Lattice Signature with Efficient Protocols, Application to Anonymous Credentials

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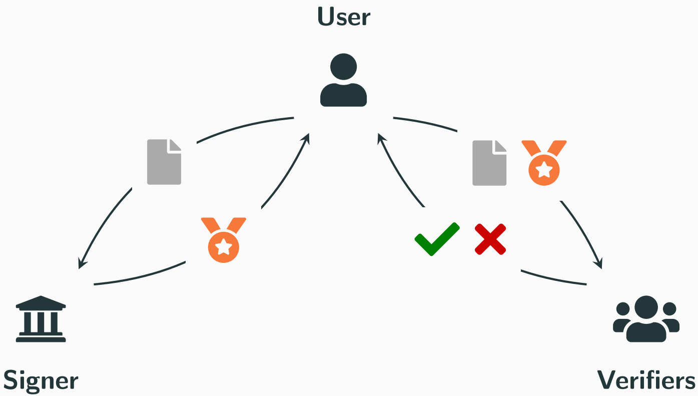
Signature with Efficient Protocols (SEP)



The message must be revealed to sign and verify. Not suited for privacy-enhancing applications.

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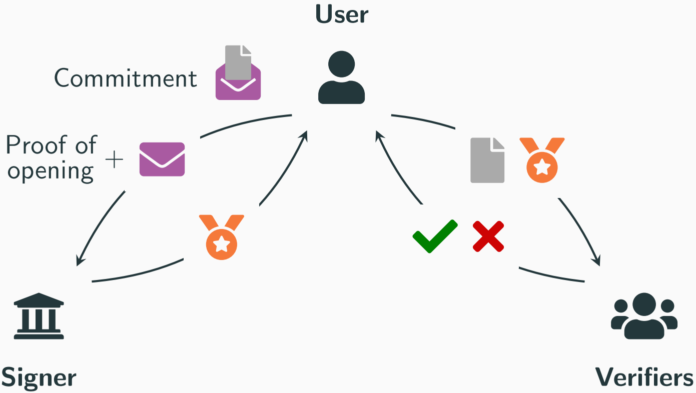

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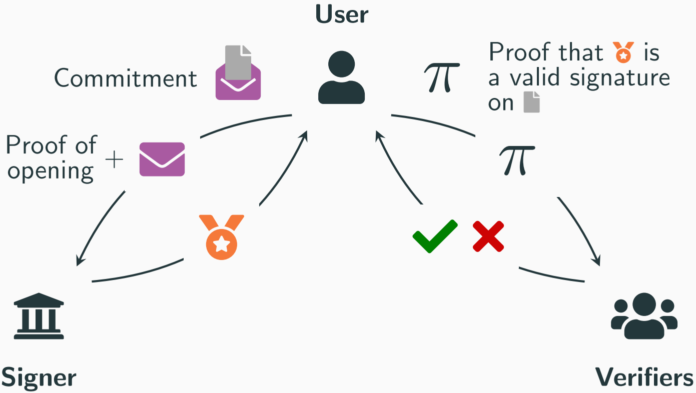

User

Commitment

Proof of opening + ✉

🏅

π Proof that 🏅 is a valid signature on 🗎

π

✓ ✗

Signer

Verifiers

Neither 🗎 nor 🏅 have to be revealed, but need for Zero-Knowledge arguments, and "structure-preserving" signature.

An Interesting Versatility

Many concrete privacy-enhancing applications.

- **Anonymous Credentials Systems**: requires the ability to
  - ✓ sign committed messages
  - ✓ prove possession of a message-signature pair in ZK
- **Group Signatures**: requires to add a verifiable encryption of the user identity
- **Blind Signatures**: requires the ability to
  - ✓ sign committed messages
  - ✓ prove possession of a signature on a public message in ZK
- **E-Cash Systems**
- etc.

Real industrial impact: EPID and DAA deployed in billions of devices (TPM, SGX). Blind/Group signatures in ISO standards

Existing Signatures with Efficient Protocols

Very efficient instantiations of SEPs in the classical setting.

- [CL02][1] Based on the Strong-RSA assumption.
- [CL04][2][BB08][3][PS16][4] Based on pairings in bilinear groups.

[BB08][PS16] are constant-size. Very efficient group signatures, anonymous credentials, etc.

- Best group signature is based on SEP: 0.16 KB

[1] J. Camenisch, A. Lysyanskaya. A signature scheme with efficient protocols. SCN 2002.

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? Those are vulnerable to quantum computing. How about **post-quantum** solutions?

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Existing PQC Signature with Efficient Protocols

Only one proposal of post-quantum signature with efficient protocols:

- [LLM+16][5] Proof of concept based on standard lattices.

		$\lvert\text{pk}\rvert$	$\lvert\text{sk}\rvert$	$\lvert\text{sig}\rvert$	$\lvert\pi\rvert$
[LLM+16]	Exact Proof	3 TB	15 GB	9 MB	10 GB
	Appr. Proof	7 TB	37 GB	14 MB	670 MB

[5] B. Libert, S. Ling, F. Mouhartem, K. Nguyen, and H. Wang. Signature schemes with efficient protocols and dynamic group signatures from lattice assumptions. ASIACRYPT, 2016.

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[LLM+16]	Exact Proof	3 TB	15 GB	9 MB	10 GB
	Appr. Proof	7 TB	37 GB	14 MB	670 MB

Today

Simpler, more compact, more efficient construction on standard lattices, and extension to ideal and module lattices.

		|pk|	|sk|	|sig|	|π|
Ours	Exact Proof	**8 MB**	**9 MB**	**270 KB**	**640 KB**

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Our Lattice Signature With Efficient Protocols

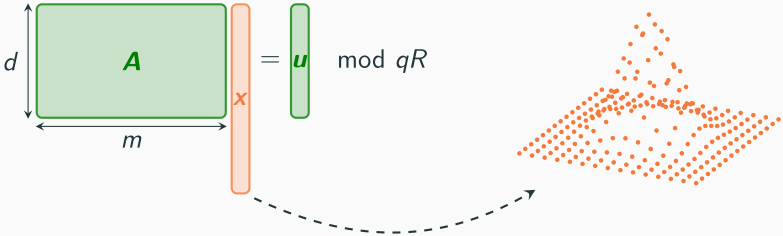
Short Integer Solution and Trapdoors

Module-SIS$_{m,d,q,\beta}$

Given $\boldsymbol{A} \hookleftarrow U((R/qR)^{d\times m})$, find a **non-zero** $\boldsymbol{x} \in R^m$ such that $\boldsymbol{A}\boldsymbol{x} = \mathbf{0} \bmod qR$, $0 < \|\boldsymbol{x}\|_2 \leq \beta$.

$R = \mathbb{Z}[x]/\langle x^n + 1\rangle$ with $n = 2^k$

Trapdoor on $\boldsymbol{A}$: piece of information used to sample Gaussian vector $\boldsymbol{x}$ such that $\boldsymbol{A}\boldsymbol{x} = \boldsymbol{u} \bmod qR$ for any syndrome $\boldsymbol{u}$



Constructing our SEP

❶ **Original Construction** from [LLM+16]

$\mathtt{sk} = \boldsymbol{T_A}$ (Trapdoor), $\boldsymbol{A}_i, \boldsymbol{u}, \boldsymbol{D}, \boldsymbol{D}_j$ uniform public
$\mathtt{sig} = ((\tau_i)_i, \boldsymbol{v}, \boldsymbol{r})$ with τ_i tag bits, $\boldsymbol{v}, \boldsymbol{r}$ short, $\boldsymbol{m}_j$ binary vectors

$$\underbrace{\left[\boldsymbol{A} \;\middle|\; \boldsymbol{A}_0 + \textstyle\sum_i \tau_i \boldsymbol{A}_i\right] \cdot}_{\boldsymbol{T_A}\text{ extends to full matrix}} \boldsymbol{v} = \boldsymbol{u} + \boldsymbol{D} \cdot \mathrm{bin}\left(\underbrace{\boldsymbol{D}_0 \boldsymbol{r} + \textstyle\sum_j \boldsymbol{D}_j [\boldsymbol{m}_j | \boldsymbol{1} - \boldsymbol{m}_j]}_{\text{Commitment ✉}}\right)$$

$\boldsymbol{w} = \mathrm{bin}\left(\boldsymbol{D}_0 \boldsymbol{r} + \sum_j \boldsymbol{D}_j [\boldsymbol{m}_j | \boldsymbol{1} - \boldsymbol{m}_j]\right)$

- $\left[\boldsymbol{A} \;\middle|\; \boldsymbol{A}_0 + \sum_i \tau_i \boldsymbol{A}_i\right] \boldsymbol{v} = \boldsymbol{u} + \boldsymbol{D}\boldsymbol{w}$
- bin-recomp$(\boldsymbol{w}) = \boldsymbol{D}_0 \boldsymbol{r} + \sum_j \boldsymbol{D}_j [\boldsymbol{m}_j | \boldsymbol{1} - \boldsymbol{m}_j]$
- $\boldsymbol{w}$ binary

ZKP details

Constructing our SEP

❷ **New Arguments** in Security Proofs (+ message packing)

$\mathtt{sk} = \boldsymbol{T}_{\boldsymbol{A}}$ (Trapdoor), $\boldsymbol{A}_i, \boldsymbol{u}, \boldsymbol{D}, \boldsymbol{D}_j$ uniform public

$\mathtt{sig} = ((\tau_i)_i, \boldsymbol{v}, \boldsymbol{r})$ with τ_i tag bits, $\boldsymbol{v}, \boldsymbol{r}$ short, $\boldsymbol{m}$ binary vector

$$[\boldsymbol{A} \mid \boldsymbol{A}_0 + \sum_i \tau_i \boldsymbol{A}_i] \cdot \boldsymbol{v} = \boldsymbol{u} + \underbrace{\boldsymbol{D}_0 \boldsymbol{r} + \boldsymbol{D}_1 \boldsymbol{m}}_{✉}$$

Before

$$\left[\boldsymbol{A} \mid \boldsymbol{A}_0 + \sum_i \tau_i \boldsymbol{A}_i\right] \cdot \boldsymbol{v} = \boldsymbol{u} + \boldsymbol{D} \cdot \mathrm{bin}\left(\boldsymbol{D}_0 \boldsymbol{r} + \sum_j \boldsymbol{D}_j [\boldsymbol{m}_j | \boldsymbol{1} - \boldsymbol{m}_j]\right)$$

Constructing our SEP

③ **Gadget Trapdoors** and **Compacting Commitment** with **Signature**

$\mathtt{sk} = \boldsymbol{R}$ (Trapdoor), $\boldsymbol{A}, \boldsymbol{u}, \boldsymbol{D}_1$ uniform public, $\boldsymbol{G} = \boldsymbol{I} \otimes [1\ 2 \ldots 2^{k-1}]$ gadget matrix
$\mathtt{sig} = (\tau, \boldsymbol{v}')$ with τ tag, $\boldsymbol{v}'$ short, $\boldsymbol{m}$ binary vector

$$[\boldsymbol{A} \mid \tau\boldsymbol{G} - \boldsymbol{A}\boldsymbol{R}]\boldsymbol{v} = \boldsymbol{u} + \underbrace{\boldsymbol{A}\boldsymbol{r} + \boldsymbol{D}_1\boldsymbol{m}}_{\text{✉}}$$

$$\iff$$

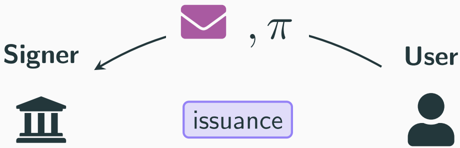
$$\begin{bmatrix}\boldsymbol{A} & \mid & \tau\boldsymbol{G} - \boldsymbol{A}\boldsymbol{R}\end{bmatrix}\begin{bmatrix}\boldsymbol{v}_1' \\ \boldsymbol{v}_2\end{bmatrix} = \boldsymbol{u} + \boldsymbol{D}_1\boldsymbol{m} \quad \text{with} \quad \boldsymbol{v}_1' = \boldsymbol{v}_1 - \boldsymbol{r}$$

Before

$$\begin{bmatrix}\boldsymbol{A} & \mid & \boldsymbol{A}_0 + \sum_i \tau_i \boldsymbol{A}_i\end{bmatrix} \cdot \boldsymbol{v} = \boldsymbol{u} + \boldsymbol{D}_0\boldsymbol{r} + \boldsymbol{D}_1\boldsymbol{m}$$

Application to Anonymous Credentials: The Protocols

Credential Issuance and Showing



❶ ✉ $= \boldsymbol{Ar} + \boldsymbol{Dm}$

❷ $\pi = \mathrm{Proof}($✉$, \boldsymbol{r}, \boldsymbol{m})$

[LNP22][6] (lin.)

[6] V. Lyubashevsky, N. K. Nguyen, M. Plançon. Lattice-Based Zero-Knowledge Proofs and Applications: Shorter, Simpler, and More General. Crypto 2022.

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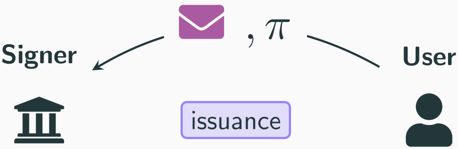

✉ , π

Signer

User

issuance

❸ Verif(✉, π)

❶ ✉ $= \boldsymbol{Ar} + \boldsymbol{Dm}$

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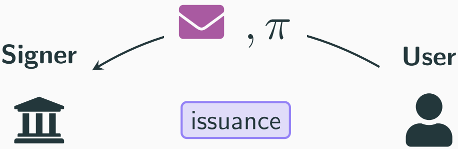

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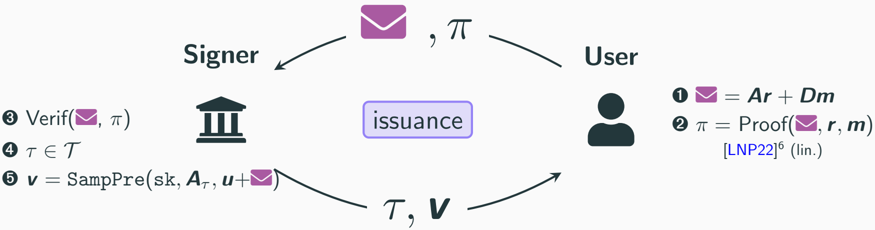

✉ , π

Signer

User

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❶ ✉ $= \boldsymbol{A}\boldsymbol{r} + \boldsymbol{D}\boldsymbol{m}$

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❺ $\boldsymbol{v} = \texttt{SampPre}(\texttt{sk}, \boldsymbol{A}_\tau, \boldsymbol{u} +$ ✉$)$

$\mathcal{T}$, $\boldsymbol{V}$

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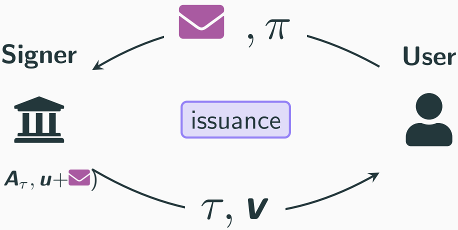

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[LNP22][6] (lin.)

❻ 🏅 $= (\tau, \boldsymbol{v} - [\boldsymbol{r}|\boldsymbol{0}]^T)$

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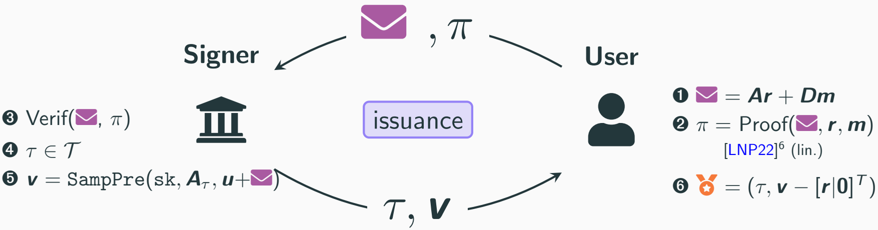

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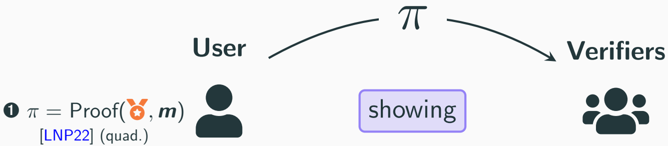

π

User

Verifiers

showing

❶ $\pi = \mathrm{Proof}($🏅$, \boldsymbol{m})$

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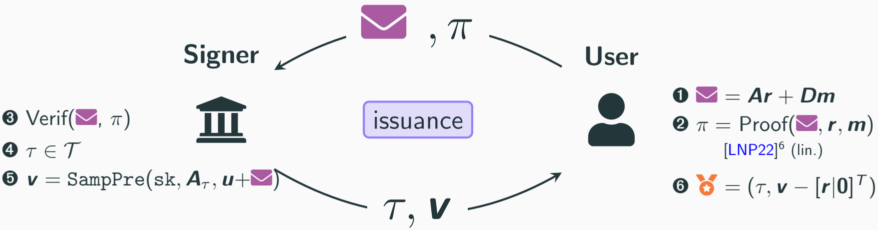

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✉ , π

$\mathcal{T}$, $\boldsymbol{V}$

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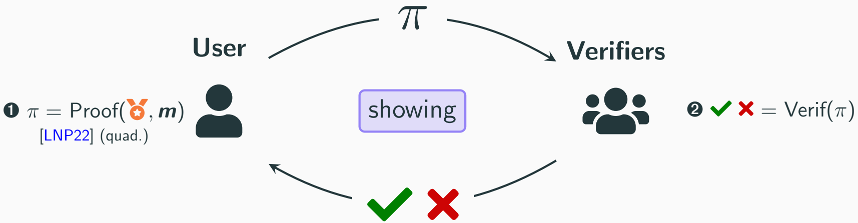
❻ 🏅 $= (\tau, \boldsymbol{v} - [\boldsymbol{r}|\boldsymbol{0}]^T)$



User

Verifiers

showing

π

✓ ✗

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❷ ✓ ✗ = Verif(π)

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Security of Anonymous Credentials

- **Anonymity**:
  - *Issuance.* No leakage of the secret key, nor concealed attributes
    - ✓ Hiding commitment, and Zero-Knowledge
  - *Showing.* No leakage of the credential, secret, concealed attributes
    - ✓ Zero-Knowledge

- **Unforgeability**: Prevent three types of forgeries.
  - *Impersonation.* Forgery using an honest user's secret key
    - ✓ Reduction to Module-SIS with matrix $\boldsymbol{D}_s$
  - *Malicious Prover.* Tricks verifiers in the zero-knowledge argument
    - ✓ Soundness of the proof system
  - *Signature Forgery.* Forges a valid credential on fresh attributes/key
    - ✓ EUF-CMA security of our signature

Conclusion

Wrapping Up

Our contribution (https://ia.cr/2022/509)

- ✓ A (more) practical **signature with efficient protocols**, under standard or structured **lattice assumptions**.
- ⇈ **Orders of magnitude more efficient** than [LLM+16].
- 📖 **Fix** of the approximate ZK proof system of [YAZ+19].
- 🛂 First **lattice-based anonymous credentials**.

Related Work

	Assumptions	Interactive Assumption	|cred|
[LLM+16]	SIS	No	670 MB (appr. proof)
Ours	MSIS/MLWE	No	730 KB
[BLNS23]	NTRU-ISIS$_f$	No	243 KB
	Int-NTRU-ISIS$_f$	Yes	62 KB

Thank you for your attention!

Questions?

References i

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