Password-Authenticated Key Exchange from Group Actions

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August 15, 2022

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Motivation

Password Authenticated Key Exchange

- Establish a session key based on
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Alice (pw)

Bob (pw)

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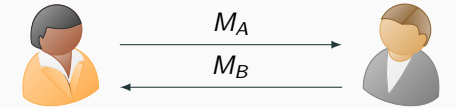

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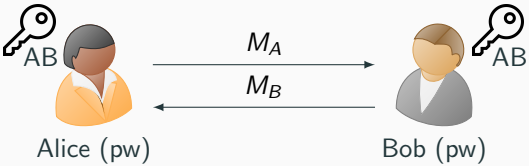

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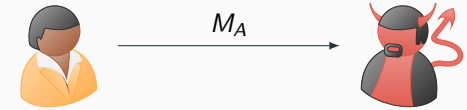

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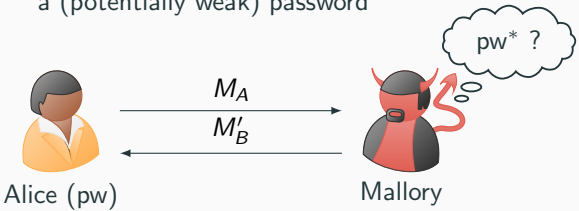

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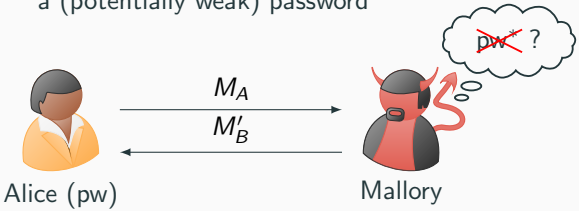

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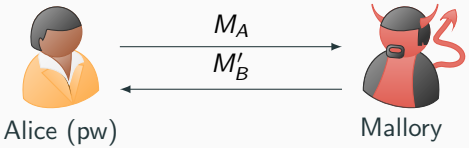

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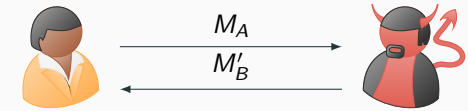

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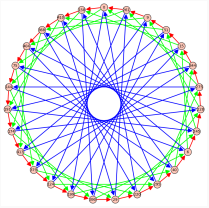

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- CSIDH as candidate for post-quantum security
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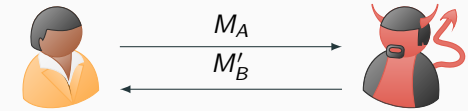

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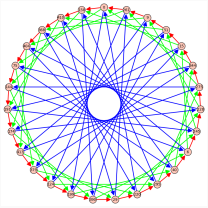

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- Limited structure of the group action
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Generic Constructions

- Quite inefficient construction using OT
- Unclear how to use the HPS of [ADMP20]

Cryptographic Group Actions

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Group Action

Let $(\mathcal{G}, \cdot)$ be a group with identity element $id \in \mathcal{G}$, and $\mathcal{X}$ a set. A map $\star : \mathcal{G} \times \mathcal{X} \to \mathcal{X}$ is a group action if it satisfies the following properties:

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- $\mathcal{G}$ and $\mathcal{X}$ are finite.
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⚠ In general, we cannot combine two elements of the set $\mathcal{X}$!

The CSIDH Group Action

CSIDH [CLM+18] can be seen as a *restricted effective* group action:

$\mathcal{G} =$ corresponds to isogenies between elliptic curves

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- DLOG: Given $g \star \tilde{x} \in \mathcal{X}$, it is hard to find $g \in \mathcal{G}$.
- CDH: Given $(g \star \tilde{x}, h \star \tilde{x}) \in \mathcal{X}^2$, it is hard to find $z = gh \star \tilde{x} \in \mathcal{X}$.
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- Strong/Gap CDH: same as CDH but with access to a decision oracle DDH, where

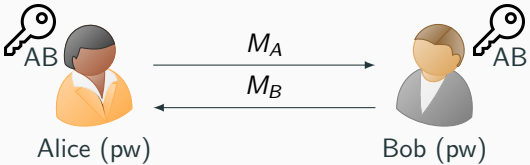
$$\mathrm{DDH}(x, y, z) = \begin{cases} 1 & \mathrm{CDH}(x, y) = z \\ 0 & \text{otherwise} \end{cases}$$

Password-Authenticated Key Exchange

Password-Authenticated Key Exchange (PAKE)

Focus

- balanced PAKE



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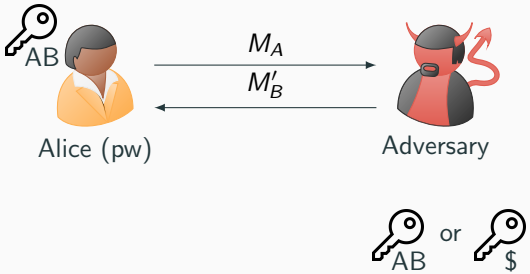

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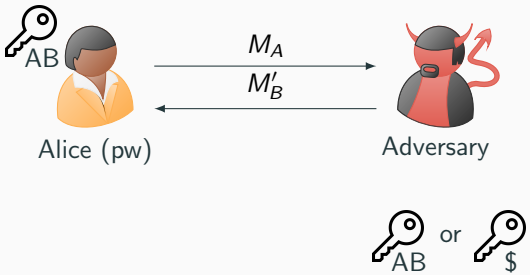

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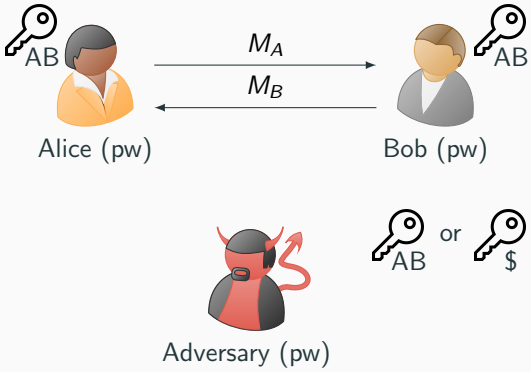
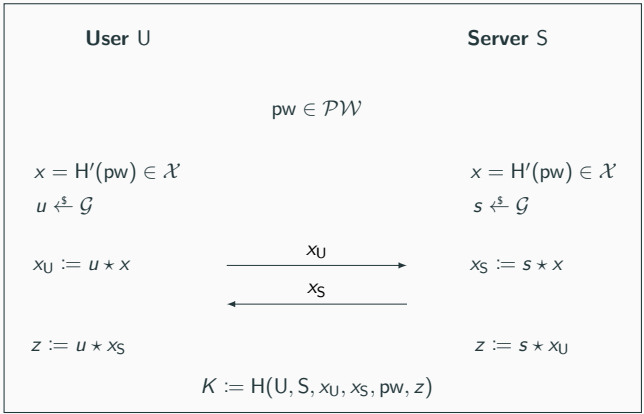


Our First Protocol

Starting Point: SPEKE

Simple Password Exponential Key Exchange [Jab96]



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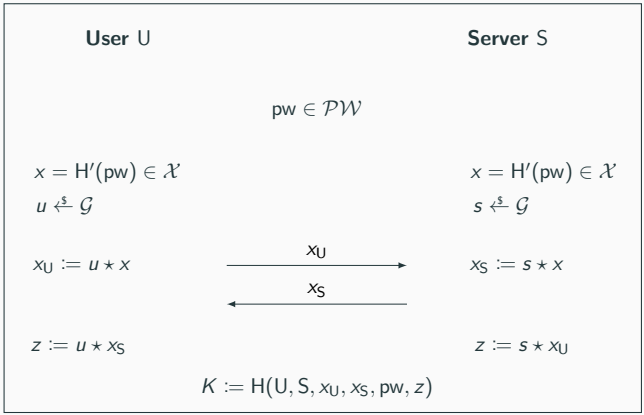
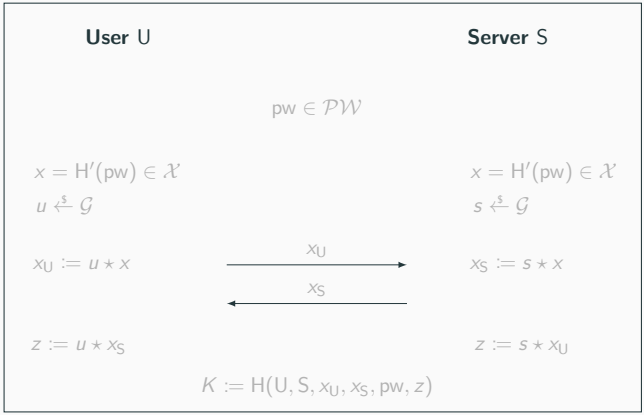


Problem: A hash function $\mathsf{H}' : \mathcal{PW} \to \mathcal{X}$ is still an open problem for CSIDH [BBD+22, MMP22].

Our Group Action PAKE

Idea: Replace the hash function by a bit-by-bit approach.



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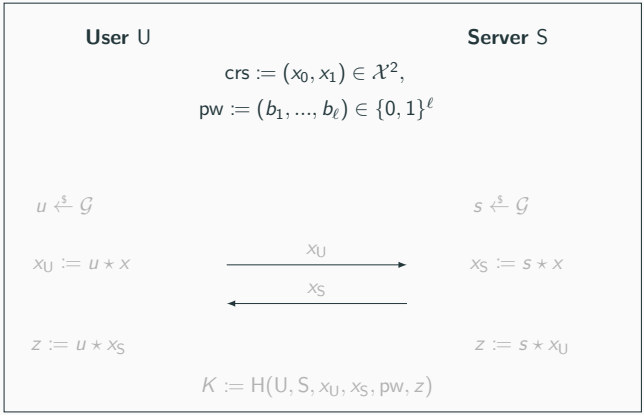

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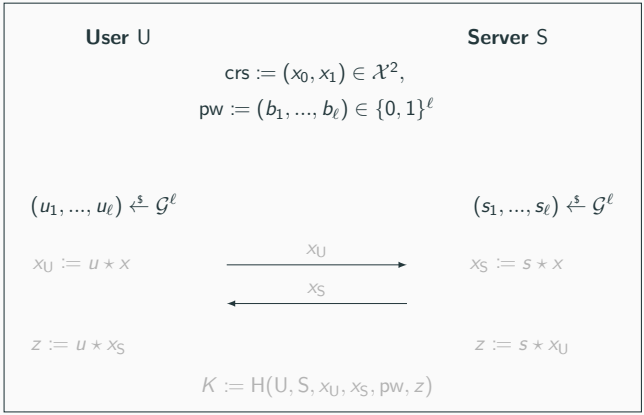

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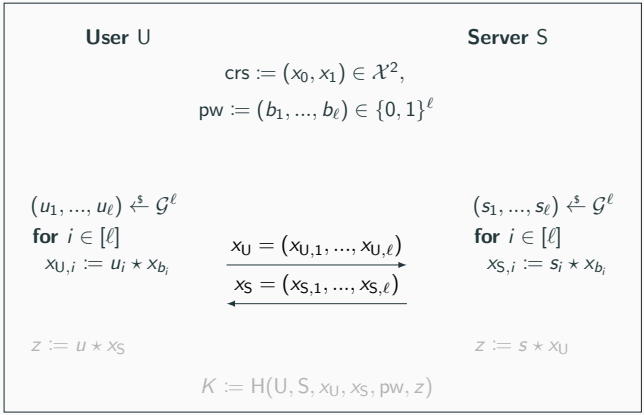

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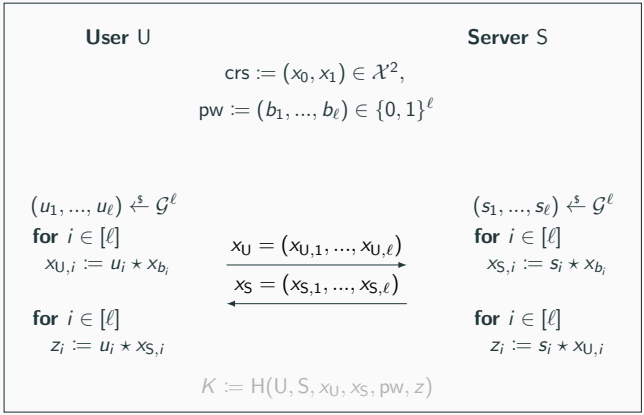

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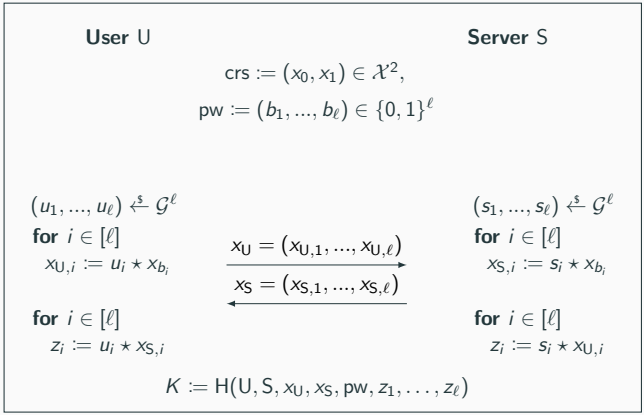

(In)Security of our Protocol

Security against Passive Adversaries

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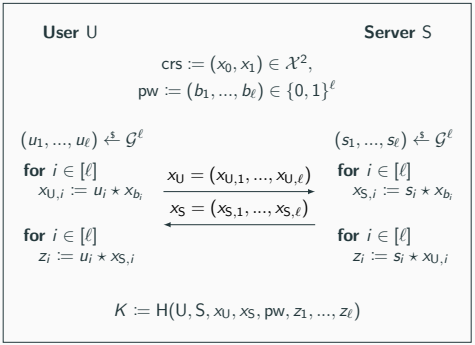

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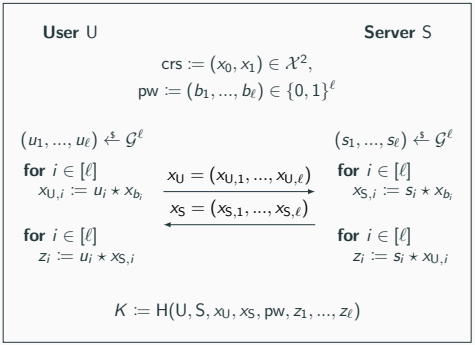

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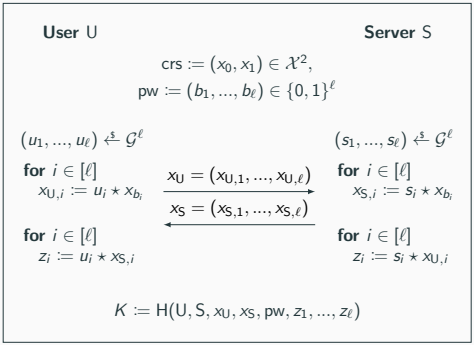

Additional Structure of the CSIDH Group Action

- For any $x \in \mathcal{X}$, we can efficiently compute its *twist* denoted by x^t.
- Let $x = g \star \tilde{x}$, then $x^t = g^{-1} \star \tilde{x}$. In particular $\tilde{x}^t = \tilde{x}$.

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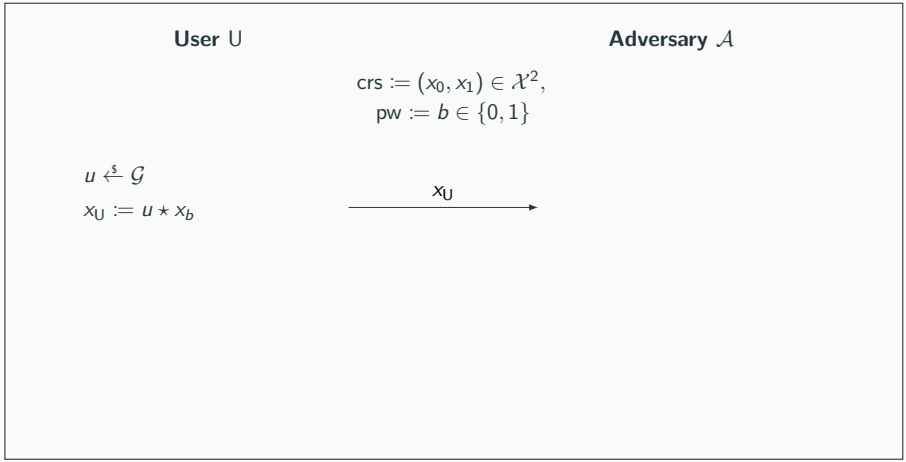
Twists yield an Offline Dictionary Attack!



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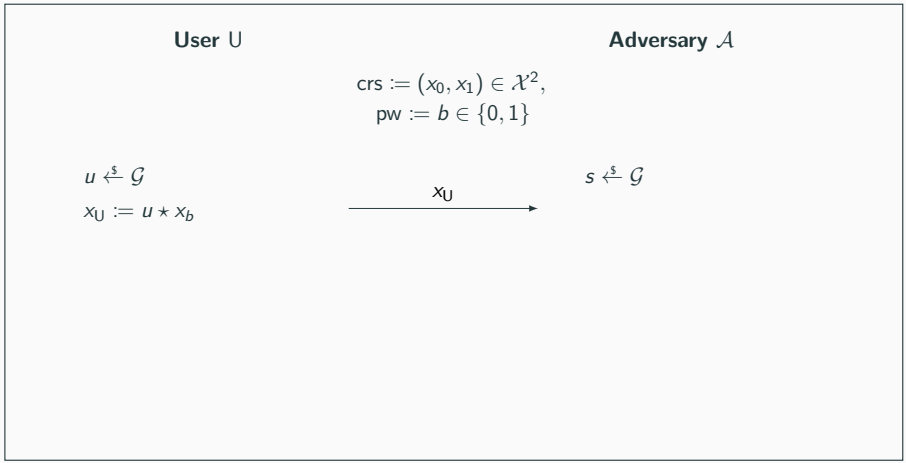

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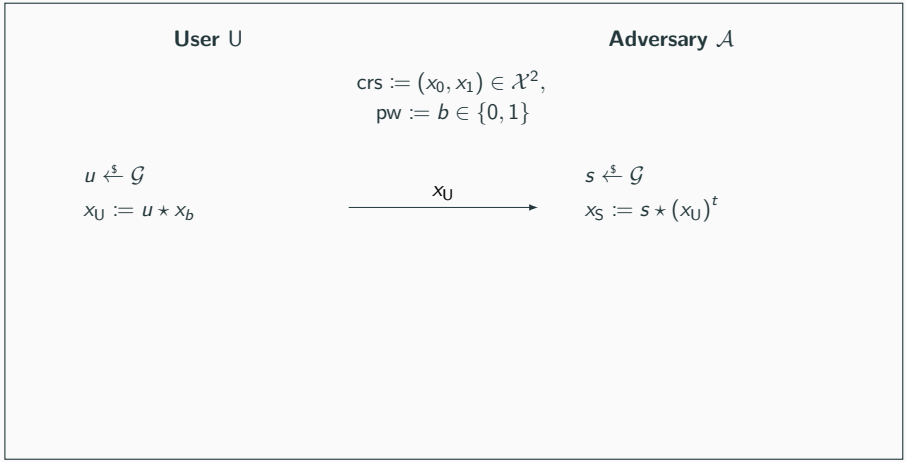

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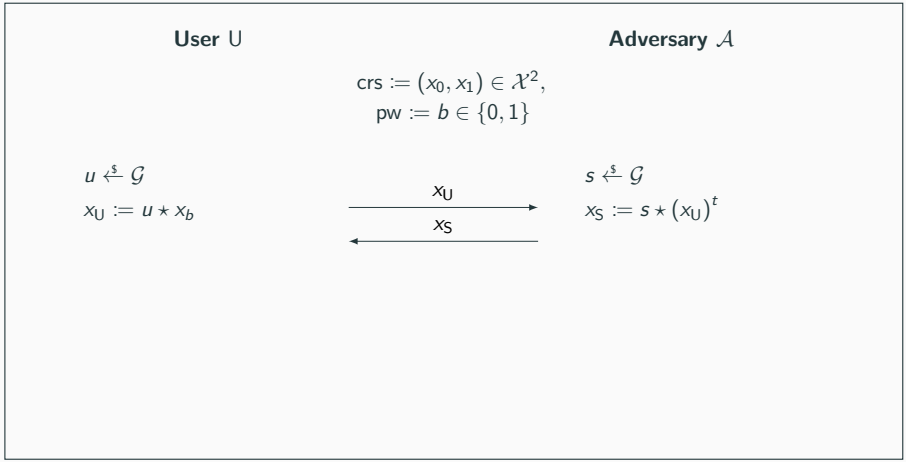

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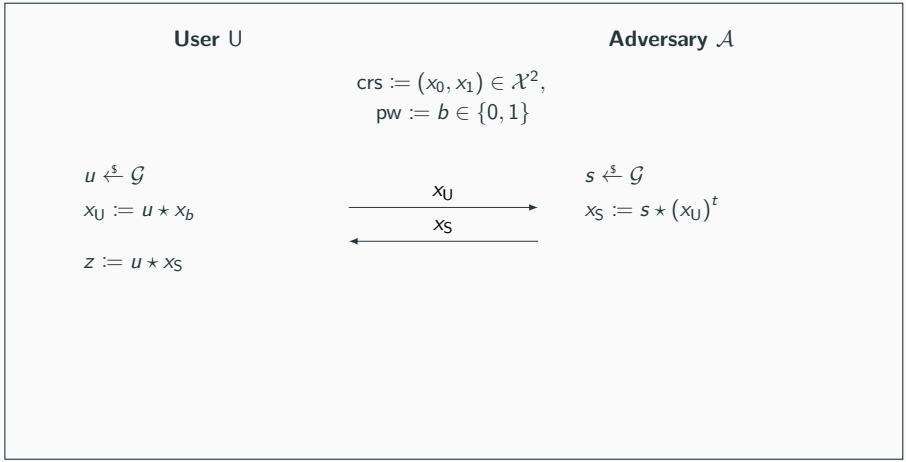

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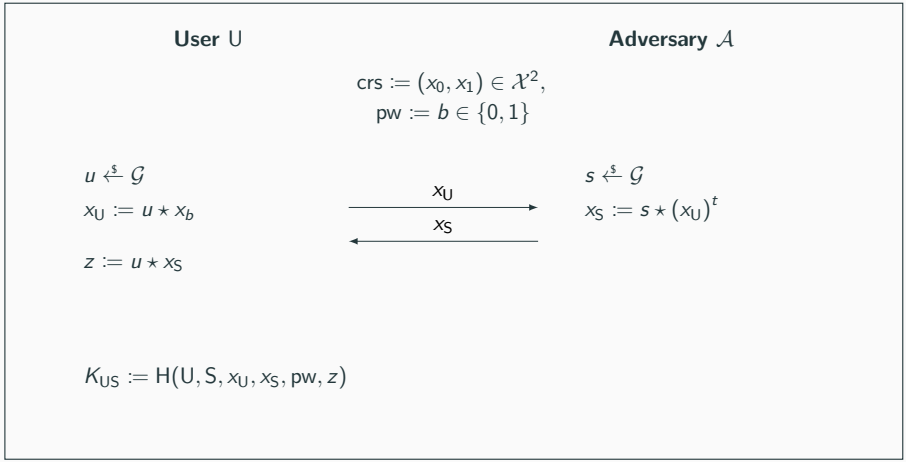

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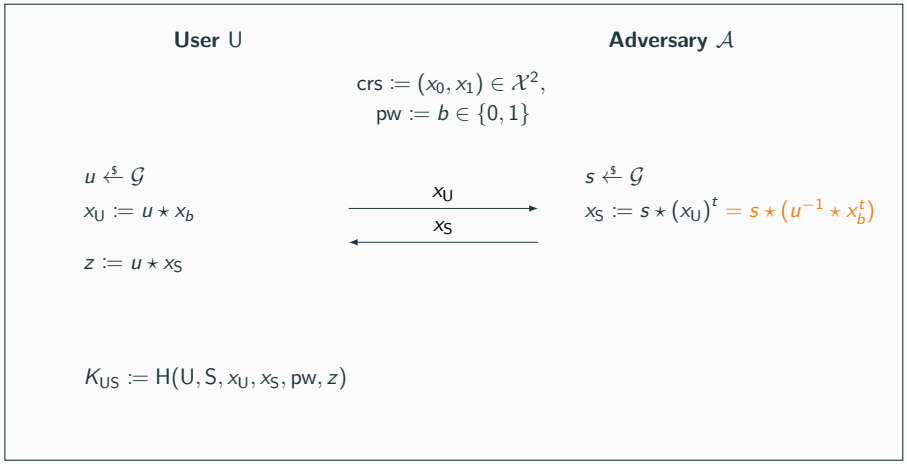

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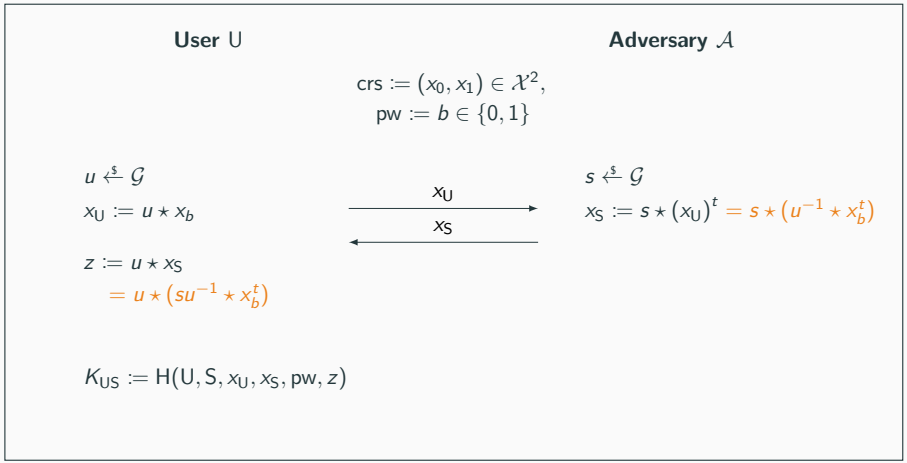

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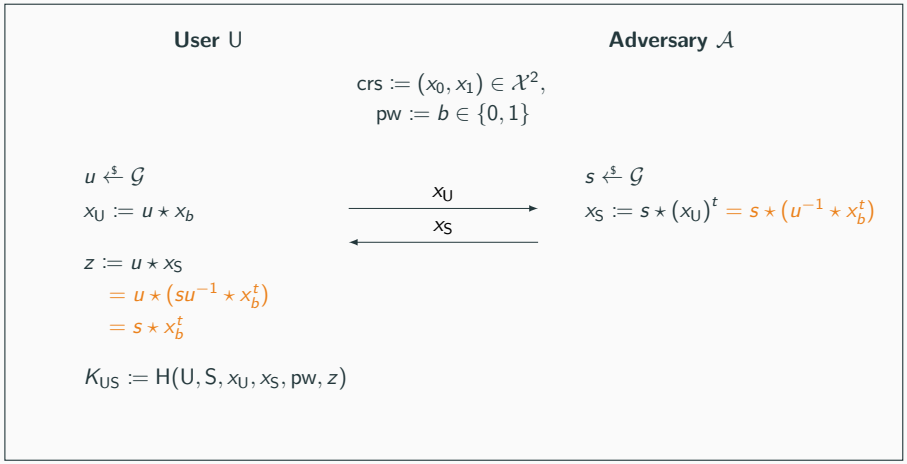

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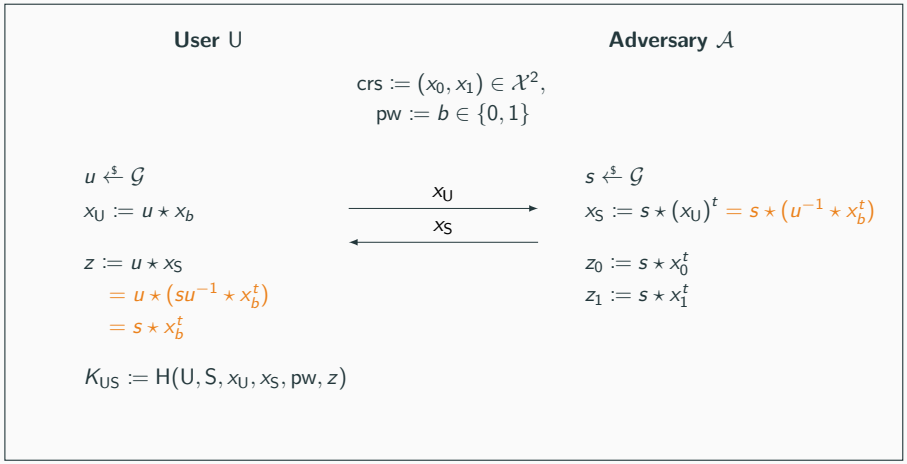

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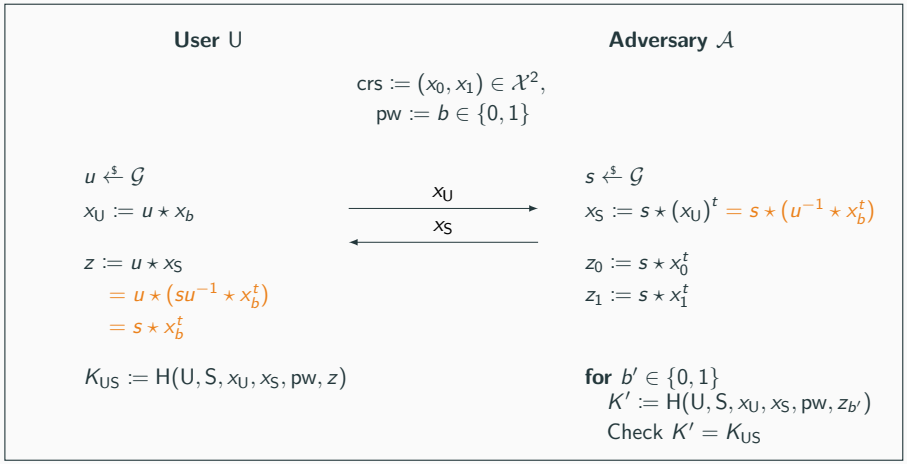

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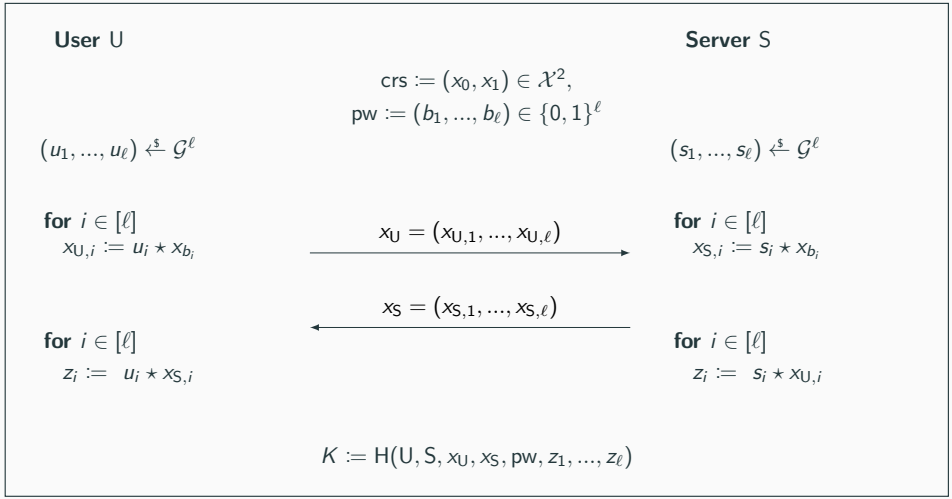
2. **Use "Cross-Terms" (**X-GA-PAKE**)**
   - Double the communication and combine elements in three ways.
   - $\mathcal{A}$ can compute at most two of the three combinations.

X-GA-PAKE


User U
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crs ≔ $(x_0, x_1) \in \mathcal{X}^2$,
pw ≔ $(b_1, ..., b_\ell) \in \{0,1\}^\ell$
$(u_1, ..., u_\ell) \xleftarrow{\$} \mathcal{G}^\ell$
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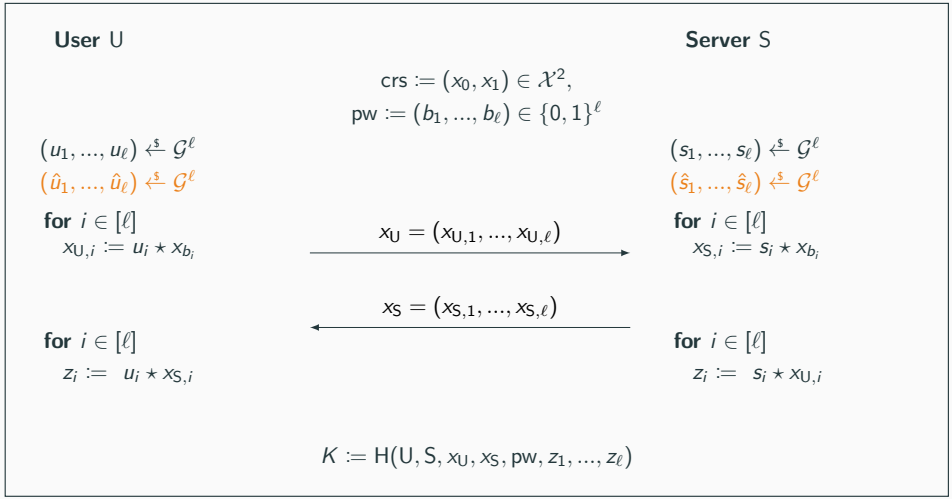
for $i \in [\ell]$
$z_i \coloneqq u_i \star x_{S,i}$
for $i \in [\ell]$
$z_i \coloneqq s_i \star x_{U,i}$
$K \coloneqq \mathsf{H}(\mathsf{U}, \mathsf{S}, x_U, x_S, \mathsf{pw}, z_1, ..., z_\ell)$

X-GA-PAKE


User U
Server S
crs ≔ (x0, x1) ∈ X^2,
pw ≔ (b1, ..., bℓ) ∈ {0,1}^ℓ
(u1, ..., uℓ) ←$ G^ℓ
(û1, ..., ûℓ) ←$ G^ℓ
(s1, ..., sℓ) ←$ G^ℓ
(ŝ1, ..., ŝℓ) ←$ G^ℓ
for i ∈ [ℓ]
xU,i ≔ ui ⋆ xbi
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for i ∈ [ℓ]
xS,i ≔ si ⋆ xbi
xS = (xS,1, ..., xS,ℓ)
for i ∈ [ℓ]
zi ≔ ui ⋆ xS,i
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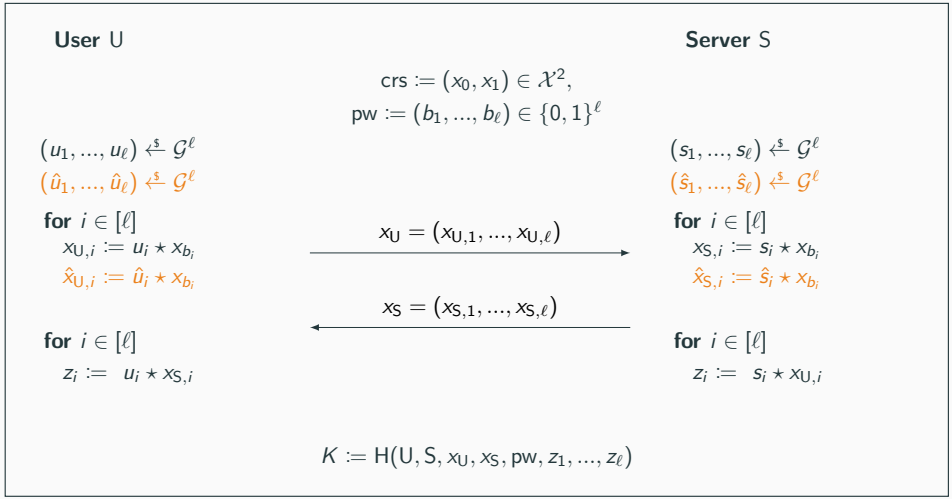
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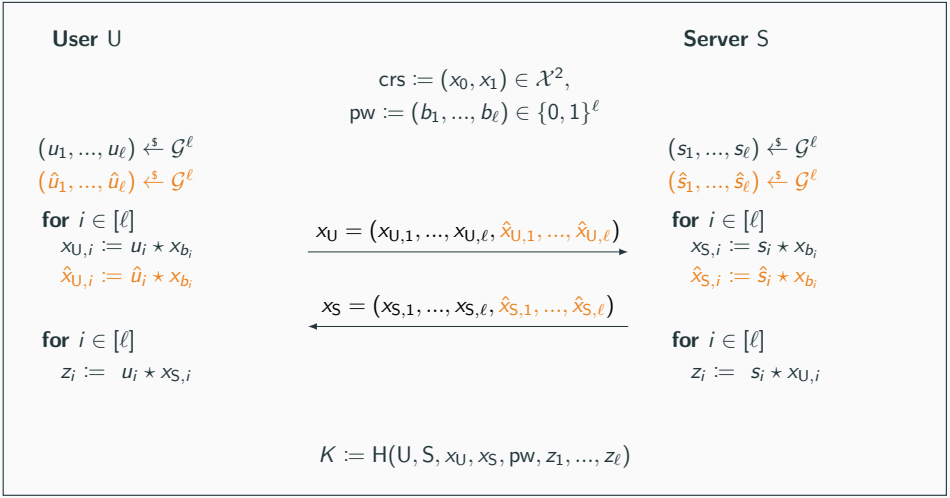
X-GA-PAKE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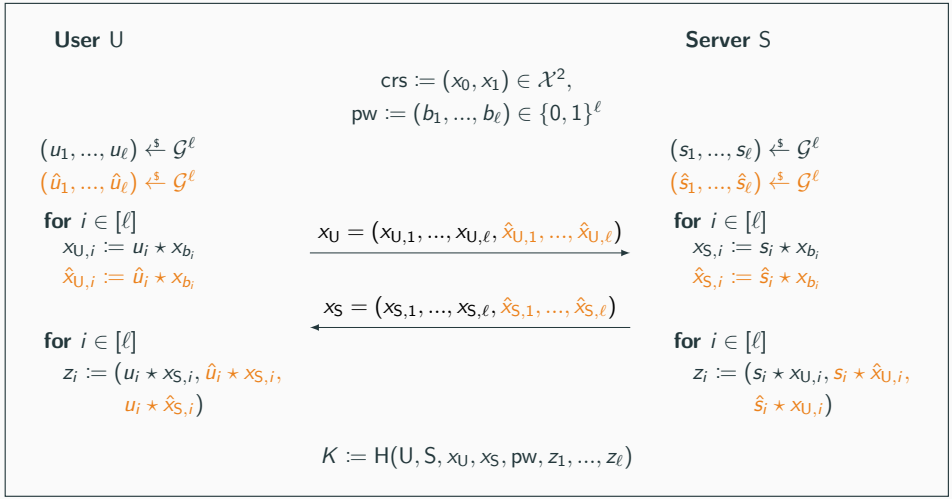
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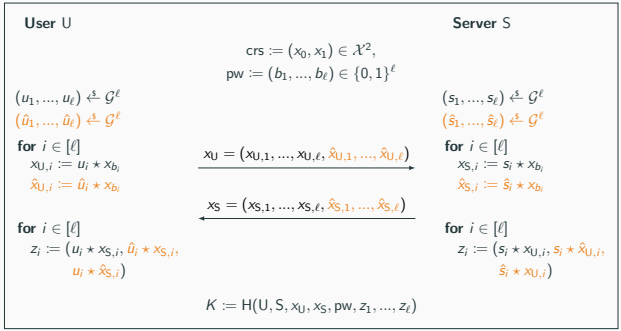
Security of X-GA-PAKE

Security against Passive Adversaries

- secure under Strong CDH + ROM



Security of X-GA-PAKE

Security against Passive Adversaries

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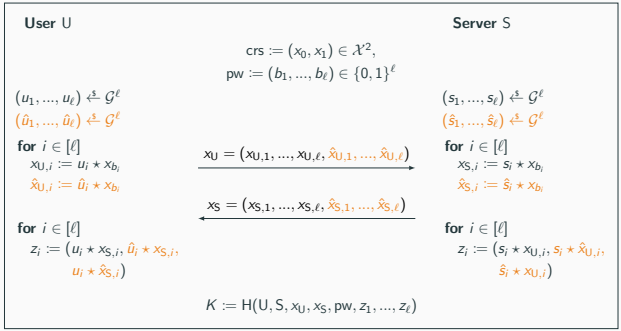
Security against Active Adversaries

- secure under Strong Square-Inverse DH + ROM



Security of X-GA-PAKE

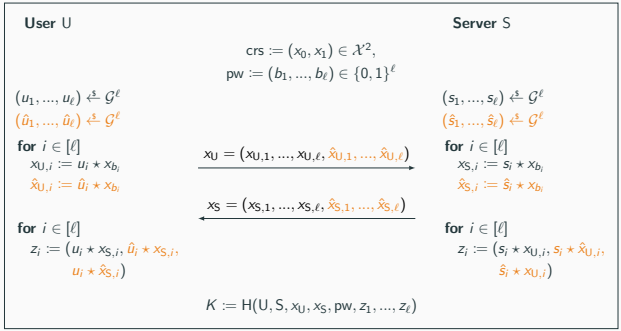
Security against Passive Adversaries

- secure under Strong CDH + ROM

Security against Active Adversaries

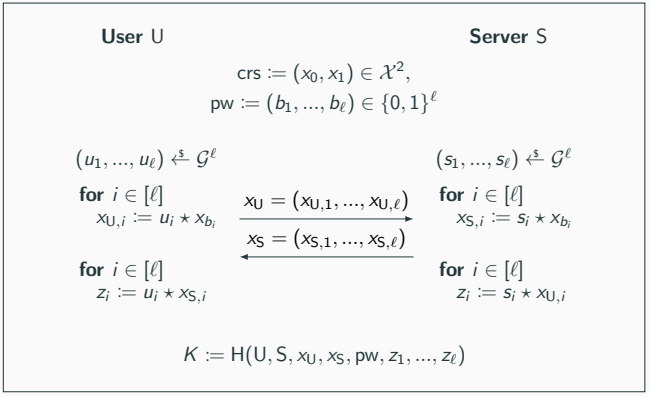
- secure under Strong Square-Inverse DH + ROM
- given $(g \star \tilde{x})$ compute (y, z_0, z_1) such that

$$z_0 = g^2 \star y$$
$$z_1 = g^{-1} \star y$$



Optimizations

Decrease the Communication and Computation Cost



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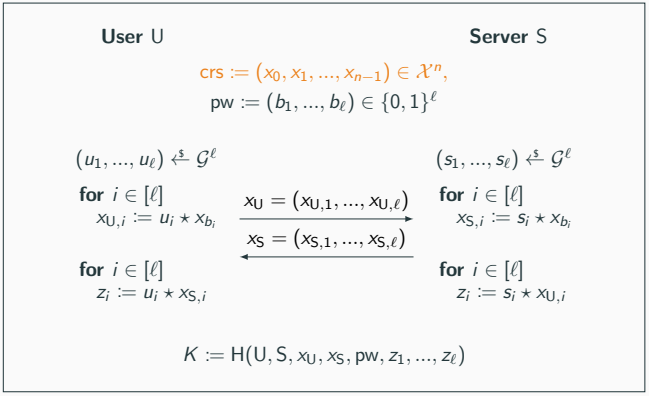

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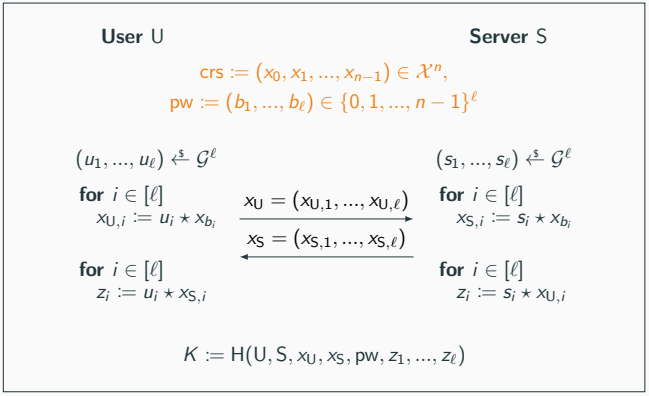

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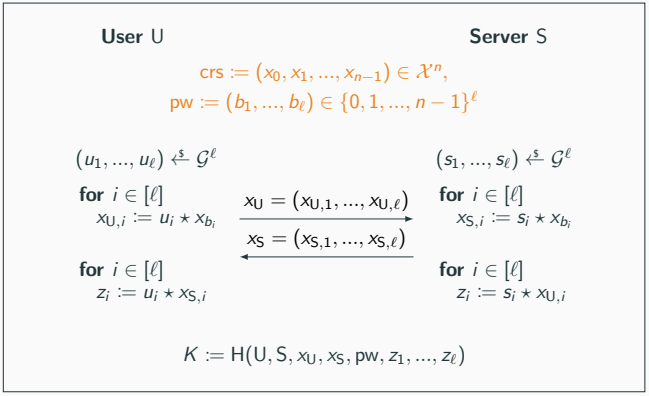
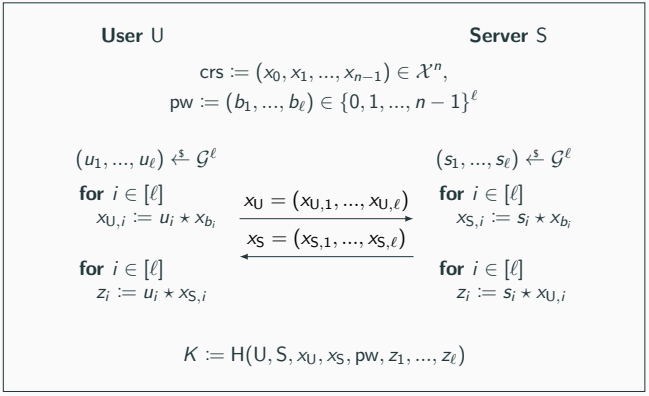


$\Rightarrow$ By increasing the number of public parameters n, we can choose a smaller ℓ.

Use Twists in the Setup



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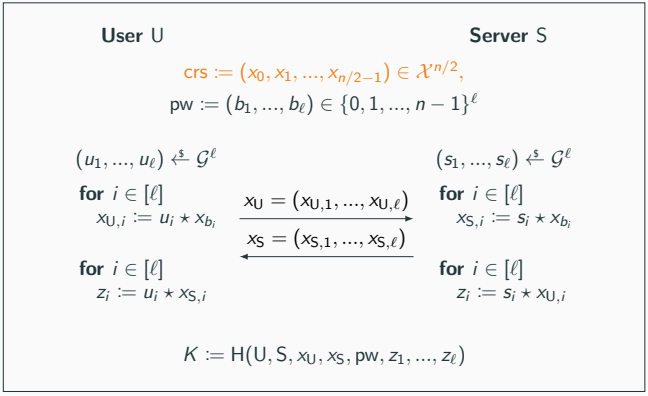

Here we implicitly define $x_{n/2+i} := x_i^t$ for $i \in \{0, 1, ..., n-1\}$.

Comparison of Com-GA-PAKE and X-GA-PAKE

	Using OT [CDVW12, LGd21]	Com-GA-PAKE	X-GA-PAKE
Set Elements	384	16	32
Evaluations	1408	32	80
Rounds	4	3	1
Security Assumption	CDH	Gap CDH	Strong Square-Inverse
Tight	no	no	yes

Here we assume $\mathcal{PW} \subset \{0,1\}^{128}$ for all schemes, i.e.,

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Results

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- The first direct constructions and provably secure PAKE protocols from CSIDH
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Thank you!

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