Signatures Resilient to Uninvertible Leakage

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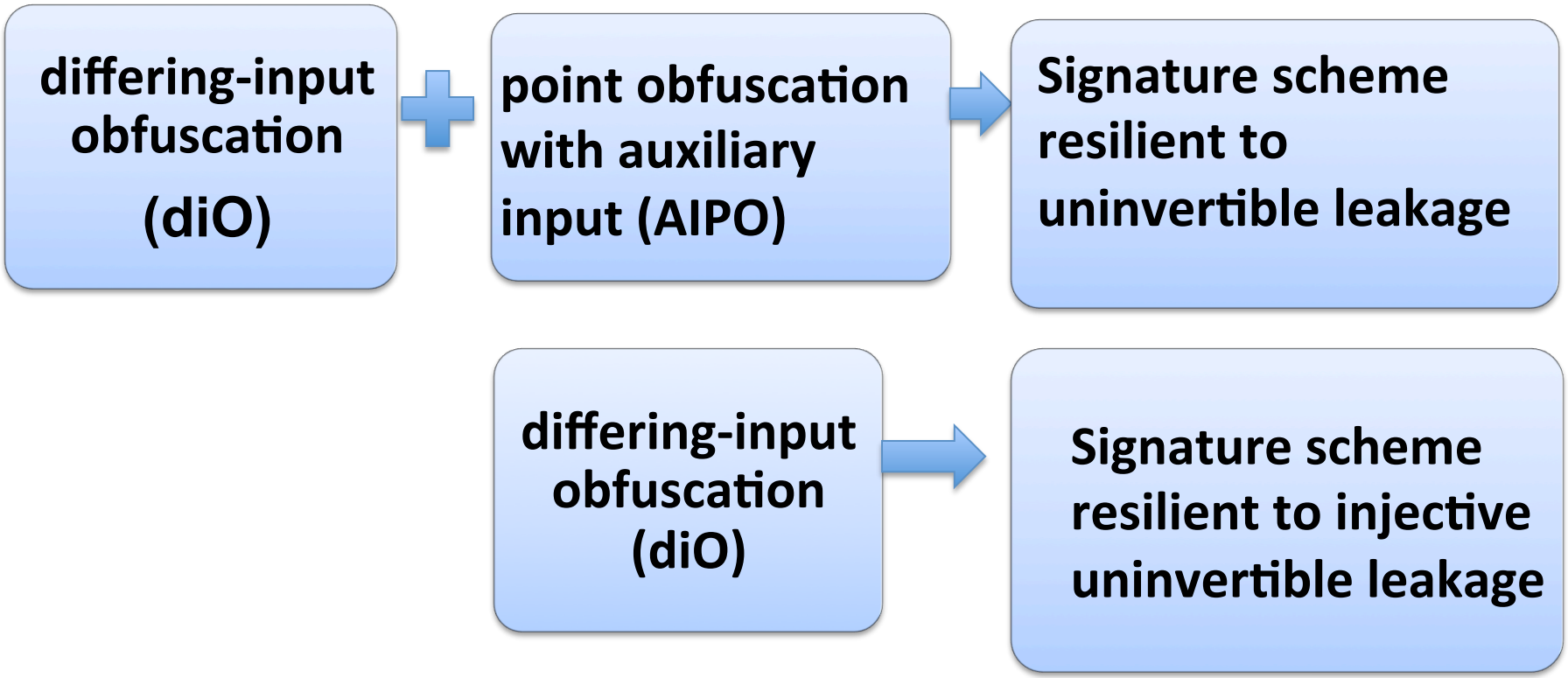
Our work


differing-input obfuscation (diO)
point obfuscation with auxiliary input (AIPO)
Signature scheme resilient to uninvertible leakage
differing-input obfuscation (diO)
Signature scheme resilient to injective uninvertible leakage

Road map

- Background
- Our result
- Tools
- Our technique

Signatures

Signer

sk

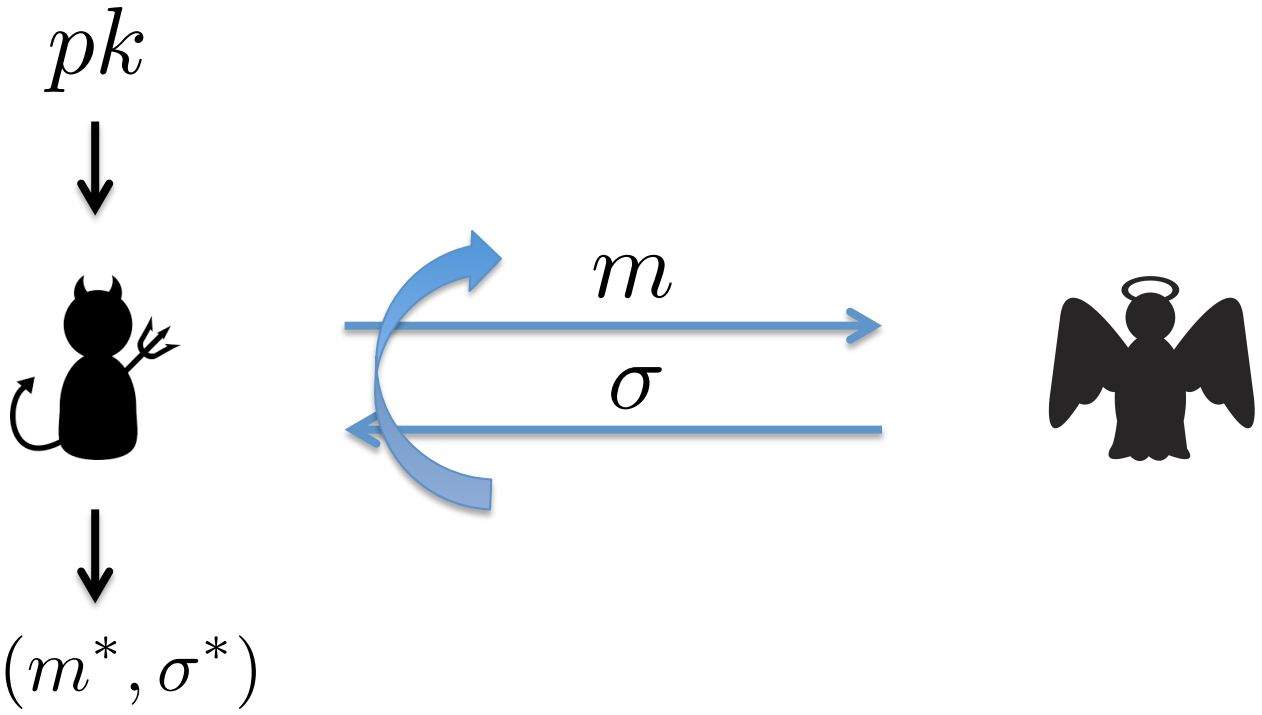
(m, σ)

Verifier

pk

$$\sigma \leftarrow \mathrm{Sign}_{sk}(m, r) \qquad \mathrm{Verify}_{pk}(m, \sigma) \stackrel{?}{=} 1$$

EUF-CMA security



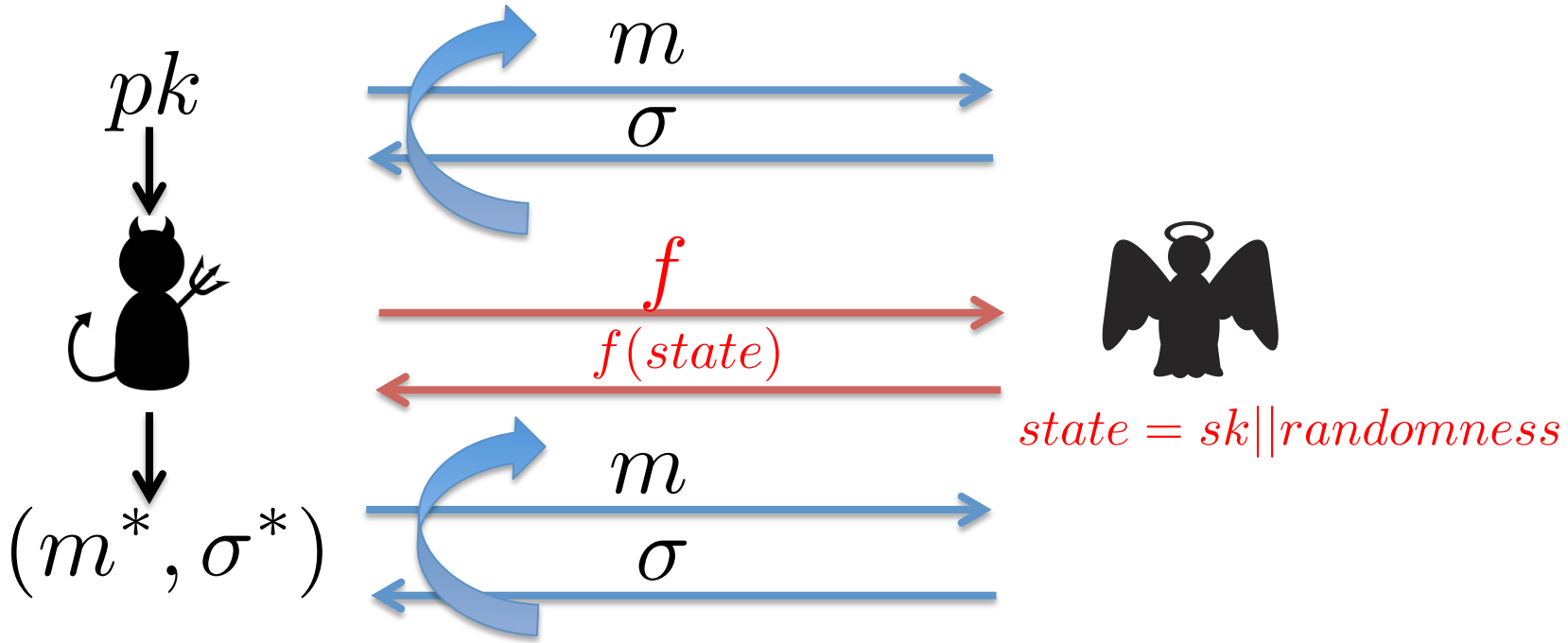
EUF-CMA security: if m* was not part of the queries, then the probability that the forgery is successful is negligible.

The secret information is completely hidden

Side channel attack

Secret information may be leaked via physical information from the device.

Leakage models



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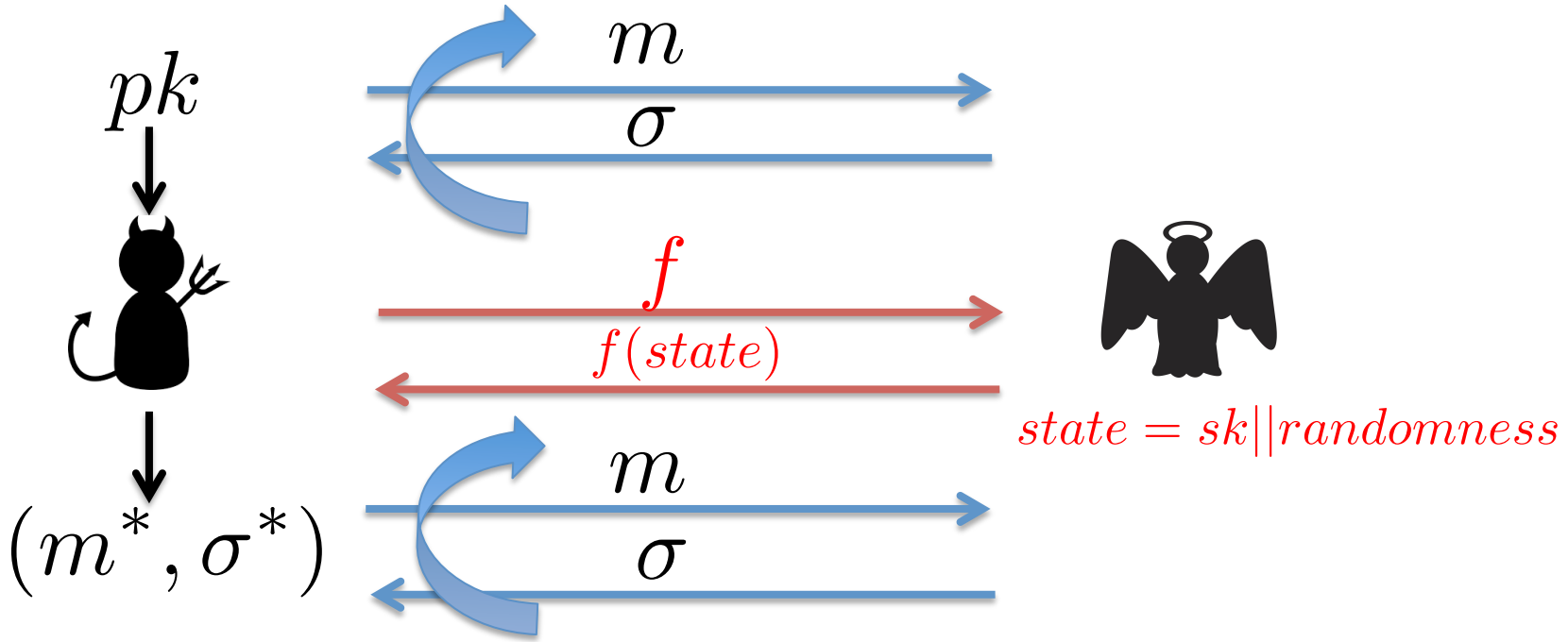
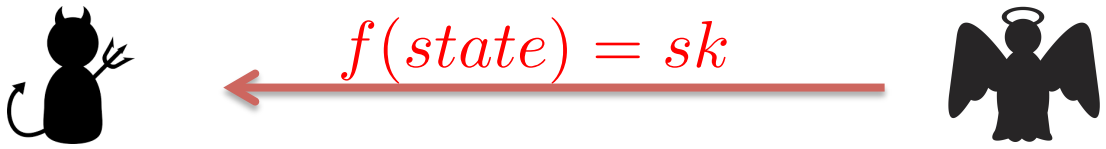
Leakage models



If f can be any function



Restriction on leakage functions

- Bounded leakage model, continual leakage model, noisy leakage model: part of the signing key is information-theoretically hidden in the presence of $f(state)$.

- Practical world: $f(state)$ typically information-theoretically determines $state$. [Standaert, Invited Talk, SKEW 2011]

Auxiliary input model [DKL09]

- Restriction on f: hard-to-invert, i.e., it is hard to computationally recover signing key from leakage.
- Trivial attack for signatures in this model:

$$f(\cdot) = sign(pk, \cdot, m^*)$$

$$f(sk) = sign(pk, sk, m^*) = \sigma^*$$

Successful forgery

More restrictions on f

- Auxiliary input model [FHNN12]:
  - f is exponentially hard-to invert, and may depend on the public parameters.
  - Full leakage is not considered.
- Selective auxiliary input model [YYH12]
  - f is independent of public parameters, but polynomially hard-to-invert.

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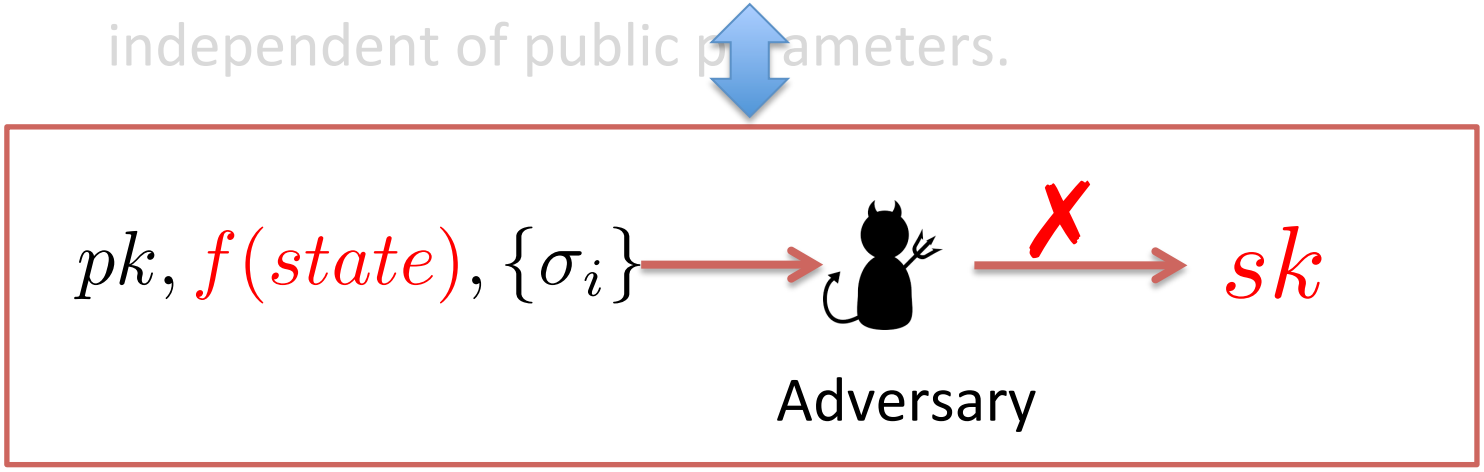
We concentrate on signatures in the latter model

More restrictions on f

- Auxiliary input model [FHNN12]:
  - is exponentially hard-to invert, selectively chosen, and may depend on the public parameters.
- Selective auxiliary input model [YYH12]
  - is polynomial hard-to-invert, selectively chosen, but independent of public parameters.



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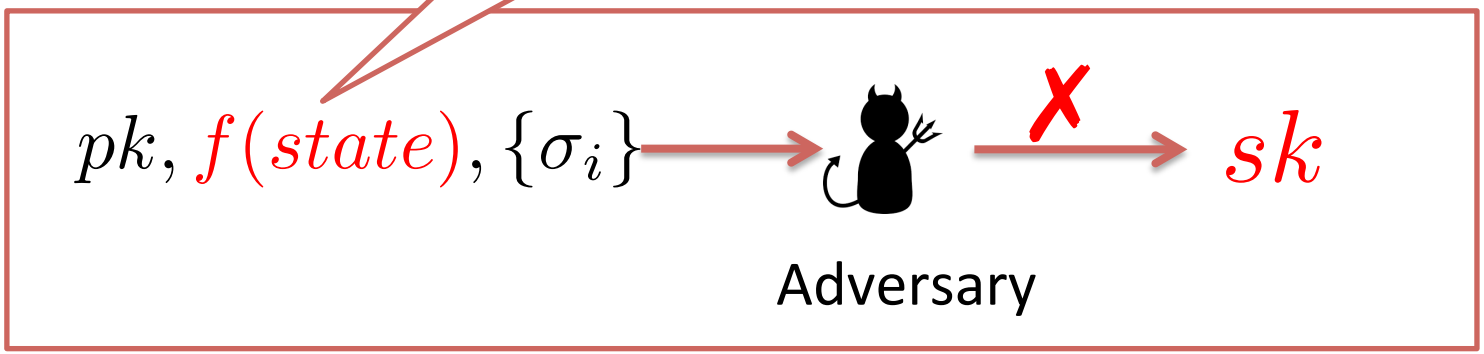
Can f be any uninvertible function?



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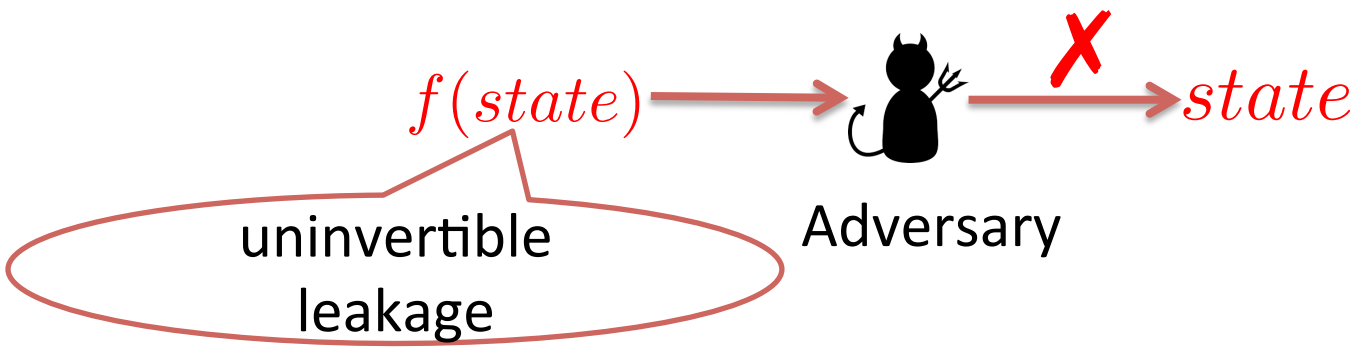
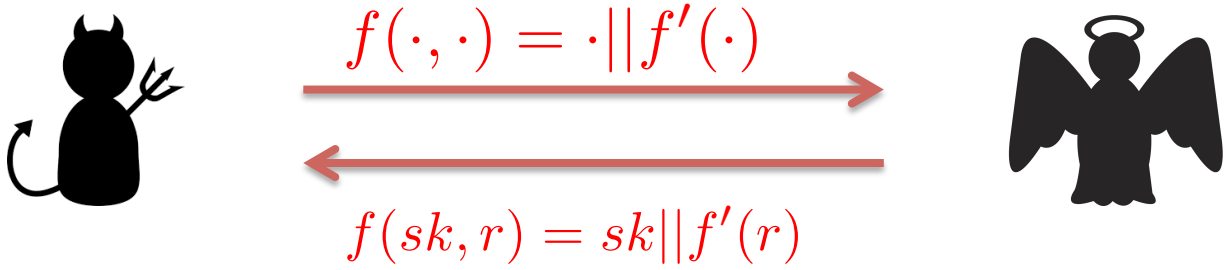


Trivial attack by using uninvertible leakage

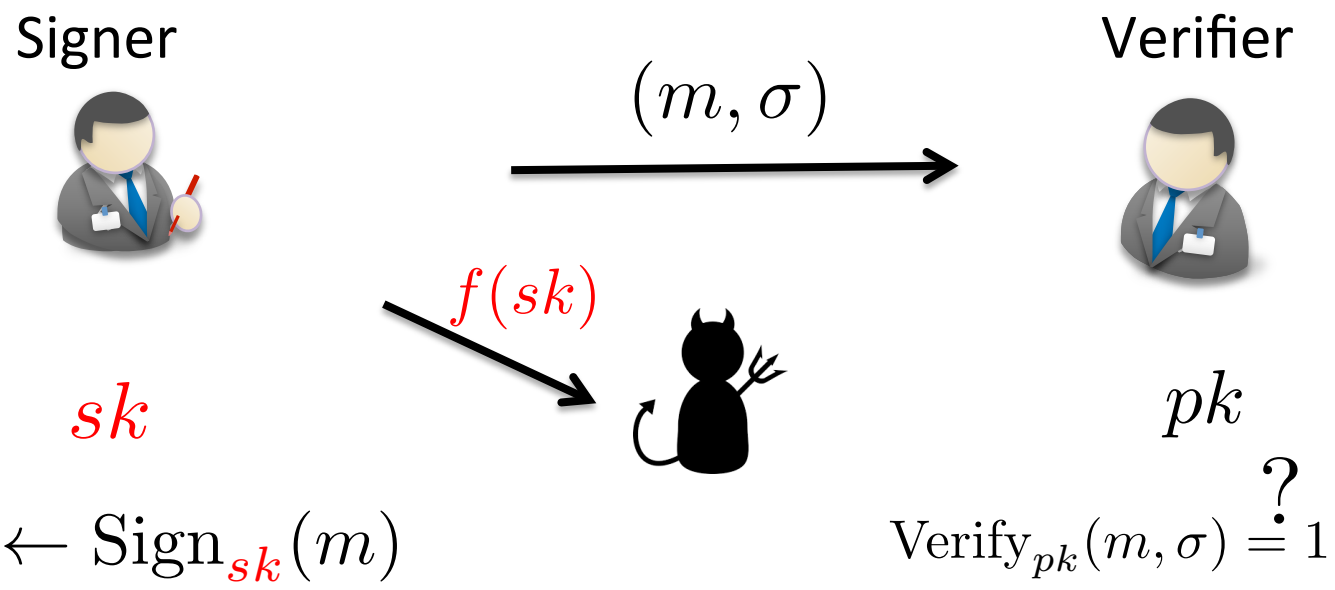
f':uninvertible



uninvertible leakage

How to avoid the trivial attack

- Deterministic signatures or signatures with public coin construction $\Rightarrow$ $state = sk$



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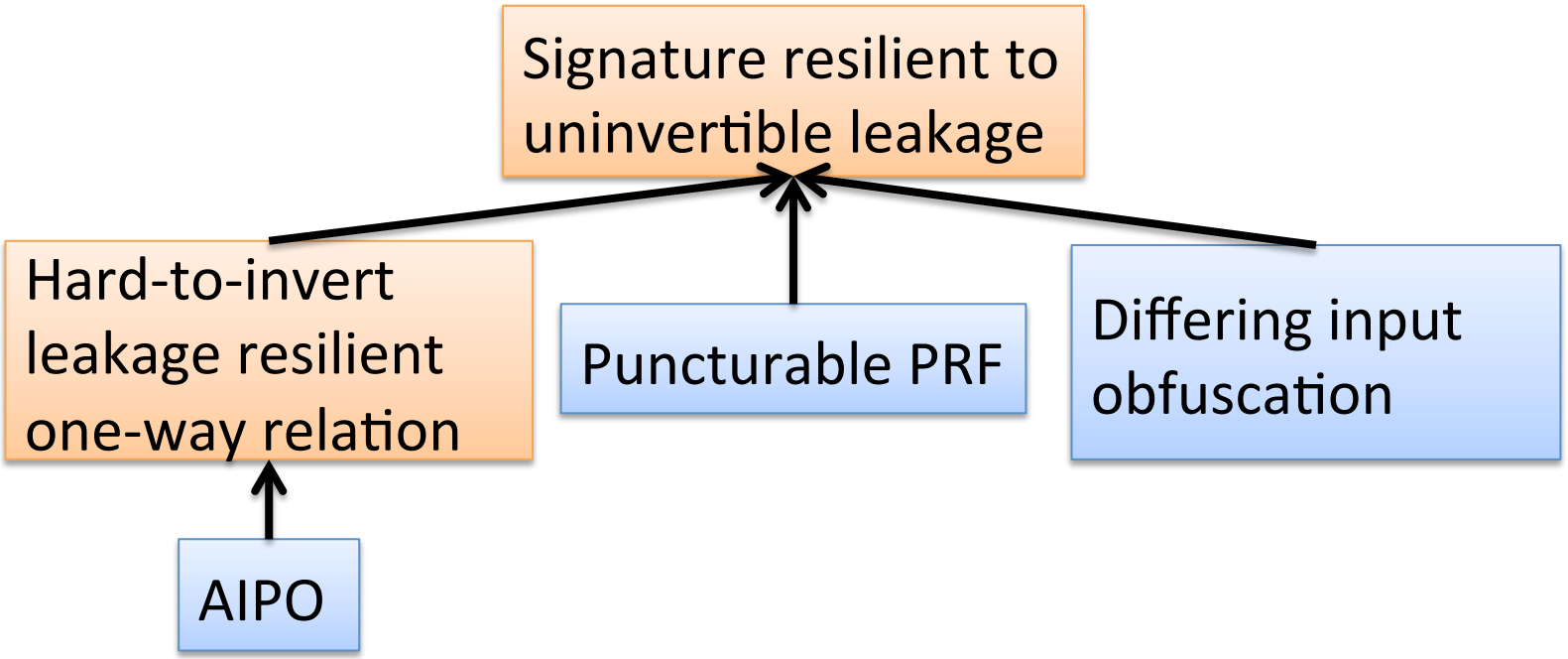
Our result

- The first signature scheme resilient to uninvertible leakage.
- The first leakage resilient (fully secure) signature scheme with public coin construction.



Comparison with previous works

	Leakage	**Hard-to-invert**	**Full leakage resiliency**	**Uninvertible leakage**
FHNN15	adaptive	exponential	✗	✗
YYH12	selective	polynomial	✓	✗
our work	selective	polynomial	✓	✓

About diO and AIPO

To achieve strong security, we make use of diO and AIPO.

- Differing input obfuscation (diO):
  - Negative results [GGHW14][BP15][BSW16].
  - However, there is no negative results, based on weak or standard assumptions, on diO for circuits yet.

- Point obfuscation with auxiliary input (AIPO)
  - Several candidates based on different assumptions [Can97][LPS04][BP12][BS16]

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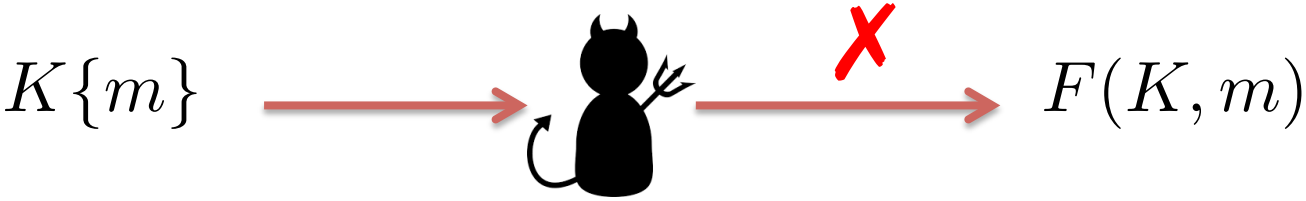
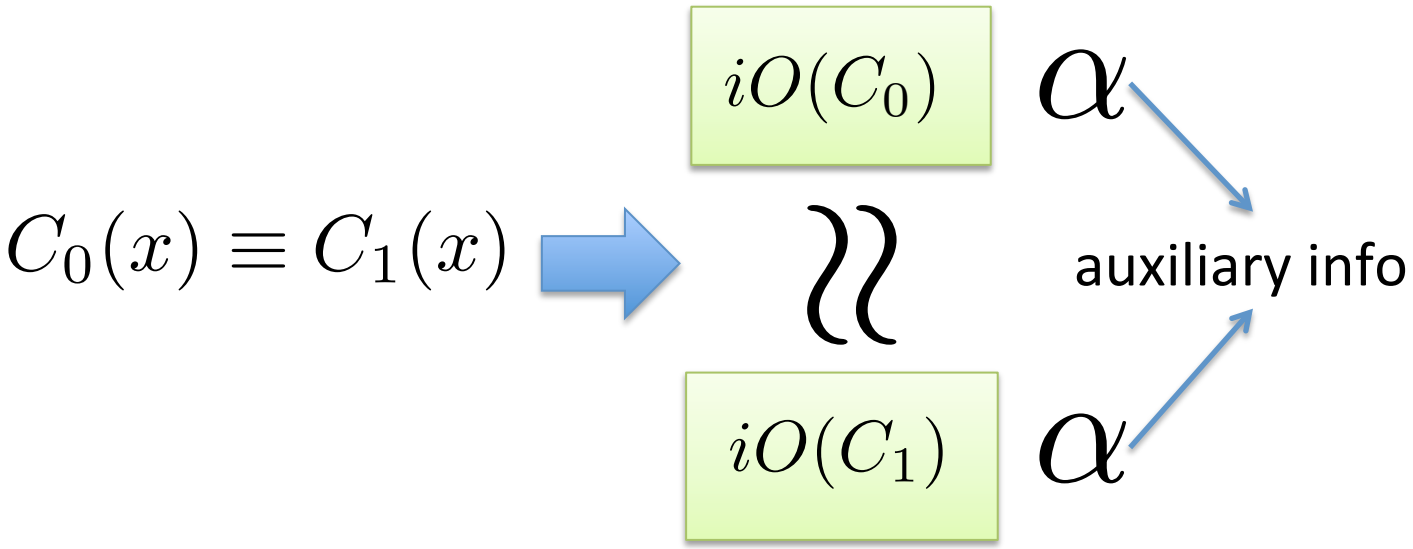
Puncturable PRF

$$K\{m\} = Puncture(K, m)$$

$$F(K\{m\}, x) = F(K, x) \qquad \text{for } x \neq m$$

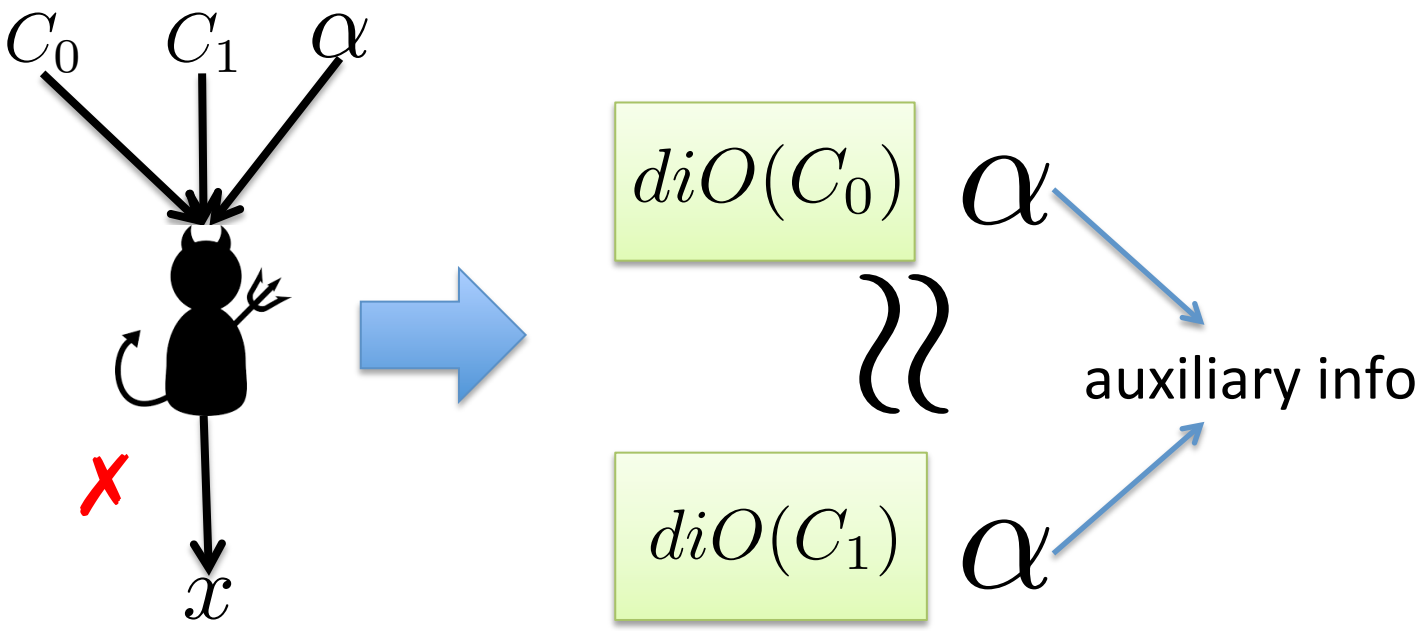


Indistinguishability obfuscation (iO)



Functionality preserving: the functionality of a circuit does not change after being obfuscated.

Differing input obfuscation (diO)



s.t. $C_0(x) \neq C_1(x)$

Functionality preserving: the functionality of a circuit does not change after being obfuscated.

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Deterministic signature (Sahai and Waters (STOC' 14))

sk K

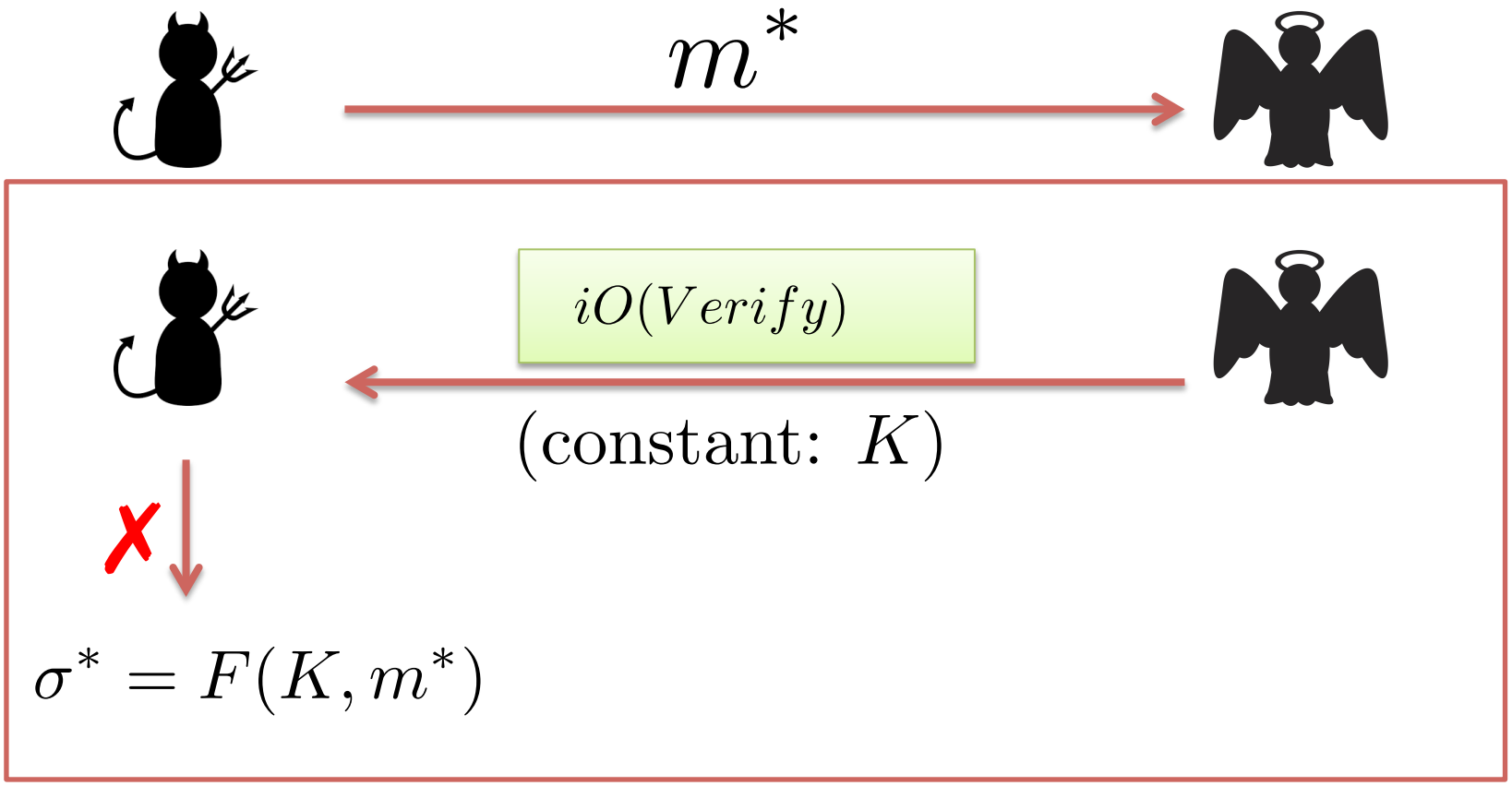
σ $\sigma = F(K, m)$

pk $iO(Verify)$

$Verify$

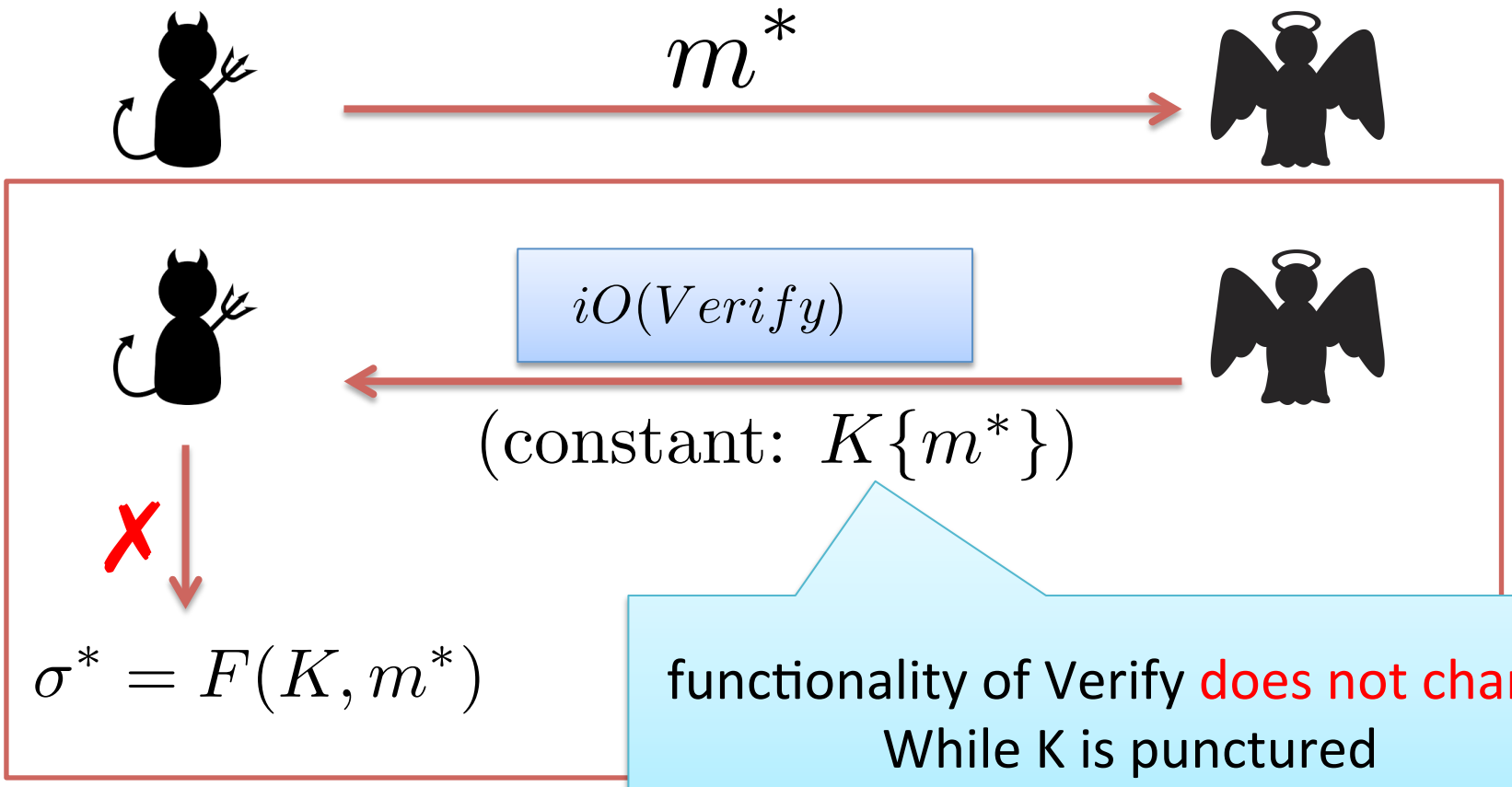
Input (m, σ)
Constant: K
Check if $F(K, m) = \sigma$

High-level idea (Sahai and Waters (STOC' 14))



Selective security

High-level idea (Sahai and Waters (STOC' 14))



Selective security

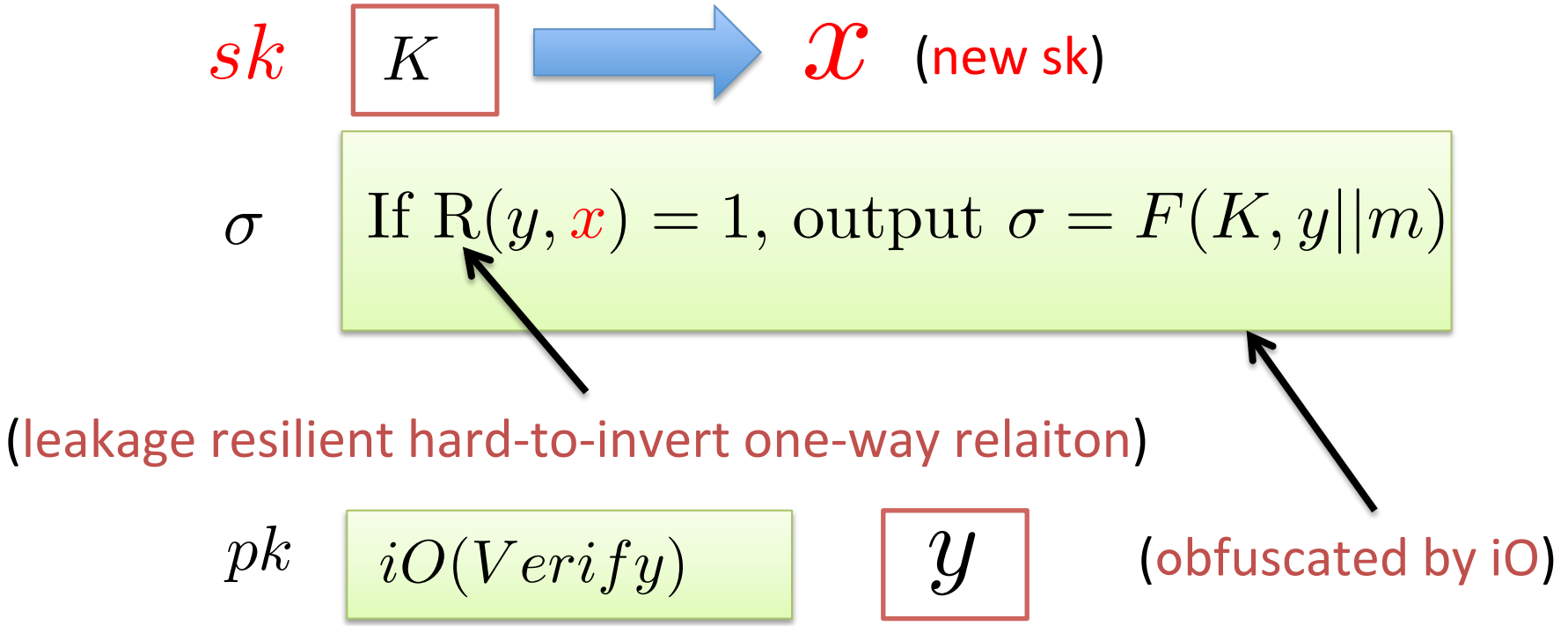
Our extension

sk K

σ $\sigma = F(K, m)$

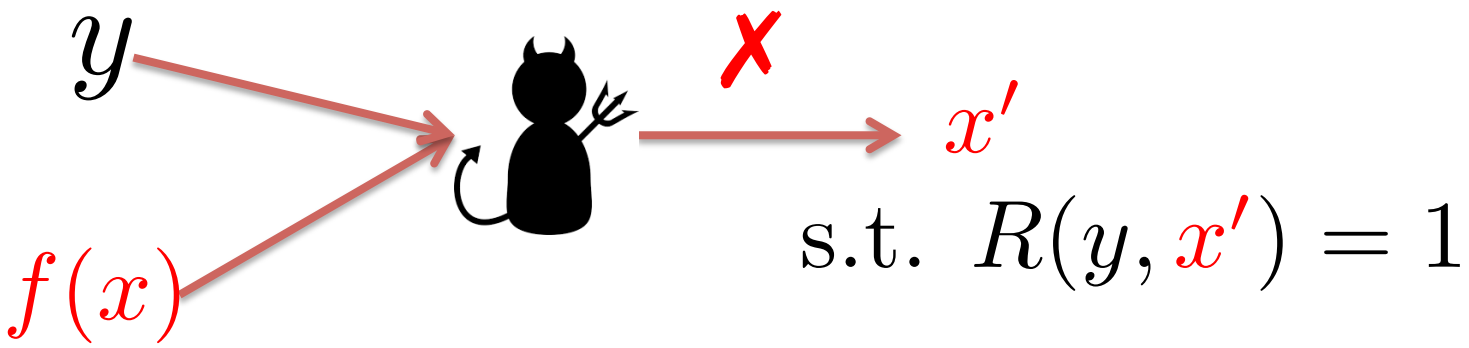
pk $iO(Verify)$

Our extension

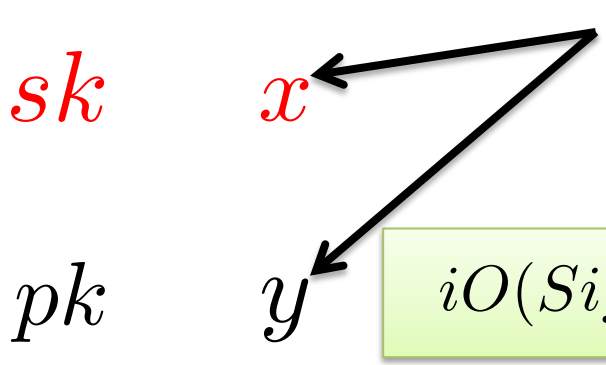


Hard-to-invert leakage resilient one-way relation (point obfuscation [BP12,BM14] based)

$$\mathrm{R}(y, x) = 1$$



Our scheme (selective secure)



Key pair of hard-to-invert leakage resilient one-way relation

$iO(Sign)$

$iO(Verify)$

input (y, x, m)

Constant: K

Check if $R(y, x) = 1$

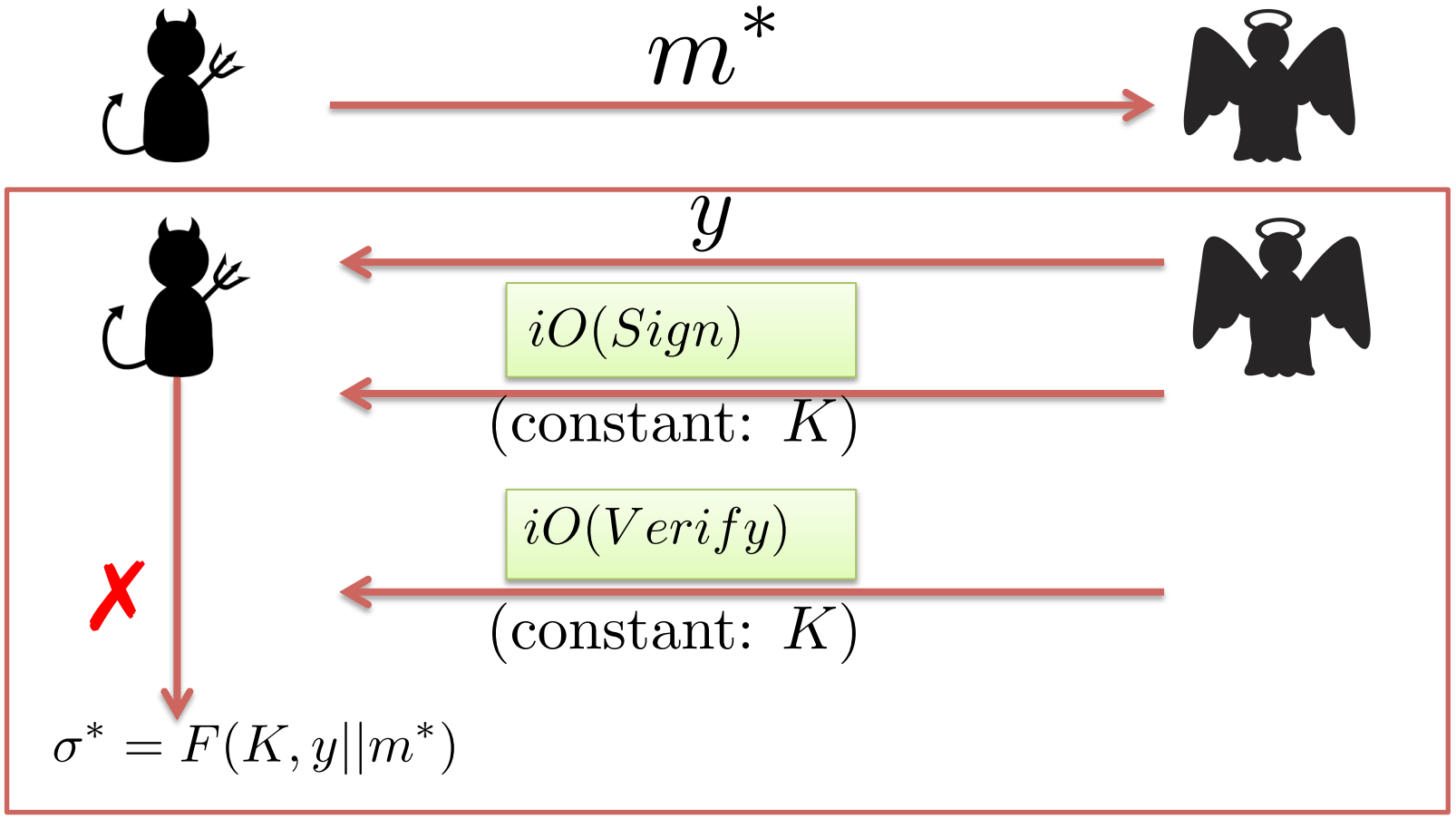
$\sigma = F(K, y||m)$

input (y, m, σ)

Constant: K

Check if $F(K, y||m) = \sigma$

High-level idea



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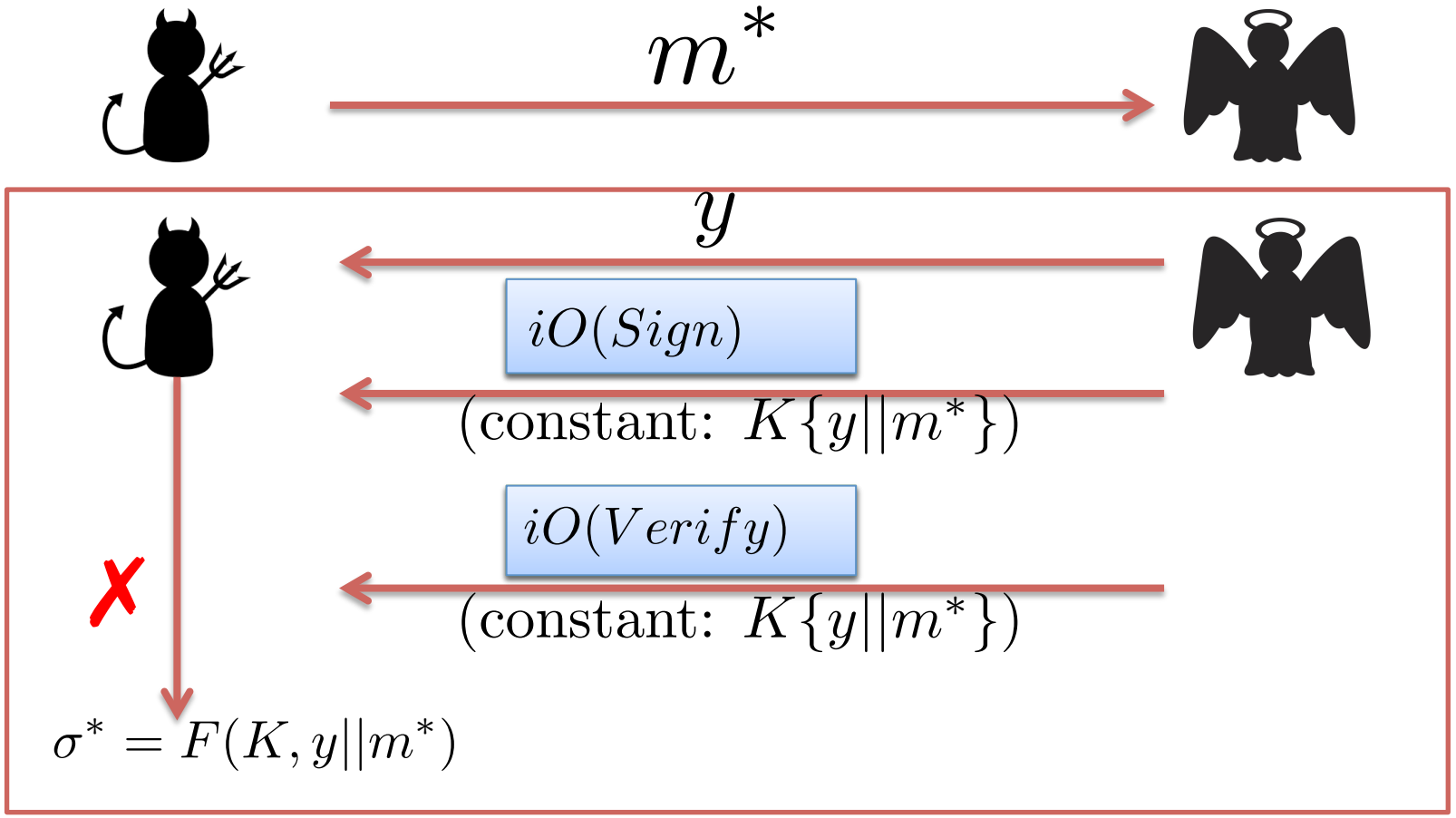

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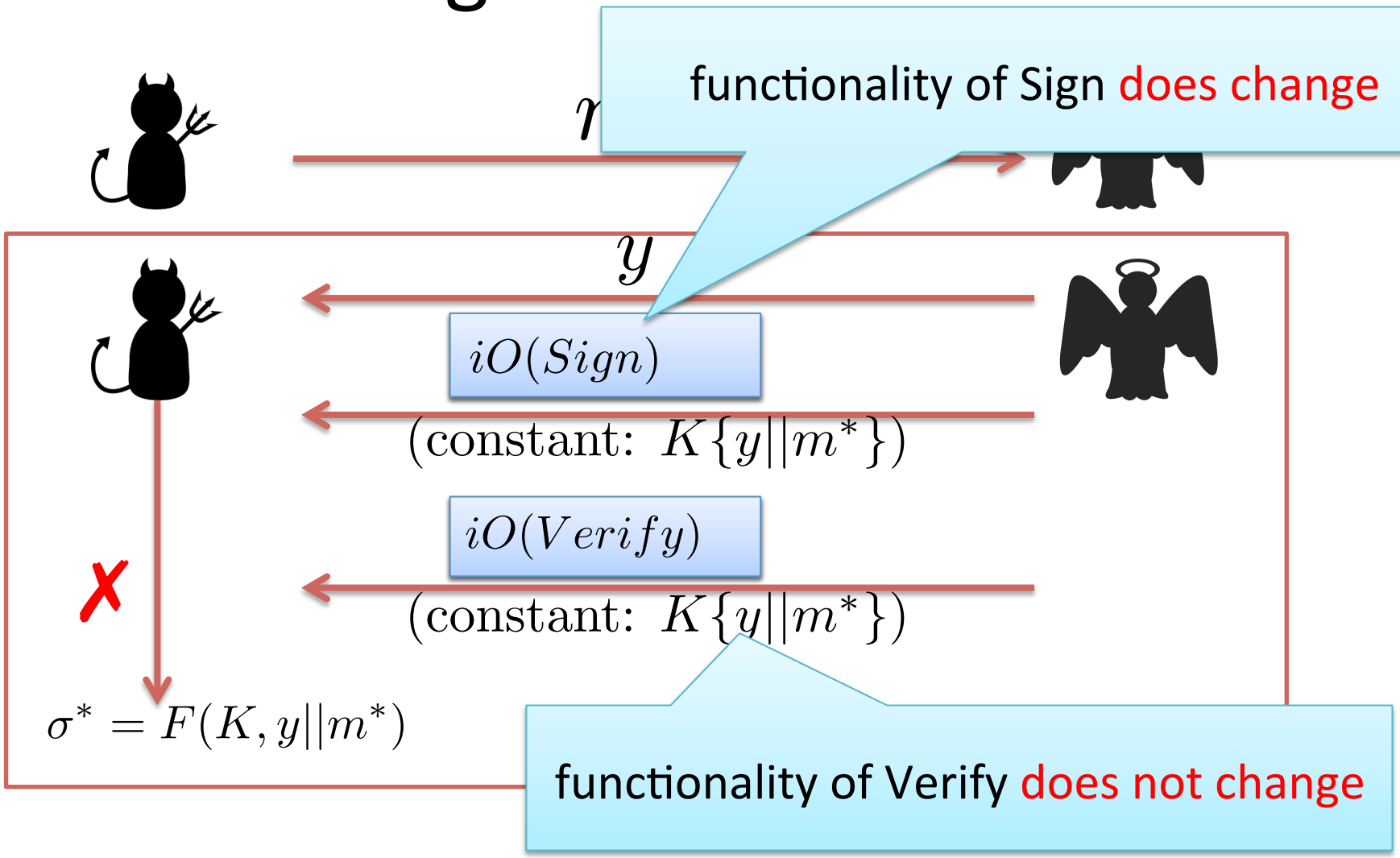
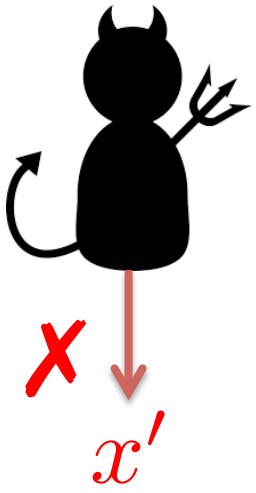


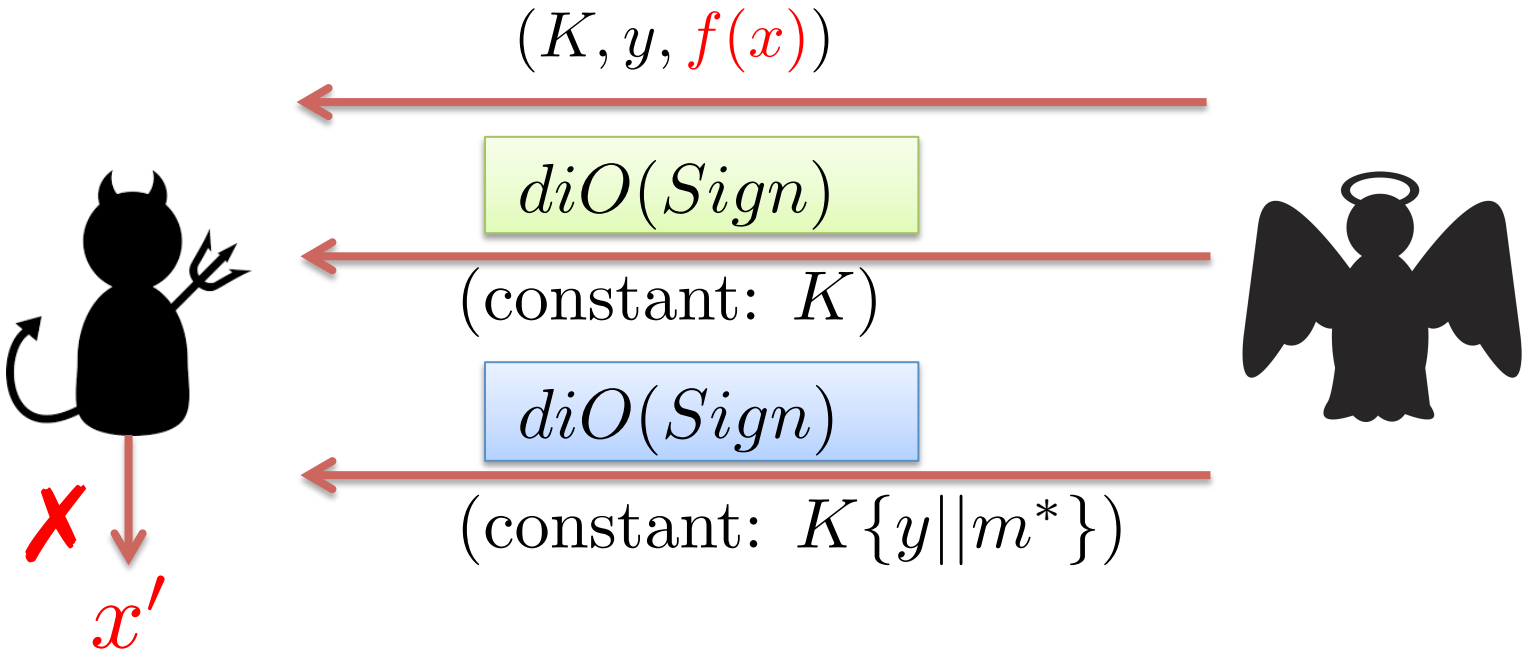
Why the view of adversary does not change if we use diO

$(y, f(x))$



x'

Why the view of adversary does not change if we use diO



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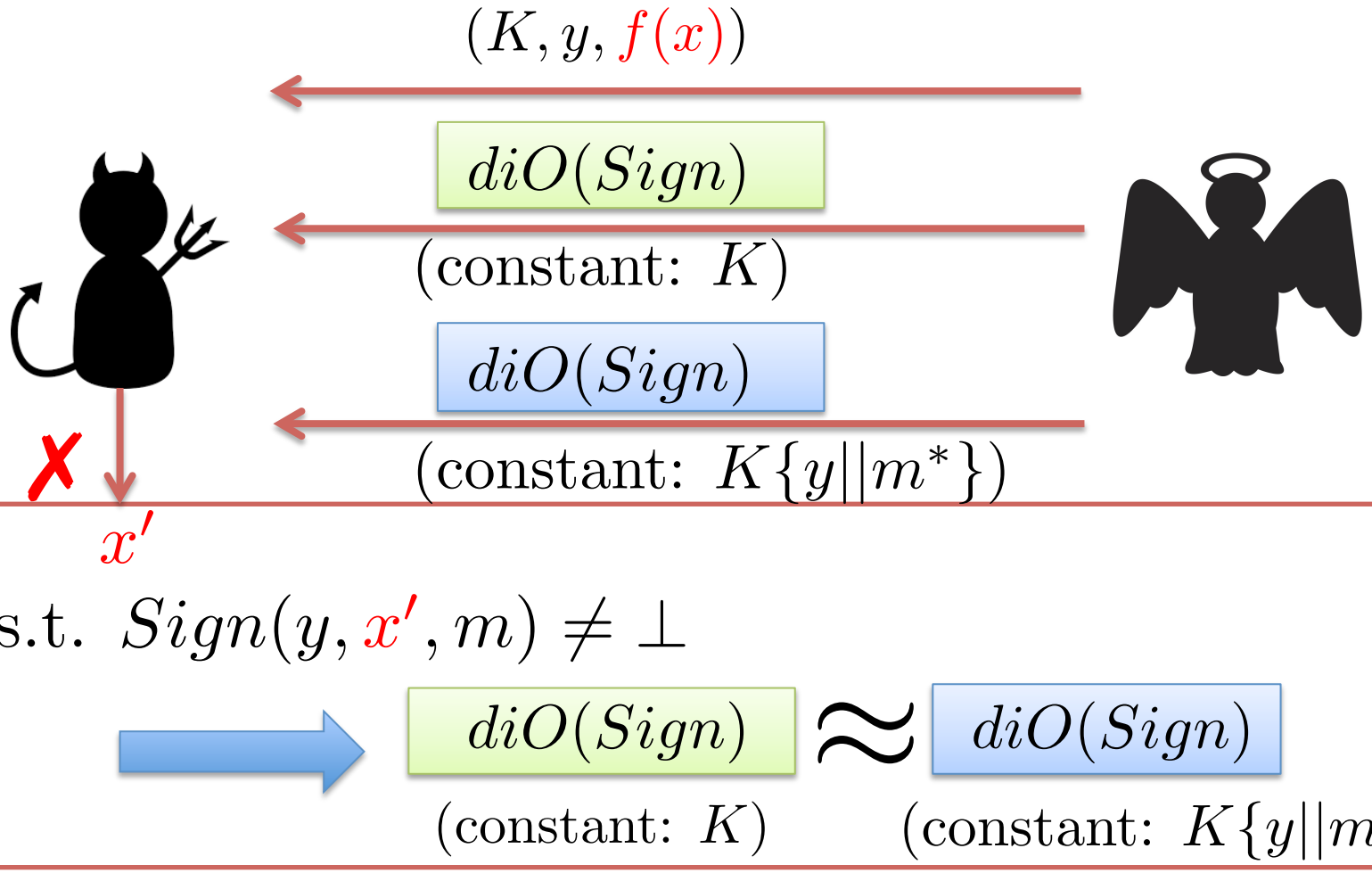
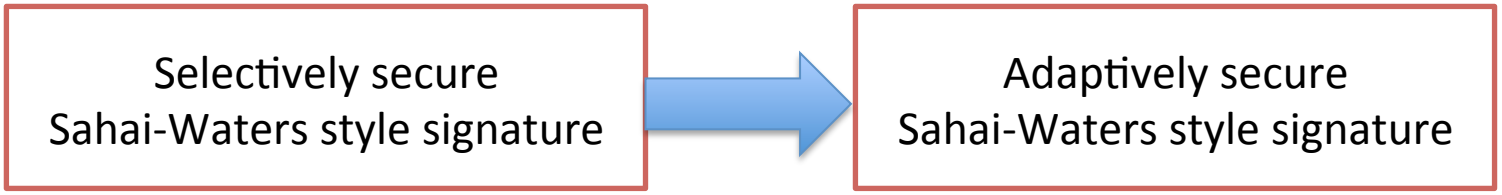


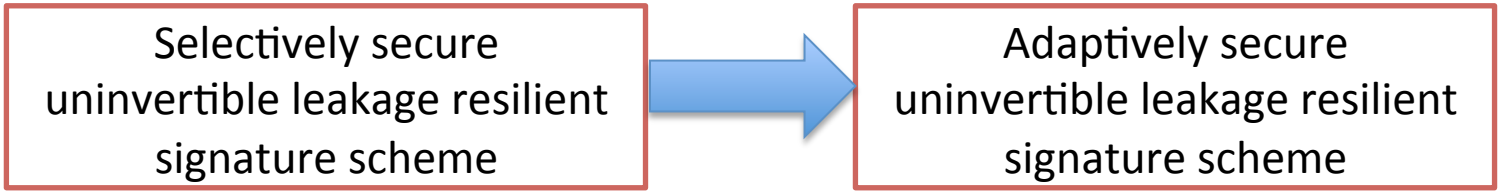
Adaptive security

Ramchen and Waters (ACM CCS' 14):

- Sahai–Waters style signature:



- Our scheme:



Signatures resilient to injective uninvertible leakage

- Building block: injective hard-to-invert leakage resilient one-way relation (based on iO).

- Based on : differing-input obfuscation.

- Without using point obfuscation.
- Why we buy this: information-theoretically determines the signing key.

Signatures resilient to injective uninvertible leakage

- Building block: injective hard-to-invert leakage resilient one-way relation (based on iO).

- Based on : differing-input obfuscation.

- Without using point obfuscation

- Why we buy this: $f(state)$ typically information-theoretically determines $state$.

Summary

- Signature resilient to uninvertible leakage
  - Based on: AIPO and diO.
- Signature resilient to injective uninvertible leakage
  - Based on : diO.

Open problem:

How to construct signatures resilient to uninvertible leakage without making use of diO, or even iO.