

Fault-Tolerant Aggregate Signatures

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Outline

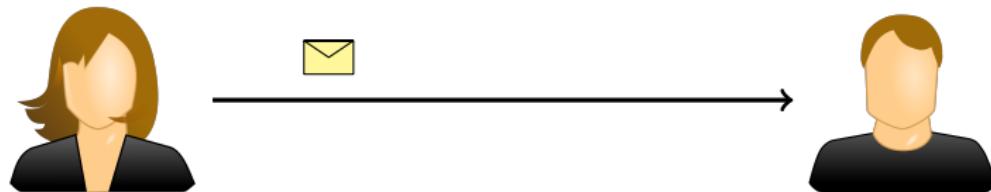
Introduction

Our Result: Fault-Tolerant Signatures

Our Approach

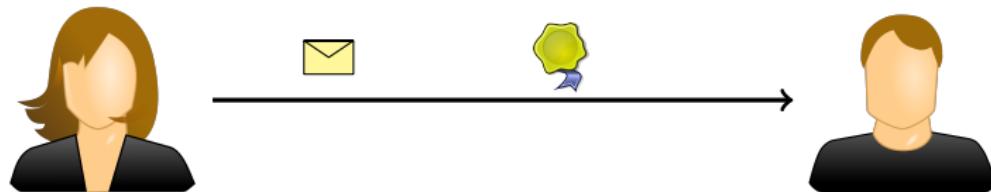
Properties

Introduction: Aggregate Signatures



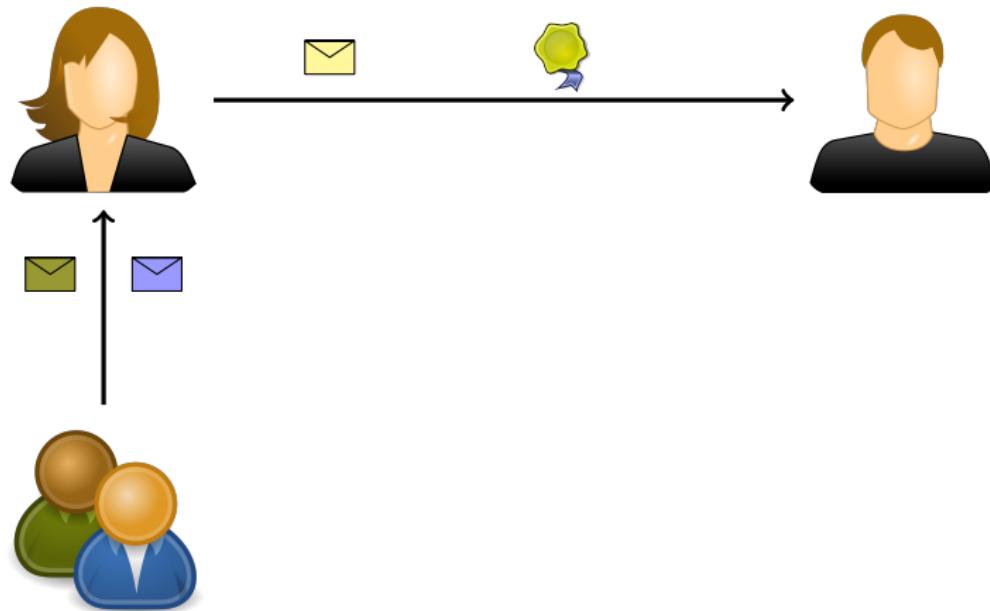
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Introduction: Aggregate Signatures



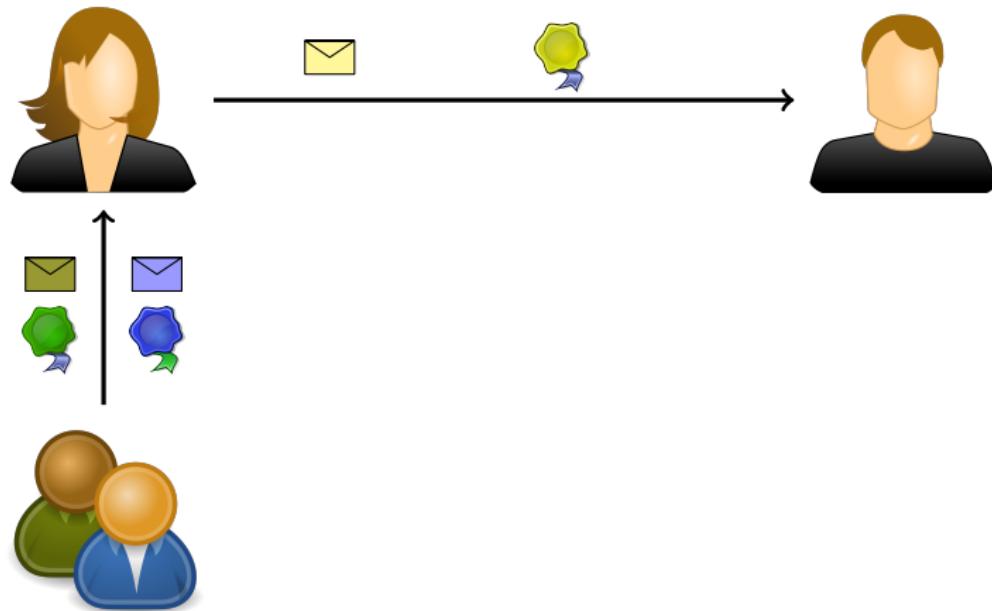
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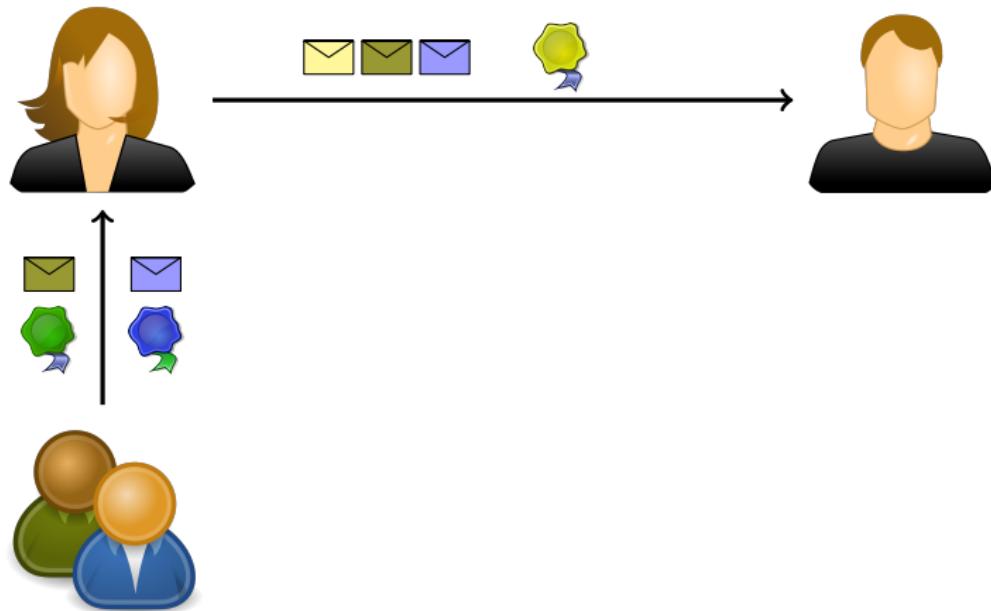
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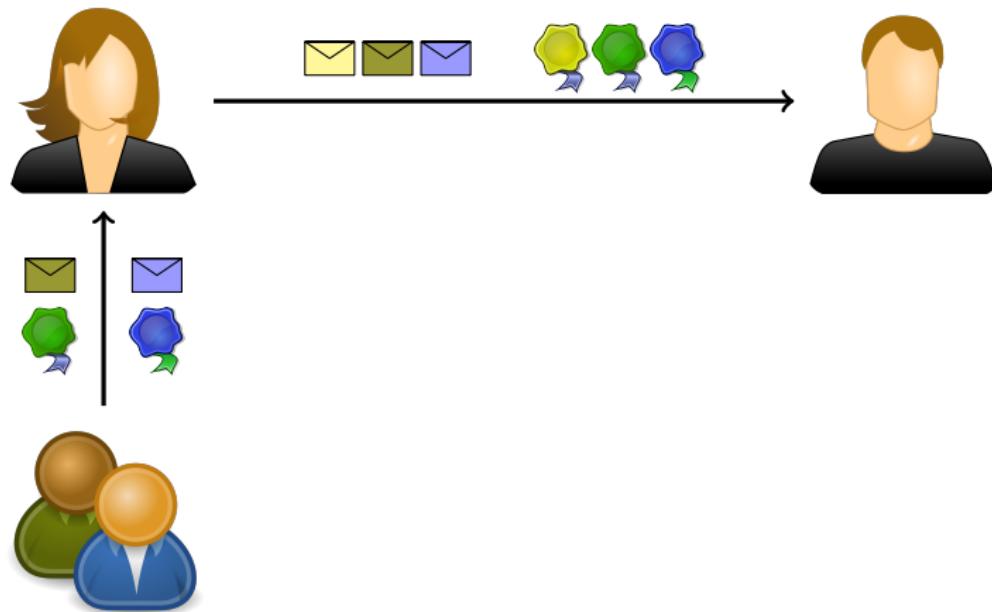
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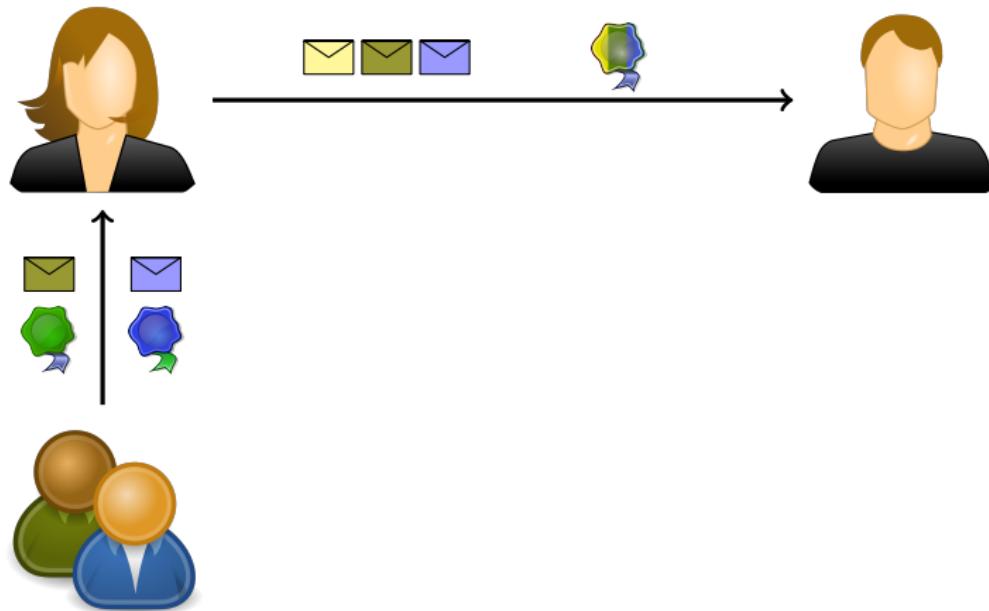
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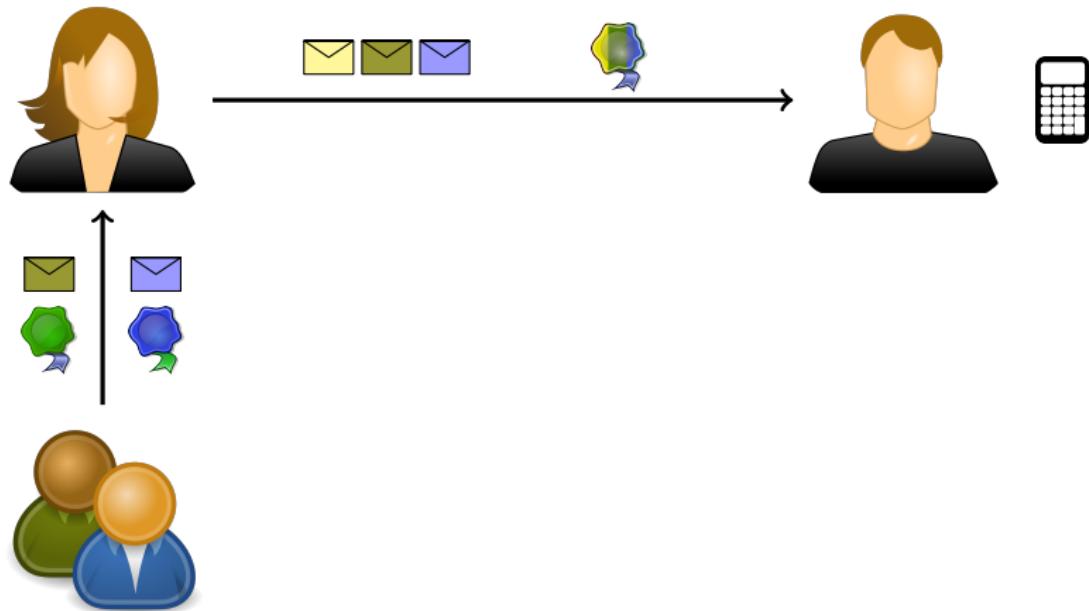
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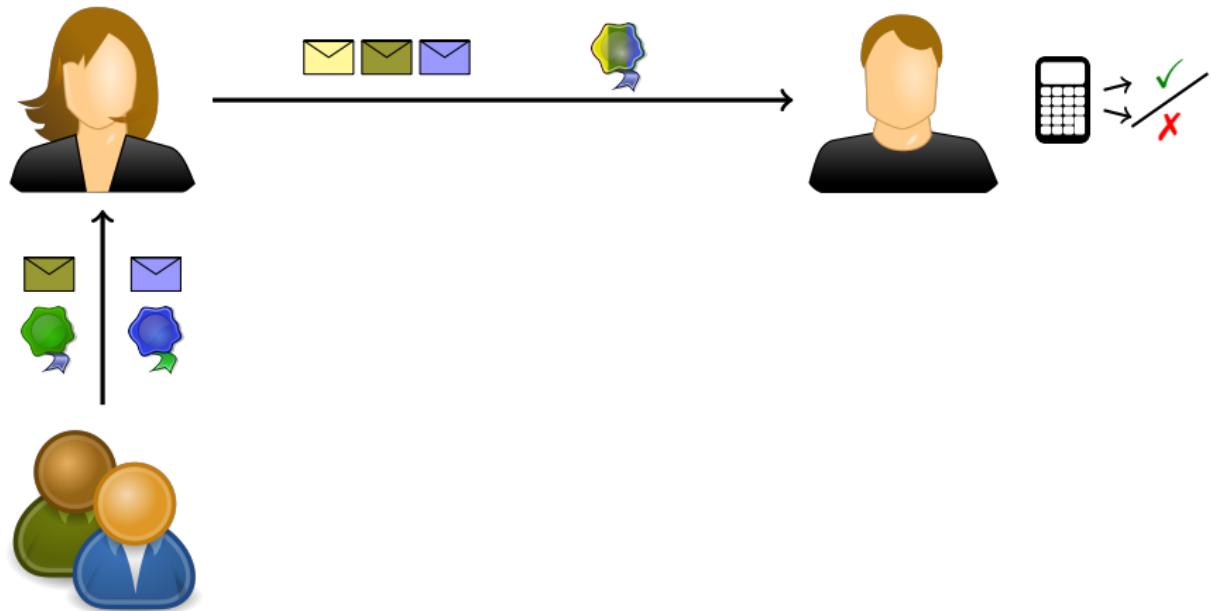
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Aggregate Signatures

What happens if Verification fails?

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⇒ Bob can not trust any message.

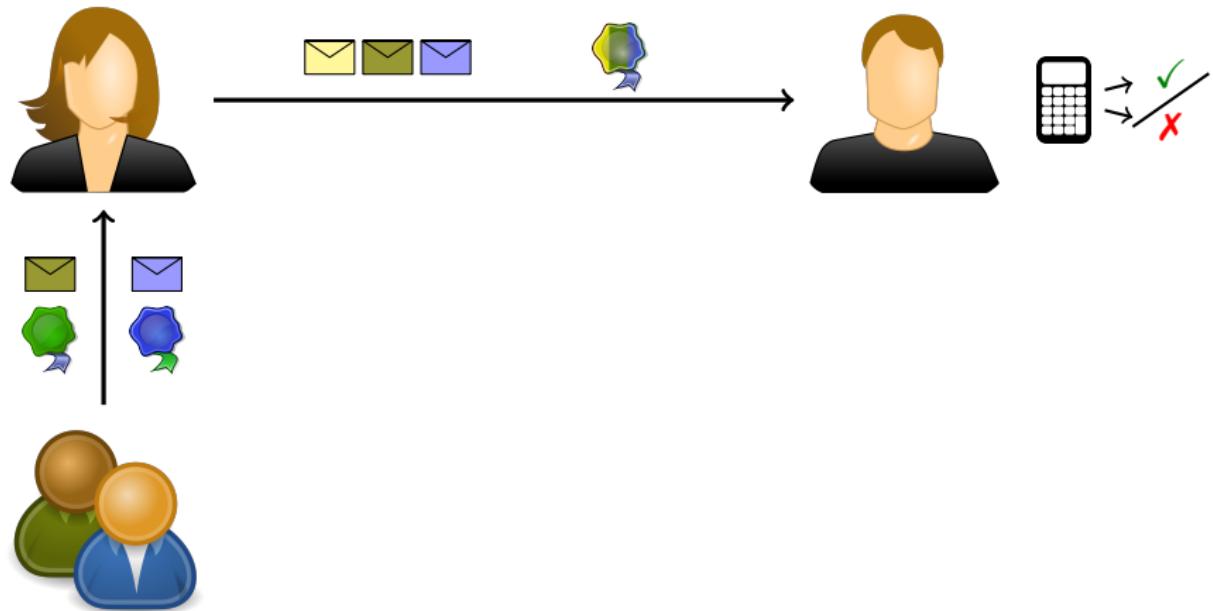
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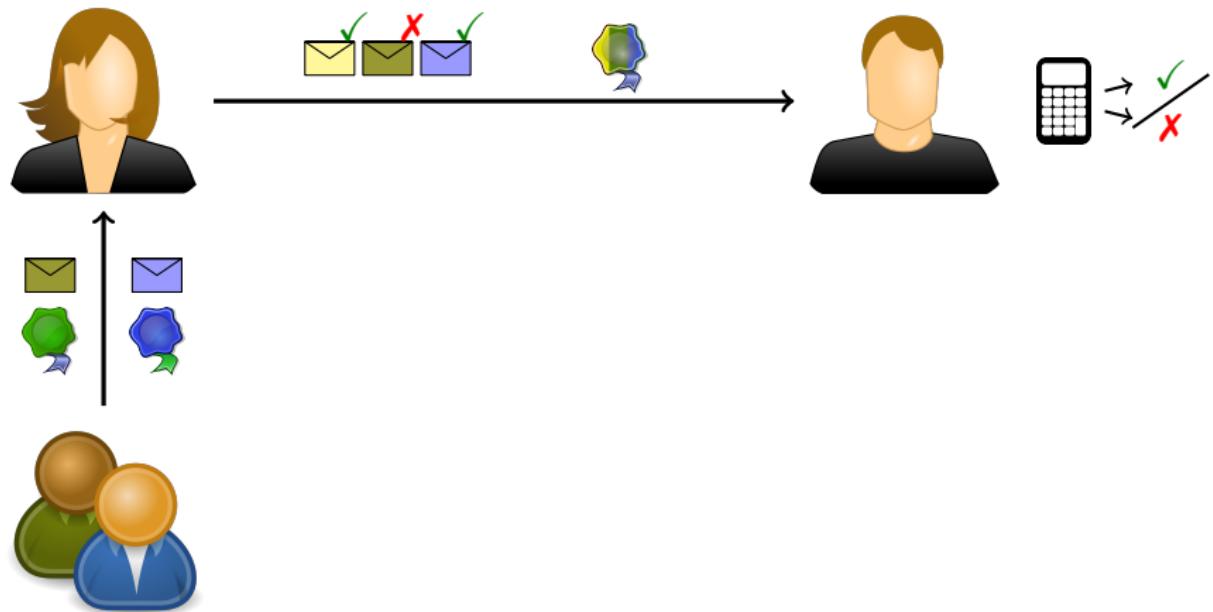
⇒ Bob can not trust any message.
⇒ resend data and/or agg. signature

Introduction: Aggregate Signatures



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Fault-Tolerance

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Definition: Fault-Tolerance (informal)

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An aggregate signature scheme is *d-fault-tolerant*, iff

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 - generalization of correctness

Our Result

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- via a black-box transformation from an arbitrary aggregate signature scheme,
- using Cover-Free-Families [KRS99].

Outline

Introduction

Our Result: Fault-Tolerant Signatures

Our Approach

Properties

Our Approach

- signature $\hat{=}$ vector of signatures of underlying scheme

$$\begin{pmatrix} \\ \\ \\ \end{pmatrix}$$

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$$\left(\begin{array}{cccccc} 1 & 0 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{array} \right) \rightsquigarrow \left(\begin{array}{c} \\ \\ \\ \end{array} \right)$$

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- signature $\hat{=}$ vector of signatures of underlying scheme
- columns $\hat{=}$ individual signatures

$$\left(\begin{array}{cccccc} \sigma_1 & 0 & 0 & \sigma_4 & 0 & \sigma_6 \\ \sigma_1 & \sigma_2 & 0 & 0 & \sigma_5 & 0 \\ 0 & \sigma_2 & \sigma_3 & \sigma_4 & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 & \sigma_5 & \sigma_6 \end{array} \right) \rightsquigarrow \left(\begin{array}{c} \\ \\ \\ \end{array} \right)$$

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$$\begin{pmatrix} \sigma_1 & 0 & 0 & \color{red}{\sigma_4} & 0 & \sigma_6 \\ \sigma_1 & \sigma_2 & 0 & 0 & \sigma_5 & 0 \\ 0 & \sigma_2 & \sigma_3 & \color{red}{\sigma_4} & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 & \sigma_5 & \sigma_6 \end{pmatrix} \rightsquigarrow \begin{pmatrix} \text{Agg}(\sigma_1, \sigma_4, \sigma_6) \\ \text{Agg}(\sigma_1, \sigma_2, \sigma_5) \\ \text{Agg}(\sigma_2, \sigma_3, \sigma_4) \\ \text{Agg}(\sigma_3, \sigma_5, \sigma_6) \end{pmatrix}$$

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$$\left(\begin{array}{cccccc} \sigma_1 & 0 & 0 & \color{red}\sigma_4\color{black} & 0 & \sigma_6 \\ \sigma_1 & \sigma_2 & 0 & 0 & \sigma_5 & 0 \\ 0 & \sigma_2 & \sigma_3 & \color{red}\sigma_4\color{black} & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 & \sigma_5 & \sigma_6 \end{array} \right) \rightsquigarrow \left(\begin{array}{c} \text{Agg}(\sigma_1, \color{red}\sigma_4\color{black}, \sigma_6) \\ \text{Agg}(\sigma_1, \sigma_2, \sigma_5) \\ \text{Agg}(\sigma_2, \sigma_3, \color{red}\sigma_4\color{black}) \\ \text{Agg}(\sigma_3, \sigma_5, \sigma_6) \end{array} \right) \begin{array}{c} \color{red}X\color{black} \\ \color{green}\checkmark\color{black} \\ \color{red}X\color{black} \\ \color{green}\checkmark\color{black} \end{array}$$

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Why does this work?

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No single column “covers” any other column.

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Incidence matrices of cover-free families [KRS99] allow for more invalid signatures.

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Properties

Recall: Verify outputs a list of valid messages

Definition (Security, informal)

A fault-tolerant signature scheme is *secure* iff no PPT adversary (with signing oracle) can forge an (aggregate) signature.

Our Construction:

- Verify outputs the union of messages in valid rows
 \implies security inherited from the underlying scheme

Definition (Compression Ratio)

Let σ^* be a maximum size aggregate signature for n individual signatures.
An aggregate signature scheme has *compression ratio* $\rho(n)$ iff

$$\frac{n}{\text{size}(\sigma^*)} \in \Theta(\rho(n)).$$

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For a fixed number of faults d , the size of a fault-tolerant signature is at least $\Omega(\log_2(n))$.

Our scheme achieves this bound.

Selective Verification

- Verification of a single message-signature pair (m_j, σ_j)
- more efficiently than full verification

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- check only relevant rows
- return early on success

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Example:

$$\left(\begin{array}{cccc} \sigma_1 & & \sigma_4 & \sigma_6 \\ \sigma_1 & \sigma_2 & & \sigma_5 \\ & \sigma_2 & \sigma_3 & \sigma_4 \\ & & \sigma_3 & \end{array} \right) \rightsquigarrow \left(\begin{array}{c} \text{Agg}(\sigma_1, \sigma_4, \sigma_6) \\ \text{Agg}(\sigma_1, \sigma_2, \sigma_5) \\ \text{Agg}(\sigma_2, \sigma_3, \sigma_4) \\ \text{Agg}(\sigma_3, \sigma_5, \sigma_6) \end{array} \right) \quad \checkmark$$

- check only relevant rows
- return early on success

Selective Verification

- Verification of a single message-signature pair (m_j, σ_j)
- more efficiently than full verification

Example:

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- check only relevant rows
- return early on success
- our construction: matrix does not need to be stored, can be generated on demand efficiently

Example Numbers

<i>d</i>	<i>m</i>	<i>n</i>
max.faults	dimension of vector	single signatures
2	25	125
5	121	1331
8	289	4913
4	289	$\approx 1.42 \cdot 10^6$
14	841	24389
26	2809	148877
50	10201	$\approx 1.03 \cdot 10^6$
83	63001	$\approx 3.97 \cdot 10^9$
510	1042441	$\approx 1.06 \cdot 10^9$

- Aggregate signature schemes can “compress” signatures from different signers.

Our Construction:

Pros:

- tolerates a fixed number of errors
- black-box transformation
- asymptotically optimal compression
- selective verification

Cons:

- a-priori upper bound on number of aggregated signatures
- compression-rate limited by fault-tolerance
- requires order among the messages

Thank you. Questions?

Contact: gunnar.hartung@kit.edu

PGP-Key ID: B1A7 C146

Fingerprint: 4C39 AC36 6FAD 9E52 3144
8352 9E37 381F B1A7 C146

S/MIME Cert: at

<https://crypto.iti.kit.edu/?id=hartung&L=2>

Definition (Security Experiment)

- *Setup Phase.* Run $(\text{pk}, \text{sk}) := \text{KeyGen}(1^\kappa)$ and start adversary \mathcal{A} with input pk .
- *Query Phase.* \mathcal{A} may adaptively issue signature queries m_i , and receives the responses $\tau_i := \text{Sign}(\text{sk}, m_i)$.
- *Forgery Phase.* \mathcal{A} outputs a claim sequence C^* and a signature τ^* .

Definition (Security)

An aggregate signature scheme with list verification is (t, q, ε) -secure if there is no adversary \mathcal{A} running in time at most t , making at most q queries to the signature oracle and winning in the above experiment with probability at least ε .

Definition (d -Cover-Free Family [KS64])

A d -CFF $\mathcal{F} = (\mathcal{S}, \mathcal{B})$ consists of:

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- $|B \setminus \bigcup_{k=1}^d B_{i_k}| \geq 1$

i.e. d subsets do not cover a different single subset.

d -Cover-Free Families

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d -Cover-Free Families

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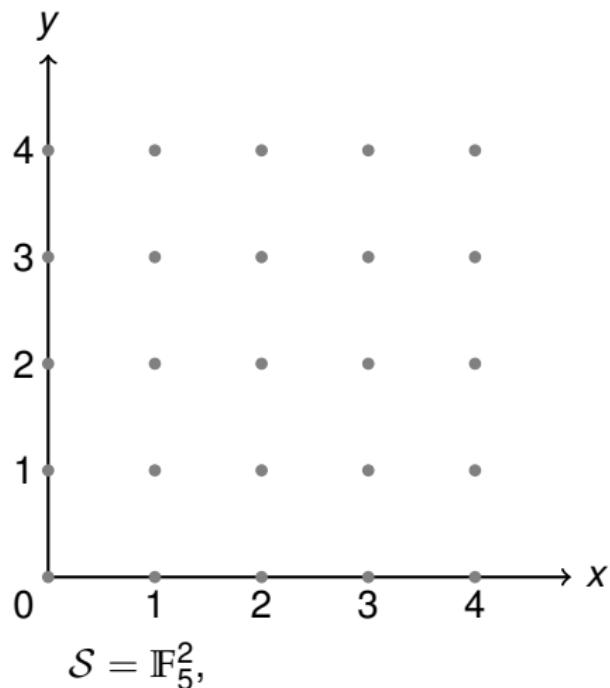
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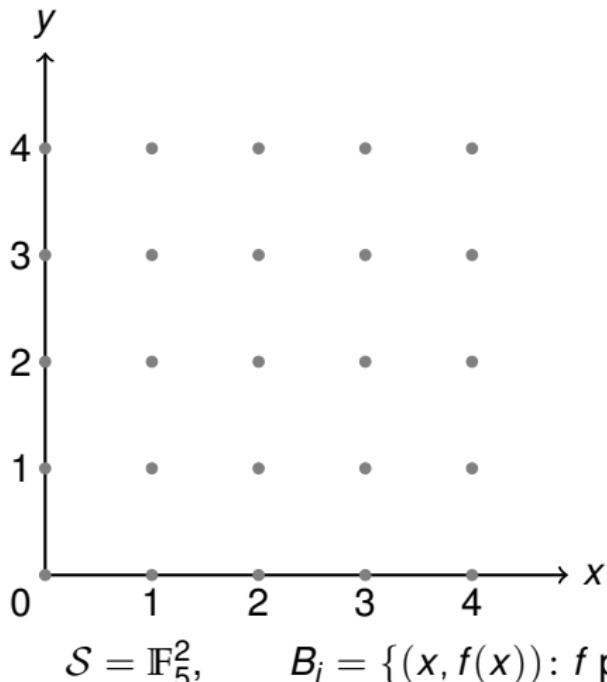
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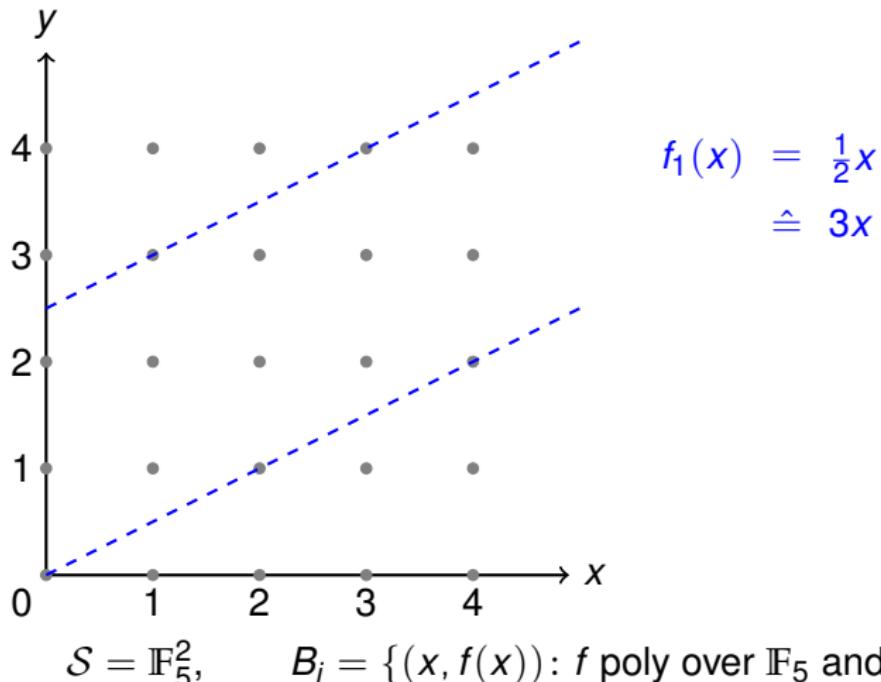
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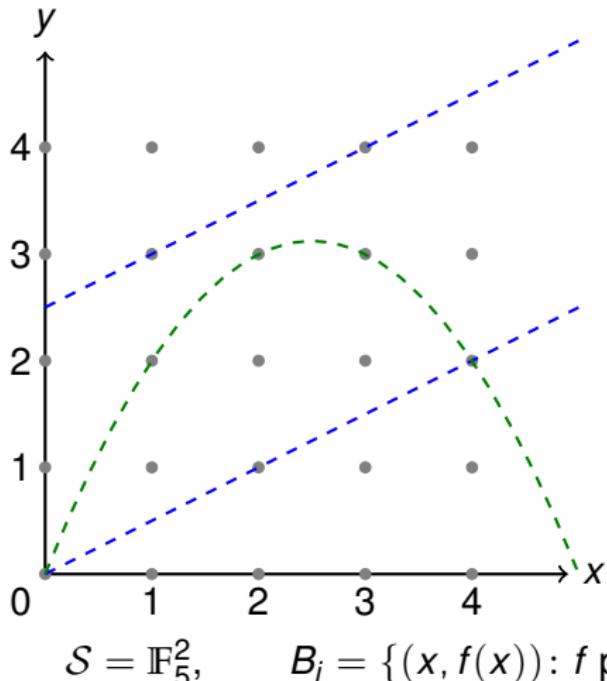
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Our Approach

Polynomial-Based Construction of a d-CFF

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Compression Ratio

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- required: $2^\ell \geq \binom{n}{n-d} \quad \rightsquigarrow \quad \ell \in \Omega(\log_2(n))$ □

References I



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