# A Short Survey of Lattice-Isomorphism-Based Cryptography

**Wessel van Woerden** (PQShield).

# Motivation

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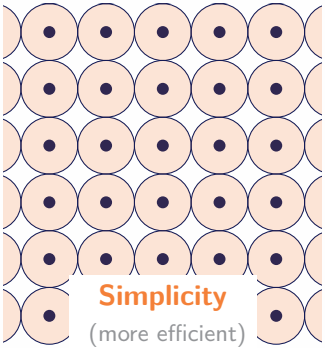
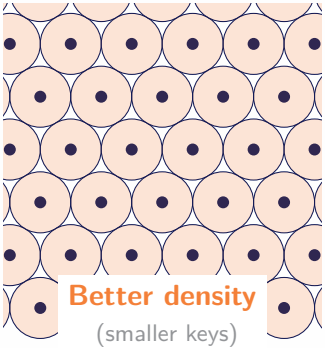


**Simplicity**
(more efficient)



**Better density**
(smaller keys)

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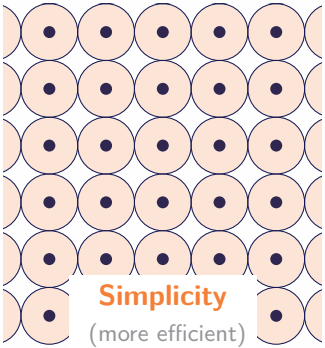


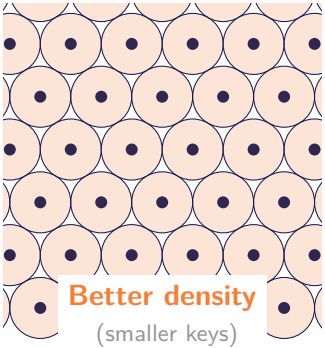


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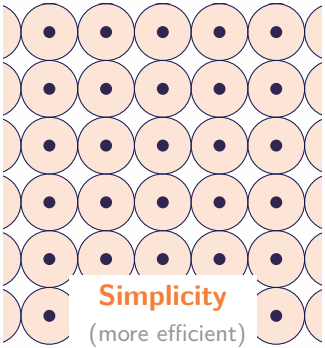


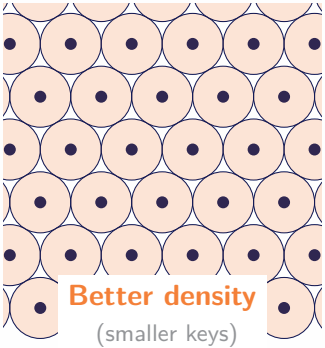


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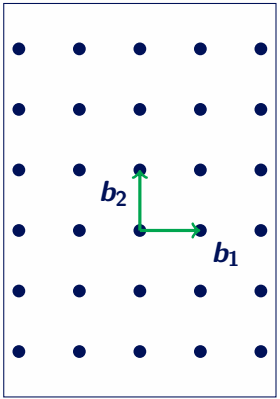
**Lattice Isomorphism Problem: yes, we can!**

# Lattices and decoding

Lattice $\mathcal{L}(B) := \{\sum_i x_i b_i : x \in \mathbb{Z}^n\} \subset \mathbb{R}^n$

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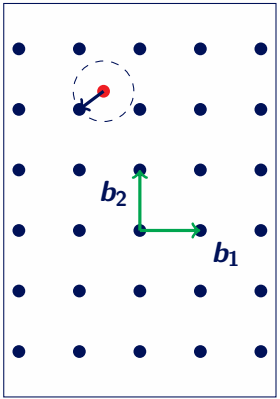


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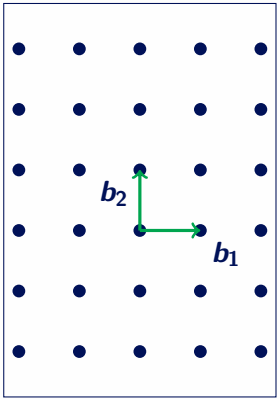


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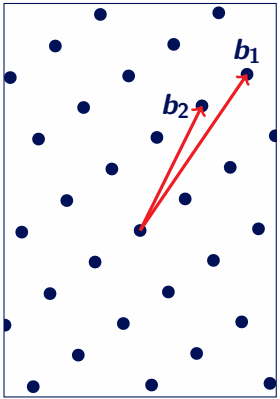


random lattice

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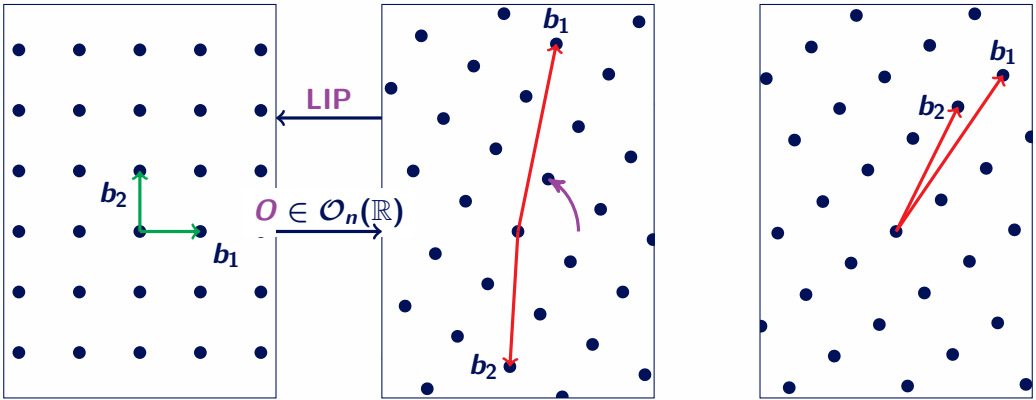


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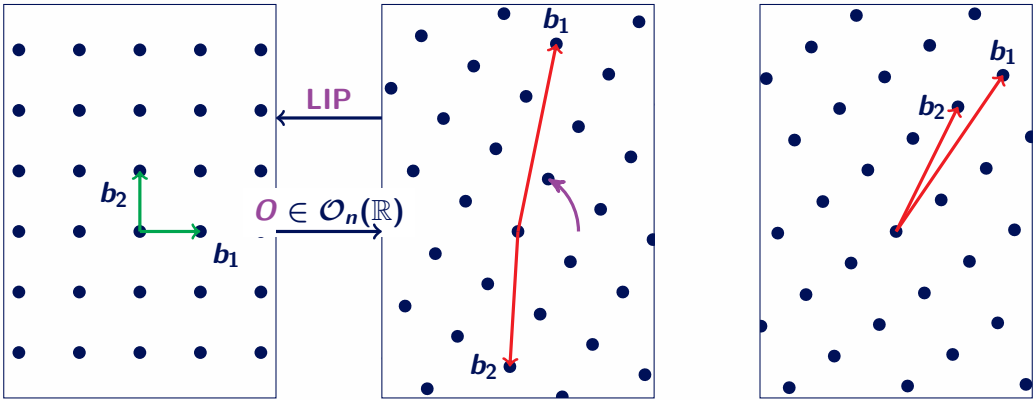


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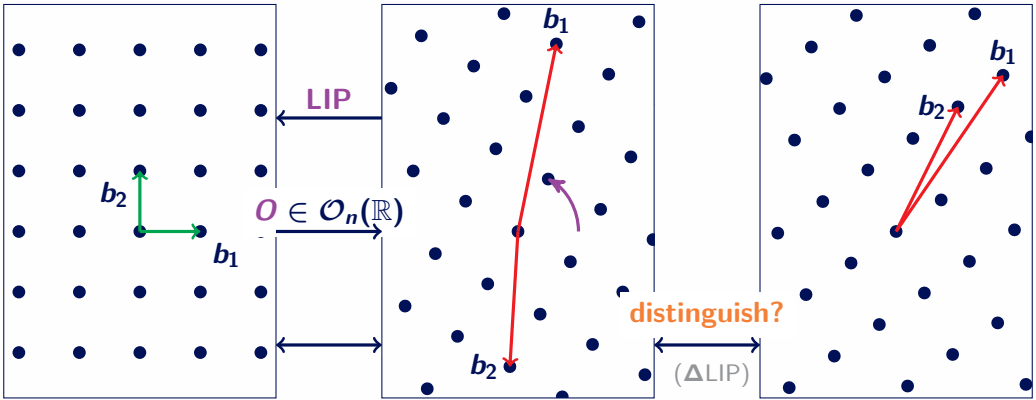


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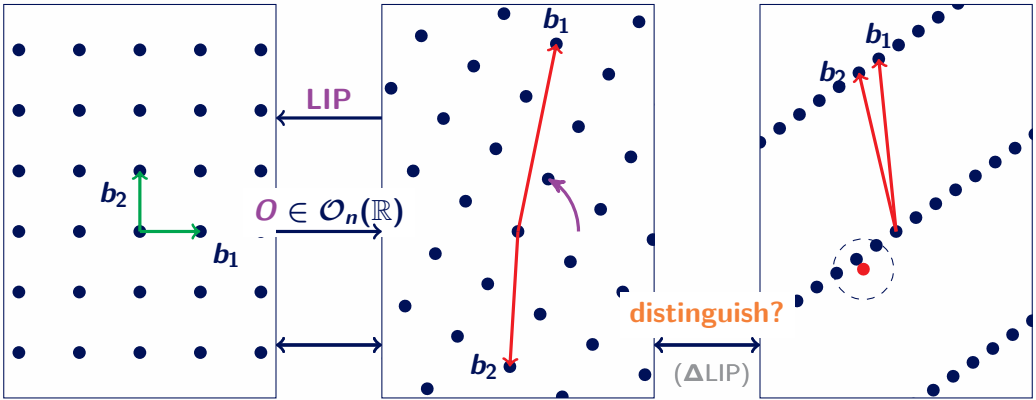


integer lattice $\mathbb{Z}^n$

decoding easy

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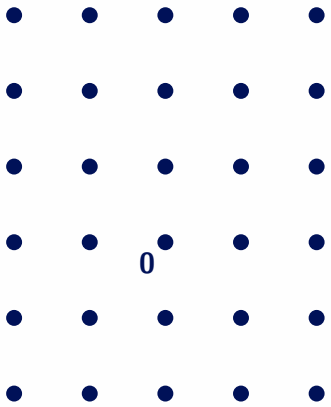
decoding hard?

dense sublattice

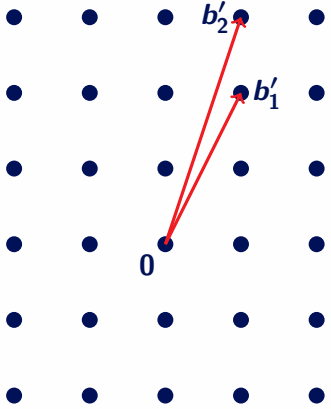
decoding hard

# Encryption scheme based on LIP

Decodable lattice




Bad basis of $\mathcal{L}$



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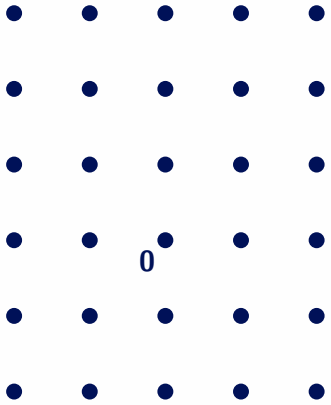
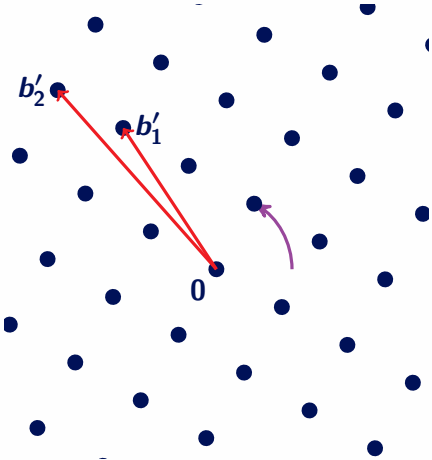



$O \in \mathcal{O}_n(\mathbb{R})$

(Secret key)

Bad basis of rotation



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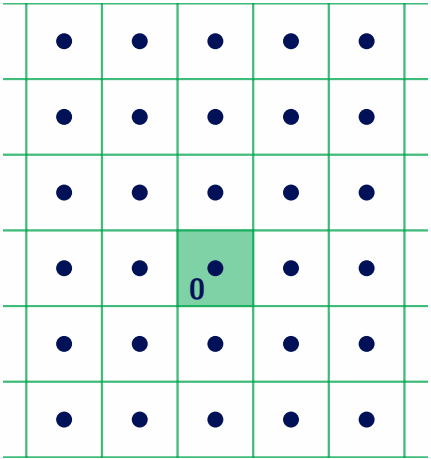


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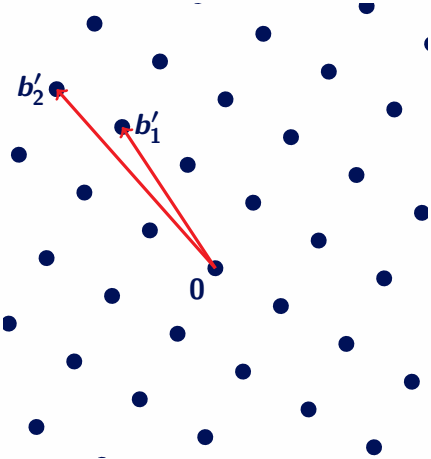


Hides (decoding) structure of $\mathcal{L}$

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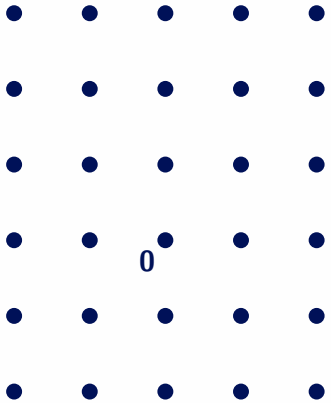


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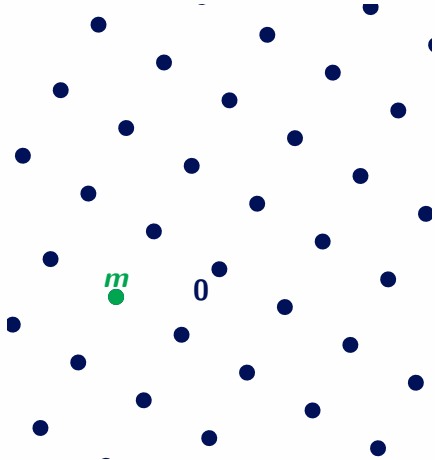

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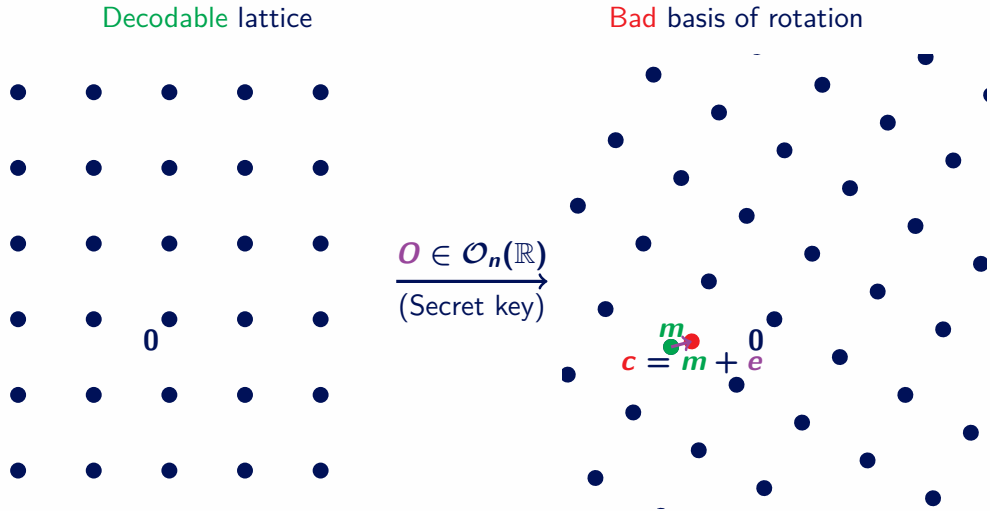


Encrypt by adding a small error

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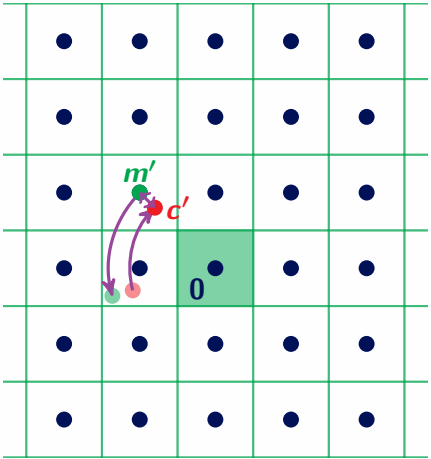


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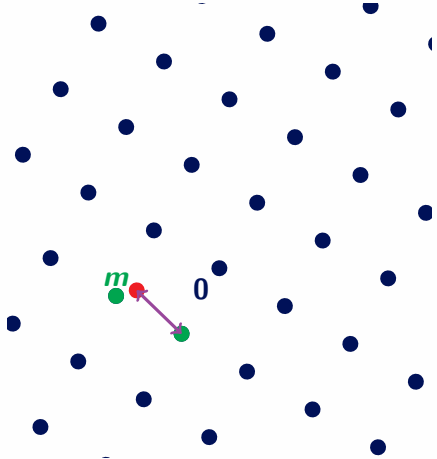


Decrypt using decoding algorithm

# Lattice Isomorphism Problem

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Given $\boldsymbol{B}, \boldsymbol{B}' \in \mathrm{GL}_n(\mathbb{R})$ of isomorphic lattices, find $\boldsymbol{O} \in \mathcal{O}_n(\mathbb{R})$ and $\boldsymbol{U} \in \mathrm{GL}_n(\mathbb{Z})$ s.t. $\boldsymbol{B}' = \boldsymbol{O} \cdot \boldsymbol{B} \cdot \boldsymbol{U}$.

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- Equivalence class $[\boldsymbol{Q}] := \{\boldsymbol{U}^\top \boldsymbol{Q} \boldsymbol{U} : \boldsymbol{U} \in \mathrm{GL}_n(\mathbb{Z})\}$.

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LIP and ΔLIP problems **depend on fixed lattice(s)**.

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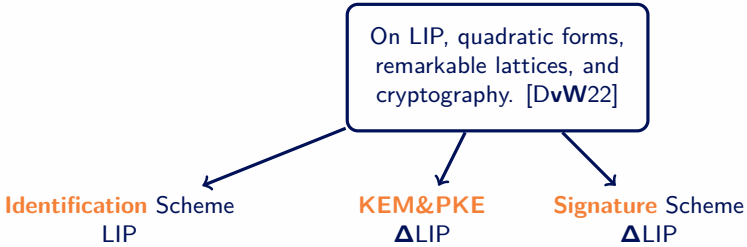

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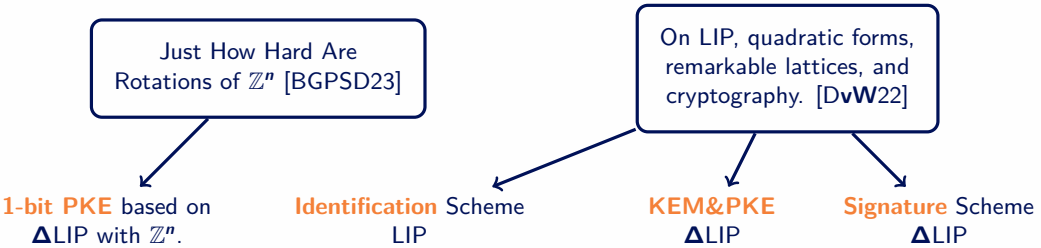

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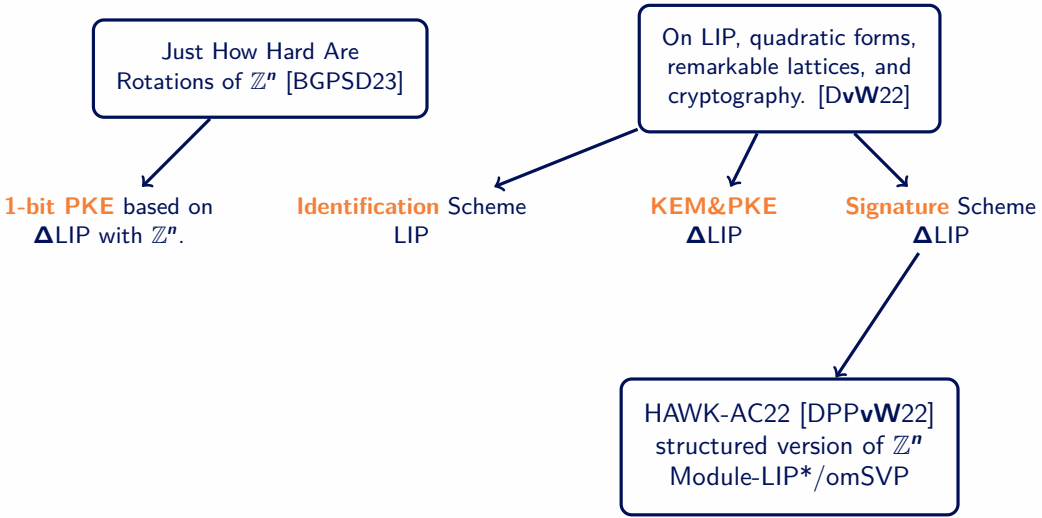

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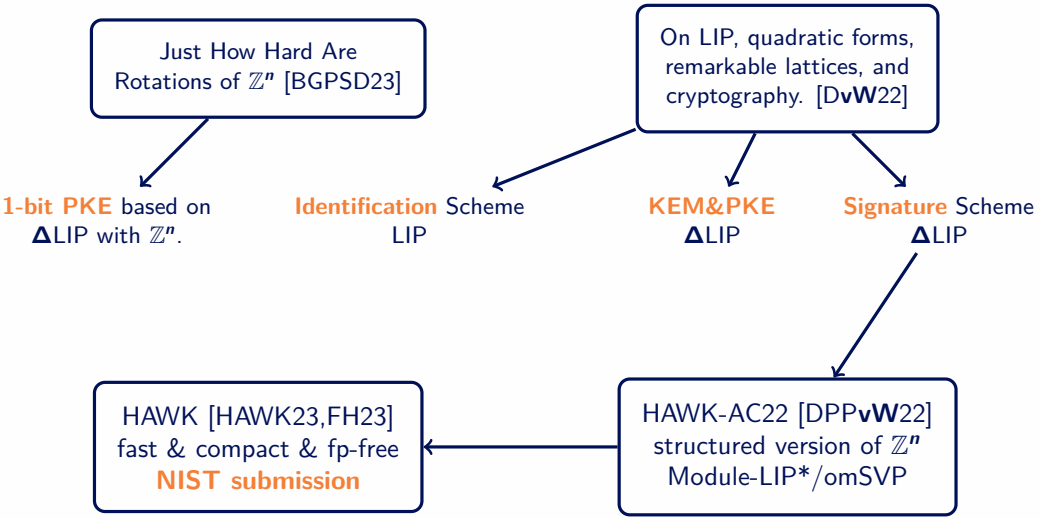


# Constructions

**KEM&PKEs**
$\mathbb{Z}^n$ or $\mathrm{BW}_n$ + **Δ**LIP
[ARLW24,CBZIPC24]

**IBE**
**Δ**LIP
[BLSD26]

Various **Commitment Schemes**
LIP (group action)
[JWLLGPW25,LJPW25]

**∞-uPKE**
**Δ**PCE [ABL25]
or **Δ**LIP (WIP)

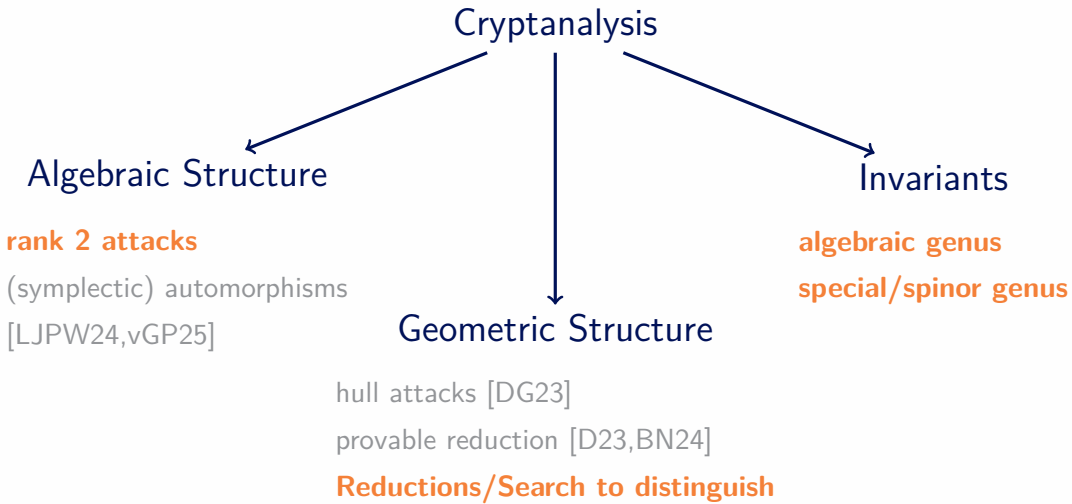
**Ring Signatures**
LIP + HAWK
[LGD26]

**Blind Signatures**
LIP (OR proofs)
[NP26]

**(F)HE**
**Δ**LIP [BMM25,
LR**vW**25,BLSD26]

Allows for **Advanced Cryptographic Constructions**

# Cryptanalysis



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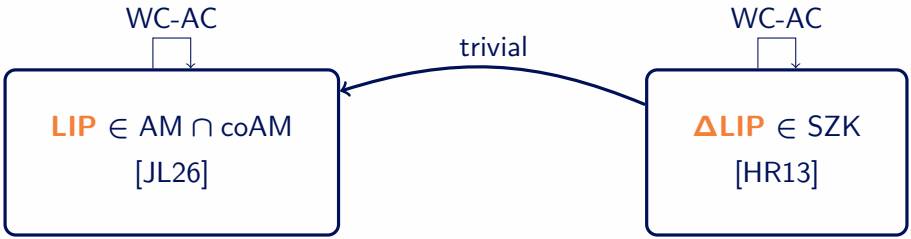

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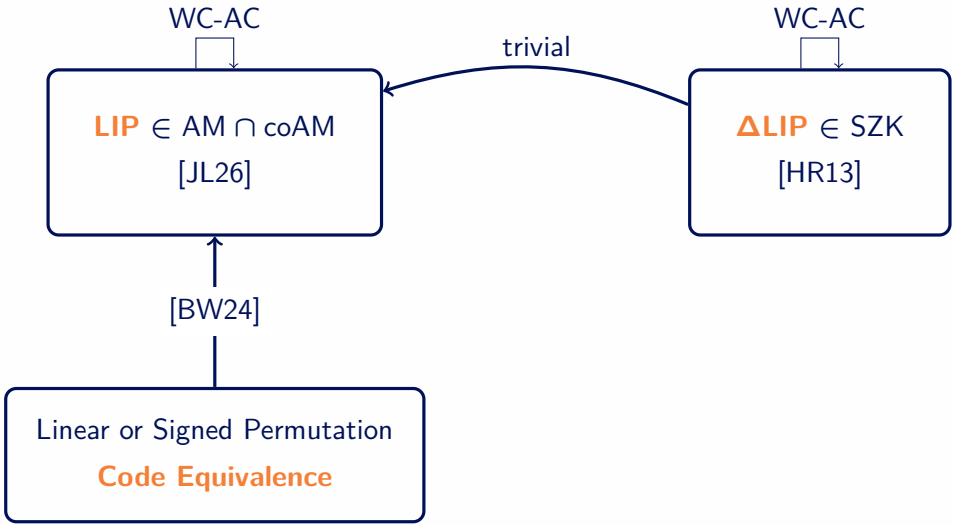
WC-AC
trivial
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LIP ∈ AM ∩ coAM
[JL26]
ΔLIP ∈ SZK
[HR13]
[BW24]
Linear or Signed Permutation
Code Equivalence

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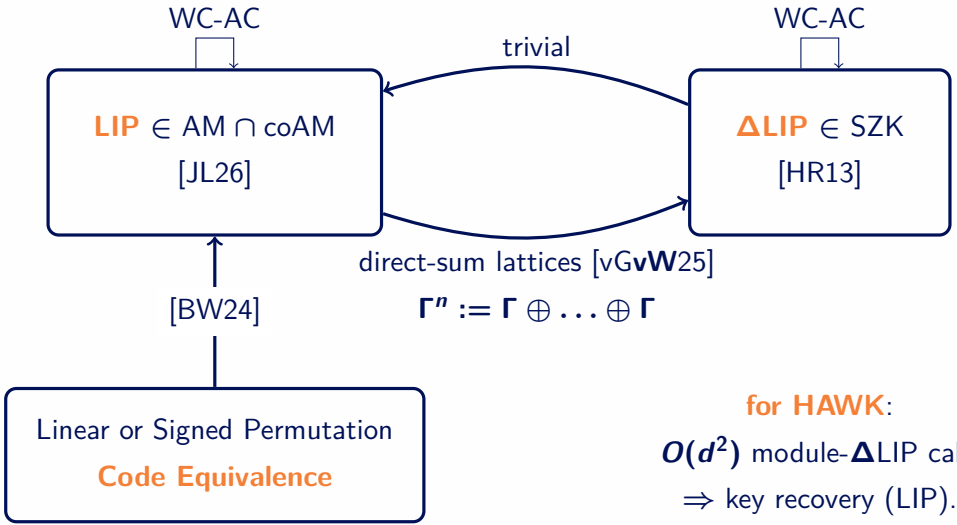


**for HAWK**:

$O(d^2)$ module-$\Delta$LIP calls

$\Rightarrow$ key recovery (LIP).

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How much **structure** is allowed?

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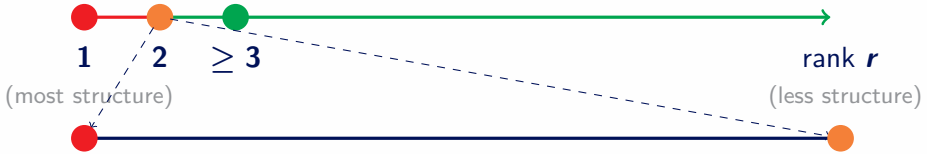

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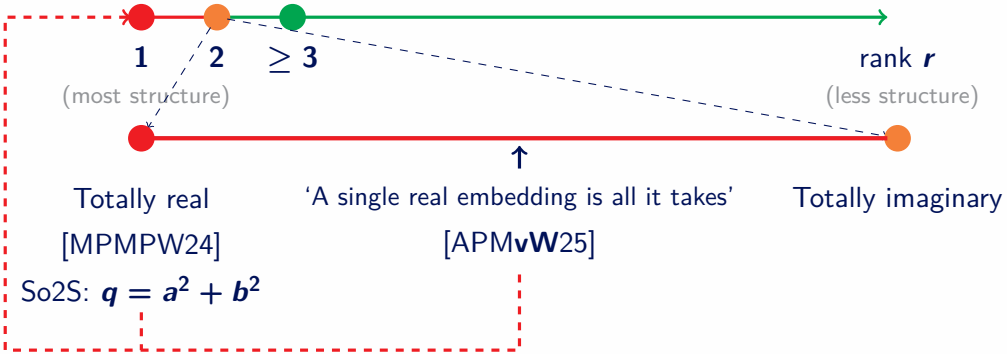

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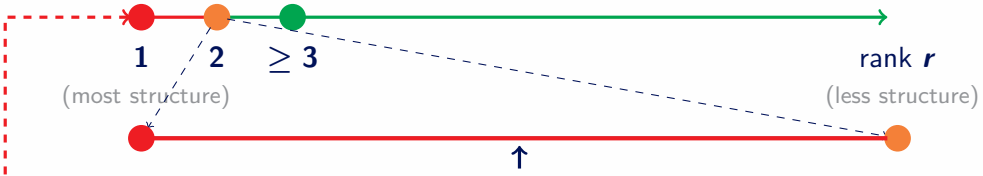



Totally real

[MPMPW24]

So2S: $q = a^2 + b^2$

'A single real embedding is all it takes'

[APM**vW**25]

Totally imaginary

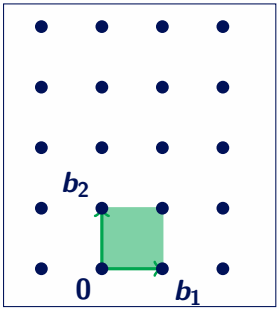
HAWK (CM field)

[CMEPMPW25,CM25]:

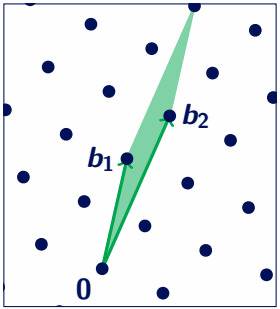
So4S: $q = a^2 + b^2 + c^2 + d^2$

**attack does not apply**

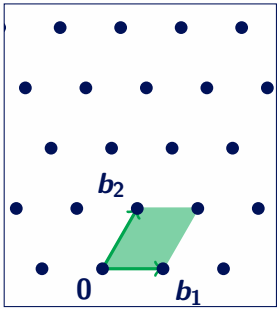
# Invariants




$\det(\mathcal{L}_1)$ $\overset{?}{=}$

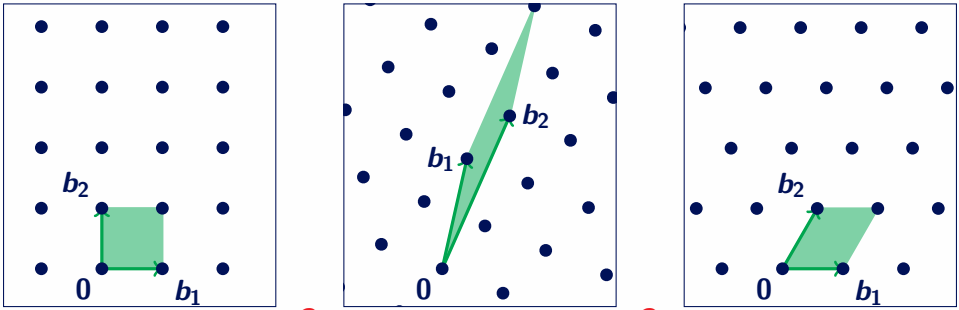



$\det(O \cdot \mathcal{L}_b)$ $\overset{?}{=}$




$\det(\mathcal{L}_2)$

# Invariants

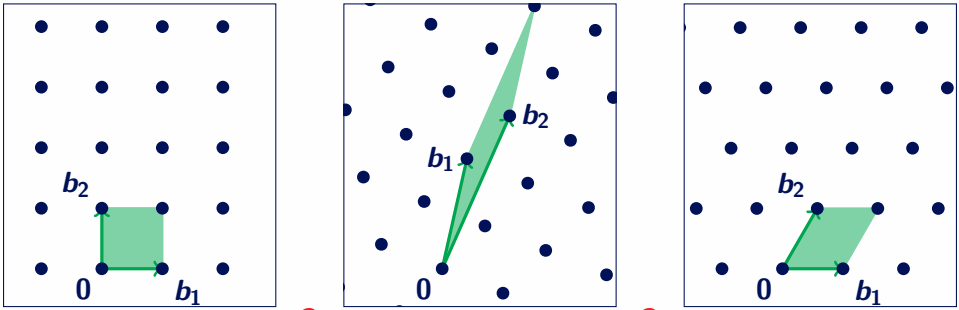



$\det(\mathcal{L}_1) \stackrel{?}{=} \det(O \cdot \mathcal{L}_b) \stackrel{?}{=} \det(\mathcal{L}_2)$

Lemma:

If $\det(\mathcal{L}_1) \neq \det(\mathcal{L}_2)$, then $\Delta$LIP can be solved efficiently.

# Invariants




Lemma:

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Conjecture [DvW22]: **Genus is the strongest** efficiently computable invariant.

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- (WIP) **WC-AC reduction** within a fixed genus for BDD, CVP, DGS, ...

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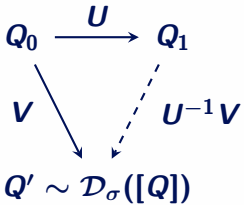


$$(Q', V) \leftarrow \mathrm{Sample}_\sigma(Q_0)$$
$$\text{for } \sigma^2 \geq \tilde{\Omega}(\max\{\|\tilde{Q}_0\|, \|\tilde{Q}_1\|\})$$

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Led to several **broken** constructions in group-action-based frameworks.

- See [NP26] for a more careful treaty of LIP as a group action.

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Thank you!

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