Non-Committing Identity Based Encryption: Constructions and Applications

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CISPA Helmholtz

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Joint work with Rishab Goyal (UW-Madison), Fuyuki Kitagawa (NTT Japan), Venkata Koppula (IITD), Ryo Nishimaki (NTT Japan) and Takashi Yamakawa (NTT Japan)

Standard Security : Definition

[Goldwasser-Micali'84]

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Challenger

Adversary

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$(sk, pk) \leftarrow Setup()$

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$$\xrightarrow{\quad\quad\quad\quad pk \quad\quad\quad\quad}$$

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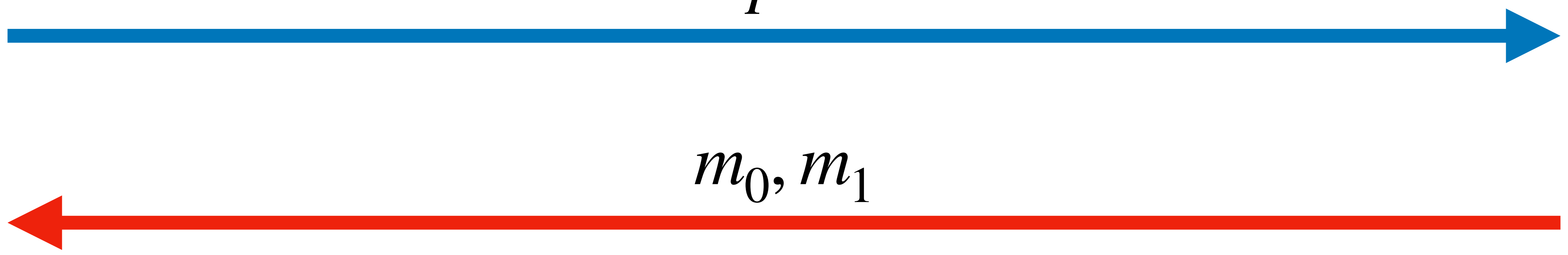

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m_0, m_1

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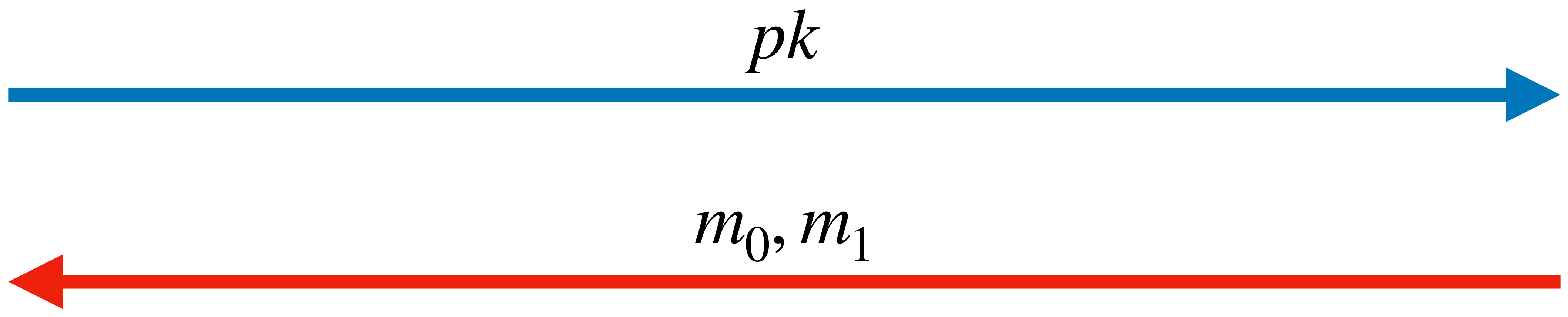

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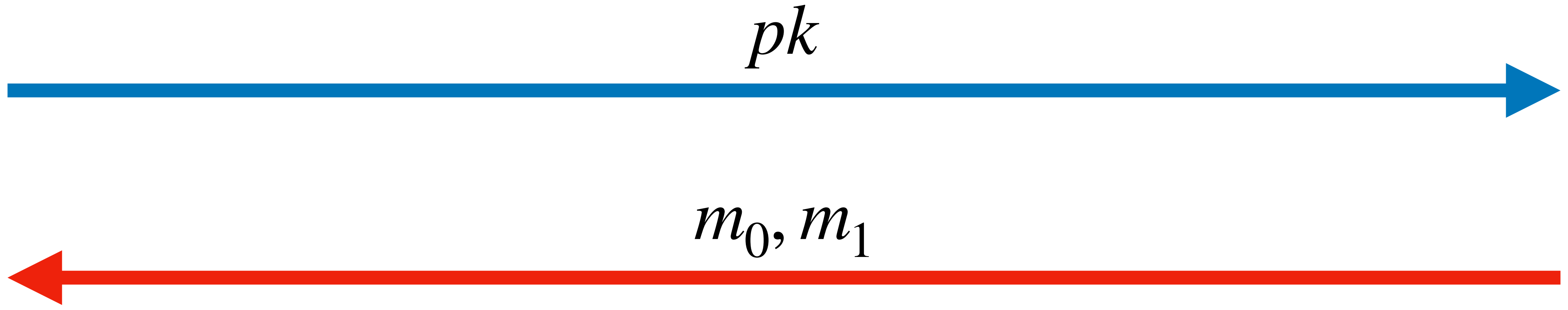

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$b \leftarrow \{0,1\}$

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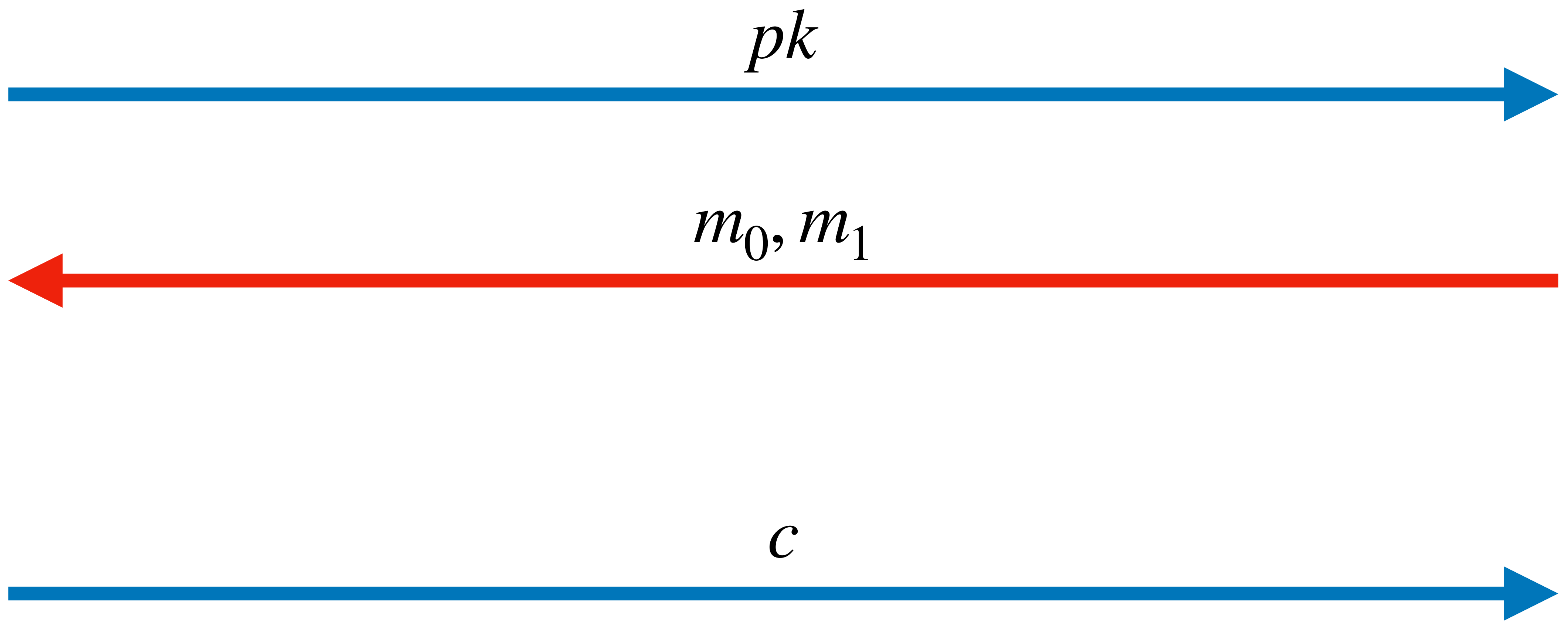

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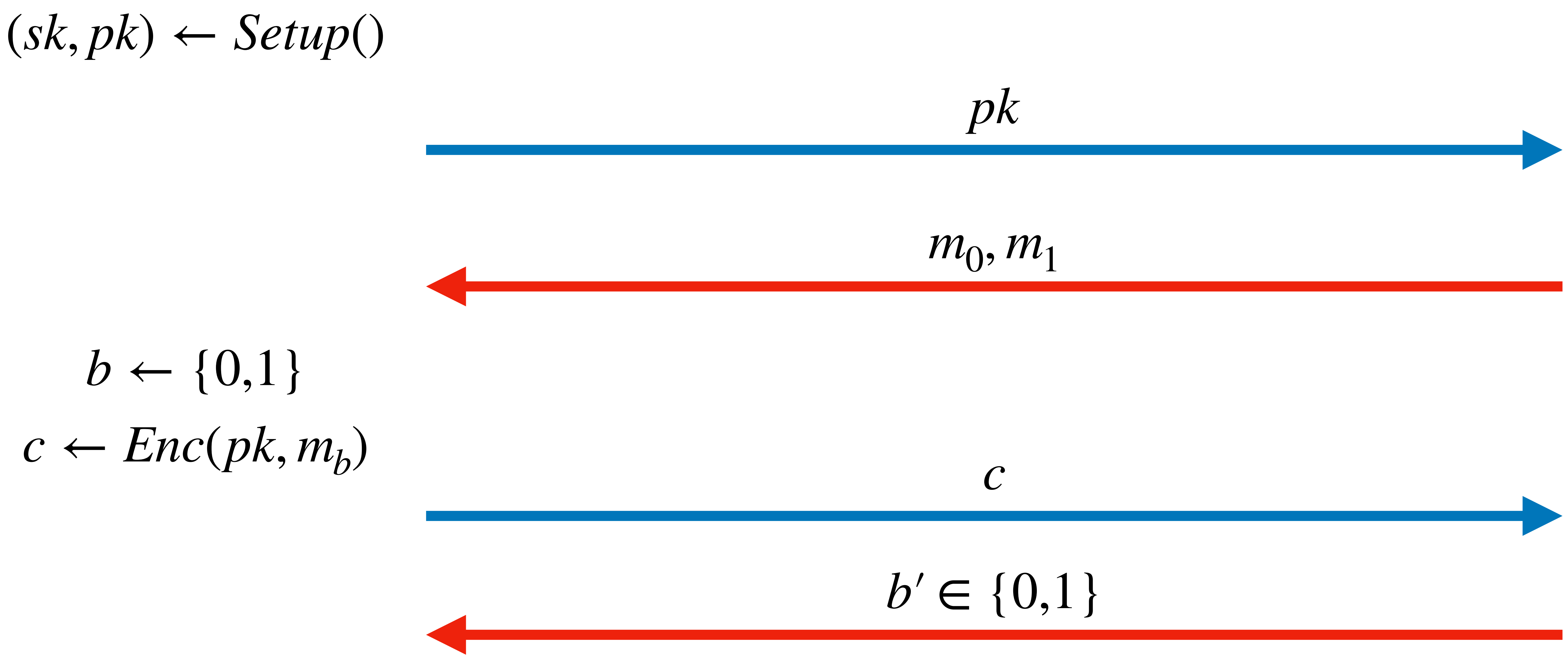

$(sk, pk) \leftarrow Setup()$

pk

m_0, m_1

$b \leftarrow \{0,1\}$

$c \leftarrow Enc(pk, m_b)$

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$b' \in \{0,1\}$

Adversary wins if $b = b'$

Incompressible Cryptography

[Dziembowski’06,Guan-Wichs-Zhandry’22]

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  - Adversary gets a challenge ciphertext ct^* for m_0, m_1 and then it has to compress/reduce its storage which contains ct^*.

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  - Make ciphertext large so that long-term storage is expensive.

  - Adversary gets a challenge ciphertext ct^* for m_0, m_1 and then it has to compress/reduce its storage which contains ct^*.

  - After which it receives sk, but still should not be able to distinguish.

Incompressible PKE Security

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Adversary 1

$(pk, sk) \leftarrow Setup()$ $\xrightarrow{pk}$

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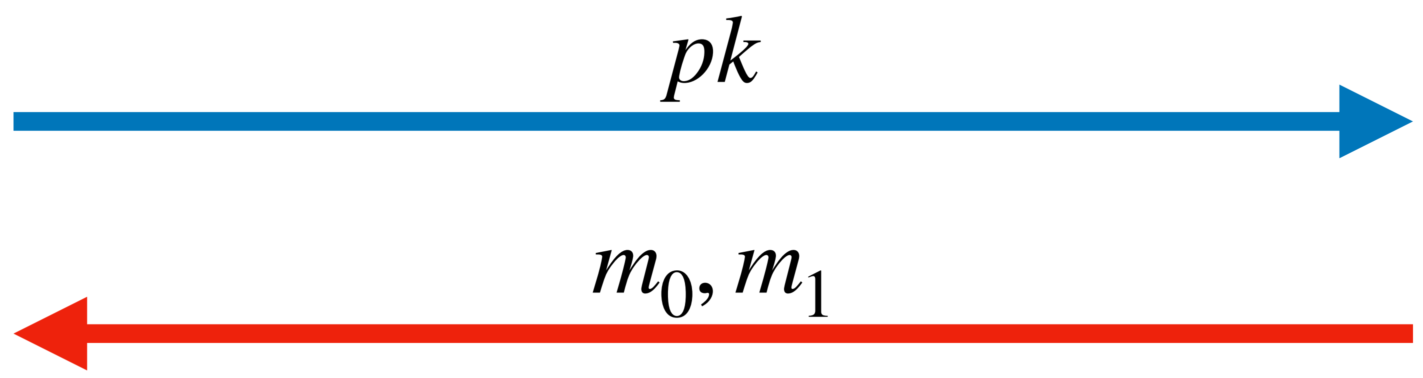

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m_0, m_1

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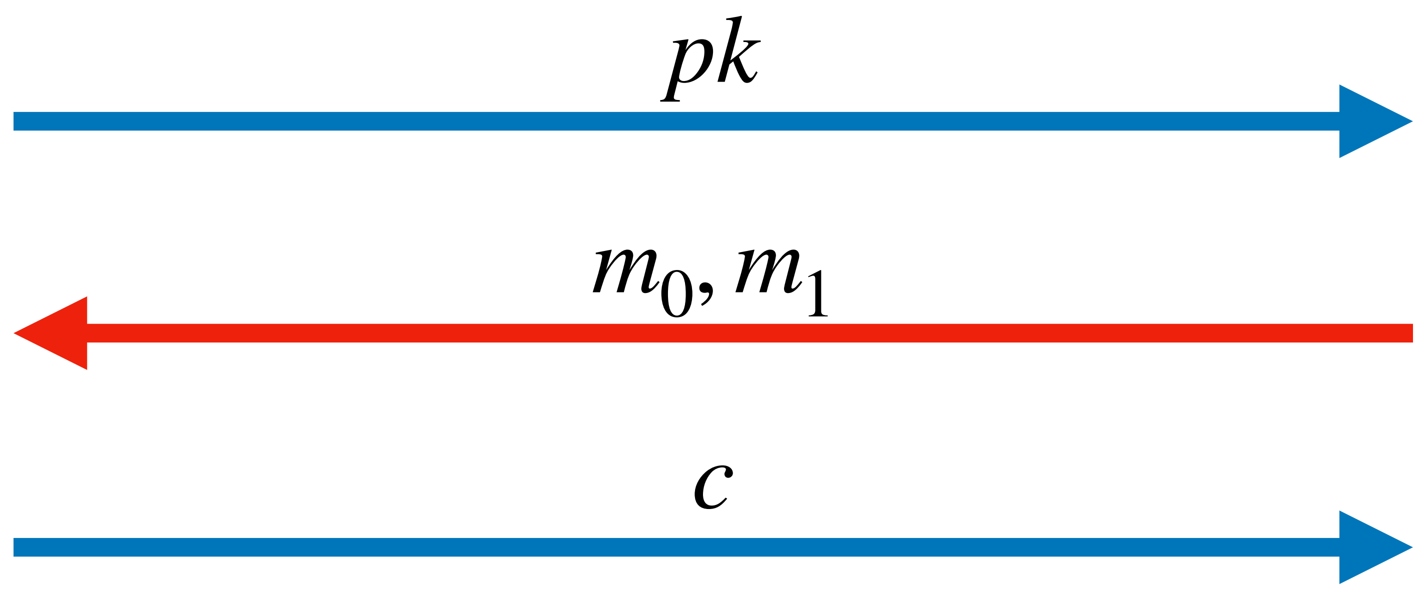

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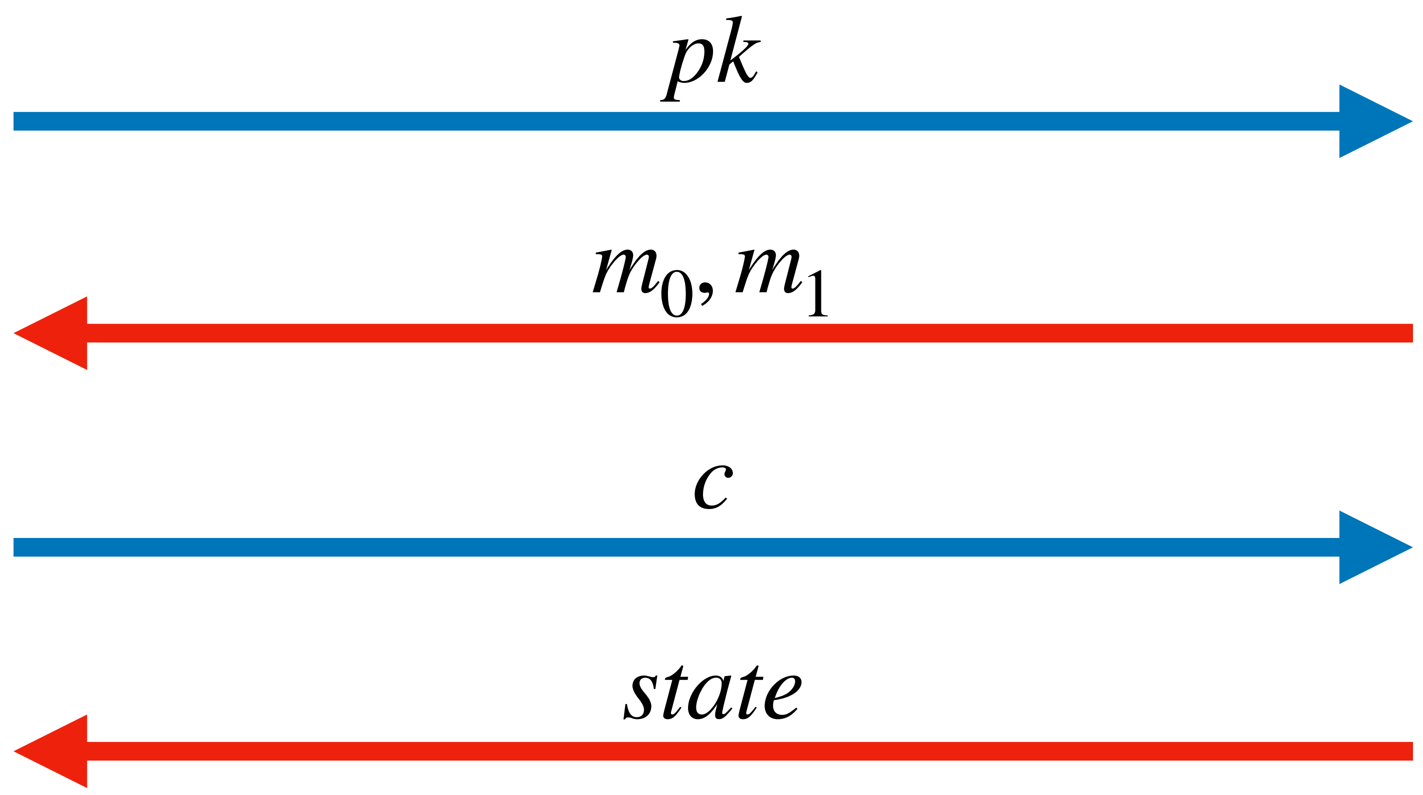

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$\xleftarrow{\quad m_0, m_1 \quad}$

$b \leftarrow \{0,1\}$

$c \leftarrow Enc(pk, m_b)$ $\xrightarrow{\quad c \quad}$

$\xleftarrow{\quad state \quad}$

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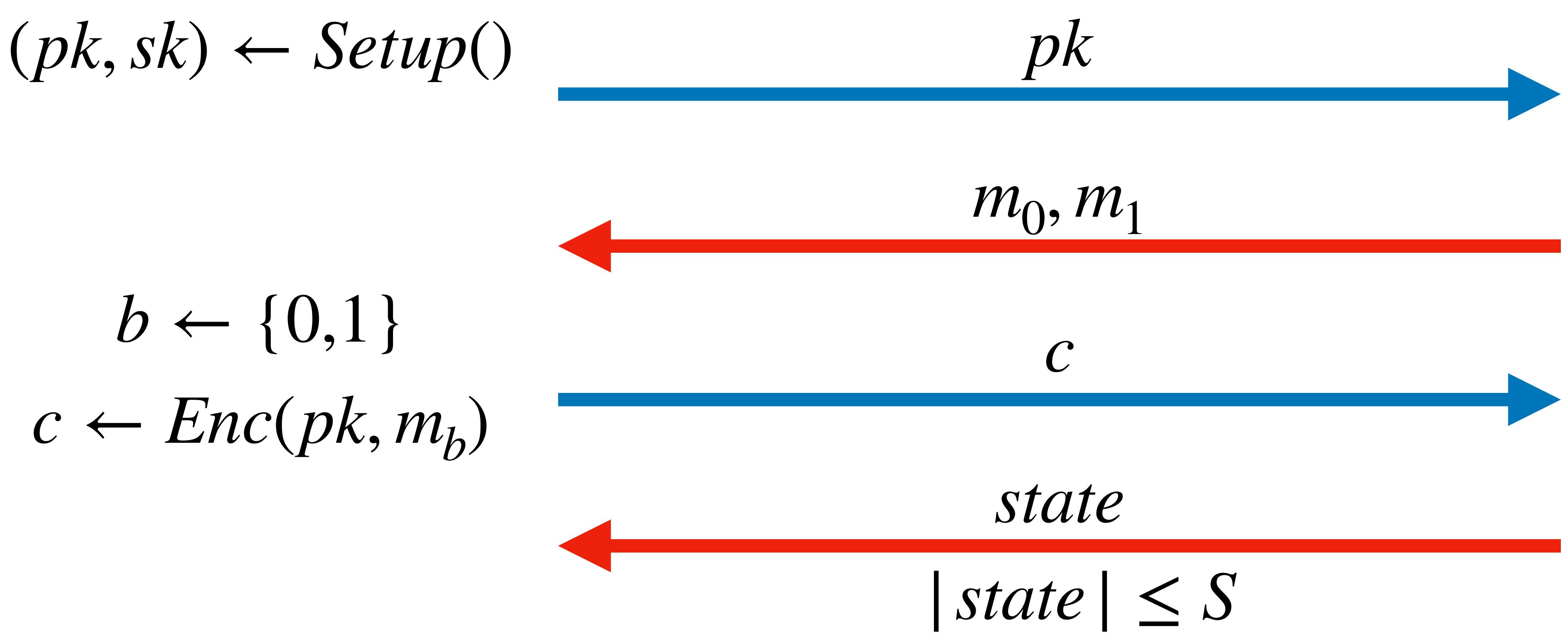

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c

$state$

$|state| \leq S$

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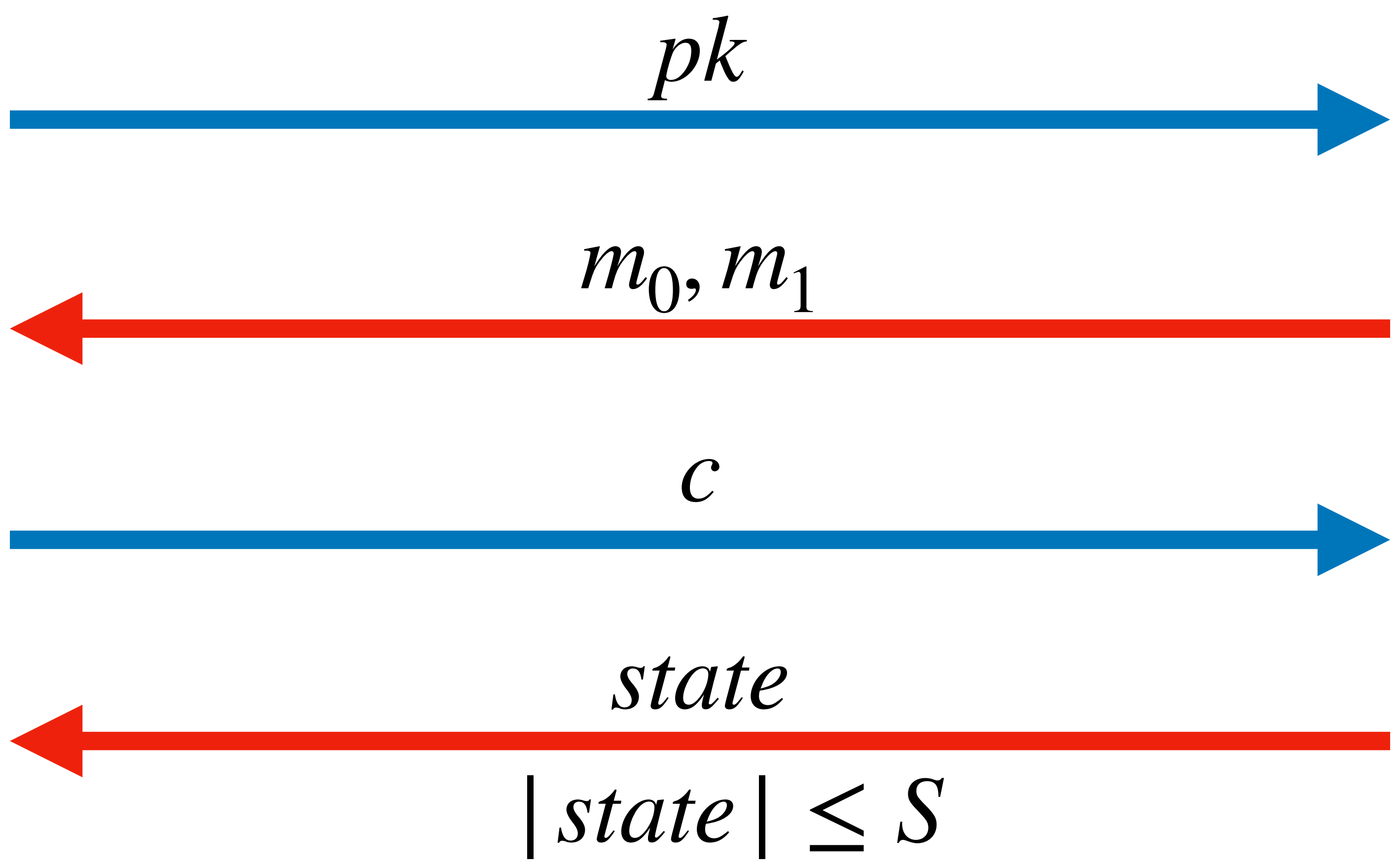

$b \leftarrow \{0,1\}$

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Adversary 2

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Adversary 1

$(pk, sk) \leftarrow Setup()$ $\xrightarrow{pk}$

$\xleftarrow{m_0, m_1}$

$b \leftarrow \{0,1\}$

$c \leftarrow Enc(pk, m_b)$ $\xrightarrow{c}$

$\xleftarrow[|state| \leq S]{state}$

Adversary 2 $\xleftarrow{pk, sk, state}$

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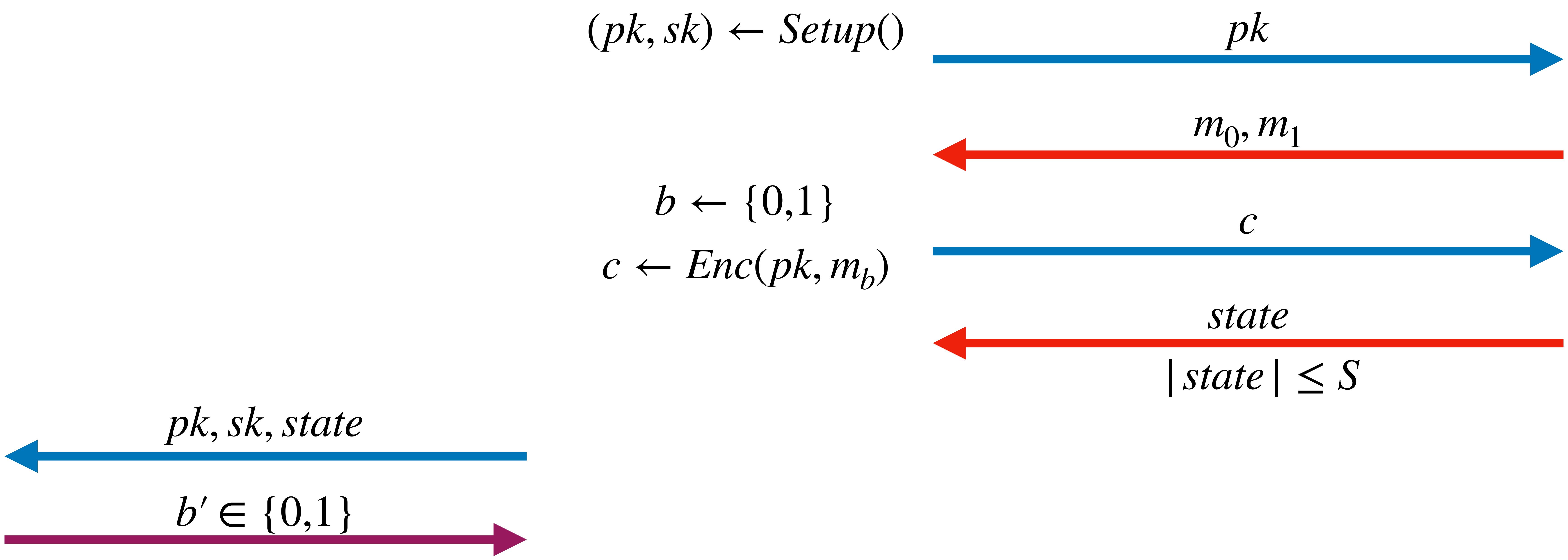

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Adversary 2

$\xleftarrow{pk, sk, state}$

$\xrightarrow{b' \in \{0,1\}}$

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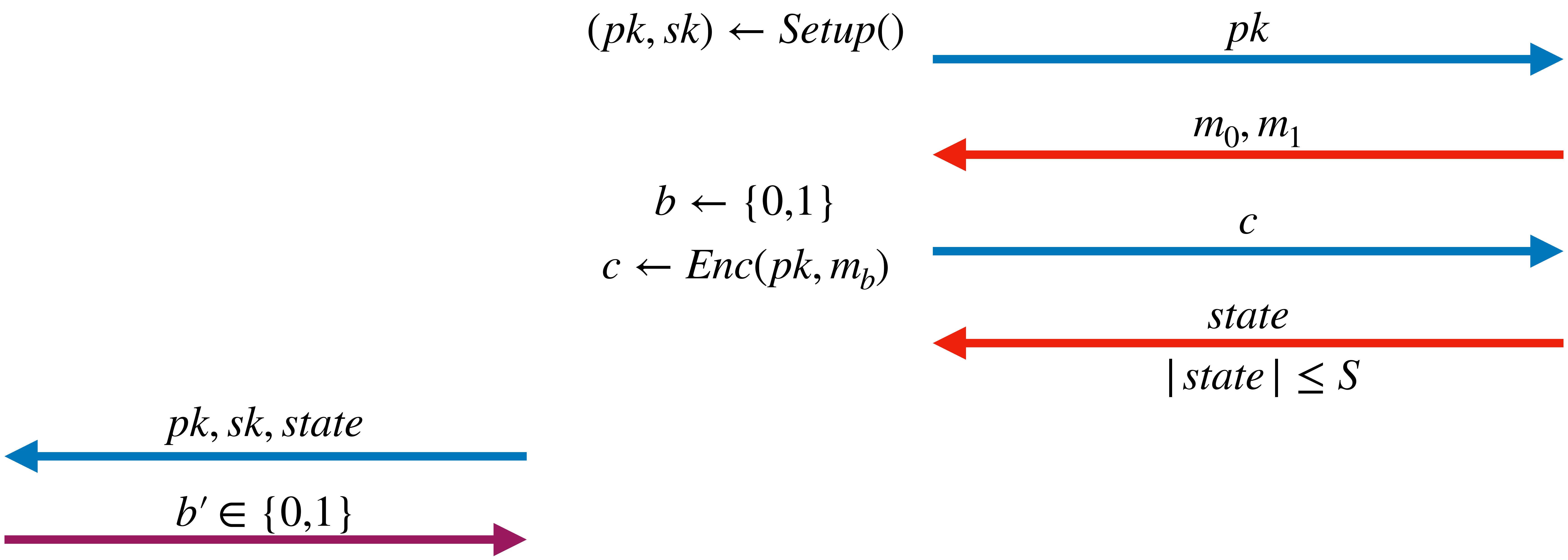

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$state$

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Adversary 2

$pk, sk, state$

$b' \in \{0,1\}$

Adversaries win if $b = b'$

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Goyal-Koppula-Rajasree-Verma'25	Extended the notion to FE, ABE and **IBE**

Incompressible PKE from NCE

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Non-Commiting Encryption

Incompressible PKE from NCE

Non-Commiting Encryption

+

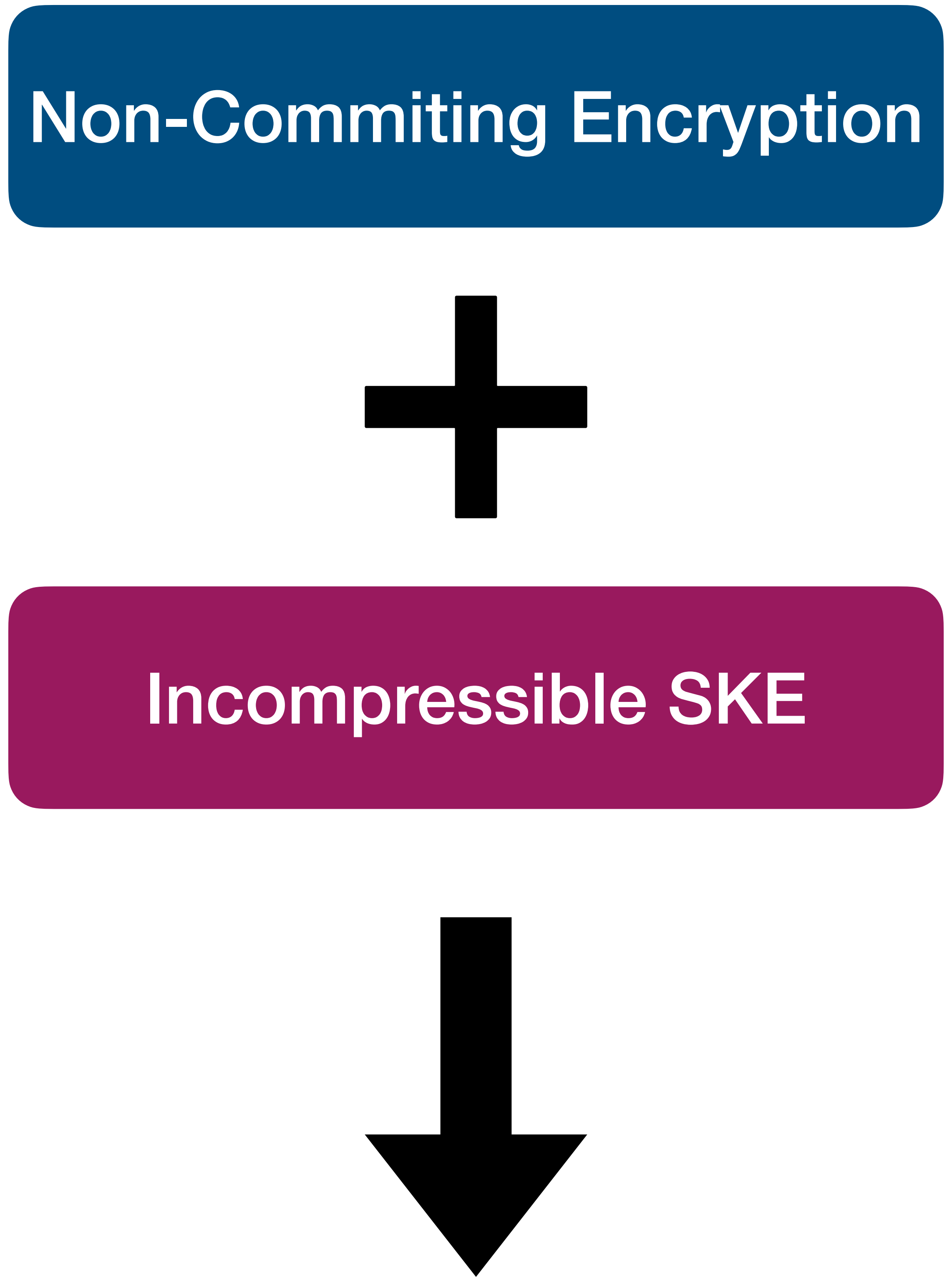
Incompressible PKE from NCE

Non-Commiting Encryption

+

Incompressible SKE

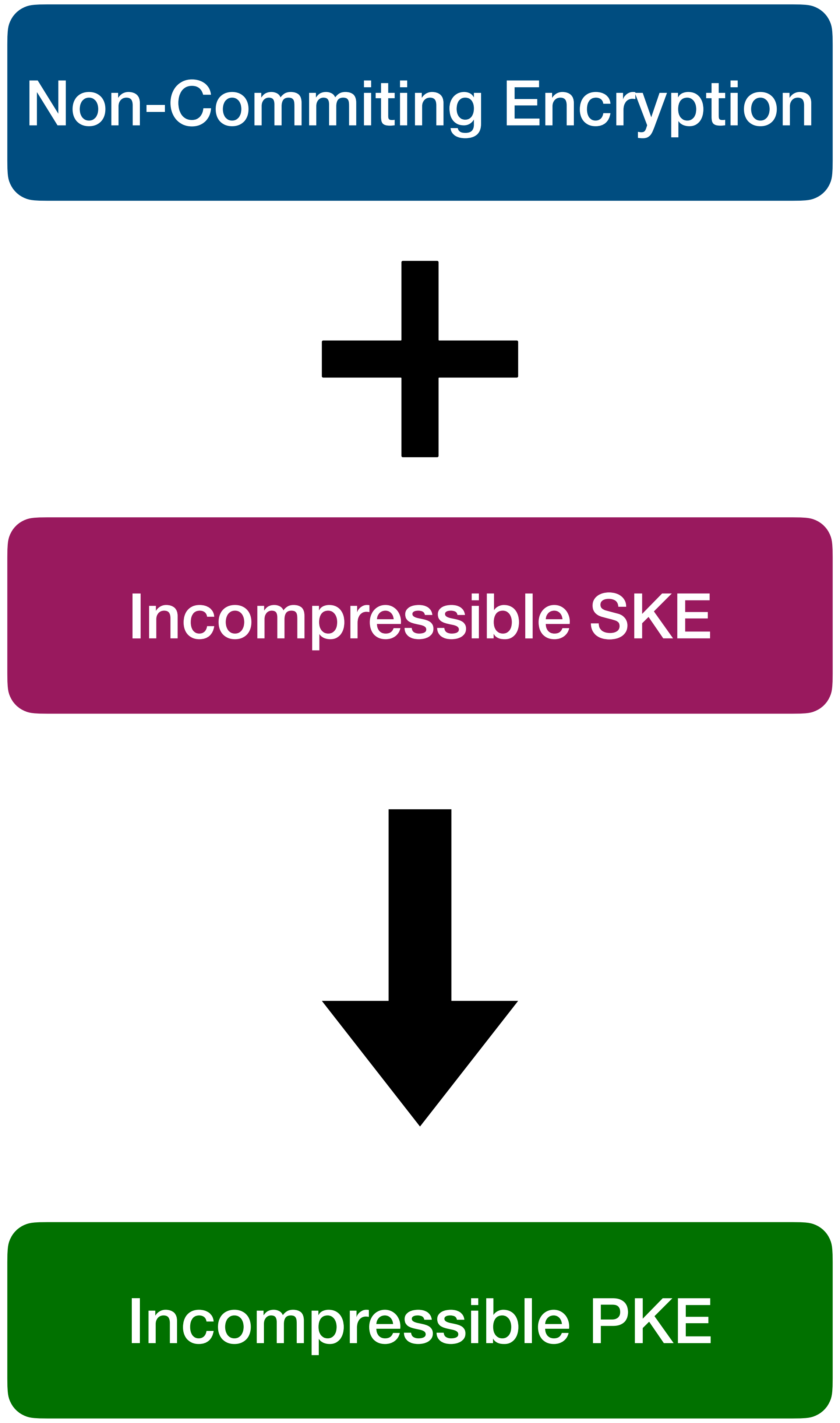
Incompressible PKE from NCE



Non-Commiting Encryption

Incompressible SKE

Incompressible PKE from NCE



Non-Commiting Encryption

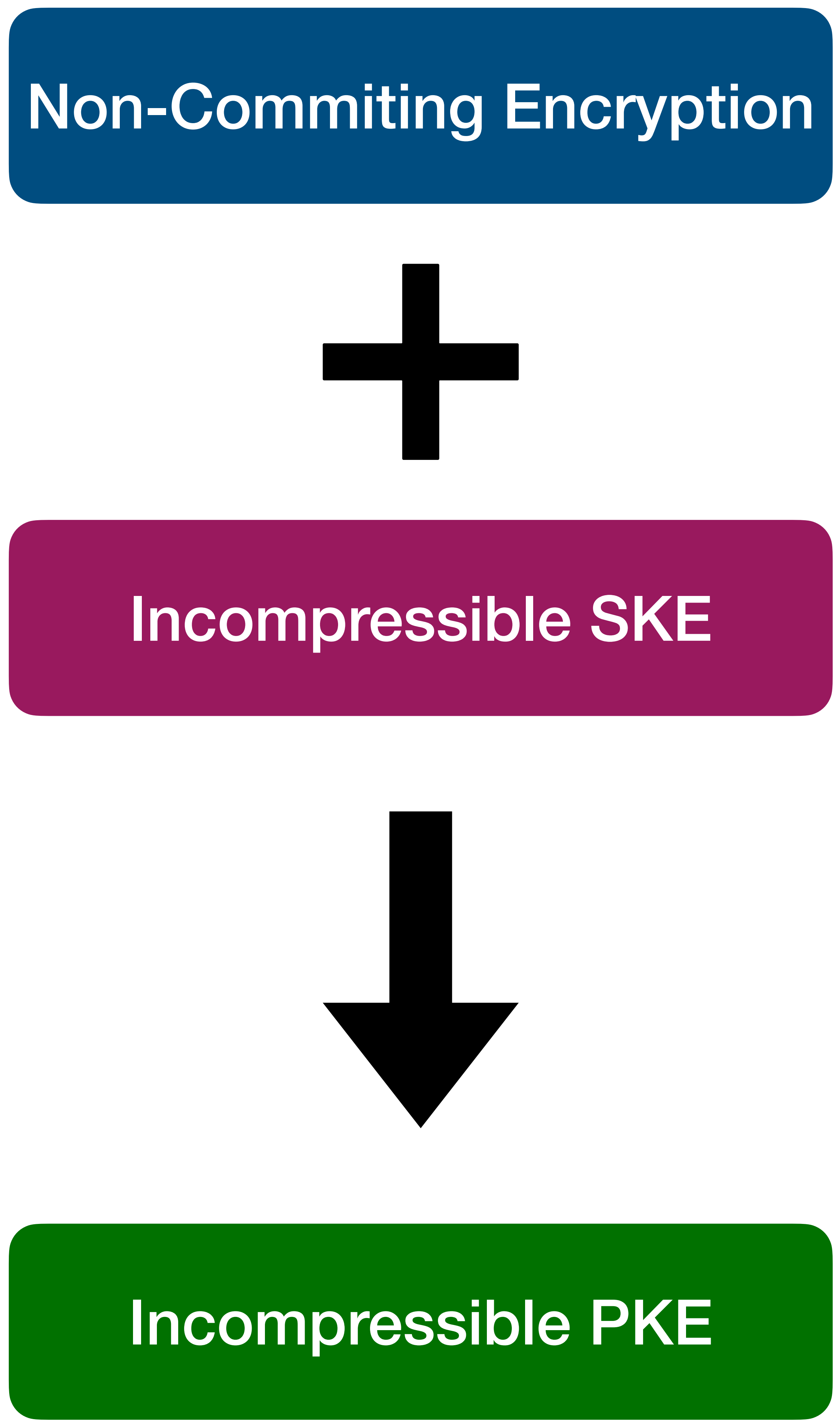
+

Incompressible SKE

↓

Incompressible PKE

Incompressible PKE from NCE



Non-Commiting Encryption

Incompressible SKE

Can be build from OWF

Incompressible PKE

Incompressible PKE from NCE

Non-Commiting Encryption

+

Incompressible SKE

Can be build from OWF

Incompressible PKE

Non-Committing Encryption (NCE)

[CFGN'96]

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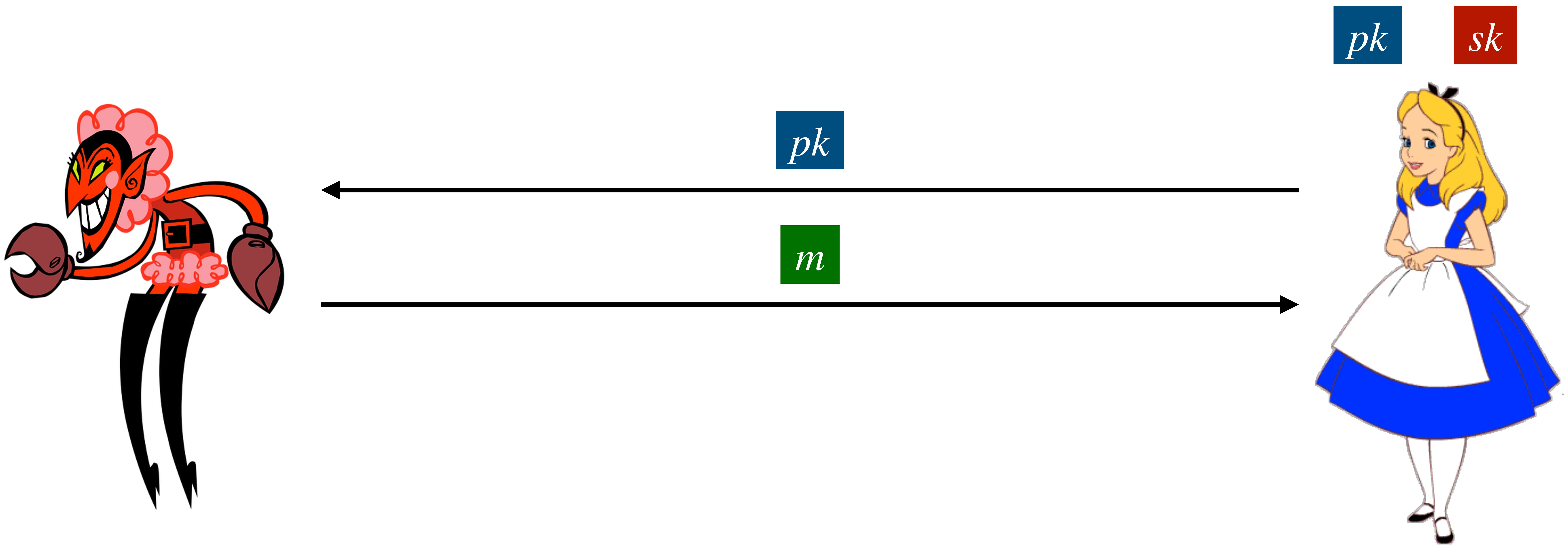
pk sk

Non-Committing Encryption (NCE)

[CFGN’96]

Non-Committing Encryption (NCE)

[CFGN'96]



pk sk

pk

m

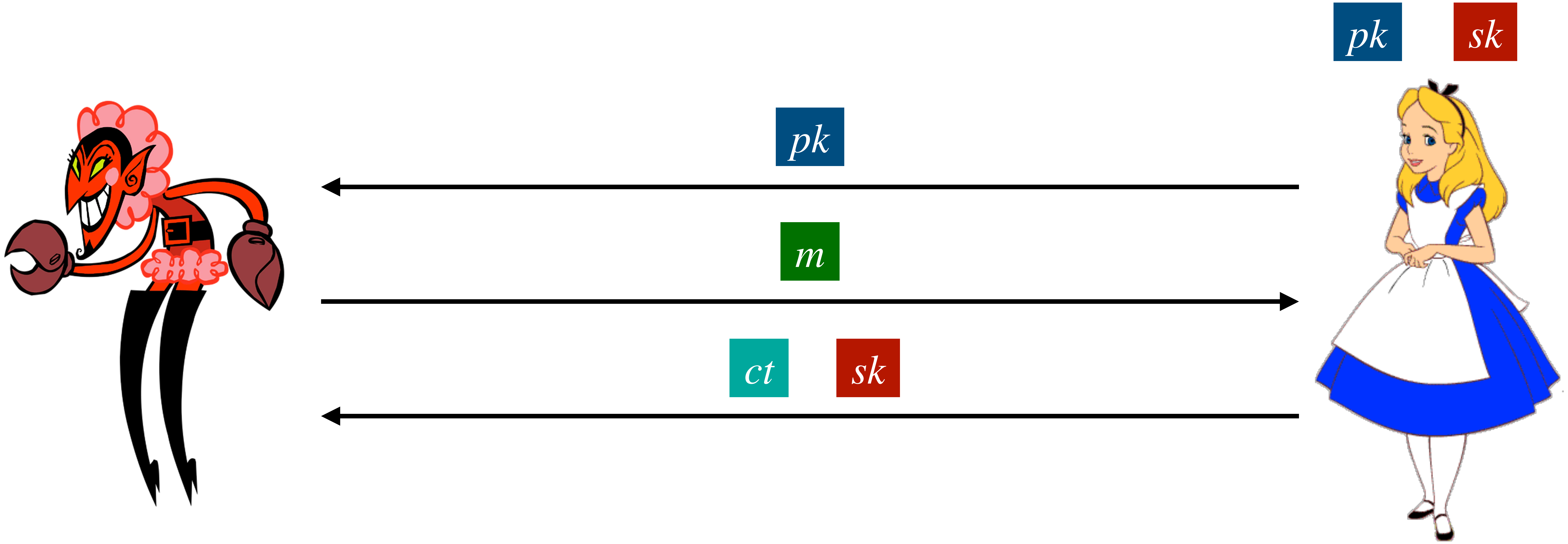
Non-Committing Encryption (NCE)

[CFGN’96]

$ct \leftarrow Enc(pk, m)$

Non-Committing Encryption (NCE)

[CFGN’96]



pk sk

pk

m

ct sk

$$ct \leftarrow Enc(pk, m)$$

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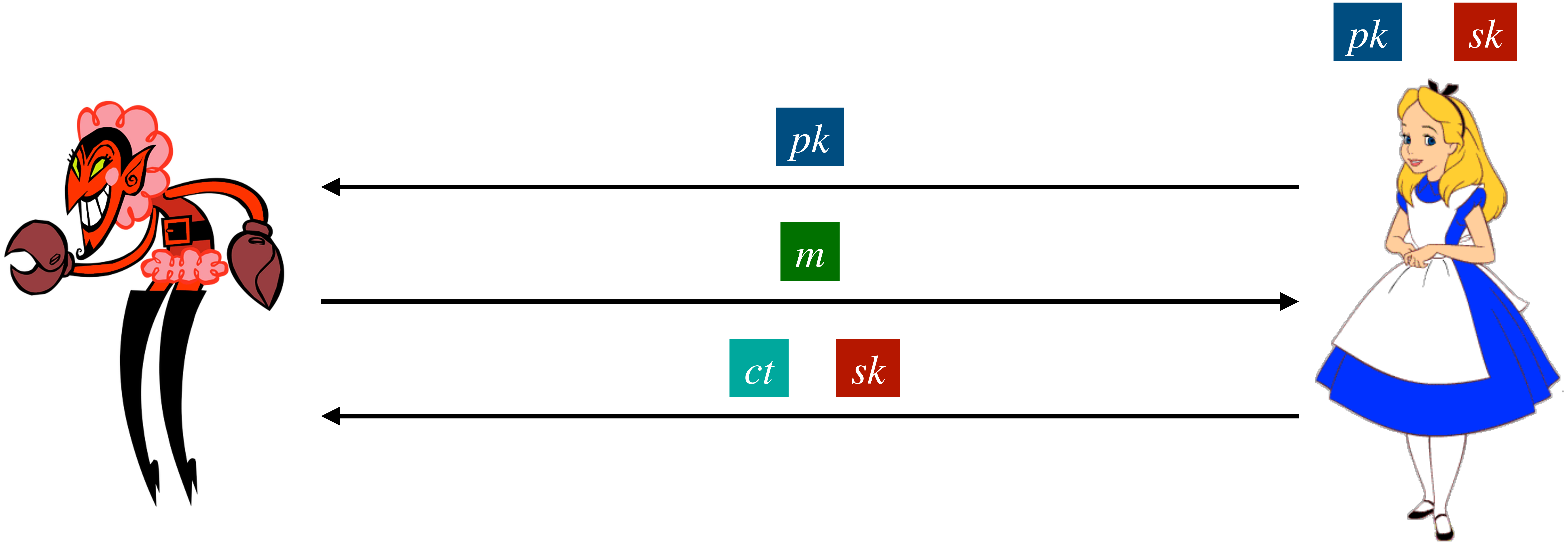

$m \leftarrow Dec(sk, ct)$

$ct \leftarrow Enc(pk, m)$

Non-Committing Encryption (NCE)

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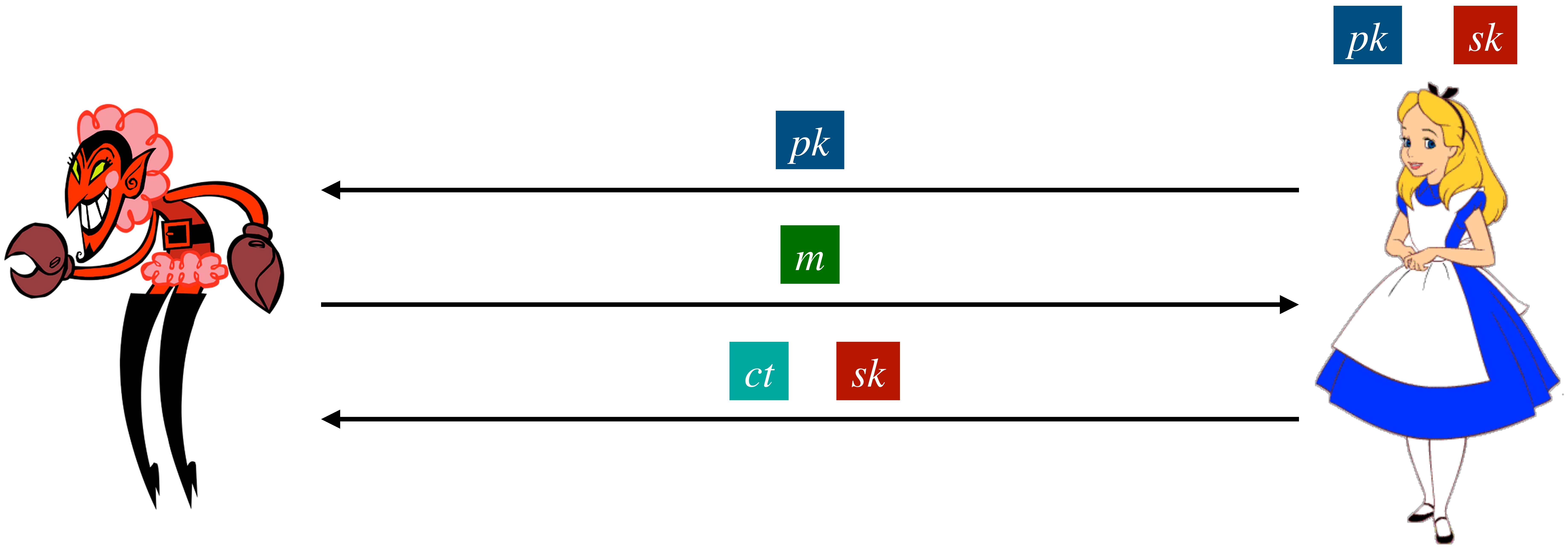

$m \leftarrow Dec(sk, ct)$

$ct \leftarrow Enc(pk, m)$

ct is committed to m

Non-Committing Encryption (NCE)

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[CFGN'96]

pk ct

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[CFGN'96]

pk ct

pk

Non-Committing Encryption (NCE)

[CFGN'96]

pk ct

pk

m

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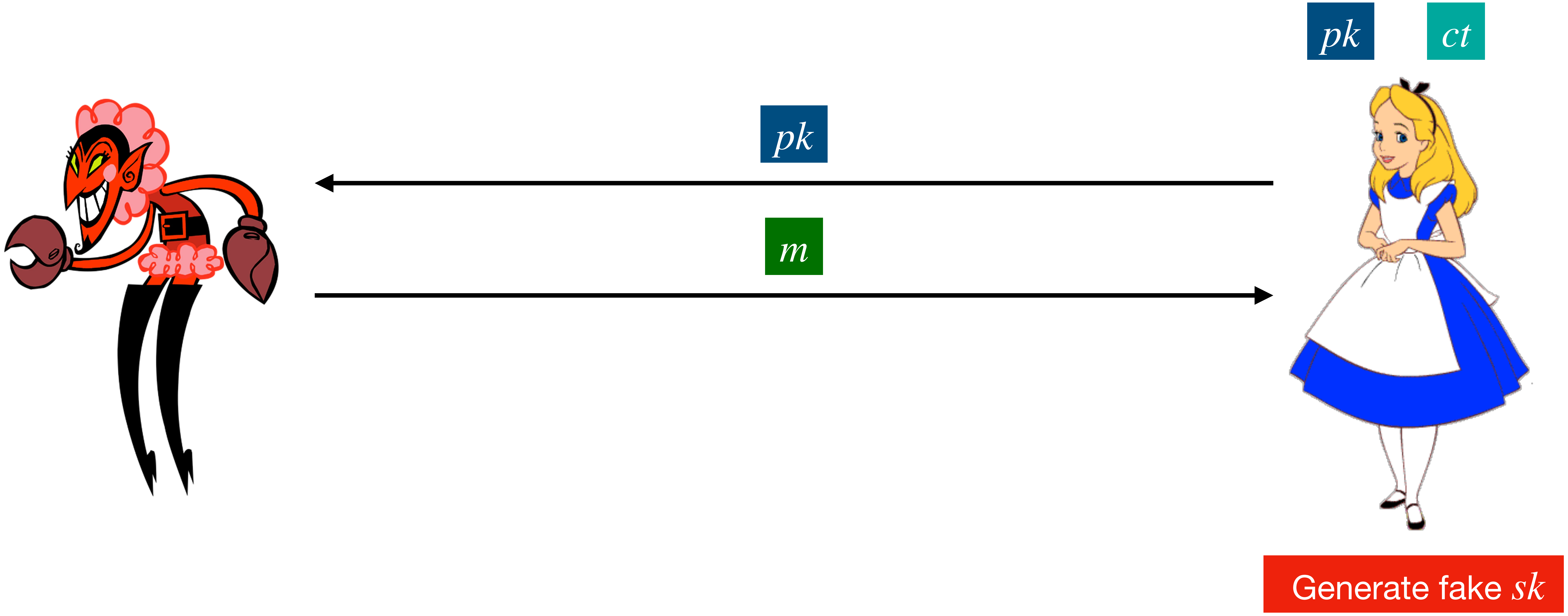

pk ct

pk

m

Generate fake sk

Non-Committing Encryption (NCE)

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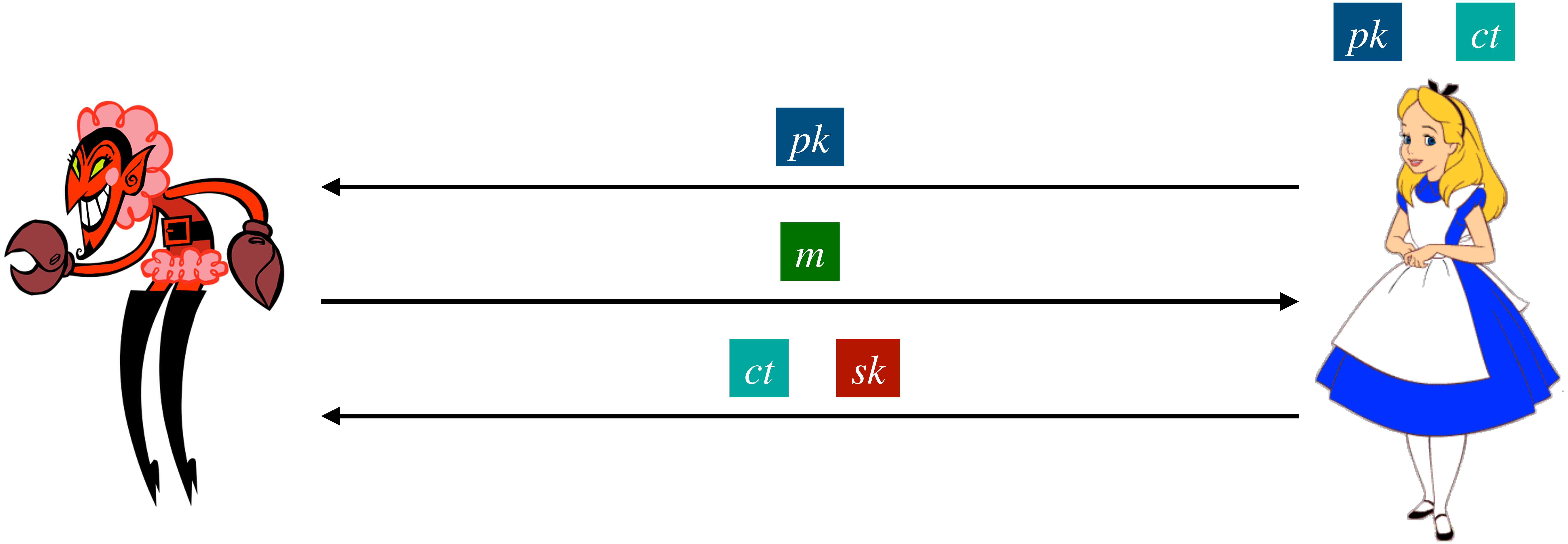

Generate fake sk

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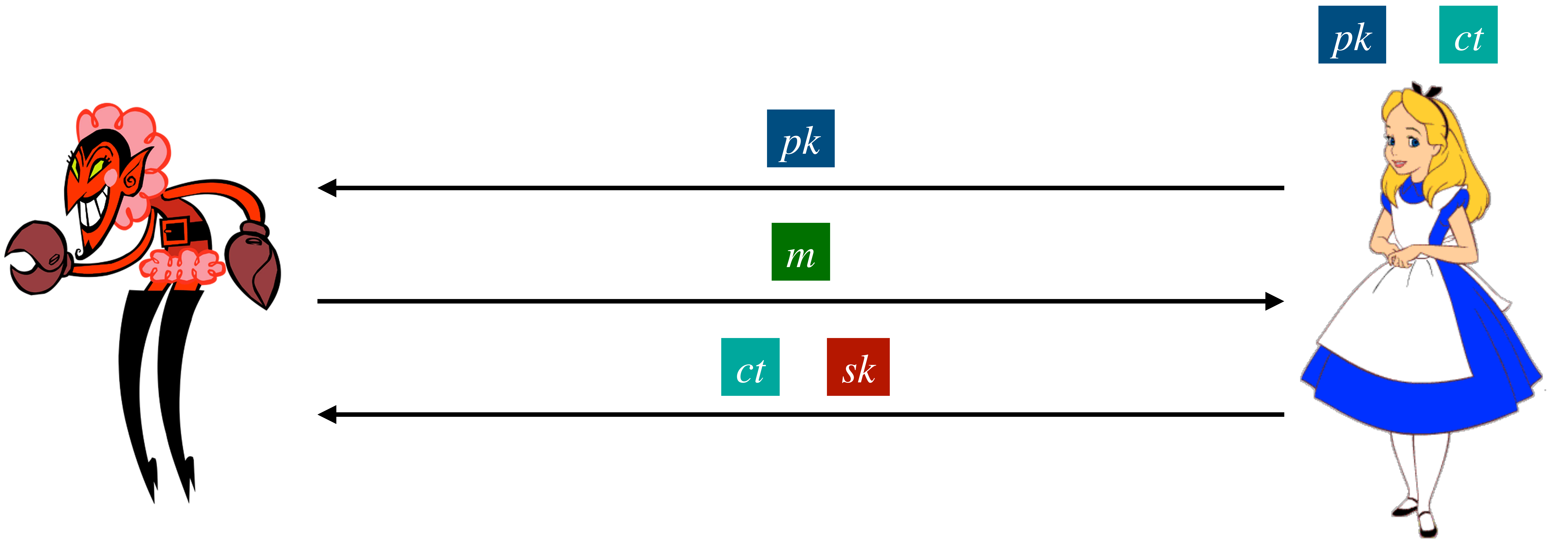

pk ct

pk

m

ct sk

$m \leftarrow Dec(sk, ct)$

Generate fake sk

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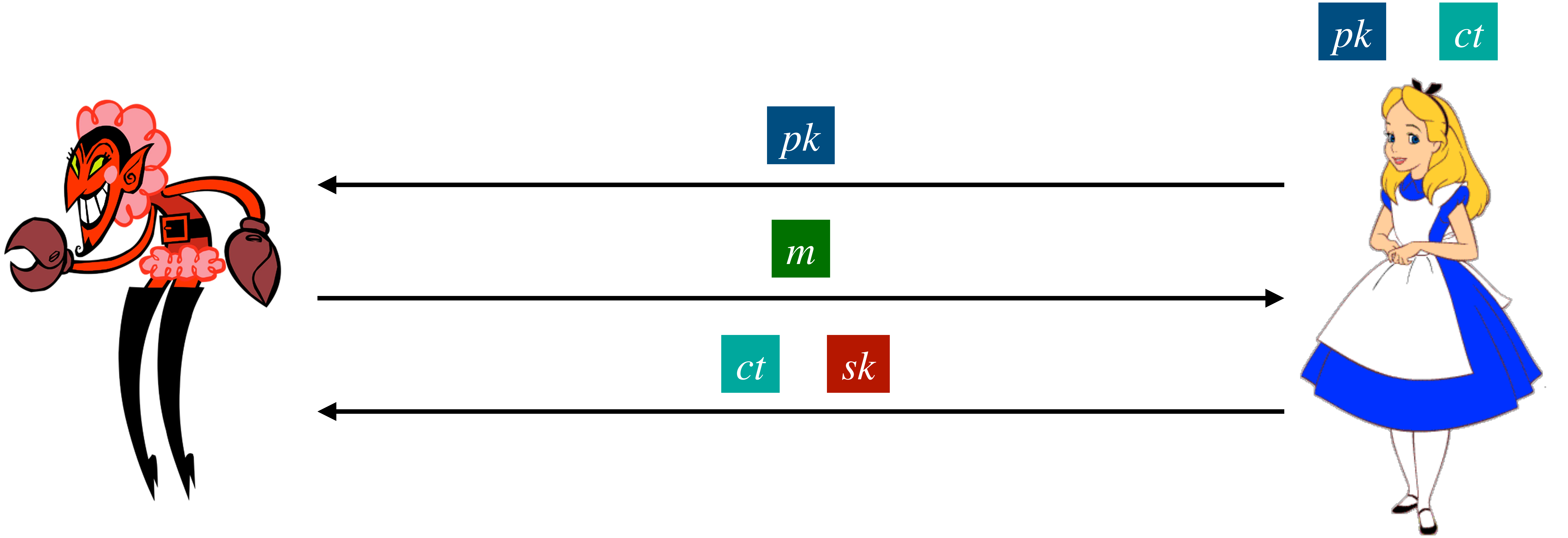

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Generate fake sk

Adaptivity in MPC

Non-Committing Encryption (NCE)

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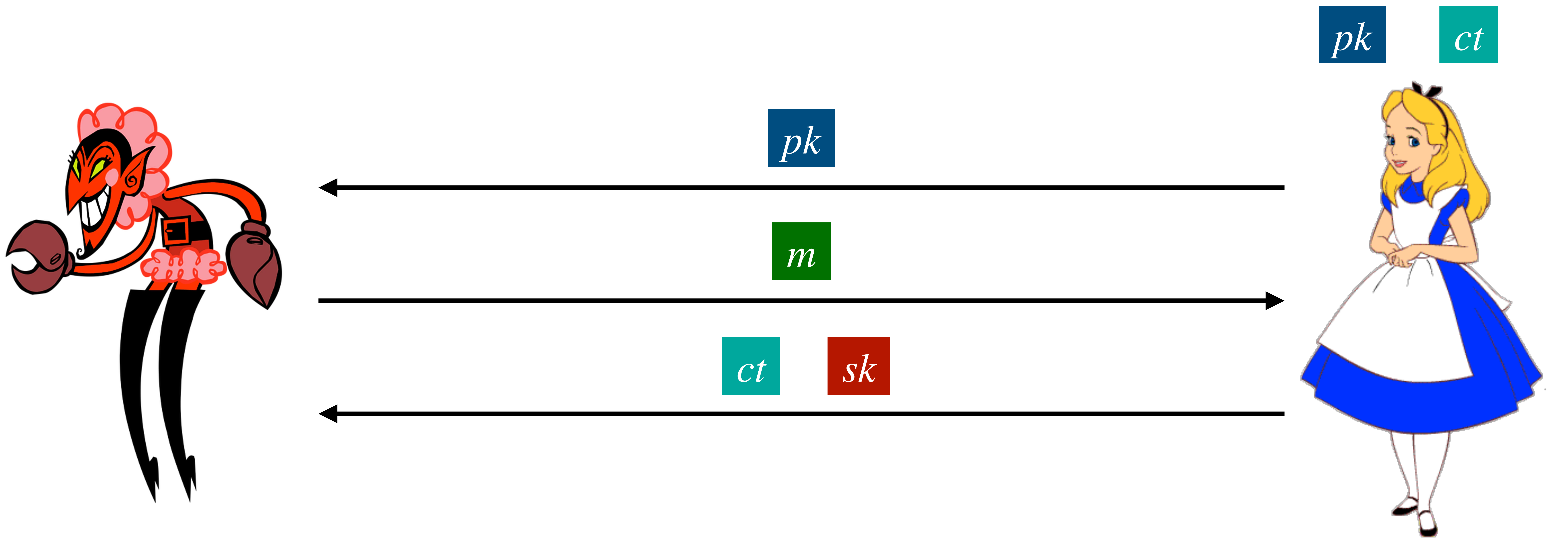

pk ct

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Adaptivity in MPC

Certified Deletion

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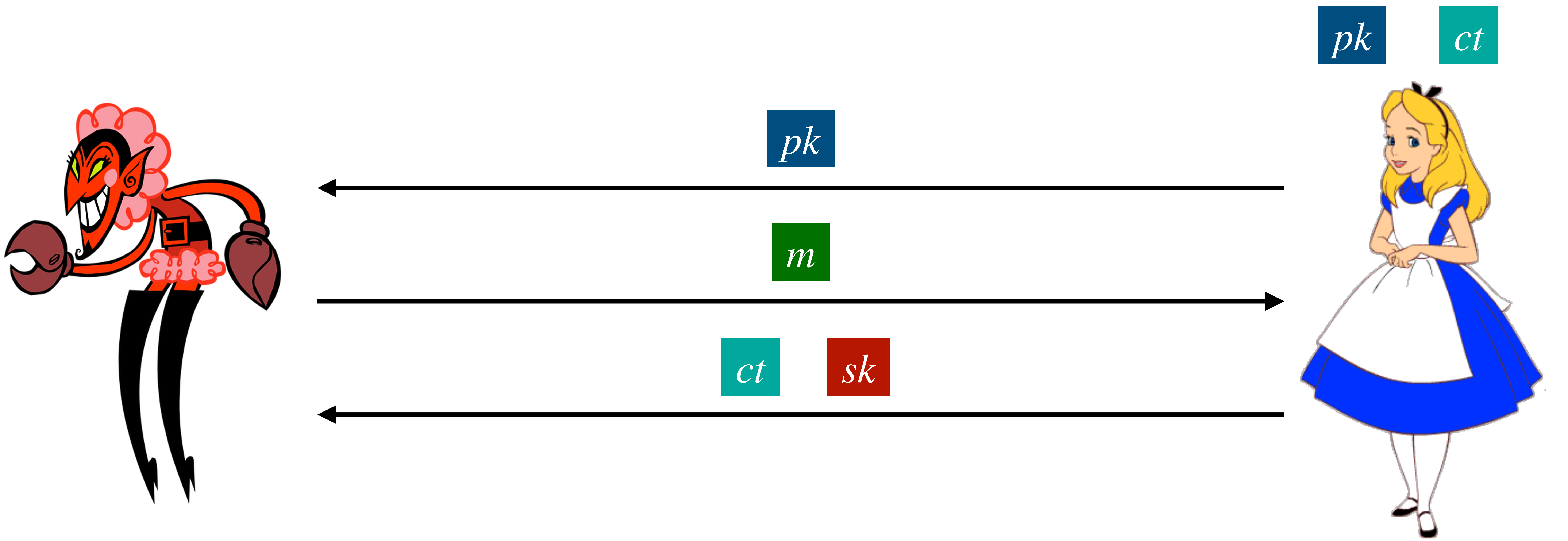

pk ct

pk

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Incompressible Cryptography

Receiver NCE Syntax

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$Setup(\lambda) \rightarrow$ public key pk , secret key sk

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$Enc($ pk $, m) \rightarrow$ ciphertext ct

Receiver NCE Syntax

$Setup(\lambda) \rightarrow$ public key pk , secret key sk

$Enc(pk, m) \rightarrow$ ciphertext ct

$Dec(sk, ct) \rightarrow m/\perp$

Receiver NCE Syntax

$Setup(\lambda) \rightarrow$ public key pk, secret key sk

$Enc(pk, m) \rightarrow$ ciphertext ct

$Dec(sk, ct) \rightarrow m/\perp$

$Sim_1(\lambda) \rightarrow$ fake public key pk^*, fake ciphertext ct^*

Receiver NCE Syntax

$Setup(\lambda) \rightarrow$ public key pk , secret key sk

$Enc($ pk $, m) \rightarrow$ ciphertext ct

$Dec($ sk $,$ ct $) \rightarrow m/\perp$

$Sim_1(\lambda) \rightarrow$ fake public key pk^* , fake ciphertext ct^*

$Sim_2(m) \rightarrow$ fake secret key sk^*

Receiver NCE Syntax

$Setup(\lambda) \rightarrow$ public key pk, secret key sk

$Enc(pk, m) \rightarrow$ ciphertext ct

$Dec(sk, ct) \rightarrow m / \perp$

Security

$$\underbrace{\{pk, sk, ct_m\}}_{Real} \approx_c \underbrace{\{pk^*, sk^*, ct^*\}}_{Simulated}$$

$Sim_1(\lambda) \rightarrow$ fake public key pk^*, fake ciphertext ct^*

$Sim_2(m) \rightarrow$ fake secret key sk^*

Identity Based Encryption

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- To encrypt a message m, a master public key mpk is used along with id.
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- To encrypt a message m, a master public key mpk is used along with id.
  - Adversary gets a challenge ciphertext ct^* for m_0, m_1 encrypted under the identity id^* and then it has to distinguish it.

  - Also obtains multiple sk_{id} where $id \neq id^*$.

(RNC)-IBE Syntax

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$Setup(\lambda) \rightarrow$ master public key mpk , master secret key msk

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$Enc(mpk, id, m) \rightarrow$ Ciphertext ct

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$KeyGen(msk , id) \rightarrow$ Secret key sk_{id}

(RNC)-IBE Syntax

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$Dec(sk_{id}, ct) \rightarrow m$

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$Setup(\lambda) \rightarrow$ master public key mpk , master secret key msk

$Enc(mpk, id, m) \rightarrow$ Ciphertext ct

$KeyGen(msk, id) \rightarrow$ Secret key sk_{id}

$Dec(sk_{id}, ct) \rightarrow m$

$Sim_1(\lambda) \rightarrow$ fake master public key mpk^* , fake ciphertext ct^*

$Sim_2(id) \rightarrow$ Fake secret key sk_{id}

$Sim_3(id^*, m) \rightarrow$ Fake master secret key msk^*

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Hiroka-Morimae-Nishimaki-Yamakawa'21	Introduced **identity based non-committing encryption** to build certified IBE with certified deletion.

Reveals randomness used during setup and encryption algorithm.

RNC-IBE Security

[Hiroka-Morimae-Nishimaki-Yamakawa’21]

RNC-IBE Security

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Challenger

Adversary

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Adversary

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RNC-IBE Security

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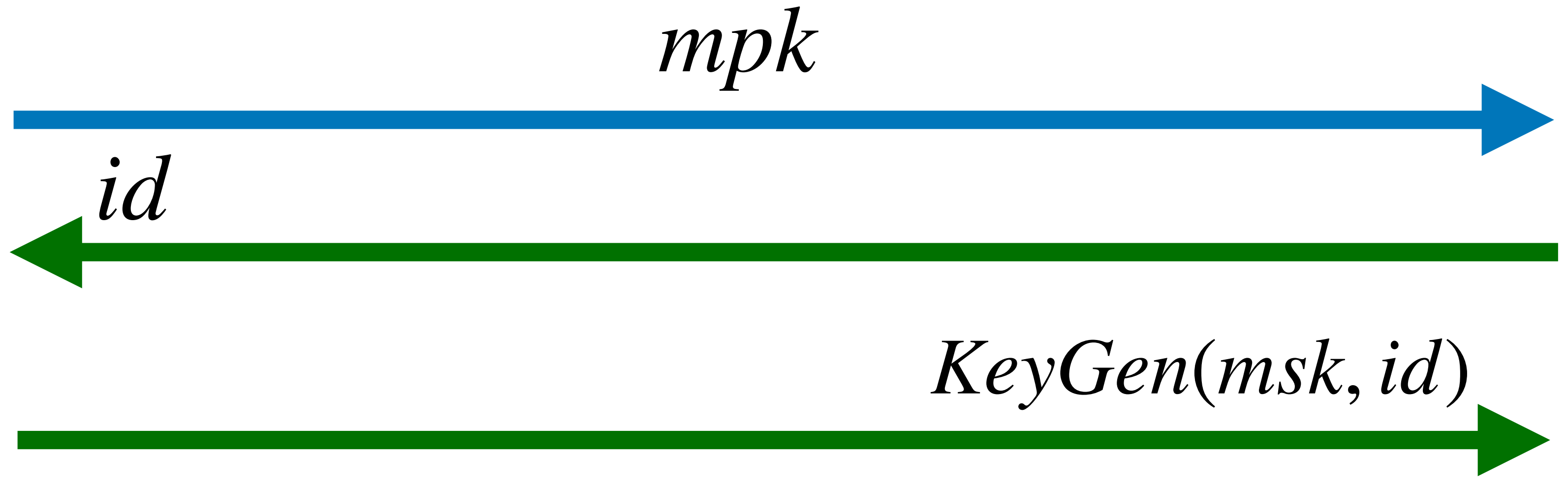

mpk

id

$KeyGen(msk, id)$

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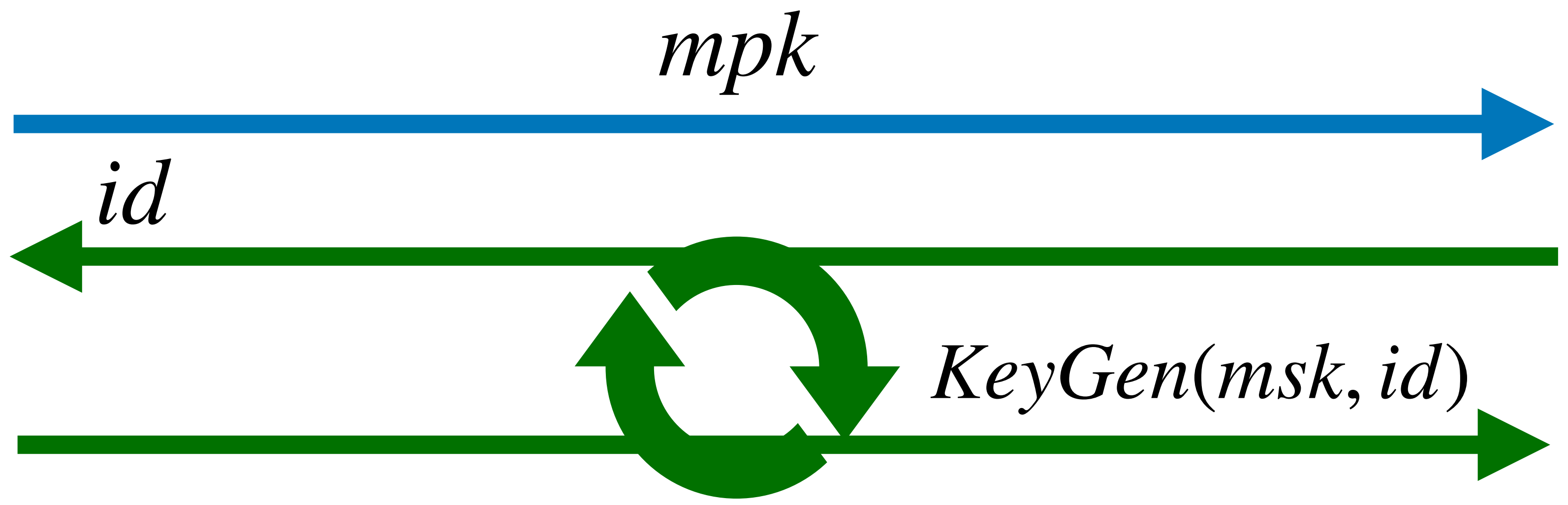

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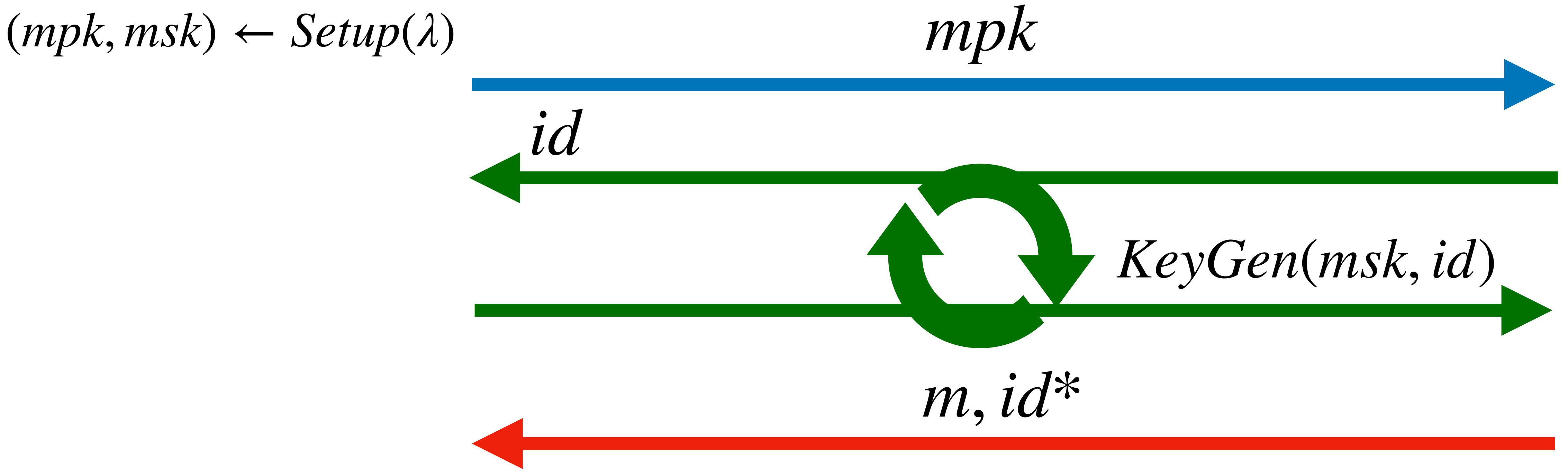

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mpk

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m, id^*

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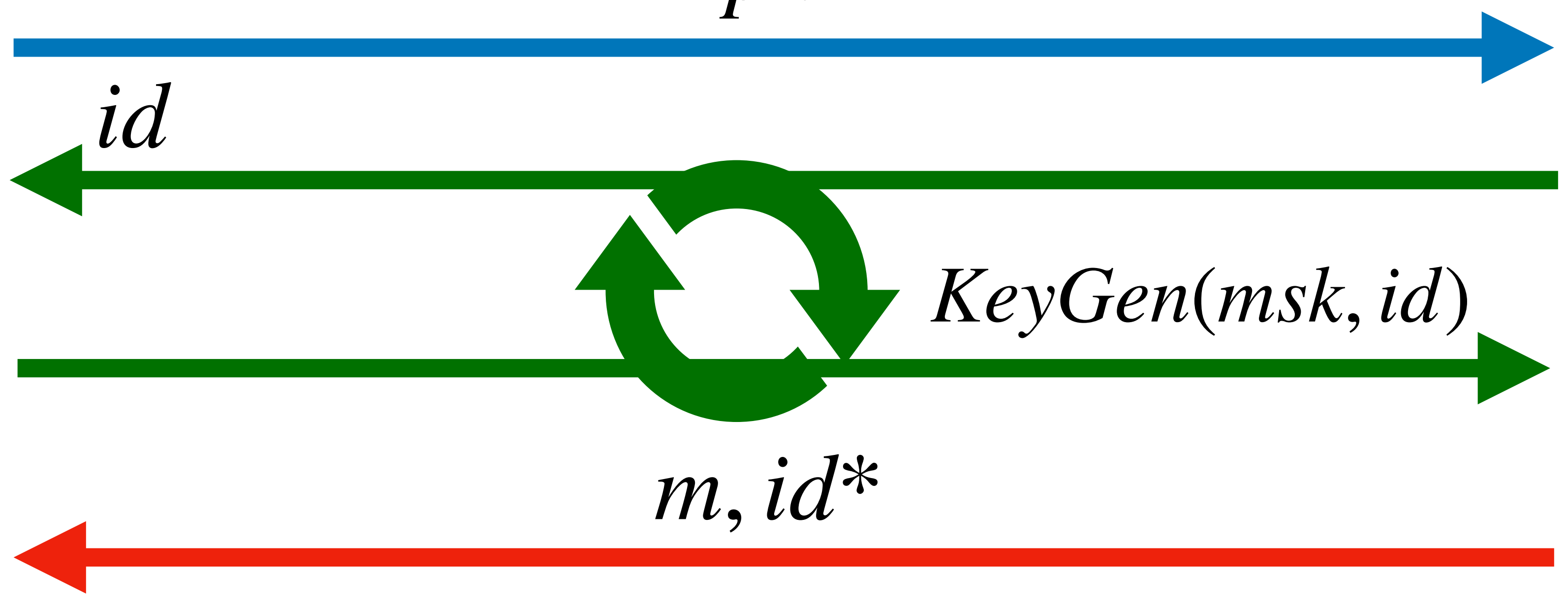

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m, id^*

$b = 0$

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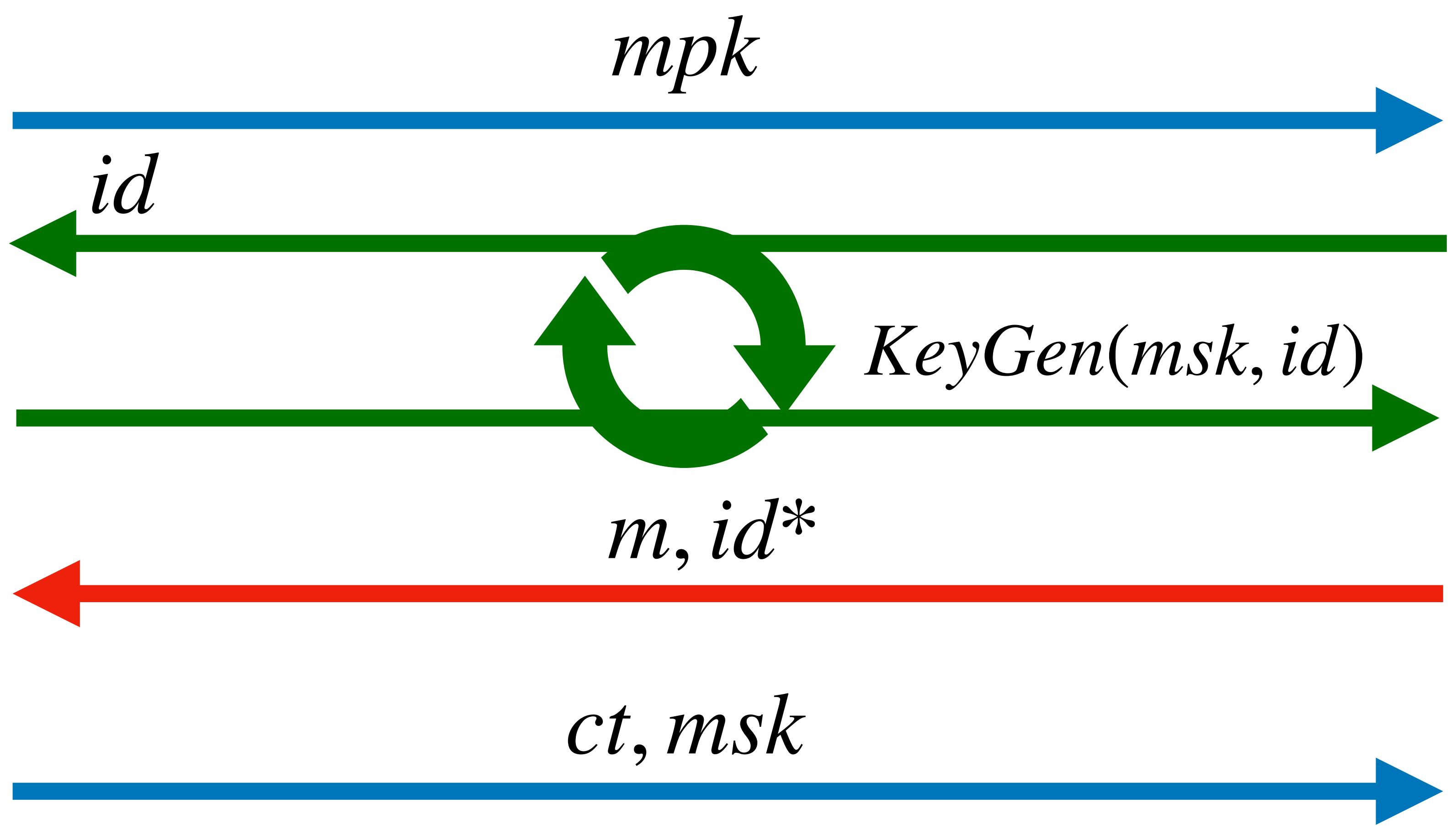

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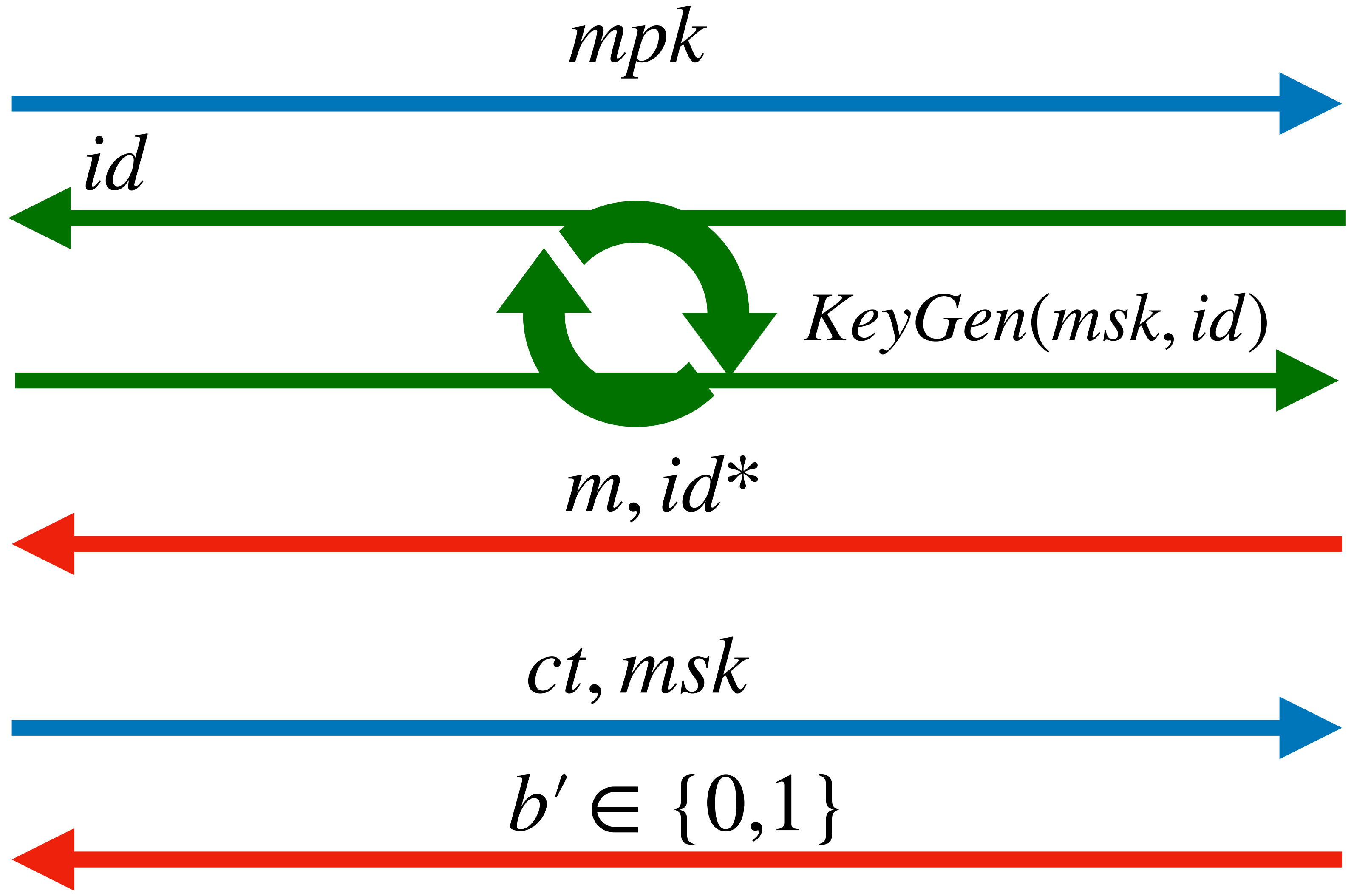

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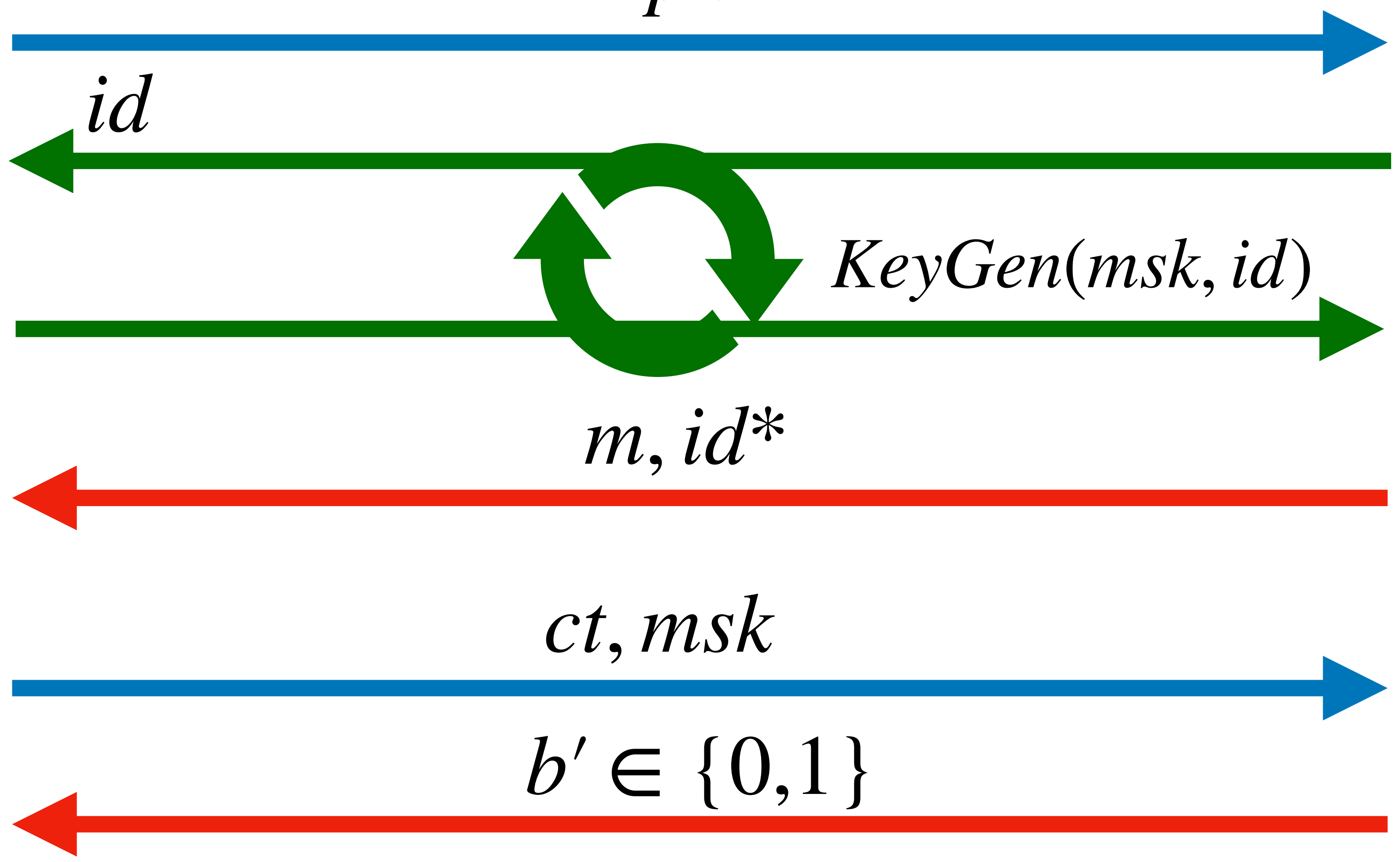

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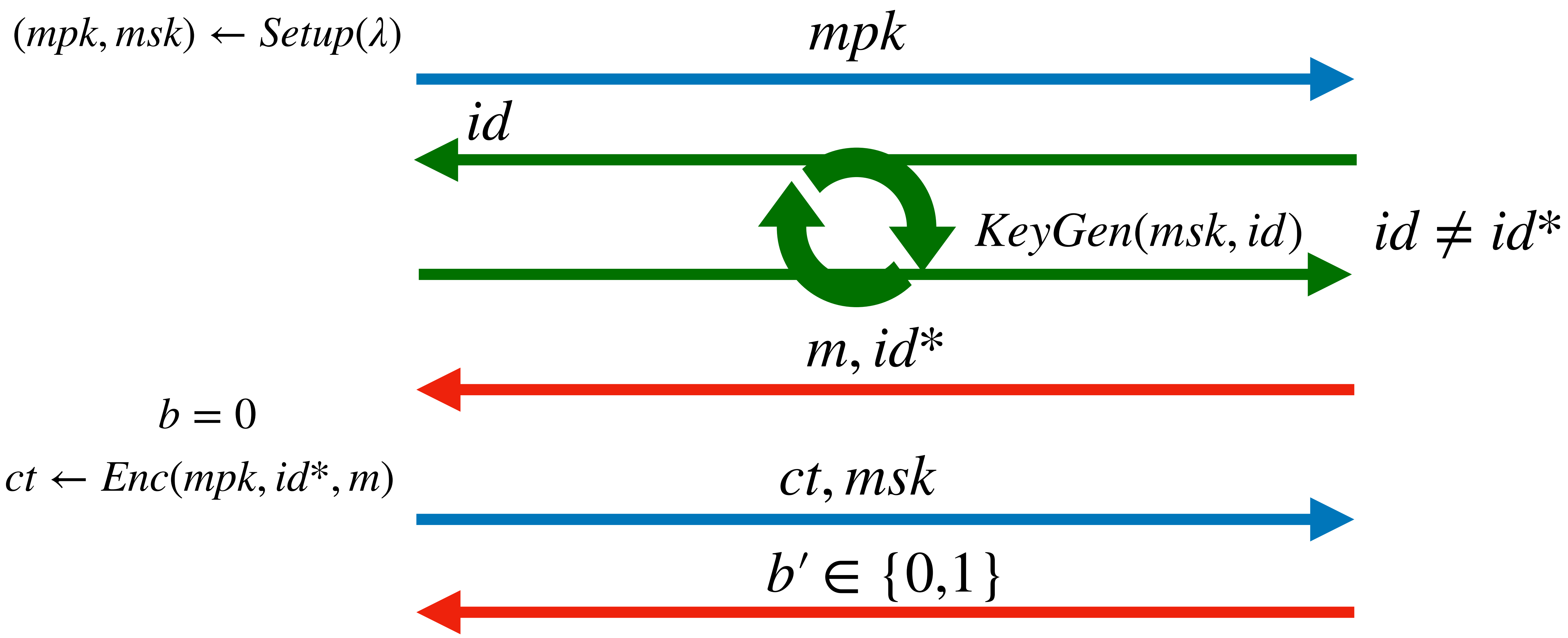
RNC-IBE Security

[Hiroka-Morimae-Nishimaki-Yamakawa’21]

Challenger

Adversary

Simulator



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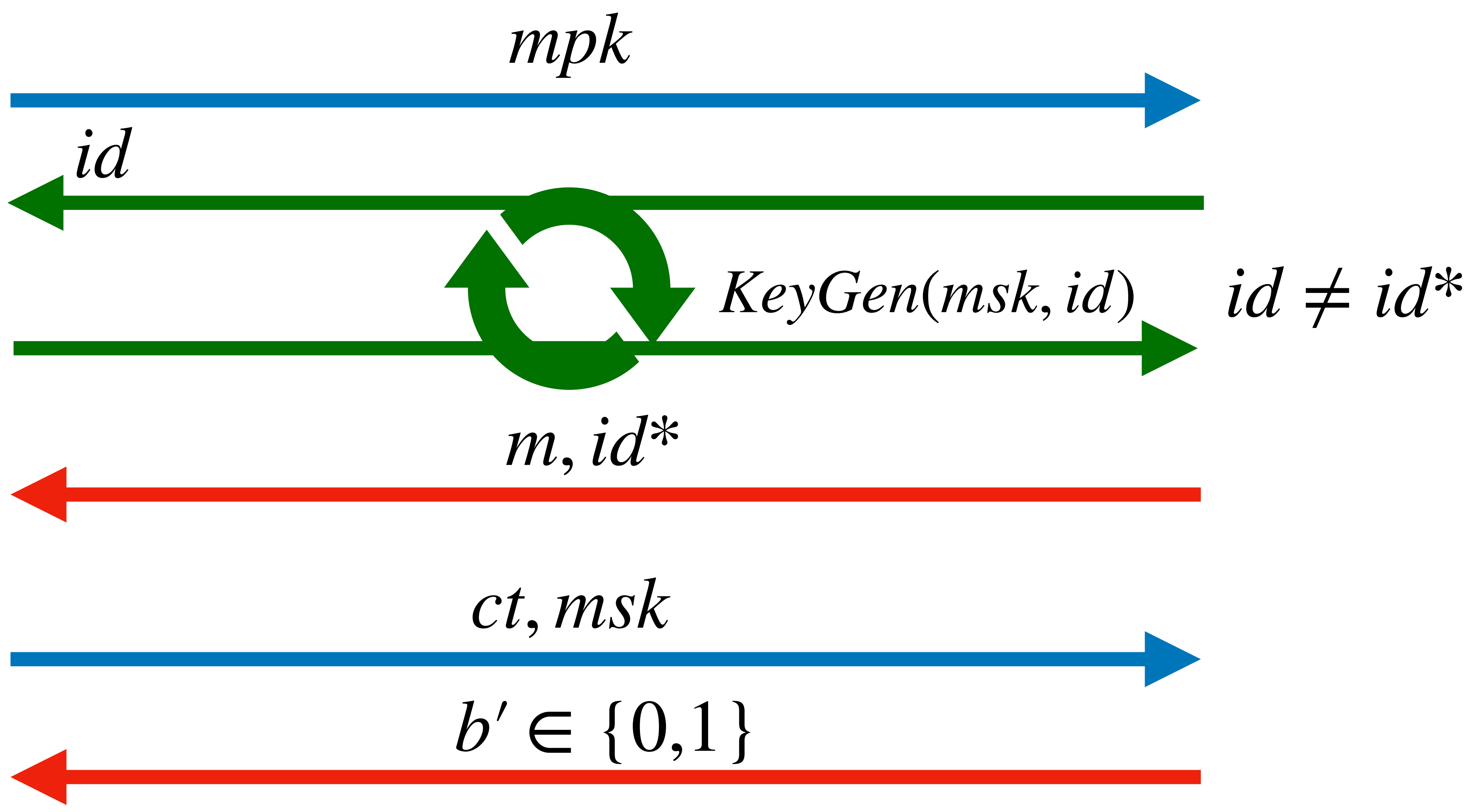

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RNC-IBE Security

[Hiroka-Morimae-Nishimaki-Yamakawa'21]

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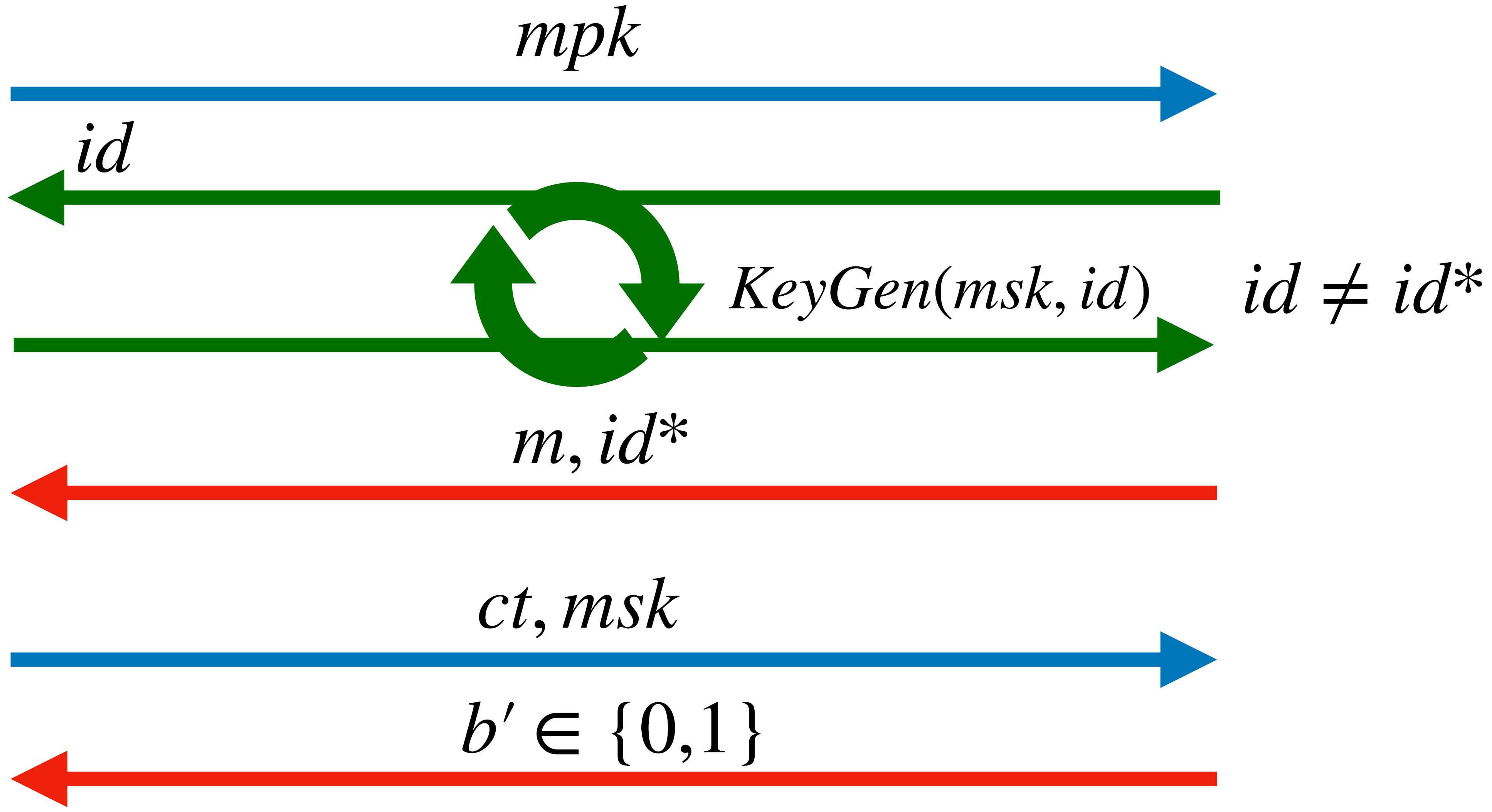

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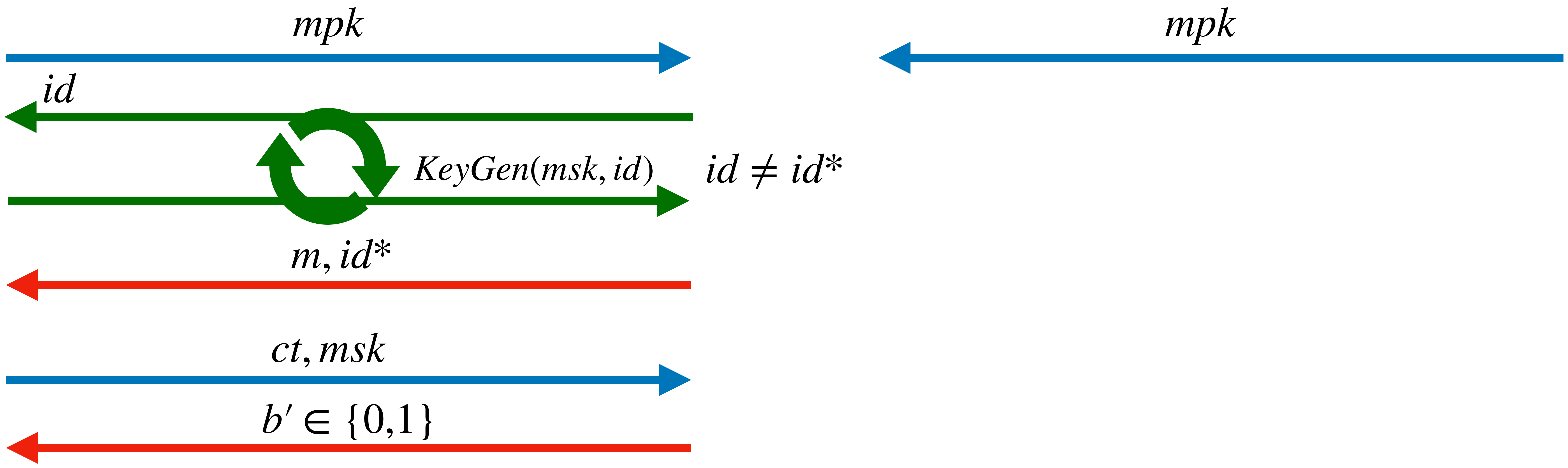

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mpk

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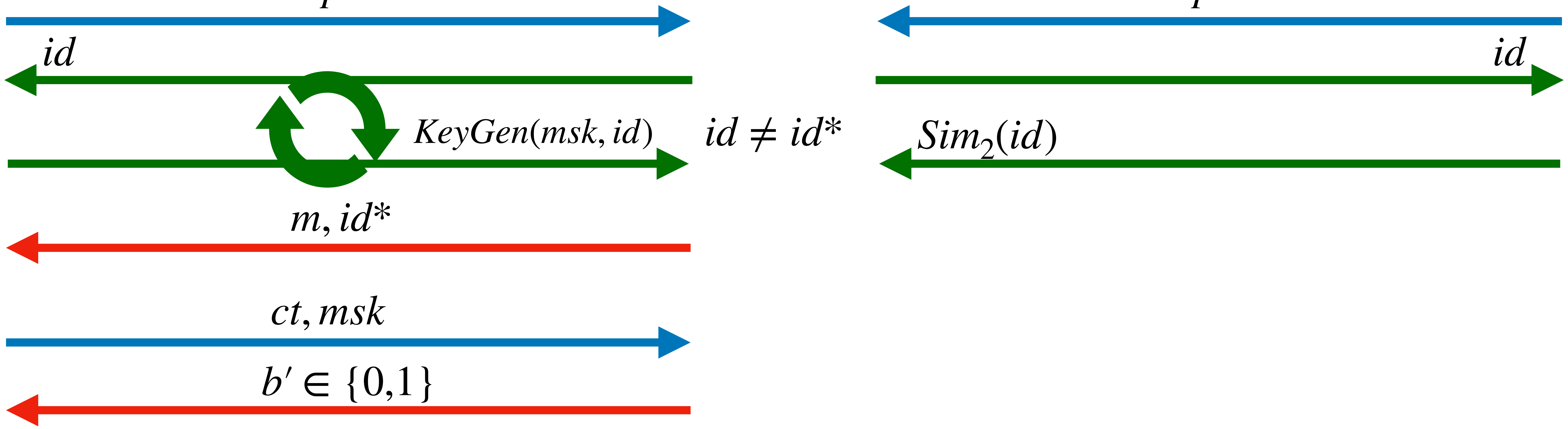

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ct, msk

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mpk

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id

$Sim_2(id)$

RNC-IBE Security

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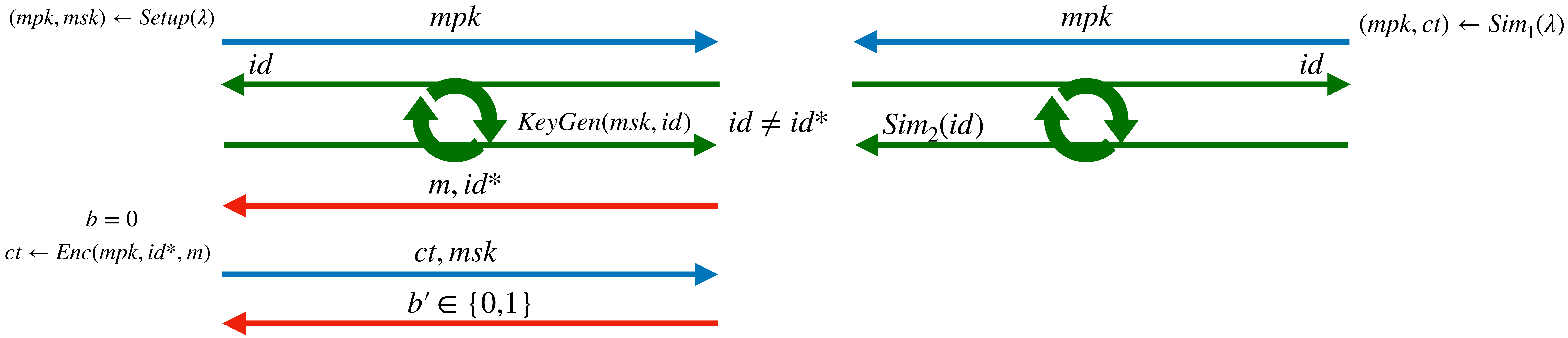

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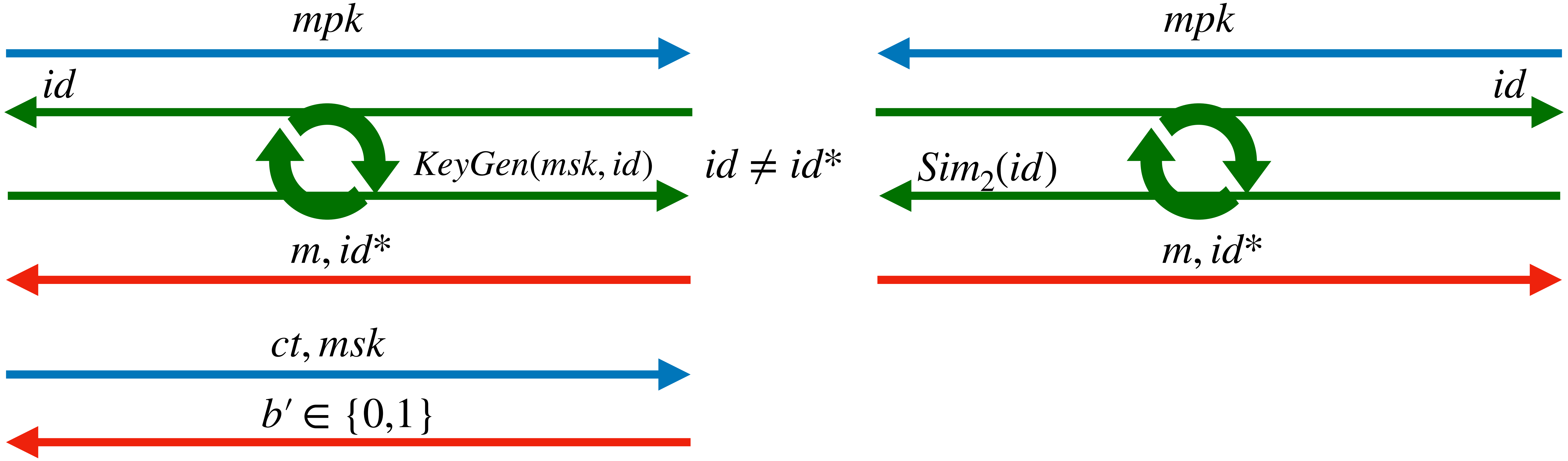

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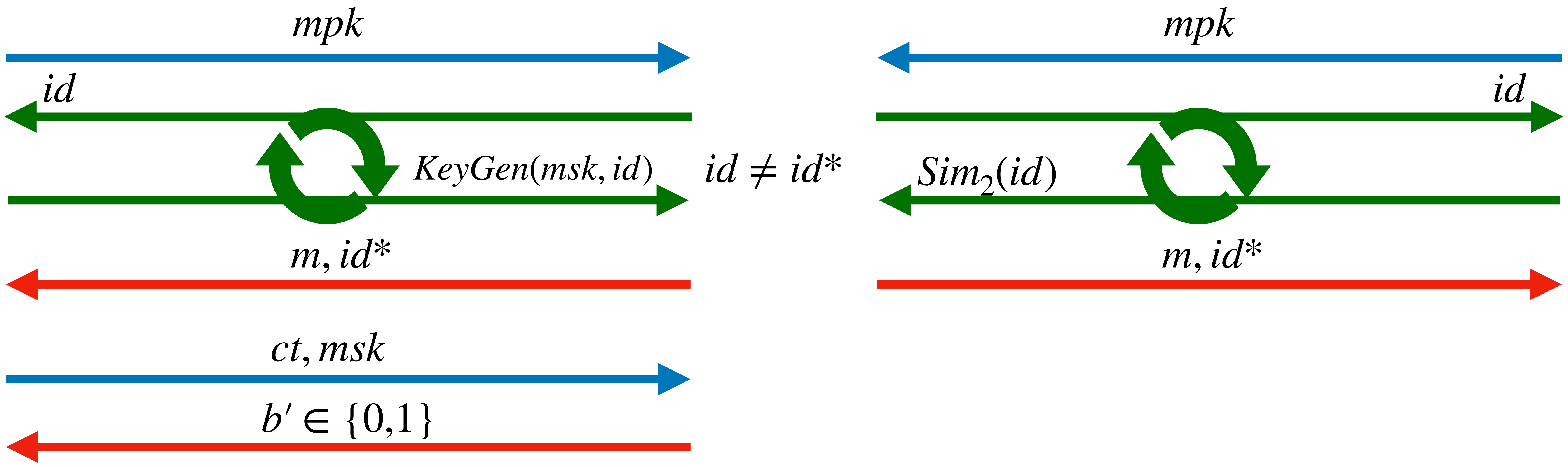

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ct, msk

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mpk

$(mpk, ct) \leftarrow Sim_1(\lambda)$

id

$Sim_2(id)$

m, id^*

$b = 1$

$msk \leftarrow Sim_3(id^*, m)$

RNC-IBE Security

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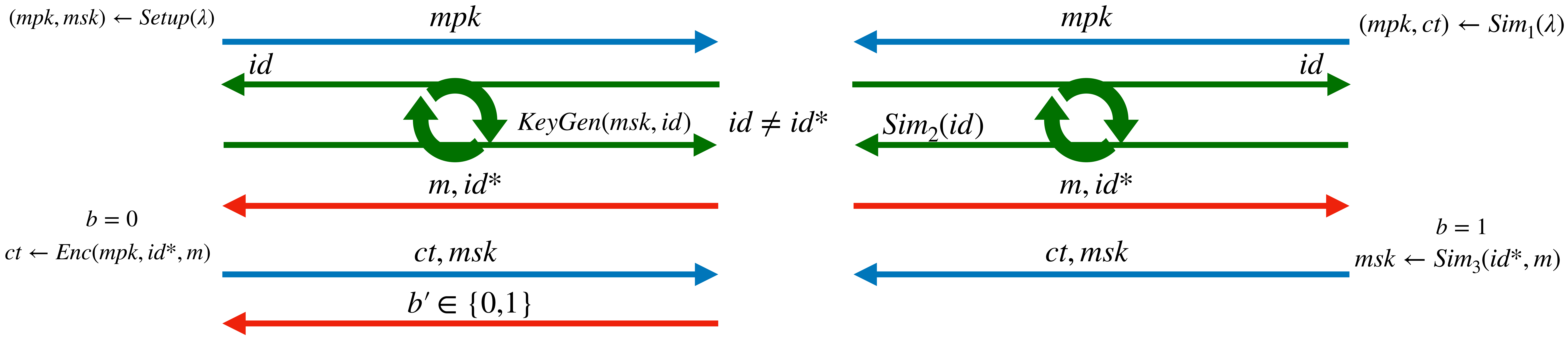

$(mpk, msk) \leftarrow Setup(\lambda)$ mpk mpk $(mpk, ct) \leftarrow Sim_1(\lambda)$

id id

$KeyGen(msk, id)$ $id \neq id^*$ $Sim_2(id)$

m, id^* m, id^*

$b = 0$ $b = 1$

$ct \leftarrow Enc(mpk, id^*, m)$ ct, msk ct, msk $msk \leftarrow Sim_3(id^*, m)$

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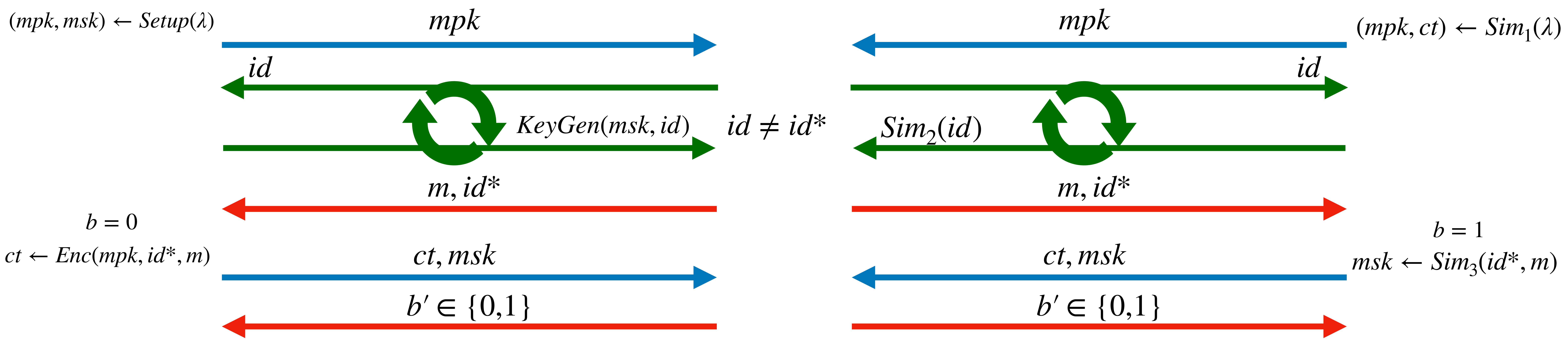

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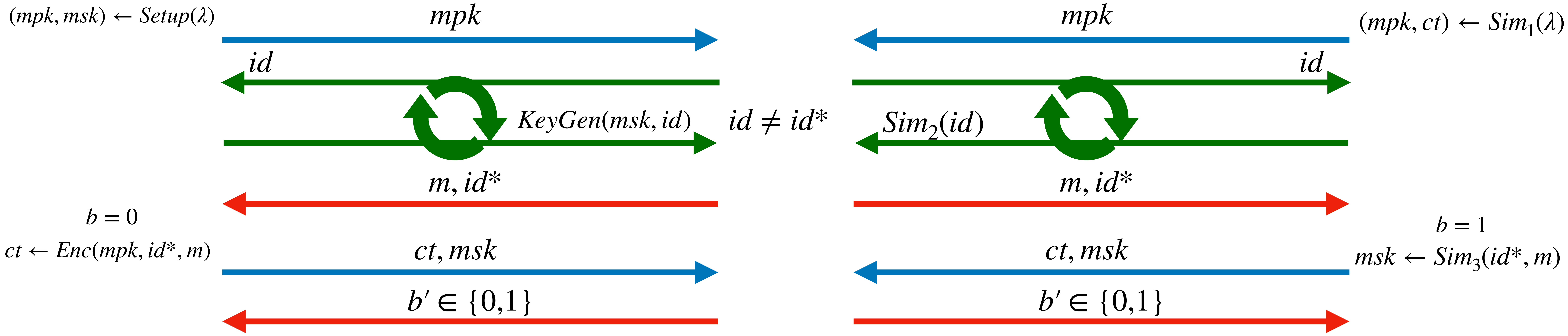

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m, id^*

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ct, msk

$b' \in \{0,1\}$

Adversary wins if $b = b'$

This work

This work

Can we build RNC-IBE from standard assumptions*?

This work

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*Prior work used indistinguishable obfuscation.

Our Results

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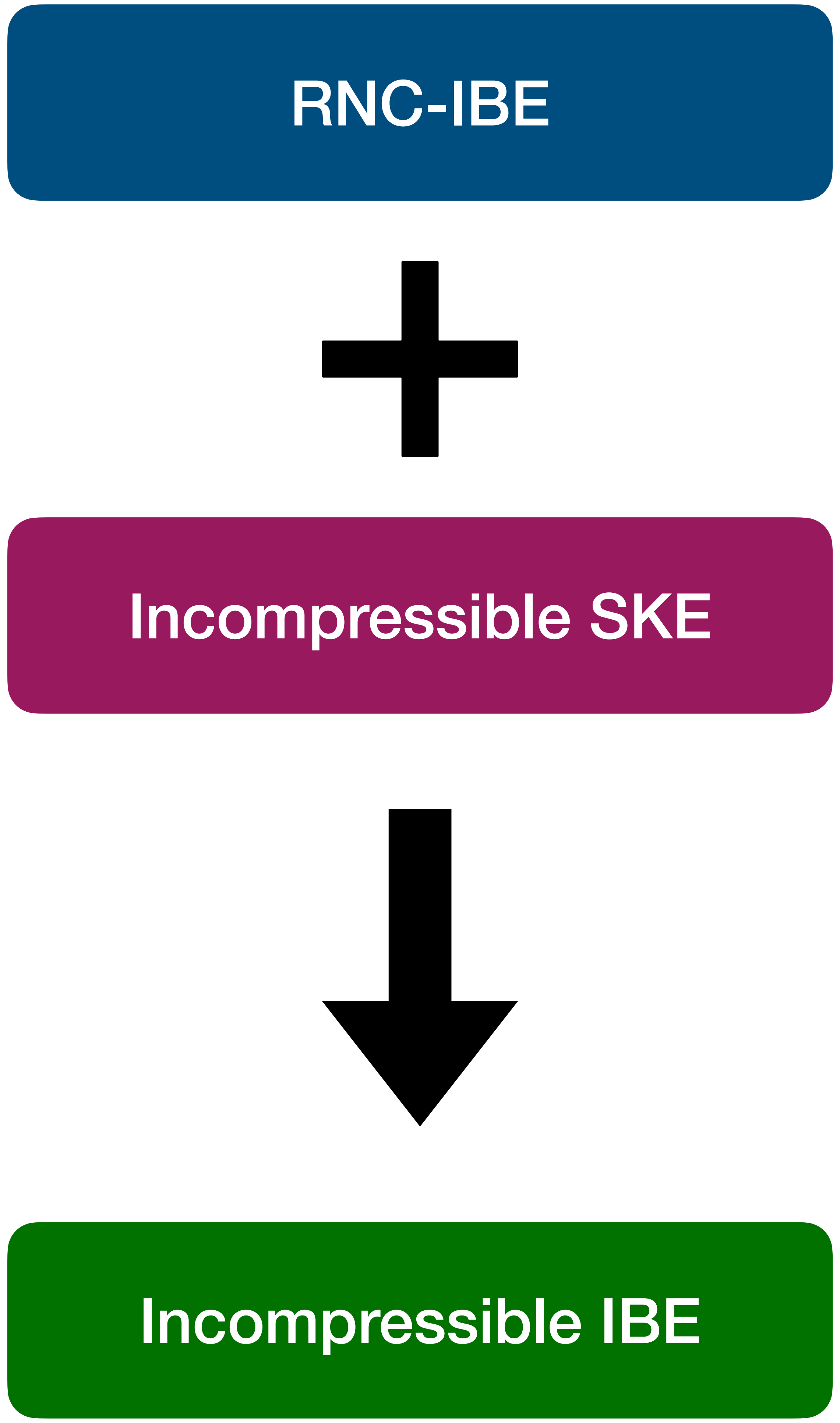

RNC-IBE

Incompressible SKE

Incompressible IBE

Our Results

- Rate-1 RNC-IBE from bilinear pairings.
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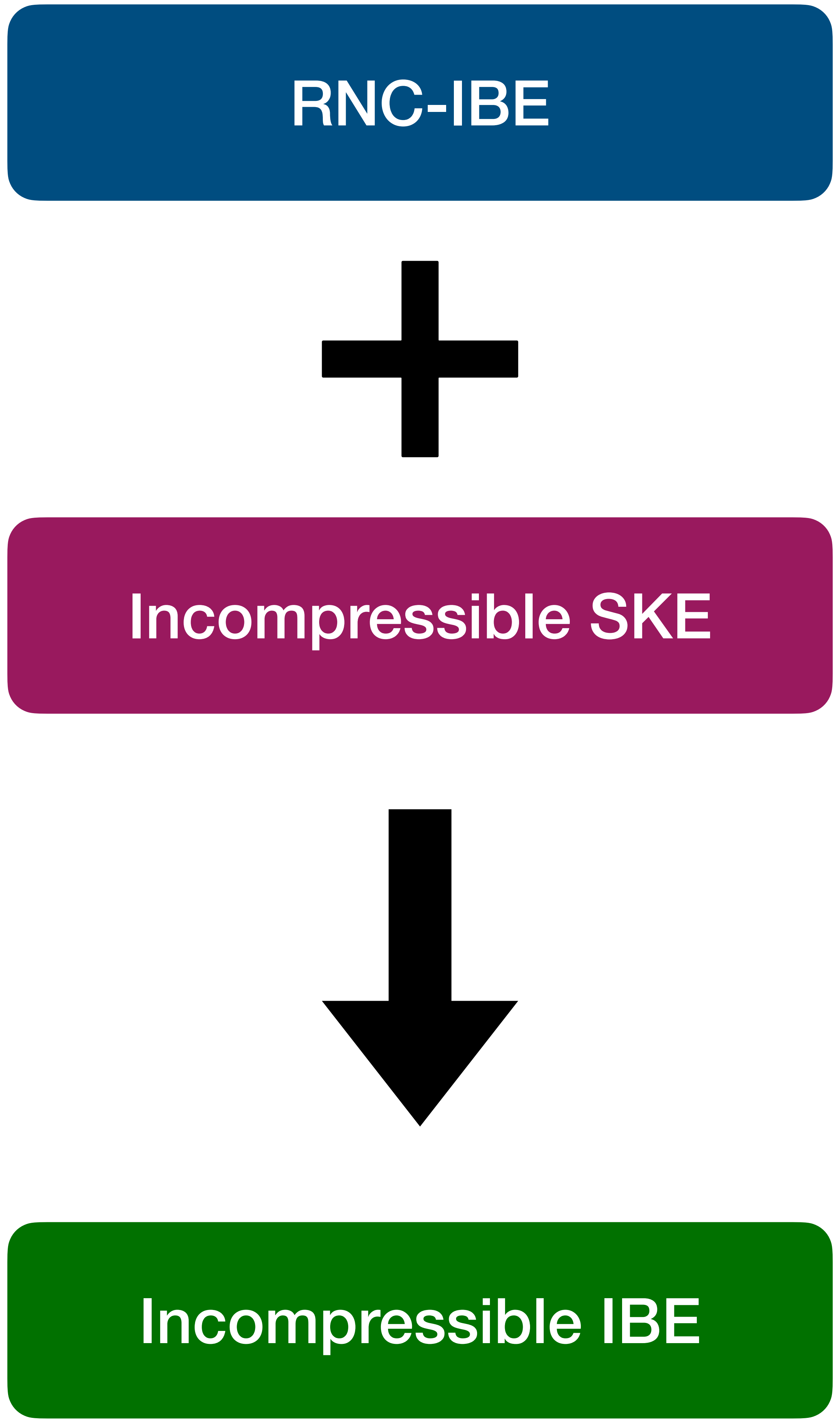
- RNC-IBE for polynomially bounded identity space from DDH, LWE.



RNC-IBE

\+

Incompressible SKE

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Bilinear Pairings

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$$e(g_1^a, g_2^b) = e(g_1, g_2)^{ab}$$

$[a]_b$ denotes g_b^a

Construction

Construction

$pp = ([a]_1, [b]_2, [W_1 a]_1, [W_2 a]_1, [W_1^T b]_2, [W_2^T b]_2)$ where $a, b \leftarrow \mathbb{Z}_p^2, W_i \leftarrow \mathbb{Z}_p^{2\times 2}$

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$$Setup \rightarrow MSK = (\quad k \leftarrow \mathbb{Z}_p^2 \quad)$$

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$$Enc(MPK, id, m \in \mathbb{G}_T) \rightarrow (\quad [ra]_1 \quad , \quad [r(W_1 + id \cdot W_2)a]_1 \quad ,$$

Construction

$pp = ([a]_1, [b]_2, [W_1 a]_1, [W_2 a]_1, [W_1^T b]_2, [W_2^T b]_2)$ where $a, b \leftarrow \mathbb{Z}_p^2, W_i \leftarrow \mathbb{Z}_p^{2\times 2}$

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$$Dec(sk_{id}, ct) \rightarrow \frac{[ra^T k]_T \cdot m \times e([r(W_1 + id \cdot W_2)a]_1 , [sb]_2)}{e([ra]_1 , [k + s(W_1 + id \cdot W_2)^T b]_2)}$$

Simulation

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$Sim_1(id*) \rightarrow$

Simulation

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k_2 **is not used anywhere**

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$Sim_3(m) \rightarrow$

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$Sim_3(m) \rightarrow$ Set $k_2 = \dfrac{\frac{r}{m} - u_1 k_1}{u_2}$ where $u = u_1 a + u_2 a^\top$

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DDH

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Incomp IBE from RNC-IBE

Incomp IBE from RNC-IBE

1. **RNC-IBE**

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1. **RNC-IBE**
2. **Incompressible SKE scheme**

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$Setup \rightarrow$

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$$Setup \rightarrow MPK = ($$

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$$RNCIBE.Enc(\ RNCIBE.MPK, \ id, \ incompSK\ )$$

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$$MSK = (\ RNCIBE.MSK\ )$$

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$$Enc(id, m) \rightarrow IncompSKE.Enc(\ incompSK\ ,\ m\ )$$

$$RNCIBE.Enc(\ RNCIBE.MPK\ ,\ id\ ,\ incompSK\ )$$

Hybrid encryption

Future Directions

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1. RNC-IBE from LWE and other assumptions.

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2. Full NC-IBE from standard assumptions.

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3. ~~Rate-1 RNC-ABE from bilinear pairings.~~

Future Directions

1. RNC-IBE from LWE and other assumptions.
2. Full NC-IBE from standard assumptions.
3. ~~Rate-1 RNC-ABE from bilinear pairings.~~
4. Strong incompressible IBE and ABE from other standard assumptions.

Thank You

https://mahe94.github.io