Universal Ring Signatures in the Standard Model

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[*]Funded by an ERC grant

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Ring signatures

Semantics

- $\mathsf{Gen}(1^\lambda) \to (\mathsf{vk}, \mathsf{sk})$
- $\mathsf{Sign}(1^\lambda, \mathsf{sk}_i, m, \underbrace{(\mathsf{vk}_1, \ldots \mathsf{vk}_\ell)}_{\text{Ring R}}) \to \Sigma$
- $\mathsf{Verify}(\Sigma, m, R) \to \{0, 1\}$

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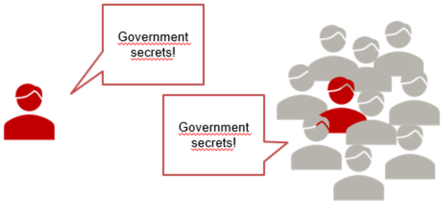

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Governments don't like whistleblowers, duh

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The situation:

Employee

Journalist

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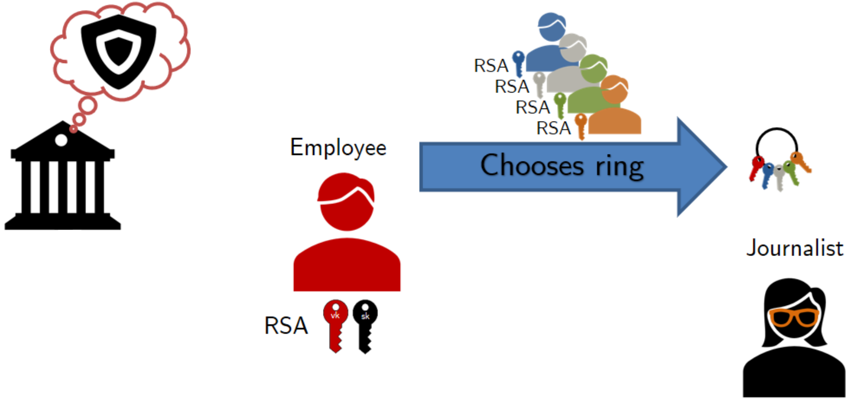

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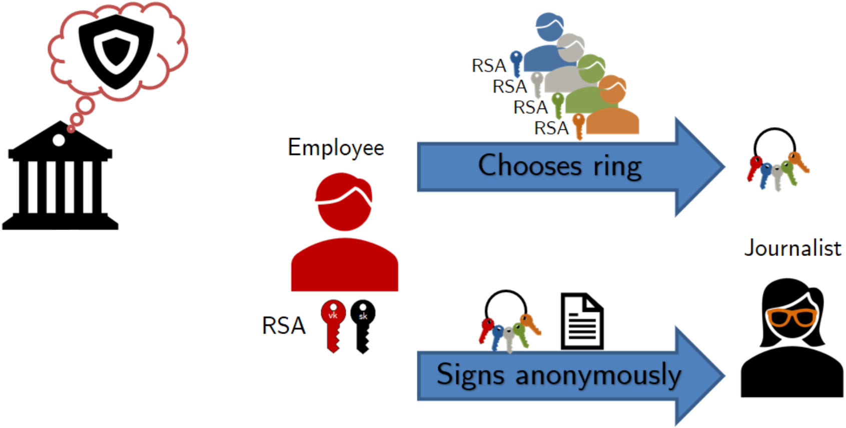

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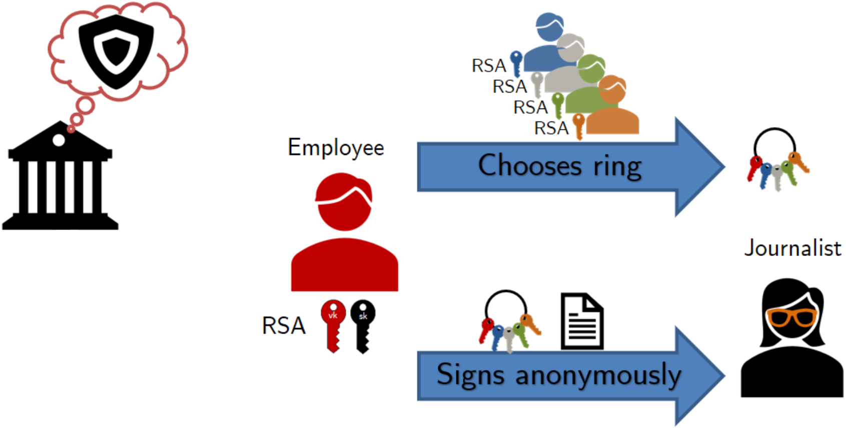

Things are never so easy...

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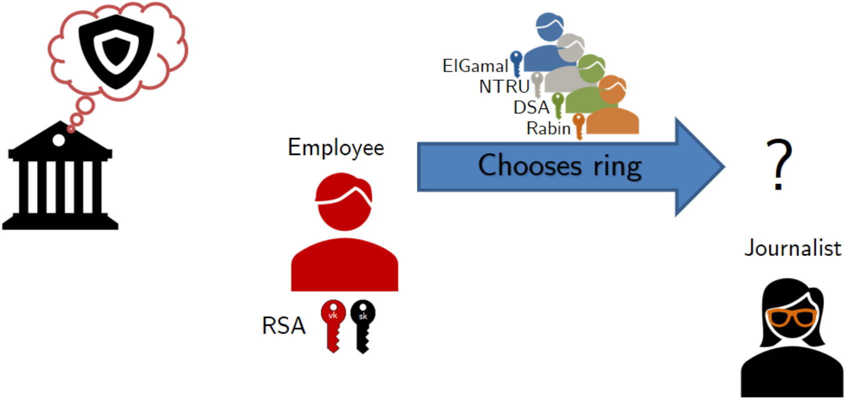

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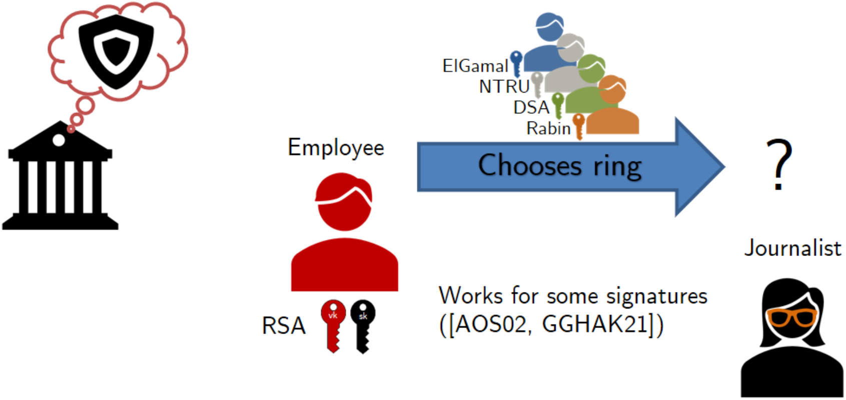

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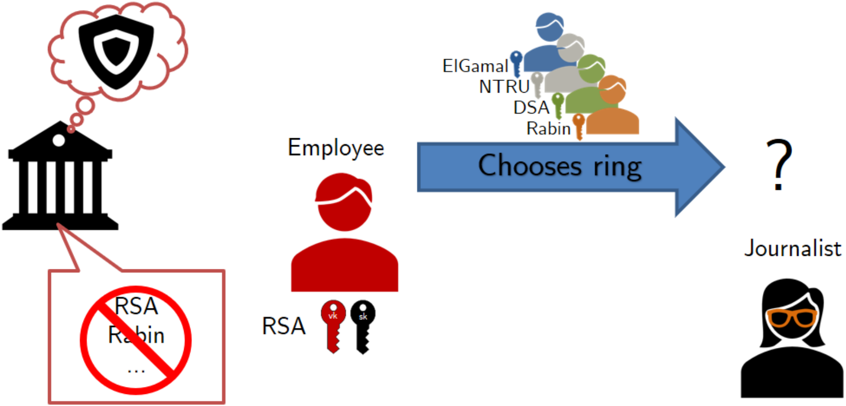

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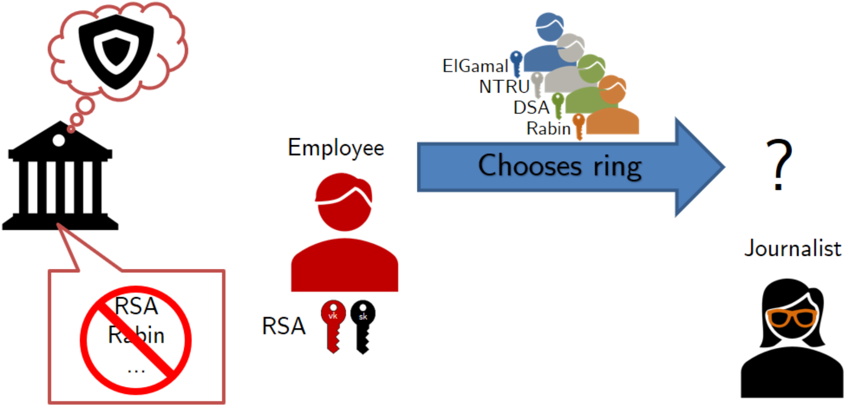
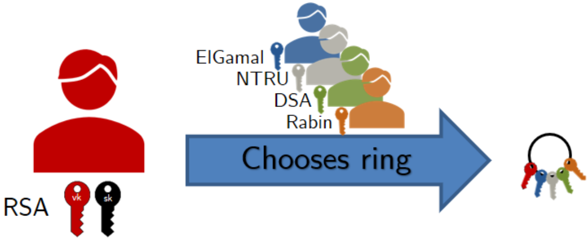


Is there protection from being used in anonymity ring?

NO

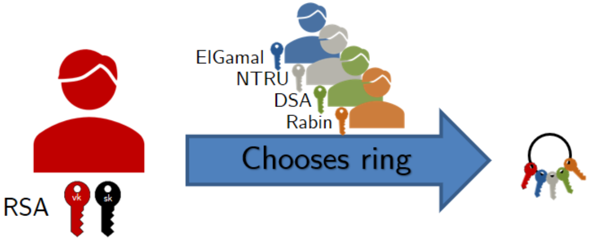
NO*

*terms and conditions apply



Ring signatures for rings of keys from ANY set of signing schemes.

Universal Ring Signatures



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- $\mathsf{Gen}(1^\lambda) \to (\mathsf{vk}, \mathsf{sk})$ \\ same as in underlying signature
- $\mathsf{Sign}(1^\lambda, \mathsf{sk}_i, m, R = (\mathsf{vk}_1, \ldots \mathsf{vk}_\ell), \underbrace{(\mathsf{Sig}_1, \ldots, \mathsf{Sig}_M)}_{\text{List of schemes } S}) \to \Sigma$
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The (too) obvious solution...

We could use a CRS or the ROM. NIZKPoK construction exists.

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Standard model it is - why is this hard?

The challenge

For any secure schemes $\mathsf{Ls} = \{\mathsf{Sig}_i\}_i$ we need:

Unforgeability

Experiment Adversary $\mathcal{A}$

$$\xleftarrow{\{\mathsf{ind}_i\}_{i\in[\ell]}}$$

$$\xrightarrow{R=(vk_i)_i,(\mathsf{vk}_i,\mathsf{sk}_i)\leftarrow \mathsf{Sig.KeyGen}_{\mathbf{ind}_i}(1^\lambda;r_i)}$$

Repeatedly:

$$\xleftarrow{\text{may ask to corrupt honest keys}}$$

$$\xleftarrow{\text{or ask for (universal ring) signatures}}$$

When done: $\xleftarrow{(\Sigma^*, m^*, R^*, S^*)}$

Wins if all schemes/keys are honest, m^* not queried to sign and signature verifies.

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$\mathcal{A}$ may NOT extract a forge for any Sig_i from Σ^*.

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How can the reduction get an edge over the adversary WITHOUT changing the key structure?

Overview

Need to hide a signature, where only the reduction can find it...

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- Allow the reduction more run-time: Complexity leveraging

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- Allow the reduction more run-time: Complexity leveraging
- Allow the reduction more information: Witness encryption

The terms and conditions

Construction	Size in R	Model	Assumptions/Caveats
[AOS02]	Linear	ROM	structured signatures[1]
[GGHAK21]	Log	ROM, CRS	structured signatures[2]
[BDW22] 1	Log	Standard	signatures are superpoly secure
[BDW22] 2	Linear	Standard	Witness Encryption, t-anonymity
[BDW22] 2b	Log	Standard	iO, t-anonymity

[1] hash-then-trapdoor-sign or three-move

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t-anonymity: Anonymity holds if $\geq t$ honest keys in R; commonly $(t = 3, 4)$

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- Let vk_i, $\mathsf{Sig}_{\mathsf{ind}}$ be corresponding to sk_i.

The solution

Complexity Leveraging

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- Compute a NIWI proof $\pi \leftarrow \mathsf{NIWI.Prove}(\cdot, \cdot)$ that the above was done correctly for one $\mathsf{vk}_i \in R$ and $\mathsf{Sig}_{\mathsf{ind}} \in S$.
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Size?

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Size? Standard trick: SPB digest ([BDH+19])

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Superpoly-Assumption!

Solution 2 - rough idea

Want: Commitment $\xrightarrow{\textit{replace}}$ WE

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Witness Encryption

Let $\mathcal{L}$ be an NP language defined by $x \in \mathcal{L} \Leftrightarrow \exists w : (x, w) \in \mathcal{R}$. A witness encryption WE has the following algorithms:

- $\mathsf{ct} \leftarrow \mathsf{WE.Enc}(1^\lambda, x, m)$
- $m \leftarrow \mathsf{WE.Dec}(w, \mathsf{ct})$

It is correct & soundness secure.

The challenge - Recall

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Experiment — Adversary $\mathcal{A}$

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$$\xrightarrow{R=(vk_i)_i,(\mathsf{vk}_i,\mathsf{sk}_i)\leftarrow\mathsf{Sig.KeyGen}_{\mathbf{ind}_i}(1^\lambda;r_i)}$$

$$\xrightarrow{\text{Additionally outputs randomness}(r_i)_i}$$

$$\xleftarrow{(m^*,R^*,S^*,(ind_1,\ldots,ind_t)),\mathsf{vk}^*_{ind_k}\in R}$$

$$\xrightarrow{\Sigma^*=\mathsf{URS.Sign}(1^\lambda,\mathsf{sk}^*_{ind_k},m^*,R^*,S^*)\text{ for } k\leftarrow_\$[t]}$$

$$\xleftarrow{\text{Guess } k'.}$$

Wins if $k=k'$.

Cannot change Gen, only degree of freedom is choice of randomness r_i!

Solution 2 - rough idea

Want: Commitment $\xrightarrow{\textit{replace}}$ WE

Independently chosen keys

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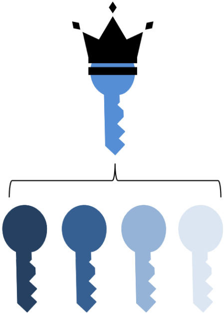

Malformed, correlated keys

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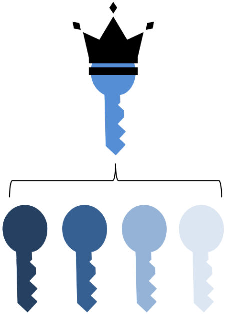
PRF key



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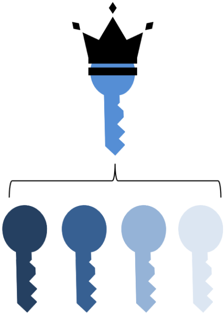

Malformed, correlated keys

Malformed keys are a much more sparse key distribution.

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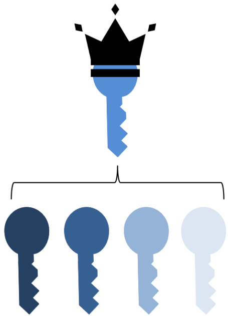

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Indistinguishable, but far.

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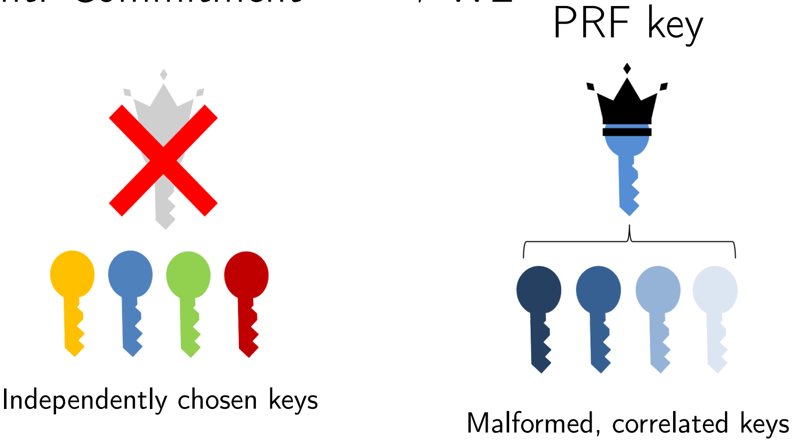

Malformed keys are a much more sparse key distribution.
Indistinguishable, but far. PRF key = witness of malformedness

Solution 2 - More concretely!

Standard keys

$(\mathsf{vk}_i, \mathsf{sk}_i) \leftarrow \mathsf{Sig.KeyGen}_{\mathsf{ind}_i}(1^\lambda; r_i)$
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Indistinguishable by pseudorandomness. PRF key K is witness!

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Assume $\kappa = \Theta(\lambda)$ e.g. if $\kappa = \lambda/2$, $t = 4$ sufficient

Putting it together

Sign

- $\sigma \leftarrow \mathsf{Sig.Sign}(\mathsf{sk}_i, m)$.
- $(\mathsf{com}_0, \gamma_0) \leftarrow \mathsf{CS.Commit}(1^\lambda, \sigma)$ and $(\mathsf{com}_1, \gamma_1) \leftarrow \mathsf{CS.Commit}(1^\lambda, 0)$.
- Compute a NIWI proof of correctness
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WE Size!

Reducing size

$\mathsf{WE.Enc}(1^\lambda, (\mathsf{vk}_i)_i, m)$

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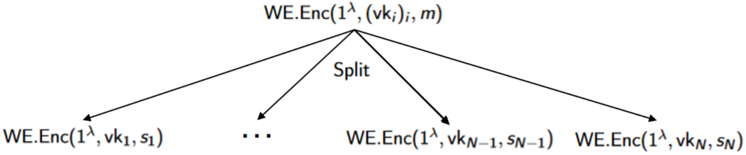

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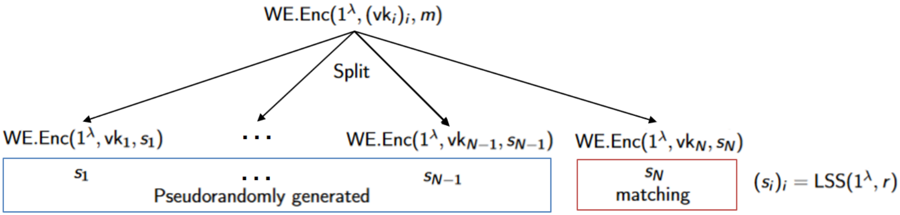

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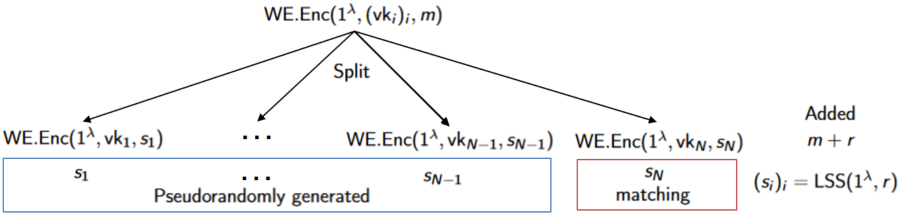

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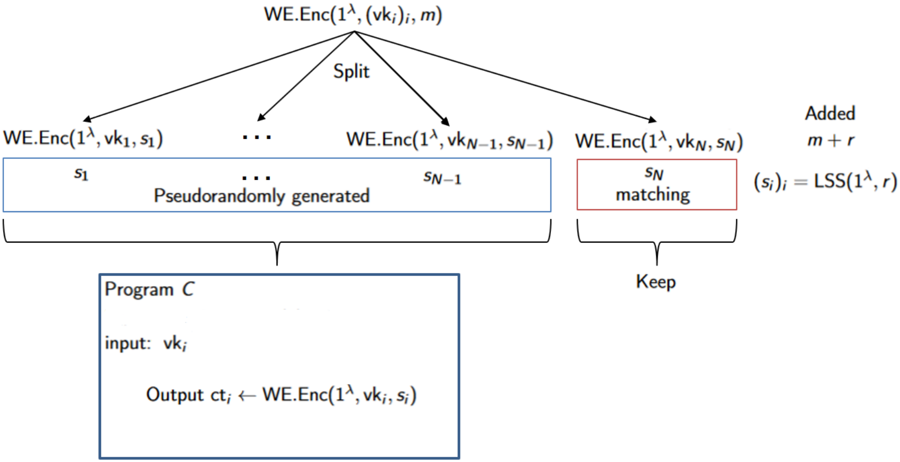

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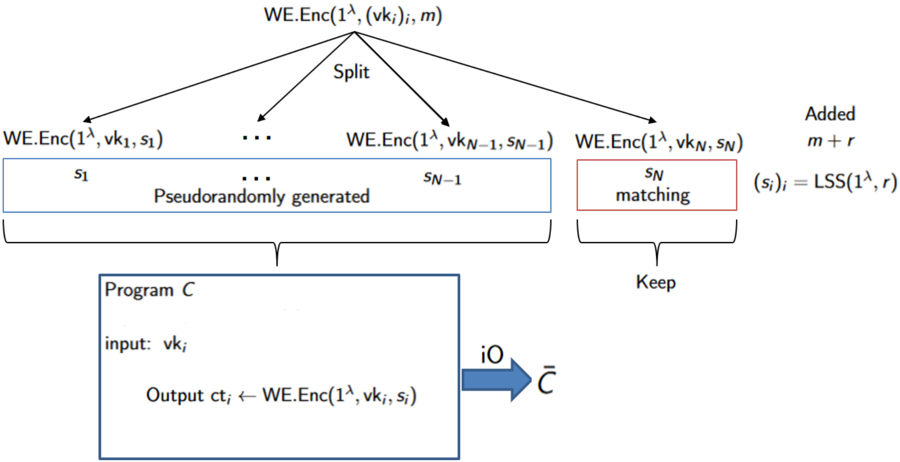

Recap

Result

We have shown, that we can always generate a ring signature for any ad hoc ring, without collaboration and regardless of the signing schemes used.

Constructions

1. Complexity leveraging, superpoly secure schemes (log size)
2. Correlated keys, Witness encryption (linear size in ring)
3. Correlated keys, special WE from iO (log size)

THANKS