On One-Shot Signatures, Quantum vs Classical Binding, & Obfuscation Permutations

Omri Shmueli
NTT Research

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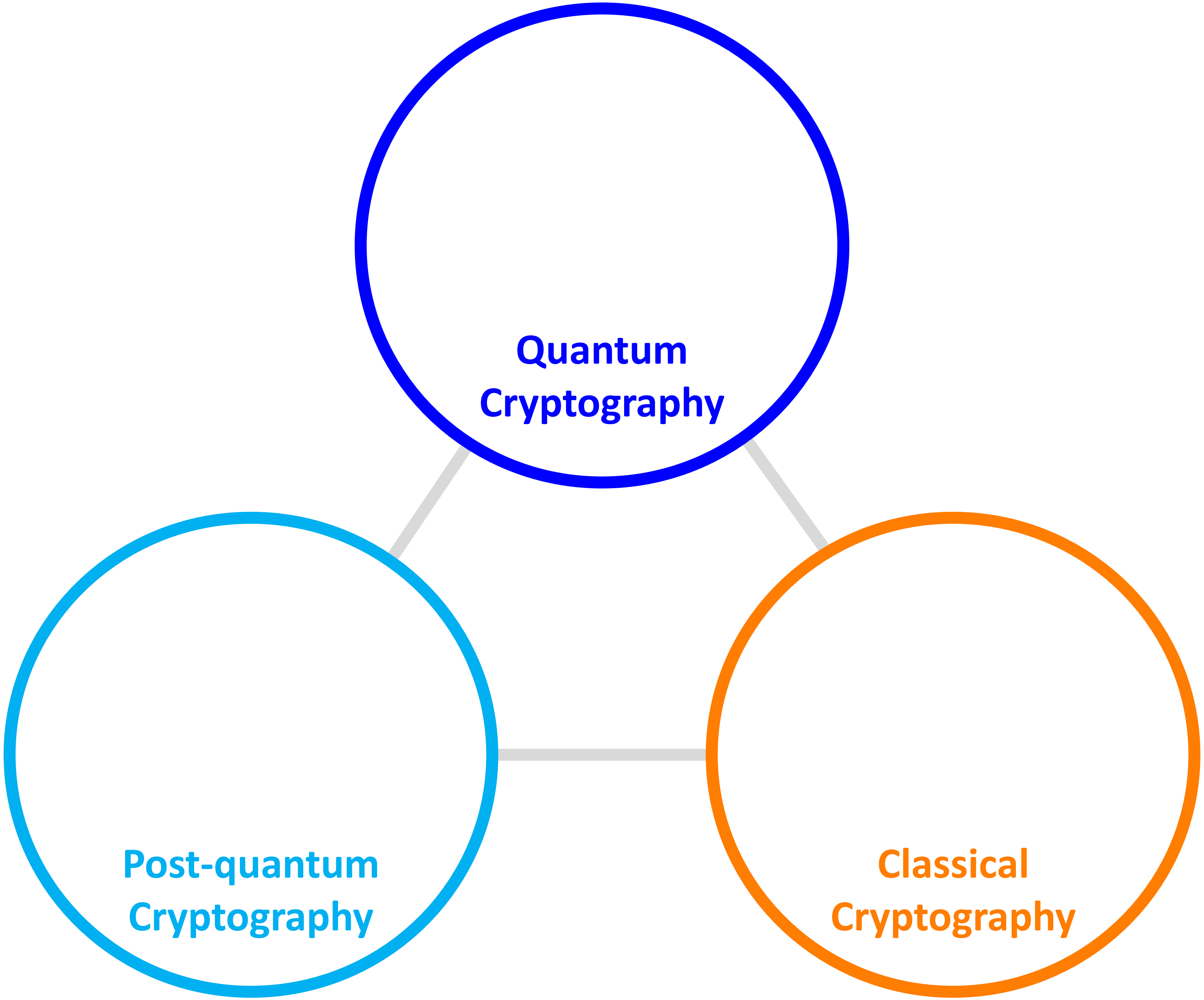
NTT Research
Stanford


Quantum
Cryptography
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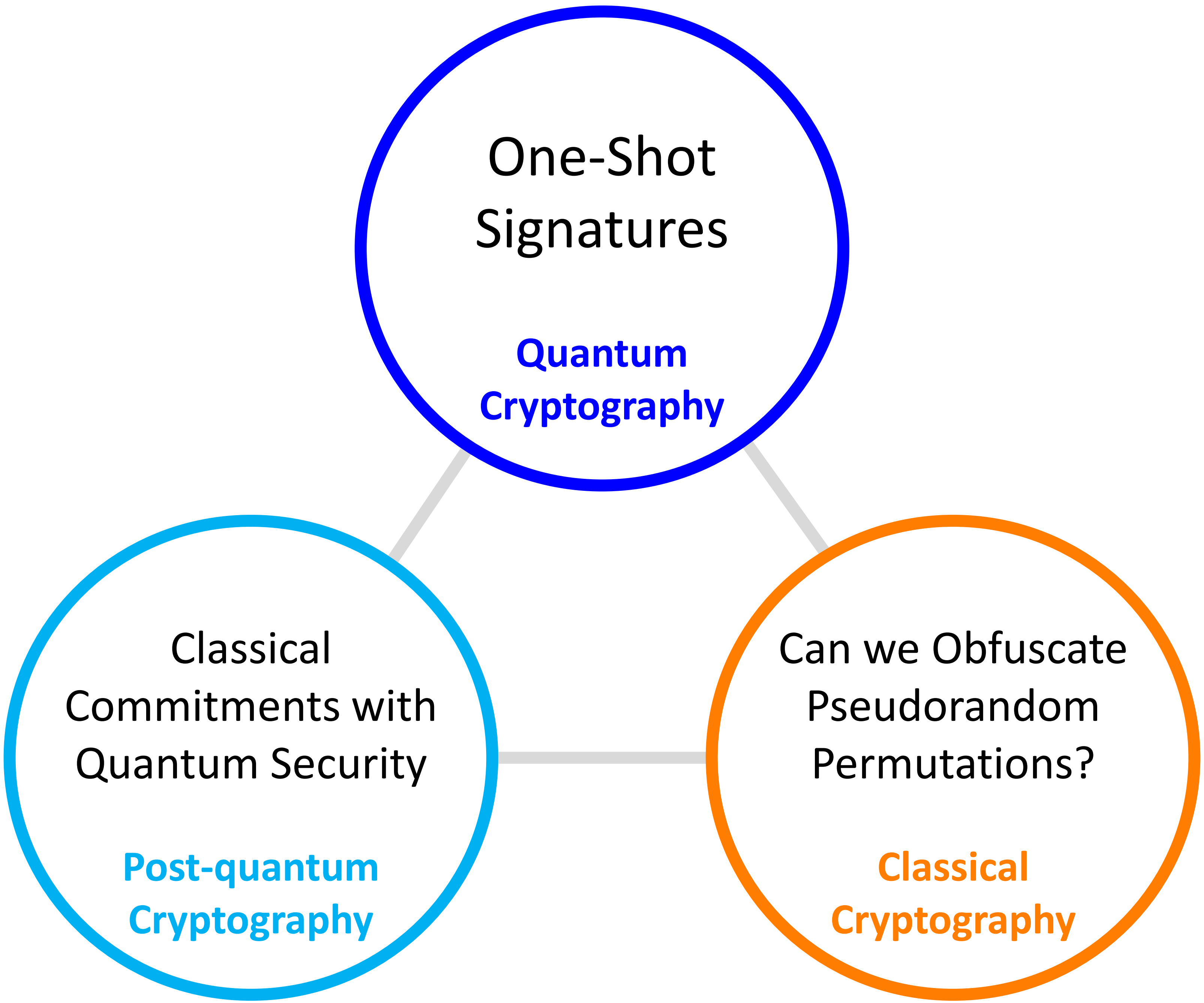
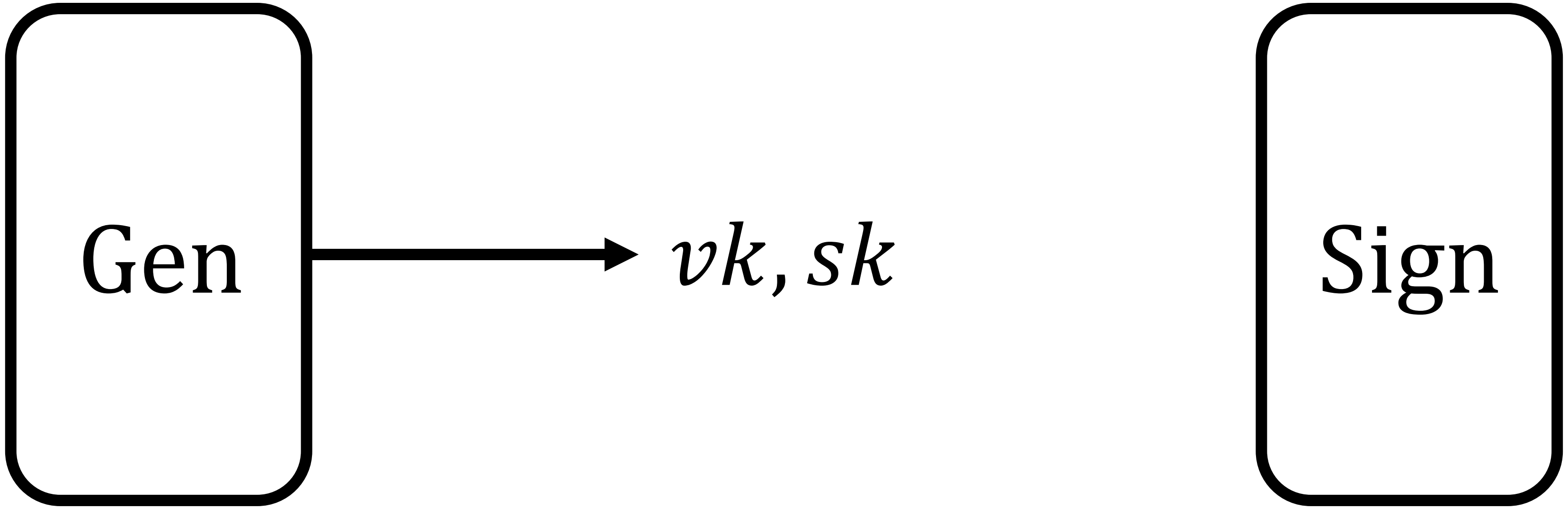

One-Shot Signatures
Quantum Cryptography
Classical Commitments with Quantum Security
Post-quantum Cryptography
Can we Obfuscate Pseudorandom Permutations?
Classical Cryptography

A Question

Is it possible to construct a ***one-time*** signature token?



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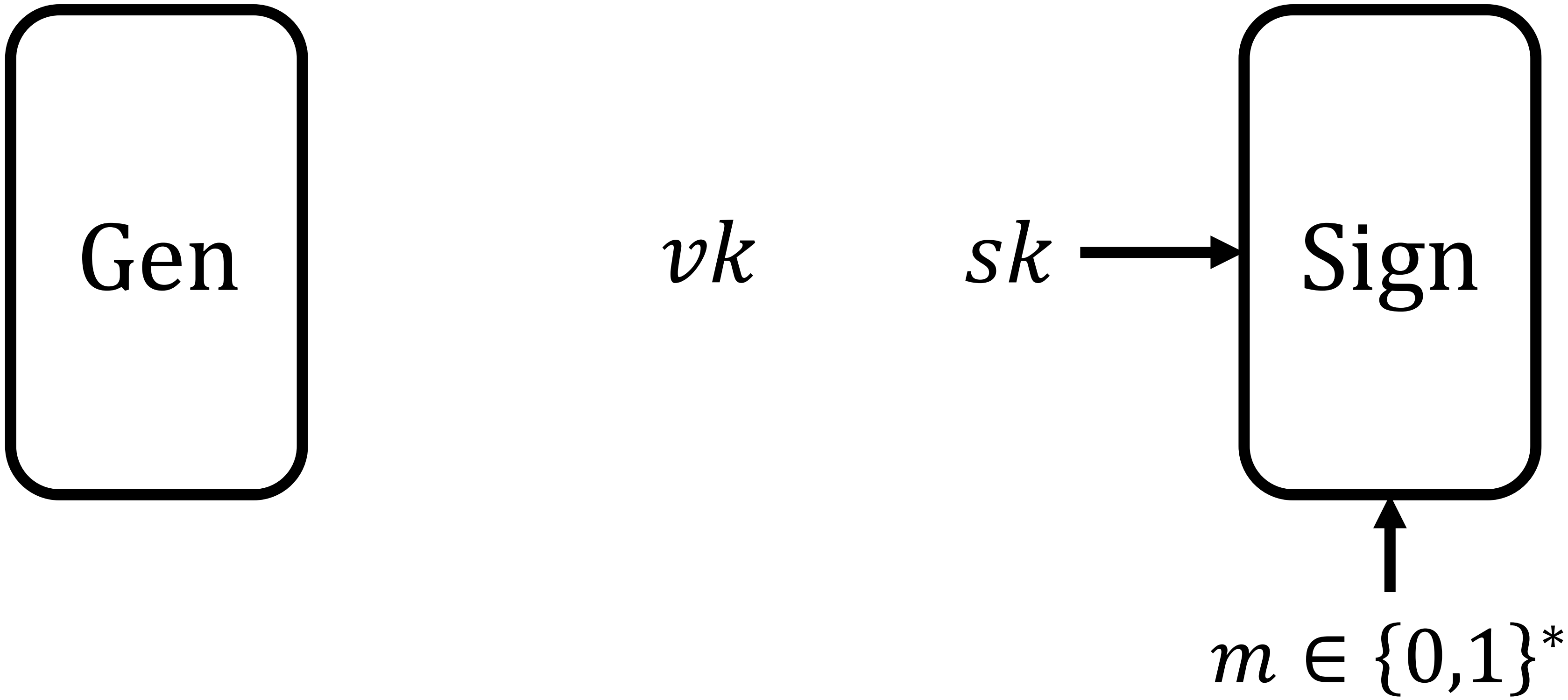

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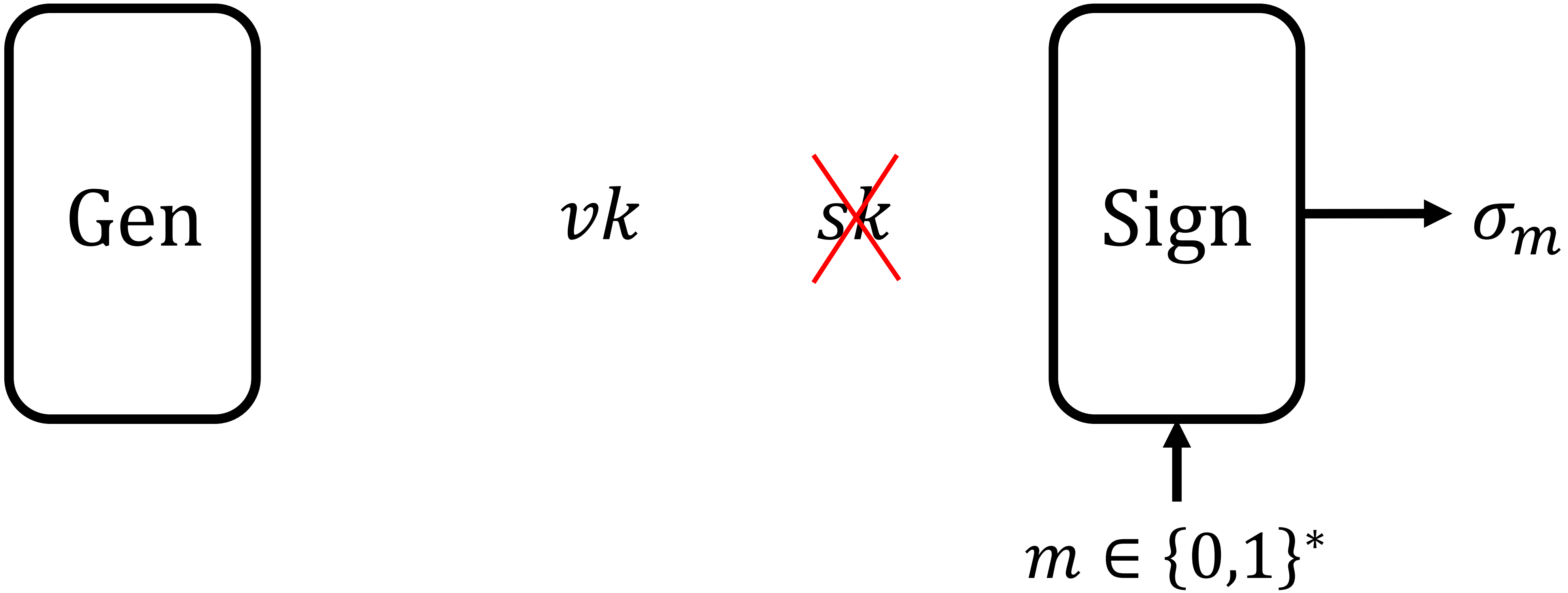

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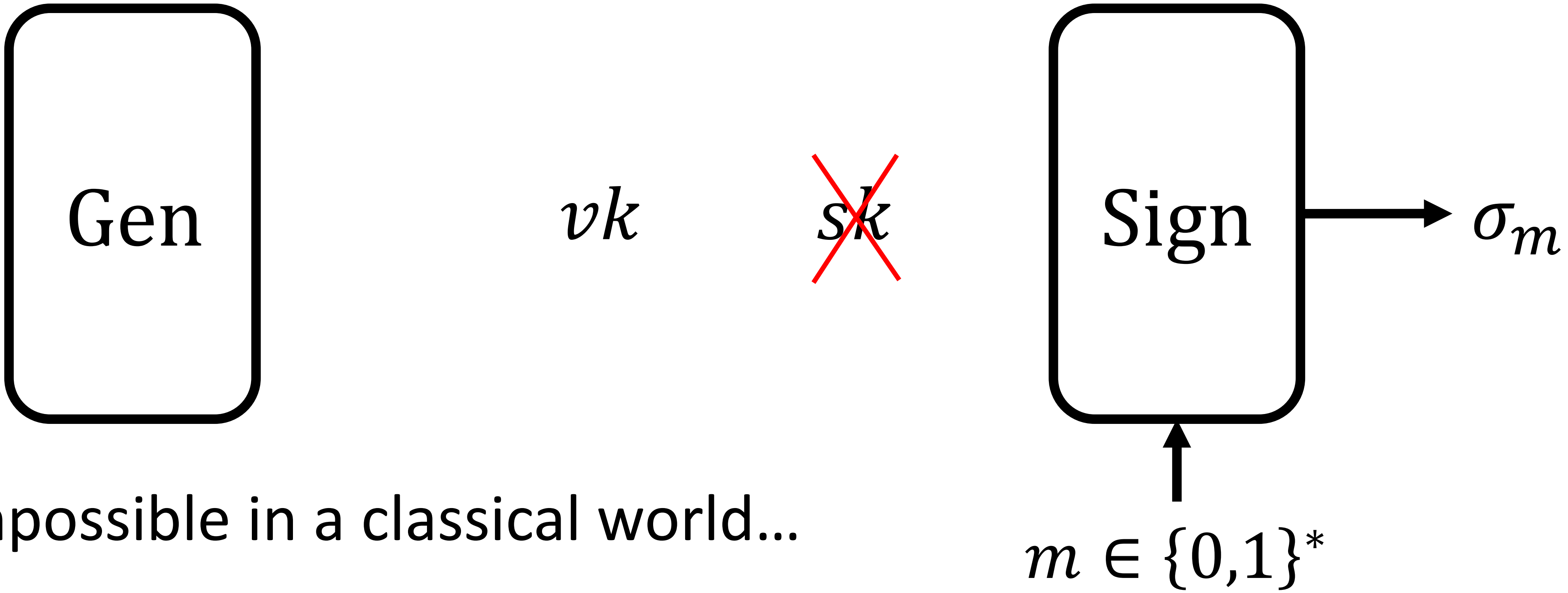

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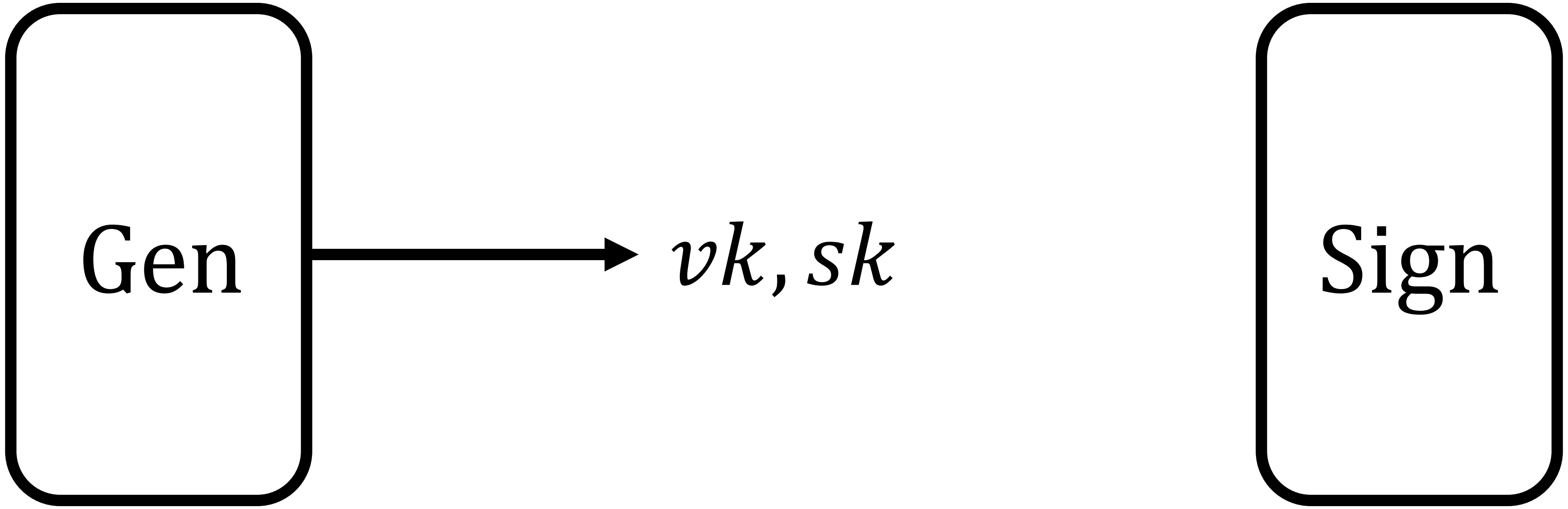

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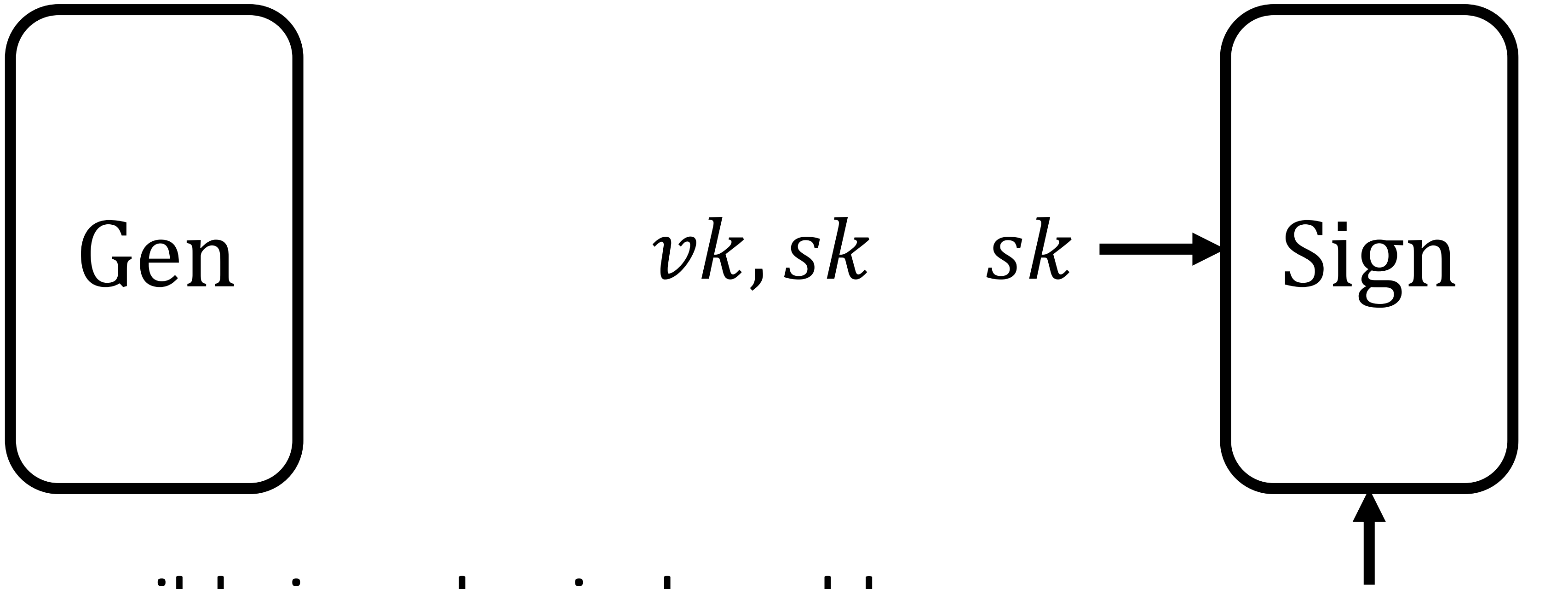

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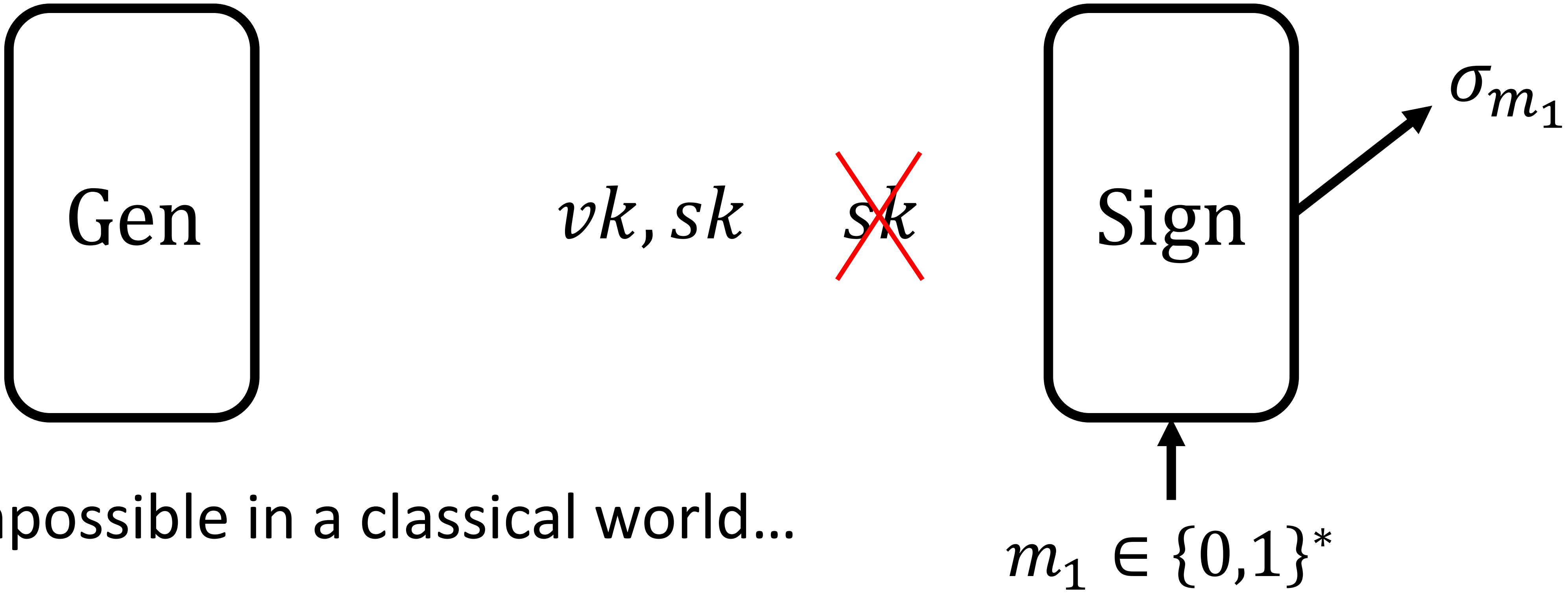

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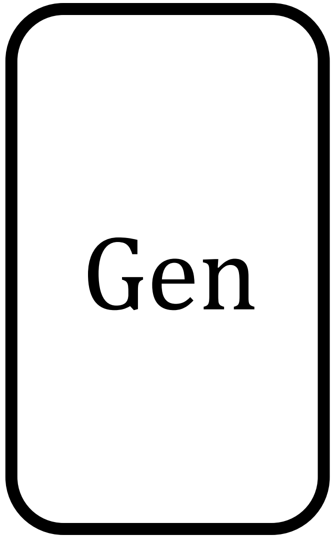

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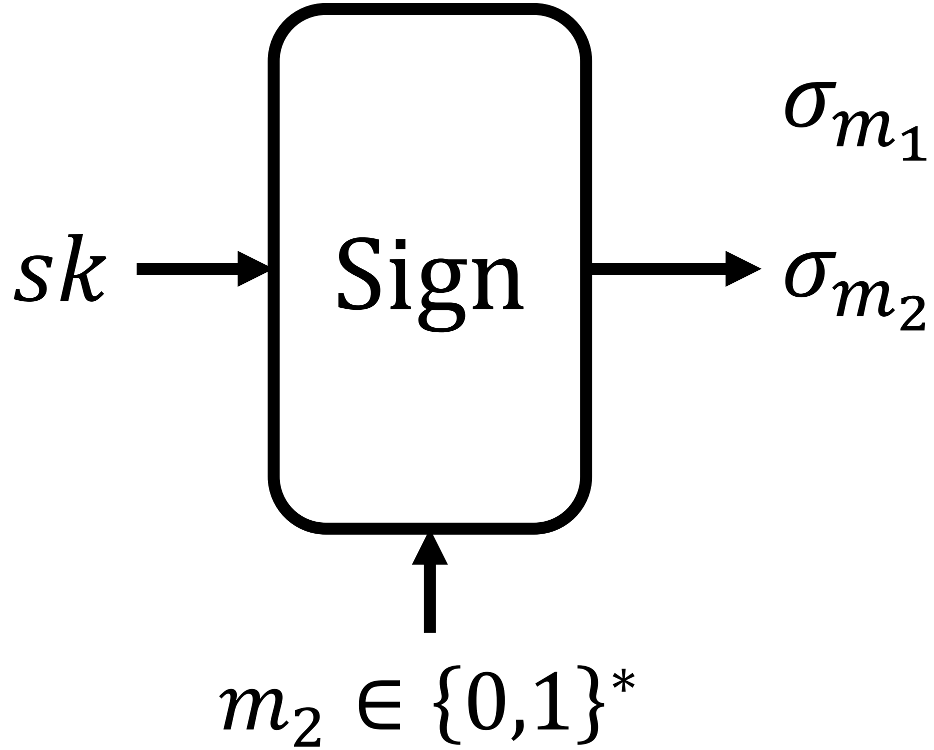

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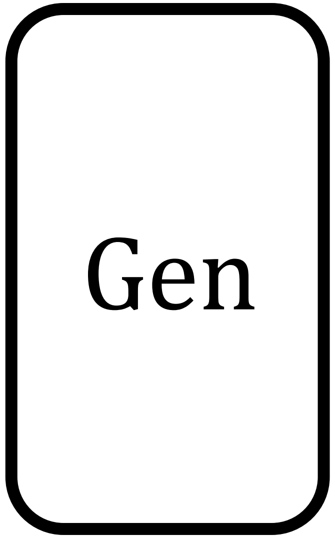

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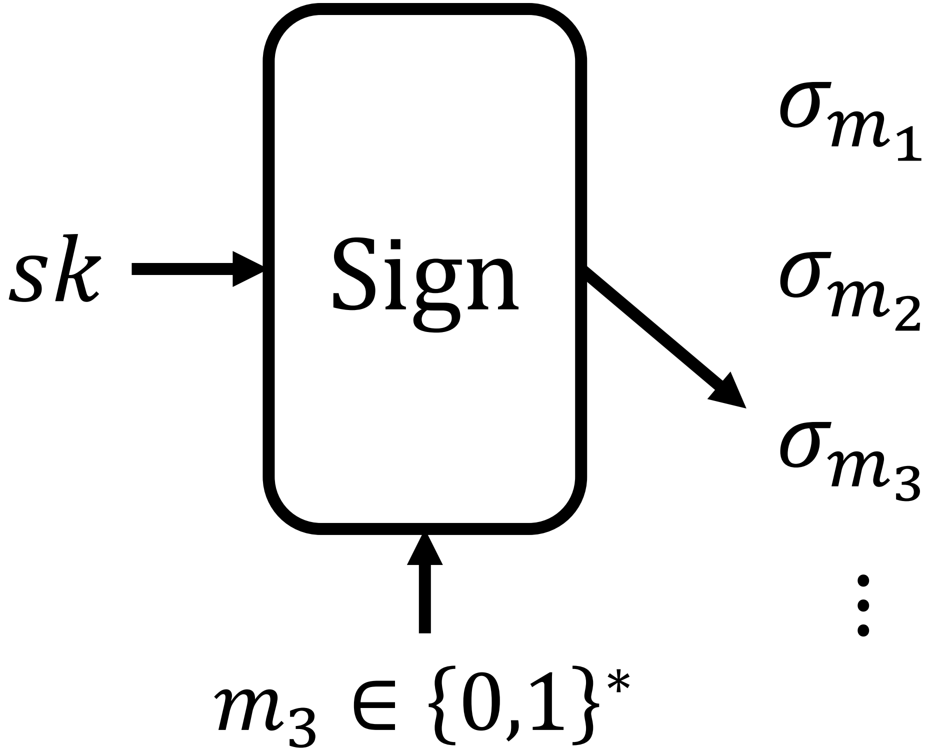

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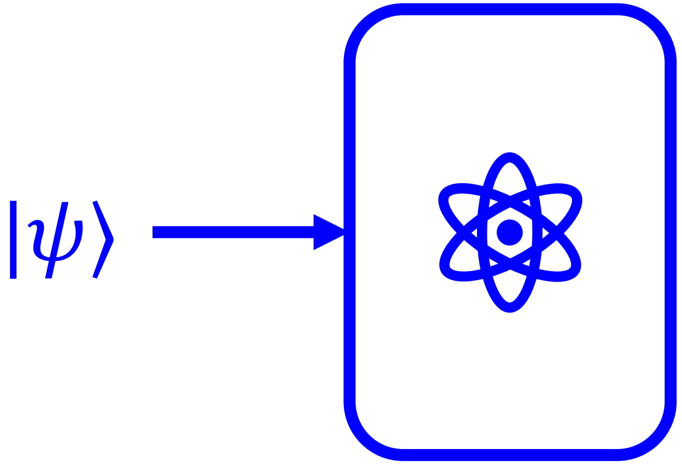
Quantum Information in Cryptography

Extracting classical information from a quantum state can degrade it.



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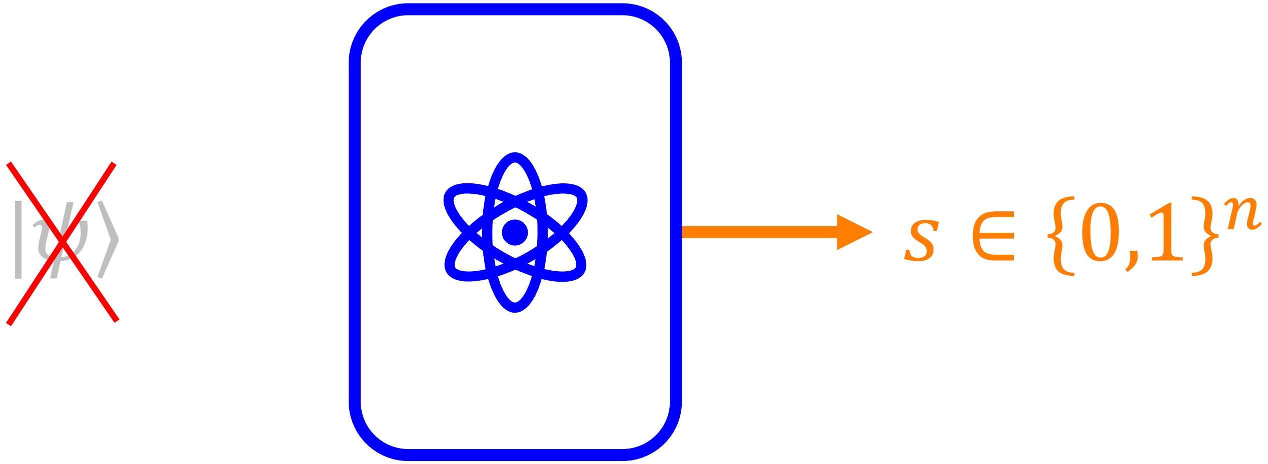

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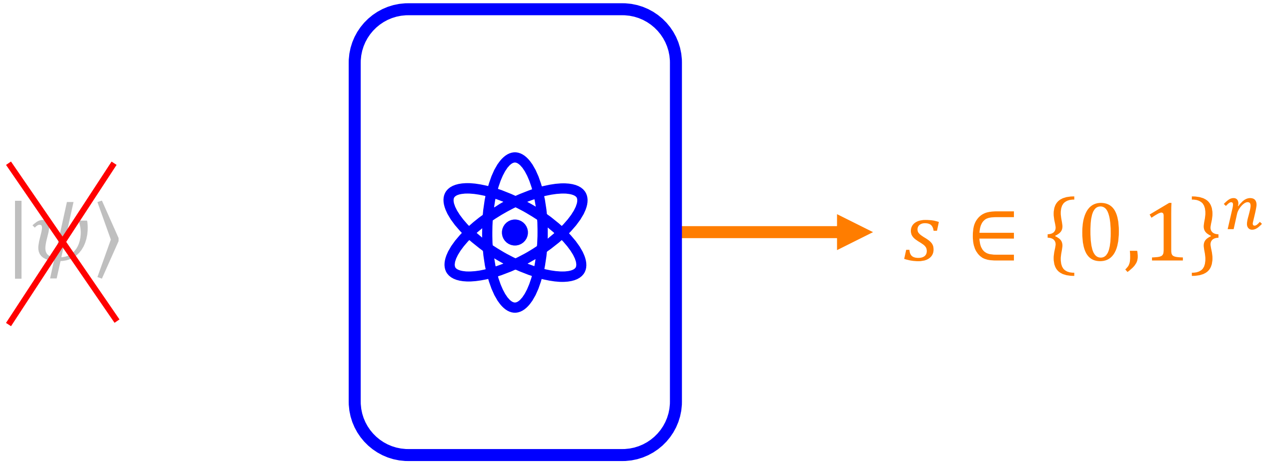

Is it possible to make this degradation ***inherent***, for the ***benefit*** of quantum cryptography?

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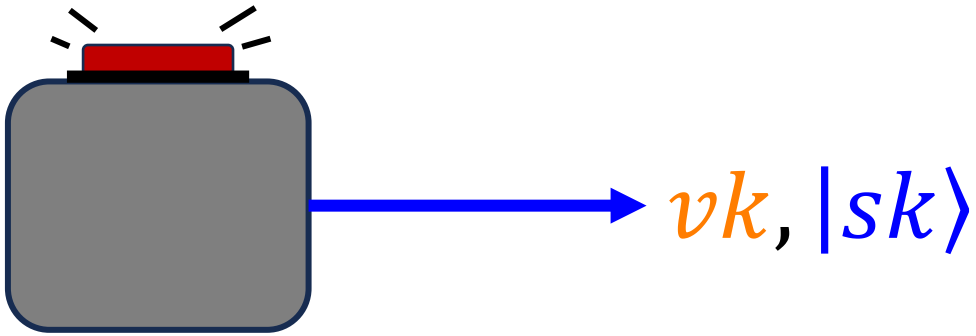

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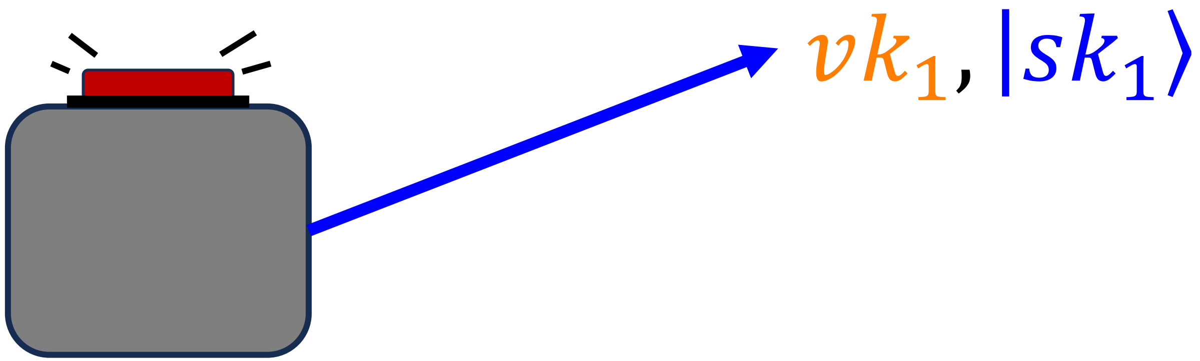

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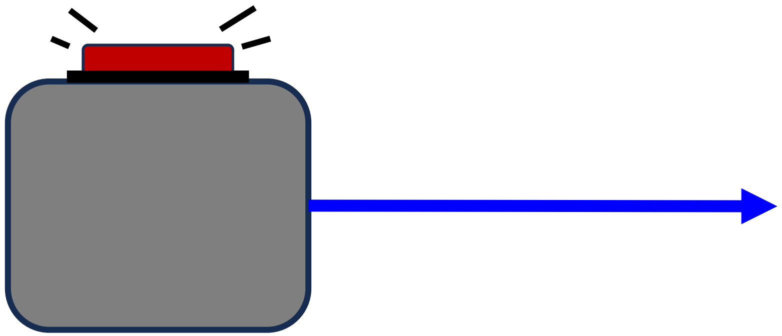

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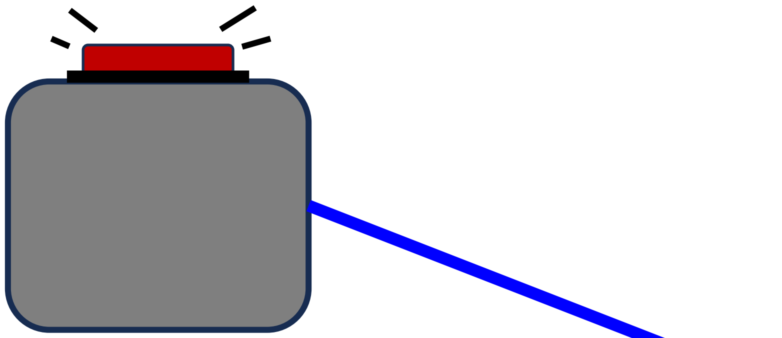

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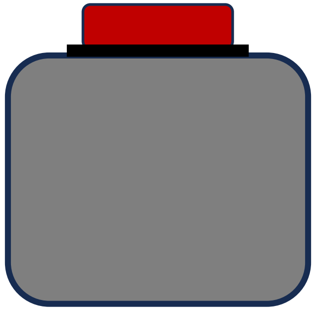

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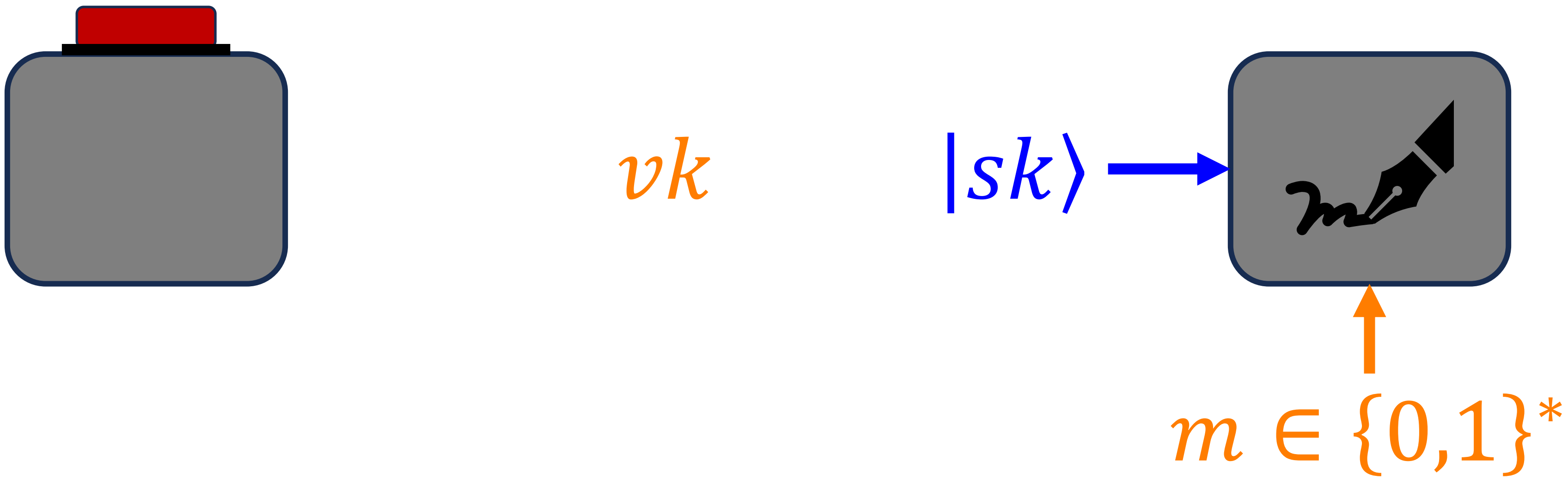

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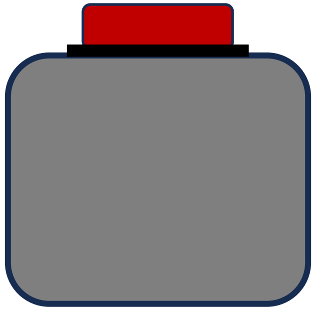

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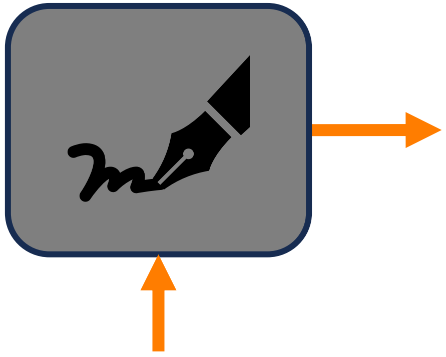

σ_m

$m \in \{0,1\}^*$

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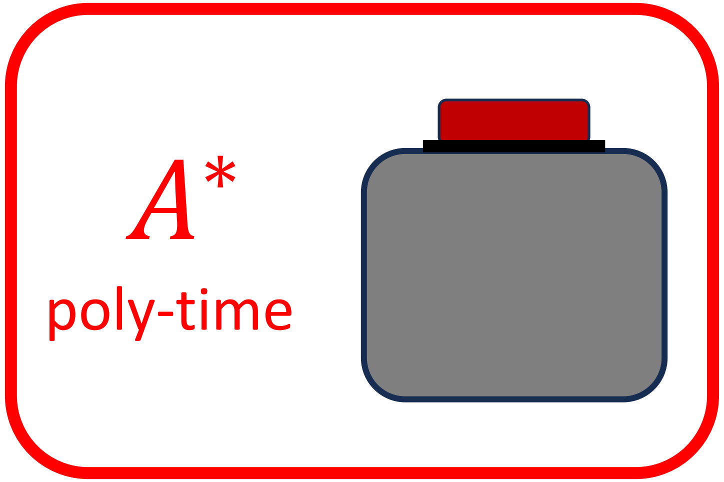

Security: Intractable to sign twice using the same key

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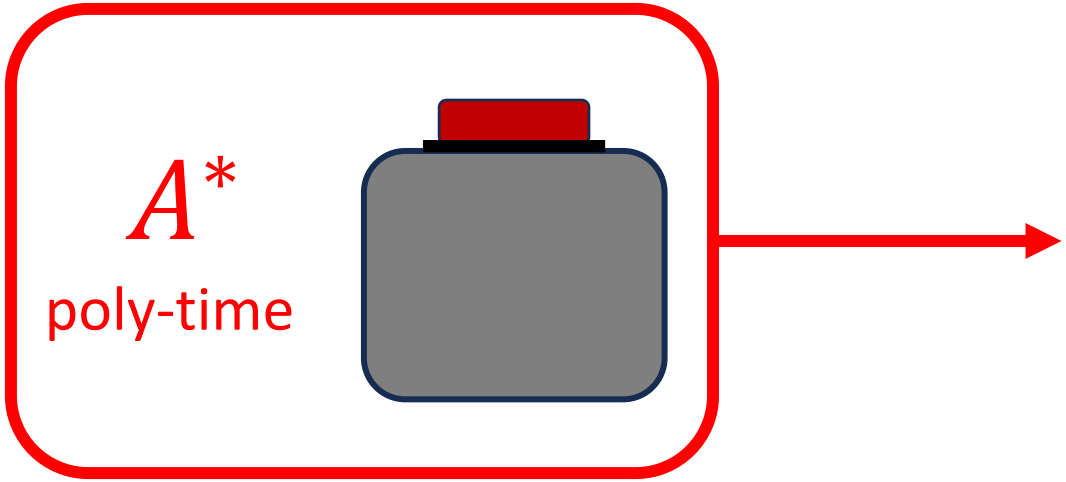

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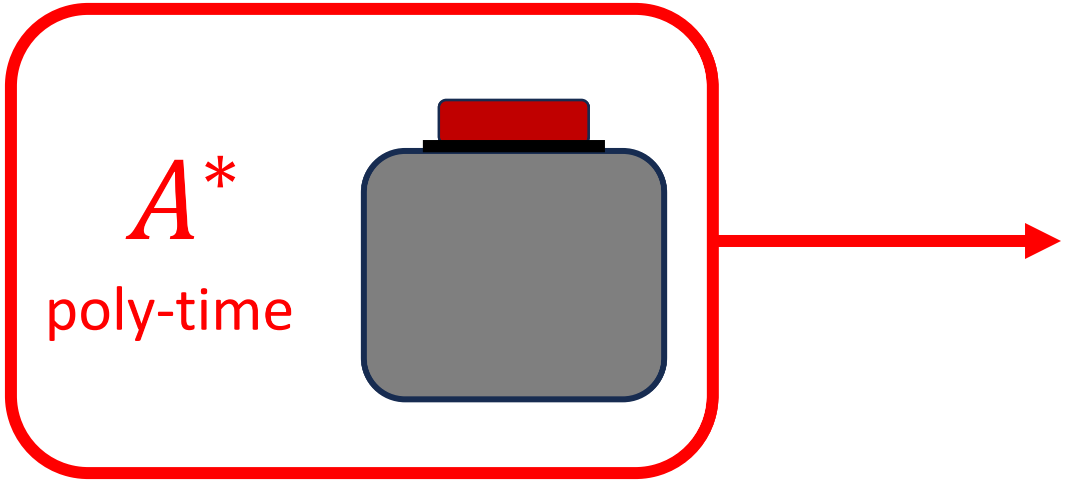

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Computationally intractable for $m_0 \neq m_1$

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  - Cryptocurrency (based on PoW) without a blockchain [Zha-17].
  - Blockchain-free smart contracts [Sat-22].
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We do not know of any other primitive in (quantum) cryptography that solves any of these problems

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  - ➢To date, the security of that construction remains unknown.

A Paradigm for Constructing One-Shot Signatures: Detour into Post-quantum Cryptography

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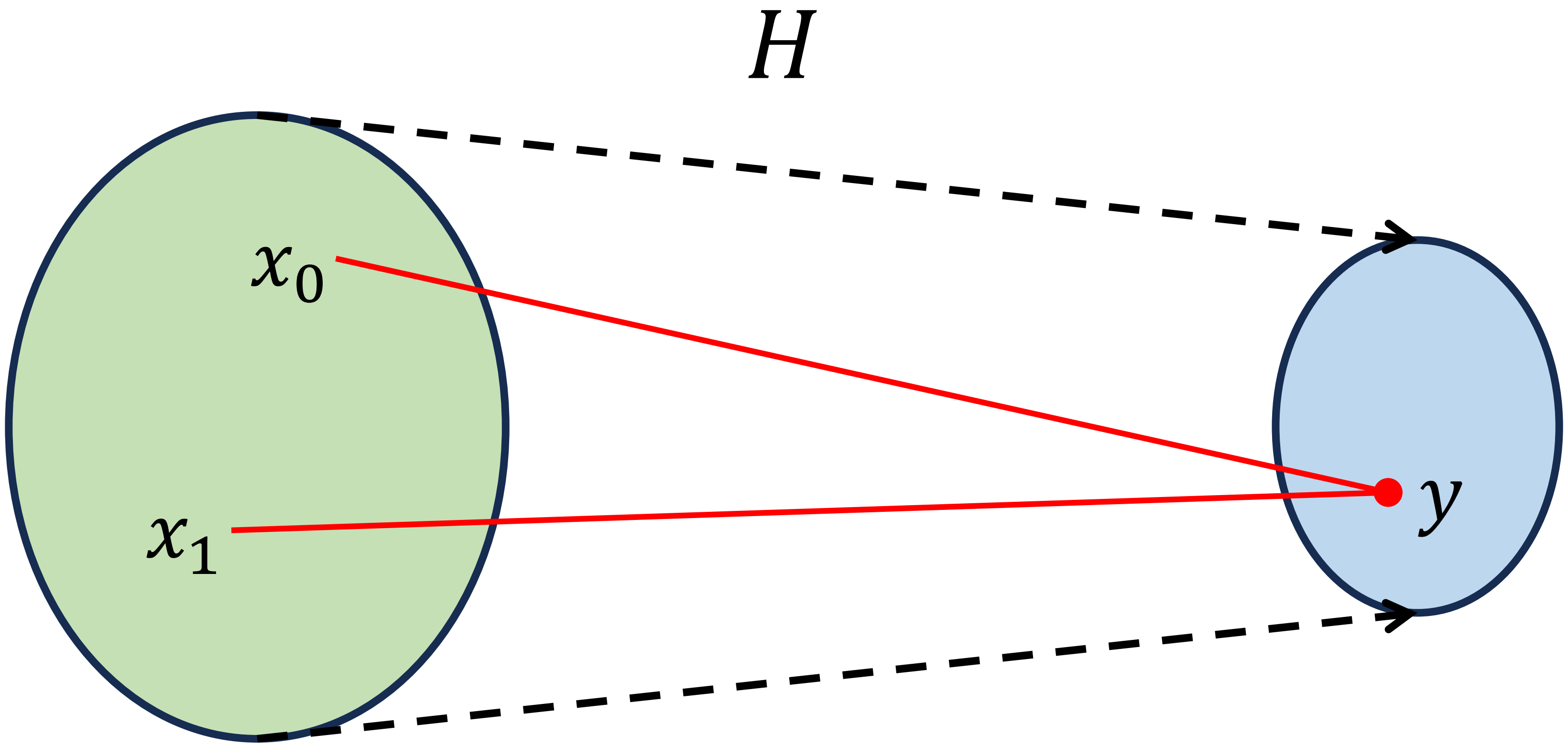
$\Uparrow$

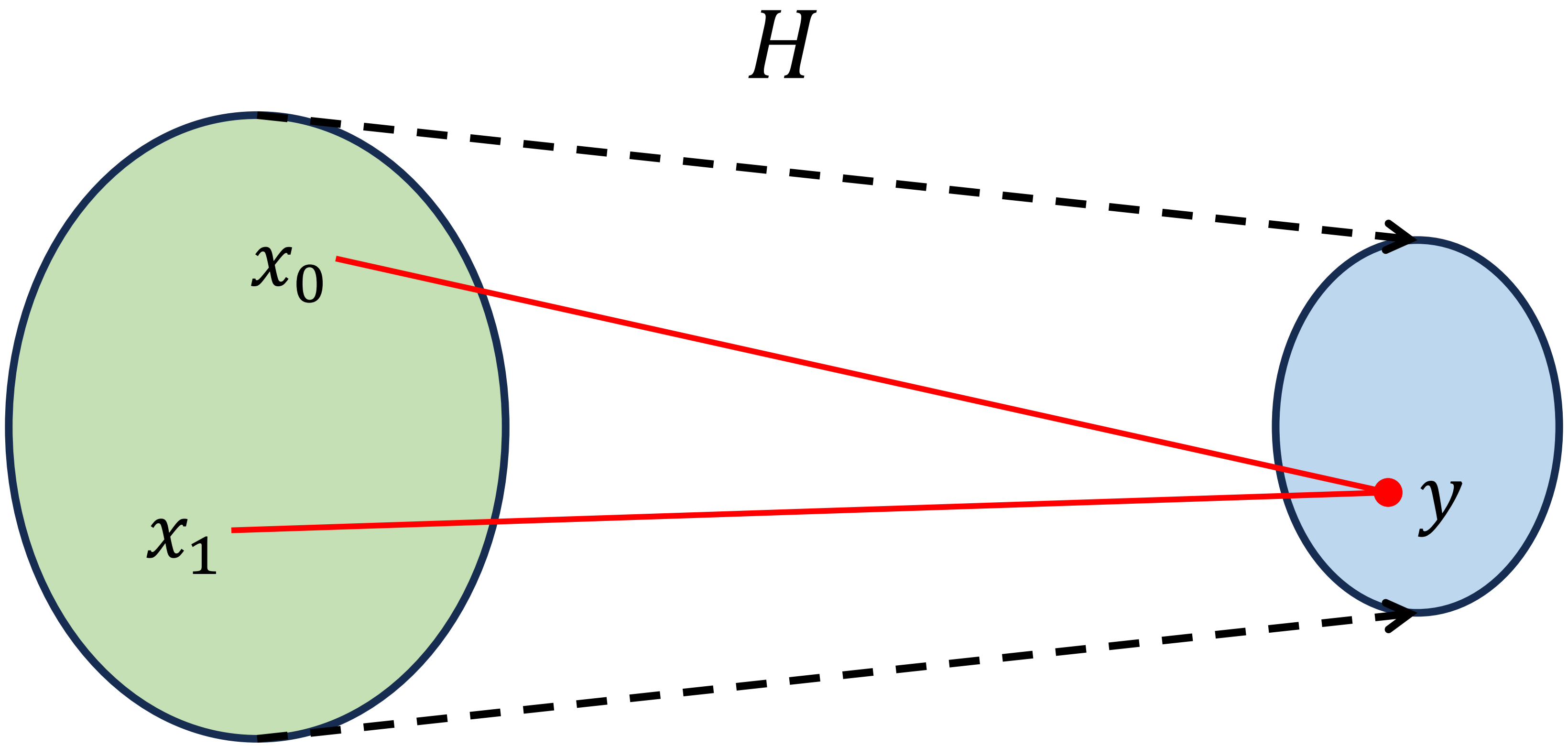
Classical **hash functions** that are post-quantum collision-resistant, may nonetheless be “insecure” against quantum computers.

Post-quantum Collision-Resistant Hash



Computationally intractable to find $x_0 \neq x_1$ s.t. $H(x_0) = H(x_1)$,
even for a quantum computer.

Post-quantum Collision-Resistant Hash

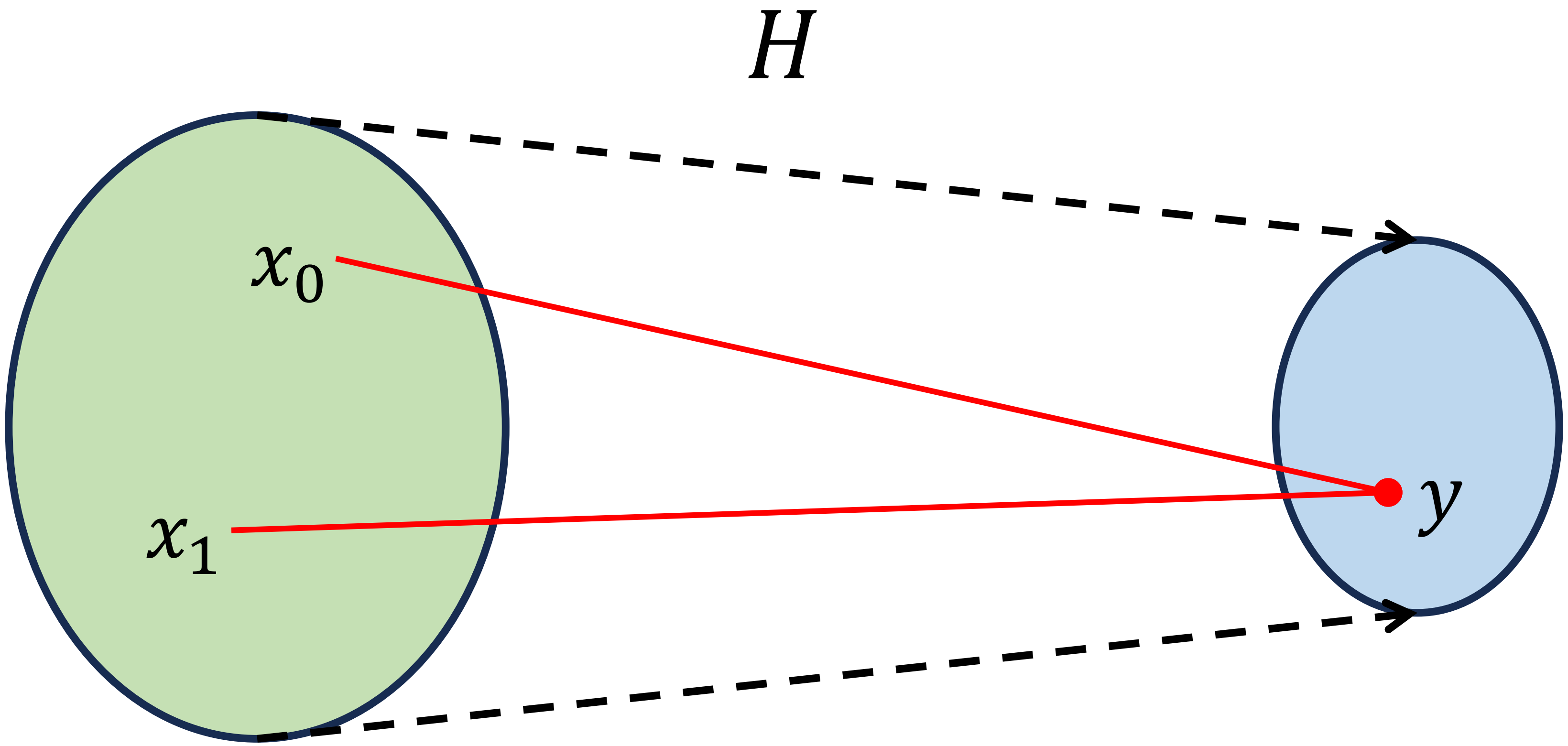


For computationally binding commitments we want:

If the adversary sends y, it is intractable for it choose x_b later.

Post-quantum Collision-Resistant Hash

For **classical** **adversaries:** The below is equivalent to collision resistance



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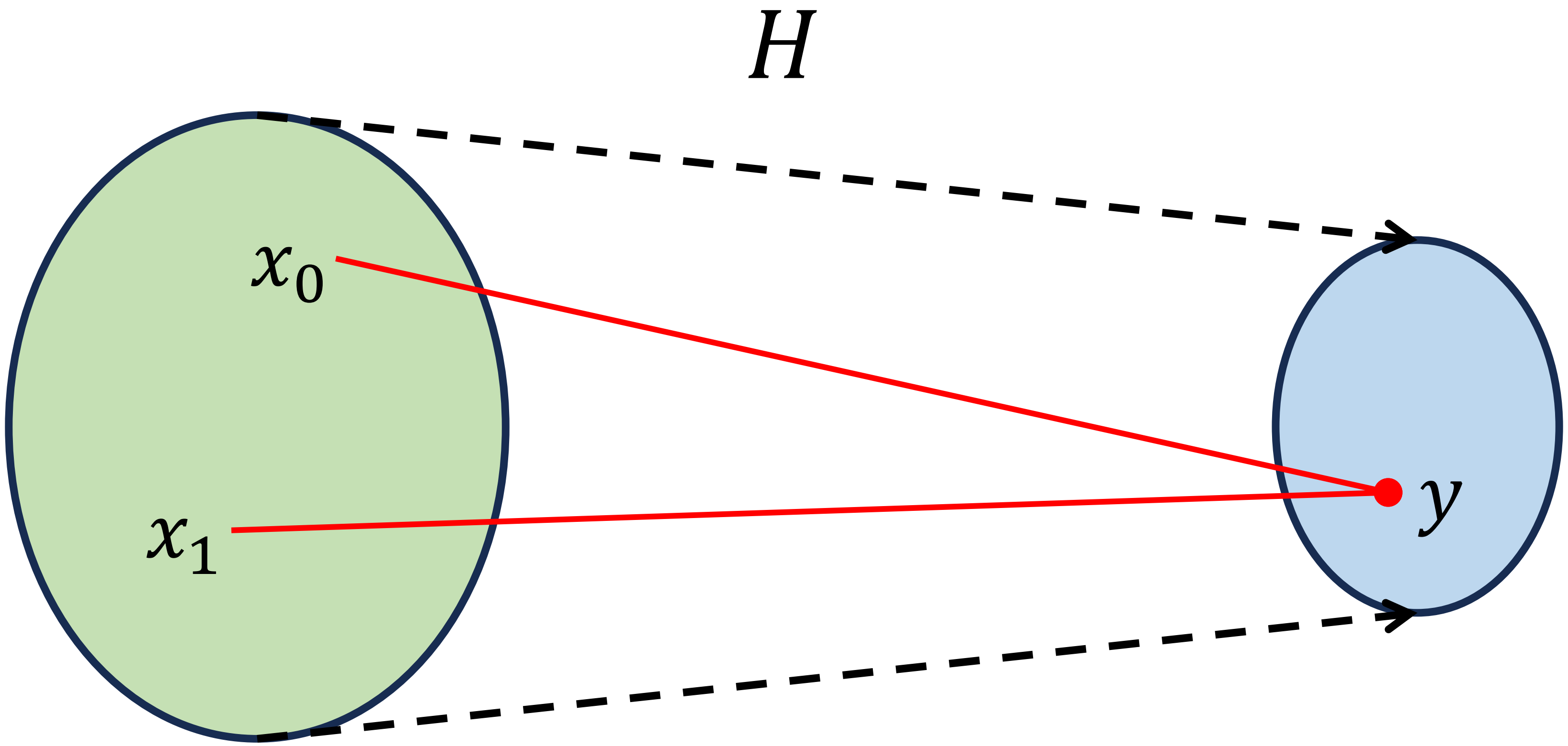

The reason of equivalence:
Rewinding!

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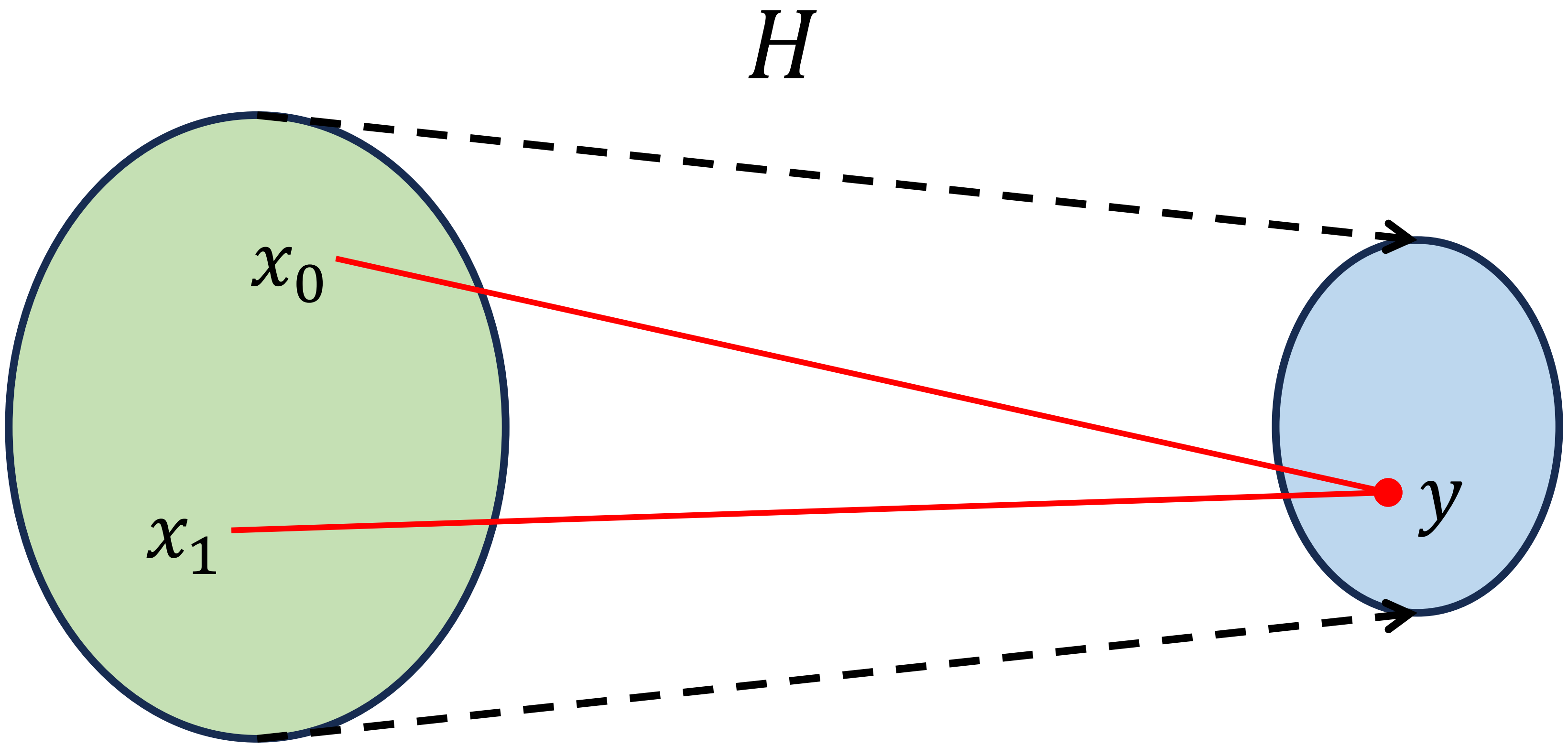

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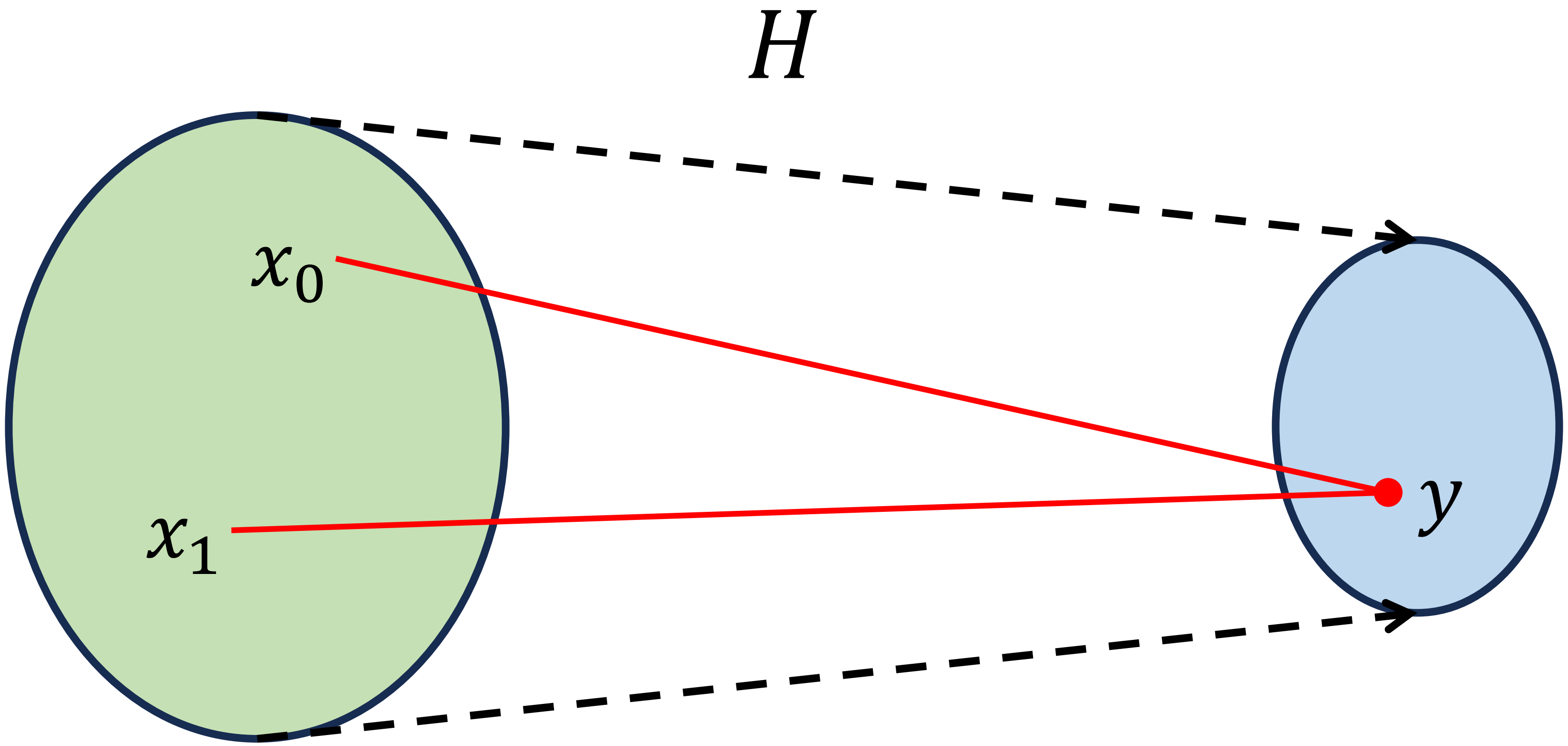

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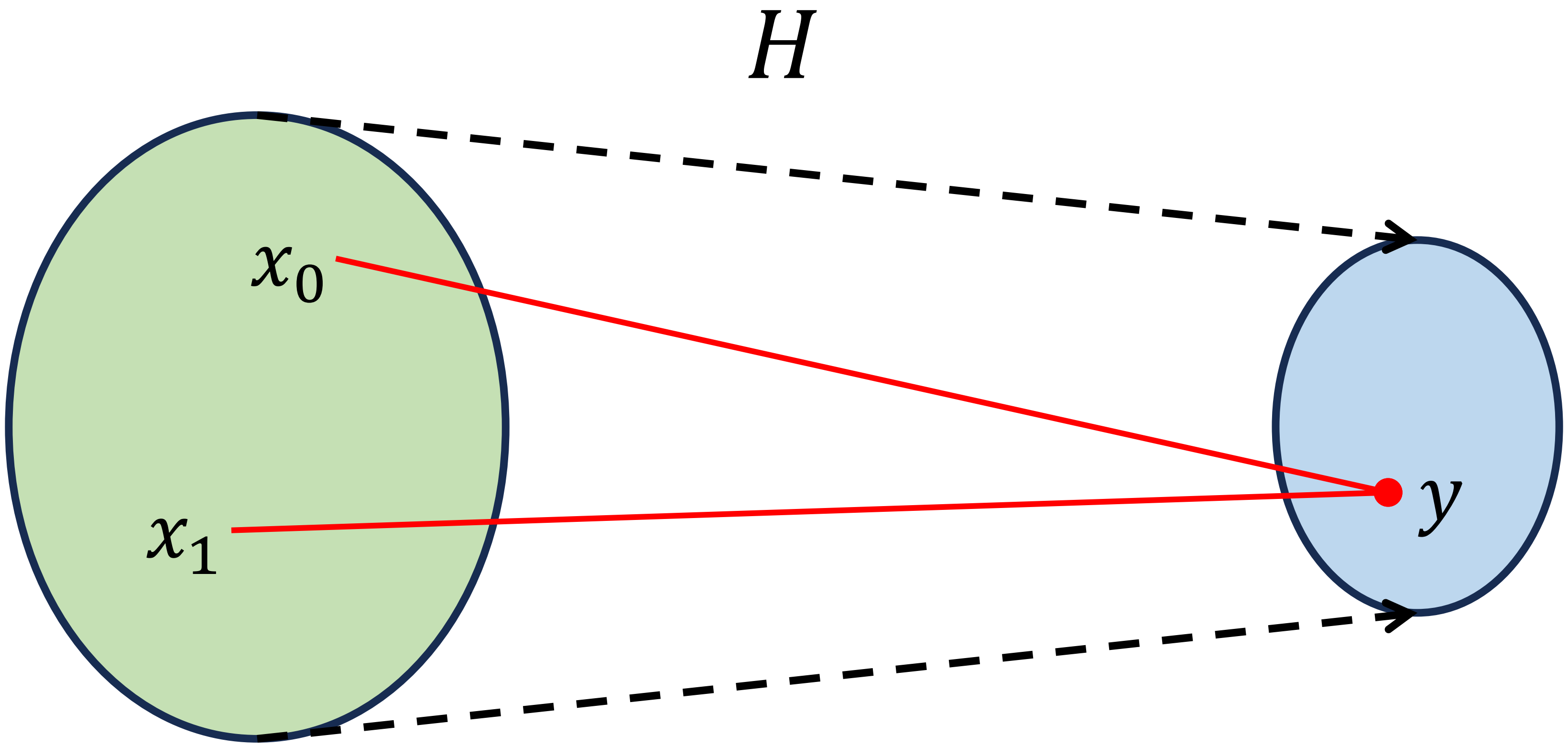

The reason: We generally <u>cannot</u> rewind quantum computers

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Quantum Rewinding is Hard

[VDG-C-97], [Wat-02], [Kob-03], [D-F-S-04], [Wat-09], [Unr-12], [H-S-S-11], [L-N-11], [A-R-U-14], [B-J-S-W-16], [Unr-16a], [Unr-16b], [B-S-20], [C-M-S-Z-21], [L-M-S-22], …

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- The adversary sends y as the commitment.
- **The issue:** The adversary has $\sum_{x\in\{0,1\}^n : H(x)=y} |x\rangle$. Theoretically, could steer the superposition to a specific preimage x (e.g., that starts with a 0).

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- For a collapsing H: $\sum_{x\in\{0,1\}^n : H(x)=y} |x\rangle \approx_c \{x : x \leftarrow H^{-1}(y)\}$.
- Plenty of constructions of **collapsing hash functions** in the standard model ([Unr-16], [L-Z-19], [Zha-22], [L-M-Z-23]).

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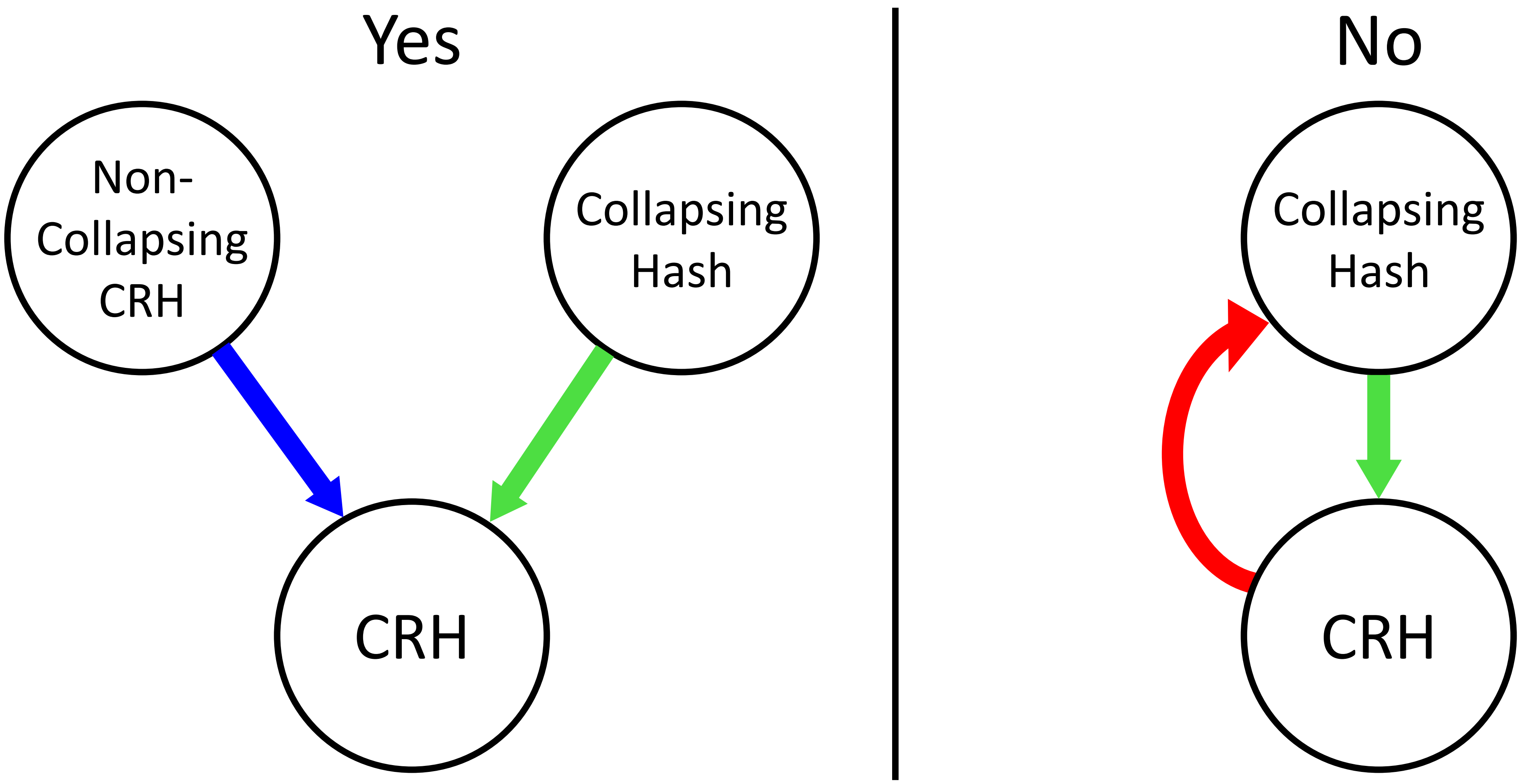

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Definition: An (always) non-collapsing CRH is (H, D) s.t. :

- H is a CRH.
- D is a quantum algorithm that can detect superpositions of H:

$$\sum_{x\in\{0,1\}^n} |x\rangle \to \sum_{x\in\{0,1\}^n} |x\rangle|H(x)\rangle \to \sum_{x\in\{0,1\}^n : H(x)=y} |x\rangle , y ,$$

$$\sum_{x\in\{0,1\}^n : H(x)=y} |x\rangle \not\approx \{x : x \leftarrow H^{-1}(y)\}$$

$\uparrow$

D

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- [Zha-17], [A-G-K-Z-20], [D-S-22]:
  Non-collapsing CRH $\Rightarrow$ One-Shot Signatures .

(+ collapsing is **necessary** for post-quantum binding)

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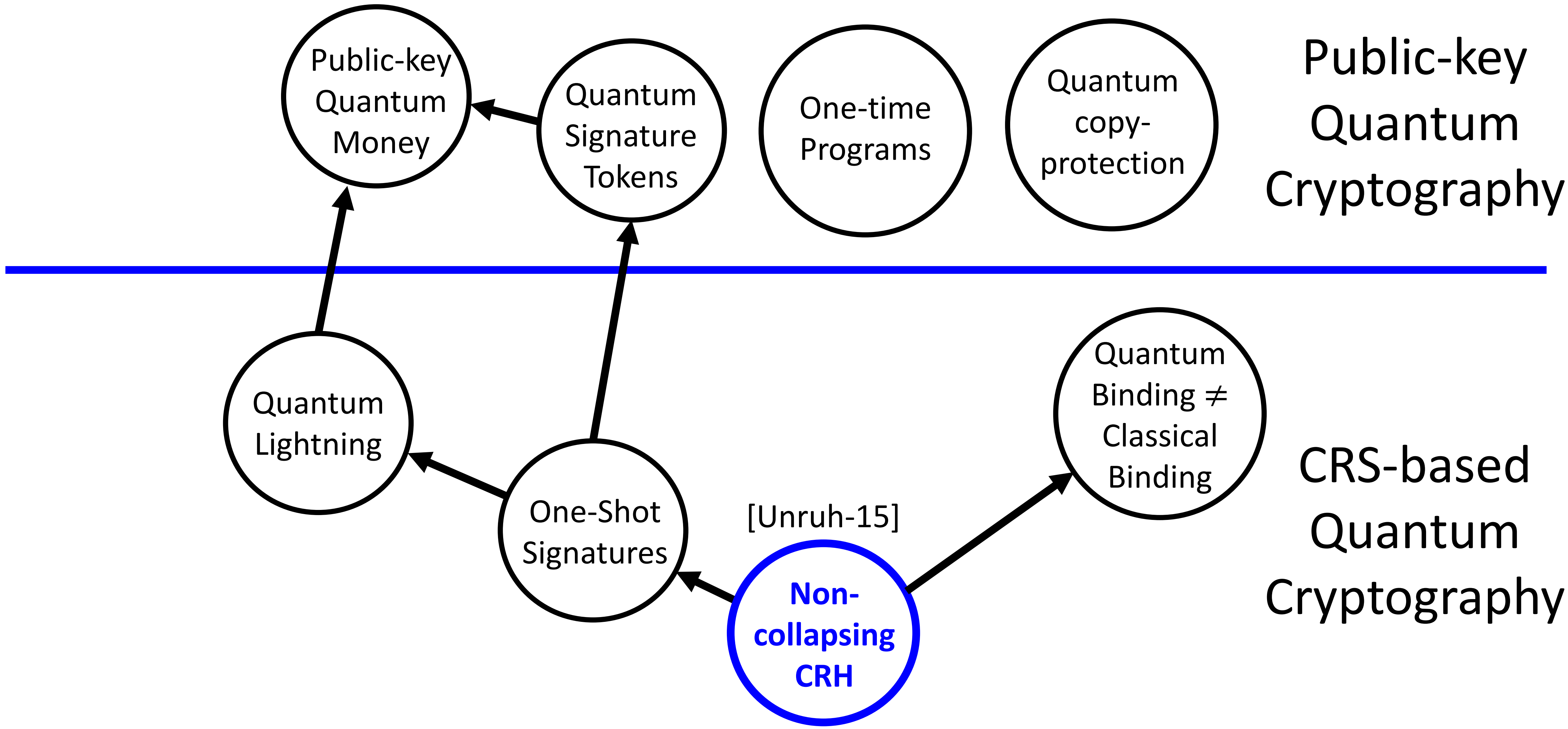

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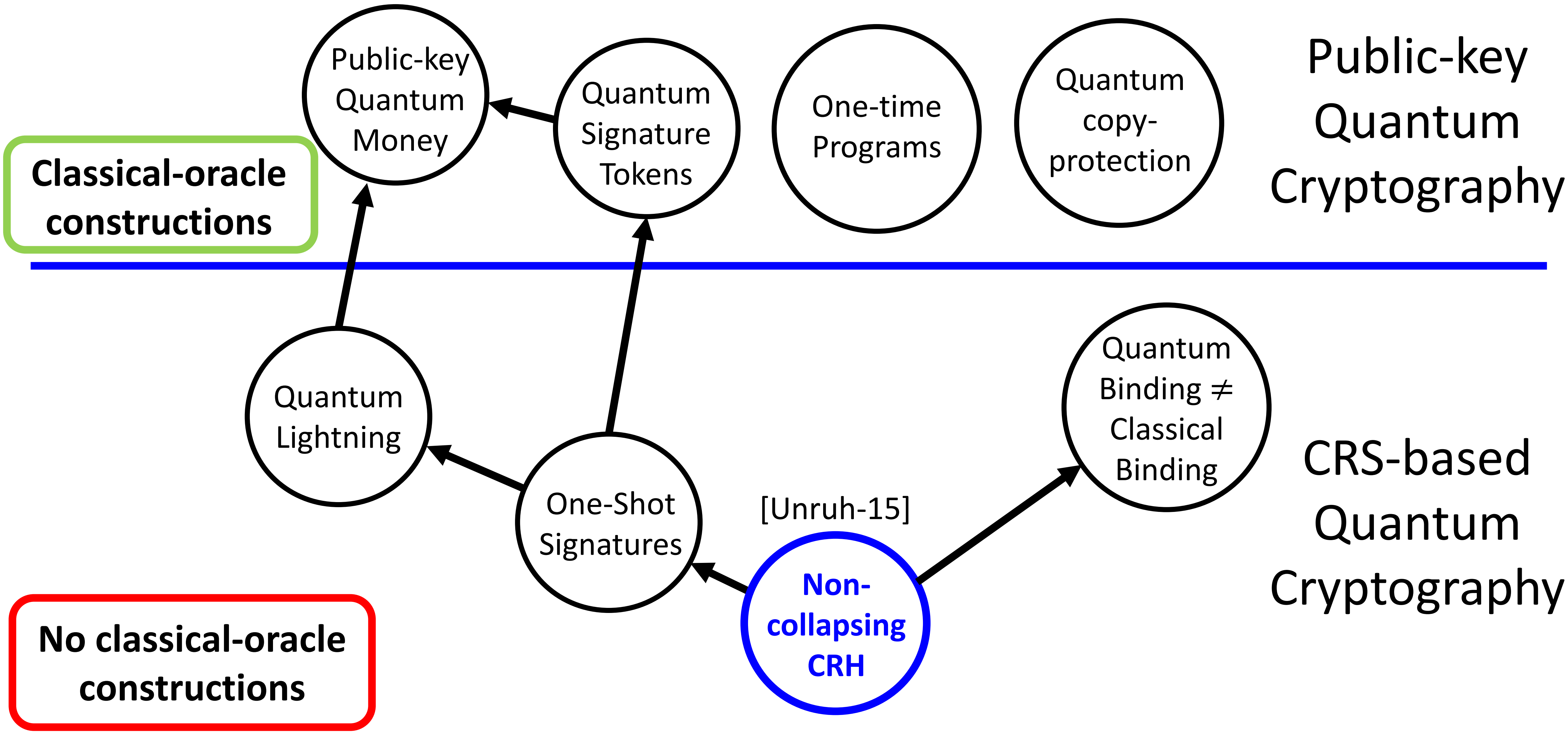

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Then, there exists a **non-collapsing CRH** in the standard model.

Intuition for Constructing a Non-collapsing CRH

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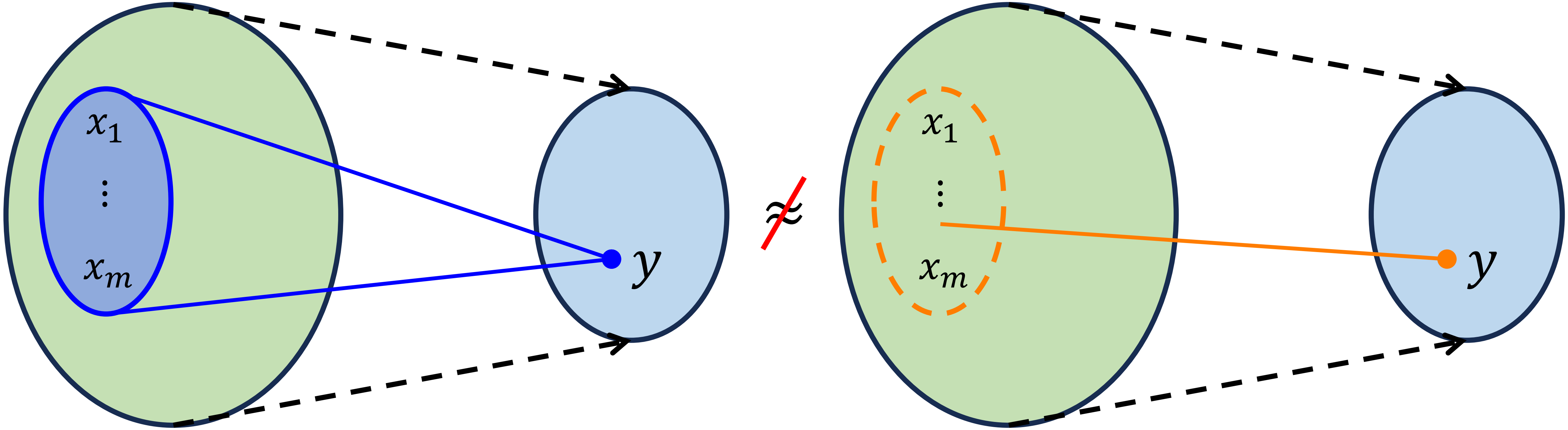

Construct a CRH where the two cases above are **distinguishable**.

Intuition for Constructing a Non-collapsing CRH

The Challenge (intuitively):

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Detecting a superposition publicly, without giving a description of the state, needs a highly structured set.

- Collision resistance:

However, what makes a hash function collision resistant is the lack of predictable structure of inputs.

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A *random permutation* $\Pi: \{0,1\}^n \to \{0,1\}^n$ can be used to mediate between two requirements:

1. Unstructured, collision-resistant sets, and
2. Structured sets, detectable in quantum superposition.

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Non-collapsing: How to detect superpositions of preimages of H?

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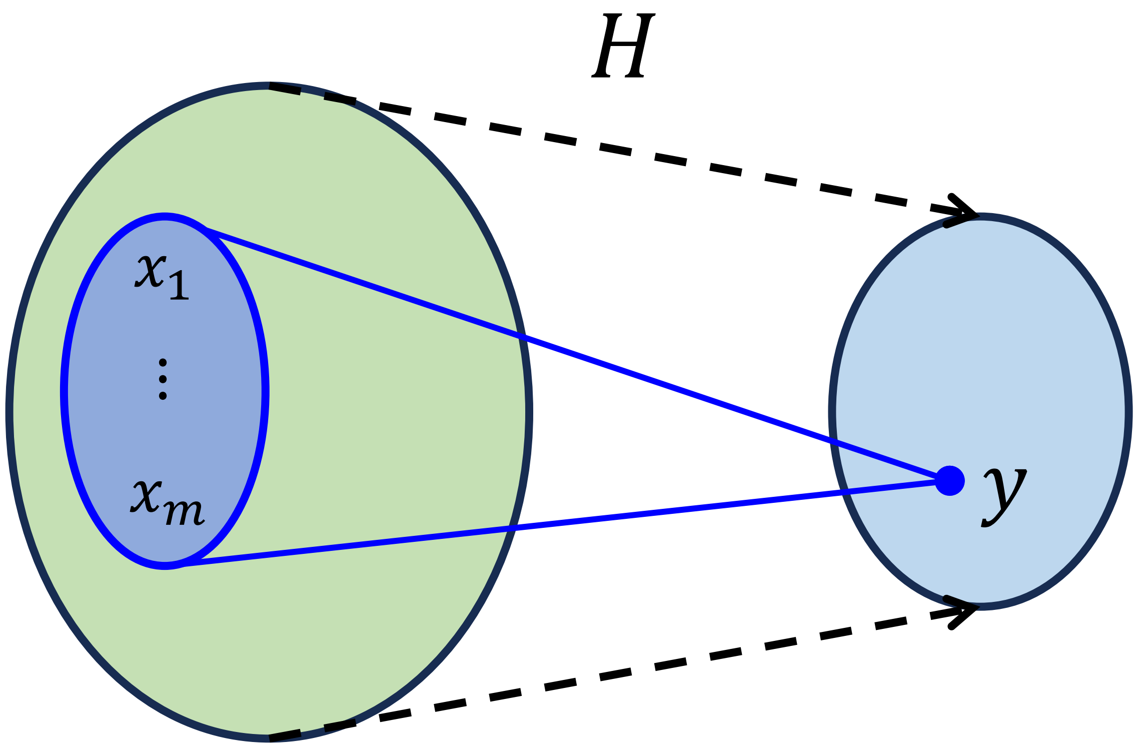
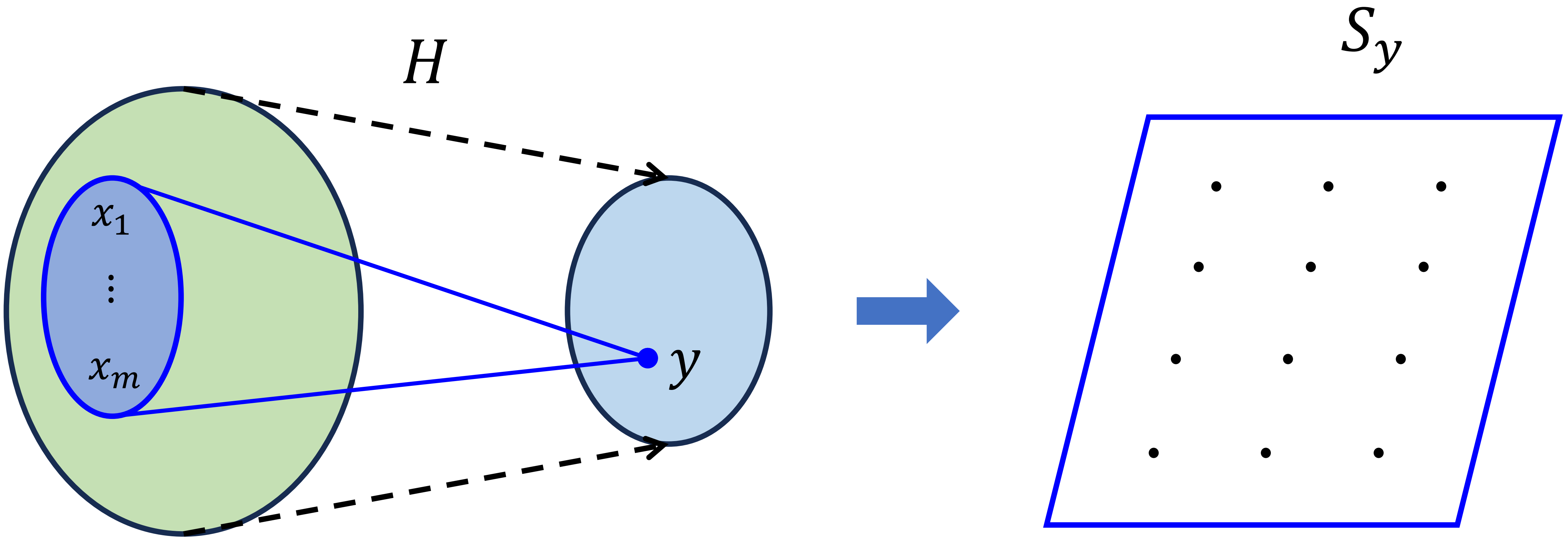


1. Compute H in superposition and measure an output y.

Intuition for Constructing a Non-collapsing CRH



2. Given y, sample a secret sparse subspace $S_y \subseteq \mathbb{Z}_2^k$.

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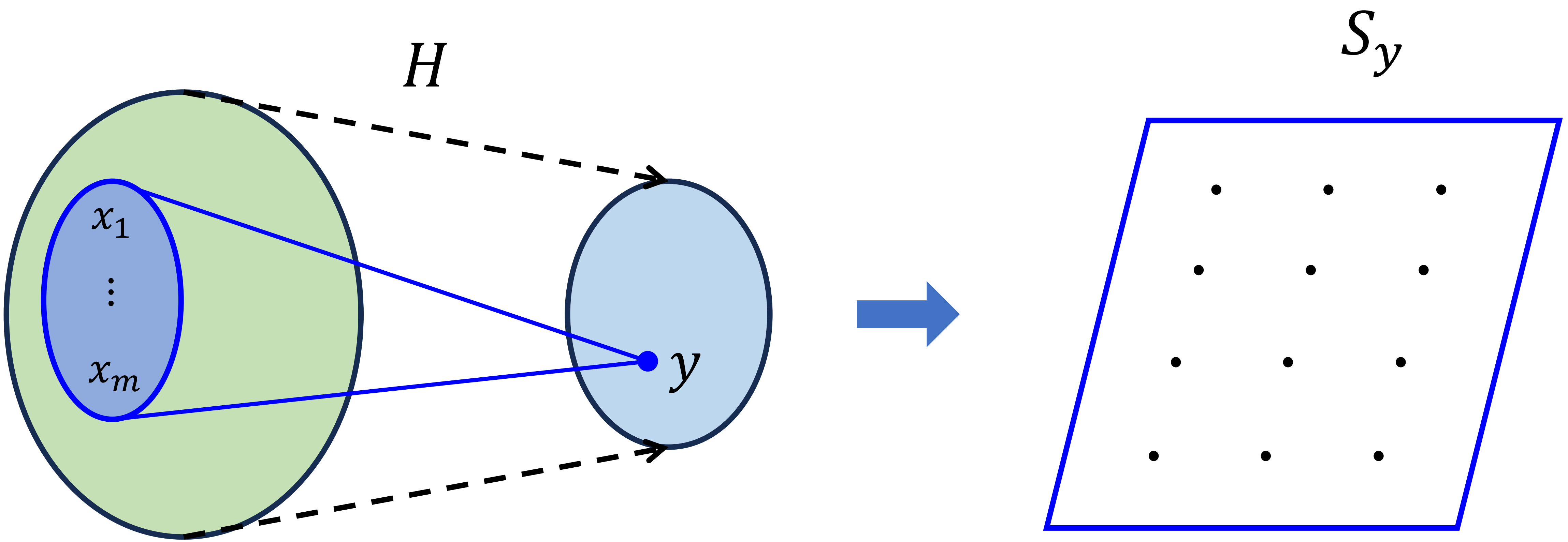

3. Note $\{J(x)\}_{x \in H^{-1}(y)} = \{0,1\}^{n/2}$. We can think of it as $\mathbb{Z}_2^{n/2}$.

These can be coordinate vectors for S_y .

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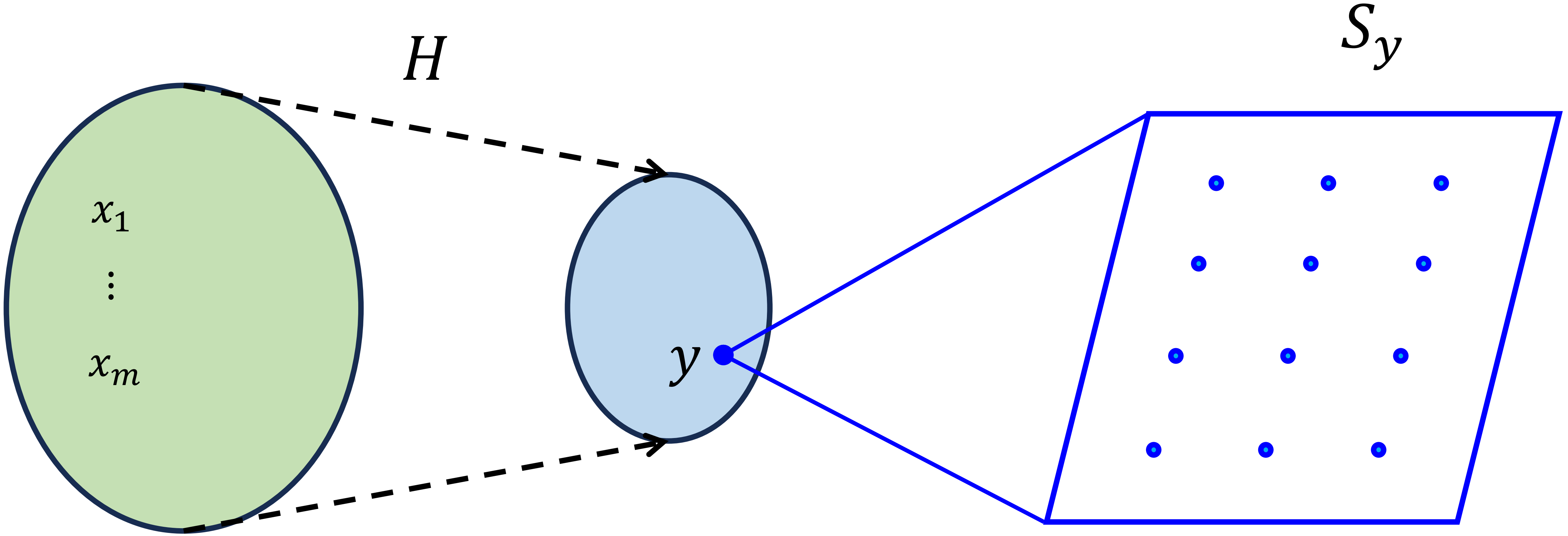

4. We show how to move between $H^{-1}(y)$ and S_y reversibly, while keeping the collision resistance of H.

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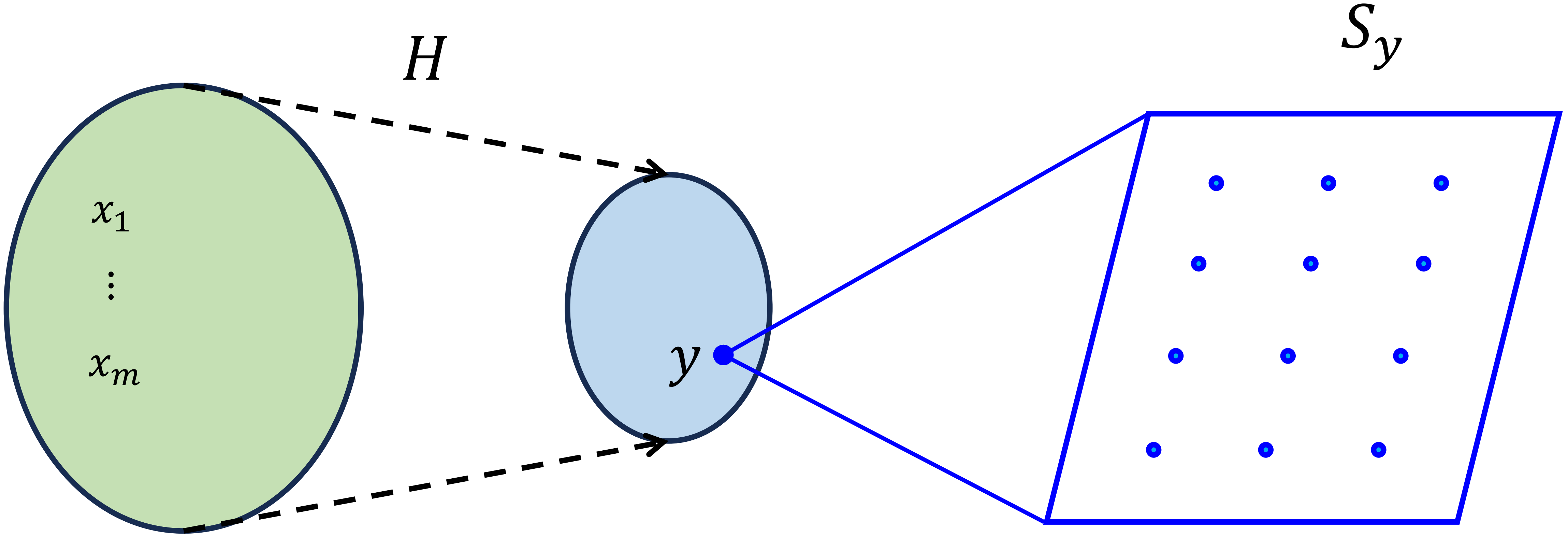

5. By known techniques [A-C-12]: Superposition over S_y can be detected publicly, without revealing it.

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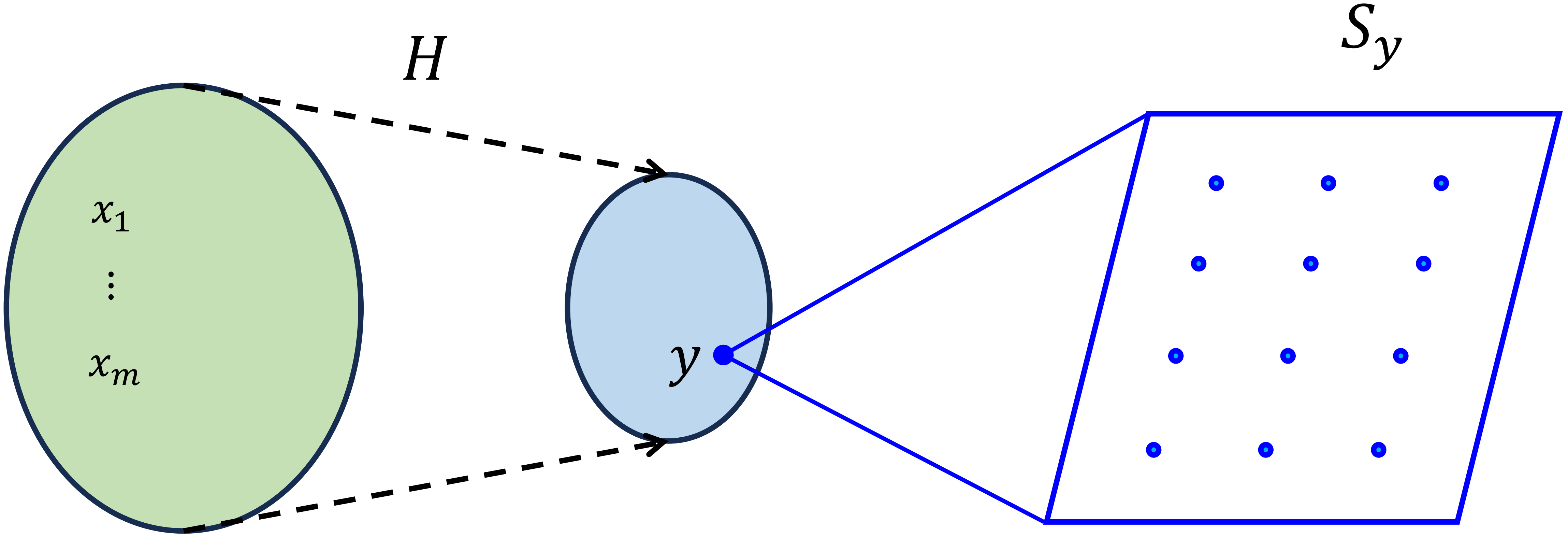
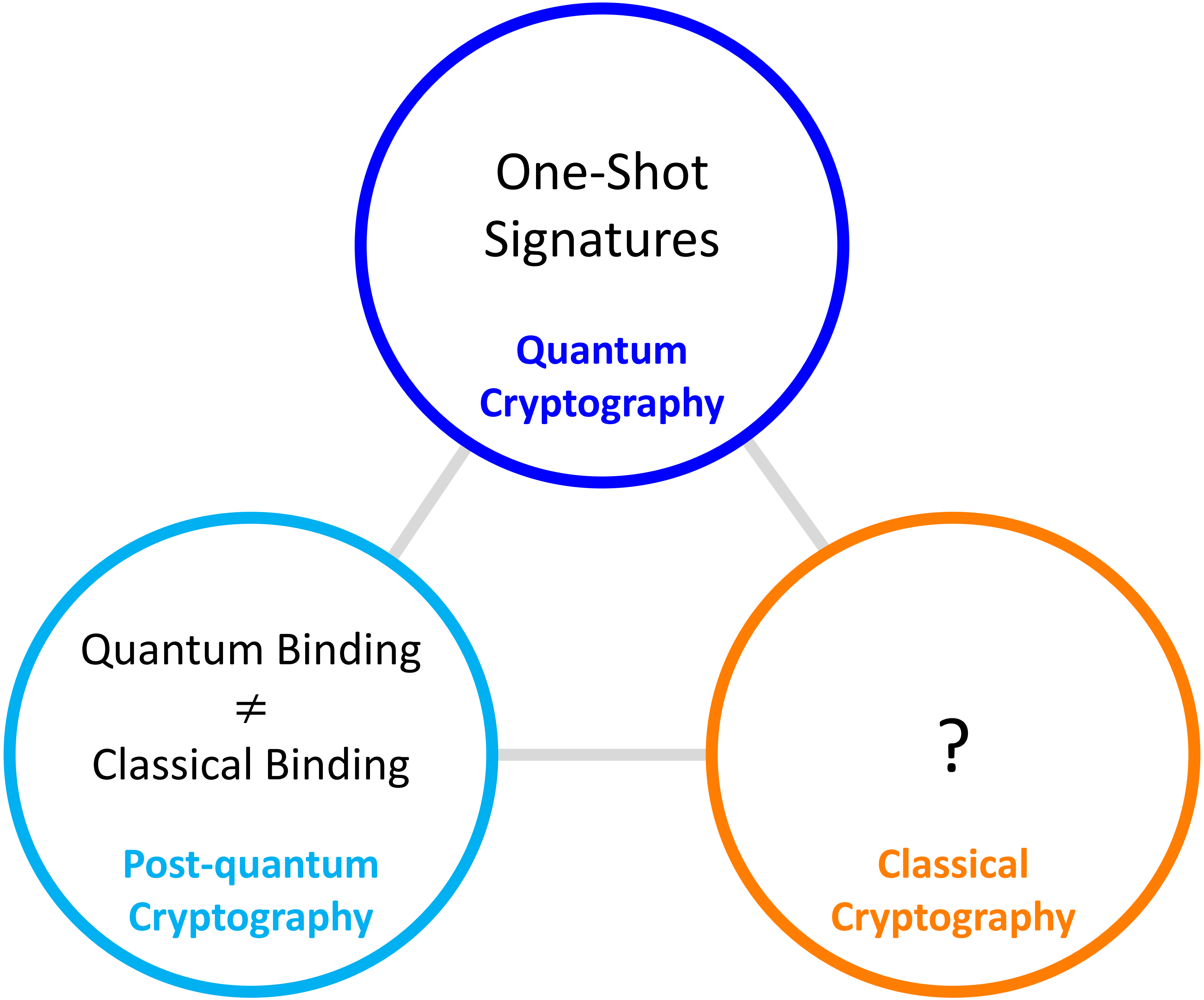


In the paper: We show how to formalize these intuitions to get a Non-collapsing CRH in a classical oracle model.


One-Shot Signatures
Quantum Cryptography
Quantum Binding
≠
Classical Binding
Post-quantum Cryptography
?
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A word on Standard-Model Security & Obfuscating Pseudorandom Permutations

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- **The challenge:** We need to obfuscate a PRP (open problem in classical cryptography, for at least a decade).
- We define a new notion: Permutable PRPs.
- Permutable PRPs allow: $iO(\Pi) \approx_c iO(\Gamma \circ \Pi)$, for a known Γ.

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We show how to obfuscate a permutable PRP and make the circuit public, without revealing the PRP.

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Theorem 3:

Assume,

- Sub-exponentially-secure **One-Way Functions**, and
- Sub-exponentially-secure **iO** for classical circuits.

Then, ∃ a **trapdoor one-way permutation** with domain $\{0,1\}^n$.

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- A purely combinatorial question: What permutations Γ are decomposable?

2. Can we construct One-Shot Signatures (or even weaker primitives) **without** indistinguishability obfuscation?

Questions?