Combining PAKEs for hybrid security

Merged talk based on concurrent works by

PAKE Combiners and Efficient Post-Quantum Instantiations

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[1] IBM Research Europe — Zurich [2] Cloudflare

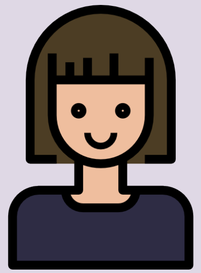
Hybrid Password Authentication Key Exchange in the UC Framework

You Lyu **Shengli Liu**

Shanghai Jiao Tong University, China

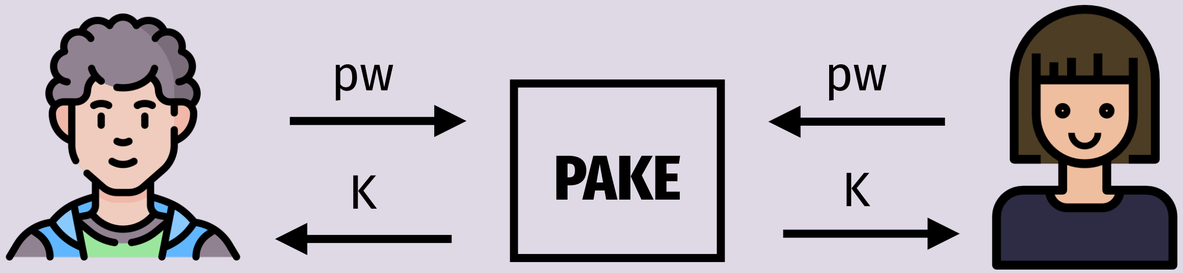
ia.cr/2024/{1621,1630}

What is a PAKE



What is a PAKE

Two parties use a password to establish a secure shared secret



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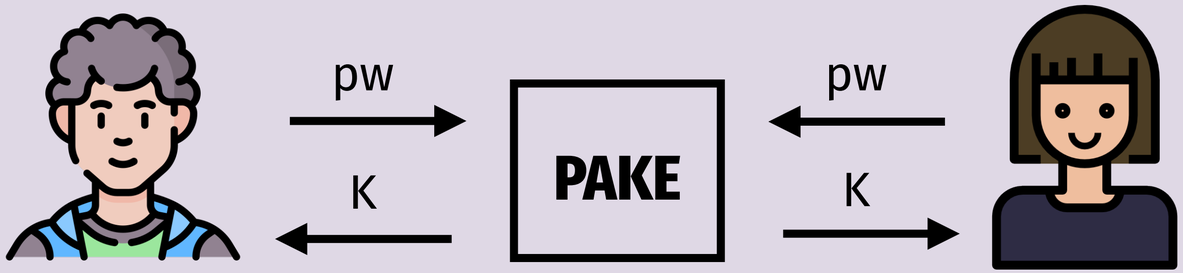

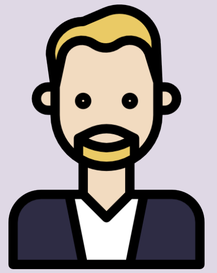

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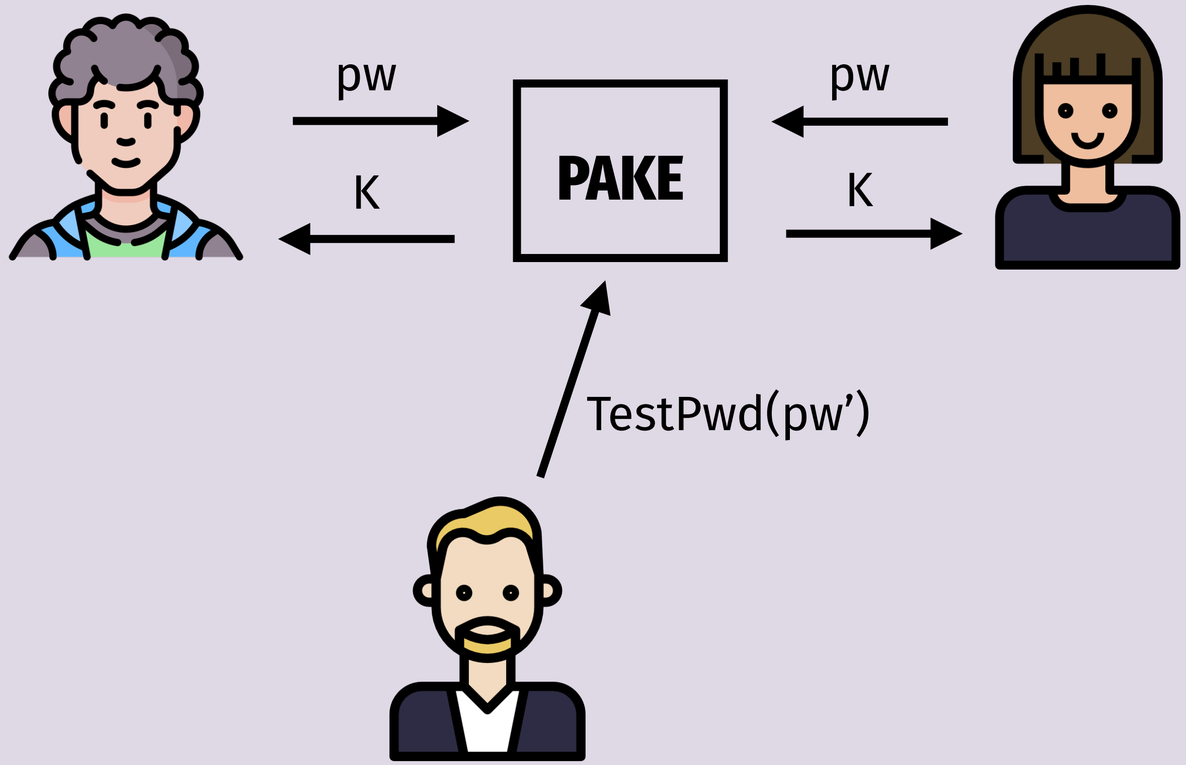

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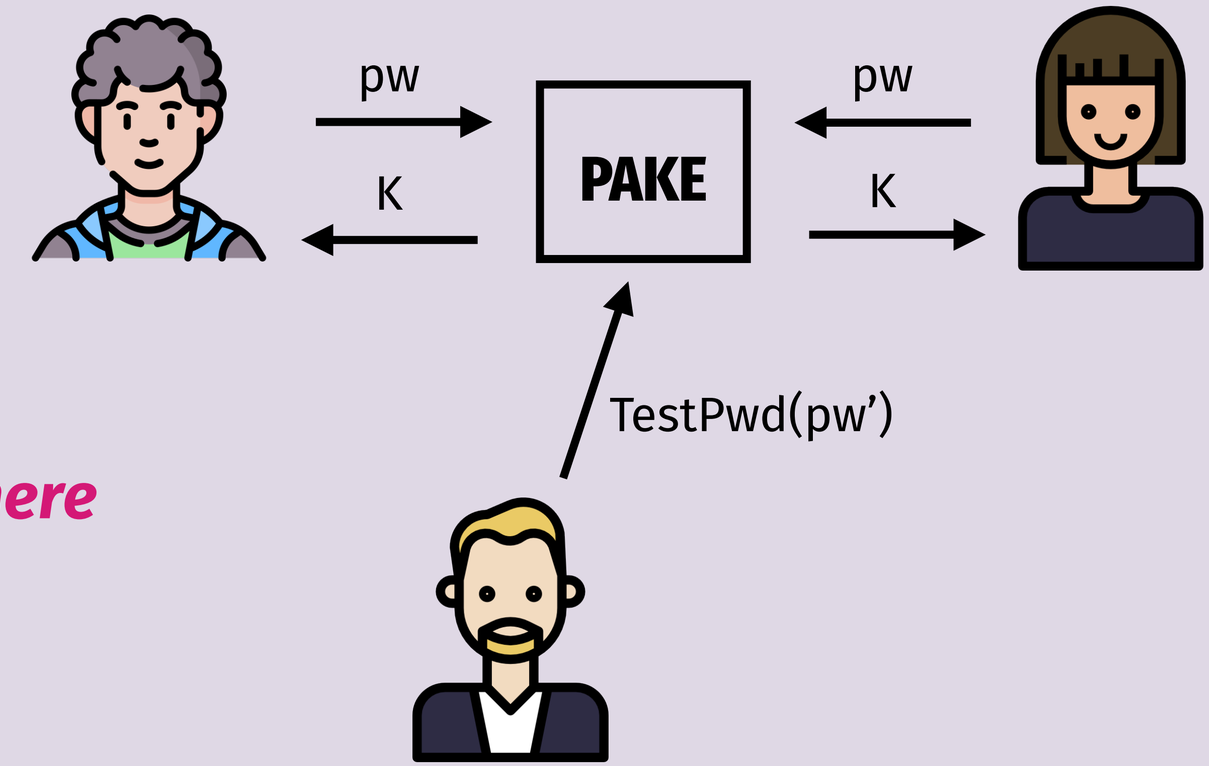
A PAKE combiner takes 2 PAKEs and produces a new PAKE

Weird! Cryptographic statements where nothing is high entropy!



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proof flawed (Appx. A.1)
result incorrect (Sects. 3.2 and 3.3, Appx. A.4)
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How do you make a hybrid PAKE?

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Our Contributions

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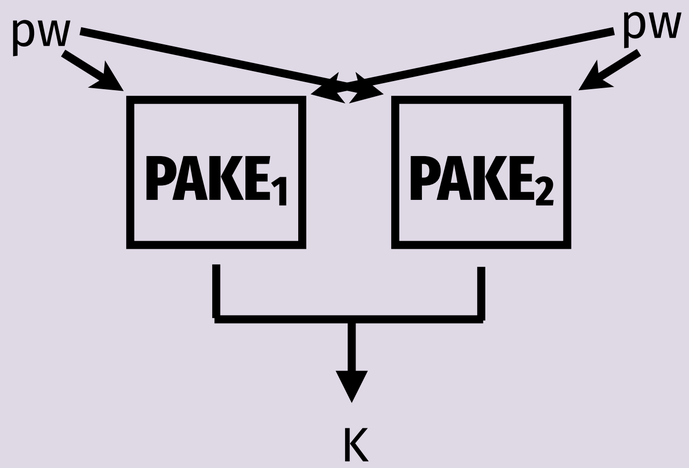
Parallel combiner (ParComb)



1-round PAKE + 1-round PAKE ⇒ 1-round PAKE

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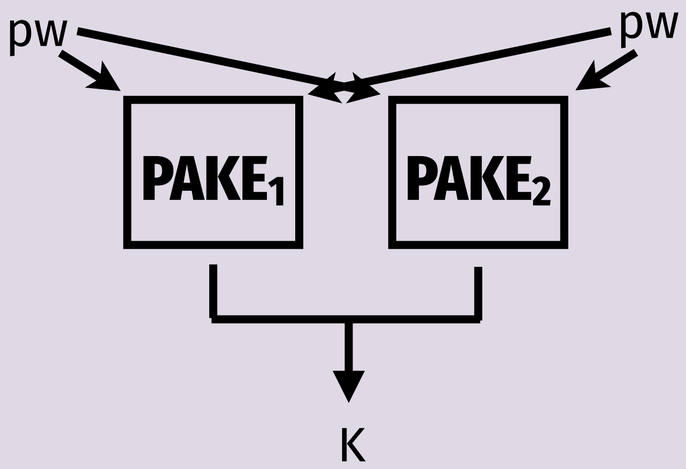

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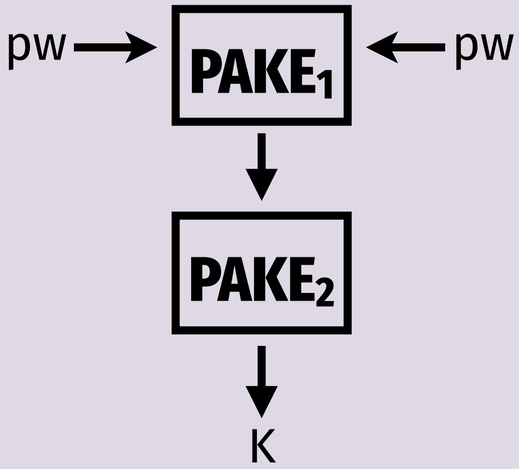

1-round PAKE + N-round PAKE ⇒ (N+1)-round PAKE

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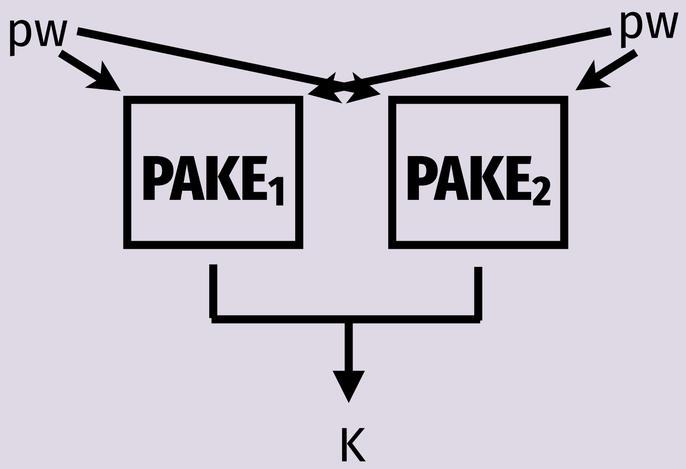

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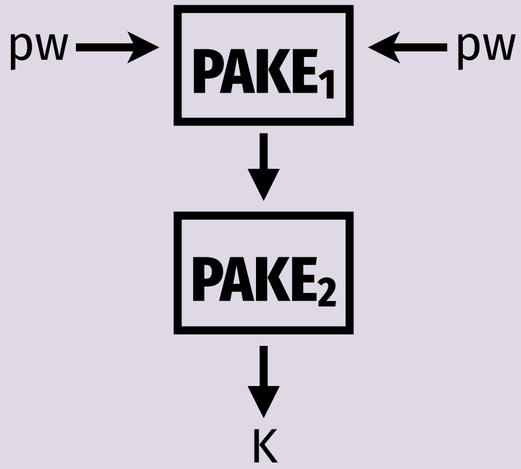

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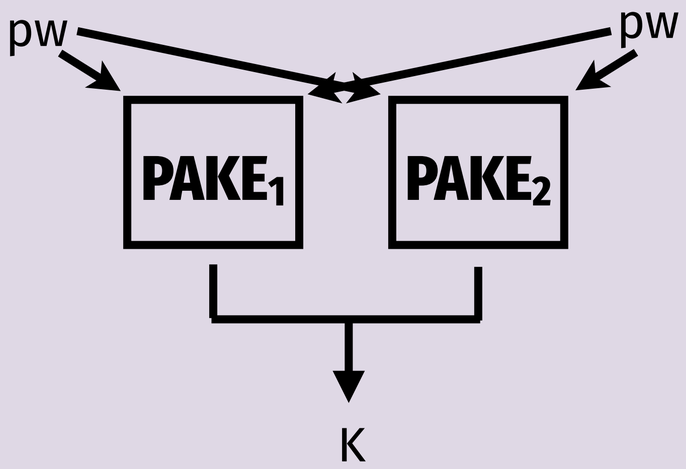

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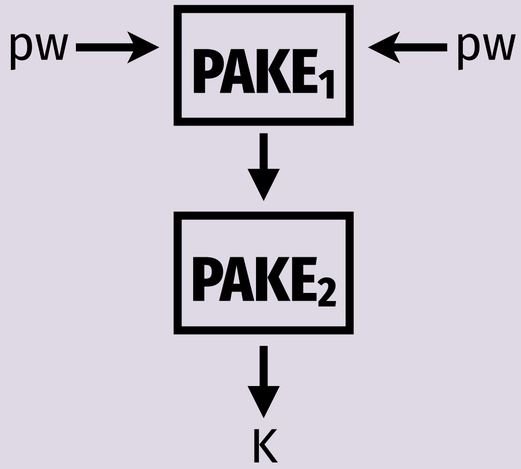

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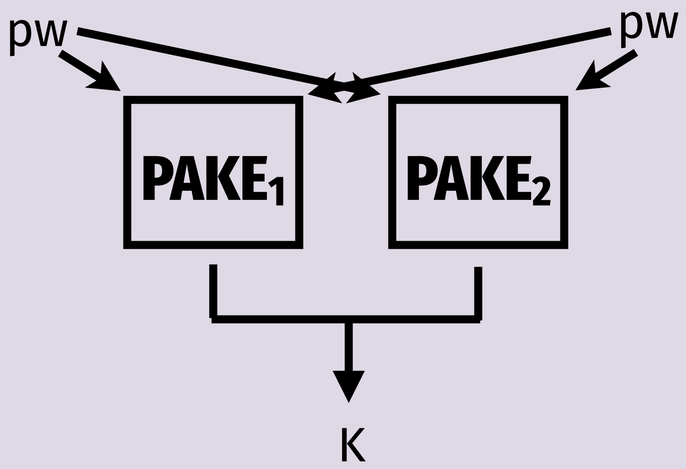

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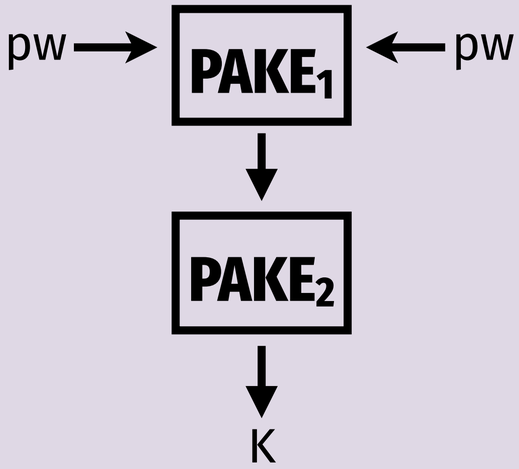

1-round PAKE + N-round PAKE ⇒ (N+1)-round PAKE

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Yields other PAKE flavors: PAKE ⇒ aPAKE, iPAKE

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KEM combiners: just run 2 KEMs and hash the outputs

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EKE w/ key conf.

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Diffie-Hellman with pw-encrypted shares

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Diffie-Hellman with pw-encrypted shares

$r \leftarrow \mathbb{F}$

$R' := \mathrm{Enc}_{pw}(rG)$

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Diffie-Hellman with

$r \leftarrow \mathbb{F}$

$R' := \mathrm{Enc}_{pw}(rG)$ **pw-encrypted shares**

keyed permutation

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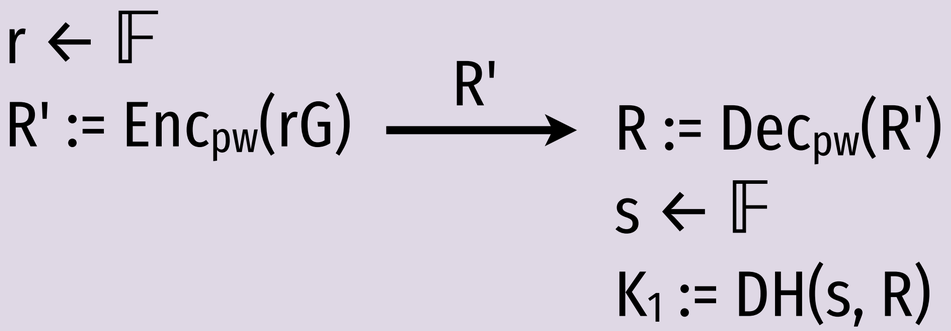

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$r \leftarrow \mathbb{F}$

$R' := \mathrm{Enc}_{pw}(rG)$ —R'→ $R := \mathrm{Dec}_{pw}(R')$

$s \leftarrow \mathbb{F}$

$K_1 := \mathrm{DH}(s, R)$

$S' := \mathrm{Enc}_{pw}(sG)$

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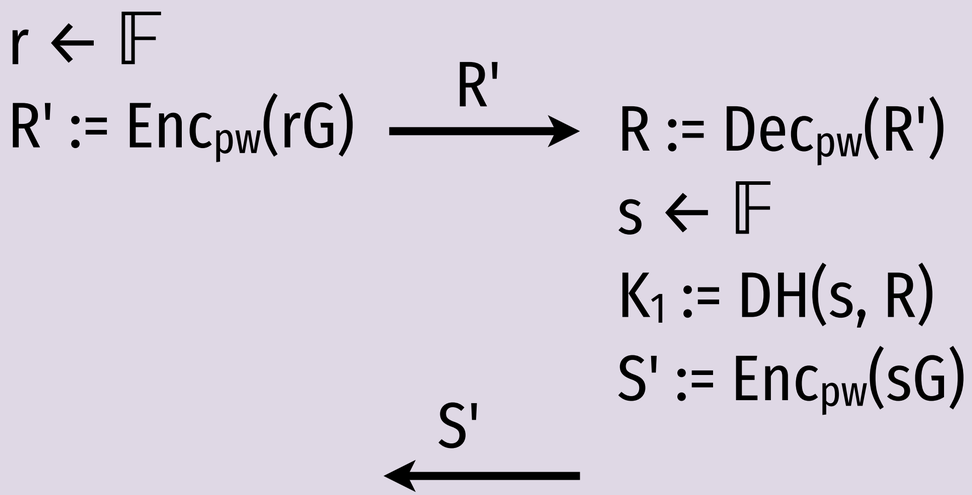

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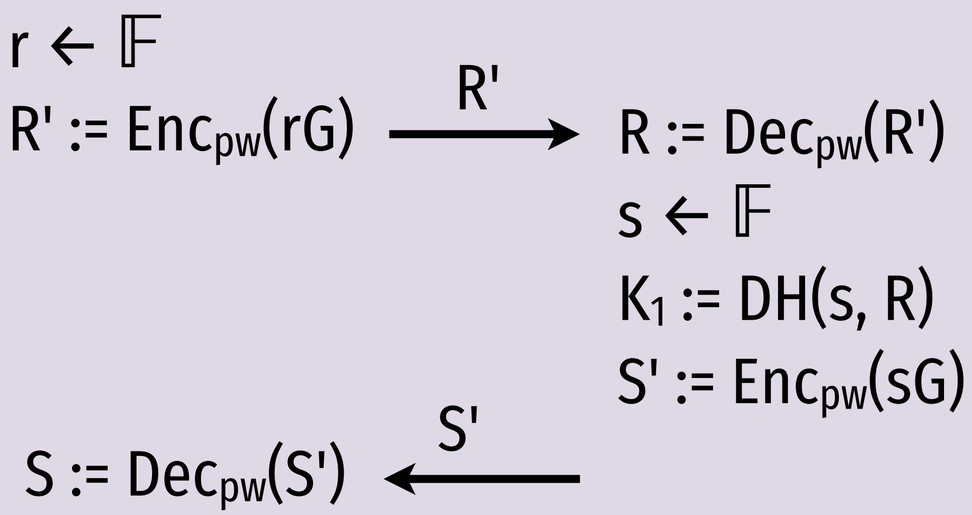

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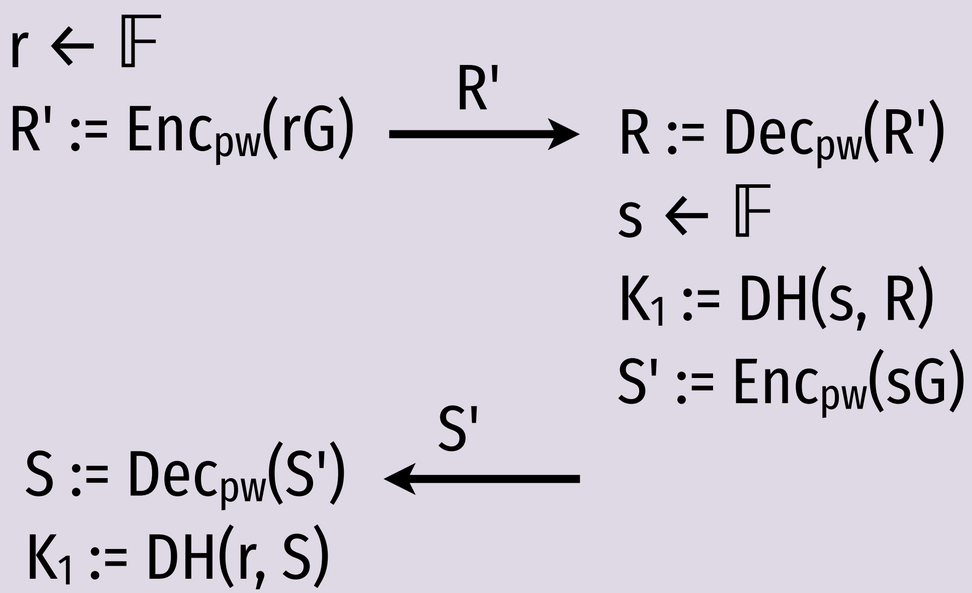

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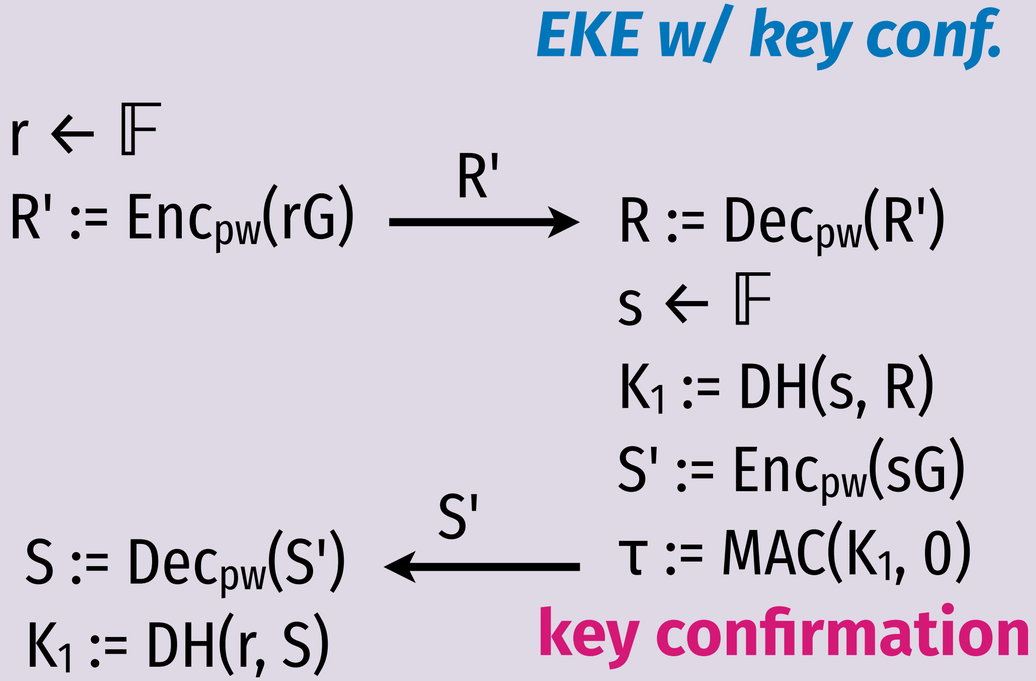

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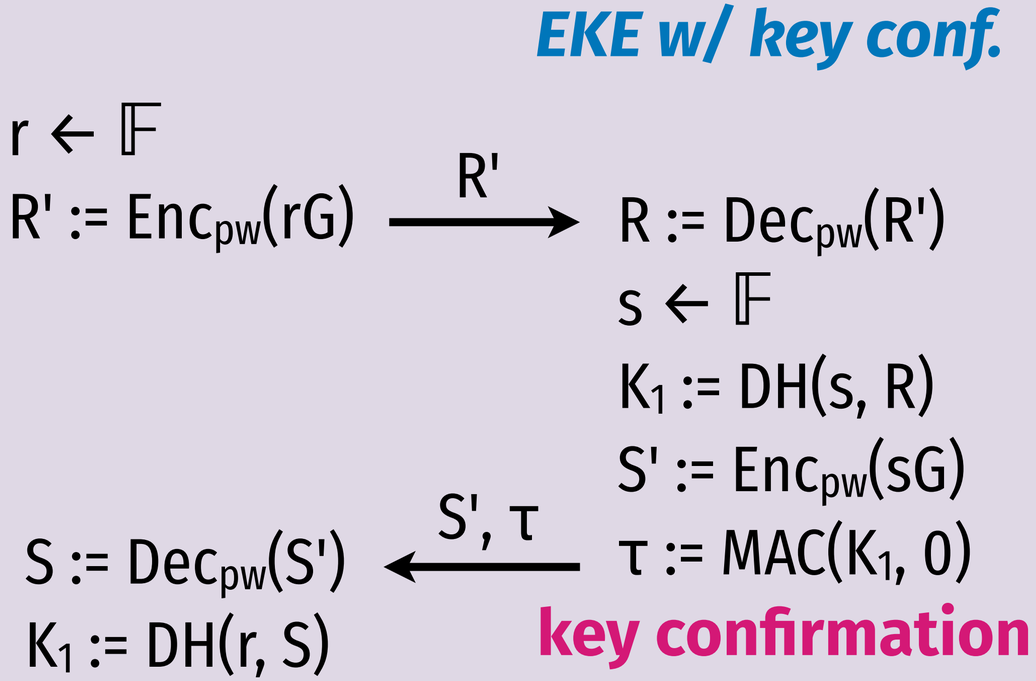

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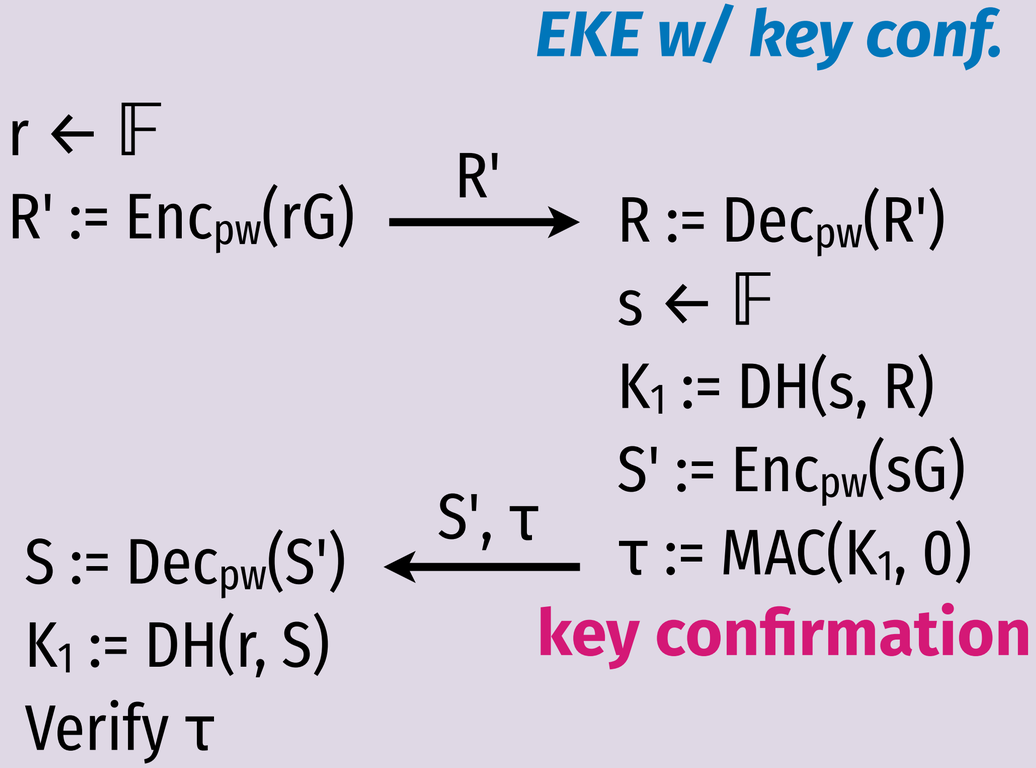

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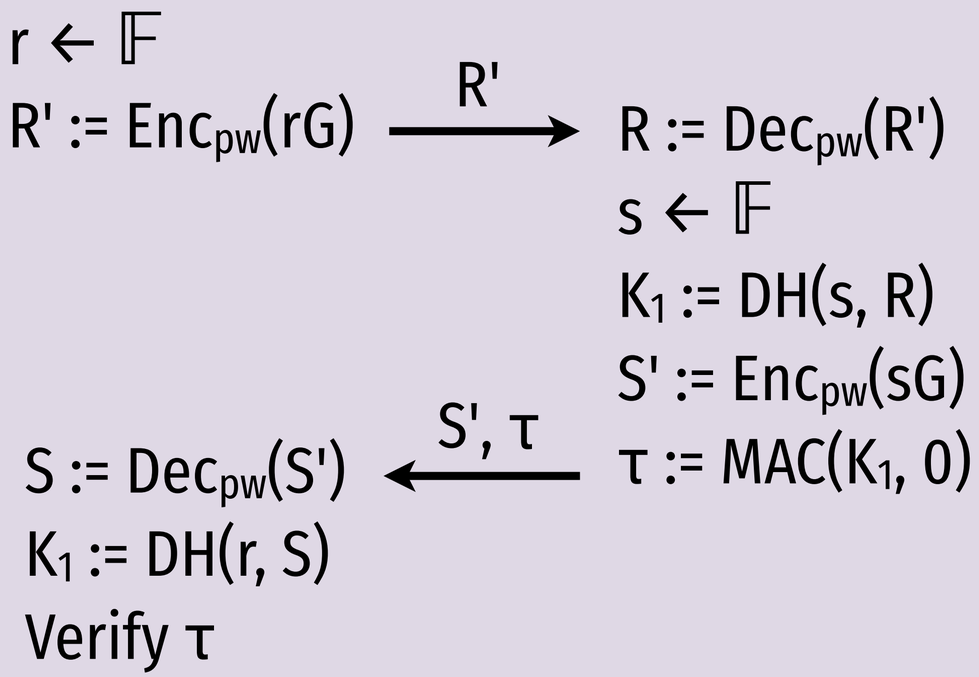

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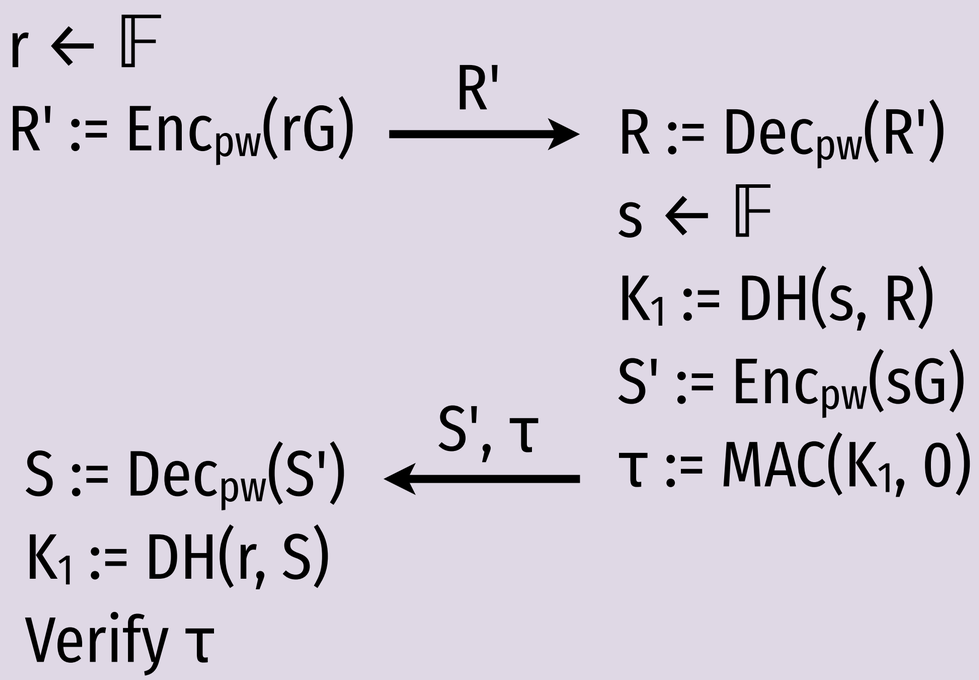

CAKE (KEM-based) w/ key conf.

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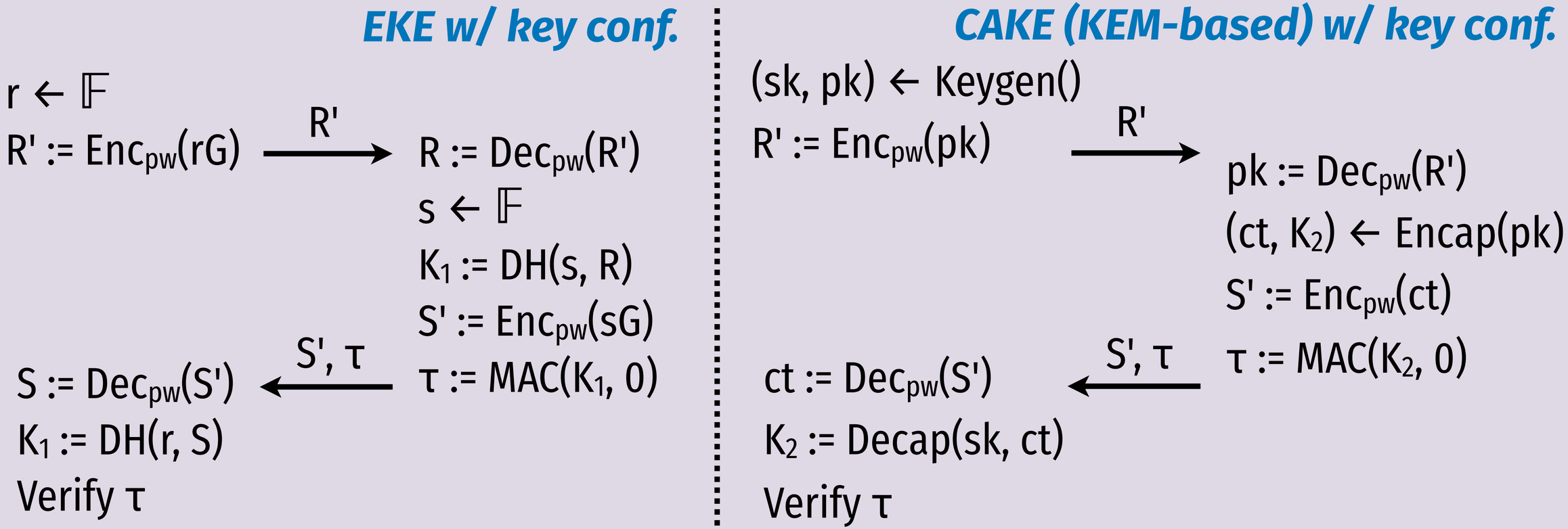

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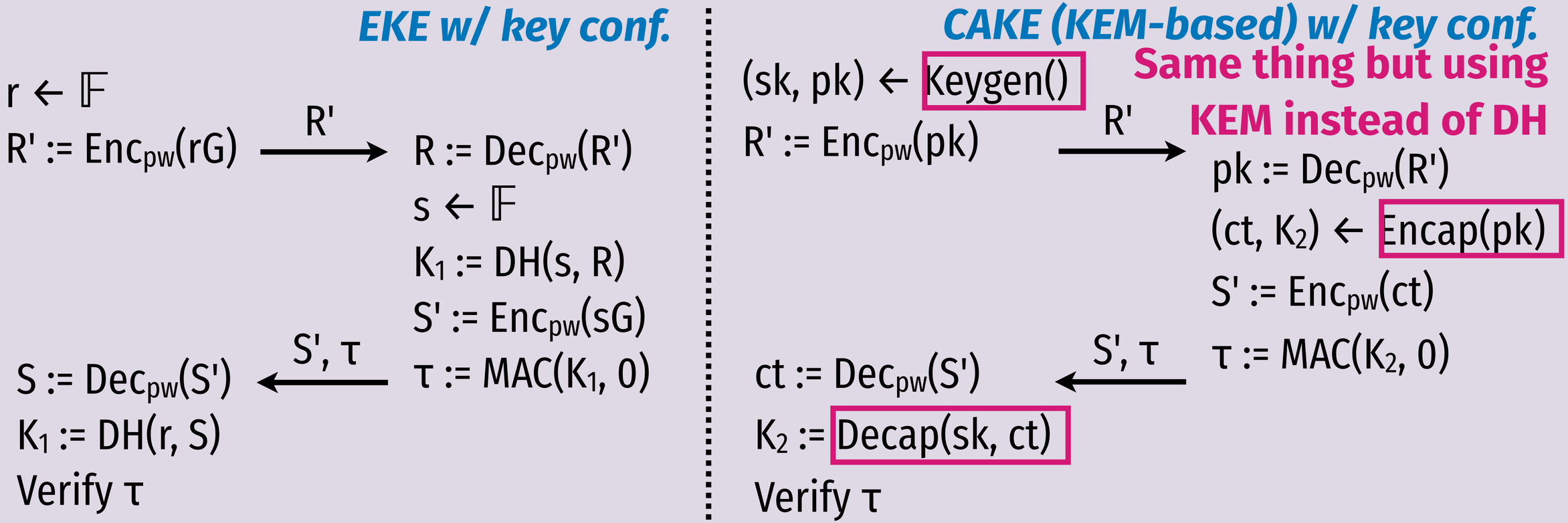

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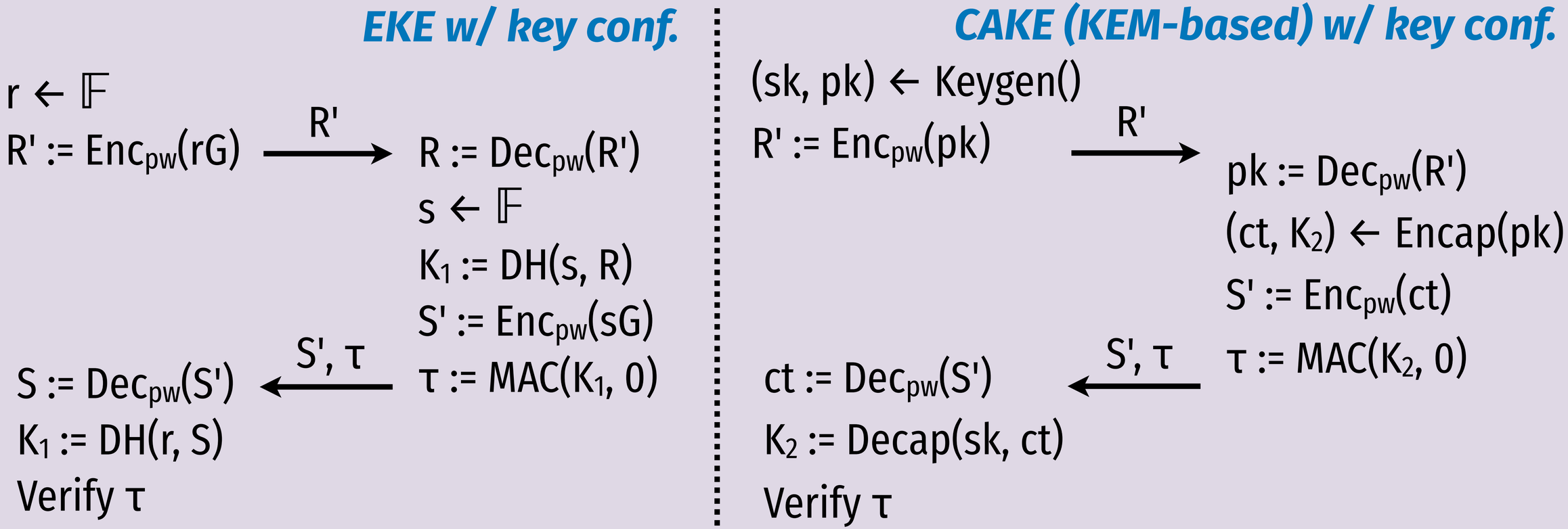

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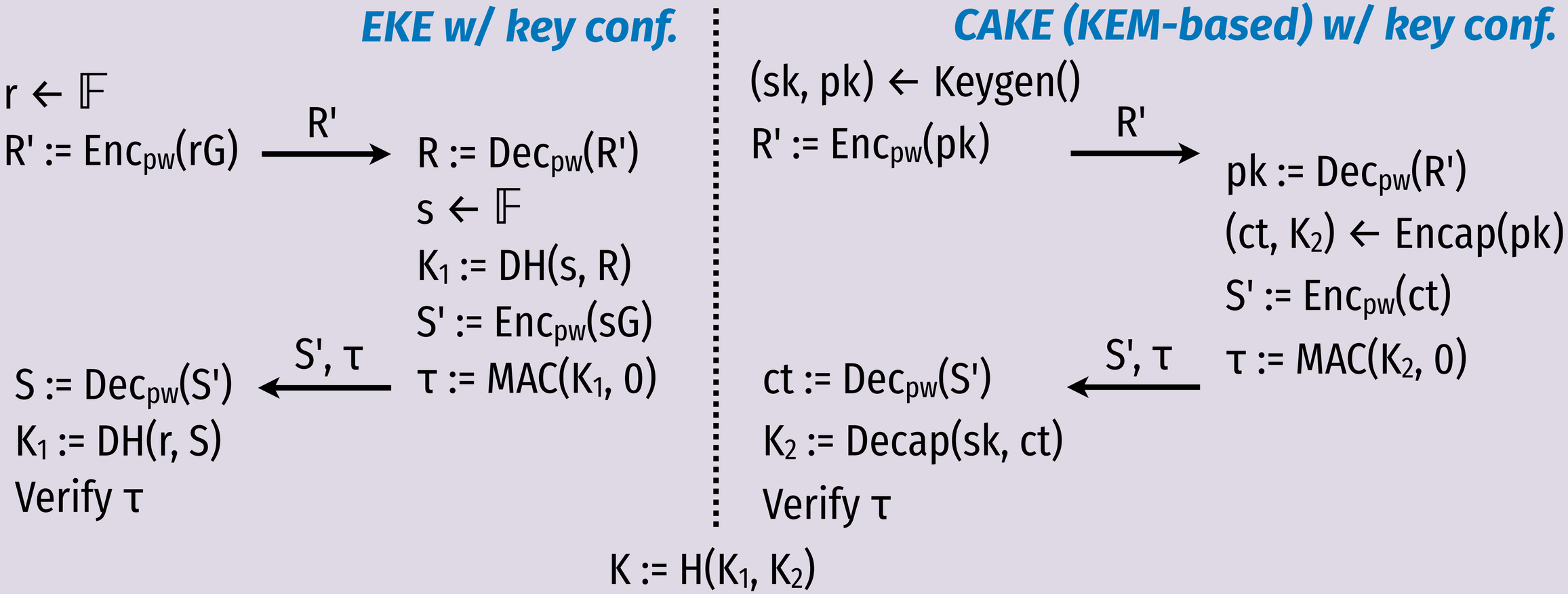

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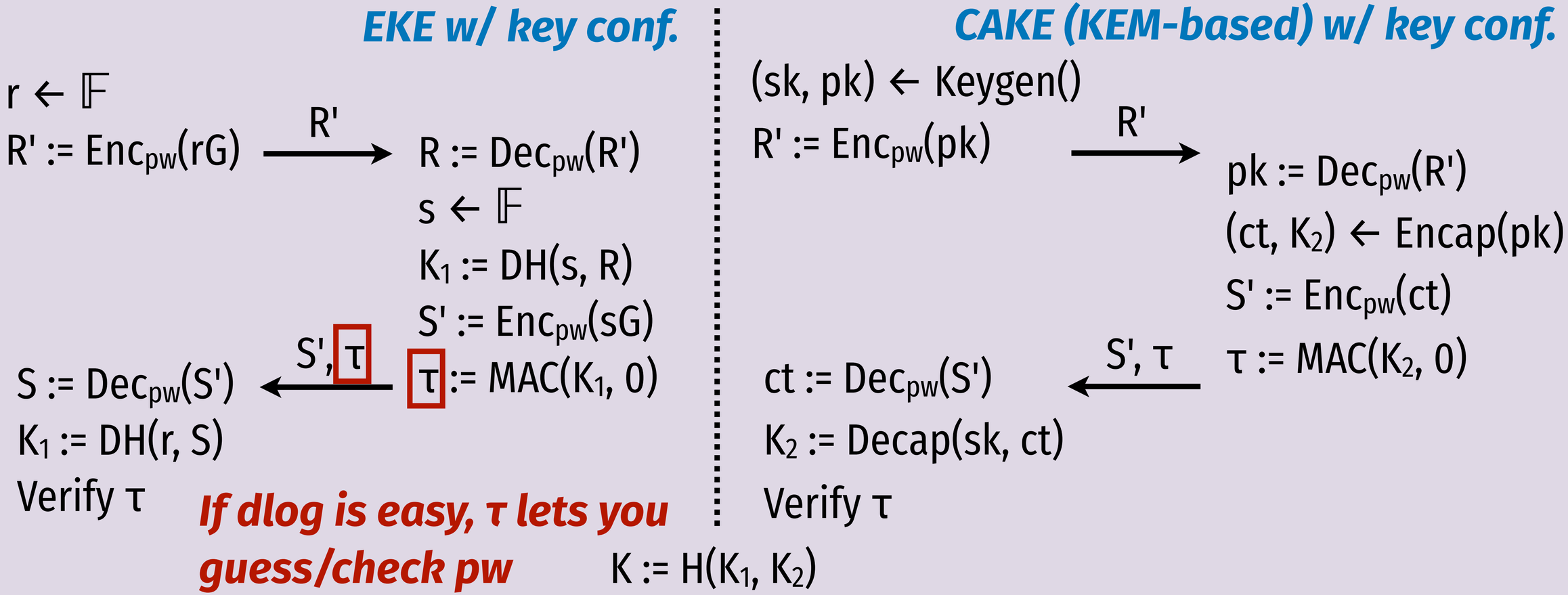

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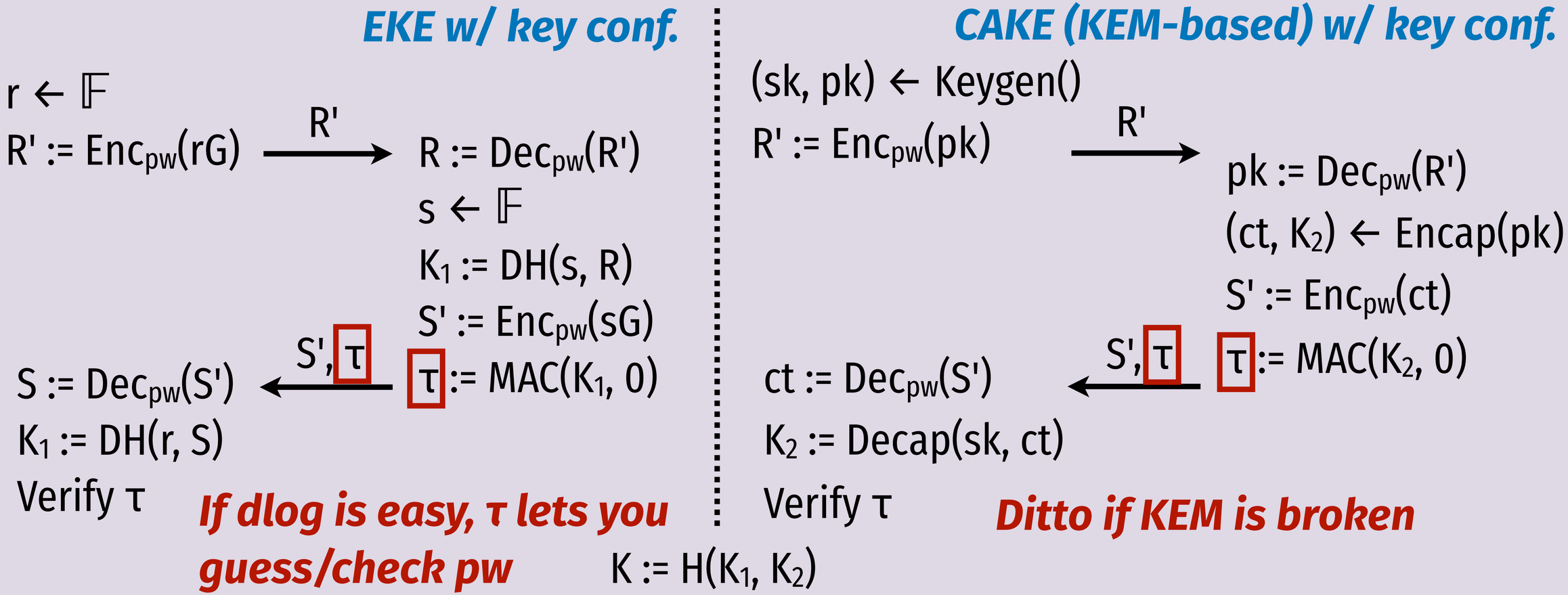

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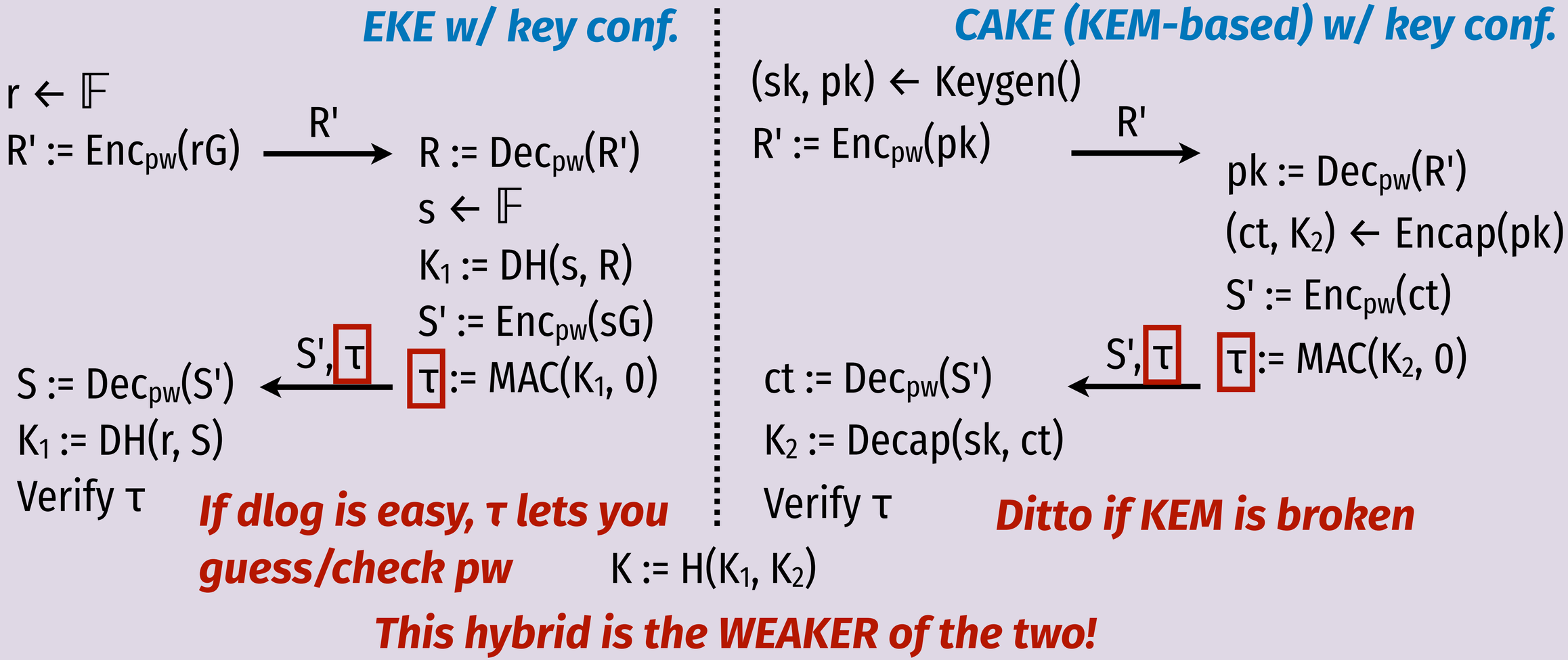

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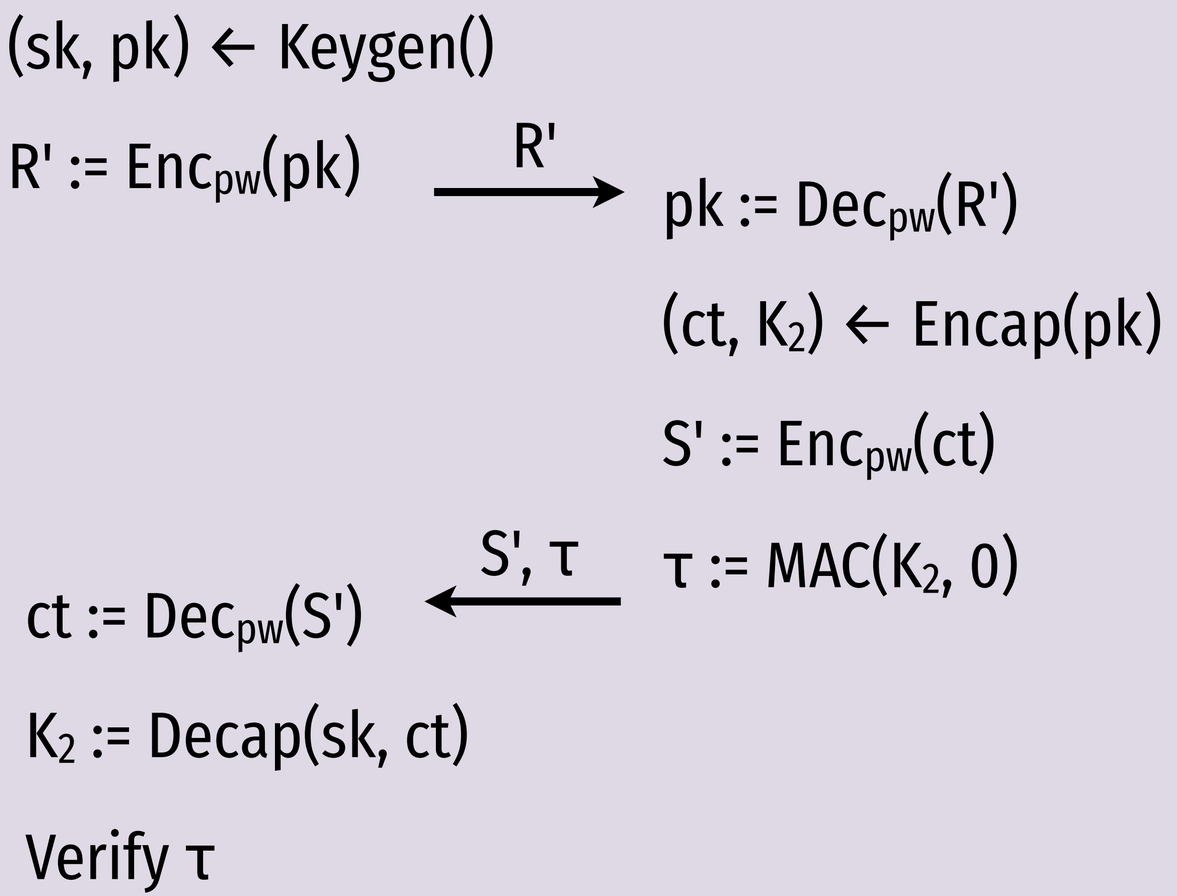
CAKE (KEM-based) with key conf.



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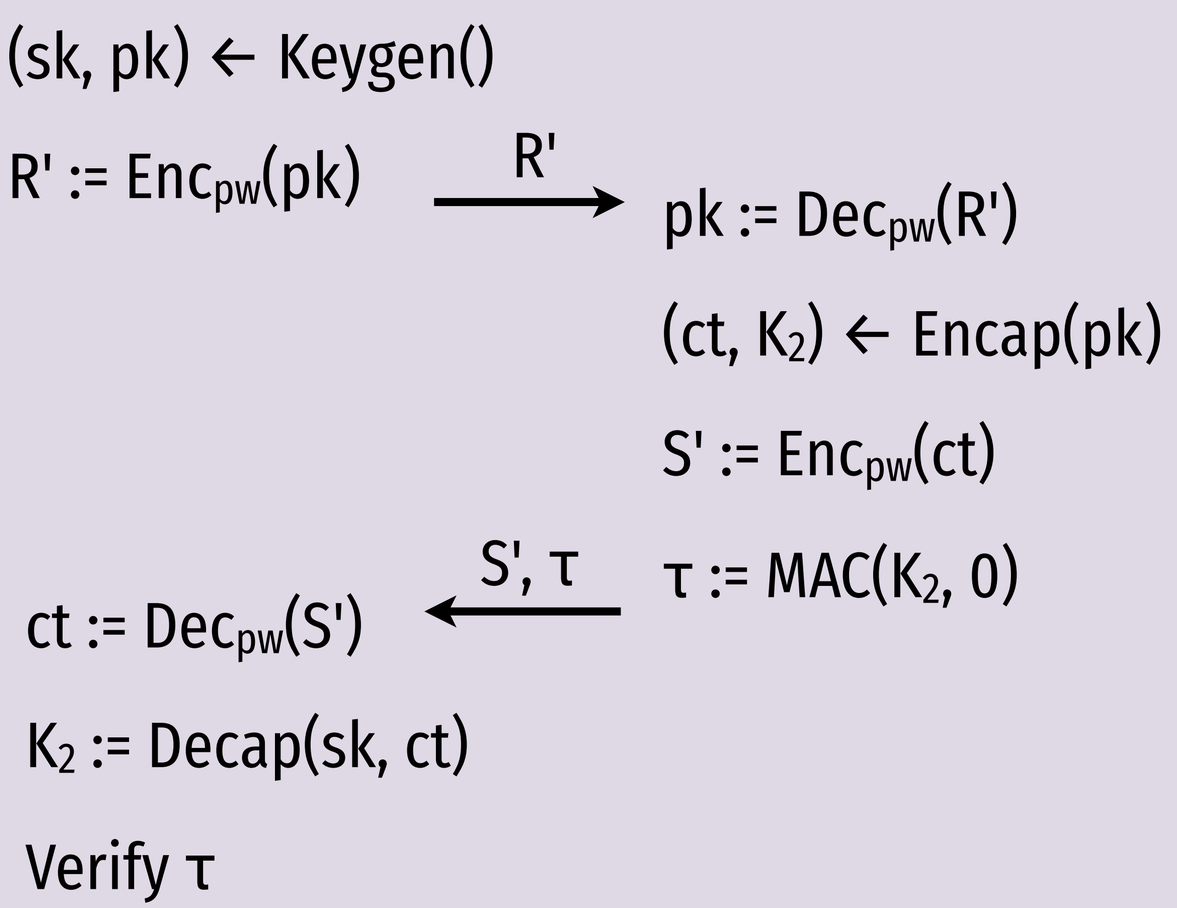

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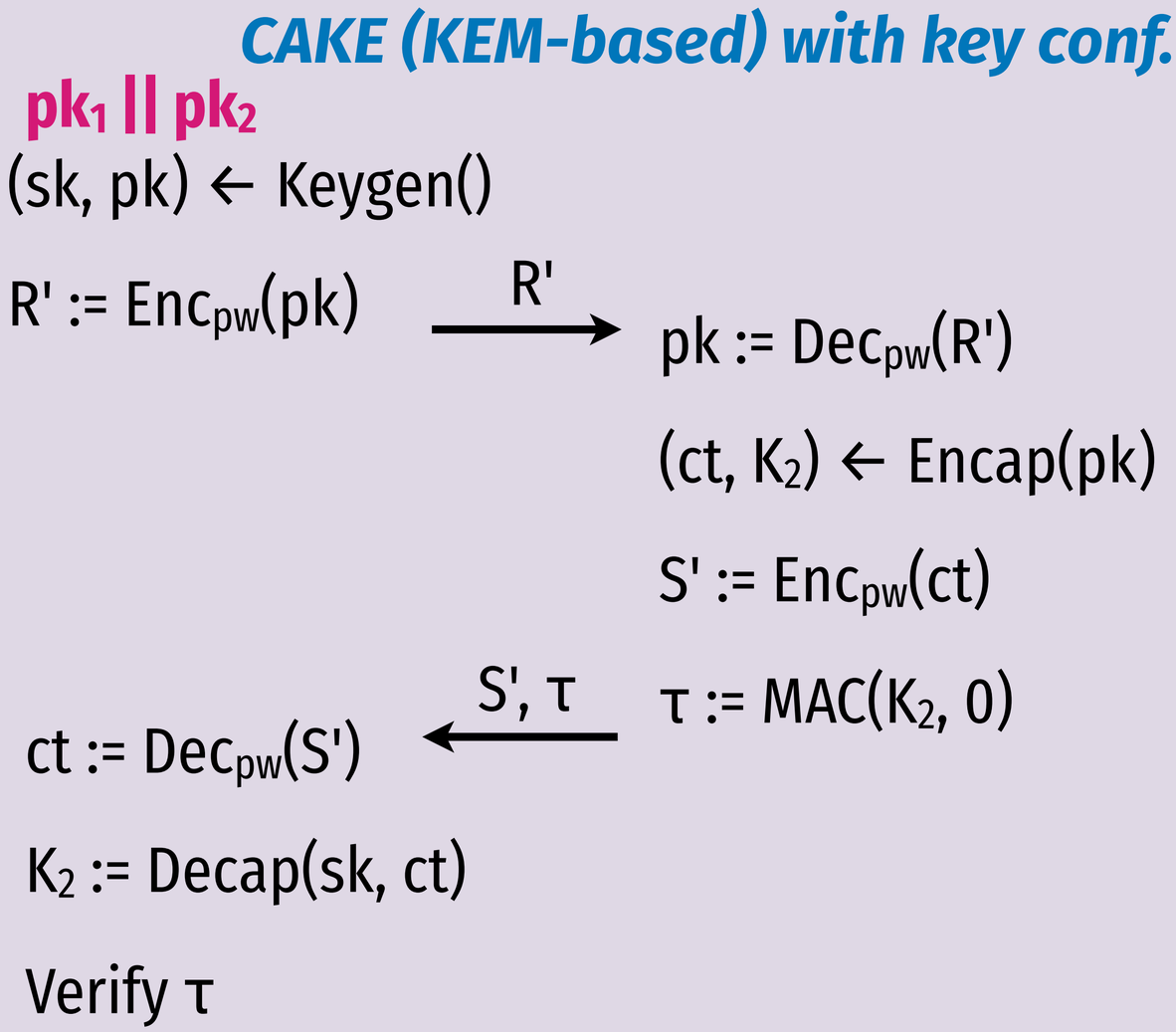

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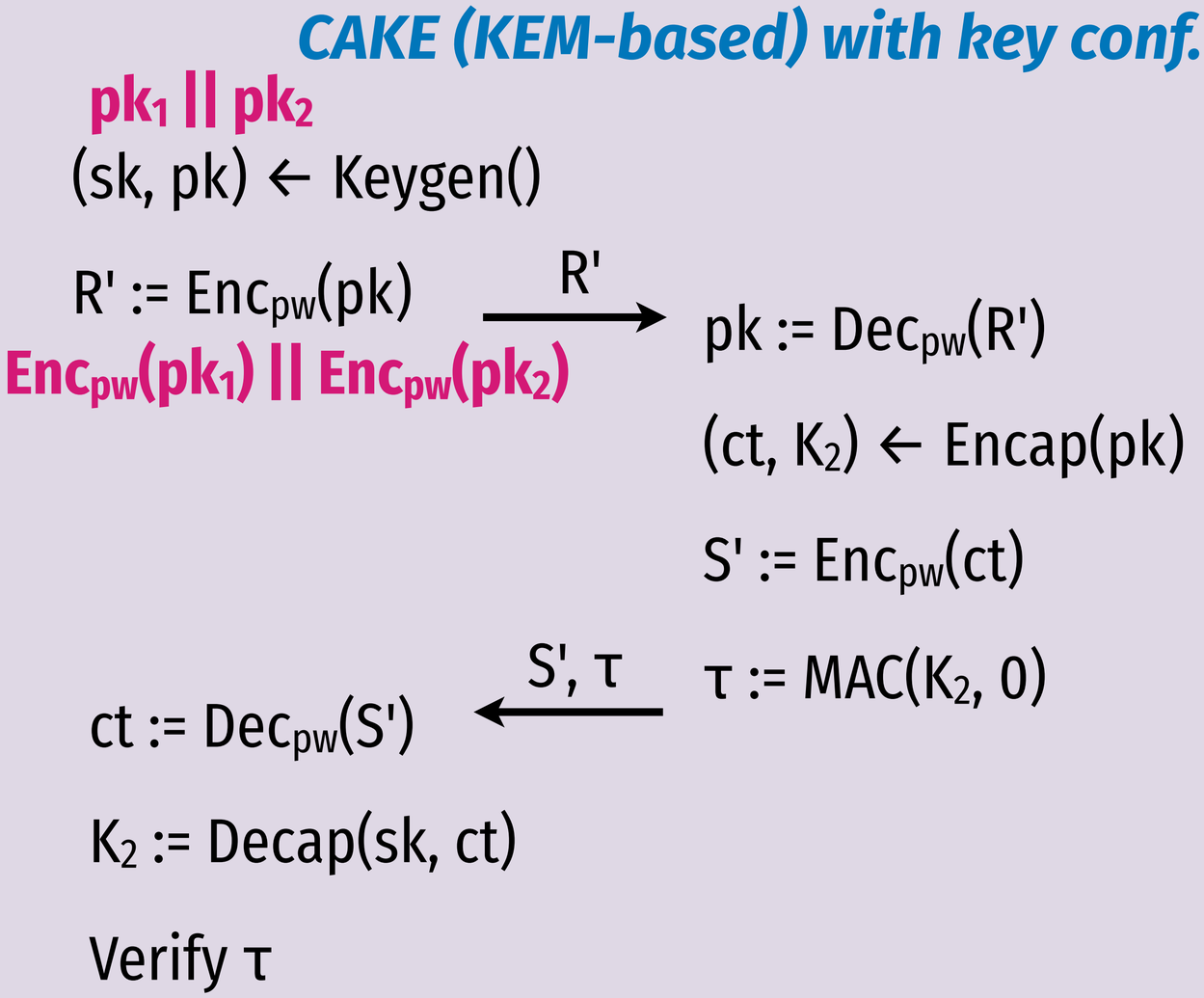

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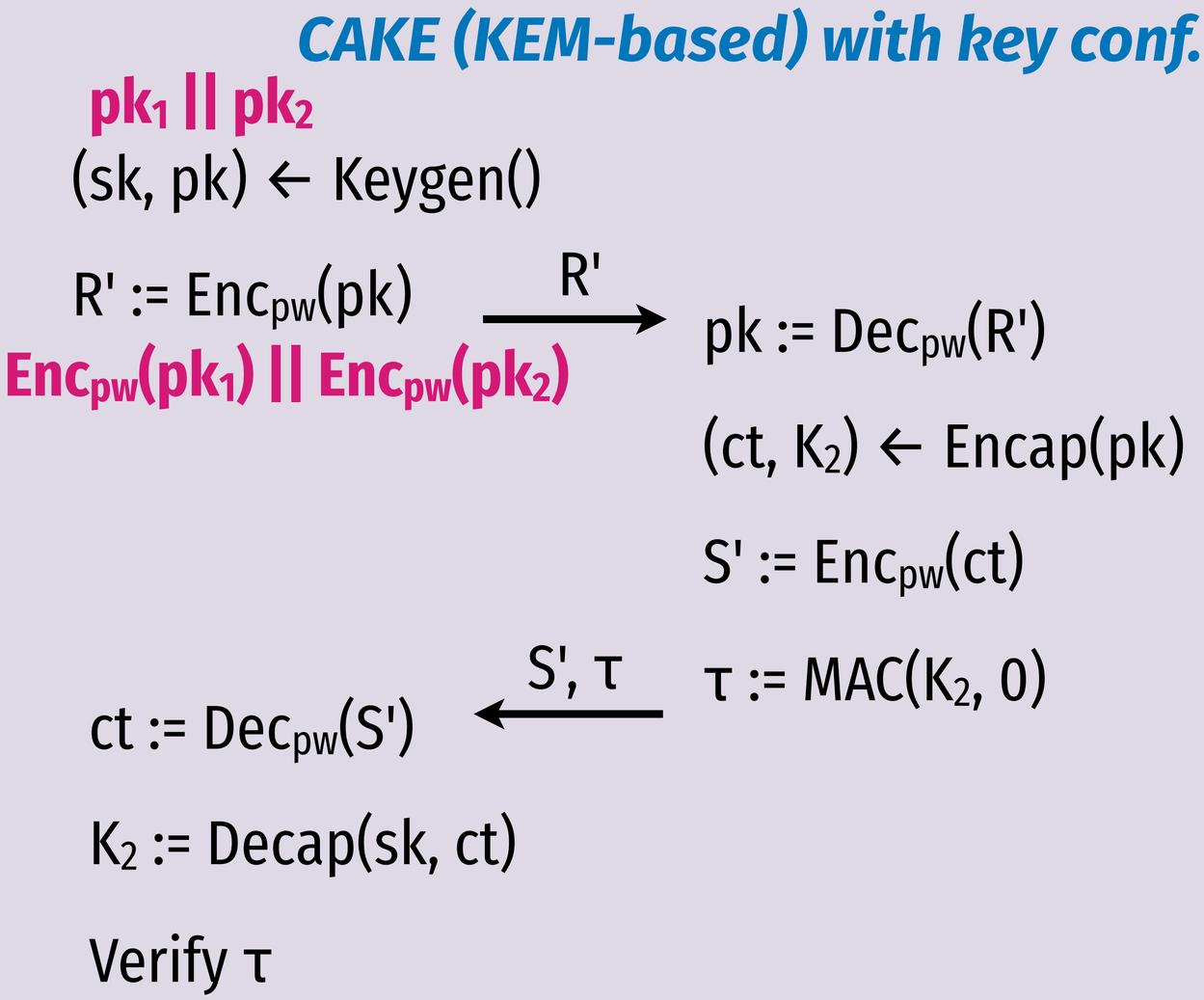

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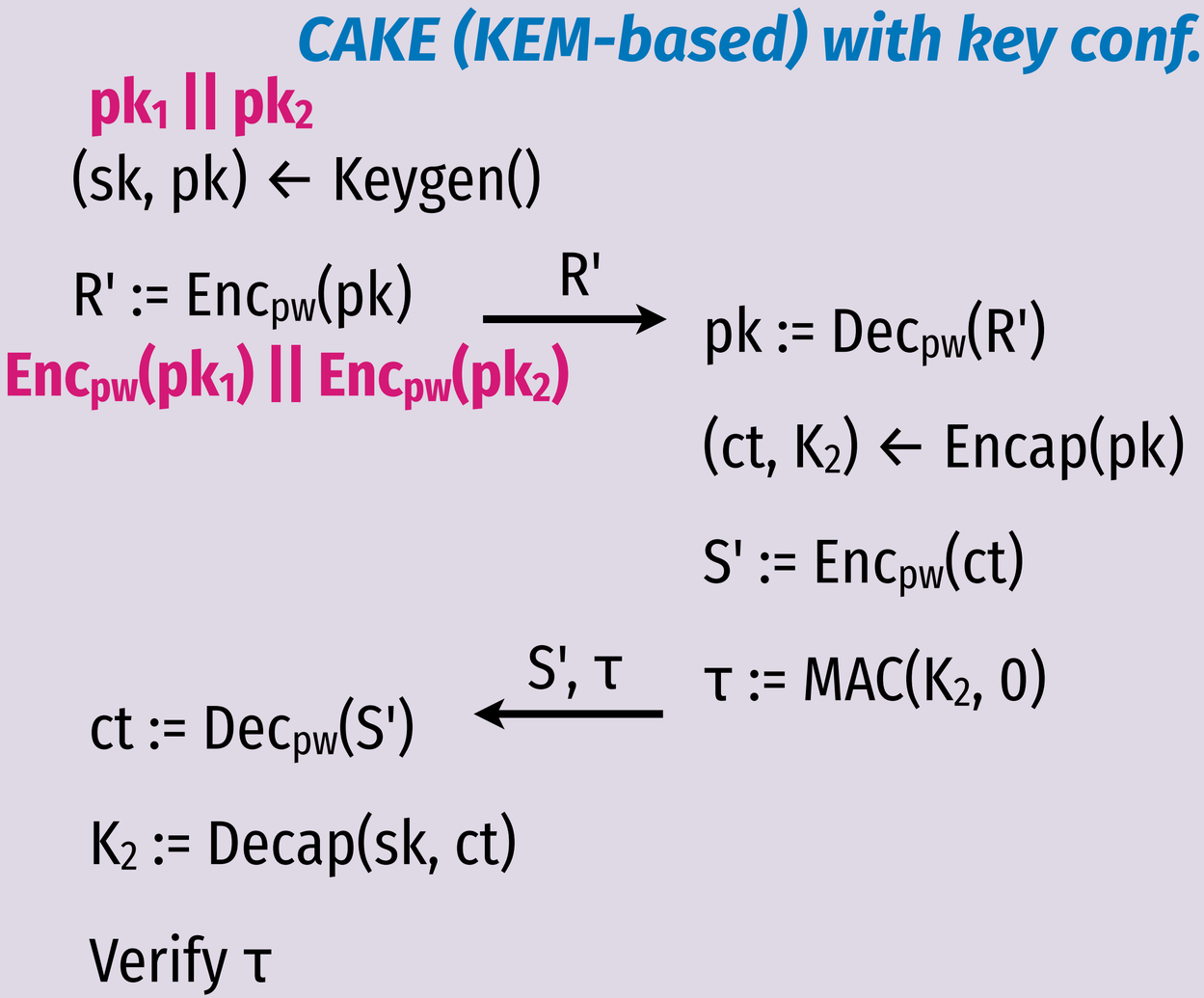


How else not to make a hybrid PAKE

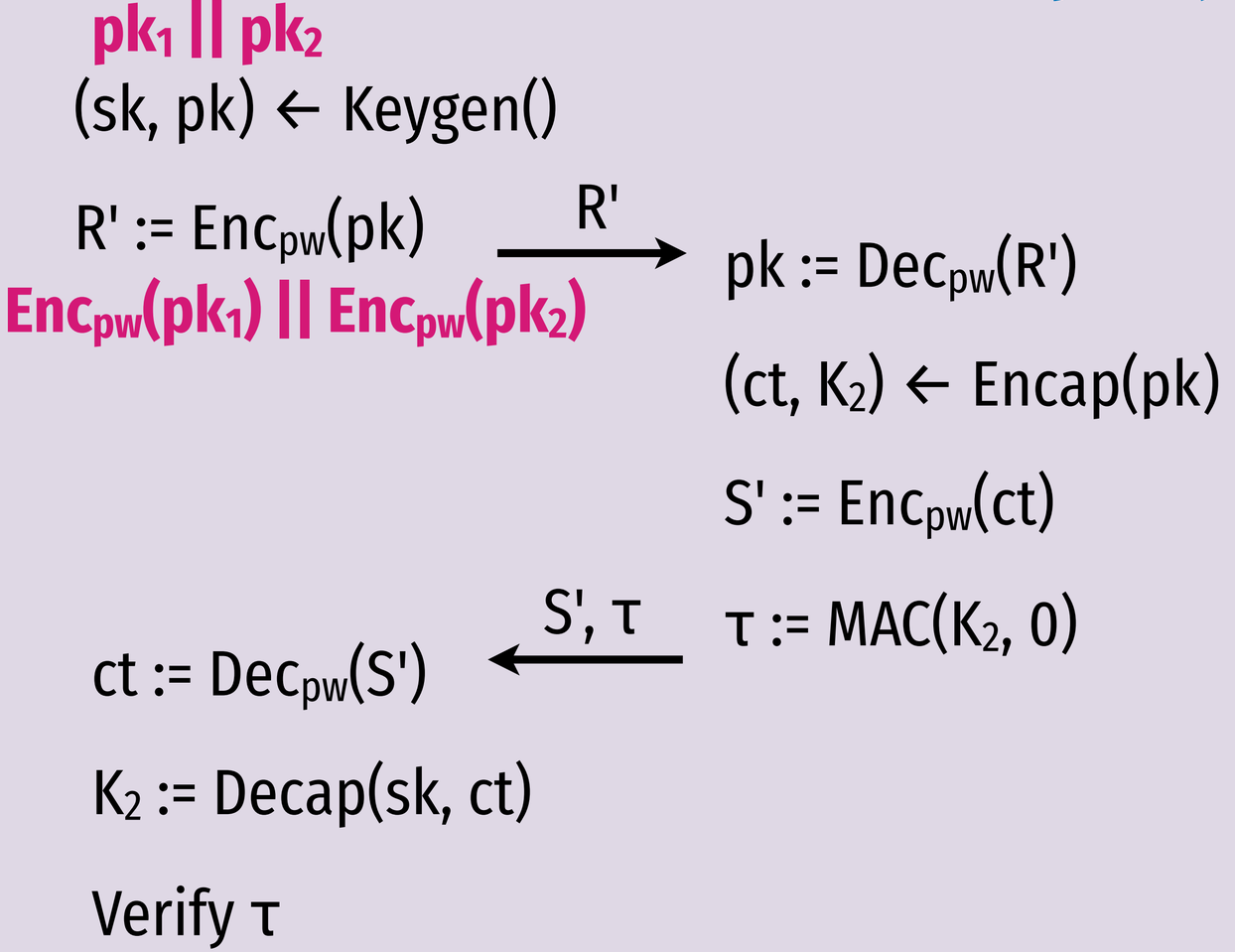
CAKE is KEM-based. Just use a **hybrid KEM**

Suppose pk_1 is an LWE sample

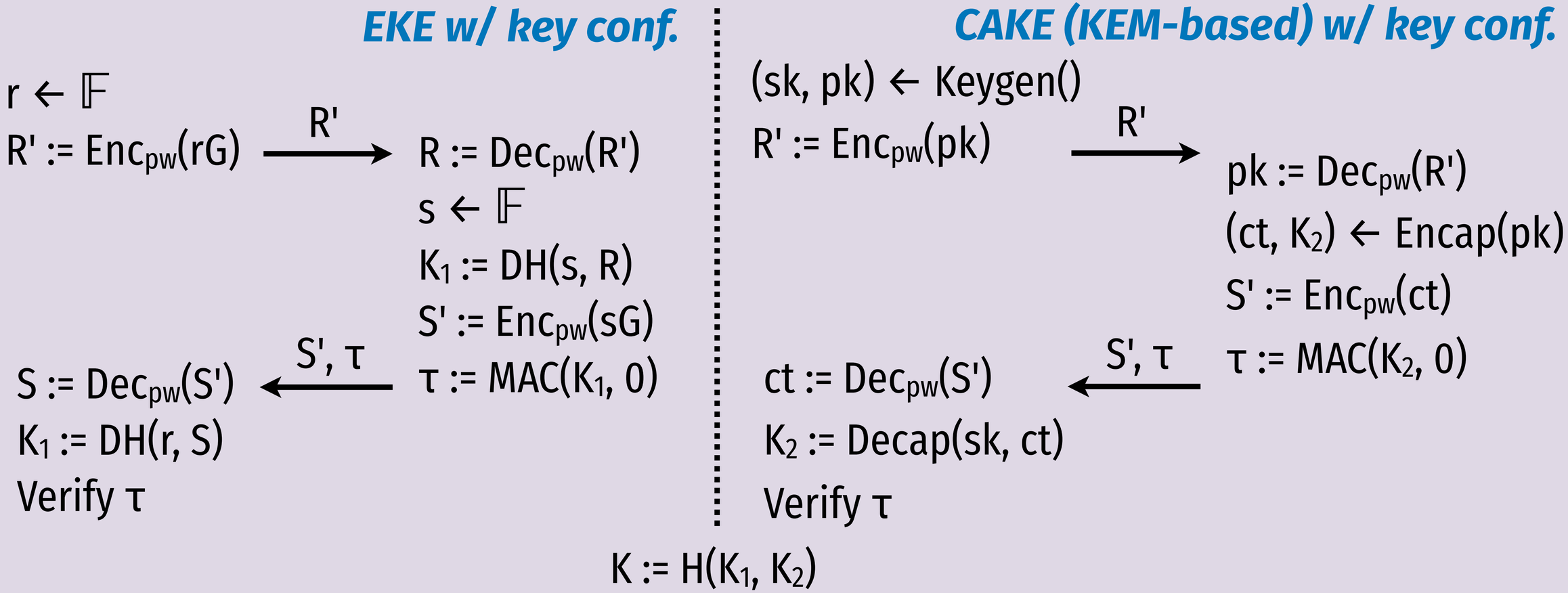
With an LWE oracle, $Enc_{pw}(pk_1)$ lets you guess/check pw

This hybrid is only as secure as LWE!

CAKE (KEM-based) with key conf.



Building ParComb



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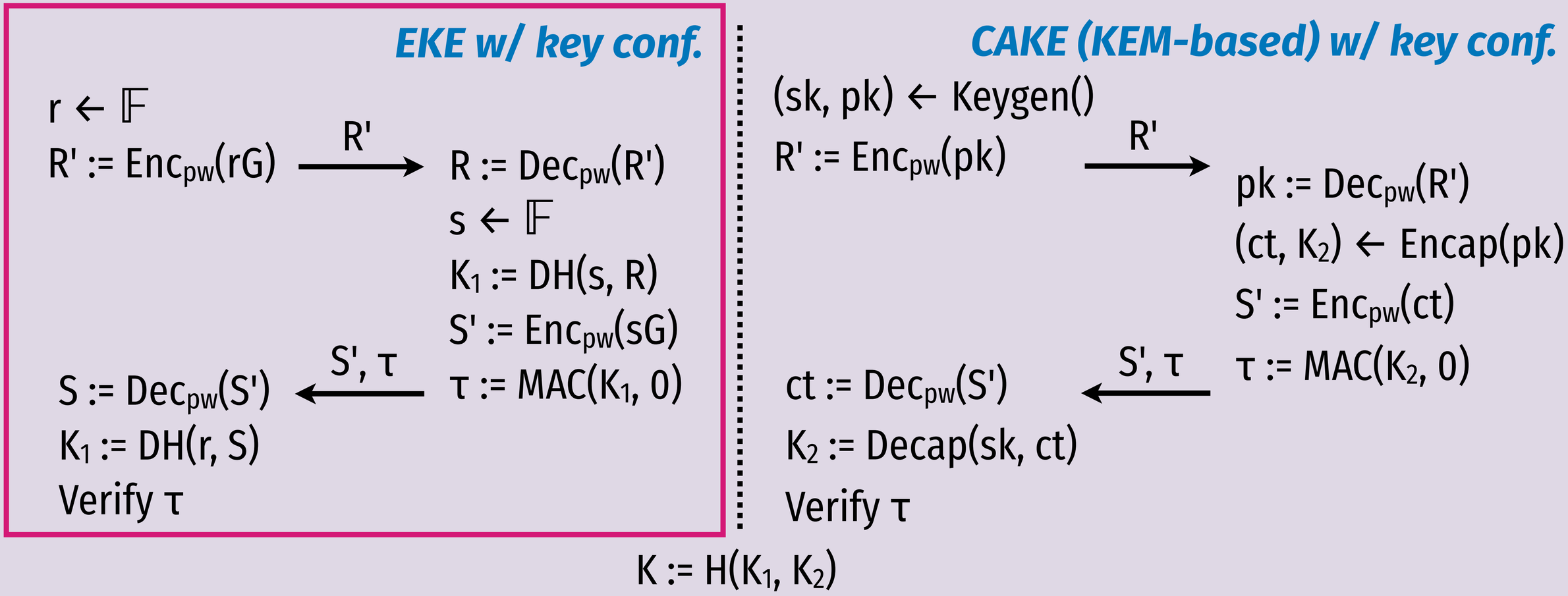

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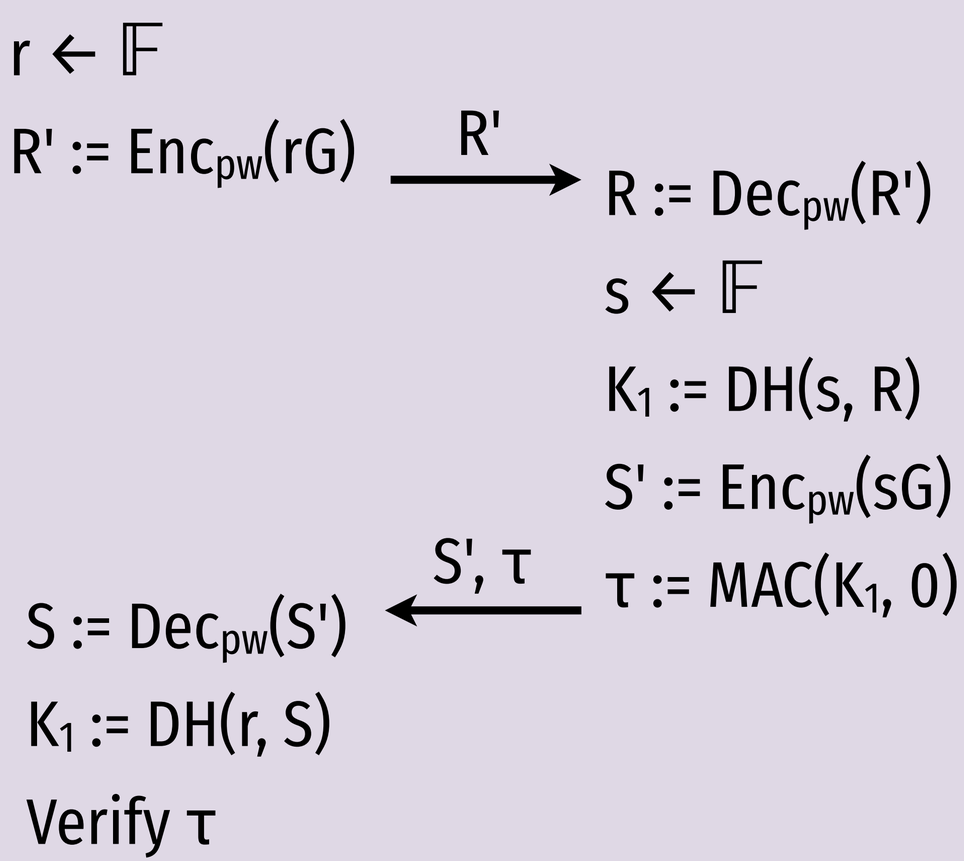
EKE w/ key conf.



Building ParComb

Observation: it seems **τ was the only issue** with the parallel example

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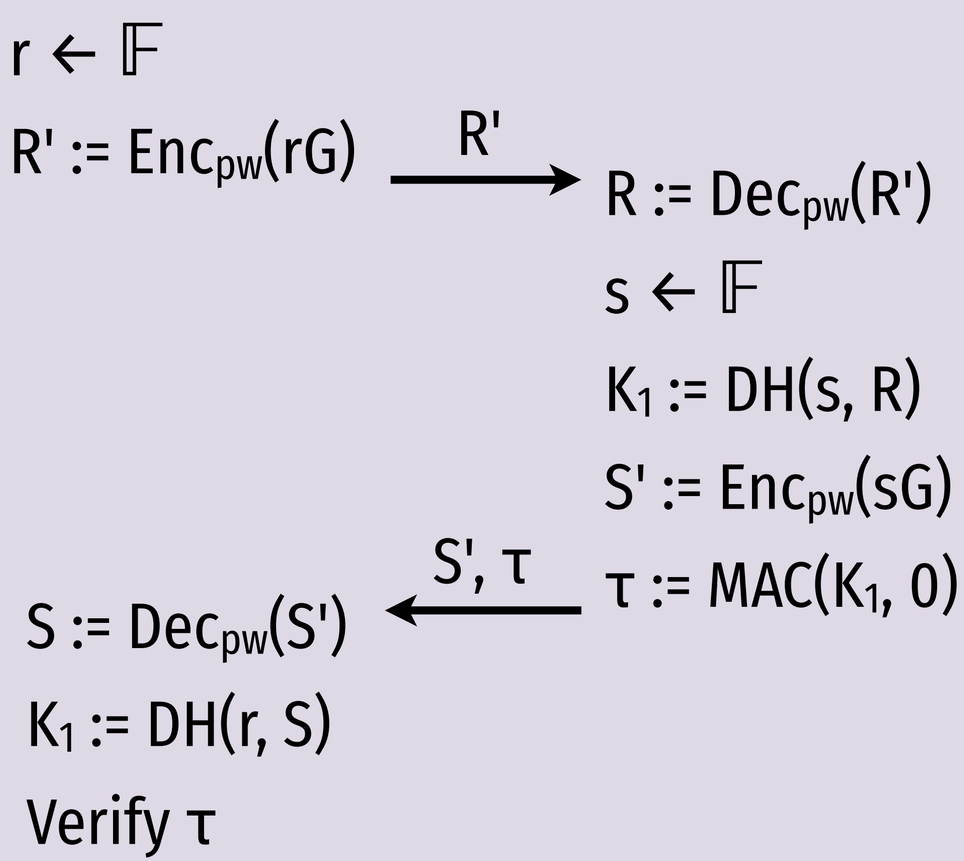

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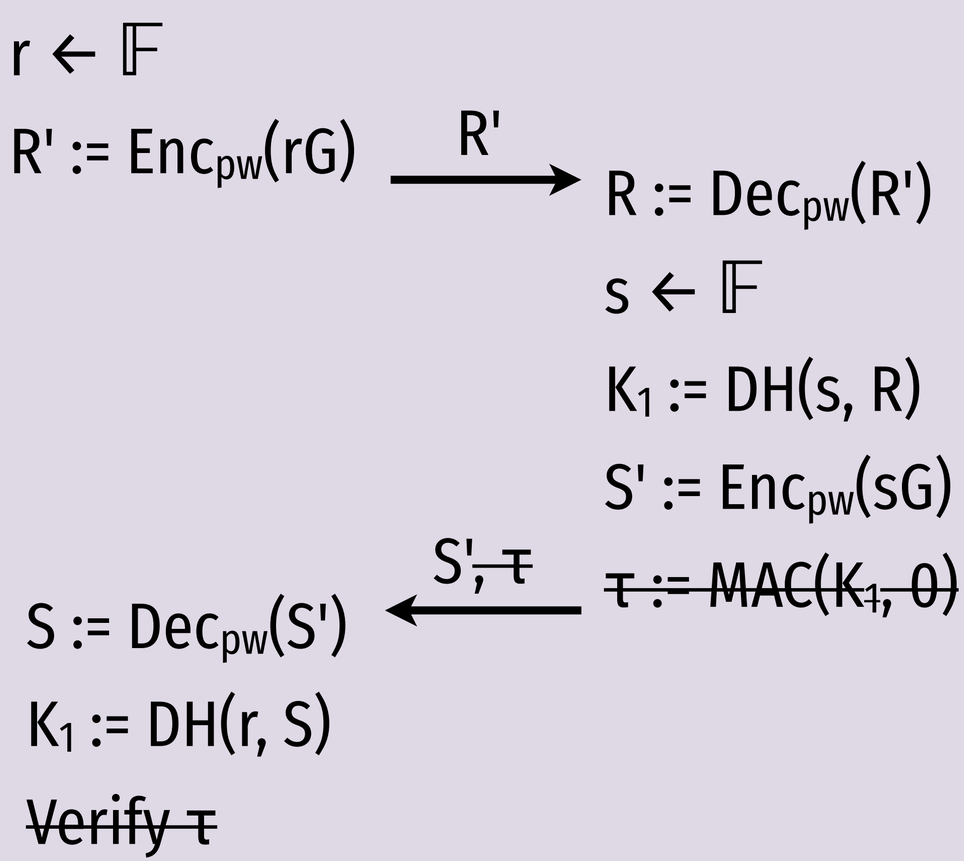

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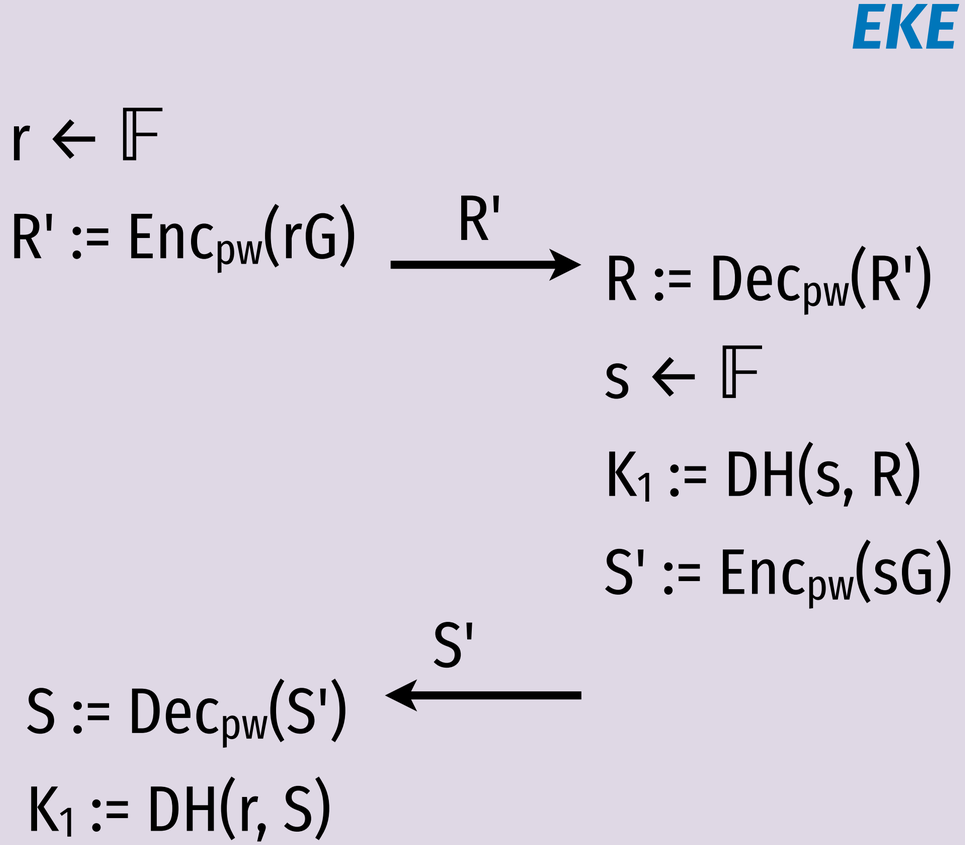

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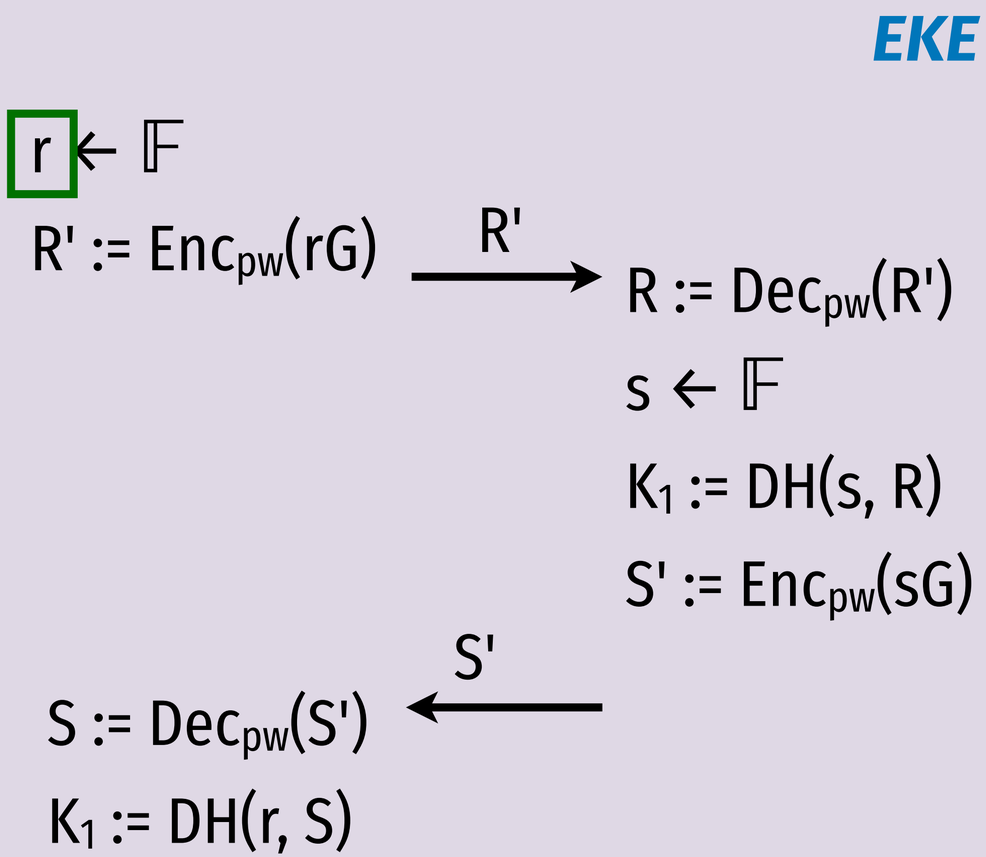

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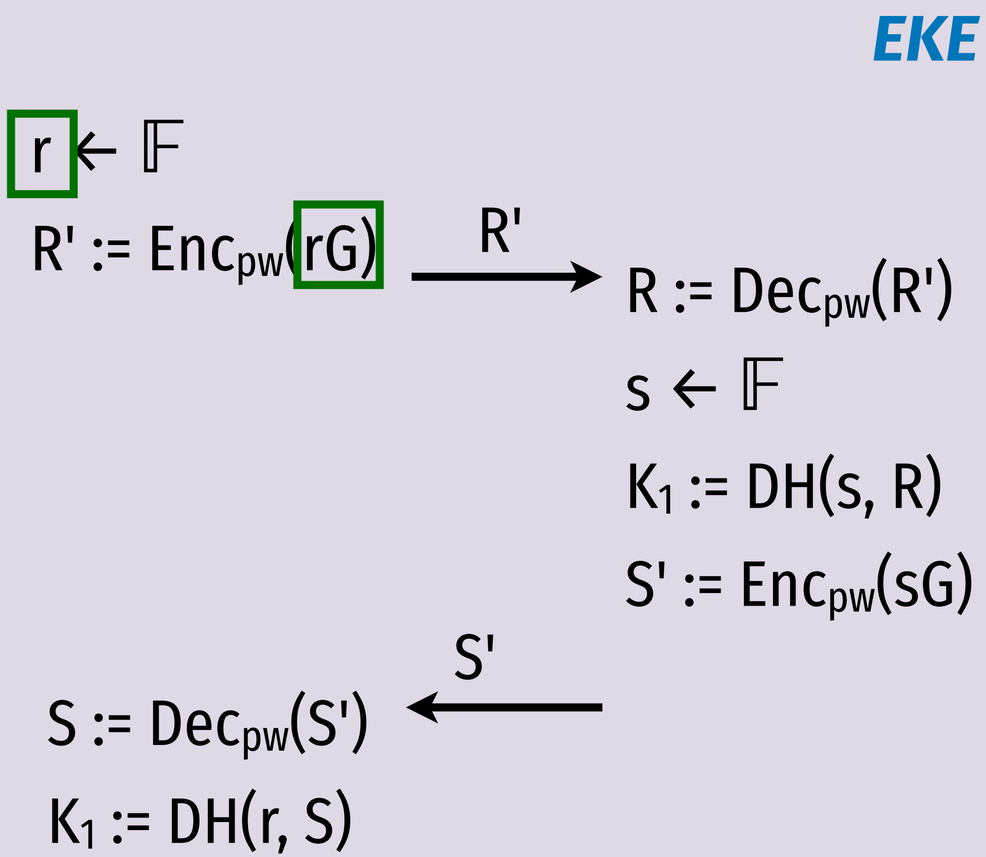

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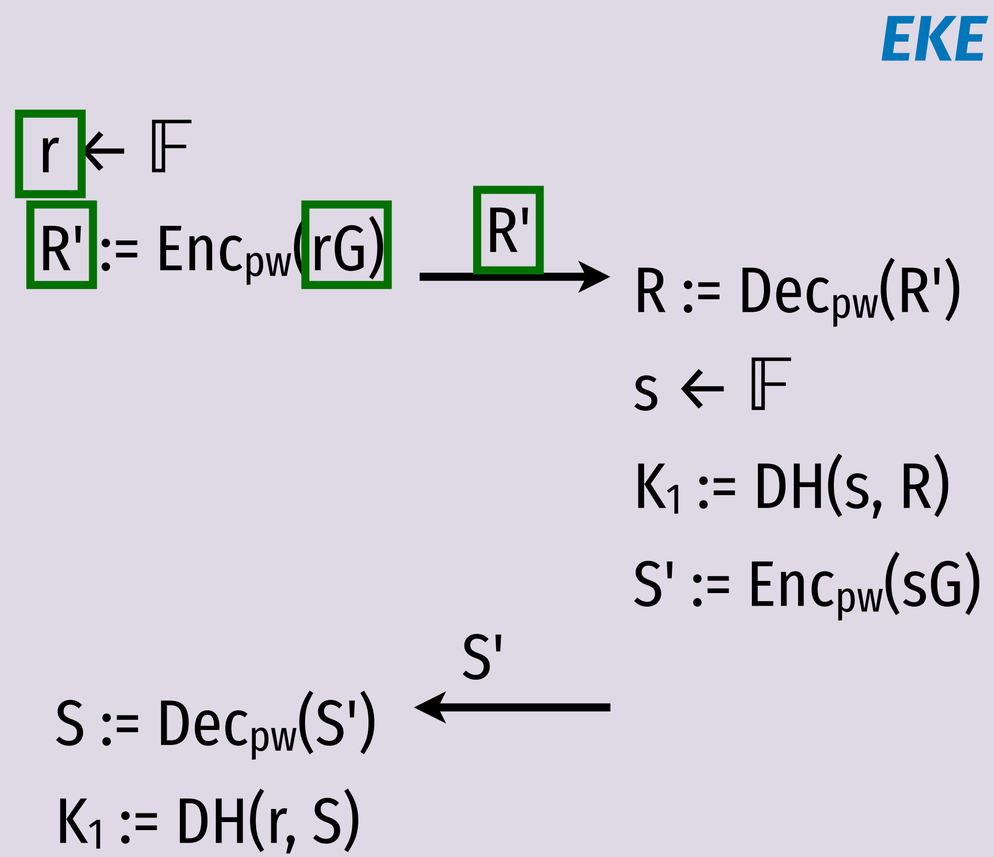

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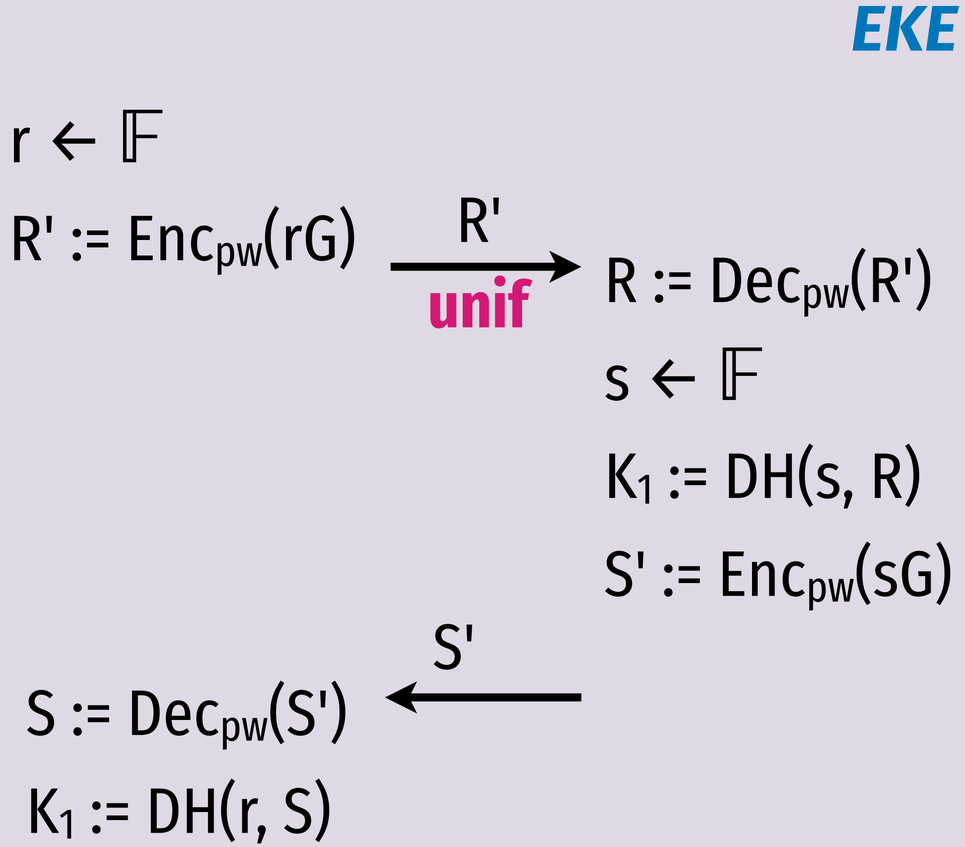

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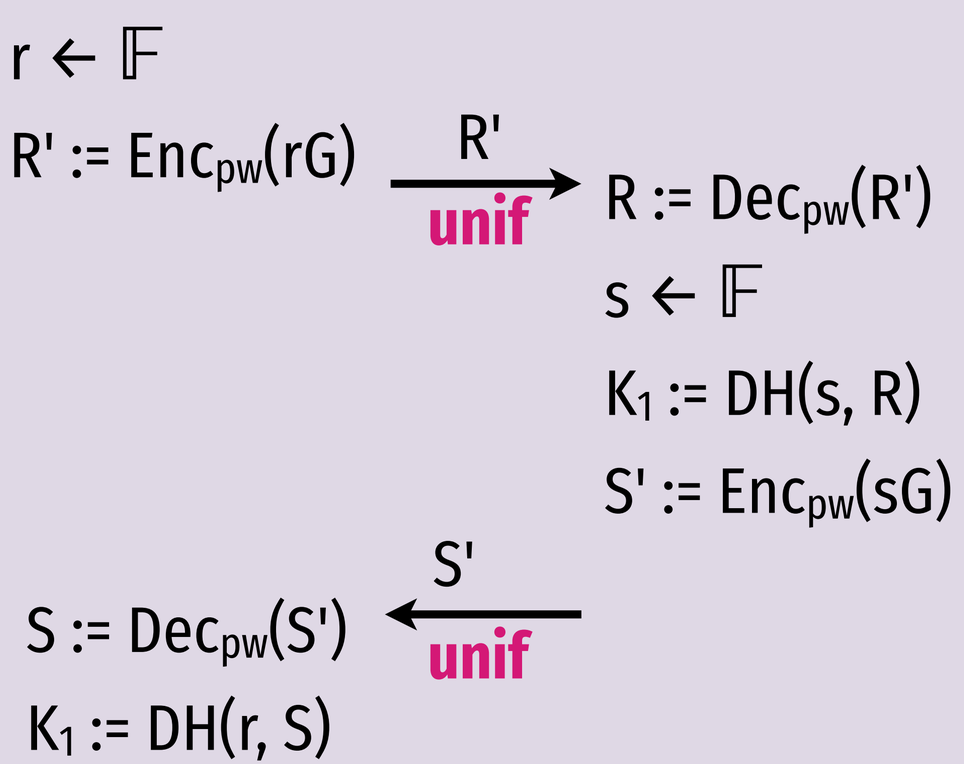

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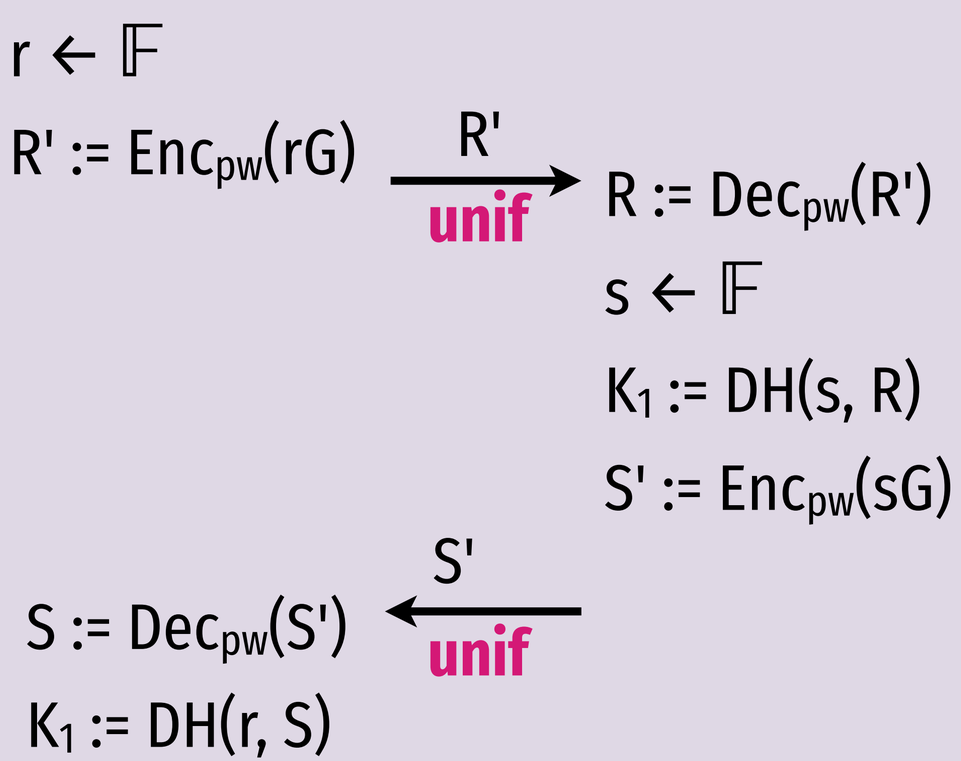
We'll call this **statistical password hiding**, or (full) DH-type PAKE



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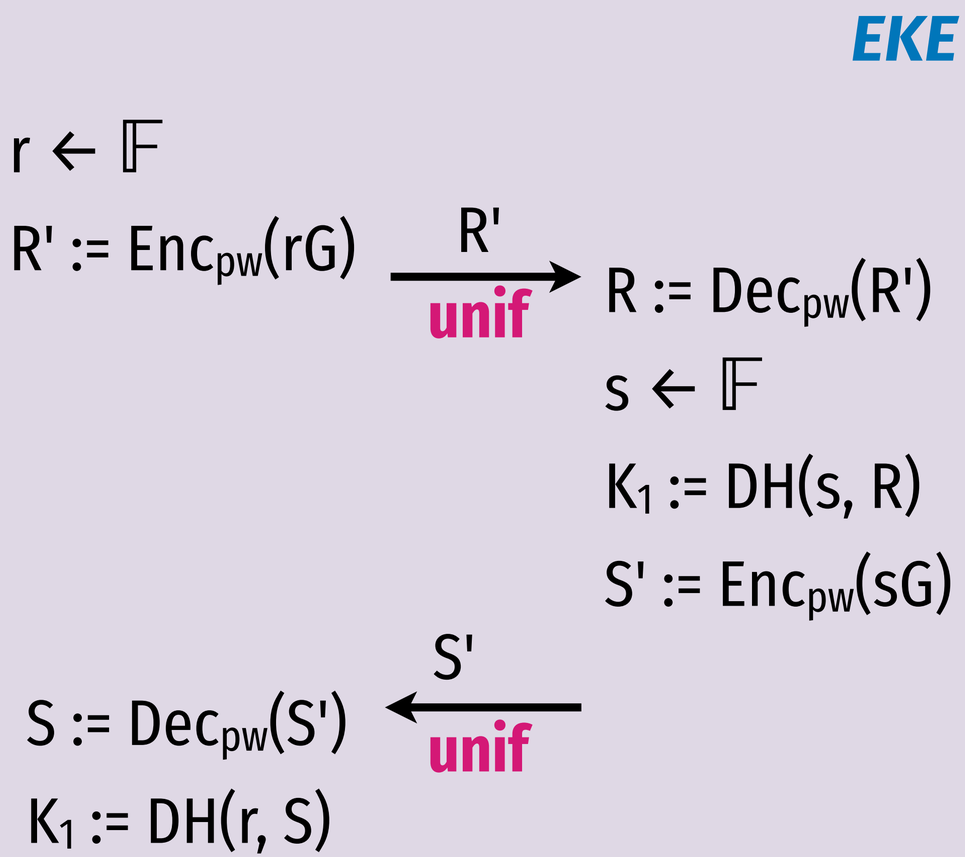
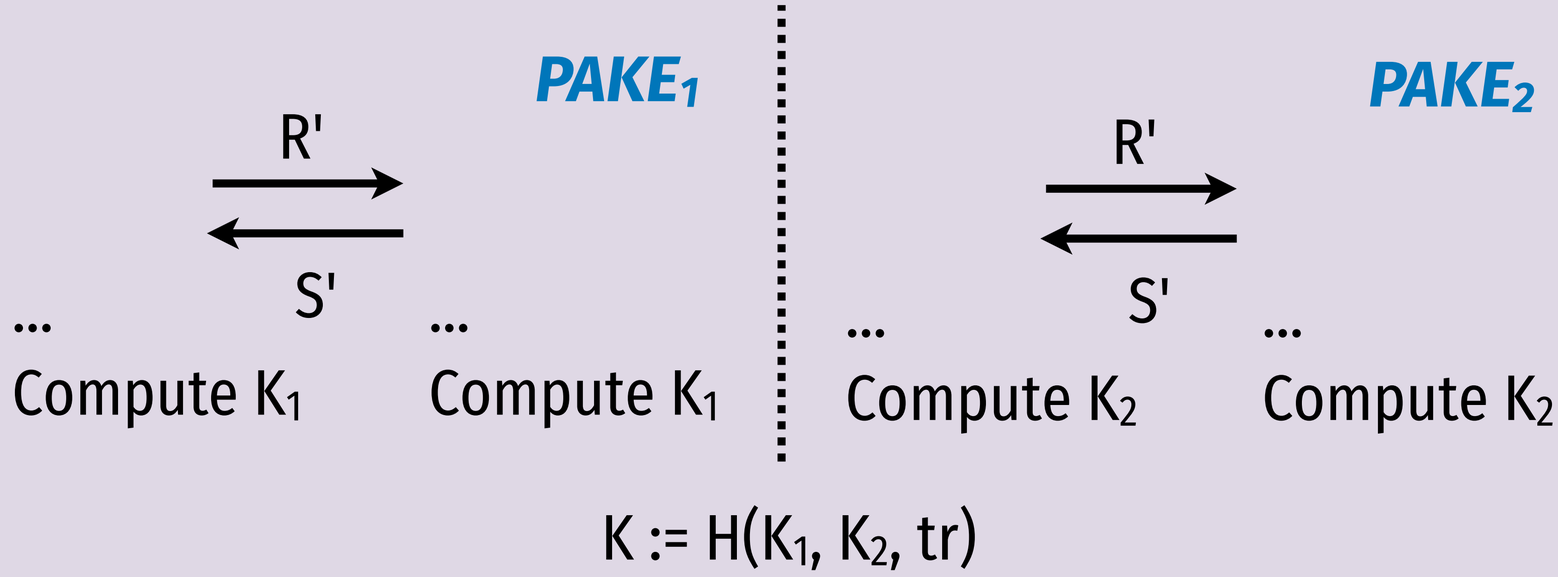


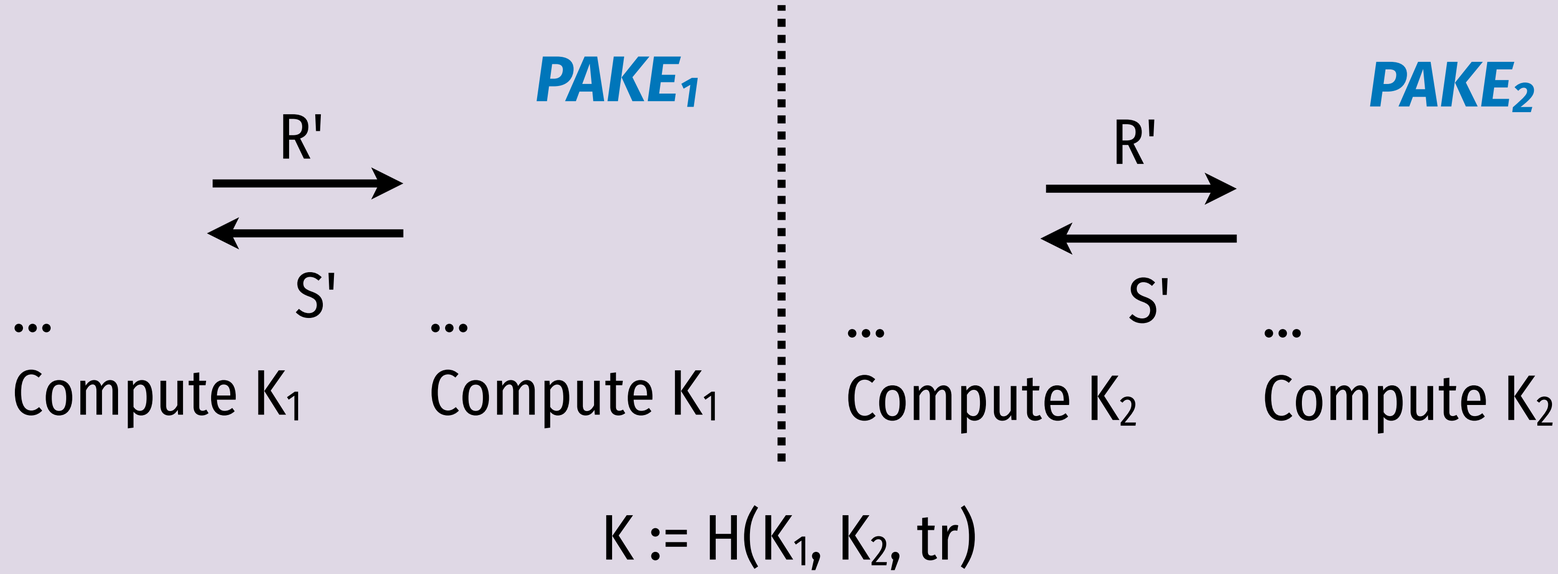
EKE, SPAKE2, CPace are stat. pw-hiding

Building ParComb



Building ParComb

Requirement: $PAKE_1$ and $PAKE_2$ are statistically password-hiding



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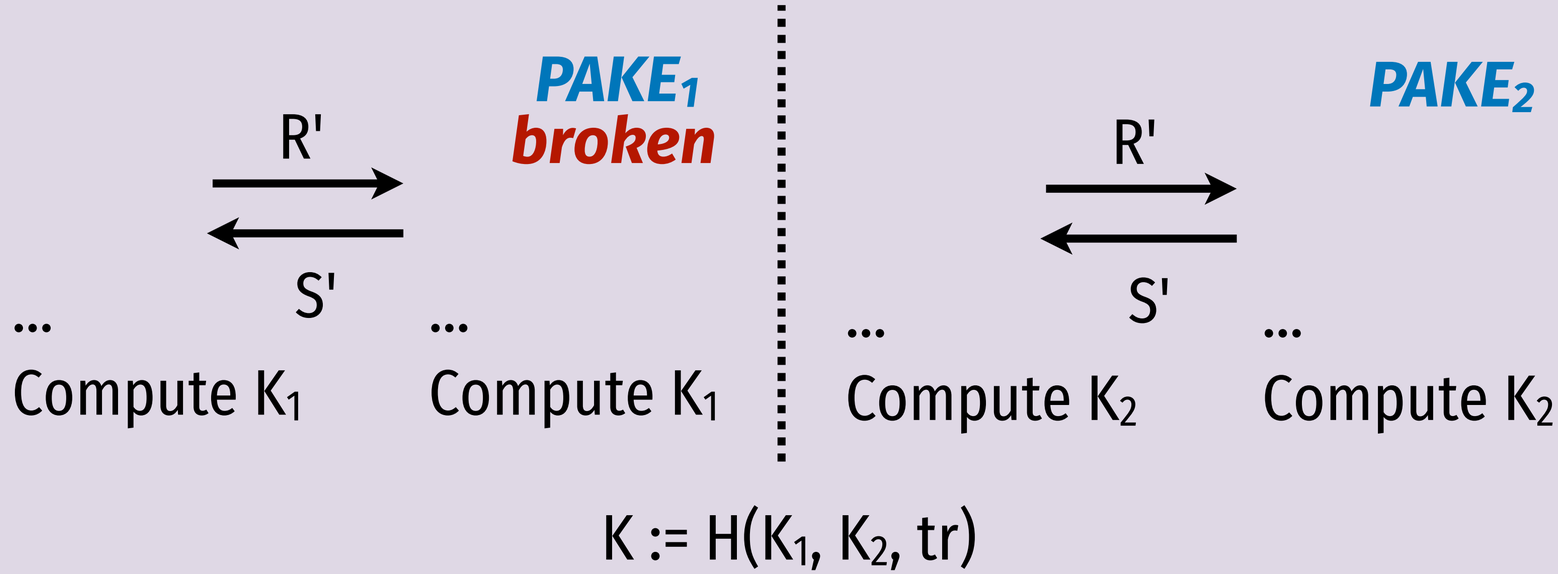

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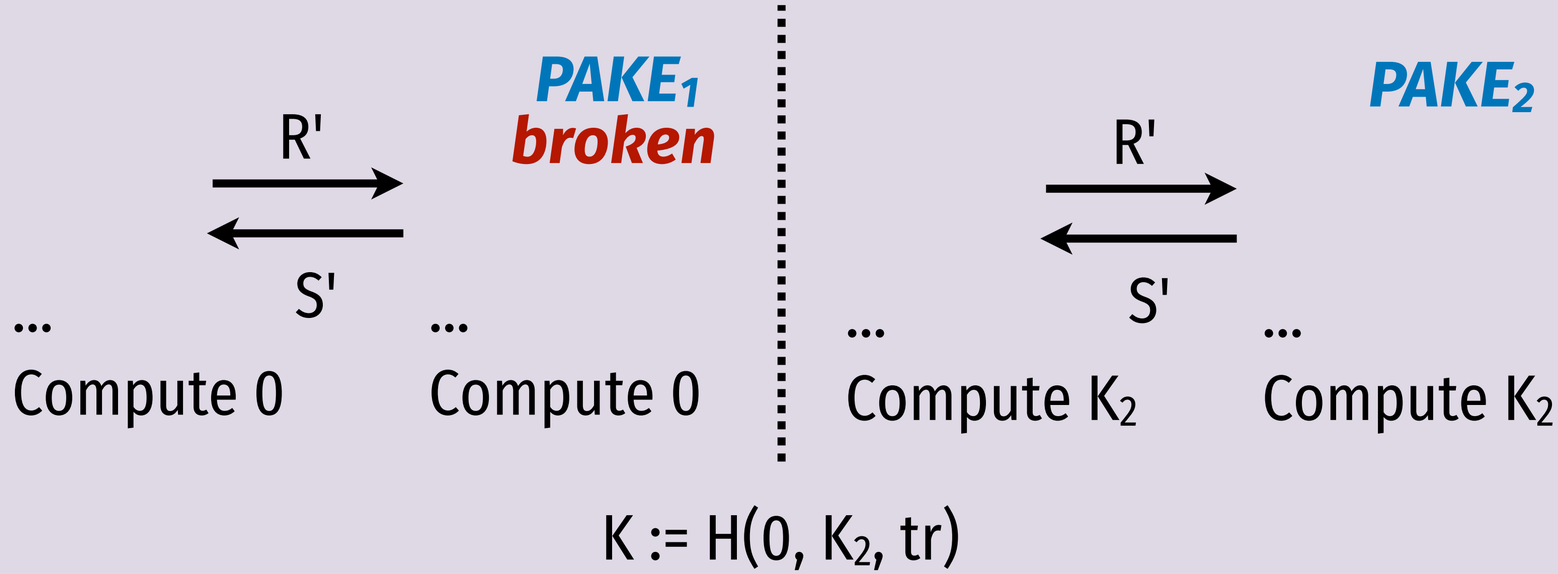

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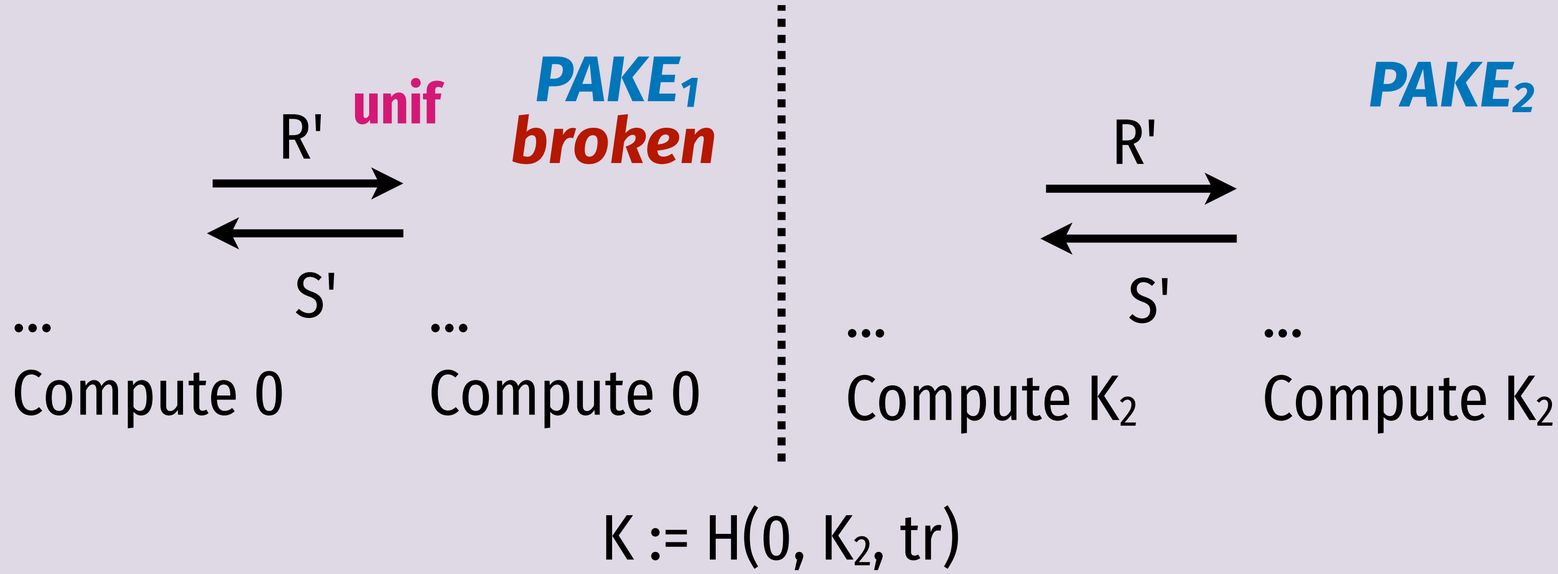

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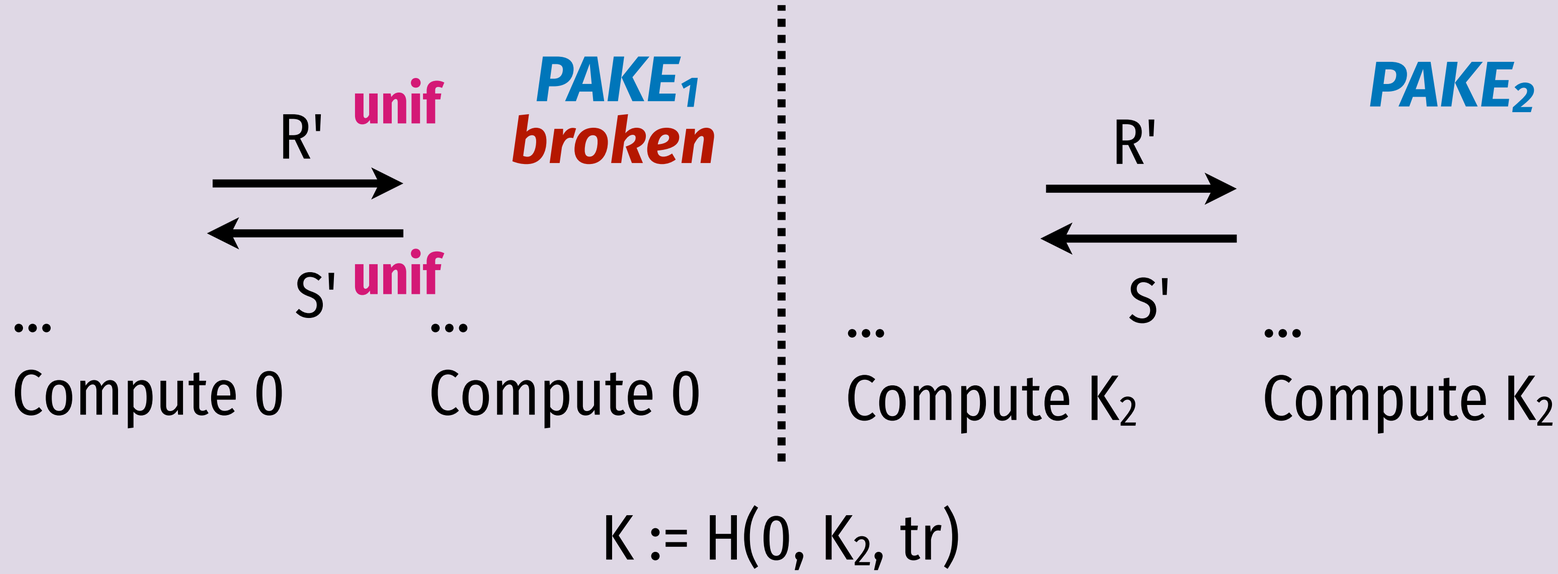

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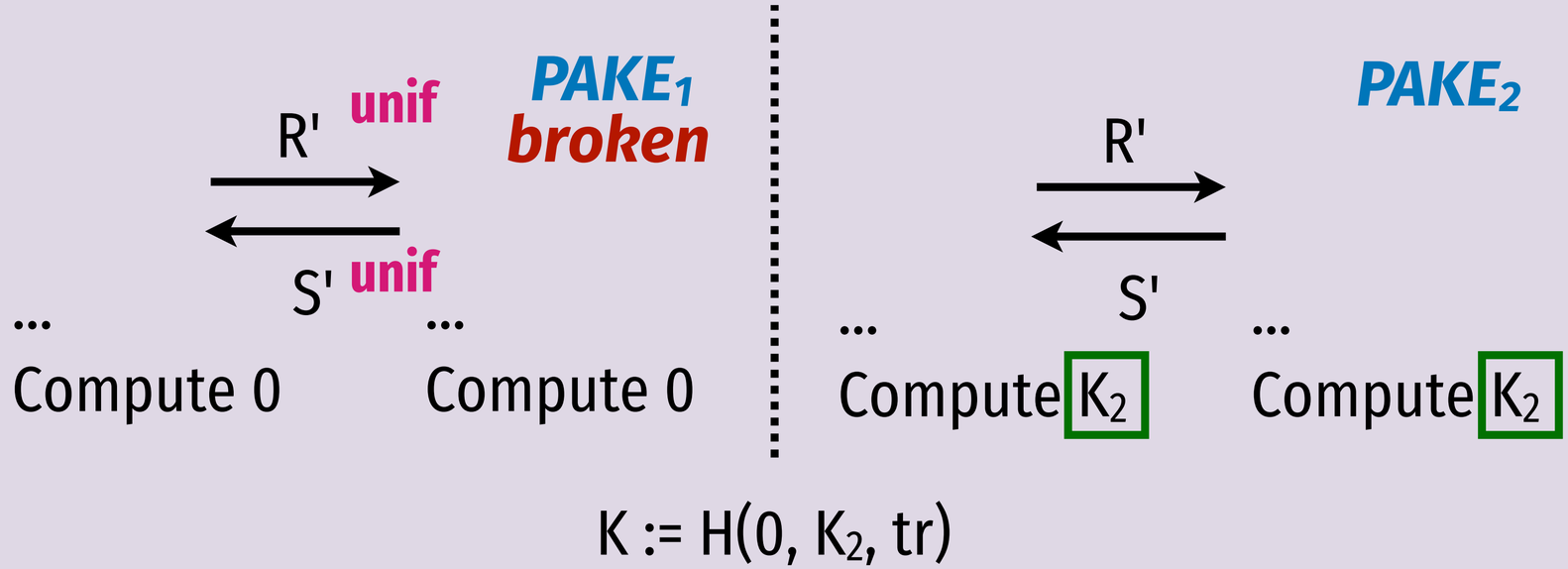

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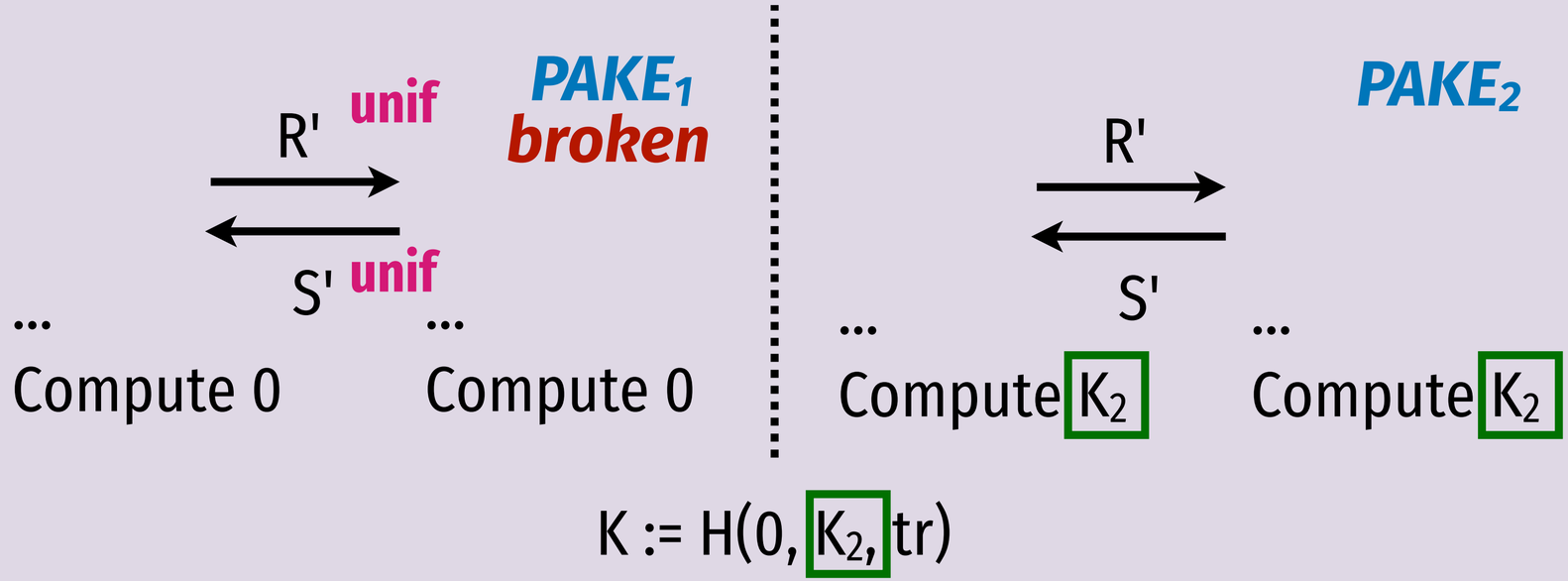

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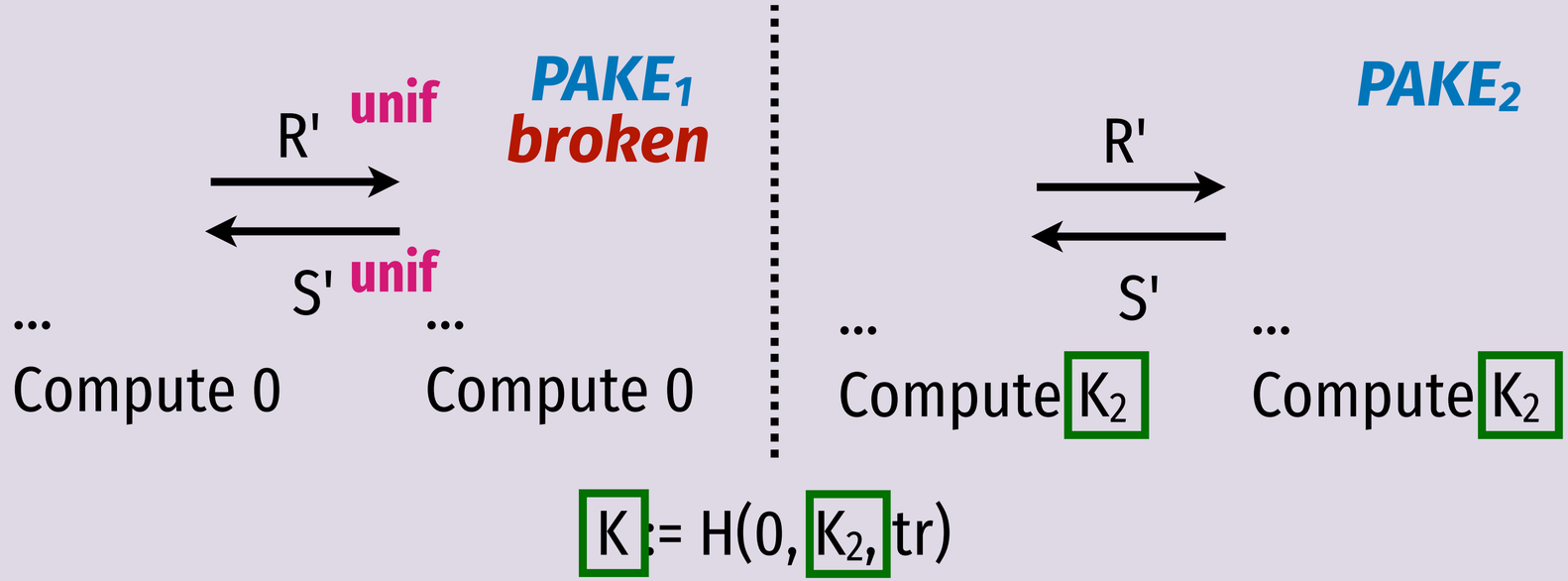

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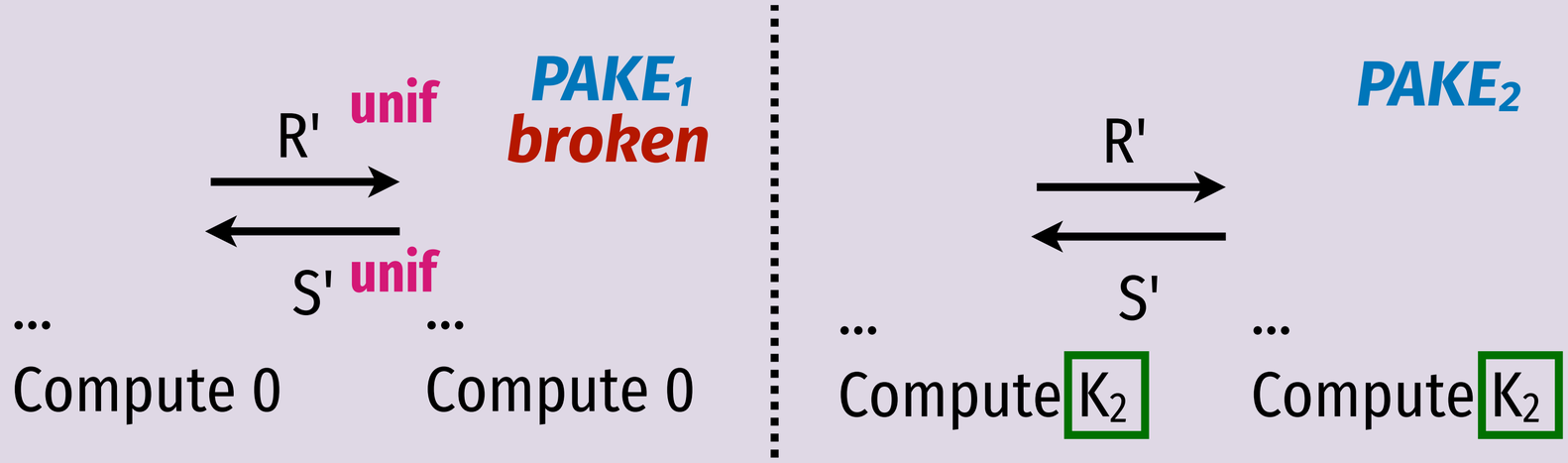
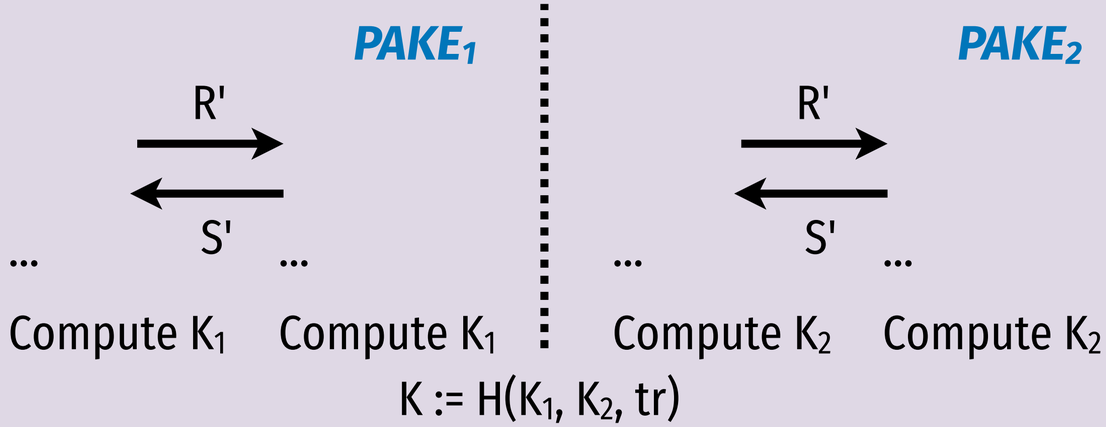


$K := H(0, K_2, tr)$

PAKE is still secure

Properties of ParComb



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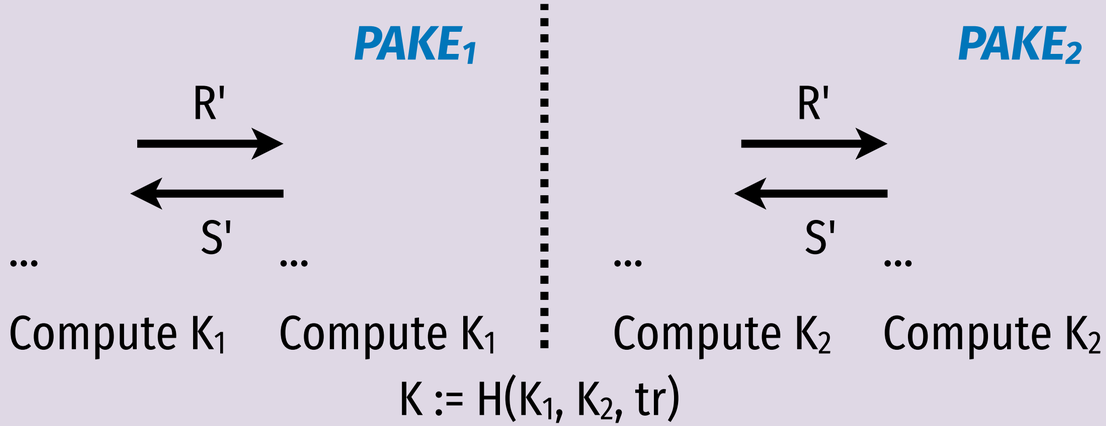

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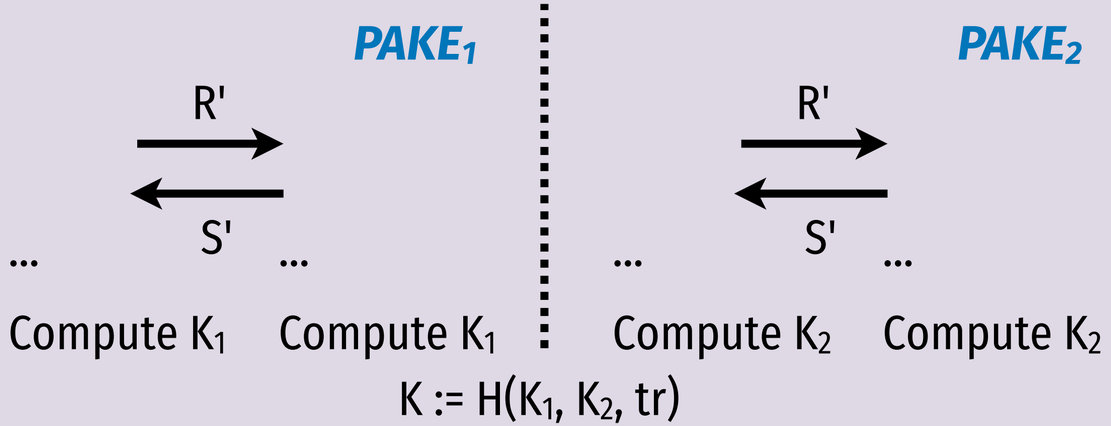
Properties of ParComb



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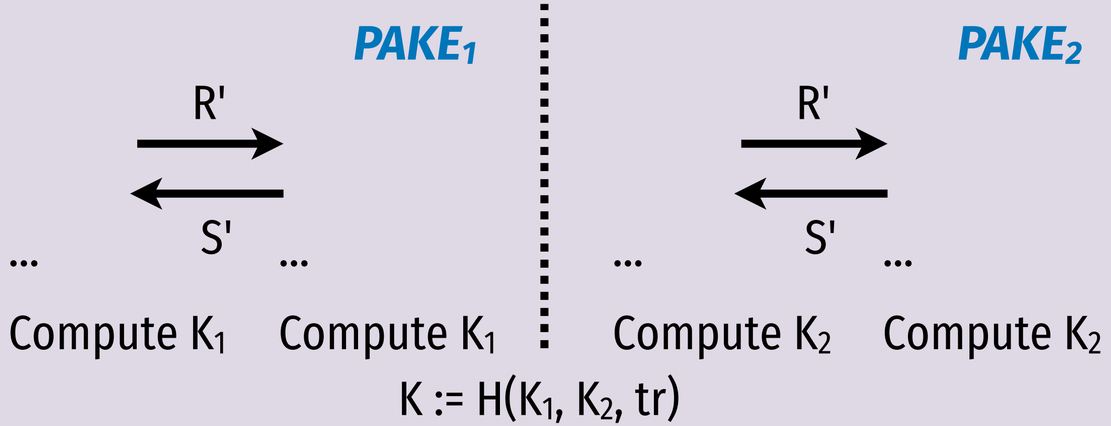
Properties of ParComb



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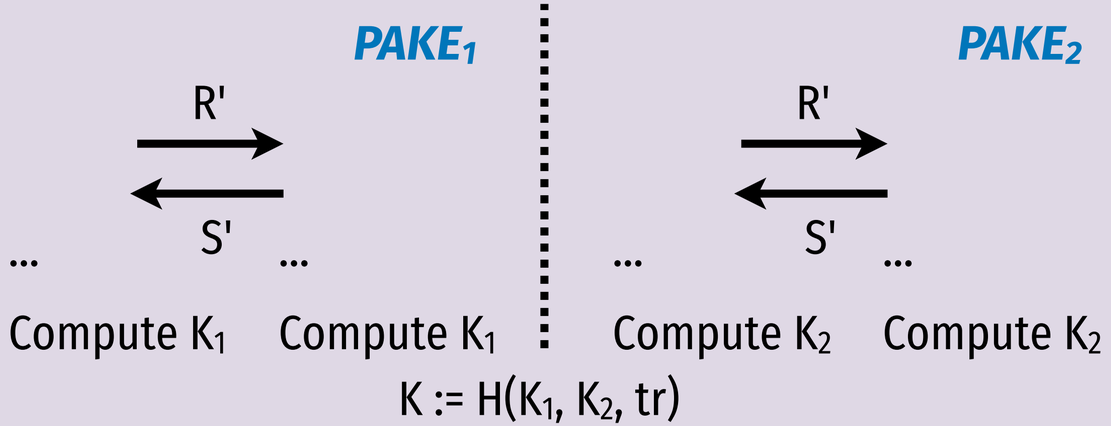

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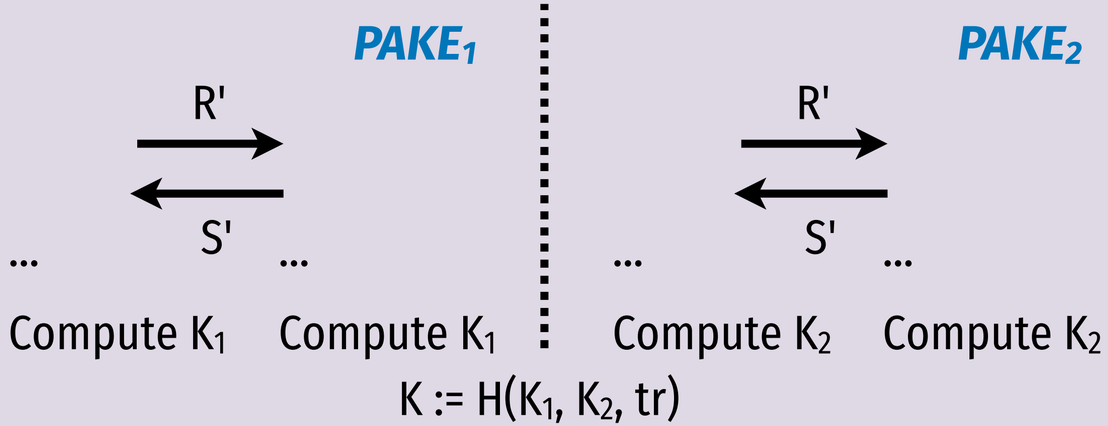
EKE

Properties of ParComb



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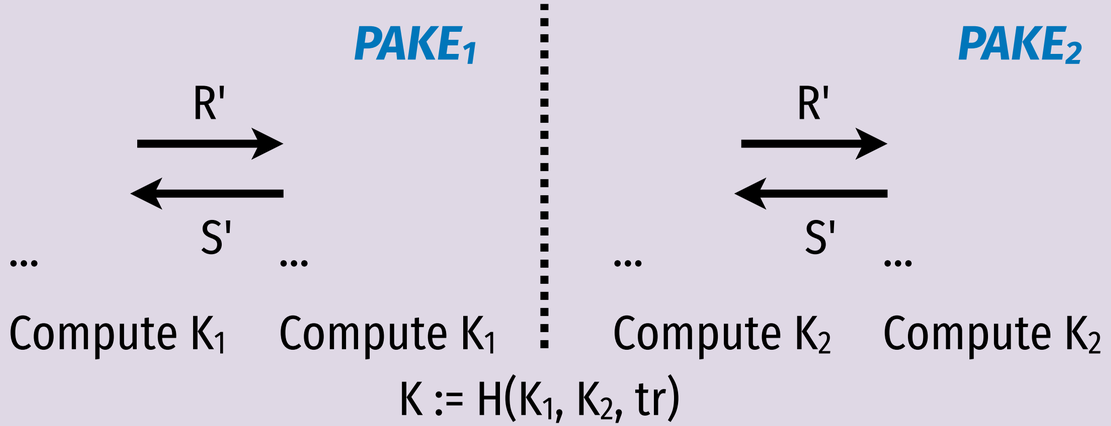
EKE

No 1-round statistically password-hiding PQ scheme realizing $\mathcal{F}_{\mathrm{PAKE}}$ exists

Properties of ParComb



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EKE

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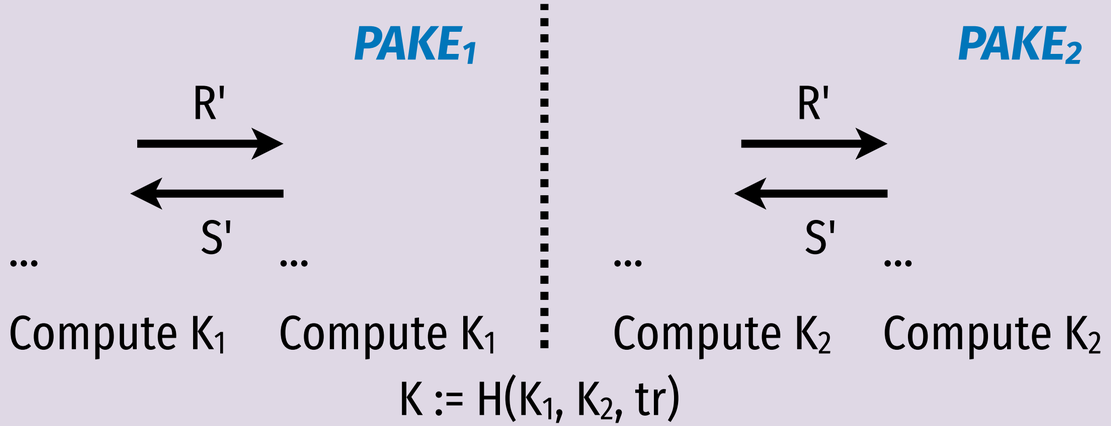
Properties of ParComb



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EKE

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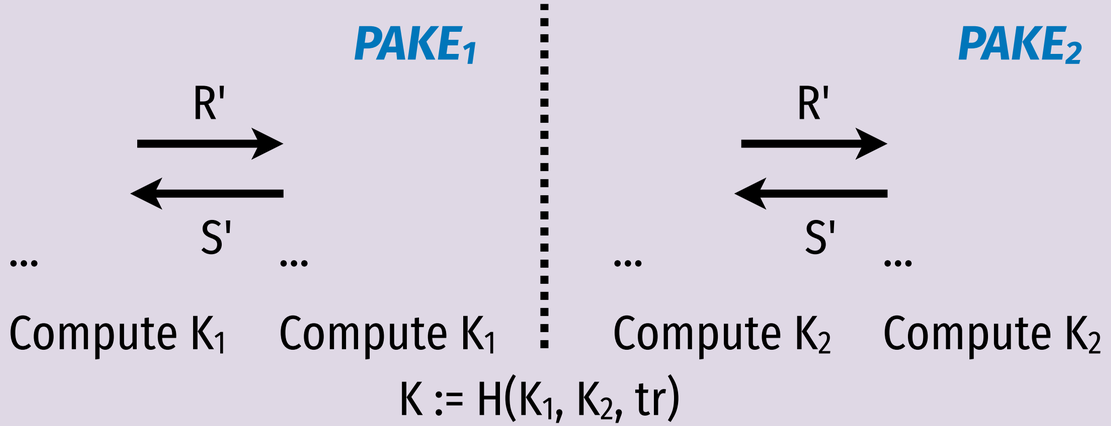
Properties of ParComb



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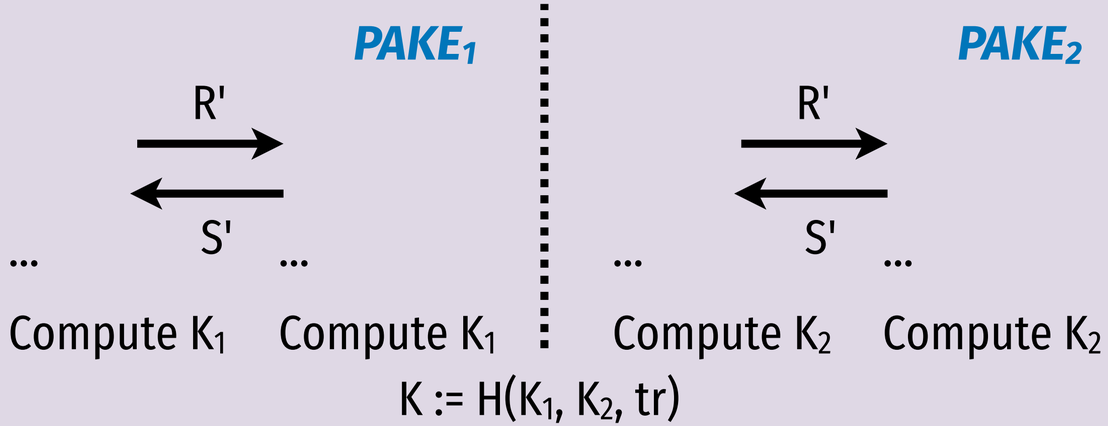
Properties of ParComb



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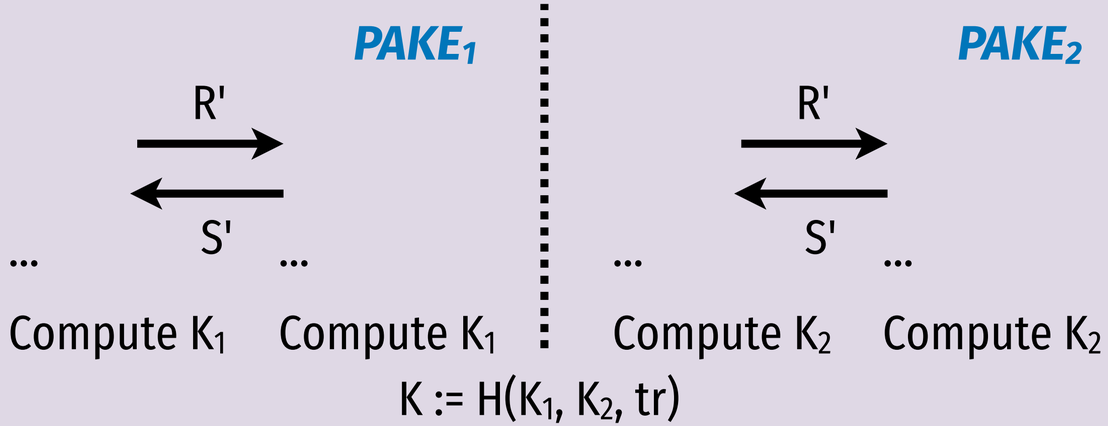
SPAKE2, CPace

Properties of ParComb



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SPAKE2,
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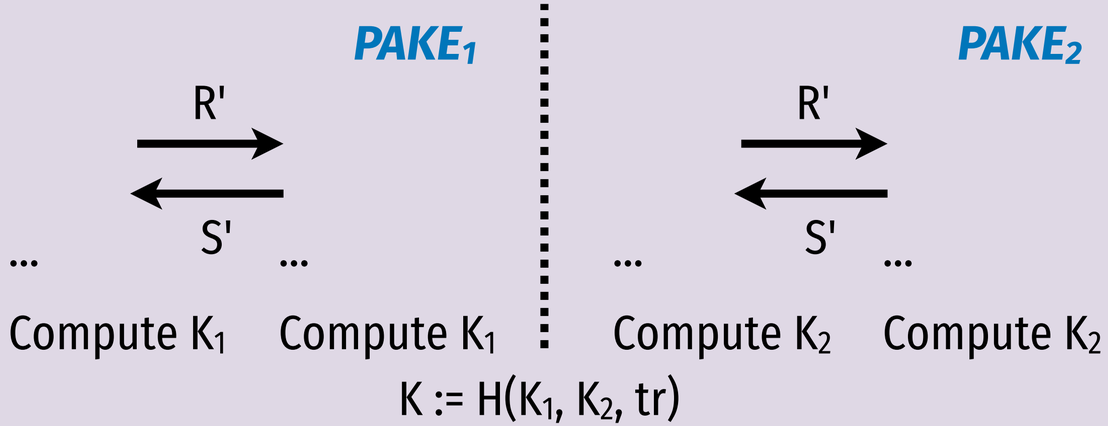
Bonus lemma: either $\mathcal{F}_{\mathbf{blePAKE}} \Rightarrow \mathcal{F}_{\mathbf{blePAKE}}$

Properties of ParComb



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SPAKE2, CPace

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Theorem 3: X-GA-PAKE (CSIDH-based) is a statistically pw-hiding 1-round blePAKE

Building SeqComb

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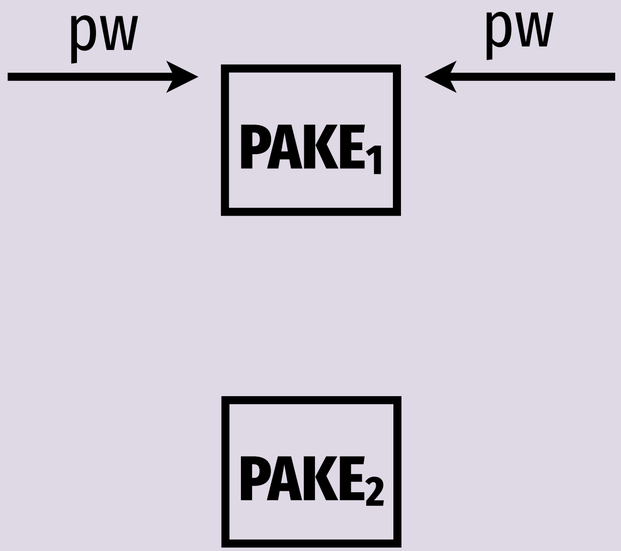
Building SeqComb



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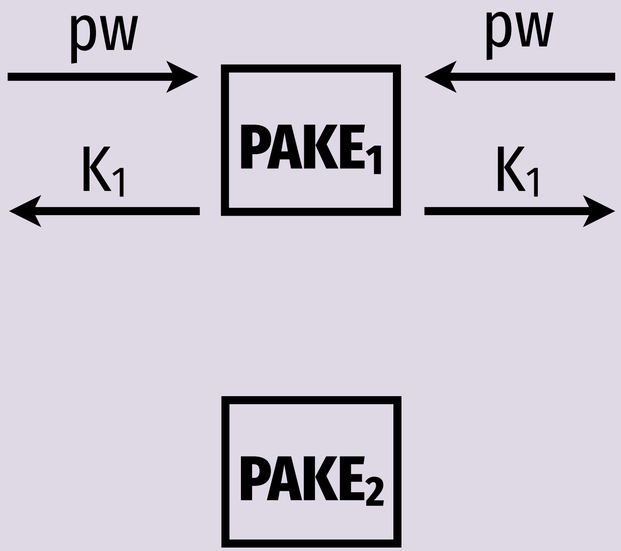

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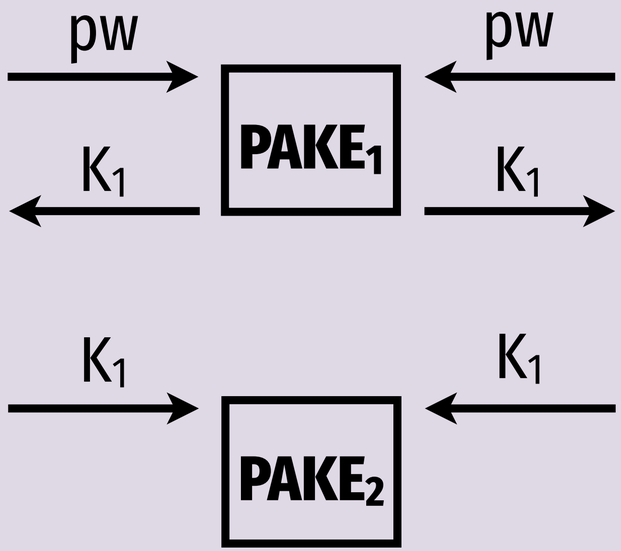

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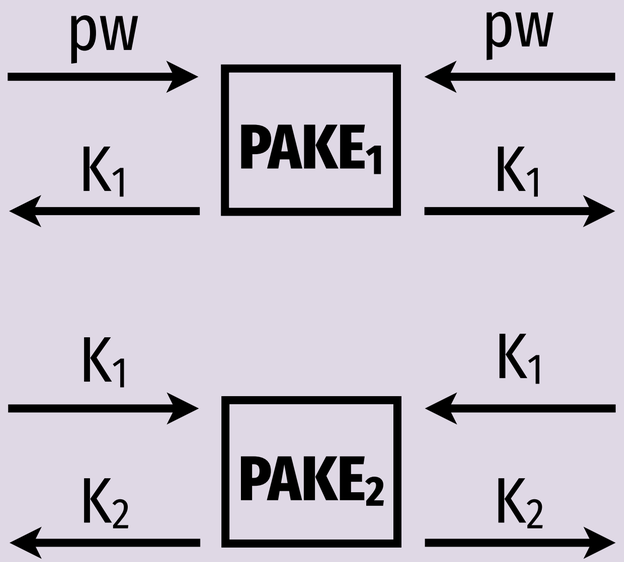

Building SeqComb

$K := H(K_1, K_2, tr)$

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$PAKE_1$ can have the τ problem

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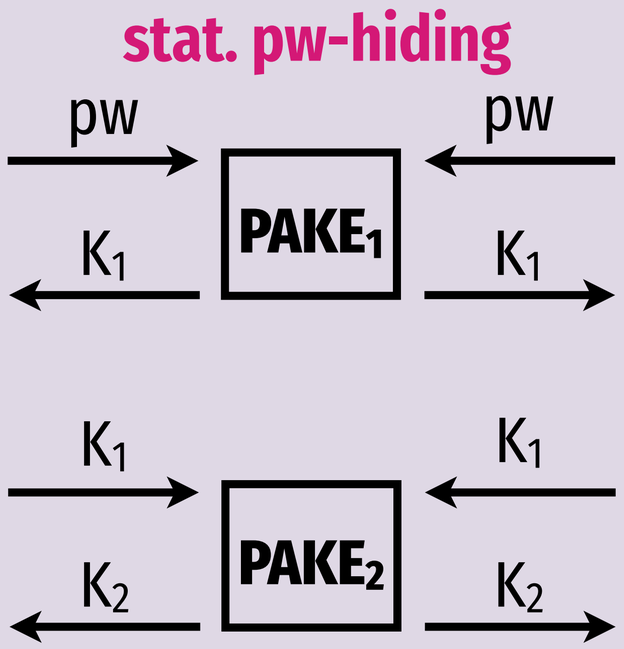

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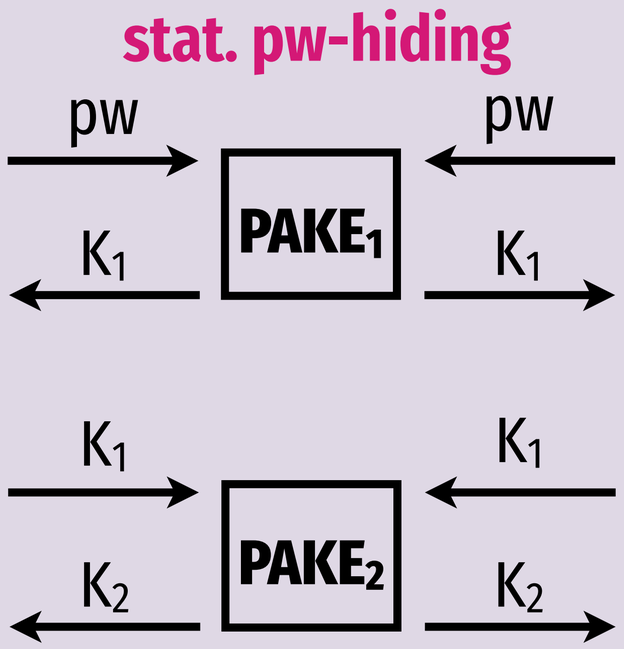

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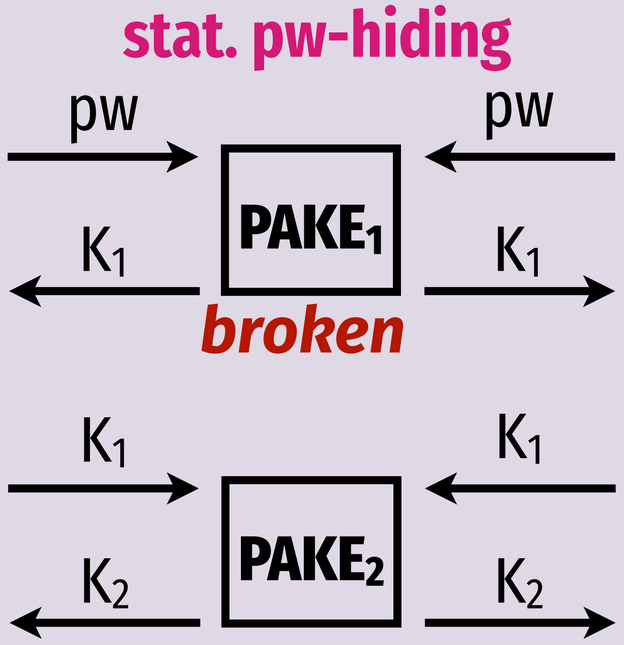
Building SeqComb



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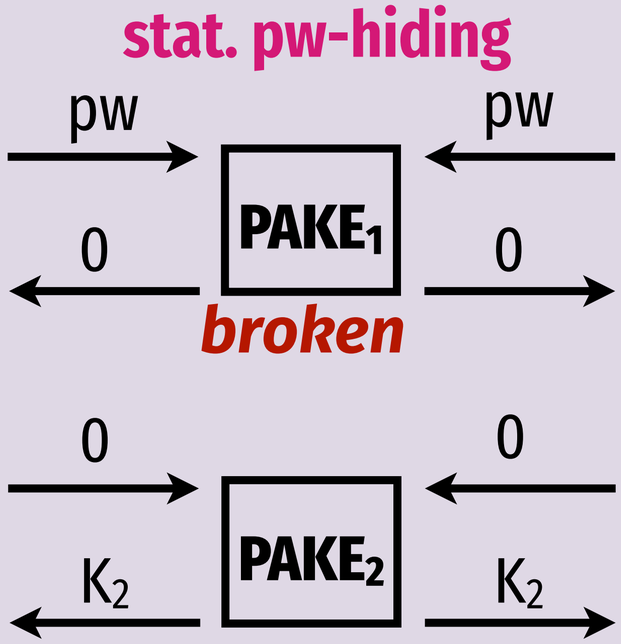
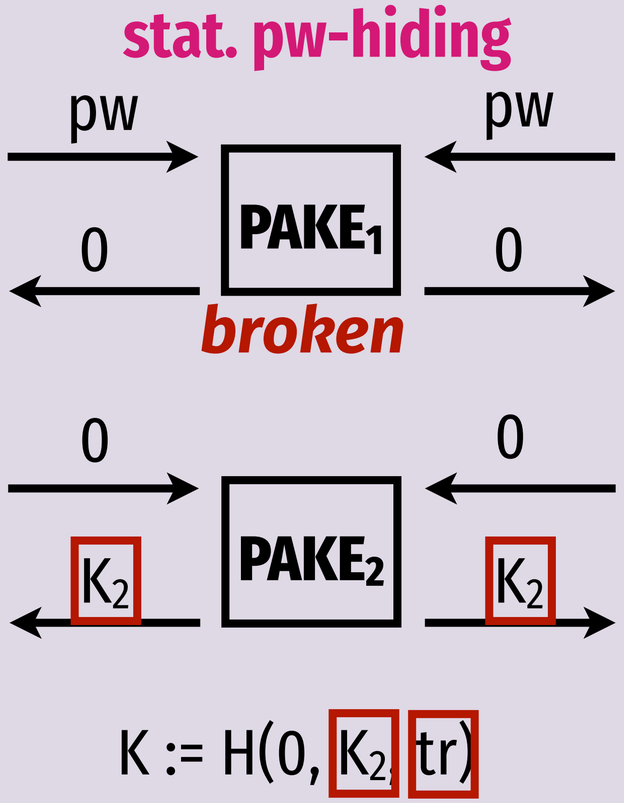
Building SeqComb



$K := H(0, K_2, tr)$

Building SeqComb



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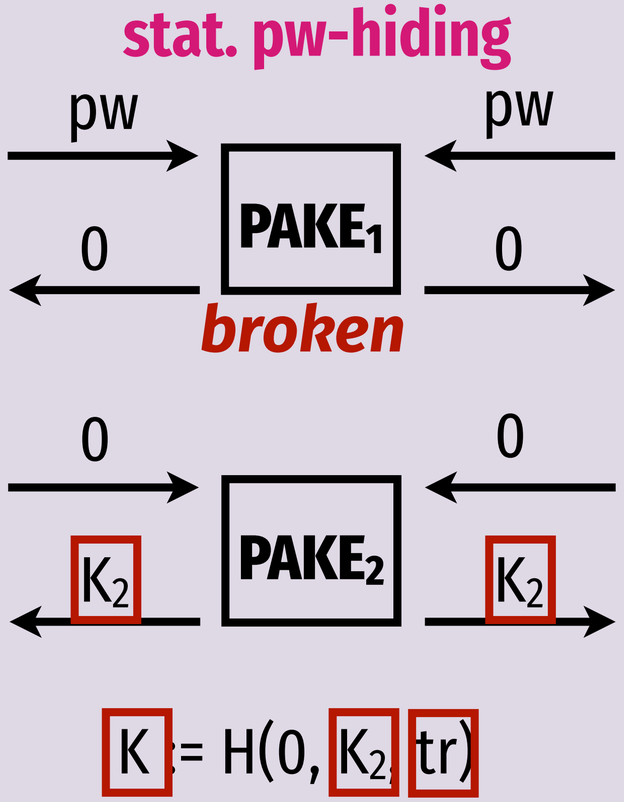
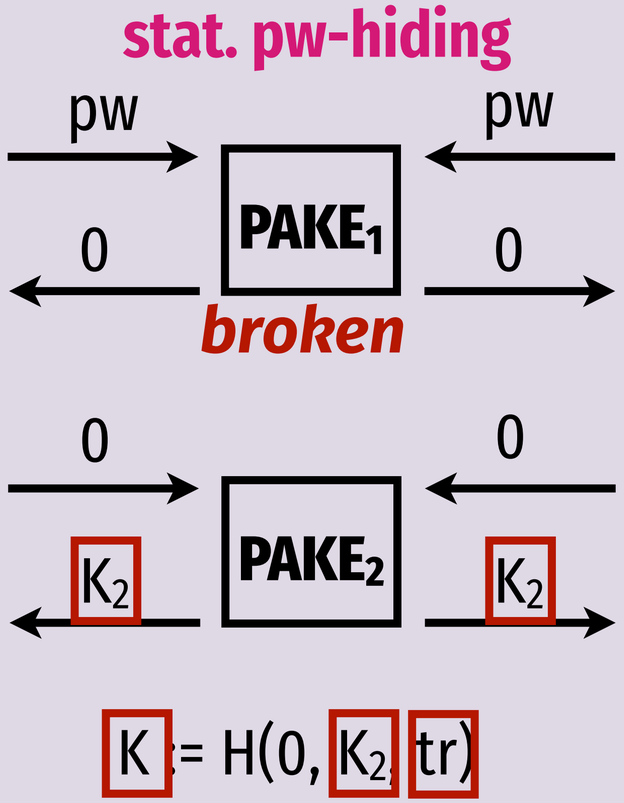


Building SeqComb

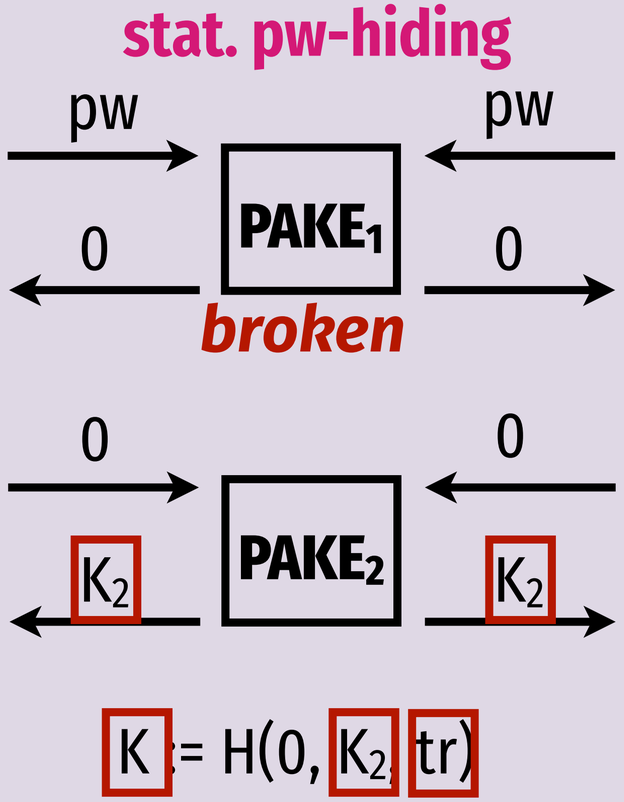
Session key is predictable!



Building SeqComb

Session key is predictable!

Input more into PAKE_2



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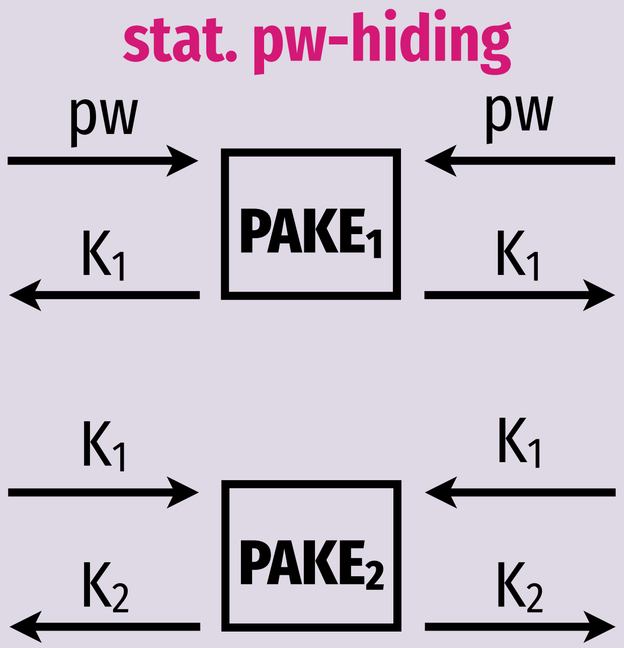

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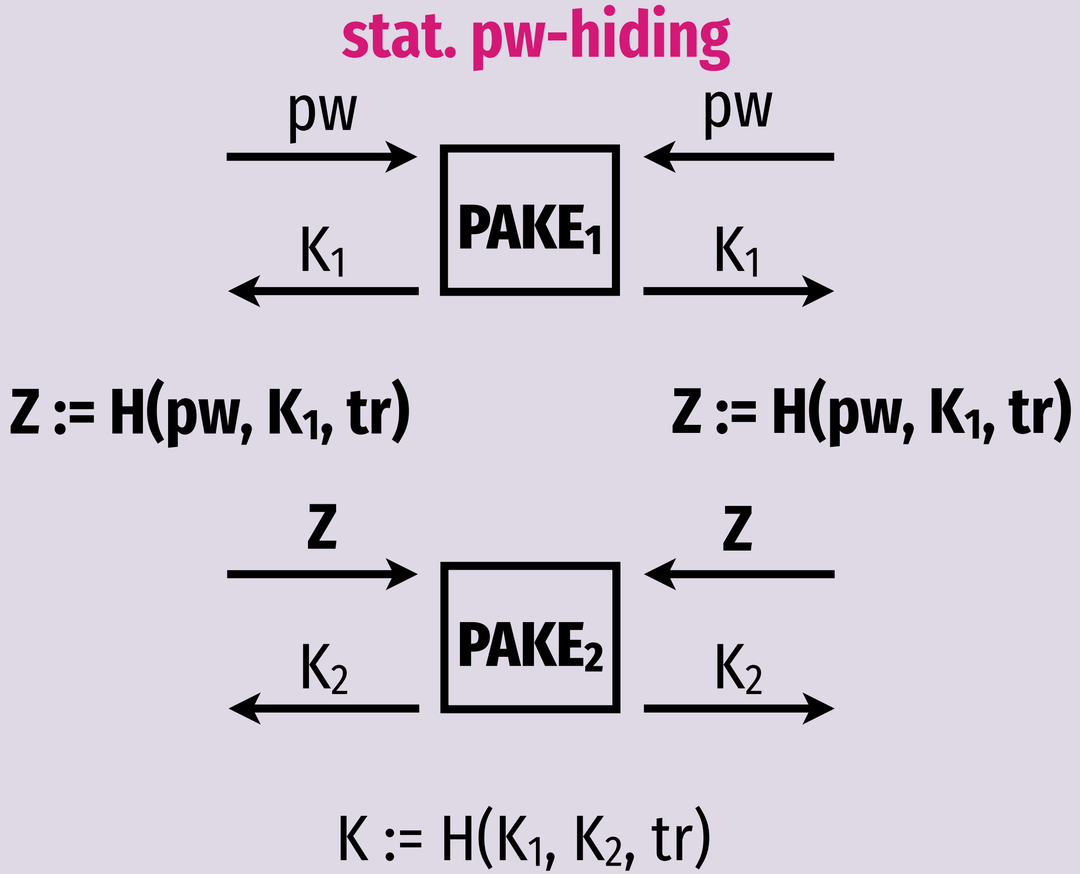

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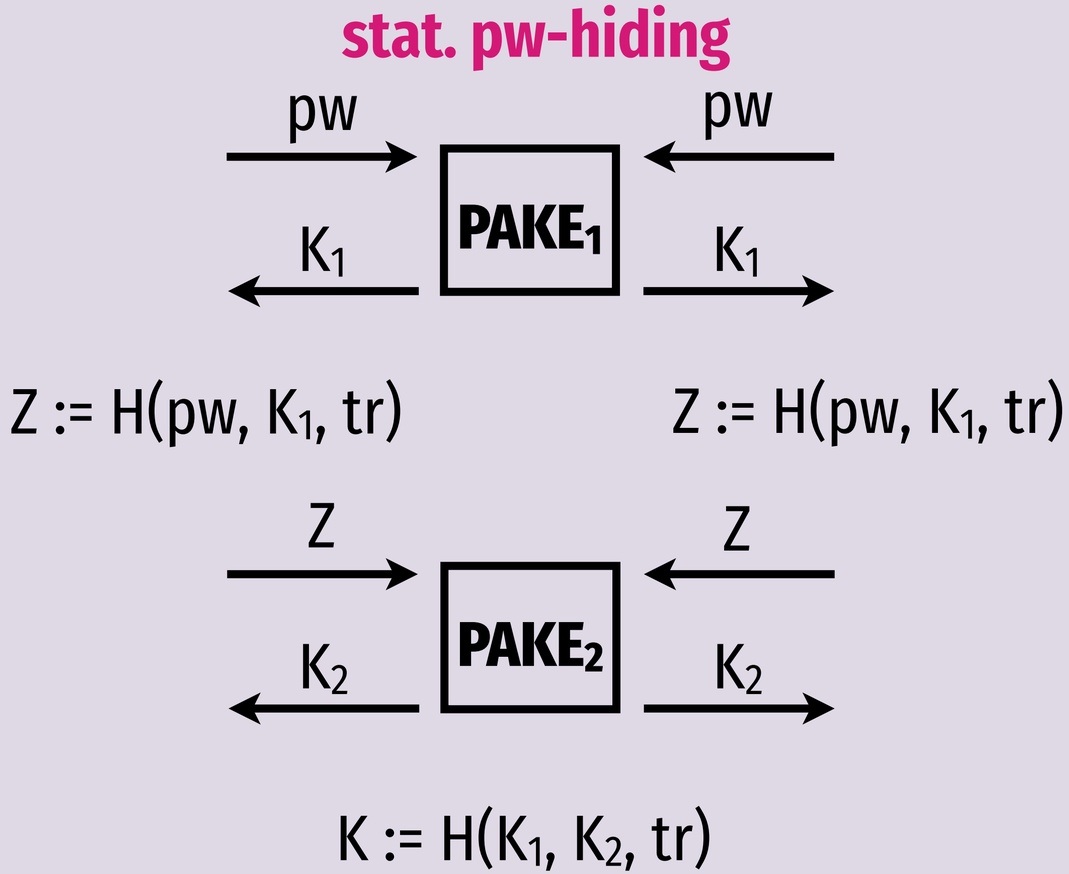

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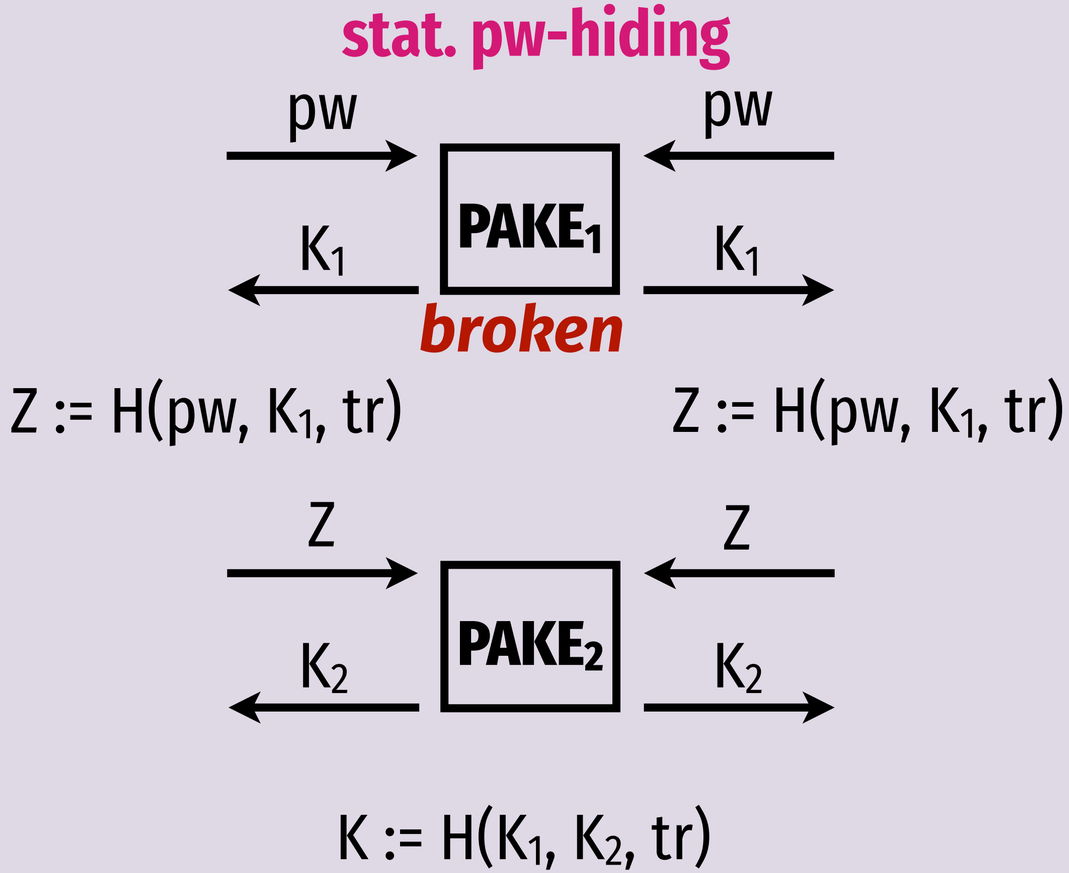

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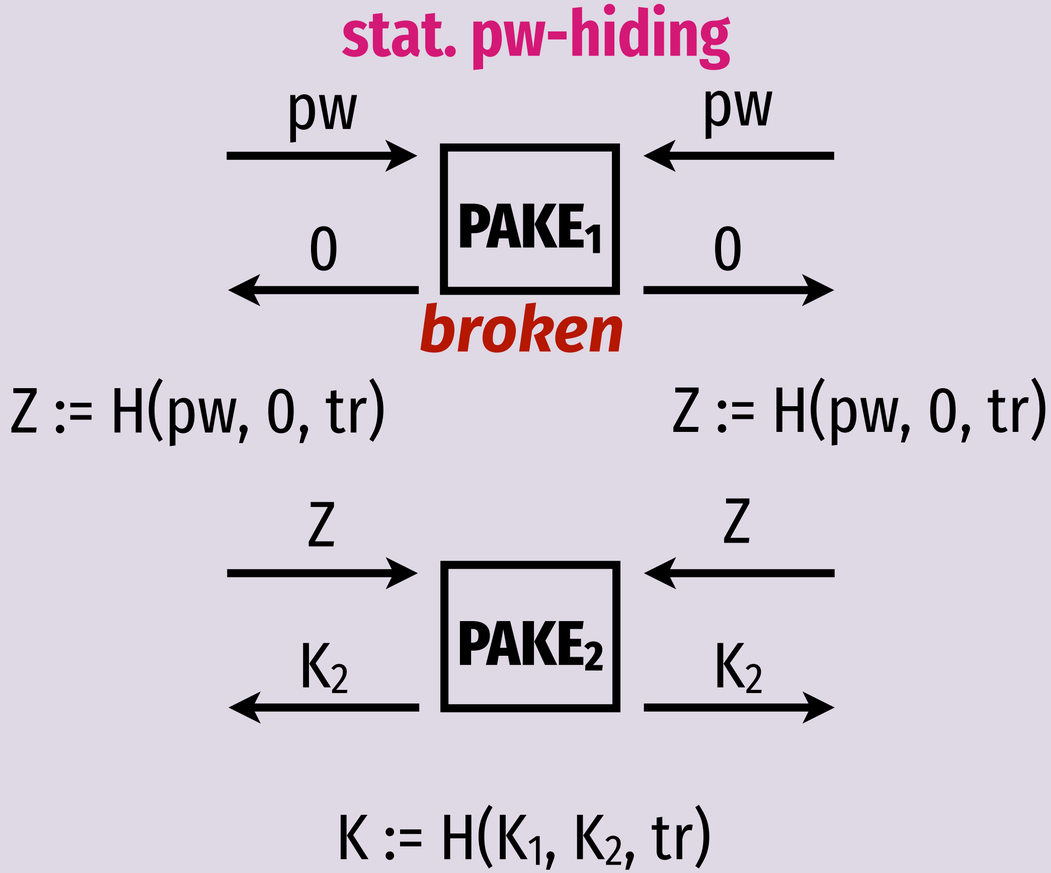

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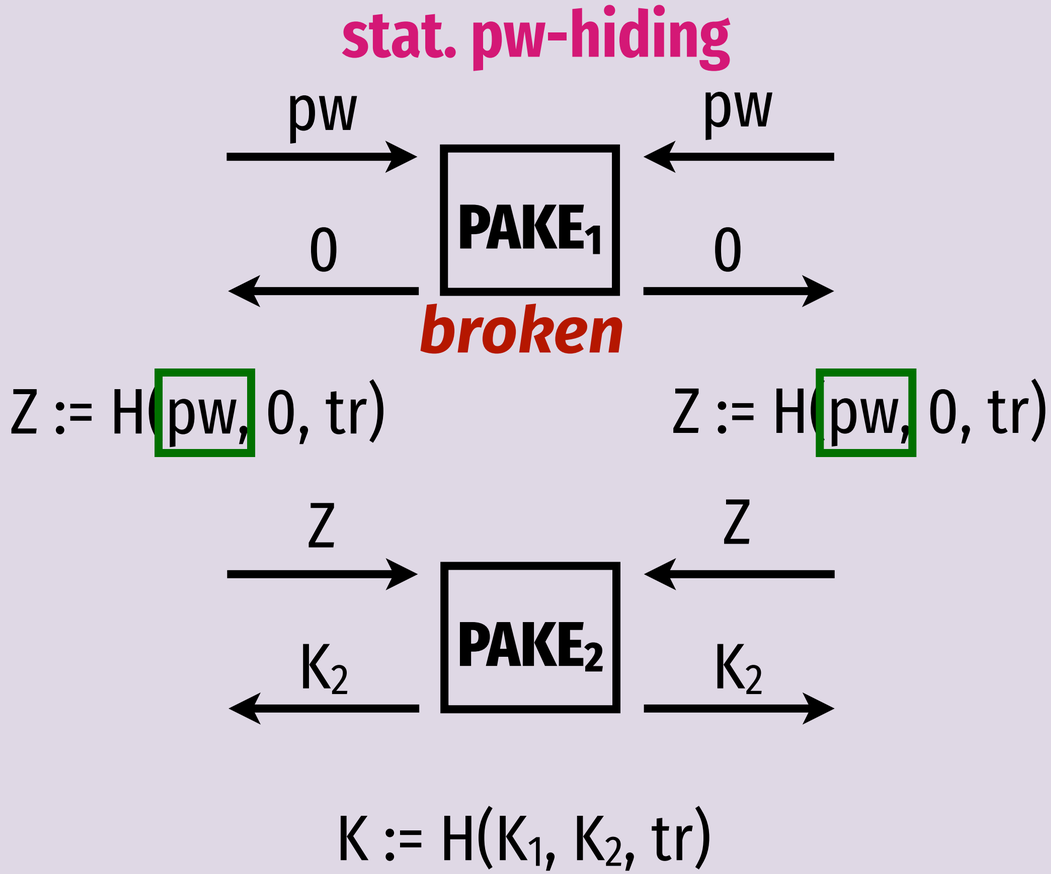

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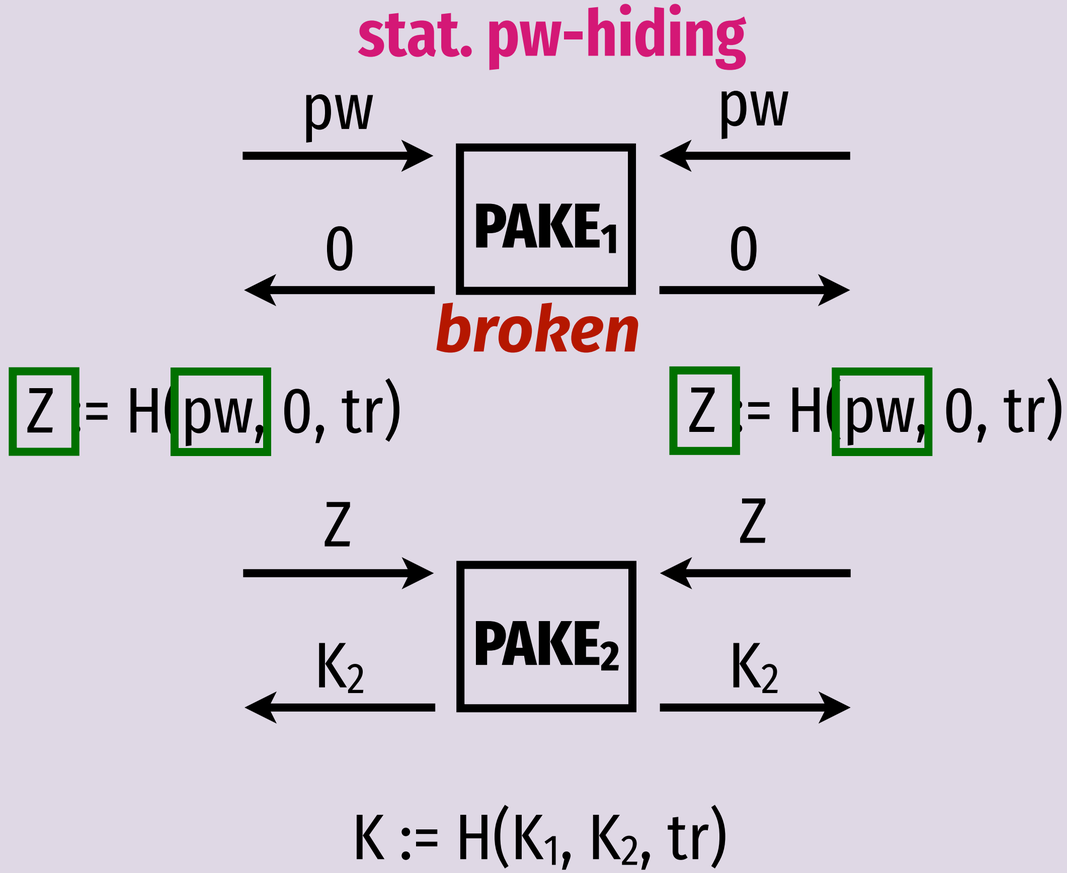

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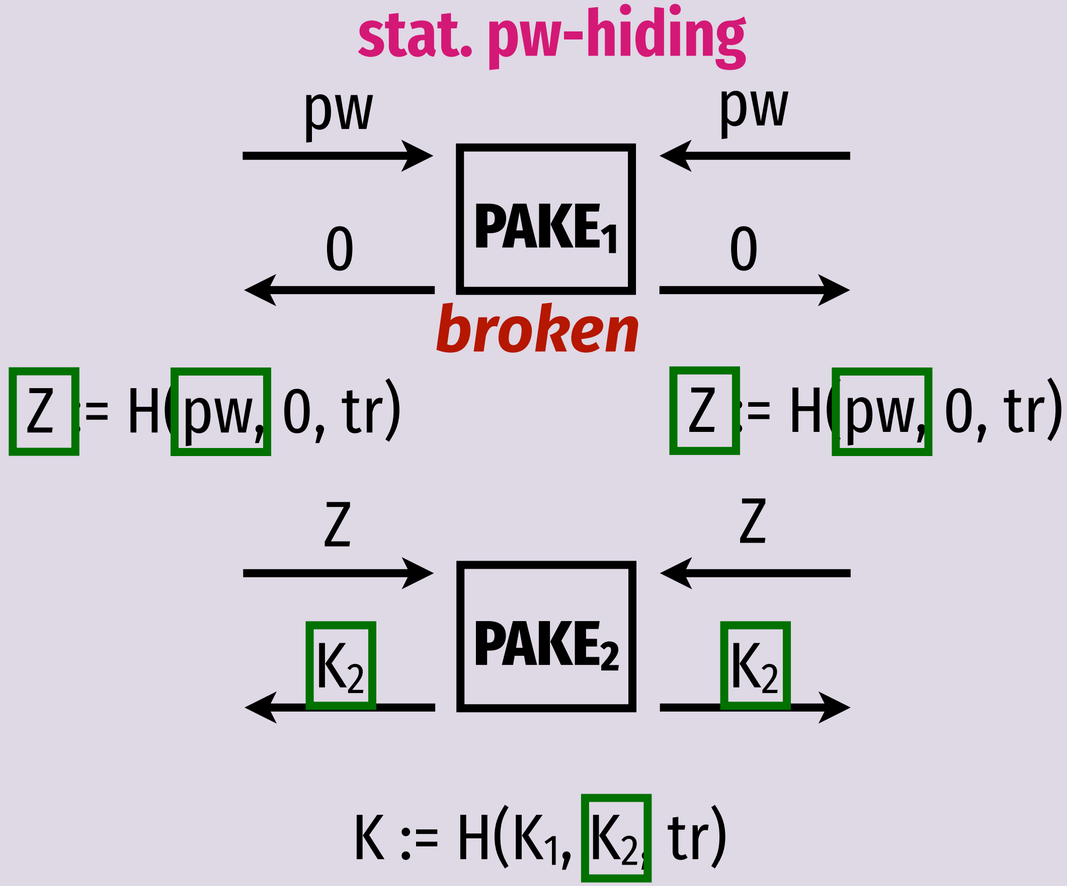

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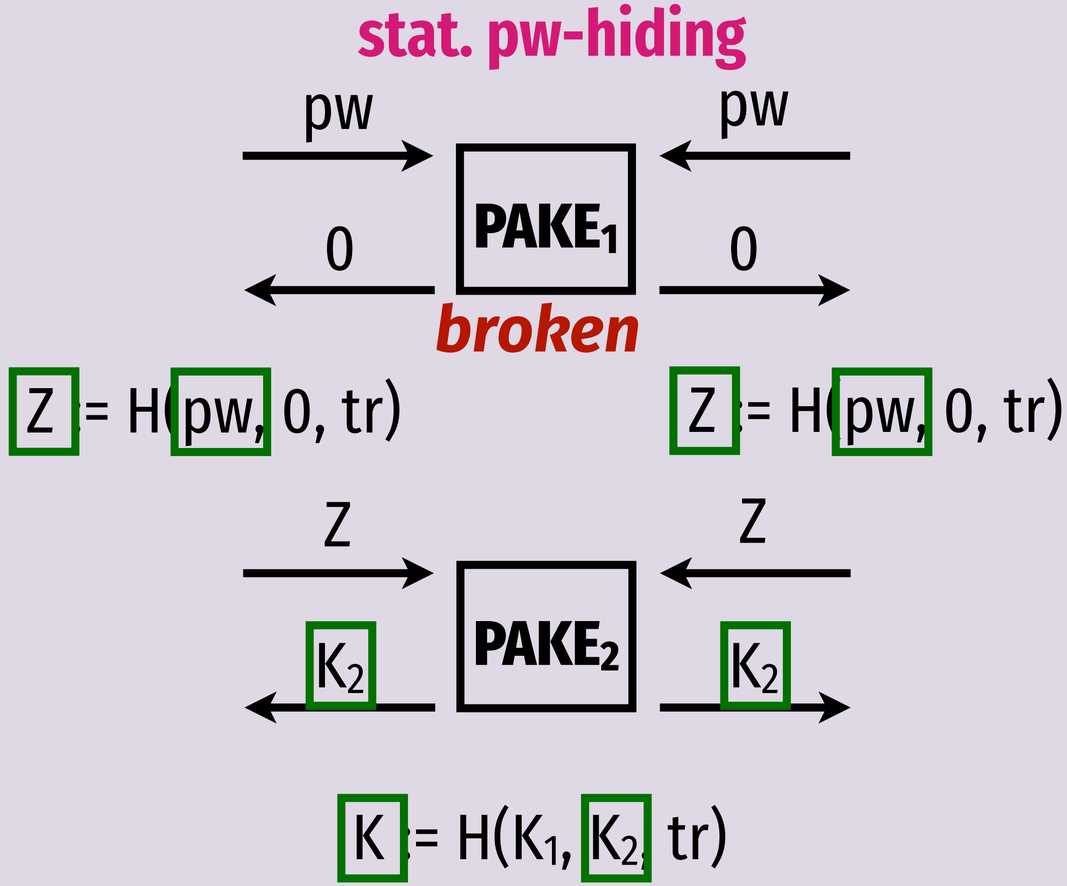
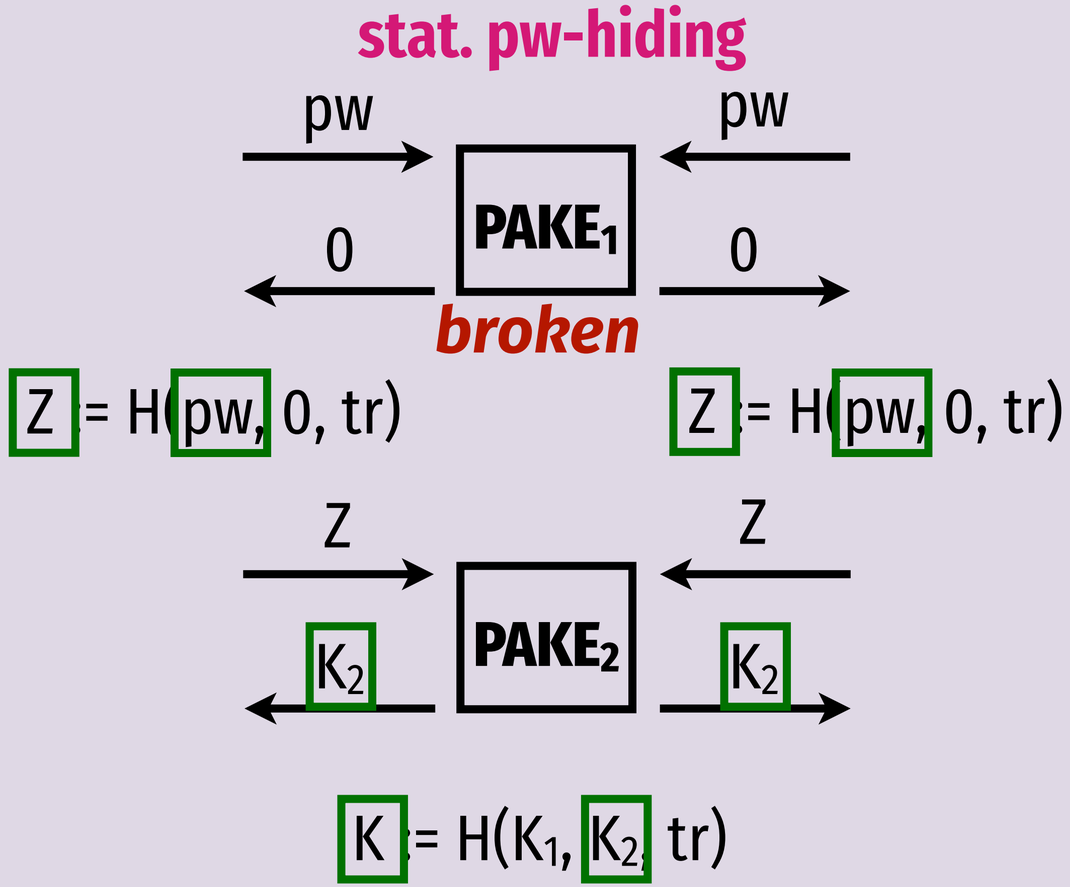


Building SeqComb

Combined PAKE is still secure!



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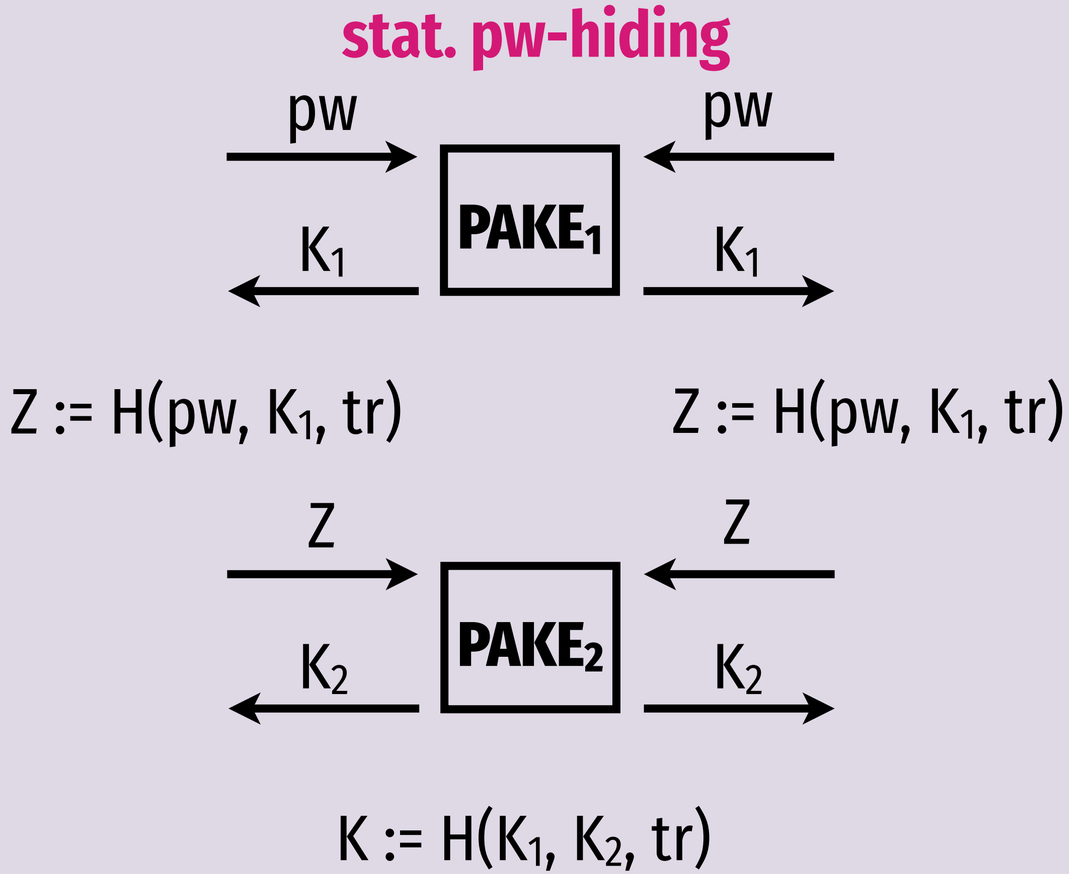

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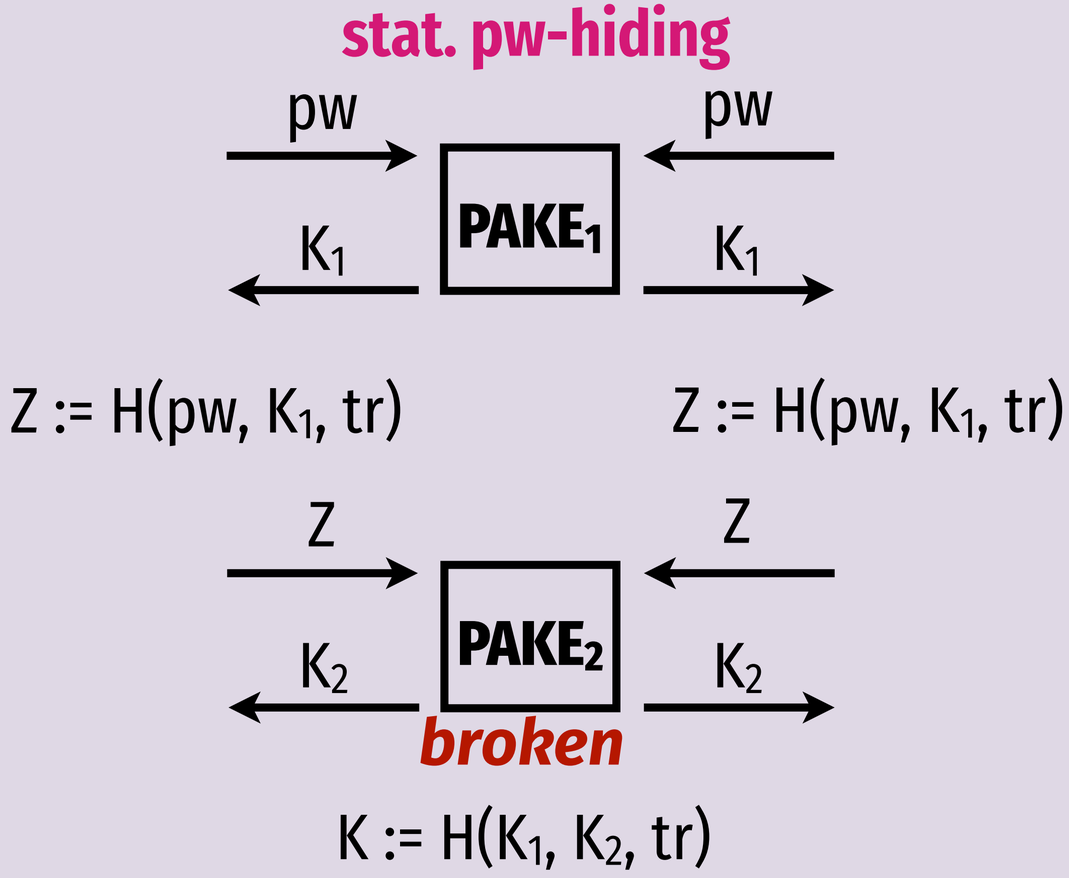
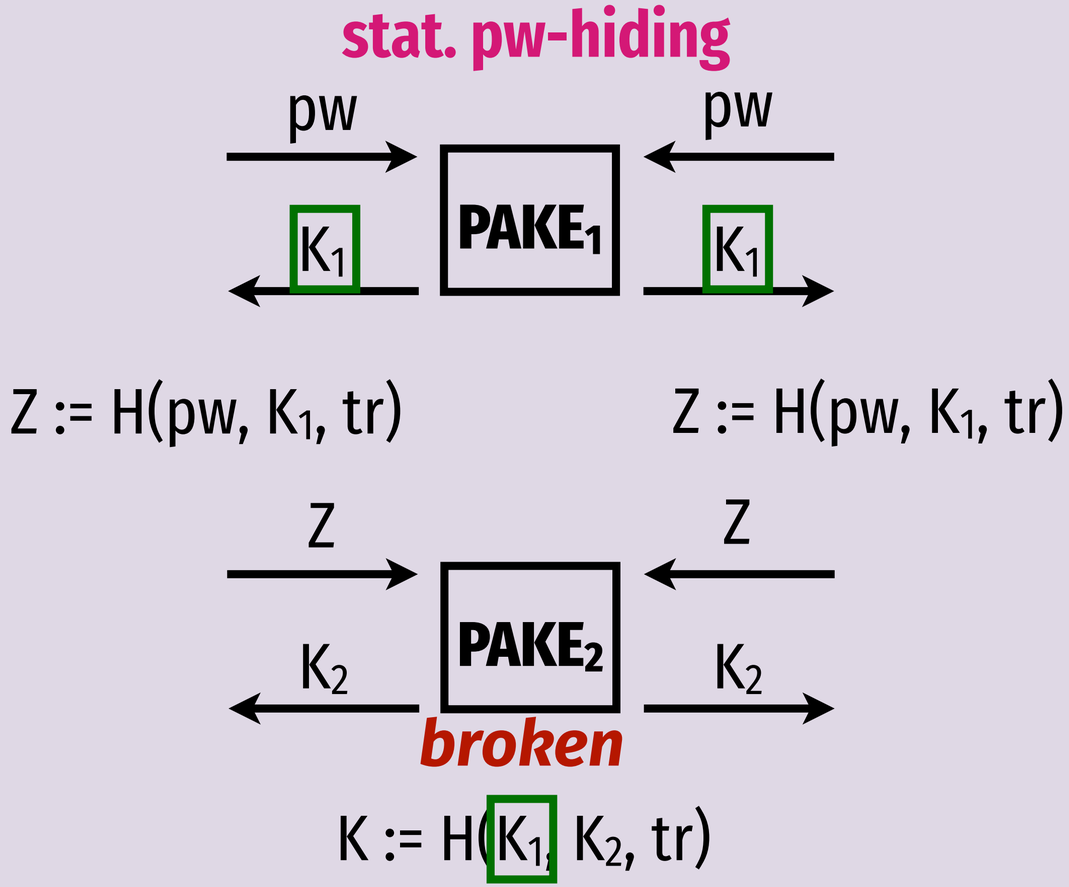


Building SeqComb



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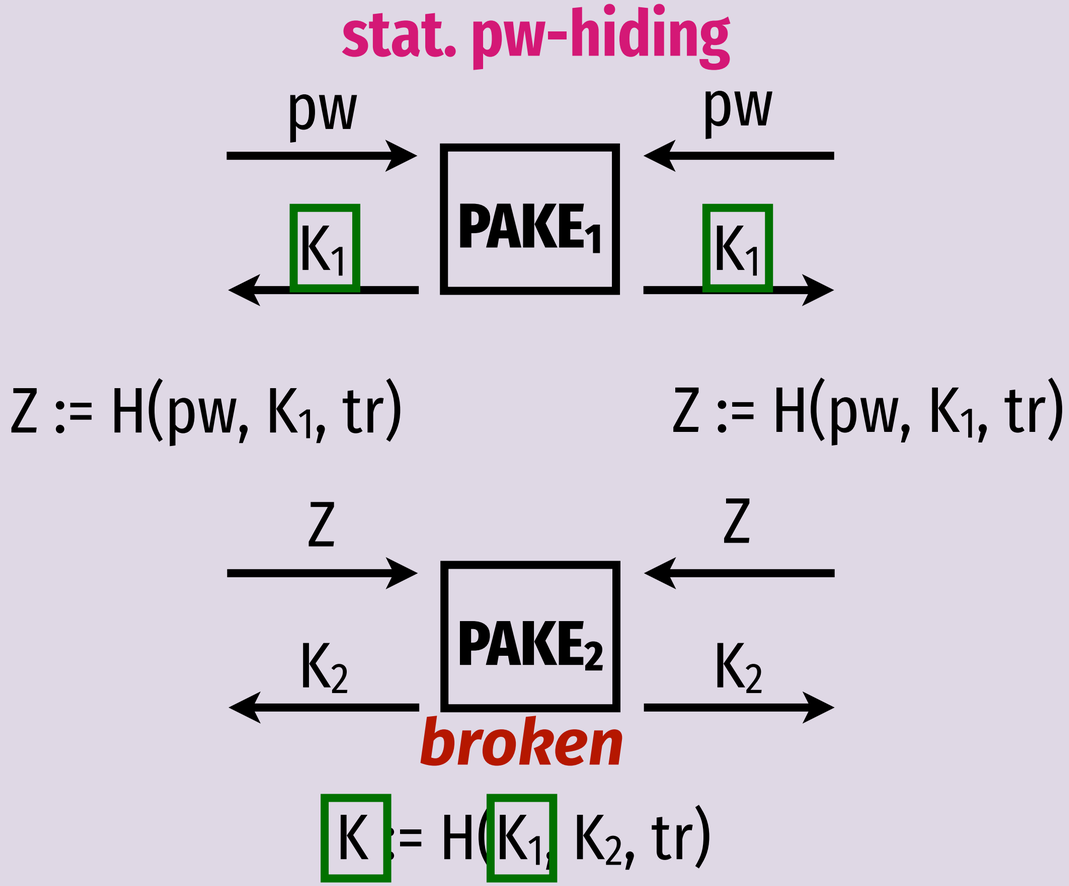
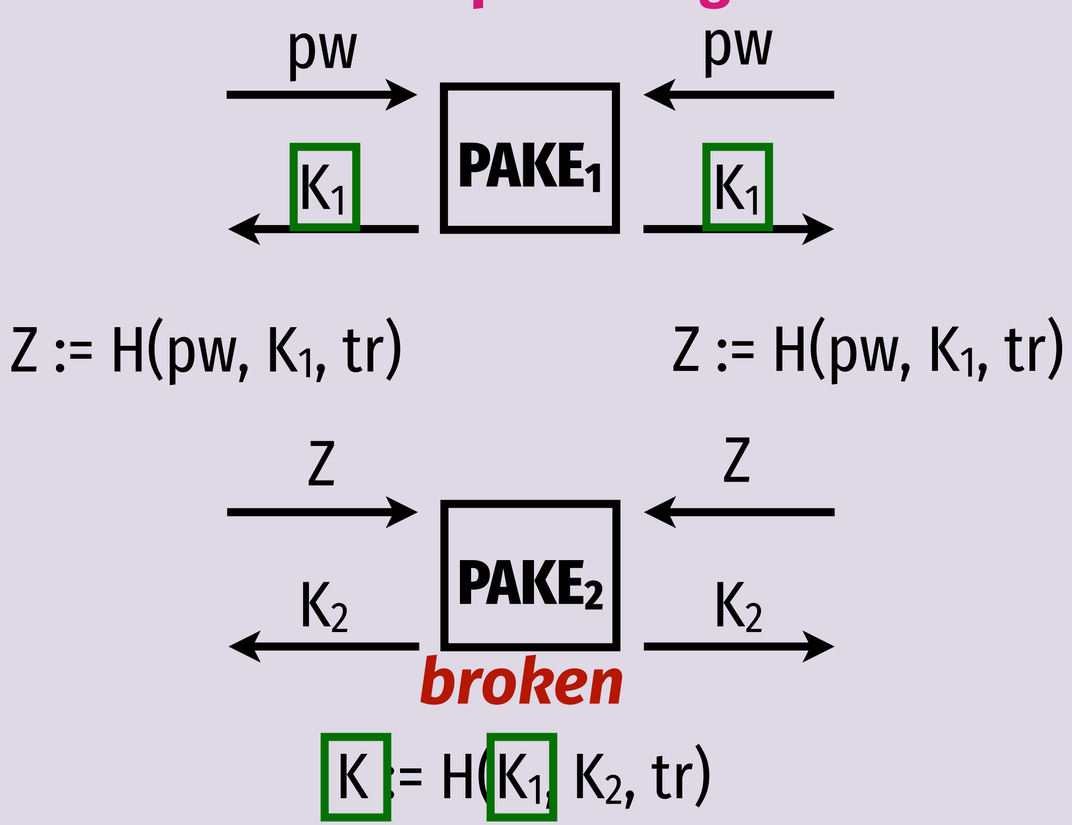


Building SeqComb

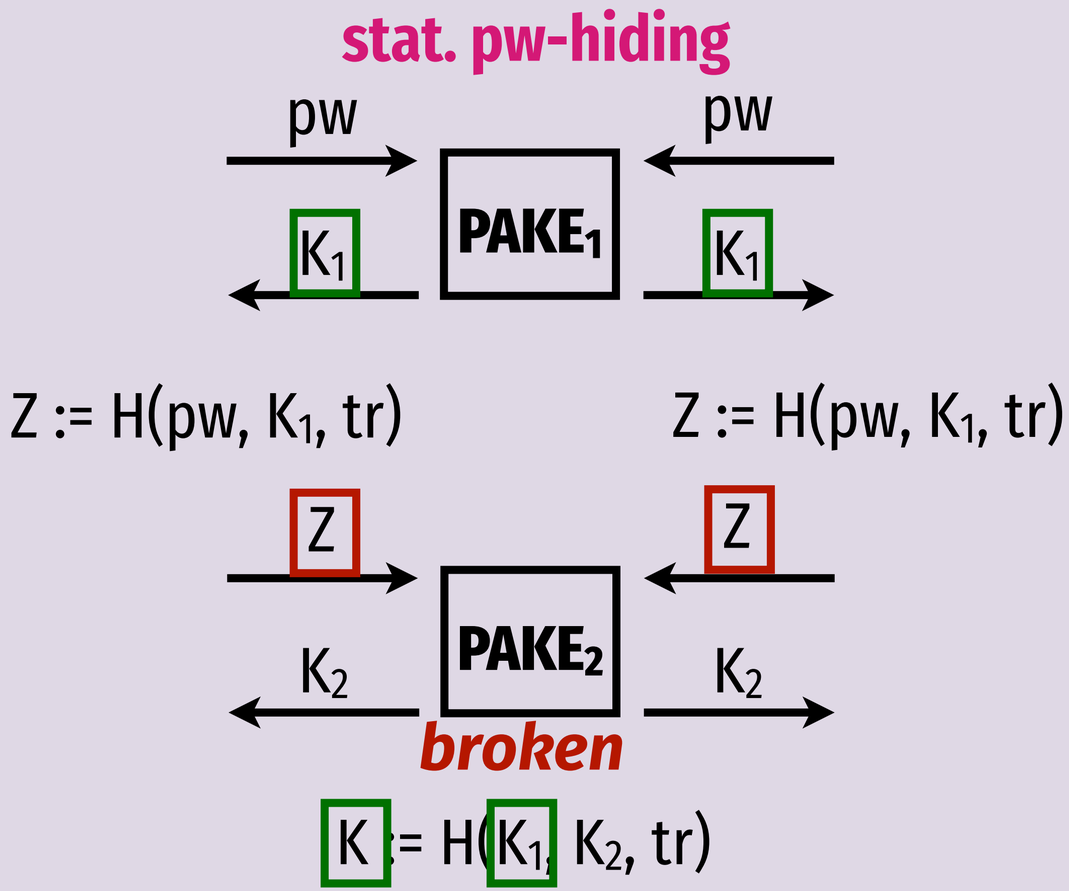
Session key is secure



Building SeqComb

Session key is secure

If Z leaks, the success of $PAKE_1$ leaks



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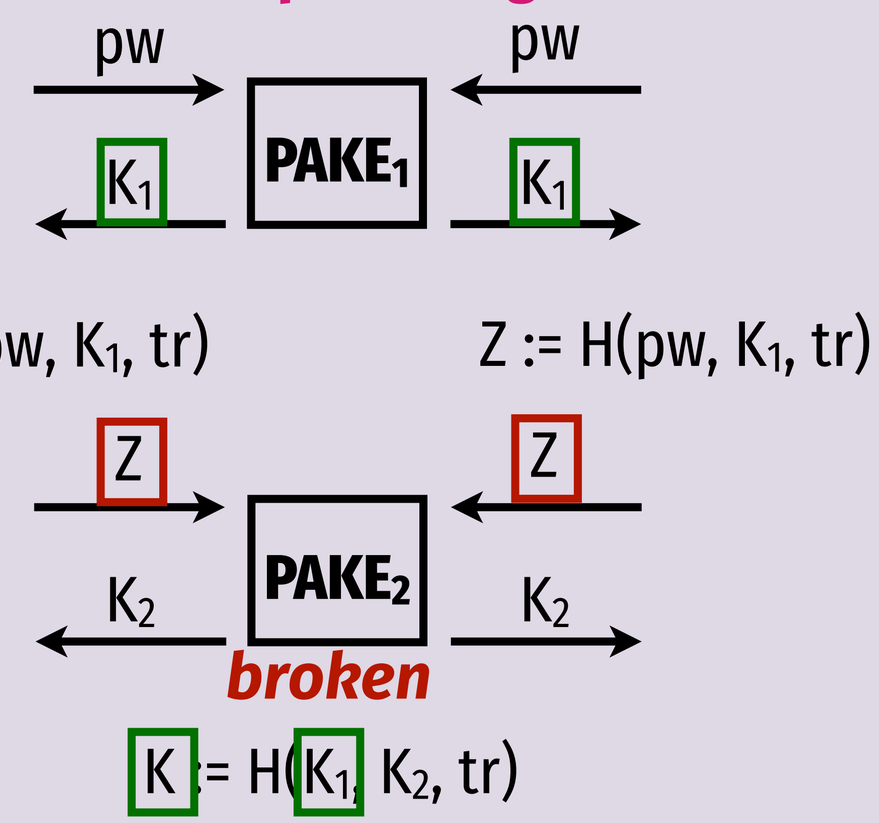
If Z leaks, the success of $PAKE_1$ leaks

New $PAKE_2$ property: **statistical preshared key equality hiding.**



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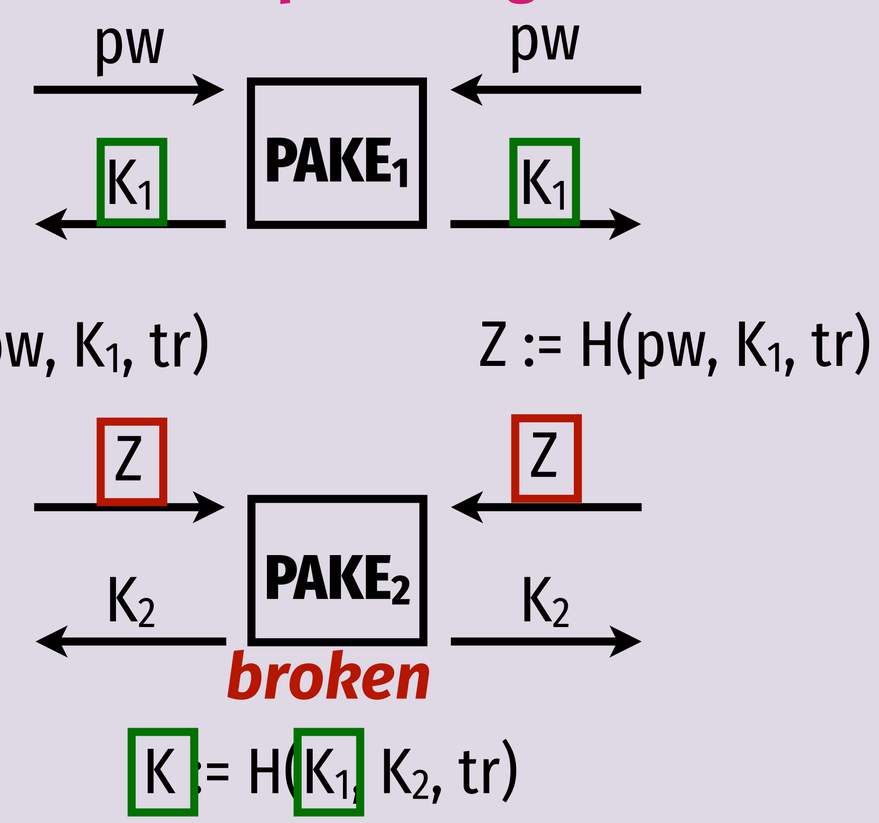

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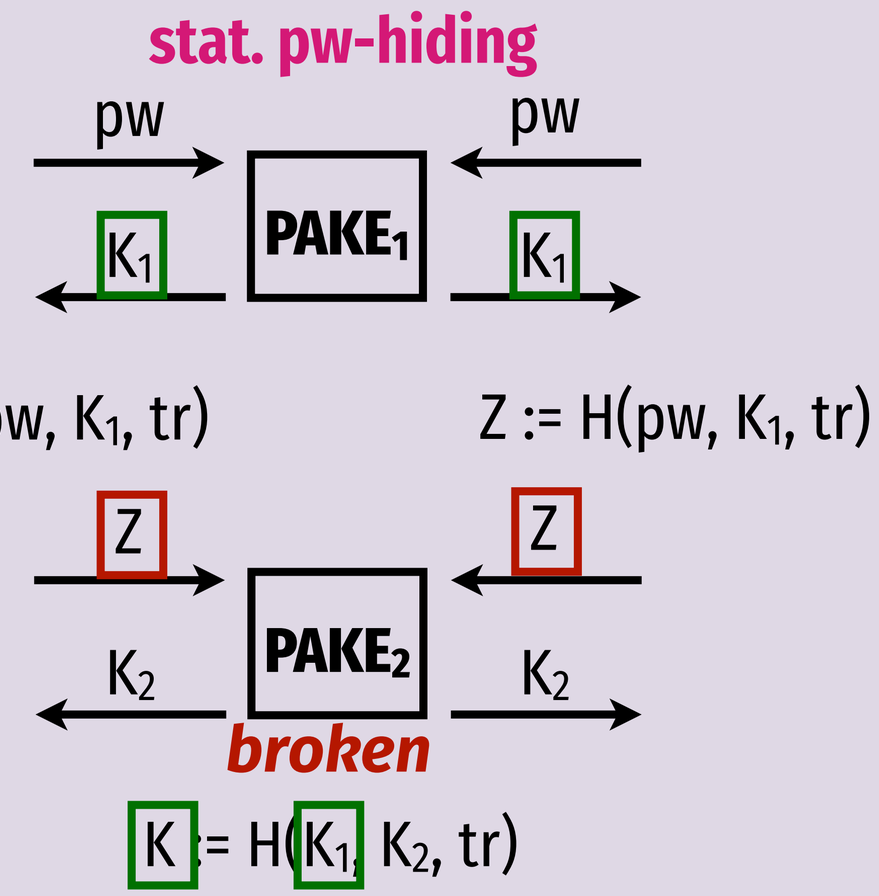
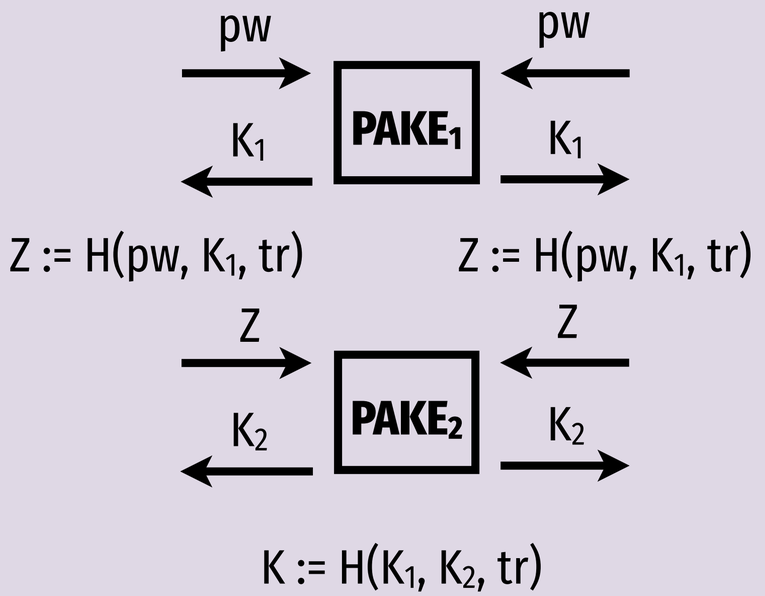


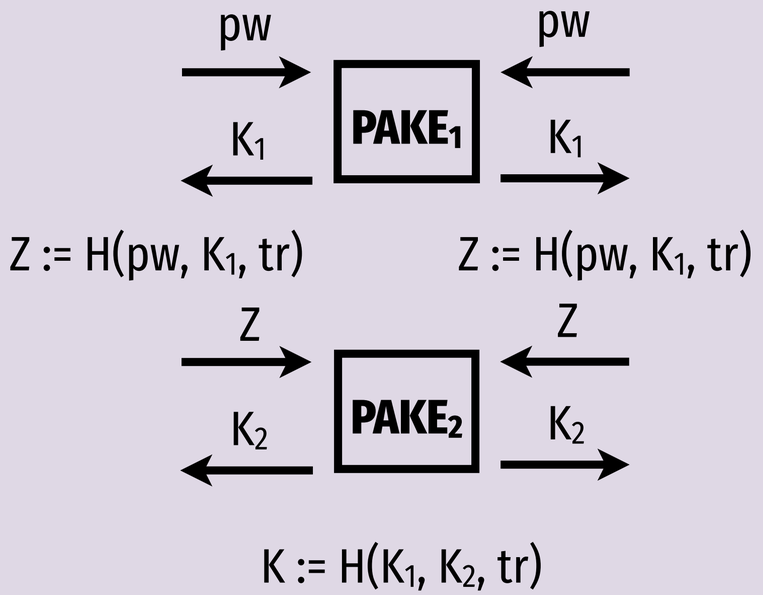
EKE-PRF and CAKE are stat. PSK-equality-hiding

Properties of SeqComb



Properties of SeqComb

Theorem 4: Let PAKE_1 be 1-round stat. pw-hiding, and PAKE_2 be stat. PSK equality-hiding. Then



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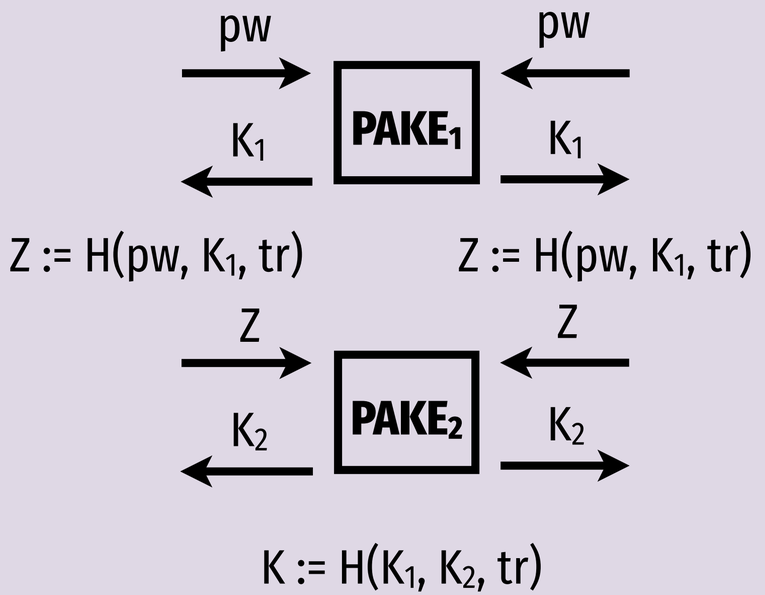

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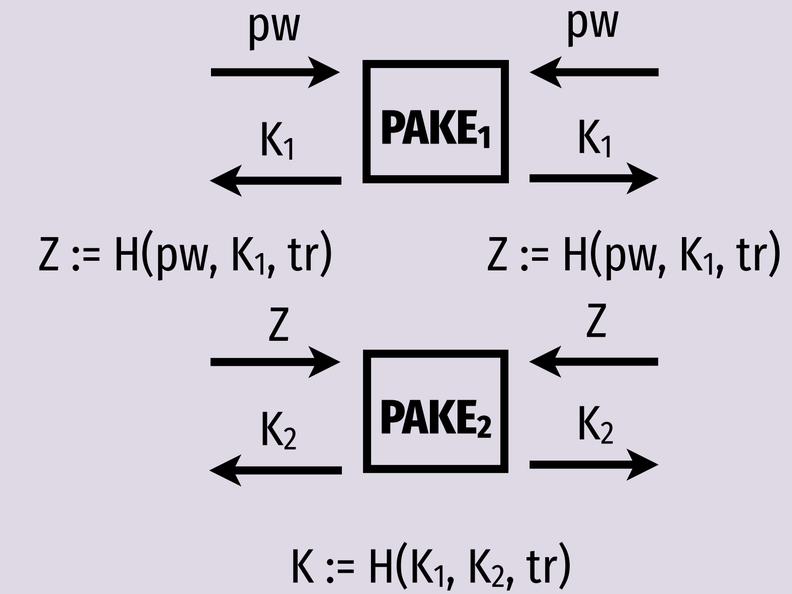

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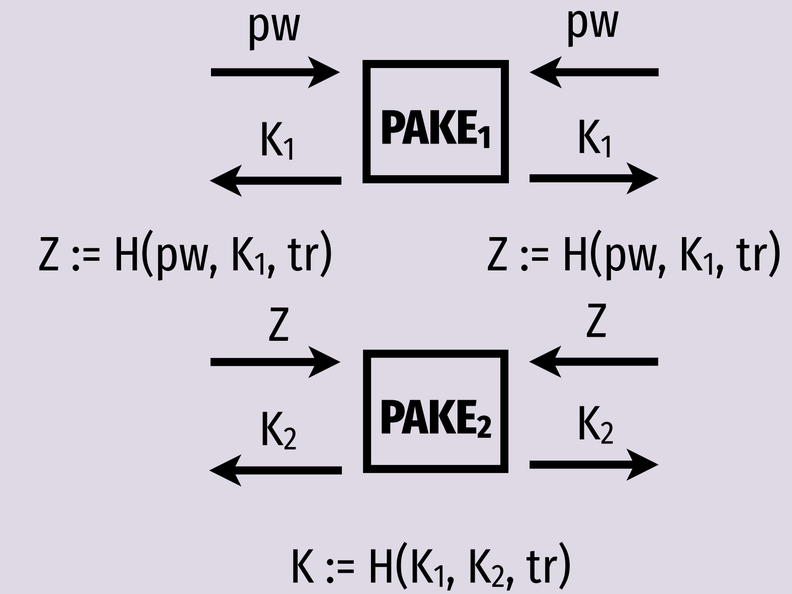
Properties of SeqComb



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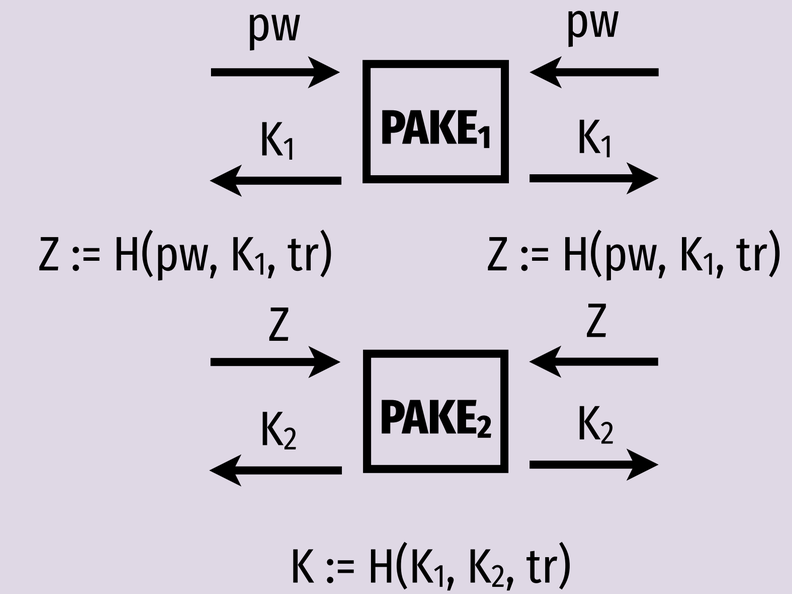
Bonus lemma: PAKE_1 $\mathcal{F}_{\mathrm{lePAKE}} \Rightarrow \mathcal{F}_{\mathrm{rlePAKE}}$

Properties of SeqComb



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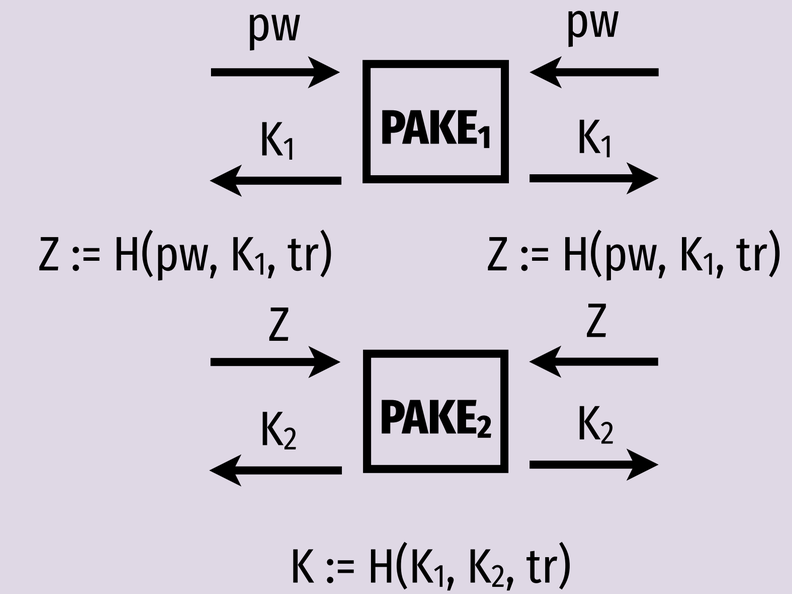
Properties of SeqComb



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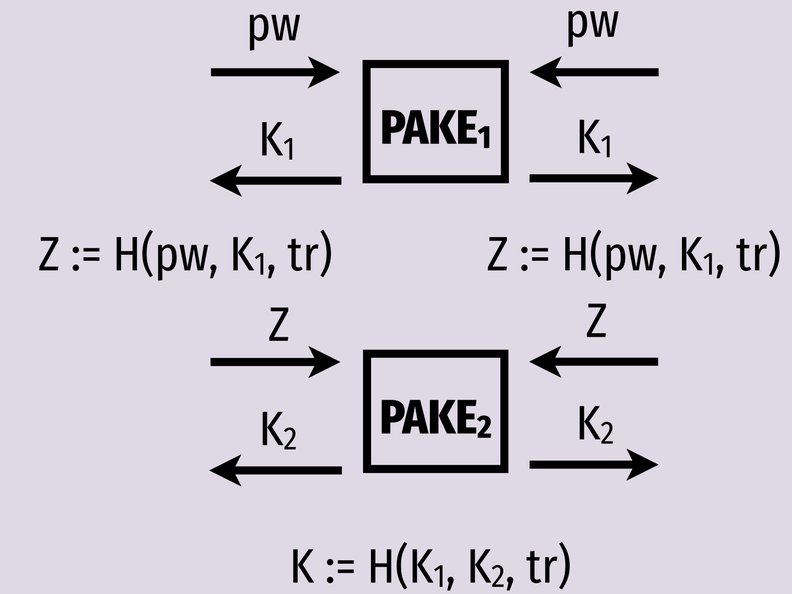

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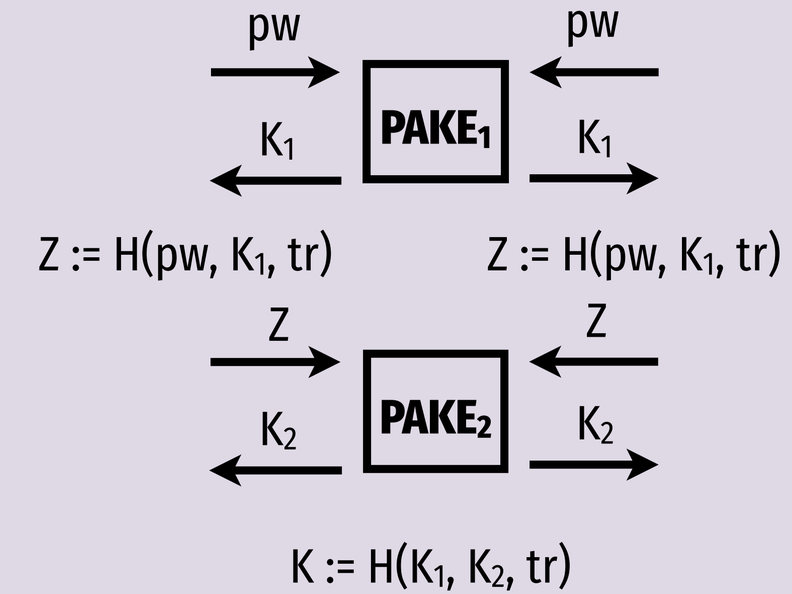
Properties of SeqComb



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Conclusion

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First construction of a **hybrid PAKE**

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Presented **two methods**, parallel and sequential

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Sequential has **mild assumptions**, working with efficient existing PAKEs

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Combiner	$PAKE_1$	$PAKE_2$	Combined	Model
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	$\mathcal{F}_{\text{blePAKE+PH}}$	$\mathcal{F}_{\text{lePAKE+PH}}$	$\mathcal{F}_{\text{blePAKE}}$	ROM
SeqComb	$\mathcal{F}_{\text{PAKE+PH}}$	$\mathcal{F}_{\text{PAKE+PEH}}$	$\mathcal{F}_{\text{PAKE}}$	ROM
	$\mathcal{F}_{\text{lePAKE+PH}}$	$\mathcal{F}_{\text{PAKE+PEH}}$	$\mathcal{F}_{\text{rlePAKE}}$	ROM
	$\mathcal{F}_{\text{PAKE+PH}}$	$\mathcal{F}_{\text{PAKE}}$	$(\mathcal{F}_{\text{PAKE}})$	QROM

+PH means stat. pw-hiding
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$(\mathcal{F})$ means nearly UC-realizes

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https://www.ietf.org/archive/id/draft-vos-cfrg-pqpake-00.html

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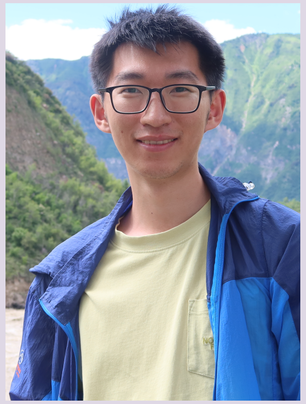


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https://www.ietf.org/archive/id/draft-vos-cfrg-pqpake-00.html

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