CISPA
HELMHOLTZ CENTER FOR INFORMATION SECURITY

When is an AKE Protocol Secure against State Reveals?

Revisiting Models, Protocols, and Transforms

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joint work with Hans Heum[2], Xiangyu Liu[1] and Doreen Riepel[1]

[1] CISPA, [2] Simula UiB

ProTeCS 2026

Authenticated Key Exchange

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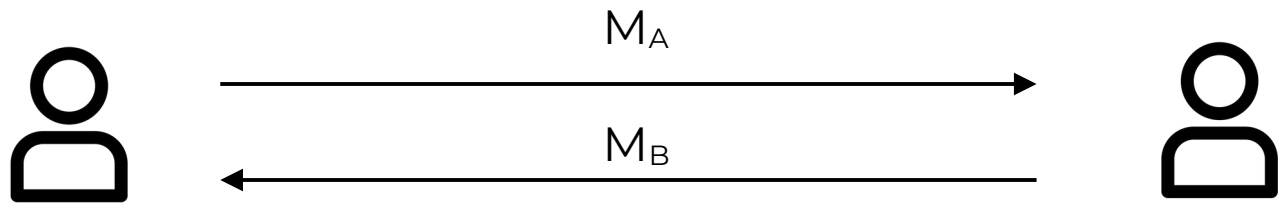

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Security Goals:

- Key Indistinguishability
- Authentication between users

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Considered Protocols:

- 2-round protocols
- Implicitly authenticated protocols

AKE: A little syntax

Alice

Bob

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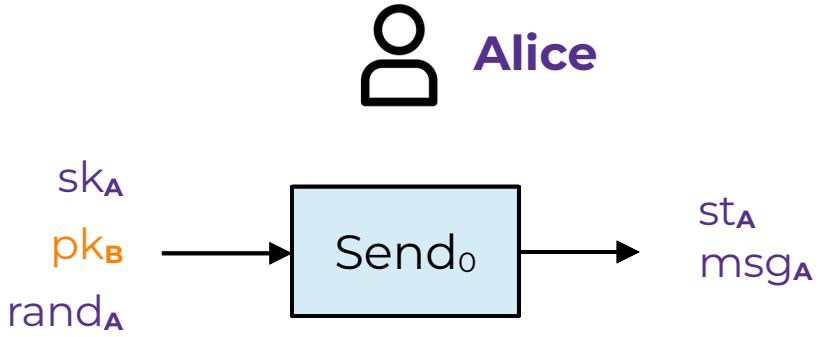

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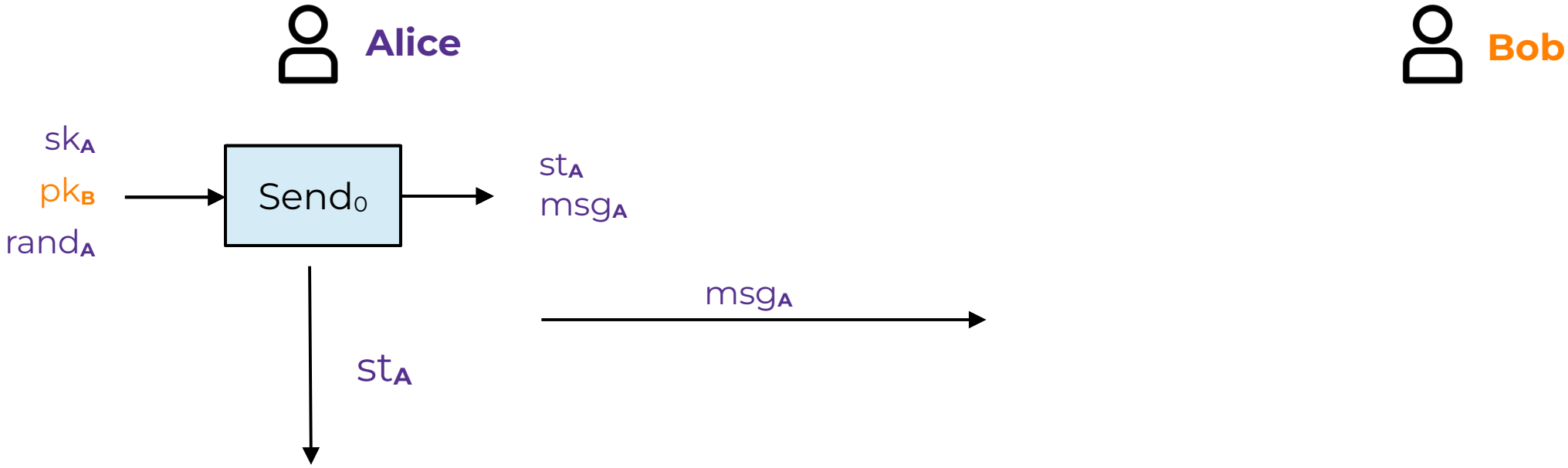

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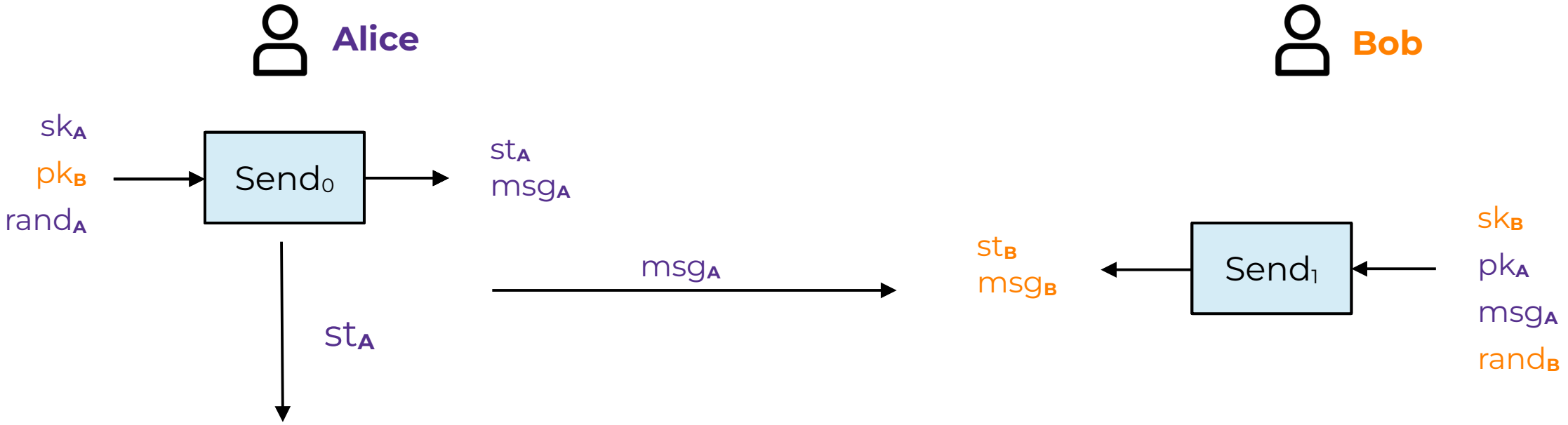

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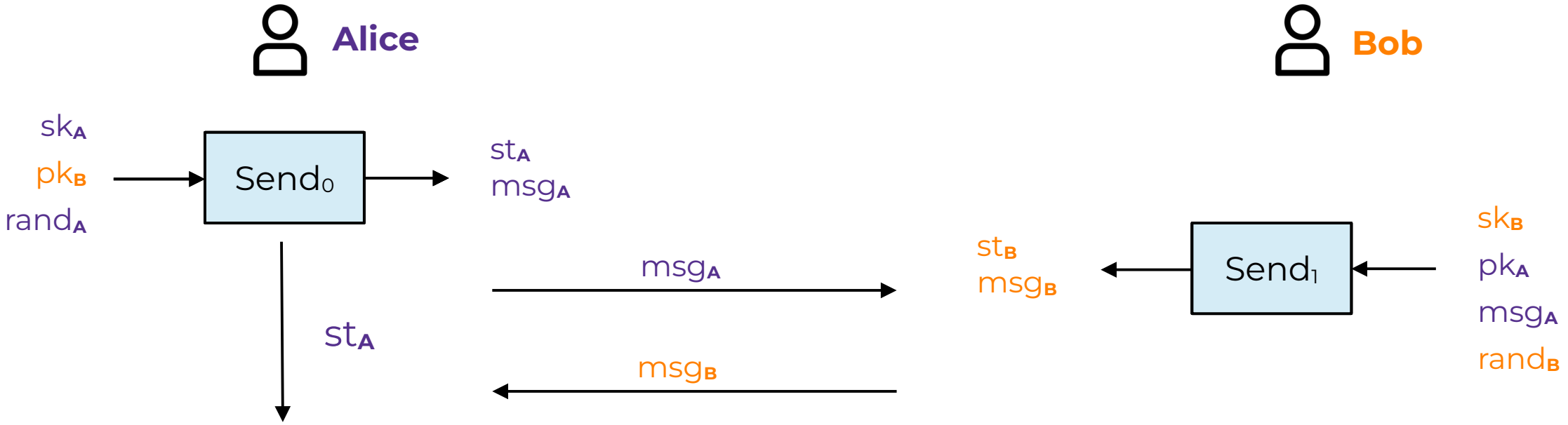

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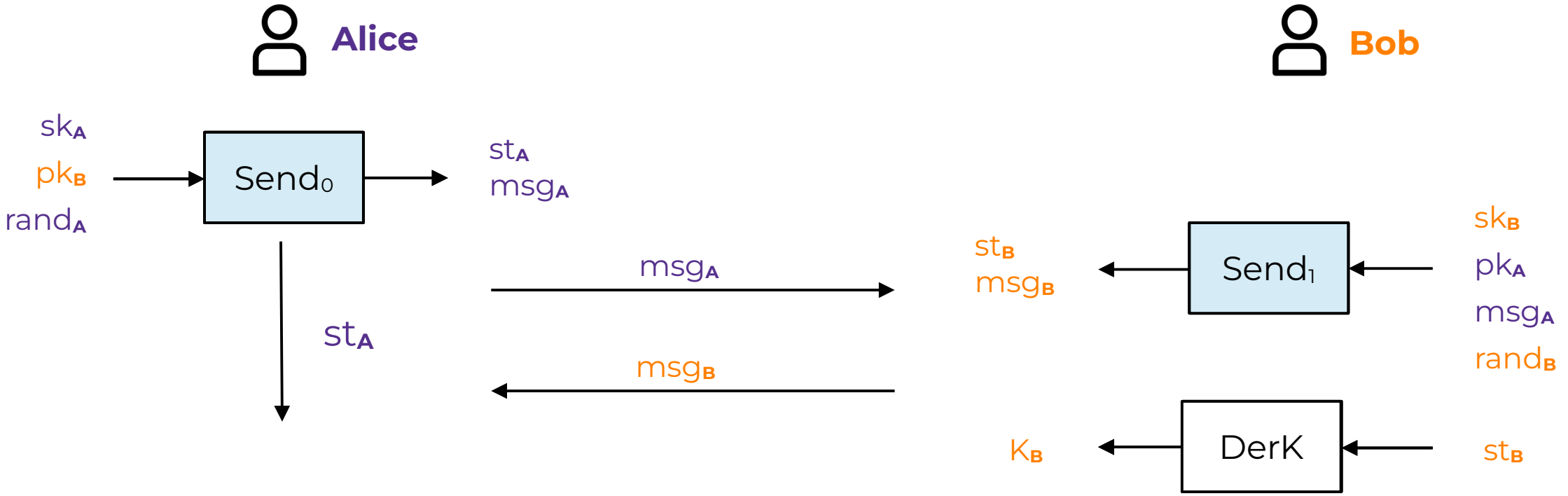

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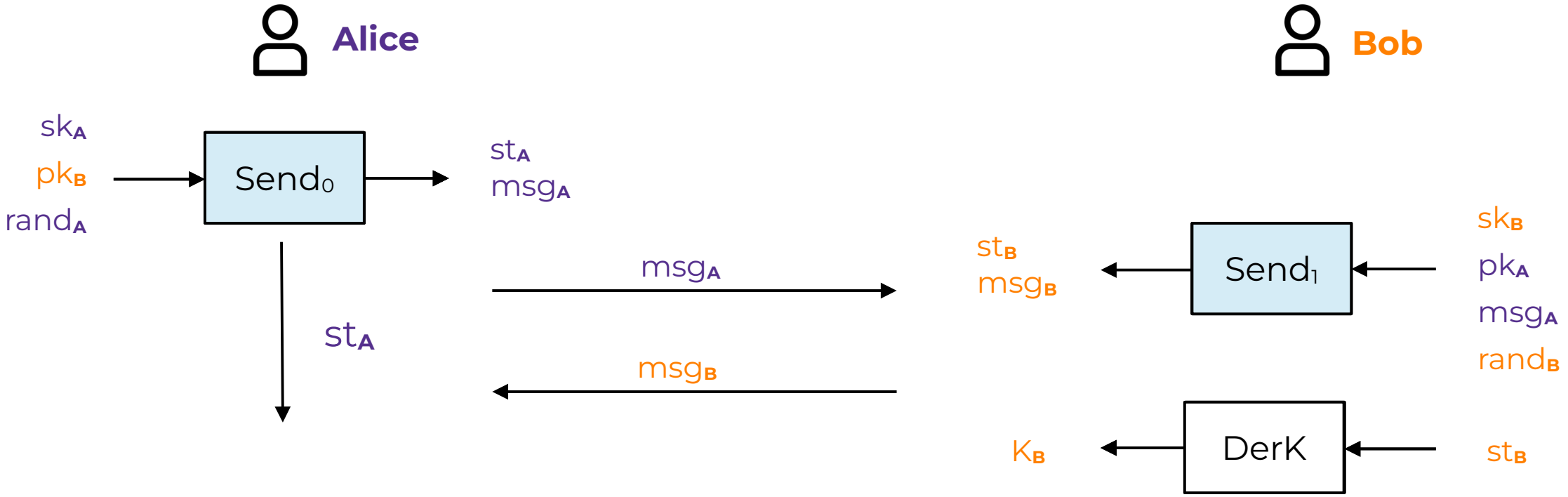

DerK captures intermediate computation and secret-key independence

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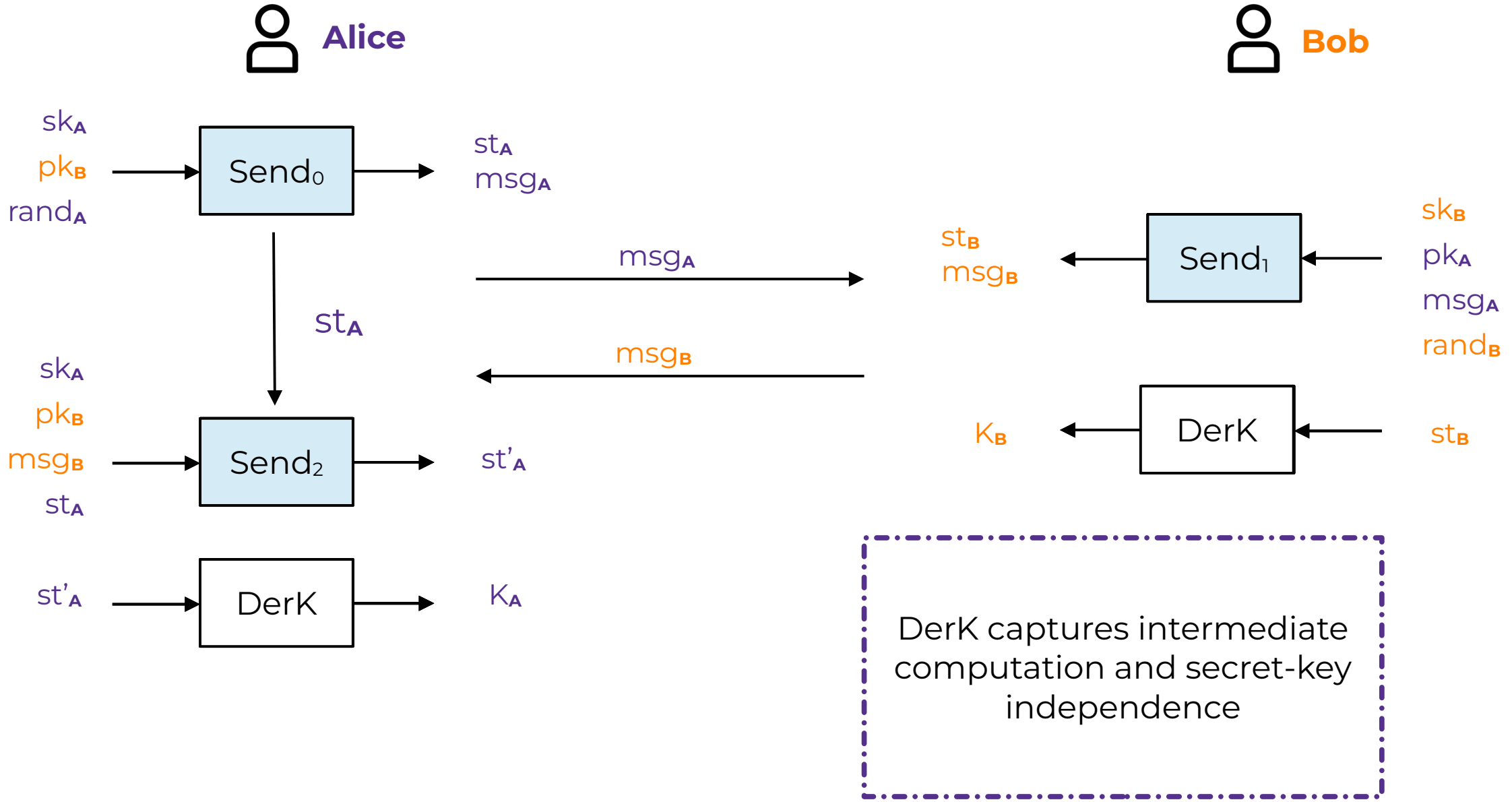

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Security is modeled as a game between Challenger and Adversary.

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- Two sessions are fully partnered if they have “matching conversations”
- **Independent sessions** are those sessions which are not partnered to the other

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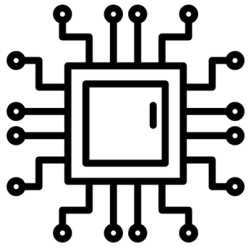
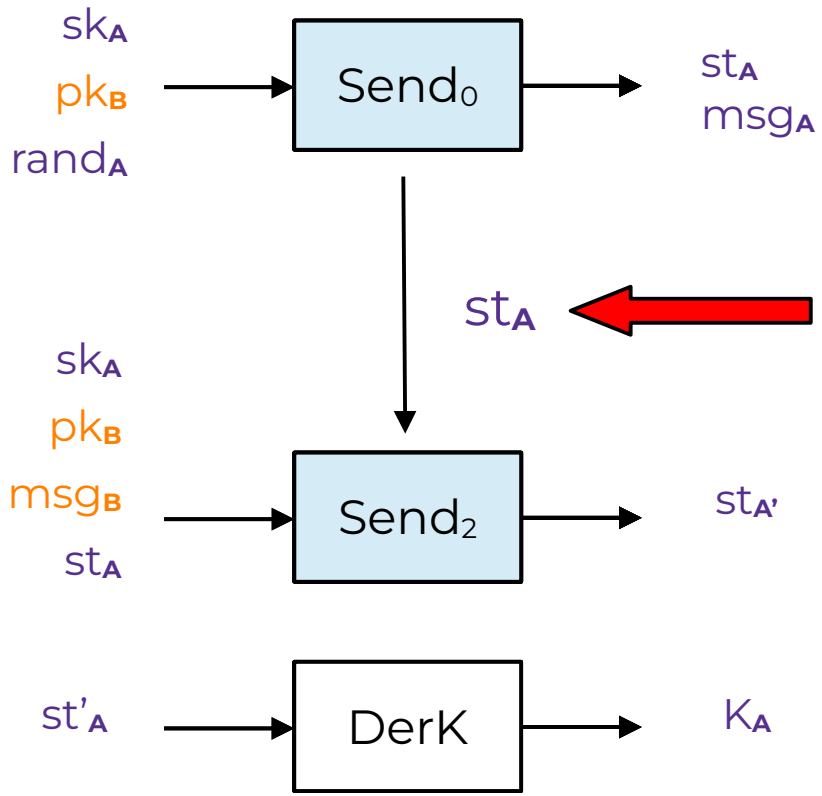
Ordinary State Reveal

- Outputs the entire state of a given session
- CK model [CK01] HMQV proven secure





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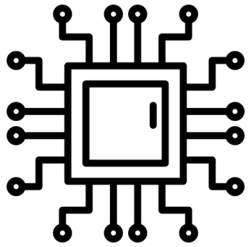

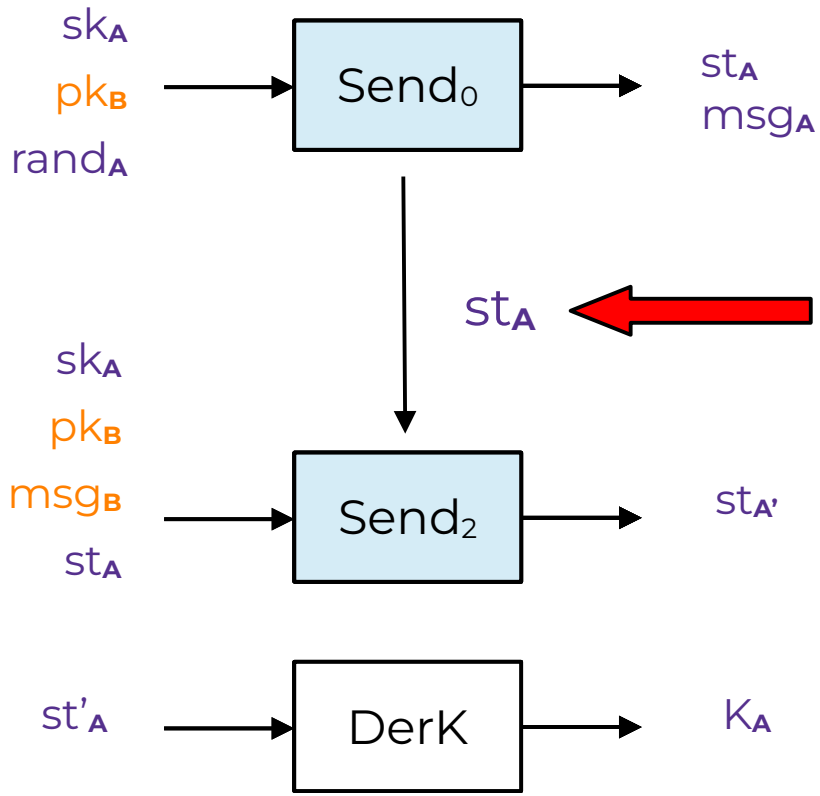

(allowed only for Alice)

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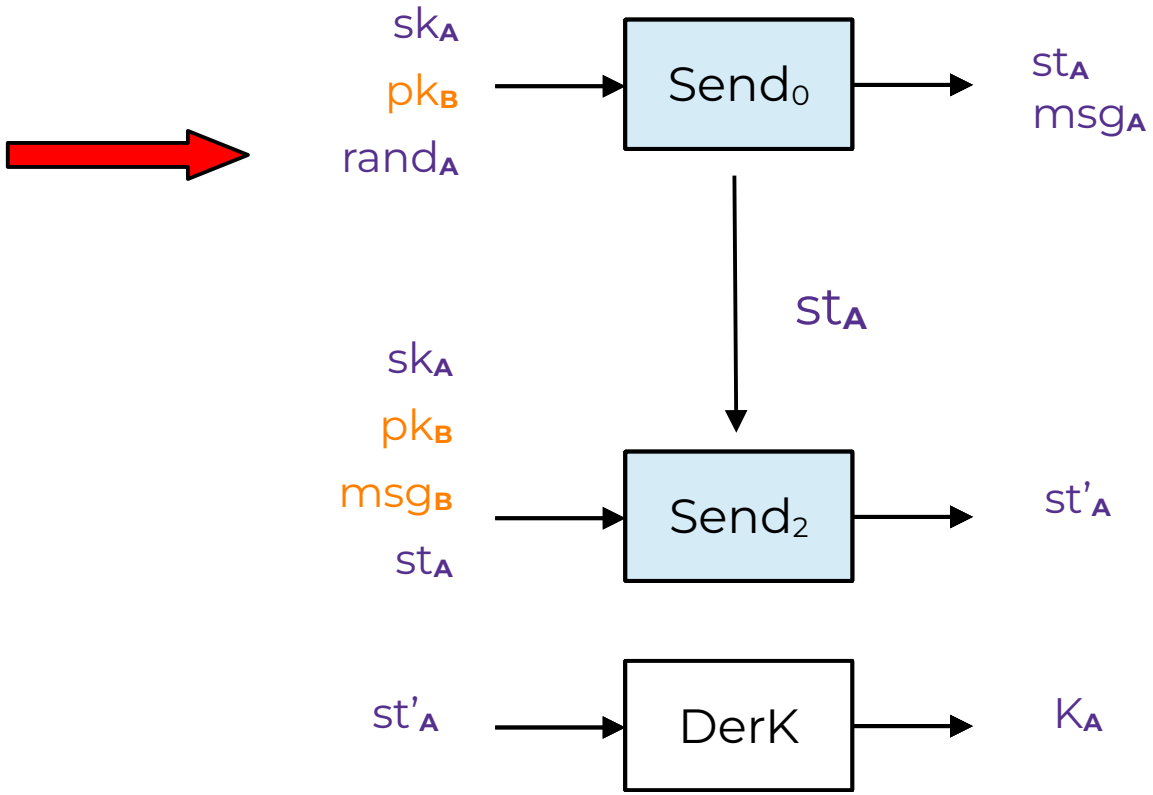
Randomness Reveal

- Outputs the randomness used in the session
- eCK model [LL07] NAXOS proven secure



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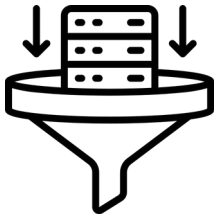
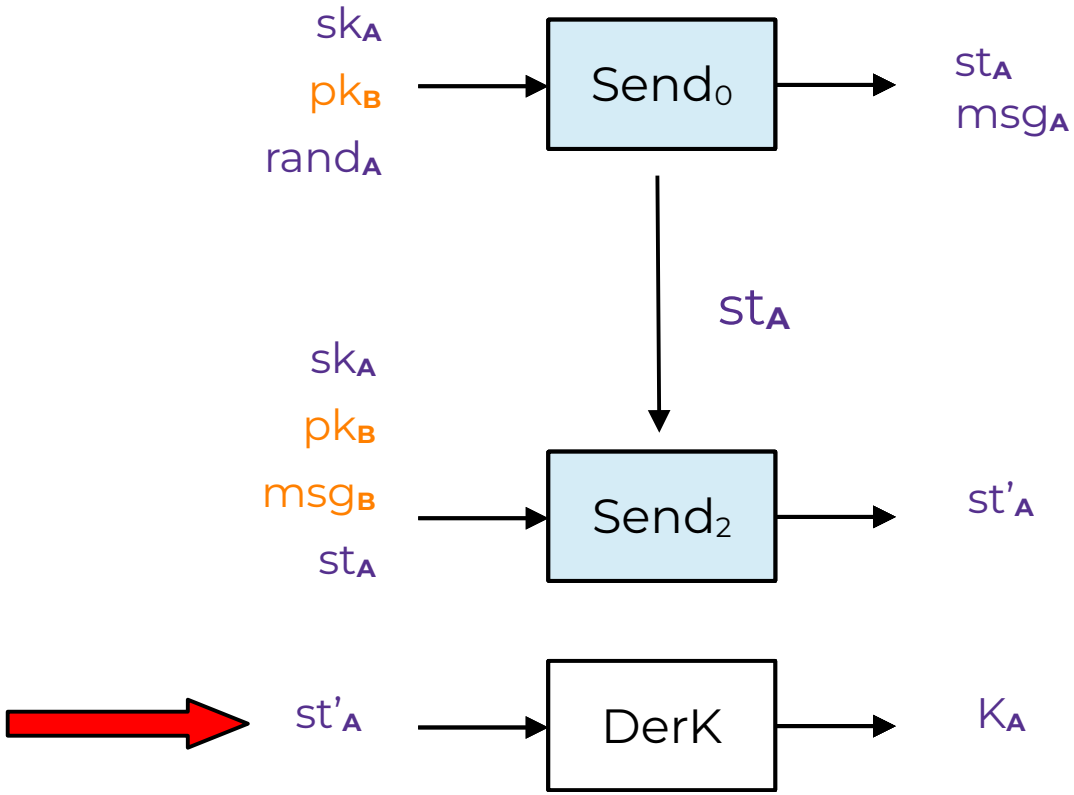
Preimage Reveal

- Outputs the input to the DerK function
- Only allowed for independent sessions
- seCK model [SEB10]





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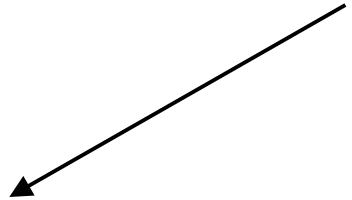

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2R transform

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The Randomness-Reinforcement (2R) transform

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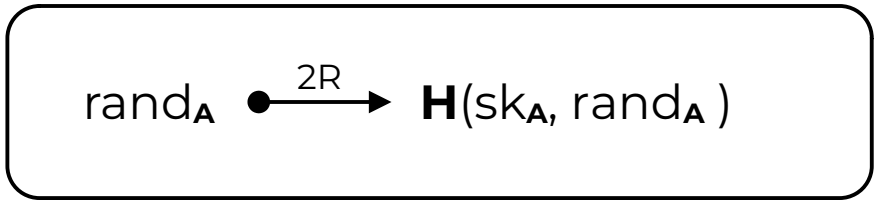
Binds long term secret key with randomness, “reinforcing” it against randomness reveals

(for both Alice and Bob)



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$\text{rand}_A \xrightarrow{2R} \mathbf{H}(\text{sk}_A, \text{rand}_A)$

“Hides” the initiator’s intermediate state by redefining it as the “plain” randomness .

(for only Alice)

$\text{st}_A \xrightarrow{2R} \text{st}_A := \text{rand}_A$

This makes state-reveal equivalent to a randomness reveal

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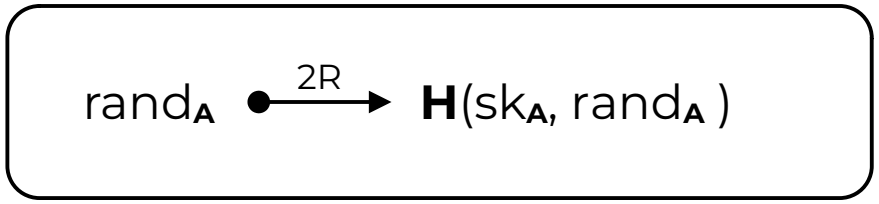

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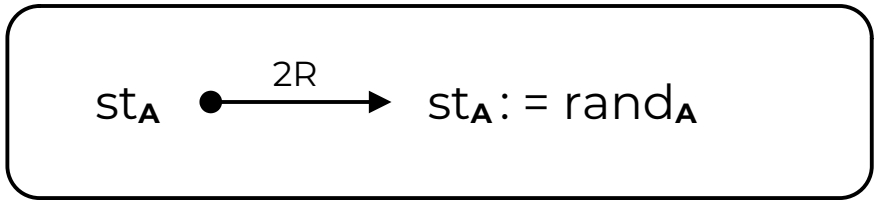

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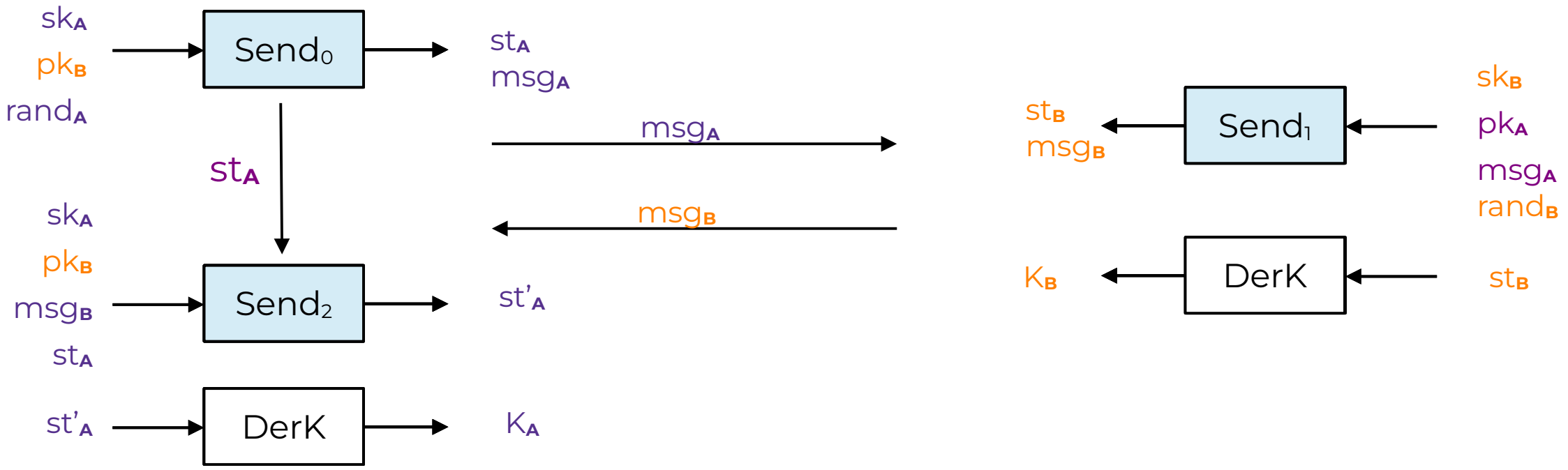
Generalization of the NAXOS[1] trick !

Brian A. LaMacchia, Kristin Lauter, and Anton Mityagin. Stronger security of authenticated key exchange, ProvSec 2007

The 2R transform



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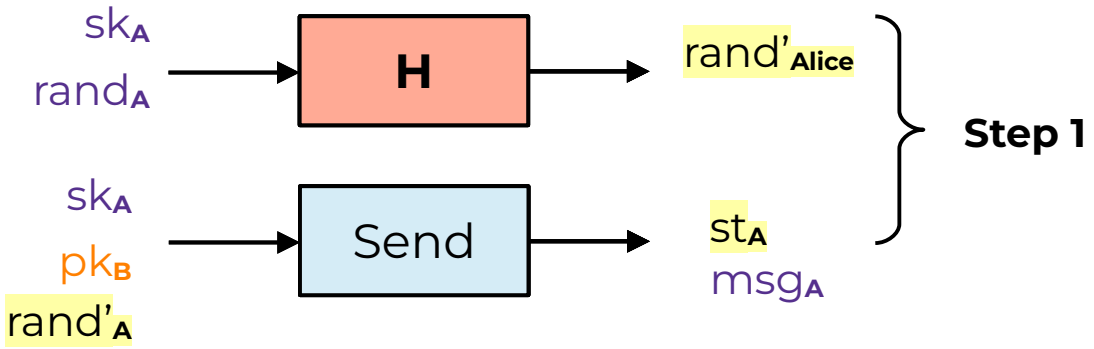

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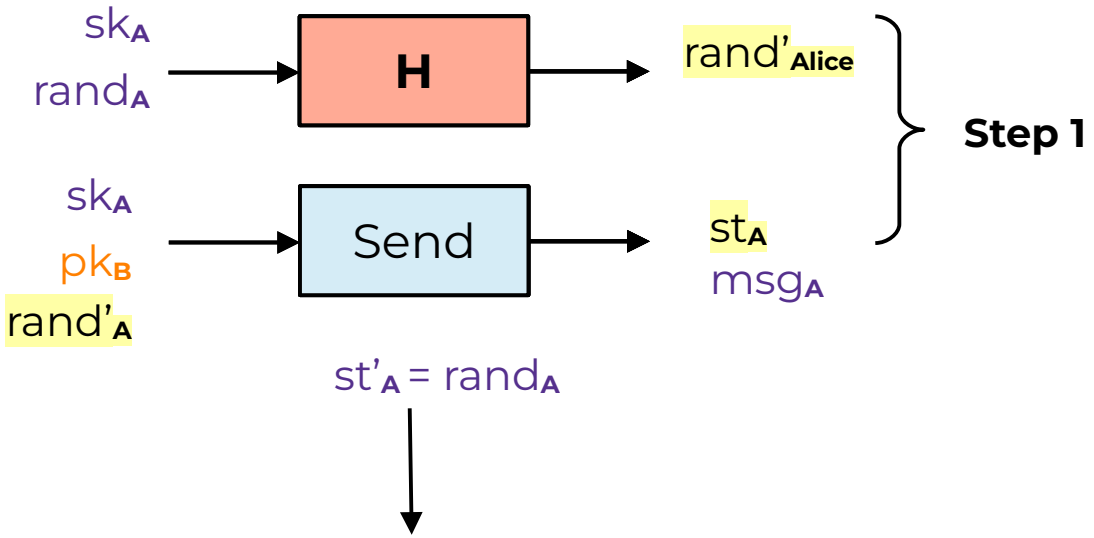

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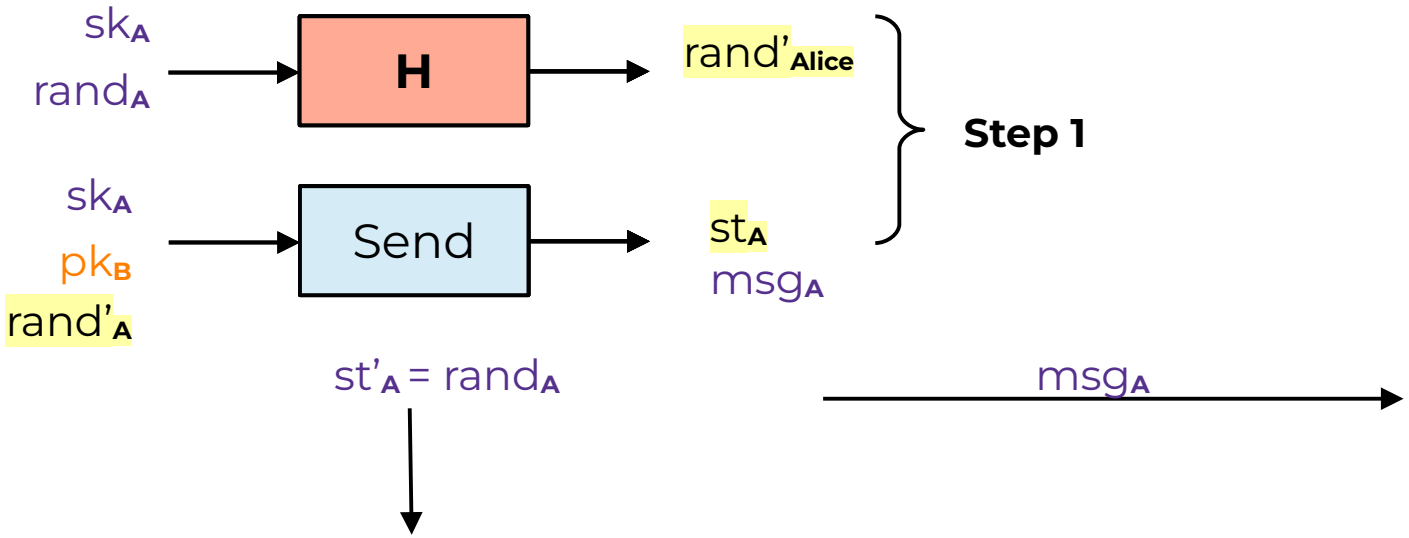

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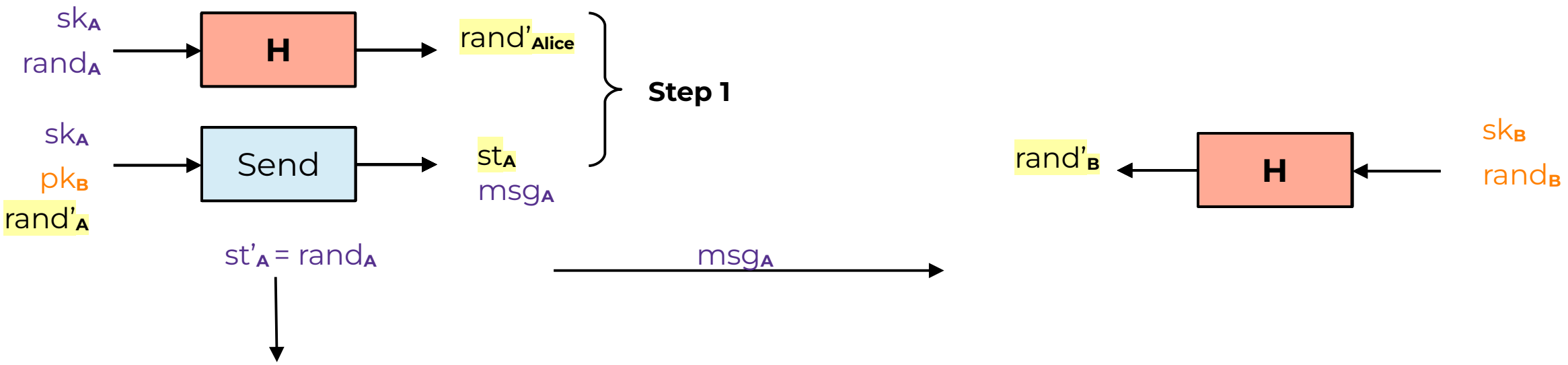

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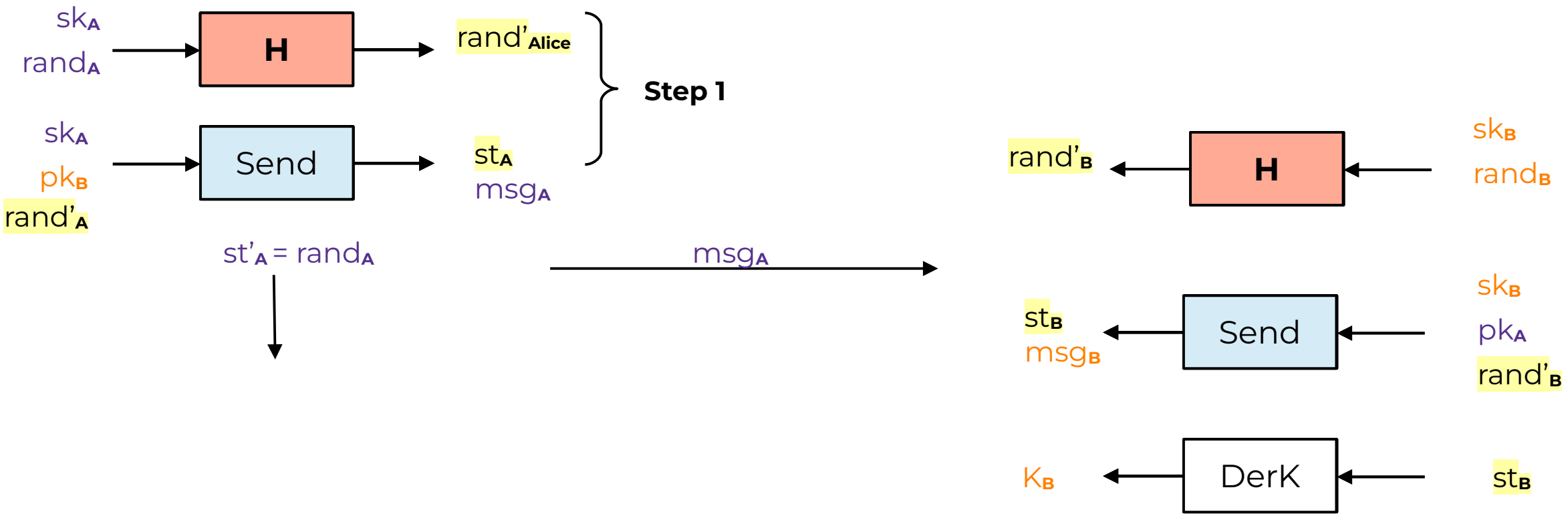

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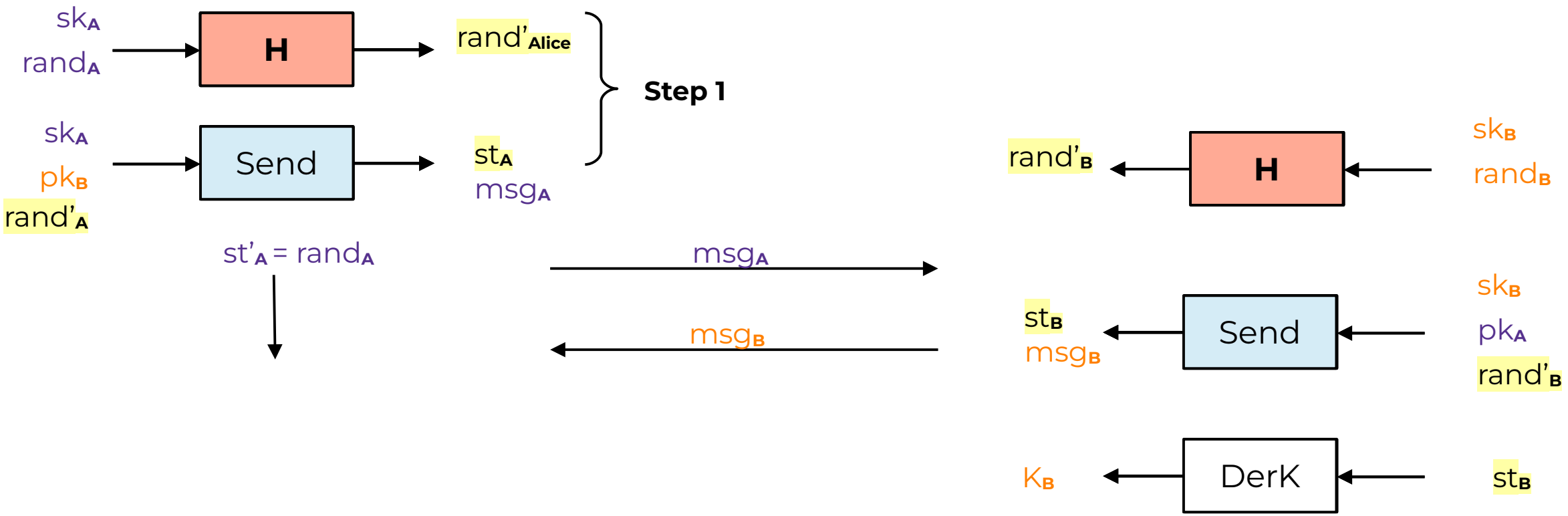

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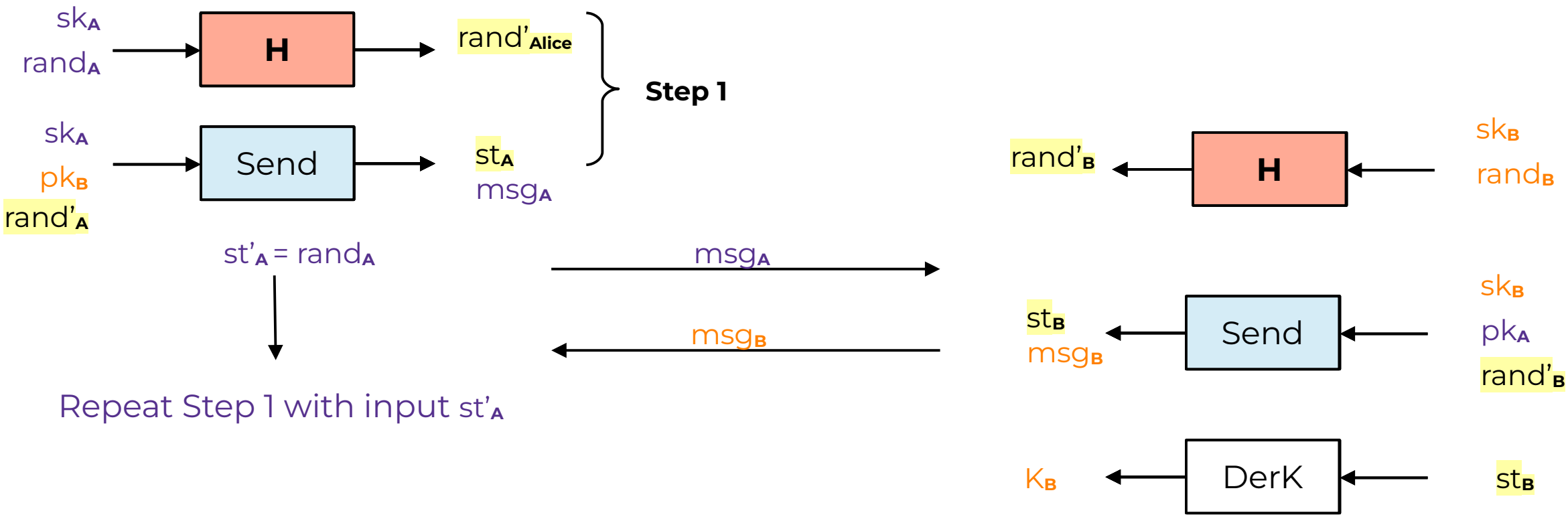

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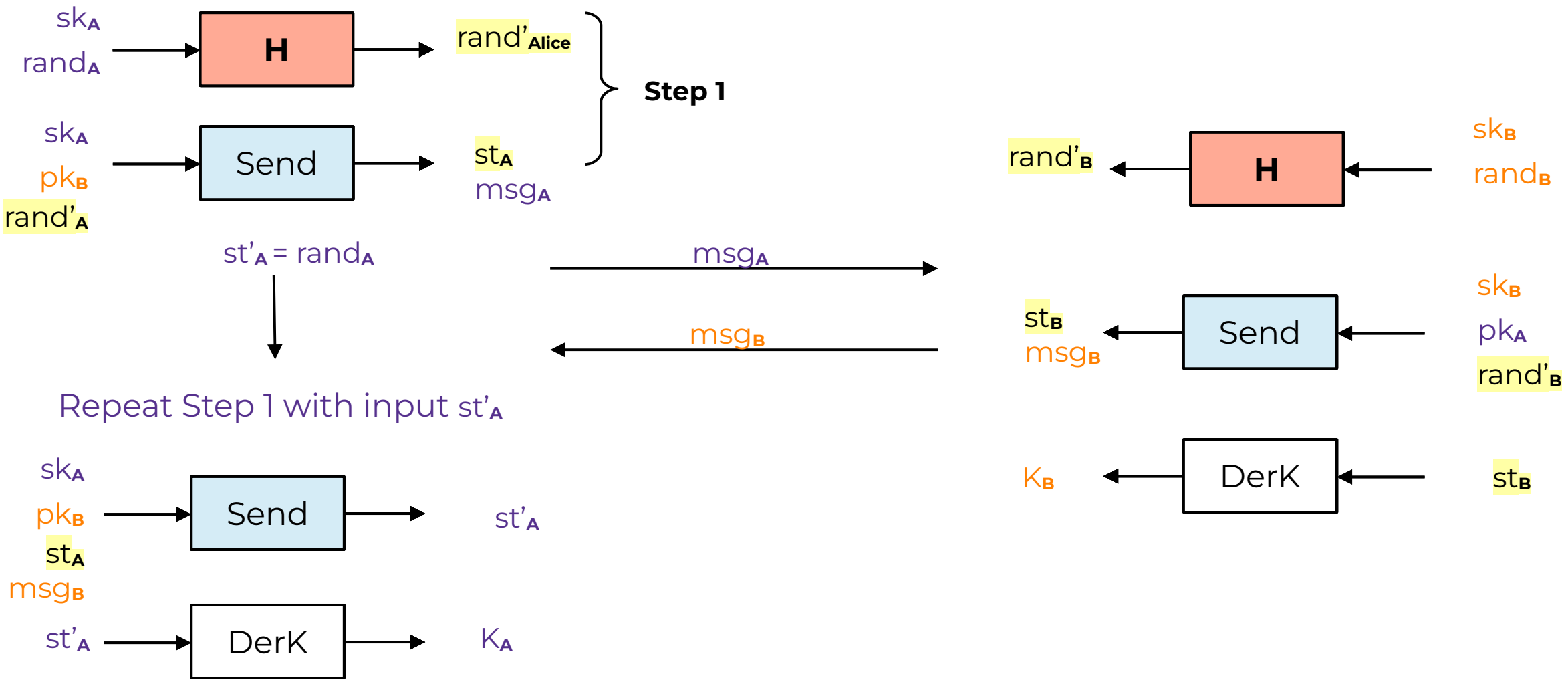

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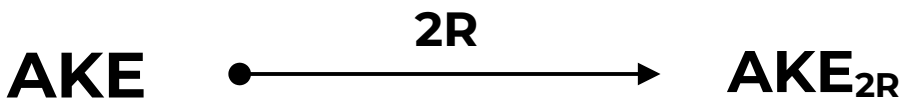
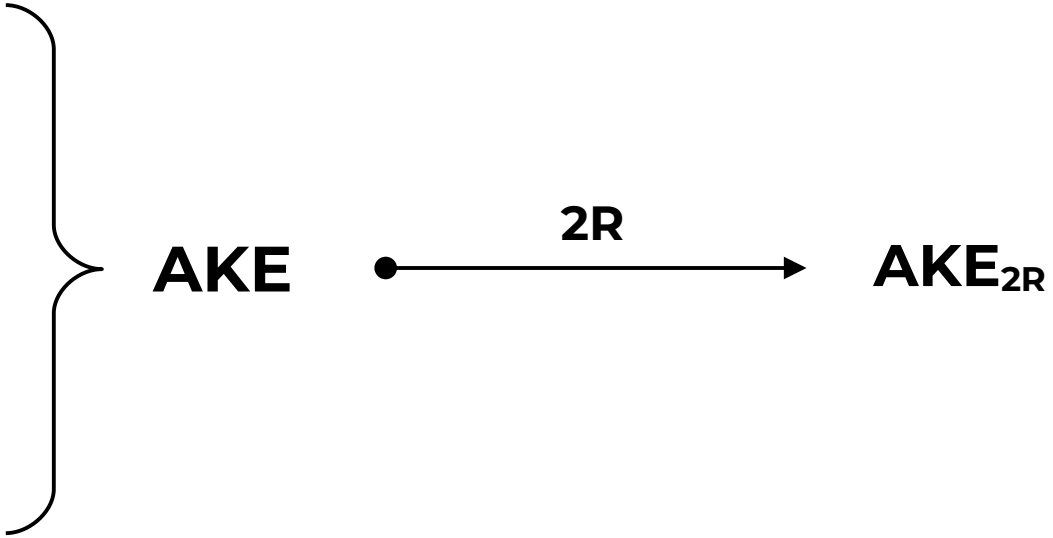


The 2R transform

Secure in our model without any state reveals of test sessions



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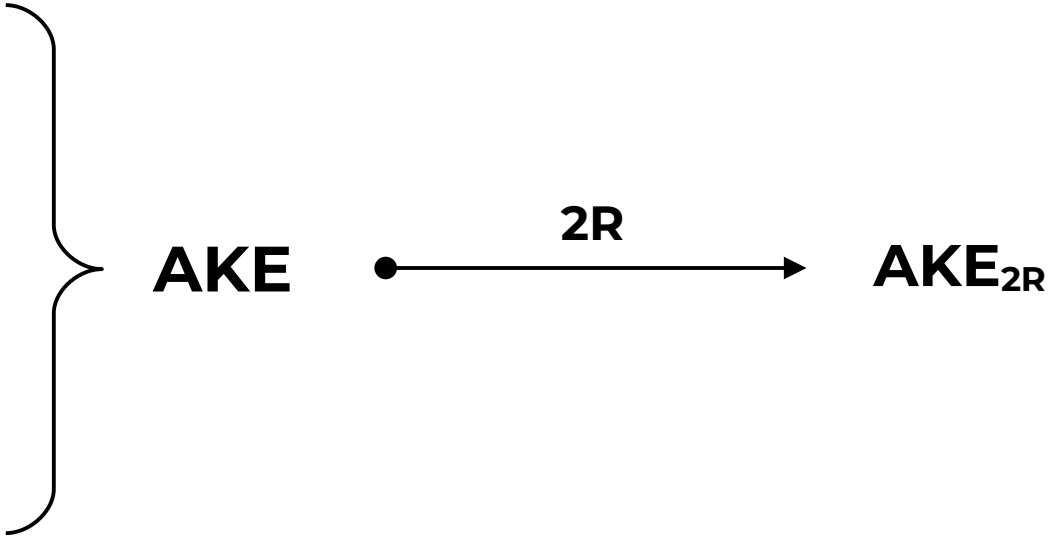

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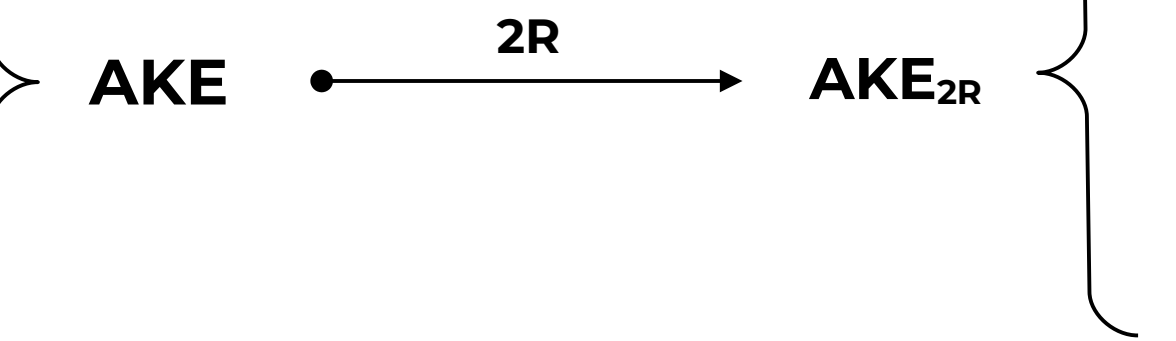

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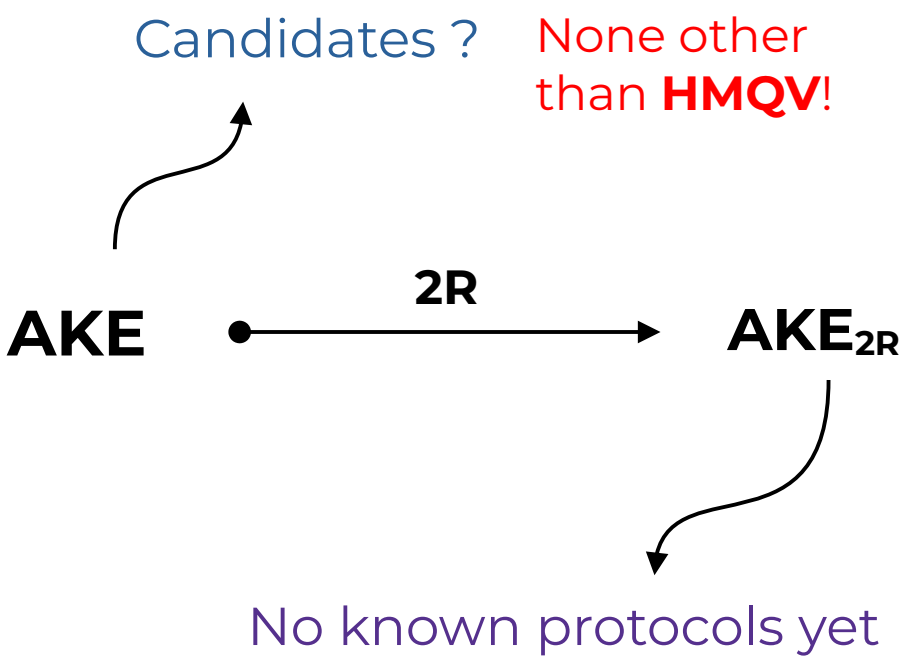

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HMQV: a curious case

Alice (a, $A = g^a$) **Bob** (b, $B = g^b$)

$x \leftarrow\$ \mathbf{Z_p}$ $X = g^x$ $y \leftarrow\$ \mathbf{Z_p}$

$Y = g^y$

$K := \mathbf{H'}(ctxt , (XA^d)^{y+be})$

$g^{(x + ad)(y + be)}$

$K := \mathbf{H'}(ctxt , (YB^e)^{x +ad})$

$g^{(y + be)(x + ad)}$

$ctxt := (A, B, X, Y)$

$d = \mathbf{H_1}(X, \mathbf{Bob})$; $e = \mathbf{H_2}(Y, \mathbf{Alice})$

Hugo Krawczyk. HMQV: A high-performance secure Diffie-Hellman protocol, CRYPTO 2005

HMQV: Properties

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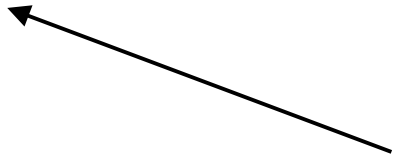
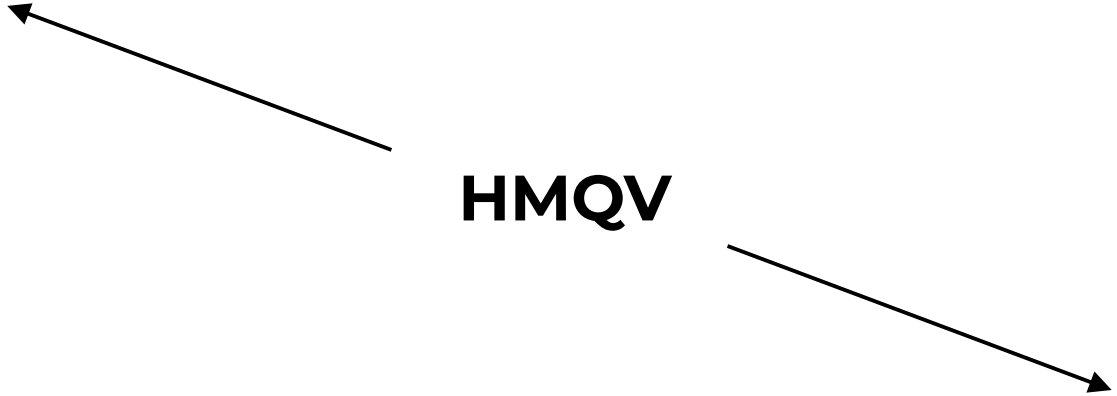


HMQV

HMQV: Properties

Secure against randomness reveal and ordinary state reveal



HMQV

Independent sessions are secure against preimage reveal

HMQV: Properties

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Post-processing of randomness

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Efficient

Signal considers implementation of a variation of it

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Good candidate for 2R transform!

HMQV + 2R transform

Alice (a, $A = g^a$)

$x \leftarrow\$ \mathbf{Z_p}$

$x' \leftarrow \mathbf{H}(x, a)$

$X' = g^{x'}$ →

← $Y' = g^{y'}$

$K := \mathbf{H'}(ctxt , (Y'B^e)^{x' + ad})$

$g^{(y' + be)(x' + ad)}$

Bob (b, $B = g^b$)

$y \leftarrow\$ \mathbf{Z_p}$

$y' \leftarrow \mathbf{H}(y, b)$

$K := \mathbf{H'}(ctxt , (X'A^d)^{y'+be})$

$g^{(x' + ad)(y' + be)}$

$ctxt := (A, B, X', Y')$

$d = \mathbf{H_1}(X', \mathbf{Bob})$; $e = \mathbf{H_2}(Y', \mathbf{Alice})$

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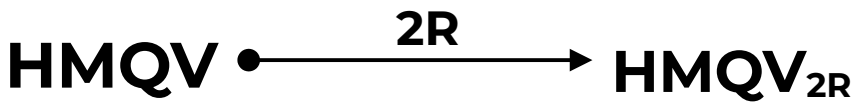
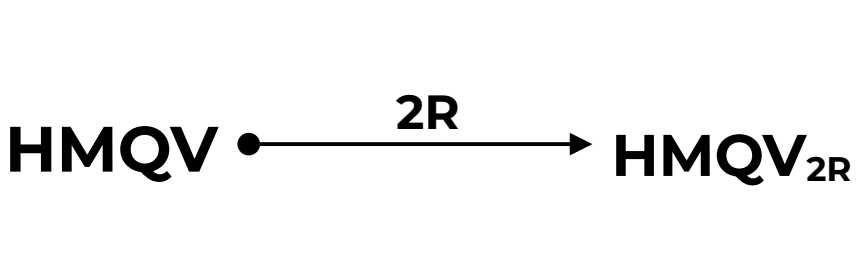


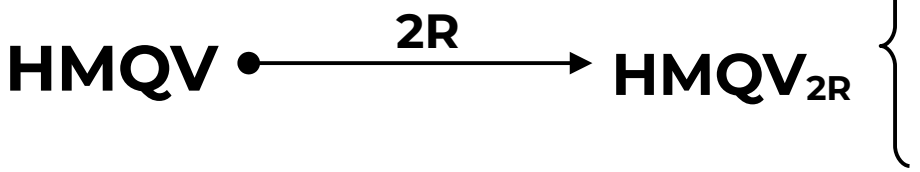
HMQV + 2R transform

Sessions independent of test sessions are secure against preimage reveals



HMQV + 2R transform

Sessions independent of test sessions are secure against preimage reveals



Sessions independent of test are secure against preimage **and** other state reveals

Desiderata

Our desires are fulfilled.

Desiderata

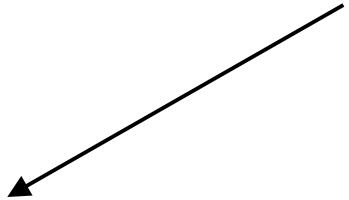
Our desires are fulfilled.

$$\mathrm{HMQV}_{\mathrm{2R}}$$

Desiderata

Our desires are fulfilled.

$\mathbf{HMQV_{2R}}$



Secure against

Ordinary state reveal and
Randomness reveal

Desiderata

Our desires are fulfilled.

$HMQV_{2R}$

Secure against

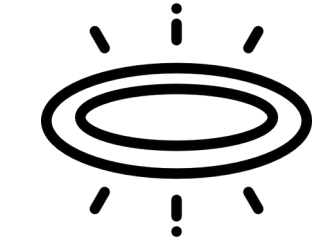
Ordinary state reveal and
Randomness reveal

Secure against

Preimage reveal **and** state-reveals
of independent sessions

Desiderata

Our desires are fulfilled.



HMQV$_{2R}$

Implicit authentication

High efficiency

Secure against

Ordinary state reveal and
Randomness reveal

Secure against

Preimage reveal **and** state-reveals
of independent sessions

Thank you for listening

Questions?