Diverse Modules and Zero-Knowledge

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Thèse effectuée à l'ENS
sous la direction de
Michel Abdalla et David Pointcheval

IBM Research

Congrès SIF 2017
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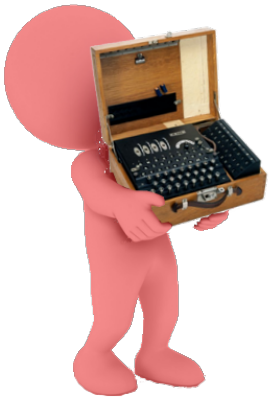
Introduction



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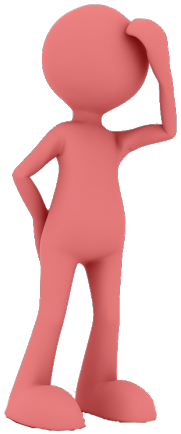

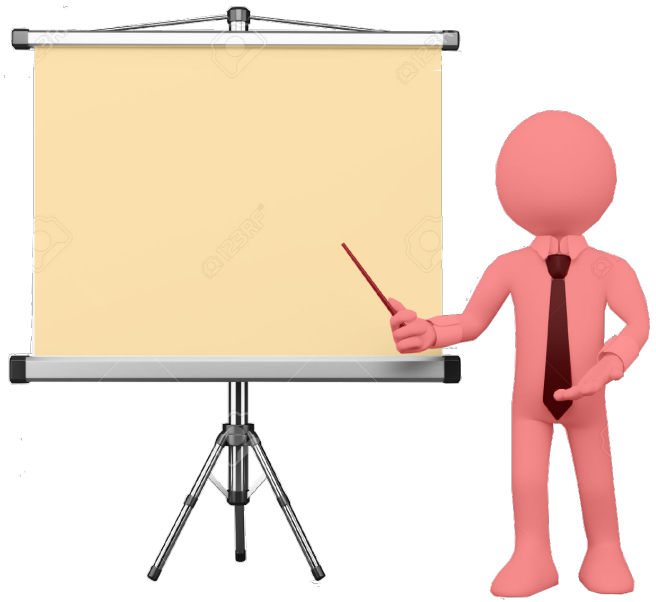

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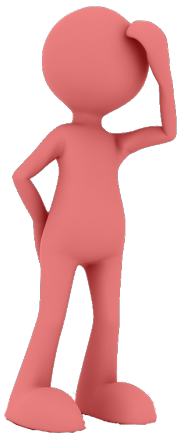
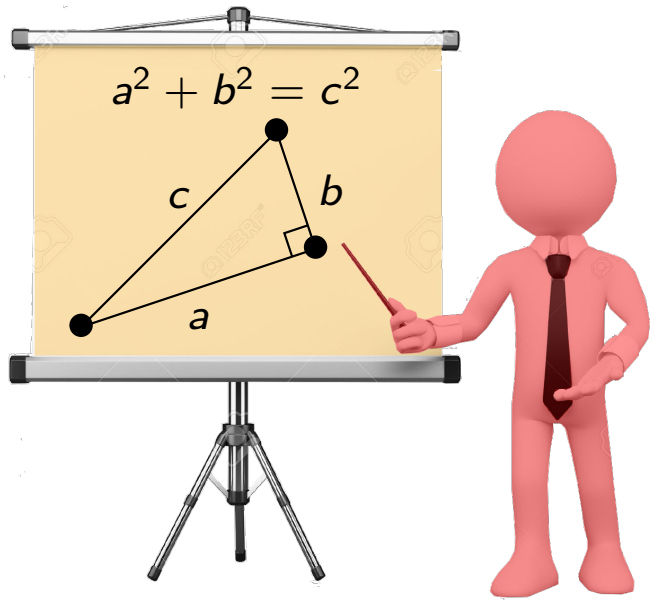
  statement — e.g., Pythagorean theorem





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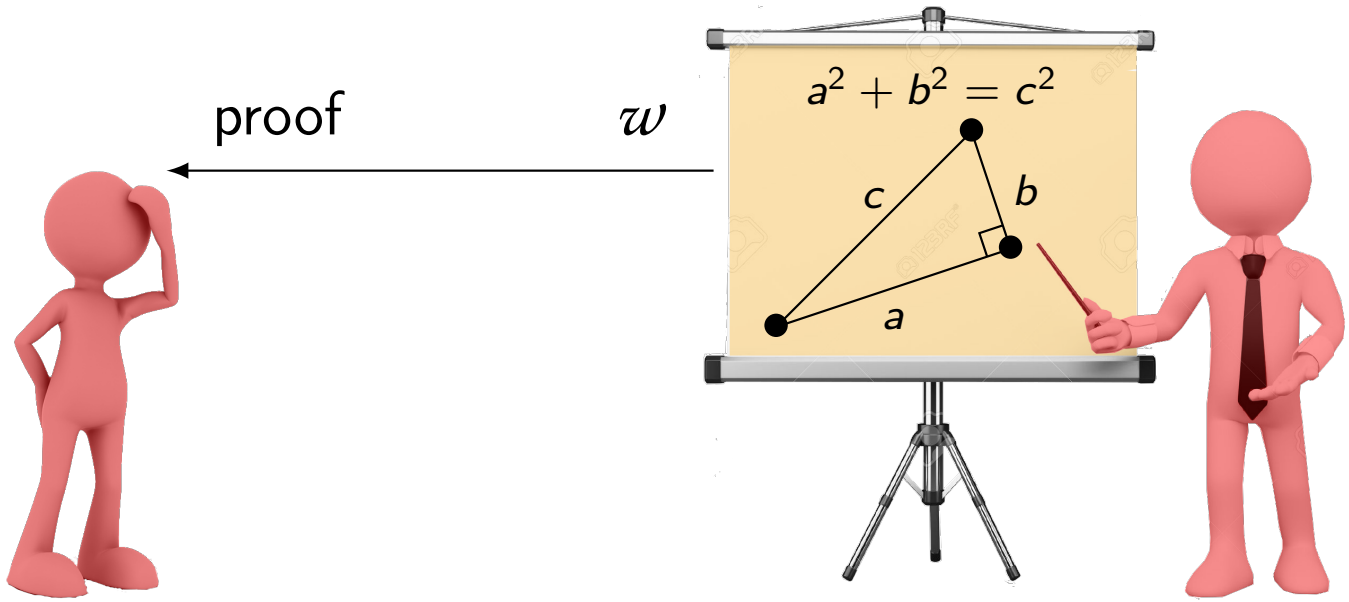

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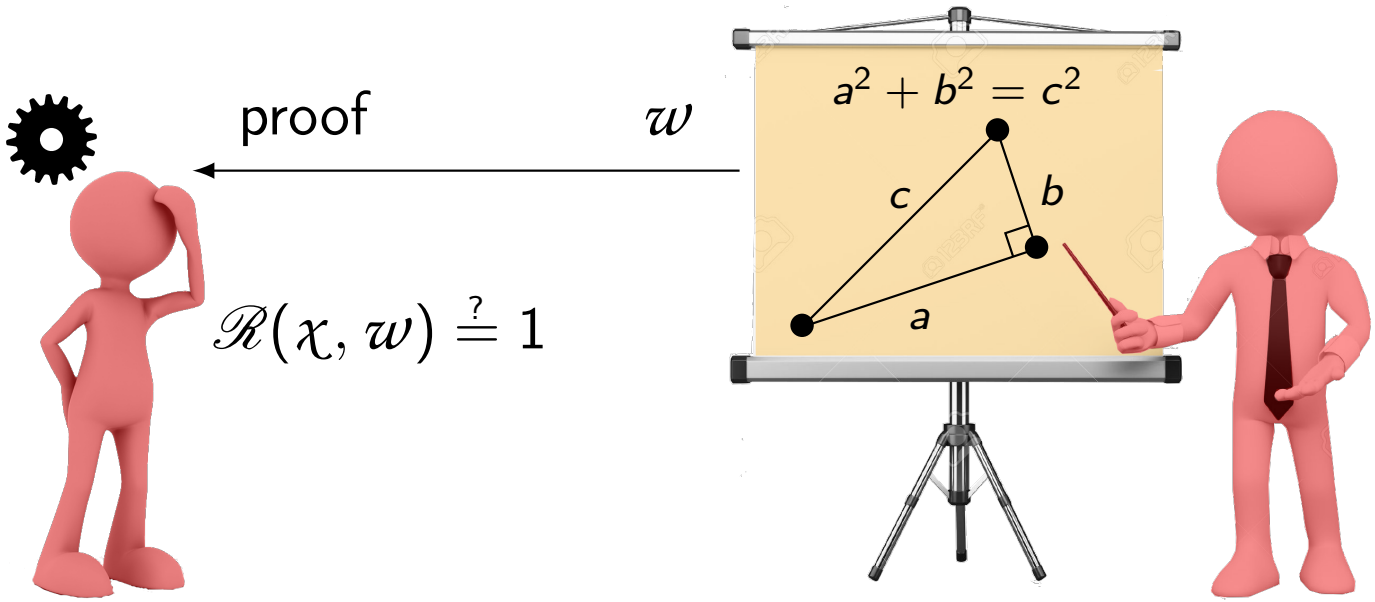

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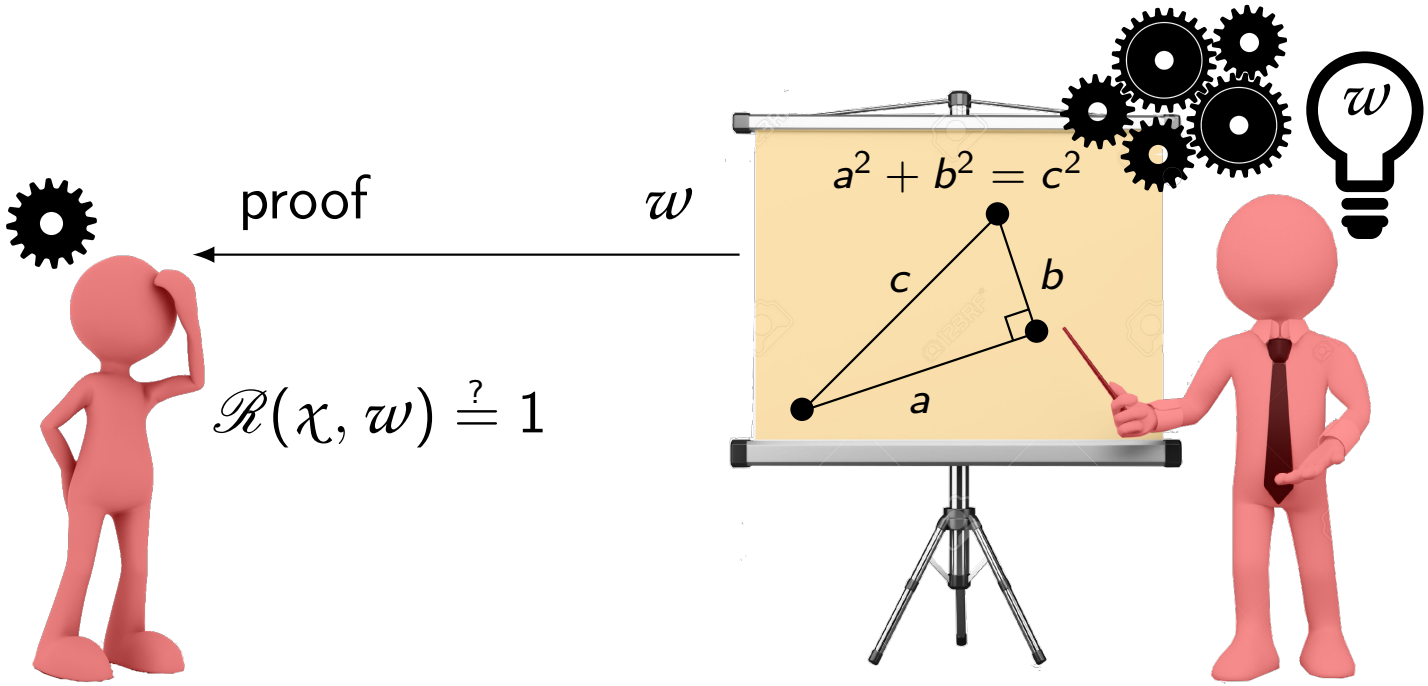

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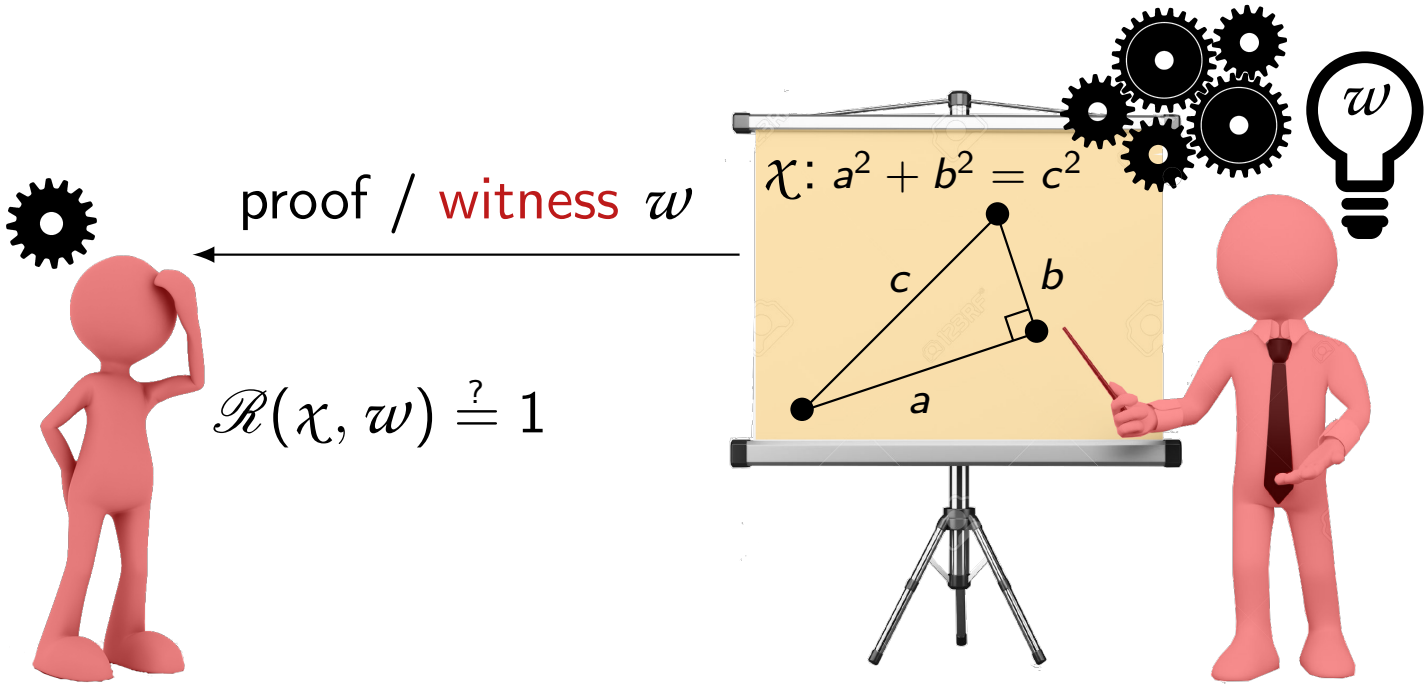
$$x \in \mathscr{L} \subseteq \mathscr{X} \iff \exists w,\ \mathscr{R}(x, w) = 1;$$



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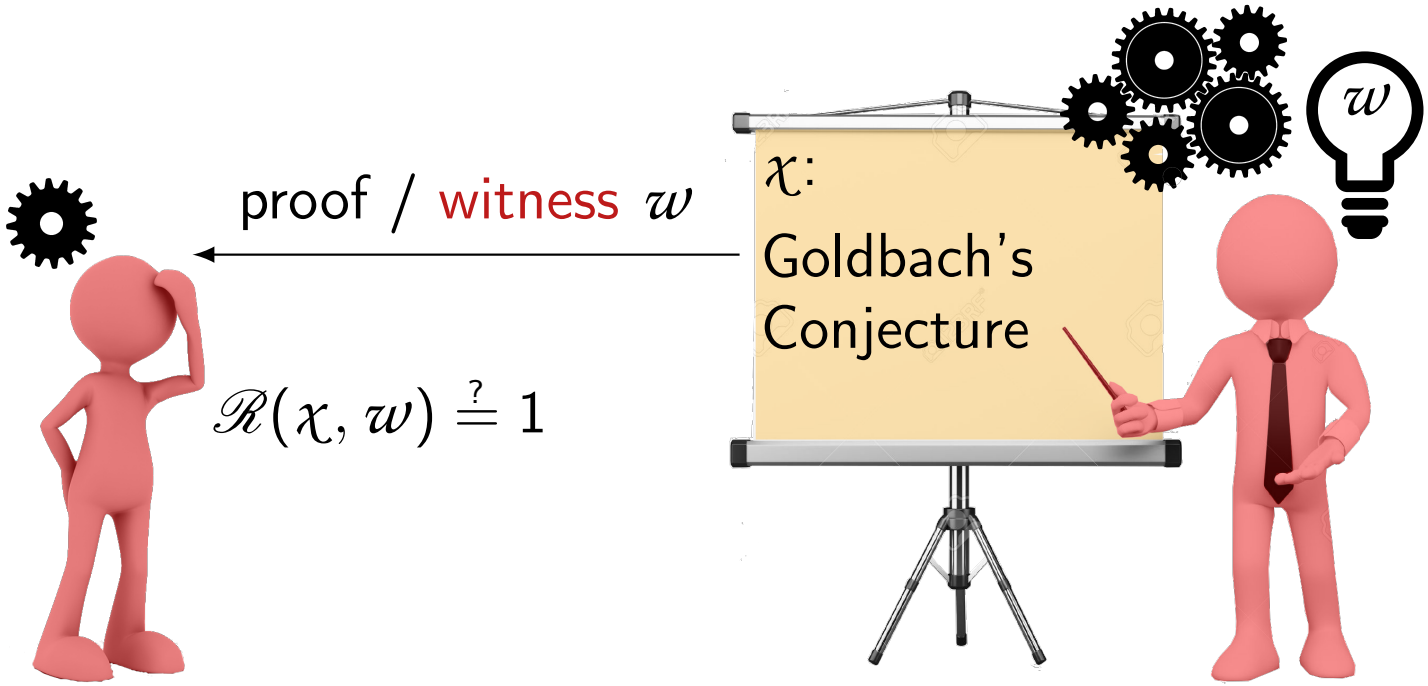

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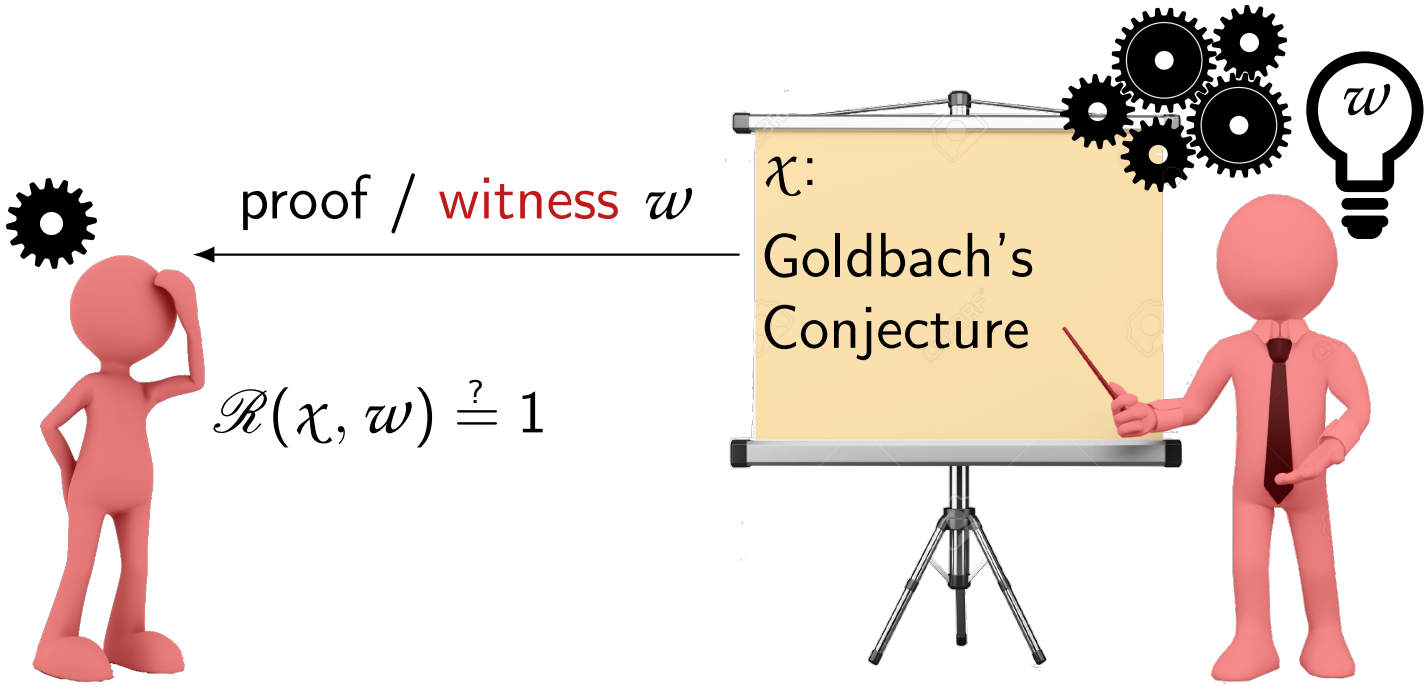
  - Goldwasser-Micali-Rackoff 1985
  - Verifier learns nothing except "$x \in \mathscr{L}$"



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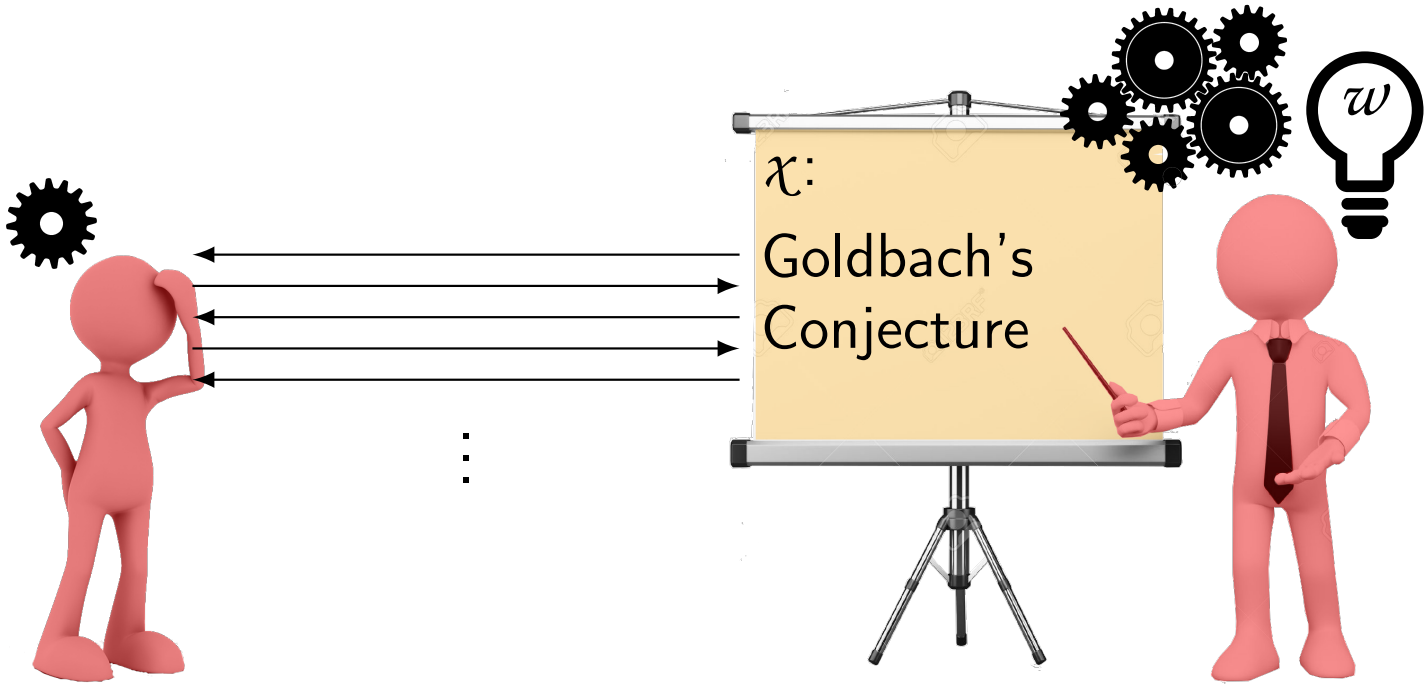

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Hash Proof Systems / Smooth Projective Hash Functions (SPHFs)

- Introduced by Cramer and Shoup [CS02]
  - → IND-CCA encryption scheme [CS98]
- Applications:
  - Password-Authenticated Key Exchange (PAKE) [KOY01, GL03, KV11]
  - Oblivious Transfer [Kal05, ABB+13]
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More Complex Languages

Smooth Projective Hash Functions (SPHFs)

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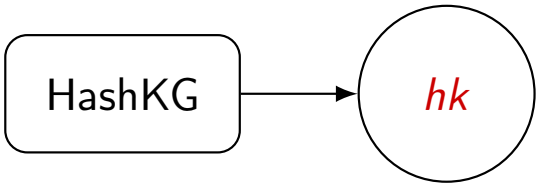
NP language $\mathscr{L}$: $x \in \mathscr{L} \subseteq \mathscr{X} \iff \exists w,\ \mathscr{R}(x, w) = 1$



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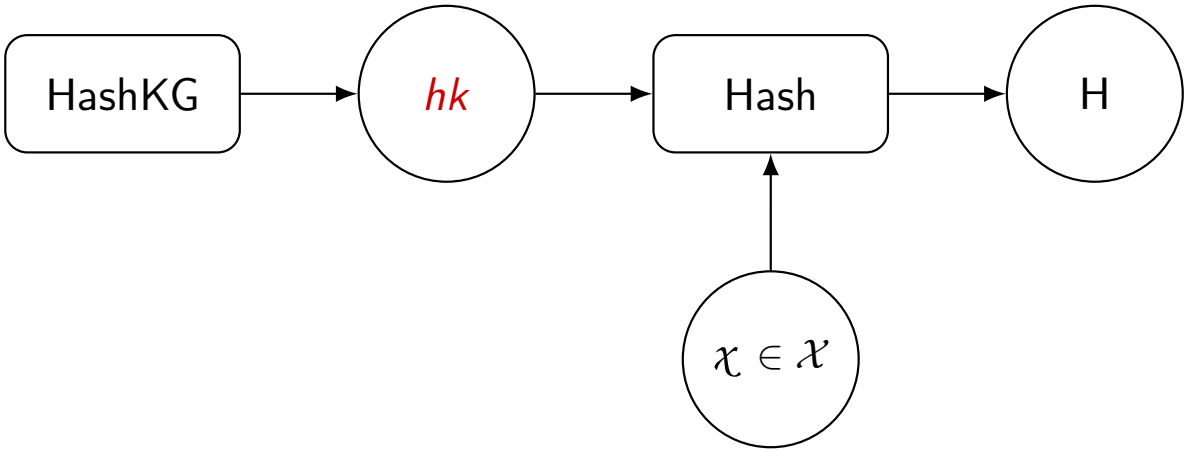

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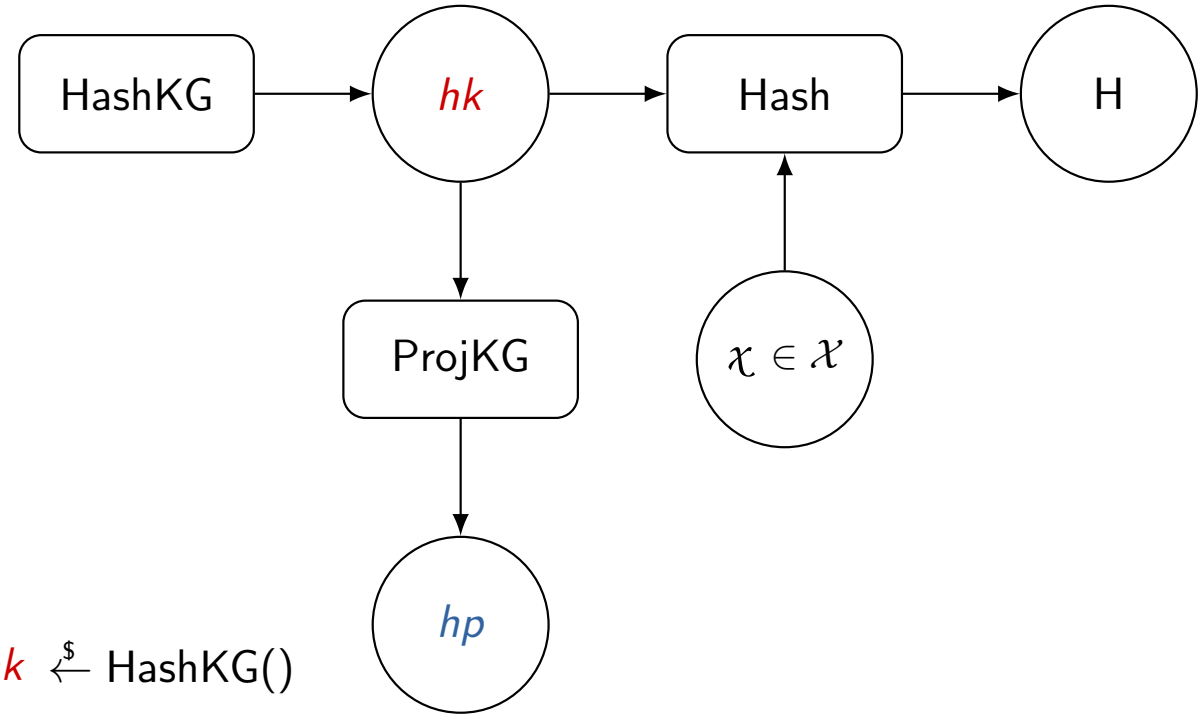

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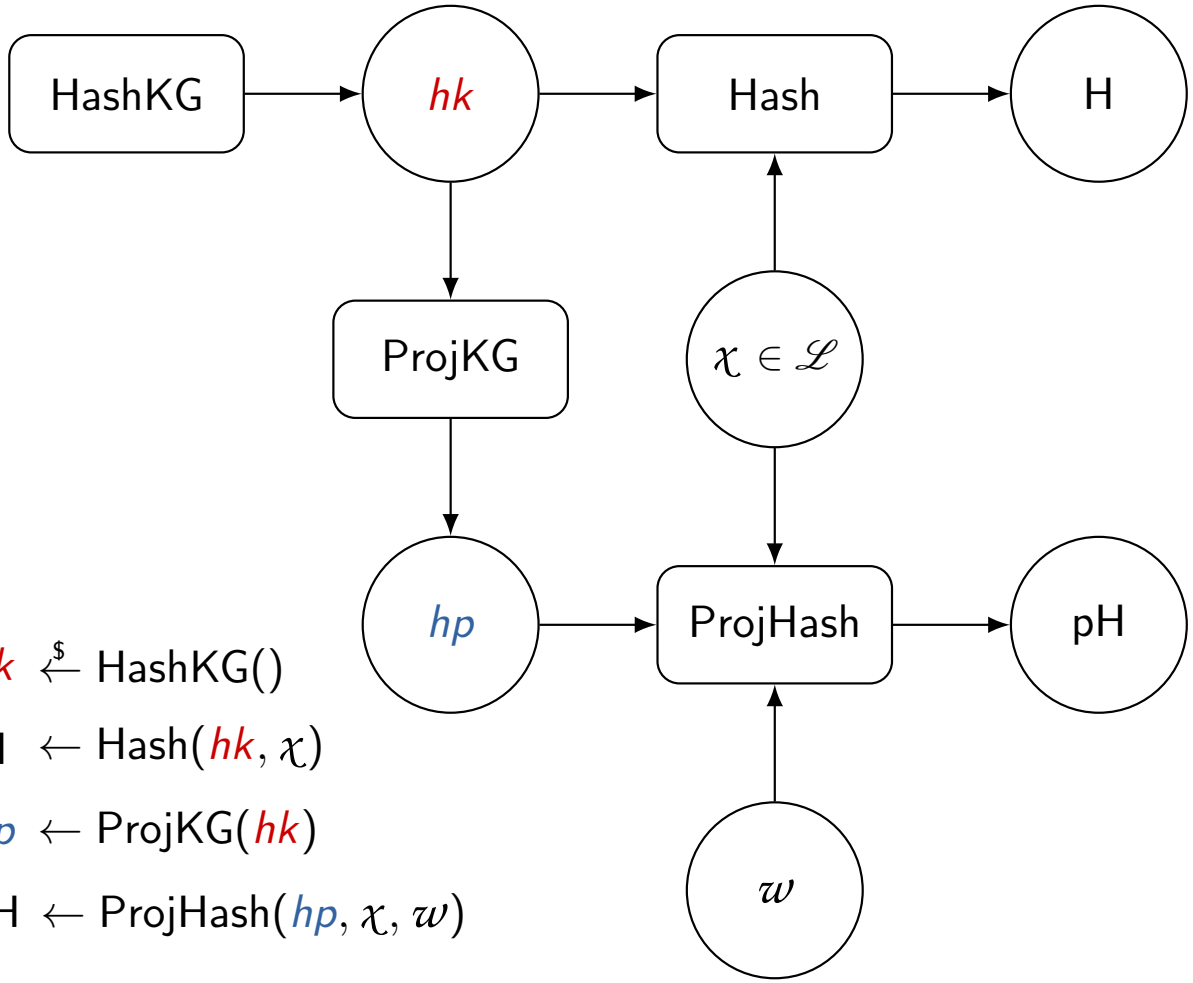

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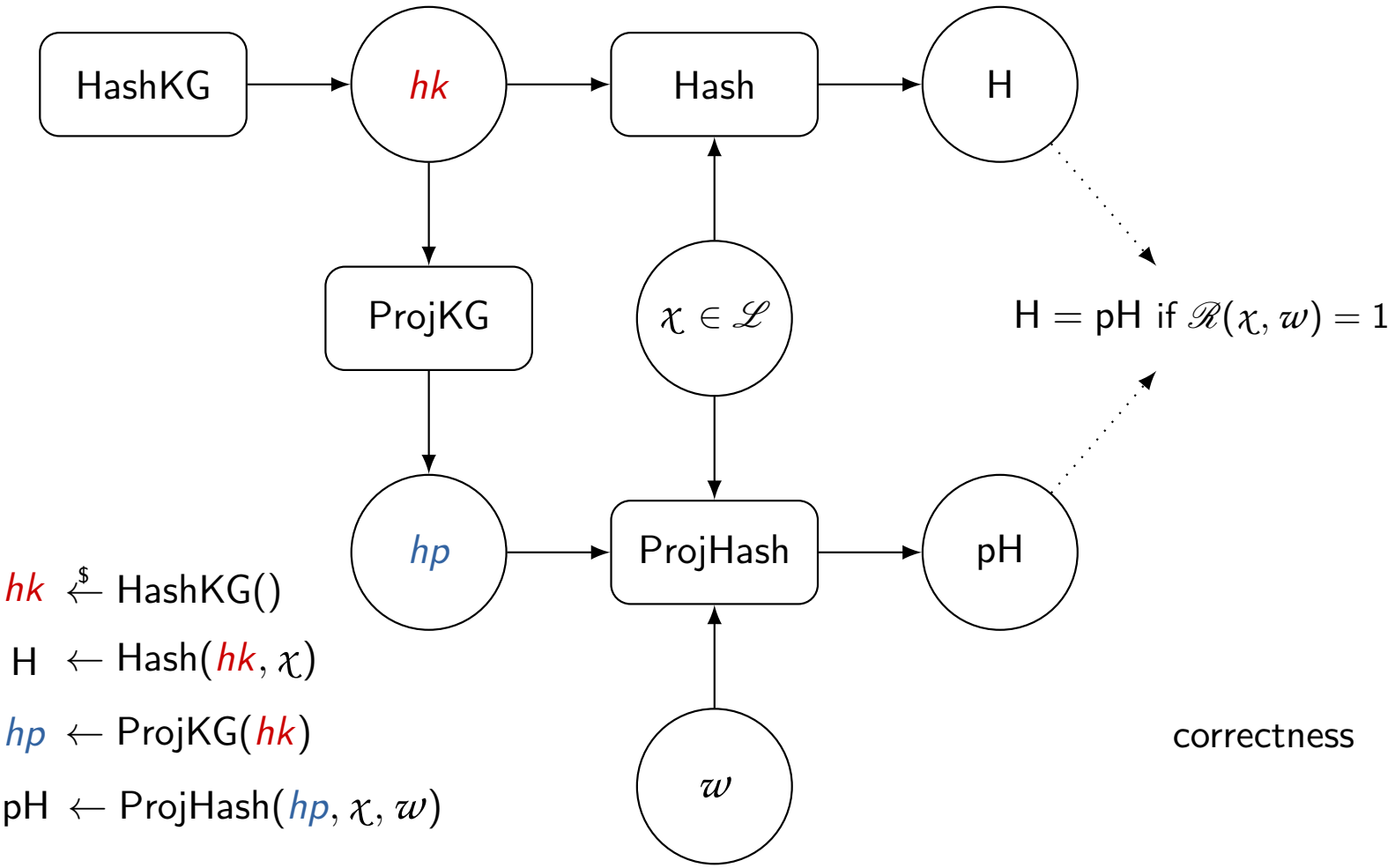

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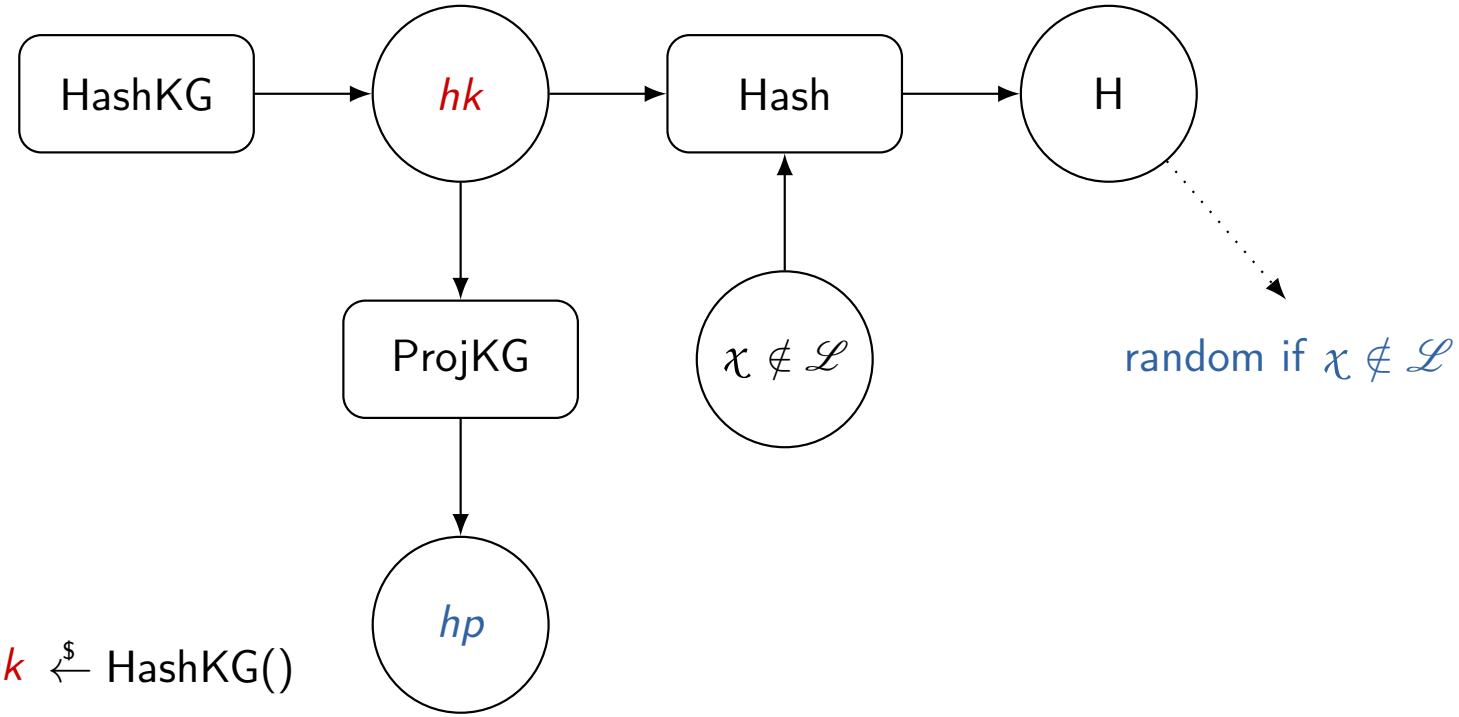

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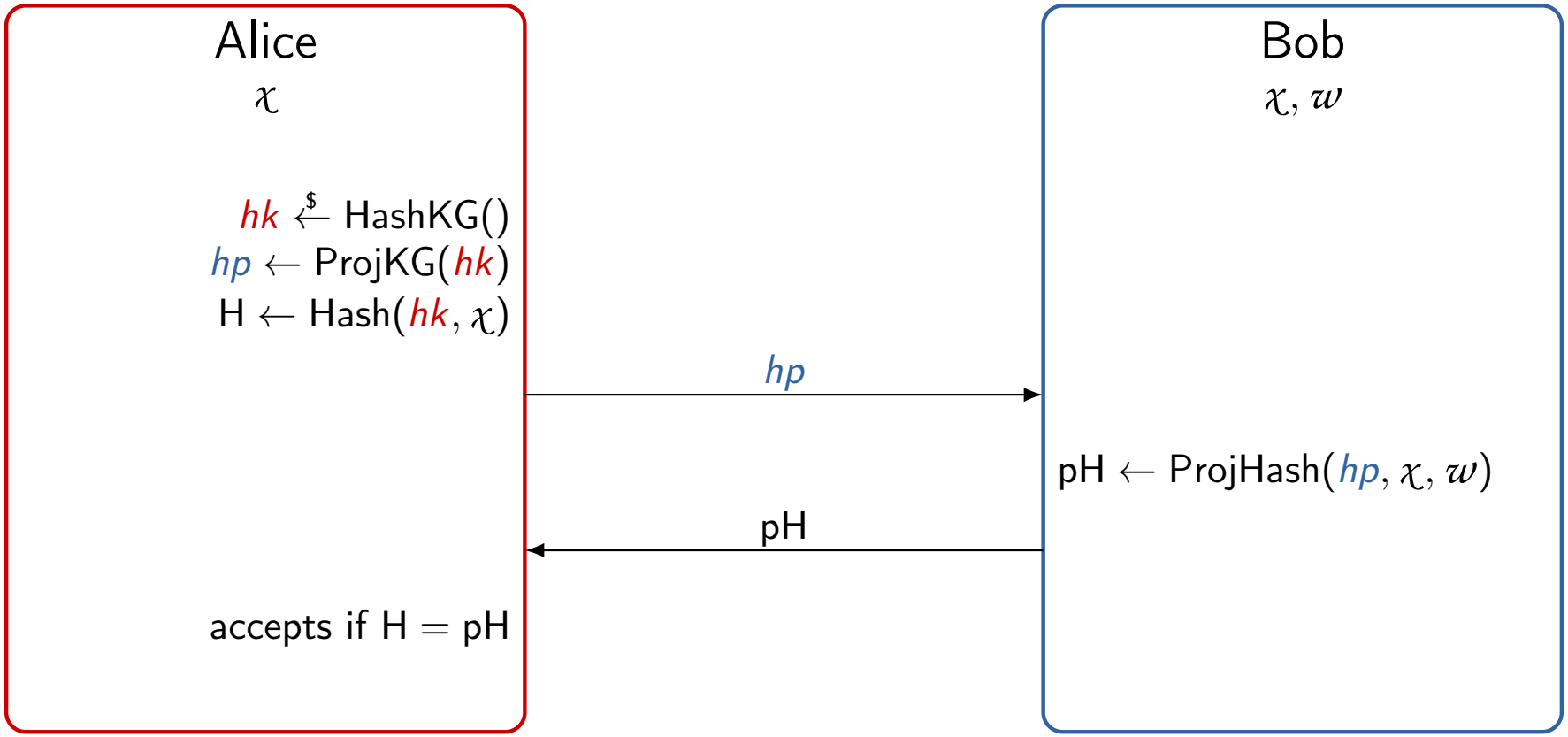
smoothness

Direct Applications of SPHFs

Honest-Verifier Zero-Knowledge Proofs

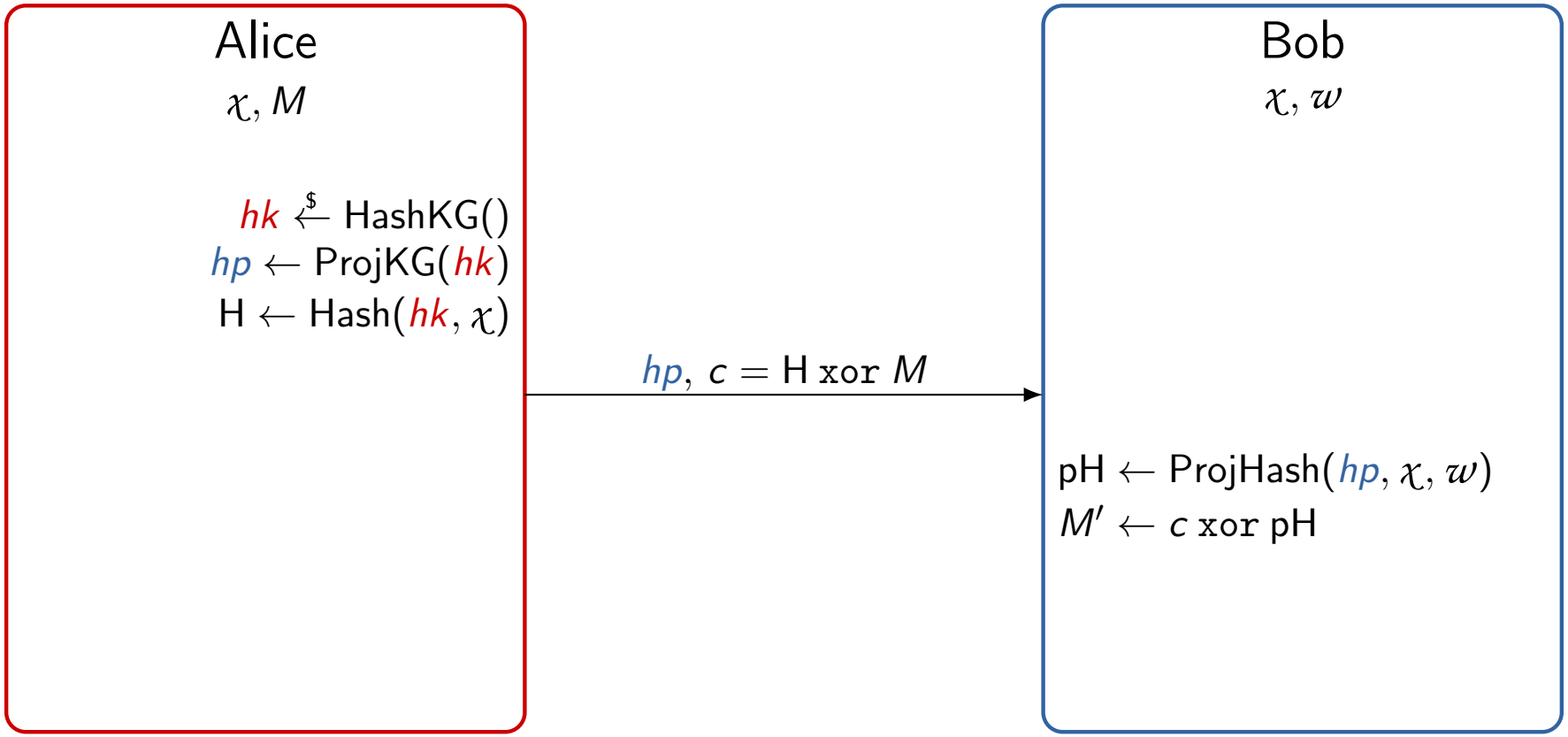
Bob wants to prove to Alice that $x \in \mathcal{L}$.



Direct Applications of SPHFs

Implicit Arguments

Alice wants to send M to Bob if $\chi \in \mathcal{L}$.



Agenda

1. Diverse Modules
   - Languages Handled by SPHFs?
   - ElGamal
   - Diverse Modules
   - Conjunctions and Disjunctions

2. (Implicit) Zero-Knowledge Arguments and Applications
   - (Implicit) Zero-Knowledge Arguments
   - Application to Two-Party Secure Computation

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- This thesis: "algebraic languages"
  - Diverse vector spaces: $\mathscr{L}$ subspace of vector space $\mathscr{X}$
    algebraic languages over prime-order cyclic groups
  - Diverse modules: $\mathscr{L}$ submodule of module $\mathscr{X}$
    module = vector space over a ring

Cyclic Groups and Hard Problems

$(\mathbb{G}, +)$ cyclic group of prime order p, generator $\boxed{g}$:

- "Encoding" of $x \in \mathbb{Z}_p$:

$$x \in \mathbb{Z}_p \qquad \mapsto \qquad x \cdot \boxed{g} \in \mathbb{G}$$

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- We assume DDH:

$$(\boxed{g},\ x \cdot \boxed{g},\ y \cdot \boxed{g},\ xy \cdot \boxed{g}) \quad \approx_c \quad (\boxed{g},\ x \cdot \boxed{g},\ y \cdot \boxed{g},\ z \cdot \boxed{g})$$

with $x, y, z \xleftarrow{\$} \mathbb{Z}_p$

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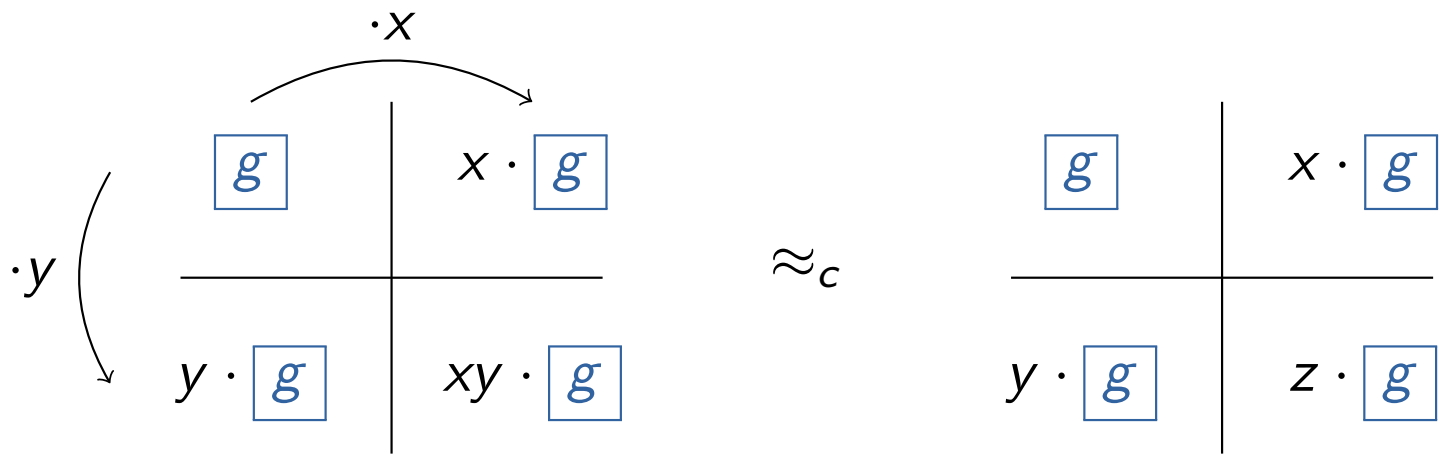

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Warm-up: ElGamal Encryption Scheme

Receiver: $s \xleftarrow{\$} \mathbb{Z}_p$ (secret)

$\boxed{g}$ $\qquad$ $\boxed{h} = s \cdot \boxed{g}$

Sender: message $\boxed{M}$, randomness $r \xleftarrow{\$} \mathbb{Z}_p$

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Security under DDH:

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SPHF for ciphertexts of $\boxed{M} = 0$

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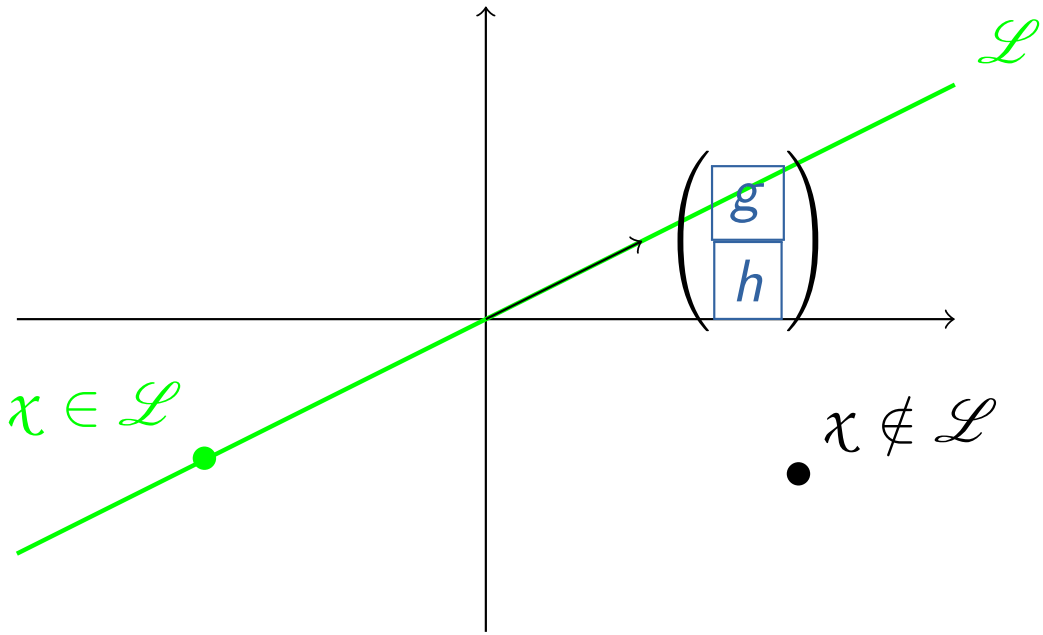
Diverse Vector Spaces [CS02, BBCPV Crypto'13]

Basically, languages of the form:

$\mathscr{L}$ is a subspace of a vector space $\mathcal{X} = \mathbb{G}^n \approx \mathbb{Z}_p^n$

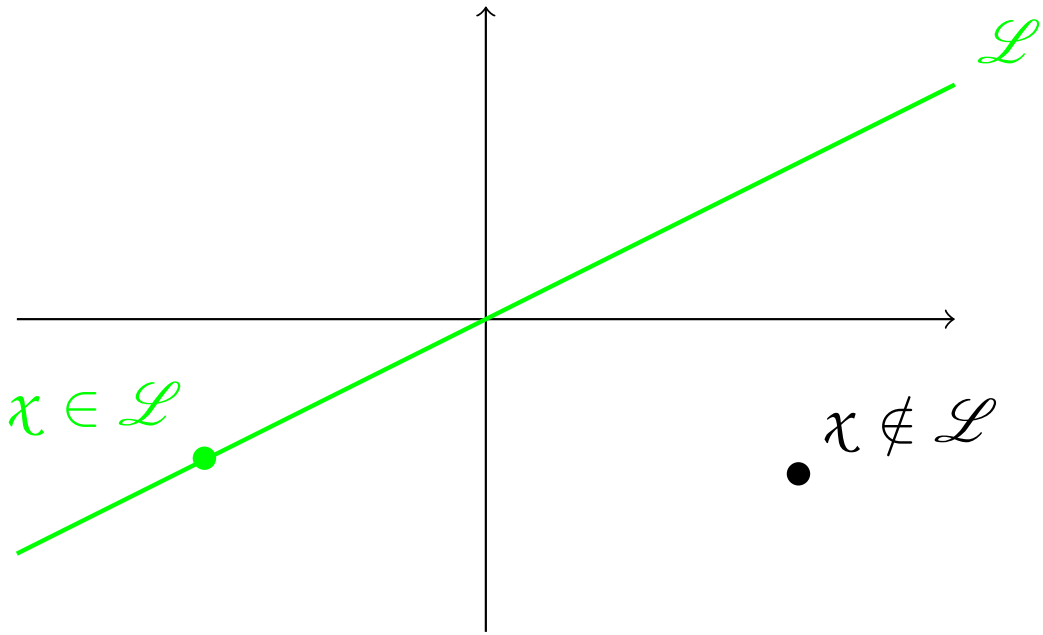


$$\mathscr{L} = \{(\boxed{u}, \boxed{v}) \mid \exists r \in \mathbb{Z}_p, \begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} g \\ h \end{pmatrix} \cdot r\} \quad \subseteq \quad \mathbb{G}^2$$

Diverse Modules

Basically, languages of the form:

$\mathscr{L}$ is a submodule of a module $\mathcal{X} = \mathbb{G}^n \approx \mathbb{Z}_M^n$



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  - conjunction
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Conjunctions and Disjunctions [ABP Eurocrypt'15]

$\mathscr{L}$ is a subspace of a vector space $\mathcal{X} \approx \mathbb{Z}_p^n$

- Conjunction of $\mathscr{L}_1 \subseteq \mathcal{X}_1$ and $\mathscr{L}_2 \subseteq \mathcal{X}_2$:

$$\mathscr{L} := \mathscr{L}_1 \times \mathscr{L}_2 \quad \subseteq \quad \mathcal{X}_1 \times \mathcal{X}_2 =: \mathcal{X}$$

Conjunctions and Disjunctions [ABP Eurocrypt'15]

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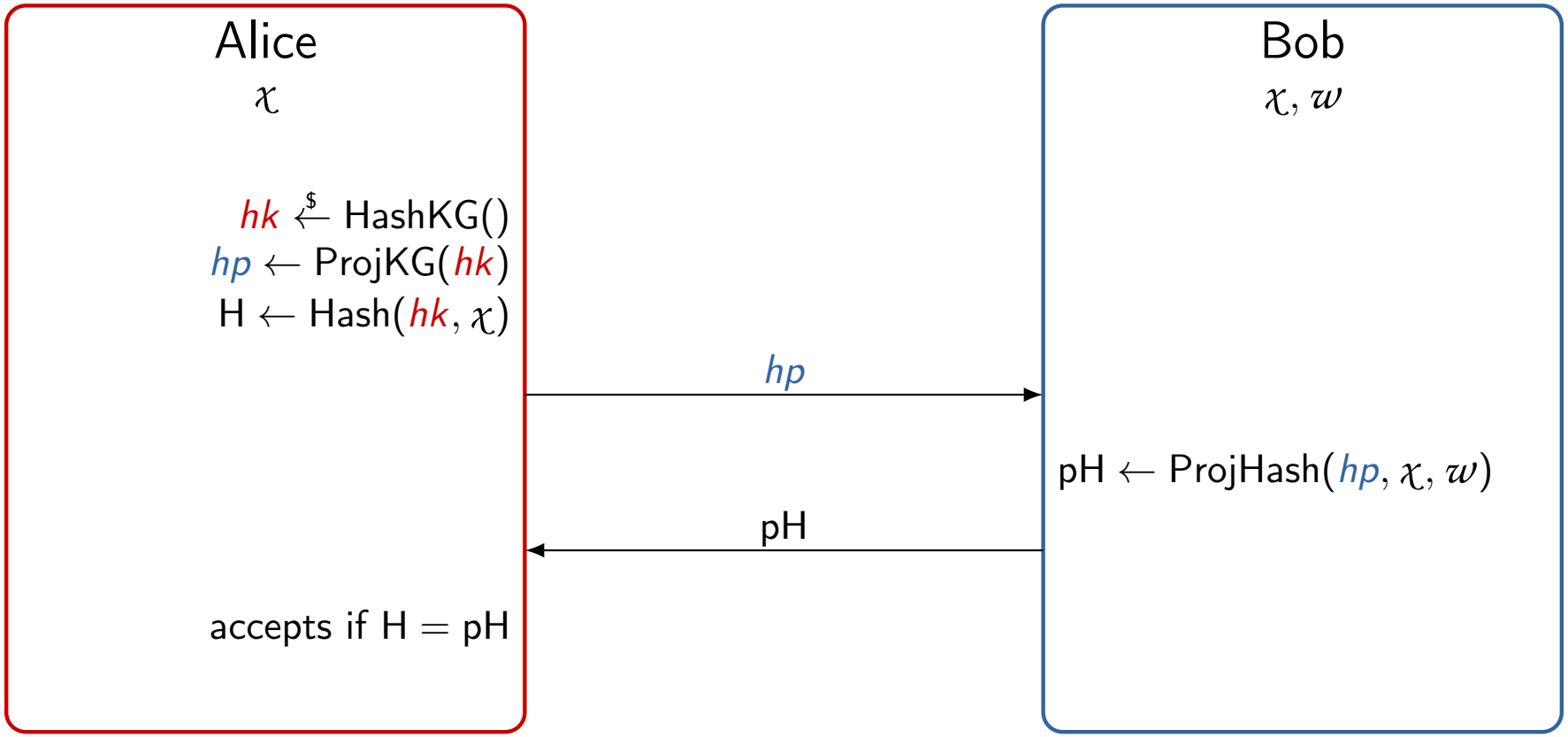
Idea: Tensor Product

$$\mathscr{L} := \langle (\mathscr{L}_1 \otimes \mathcal{X}_2) \cup (\mathcal{X}_1 \otimes \mathscr{L}_2) \rangle \quad \subseteq \quad \mathcal{X}_1 \otimes \mathcal{X}_2 =: \mathcal{X}$$

Direct Applications of SPHFs

Honest-Verifier Zero-Knowledge Proofs

Bob wants to prove to Alice that $x \in \mathcal{L}$.

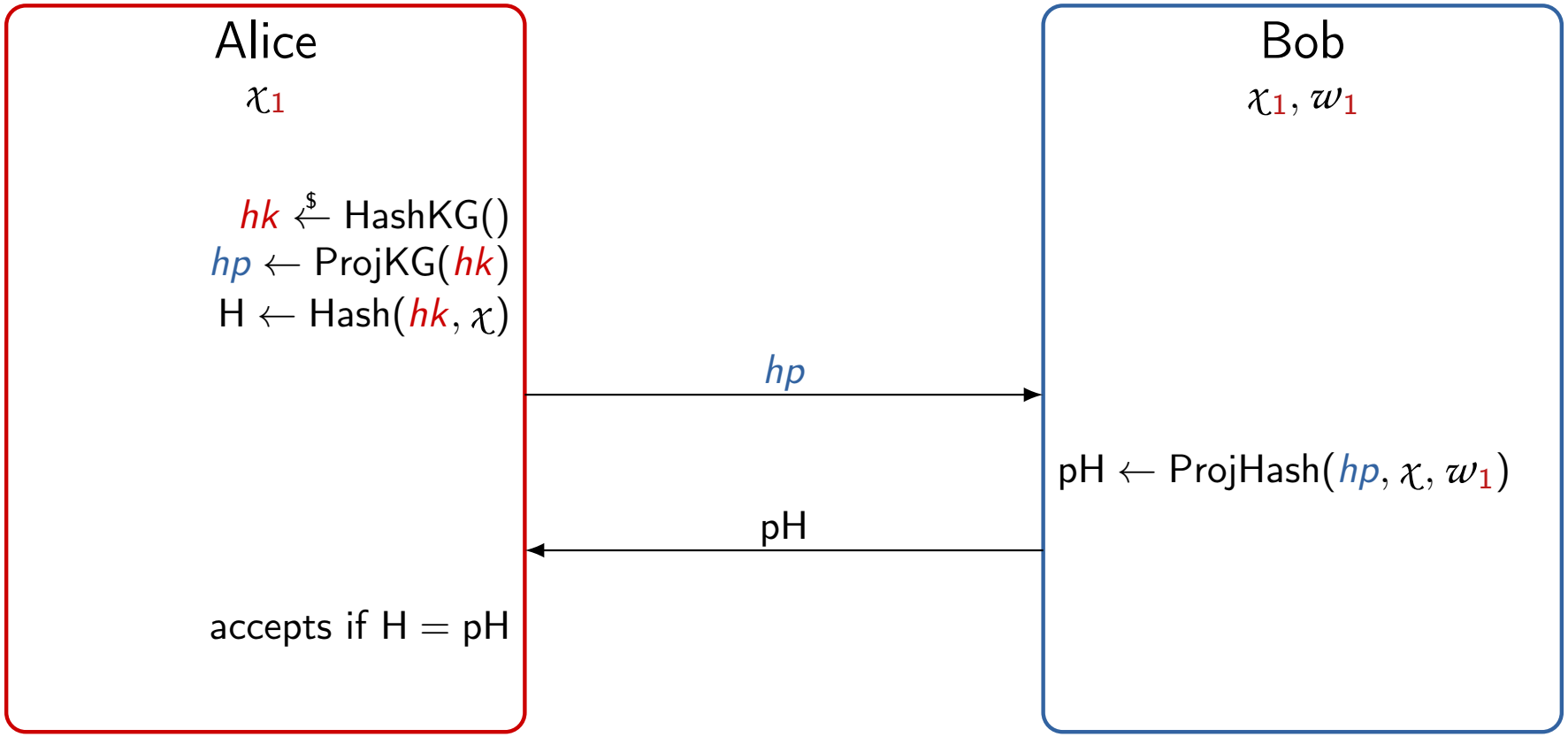


Applications of SPHFs for Disjunction of Languages

Zero-Knowledge Arguments [BBCPV Crypto'13]

Bob wants to prove to Alice that $x_1 \in \mathcal{L}_1$ in zero-knowledge.

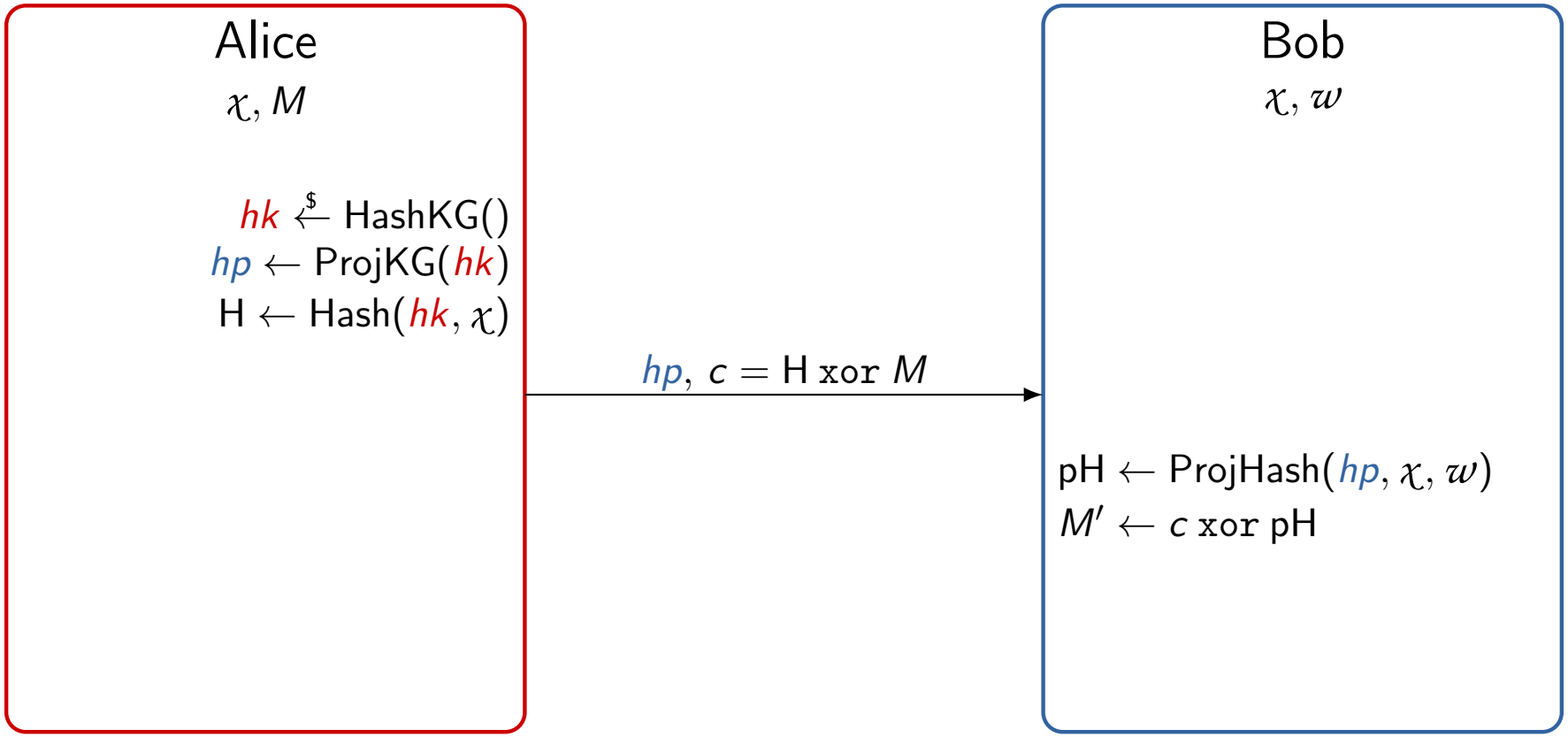
$x = (x_1, x_2)$ — CRS: x_2



Direct Applications of SPHFs

Implicit Arguments

Alice wants to send M to Bob if $x \in \mathcal{L}$.



Applications of SPHFs for Disjunction of Languages

Implicit Zero-Knowledge Arguments (iZK) [BCPW, Crypto'15]

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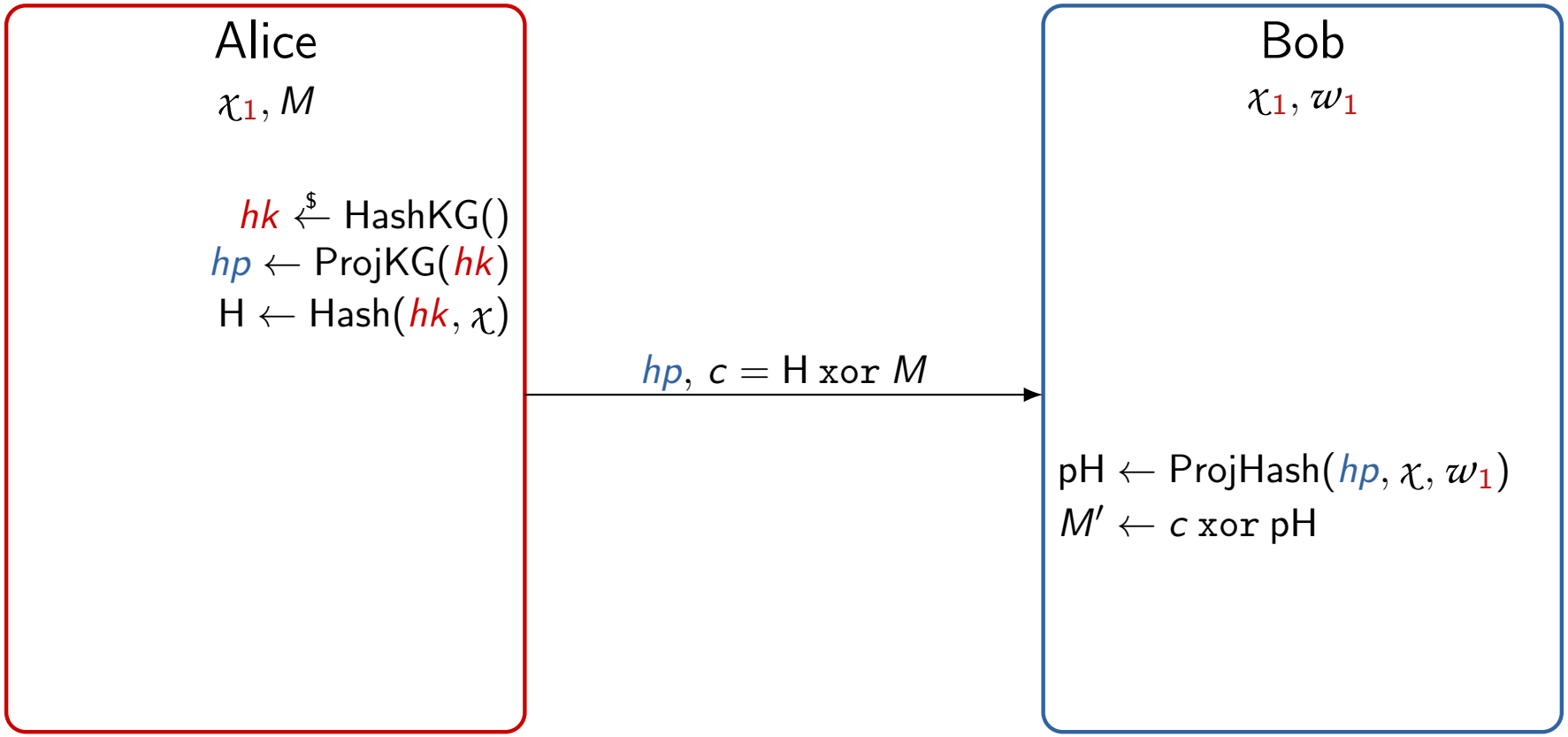

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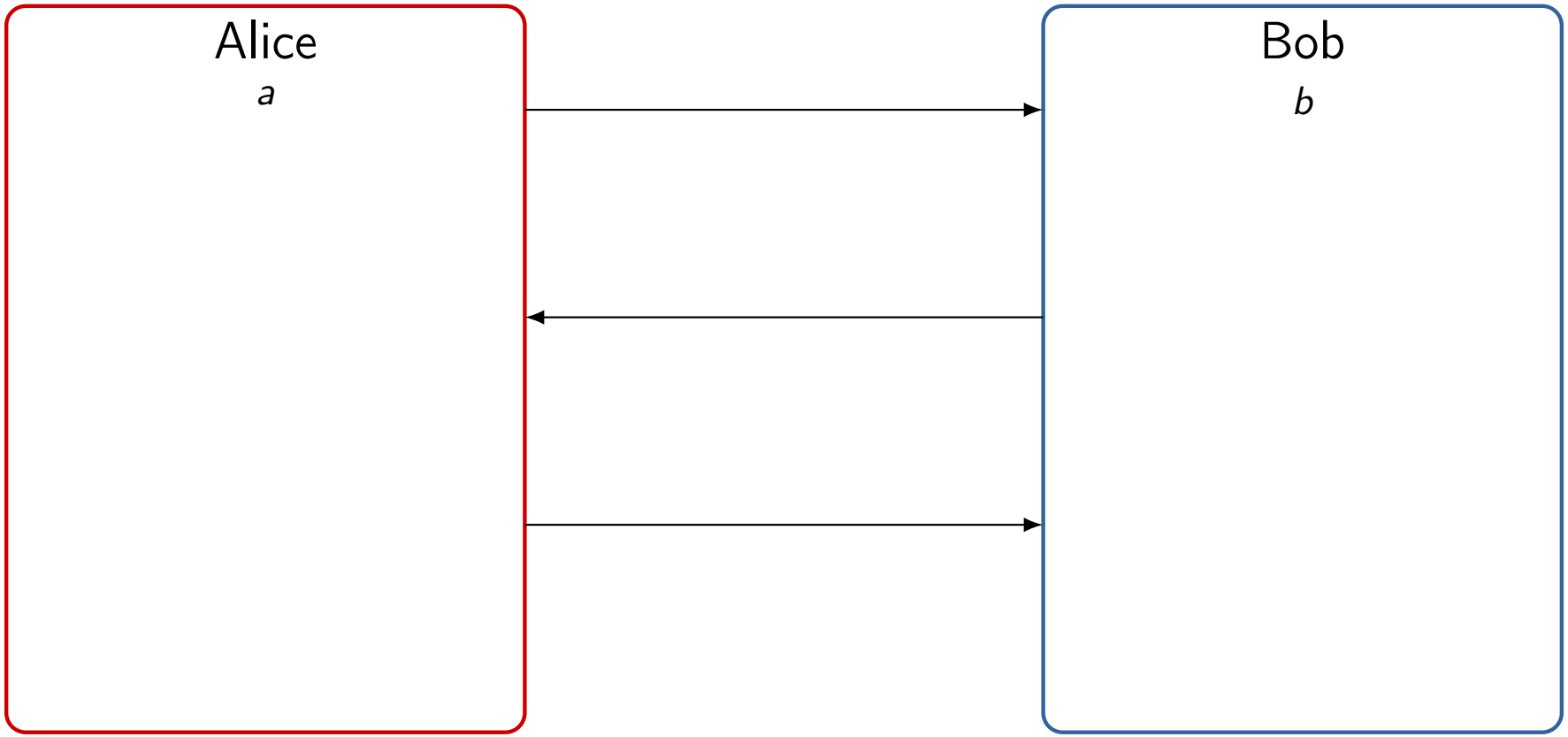
Alice has input a, Bob has input b, Bob wants to get $f(a, b)$



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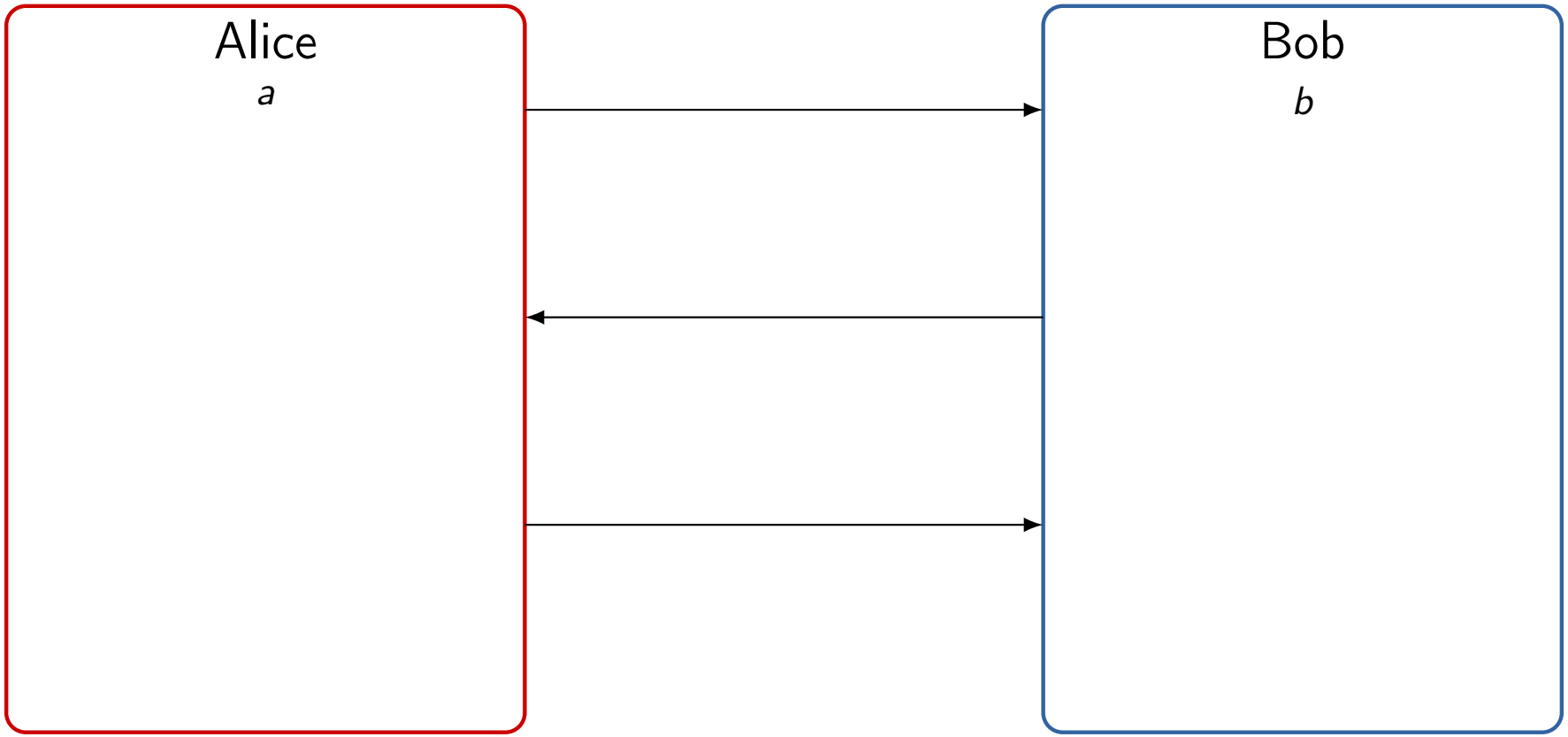

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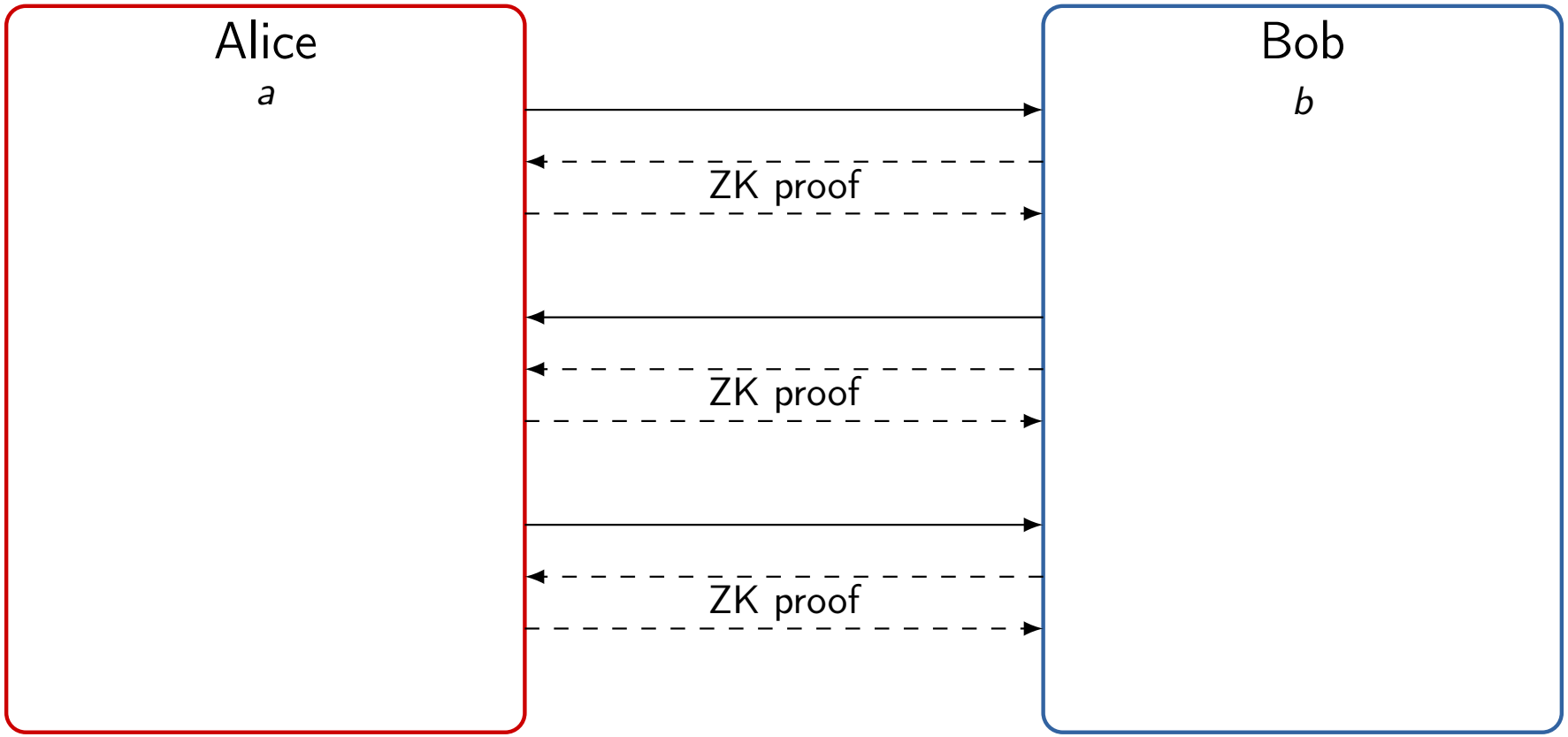

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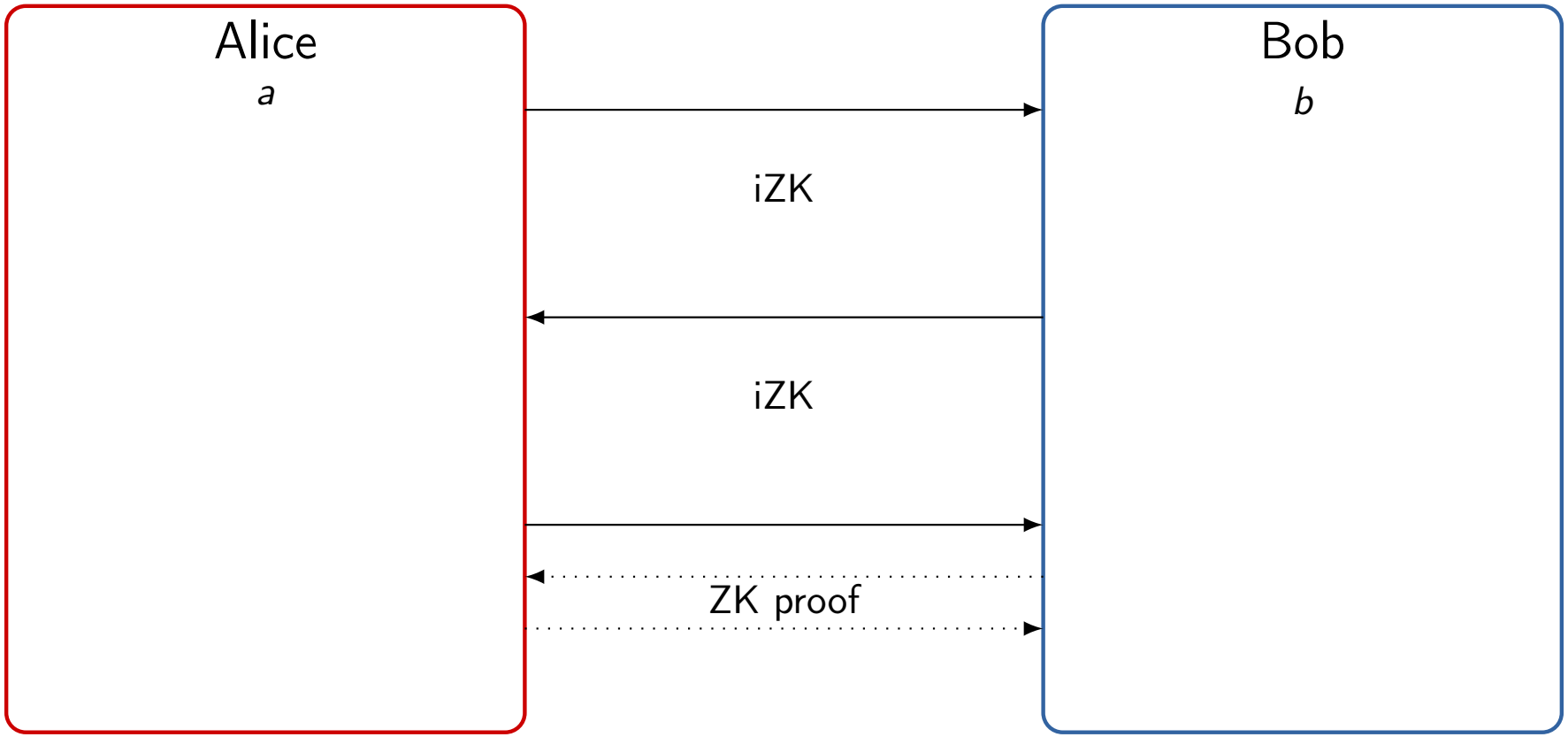

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  - iZK / TSPHFs = zero-knowledge versions of SPHFs
    $\longrightarrow$ lightweight alternative to zero-knowledge arguments
    e.g., two-party secure computation
  - SPHFs $\longrightarrow$ PAKE, OT, HVZK, WE, ...
  - constant-size QA-NIZK

Thank you for your attention! Questions?

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