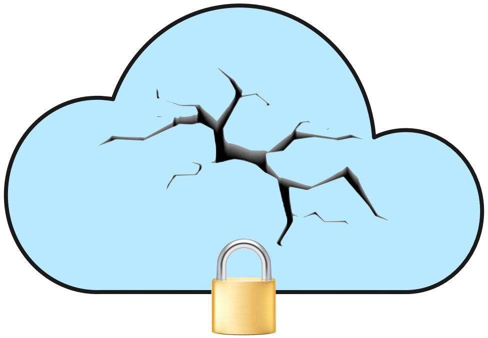


Securing data in compromised clouds

Raluca Ada Popa

UC Berkeley

riselab UC Berkeley

PREVEIL

raluca.popa@berkeley.edu

@ralucaadapopa

Massive cloud attacks are relentless

Yahoo 2014: Equifax 2017: Capital One 2019:

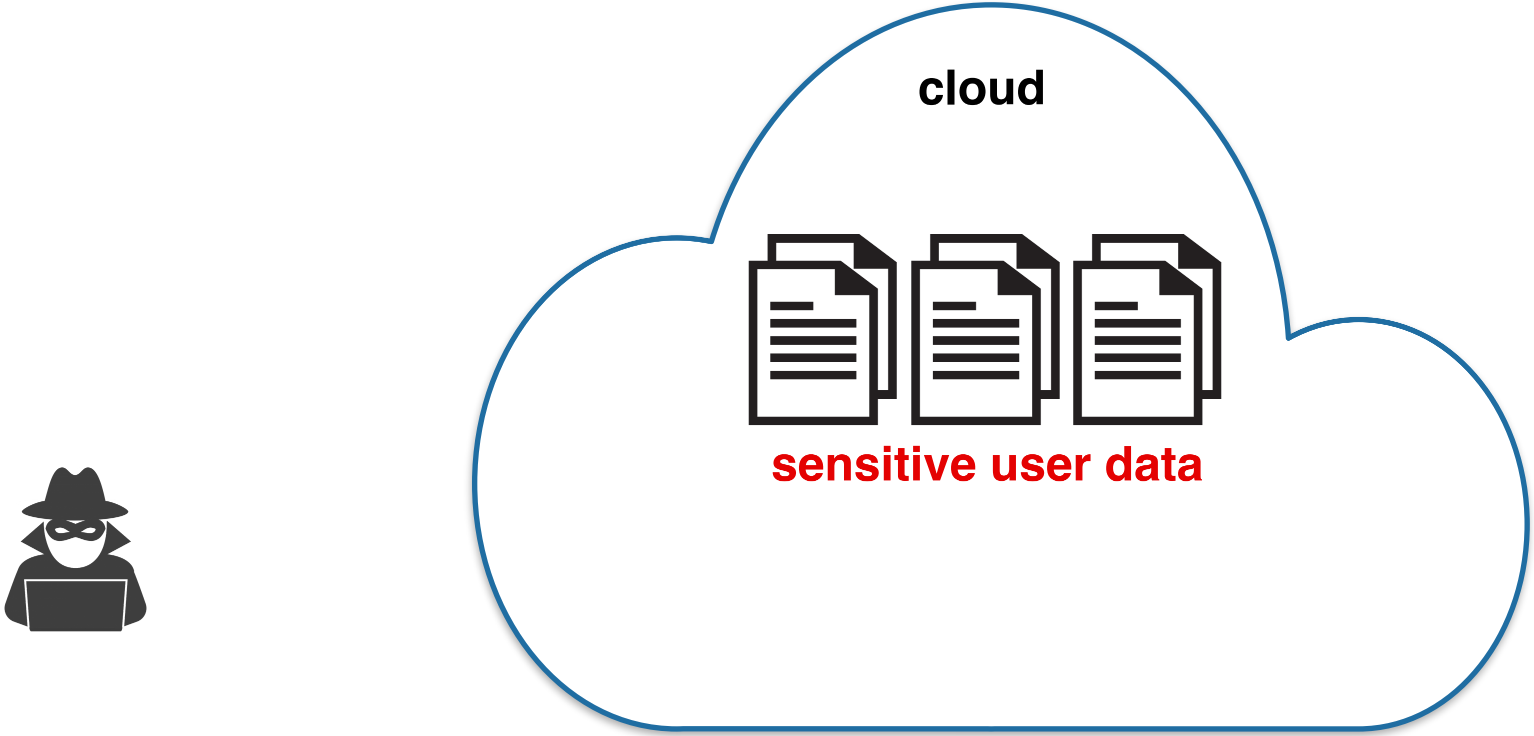
user records breached

Massive cloud attacks are relentless

Yahoo 2014:	Equifax 2017:	Capital One 2019:
500,000,000	147,000,000	100,000,000

user records breached

Traditional security has a fundamental weakness



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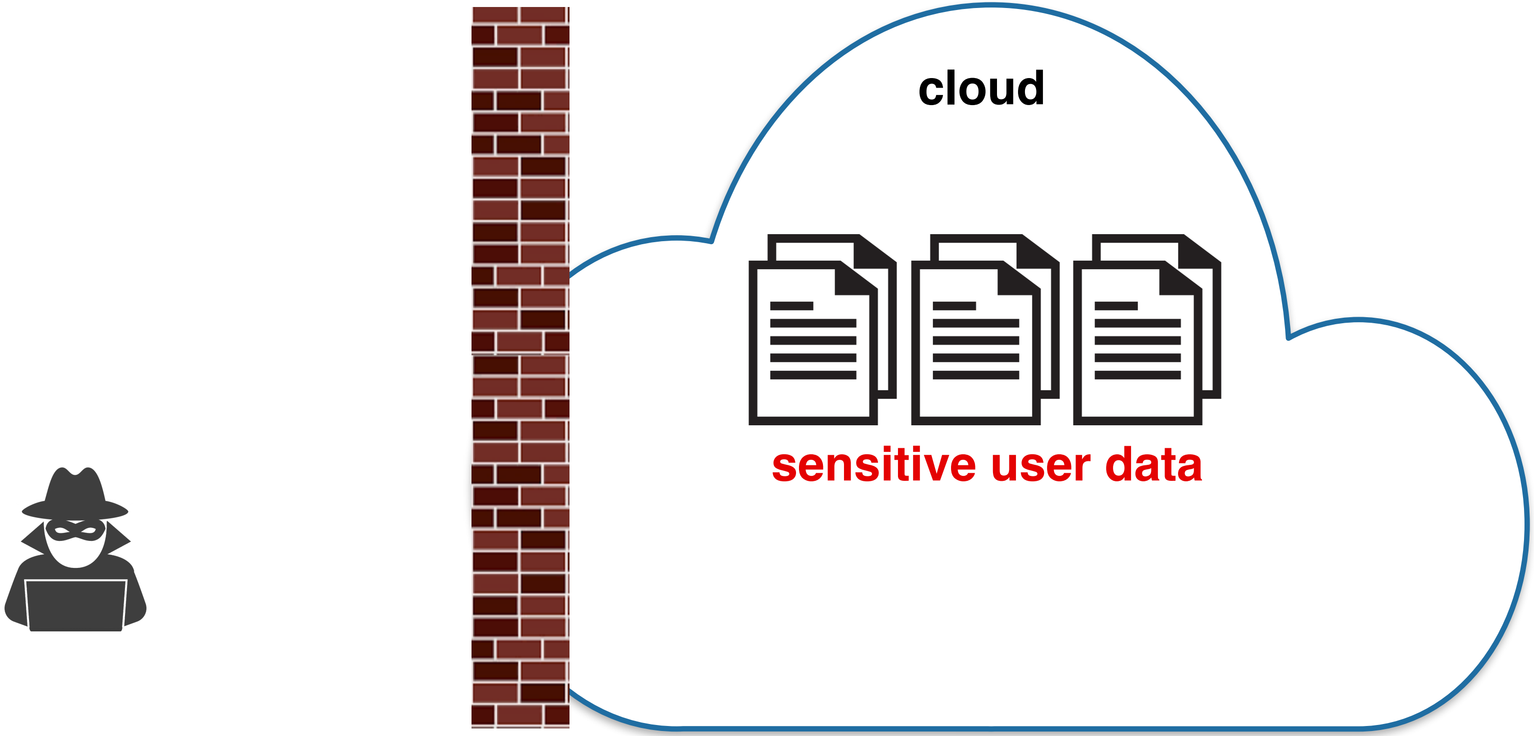
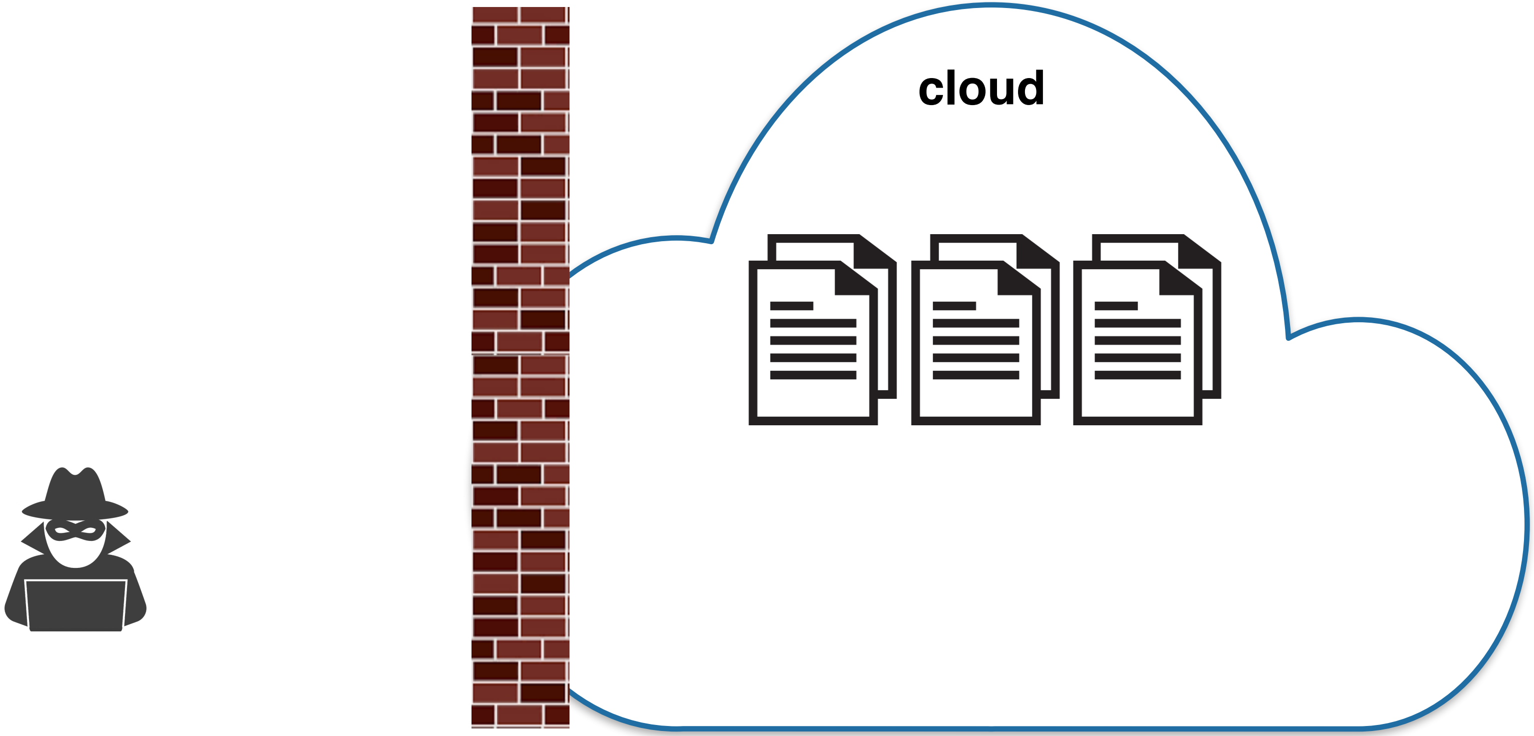


Attackers eventually break in



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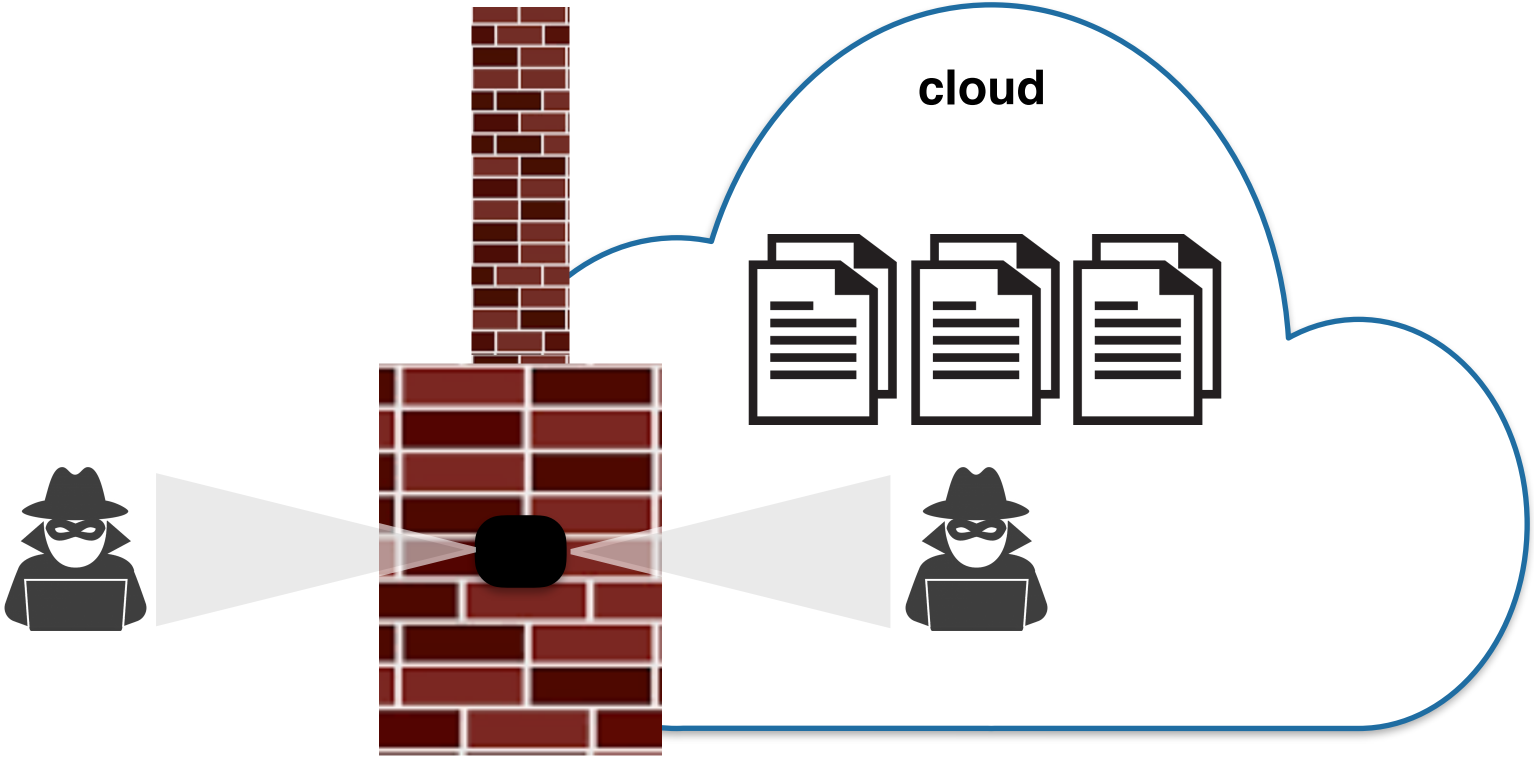
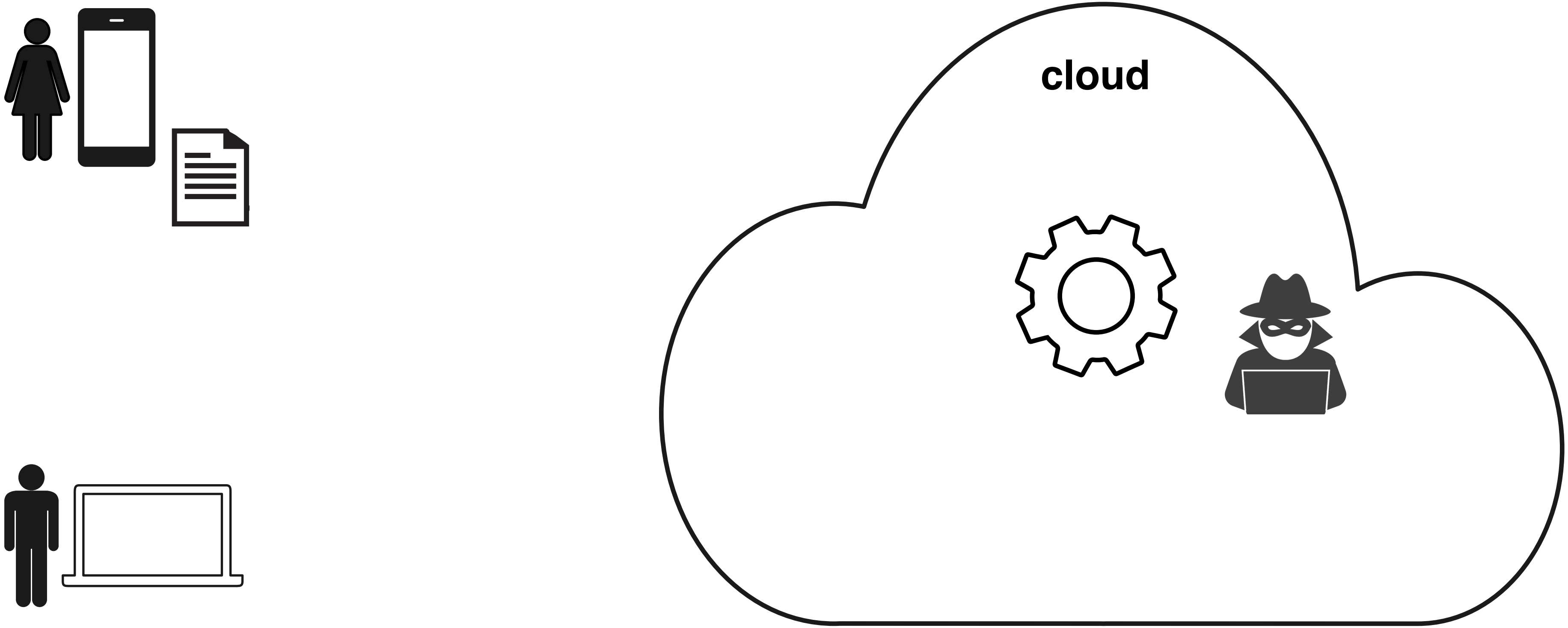


Assume the attacker will break in

“in the cloud […] applications need to protect themselves instead of relying on firewall-like techniques”

Werner Vogels,
Amazon CTO

Standard use of encryption



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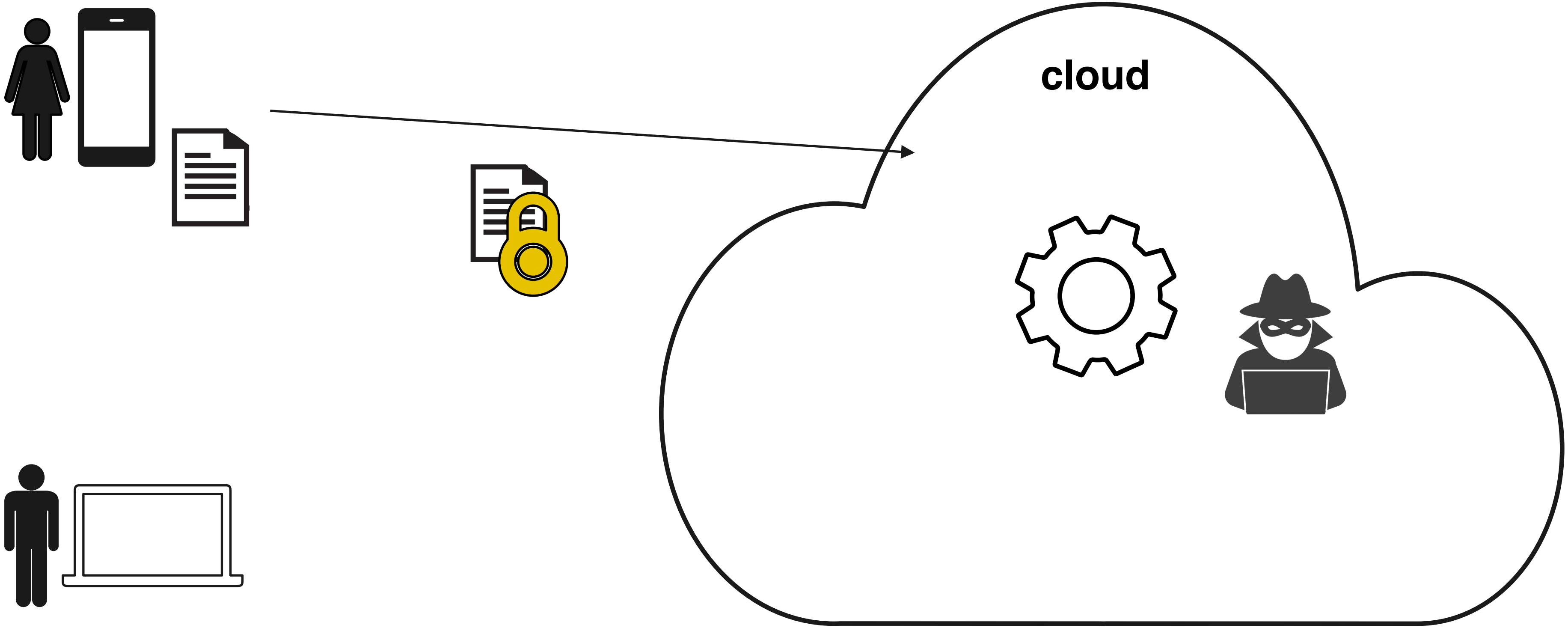

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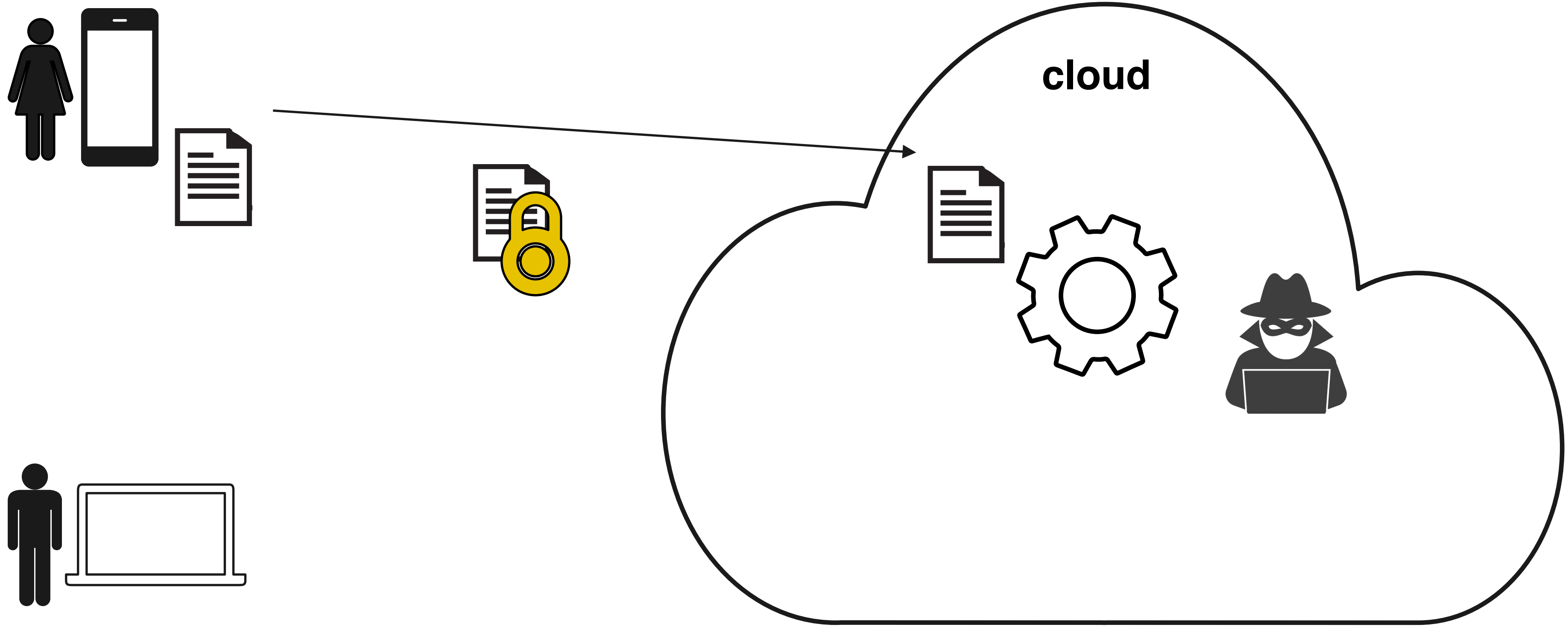

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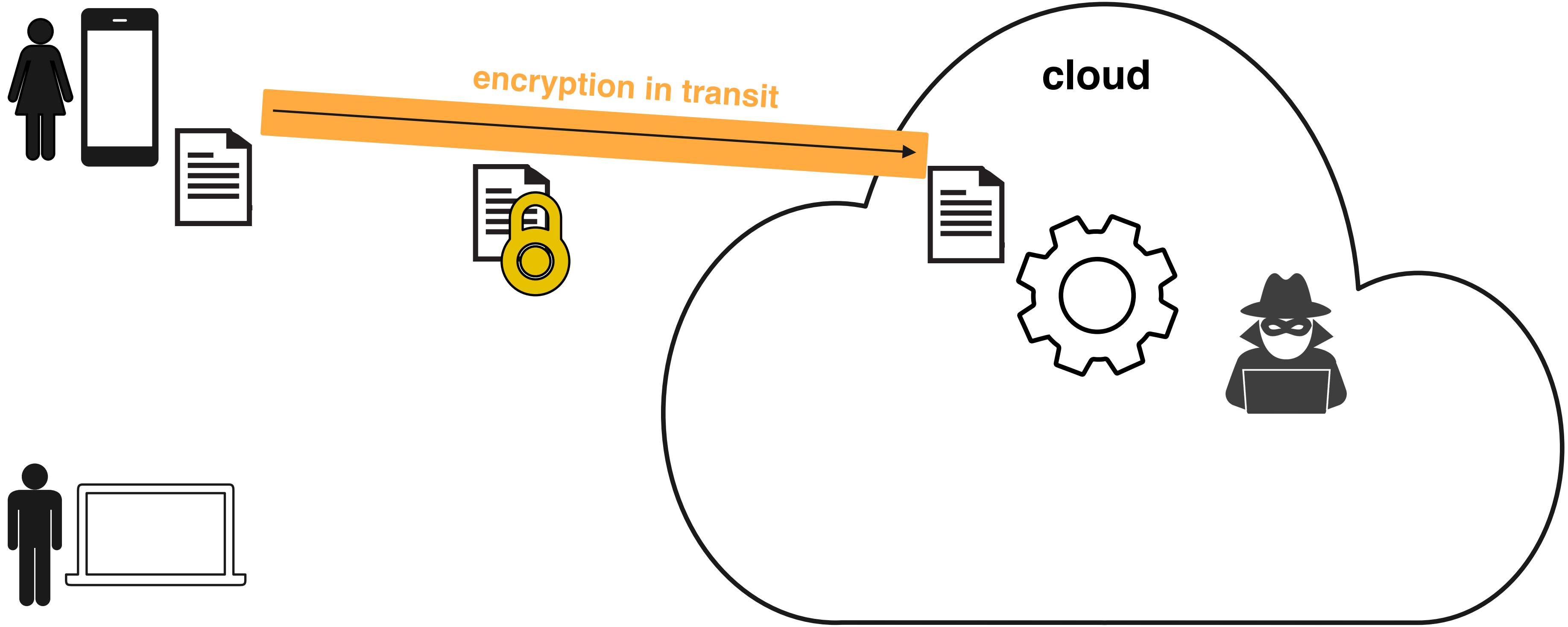

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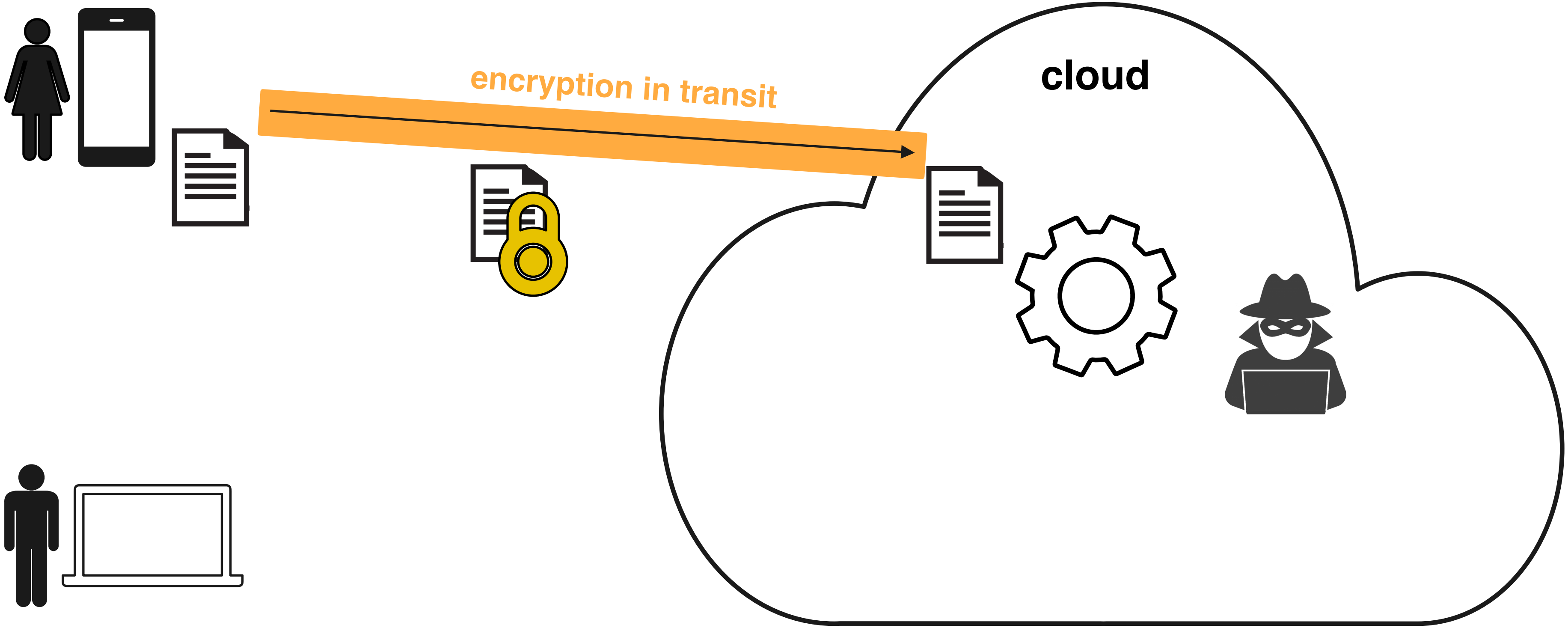

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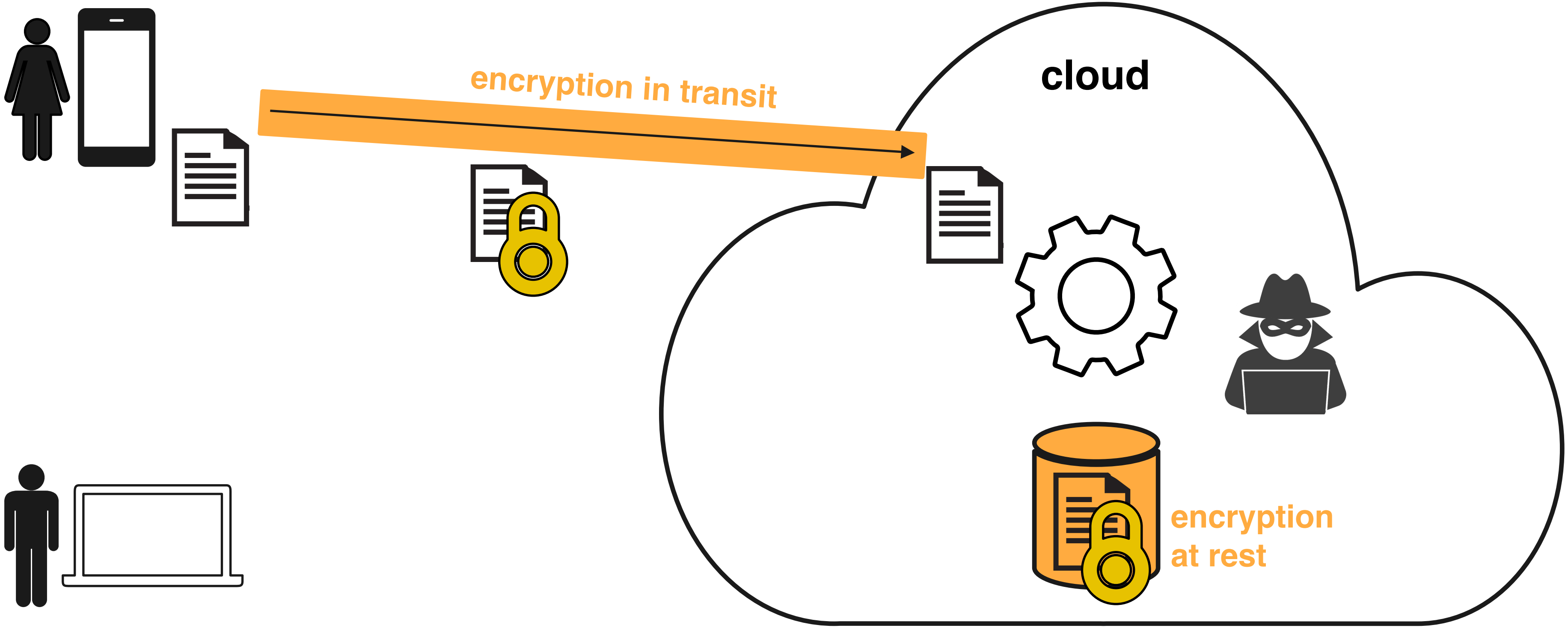

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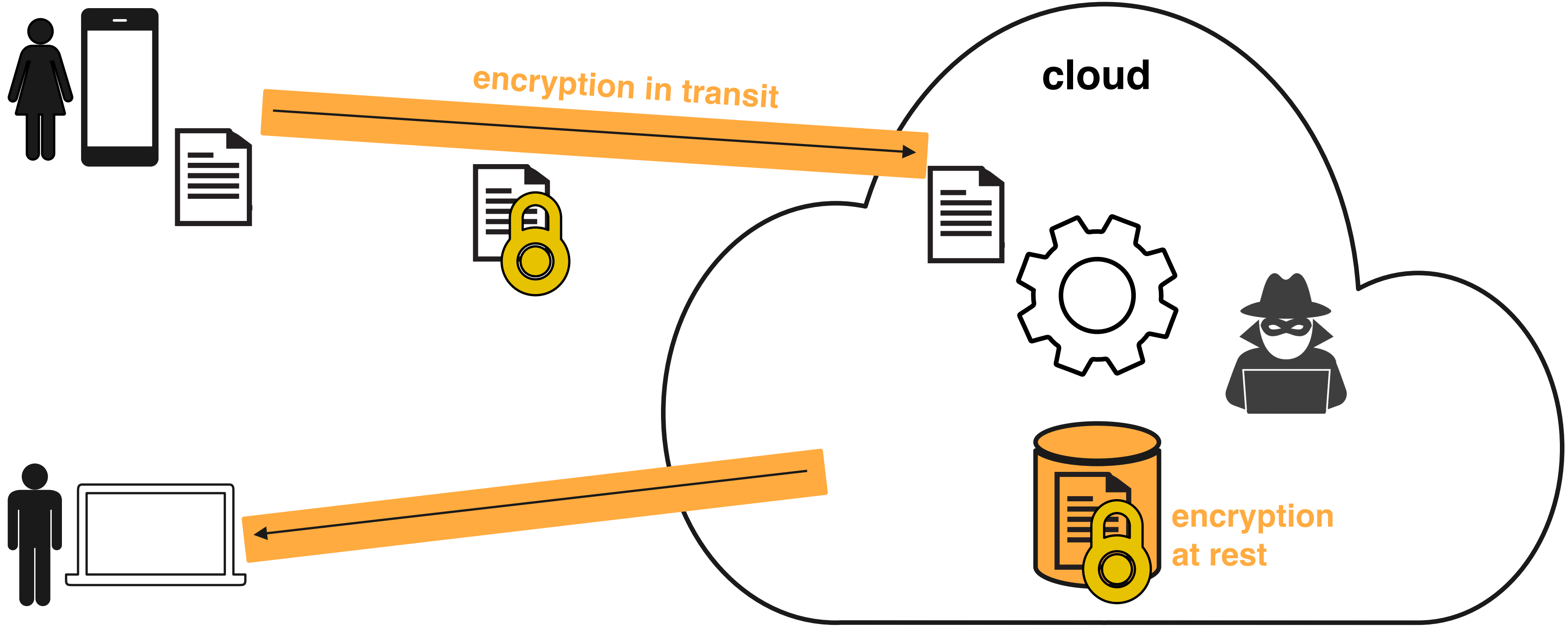
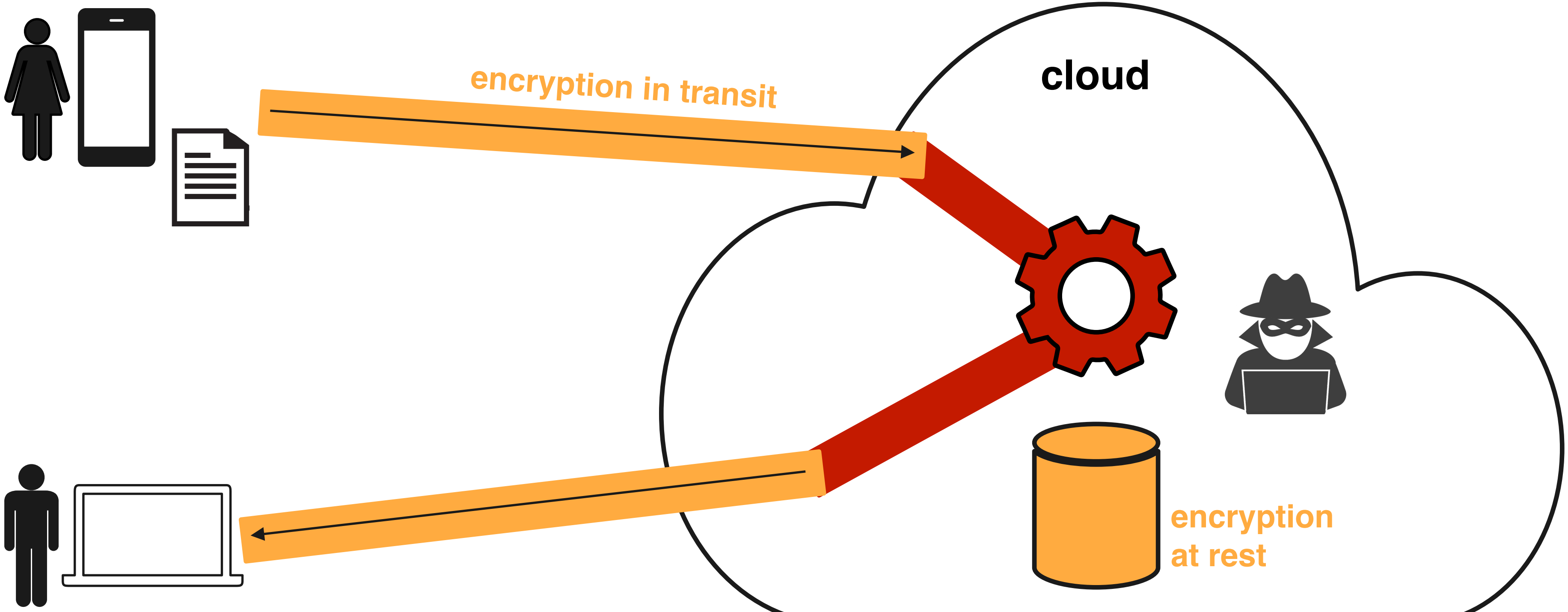


Use encryption



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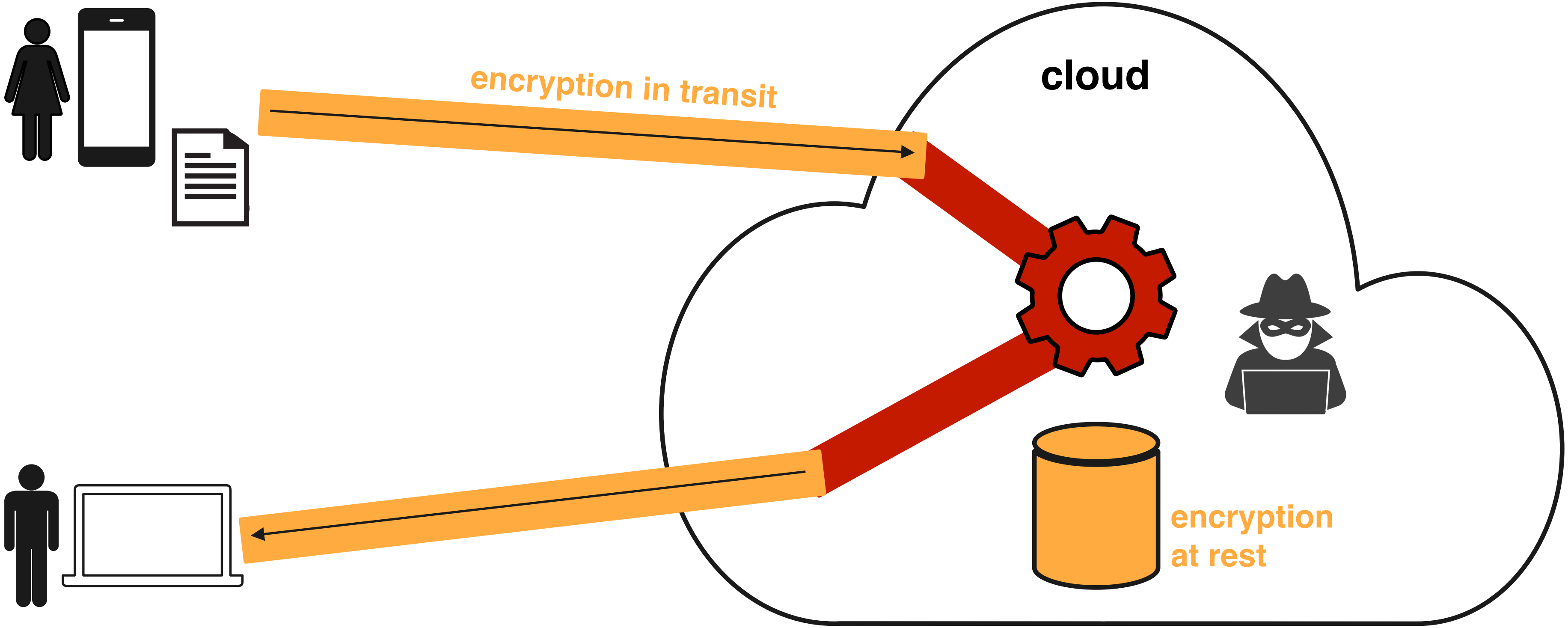

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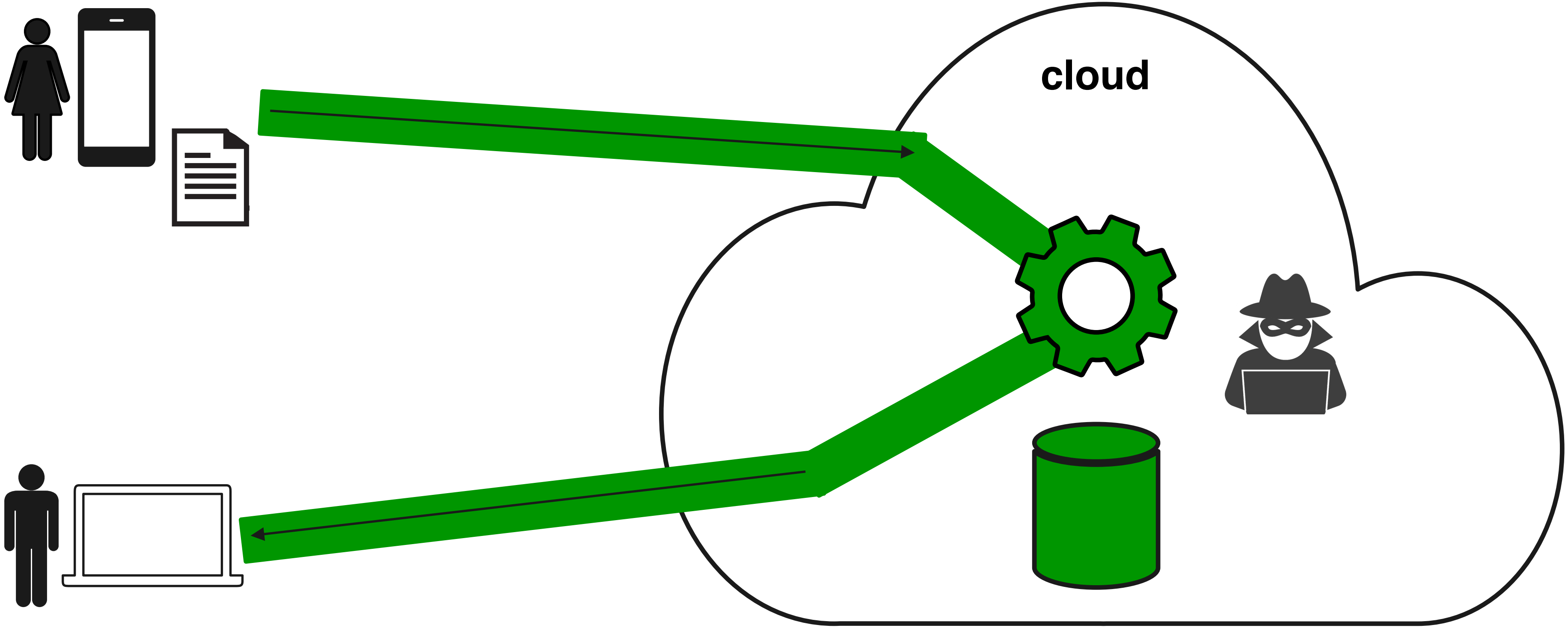

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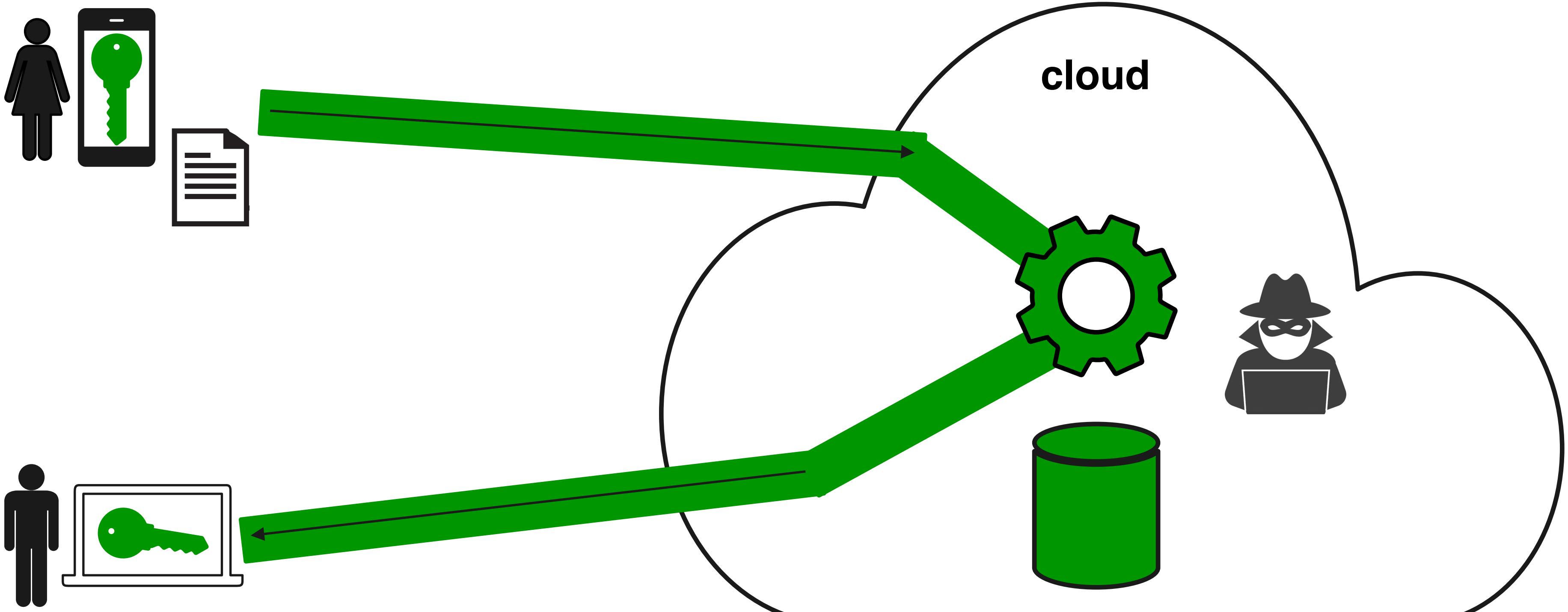

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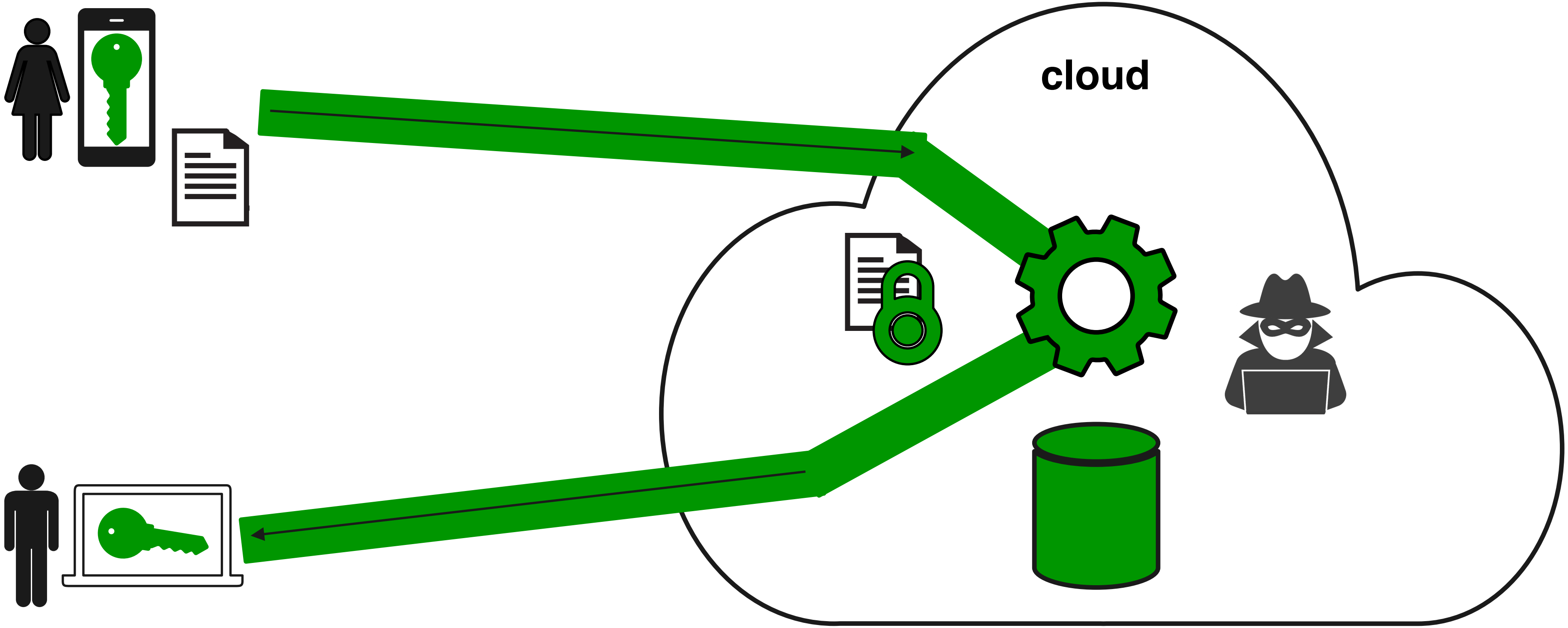

Systems in the cloud

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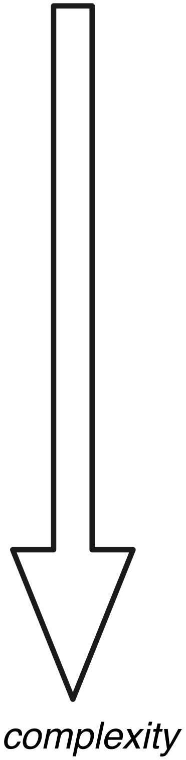

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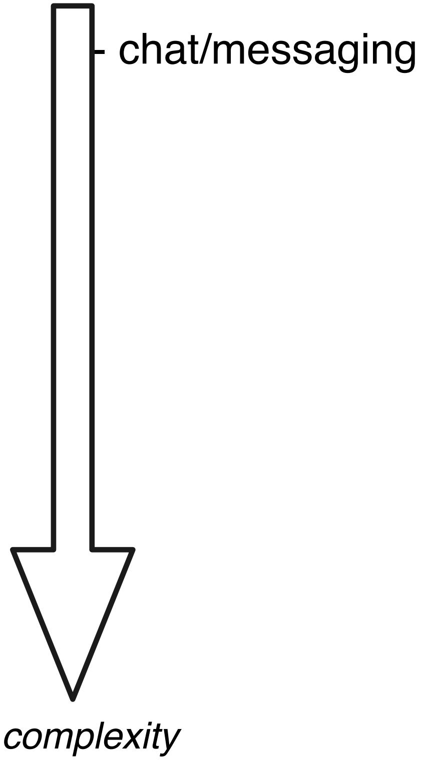

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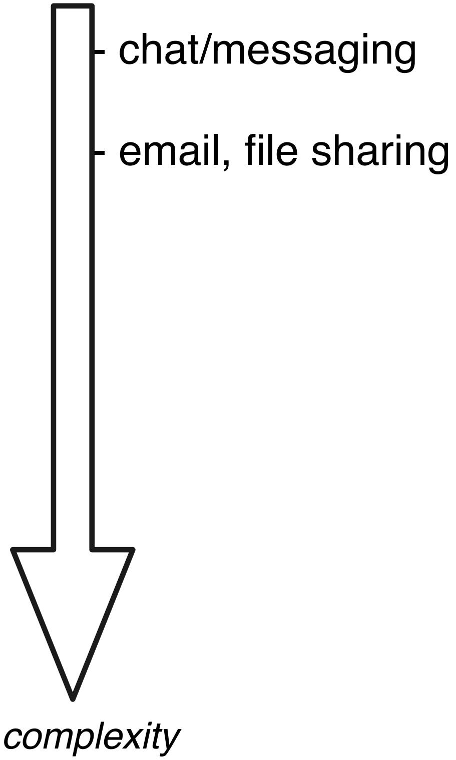

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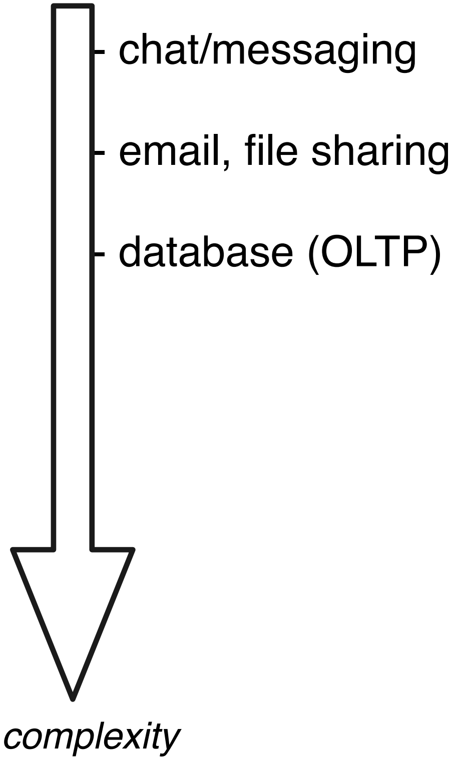
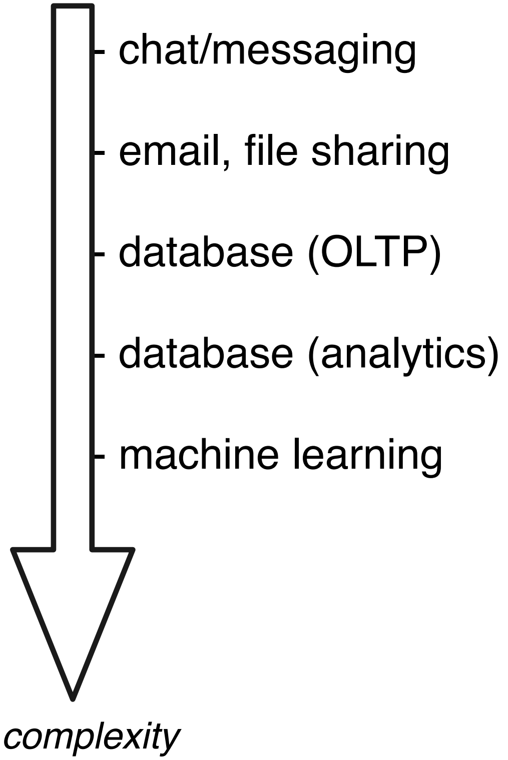


Systems in the cloud

- chat/messaging
- email, file sharing
- database (OLTP)
- database (analytics)

complexity

Systems in the cloud



My work

- chat/messaging — **JEDI**[USEC19] **WAVE**[USEC19]
- email, file sharing — **Verena**[IEEESP16] **Mylar** [NSDI14] **CloudProof** [Usenix11]

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- database (OLTP) — **Arx**[VLDB19], **Oblix**[IEEESP18], **CryptDB**[SOSP11],**mOPE**[IEEESP13], **BlindBox**[SIGCOMM15],**Embark**[NSDI16]
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End-to-end (E2E) encrypted chat/messaging

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Widely adopted industry solutions

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Widely adopted industry solutions

WhatsApp

Research on many-to-many (JEDI[USEC19]), constrained devices (e.g. IoT WAVE[USEC19]), usability

E2E encrypted email and file sharing

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ProtonMail

tresorit

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PREVEIL

- Research focusing on malicious cloud attackers (Verena[IEEESP16]), usability, search

Systems in the cloud

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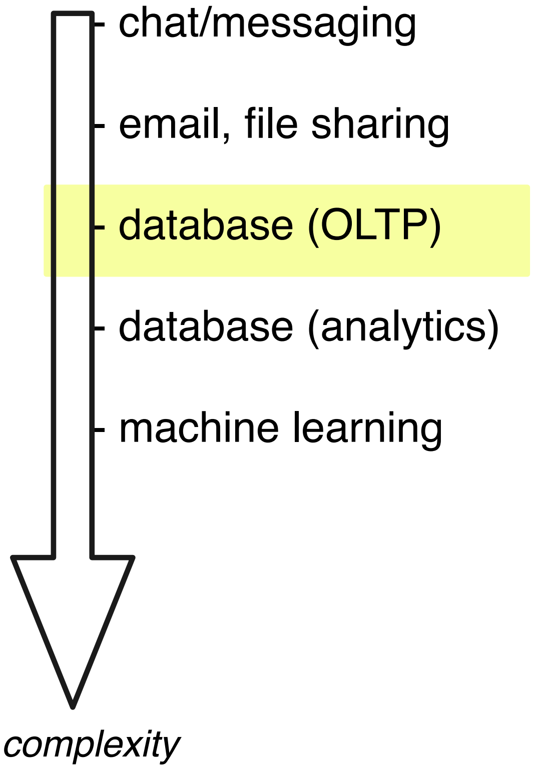
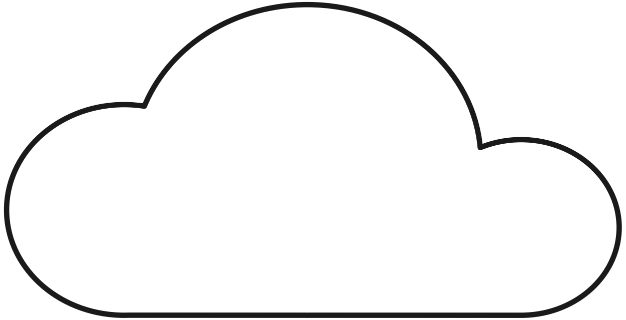
complexity

Systems in the cloud



Computation on encrypted data [RAD78, Gentry09]



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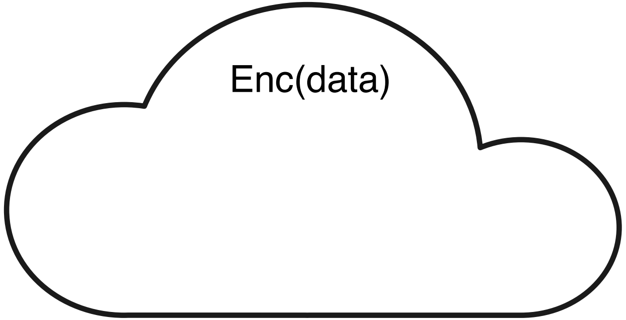

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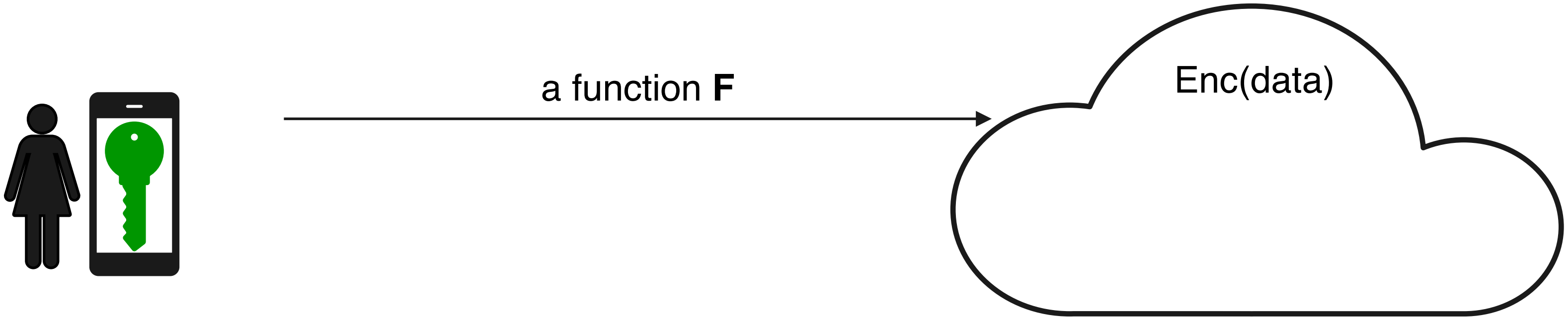

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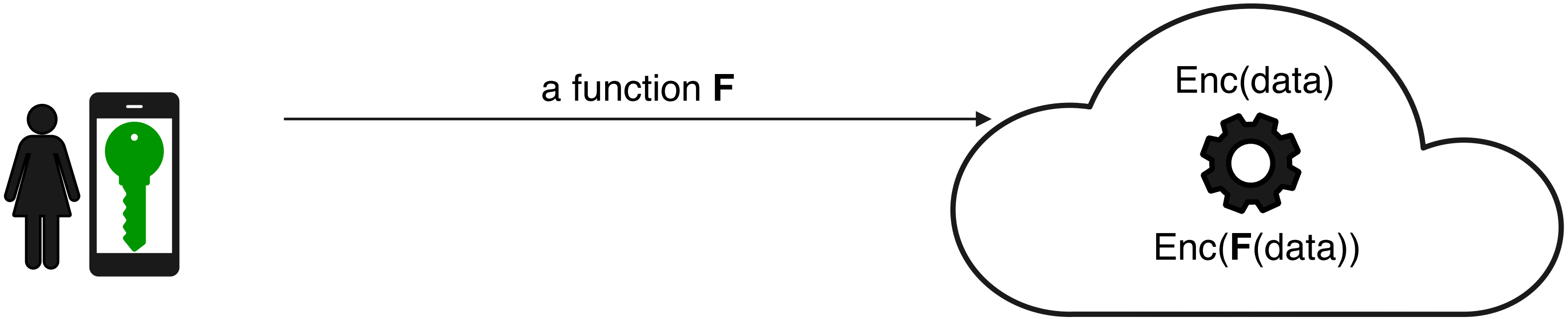

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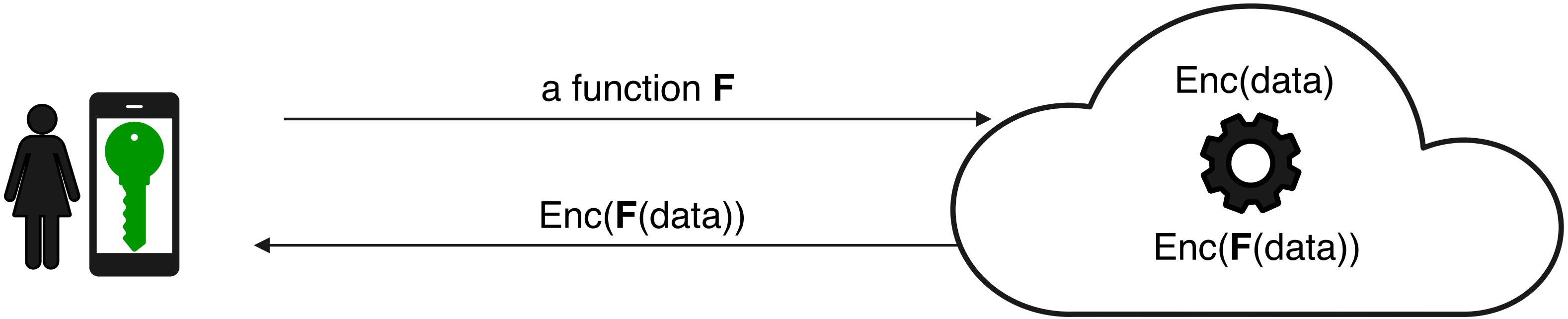

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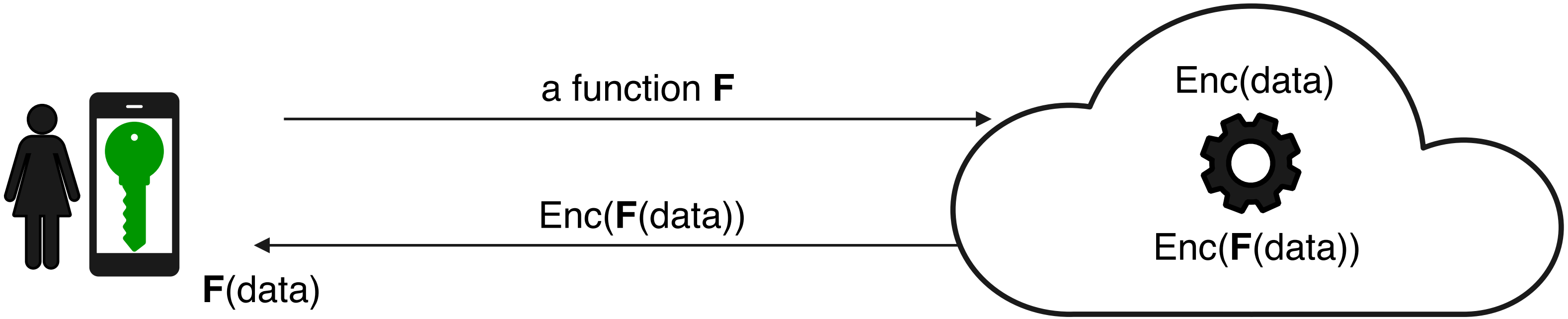

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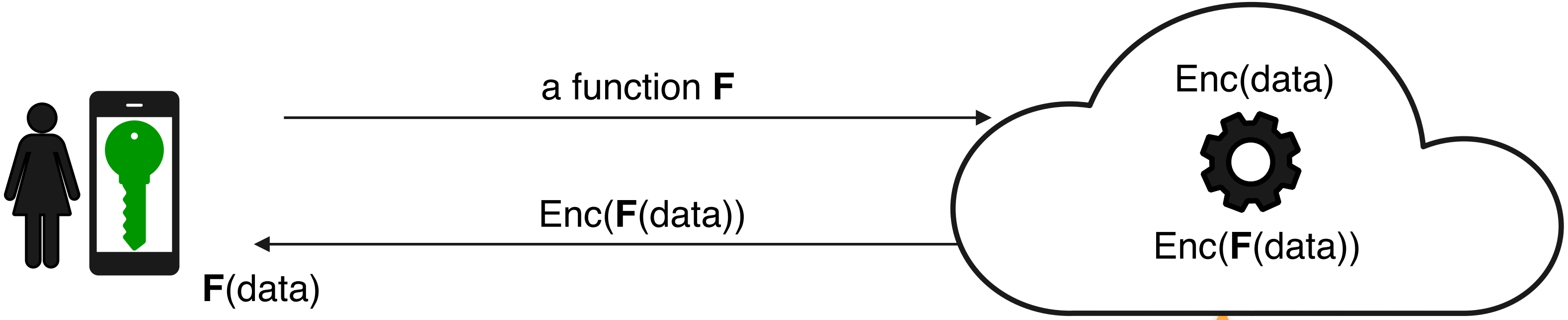

Example: Paillier cryptosystem, **F** = +

Enc(x) = $g^x r^n \bmod n^2$

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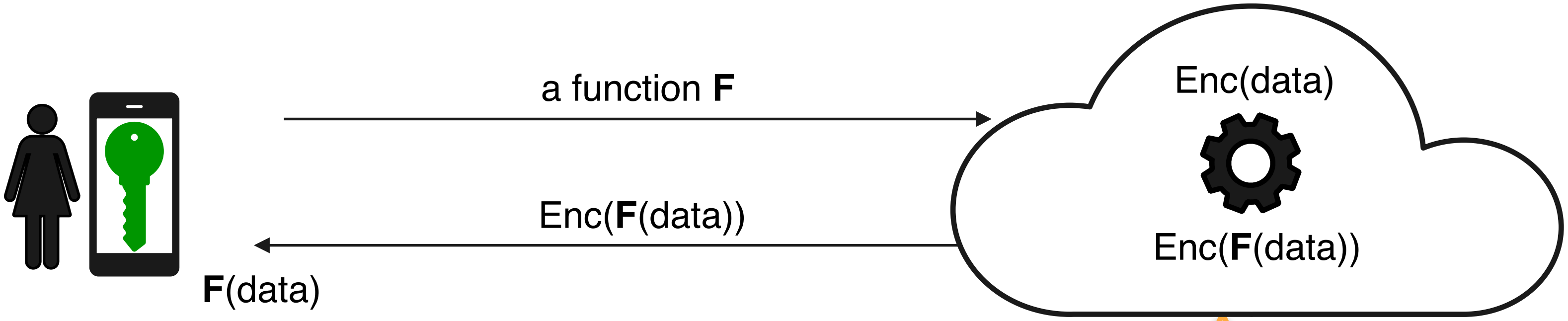

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Enc(y) = $g^y r^n \bmod n^2$

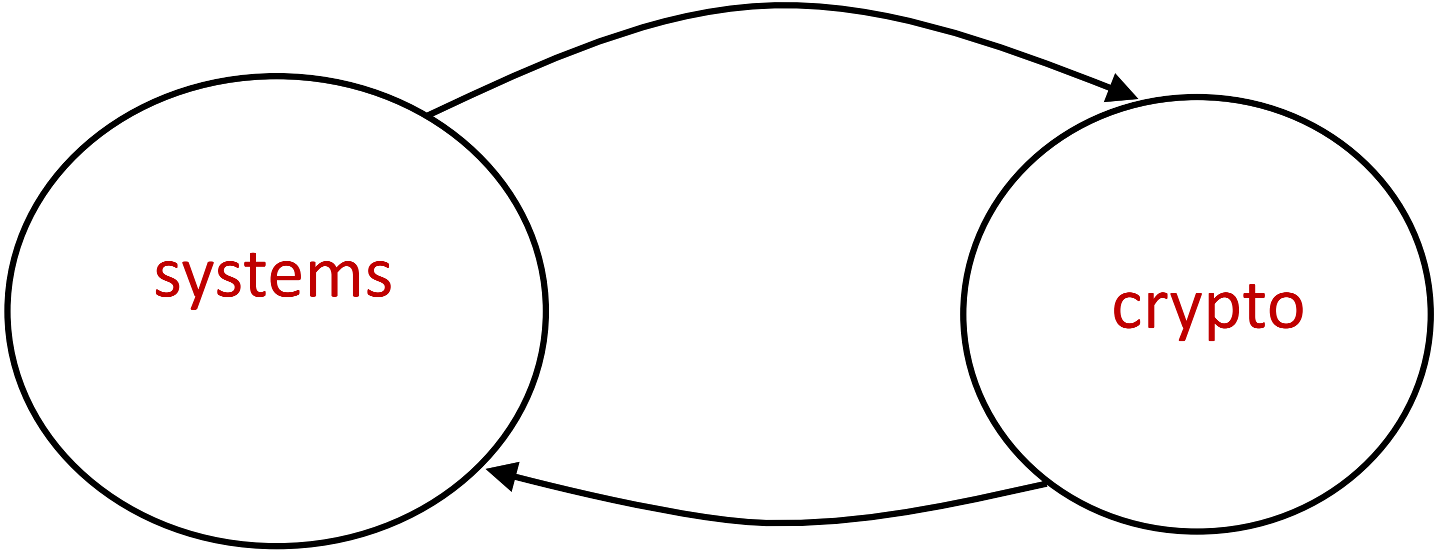
(multiply)

Enc(x) * Enc(y) = $g^{x+y}(rr')^n \bmod n^2$ = Enc(x+y)

Fully homomorphic encryption [Gentry09]

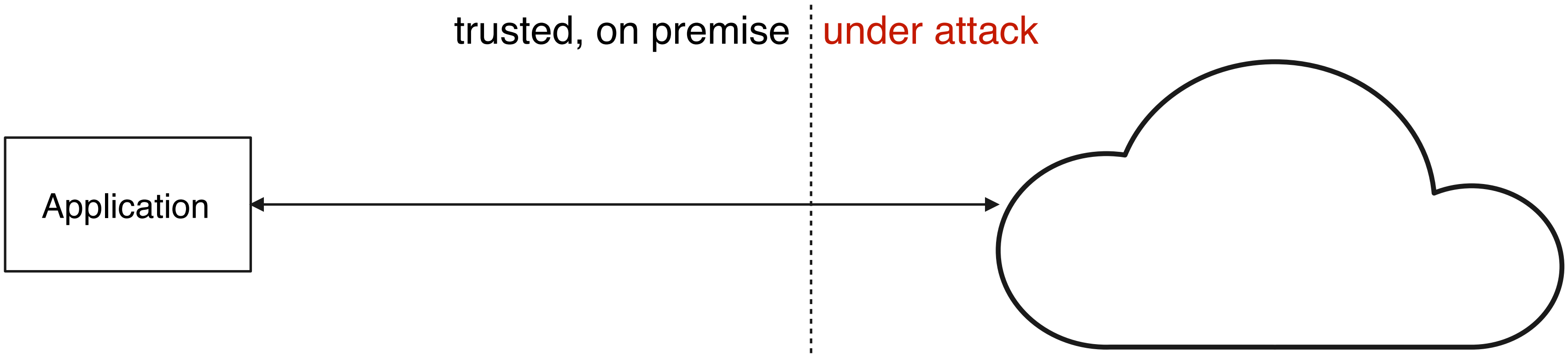
- enables general functions on encrypted data
- despite much progress, remains orders of magnitude too slow

Approach to build practical systems: co-design systems and cryptography



Encrypted databases: CryptDB [SOSP11]

CryptDB was the first DBMS to process SQL queries on encrypted data



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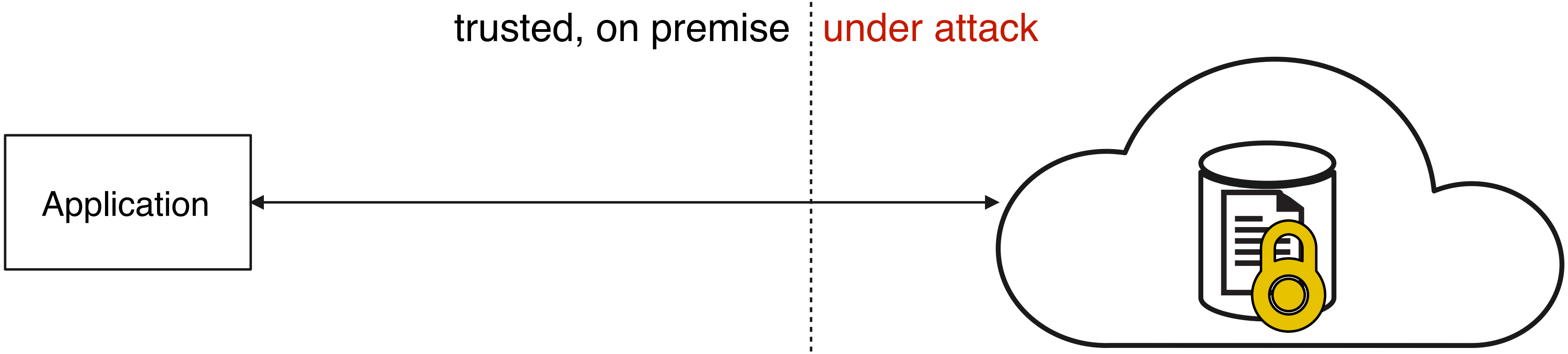

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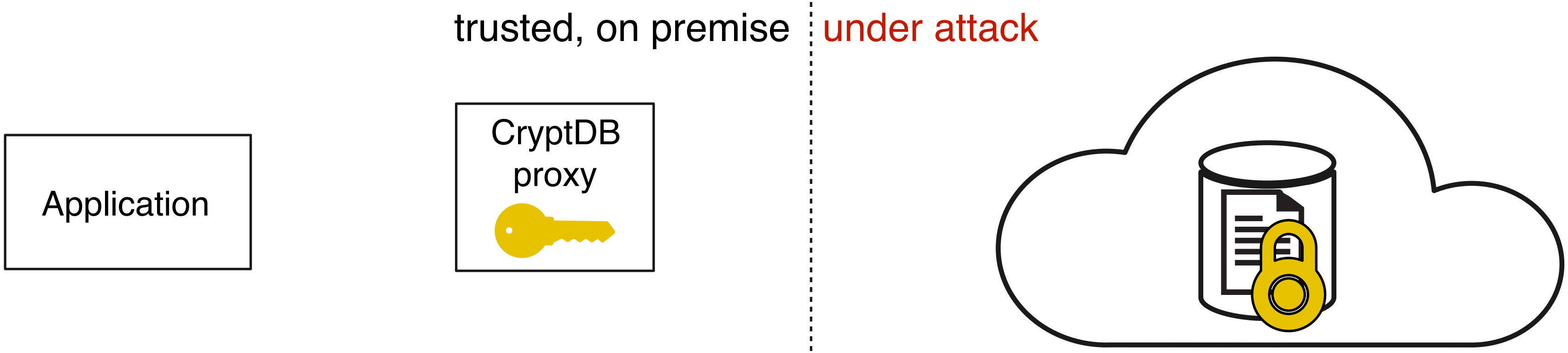

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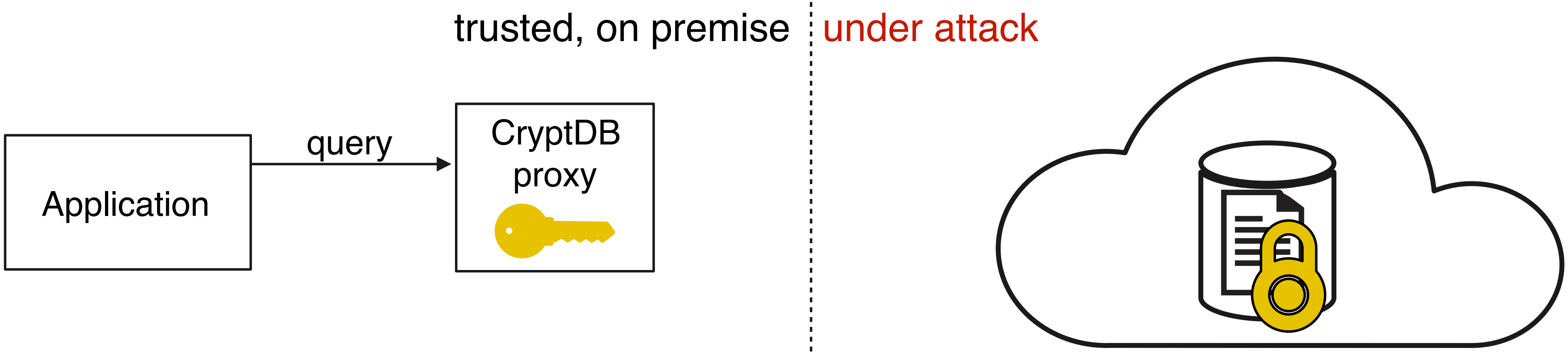

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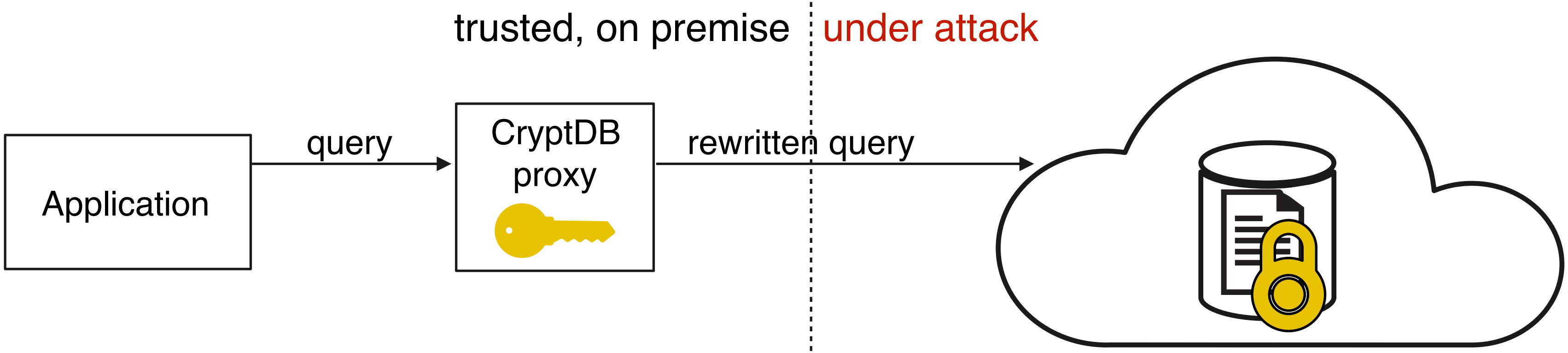

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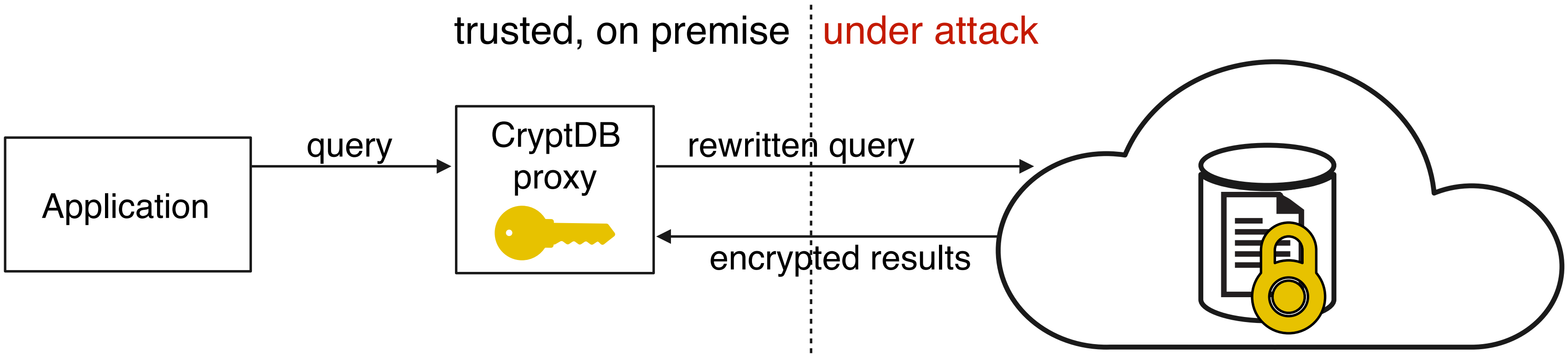

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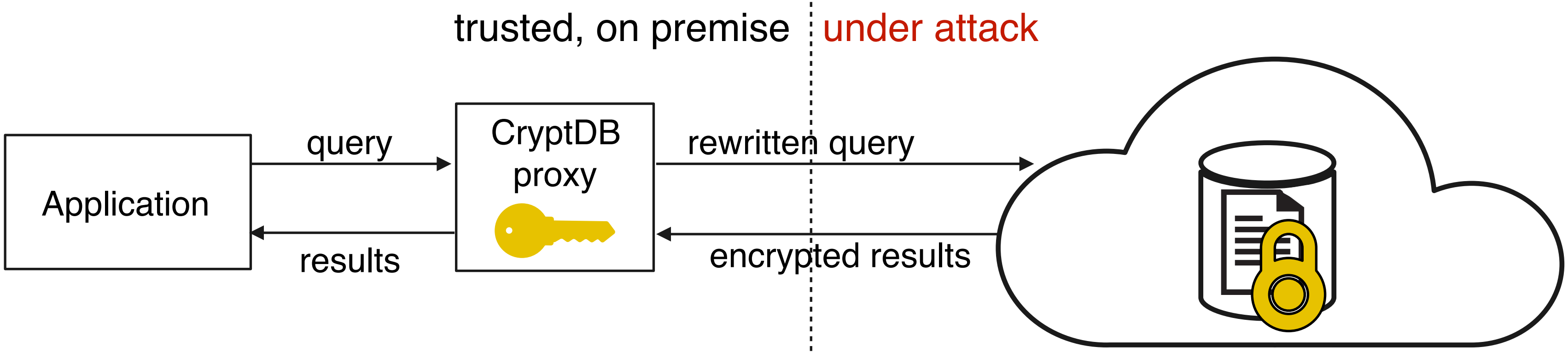

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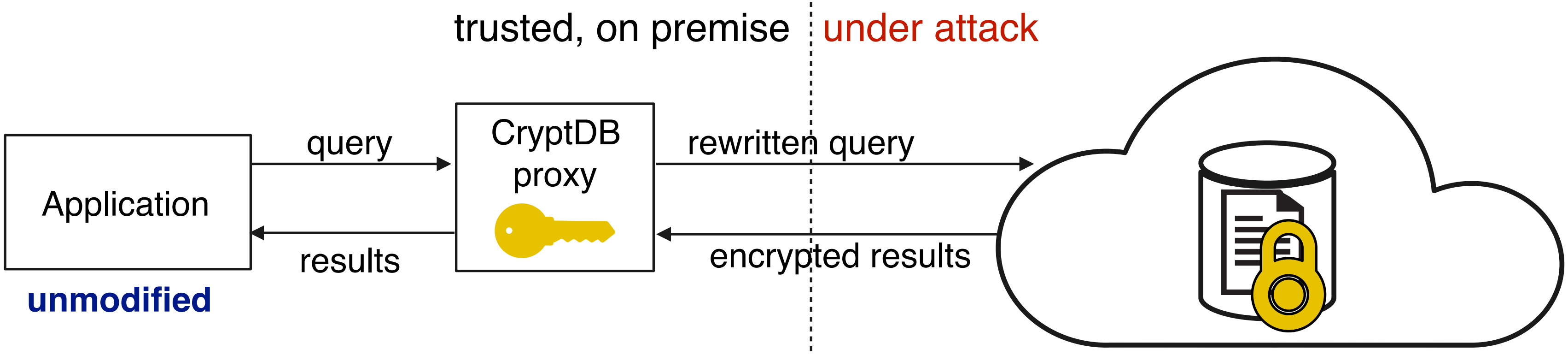

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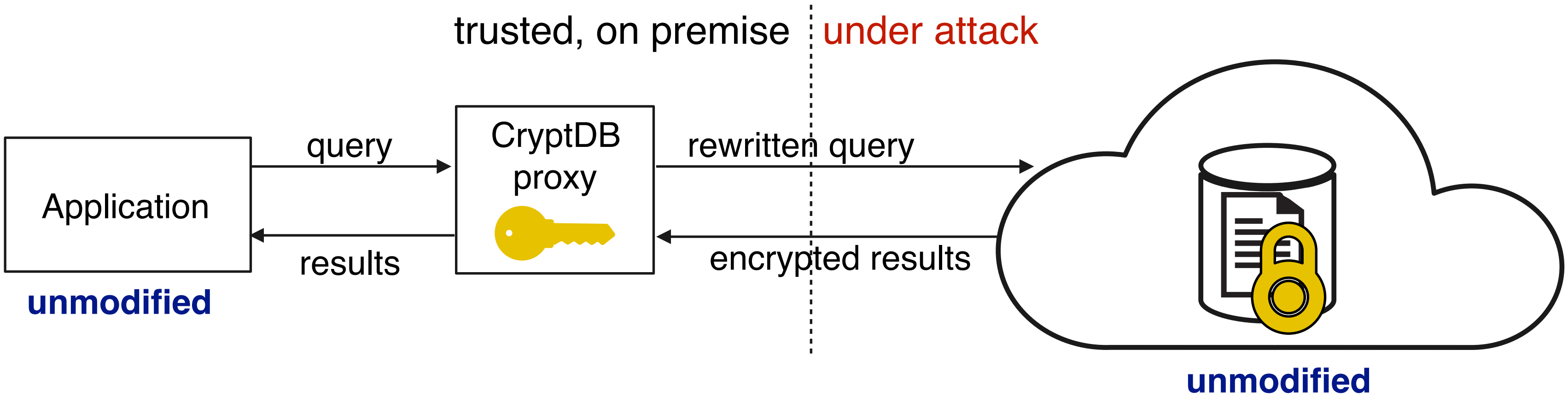

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Supported all of TPC-C, 27% throughput loss

A rich line of work followed

- Academic work:

  Cipherbase, CMD, Cryptsis, Autocrypt, Clome, SensorCloud, [ABE+13], [TKM+13], Seabed [PBC+16], BlindSeer[PKV+14], [CJJ+14], [FJK+15], [K15], Arx, MrCrypt, Monomi, [NKW15],[DDC16],[GSB17],KKN+16], [DCF+20],… > 1000 citations.

- Industry deployments:

  Microsoft AlwaysEncrypted

  Google's EncryptedBigQuery

  SAP SEEED

  skyhigh

  …

Lesson: co-design of systems and cryptography

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A recipe:

1. Focus on a workload. Identify a set of core operations the system needs
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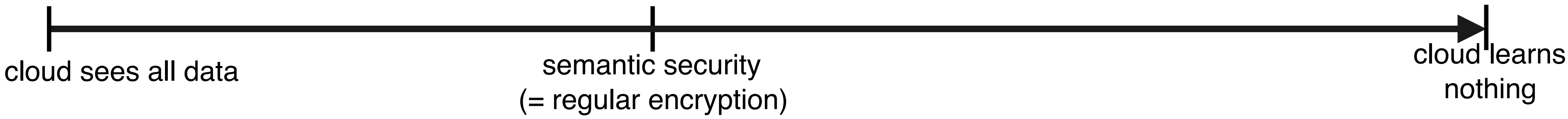

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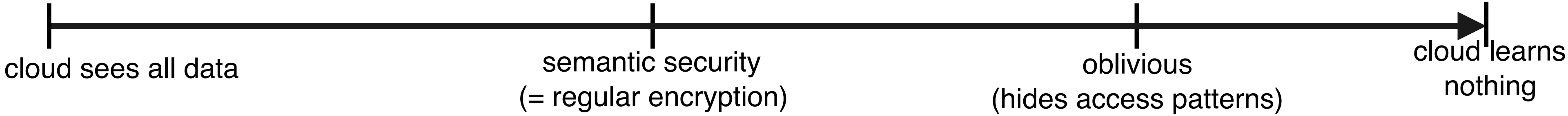

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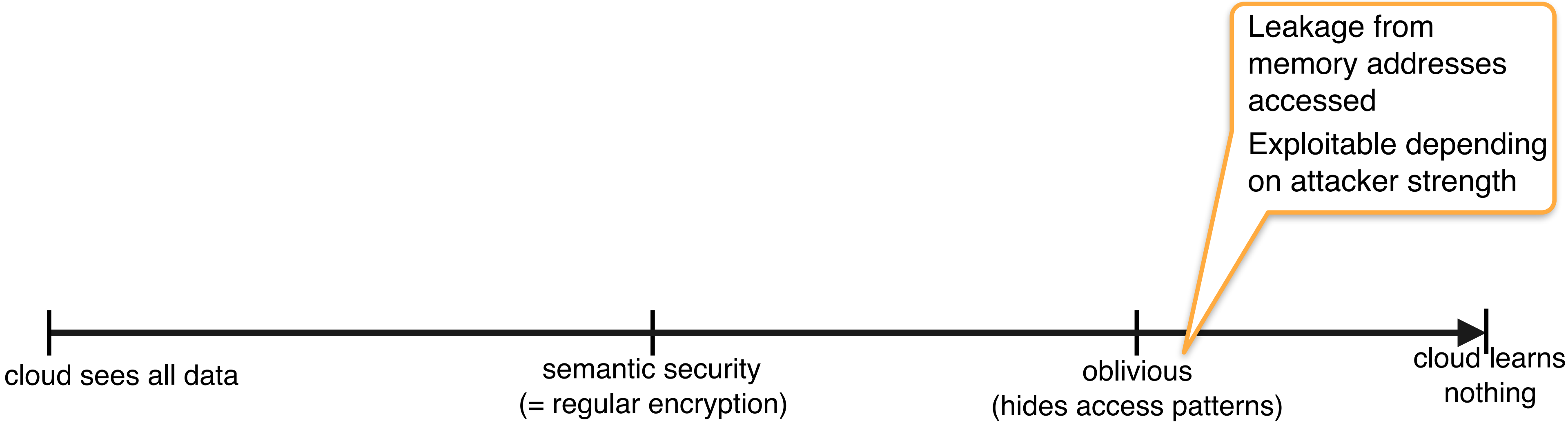

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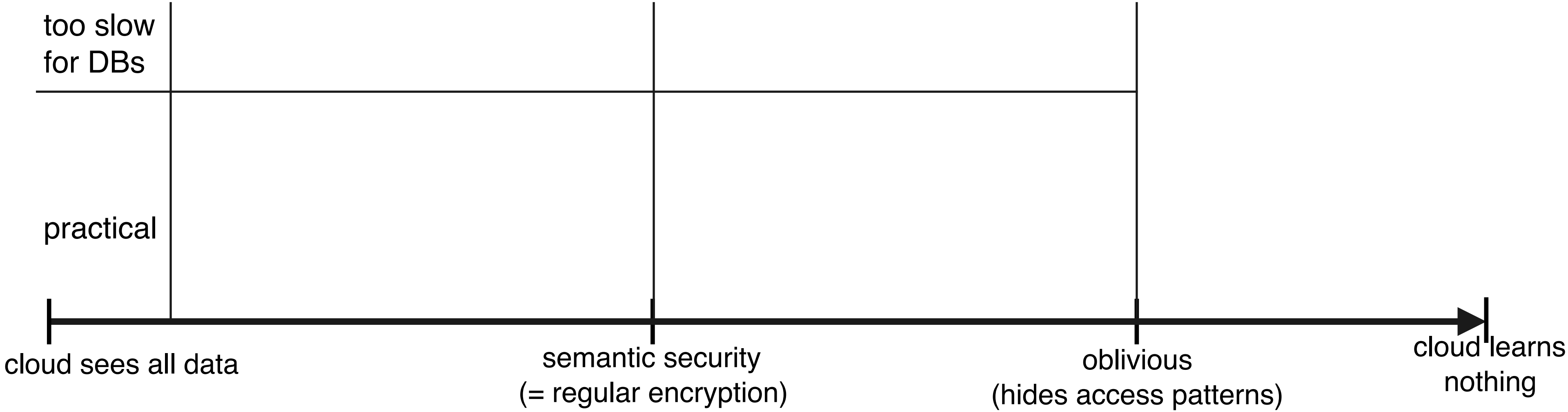

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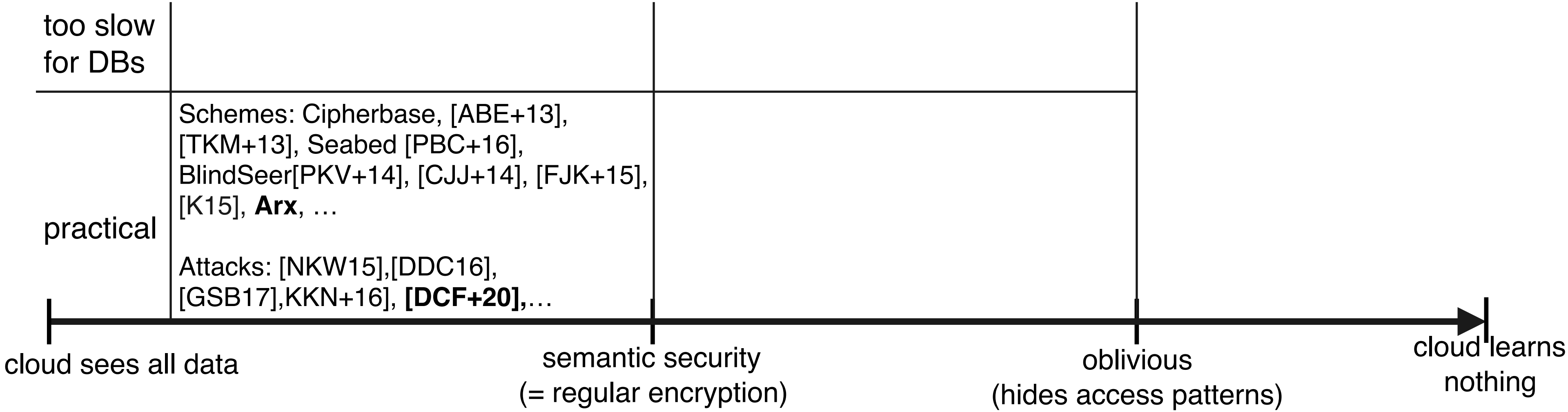

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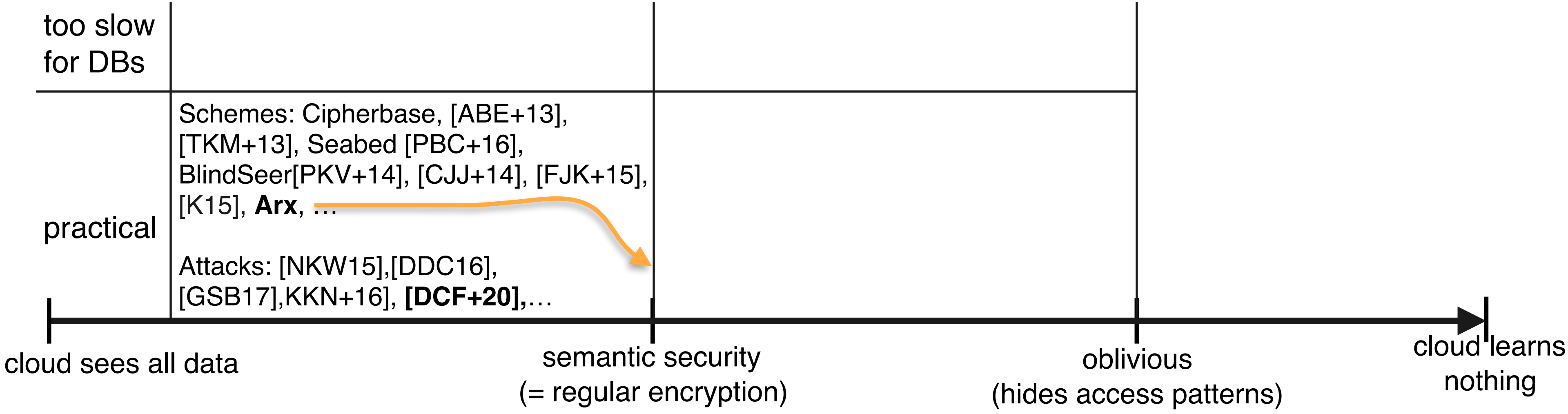

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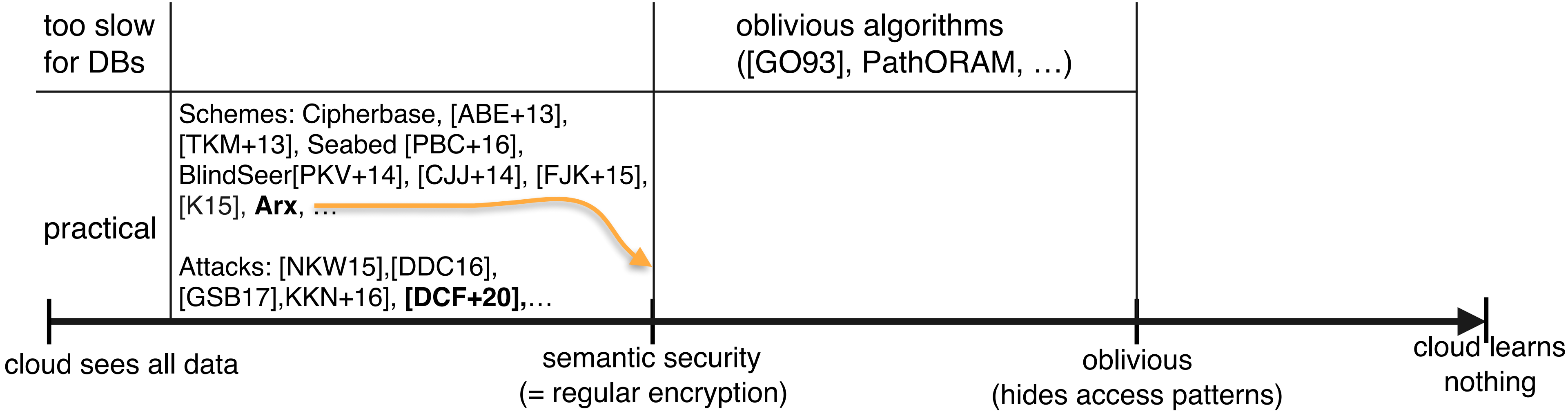

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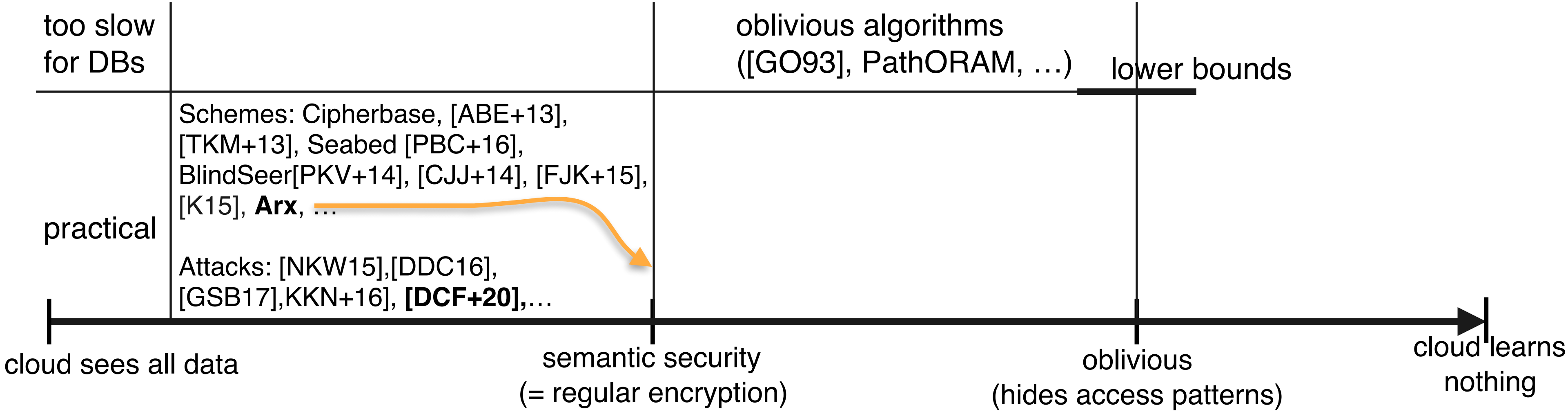

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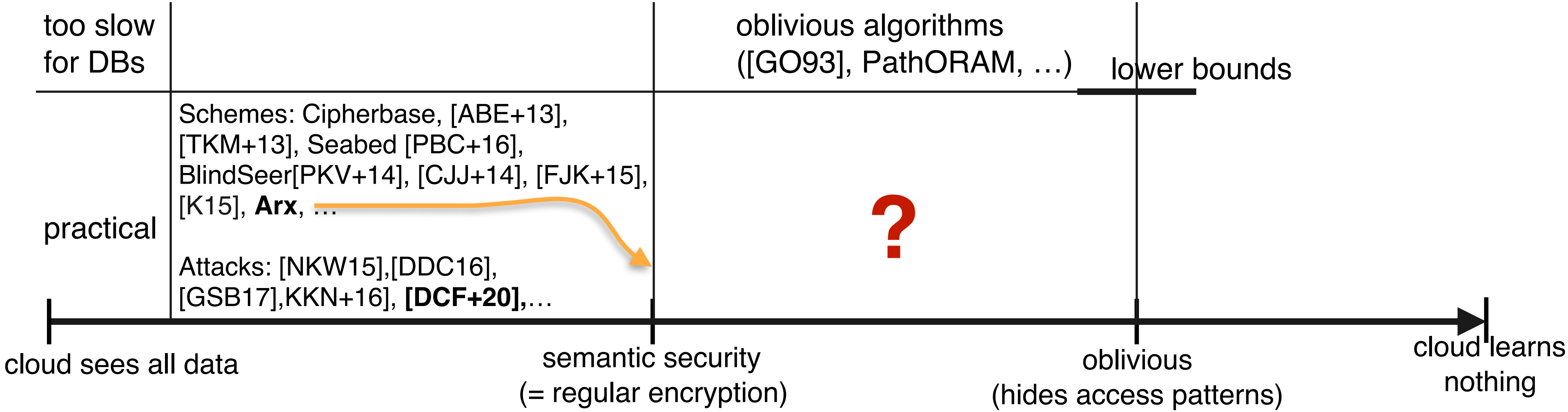

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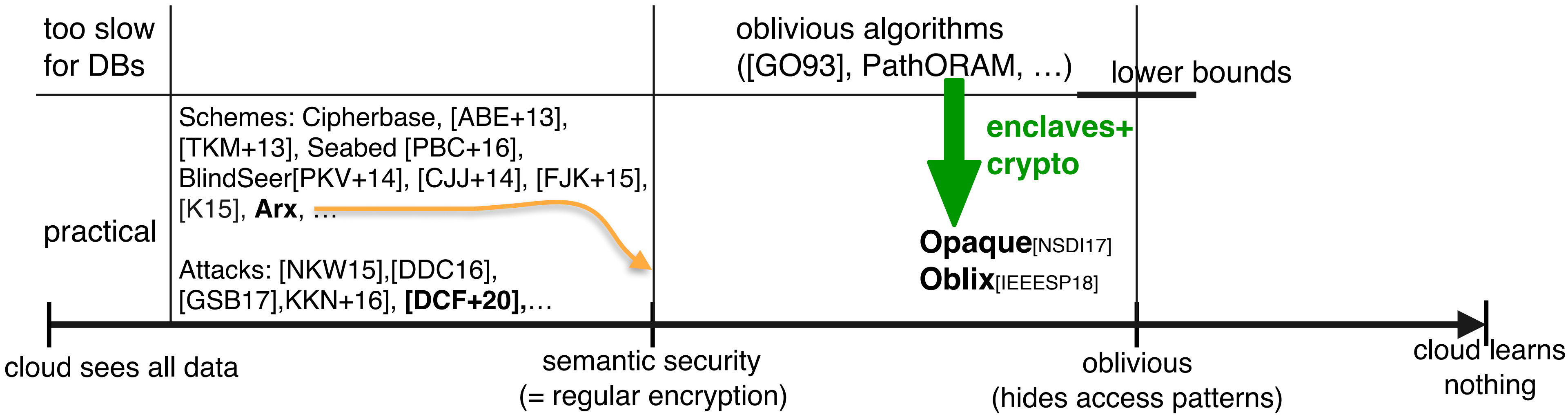

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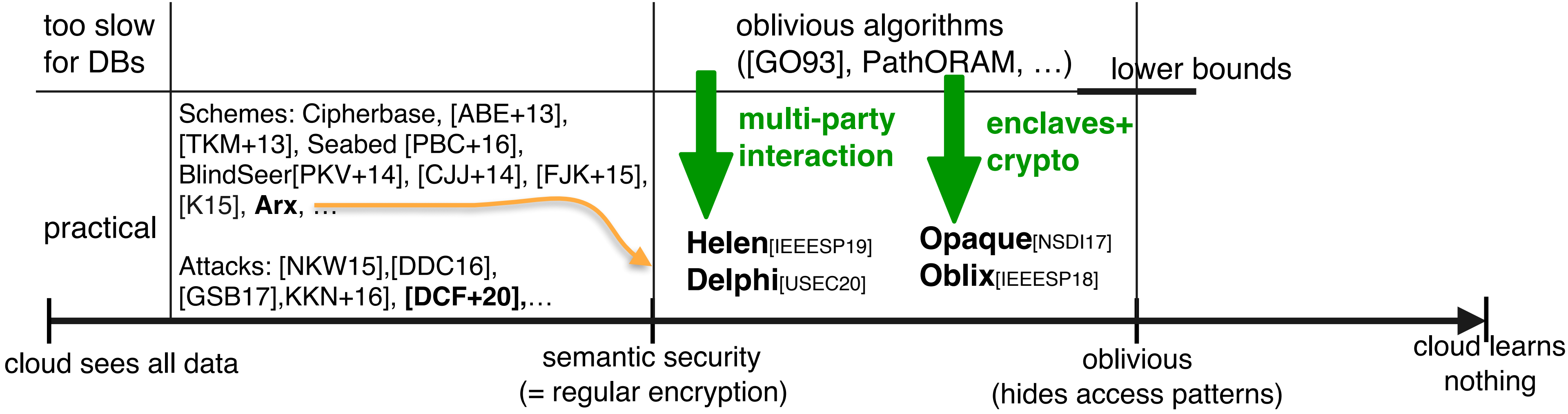

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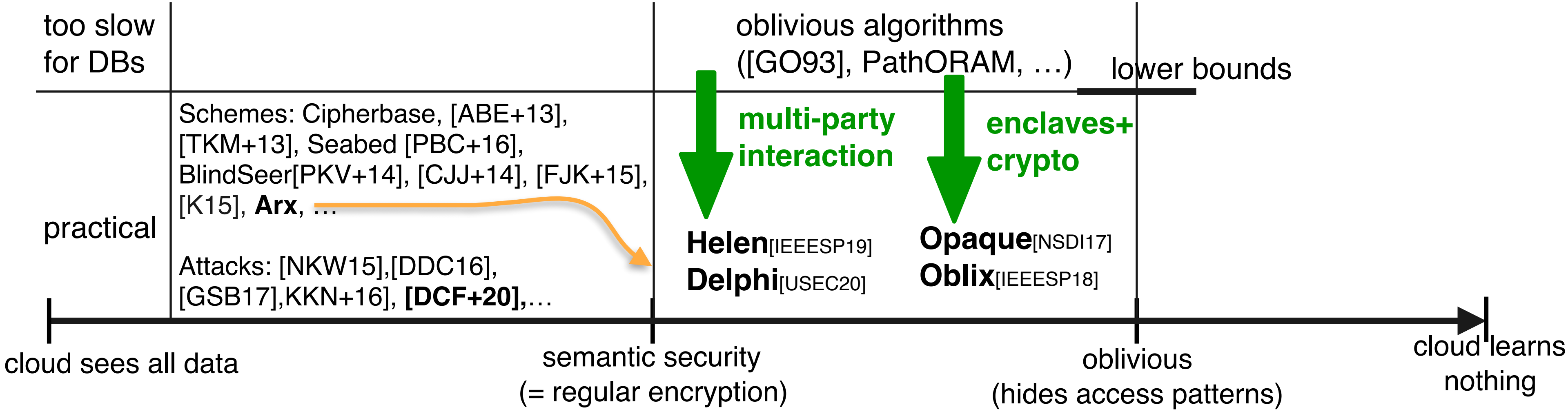
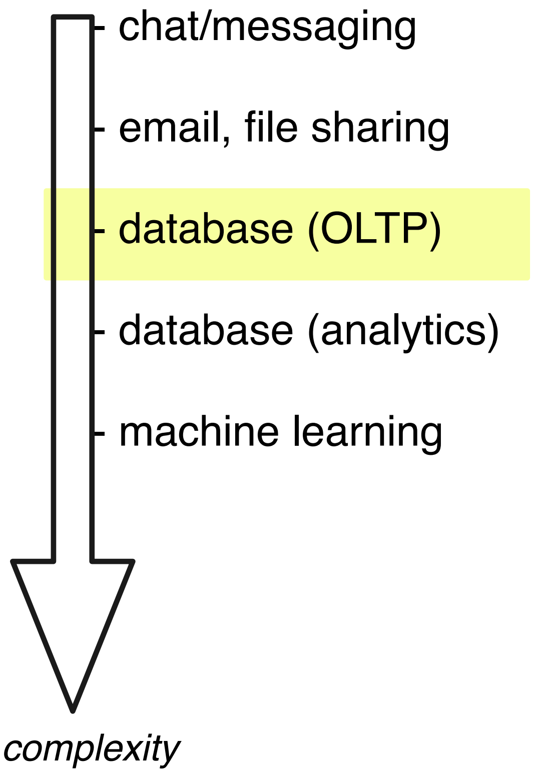


Systems in the cloud



Systems in the cloud

- chat/messaging
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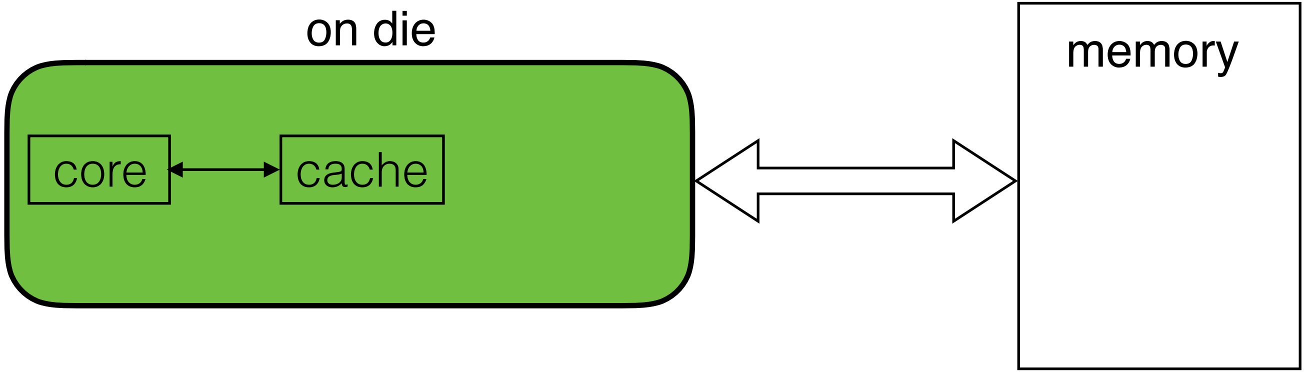
complexity

Hardware enclaves 101

Hardware enclaves (Intel SGX)

- Hardware-enforced isolated execution environment



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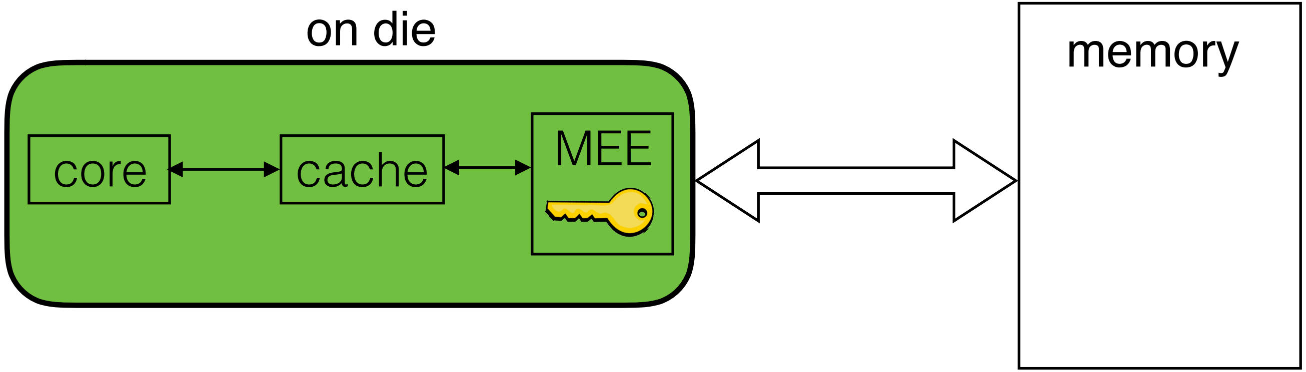

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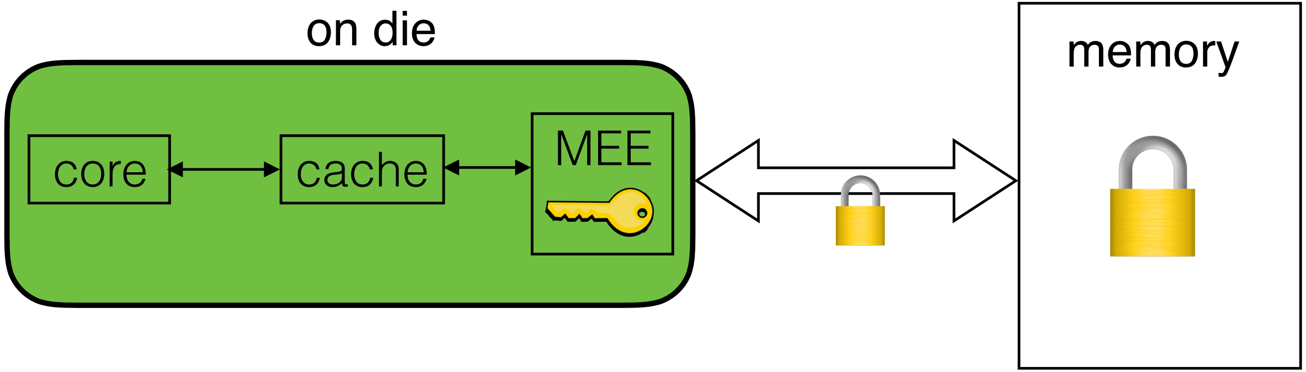

Hardware enclaves (Intel SGX)

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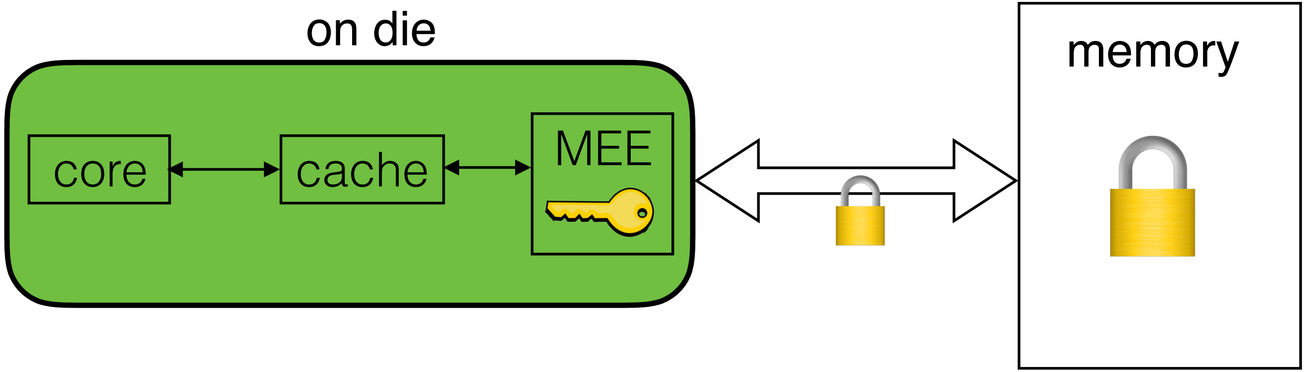
- Data decrypted only on the processor



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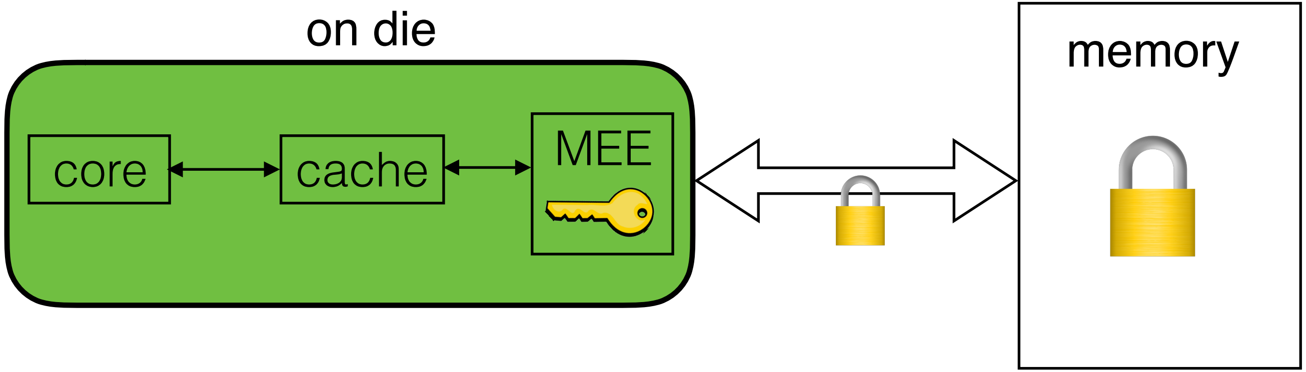

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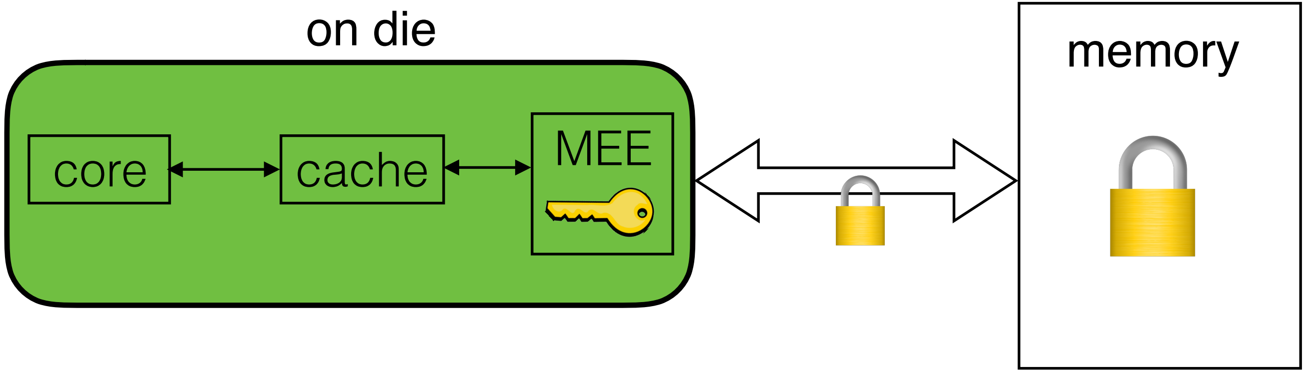
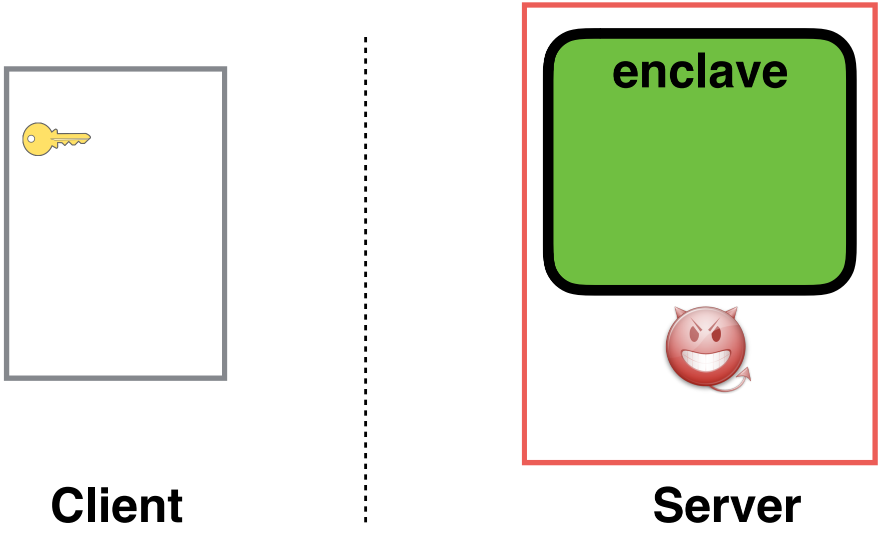


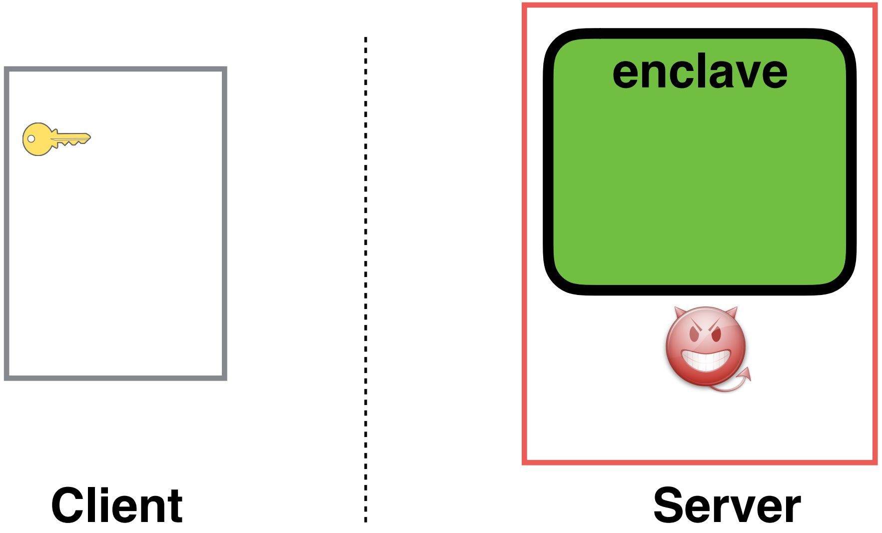
- Cloud offerings: Azure Confidential Computing, Alibaba Cloud

Remote attestation



Remote attestation

Enables verifying which code runs in the enclave and performing key exchange



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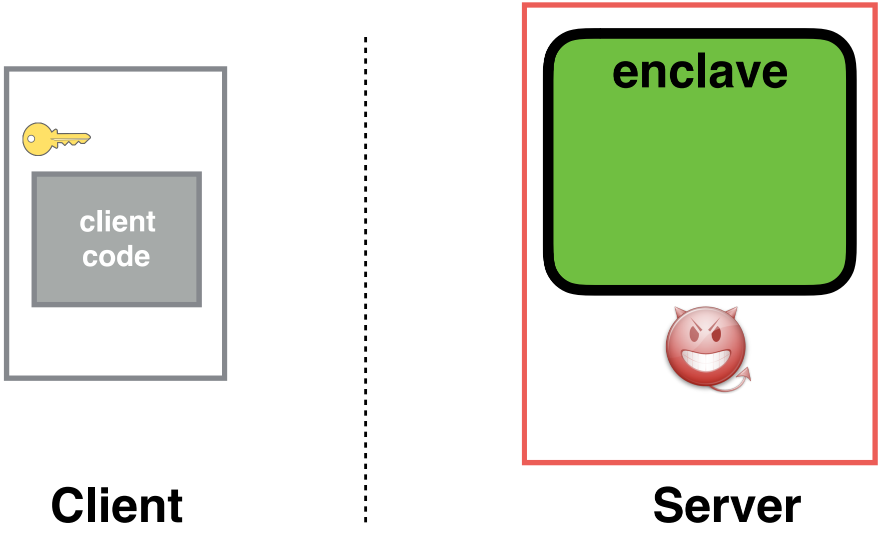

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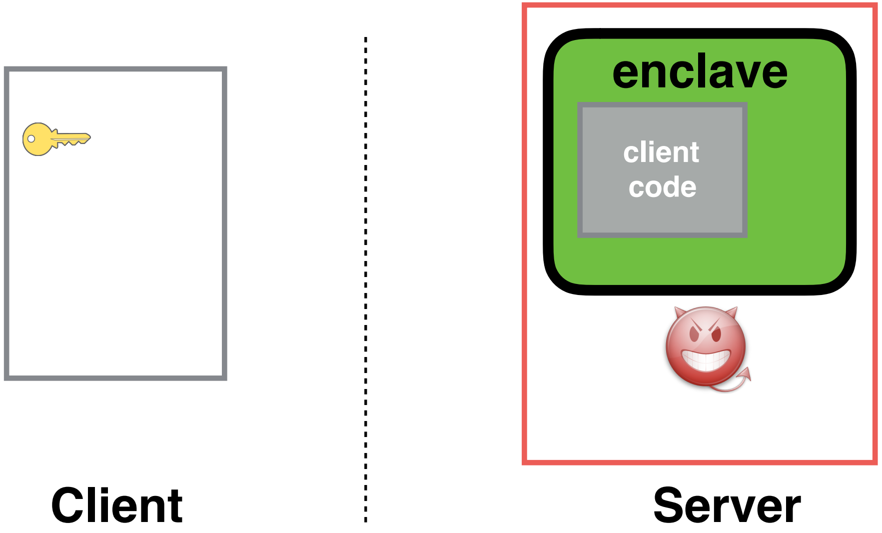

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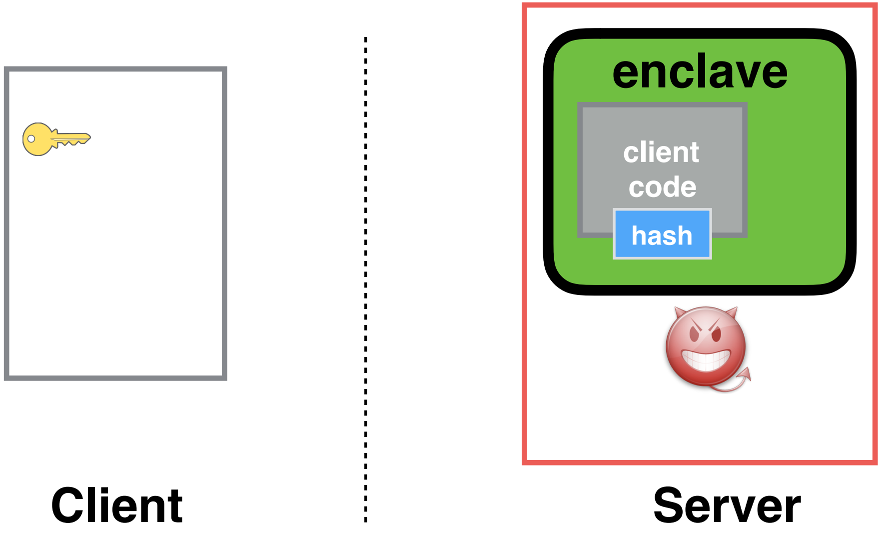

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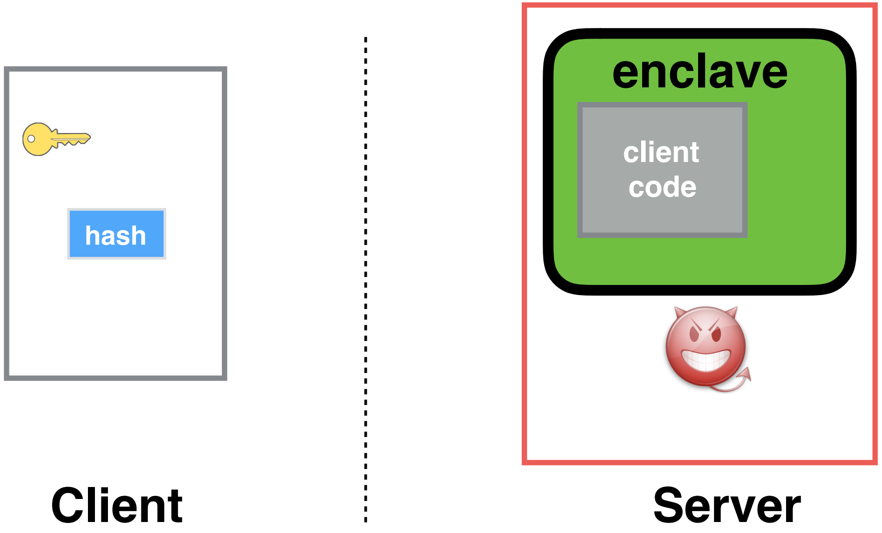

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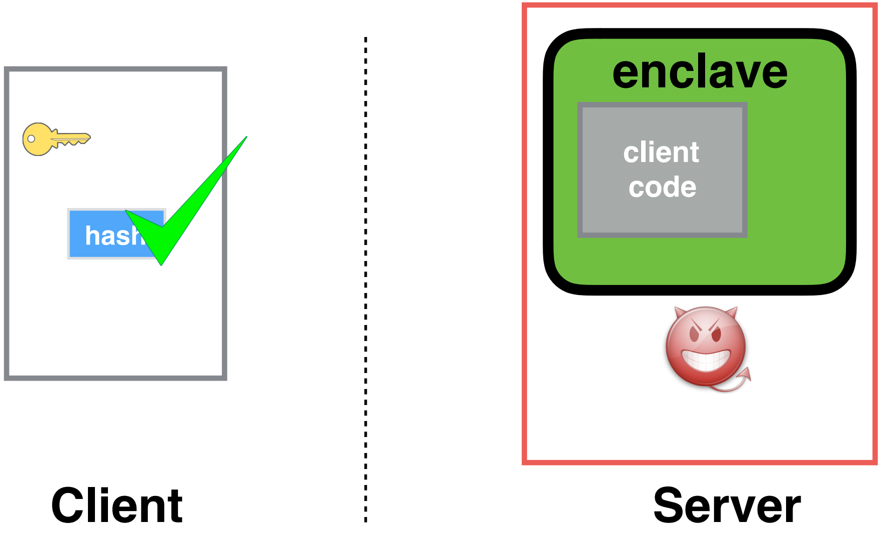

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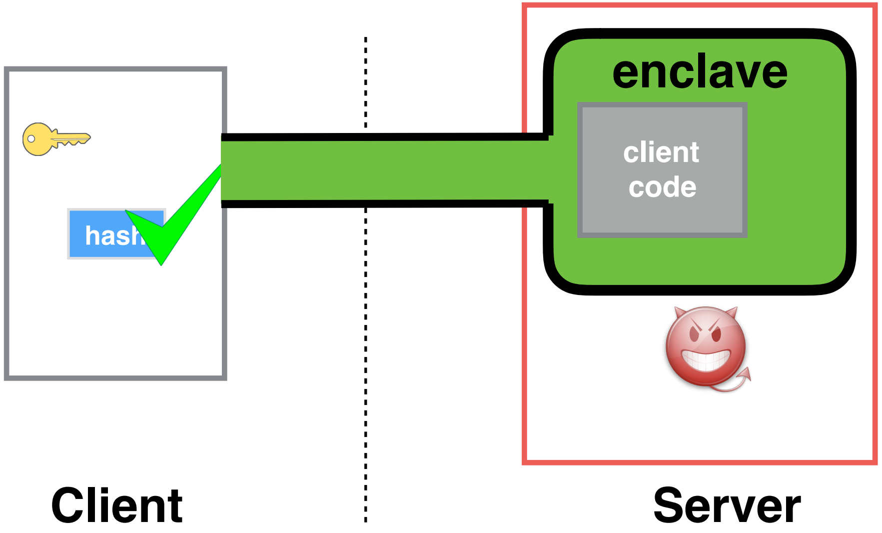

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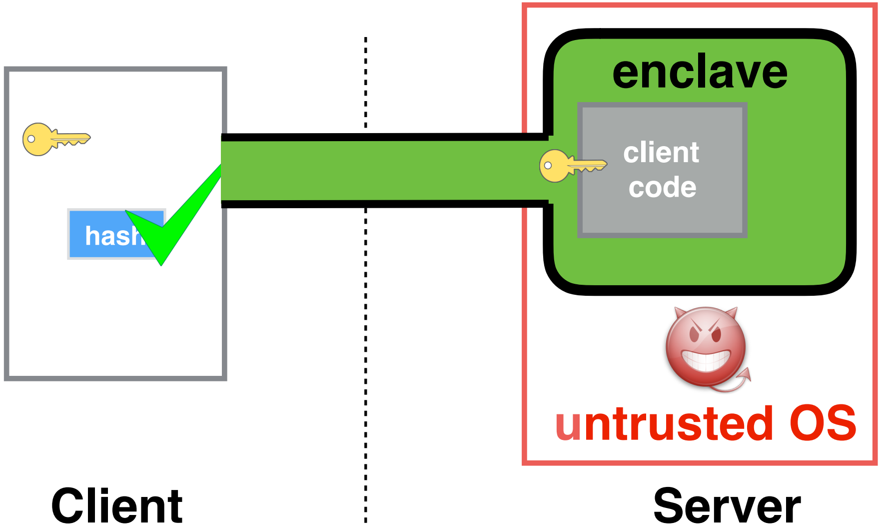

Side channels

Enclaves suffer from many side channels:

- cache-timing attacks ([Gotzfried et al17],[Brasser17,…])
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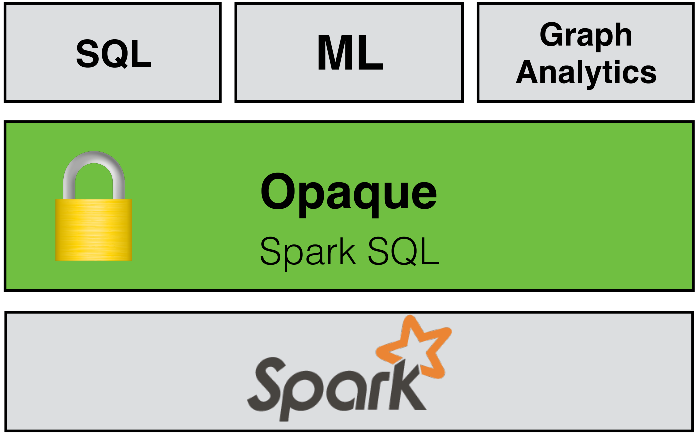
Synergy: enclaves remove expensive network communication of oblivious algorithms

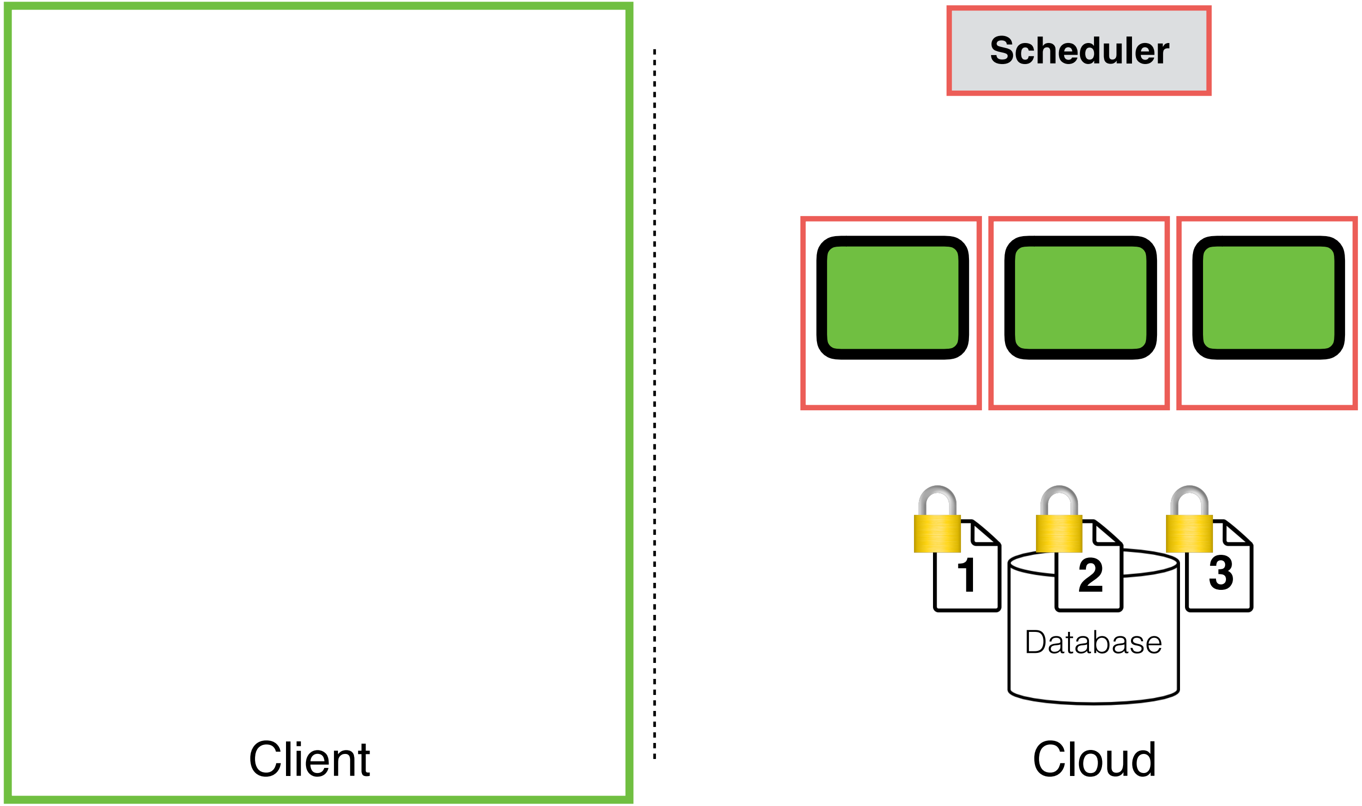
[NSDI17]

Opaque*: oblivious and encrypted distributed analytics platform



* Oblivious Platform for Analytic QUEries

Query execution



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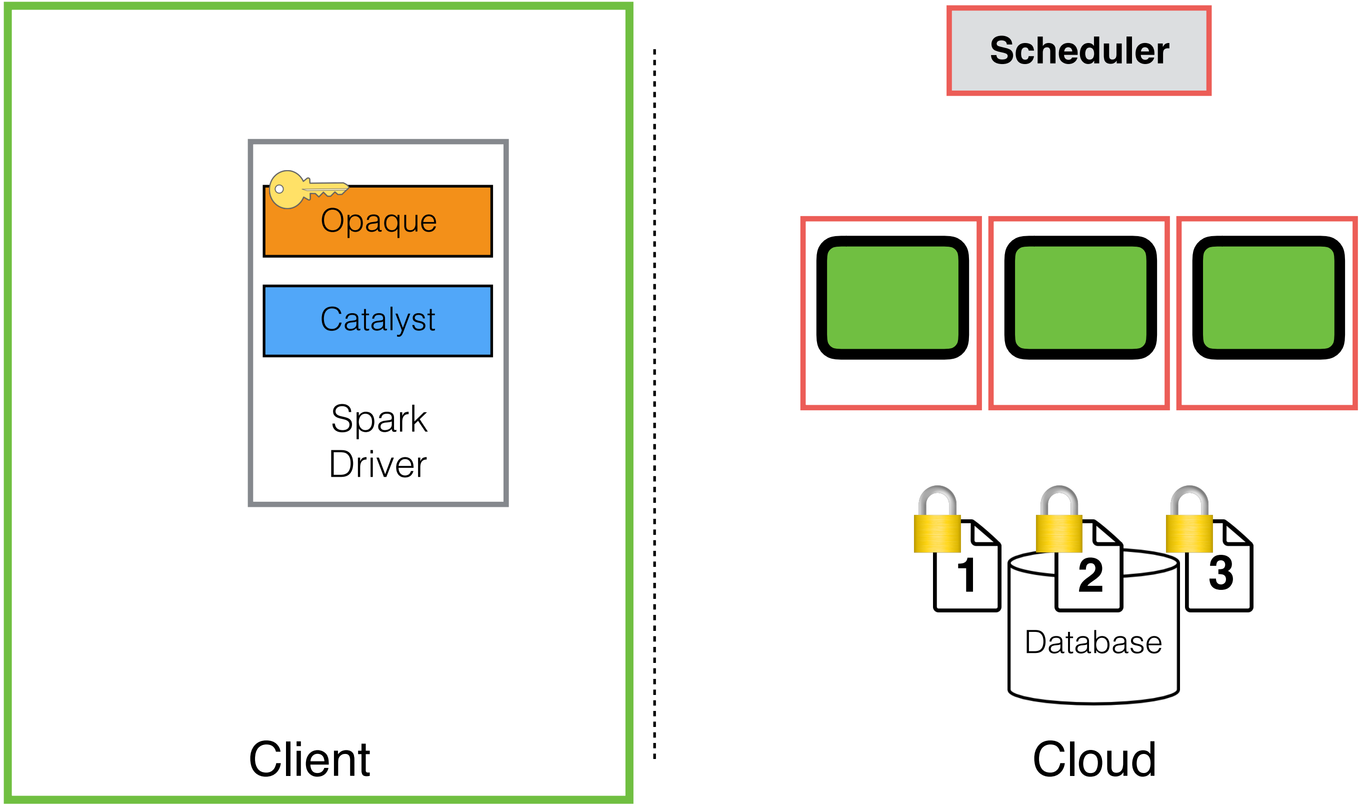

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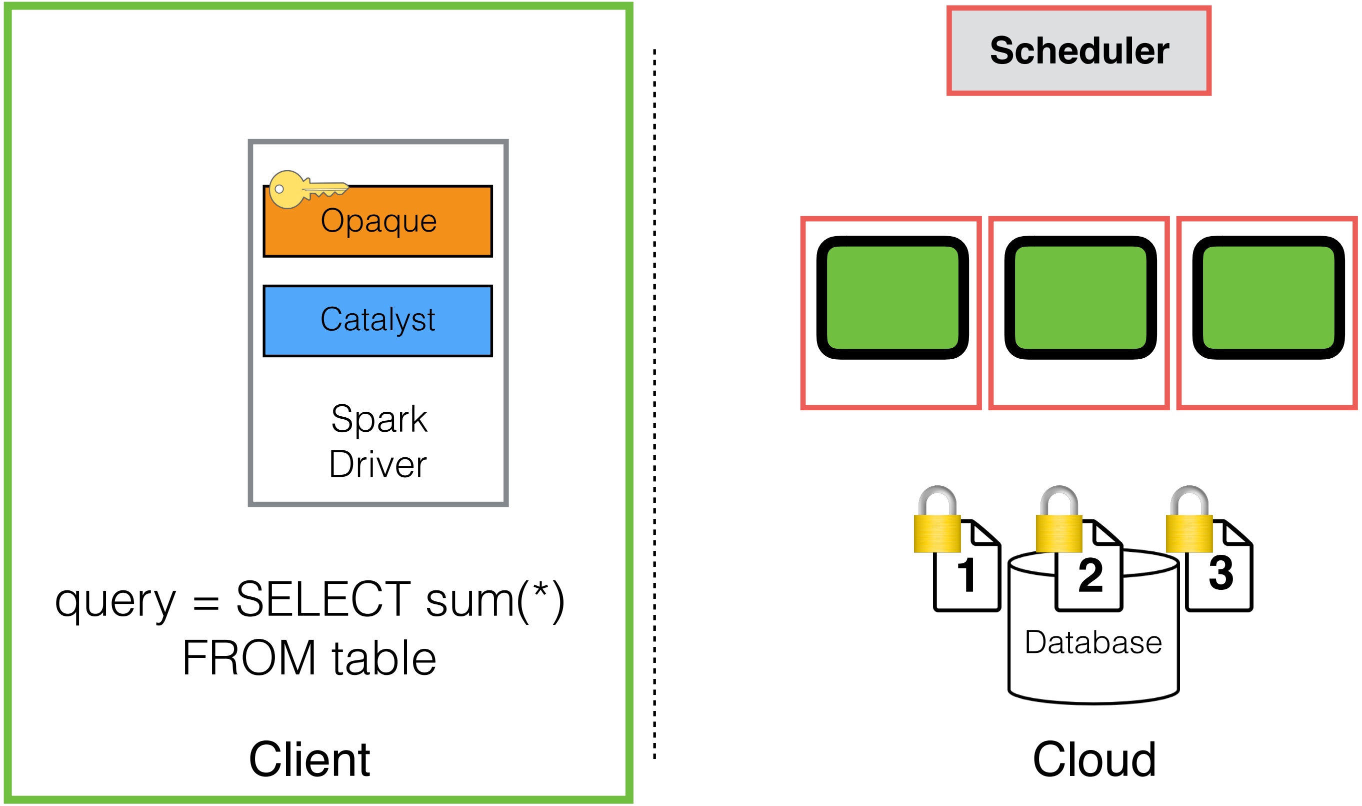

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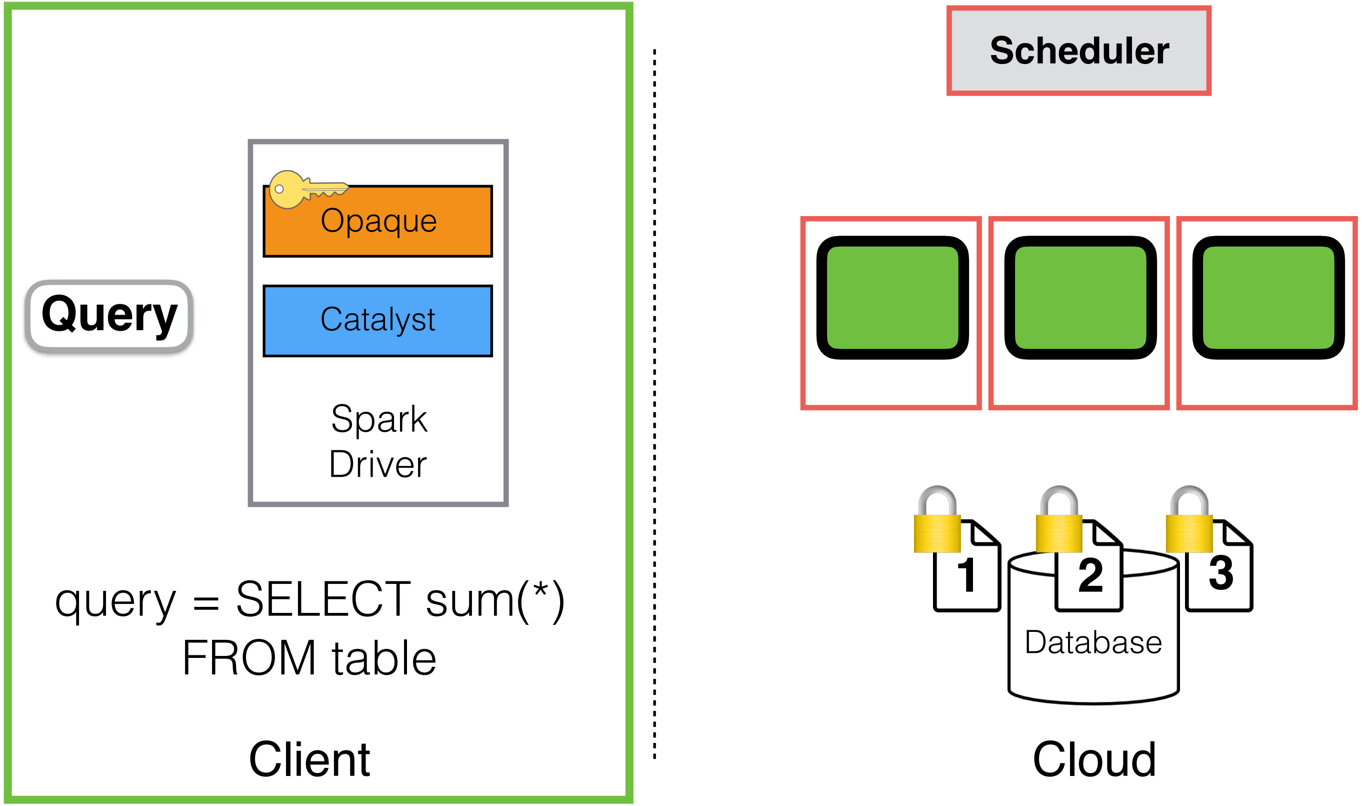

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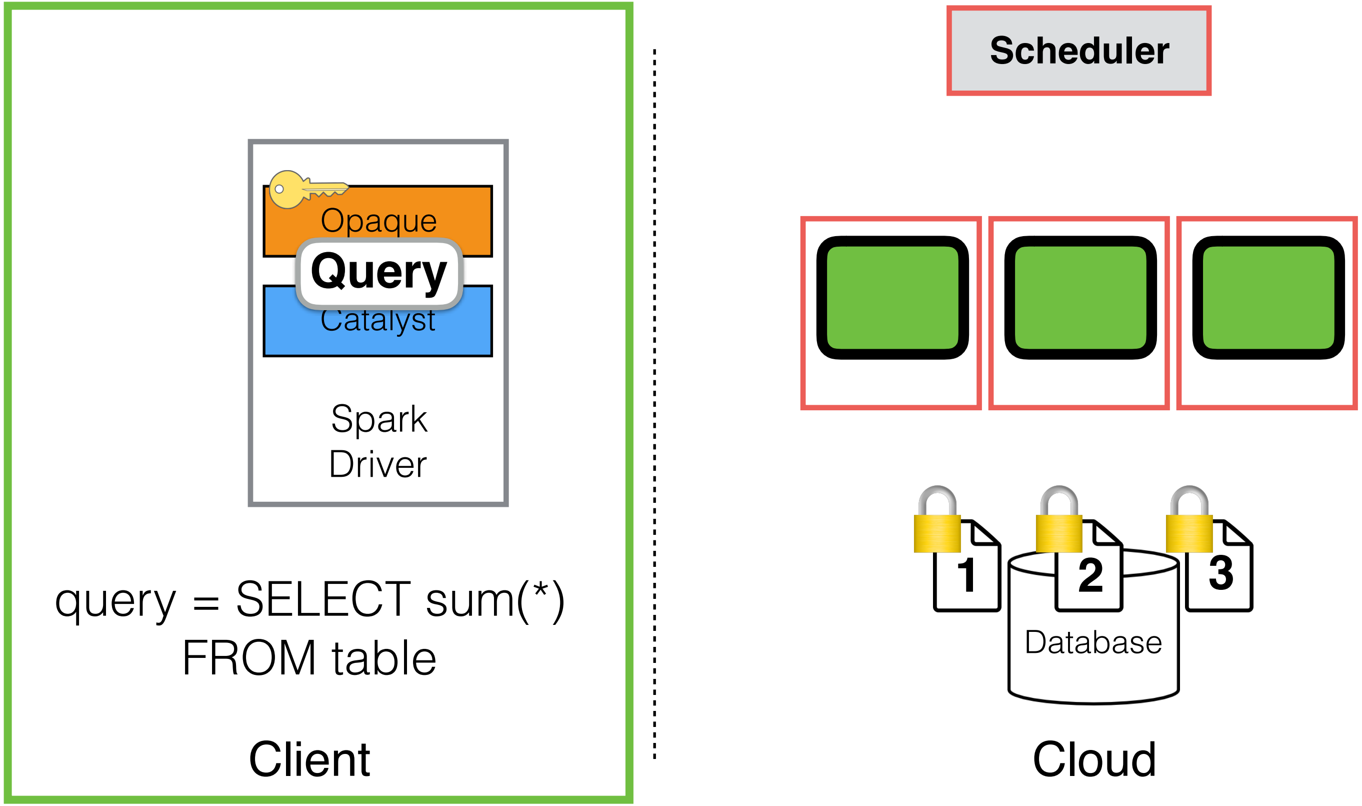

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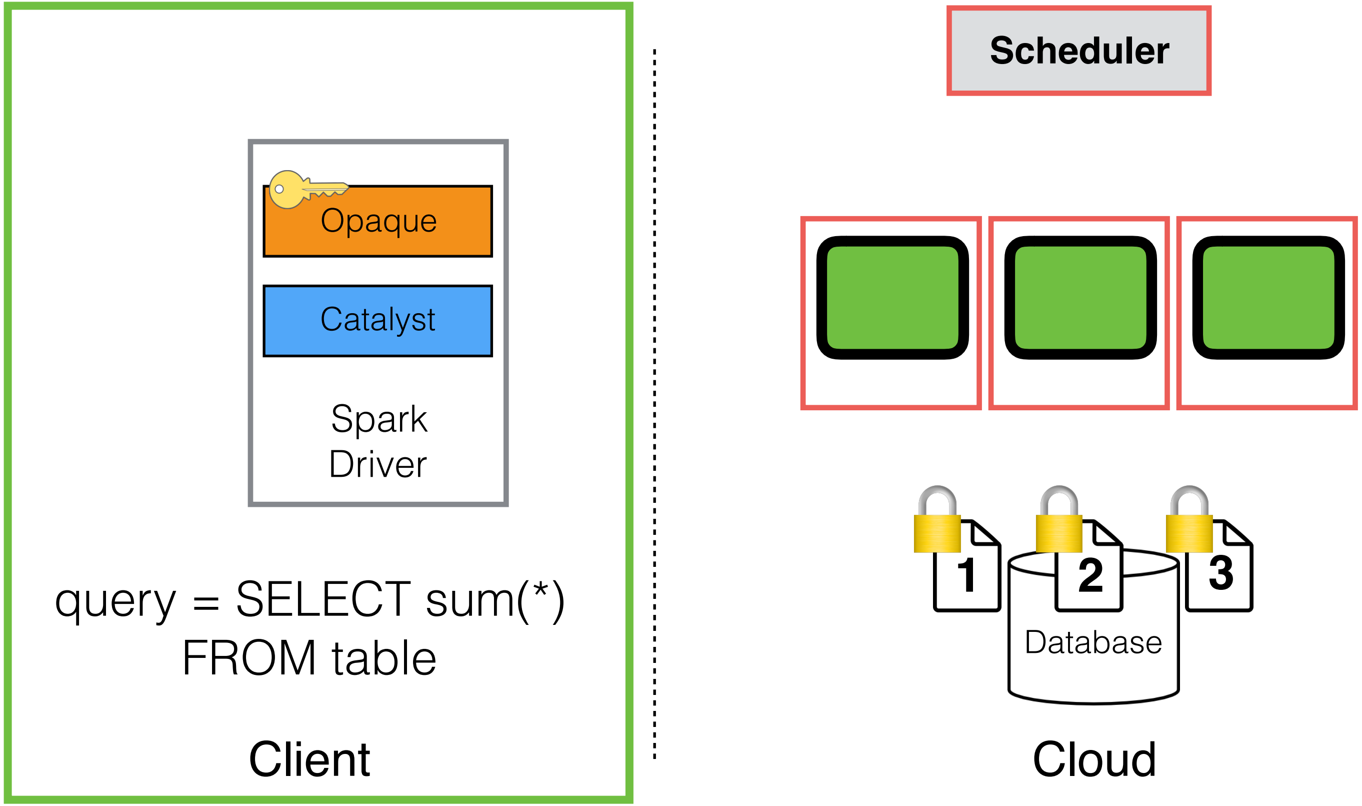

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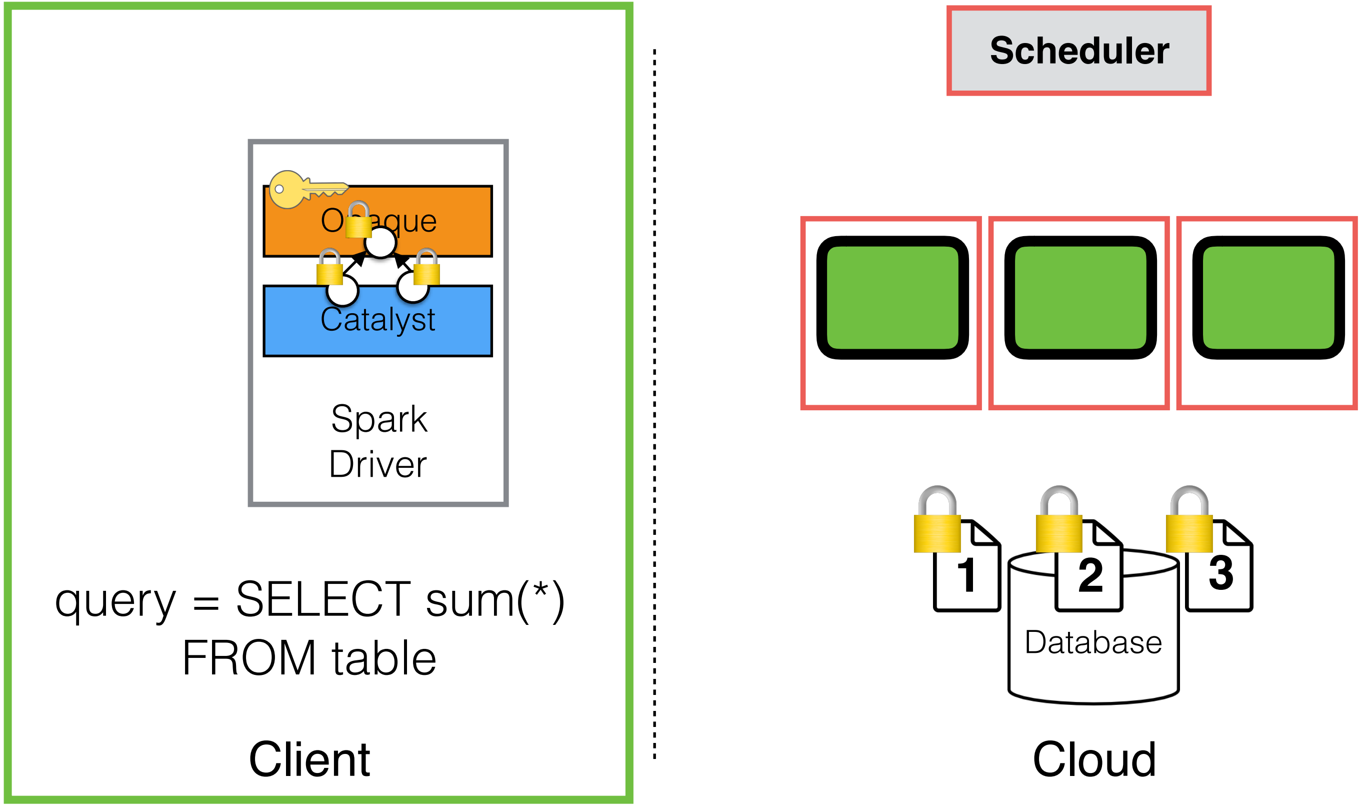

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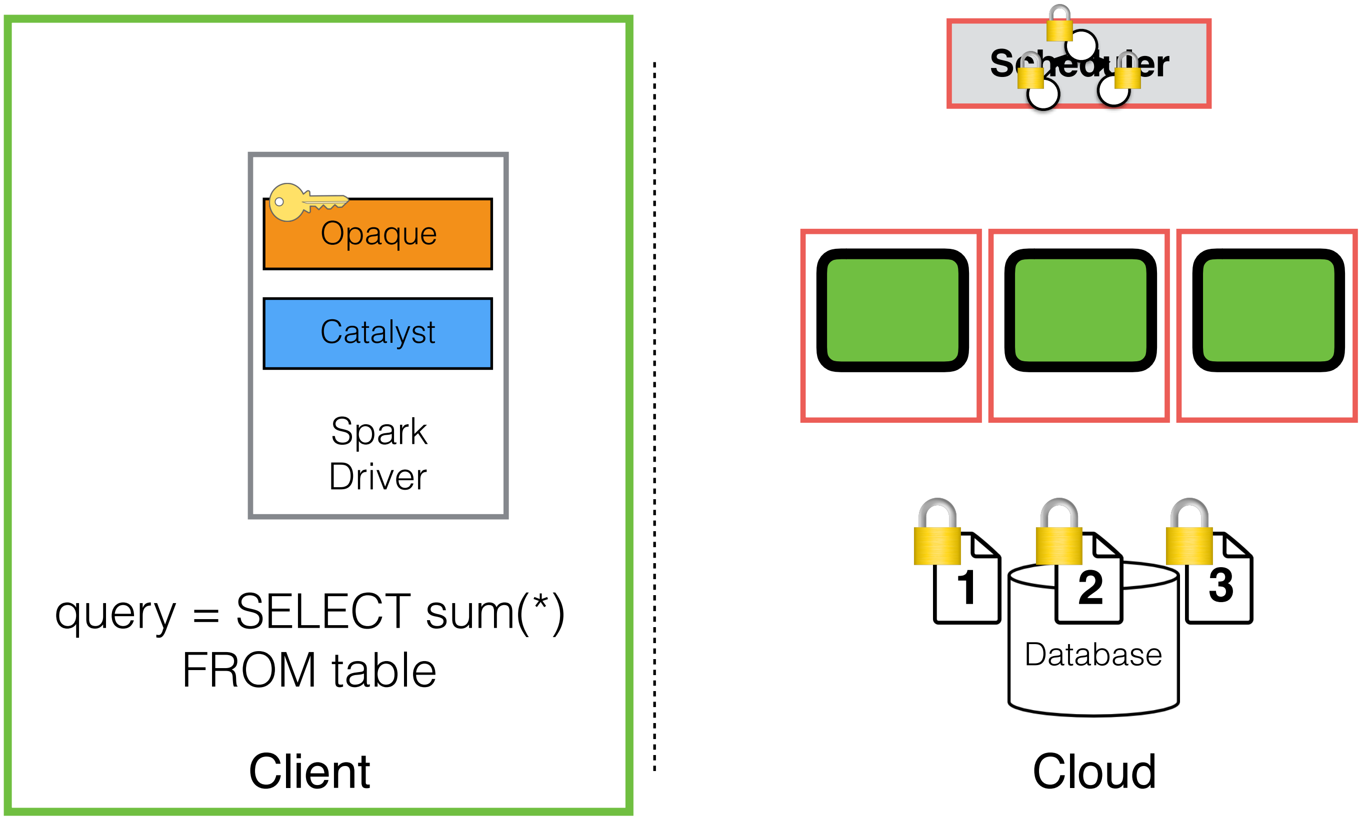

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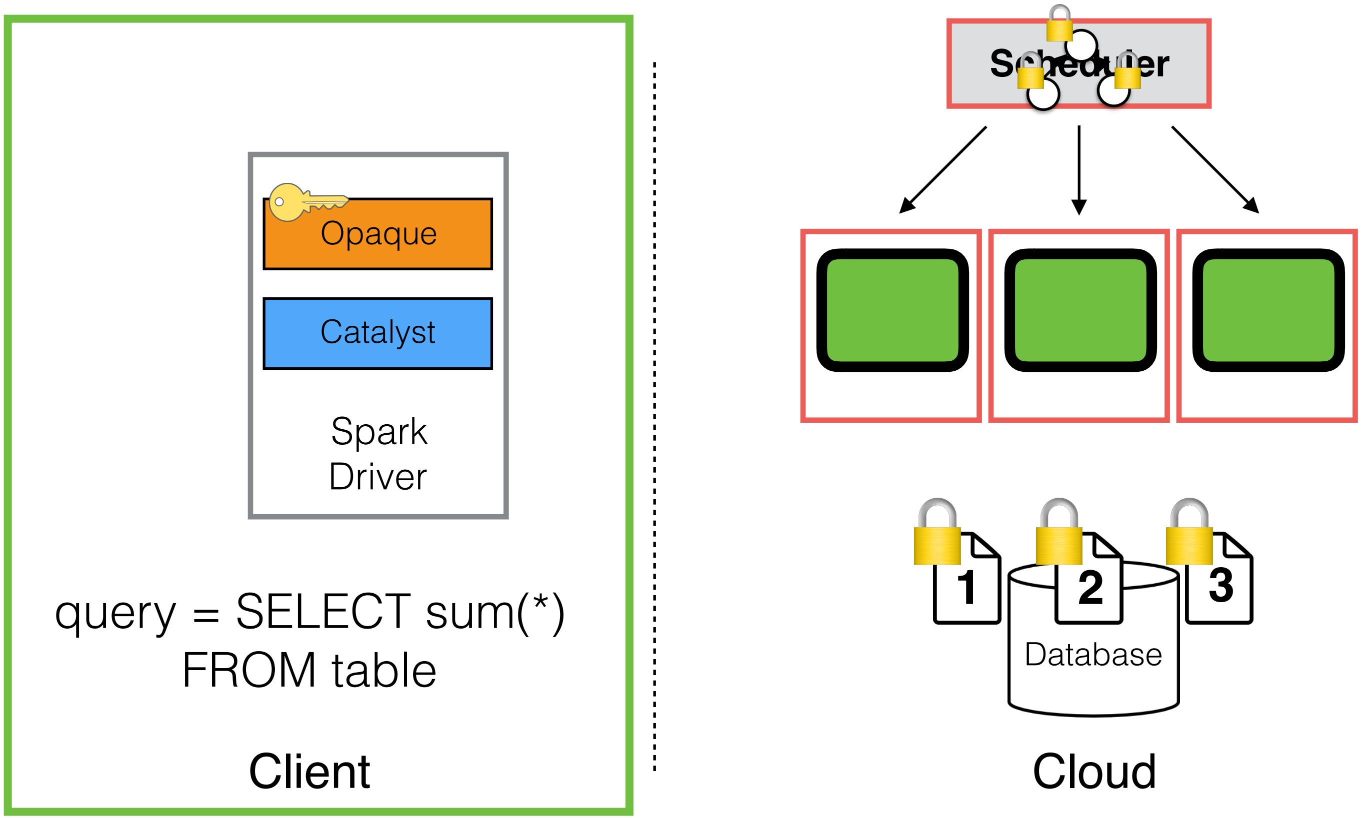

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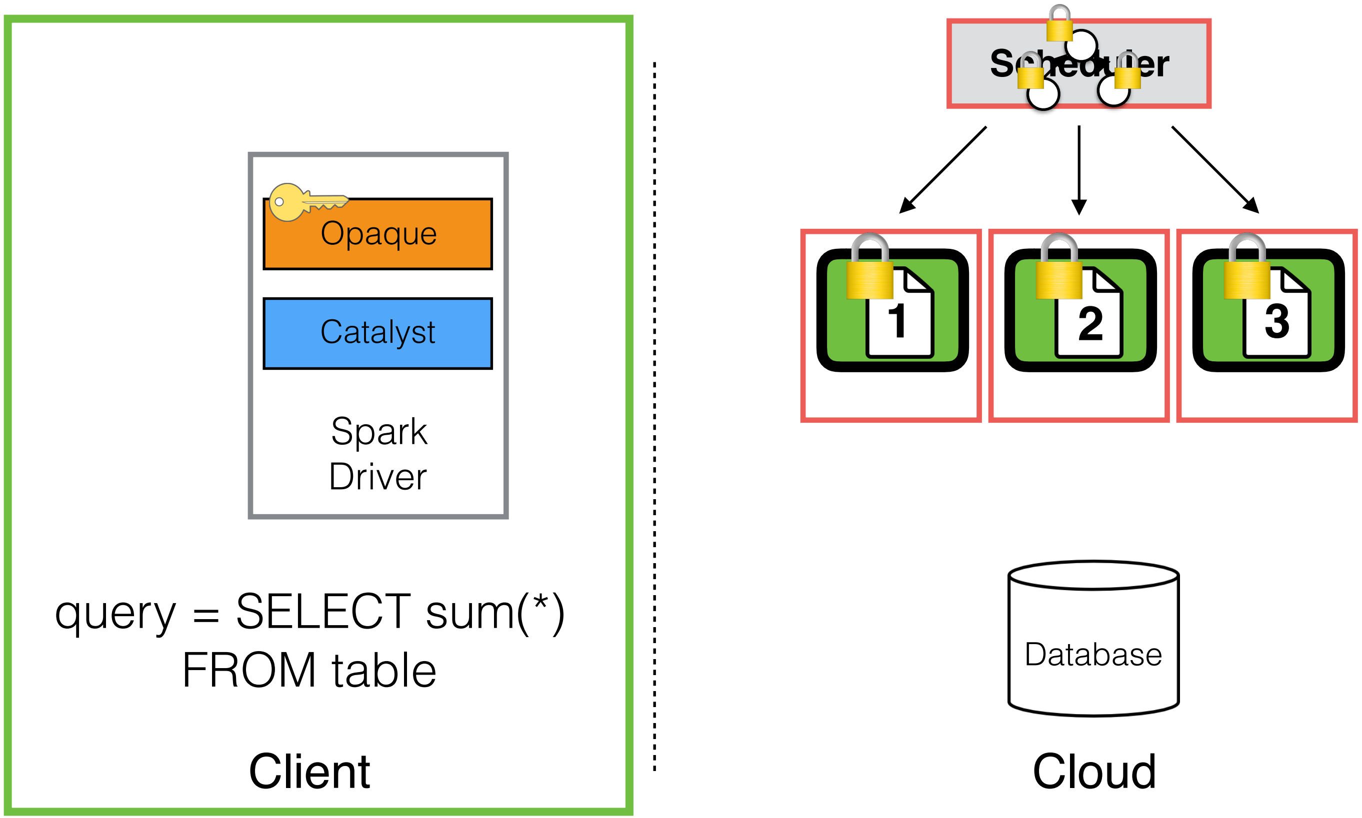

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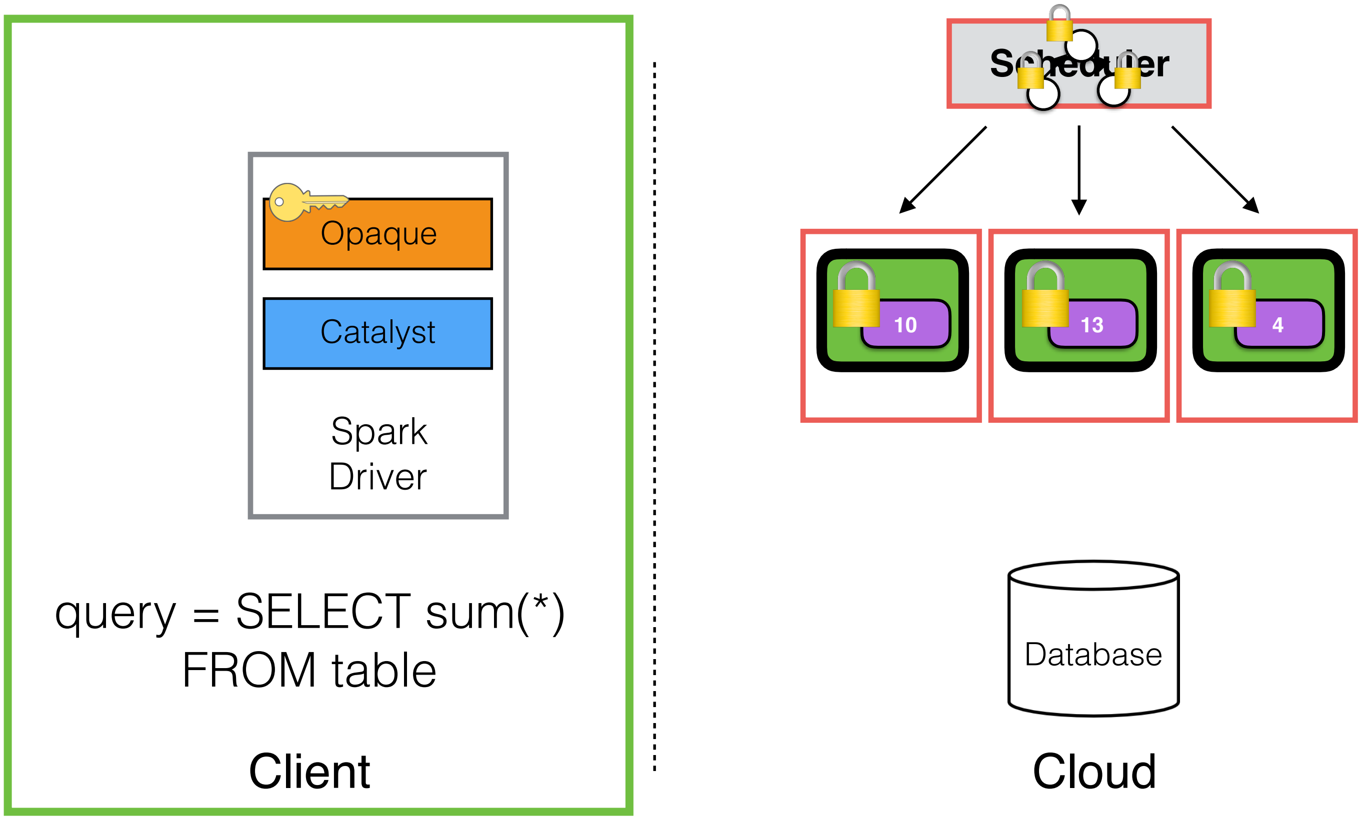

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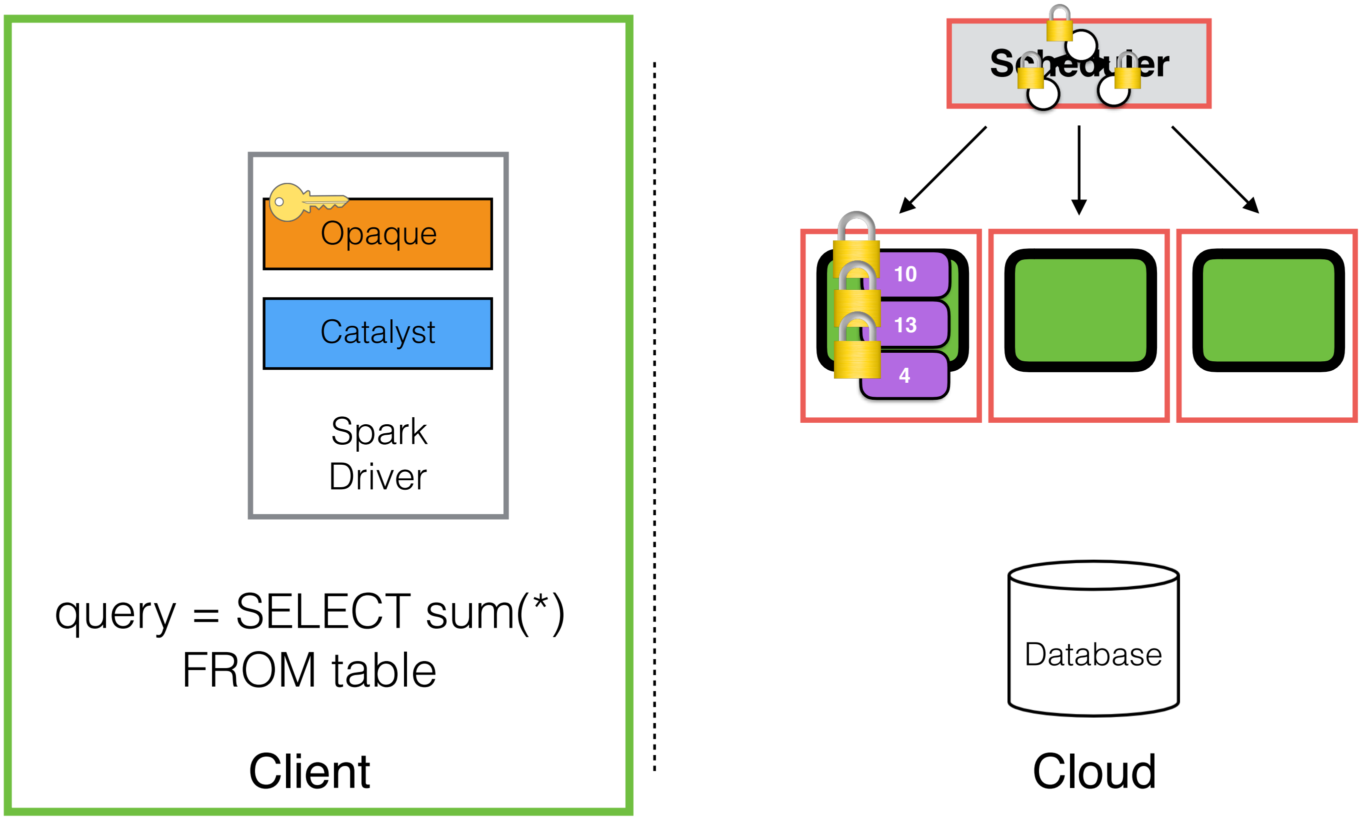

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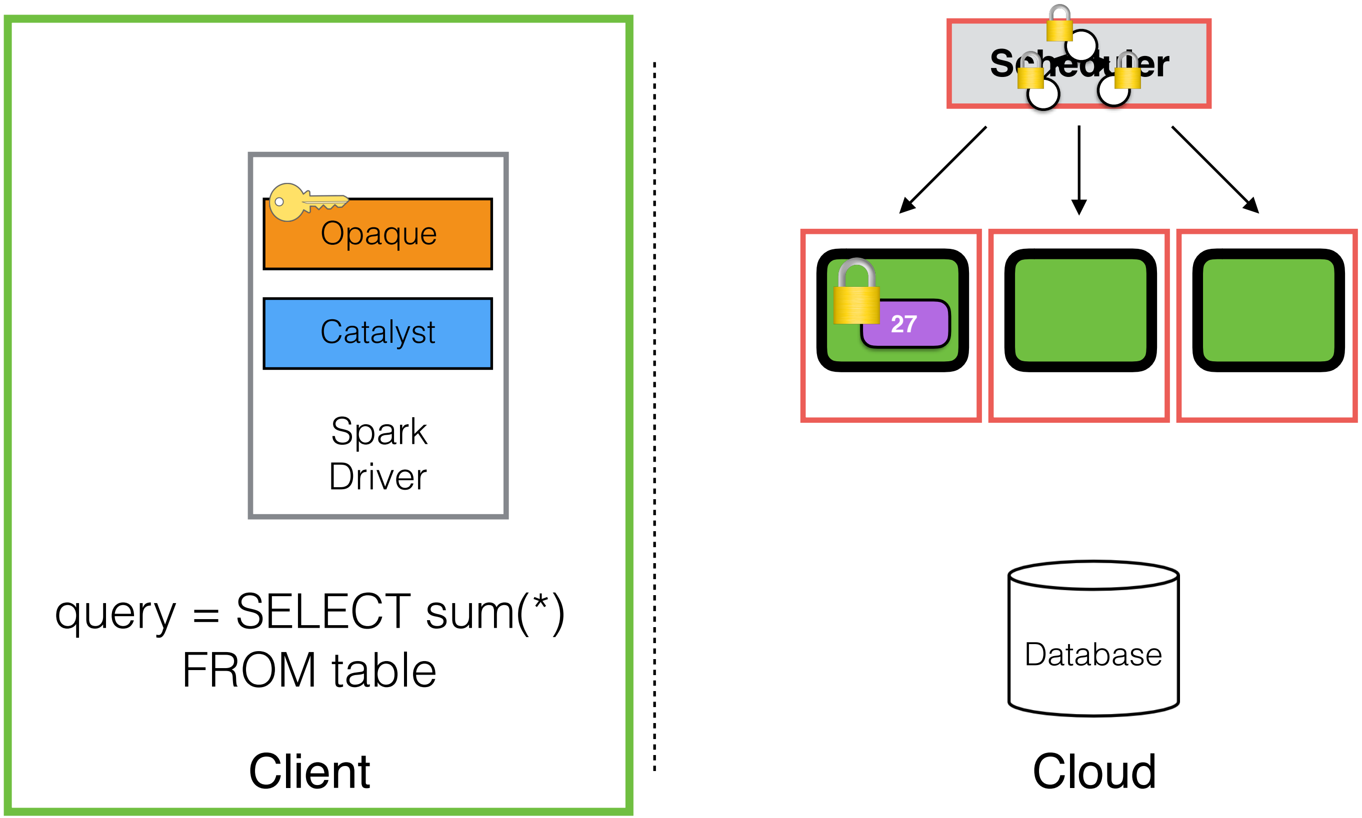

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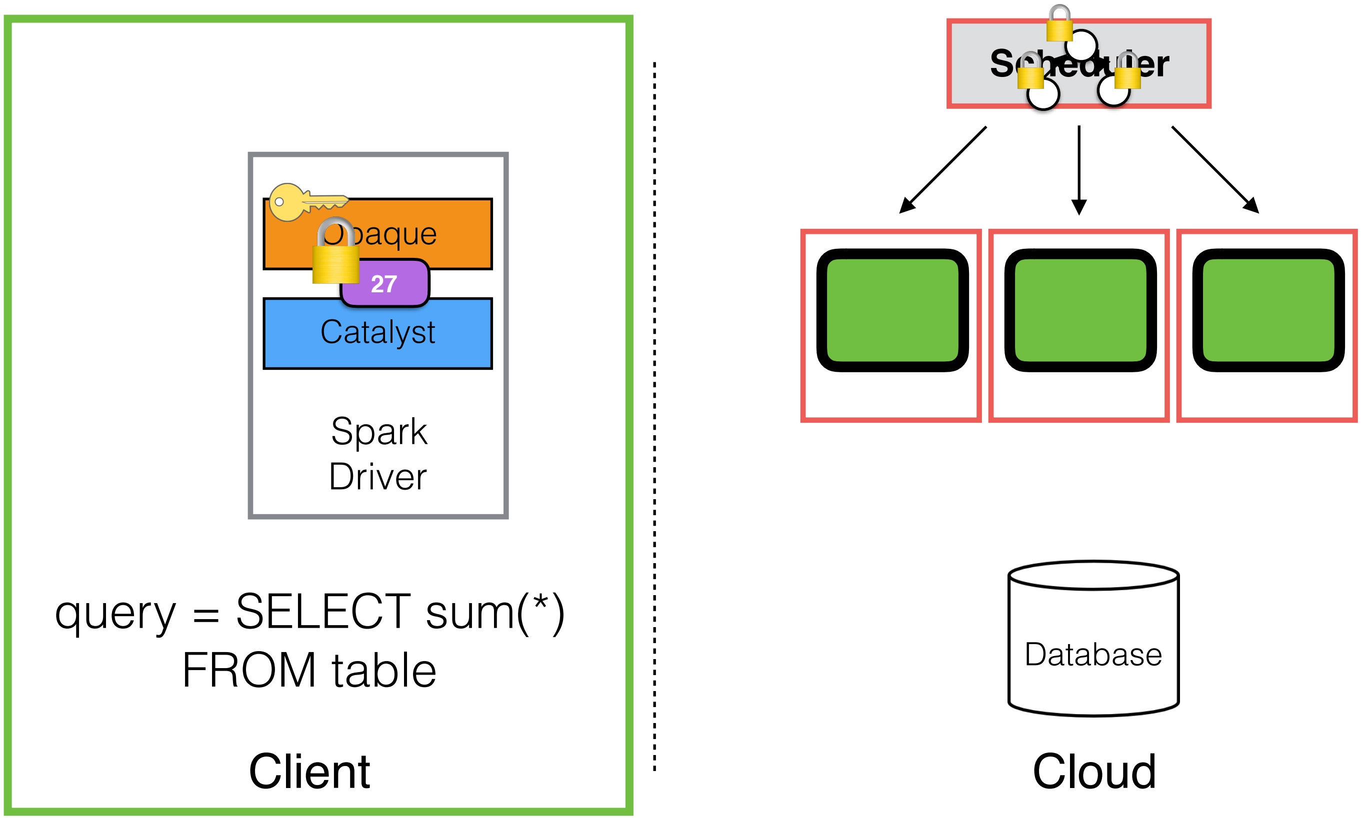

Opaque components

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Data encryption and authentication

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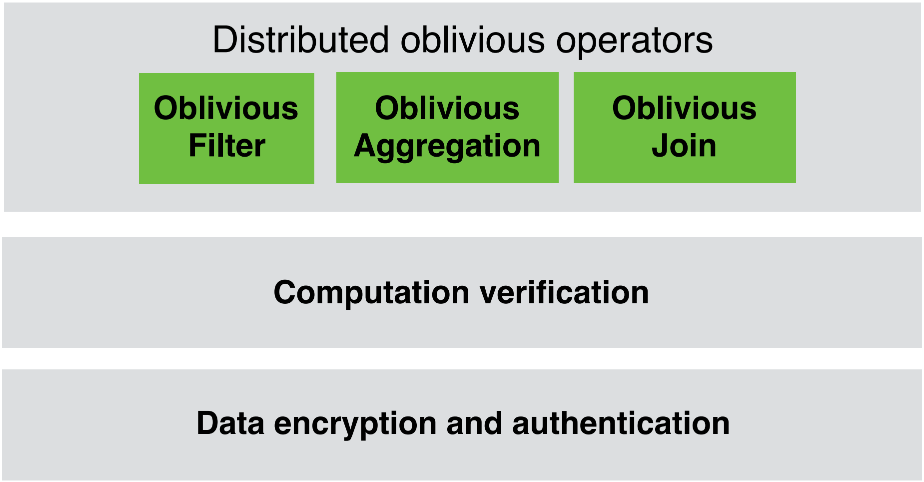
Computation verification

Data encryption and authentication

Opaque components



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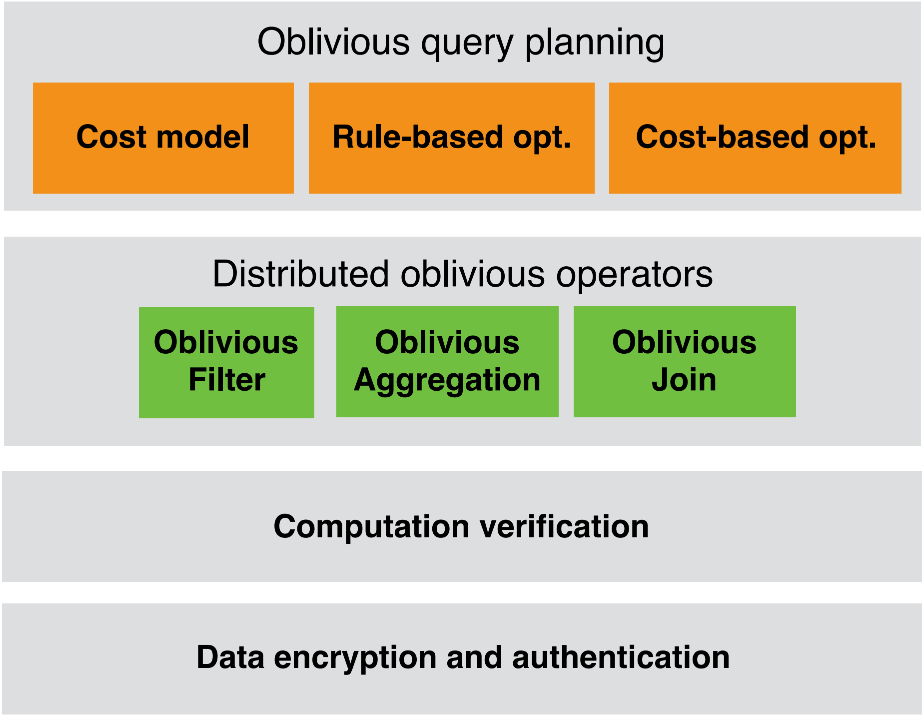
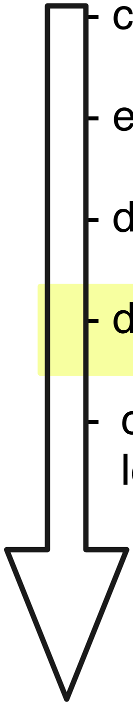


Open source

https://github.com/ucbrise/opaque

Adoption: IBM RestAssured, Ericsson, Alibaba

Systems in the cloud



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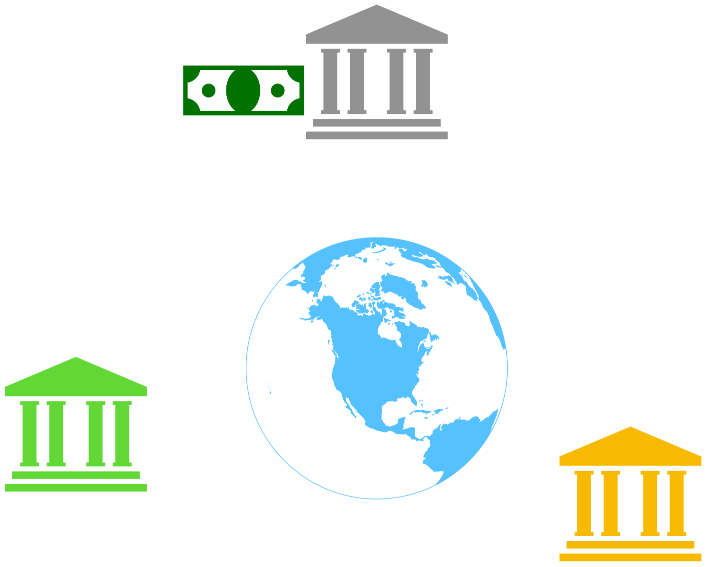

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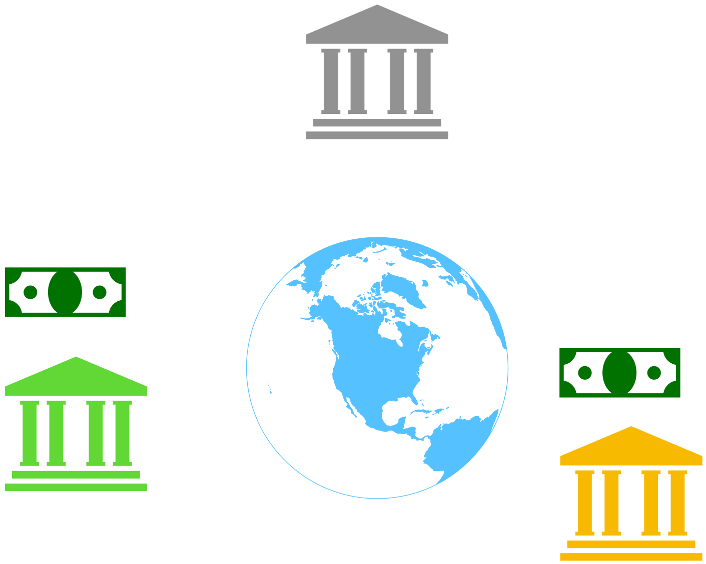

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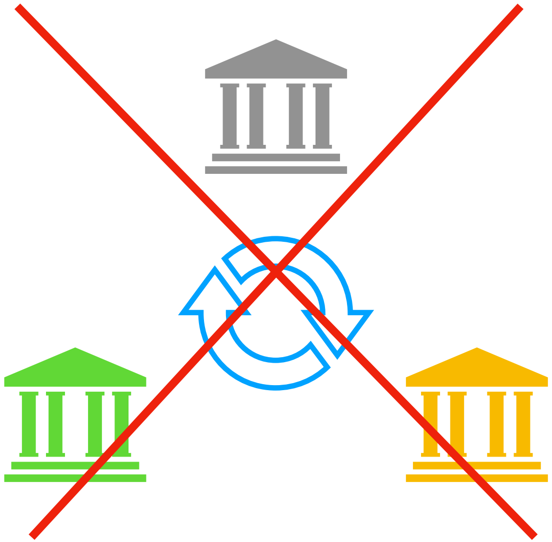

Money laundering detection

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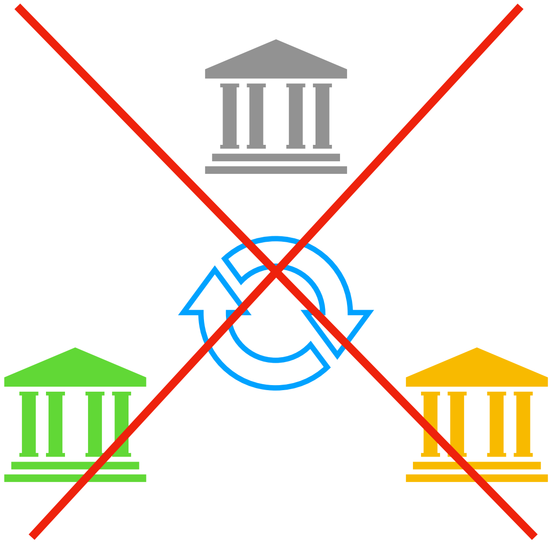
- **Cannot share data because these banks are competing with each other**



Two approaches

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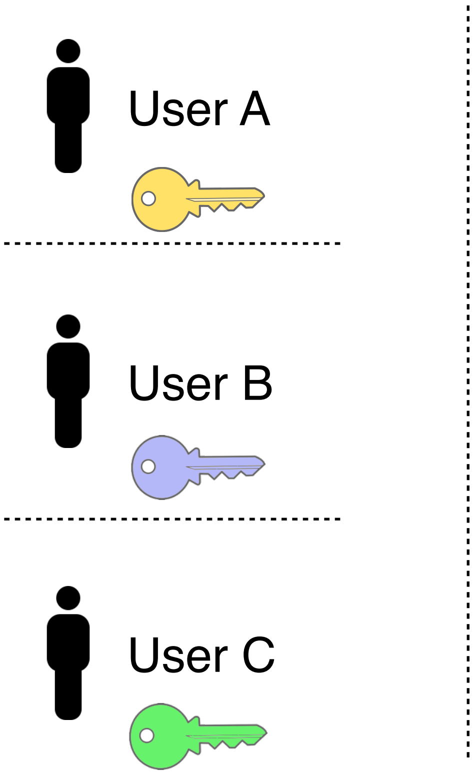
A different setup tradeoff:

- Hardware enclaves + oblivious algorithms
- Secure multi-party computation

Secure collaborative ML via enclaves



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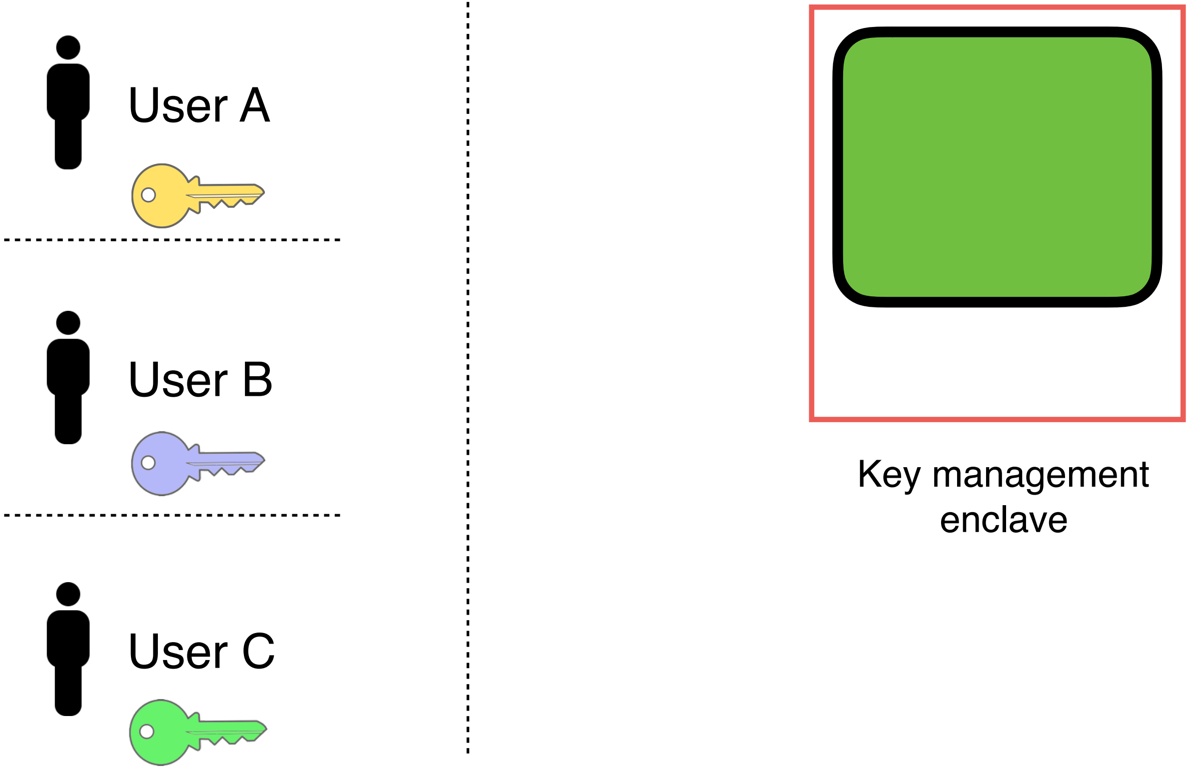

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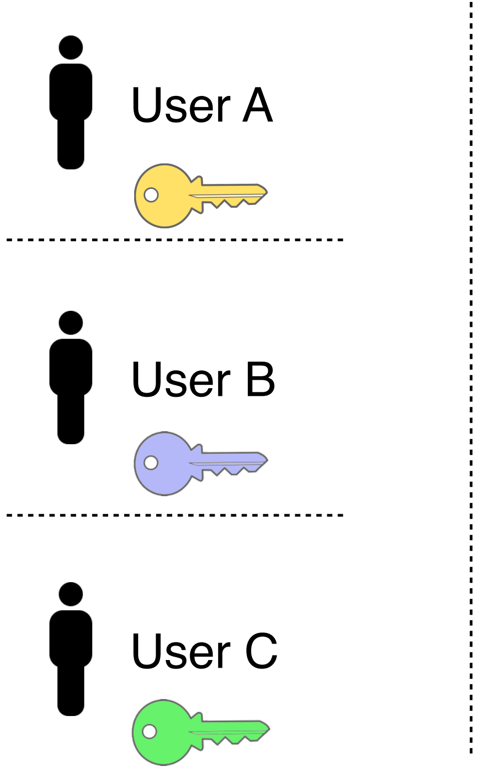

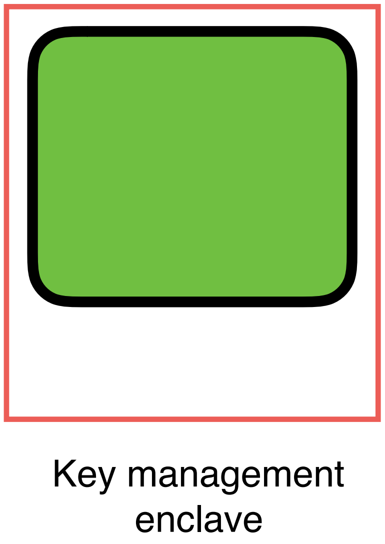

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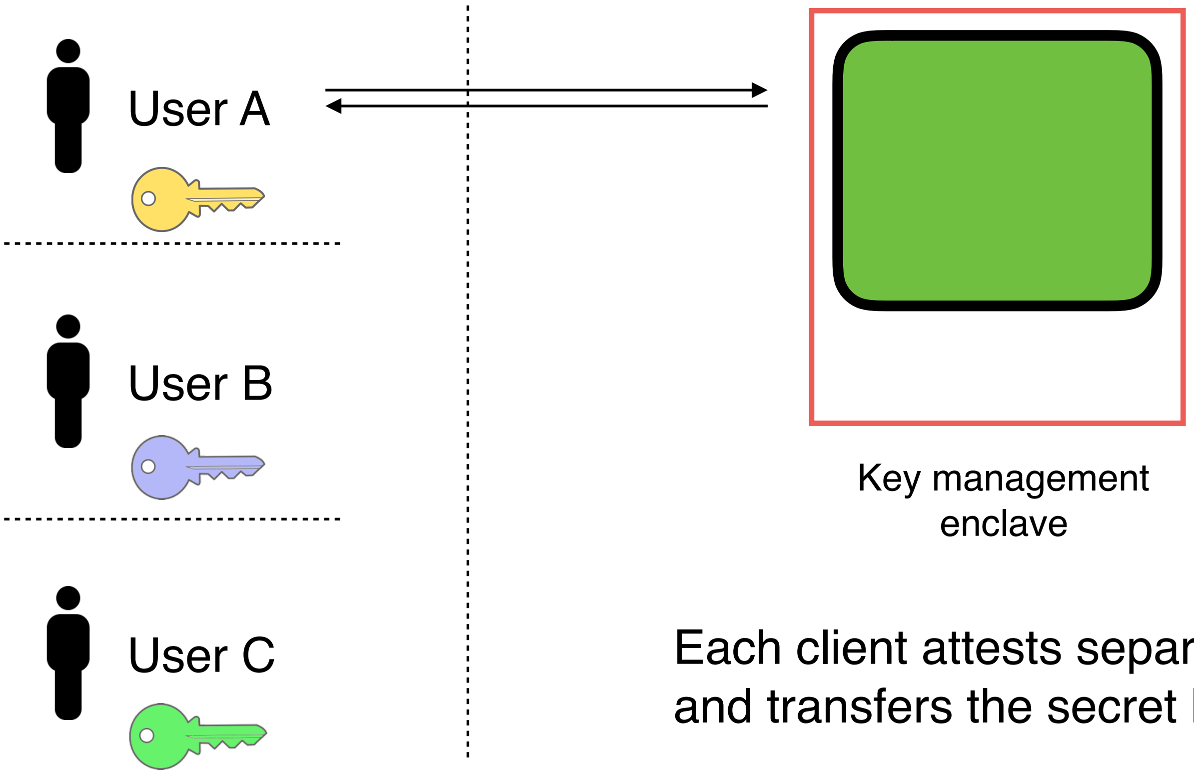

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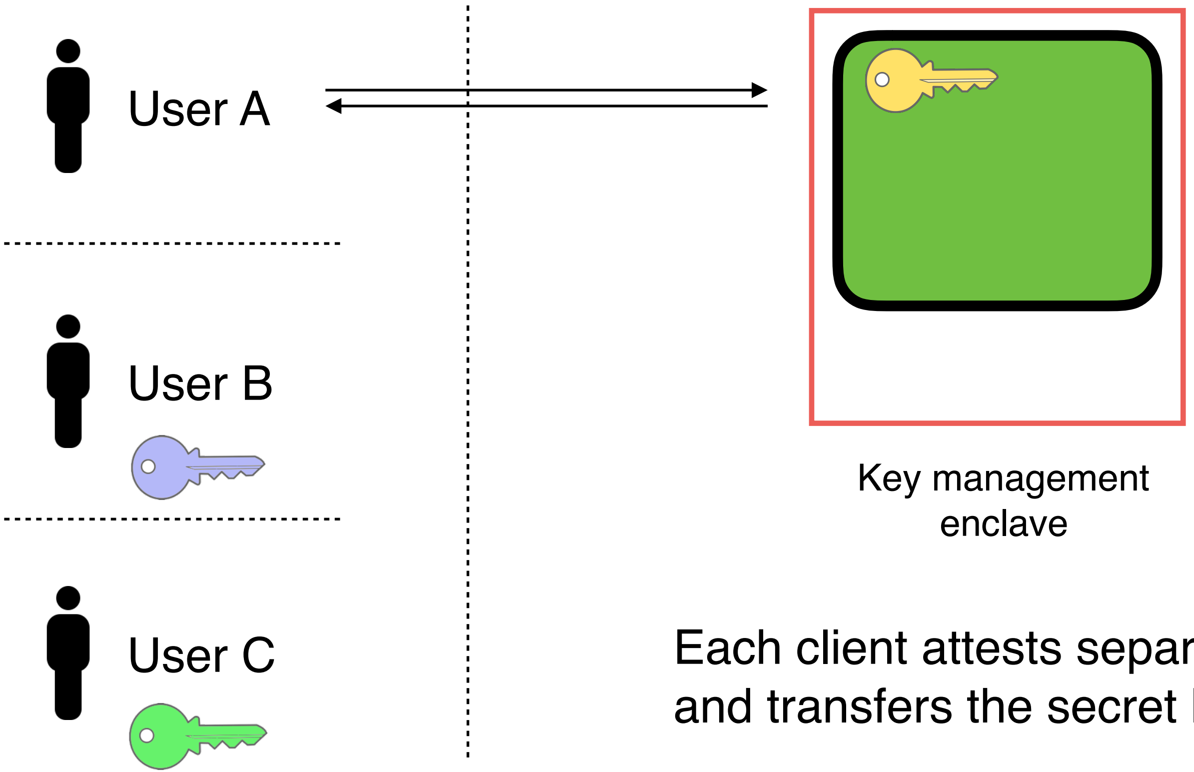

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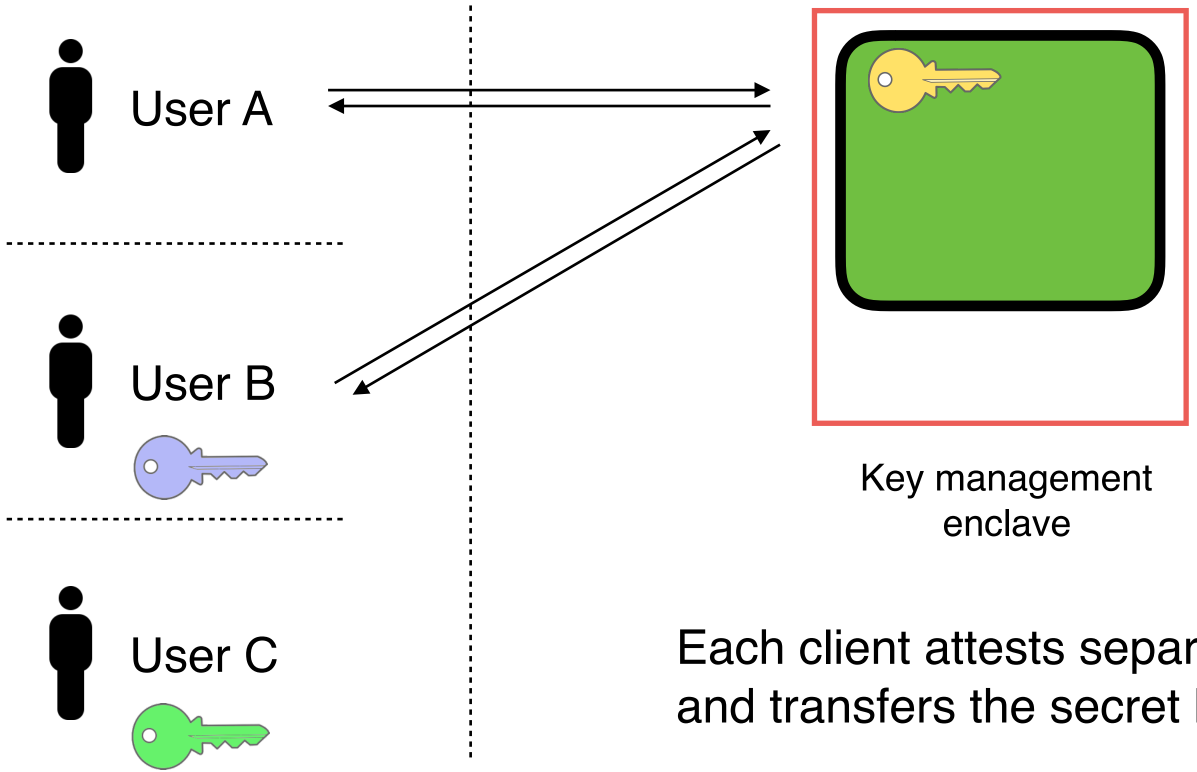

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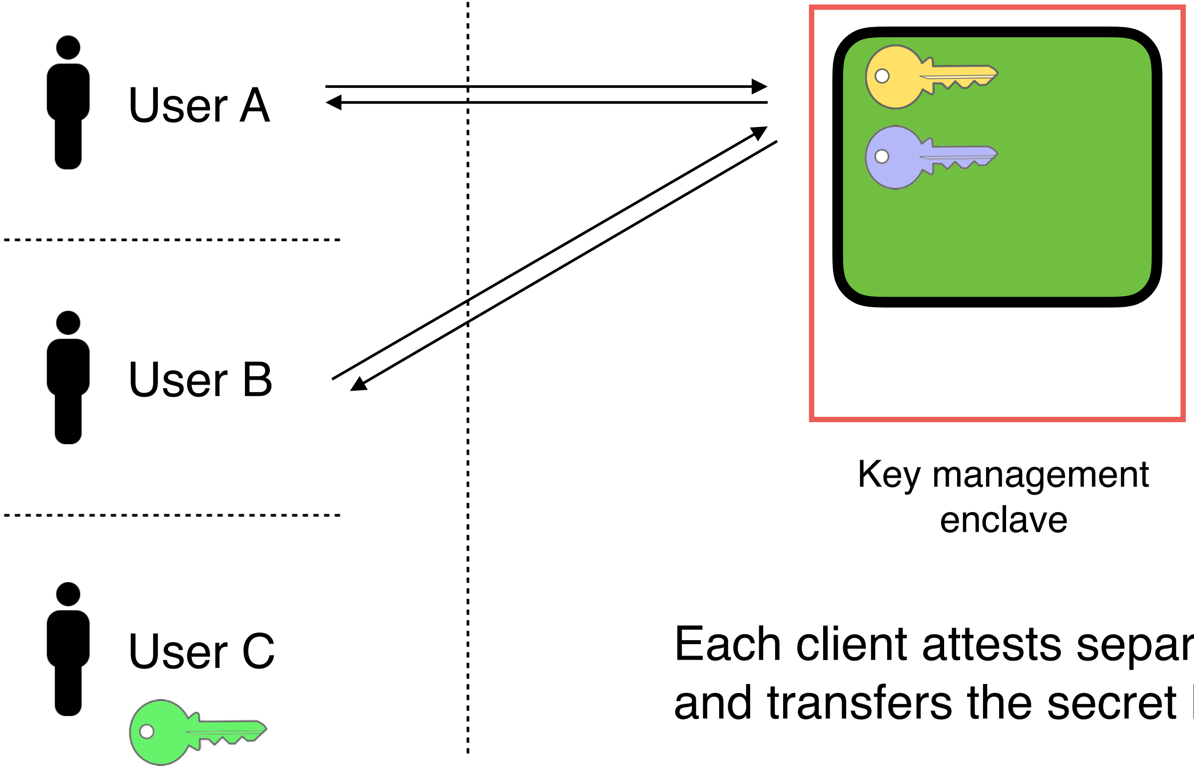

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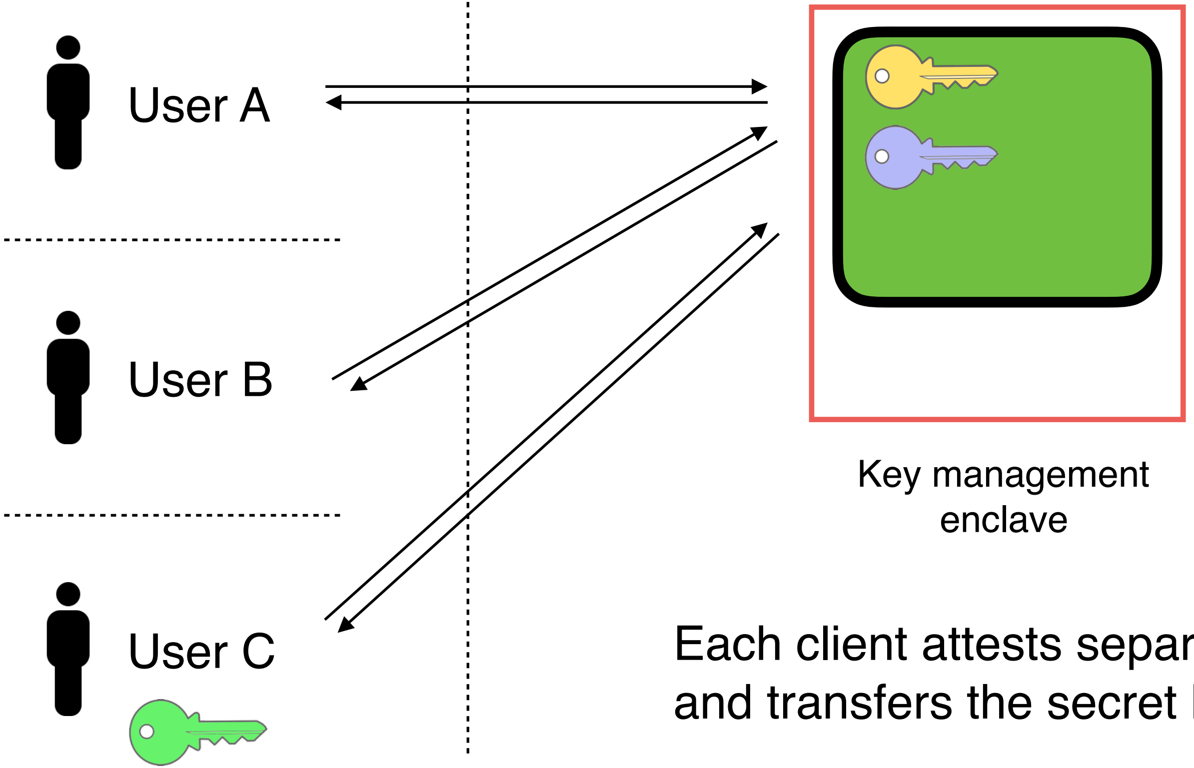

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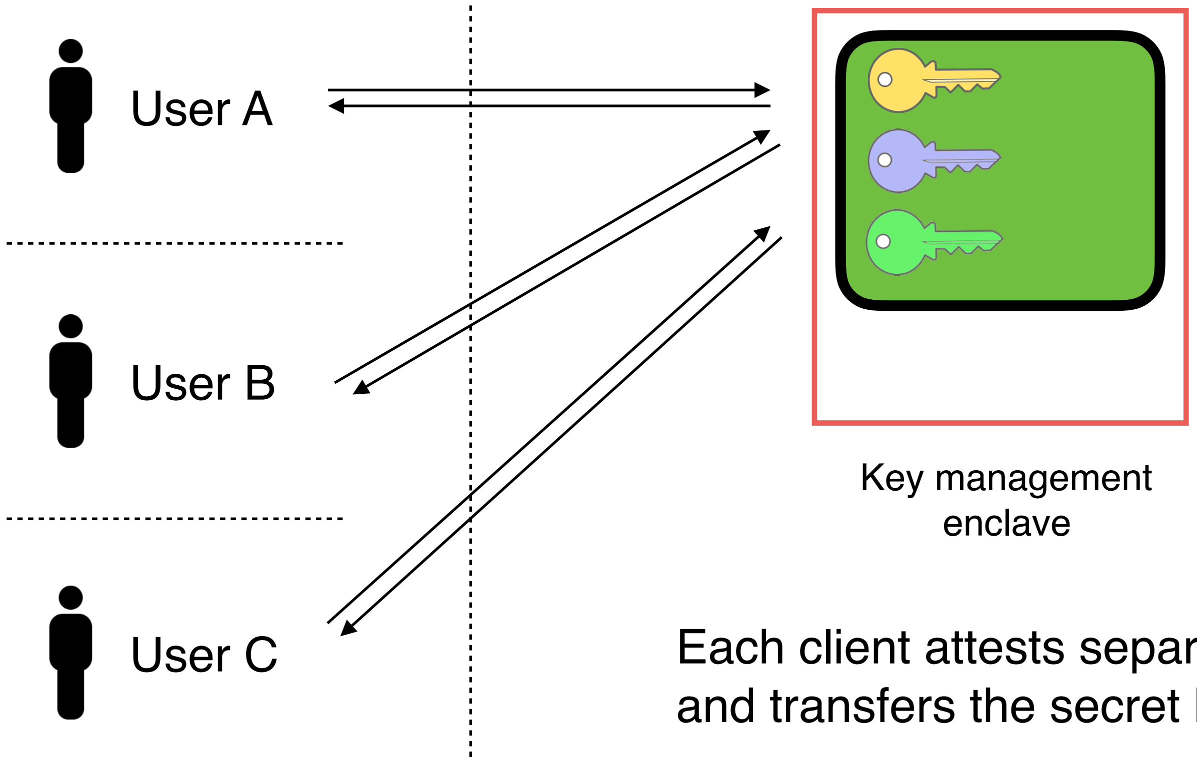

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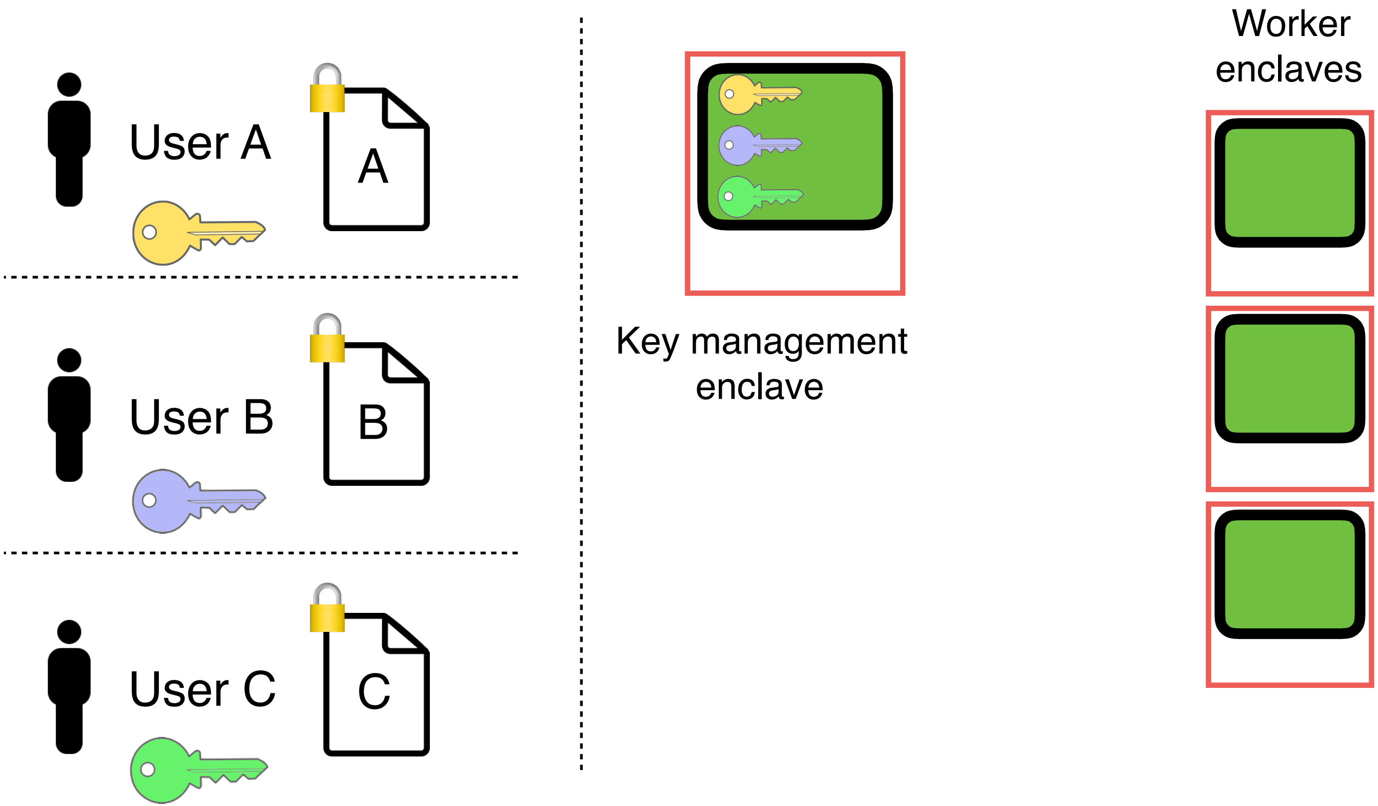

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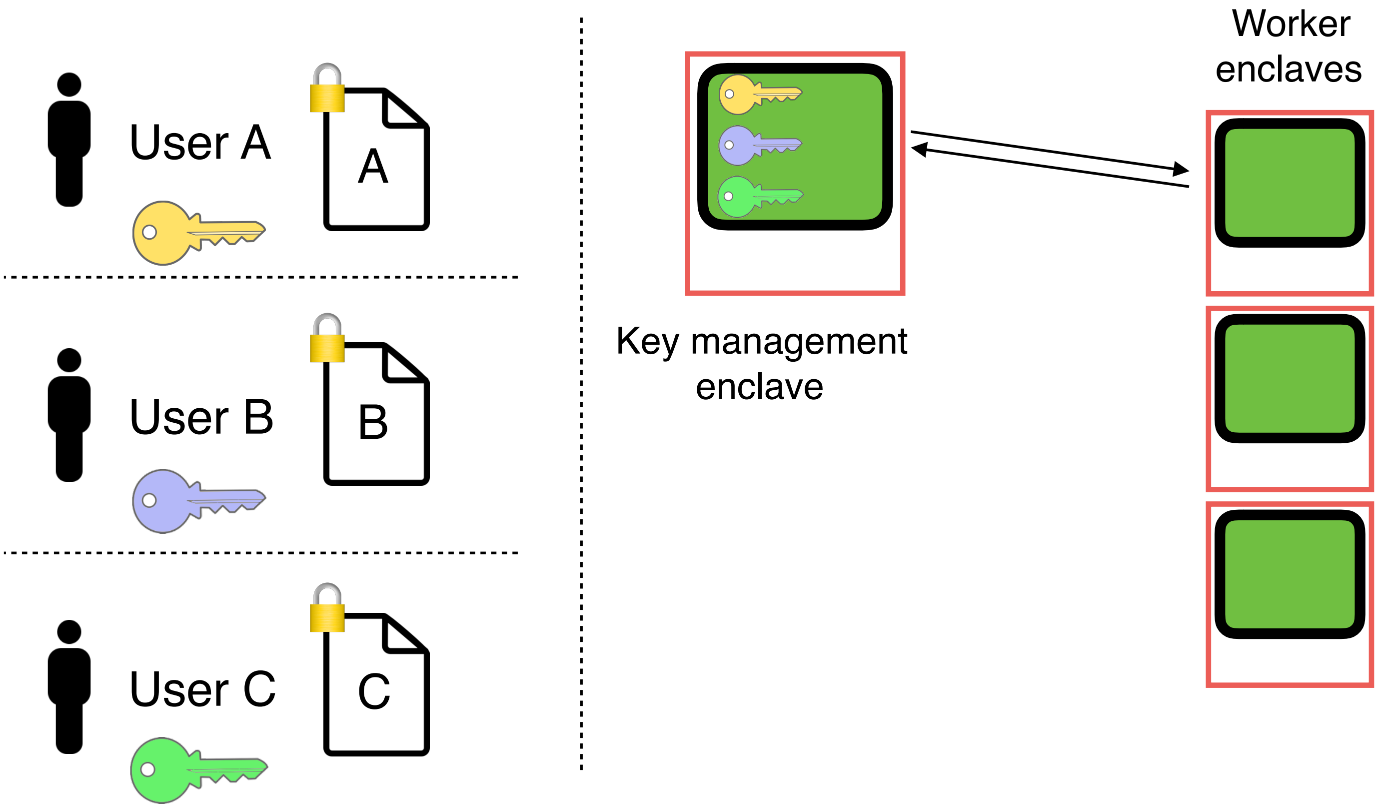

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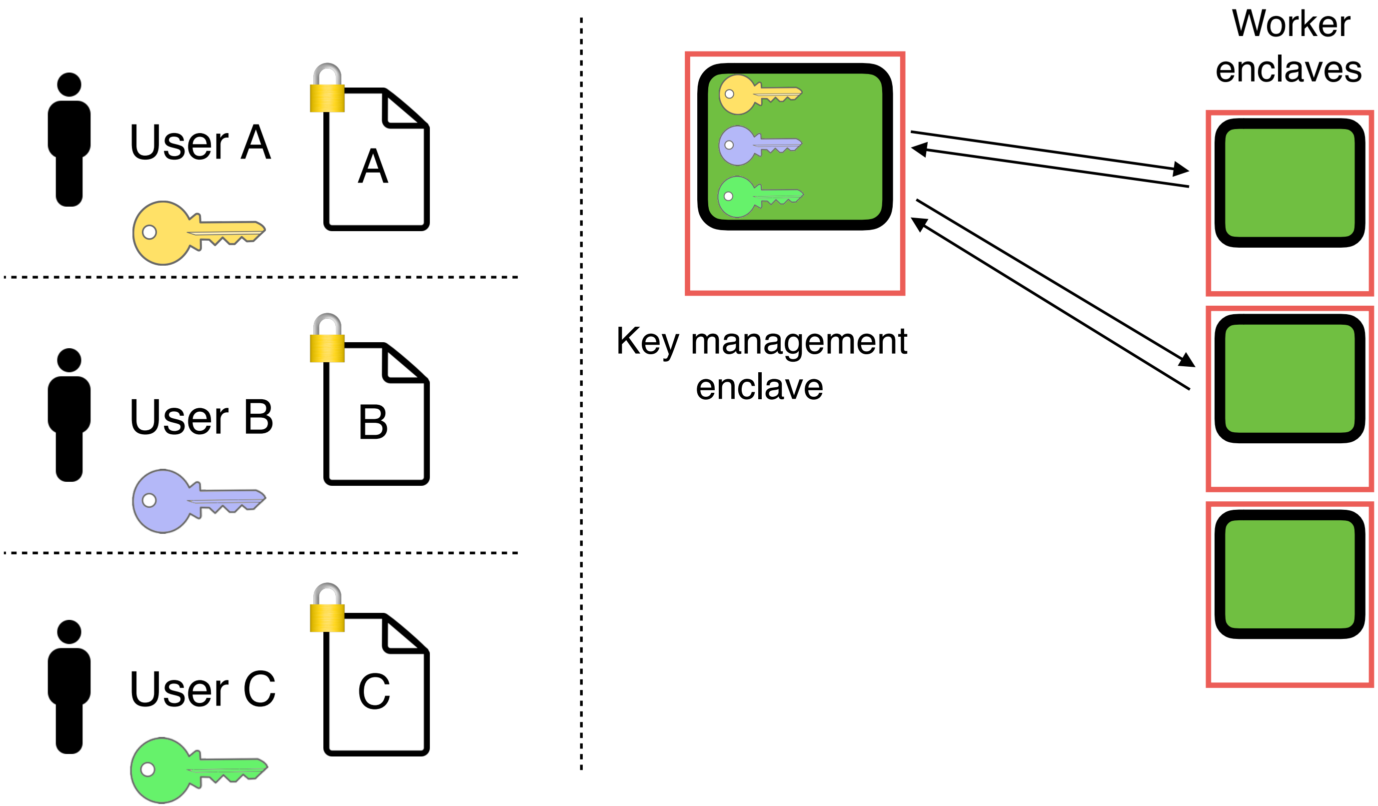

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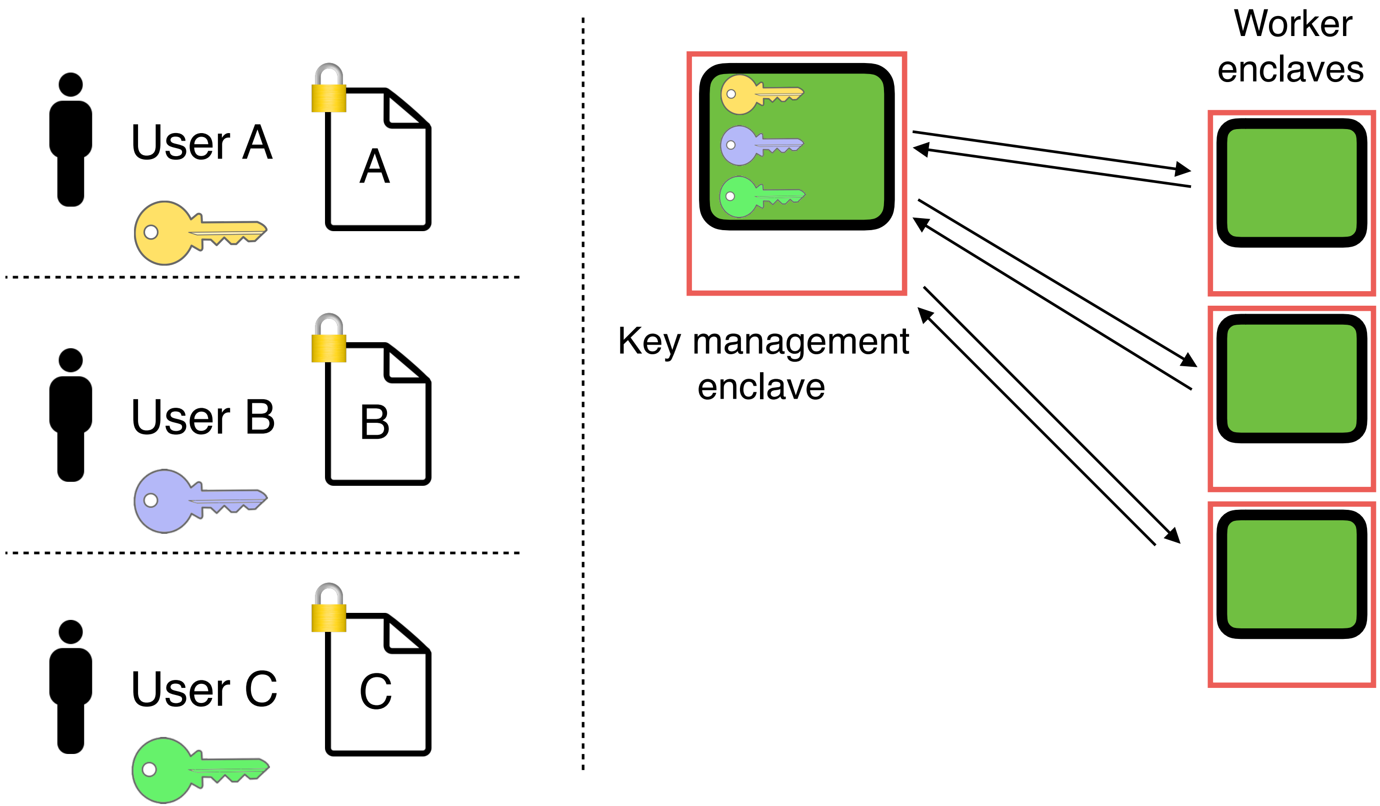

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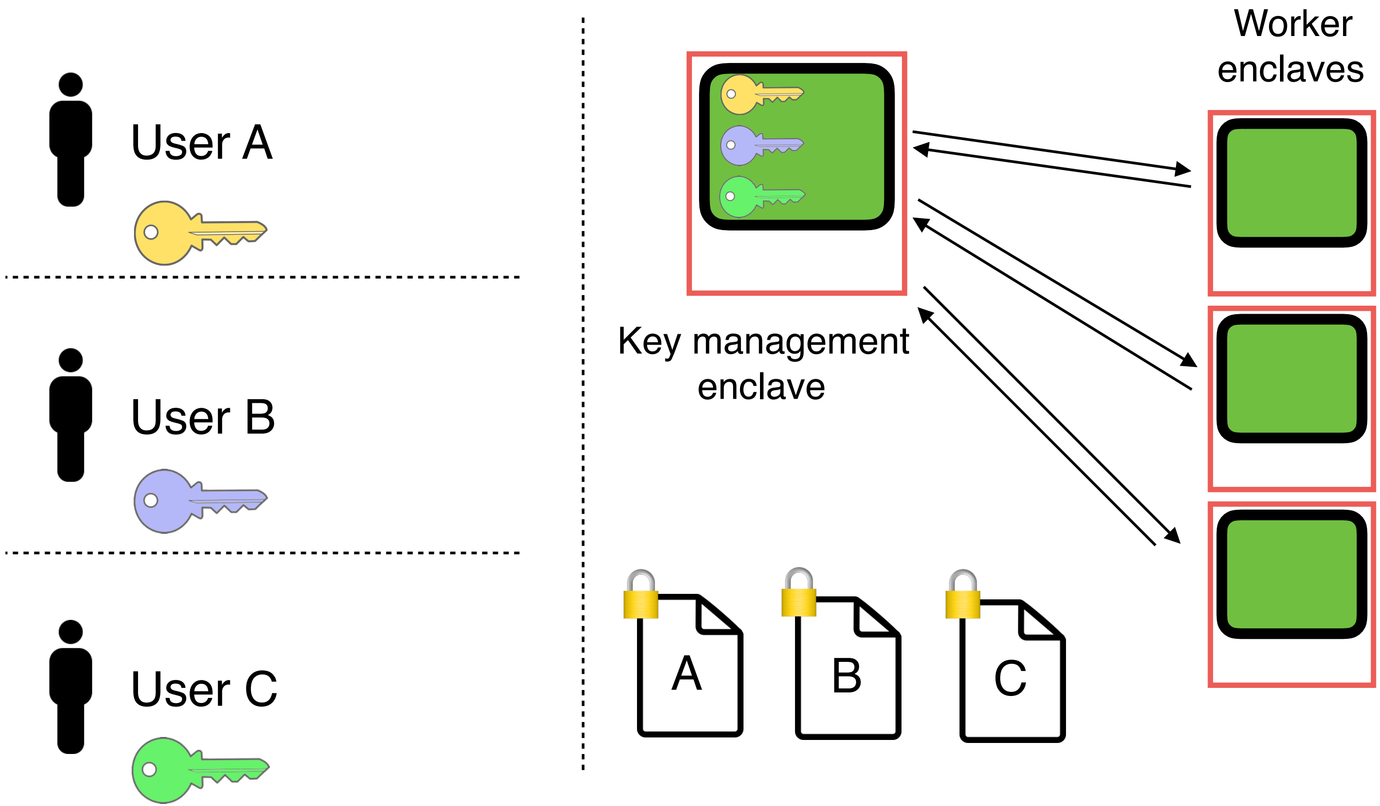
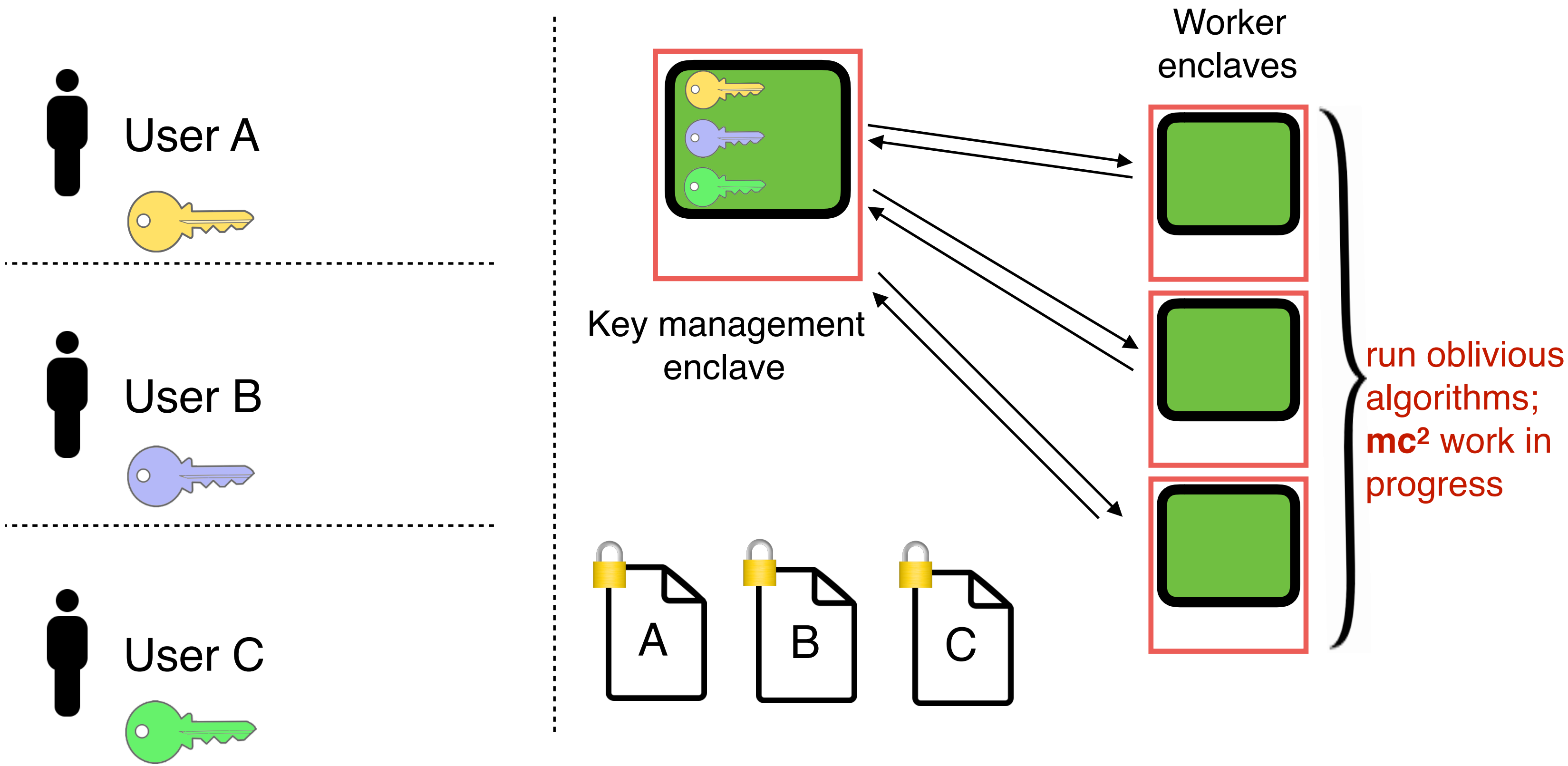
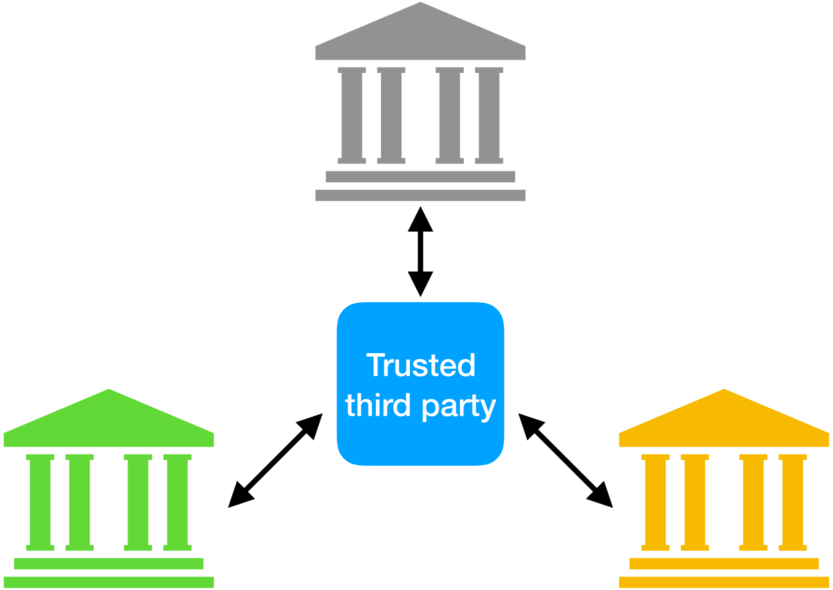


Secure collaborative ML via enclaves



Secure multiparty computation

(MPC [Yao82,GMW87,BGW88])



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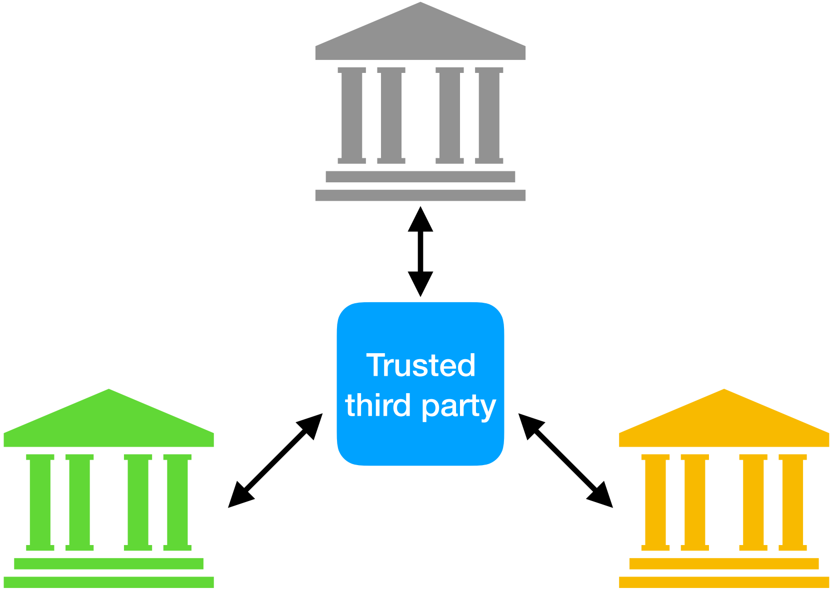

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Main challenge: Performance

Generic secure multi-

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[SPDZ]

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Example: train linear models

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3 months

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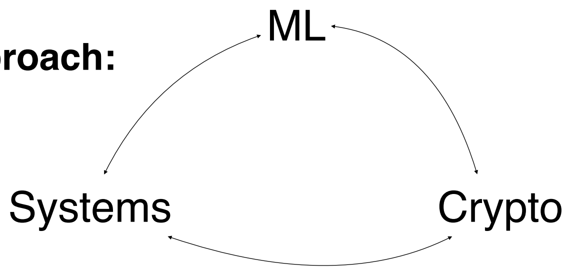
Our approach:



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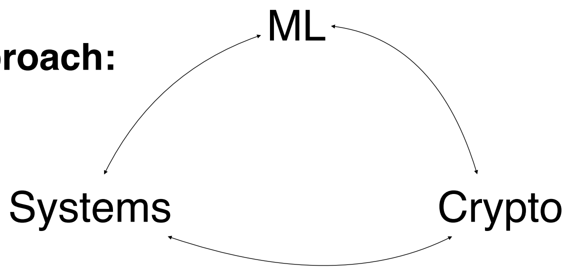

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Helen [IEEESP'19]

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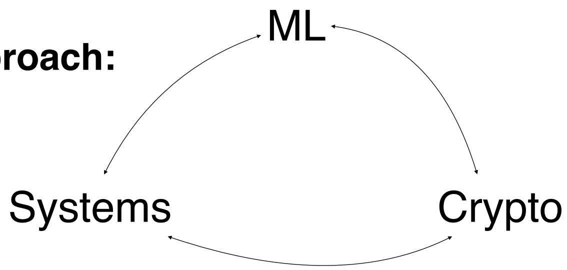

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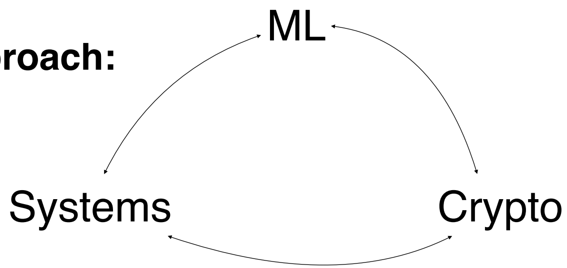

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3 months → **< 3 hours**

Delphi [USEC20]: secure inference for neural networks

mc^2: work in progress

multi-party **c**ryptographic
collaboration

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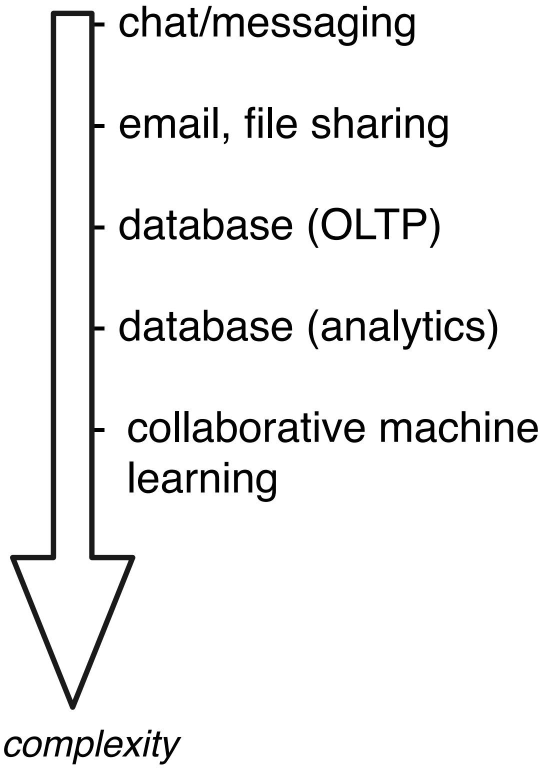
Potential societal impact is exciting

Systems in the cloud



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- Co-design systems and cryptography for performance

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Thank you!

raluca.popa@berkeley.edu @ralucaadapopa