Better understanding of attacks
  - Practical implementations
- What about a large scale adoption?

Conclusion

What about a large scale adoption?

- Probably still too inefficient for large scale databases (think TB)
- Not suited for complex queries yet (think SQL)

- Maybe we are asking for too much security? 🤔
- Basic database encryption would higher the cost of database theft (memory dumps are hard) and prevent 90% of today's leaks

0% of leaked databases were encrypted

Questions?

Slides: https://raphael.bost.fyi/publications/
Code: https://github.com/opensse/