Signature-in-Signature: the Last Line of Defence in Case of Signing Key Compromise

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Fairy tale of digital signatures

SSCD: legally binding electronic signatures/seals must be created by an SSCD (Secure Signature Creation Device)

Hope:
- SSCD designed so that it prevents key leakage,
- without the owner's consent SSCD will not create a signature.

Invalidation: signature/seal legally binding unless created after key revocation time.

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unless: ...we find a method to fish out forged signatures.

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Limit the overhead

To leverage exisiting schemes and not rely on excessive external systems (blockchain, mediator schemes, . . .).

Our solution

Inner

A standard signature contains an **inner signature** that is

cryptographically undetectable – even for a holder of the (leaked) signing key

verifiable in a standard way **once the signing key is revealed together with the inner public key**

Example: inner signature creation on top of Schnorr signature

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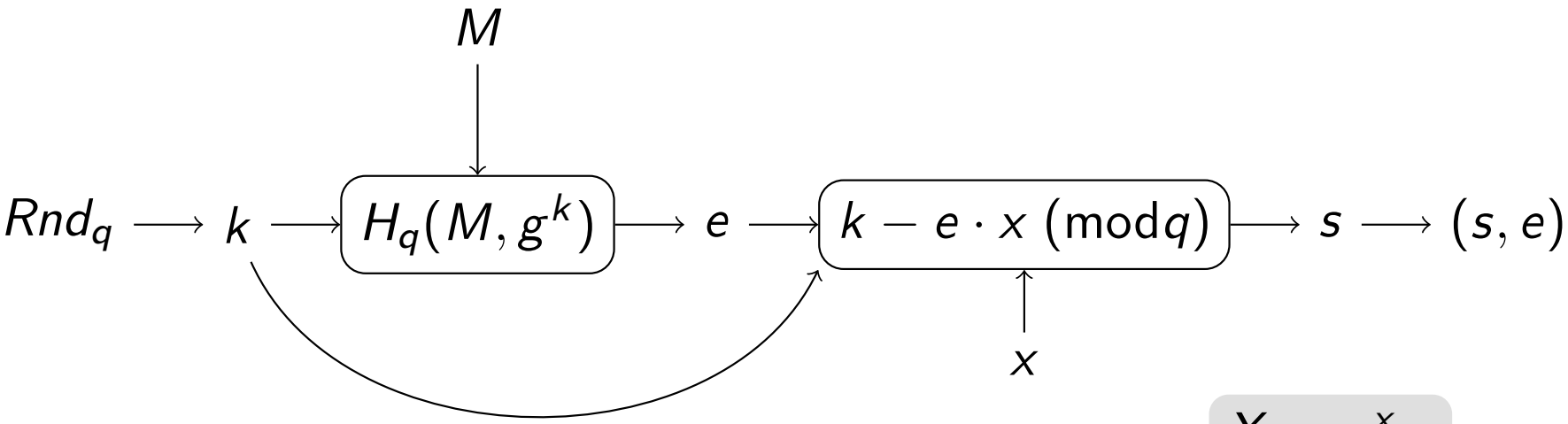
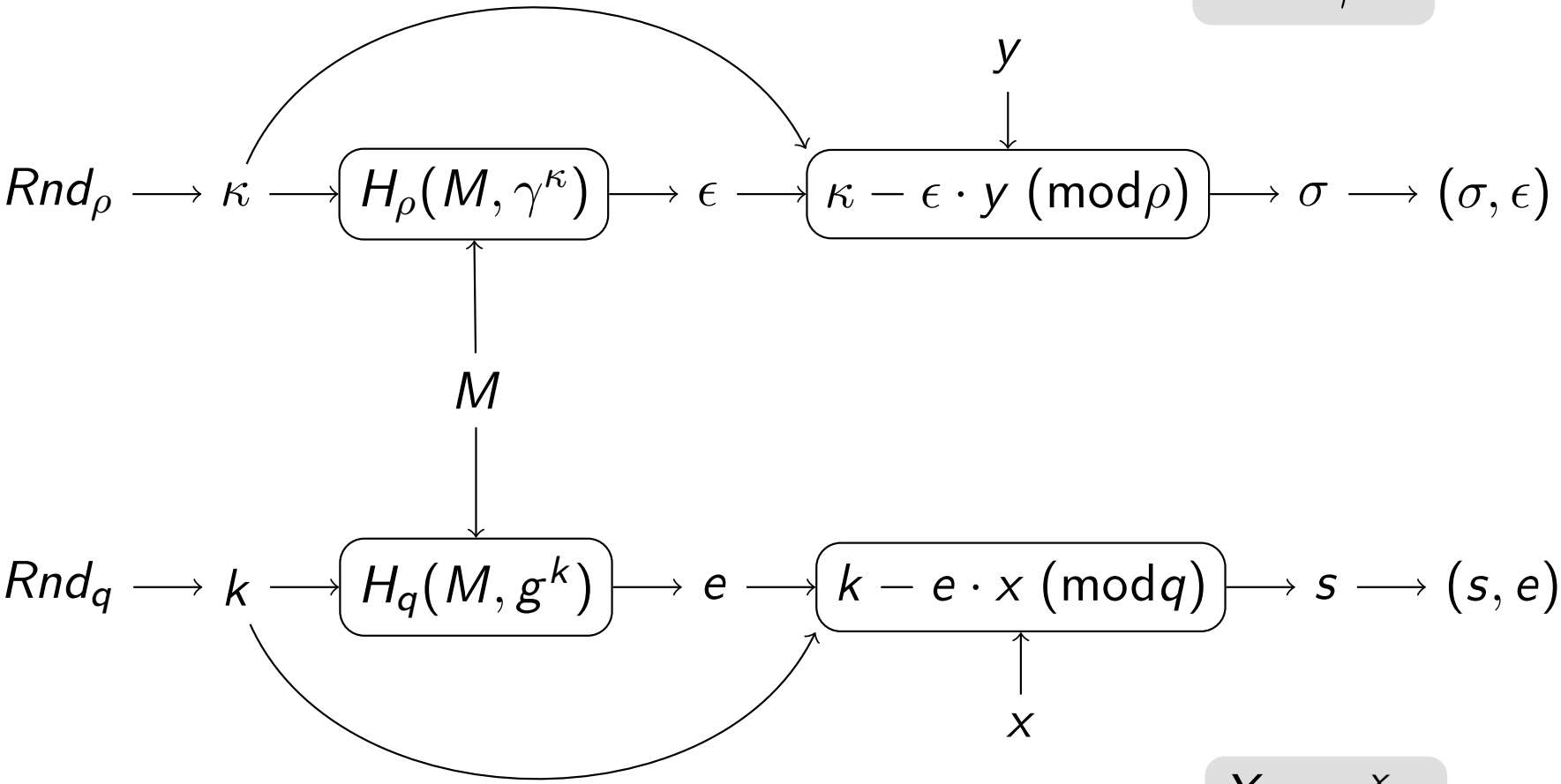


Example: inner signature creation on top of Schnorr signature

$\frac{\log q}{\log \rho} \geq 2$

$Y = \gamma^y$



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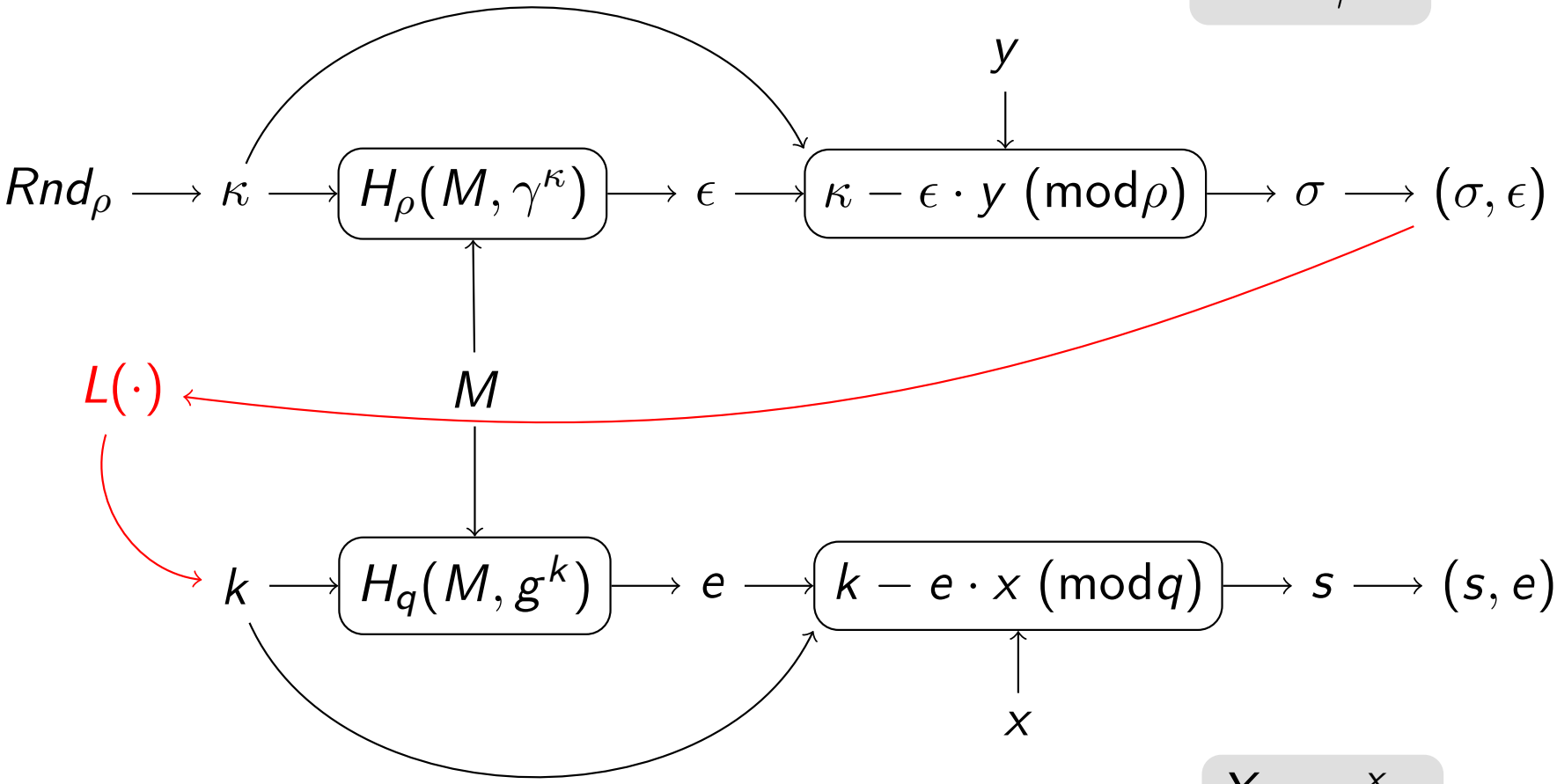

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Inner signature verification

given: inner public key Y, device's secret (compromised) key x are given.

procedure: for a signature (s, e) under M:

1. recompute ephemeral k as $k := s + e \cdot x \mod q$
2. retrieve inner signature(s): $(\sigma, \epsilon) := L^{-1}(k)$
3. (s, e) is valid if (σ, ϵ) verifies with Y for M.

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Note: L is an invertible encoding function: given $L(\alpha, \beta)$ it should be possible to derive α, β.

Properties (1)

For the outer signature k is no longer random, but:

Schnorr pseudorandomness

Given message M, secret key x and a number s, it is infeasible to decide whether exists k fulfilling $s = k - x \cdot Hash(M, g^k)$ or s is random.

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Hence: hard to tell if the inner signature is hidden in a single instance of a Schnorr signature.

Properties (2)

Adversary managed to break X (?) and calculated x, so maybe he can do the same with Y?

- recover ephemeral values for outer signagures
- use L^{-1} to create candidate pairs of inner signatures
- break them...

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... however:

Secrecy of the public key

1. It is infeasible to derive the public key from Schnorr pair (σ, ϵ) or decide that no matching key exists.
2. It is infeasible to decide if two signatures $(s_0, e_0), (s_1, e_1)$ under M_0, M_1, respectively, correspond to the same public key.

Further notes

- Subsequent inner signatures can be linked

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- Implementation is ongoing, a few workable options presented in Appendix.

Thank you for your attention!