Decentralized Multi-Authority ABE for DNFs from LWE

By Pratish Datta,

Joint work with Ilan Komargodski, Brent Waters

NTT Research, Hebrew University, UT Austin

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Attribute-Based Encryption

[SW05,GPSW06,…]

- A secret key allows one to decrypt all ciphertext that satisfy

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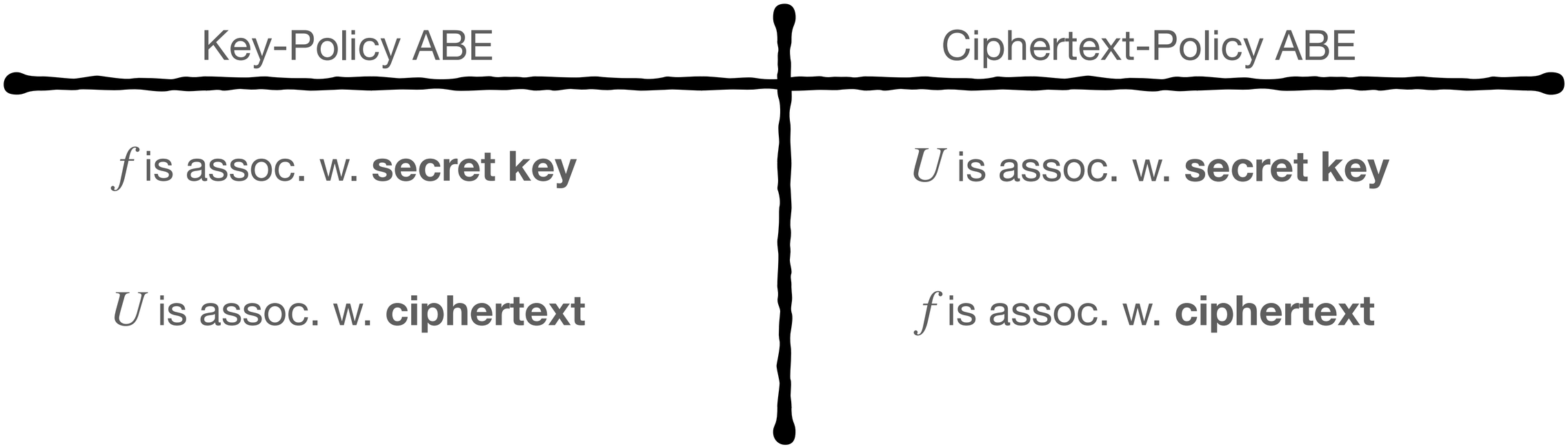

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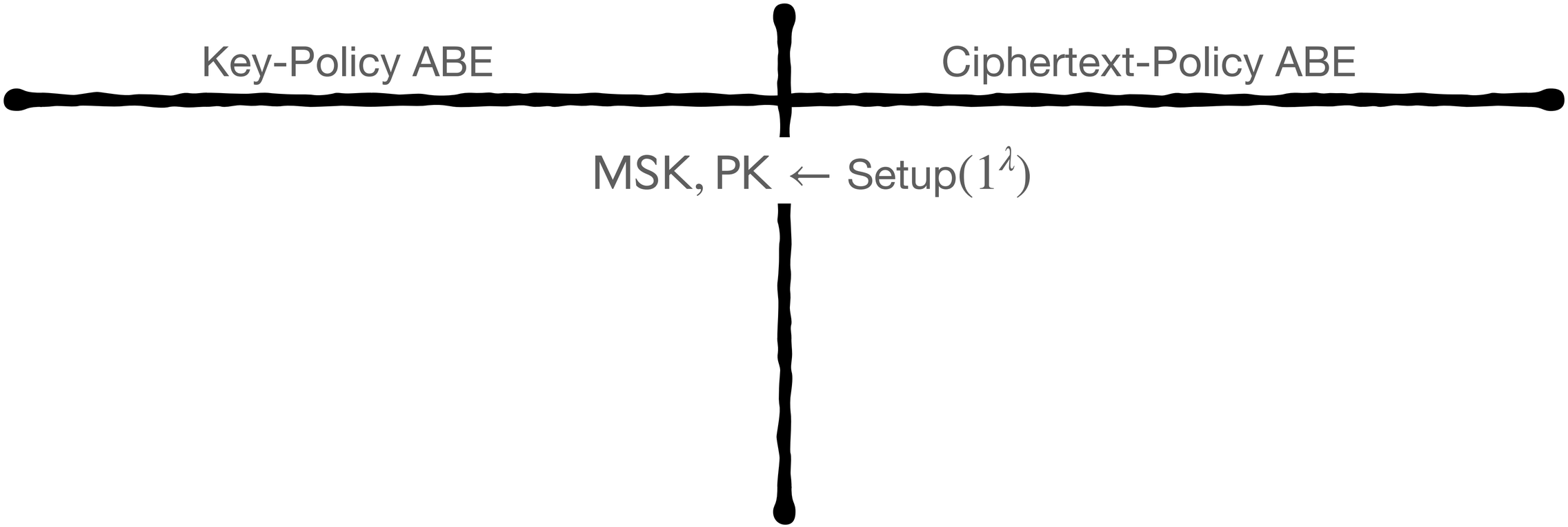

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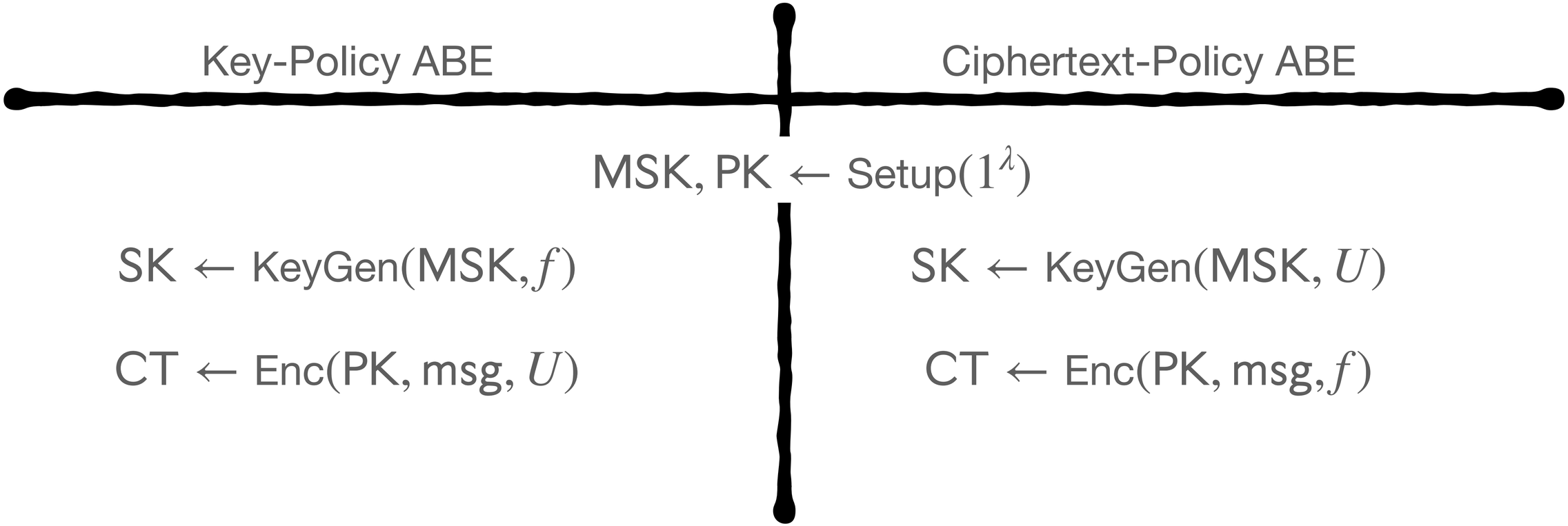

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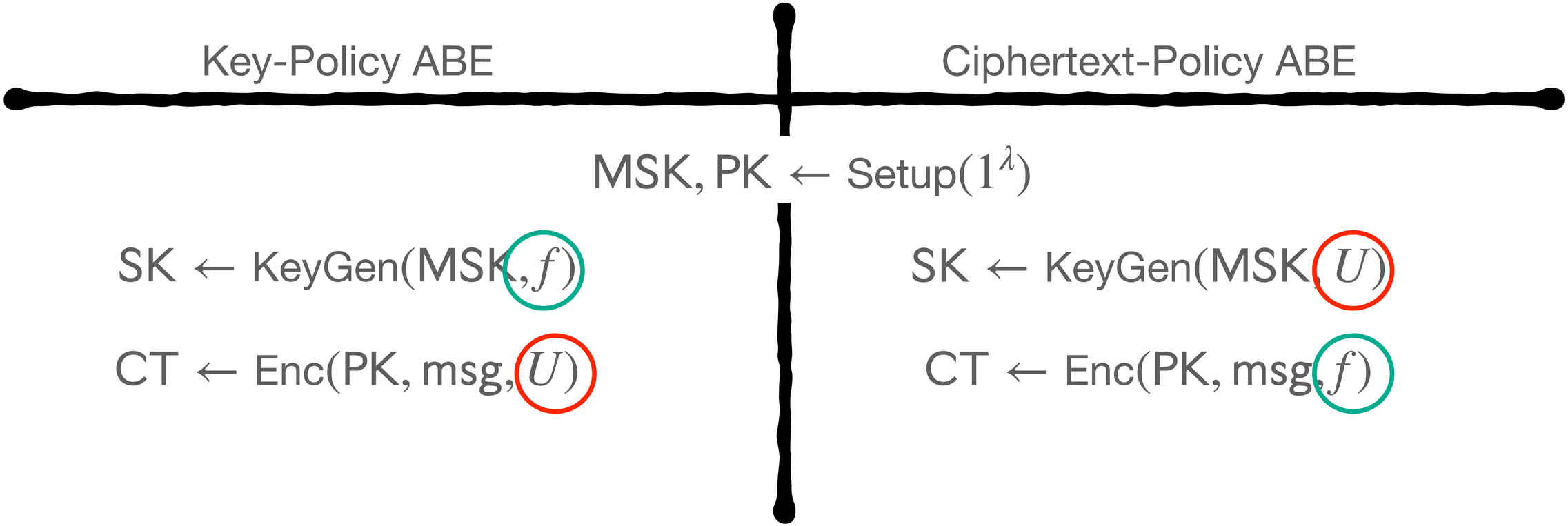

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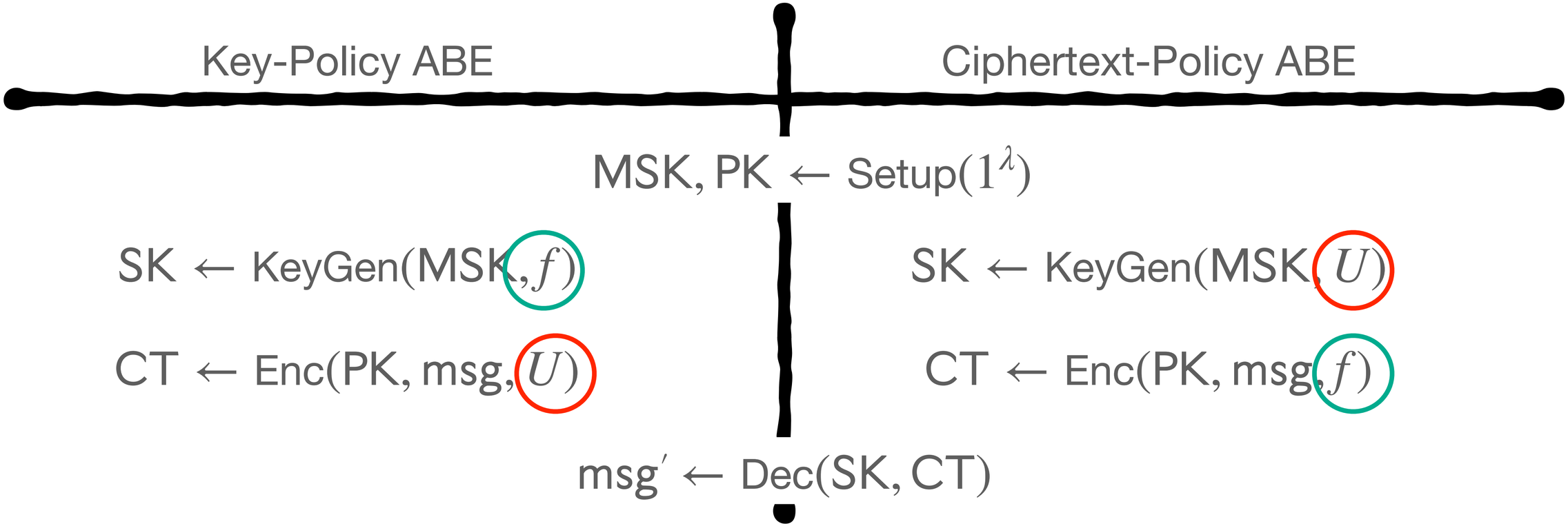

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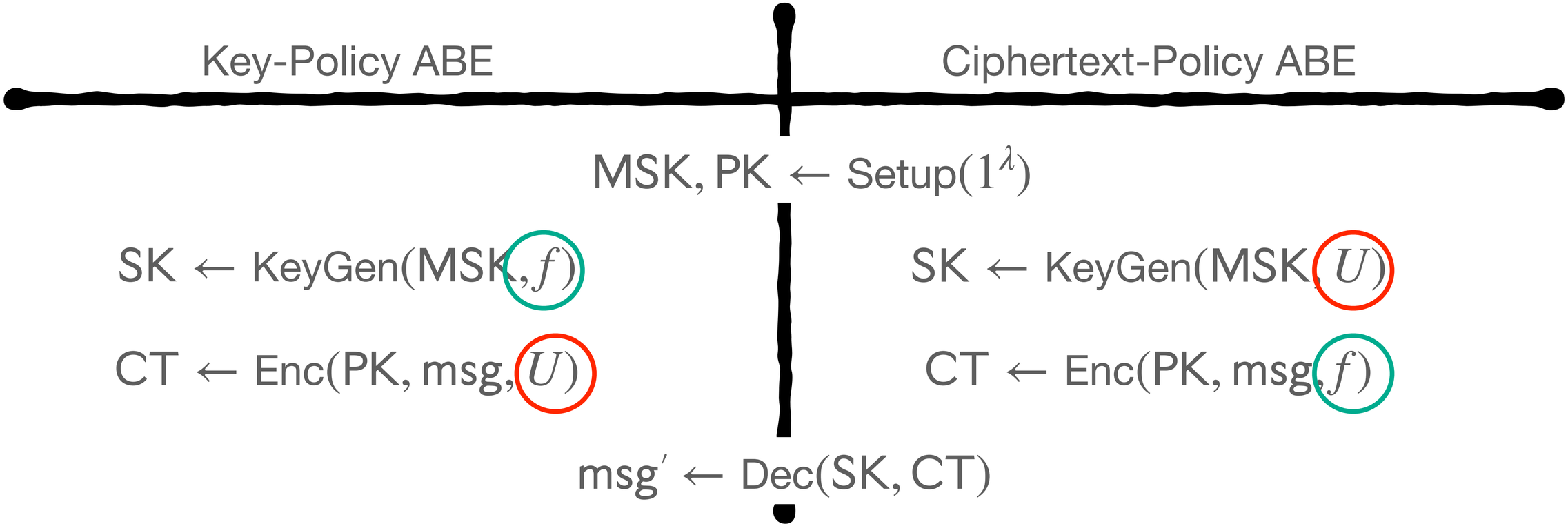

Correctness: If $f(U) =$ true then $\text{msg}' = \text{msg}$

Security: If $f(U) =$ false then msg is “hidden”

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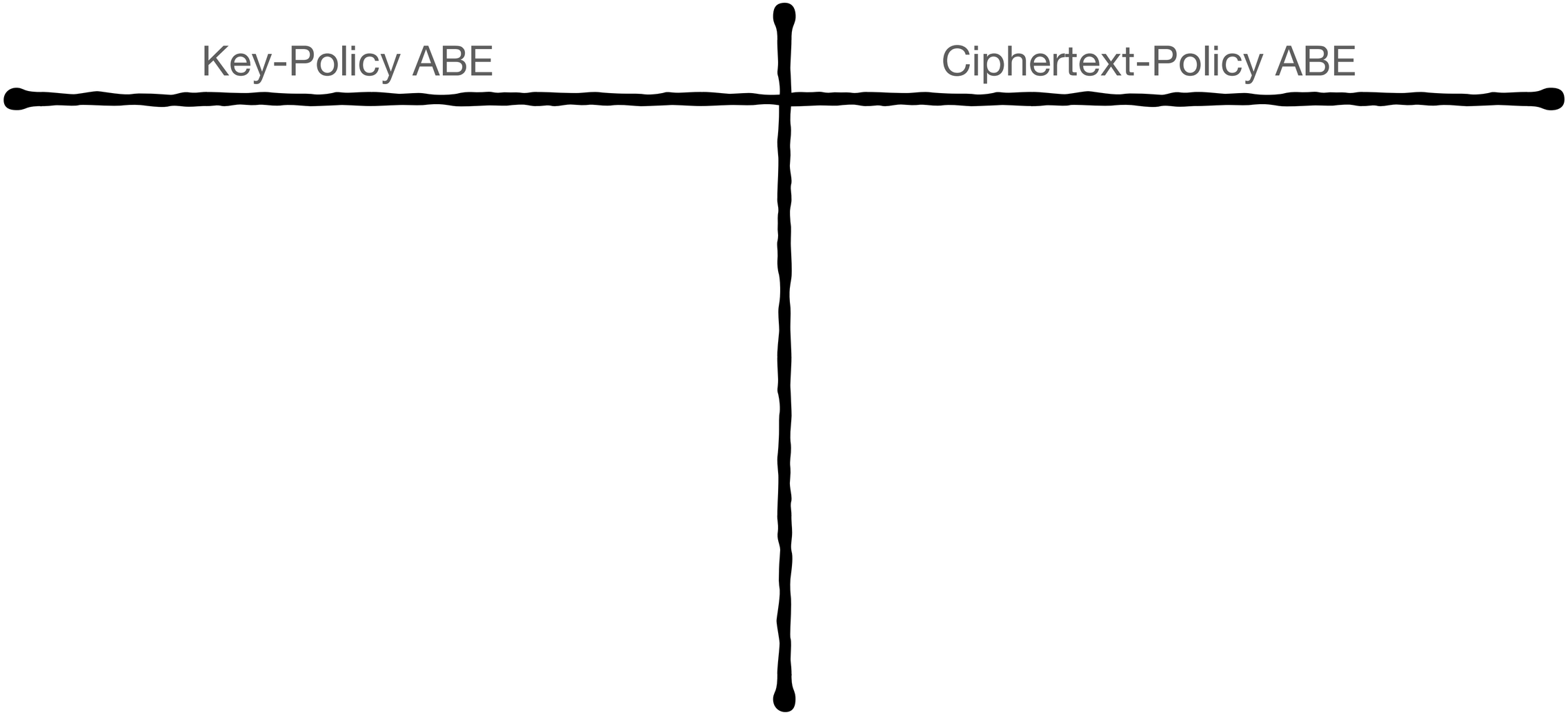

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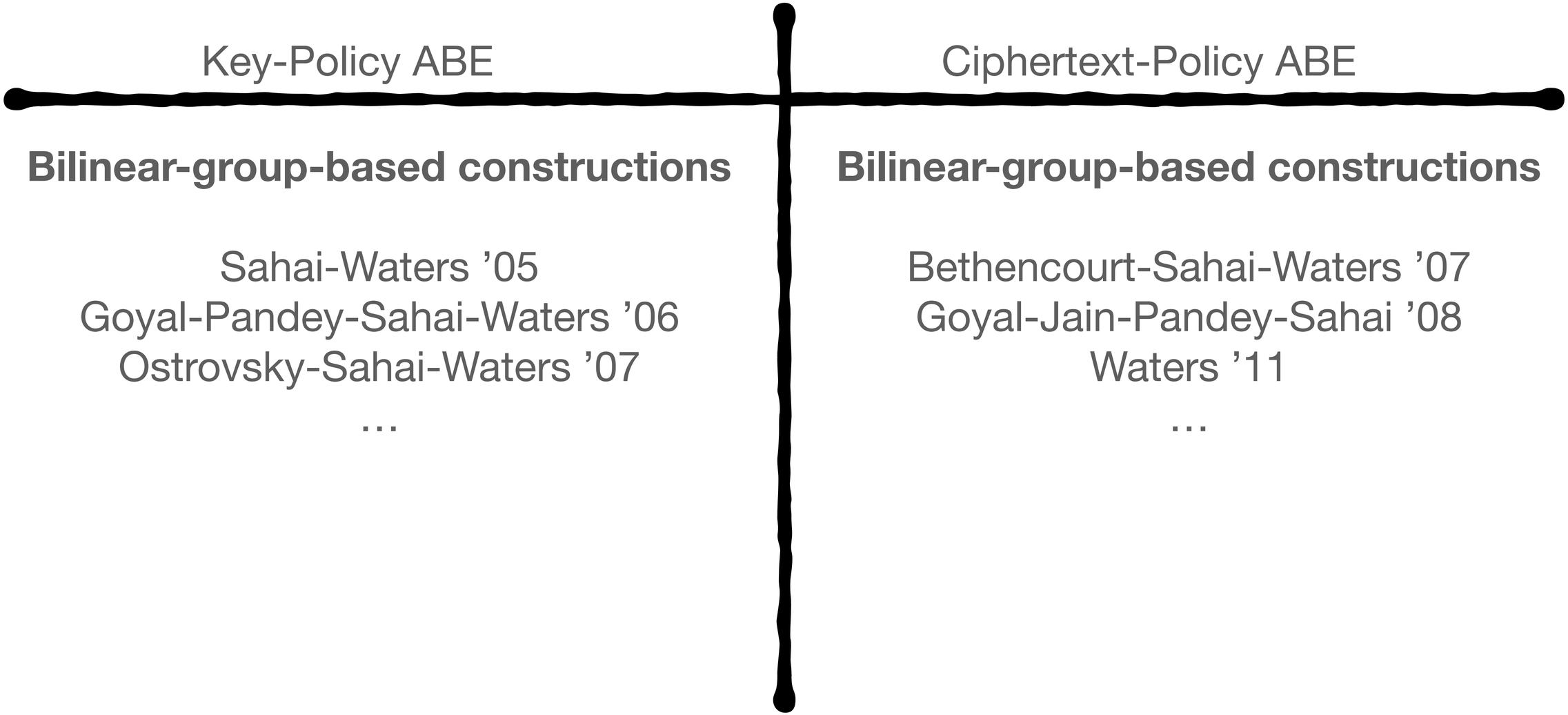

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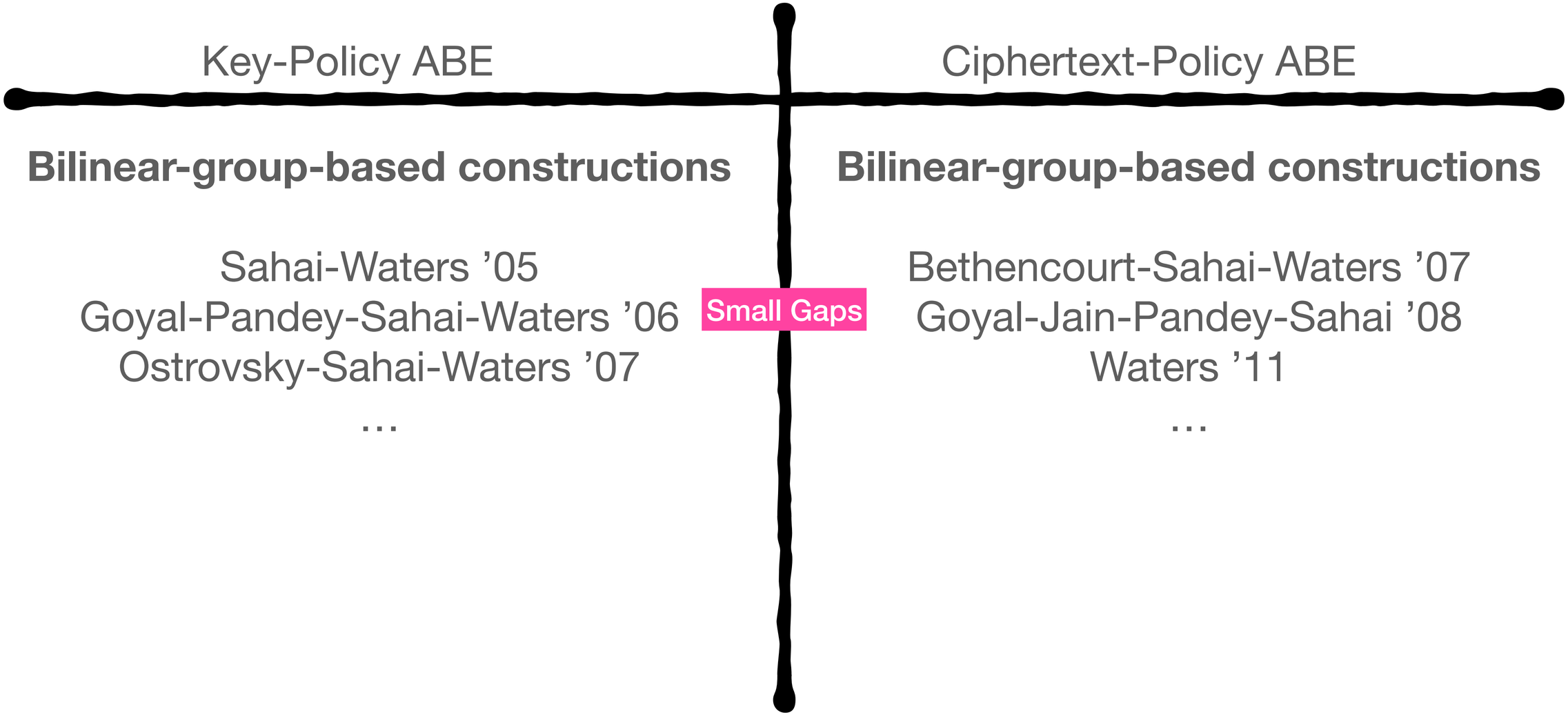

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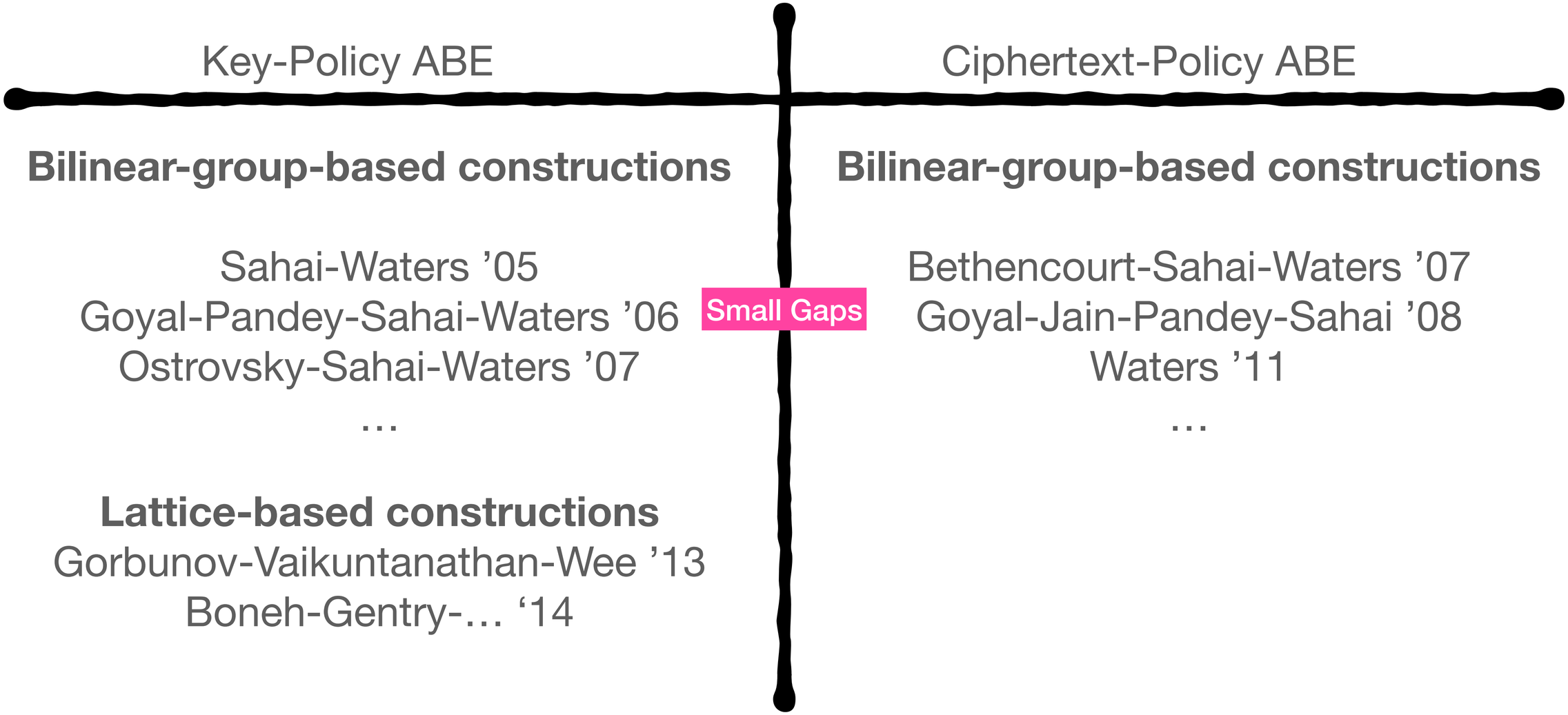

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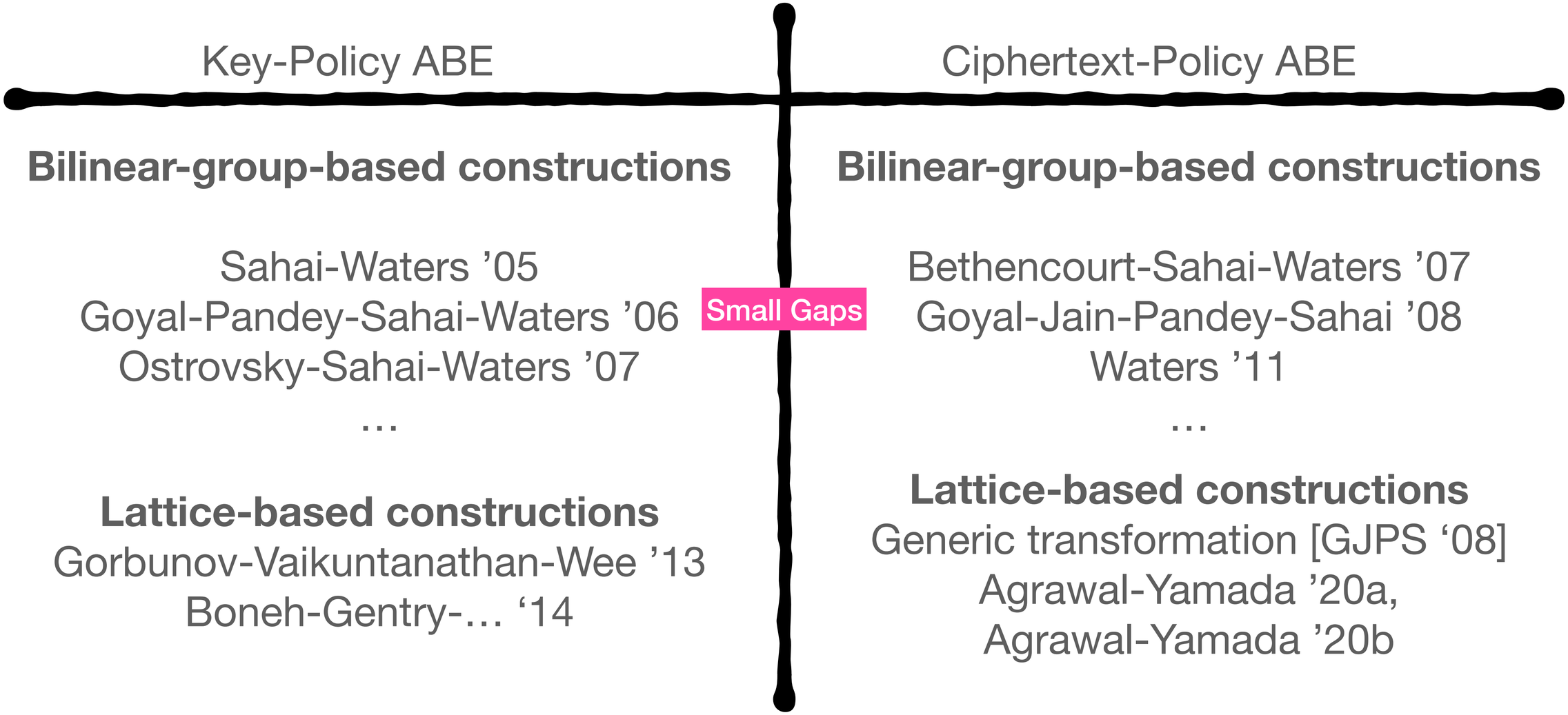

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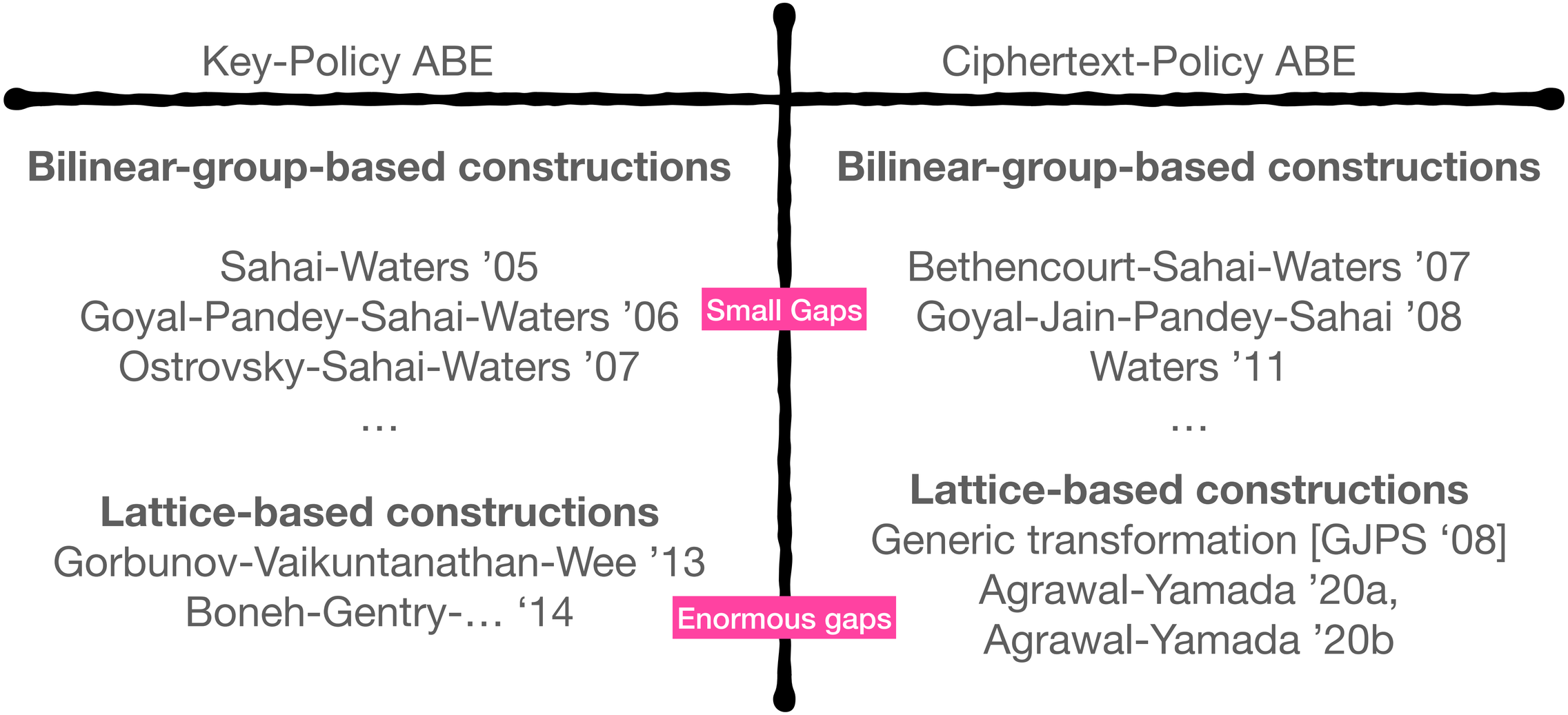

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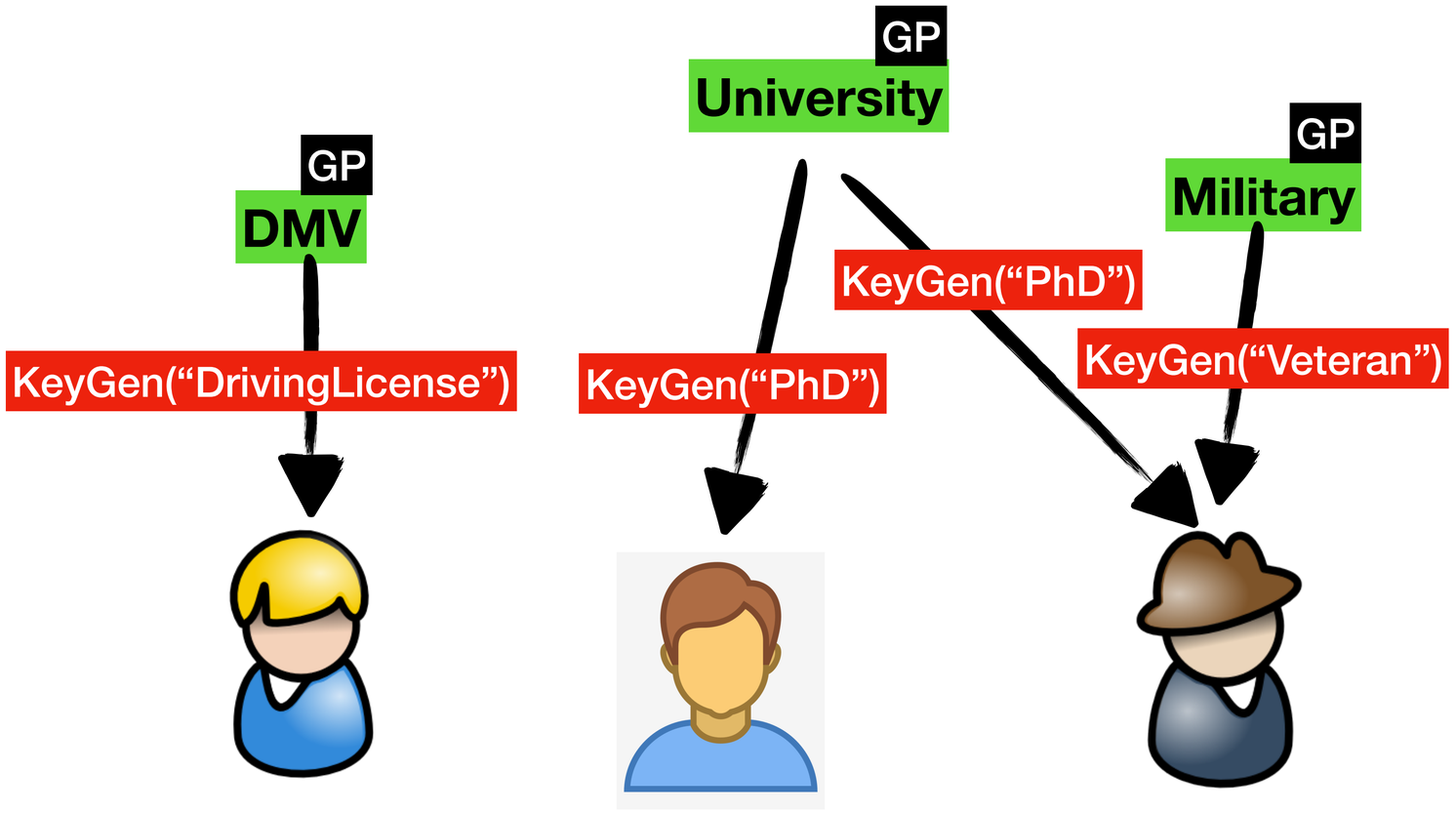
- “Multi-Authority” ABE
  - Chase ’07, …, Lewko-Waters ’11, Okamoto-Takashima ‘13, Rouselakis-Waters ‘15

MA-ABE

- Anyone can become an authority
  - No coordination except global PublicParams
- Different authorities control different attributes
- No bound on # of authorities
- Each authority can issue secret keys to users possessing attributes under their control
  - without any interaction with other authorities

MA-ABE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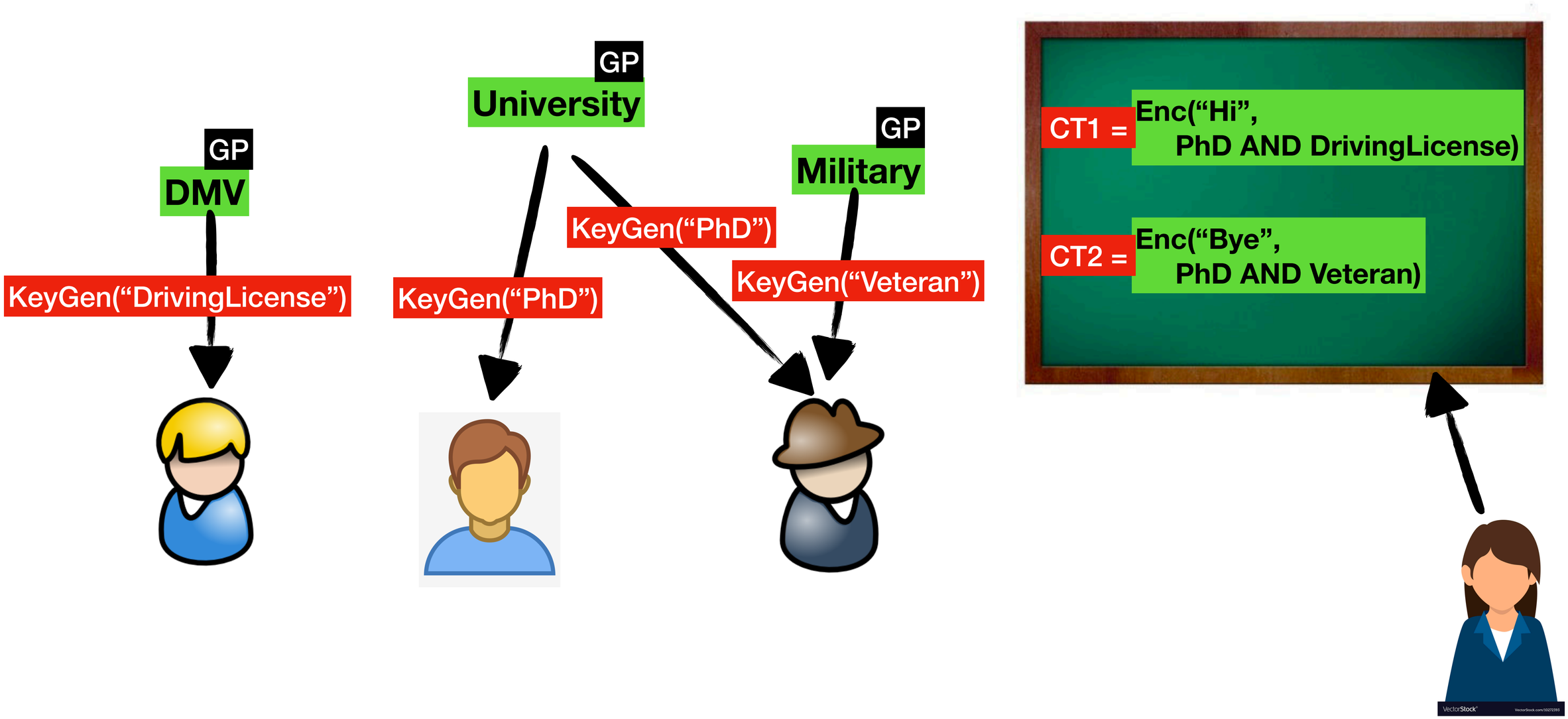
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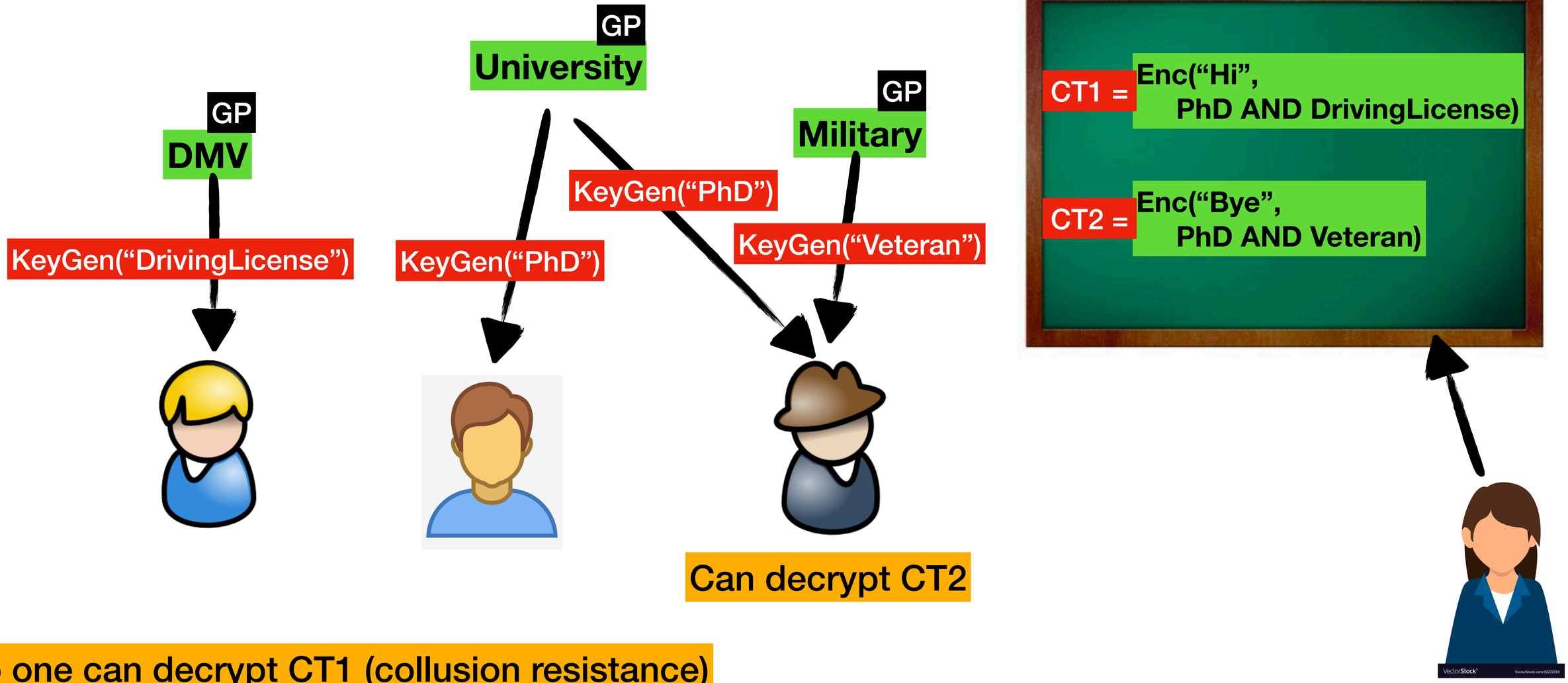

No one can decrypt CT1 (collusion resistance)

The GID Model

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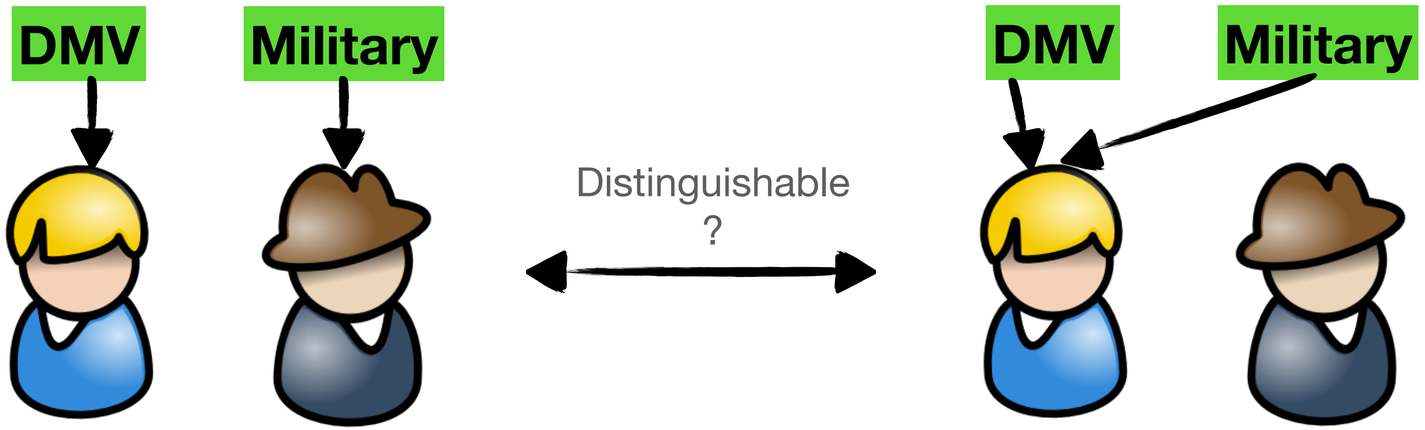

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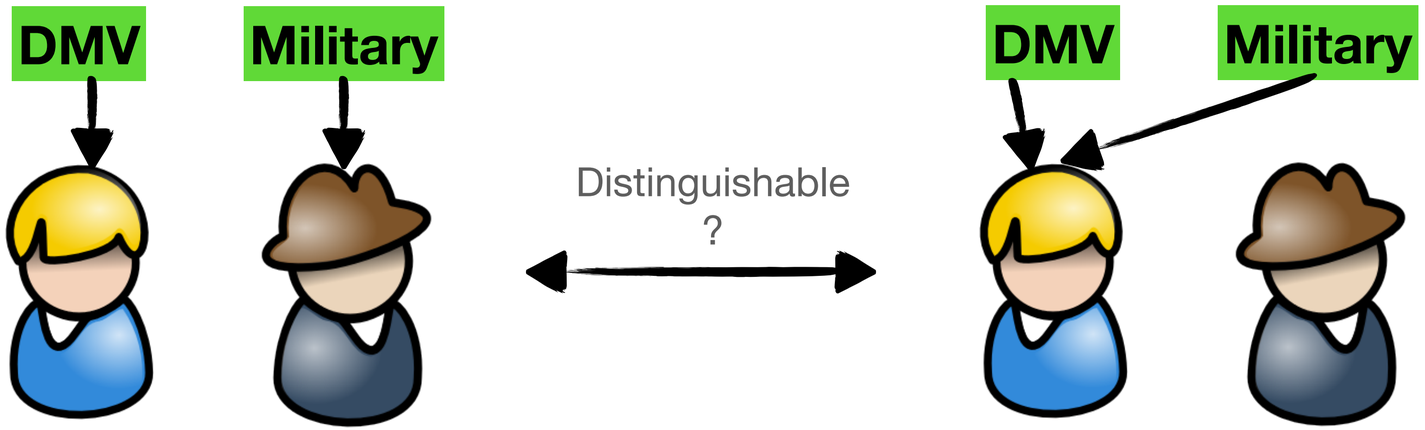

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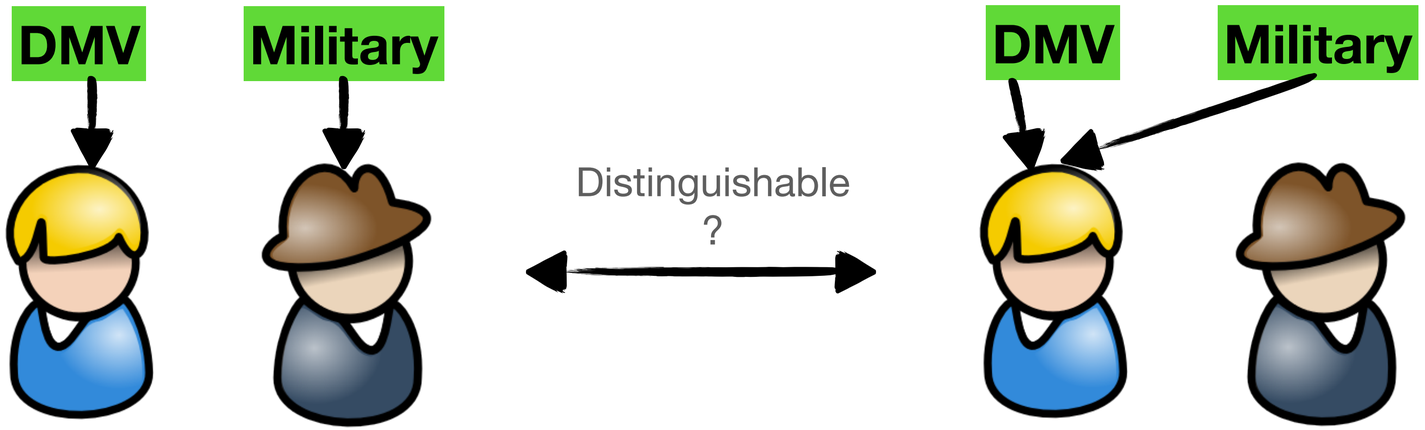

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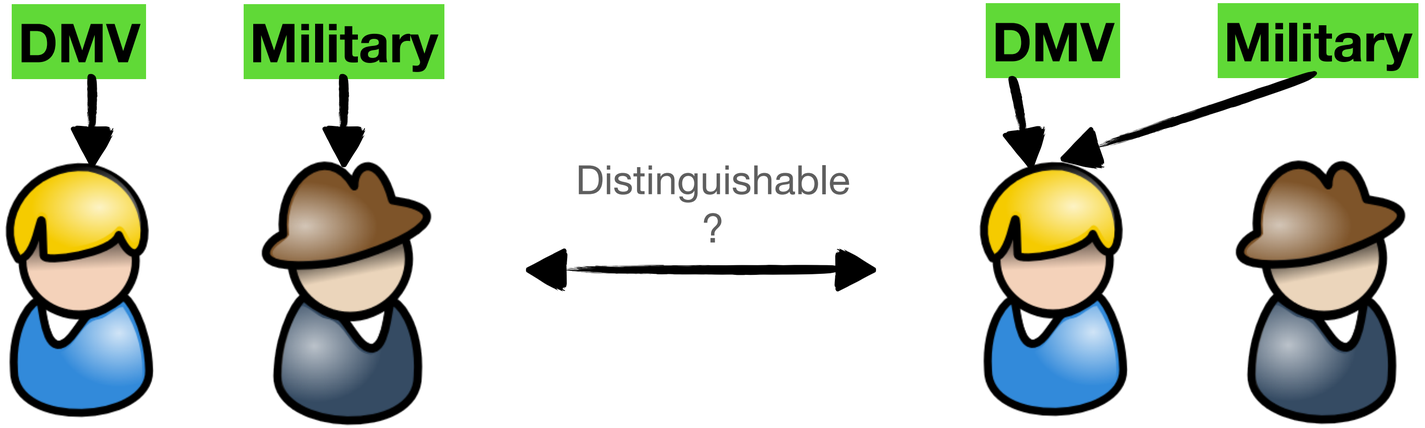

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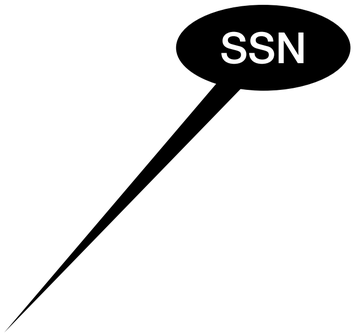

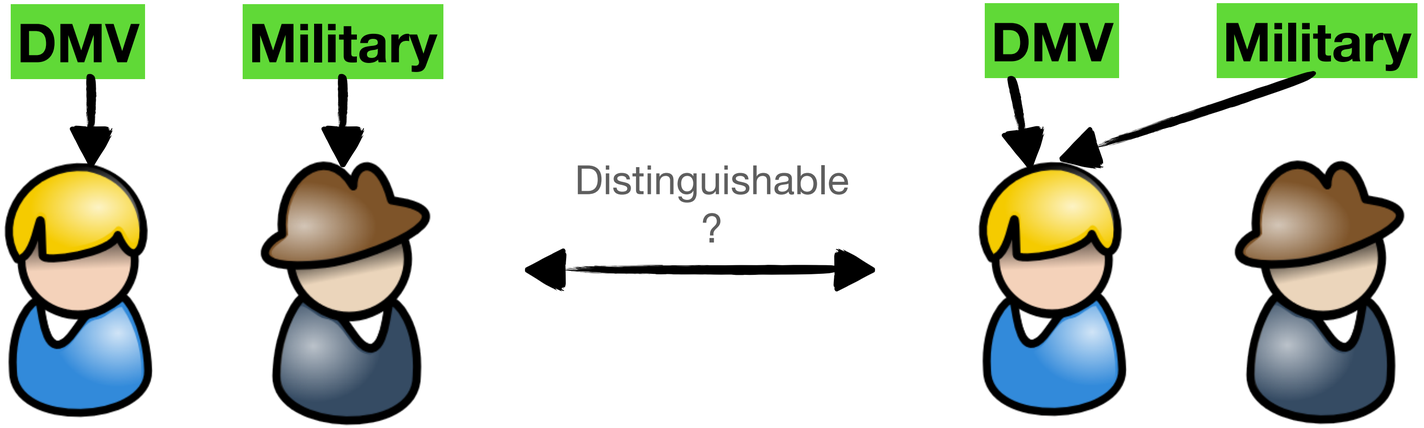

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Security: If $f(U) = \text{false}$ then msg is "hidden"
(Collusion among users and some corrupt authorities is allowed)

MA-ABE (Main) Known Constructions

& Our Main Result

Schemes	Supported Policy Class	Assumption	Attribute per Authority	Security
Lewko-Waters ‘11	NC1	Subgroup decision (composite order)	Bounded	Adaptive
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There exist an MA-ABE scheme in the GID model for access policies captured by DNF formulas that is statically secure against an arbitrary collusion of parties in the random oracle model and assuming the LWE assumption.

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DNF = OR of ANDs

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sub-exp. modulus-to-noise ratio

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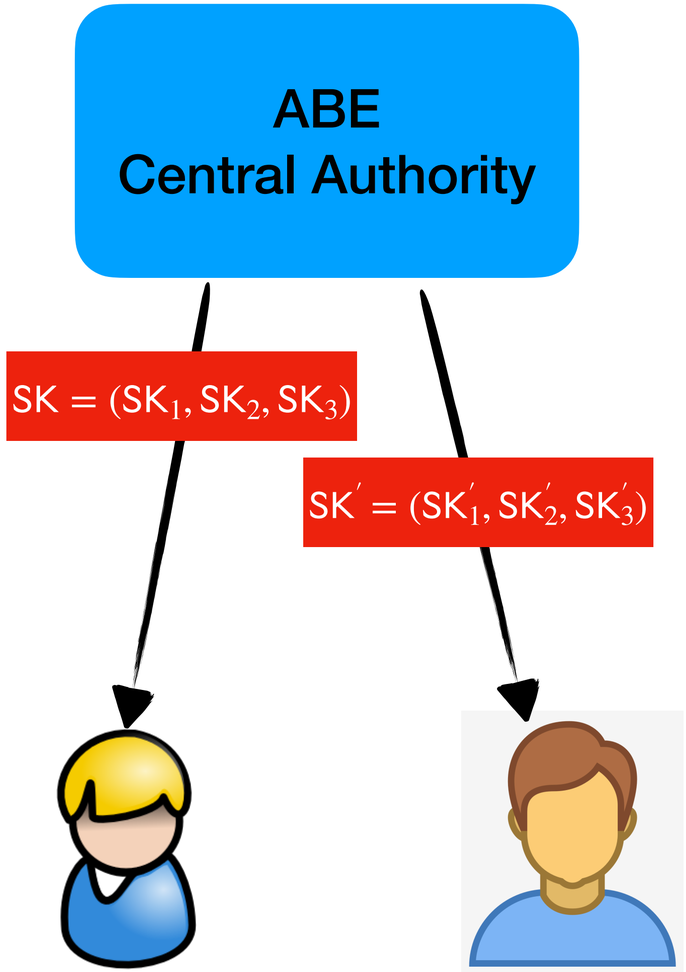

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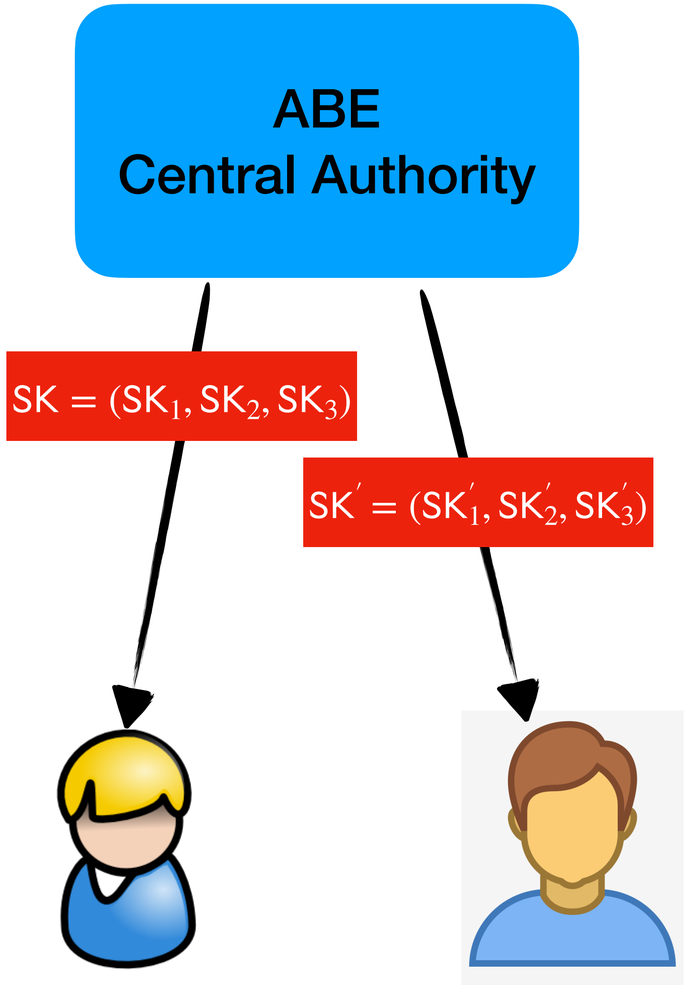

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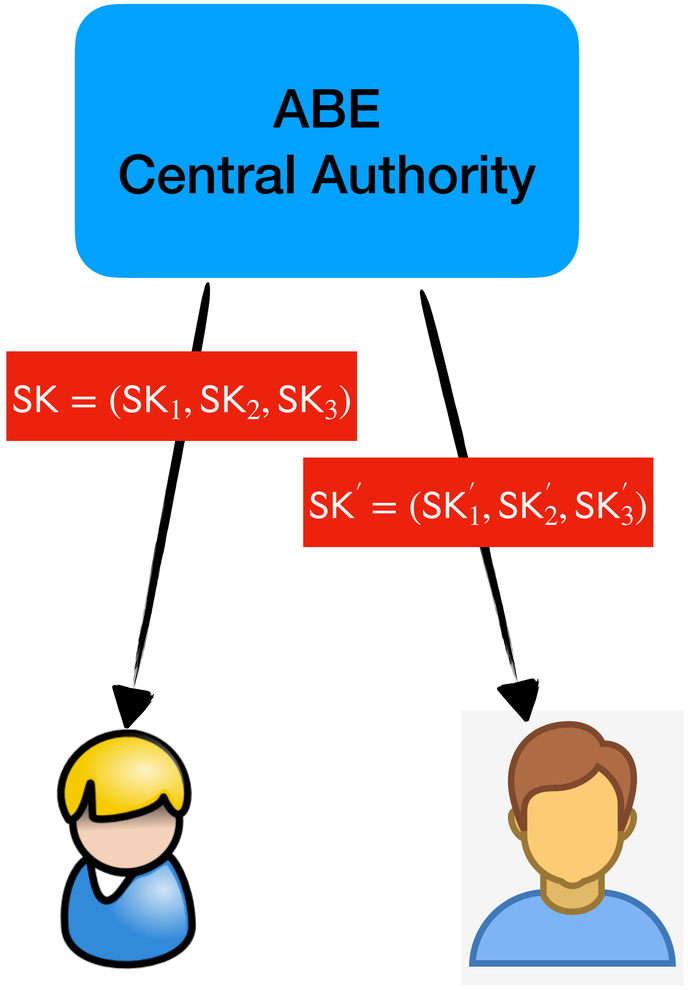

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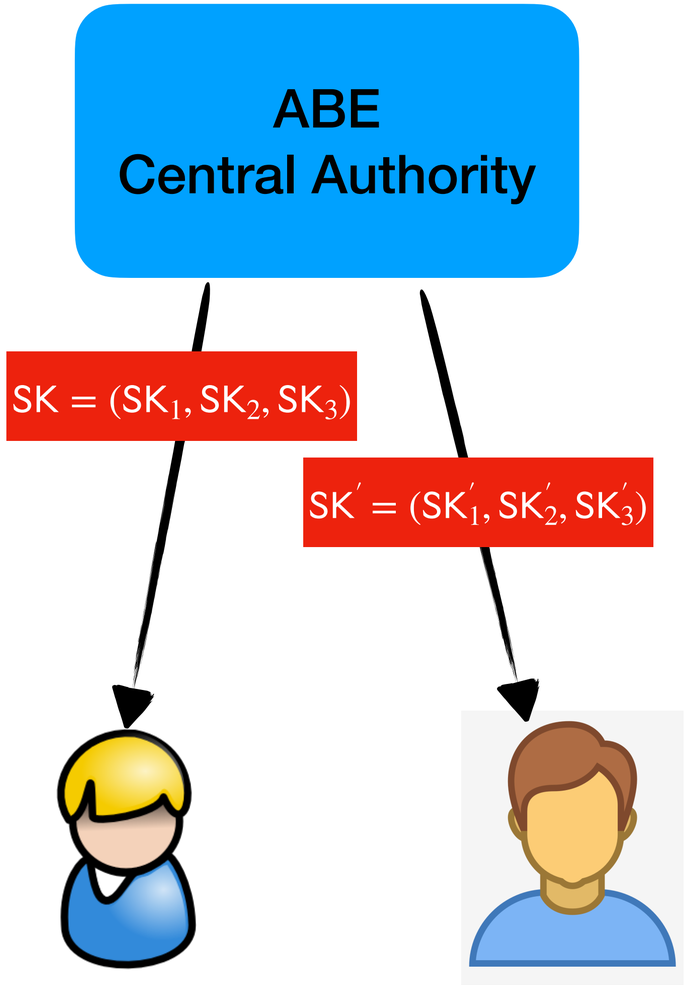

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MA challenge 2

Should support arbitrary authorities joining on the fly

Keys should be “piecewise”. Master PK and user SK should consist of components specific to attributes

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(Non-Monotone) Linear Secret Sharing Schemes (LSSS)

[Shamir,KW93…]

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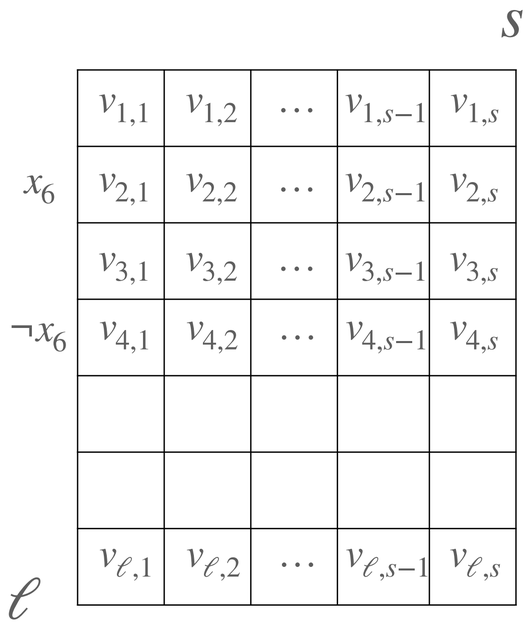
$$M \in \mathbb{Z}_q^{\ell \times s}$$

$$\rho : [\ell] \mapsto \text{parties} \cup \neg\text{parties}$$

Monotone / non-monotone



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Width of LSSS ≈ policy size

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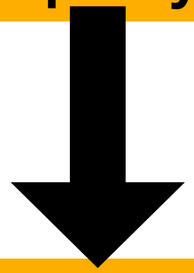
The Recipe

Non-monotone LSSS* with linear ind. property for $\mathscr{C}$



CP-ABE for $\mathscr{C}$

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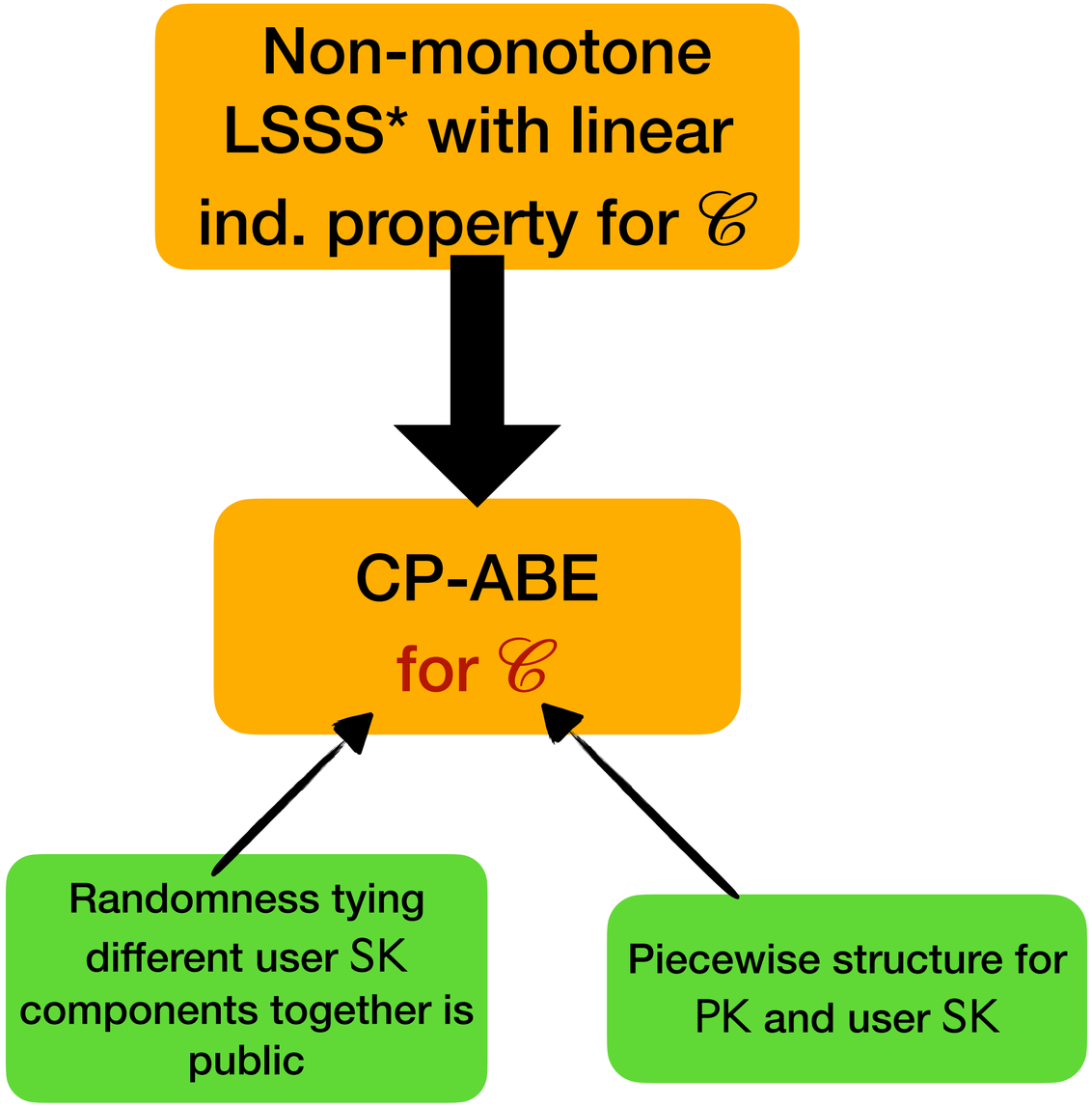
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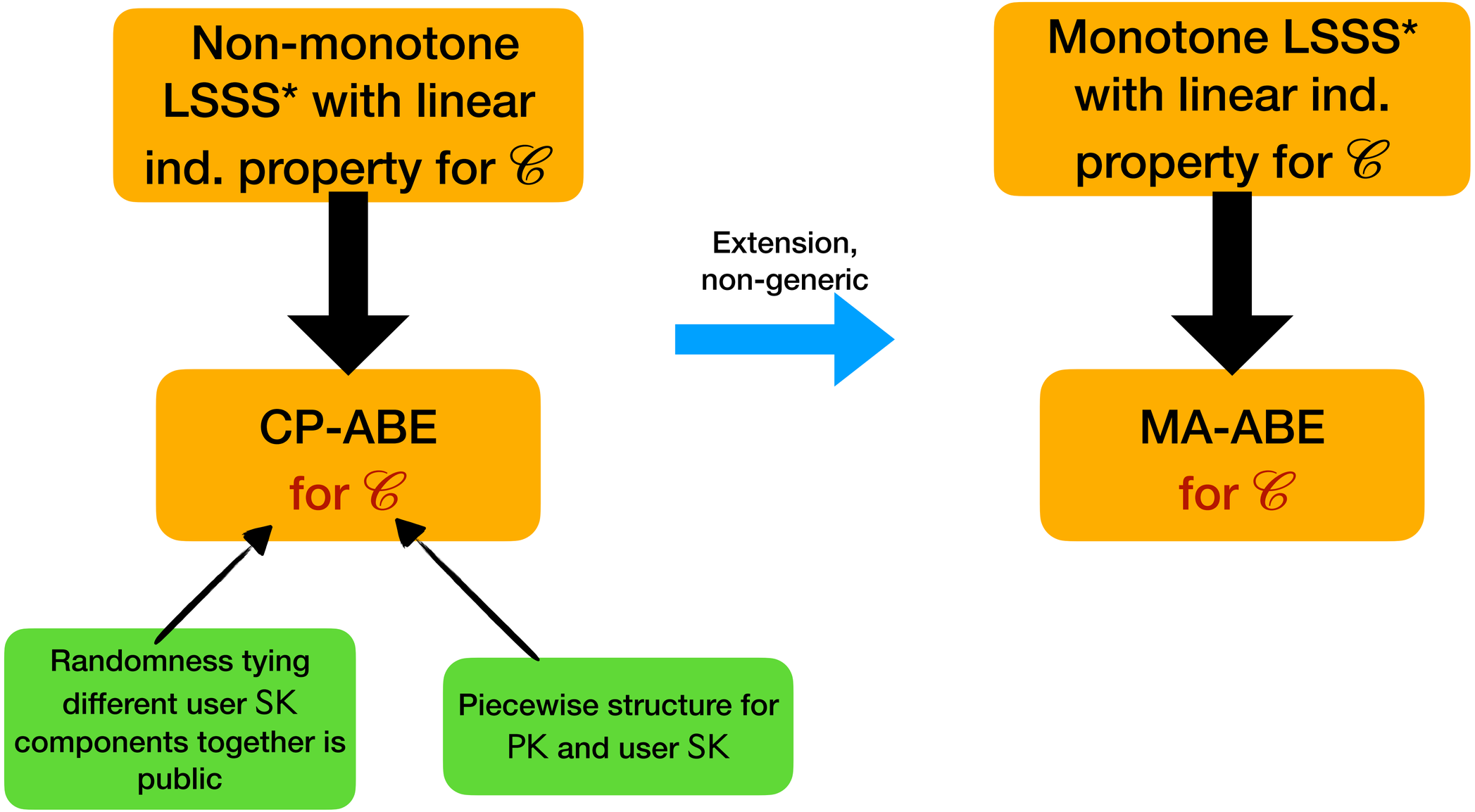
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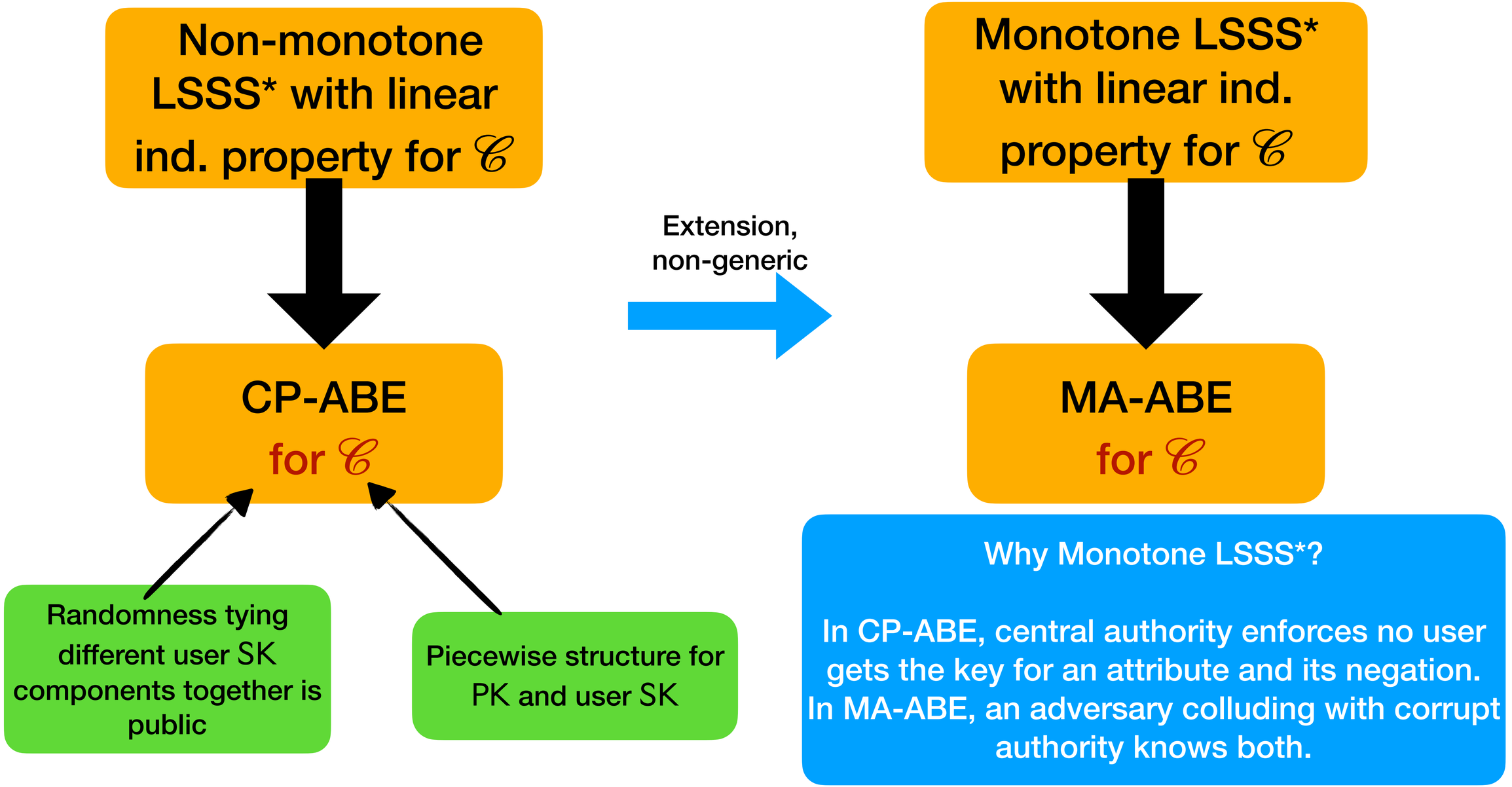
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Why Monotone LSSS*?
In CP-ABE, central authority enforces no user gets the key for an attribute and its negation.
In MA-ABE, an adversary colluding with corrupt authority knows both.

The CP-ABE Scheme

Setup$(1^\lambda, \mathbb{U})$**:**

For each attribute $u \in \mathbb{U}$, sample

- $\mathbf{A}_u \leftarrow \mathbb{Z}_q^{n \times m}$ together with a trapdoor $\mathbf{A}_u^{-1}$
- $\mathbf{H}_u \leftarrow \mathbb{Z}_q^{n \times m}$

Sample $\mathbf{y} \leftarrow \mathbb{Z}_q^n$

Output:

$$\text{PK} = (\mathbf{y}, \{\mathbf{A}_u\}, \{\mathbf{H}_u\}), \quad \text{MSK} = \{\text{PK}, \mathbf{A}_u^{-1}\}$$

The CP-ABE Scheme

KeyGen(MSK, U**):** // U is a set of attributes

Sample $\hat{\mathbf{t}} \leftarrow \text{noise}^{m-1}$ and set $\mathbf{t} = (1, \hat{\mathbf{t}})$

For each attribute u, sample $\mathbf{k}_u \leftarrow \mathbf{A}_u^{-1}(\mathbf{H}_u \cdot \mathbf{t}^\top)$

Output:

$$\text{SK}_U = (\{\mathbf{k}_u\}, \mathbf{t})$$

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Public nature of randomness is important for MA-ABE

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The CP-ABE Scheme

Enc(PK, **msg** $\in \{0,1\}, (M, \rho)$**):**

// $M = \begin{bmatrix} M_1 \\ M_2 \\ \cdots \\ M_\ell \end{bmatrix} \in \mathbb{Z}_q^{\ell \times s}$

Sample $\mathbf{s} \leftarrow \mathbb{Z}_q^n, \mathbf{v}_2, \ldots, \mathbf{v}_s \leftarrow \mathbb{Z}_q^m$

Compute:

$$\mathbf{c}_i = \mathbf{s}\mathbf{A}_{\rho(i)} + \text{noise}_i$$

$$\hat{\mathbf{c}}_i = M_i \cdot \begin{bmatrix} \mathbf{s}\mathbf{y}^\top & 0 & \ldots & 0 \\ & \mathbf{v}_2 & & \\ & \mathbf{v}_3 & & \\ & \cdots & & \\ & \mathbf{v}_s & & \end{bmatrix} - \mathbf{s}\mathbf{H}_{\rho(i)} + \hat{\text{noise}}_i$$

Output:

$$\text{CT} = (\{\mathbf{c}_i\}_{i\in[\ell]}, \{\hat{\mathbf{c}}_i\}_{i\in[\ell]}, C = \text{MSB}(\mathbf{s}\mathbf{y}^\top) \oplus \text{msg})$$

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The CP-ABE Scheme

Dec($\mathsf{SK}_U, \mathsf{CT}$**):**

If U does not satisfy (M, ρ), output $\perp$
Else do the following:

I — Indices of rows of M corresponding to available attributes

$\{w_i\}_{i \in I} \in \{0,1\}$ — Reconstruction coefficients

Compute:

$$K' = \sum_{i \in I} w_i (\mathbf{c}_i \mathbf{k}_{\rho(i)}^\top + \hat{\mathbf{c}}_i \mathbf{t}^\top)$$

Output:

$$\mathsf{msg}' = C \oplus \mathsf{MSB}(K')$$

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Correctness

(Ignoring small noise-like terms)

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$$\mathbf{c}_i \mathbf{k}_{\rho(i)}^\top + \hat{\mathbf{c}}_i \mathbf{t}^\top = \mathbf{s}\mathbf{A}_{\rho(i)} \mathbf{k}_{\rho(i)}^\top + M_i \cdot \begin{bmatrix} \mathbf{s}\mathbf{y}^\top & 0 & \dots & 0 \\ & \mathbf{v}_2 & & \\ & \mathbf{v}_3 & & \\ & \dots & & \\ & \mathbf{v}_s & & \end{bmatrix} \mathbf{t}^\top - \mathbf{s}\mathbf{H}_{\rho(i)} \mathbf{t}^\top$$

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Reconstruction gives $\mathbf{s}\mathbf{y}^\top$

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- Better parameters (even for CP-ABE)
- Unbounded number of attributes per authority (we only get bounded)

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Thank you!

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