Cryptography for the quantum internet

Elements of a “quantum TLS”

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Colloquium

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QuSoft
Research Center for Quantum Software

CWI
Centrum Wiskunde & Informatica

Quantum computers

Quantum computers

- Accelerating effort to build a quantum computer

Quantum computers

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- Major investments:

QUTech
Google
IBM
nationale wetenschaps agenda
intel
Microsoft
QUANTUM FLAGSHIP

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- Many applications! (In theory)
  - Quantum chemistry
  - Quantum Key Distribution
  - Quantum Money
  - Cryptanalysis
  - Machine learning
  - Distributed quantum computing
  - Multiparty quantum computation
  - …

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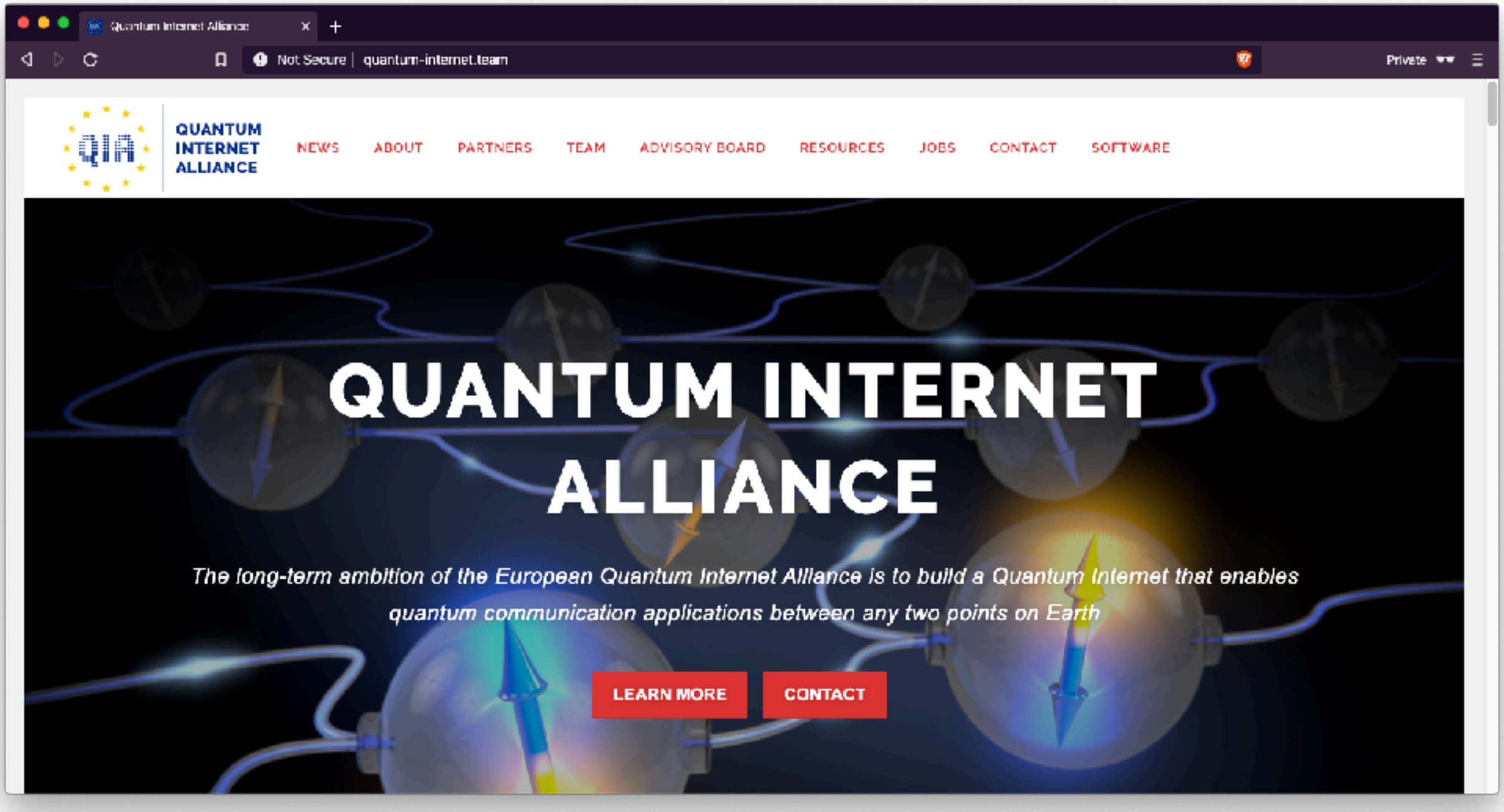
Need a quantum network!

Quantum internet



Quantum internet

Quantum internet

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How can we secure the Quantum internet?

Internet crypto

Let’s have a look how the classical internet is secured.

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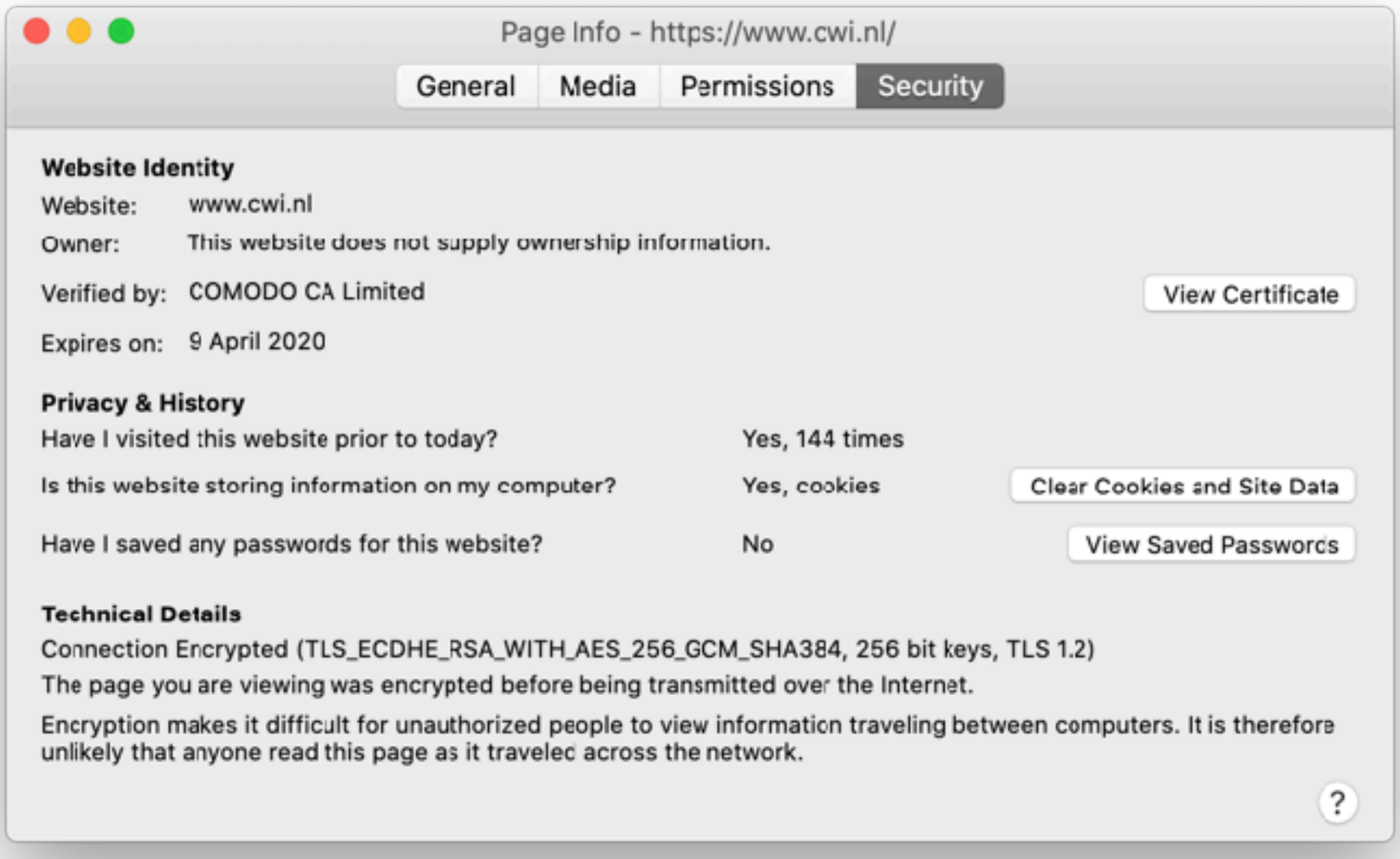

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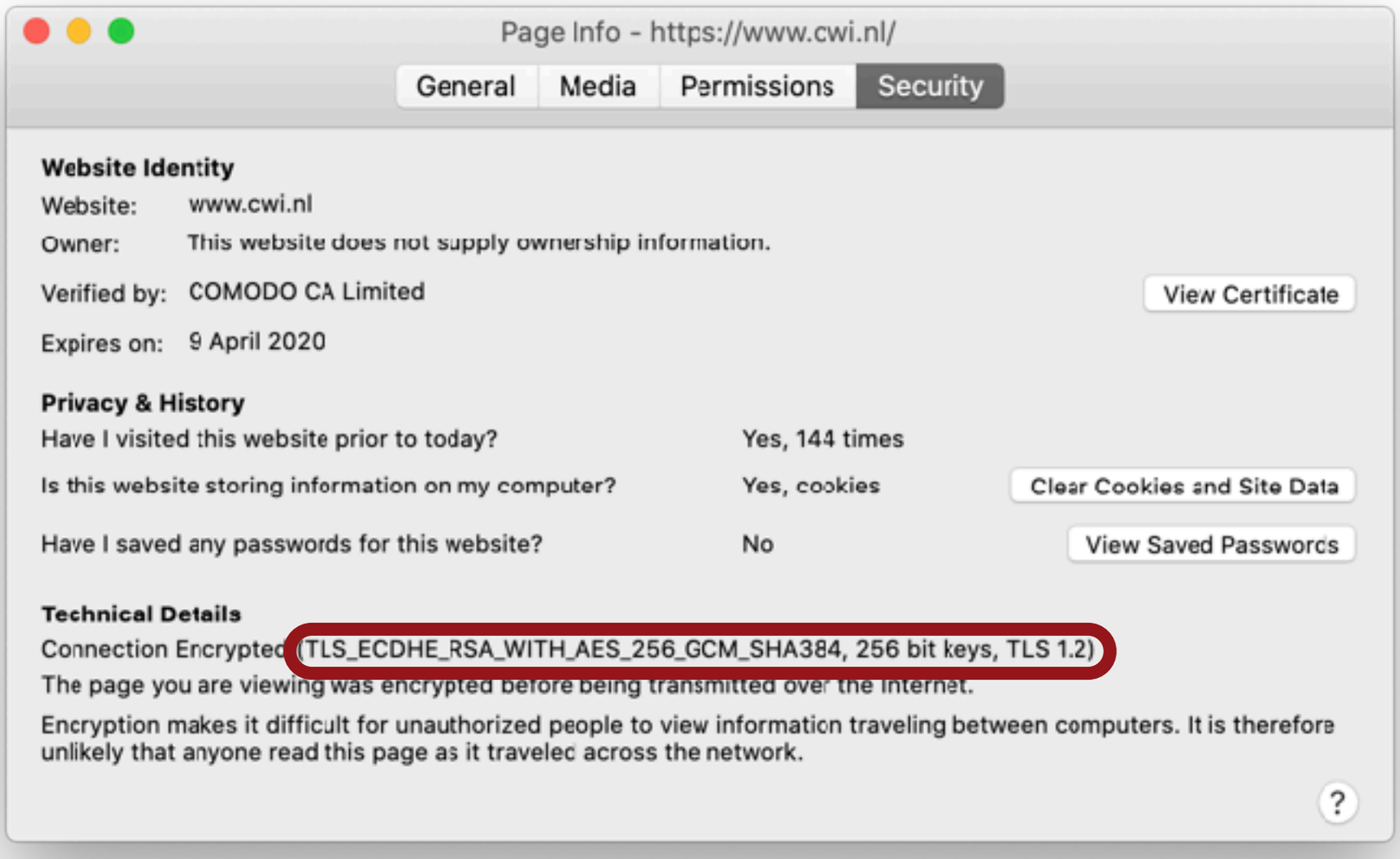


The TLS protocol

The TLS protocol

Functionalities

The TLS protocol

Functionalities

(Server) authentication

The TLS protocol

Functionalities

(Server) authentication

Key establishment

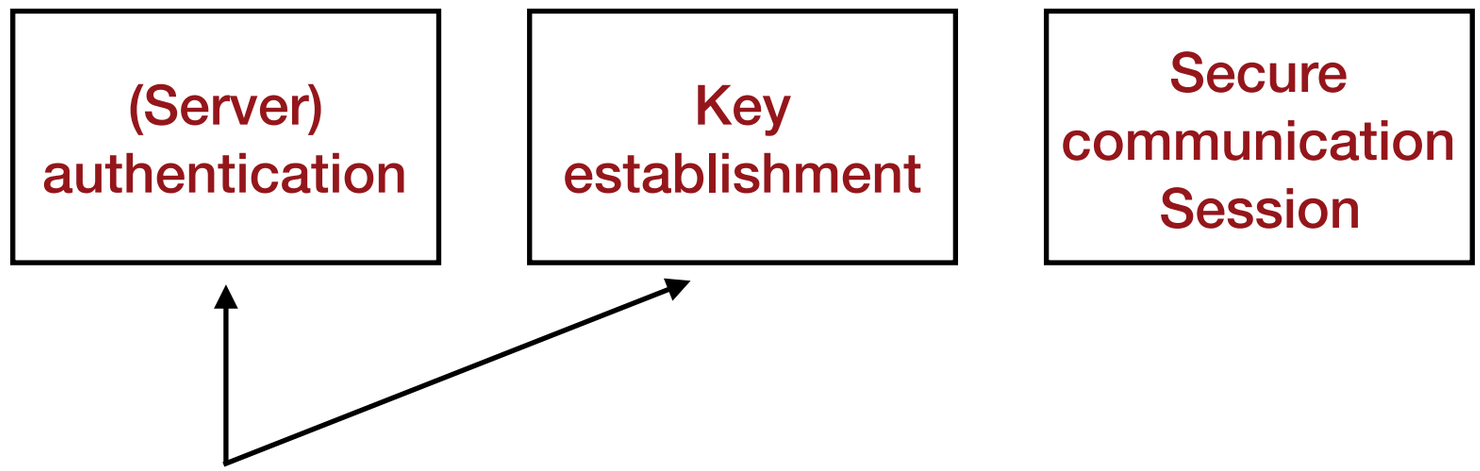
The TLS protocol

Functionalities

- (Server) authentication
- Key establishment
- Secure communication Session

The TLS protocol

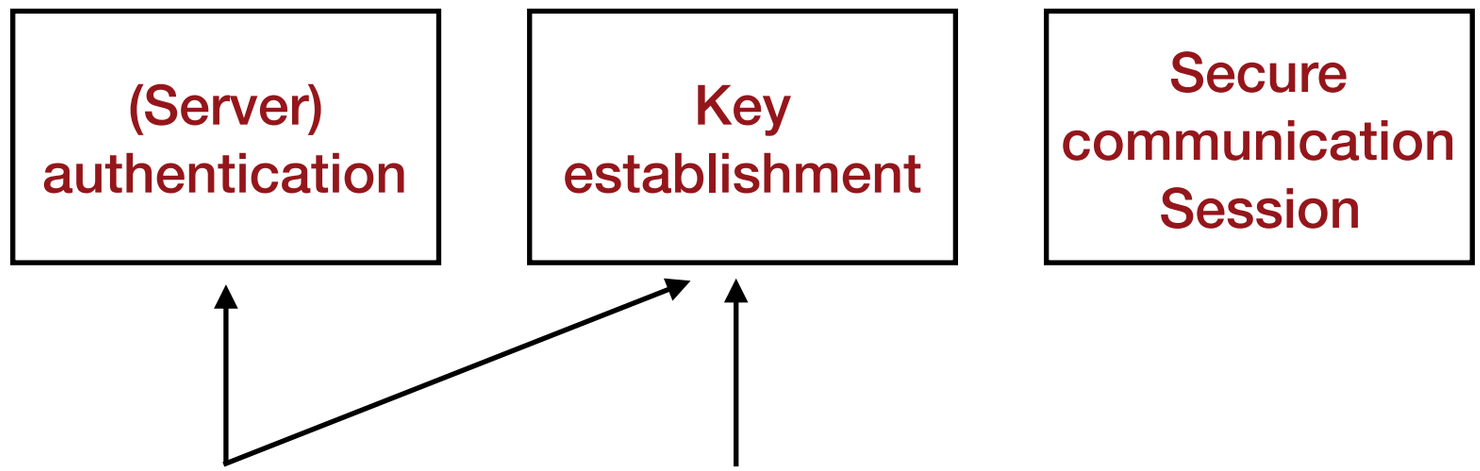
Functionalities



Protocols

The TLS protocol

Functionalities



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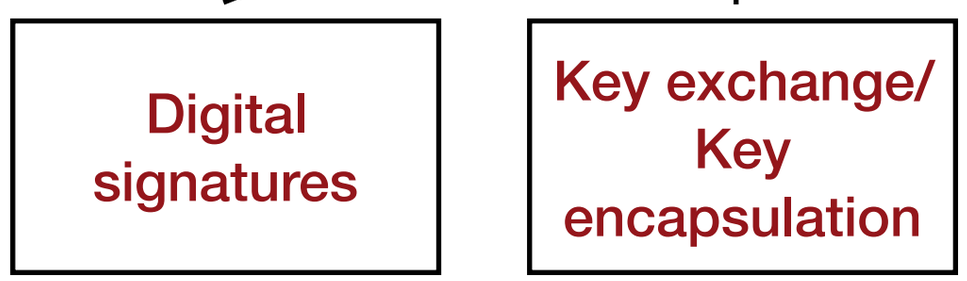

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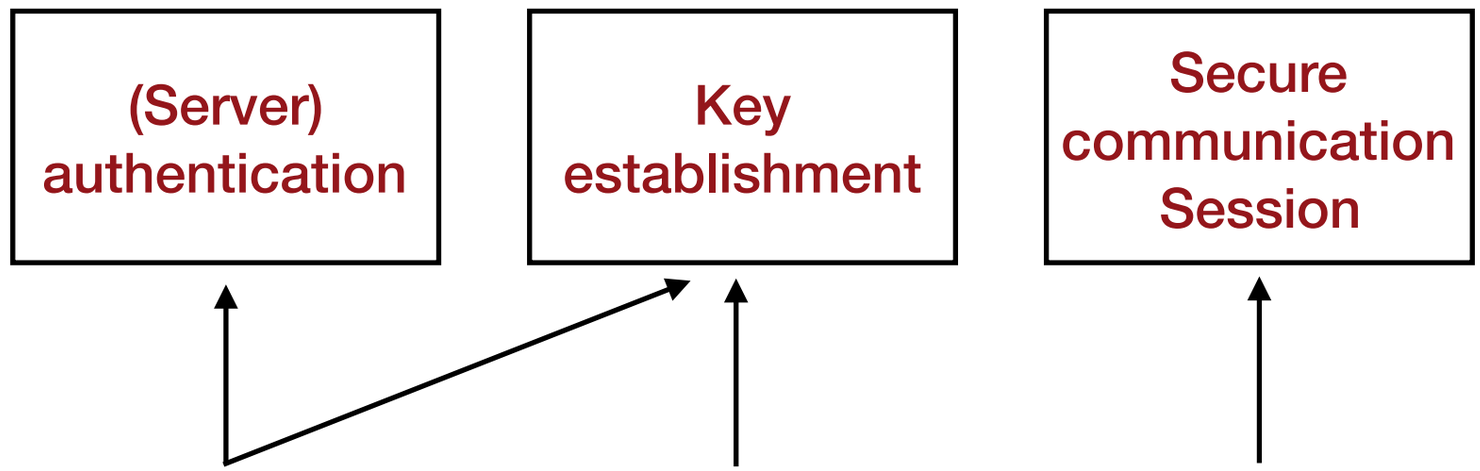

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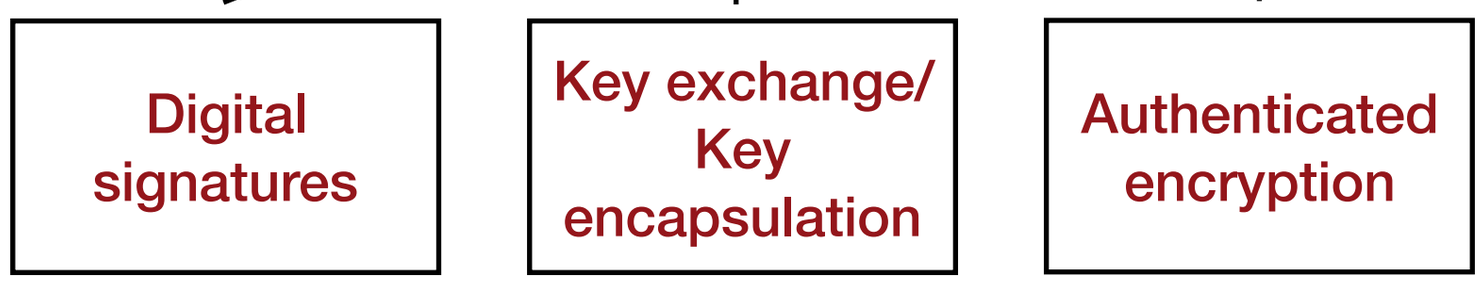

The TLS protocol

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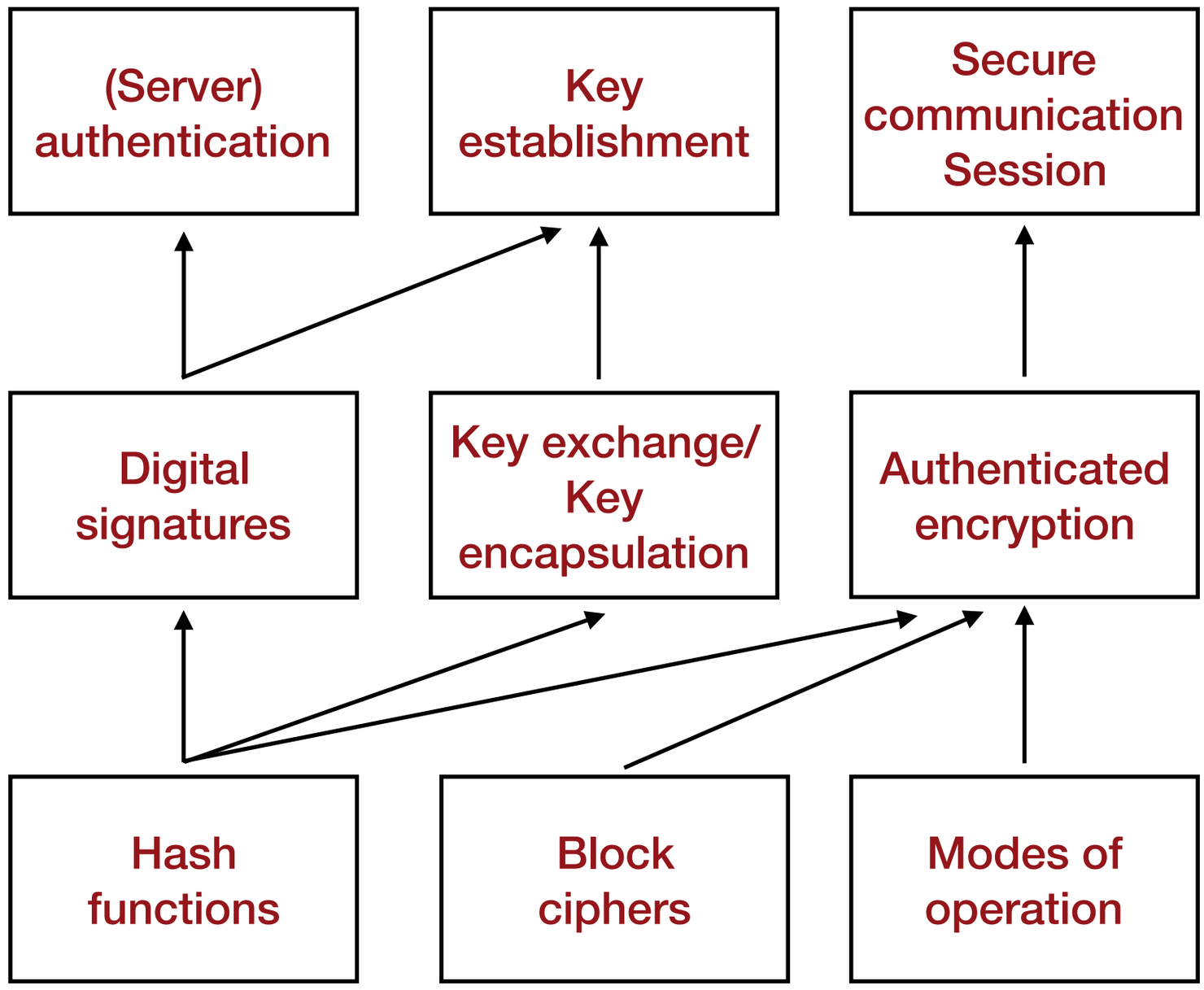
Cryptographic Ingredients



The TLS protocol

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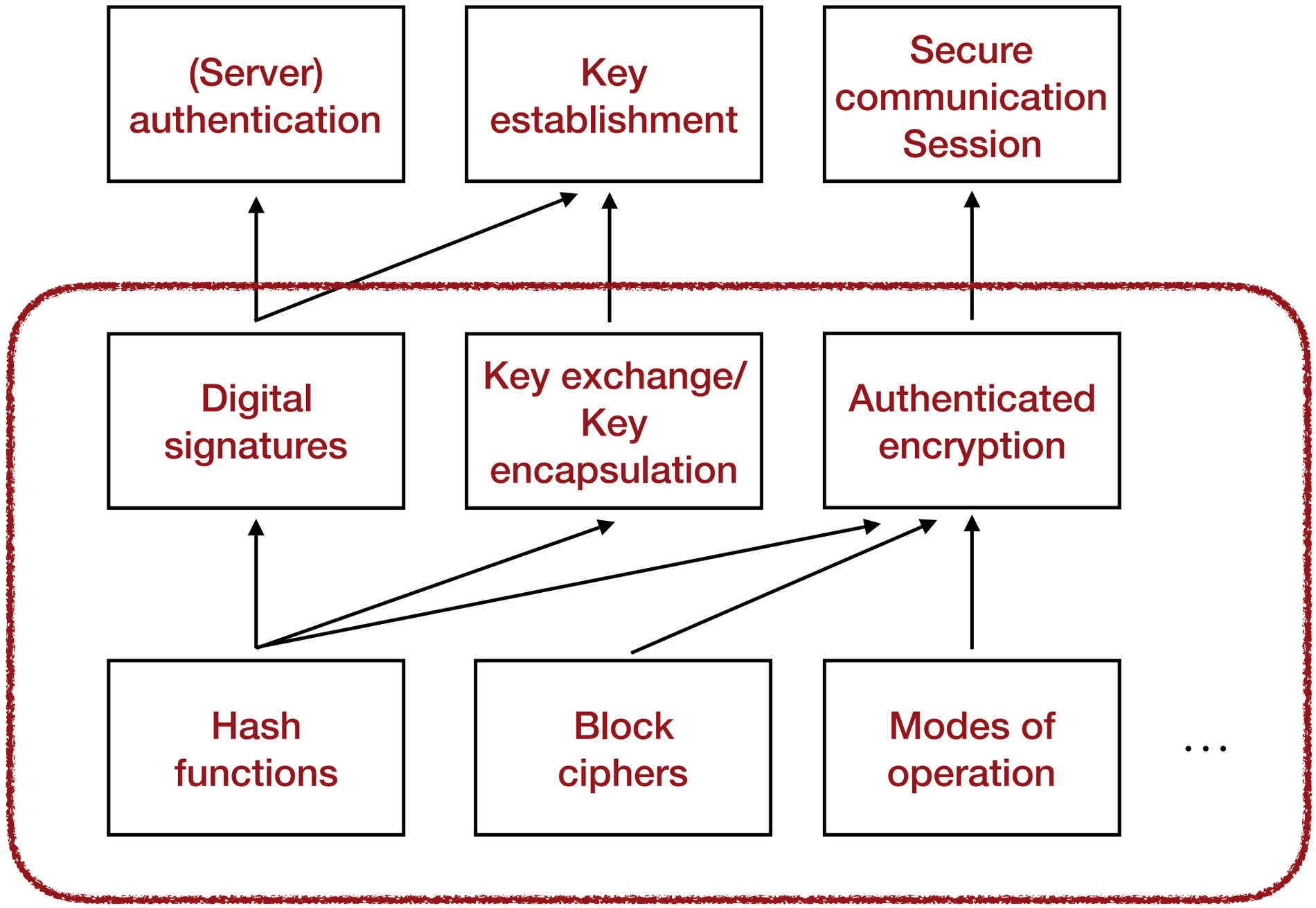
Quantum-ready?



Outline

- Are we ready for encrypting the quantum internet?
  - Digital signatures I
  - Hash functions
  - Digital signatures II
  - Key exchange/key encapsulation
  - Authenticated Encryption
- Summary and open problems

Are we ready for encrypting the quantum internet?

Digital Signatures I

Digital signatures

Digital signatures

Alice

Bob

Digital signatures

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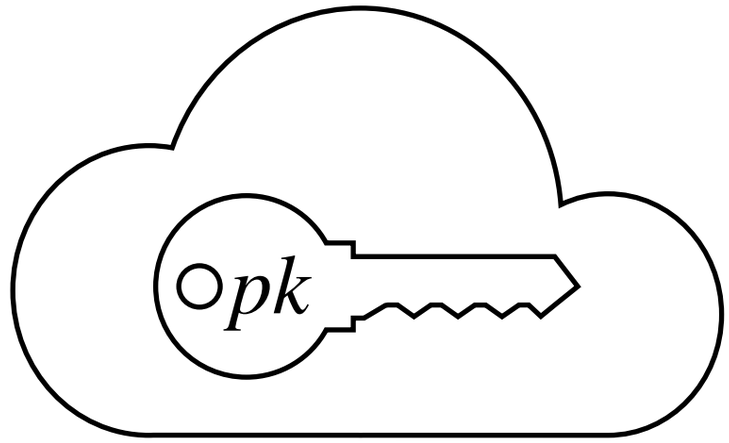
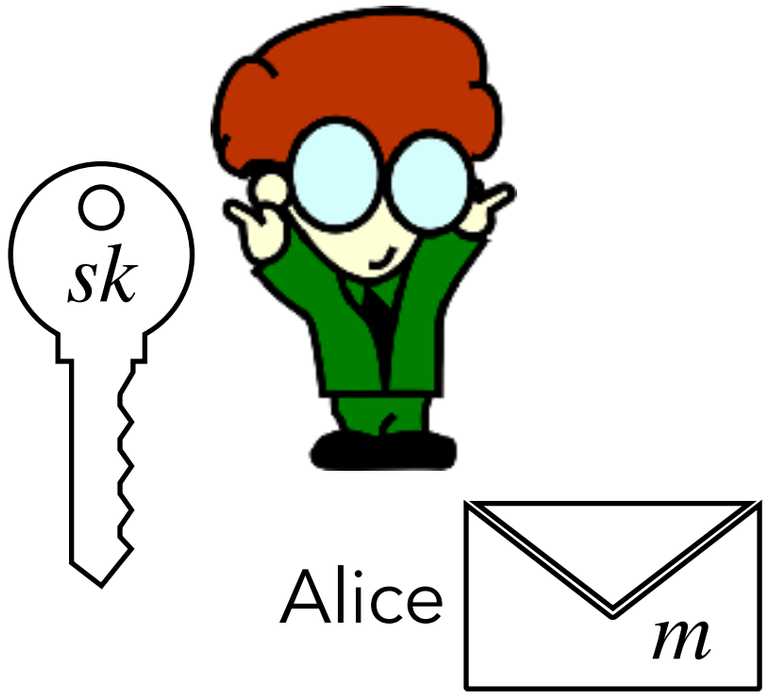
Digital signatures





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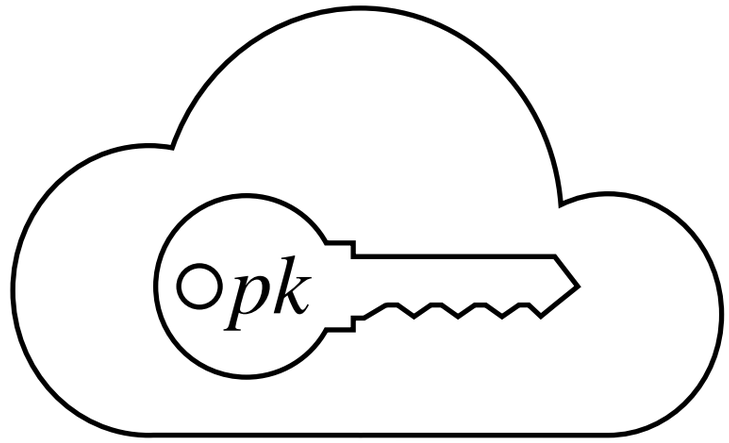

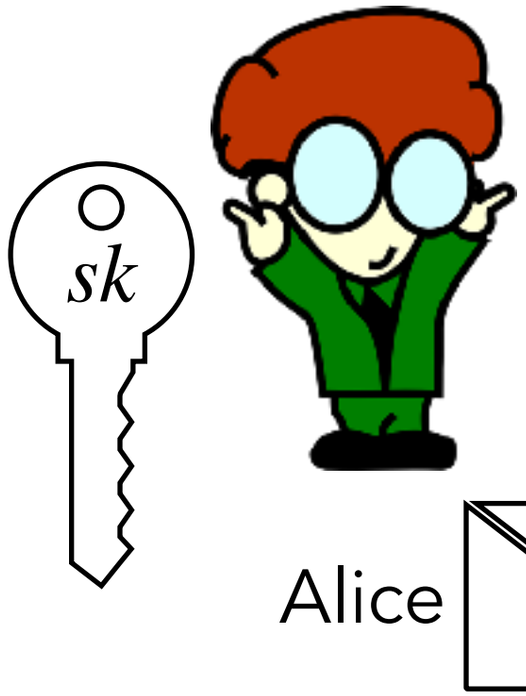

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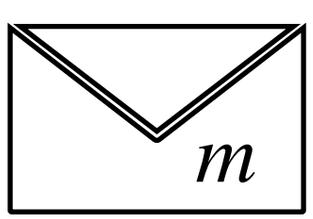

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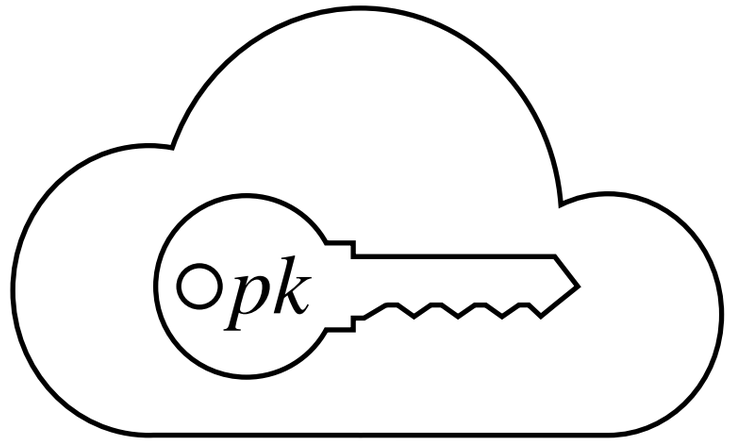
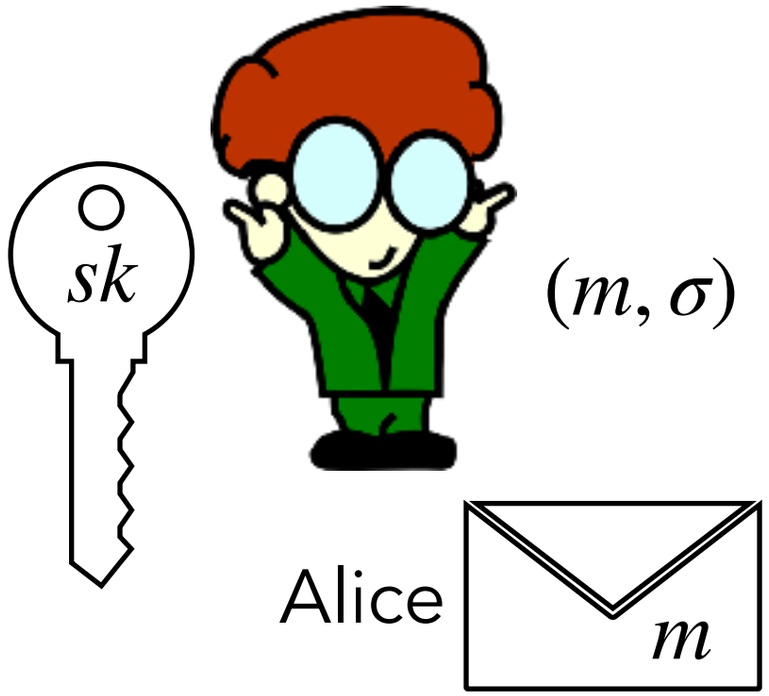
$$\sigma = \mathrm{Sign}_{sk}(m)$$

Digital signatures





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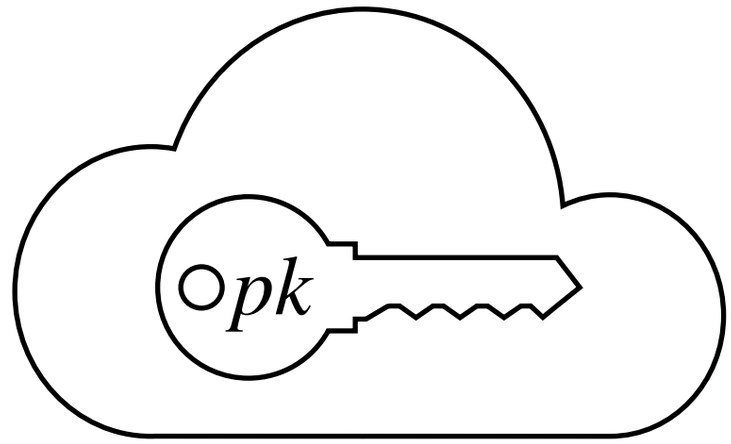

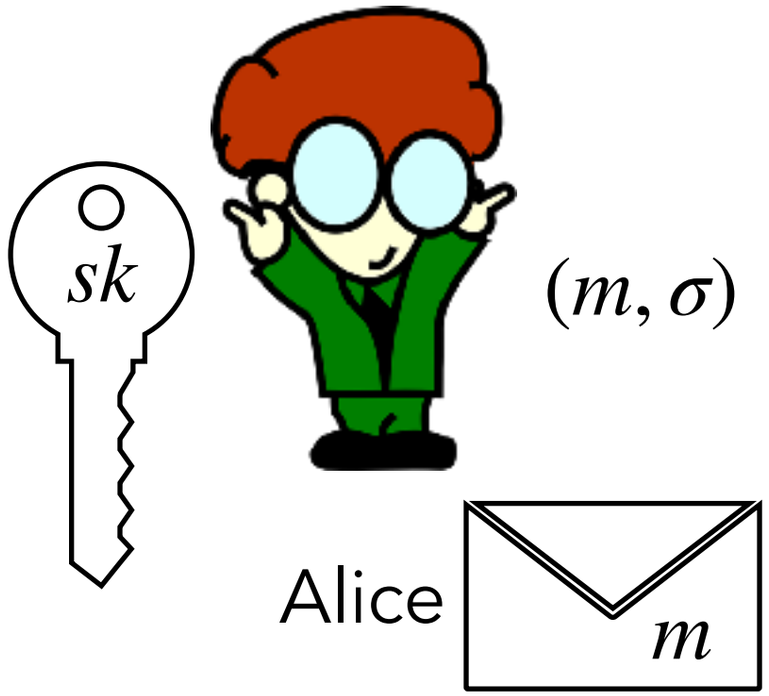

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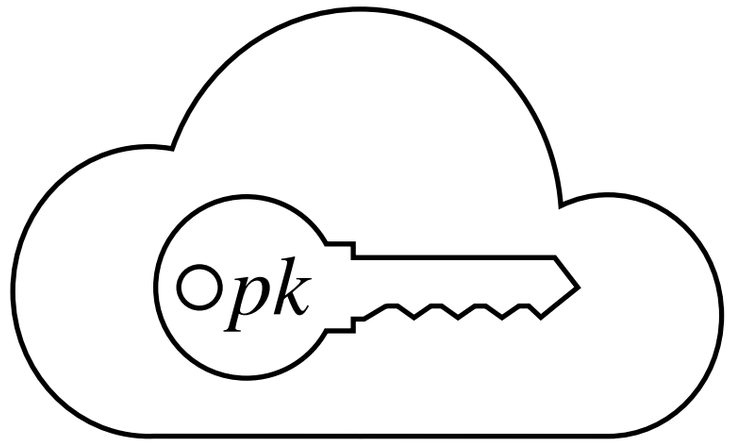

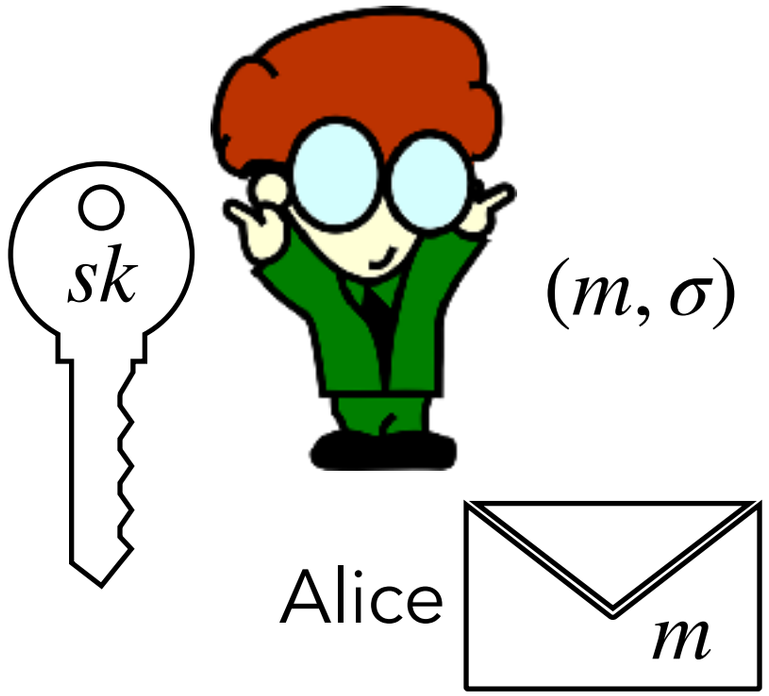

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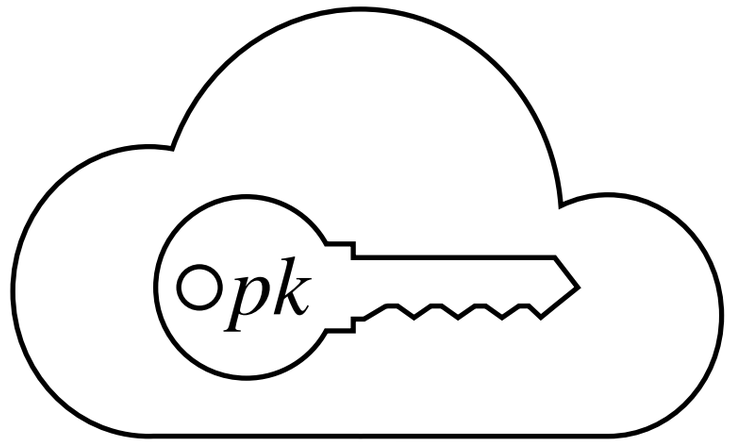

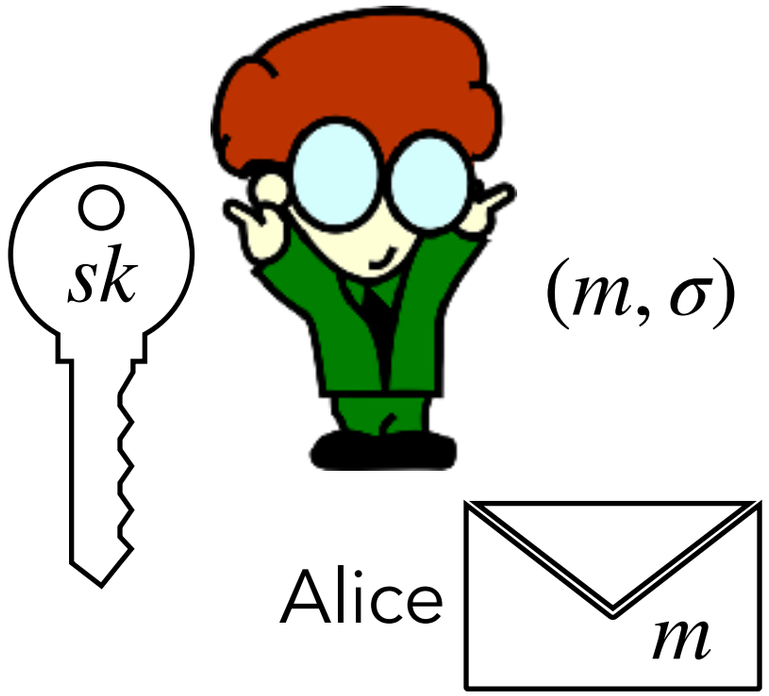

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Slightly simplified...

Quantum digital signatures

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Is this the end of “Project Quantum TLS”?

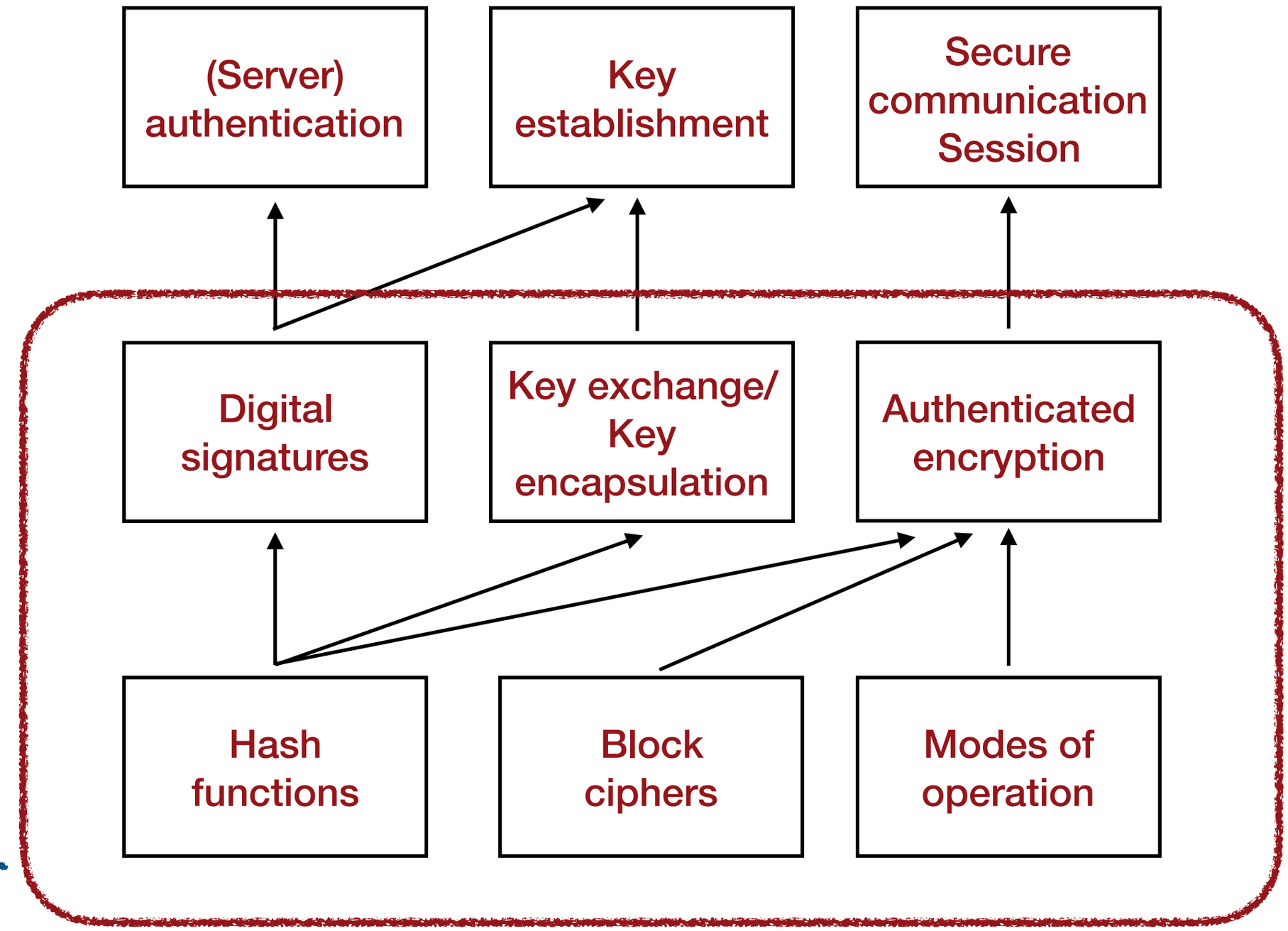
The TLS protocol

Functionalities

Protocols

Cryptographic Ingredients

Quantum-ready?



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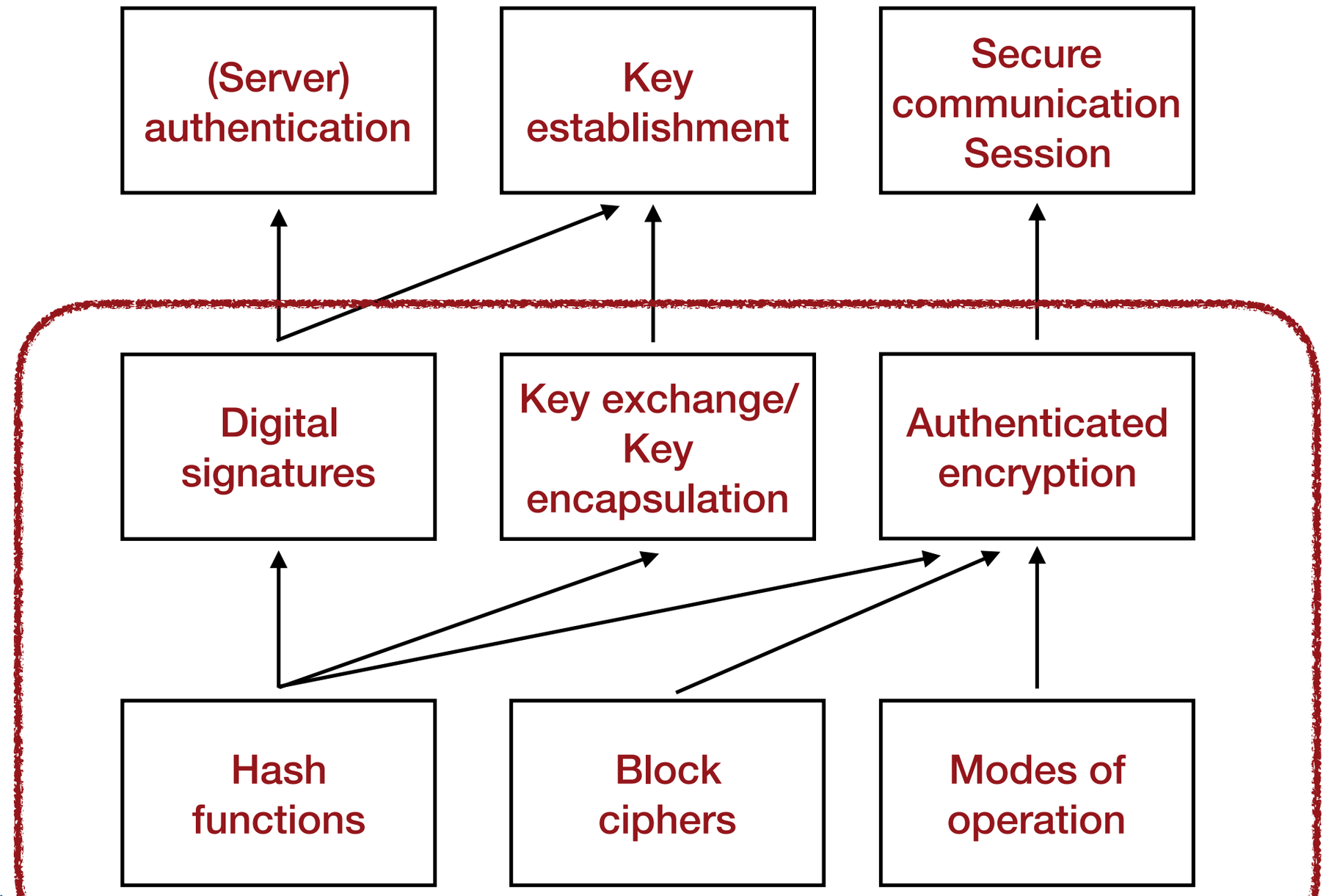

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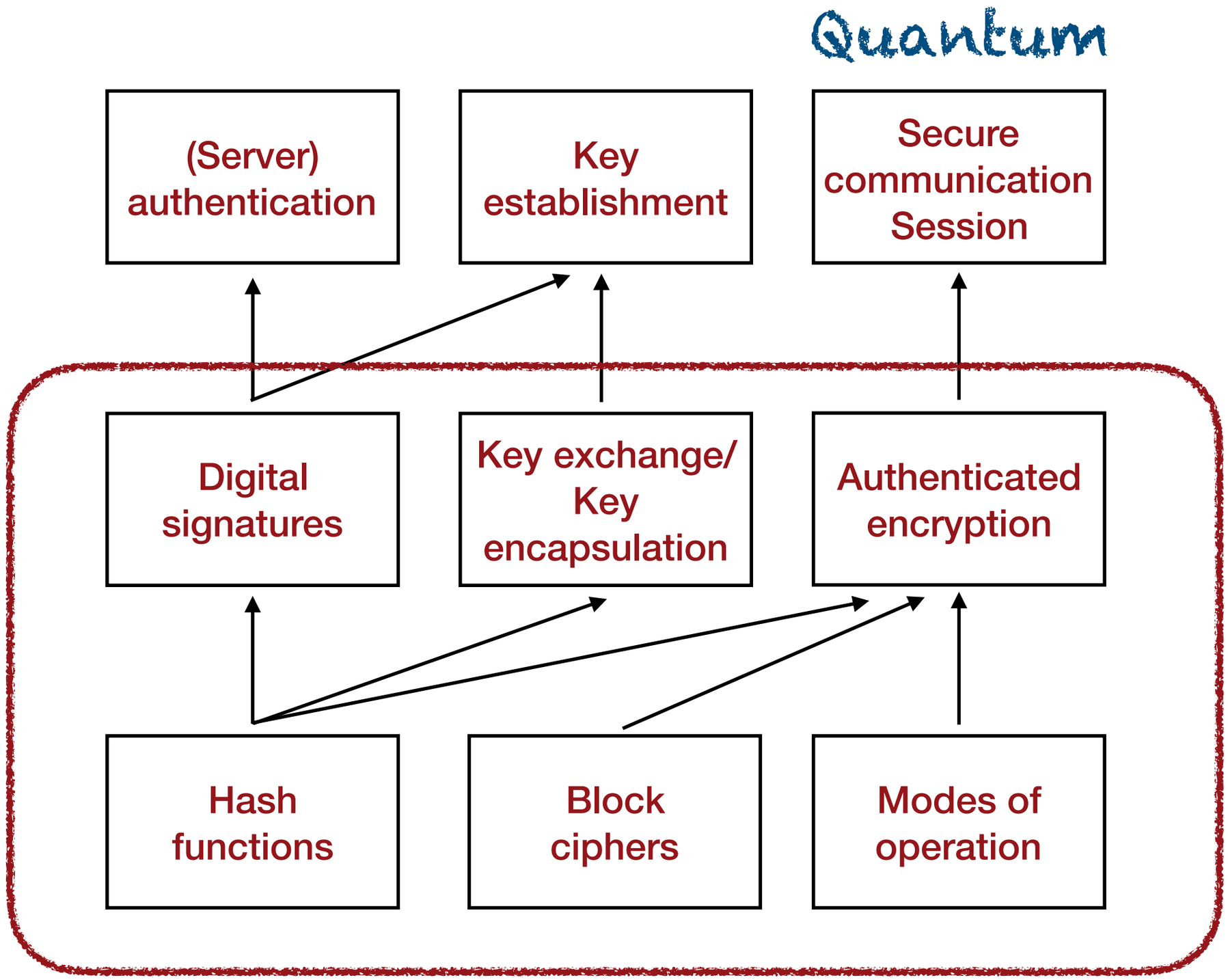

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"post-quantum"

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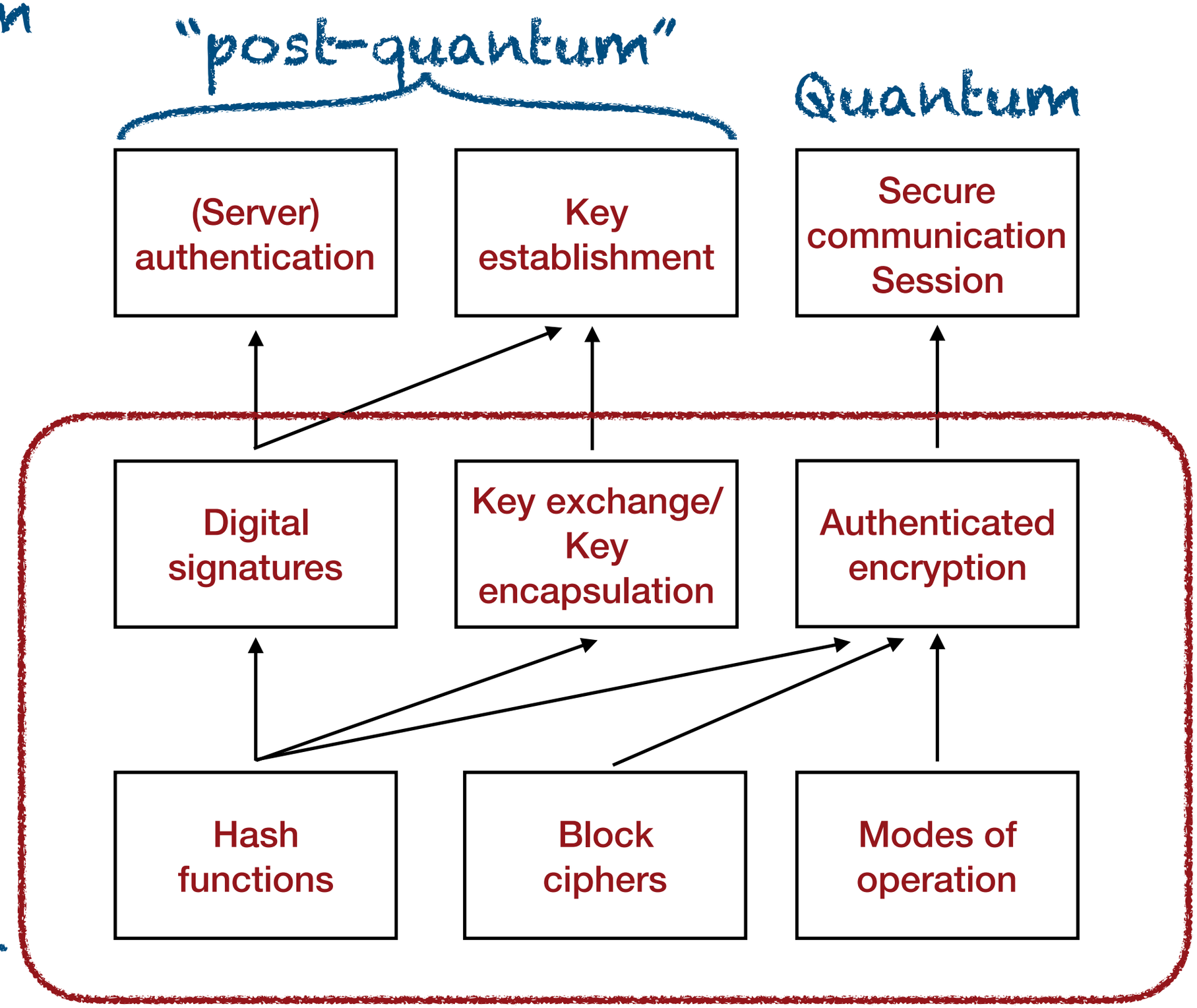

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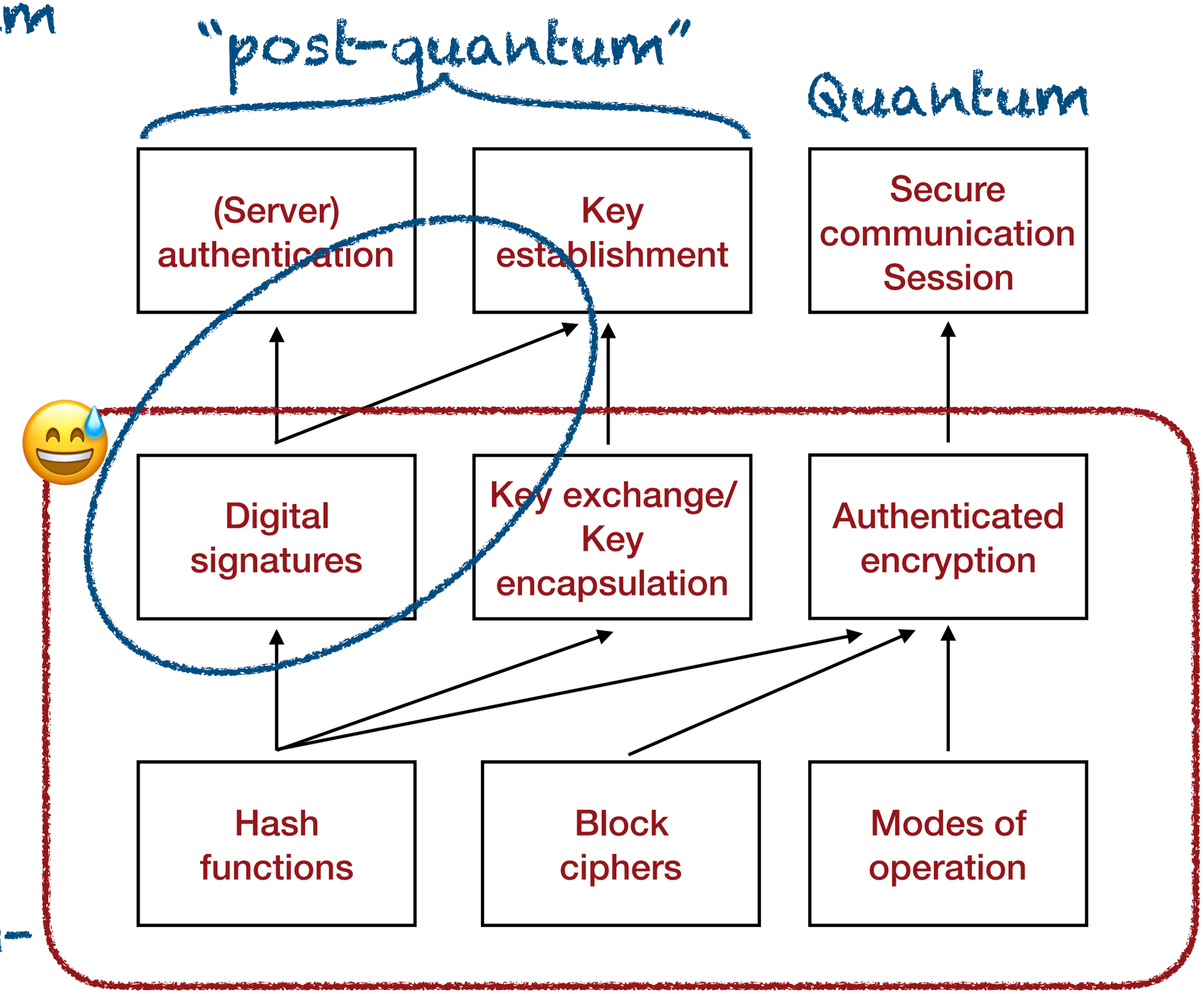
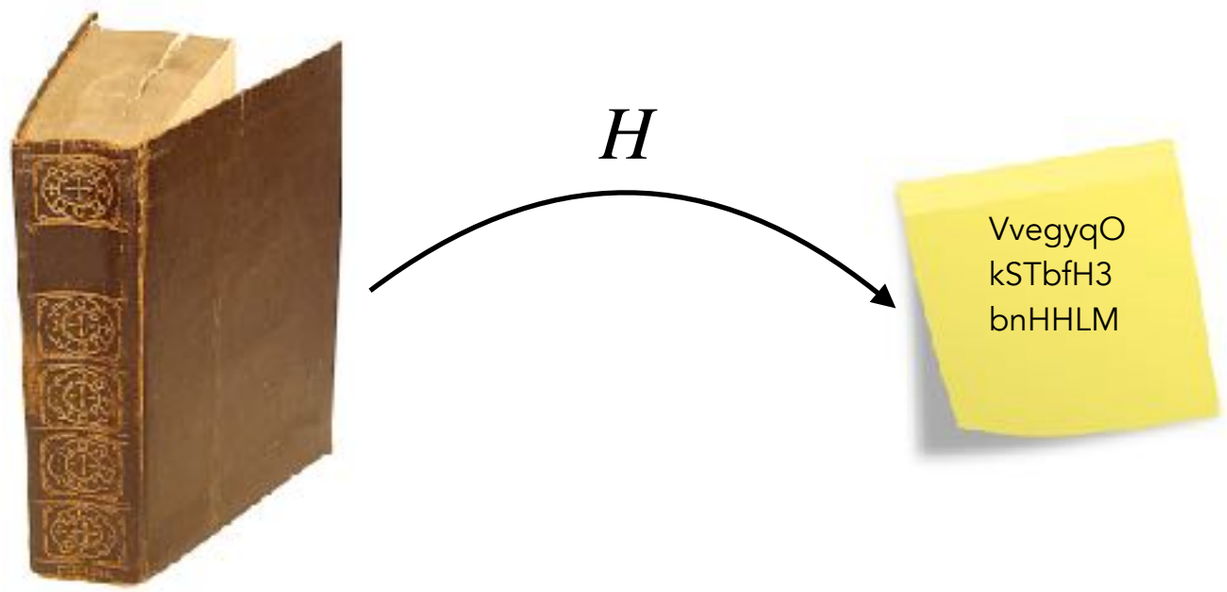


Are we ready for encrypting the quantum internet?

Hash Functions

Hash functions



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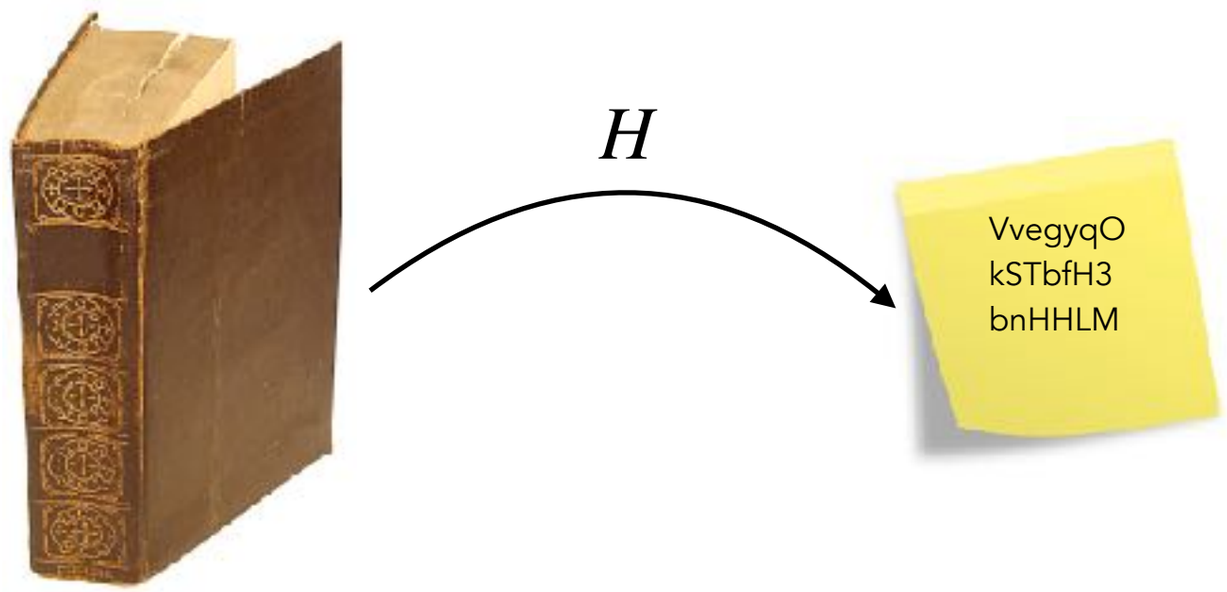

Ubiquitous in cryptography. Examples:

- Key encapsulation mechanisms
- Digital signatures
- Message authentication codes
- …

Hash function security

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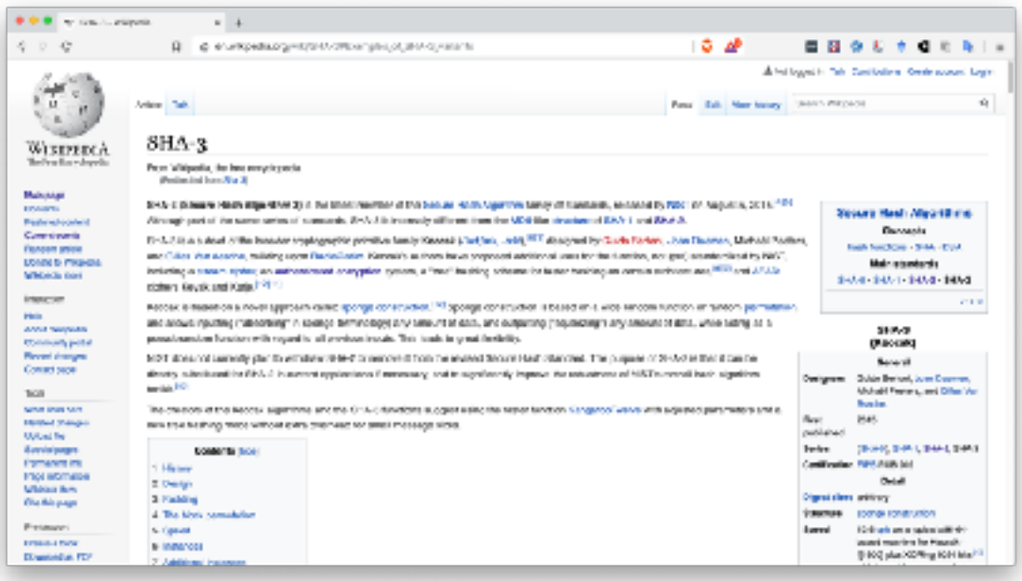

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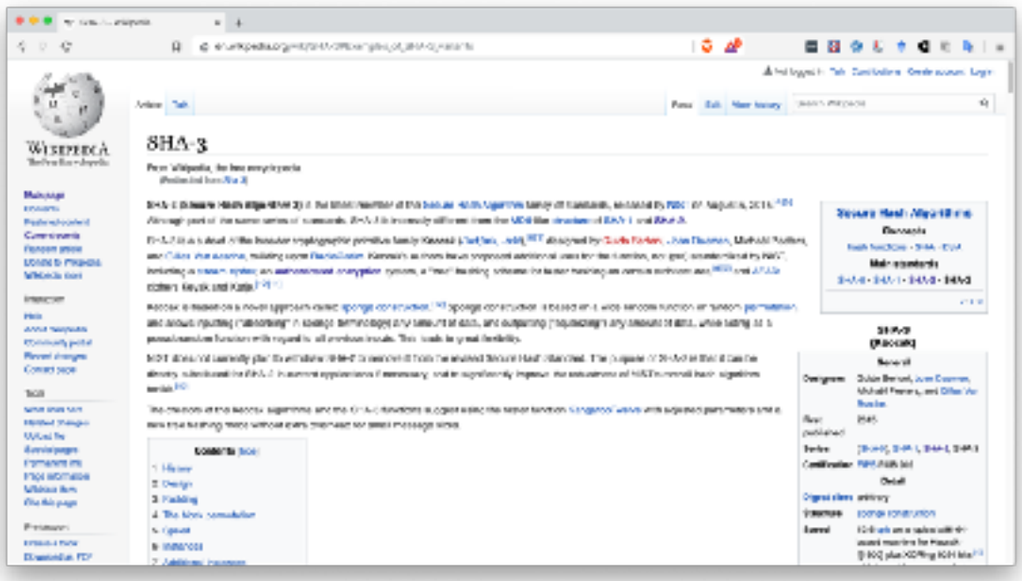

Model

$H : \{0,1\}^* \to \{0,1\}^n$

Uniformly random

All agents have oracle access to H

Hash function security

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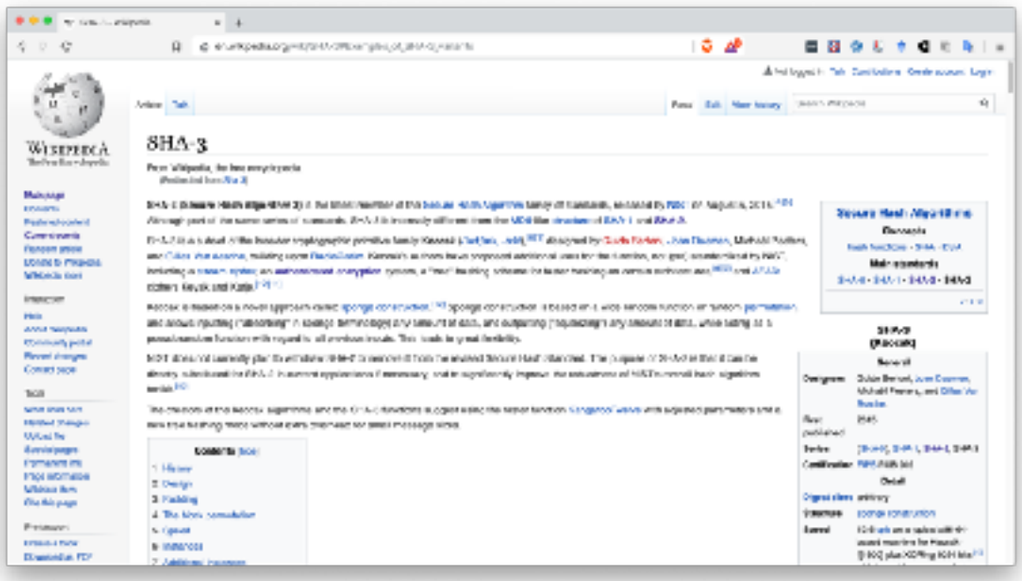
Reality



Model

$H : \{0,1\}^* \to \{0,1\}^n$

Uniformly random

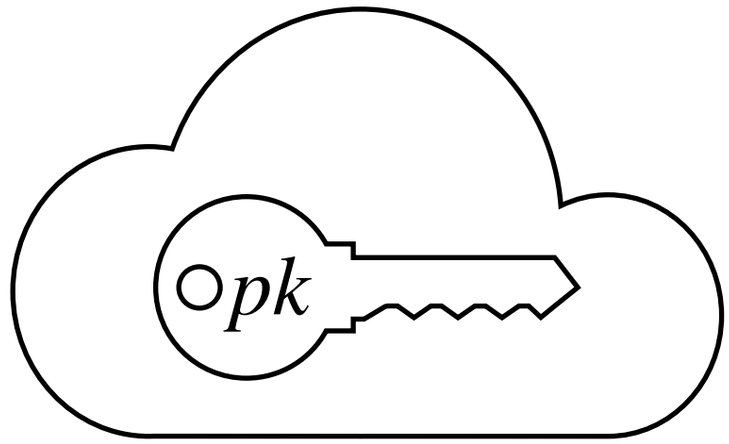
All agents have quantum oracle access to H

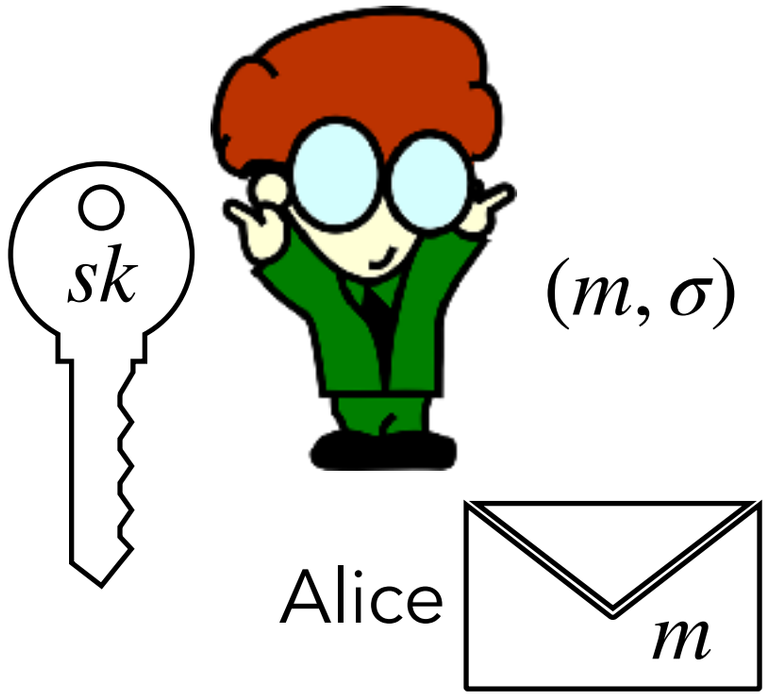
Quantum Random Oracle Model (Boneh et al. ’10)

Are we ready for encrypting the quantum internet?

Digital Signatures II

Digital signatures





Bob

$\sigma = \mathrm{Sign}_{sk}(m)$

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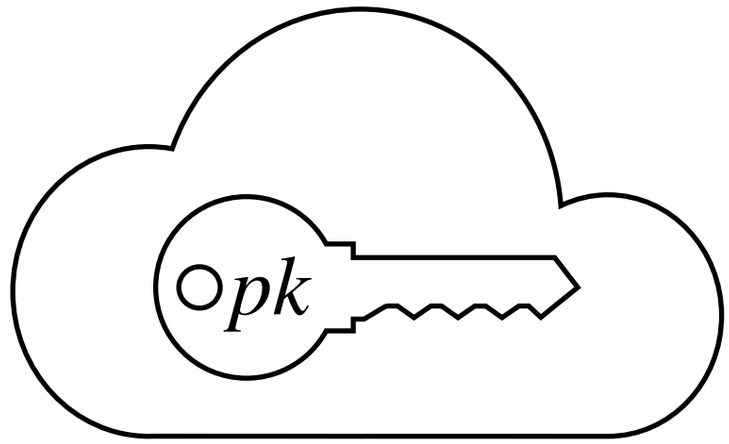
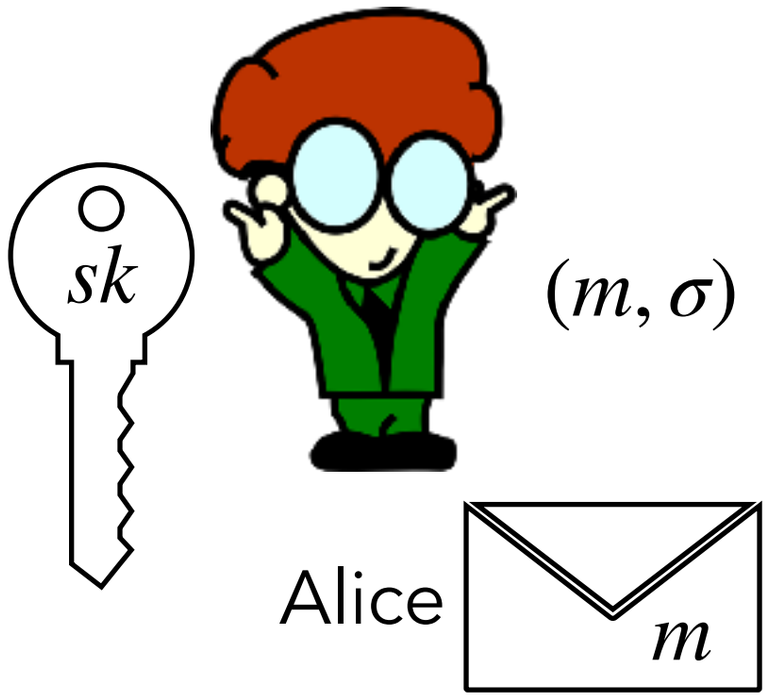
Digital signatures





(m, σ)

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Computed in polynomial time

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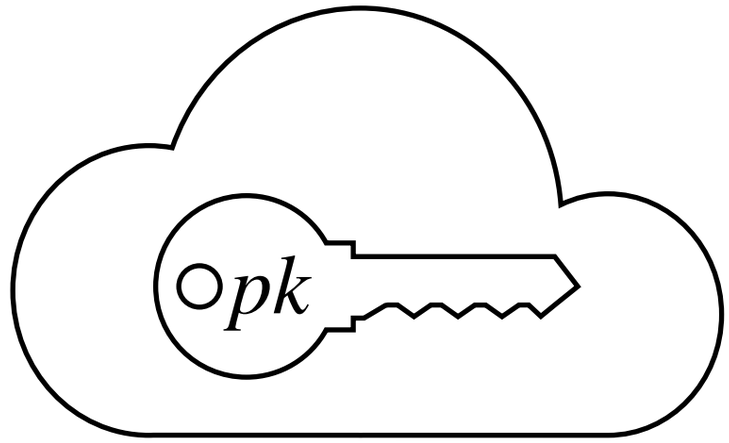
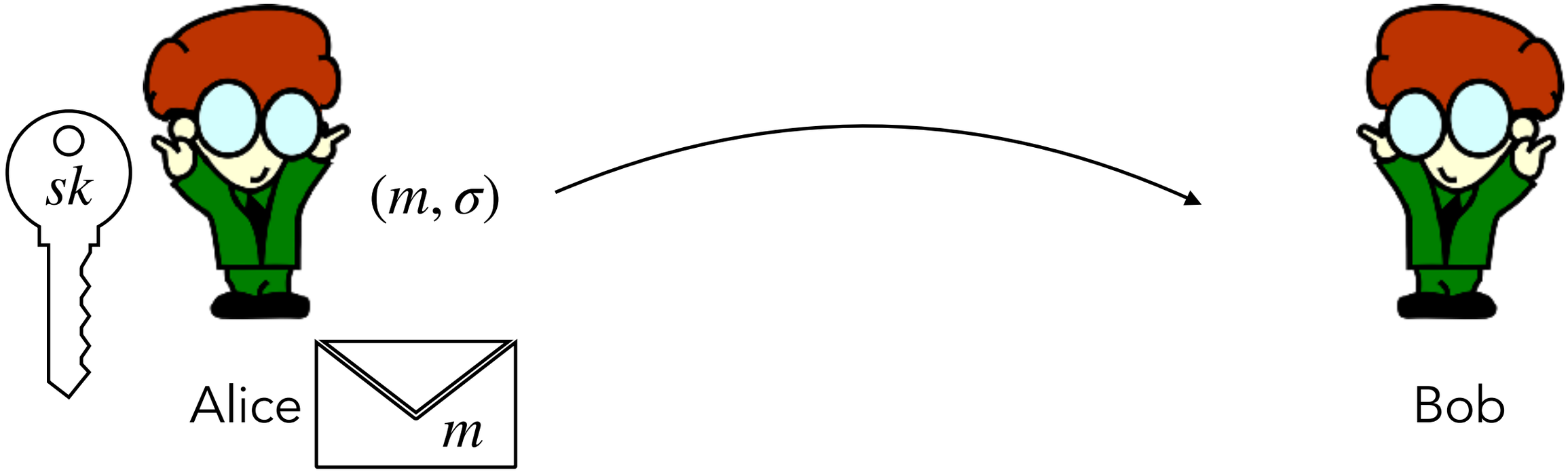
Digital signatures

post-quantum





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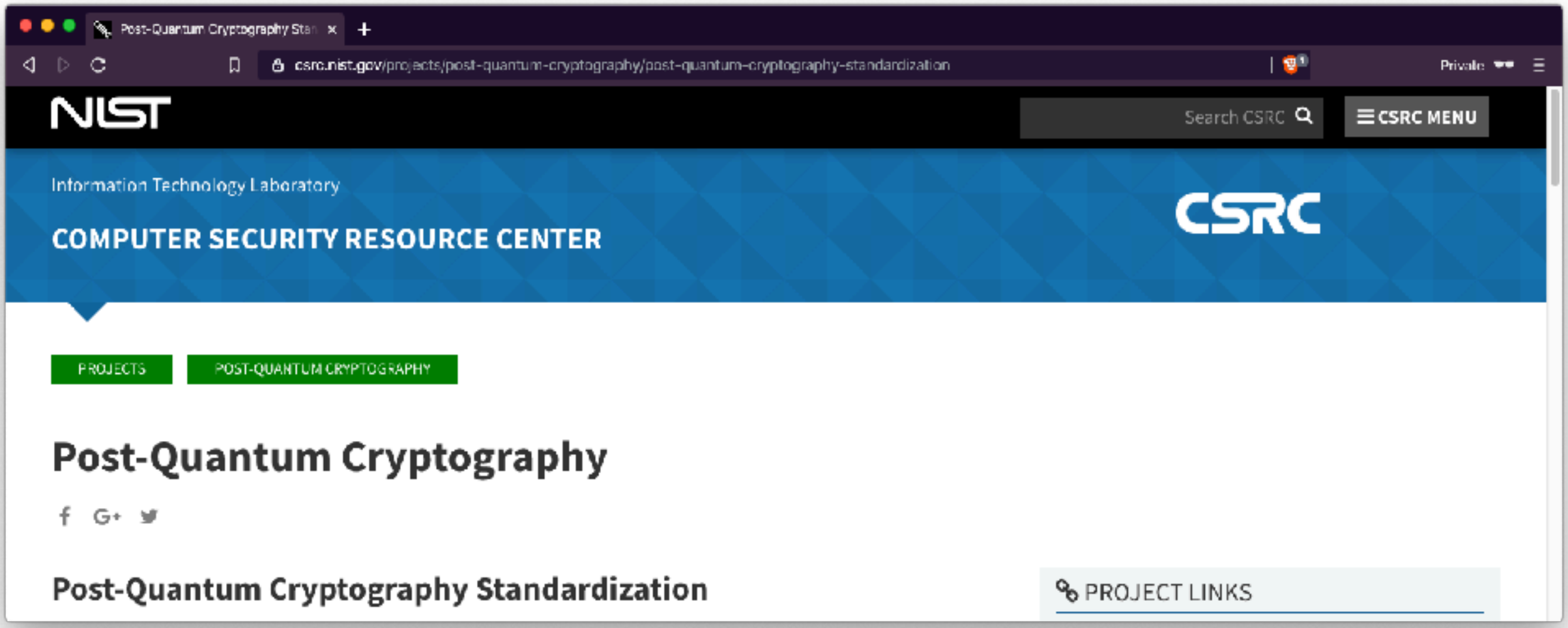
NIST competition



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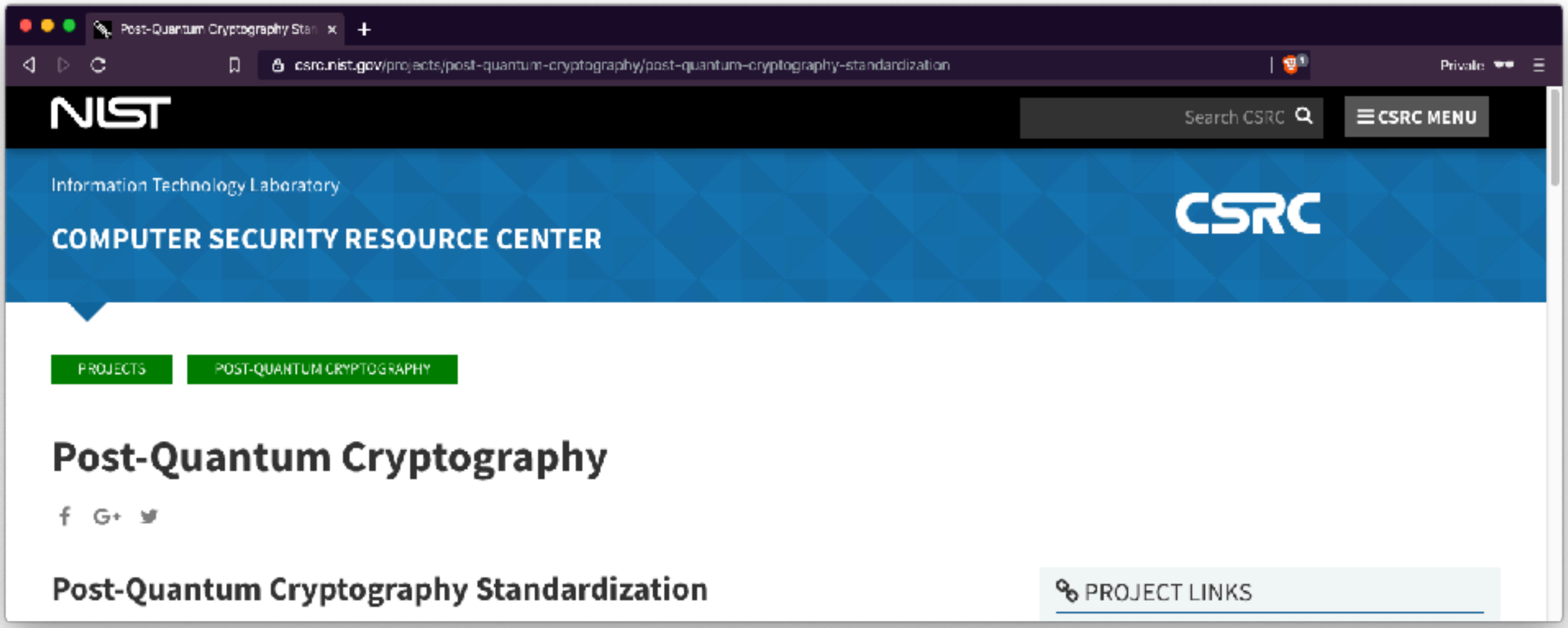
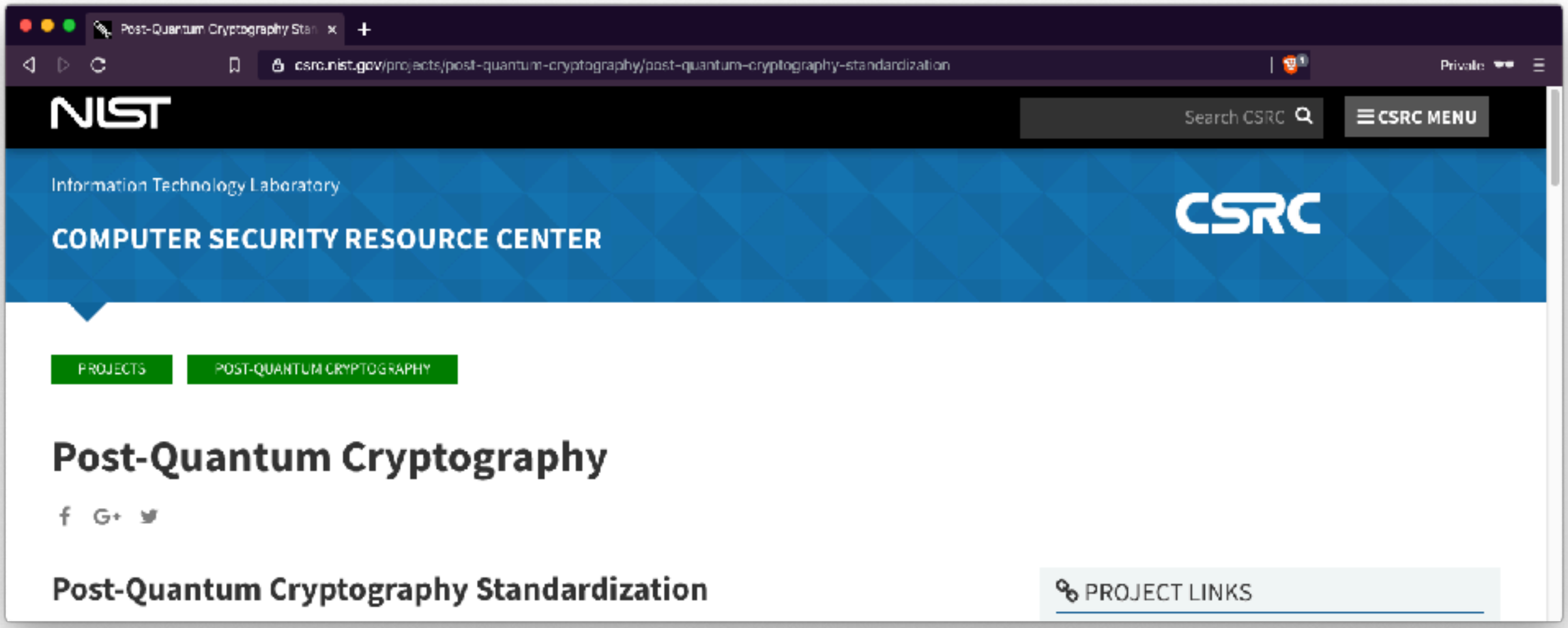


Goal: Standardize post-quantum secure signatures and key encapsulation mechanisms.

NIST competition



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4/9 round 2 signature schemes use *Fiat Shamir transformation*

Fiat Shamir transformation

Removes interaction from *identification schemes* using hash functions

Like signature but
with interactive verification

Fiat Shamir transformation

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Key Exchange

Post-quantum key exchange

This is what Quantum Key Distribution (QKD) can do!*

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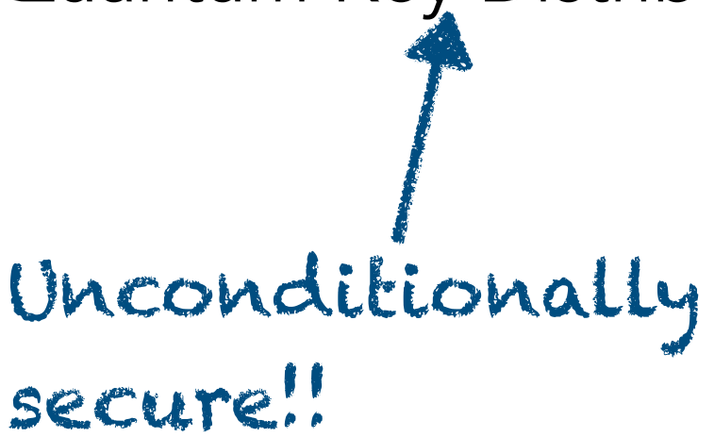

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+Classical $\Longrightarrow$ more efficient

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Alternative: post-quantum secure Key Encapsulation

+ Classical $\Longrightarrow$ more efficient
− Computational assumptions (similar to signatures, current internet crypto…)

Are we ready for encrypting the quantum internet?

Authenticated Encryption

The TLS protocol

Quantum

"post-quantum"

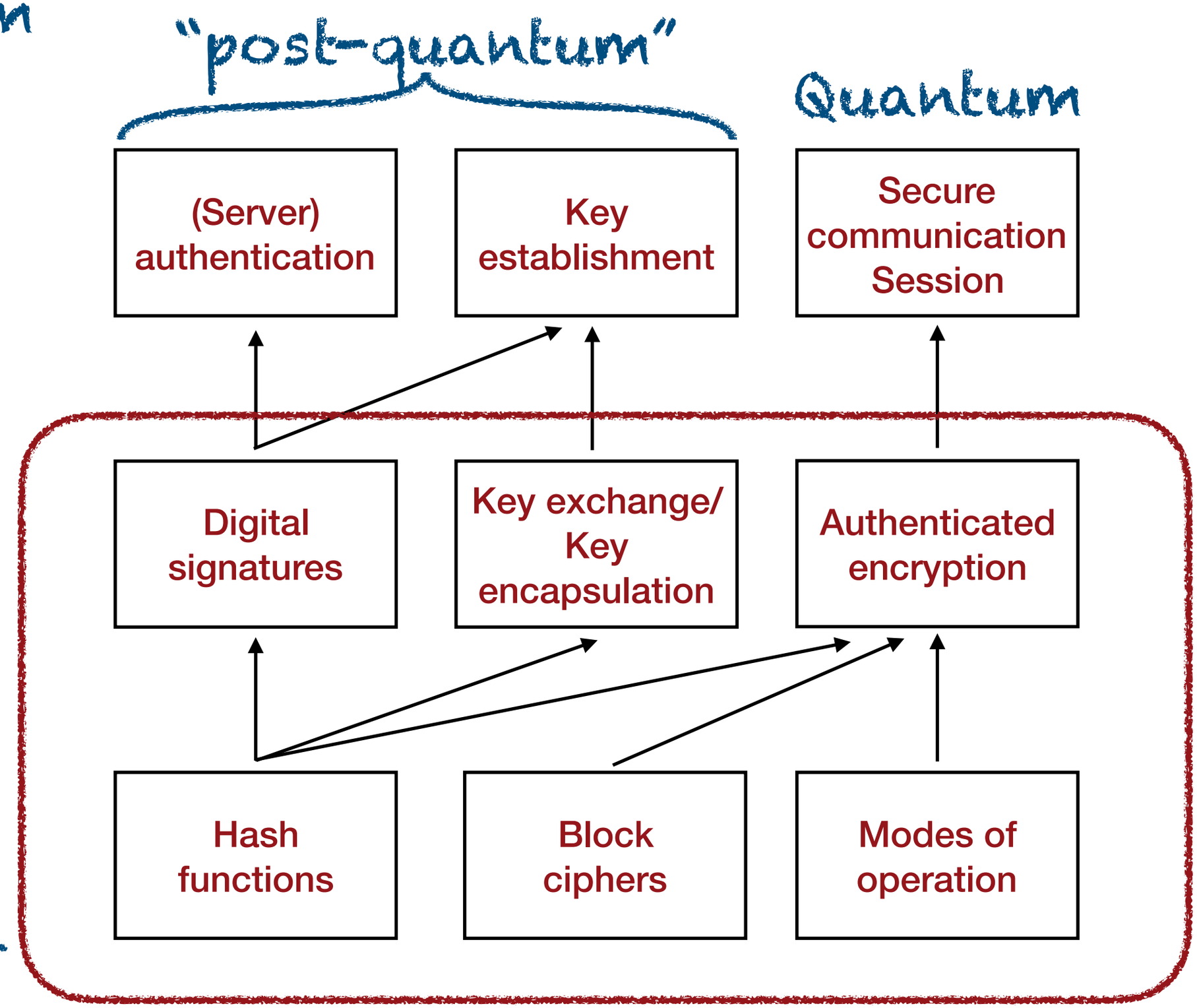
Quantum

Functionalities

Protocols

Cryptographic Ingredients

Quantum-ready?



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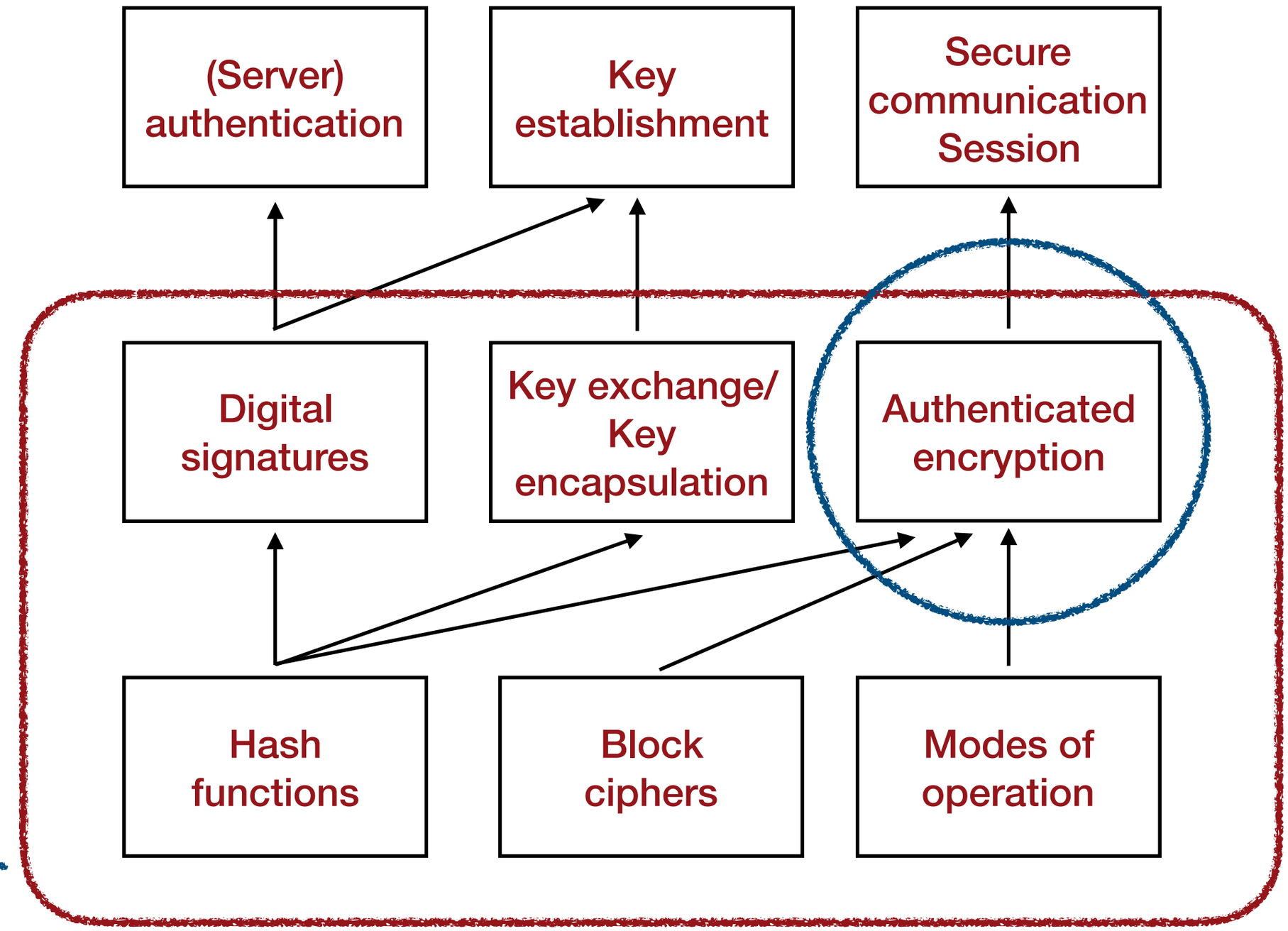


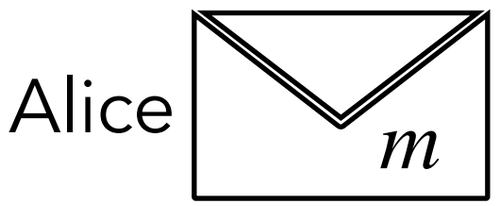
Authenticated Encryption

Authenticated Encryption

Alice

Bob

Authenticated Encryption



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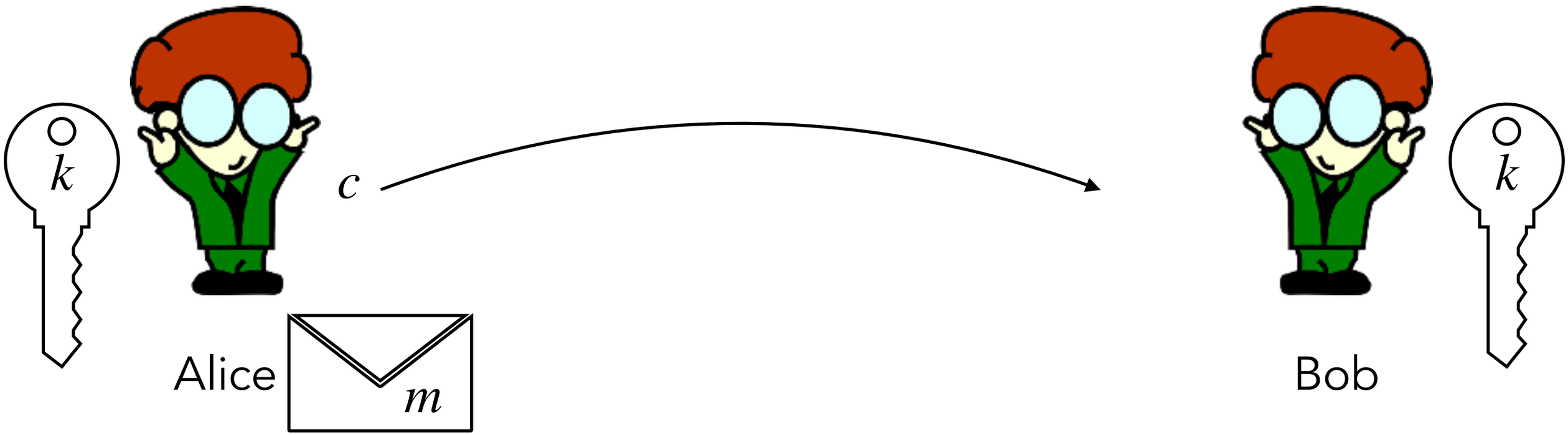

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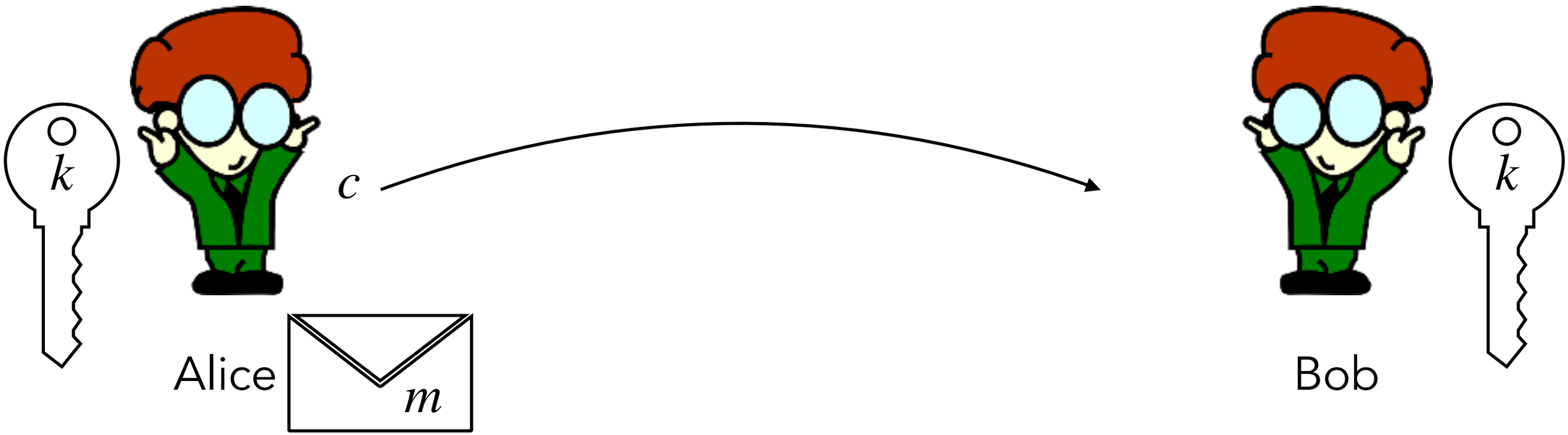

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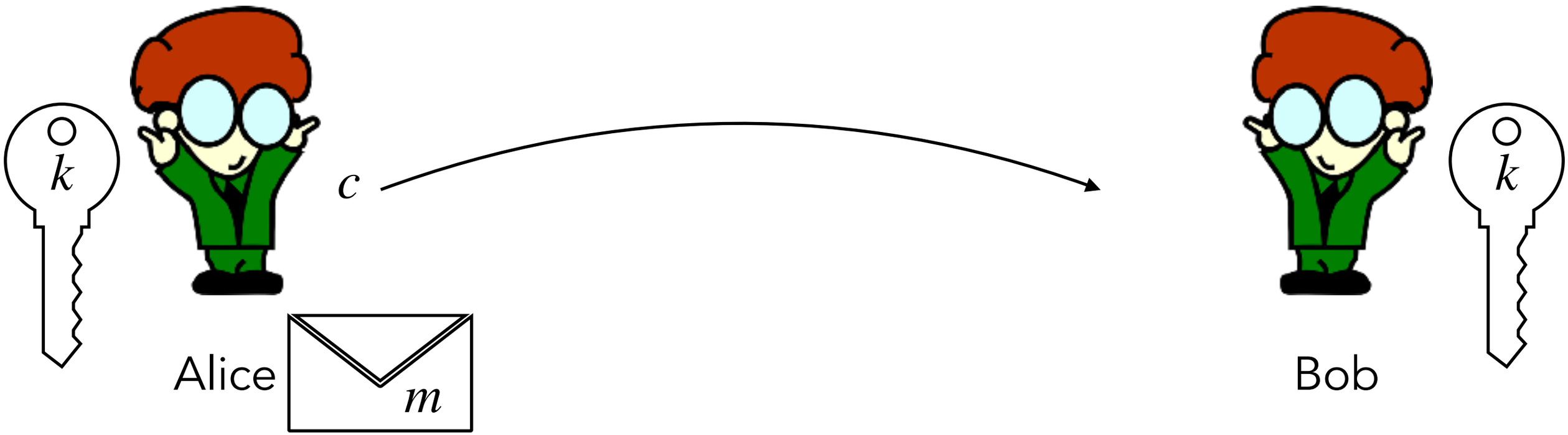

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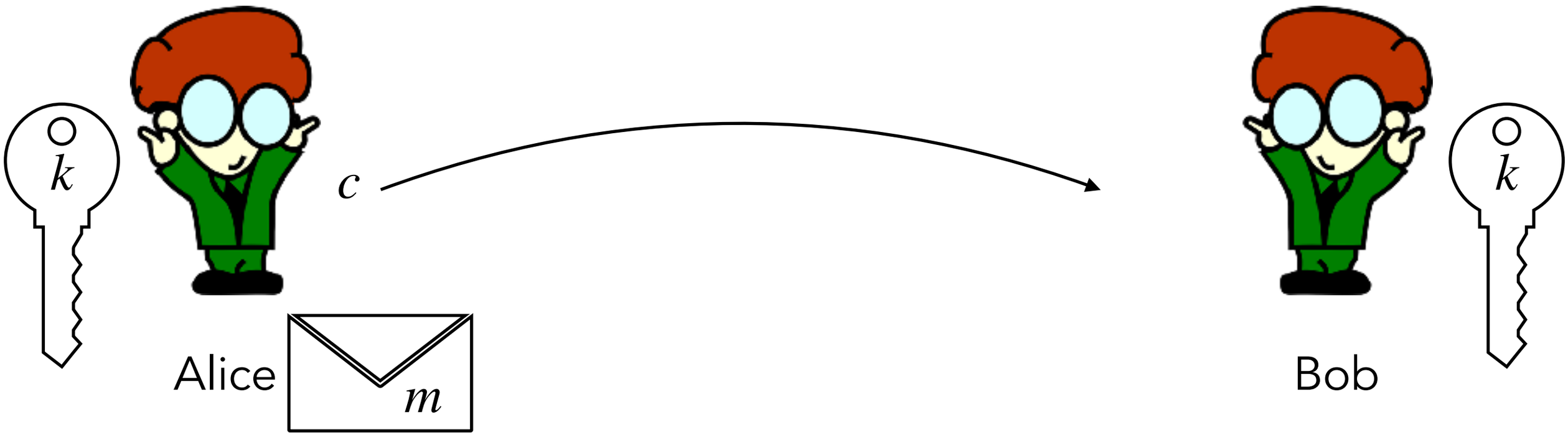

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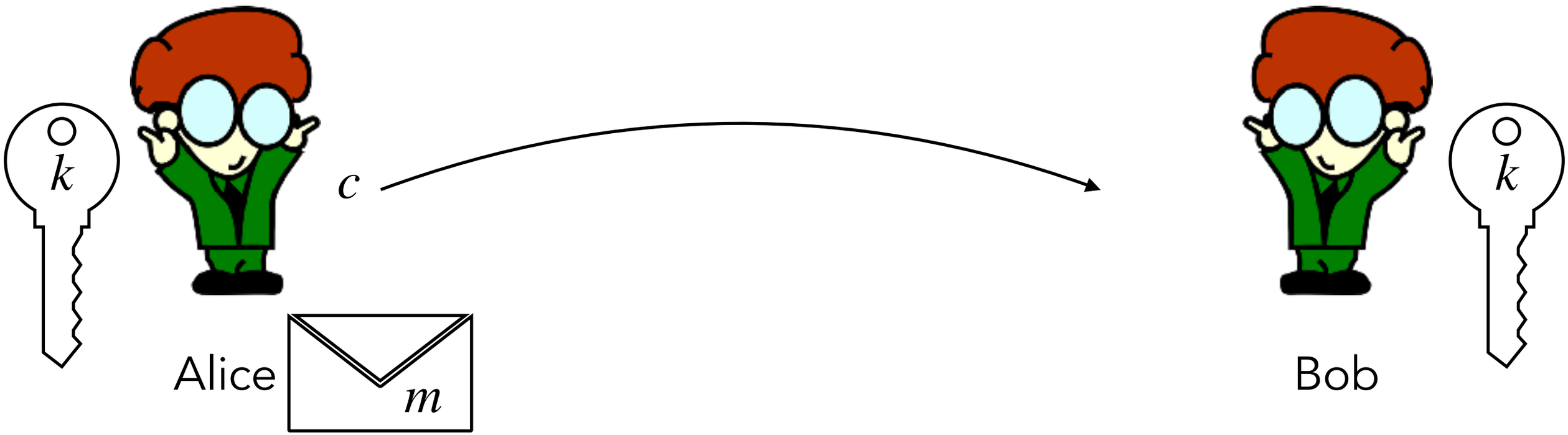

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Slightly simplified...

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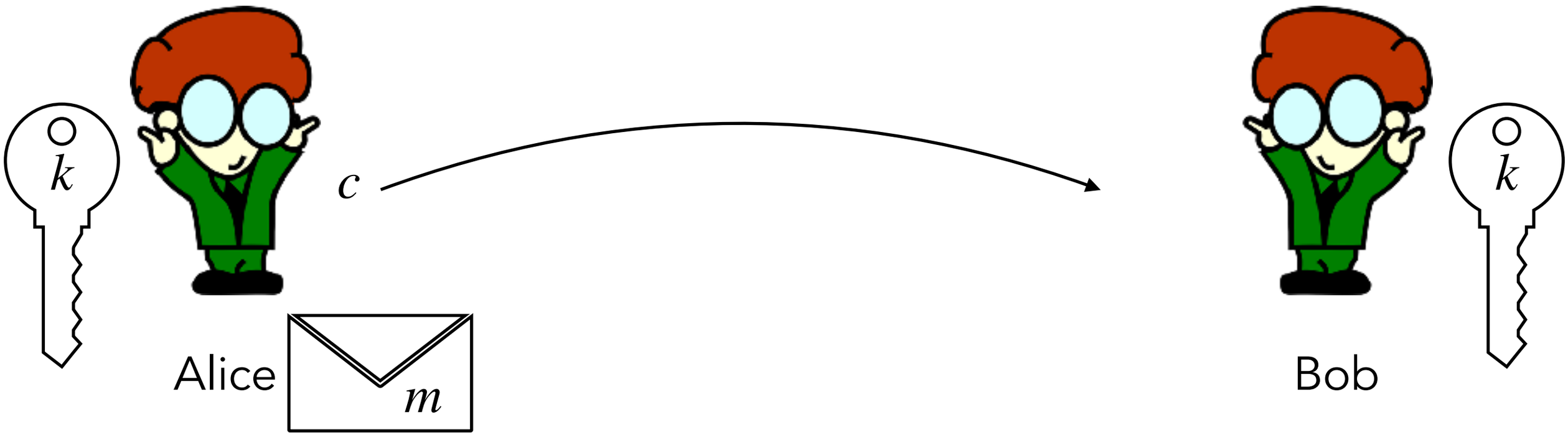

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Confidentiality+Integrity=Authenticated encryption

Real vs. Ideal

Alternative characterization (Shrimpton ’04):

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Real

Ideal

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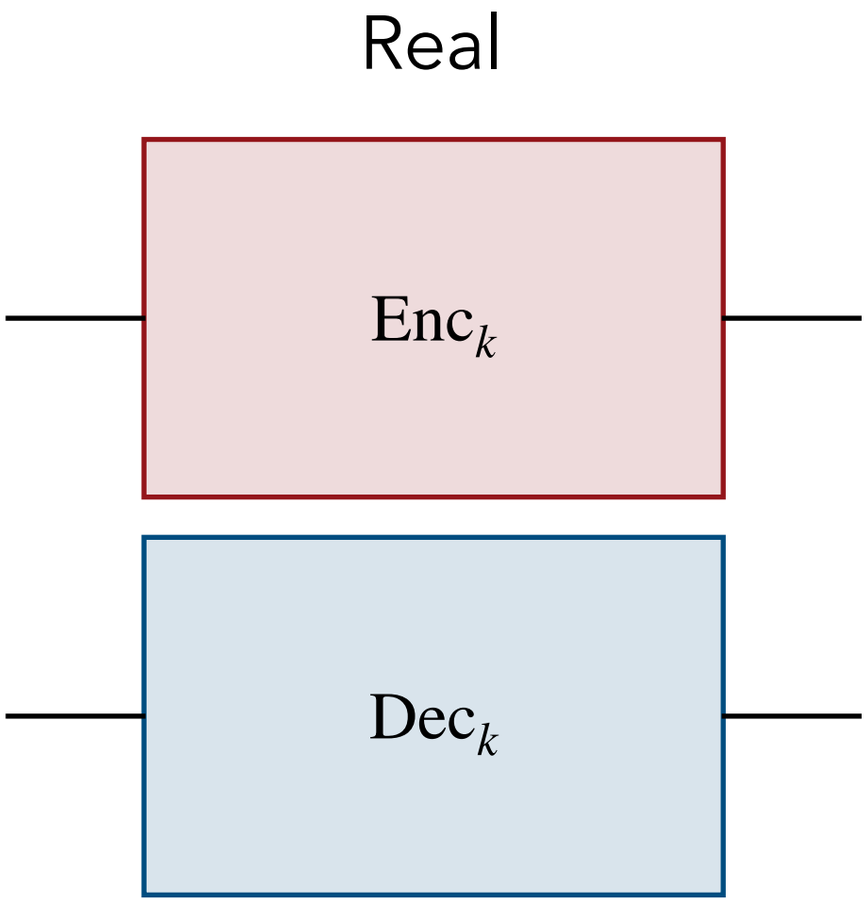

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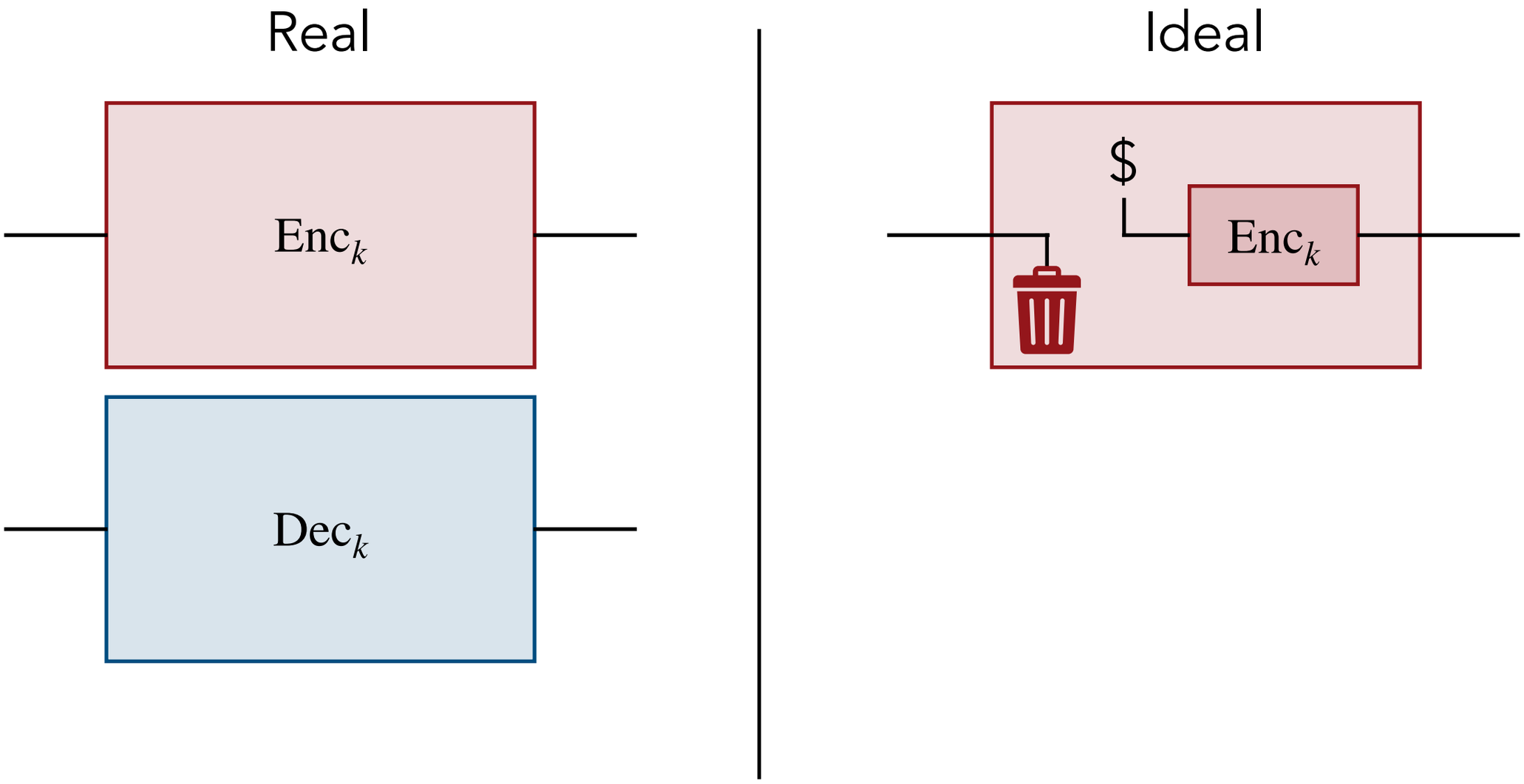

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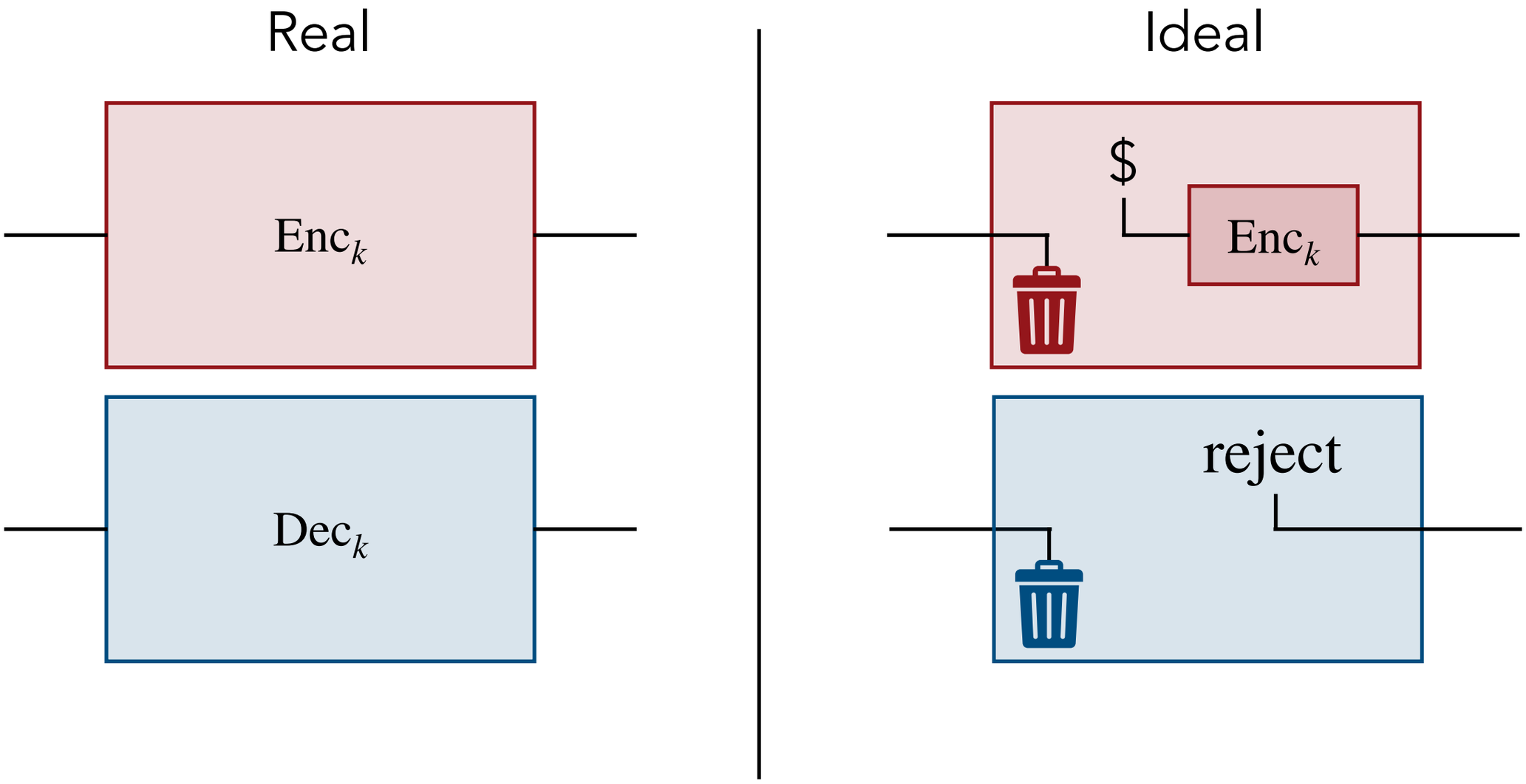

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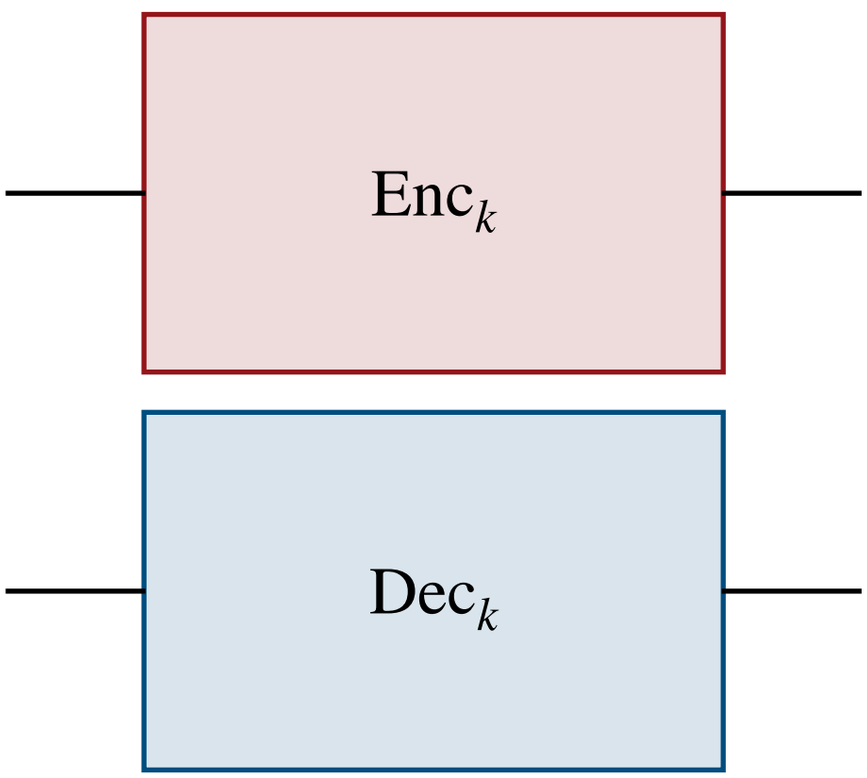

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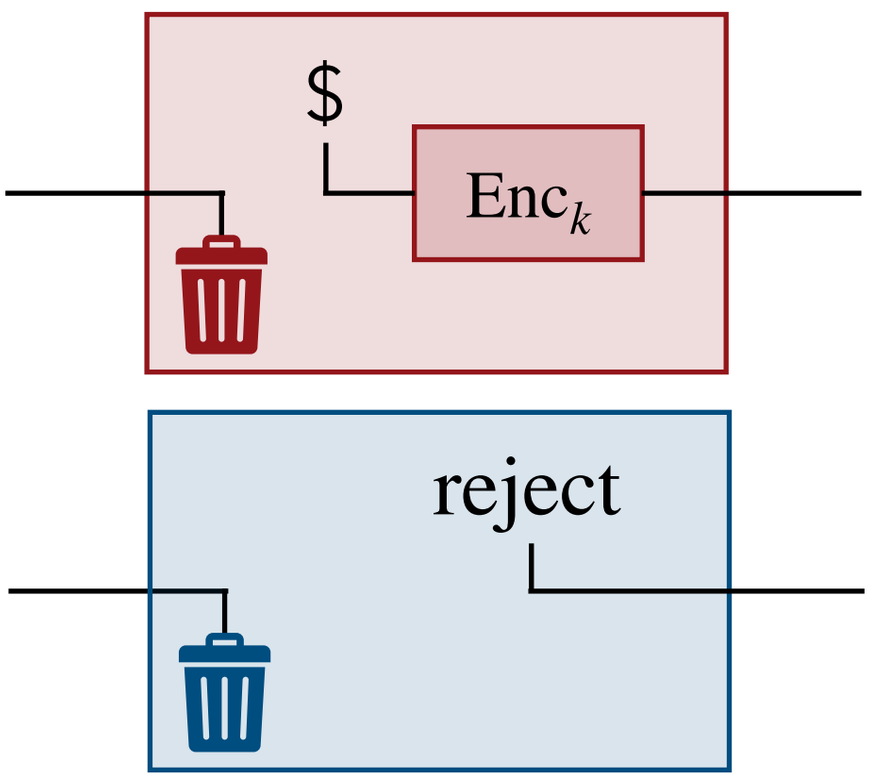

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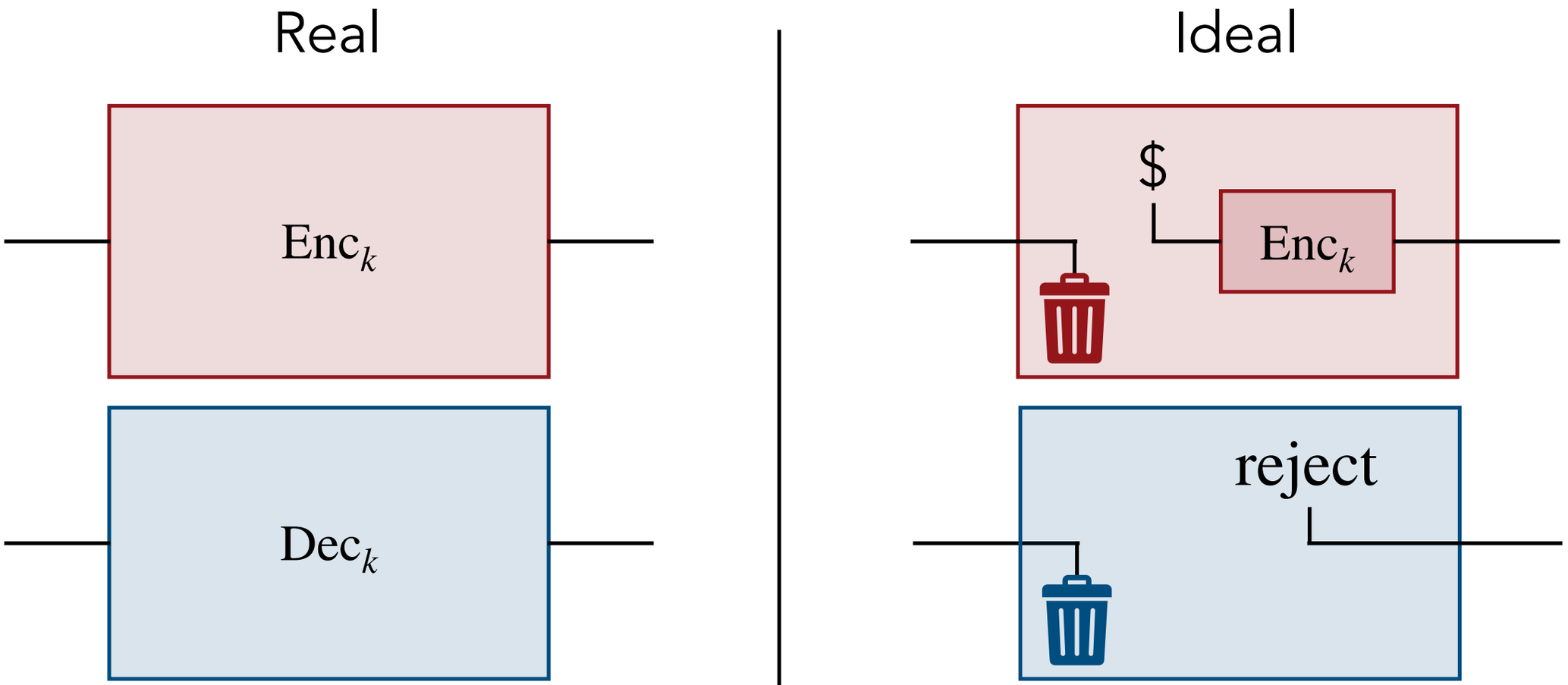

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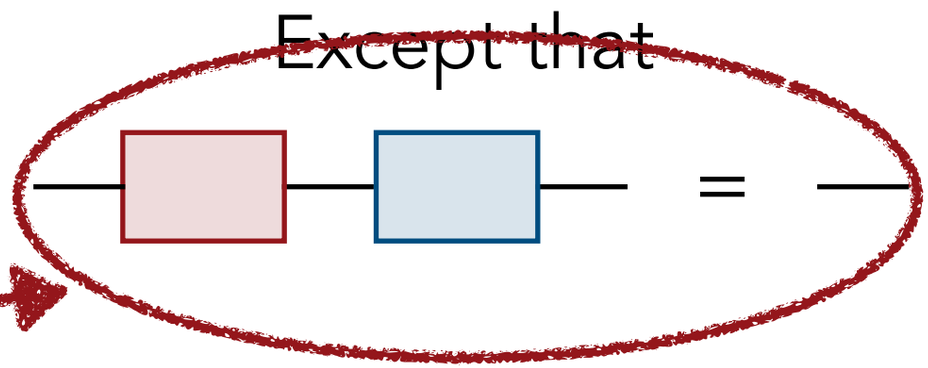

Enforced by keeping a list of input-output-pairs of

Quantum authenticated encryption

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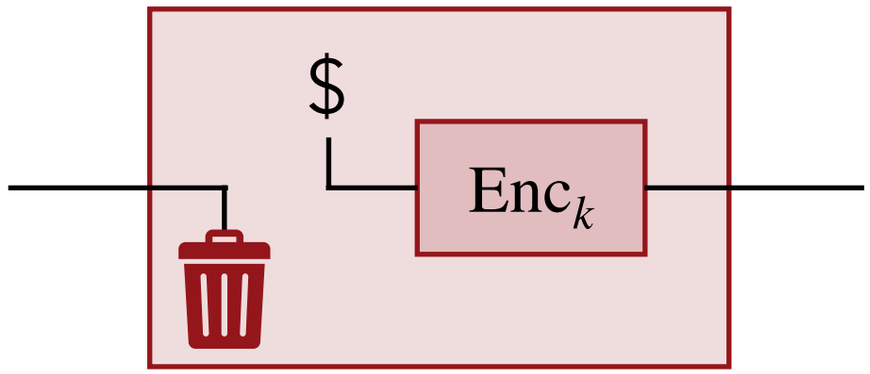

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Alagic, Gagliardoni, M '18: Definition of quantum authenticated encryption

- Reduces to authenticated encryption for classical schemes
- Can be satisfied with simple hybrid encryption

Summary and open problems

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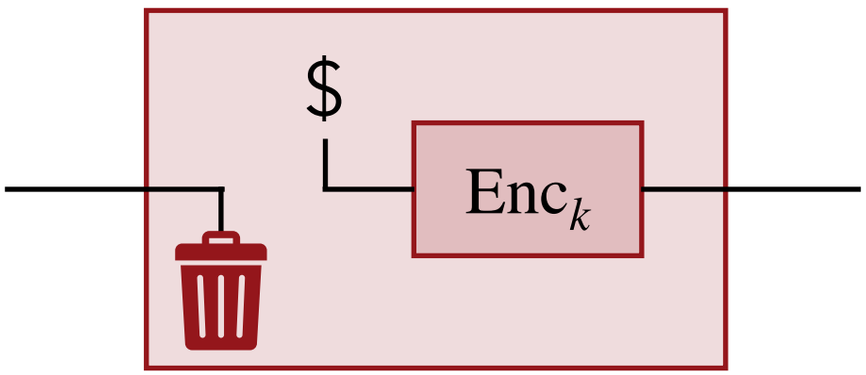
  - Noninteractive verification of quantum computation…



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