SPHF-Friendly Non-Interactive Commitments

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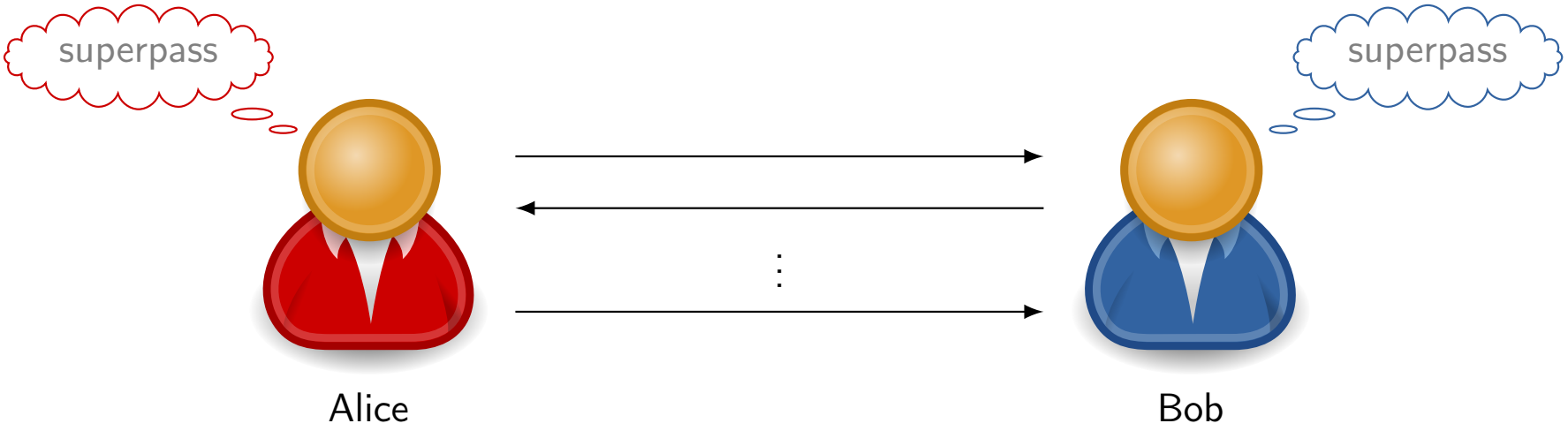
PAKE: Password-Authenticated Key Exchange

Goal: establishing a common secret key
from only a common low-entropy password



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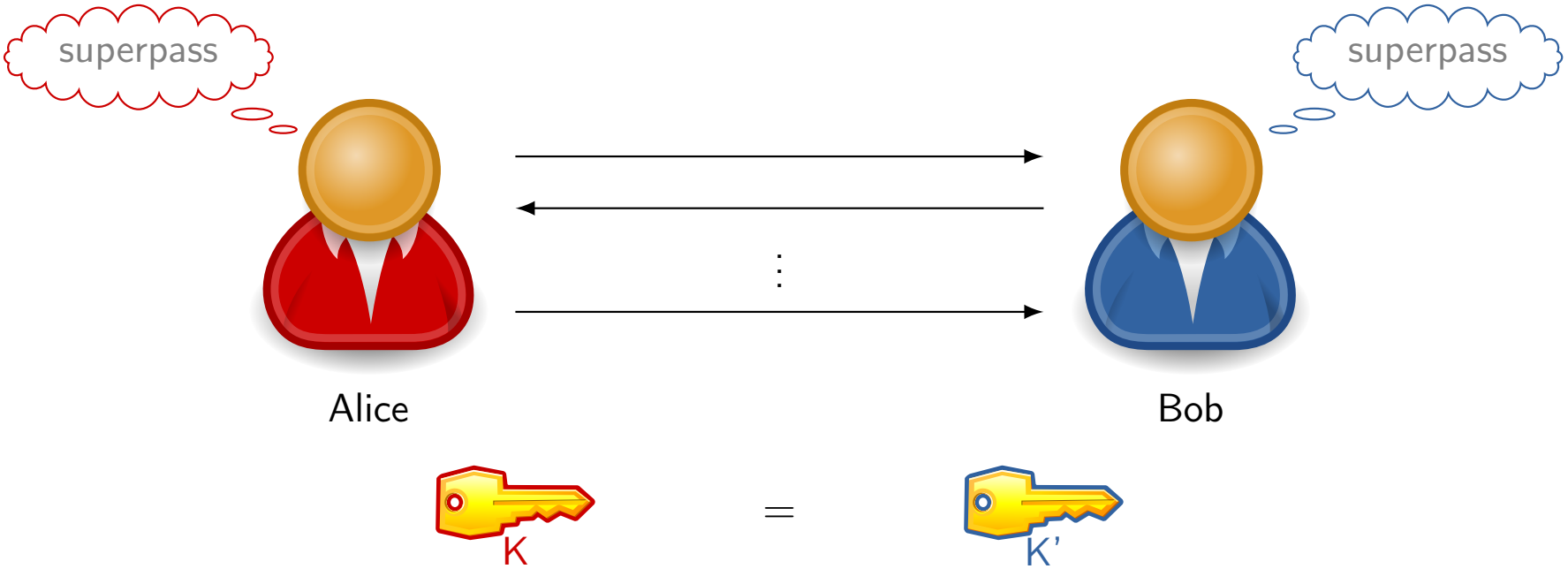

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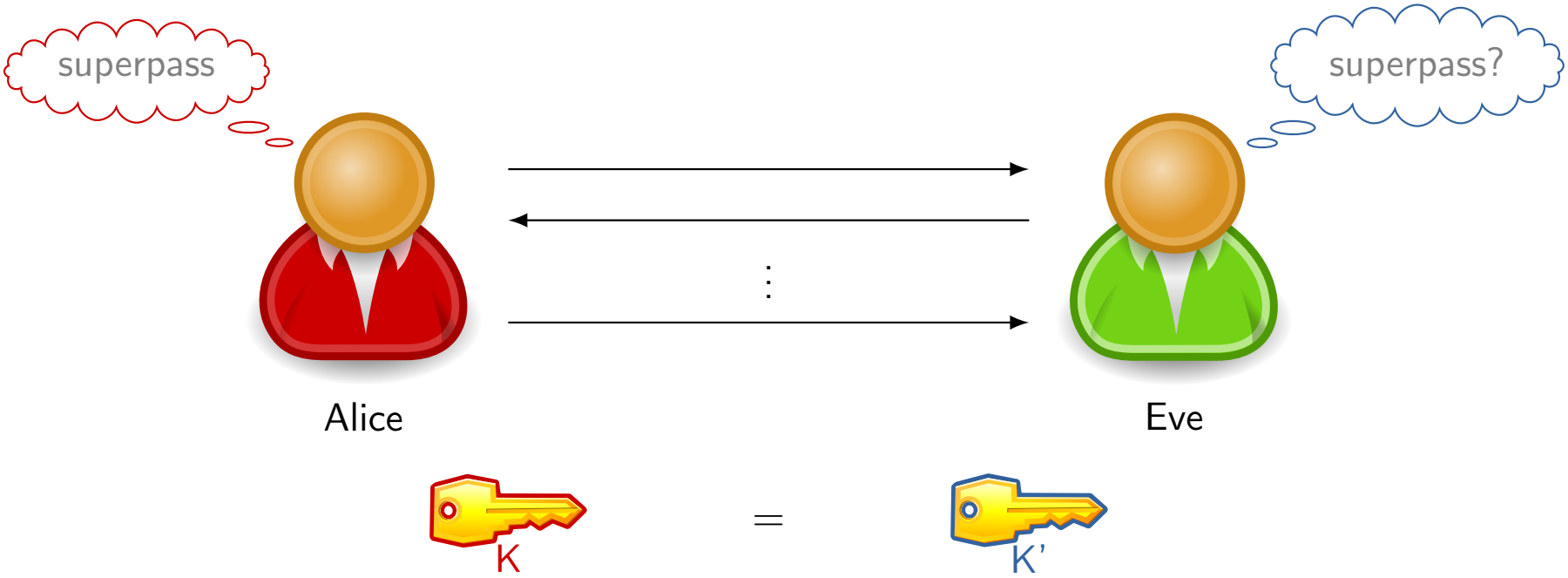

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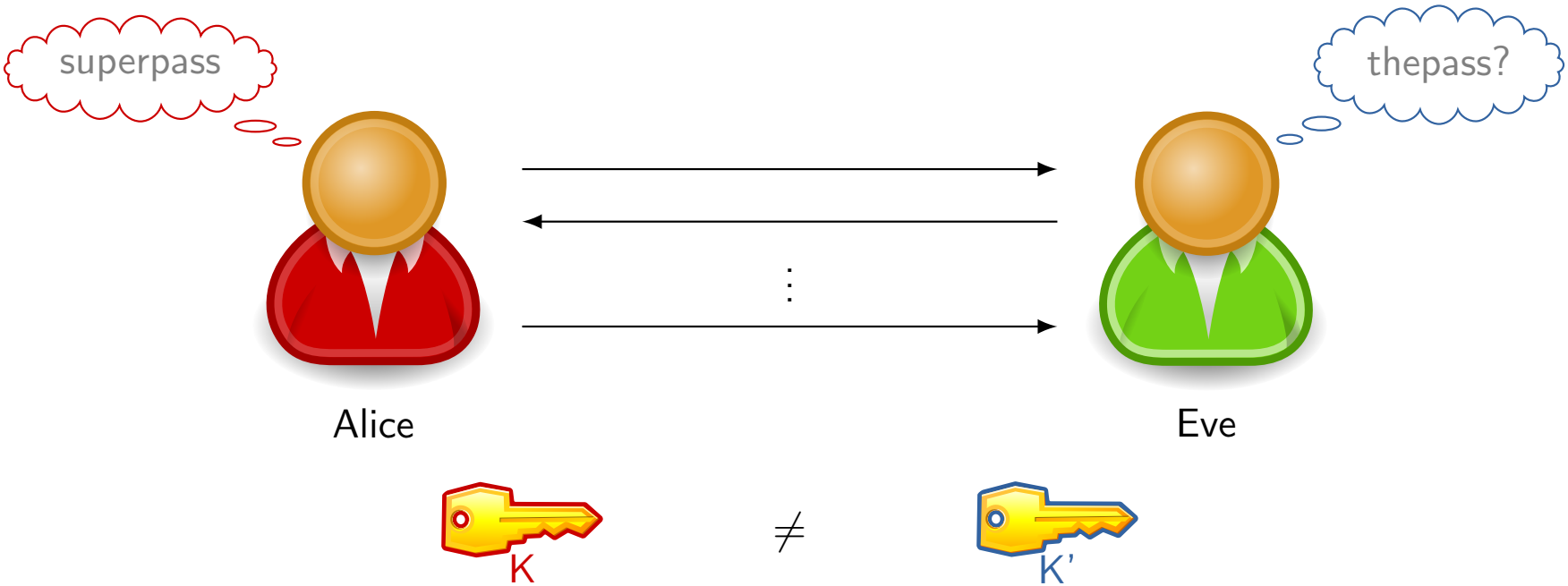

Intuitive security notion: only online dictionary attack works:

- at most one password can be tested per interaction;
- impossible to test password from an honest transcript.

PAKE: Password-Authenticated Key Exchange

Model Used

- one-round:
  - one flow per user (possibly simultaneous),
- UC [Can01],
- with adaptive corruptions (with erasures):
  - corruption of a user = learning the internal state,
  - possible at any time,
- in the standard model:
  - without random oracle.

UC PAKE: State of the Art

	Adaptive	One-round	Complexity (group elements)	Assumption
[BCLPR05]	✓	✗	very high	
[ACP09]	✓	✗	$\approx 44 \cdot m \cdot \mathfrak{K}$	DDH
[KV11]	✗	✓	≈ 140	DLIN
[BBCPV13]	✗	✓	≈ 22	SXDH

- m: size of the password
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PAKE: Construction Sketch

In most efficient PAKE schemes:

- each user **commits** to his password, and
- using an **SPHF** (Smooth Projective Hash Function), they prove that they committed to the good password.

Construction introduced and used in [KOY01, GL03, KV11].

Non-Interactive Commitment

$\mathsf{Com}(\pi)$	generates a commitment C of π and a decommitment information δ
$\mathsf{VerCom}(C, \pi, \delta)$	checks C commits to π using δ

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$$\mathsf{VerCom}(C, \pi, \delta) = 1 \quad \text{and} \quad \mathsf{VerCom}(C, \pi', \delta') = 1$$

hiding no poly-time adv. can distinguish:

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Implicit CRS: $\rho \xleftarrow{\$} \mathsf{SetupCom}(1^{\mathfrak{K}})$.

SPHF: Smooth Projective Hash Function [CS02, KV11]

NP language family $\mathrm{L}_{\mathsf{aux}} = \{C \in \mathcal{X} \mid \exists w,\ \mathcal{R}_{\mathsf{aux}}(C, w) = 1\}$
(w: witness)

$\mathsf{HashKG}(1^{\lambda})$	generates a hashing key hk
$\mathsf{Hash}(\mathsf{hk}, \mathsf{aux}, C)$	computes the hash value H of $C \in \mathcal{X}$
$\mathsf{ProjKG}(\mathsf{hk})$	derives a projection key hp
$\mathsf{ProjHash}(\mathsf{hp}, \mathsf{aux}, C, w)$	computes the hash value H of $C \in \mathrm{L}_{\mathsf{aux}}$ (if $\mathcal{R}_{\mathsf{aux}}(C, w) = 1$)

In this talk:

hp does not depend on C (contrary to [GL03]) nor on aux.

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Properties of SPHF

correctness for any hk and corresponding hp, for all $C \in \mathrm{L}_{\mathsf{aux}}$ and w such that $\mathcal{R}_{\mathsf{aux}}(C, w) = 1$:

$$\mathsf{Hash}(\mathsf{hk}, \mathsf{aux}, C) = \mathsf{ProjHash}(\mathsf{hp}, \mathsf{aux}, C, w);$$

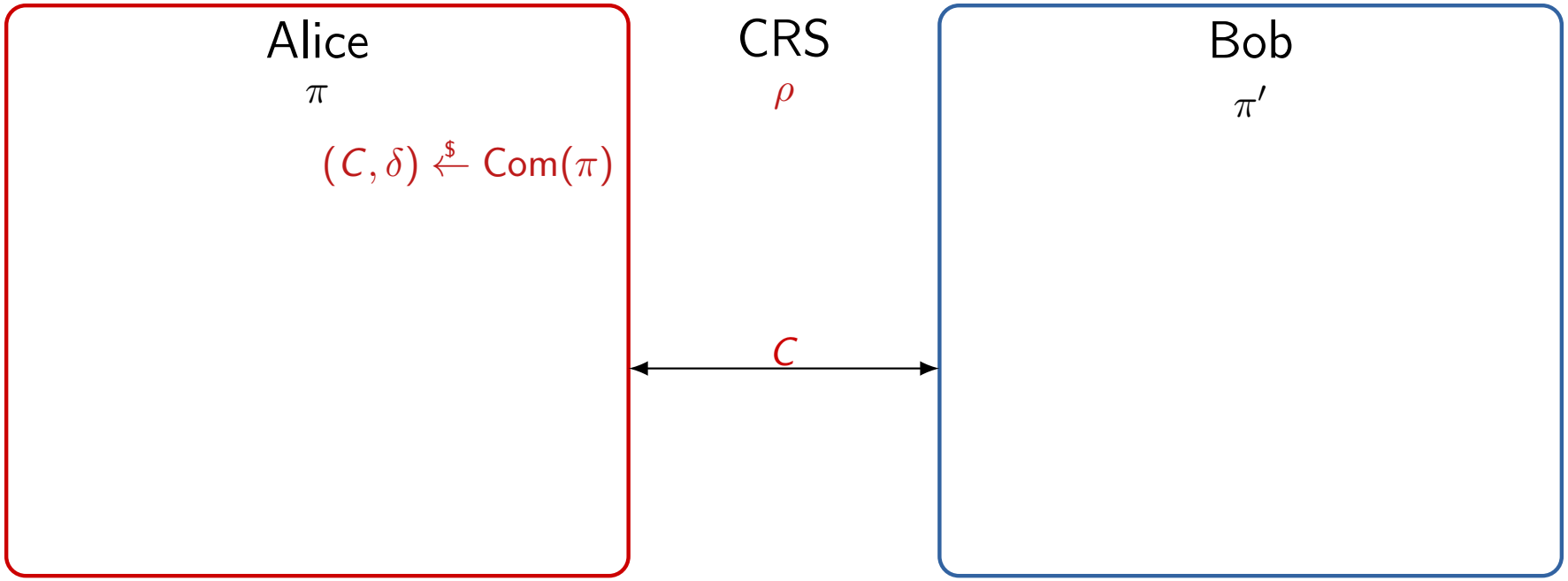
smoothness (definition of [KV11])

- for any function f onto $\mathcal{X} \setminus \mathrm{L}_{\mathsf{aux}}$,
- given a projection key hp,
- $C = f(\mathsf{hp}) \notin \mathrm{L}_{\mathsf{aux}}$,
- $\mathsf{Hash}(\mathsf{hk}, \mathsf{aux}, C) \approx_s$ random.

Contributions

- formalization of SPHF-friendly commitments:
  - ◇ implicit in [ACP09];
- construction of an efficient SPHF-friendly commitment:
  - ◇ inspired by [CF01, CLOS02, ACP09];
  - \+ $O(m)$ elements instead of $O(m\mathfrak{K})$ elements;
- applications:
  - adaptive UC commitment;
  - first one-round adaptive UC PAKE;
  - 1-out-of-k UC OT more efficient than [CKWZ13].

PAKE Construction Sketch



Language for SPHF: valid commitments of aux ($= \pi$ or π'):

$$\mathcal{R}_{\mathsf{aux}}(C, \delta) = 1 \quad \Longleftrightarrow \quad \mathsf{VerCom}(C, \mathsf{aux}, \delta) = 1.$$

Correctness if $\pi = \pi'$, $H_A = H'_A$;

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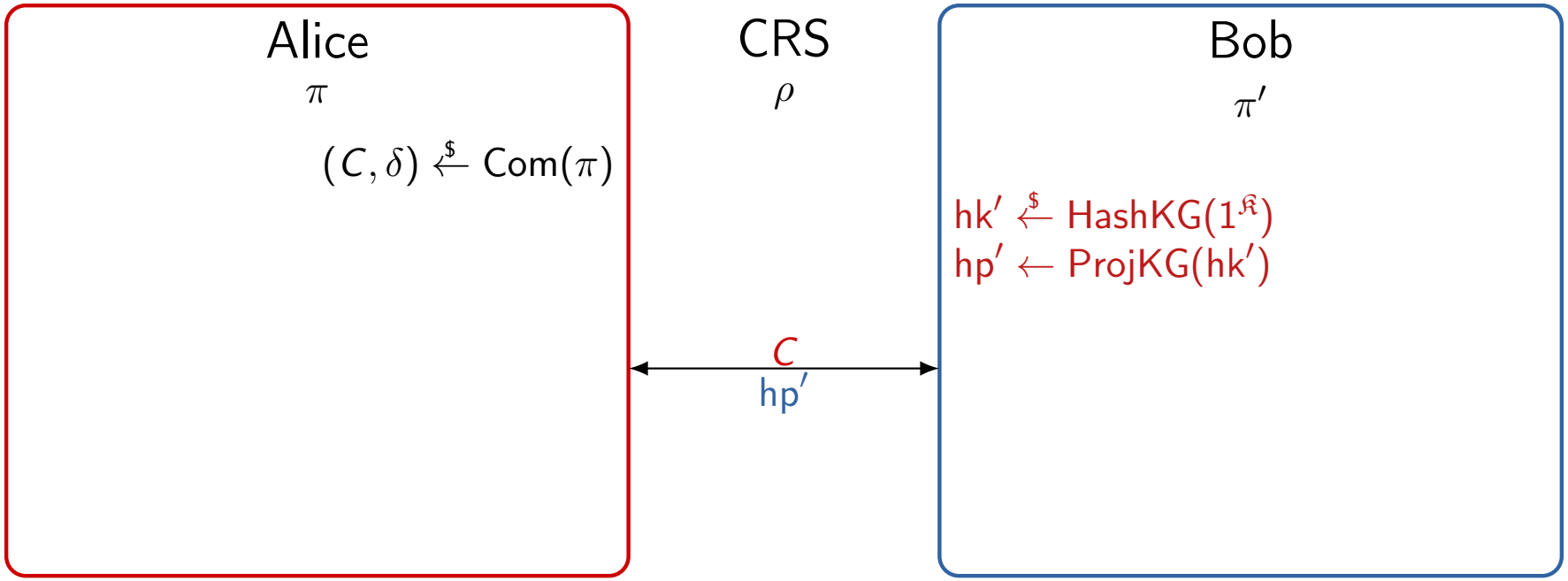

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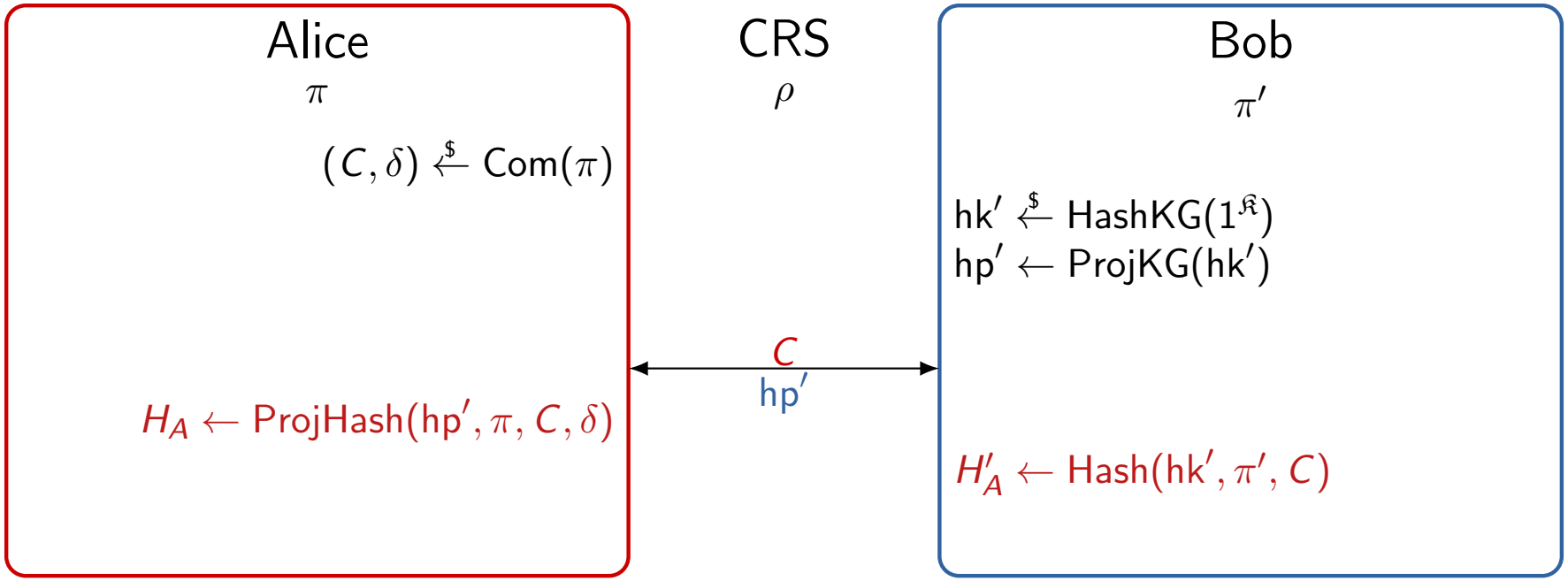

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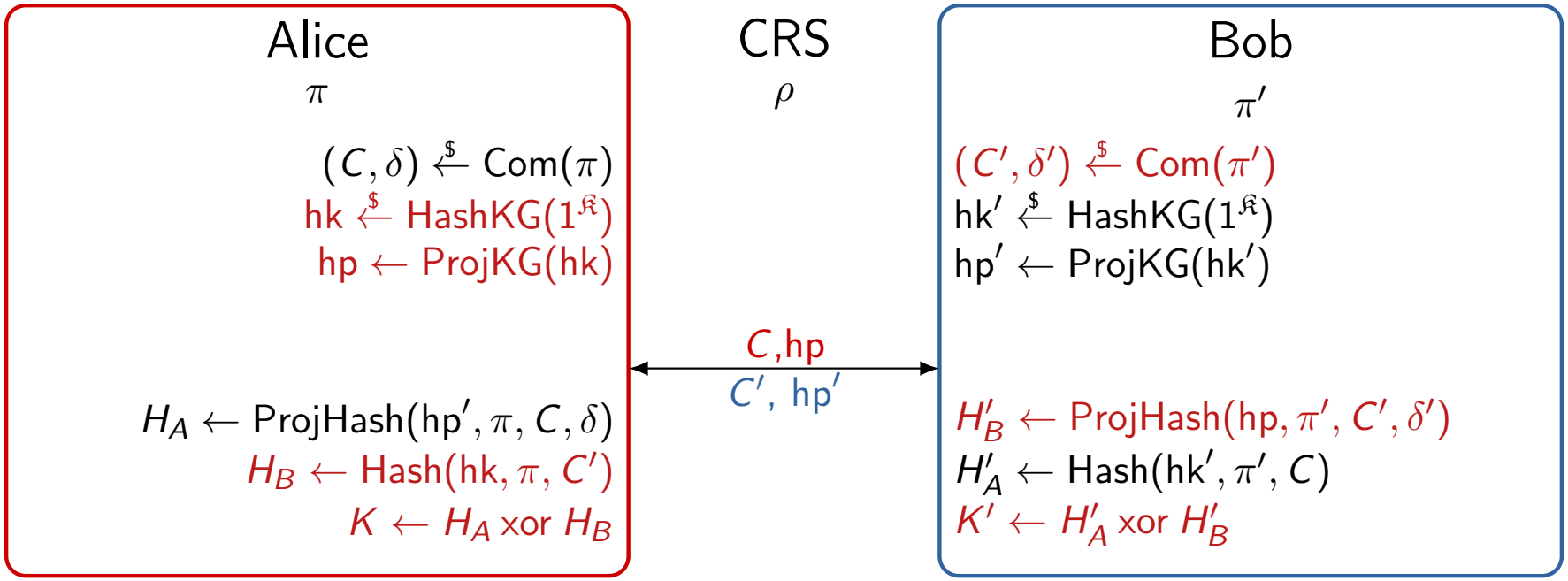

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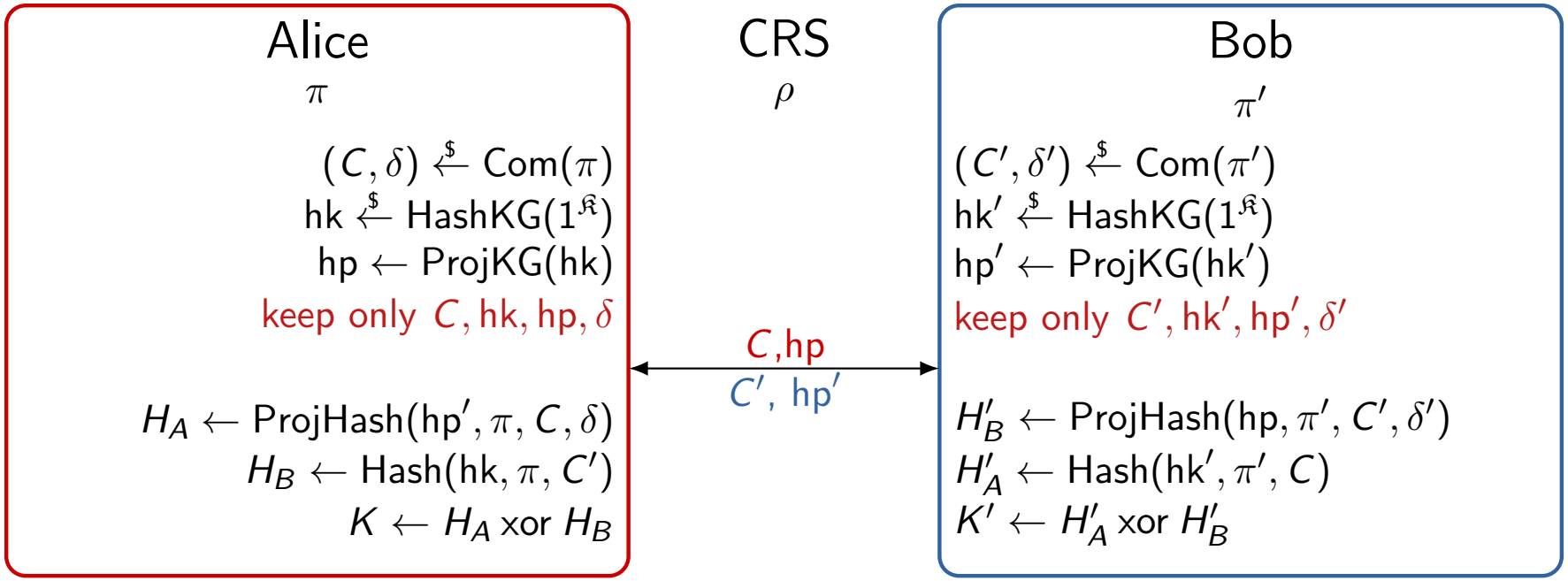

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Security ?
Equivocability

In UC model, with adaptive corruptions:

- need to simulate a user w/o knowing its password π;
  - $\rightarrow$ need to generate hp and C
- and when corrupted, we learn π
  - $\rightarrow$ need to generate δ:

$$\mathsf{VerCom}(C, \pi, \delta) = 1.$$

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Equivocability

In UC model, with adaptive corruptions:

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- and when corrupted, we learn π
  - $\rightarrow$ need to generate $\delta \leftarrow \mathsf{OpenCom}(\mathsf{eqk}, \pi)$:

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$\longrightarrow$ commitment property: **equivocablility**

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$$\text{hiding} \quad \Leftarrow \quad \text{equivocability}$$

Security ?

Equivocable Commitments — Examples

[Ped91] Pedersen scheme:

CRS	cyclic group $\mathbb{G}$, generators g and $T = g^t$
$\mathsf{Com}(\pi)$	$r \xleftarrow{\$} \mathbb{Z}_p$, $C = g^r \cdot T^\pi$, $\delta = r$
$\mathsf{VerCom}(C, \pi, \delta)$	$C \stackrel{?}{=} g^\delta \cdot T^\pi$
$\mathsf{SimCom}(t)$	$u \xleftarrow{\$} \mathbb{Z}_p$, $C = g^r$, $\mathsf{eqk} = u$
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\end{aligned}$$

[Har11] Haralambiev TC4 scheme:

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\text{CRS} &\quad (\mathbb{G}_1, \mathbb{G}_2, \mathbb{G}_t, e, g_1, g_2),\ T = g_2^t \\
\text{Com}(\pi) &\quad r \xleftarrow{\$} \mathbb{Z}_p,\ C = g_2^r \cdot T^\pi,\ \delta = g_1^r \\
\text{VerCom}(C, \pi, \delta) &\quad e(g_1, C/T^\pi) \stackrel{?}{=} e(\delta, g_2) \\
\text{SimCom}(t) &\quad u \xleftarrow{\$} \mathbb{Z}_p,\ C = g_2^r,\ \text{eqk} = u \\
\text{OpenCom}(\text{eqk}, \pi) &\quad \delta = g_1^{\text{eqk}-tx}
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  i.e., no poly-time adv. can find C, δ, π s.t.:

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$\longrightarrow$ commitment property: **extractability**

$$\text{binding} \quad \Leftarrow \quad \text{extractability}$$

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- even when simulating commitments !

$\longrightarrow$ commitment property: **strong extractability**

$$\text{binding} \quad \Leftarrow \quad \text{extractability} \quad \Leftarrow \quad \text{strong extractibility}$$

Security ?

Extractable Commitments — Examples

ElGamal [ElG84] or Cramer-Shoup [CS98] encryption scheme

CRS	cyclic group $\mathbb{G}_1$, public key pk
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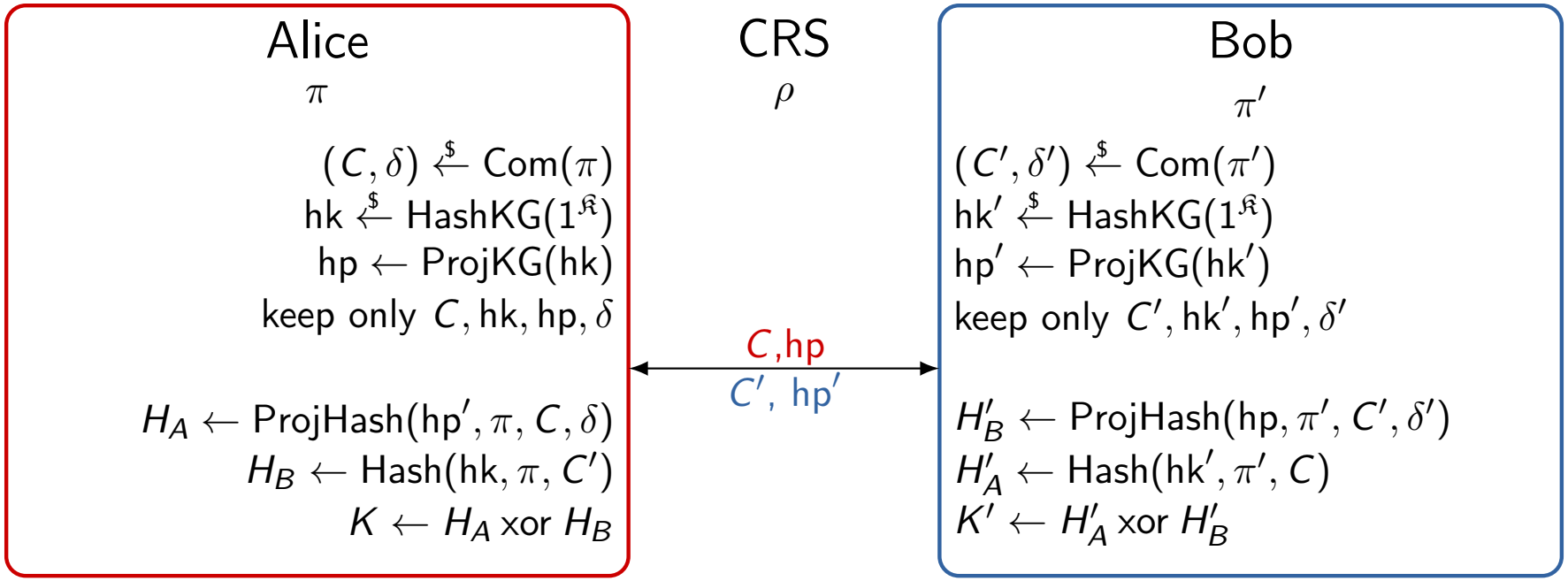

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Robustness

$$L_\pi = \{C \in \mathcal{X} \mid \exists \delta,\ \mathsf{VerCom}(C, \pi, \delta) = 1\}.$$

For a strong extractable commitment, we may have:

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$\longrightarrow$ commitment property: **robustness**:

no poly-time adv. can find C s.t.:

$$\exists \delta, \pi,\ \mathsf{VerCom}(C, \pi, \delta) = 1 \quad \text{and} \quad \mathsf{ExtCom}(\tau, C) \neq \pi.$$

$$\text{strong extractibility} \quad \Leftarrow \quad \text{robustness}$$

Summary

$$\begin{array}{lllllll} \text{hiding} & \Leftarrow & \text{equivocability} & \Leftarrow & \text{strong equivocability} & & \\ \text{binding} & \Leftarrow & \text{extractability} & \Leftarrow & \text{strong extractibility} & \Leftarrow & \text{robustness} \end{array}$$

Summary

hiding $\Leftarrow$ equivocability $\Leftarrow$ strong equivocability

binding $\Leftarrow$ extractability $\Leftarrow$ strong extractibility $\Leftarrow$ robustness

equivocability + robustness $\rightsquigarrow$ SPHF-friendly commitment

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equivocability + robustness $\rightsquigarrow$ SPHF-friendly commitment

equivocability + strong extractability $\rightsquigarrow$ (adaptive) UC commitment

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hiding $\Leftarrow$ equivocability $\Leftarrow$ strong equivocability
binding $\Leftarrow$ extractability $\Leftarrow$ strong extractibility $\Leftarrow$ robustness

equivocability + robustness $\rightsquigarrow$ SPHF-friendly commitment

equivocability + strong extractability $\rightsquigarrow$ (adaptive) UC commitment
strong equivocability + extractability $\rightsquigarrow$ (adaptive) UC commitment

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[ACP09]	✓	$(m + 16m\mathfrak{K}) \times \mathbb{G}$	$2m\mathfrak{K} \times \mathbb{Z}_p$	DDH
[FLM11], 1	✗	$5 \times \mathbb{G}$	$16 \times \mathbb{G}$	DLIN
[FLM11], 2	✗	$37 \times \mathbb{G}$	$3 \times \mathbb{G}$	DLIN
here	✓	$8m \times \mathbb{G}_1 + m \times \mathbb{G}_2$	$m \times \mathbb{Z}_p$	SXDH

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Why schemes in [FLM11] are not robust ?

- C is an encryption of π;
- δ is a NIZK that C encrypts π
  - $\rightarrow$ can be simulated!

Our SPHF-Friendly Commitment Scheme

- bilinear group $(\mathbb{G}_1, \mathbb{G}_2, \mathbb{G}_t, e, g_1, g_2)$,
- $T = g_2^t$ for Haralambiev TC4 commitment, $\pi = 101$
- pk for Cramer-Shoup in $\mathbb{G}_1$.

1	0	1
r_1	r_2	r_3
$d_{1,1} = g_1^{r_1}$	$d_{2,0} = g_1^{r_2}$	$d_{3,1} = g_1^{r_3}$
$a_1 = g_2^{r_1} \cdot T^1$	$a_2 = g_2^{r_2} \cdot T^0$	$a_3 = g_3^{r_3} \cdot T^1$

$C = (a_1, a_2, a_3)$ $\delta = (d_1, d_2, d_3)$

Our SPHF-Friendly Commitment Scheme

- bilinear group $(\mathbb{G}_1, \mathbb{G}_2, \mathbb{G}_t, e, g_1, g_2)$,
- $T = g_2^t$ for Haralambiev TC4 commitment, $\pi = 101$
- pk for Cramer-Shoup in $\mathbb{G}_1$.

1	0	1
r_1	r_2	r_3
$d_{1,1} = g_1^{r_1}$	$d_{2,0} = g_1^{r_2}$	$d_{3,1} = g_1^{r_3}$
$a_1 = g_2^{r_1} \cdot T^1$	$a_2 = g_2^{r_2} \cdot T^0$	$a_3 = g_3^{r_3} \cdot T^1$
$b_{1,1} = \mathsf{CS}(d_{1,1}; s_{1,1})$	$b_{2,0} = \mathsf{CS}(d_{2,0}; s_{2,0})$	$b_{3,1} = \mathsf{CS}(d_{3,1}; s_{3,1})$

$C = (a_1, a_2, a_3, b_{1,1}, b_{2,0}, b_{3,1})$ $\delta = (s_{1,1}, s_{2,0}, s_{3,1})$

Our SPHF-Friendly Commitment Scheme

- bilinear group $(\mathbb{G}_1, \mathbb{G}_2, \mathbb{G}_t, e, g_1, g_2)$,
- $T = g_2^t$ for Haralambiev TC4 commitment, $\pi = 101$
- pk for Cramer-Shoup in $\mathbb{G}_1$.

1	0	1
r_1	r_2	r_3
$d_{1,0} = 1$ $d_{1,1} = g_1^{r_1}$	$d_{2,0} = g_1^{r_2}$ $d_{2,1} = 1$	$d_{3,0} = 1$ $d_{3,1} = g_1^{r_3}$
$a_1 = g_2^{r_1} \cdot T^1$	$a_2 = g_2^{r_2} \cdot T^0$	$a_3 = g_3^{r_3} \cdot T^1$
$b_{1,0} = \mathsf{CS}(d_{1,0}; s_{1,0})$ $b_{1,1} = \mathsf{CS}(d_{1,1}; s_{1,1})$	$b_{2,0} = \mathsf{CS}(d_{2,0}; s_{2,0})$ $b_{2,1} = \mathsf{CS}(d_{2,1}; s_{2,1})$	$b_{3,0} = \mathsf{CS}(d_{3,0}; s_{3,0})$ $b_{3,1} = \mathsf{CS}(d_{3,1}; s_{3,1})$

$$C = (a_1, a_2, a_3, b_{1,0}, b_{1,1}, b_{2,0}, b_{2,1}, b_{3,0}, b_{3,1}) \qquad \delta = (s_{1,1}, s_{2,0}, s_{3,1})$$

Our SPHF-Friendly Commitment Scheme

- bilinear group $(\mathbb{G}_1, \mathbb{G}_2, \mathbb{G}_t, e, g_1, g_2)$,
- $T = g_2^t$ for Haralambiev TC4 commitment, $\pi = 101$
- pk for Cramer-Shoup in $\mathbb{G}_1$.

1	0	1
r_1	r_2	r_3
$d_{1,0} = g_1^{r1+t}$ $d_{1,1} = g_1^{r_1}$	$d_{2,0} = g_1^{r_2}$ $d_{2,1} = g_1^{r2-t}$	$d_{3,0} = g_1^{r3+t}$ $d_{3,1} = g_1^{r_3}$
$a_1 = g_2^{r_1} \cdot T^1$	$a_2 = g_2^{r_2} \cdot T^0$	$a_3 = g_3^{r_3} \cdot T^1$
$b_{1,0} = \mathsf{CS}(d_{1,0}; s_{1,0})$ $b_{1,1} = \mathsf{CS}(d_{1,1}; s_{1,1})$	$b_{2,0} = \mathsf{CS}(d_{2,0}; s_{2,0})$ $b_{2,1} = \mathsf{CS}(d_{2,1}; s_{2,1})$	$b_{3,0} = \mathsf{CS}(d_{3,0}; s_{3,0})$ $b_{3,1} = \mathsf{CS}(d_{3,1}; s_{3,1})$

equivocability ?

$C = (a_1, a_2, a_3, b_{1,0}, b_{1,1}, b_{2,0}, b_{2,1}, b_{3,0}, b_{3,1})$ $\delta = (s_{1,1}, s_{2,0}, s_{3,1})$

Our SPHF-Friendly Commitment Scheme

- bilinear group $(\mathbb{G}_1, \mathbb{G}_2, \mathbb{G}_t, e, g_1, g_2)$,
- $T = g_2^t$ for Haralambiev TC4 commitment, $\pi = 101$
- pk for Cramer-Shoup in $\mathbb{G}_1$.

1	0	1
r_1	r_2	r_3
$d_{1,0} = 1$ $d_{1,1} = g_1^{r_1}$	$d_{2,0} = g_1^{r_2}$ $d_{2,1} = 1$	$d_{3,0} = 1$ $d_{3,1} = g_1^{r_3}$
$a_1 = g_2^{r_1} \cdot T^1$	$a_2 = g_2^{r_2} \cdot T^0$	$a_3 = g_3^{r_3} \cdot T^1$
$b_{1,0} = \mathsf{CS}(d_{1,0}; s_{1,0})$ $b_{1,1} = \mathsf{CS}(d_{1,1}; s_{1,1})$	$b_{2,0} = \mathsf{CS}(d_{2,0}; s_{2,0})$ $b_{2,1} = \mathsf{CS}(d_{2,1}; s_{2,1})$	$b_{3,0} = \mathsf{CS}(d_{3,0}; s_{3,0})$ $b_{3,1} = \mathsf{CS}(d_{3,1}; s_{3,1})$

robustness ?

$C = (a_1, a_2, a_3, b_{1,0}, b_{1,1}, b_{2,0}, b_{2,1}, b_{3,0}, b_{3,1})$ $\delta = (s_{1,1}, s_{2,0}, s_{3,1})$

Our SPHF-Friendly Commitment Scheme

The SPHF

- language: pairing equations over Cramer-Shoup ciphertexts;
- SPHF: using methods in [BBCPV13].

Thank you for your attention!

- formalization of SPHF-friendly commitments:
  - ◇ implicit in [ACP09];
- construction of an efficient SPHF-friendly commitment:
  - ◇ inspired by [CF01, CLOS02, ACP09];
  - \+ $O(m)$ elements instead of $O(m\mathfrak{K})$ elements;
- applications:
  - adaptive UC commitment;
  - first one-round adaptive UC PAKE;
  - 1-out-of-k UC OT more efficient than [CKWZ13].

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