Generic Double-Authentication Preventing Signatures and a Post-Quantum Instantiation

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[1] work done while at Graz University of Technology

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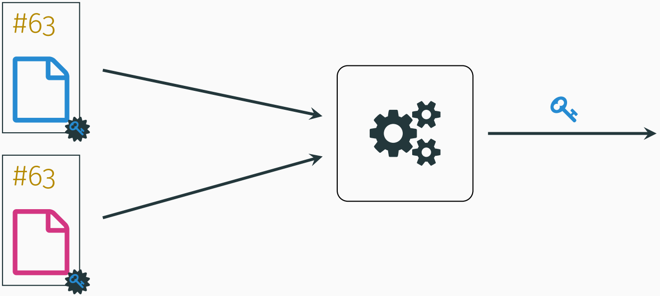
Introduction

Digital Signatures

Applications

- Signing transactions in cryptocurrencies
- Certificate and software signing
- And many more

Double-Authentication Preventing Signatures [PS14]



- Same context (address), different content

» Extract secret key

- Extraction from honest or malicious keys

Double-Authentication Preventing Signatures [PS14] (cont.)

Applications

- Deterring certificate subversion
- Double-spending prevention in offline payment channels
- Non-equivocation contracts

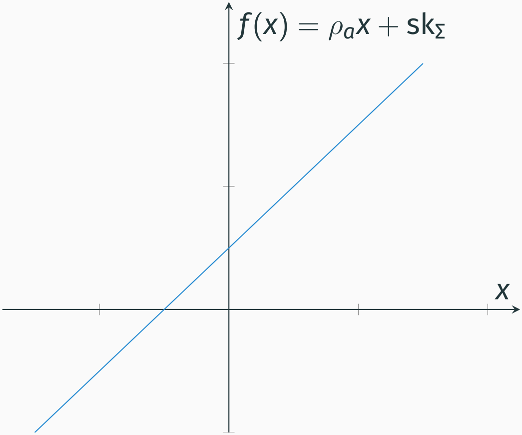
Existing DAPS

Approach	Address space	Extraction	Setting	Generic
[PS14]	exponential	**DSE**	factoring	×
[RKS15]	exponential	**DSE**	DLOG	×
[BPS17]	exponential	**DSE**	factoring	×
[BKN17]	exponential	**DSE**	SIS+LWE	×
[DRS18]	small	wDSE*	DLOG	✓
[Poe18]	small	**DSE**	DLOG	×

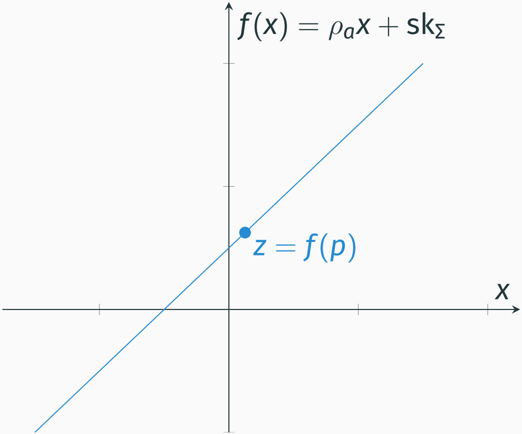
Can we build efficient DAPS without address space limitation from existing signature schemes in a black-box way?

DAPS without Structured Hardness Assumptions

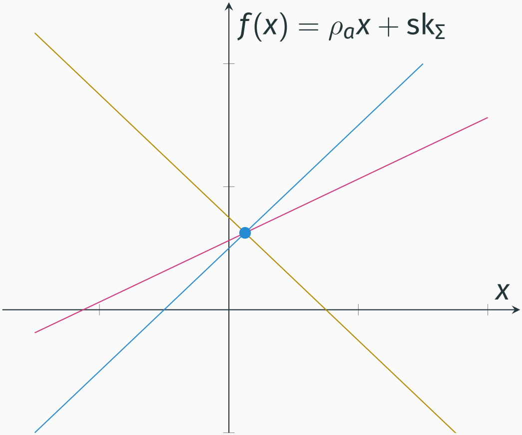
Shamir Secret Sharing



Shamir Secret Sharing

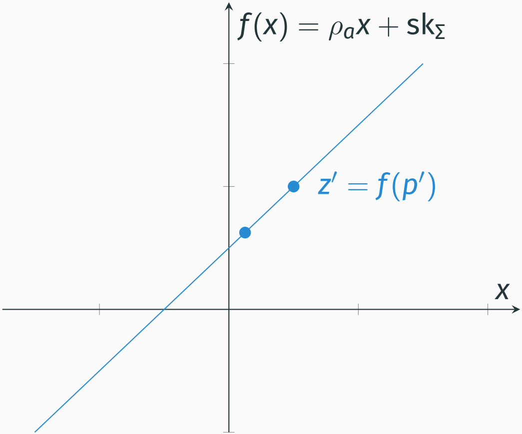


Shamir Secret Sharing



- One point reveals nothing about sk_Σ

Shamir Secret Sharing



- Two points allow to recover sk_Σ

The [DRS18] Approach

- DLOG-based signature scheme Σ

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+ Extend signature with secret share of private key
  Sharing polynomial is address dependent

» Extraction of Σ key

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- \+ Add consistency proof of share
- » Store encrypted coefficients in public key

The [DRS18] Approach

- DLOG-based signature scheme Σ
- + Extend signature with secret share of private key
  Sharing polynomial is address dependent
- » Extraction of Σ key
- + Add consistency proof of share
- » Store encrypted coefficients in public key
- » Polynomially sized address space

Resolving the Address Space Limitation

- Derive coefficients of sharing polynomial using PRF $\mathcal{F}$

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» Signature-of-knowledge style signature

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+ Only requirement: Σ public key image of one-way function

Construction

sk_Σ

pk_Σ

Construction

sk_Σ $\mathsf{sk}_\mathcal{F}$

pk_Σ β c

Construction

sk_Σ $\mathsf{sk}_\mathcal{F}$

pk_Σ $\beta \longrightarrow c$

commit to $\mathsf{sk}_\mathcal{F}$

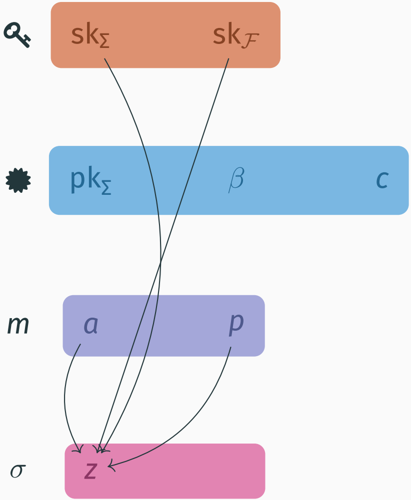
Construction

🔑 sk_Σ $\mathsf{sk}_\mathcal{F}$

✹ pk_Σ β c

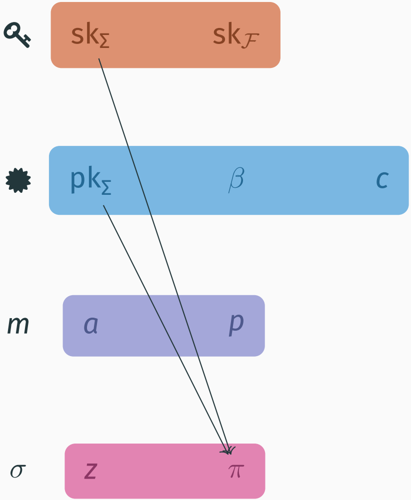
m a p

Construction



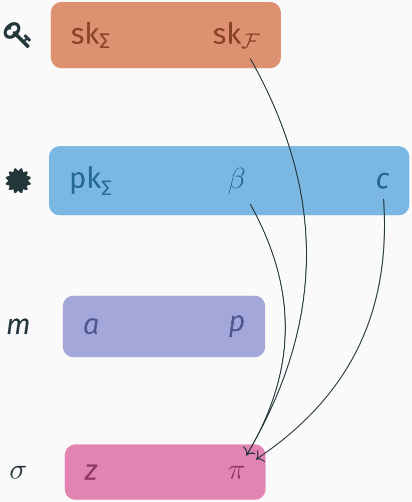
secret sharing of $\mathbf{sk}_\Sigma$

Construction



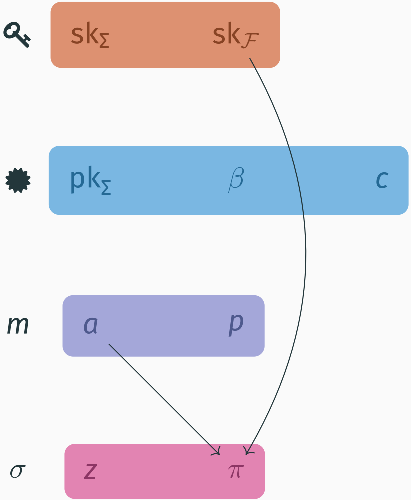
consistency proof of Σ keys

Construction



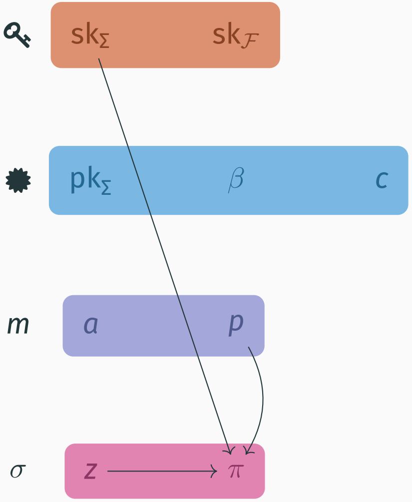
consistency proof of PRF commitment

Construction



consistency proof of sharing polynomial computation

Construction



consistency proof of secret sharing

Wrap Up

Generic approach:

- Σ with OWF relation between secret and public key
- **+** Verifiable Shamir secret sharing of Σ secret key
- **+** Sharing polynomial determined by address

$$f_a(x) = \mathcal{F}(\mathsf{sk}_{\mathcal{F}}, a) \cdot x + \mathsf{sk}_{\Sigma}$$

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$$f_a(x) = \mathcal{F}(\mathsf{sk}_{\mathcal{F}}, a) \cdot x + \mathsf{sk}_{\Sigma}$$

- Zero-knowledge proof of consistency

Wrap Up (cont.)

Security (informal)

- Unforgeability from simulation-sound extractability, PRF and OWF properties
- Extraction from fixed-value-key-binding of PRF

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Extension

+ Extendable to N-authentication preventing signatures

» Use degree $N - 1$ sharing polynomial

Instantiation

From Picnic:

- + OWF built from block cipher LowMC
- » Use LowMC also for PRF
- » Estimated signature size: 408 KB

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Instantiation

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From SPHINCS:

- Secret-key-to-public-key relation more expensive
- Multiple evaluations of hash functions for consistency proof

From stuctured hardness assumptions:

- + Fulfill secret-key-to-public-key relation requirement
- ? Suitable proof system
- » Recent progress [AGM18]

Extending Any Signature Scheme

Black-box Extension

Signature scheme **Σ**

Sign(-Σ, ...) Verify(-Σ, ...)

Black-box Extension

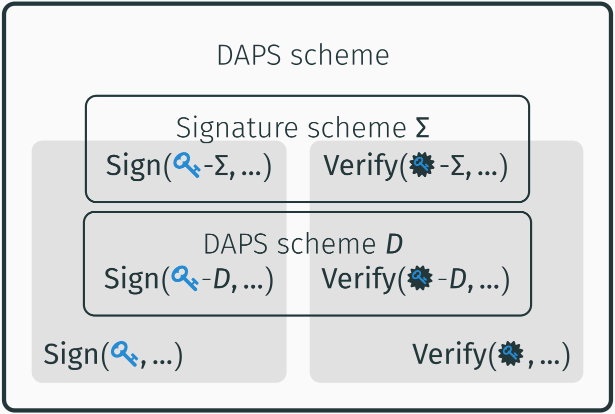
Signature scheme Σ

Sign(-Σ, ...) Verify(-Σ, ...)

DAPS scheme D

Sign(-D, ...) Verify(-D, ...)

Black-box Extension



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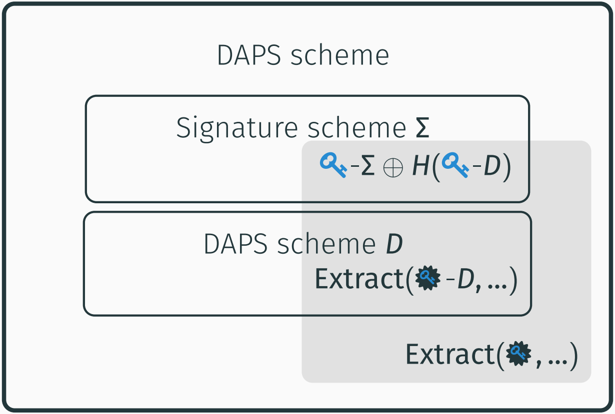

Black-box Extension (cont.)

- Extend any signature scheme to DAPS

+ From any other DAPS

» DAPS from standard signatures like EdDSA, ECDSA

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Security (informal)

- Unforgeability from unforgeability of signature scheme
- Extraction from extraction of DAPS

Conclusion

DAPS Constructions

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[RKS15]	exponential	DSE	DLOG	$\times$
[BPS17]	exponential	DSE	factoring	$\times$
[BKN17]	exponential	DSE	lattices	$\times$
[DRS18]	small	wDSE*	DLOG	✓
[Poe18]	small	DSE	DLOG	$\times$
Constr. 1	exponential	wDSE	symmetric	✓
Constr. 2	exponential	DSE	any	✓

Conclusion

Contribution

- ✔ Generic constructions of DAPS
- ✔ Construction 1: DAPS from symmetric-key primitives
- ✔ Construction 2: Extension of any signature scheme to DAPS

Questions?

Full version: `https://ia.cr/2018/790`

Supported by: prisma cloud

References i

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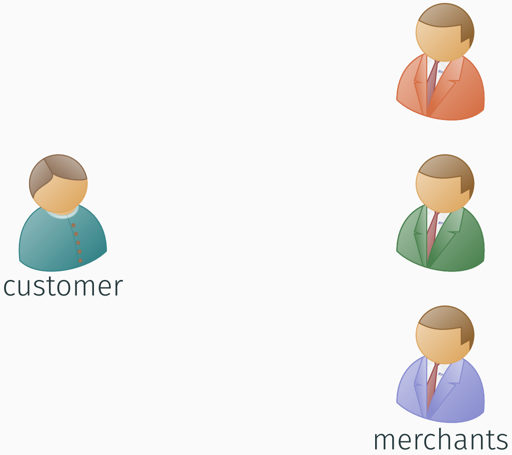
Penalize Double-Spending



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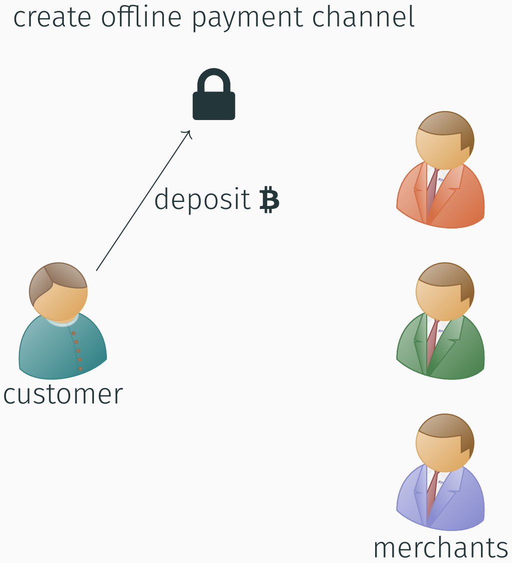

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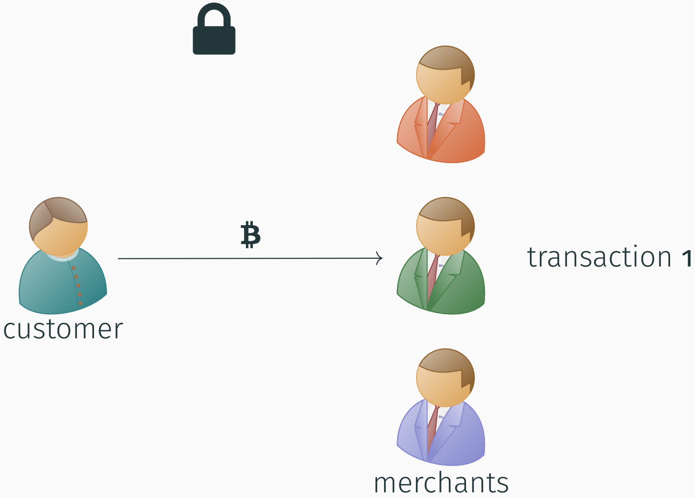

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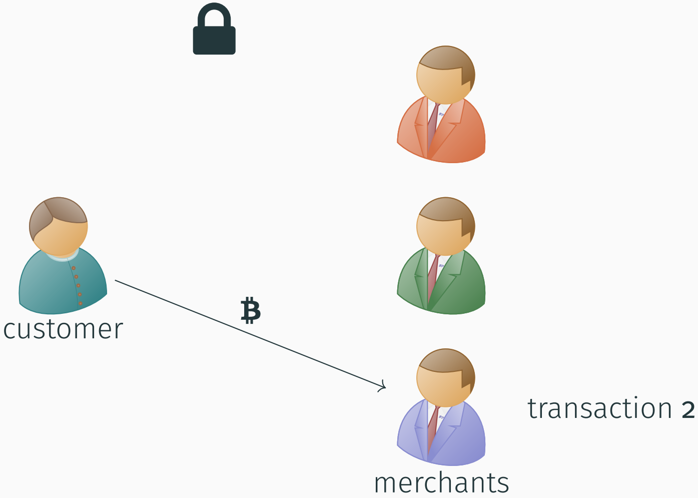

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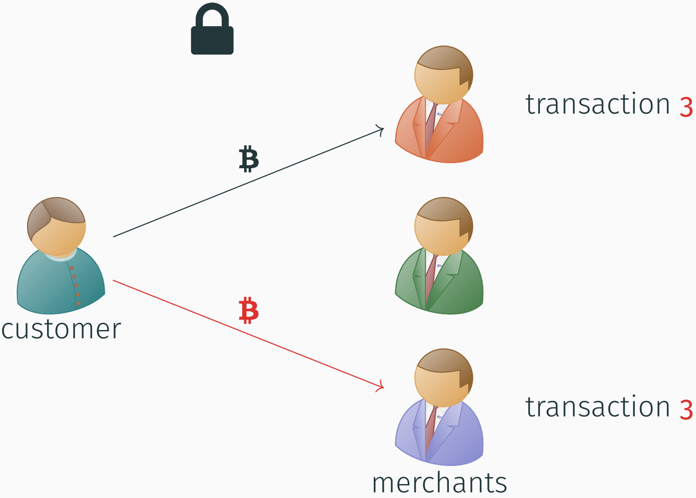

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