TU Graz

SCIENCE
PASSION
TECHNOLOGY

Lightweight UOV Accelerator with Oil Space Blinding

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RIGOLETTO
HIGH PERFORMANCE
RISC-V SOLUTIONS

Outline

1 Motivation and Background

2 Lightweight UOV Acceleration

3 Side-Channel Security of UOV

NIST's Additional Signatures: Round 2 → 3

Multivariate

UOV
MAYO
QR-UOV
SNOVA

Isogeny

SQIsign

MPC-in-the-Head

MQOM
SDitH
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Symmetric

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Rigoletto Goal: Lightweight PQC Co-processor

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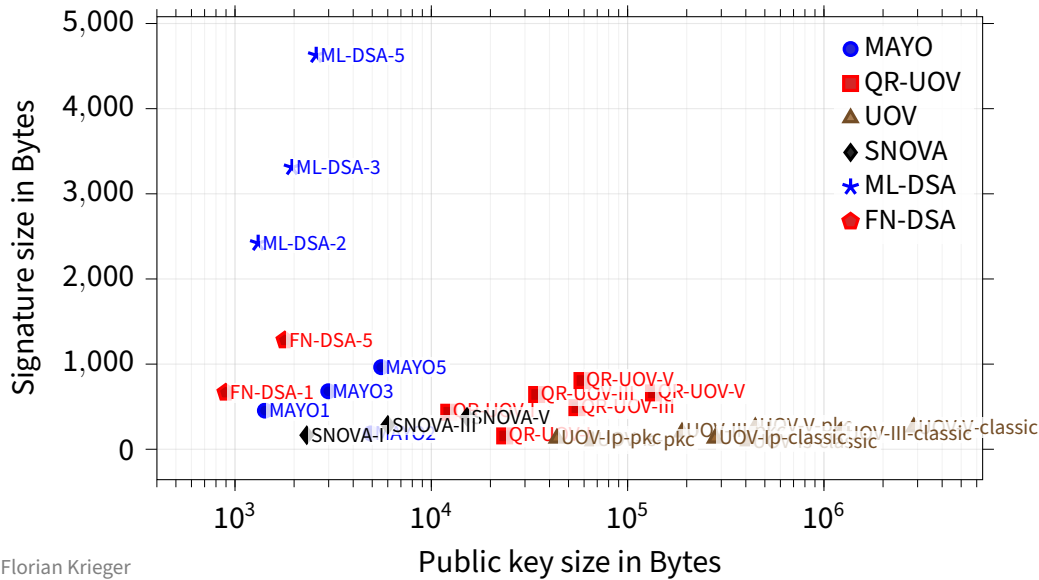

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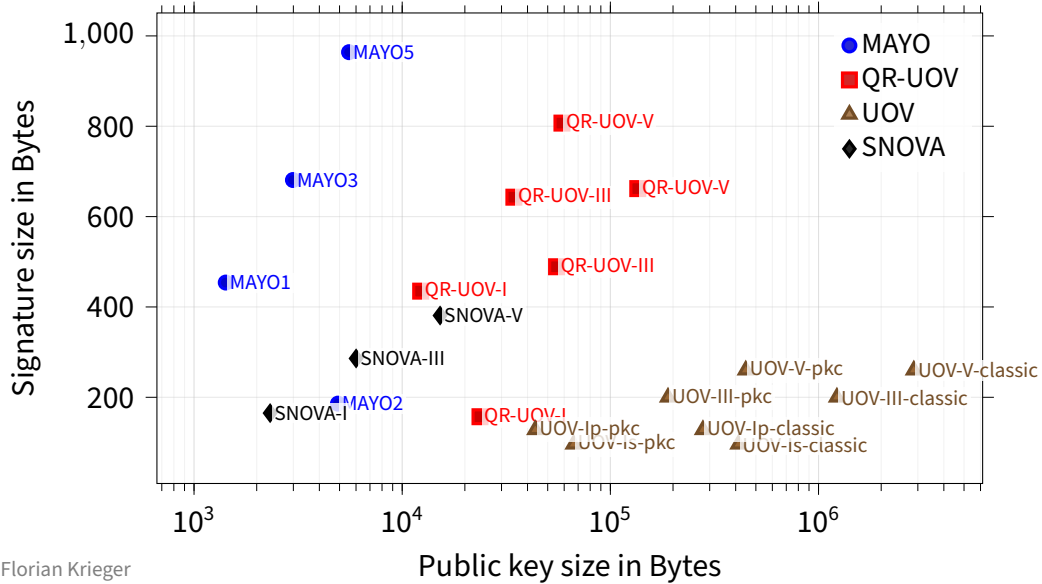
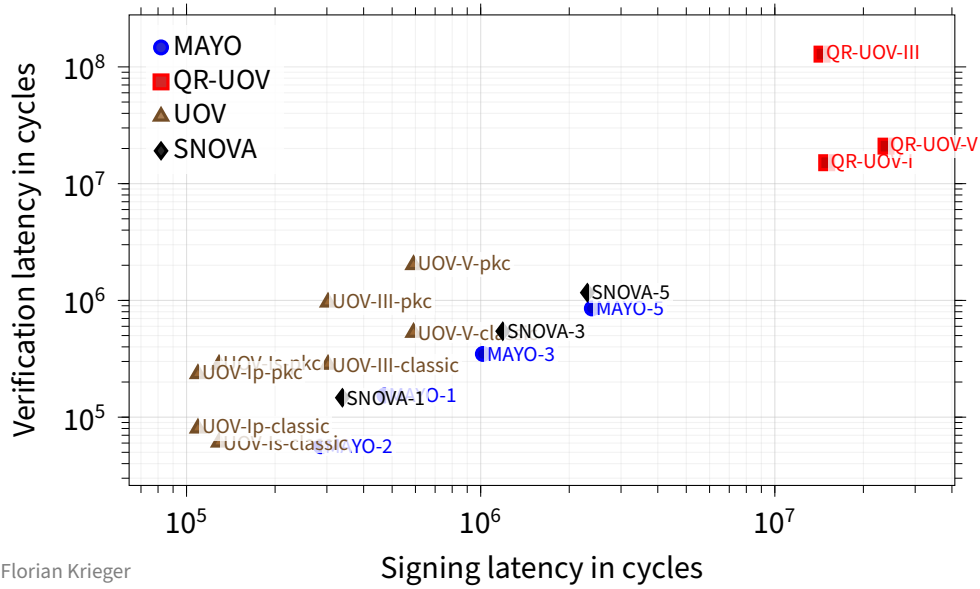


Performance in SW [WP26]



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   → Linear equation system

UOV Signing and Verification (with some details omitted)

- Key expansion

UOV.Sign(csk, μ)

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The Research Problem: Lightweight UOV Acceleration

- No lightweight UOV hardware accelerator
- UOV needs large memories
  - Up to 1.6 MB in existing HW
  - Problematic for low-end deployment
- Lightweight SCA countermeasures

Lightweight UOV Acceleration

Reducing the memory consumption

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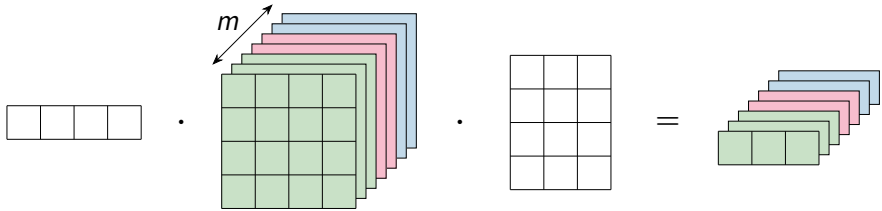

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single row vector

$\{\mathbf{P}_i\}_{i \in [m]}$
set of m matrices

$\bar{\mathbf{O}}$ or $\mathbf{v}$
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m results
m vectors
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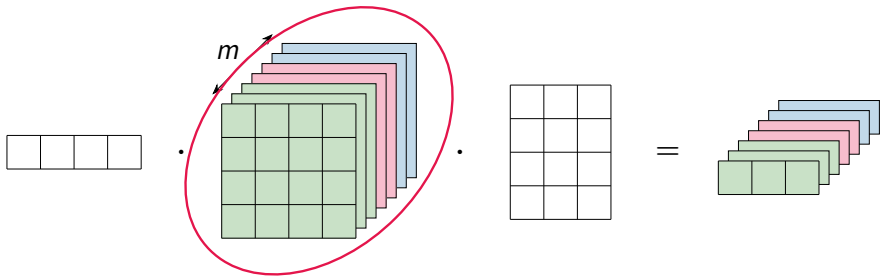

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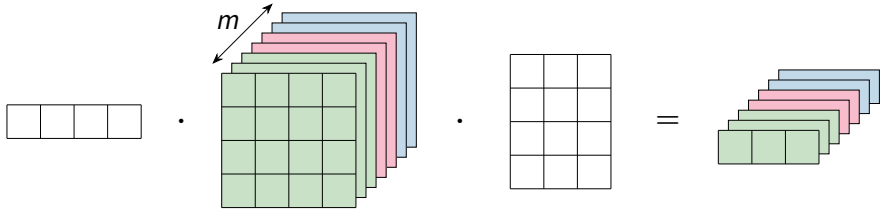
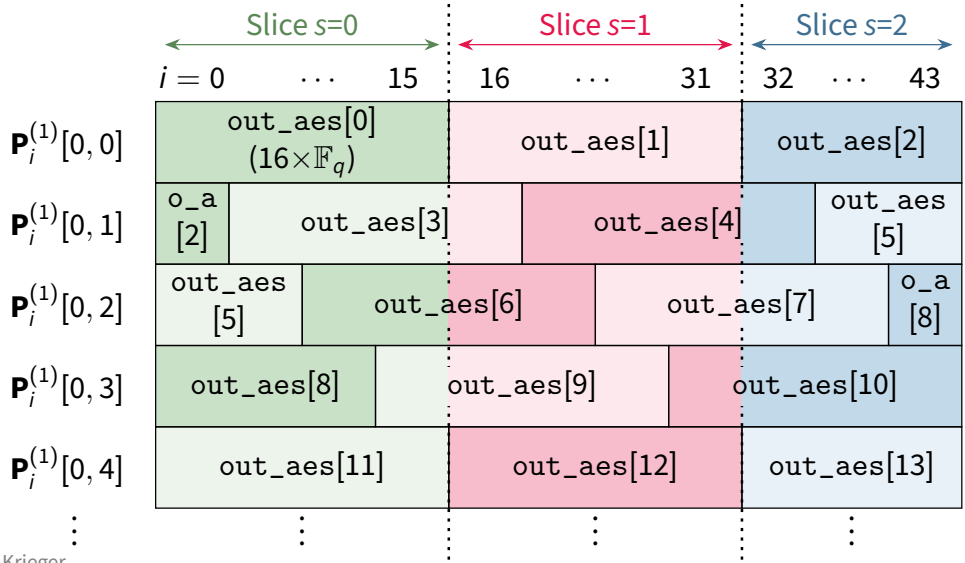


- $\mathbf{P}_i$ sampled from AES-128-CTR
- Unfavorable data layout

On-the-Fly Generation: Data Rearrangement



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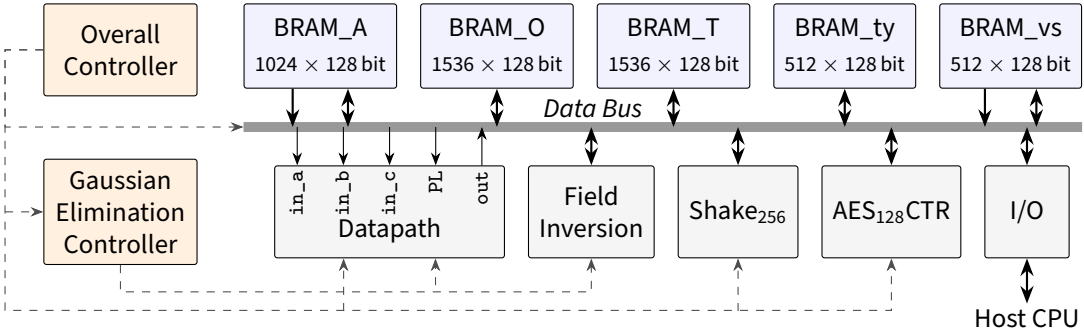

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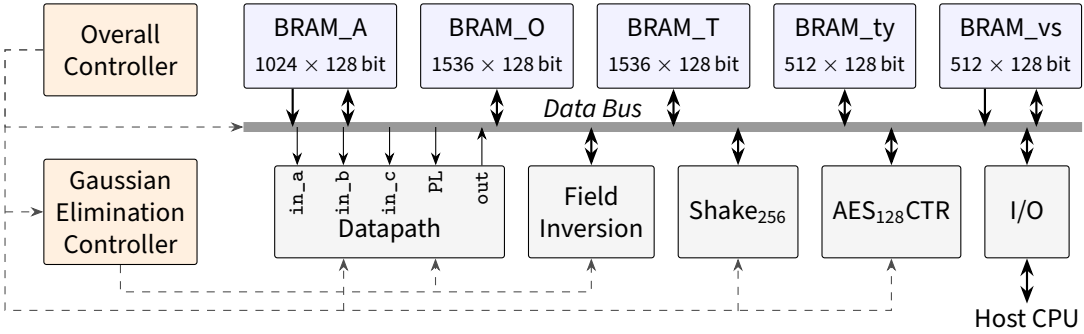

up to 16×
less on-chip memory

up to 5.1×
faster signing

up to 74×
better ATP

Best case vs. prior UOV hardware [Beu+23].

Side-Channel Security of UOV

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6: $\quad \mathbf{A} \leftarrow \mathbf{0}_{m \times m}, \quad \mathbf{y} \leftarrow \mathbf{0}_m$
7: $\quad$ **for** $i = 0$ **upto** $m - 1$ **do**
8: $\quad\quad \mathbf{A}[i,:] \leftarrow \mathbf{v}^\top \left(\mathbf{P}_i^{(1)} + \mathbf{P}_i^{(1)^\top} \;\middle|\; \mathbf{P}_i^{(2)} \right) \bar{\mathbf{O}}$
9: $\quad\quad \mathbf{y}[i] \leftarrow \mathbf{v}^\top \mathbf{P}_i^{(1)} \mathbf{v}$
10: $\quad$ Solve $\mathbf{Ax} = \mathbf{t} - \mathbf{y}$ for $\mathbf{x}$ if possible, else repeat
11: $\quad \mathbf{s} \leftarrow \begin{pmatrix} \mathbf{v} \\ \mathbf{0}_m \end{pmatrix} + \bar{\mathbf{O}}\mathbf{x}$; $\quad$ **return** $\sigma = (\mathbf{s}, \text{salt})$

All attacks recover a vector of the oil space $\mathbf{o} \in O$

Countermeasures for UOV

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- ? More lightweight SCA countermeasures

UOV's Equivalent Keys: Blinding

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UOV's Equivalent Keys: Blinding

- $\bar{\mathbf{O}}$ is a secret basis of O
- There are many bases spanning **the same** O
- Randomize basis $\bar{\mathbf{O}}_b$ for each signing

$$\bar{\mathbf{O}}_b = \bar{\mathbf{O}} \cdot \mathbf{R} \text{ with random invertible } \mathbf{R}$$

Blinded UOV

UOV.BlindedSign$(\text{seed}_{\text{pk}}, \text{seed}_{\text{sk}}, \bar{\mathbf{O}}_b, \mu)$

1: Load $\bar{\mathbf{O}}_b$ from persistent storage
2: $\{\mathbf{P}_i^{(1)}\}, \{\mathbf{P}_i^{(2)}\} \leftarrow \text{AES}_{128}\text{CTR}(\text{seed}_{\text{pk}})$
3: $\text{salt} \xleftarrow{\$} \{0,1\}^{\text{salt\_len}}$, $\mathbf{t} \leftarrow \text{Shake}_{256}(\mu \,\|\, \text{salt})$
4: **for** ctr $= 0$ **upto** 255 **do**
5: $\quad \mathbf{v} \leftarrow \text{Shake}_{256}(\mu \| \text{salt} \| \text{seed}_{\text{sk}} \| \text{ctr})$
6: $\quad \mathbf{R} \xleftarrow{\$} \text{GL}_m(\mathbb{F}_q)$; $\quad \bar{\mathbf{O}}_b \leftarrow \bar{\mathbf{O}}_b \cdot \mathbf{R}$ $\quad \triangleright$ re-randomize the basis
7: $\quad \mathbf{A} \leftarrow \mathbf{0}_{m \times m}$, $\quad \mathbf{y} \leftarrow \mathbf{0}_m$
8: $\quad$ **for** $i = 0$ **upto** $m - 1$ **do**
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12: $\quad \mathbf{s} \leftarrow \begin{pmatrix} \mathbf{v} \\ \mathbf{0}_m \end{pmatrix} + \bar{\mathbf{O}}_b \mathbf{x}$; $\quad$ store $\bar{\mathbf{O}}_b$; $\quad$ **return** $\sigma = (\mathbf{s}, \text{salt})$

Blinded UOV

- Makes DPA attacks more difficult
  → Long-term secret $\bar{\mathbf{O}}$ is turned into ephemeral secret $\bar{\mathbf{O}}_b$

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  → Long-term secret $\bar{\mathbf{O}}$ is turned into ephemeral secret $\bar{\mathbf{O}}_b$
- Most signing steps remain the same
- The effect of blinding cancels in **s**
  → **s** is identical to unblinded case

Sampling Random Invertible Matrices

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Can we do better?

?

The LU Approach

$$\mathbf{R} = \mathbf{L} \cdot \mathbf{U} = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ l_{1,0} & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ l_{m-1,0} & l_{m-1,1} & \cdots & 1 \end{bmatrix} \cdot \begin{bmatrix} u_{0,0} & u_{0,1} & \cdots & u_{0,m-1} \\ 0 & u_{1,1} & \cdots & u_{1,m-1} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & u_{m-1,m-1} \end{bmatrix}$$

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! Not uniformly random over $\mathrm{GL}_m(\mathbb{F}_q)$

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- Slight bias in the diagonal elements of **R**
  - $r_{i,i}$ tend to be non-zero

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- More than $2^{15,000}$ **R** matrices possible

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- ⊕ Reuses the Gaussian elimination datapath
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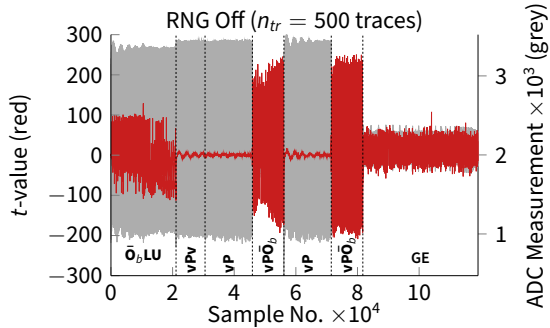
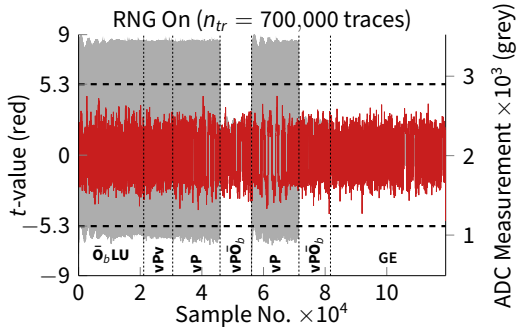
LU approach (ours)

- ⊕ Constant time
- ⊕ Only reuses existing datapath
- ⊕ $< 30\%$ signing latency overhead
- ⊘ Not uniform over $\mathrm{GL}_m(\mathbb{F}_q)$

TVLA


RNG Off (n_{tr} = 500 traces)
t-value (red)
ADC Measurement $\times 10^3$ (grey)
Sample No. $\times 10^4$
$\bar{O}_b$LU
vPv
vP
vP$\bar{O}_b$
vP
vP$\bar{O}_b$
GE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Comparison

	vs. UOV HW [Beu+23]	
Security level	**Signing**	
1	4.7× faster	
3	4.7× faster	
5	5.1× faster	

Comparison

	vs. UOV HW [Beu+23]	
Security level	**Signing**	**Signing** (blinded)
1	4.7× faster	3.9× faster
3	4.7× faster	3.8× faster
5	5.1× faster	4.0× faster

Comparison

	vs. UOV HW [Beu+23]		
Security level	**Signing**	**Signing** (blinded)	**BRAMs**
1	4.7× faster	3.9× faster	2.2× fewer
3	4.7× faster	3.8× faster	8.4× fewer
5	5.1× faster	4.0× faster	16× fewer

Comparison

	vs. UOV HW [Beu+23]			vs. MAYO HW [Hir+24]
Security level	**Signing**	**Signing** (blinded)	**BRAMs**	**ATP**
1	4.7× faster	3.9× faster	2.2× fewer	1.25× worse
3	4.7× faster	3.8× faster	8.4× fewer	1.05× worse
5	5.1× faster	4.0× faster	16× fewer	1.6× better

Conclusion

- Low-memory UOV accelerator
- Lightweight blinding countermeasure
- Concepts also extend to other MQ schemes

ia.cr/2026/1451

Support the NIST selection process with implementation-specific insights.

TU Graz

SCIENCE
PASSION
TECHNOLOGY

Lightweight UOV Accelerator with Oil Space Blinding

Florian Krieger

Institute of Information Security, Graz University of Technology

RIGOLETTO
HIGH PERFORMANCE
RISC-V SOLUTIONS

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