Improving Speed and Security in Updatable Encryption Schemes

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Key Rotation

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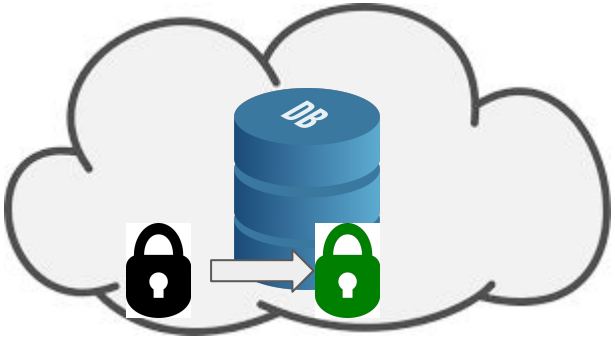
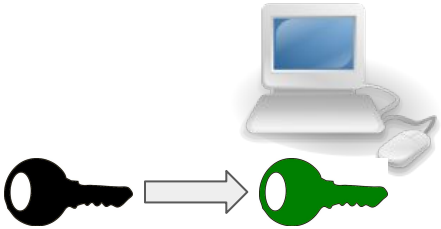


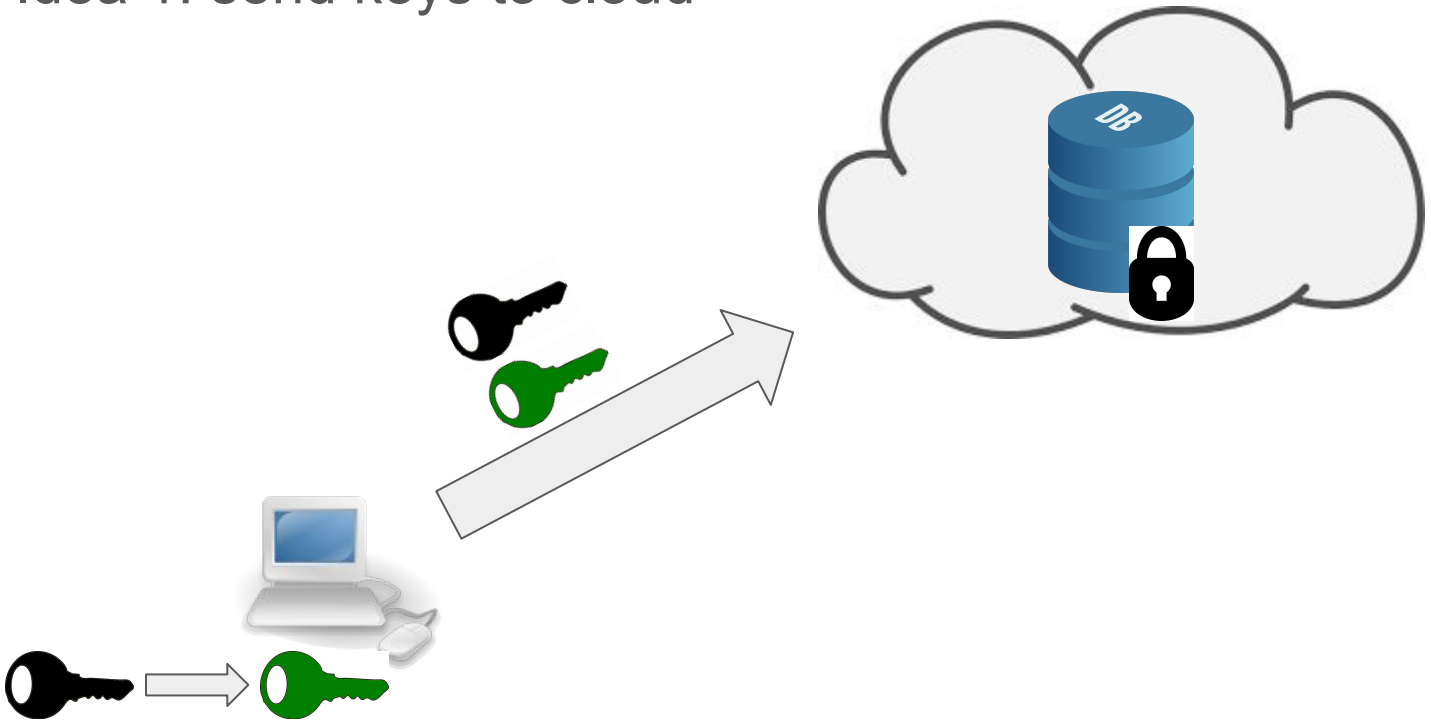


Many Good Reasons to Rotate Keys

1. Retire compromised keys
2. Proactively refresh keys
3. Access control enforcement
4. Recommended by NIST (Special Publication 800-57)
5. Recommended by Google (cloud.google.com/kms/docs/key-rotation)
6. Required by PCI DSS (PCI DSS 3.6.4)

How to Rotate Keys in the Cloud?

Idea 1: send keys to cloud



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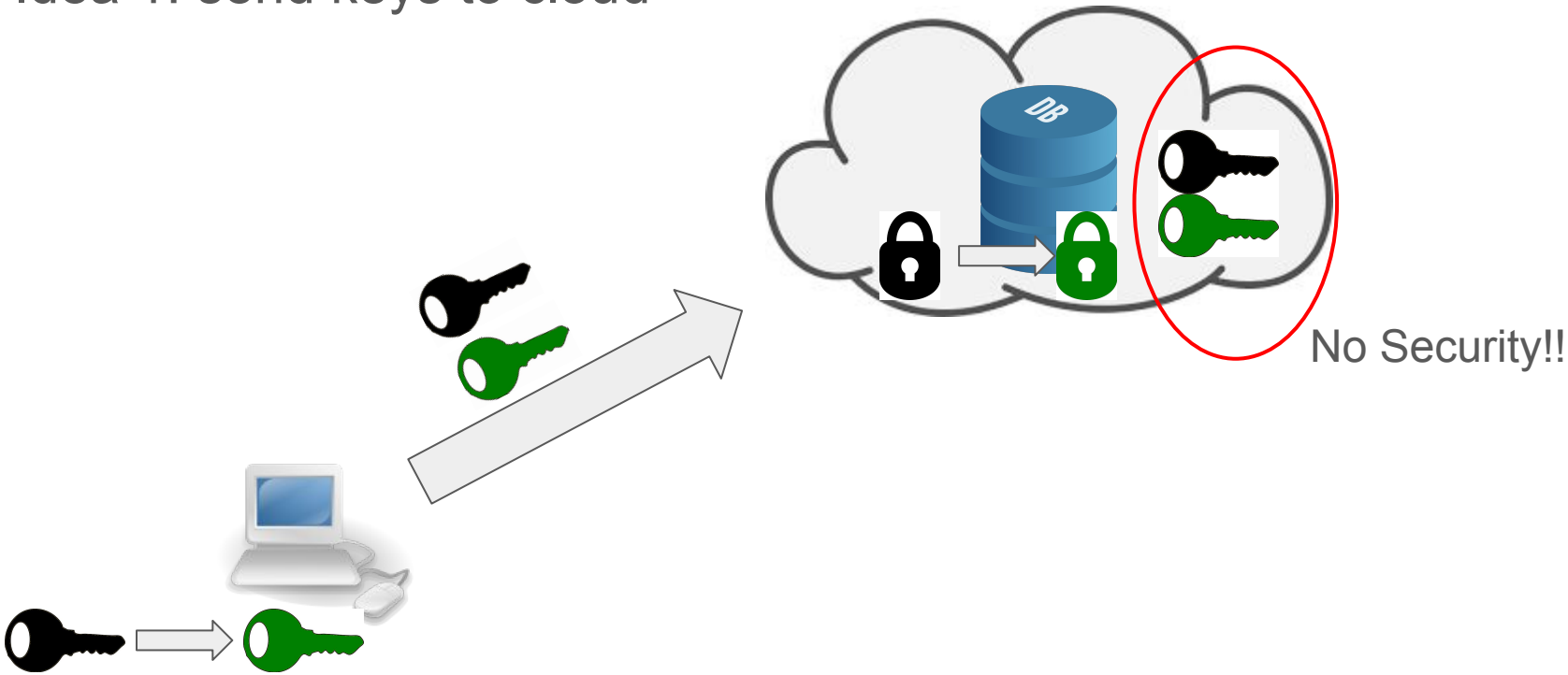

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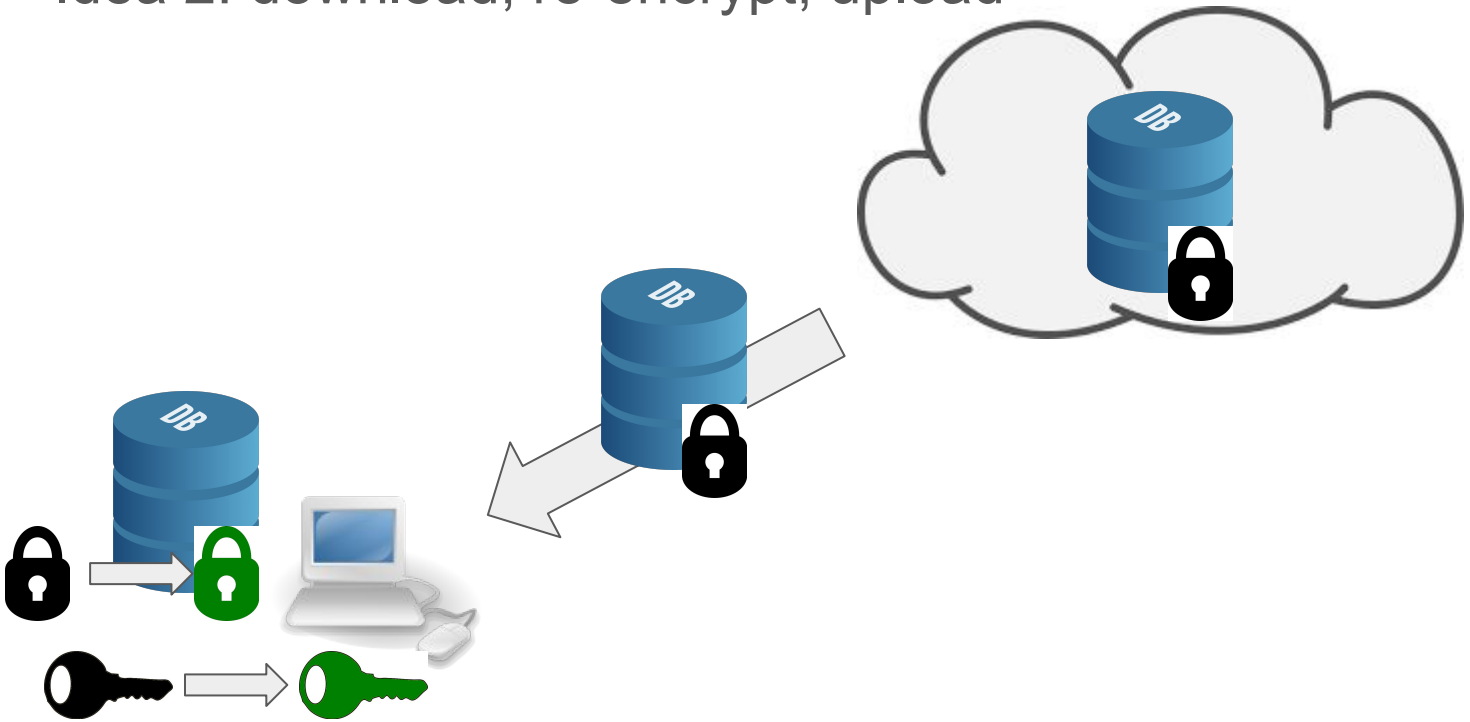

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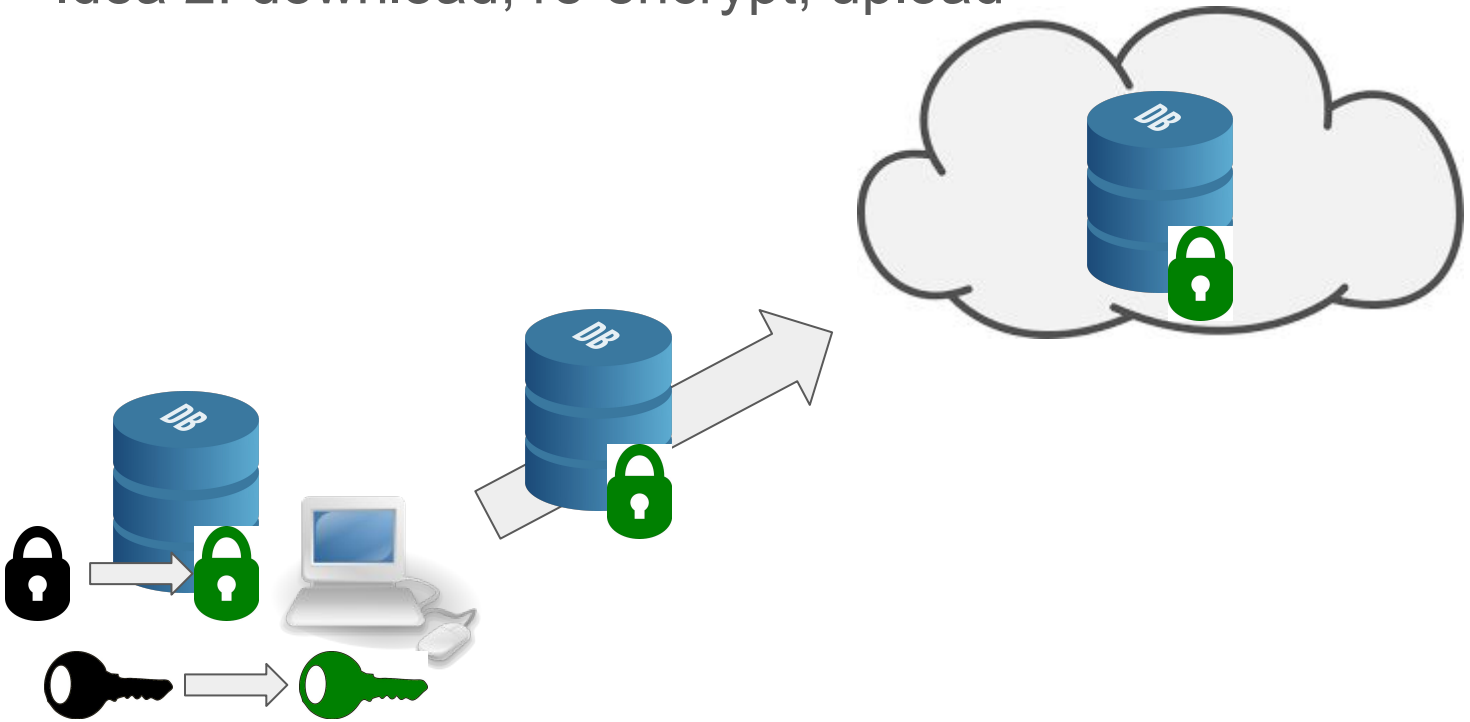

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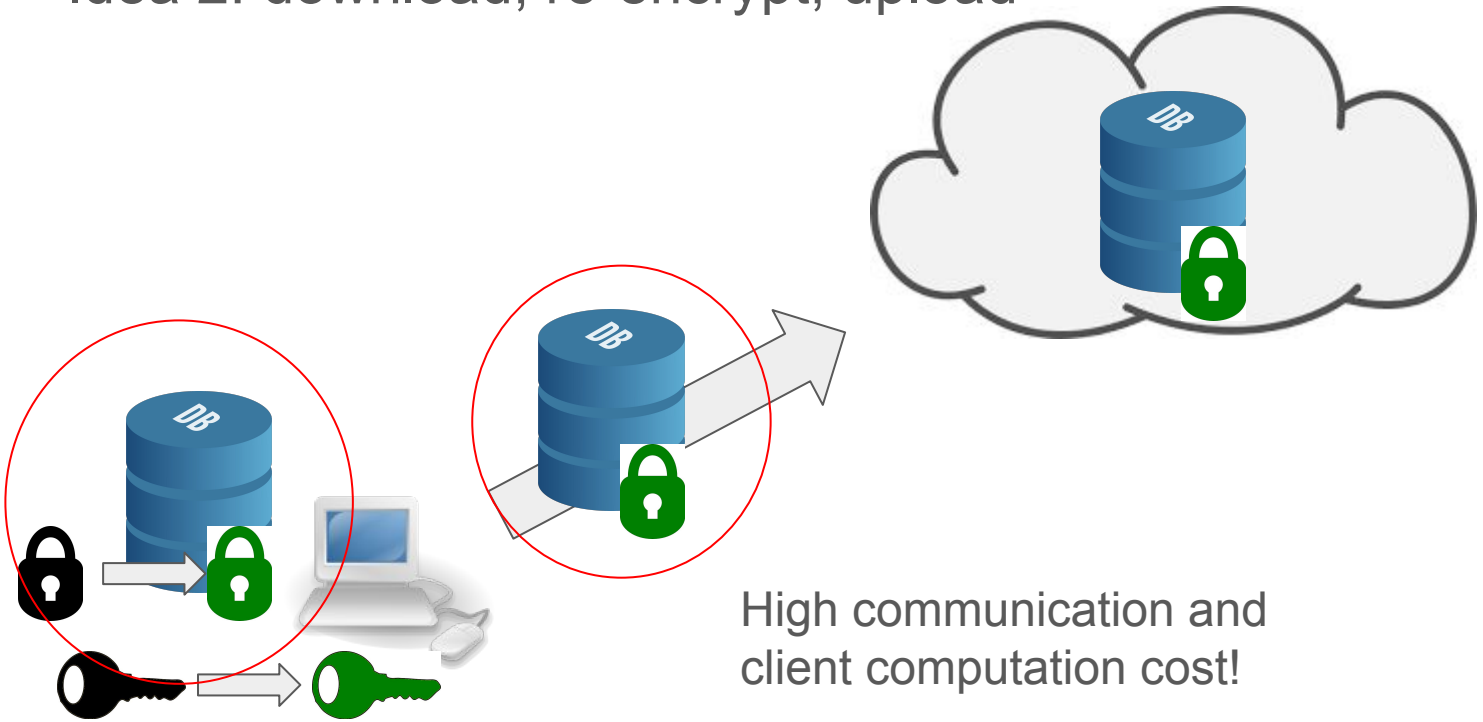

High communication and client computation cost!

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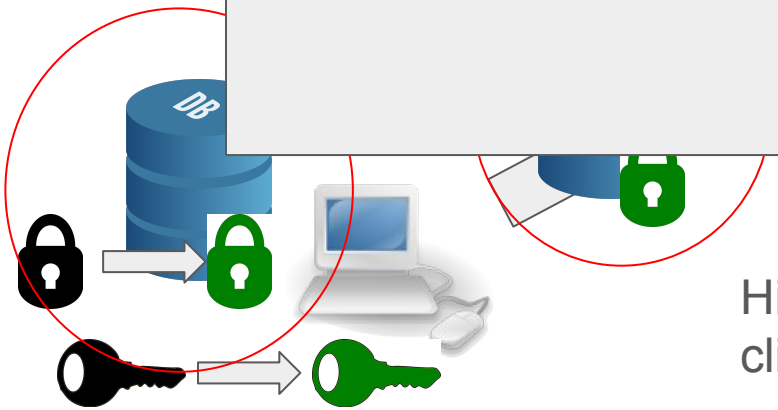
Can we do better?

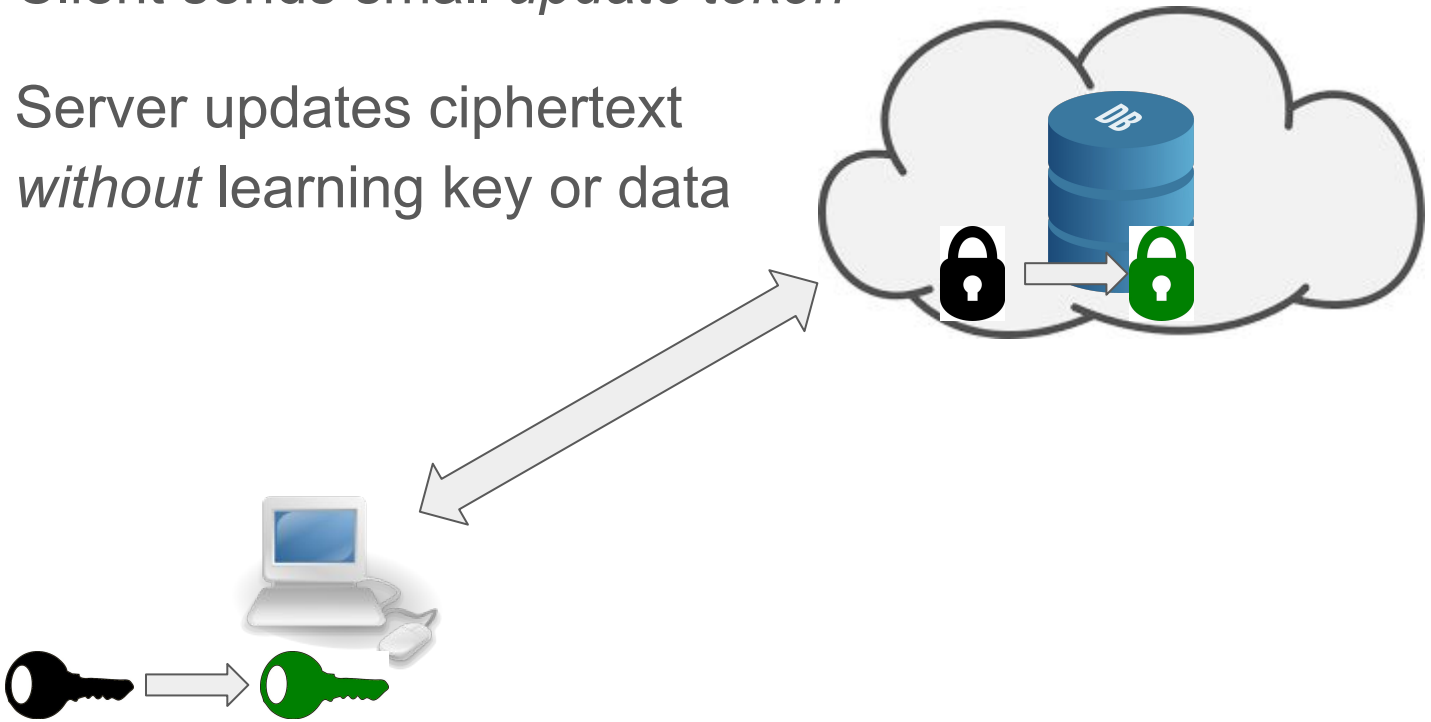


High communication and client computation cost!

Updatable Encryption [BLMR13, EPRS17, LT18, KLR19, BDGJ19]

Client sends small *update token*

Server updates ciphertext *without* learning key or data



Our Contributions

Improvements over prior security definitions

- Additional requirements for security

Two new constructions of updatable encryption

- From Nested AES: very fast, only supports *bounded* updates
- From KH-PRF based on RLWE: ~500x faster than prior work

Performance evaluation and comparison to prior work

Defining Security [EPRS17]

Four properties to achieve:

- Correctness
- Compactness
- Confidentiality
- Integrity

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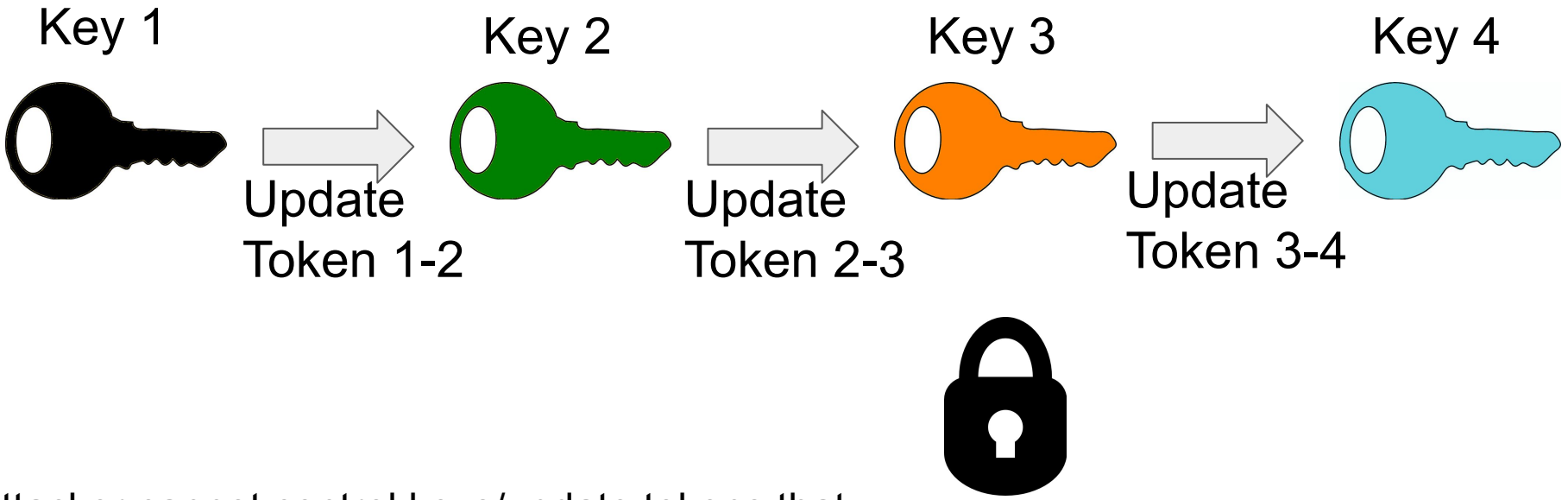

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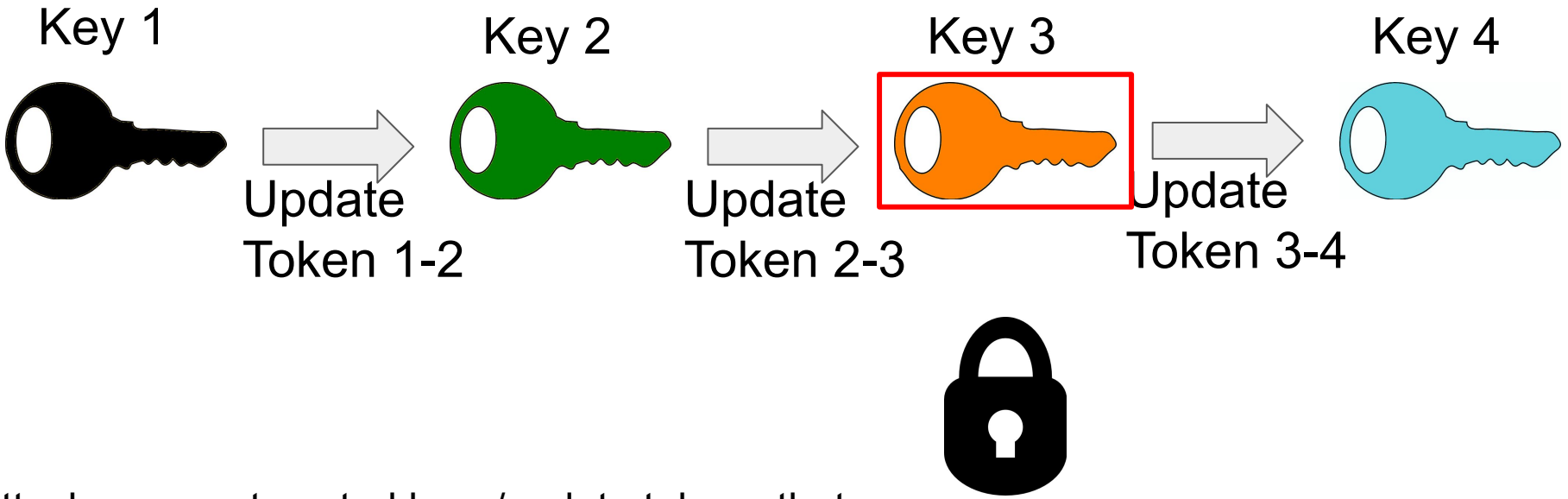

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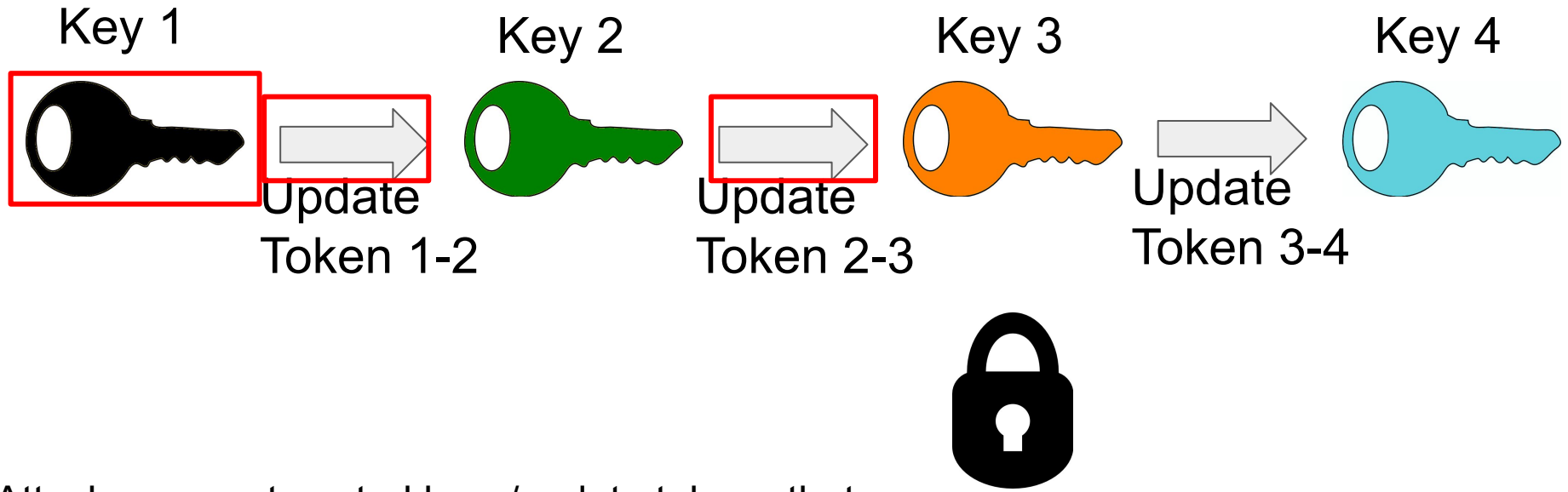

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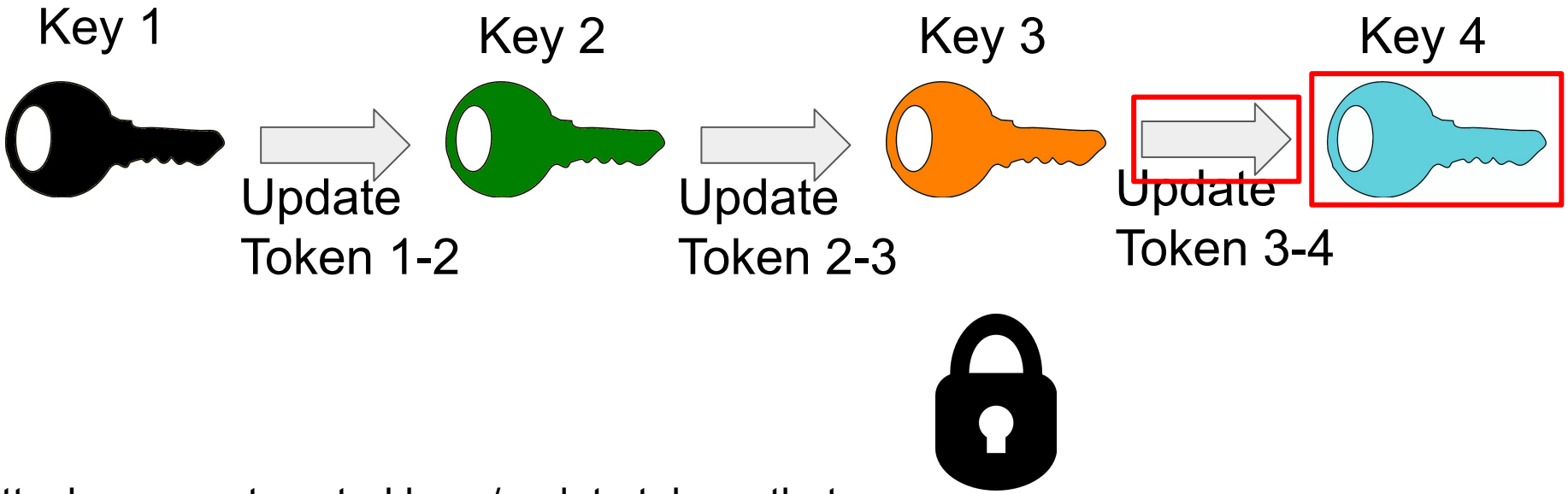

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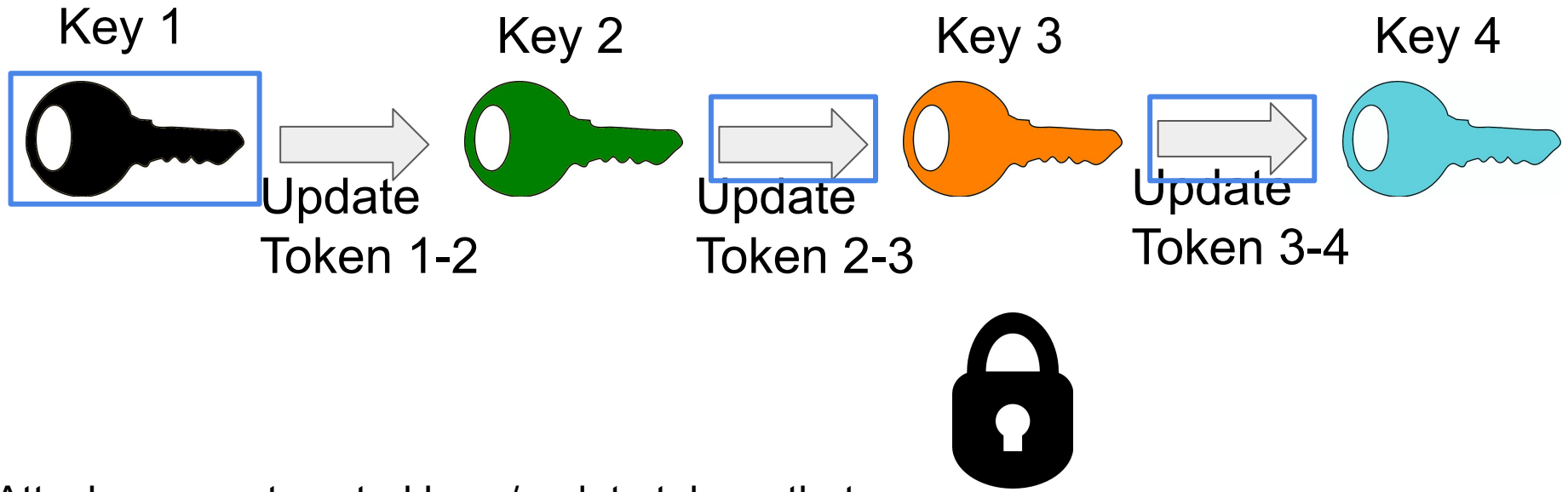

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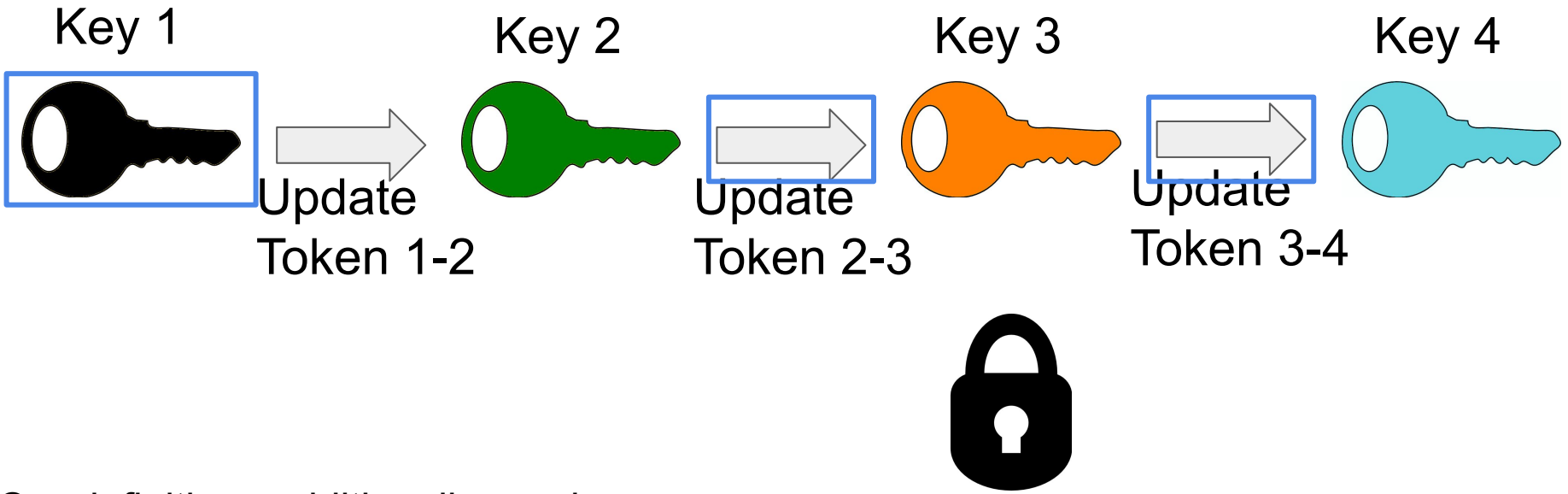
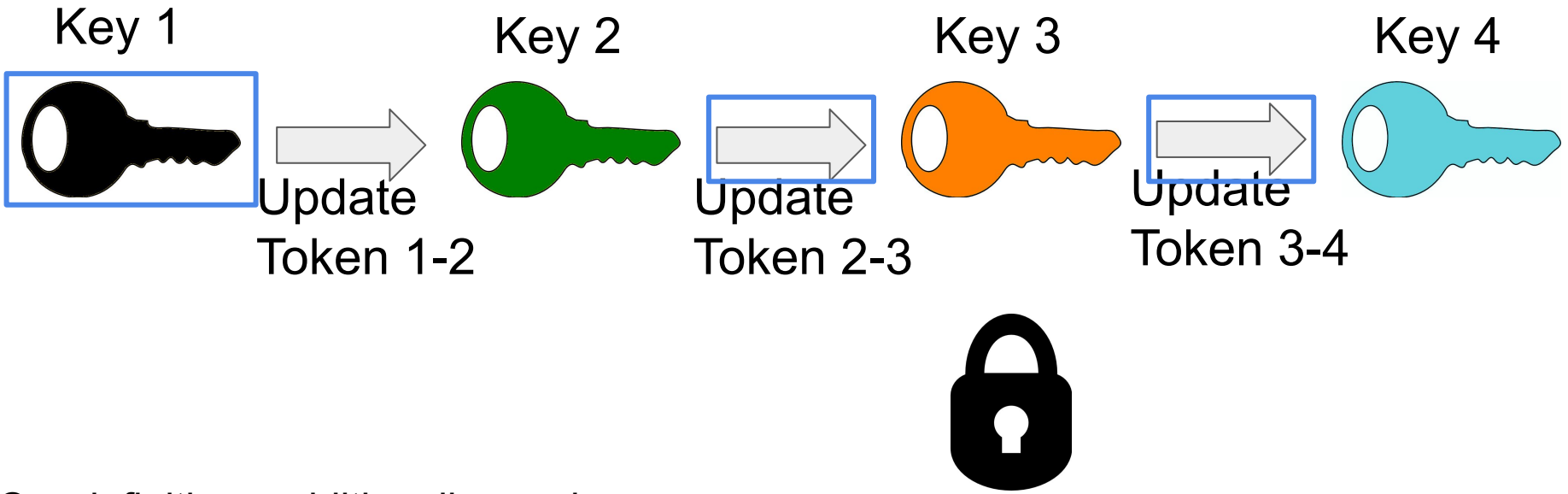


Our definitions additionally require hiding ciphertext age from attacker

Confidentiality

Note: cloud must always be trusted not to keep old ciphertexts



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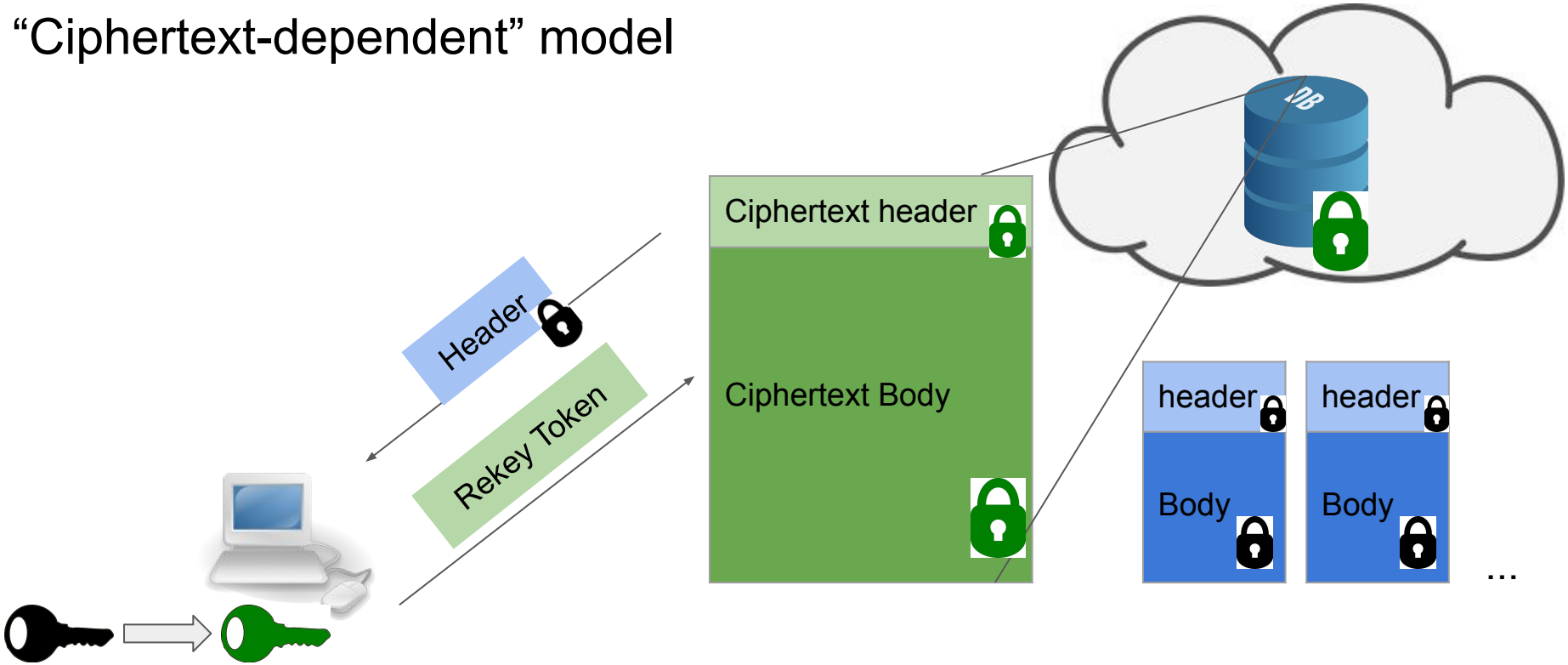
Building Updatable Encryption [BLMR13, EPRS17]

"Ciphertext-dependent" model



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Very fast, simple scheme

Only requires authenticated encryption (AES-GCM) and a PRG

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Caveats:

- Only works for a *bounded* number of re-encryptions, decided at encryption time
- Decryption time will be linear in the number of re-encryptions

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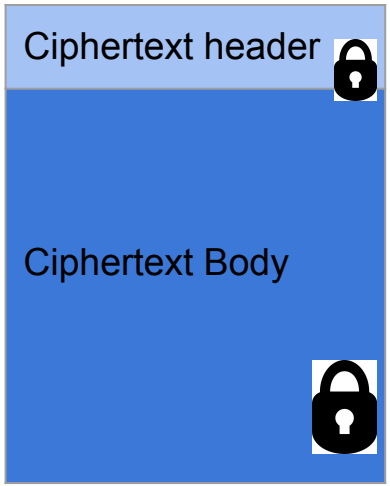

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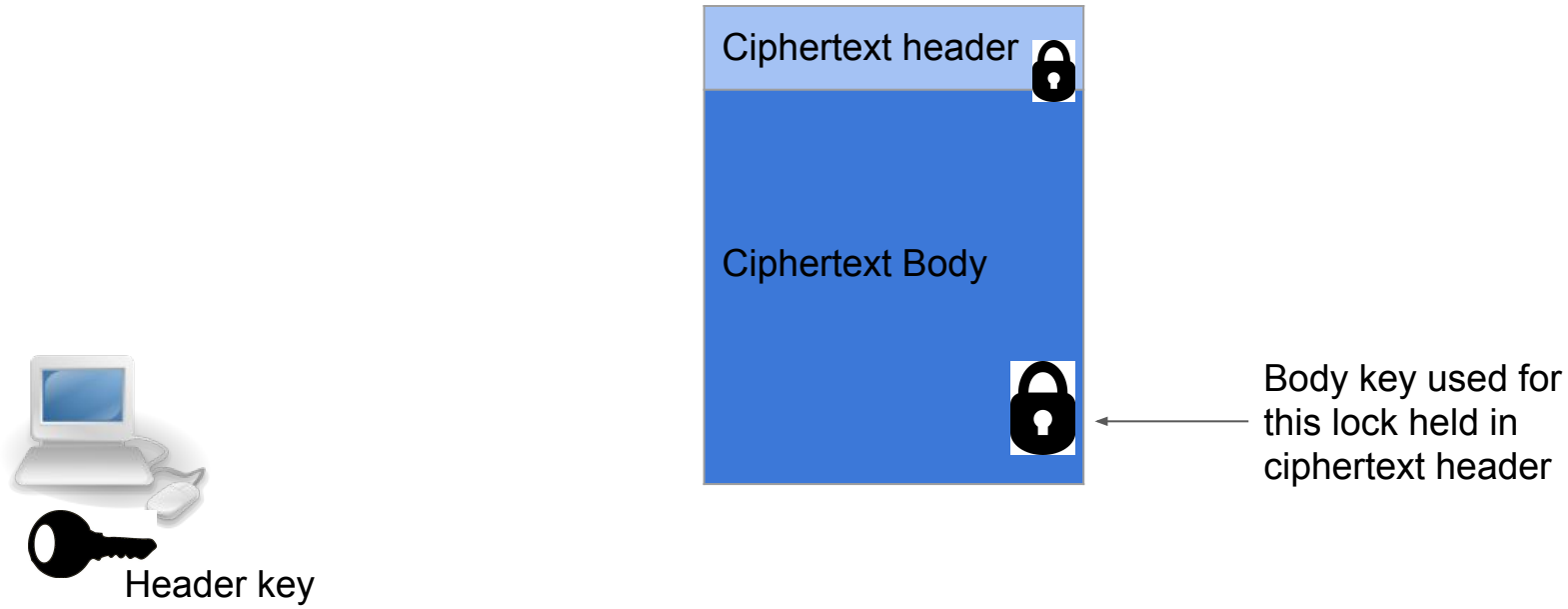

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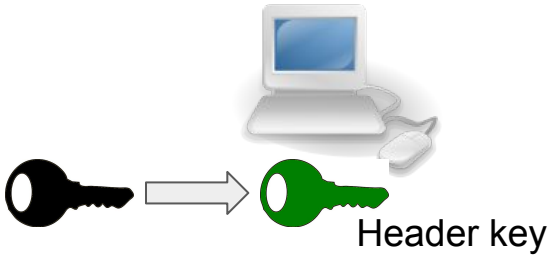

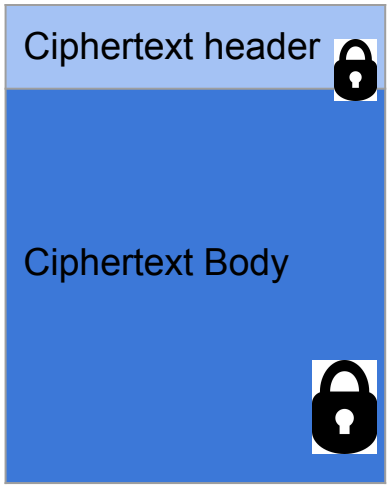

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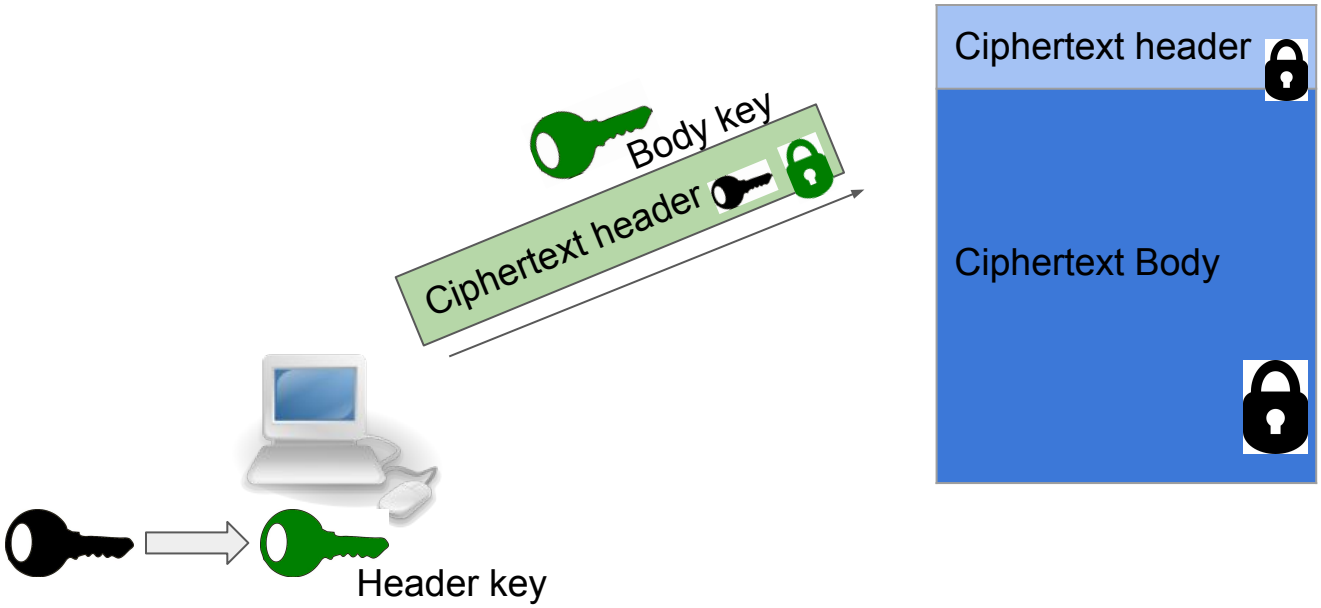

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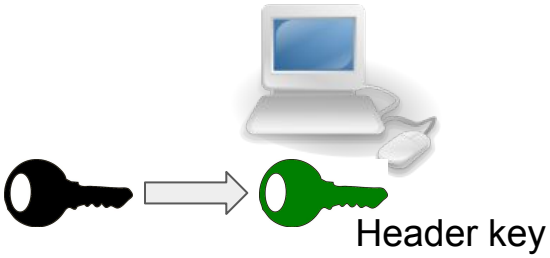

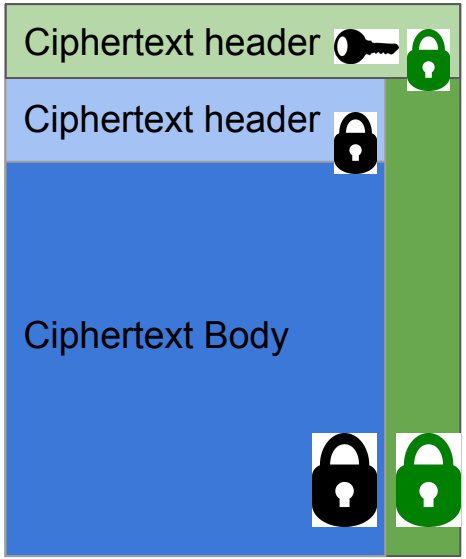

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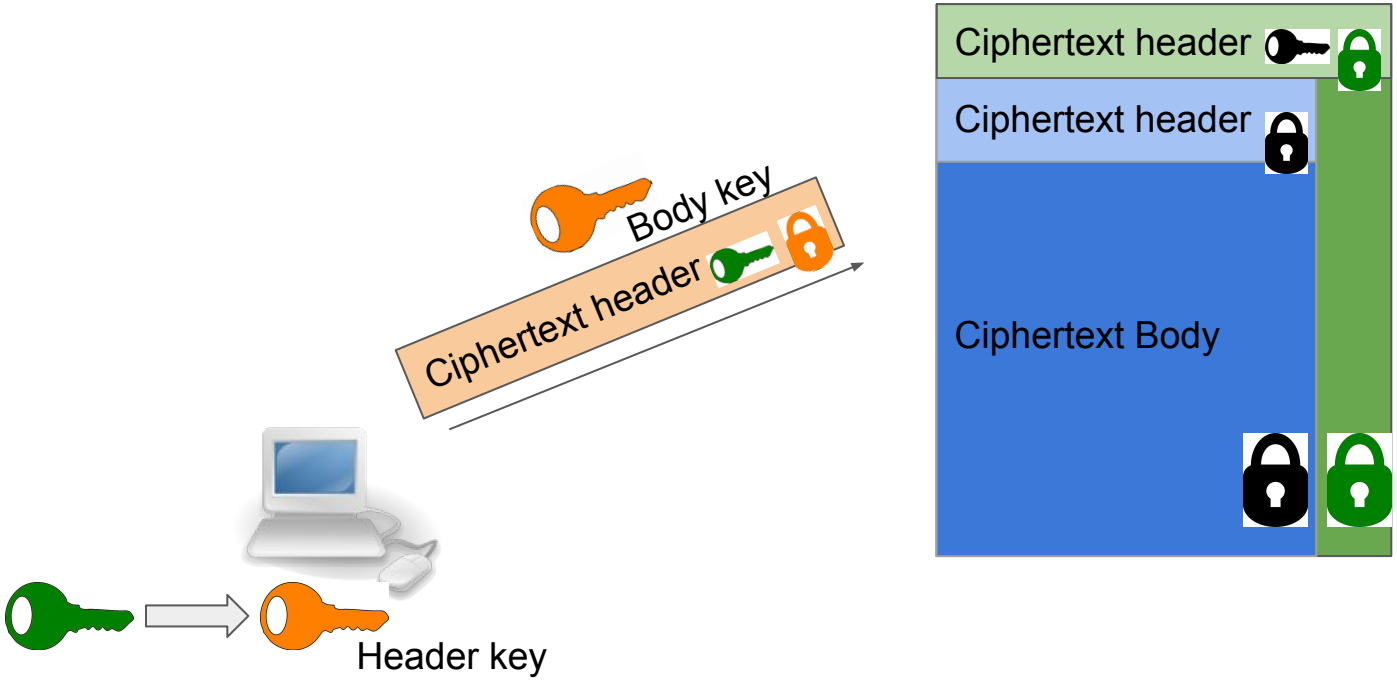

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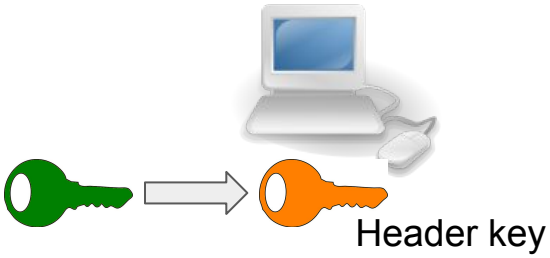
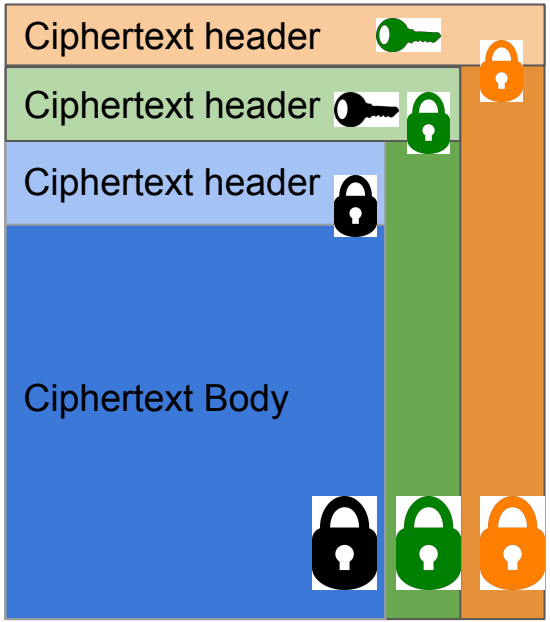
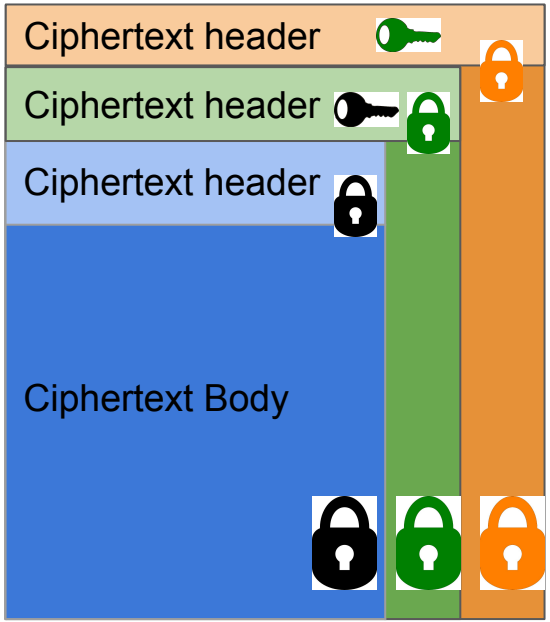




Updatable Encryption from Nested AES

Re-Encryption: wrap previous layer

Decryption: unwrap all layers



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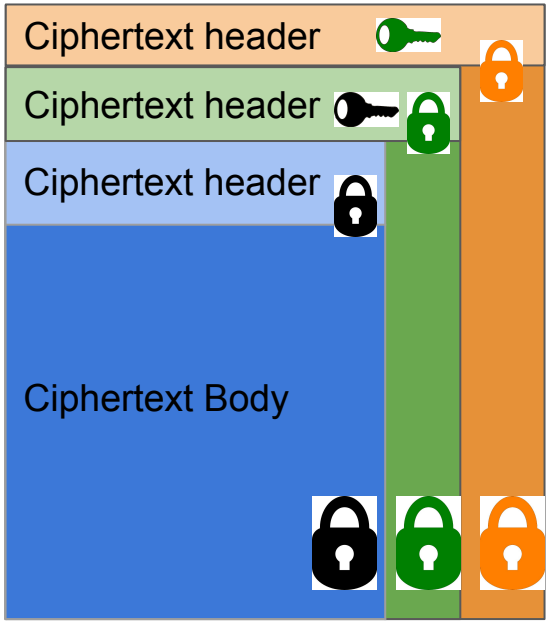

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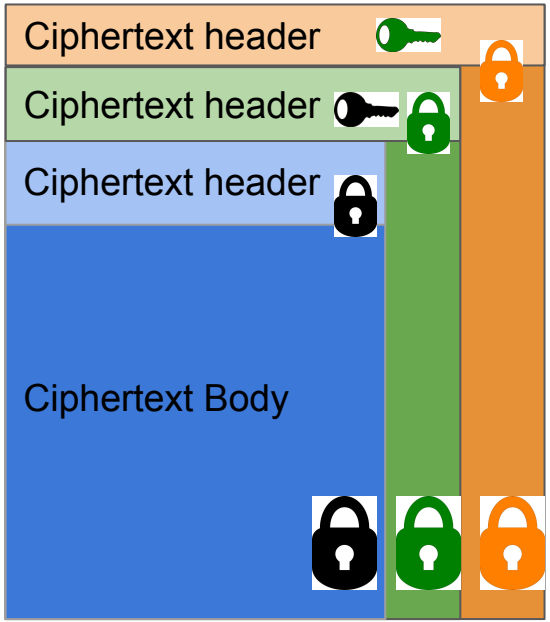
Note: this satisfies prior definitions



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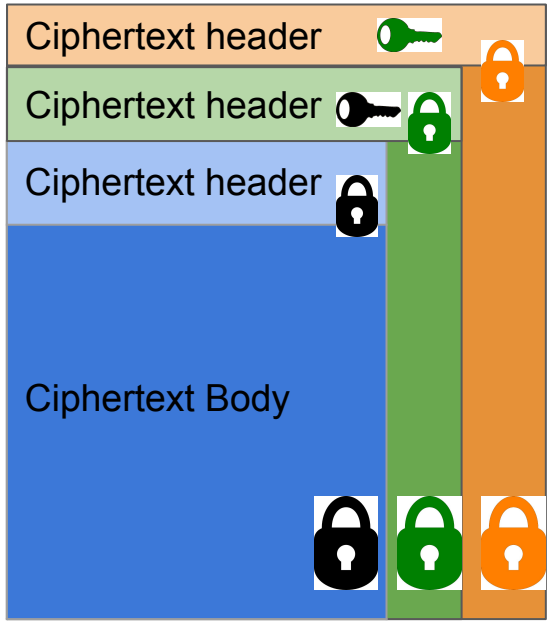

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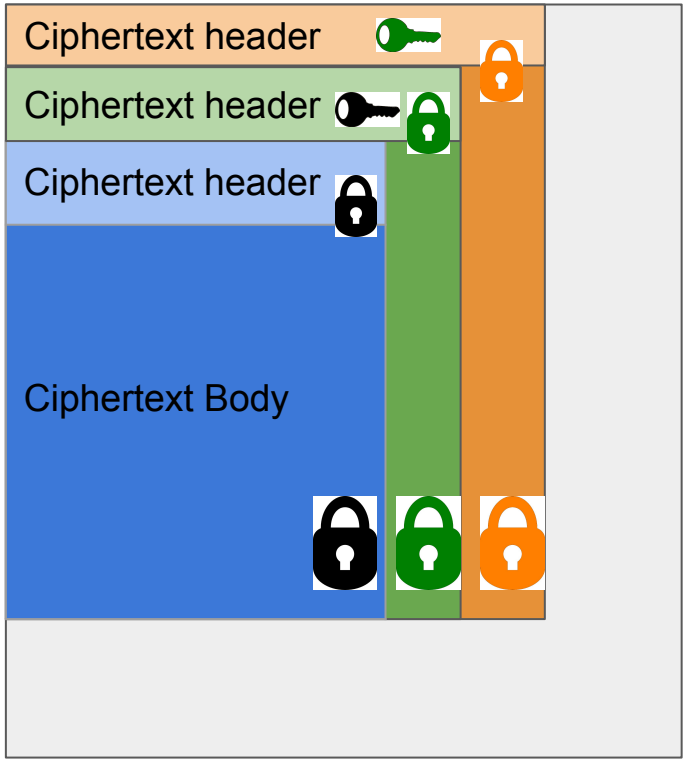

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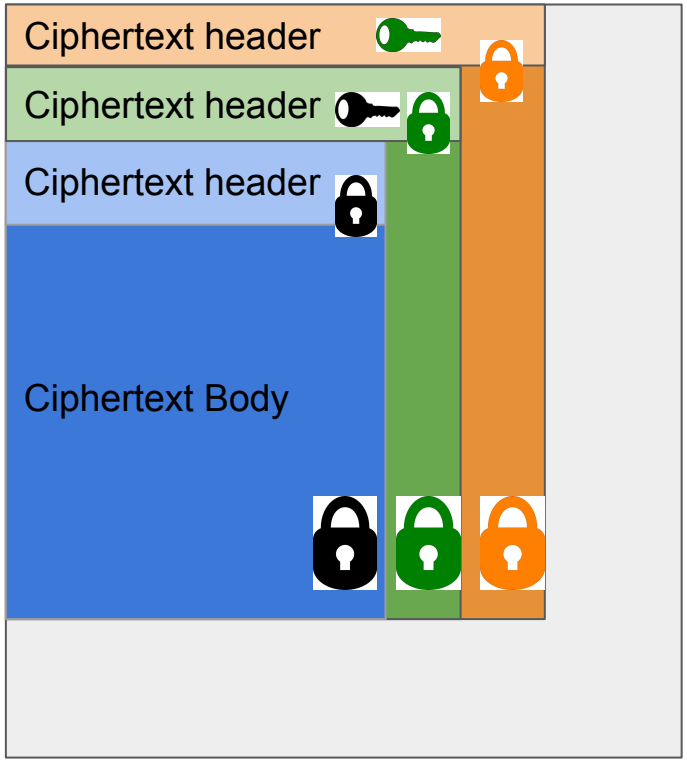

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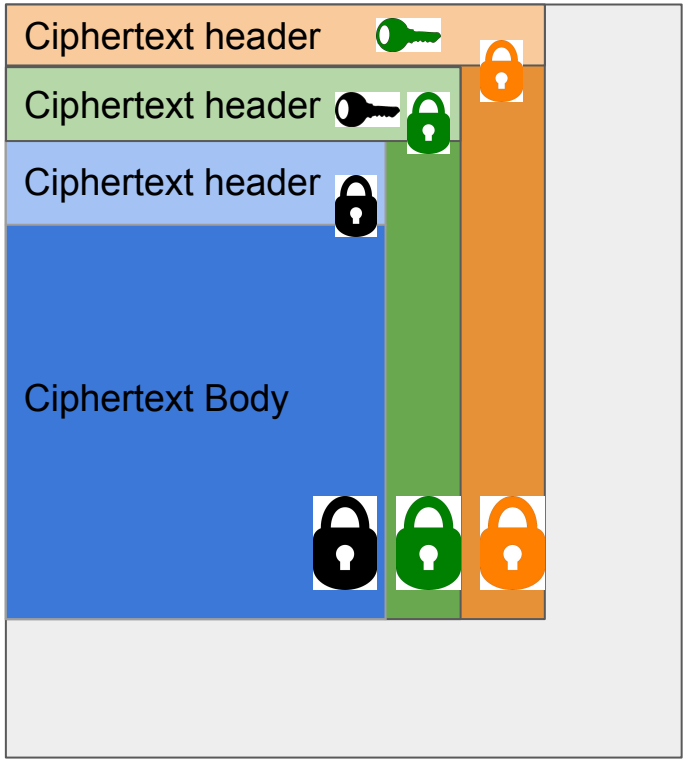

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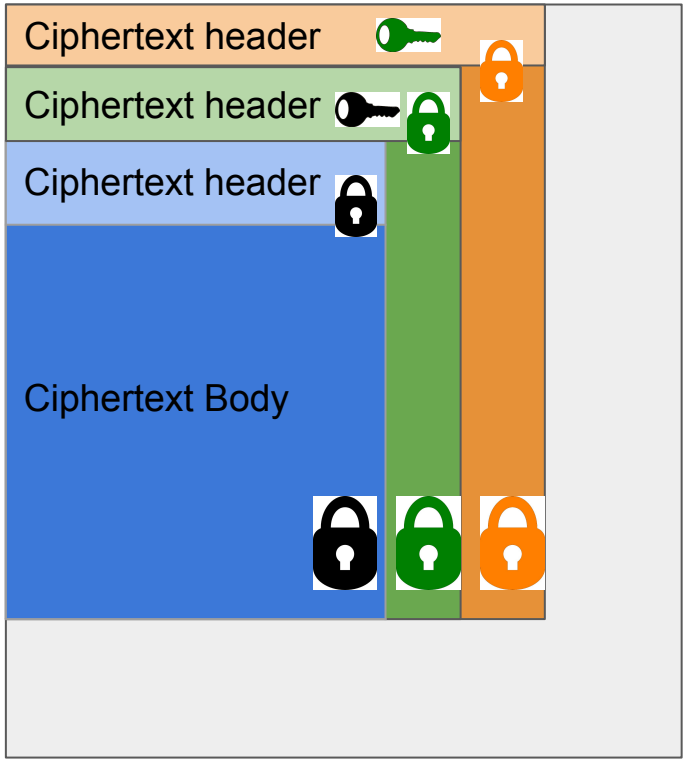

Updatable Encryption from KH-PRFs [BLMR13, EPRS17]

Supports as many re-encryptions as you want

Decryption time does not depend on number of re-encryptions

Still fast, but slower than nested scheme

New caveat: somewhat weaker integrity and age-hiding guarantee

Tool: Key-Homomorphic PRFs (KHPRFs) [NPR99]

Standard PRF (e.g. AES): *F(k, x)* looks random if not given *k*

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Key-Homomorphic PRF: Same security property, new functionality

$$F(k_1, x) \boxplus F(k_2, x) = F(k_1 + k_2, x)$$

Example: $F(k,x) = H(x)^k$

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Ciphertext header:

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$c_0 = m_0 + F(k_1, 0)$
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Almost KH-PRFs [BLMR13]

EPRS17 uses a KH-PRF based on the DDH assumption*

$$F(k_1, x) + F(k_2, x) = F(k_1 + k_2, x)$$

*In Random Oracle model

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We use a new *almost KH-PRF* based on the Ring-LWE assumption*

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See paper for construction

Result: ~500x faster performance

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F(

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Why lattice crypto?

Evaluation

Encryption and Re-encryption

Throughput for encrypting/re-encrypting 32KB messages (MB/sec)

	ReCrypt [EPRS17]	Almost KH-PRF	Nested (128 layers)
Encrypt	0.12	61.90	1836.9
Re-encrypt	0.15	83.06	2606.8

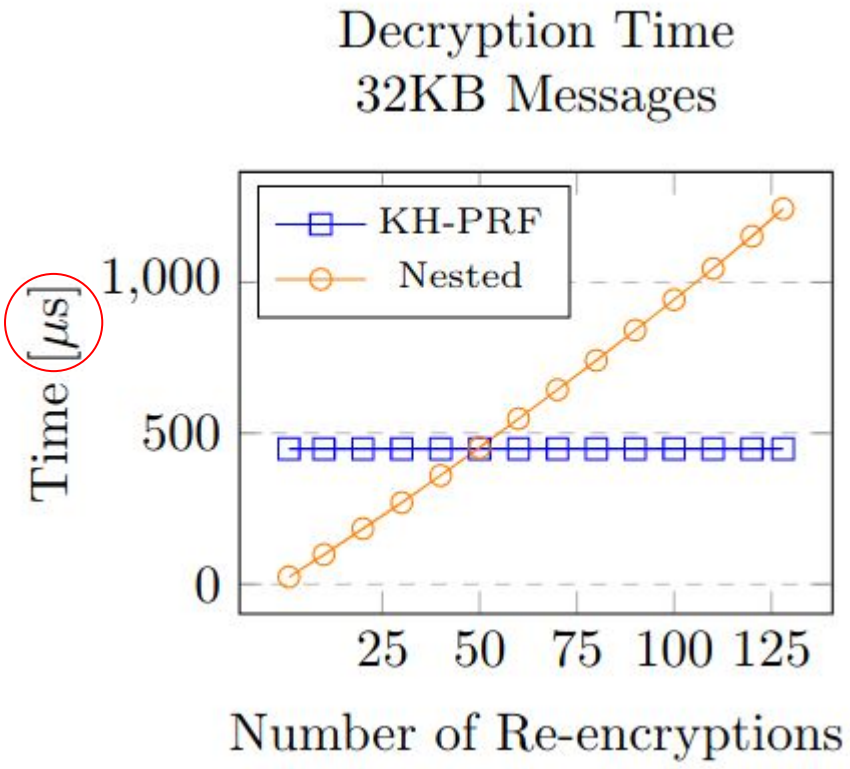
Almost KH-PRF is ~500x faster than ReCrypt

Nested AES is ~30x faster than almost KH-PRF

Decryption

Nested construction faster for up to 50 re-encryptions

ReCrypt (not shown) 500x slower than KH-PRF construction



Ciphertext Expansion

Nested AES and ReCrypt have smallest ciphertext expansion

KH-PRF or Nested AES for many re-encryptions have larger ciphertext expansion

Ciphertext Expansion 32KB Messages	
KH-PRF UAE	
$\|q\| = 28$	133%
$\|q\| = 60$	36%
$\|q\| = 120$	20%
$\|q\| = 128$	19%
Nested UAE	
$t = 20$	3%
$t = 128$	19%
ReCrypt [EPRS17]	3%

Improving Updatable Encryption

Improved security definitions for updatable encryption

Two new constructions -- from Nested AES and RLWE-based KH-PRF

Orders of magnitude performance improvement over prior work

Paper: `eprint.iacr.org/2020/222.pdf`

Source Code: `https://github.com/moshih/UpdateableEncryption_Code`

Contact: `saba@cs.stanford.edu`