Continuous Non-Malleable Key Derivation and Its Application to Related-Key Security

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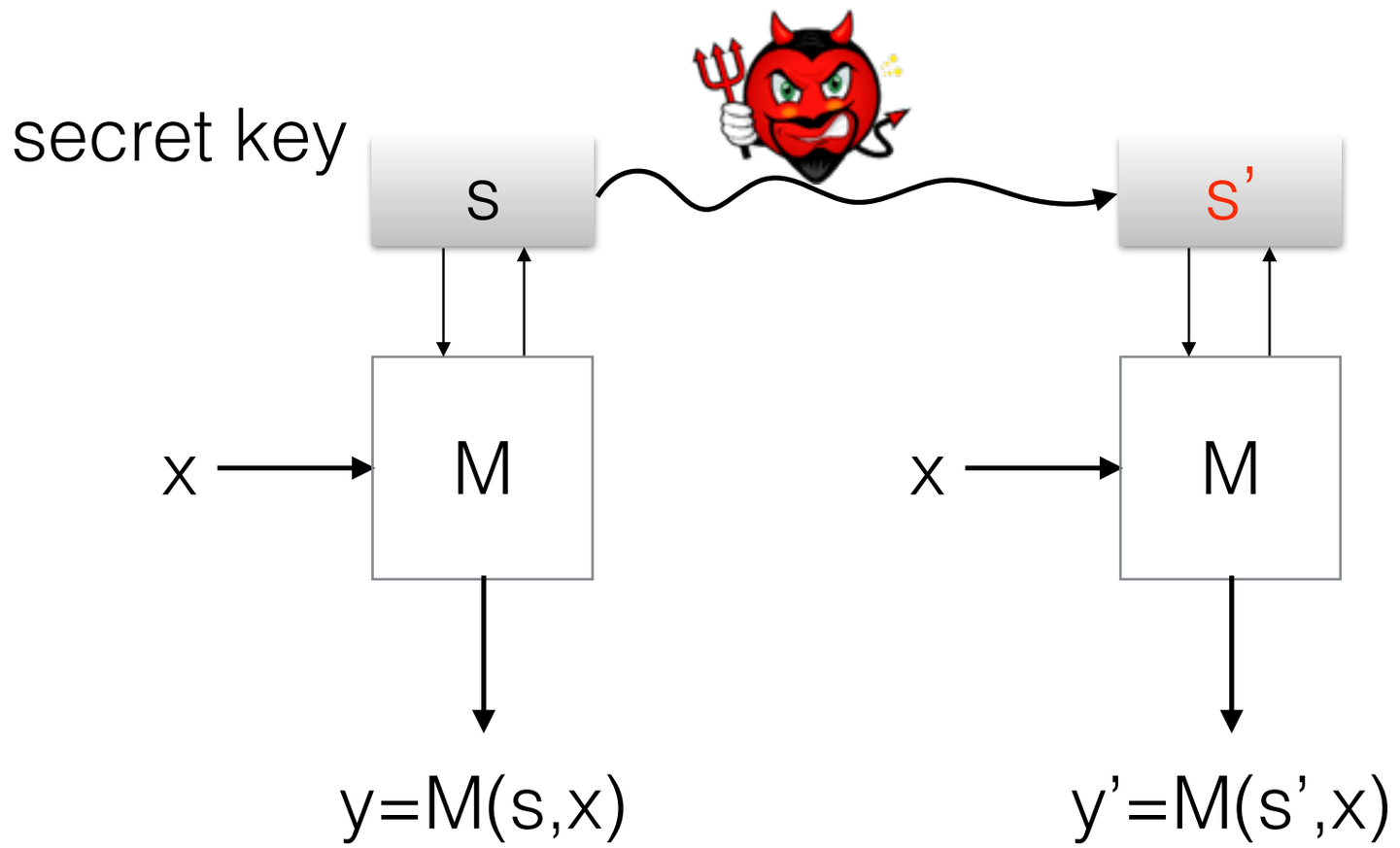
- Conclusion

Related-Key Attacks

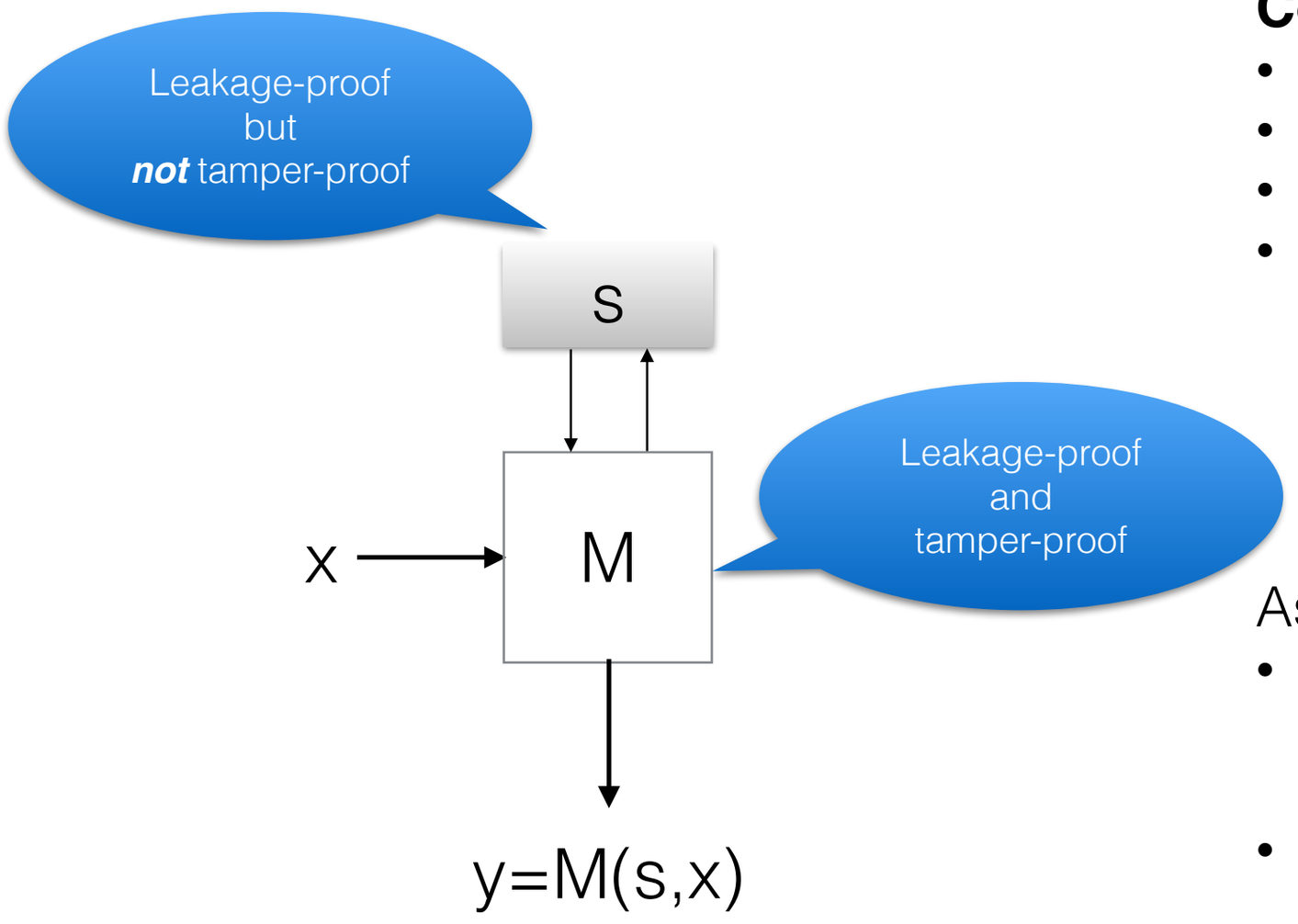
Scenario

- Hardware implementation
- Fault attacks: heat it or cut wires to inject faults.



Related-Key Attacks

Assumption



Composition of a system:

- Algorithm (codes)
- Public parameters
- Public keys (if any)
- Secret keys

Assumptions:

- Algorithm (codes) and PPs in a tamper-proof hardware device
- Only public keys and secret keys may be subjective to tampering attacks.
- The device does not leak any information on the secret key.

Related-Key Attacks

Tamper functions

- Related-key derivation (RKD) functions (following BK03)
  - From SK space to SK space

$$F: S \longmapsto S$$
$$f: \quad s \longmapsto f(s)$$

- If the public key pk is involved in an algorithm M, it might be subject to tampering attacks as well.
- In practice, the adversary has already known pk. So, tampering with pk is just dependent on the adversary's view, not the secret key.
  - pk' is implicitly determined by RKD function f.
  - Different to the split-state model [DP08,FMNV14]: s is divided into two parts (s_1,s_2).

$$F: \quad S \times PK \longmapsto S \times PK$$
$$f: \quad (s,pk) \longmapsto (f(s),pk')$$

fxg: $(s_1,s_2) \longmapsto (f(s_1),g(s_2))$, f, g are independent of each other.

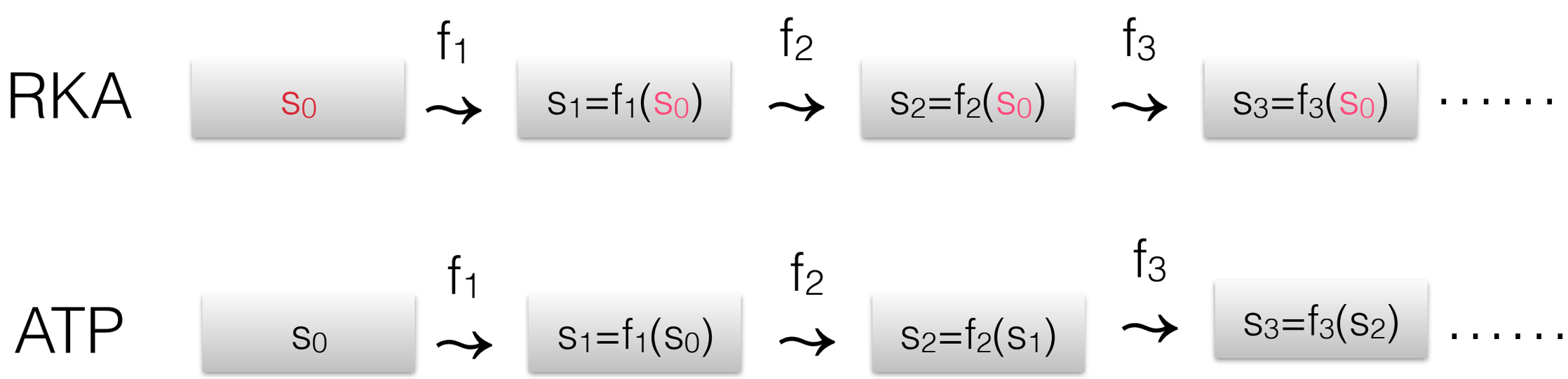
The adversary does not know the result $g(s_2)$.

Related-Key Attacks

Two security models

- Related-key attacks (RKA) security [BK03] and Algorithmic tamper-proof (ATP) security [GLMMR04]

non-persistent vs persistent [JW15]



Related-Key Attacks

Two security models

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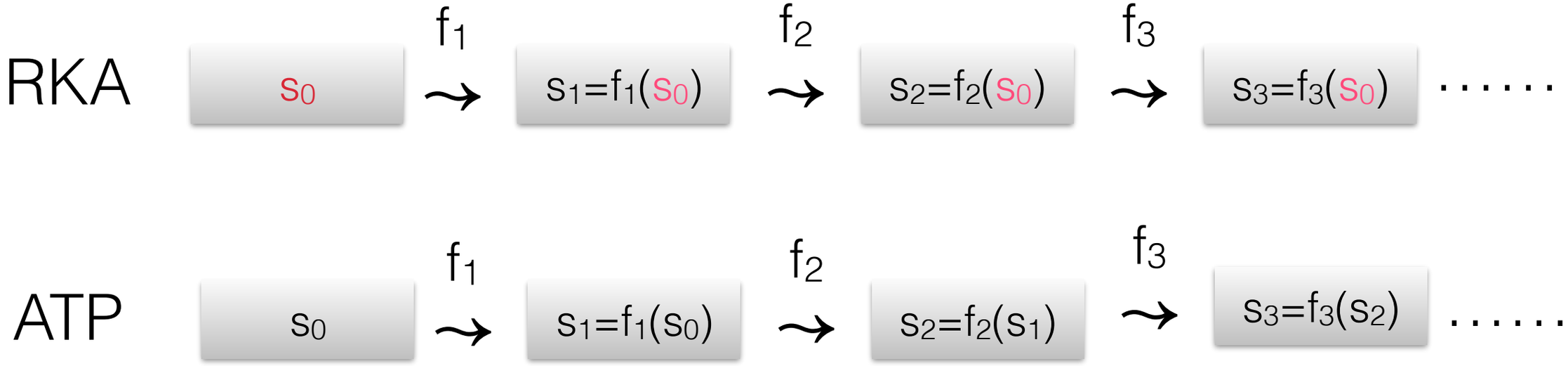
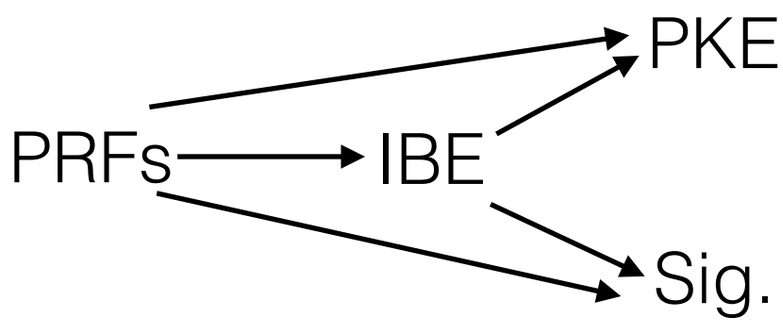


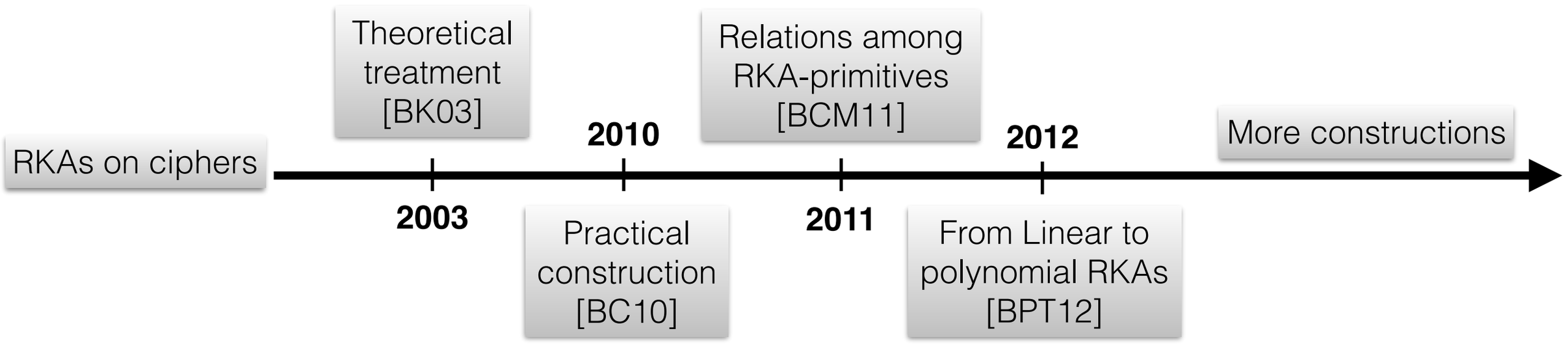
This paper: RKA model.
We would like the RKD function class is as rich as possible.

Previous Works on RKAs

Specific Constructions

- Specific primitives, specific computational assumptions
- RKA secure: PRFs, IBE, Signature, PKE…





Previous Works on RKAs

Specific Constructions

- Limitations:
  1. Simple RKD functions: linear, affine or **polynomials** (bounded degree).
  2. Parameter depends on the RKD functions and based on non-standard assumptions

Example in [BPT12]:

To compute $g^{f(s)}$ without known s for polynomial $f(x)=a_0+a_1x+\ldots+a_dx^d$ public keys must provide the following elements:

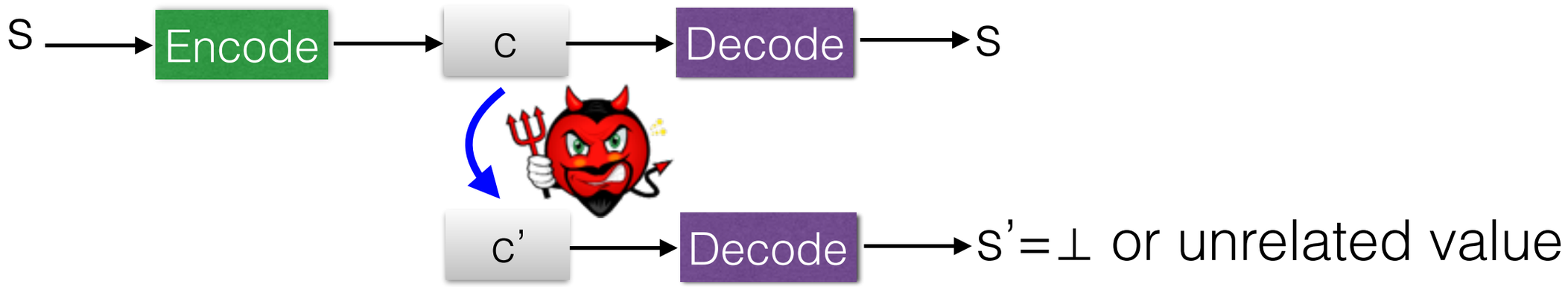
$$g^s, g^{s^2}, \ldots, g^{s^d} \Rightarrow g^{f(s)}=g^{a_0}*(g^s)^{a_1}*\ldots*(g^{s^d})^{a_d}$$

d-extended DBDH assumption

Previous Works

Generic Approach

- Tamper-resilient codes, mainly including
  - Algebraic Manipulation Detection codes [CDF+08]
  - Non-malleable codes [DPW10,FMVW14,…]
  - Continuous NMC [FMNV14,JW15,…]



- AMD and NMC: **single-time** tampering, but RKA multi-time non-persistent tampering.
- Continuous NMC: **multi-time** tampering (persistent or **non-persistent**)
- Concurrent work [JW15]: simple and efficient, but public parameter depends on tamper functions, i.e. O(log |F|).

Contributions

- New notion: Continuous non-malleable key derivation function (cnm-KDF)

- A generic construction from one-time lossy filter, one-time signature and pairwise independent hash functions, instantiated under standard assumptions.

- RKD functions: any bounded-degree polynomials (generalized to functions with high output entropy and input-output collision resistance (HOE&IOCR))

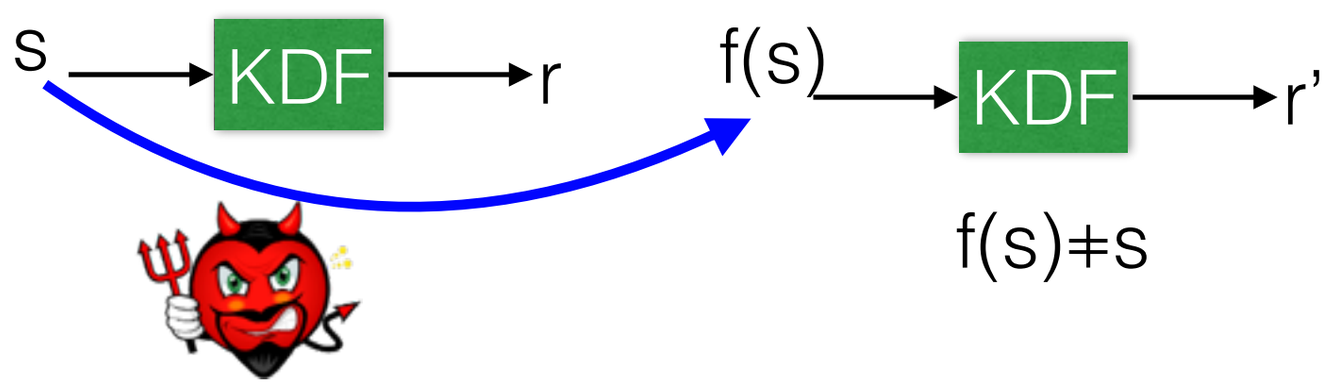
- Application to RKA-IBE, RKA-PKE, RKA-Sig.

Continuous Non-Malleable KDF

Definition and Security

- Inspired by non-malleable KDF [FMVW14]

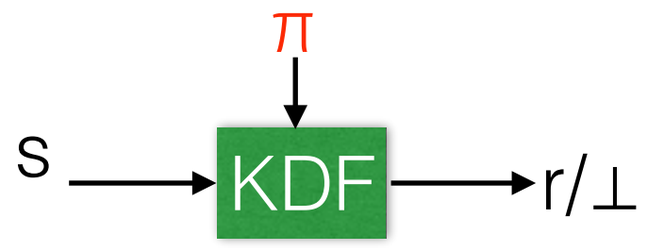
- Standard security: r is random from Adv.'s view (given KDF descriptions)
- Non-malleability: r is random even given one r'.

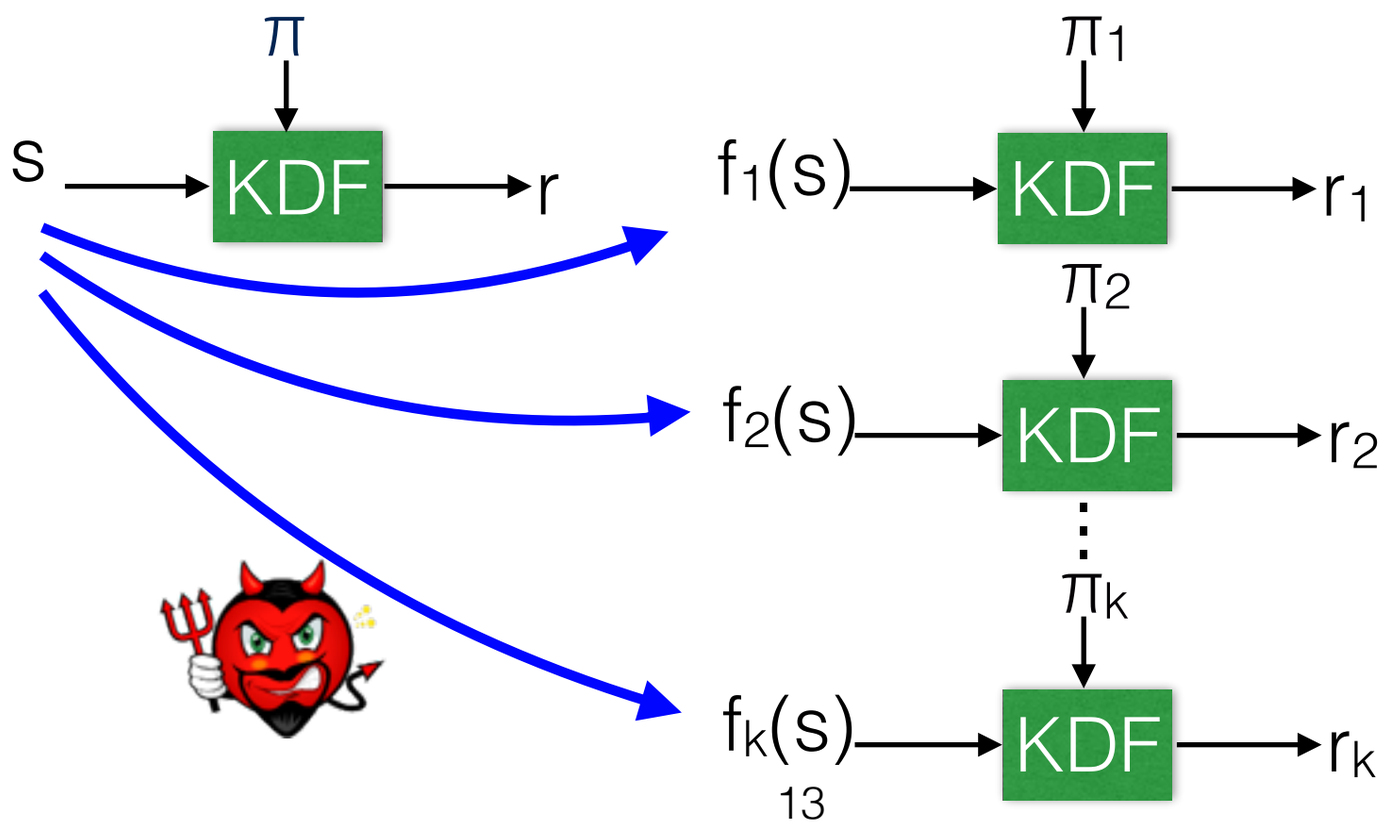


Continuous Non-Malleable KDF

Definition and Security

- cnm-KDF: Input takes an auxiliary input π. Output may be failure symbol.
- View π as a proof or authentication of s. Failure symbol means π is invalid.
- r is random even given multiple r_1, r_2…

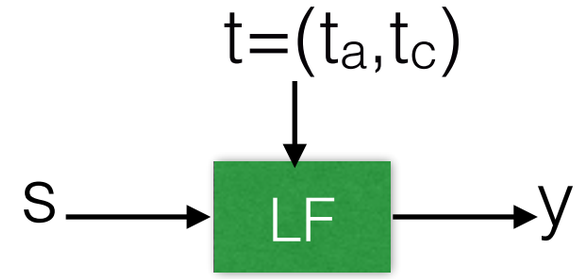




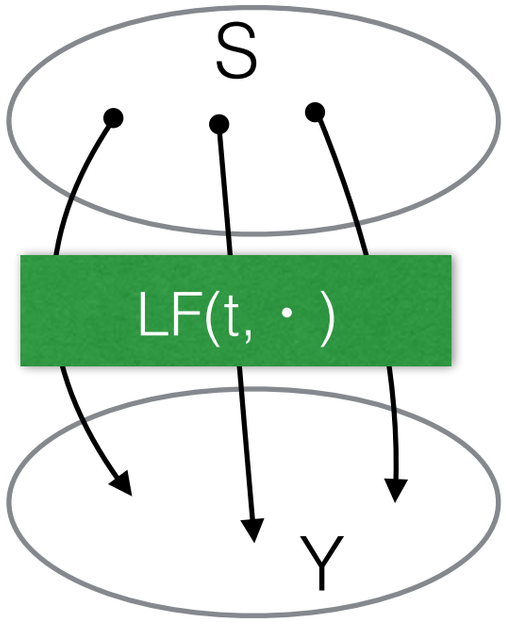
Continuous Non-Malleable KDF

Generic Construction

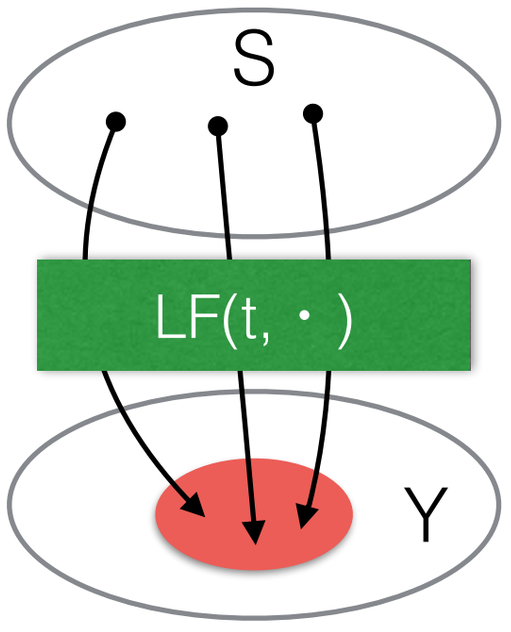
- Components: one-time lossy filter [QL13], one-time signature and pairwise independent hash function.
- Properties of LF:
  - works in two indistinguishable modes.
  - hard to generate a non-injective tag.



Injective



|S|=|Y|



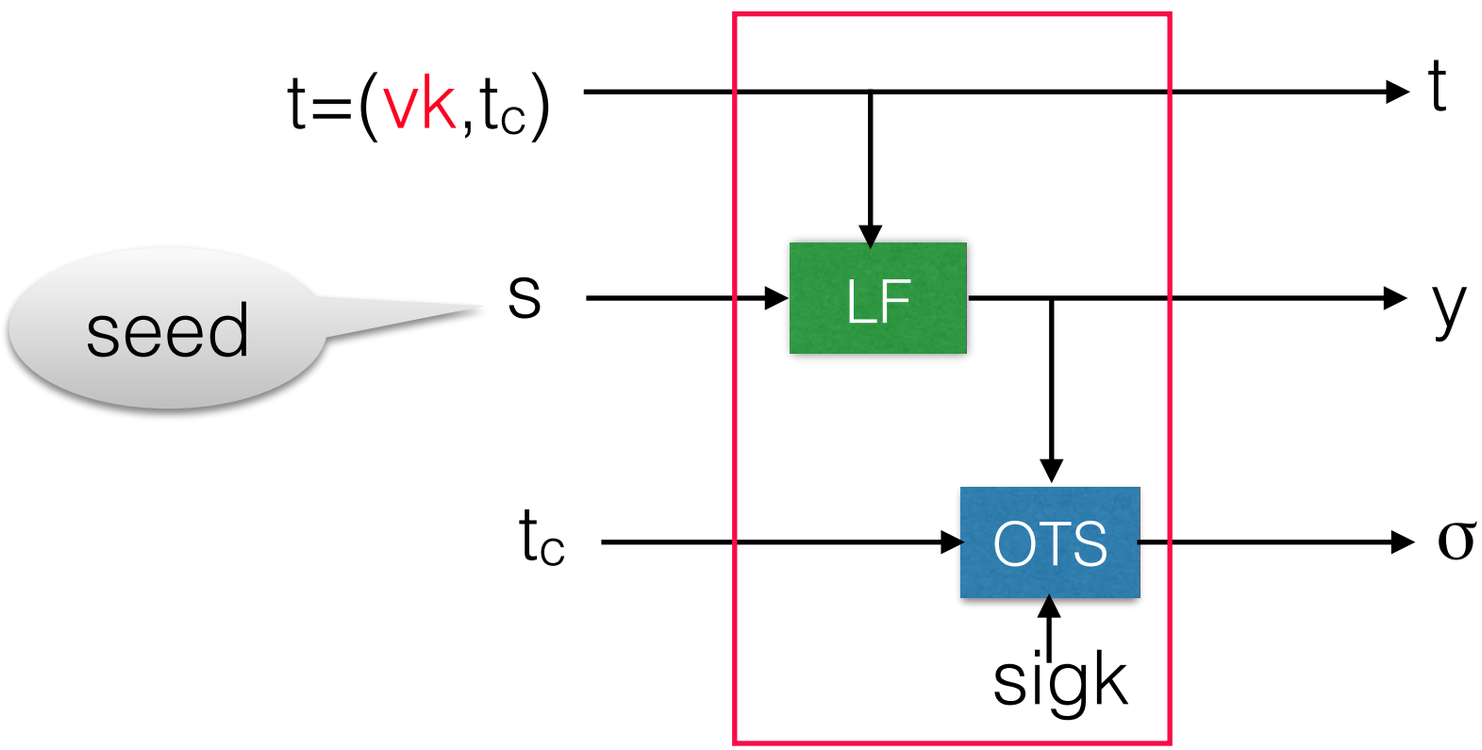
|S|>>|Y|

Lossy

Continuous Non-Malleable KDF

Generic Construction

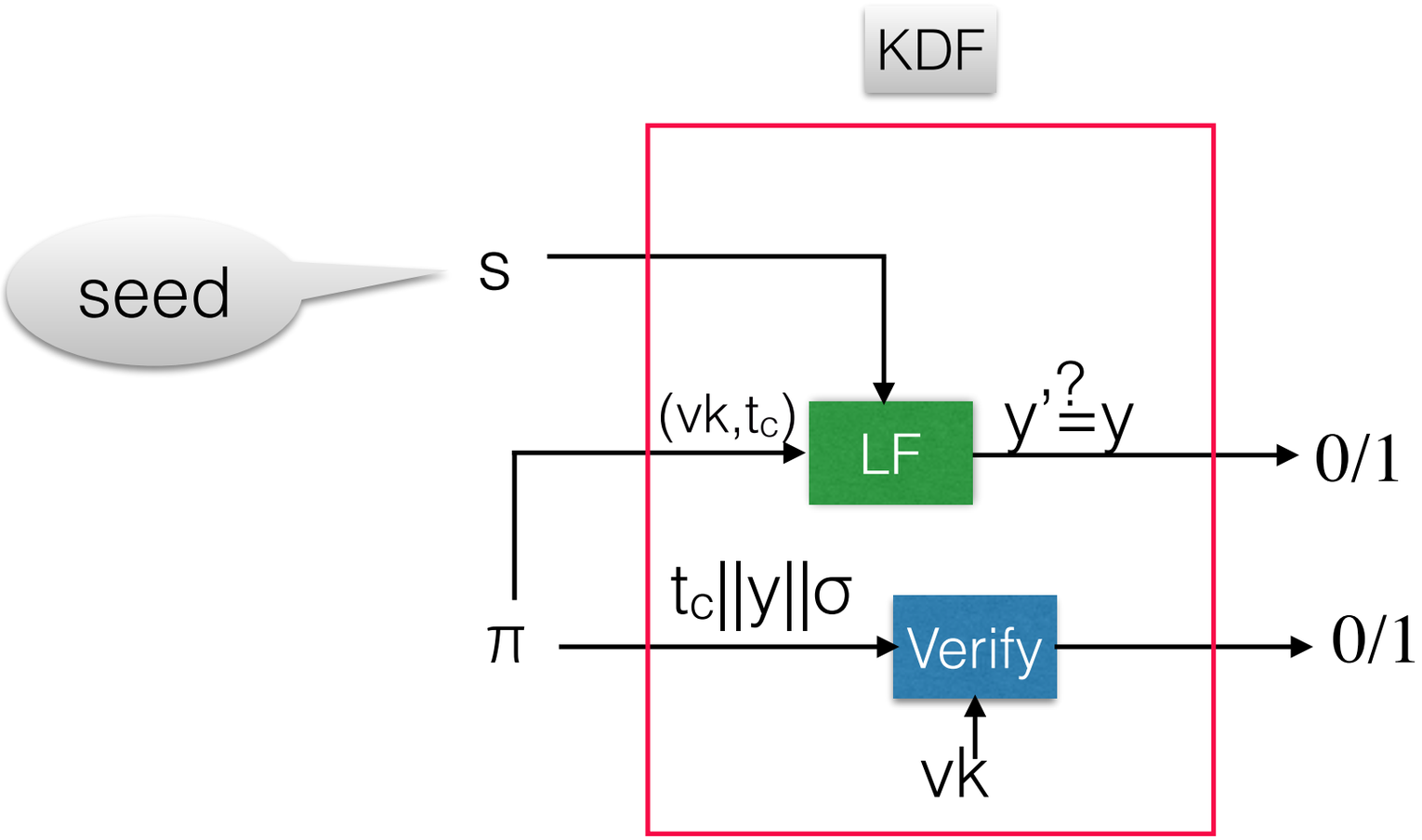
- Sample algorithm: seed s←S and proof π.
- (vk,sigk)← OTS.Gen



Continuous Non-Malleable KDF

Generic Construction

- KDF: input $\pi=(vk,t_c)||y||\sigma$, output $\perp$ or r.



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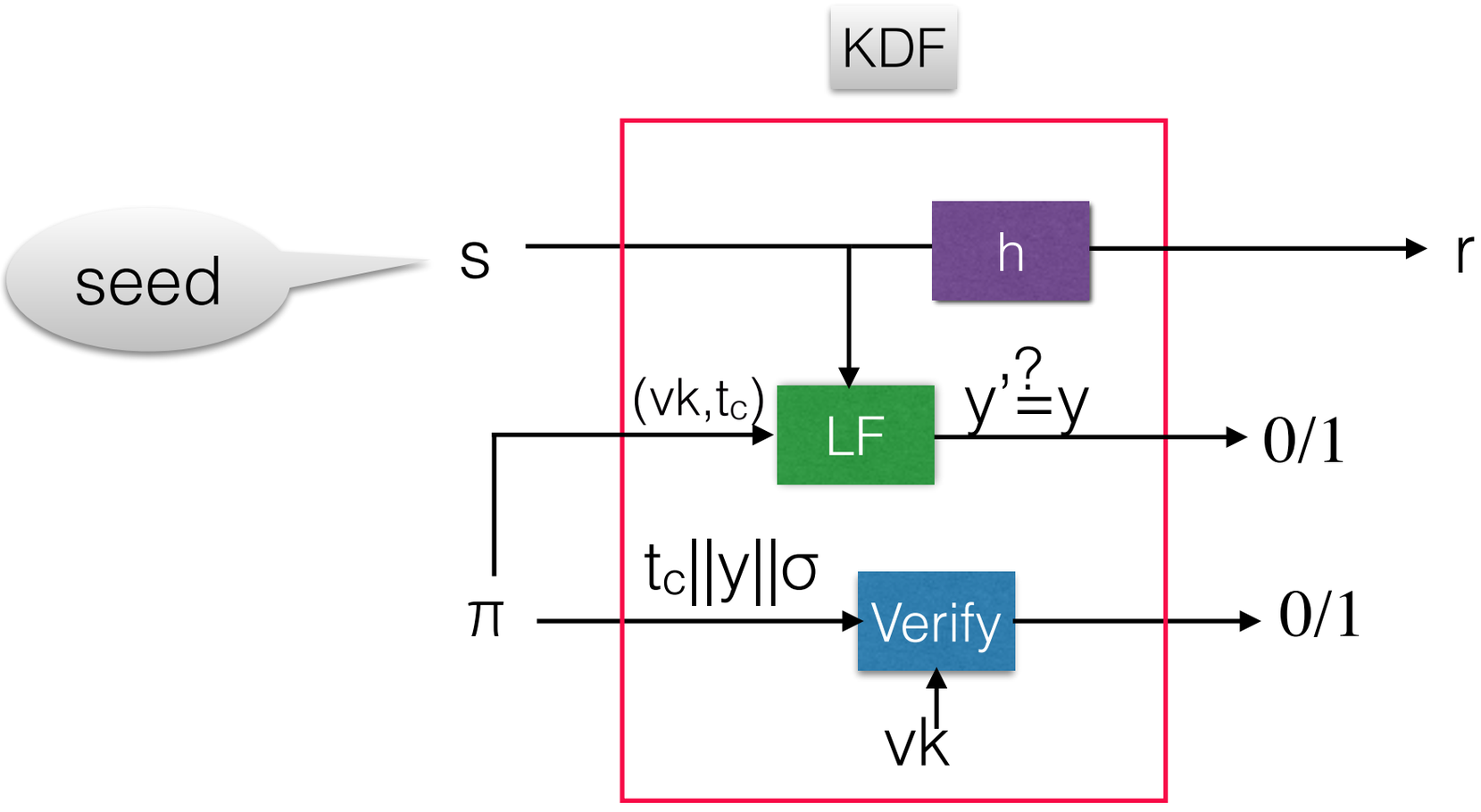


Continuous Non-Malleable KDF

Security Proof

- RKD functions: all degree-d polynomials over a finite field.
- Two properties of above RKD functions.
- Lemma 3: Suppose X be any random variable over some finite field and $H_\infty(X) \geq n$, then

$H_\infty(f(X)) \geq n - \log d$

f is non-constant

$\Pr[f(X)=X] \leq d/2^n$

f is not identity

Continuous Non-Malleable KDF

Security Proof

- Highlight the idea of our proof: reject all non trivial queries.

Target: $\pi^*=t^*||y^*||\sigma^*$ and $r^*=h(s^*)$ or random)

Query: $(f,\pi'=t'||y'||\sigma')$

Trivial queries without s^*:

- f is a constant function, output $KDF_{\pi'}(f)$
- f=id and $\pi'=\pi^*$, output the symbol same*

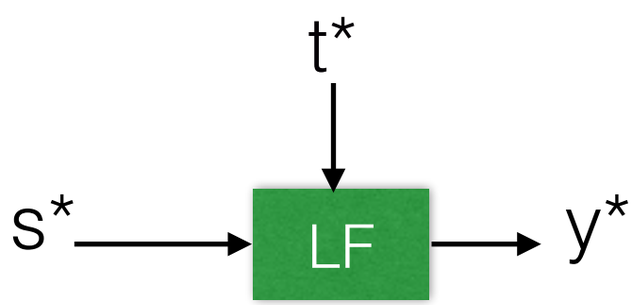
Continuous Non-Malleable KDF

Security Proof

- Highlight the idea of our proof:

Target: $\pi^*=t^*||y^*||\sigma^*$ and $r^*=h(s^*)$ or random) Query: $(f,\pi'=t'||y'||\sigma')$

(1) From injective to lossy: y^* reveals few information on s^*. $f(s^*)$ has high residual entropy.



Continuous Non-Malleable KDF

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(1) From injective to lossy: y^* reveals few information on s^*. $f(s^*)$ has high residual entropy.

(2) One-time signature: t^* can not be re-used.

(3) Hard to generate a fresh non-injective tag even given t^*: t' is injective.

Continuous Non-Malleable KDF

Security Proof

- Highlight the idea of our proof:

Target: $\pi^*=t^*||y^*||\sigma^*$ and $r^*=h(s^*)$ or random) Query: $(f,\pi'=t'||y'||\sigma')$

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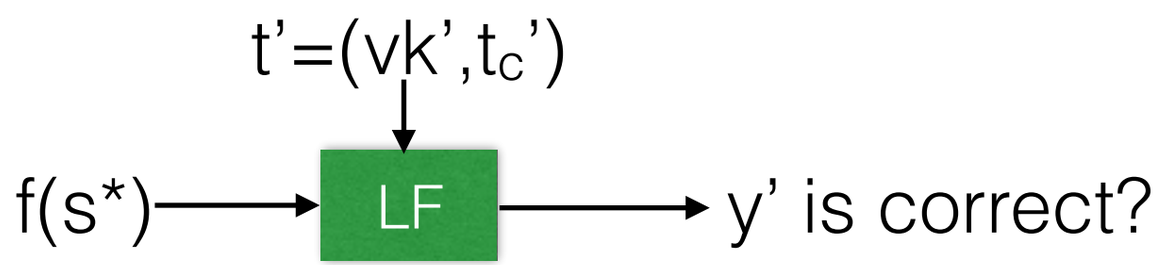
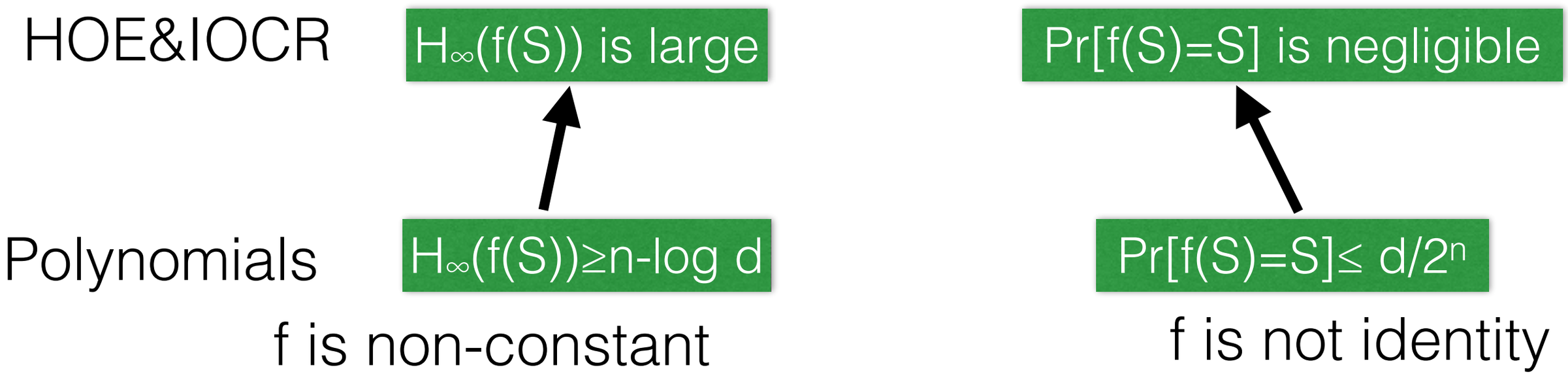


Continuous Non-Malleable KDF

Generalization

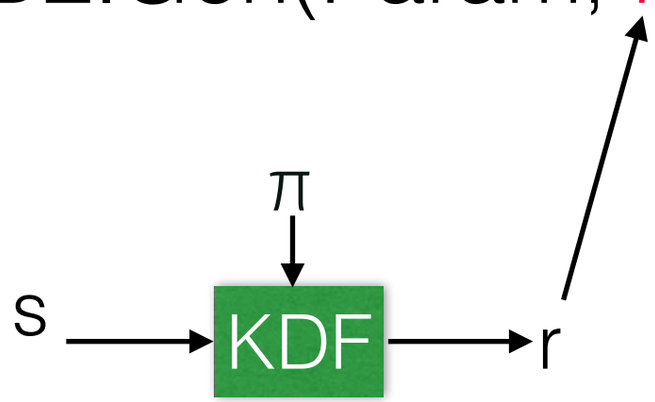
- From polynomial to High Output Entropy and Input-Output Collision Resistance.



Applications

RKA-secure IBE, PKE, Sig.

- (mpk,msk)←IBE.Gen(Param; r)



- mpk'=(mpk,π) and msk'=s
- Thm.: If cnm-KDF is secure w.r.t. F, the new IBE is RKA-secure w.r.t. the same RKD function class.

- RKA-IBE ⇒ RKA-PKE or RKA-Sig. [BCM11]
- Or direct construct RKA-PKE and RKA-Sig.

Conclusion

- A strengthened security model for non-malleable KDFs
- A generic construction of cnm-KDF w.r.t. polynomials or HOE&IOCR.
- Application to RKA-secure IBE, PKE and Signature.

Thanks!

http://eprint.iacr.org/2015/003