Registered Functional Encryptions from Pairings

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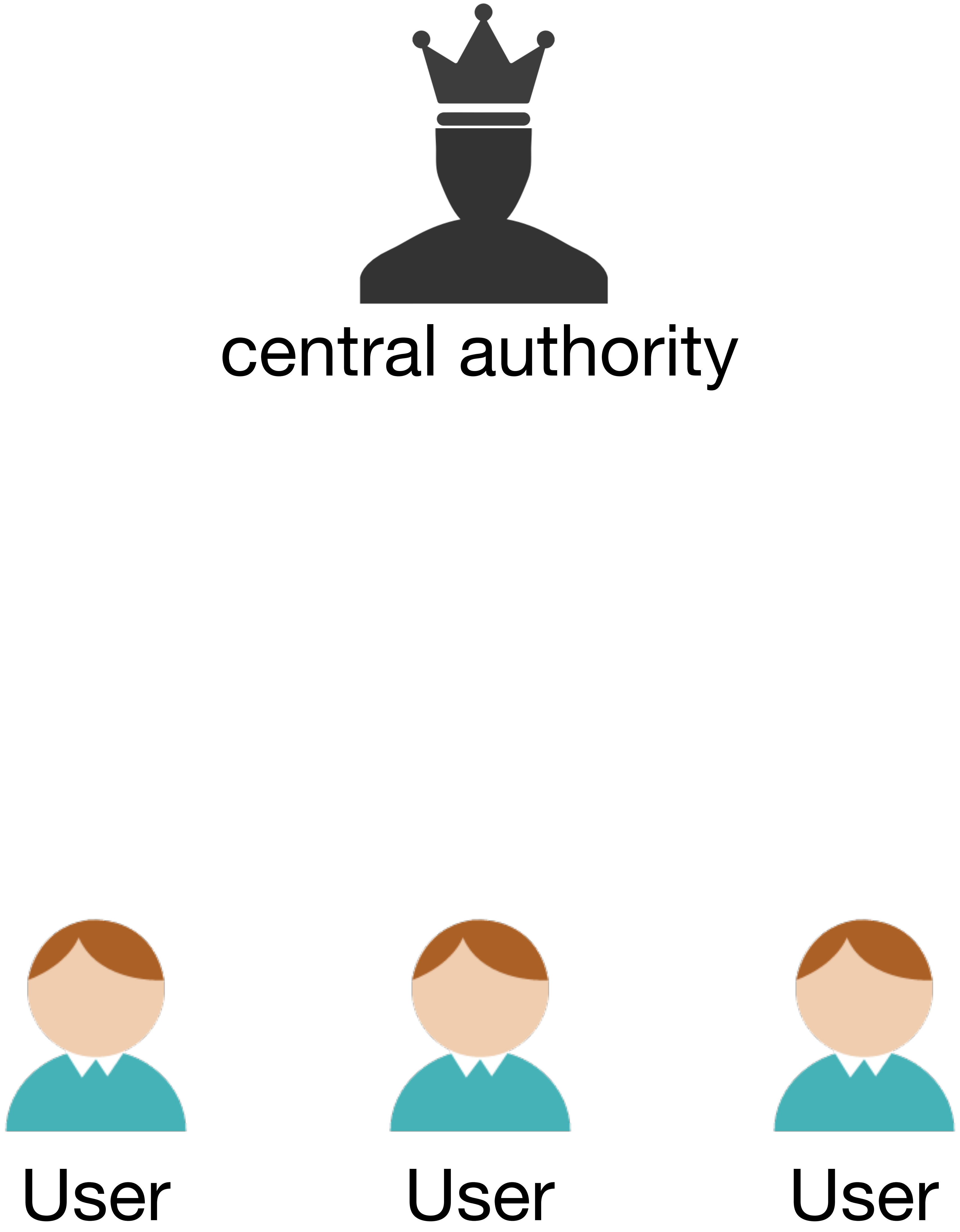
Functional Encryption



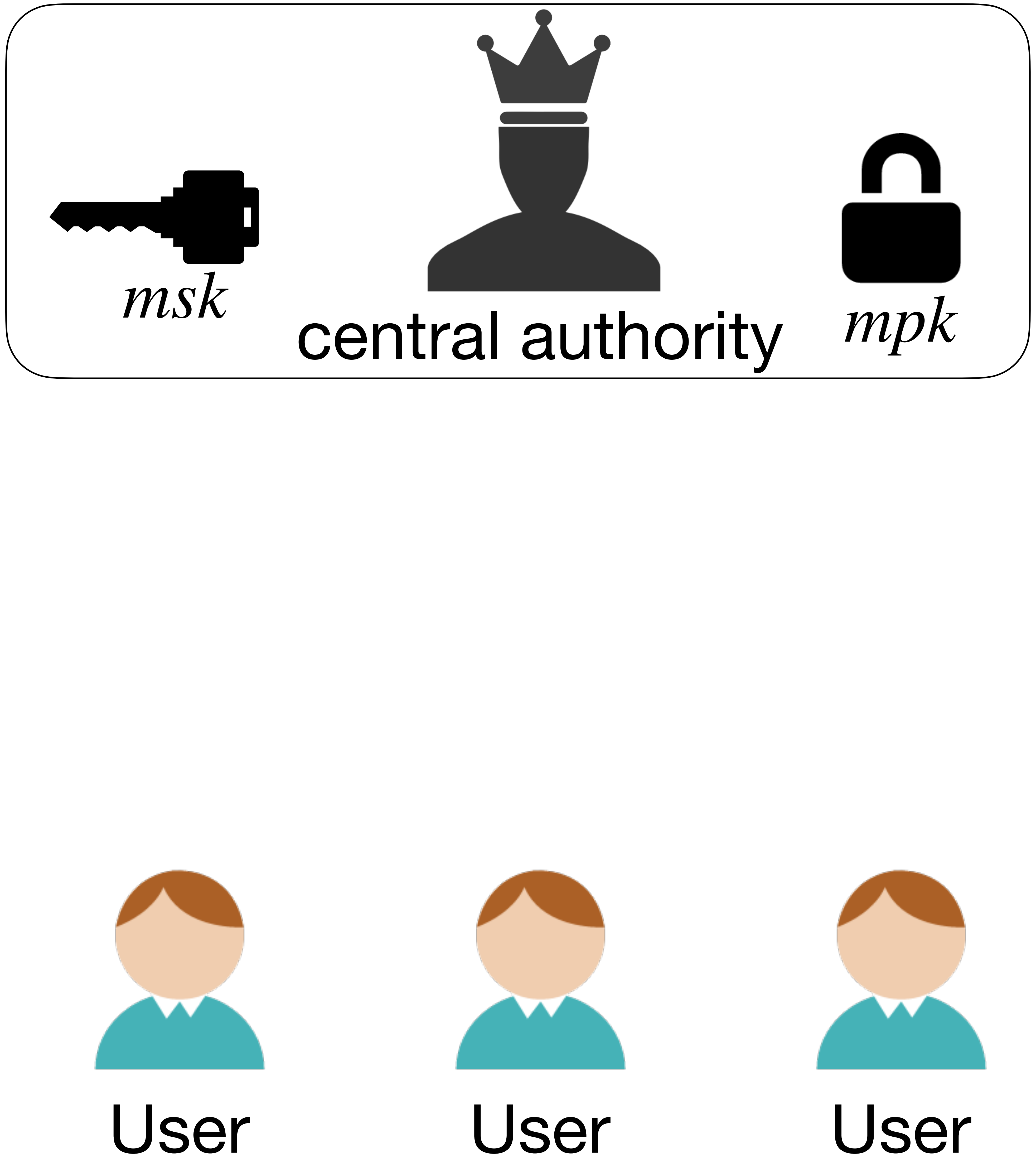
central authority

User

User

User

Functional Encryption



msk

central authority

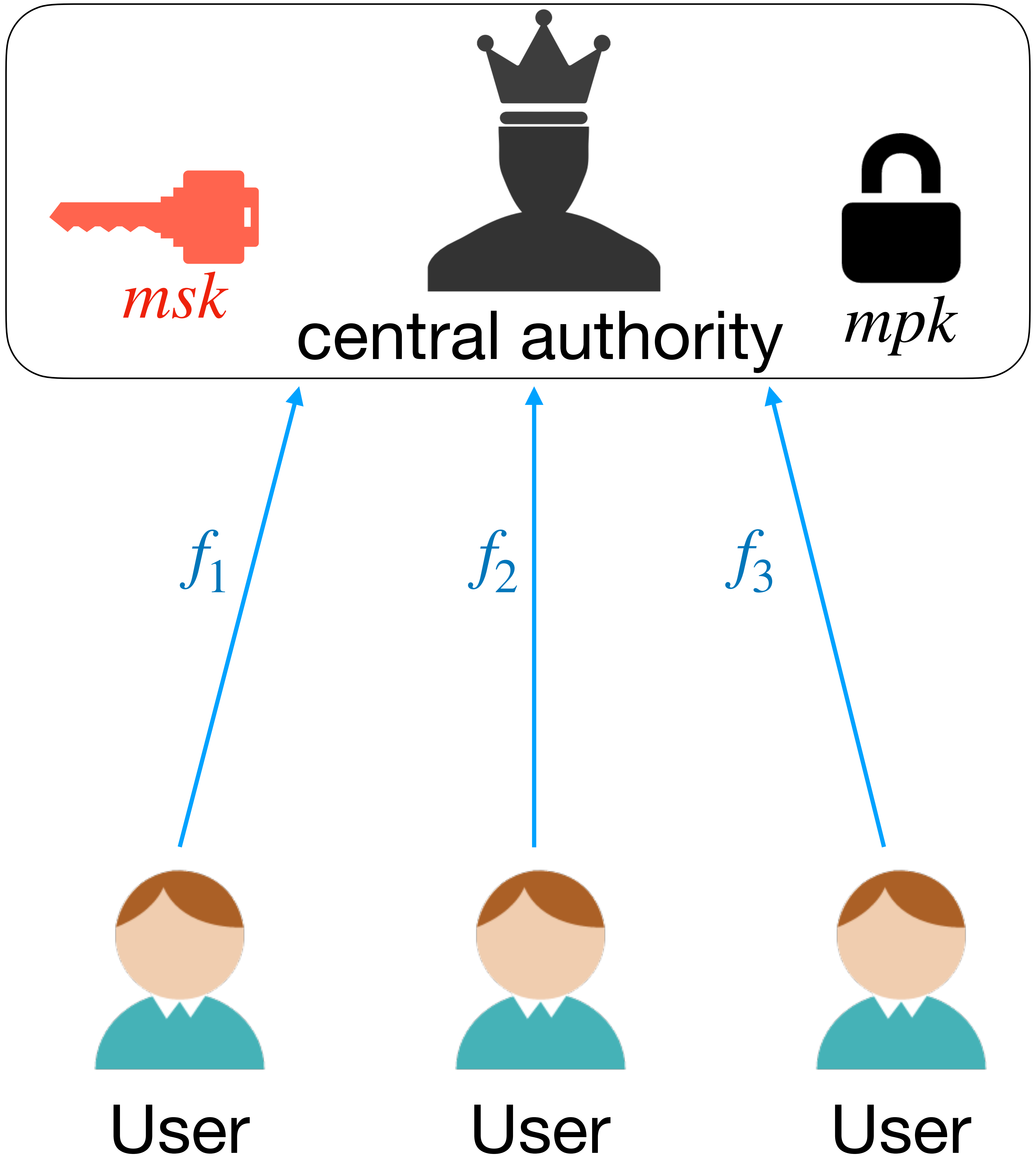
mpk

User

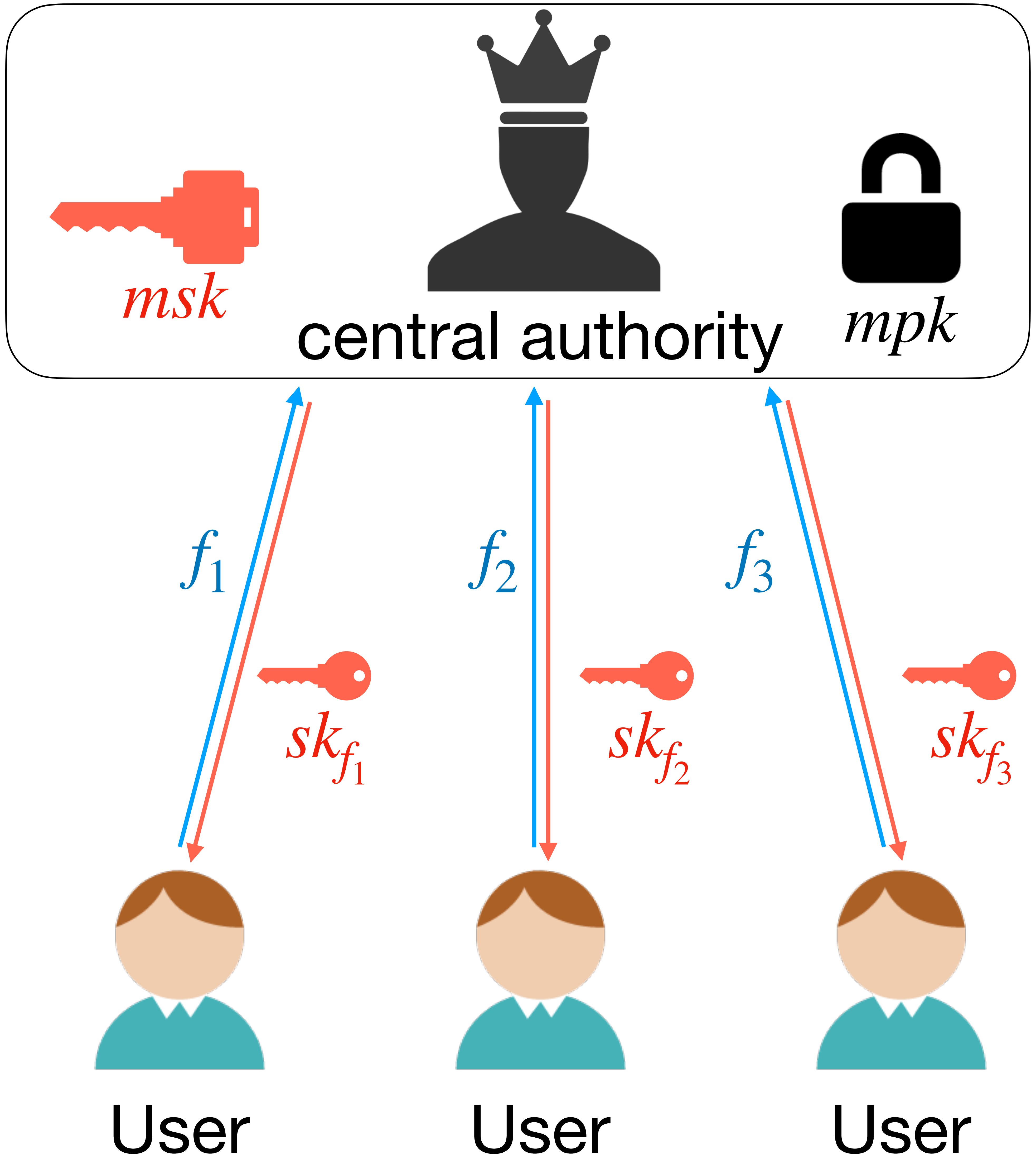
User

User

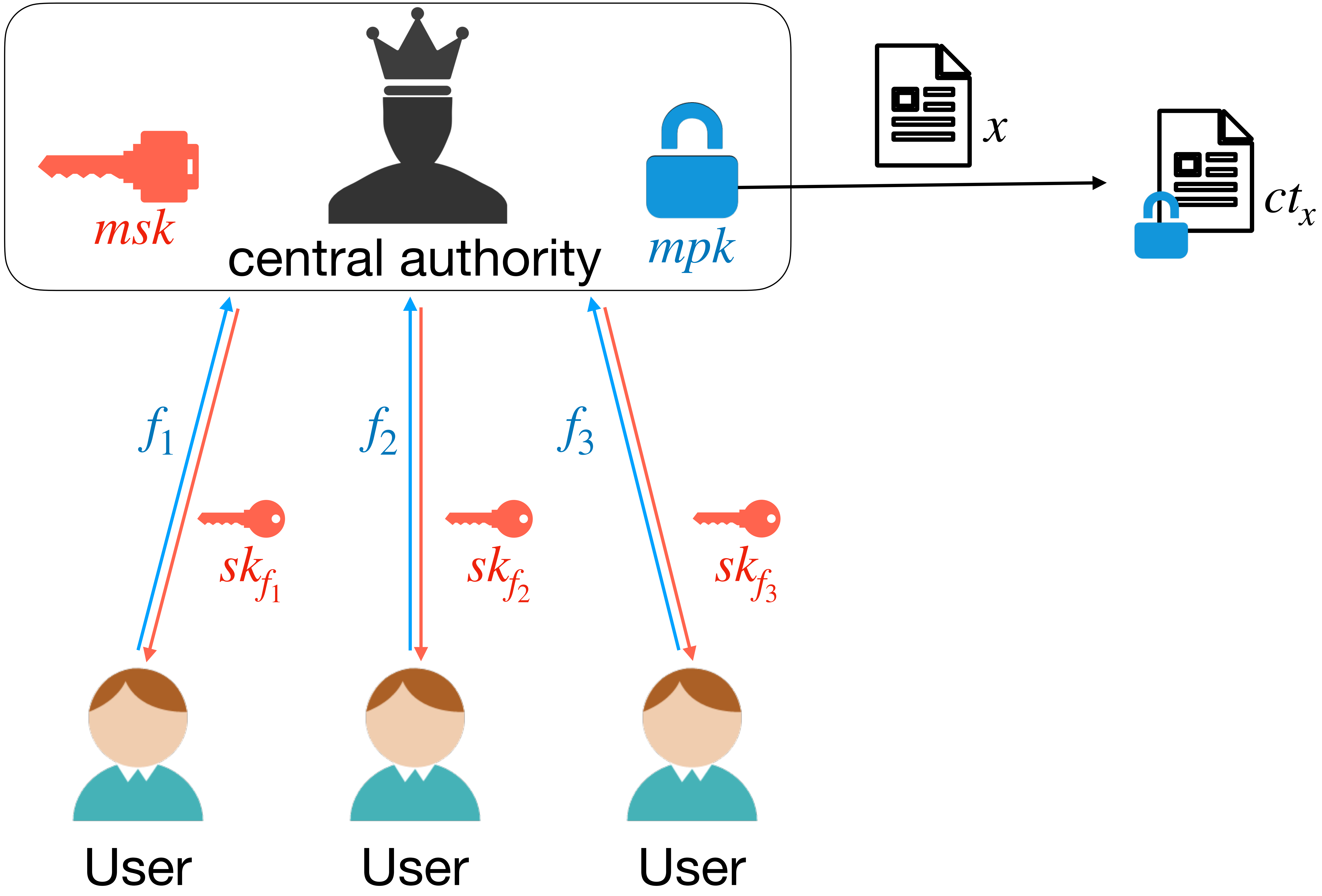
Functional Encryption



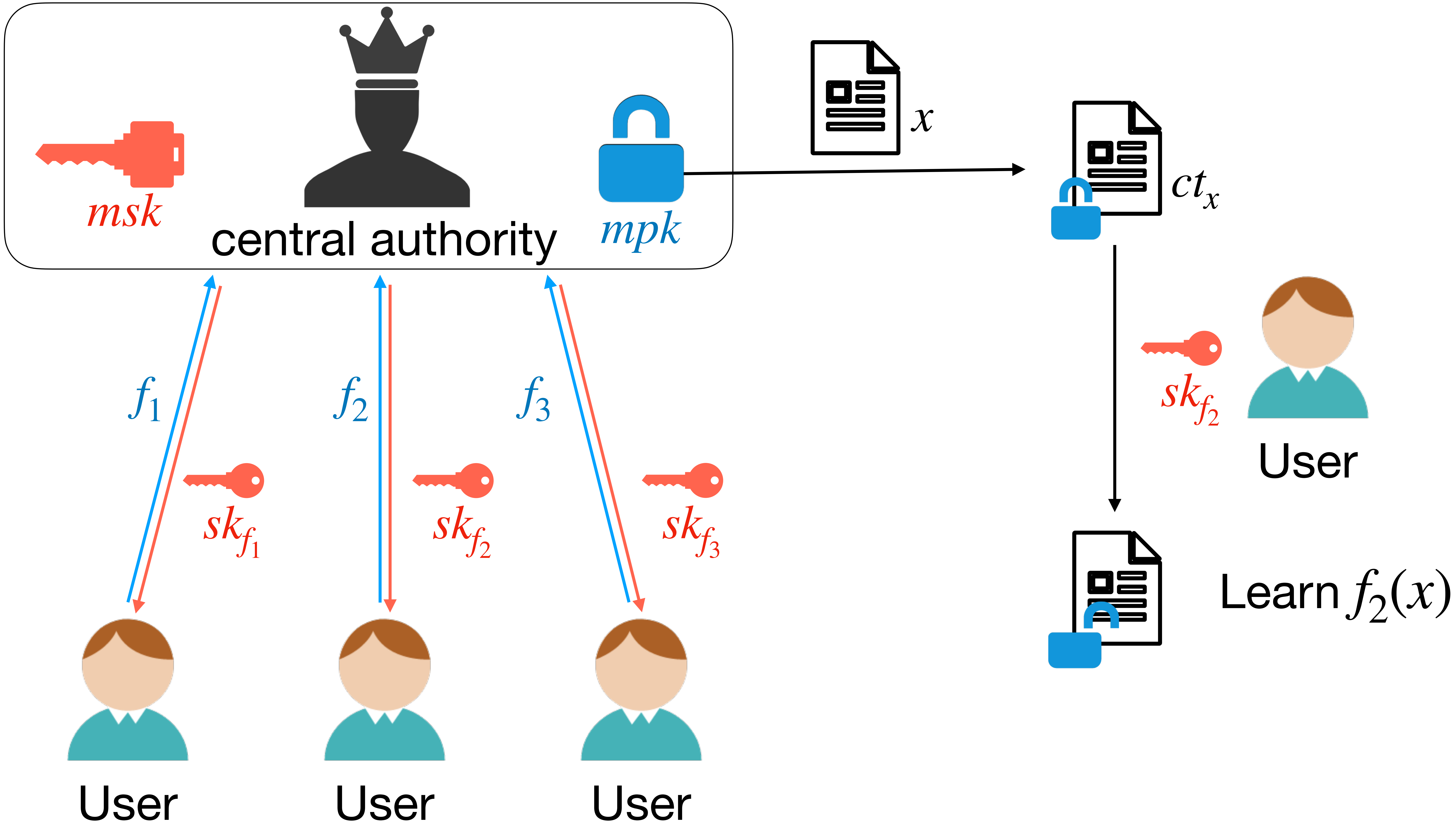
Functional Encryption



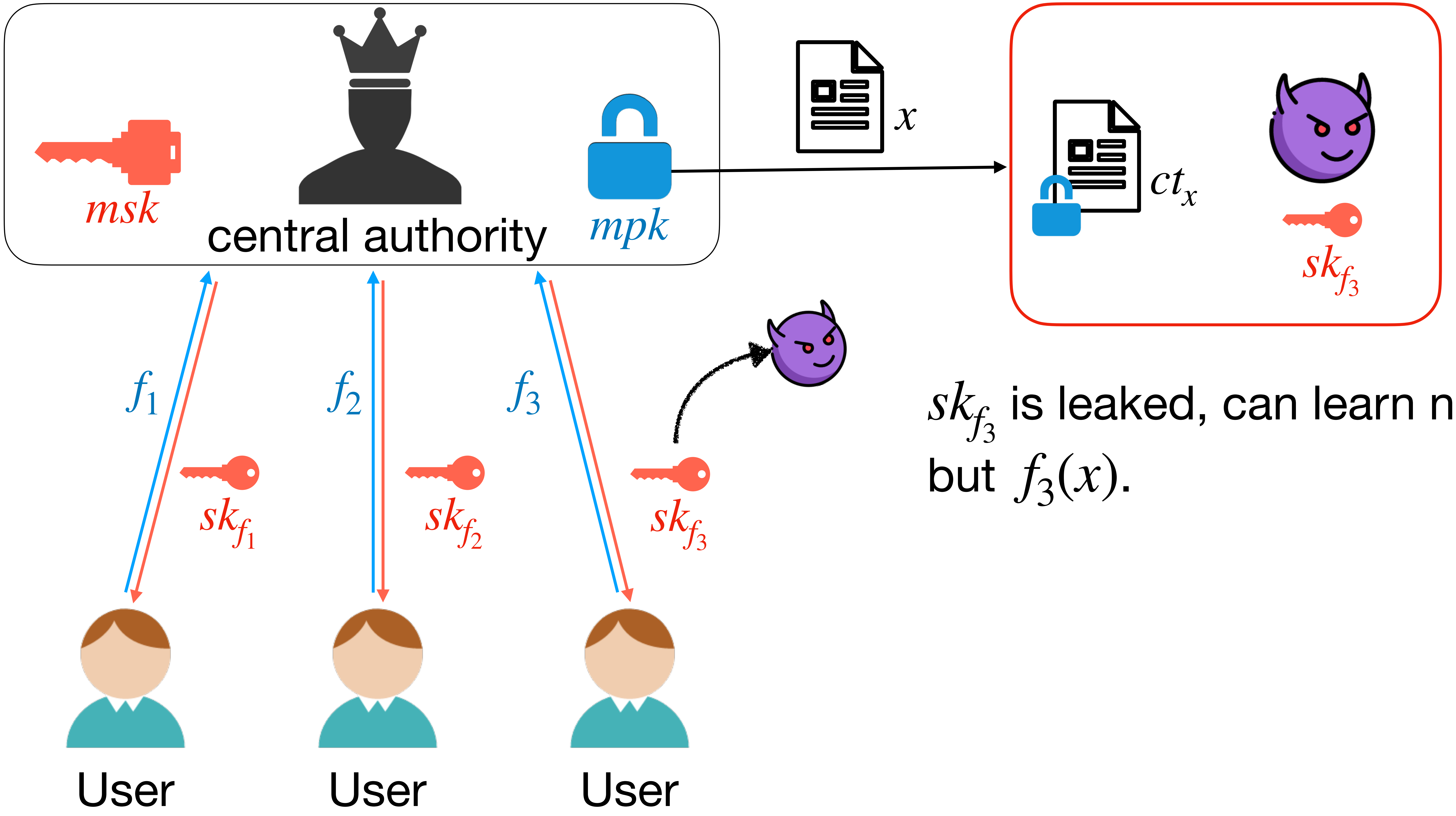
Functional Encryption



Functional Encryption

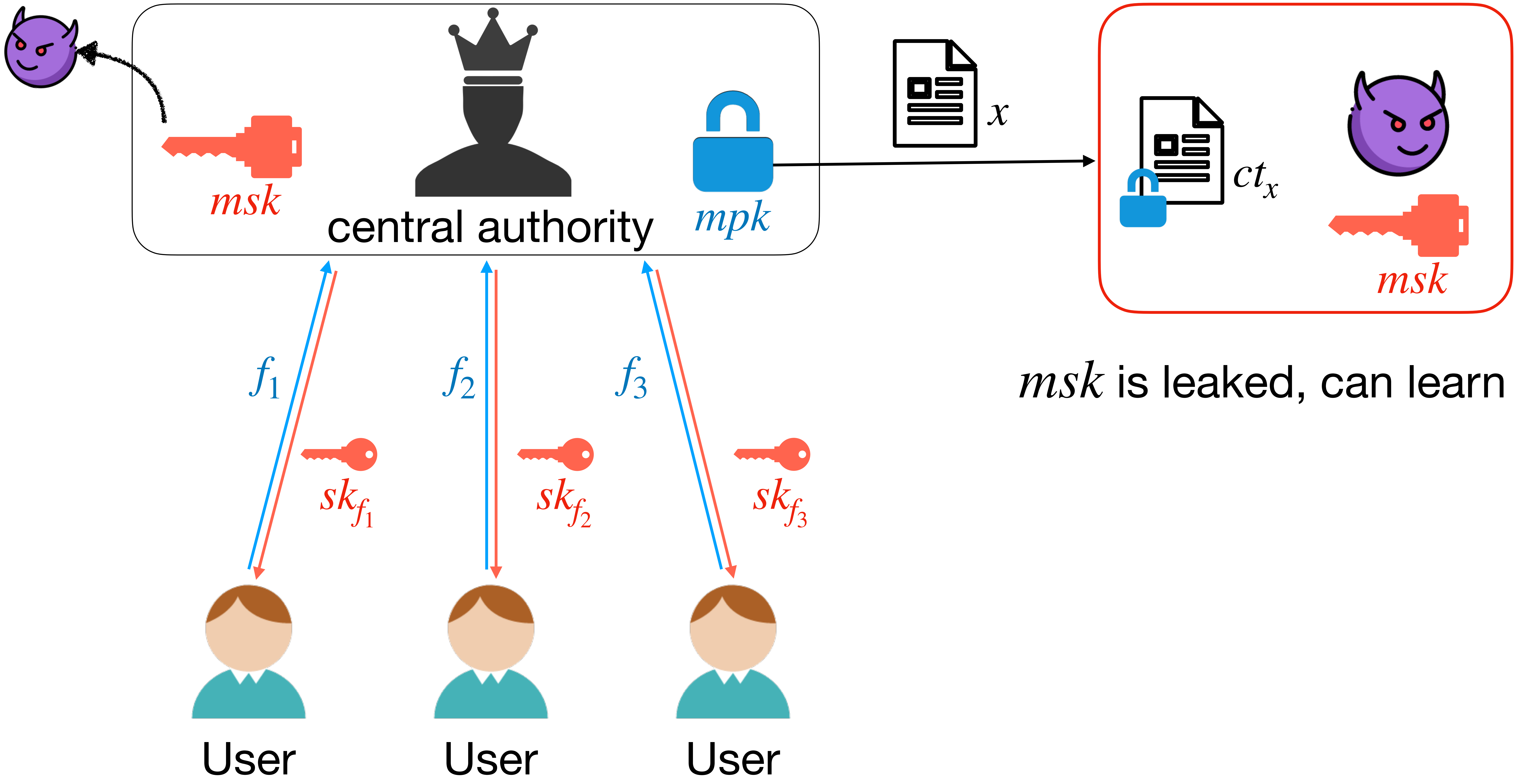


Functional Encryption: Security



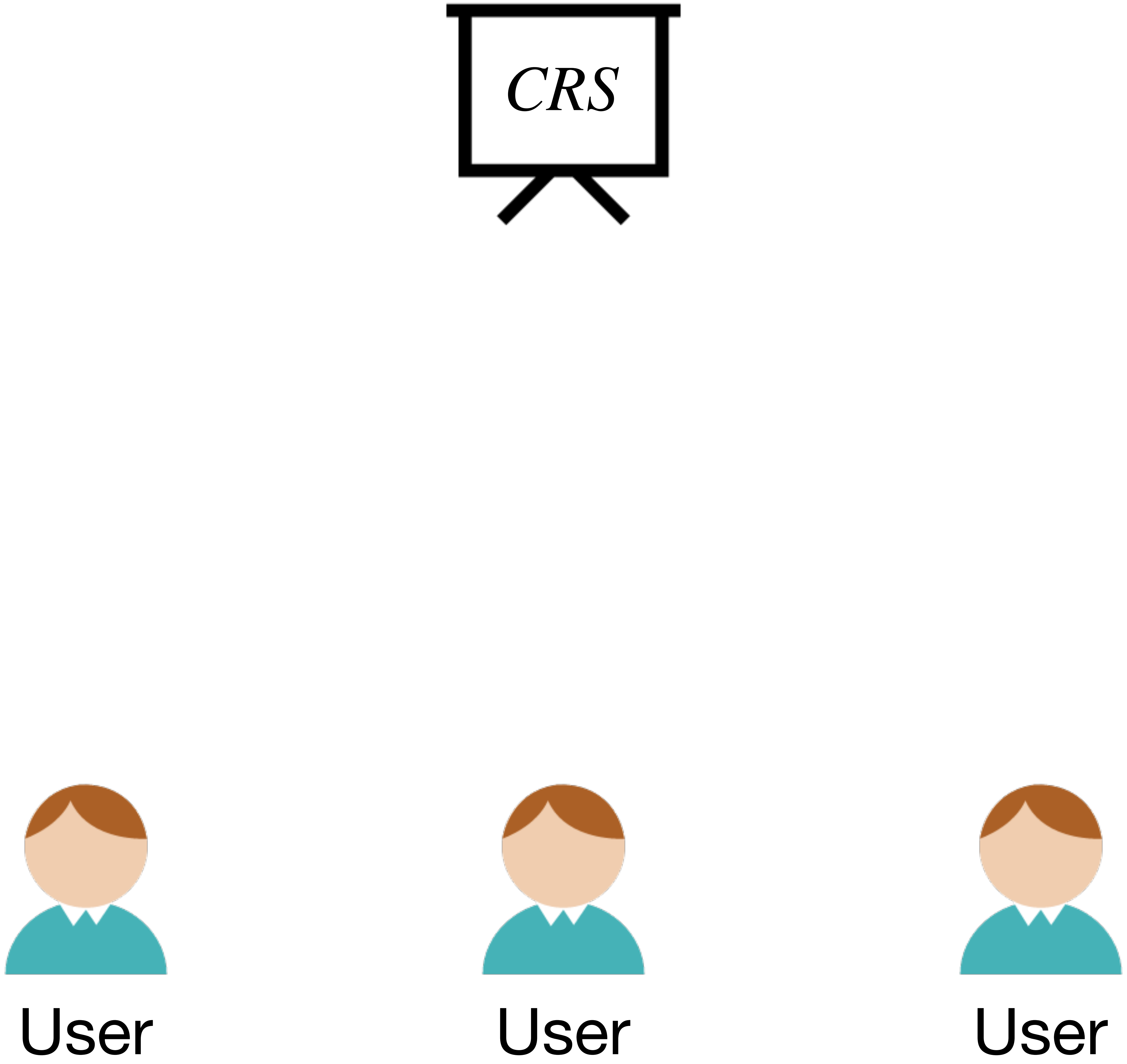
sk_{f_3} is leaked, can learn nothing but $f_3(x)$.

Functional Encryption: Key-Escrow Problem



msk is leaked, can learn any $f(x)$

Registered Functional Encryption



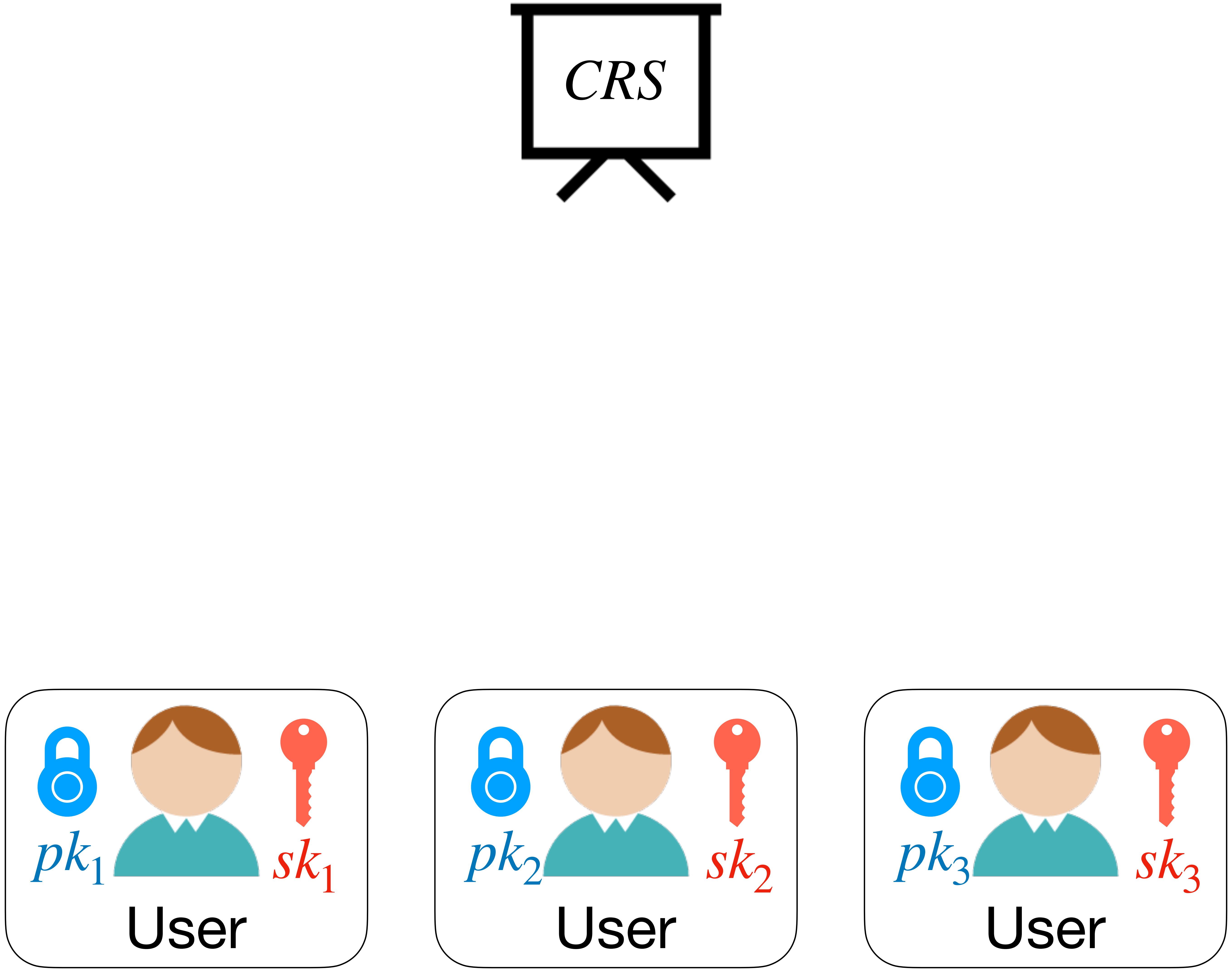
CRS

User

User

User

Registered Functional Encryption



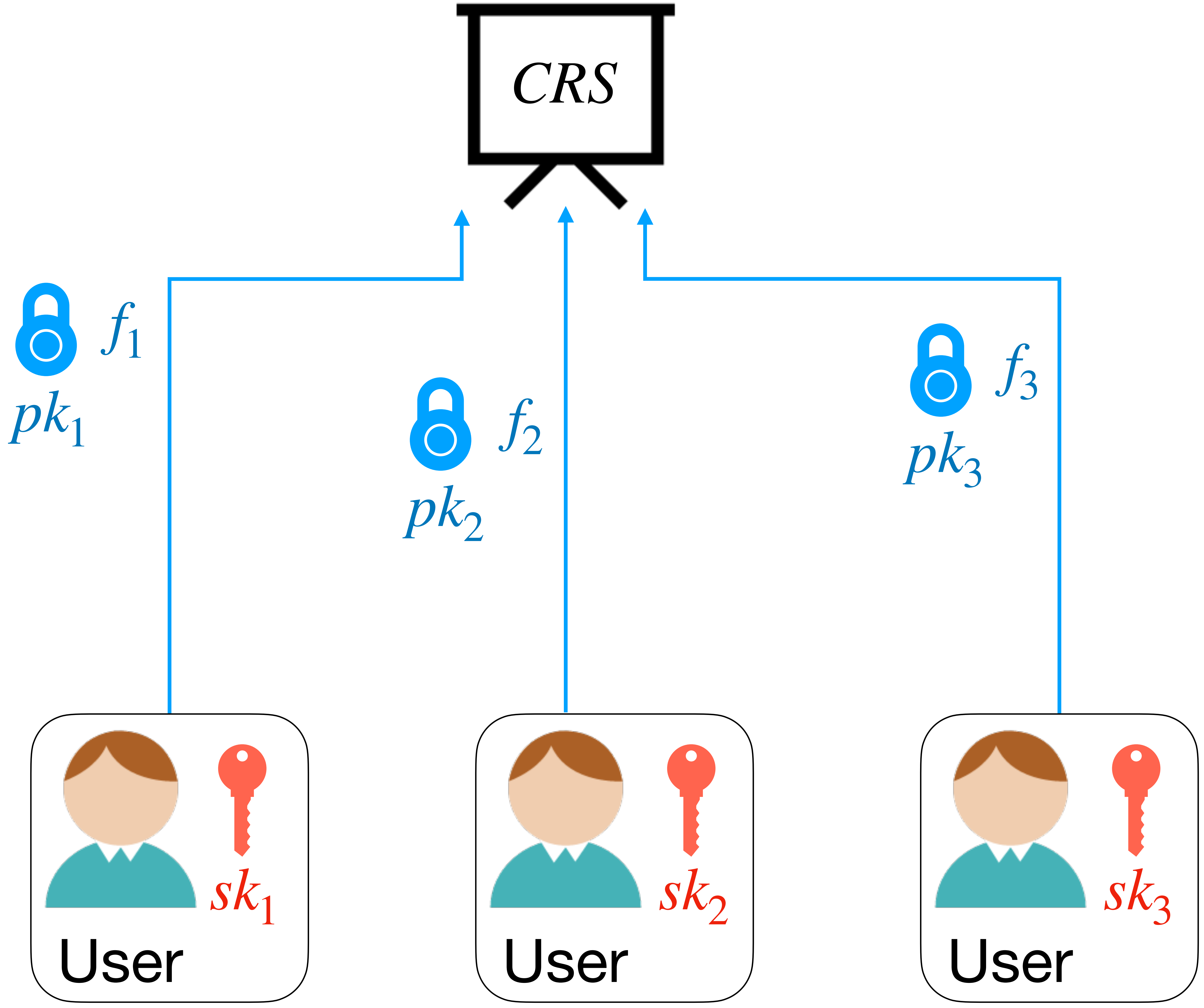
CRS

pk_1 sk_1 User

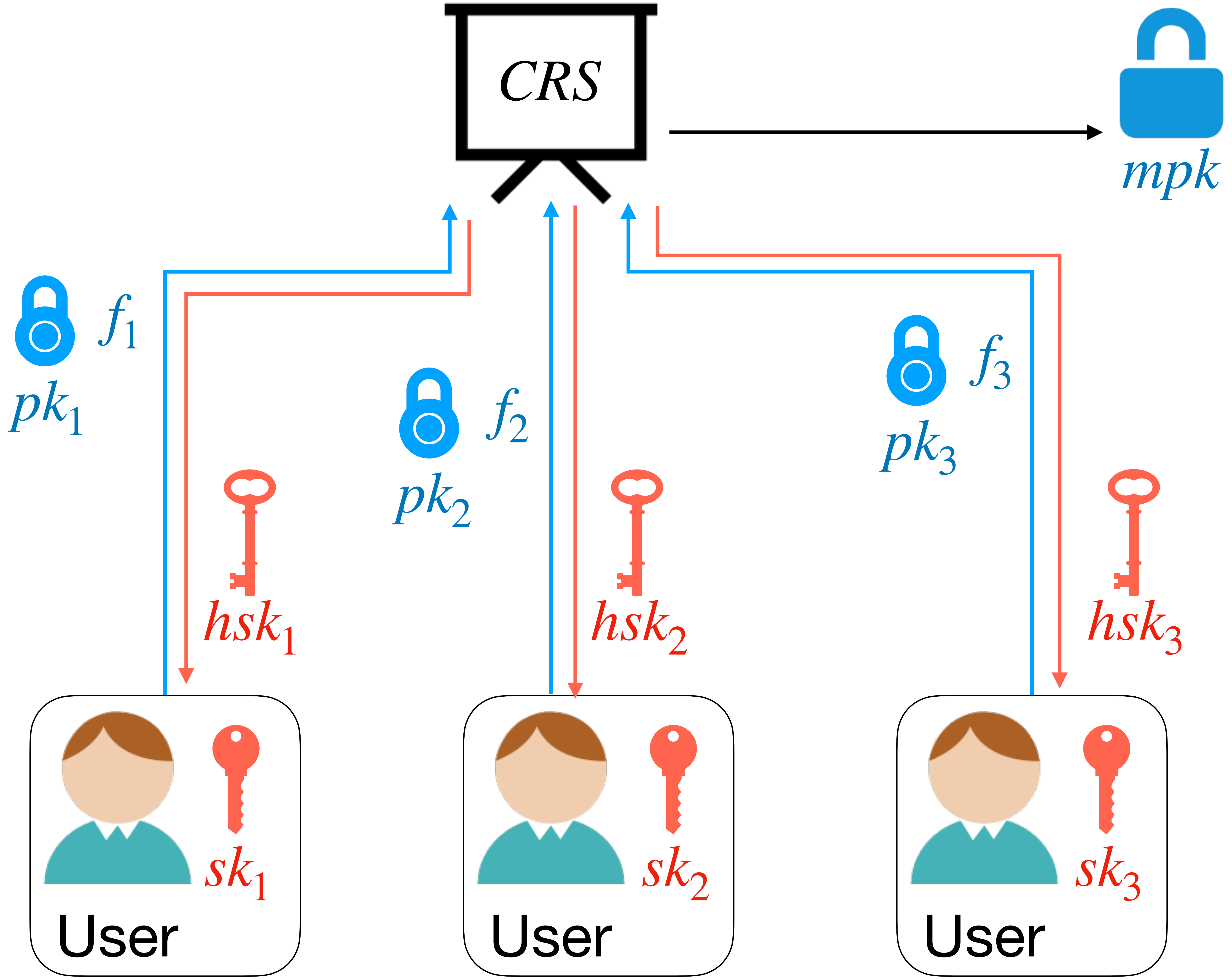
pk_2 sk_2 User

pk_3 sk_3 User

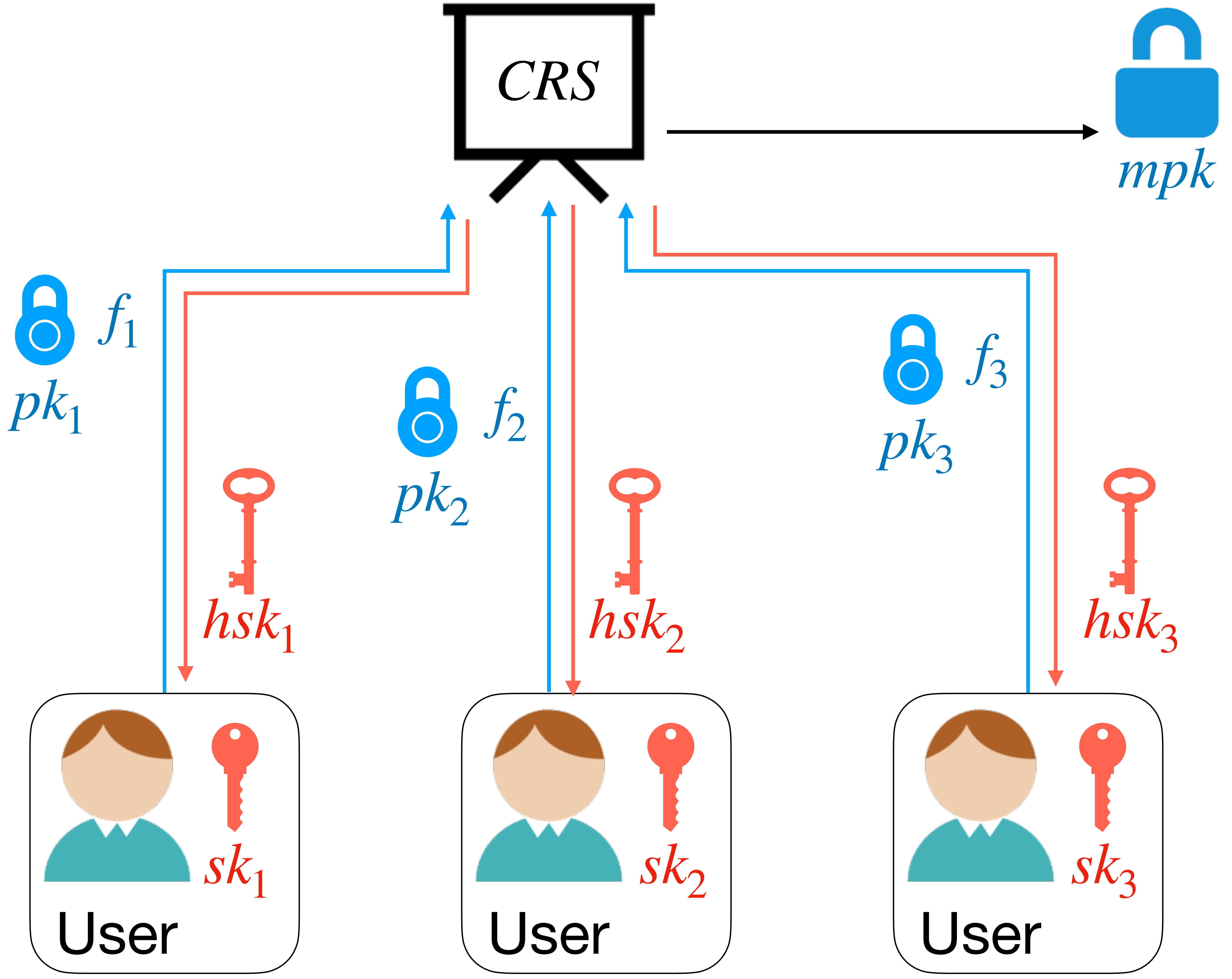
Registered Functional Encryption



Registered Functional Encryption



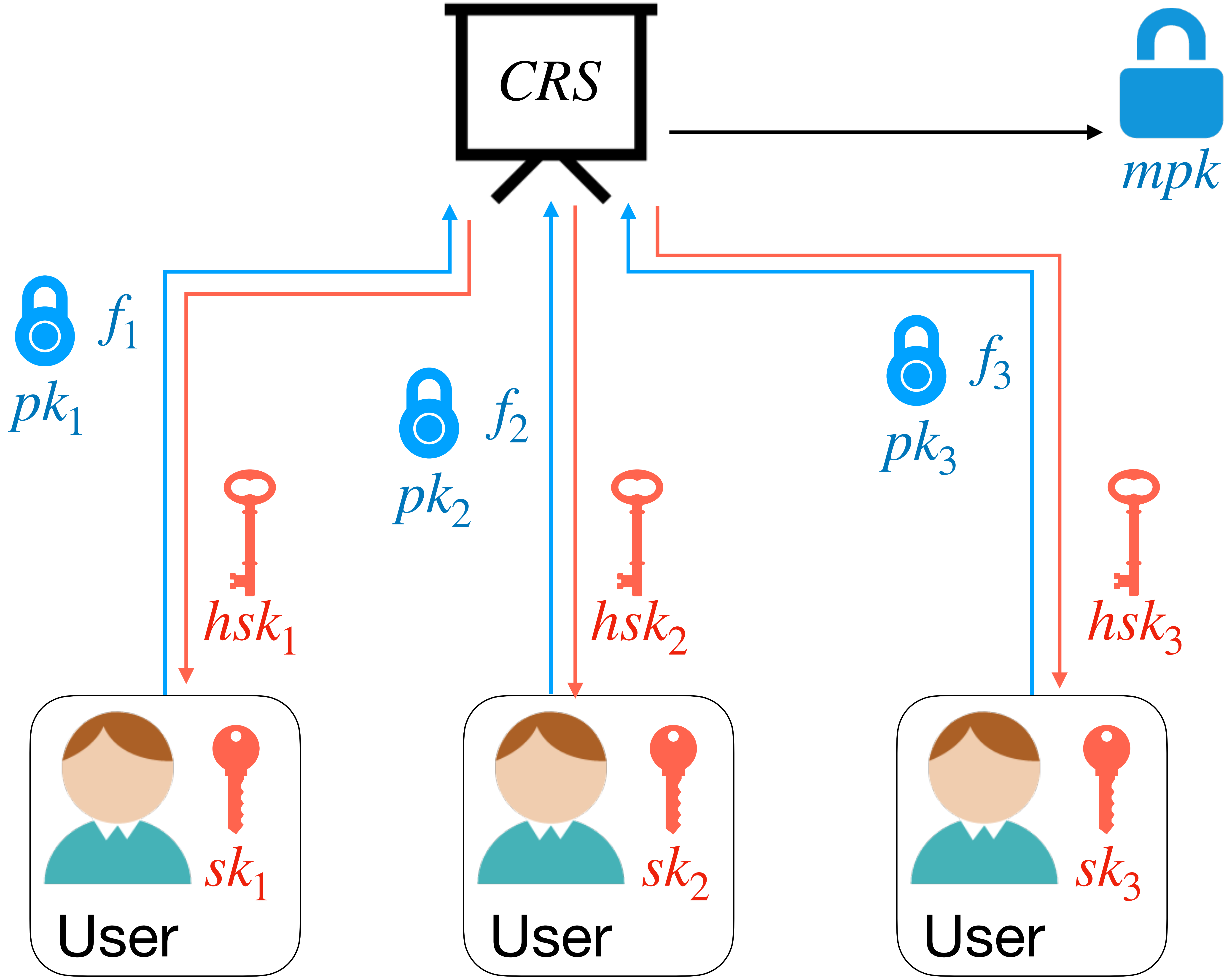
Registered Functional Encryption



full-fledged Reg-FE: register "*one by one*".

mpk and hsk are updatable.

Registered Functional Encryption

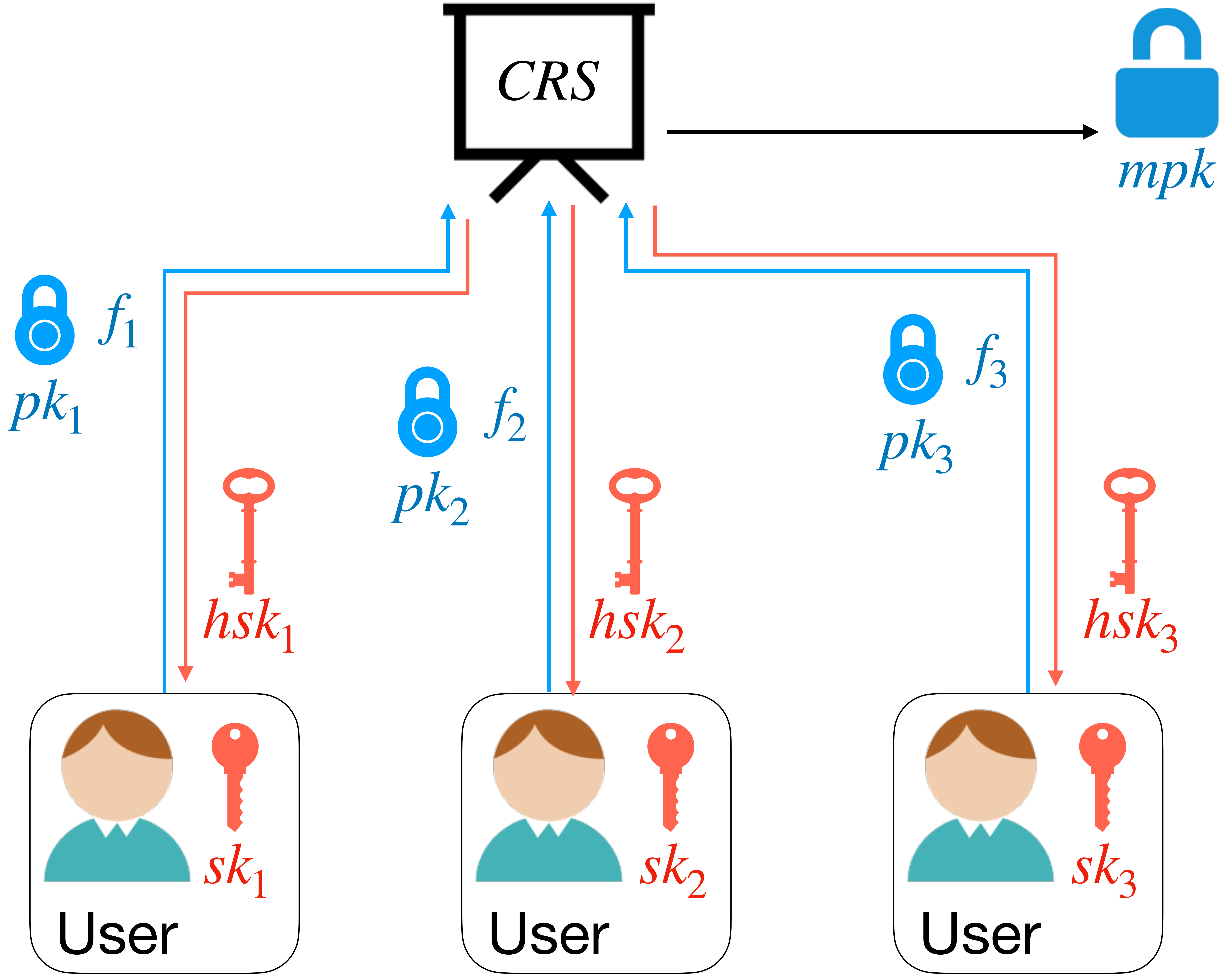


full-fledged Reg-FE: register "*one by one*".

mpk and hsk are updatable.

Size: O(poly(Log L))

Registered Functional Encryption

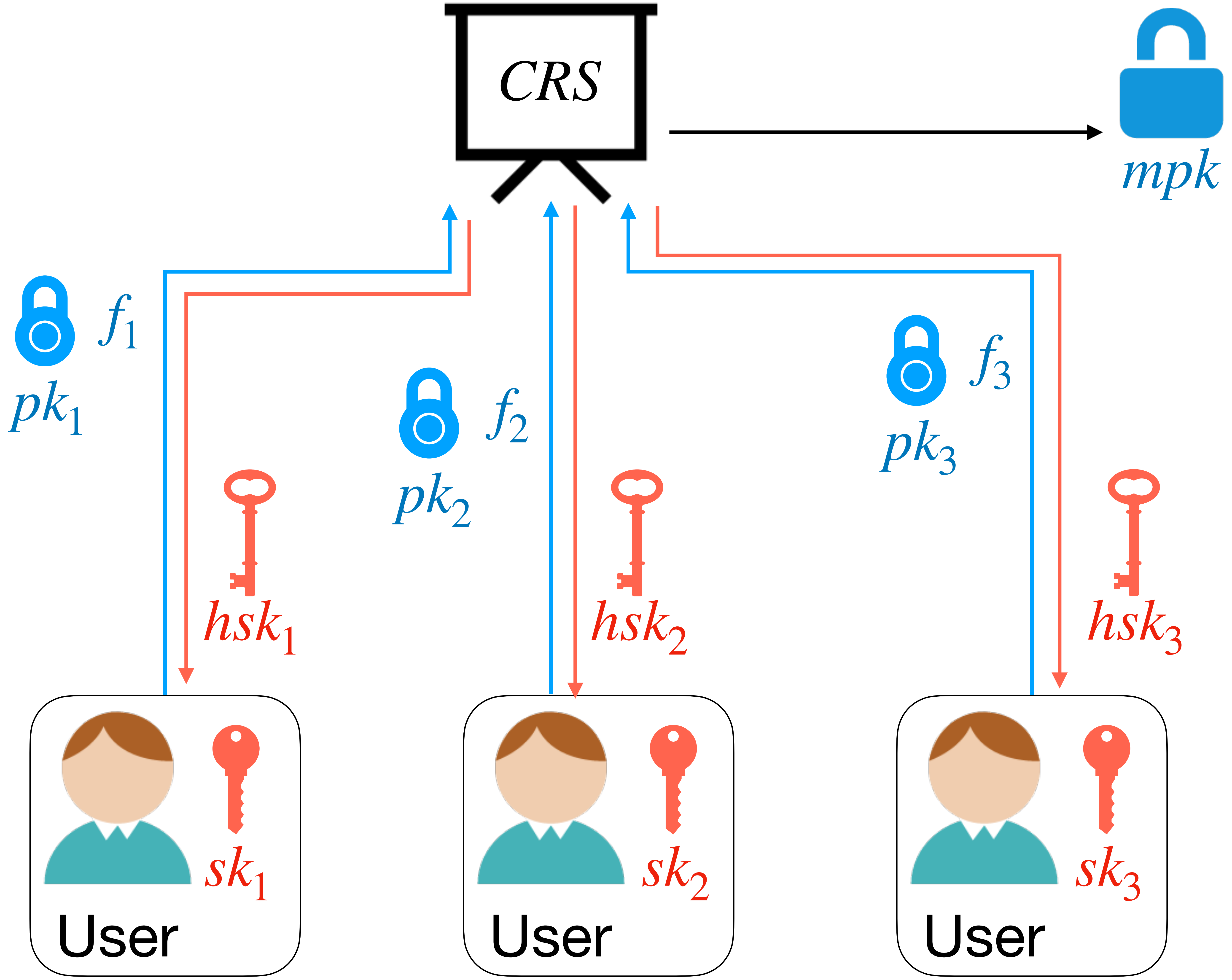


full-fledged Reg-FE: register "*one by one*".

mpk and hsk are updatable.

Update time: O(Log L)

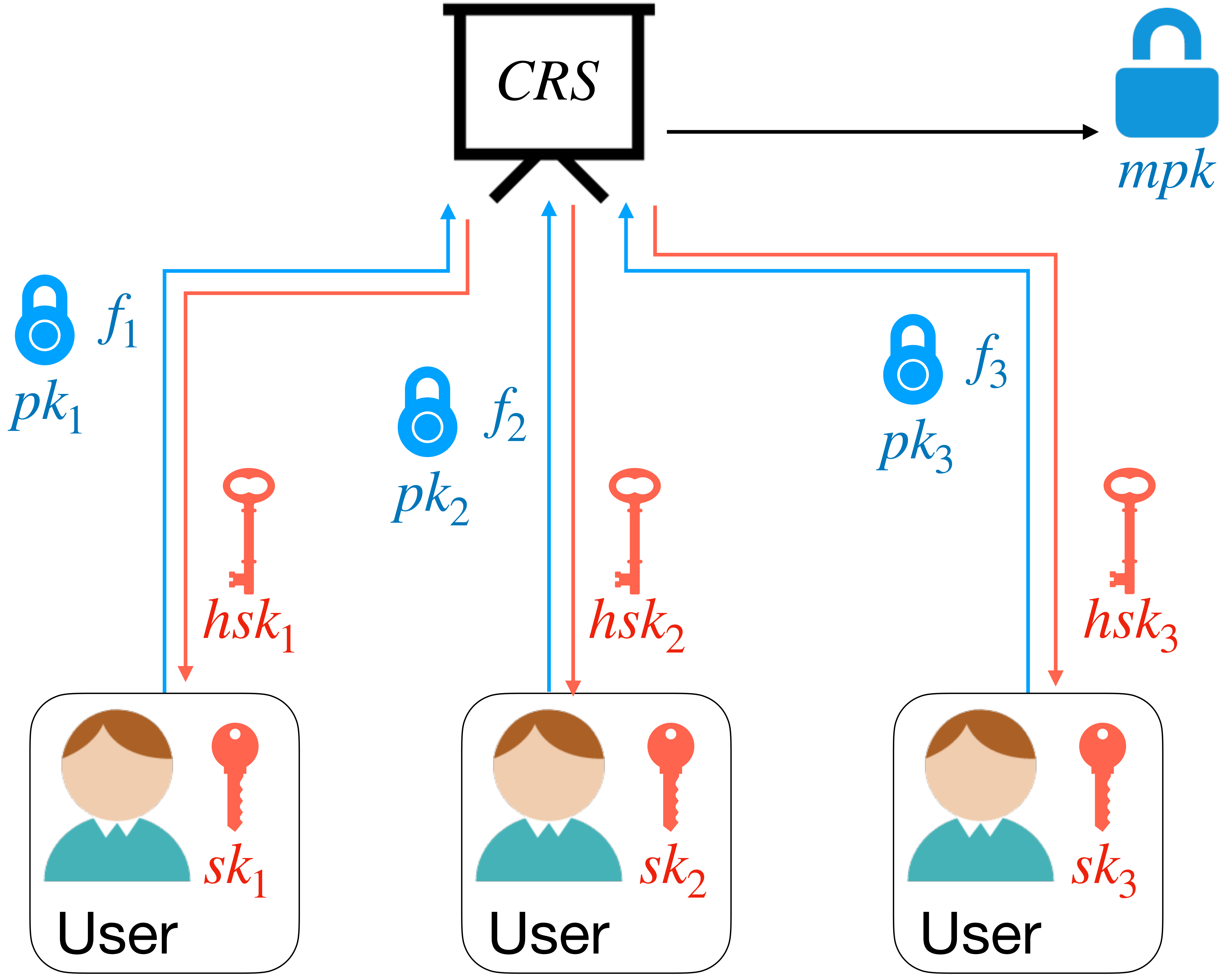
Registered Functional Encryption



slotted Reg-FE: register "*at once time*".

mpk and hsk are generated at once.

Registered Functional Encryption



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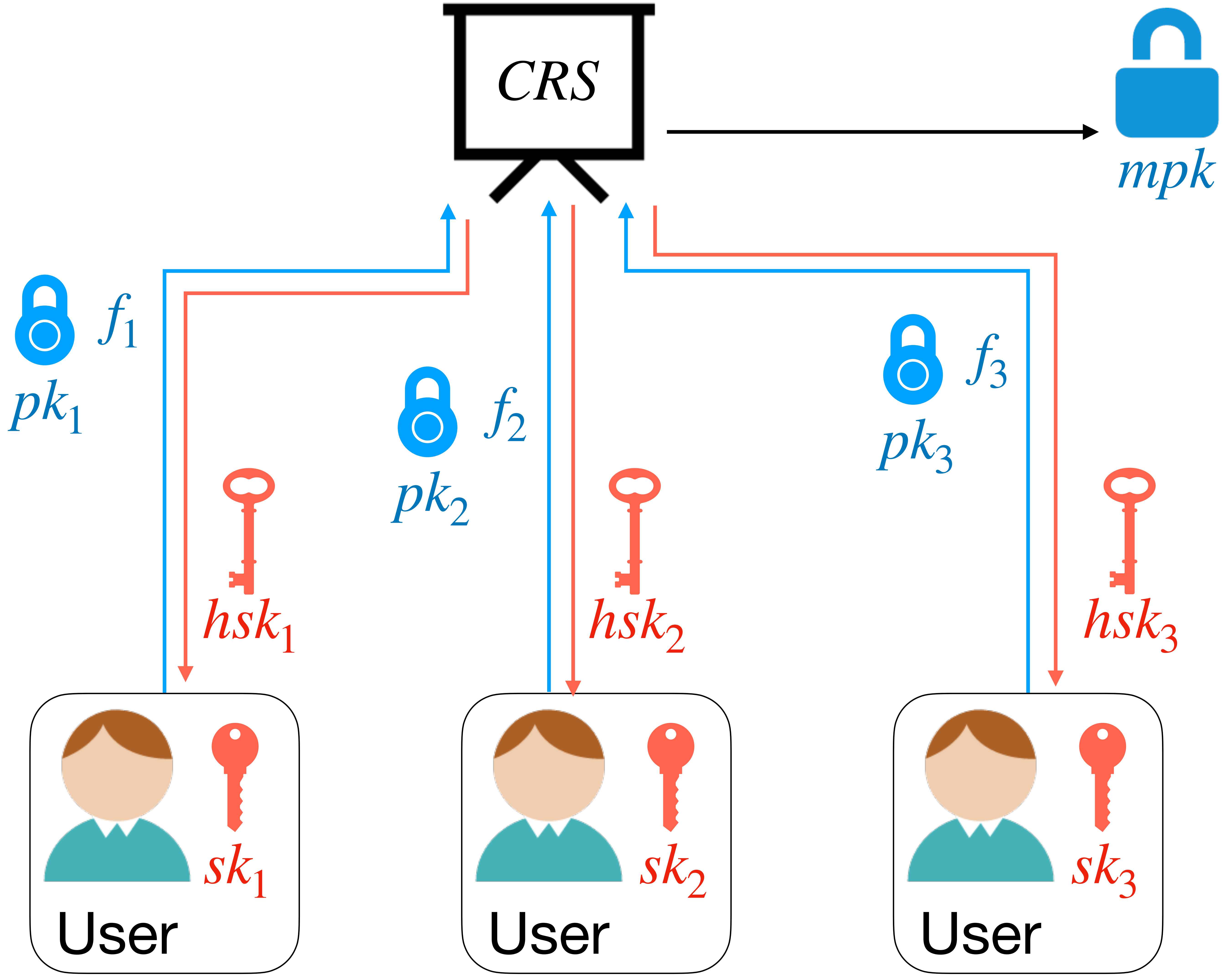
mpk and hsk are generated at once.

Size: O(poly(Log L))

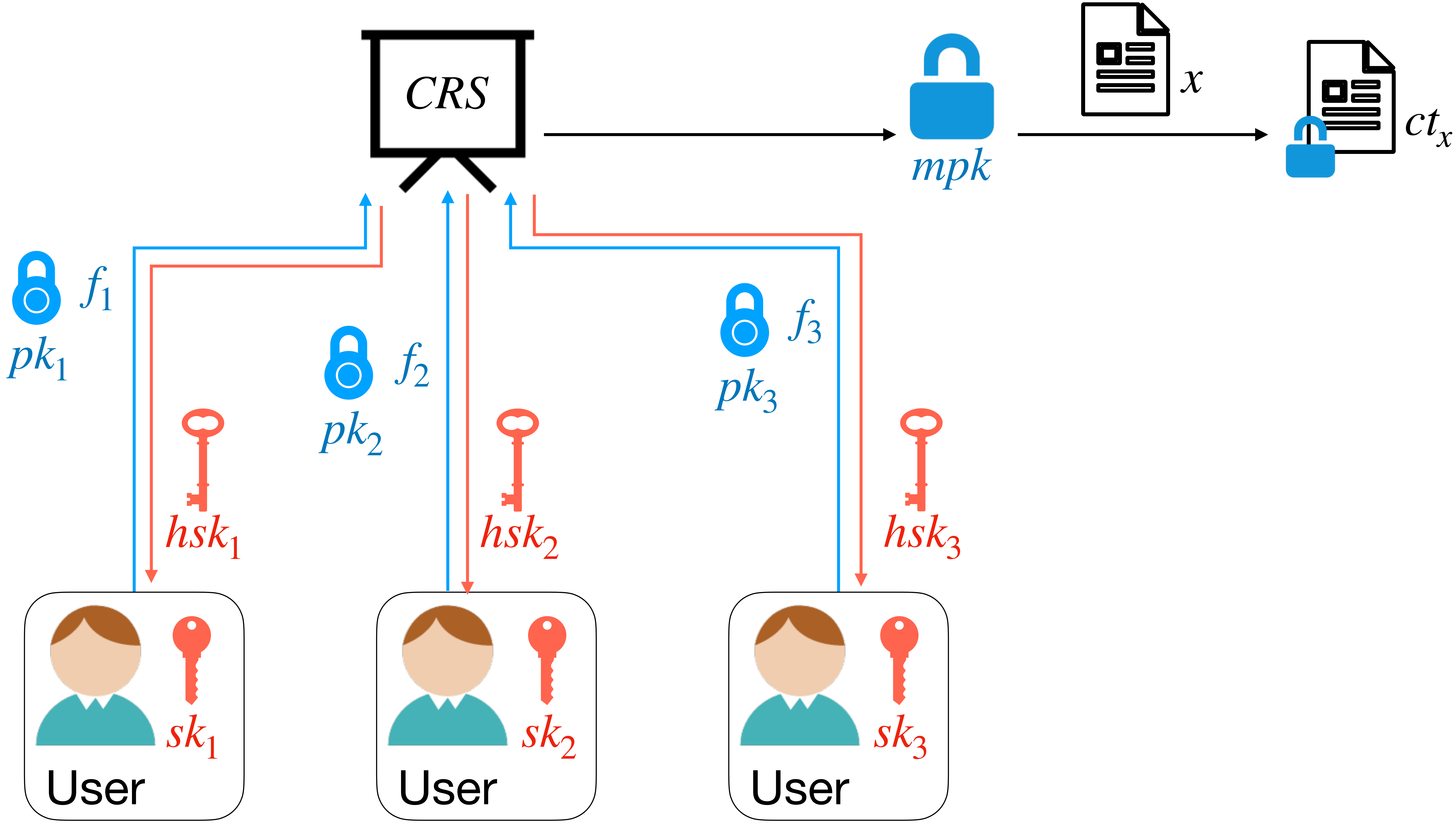
Registered Functional Encryption



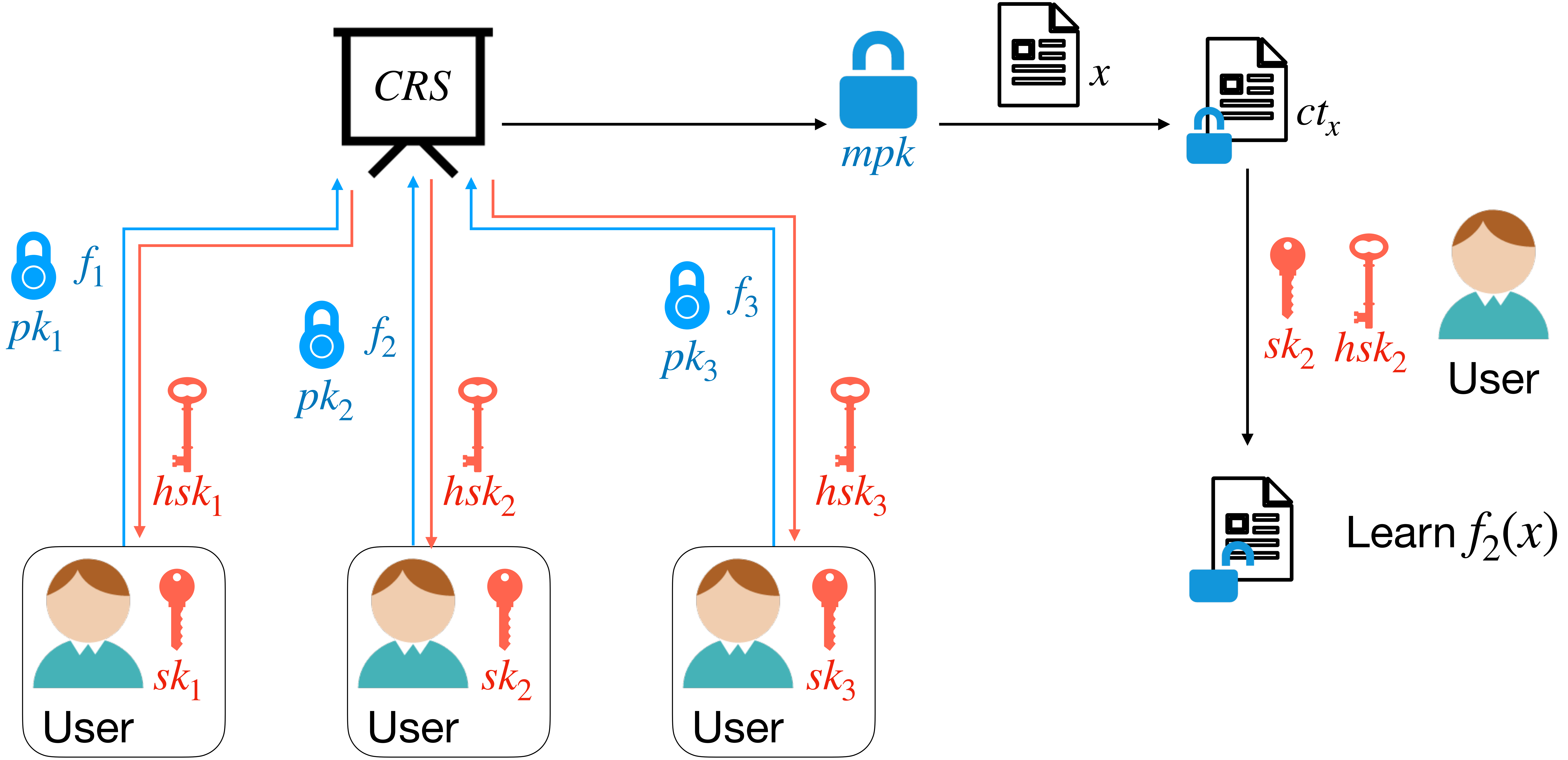
Transformation in [HLWW23]:

Slotted Reg-FE ==> Reg-FE

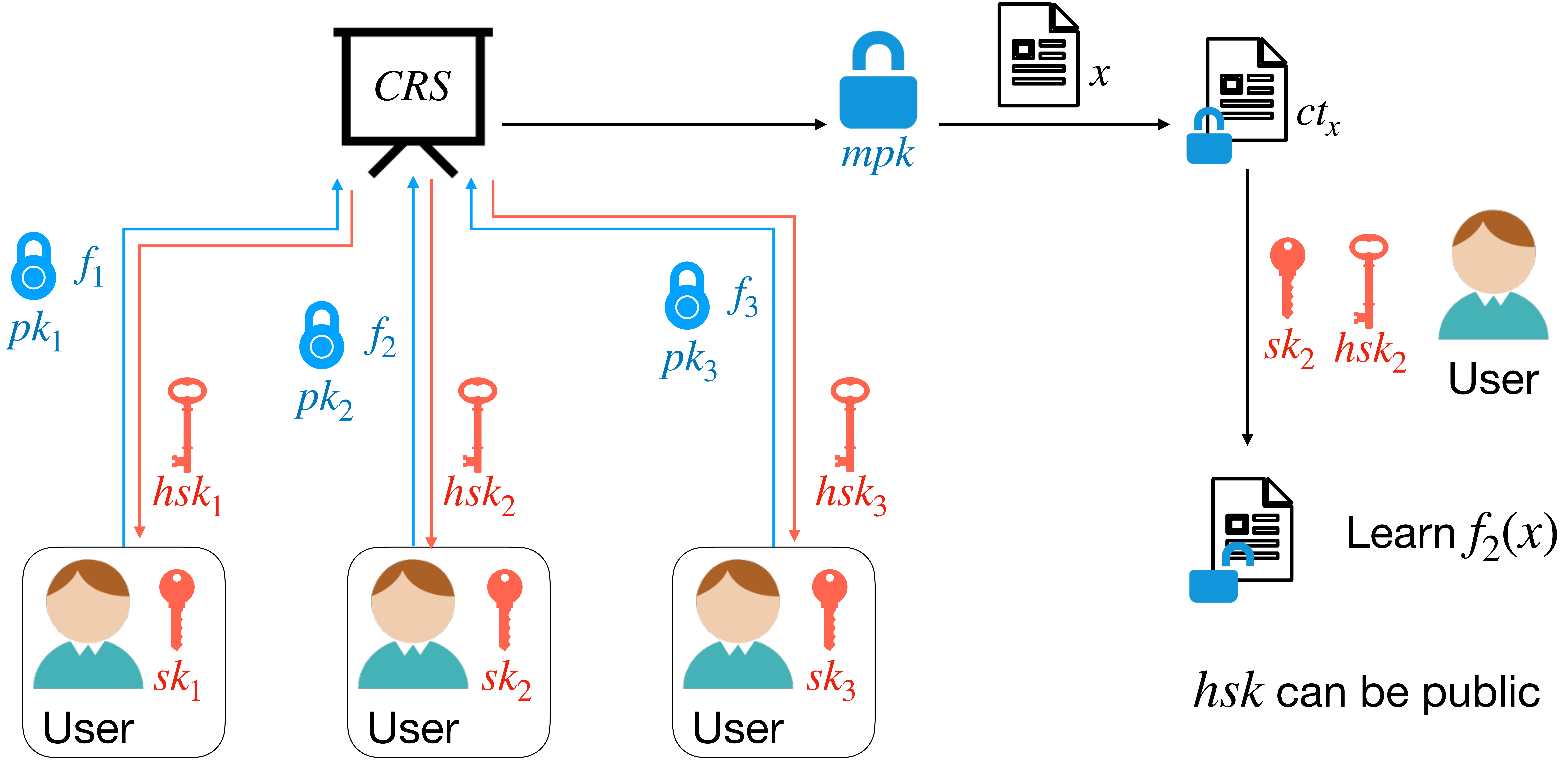
Registered Functional Encryption



Registered Functional Encryption

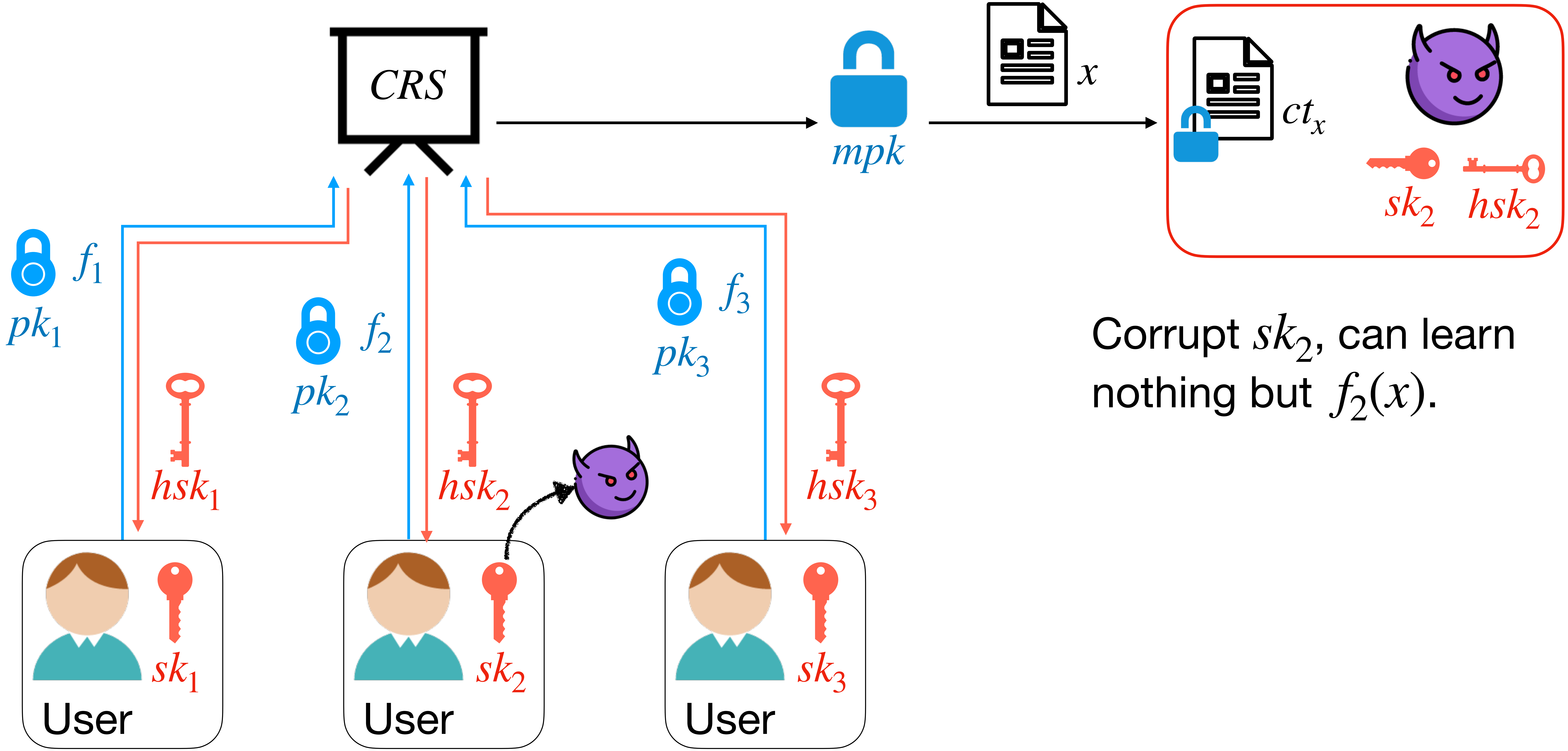


Registered Functional Encryption



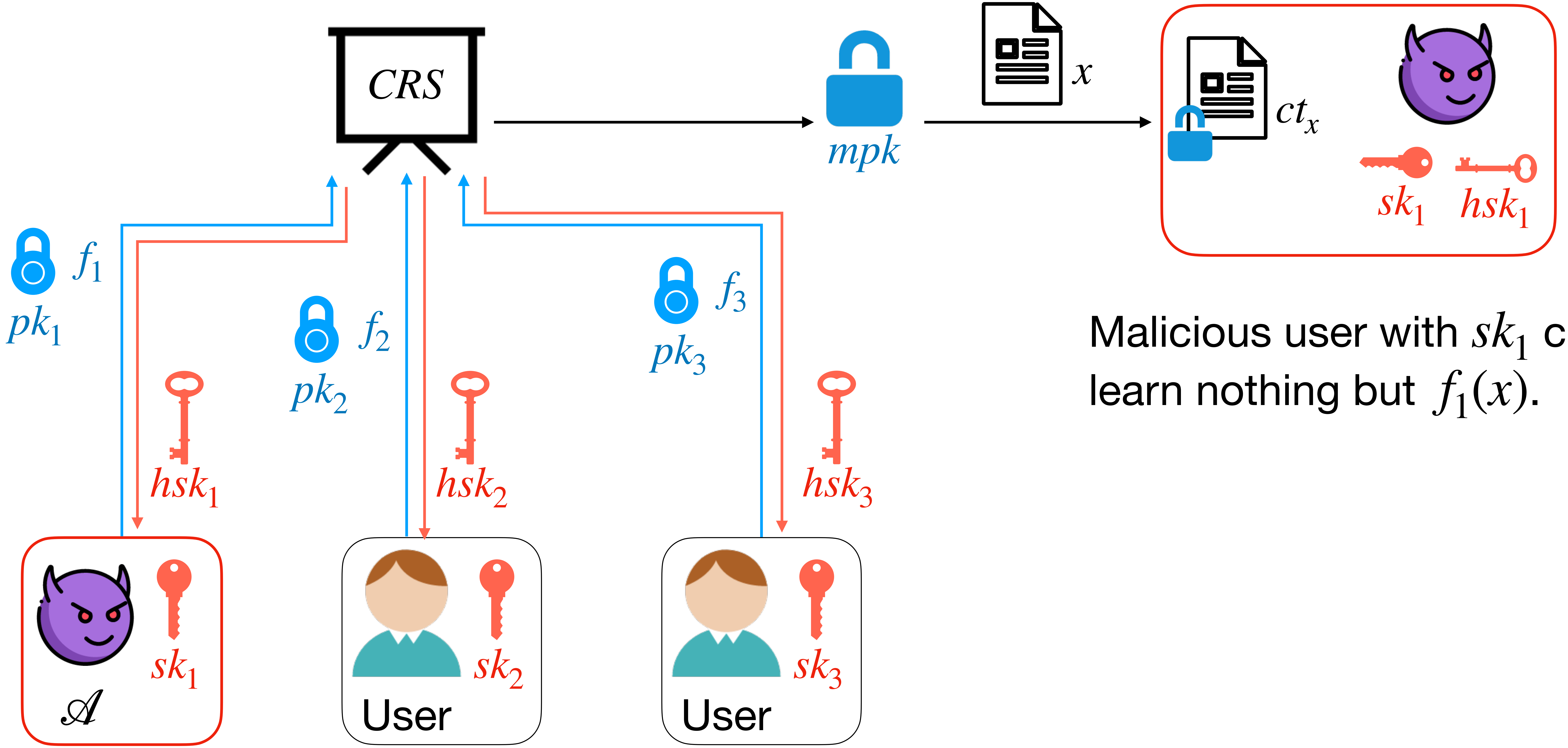
hsk can be public

Registered Functional Encryption: Security



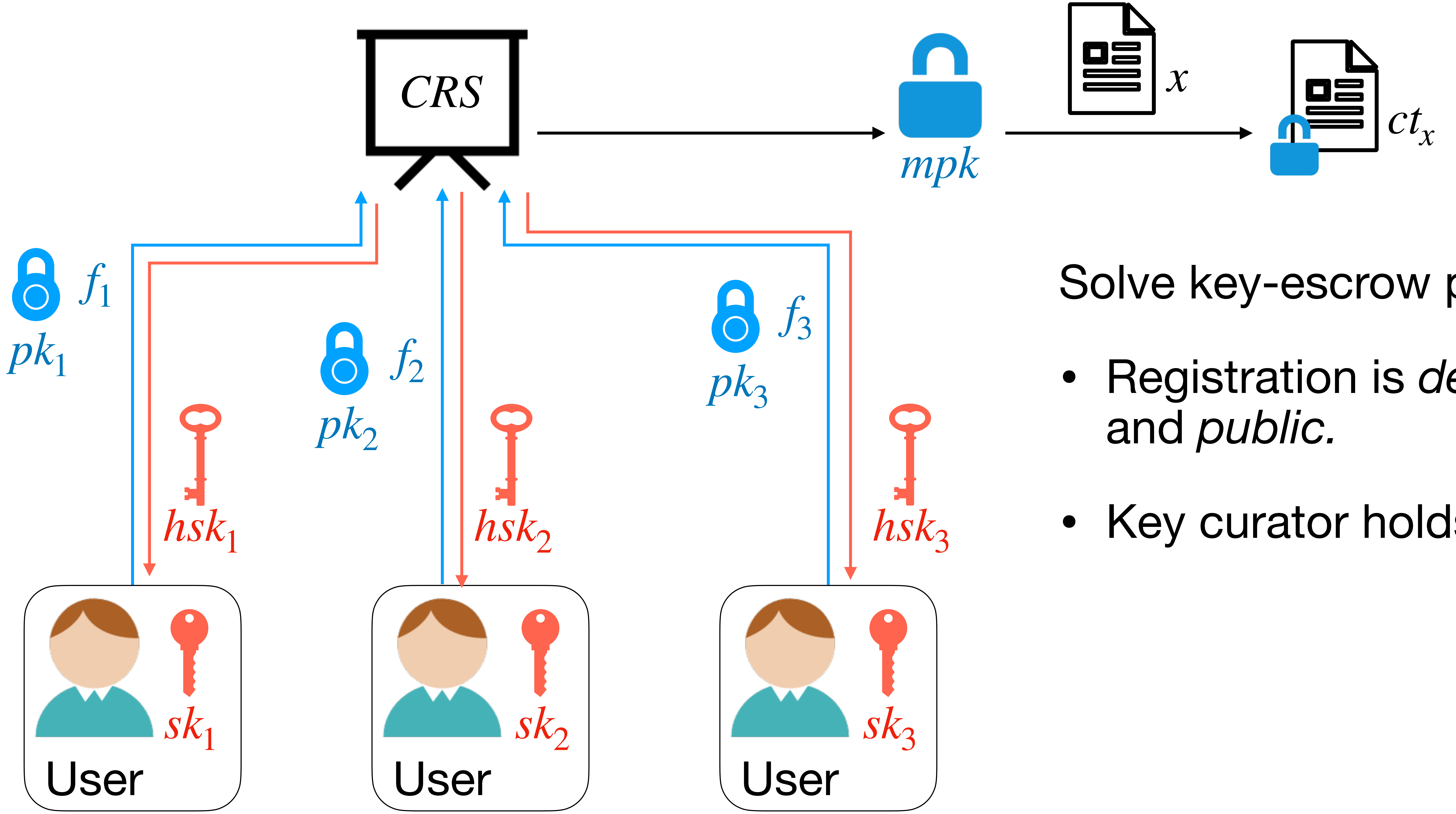
Corrupt sk_2, can learn nothing but $f_2(x)$.

Registered Functional Encryption: Security



Malicious user with sk_1 can learn nothing but $f_1(x)$.

Registered Functional Encryption



Solve key-escrow problem:

- Registration is *deterministic* and *public.*
- Key curator holds *no secret*.

Our Result

Scheme	Function	Security	Assumptions	Size of ciphertext
Main Result				
Reg-IPFE (1)	Linear	Ad-IND	k-lin	n Log L
Reg-QFE	Quadratic	Sel*-SIM	bi-k-lin	n + Log L

Our Result

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Related Work				
[DP23, FFM+23]	General	Ad-IND	iO+SSB	n Log L
[HLWW23]	Boolean (ABE)	Ad-IND	Static	n Log L
[ZZGQ23]	Boolean (ABE)	Ad-IND	k-lin	n Log L

Our Result

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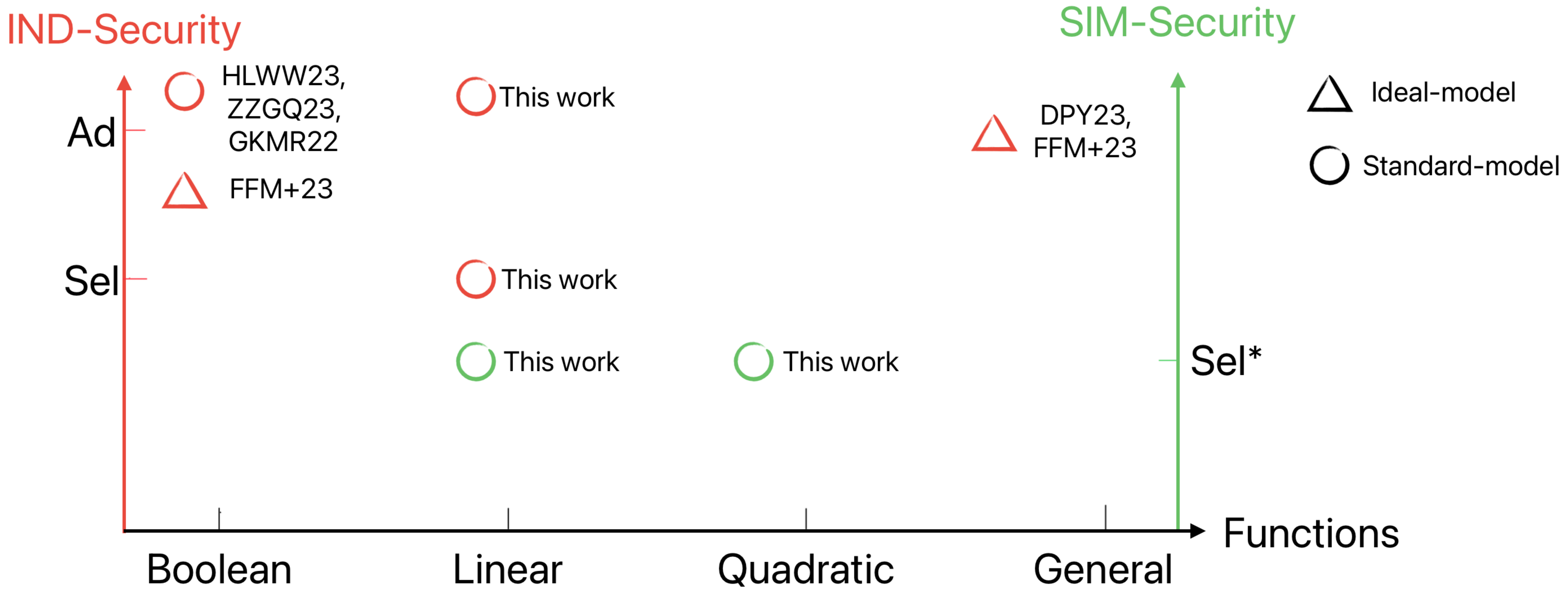
Our Result

Scheme	Function	Security	Assumptions	Size of ciphertext
Main Result				
Reg-IPFE (1)	Linear	Ad-IND	k-lin	n Log L
Reg-QFE	Quadratic	Sel*-SIM	bi-k-lin	n + Log L
Implication				
Reg-IPE	Boolean	Ad-IND & Fully AH	k-lin	n Log L
Reg-IPFE (2)	Linear	Sel-IND	k-lin	n + Log L
Reg-IPFE (3)	Linear	Sel*-SIM	bi-k-lin	n + Log L

Our Result


IND-Security
SIM-Security
Ad
Sel
Sel*
HLWW23,
ZZGQ23,
GKMR22
FFM+23
This work
This work
This work
This work
DPY23,
FFM+23
△ Ideal-model
○ Standard-model
Functions
Boolean
Linear
Quadratic
General

sReg-IPFE with Adaptive IND-Security

IPFE [ABDP15]

$L-$slot Reg-IPFE

$$mpk = [\mathbf{w}]$$

$$sk = \mathbf{w}\mathbf{y}^\top$$

$$ct = [s, s\mathbf{w} + \mathbf{x}]$$

$pk, sk = [\mathrm{u}], u$

Register $(pk, \mathbf{y})$

$$crs = [\mathbf{w}_j], \quad \forall j \in [L]$$

$$pk_i, sk_i = [u_i], u_i$$

$$mpk = [\sum_j \mathbf{w}_j, \sum_j (u_j + \mathbf{w}_j\mathbf{y}_j^\top)]$$

$$ct = [s, s\sum_j \mathbf{w}_j + \mathbf{x}, s\sum_j (u_j + \mathbf{w}_j\mathbf{y}_j^\top)]$$

sReg-IPFE with Adaptive IND-Security

To L-slot Reg-IPFE: fix the correctness

$$crs = [\mathbf{w}_j], \quad \forall j \in [L]$$

$$pk_i, sk_i = [u_i], u_i$$

$$mpk = [\sum_j \mathbf{w}_j, \sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]$$

$$ct = [s, s\sum_j \mathbf{w}_j + \mathbf{x}, s\sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]$$

sk Decrypt:

$$(s\sum_j \mathbf{w}_j + \mathbf{x}) \cdot \mathbf{y}_i^\top - s\sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top) + s \cdot u$$

$$= \mathbf{x}\mathbf{y}_i^\top - s\sum_{j \neq i} (u_j + \mathbf{w}_j \mathbf{y}_j^\top) + s\sum_{j \neq i} \mathbf{w}_j \mathbf{y}_i^\top$$

sReg-IPFE with Adaptive IND-Security

To L-slot Reg-IPFE: fix the correctness

hsk sk

$$crs = [\mathbf{w}_j]_1, \quad \forall j \in [L]$$

$$pk_i, sk_i = [u_i]_1, u_i$$

$$mpk = [\sum_j \mathbf{w}_j, \sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]_1$$

$$hsk_i = [r_i, r_i \sum_{j \neq i} \mathbf{w}_j, r_i \sum_{j \neq i} (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]_2$$

$$ct = [s, s \sum_j \mathbf{w}_j + \boxed{s\mathbf{x}}, s \sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]_1$$

Decrypt:

$$(sr_i \sum_j \mathbf{w}_j + sr_i \mathbf{x}) \cdot \mathbf{y}_i^\top - sr_i \sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top) + sr_i \cdot u$$

$$= sr_i \cdot \mathbf{x}\mathbf{y}_i^\top \cancel{- sr_i \sum_{j \neq i} (u_j + \mathbf{w}_j \mathbf{y}_j^\top) + sr_i \sum_{j \neq i} \mathbf{w}_j \mathbf{y}_i^\top}$$

sReg-IPFE with Adaptive IND-Security

To L-slot Reg-IPFE: proof strategy

Dual-system used in [HLWW23,ZZGQ23]

😈 ?

$$crs = [\mathbf{w}_j]_1, \quad \forall j \in [L]$$

$$[r_i, r_i\mathbf{w}_j]_2, \quad \forall i, j \in [L], i \neq j$$

$$pk_i, sk_i = ([u_i]_1, \{[r_j u_i]_2\}_{j \neq i}), u_i$$

$$mpk = [\sum_j \mathbf{w}_j, \sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]_1$$

$$hsk_i = [r_i, r_i \sum_{j \neq i} \mathbf{w}_j, r_i \sum_{j \neq i} (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]_2$$

$$ct = [s, s \sum_j \mathbf{w}_j + s\mathbf{x}, s \sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]_1$$

sReg-IPFE with Adaptive IND-Security

To L-slot Reg-IPFE: proof strategy

~~Dual-system used in [HLWW23,ZZGQ23]~~

Nested dual-system method [LW11]

$$crs = [\mathbf{w}_j]_1, \quad \forall j \in [L]$$

$$[r_i, r_i\mathbf{w}_j]_2, \quad \forall i, j \in [L], i \neq j$$

$$pk_i, sk_i = ([u_i]_1, \{[r_j u_i]_2\}_{j \neq i}), u_i$$

$$mpk = [\sum_j \mathbf{w}_j, \sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]_1$$

$$hsk_i = [r_i, r_i \sum_{j \neq i} \mathbf{w}_j, r_i \sum_{j \neq i} (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]_2$$

$$ct = [s, s\sum_j \mathbf{w}_j + s\mathbf{x}, s\sum_j (u_j + \mathbf{w}_j \mathbf{y}_j^\top)]_1$$

sReg-IPFE to sReg-QFE: Attempt

Attempt: IPFE ==> QFE [Wee20]

$$mpk = [\mathbf{A}_1]_1, [\mathbf{A_2}]_2;$$

$$ct = \underbrace{[\mathbf{s}_1\mathbf{A}_1 + \mathbf{x}_1]_1}_{\mathbf{y}_1}, \underbrace{[\mathbf{s}_2\mathbf{A}_2 + \mathbf{x}_2]_2}_{\mathbf{y}_2}, \underbrace{iEnc(\mathbf{x})}_{ct_0};$$

$$sk_{\mathbf{f}} = iKey([\mathbf{M}\mathbf{f}^\top]_2)$$

sReg-IPFE to sReg-QFE: Attempt

Attempt: IPFE ==> QFE [Wee20]

$$mpk = [\mathbf{A}_1]_1, [\mathbf{A}_2]_2;$$

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$$sk_{\mathbf{f}} = iKey([\mathbf{M}\mathbf{f}^\top]_2)$$

$$\mathsf{x} = (\mathsf{s}_1 \otimes \mathsf{x}_2 \| \mathsf{x}_1 \otimes \mathsf{s}_2 \| \mathsf{s}_1 \otimes \mathsf{s}_2)$$

$$\mathsf{M} = \begin{pmatrix} \mathsf{A}_1 \otimes \mathsf{I} \\ \mathsf{I} \otimes \mathsf{A}_2 \\ \mathsf{A}_1 \otimes \mathsf{A}_2 \end{pmatrix}$$

sReg-IPFE to sReg-QFE: Attempt

Attempt: IPFE ==> QFE [Wee20]

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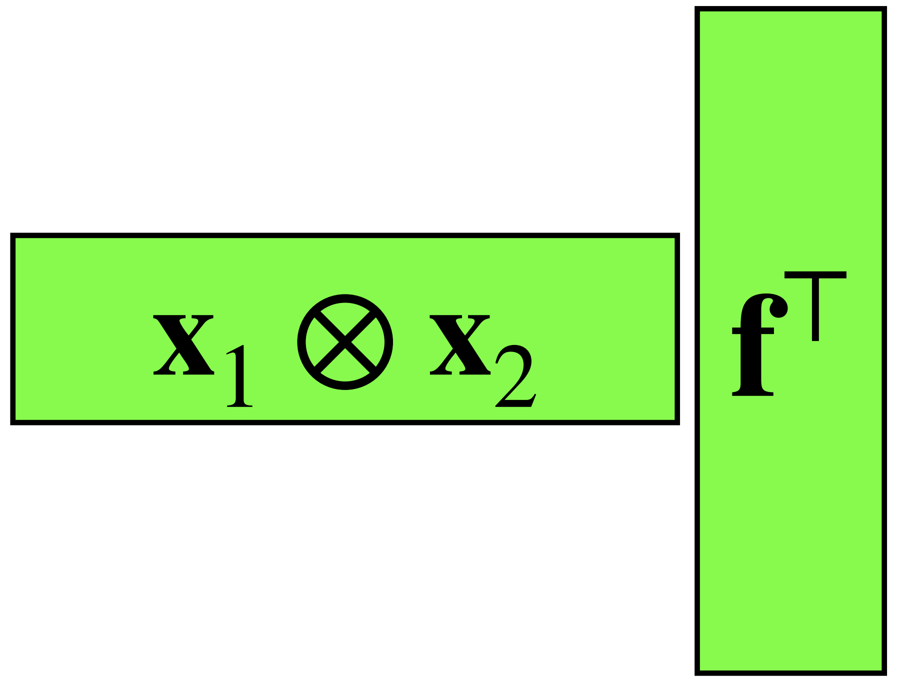
$$sk_{\mathbf{f}} = iKey([\mathbf{M}\mathbf{f}^\top]_2)$$

$$\mathbf{x} = (\mathbf{s}_1 \otimes \mathbf{x}_2 \| \mathbf{x}_1 \otimes \mathbf{s}_2 \| \mathbf{s}_1 \otimes \mathbf{s}_2)$$

$$\mathbf{M} = \begin{pmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{pmatrix}$$

Decryption goal:



$\mathbf{x}_1 \otimes \mathbf{x}_2$ $\mathbf{f}^\top$

sReg-IPFE to sReg-QFE: Attempt

Attempt: IPFE ==> QFE [Wee20]

$$mpk = [\mathbf{A}_1]_1, [\mathbf{A}_2]_2;$$

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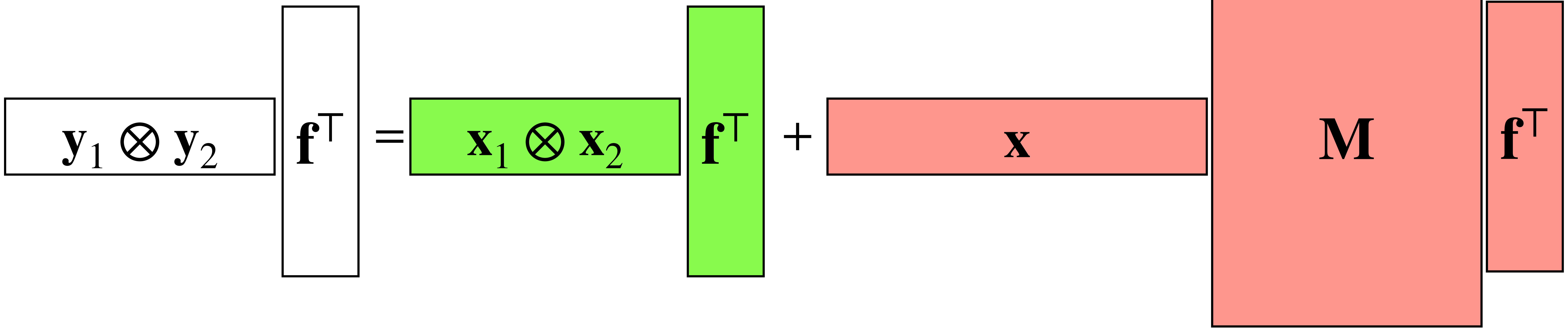
$$sk_{\mathbf{f}} = iKey([\mathbf{M}\mathbf{f}^\top]_2)$$

$$\mathbf{x} = (\mathbf{s}_1 \otimes \mathbf{x}_2 \| \mathbf{x}_1 \otimes \mathbf{s}_2 \| \mathbf{s}_1 \otimes \mathbf{s}_2)$$

$$\mathbf{M} = \begin{pmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{pmatrix}$$



$$\mathbf{y}_1 \otimes \mathbf{y}_2 \; \mathbf{f}^\top = \mathbf{x}_1 \otimes \mathbf{x}_2 \; \mathbf{f}^\top + \mathbf{x} \; \mathbf{M} \; \mathbf{f}^\top$$

sReg-IPFE to sReg-QFE: Attempt

Attempt: IPFE ==> QFE [Wee20]

$$mpk = [\mathbf{A}_1]_1, [\mathbf{A}_2]_2;$$

$$ct = \underbrace{[\mathbf{s}_1\mathbf{A}_1 + \mathbf{x}_1]_1}_{\mathbf{y}_1}, \underbrace{[\mathbf{s}_2\mathbf{A}_2 + \mathbf{x}_2]_2}_{\mathbf{y}_2}, \underbrace{iEnc(\mathbf{x})}_{ct_0};$$

$$sk_{\mathbf{f}} = iKey([\mathbf{M}\mathbf{f}^\top]_2)$$

$$\mathbf{x} = (\mathbf{s}_1 \otimes \mathbf{x}_2 \| \mathbf{x}_1 \otimes \mathbf{s}_2 \| \mathbf{s}_1 \otimes \mathbf{s}_2)$$

$$\mathbf{M} = \begin{pmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{pmatrix}$$

$$\boxed{\mathbf{y}_1 \otimes \mathbf{y}_2}\,\boxed{\mathbf{f}^\top} = \boxed{\mathbf{x}_1 \otimes \mathbf{x}_2}\,\boxed{\mathbf{f}^\top} + \cancel{\boxed{\mathbf{x}}\,\boxed{\mathbf{M}}\,\boxed{\mathbf{f}^\top}} \Leftarrow \boxed{iDec(ct_0, sk_{\mathbf{f}})}$$

sReg-IPFE to sReg-QFE: Challenge-1

$$iDec(ct_0, sk_i, hsk_i) \longrightarrow [sr_i \cdot \mathbf{xMf}^\top]_T$$

Brute-force search with varied DLOG base

sReg-IPFE to sReg-QFE: Challenge-1

$$iDec(ct_0, sk_i, hsk_i) \longrightarrow [sr_i \cdot \mathbf{xMf}^\top]_T$$

Brute-force search with varied DLOG base

$$\mathbf{x} = (\mathbf{s}_1 \otimes \mathbf{x}_2 \| \mathbf{x}_1 \otimes \mathbf{s}_2 \| \mathbf{s}_1 \otimes \mathbf{s}_2)$$

$$\mathbf{M} = \begin{pmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{pmatrix}$$

sReg-IPFE to sReg-QFE: Challenge-1

$$iDec(ct_0, sk_i, hsk_i) \longrightarrow [sr_i \cdot \mathbf{xMf}^\top]_T$$

~~Brute-force search with varied DLOG base~~

$$\mathbf{x} = (\mathbf{s}_1 \otimes \mathbf{x}_2 \| \mathbf{x}_1 \otimes \mathbf{s}_2 \| \mathbf{s}_1 \otimes \mathbf{s}_2)$$

Too Large!

$$\mathbf{M} = \begin{pmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{pmatrix}$$

sReg-IPFE to sReg-QFE: Solution-1

$$iDec(ct_0, sk_i, hsk_i) \longrightarrow [sr_i \cdot \mathbf{xMf}^\top]_T$$

Need fixed DLOG base

sReg-IPFE to sReg-QFE: Solution-1

$$iDec(ct_0, sk_i, hsk_i) \longrightarrow [sr_i \cdot \mathbf{x}\mathbf{M}\mathbf{f}^\top]_T$$

Need fixed DLOG base

$$hsk_i = [r_i, r_i \sum_{j \neq i} \mathbf{w}_j, r_i \sum_{j \neq i} (u_j + \mathbf{w}_j \mathbf{M}\mathbf{f}_j^\top)]_2$$

$$ct_0 = [s, s \sum_j \mathbf{w}_j + s\mathbf{x}, s \sum_j (u_j + \mathbf{w}_j \mathbf{M}\mathbf{f}_j^\top)]_1$$

sReg-IPFE to sReg-QFE: Solution-1

$$iDec(ct_0, sk_i, hsk_i) \longrightarrow [sr_i \cdot \mathbf{x}\mathbf{M}\mathbf{f}^\top]_T$$

Need fixed DLOG base

$$hsk_i = [r_i, r_i\mathbf{w}_i\mathbf{M}\mathbf{f}_i^\top + \mathbf{w}\mathbf{M}\mathbf{f}_i^\top, r_i \sum_{j\neq i} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top)]_2$$

$$ct_0 = [s, s\mathbf{w} + \mathbf{x}, s \sum_{j} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top)]_1$$

sReg-IPFE to sReg-QFE: Solution-1

$$iDec(ct_0, sk_i, hsk_i) \longrightarrow [sr_i \cdot \mathbf{x}\mathbf{M}\mathbf{f}^\top]_T$$

Need fixed DLOG base

$$hsk_i = [r_i, r_i\mathbf{w}_i\mathbf{M}\mathbf{f}_i^\top + \mathbf{w}\mathbf{M}\mathbf{f}_i^\top, r_i \sum_{j \neq i} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top)]_2$$

$$ct_0 = [s, s\mathbf{w} + \mathbf{x}, s \sum_{j} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top)]_1$$

Decrypt:

$$\boxed{\begin{aligned}&(s\mathbf{w} + \mathbf{x}) \cdot \mathbf{M}\mathbf{f}_i^\top - s(r_i\mathbf{w}_i\mathbf{M}\mathbf{f}_i^\top + \mathbf{w}\mathbf{M}\mathbf{f}_i^\top) + sr_i \sum_{j} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top) - sr_i \cdot u \\ &= \mathbf{x}\mathbf{M}\mathbf{f}_i^\top + sr_i \sum_{j \neq i} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top)\end{aligned}}$$

sReg-IPFE to sReg-QFE: Solution-1

$$iDec(ct_0, sk_i, hsk_i) \longrightarrow [1 \cdot \mathbf{x}\mathbf{M}\mathbf{f}^\top]_T$$

With fixed DLOG base

$$hsk_i = [r_i, r_i\mathbf{w}_i\mathbf{M}\mathbf{f}_i^\top + \mathbf{w}\mathbf{M}\mathbf{f}_i^\top, r_i \sum_{j\neq i} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top)]_2$$

$$ct_0 = [s, s\mathbf{w} + \mathbf{x}, s \sum_{j} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top)]_1$$

Decrypt:

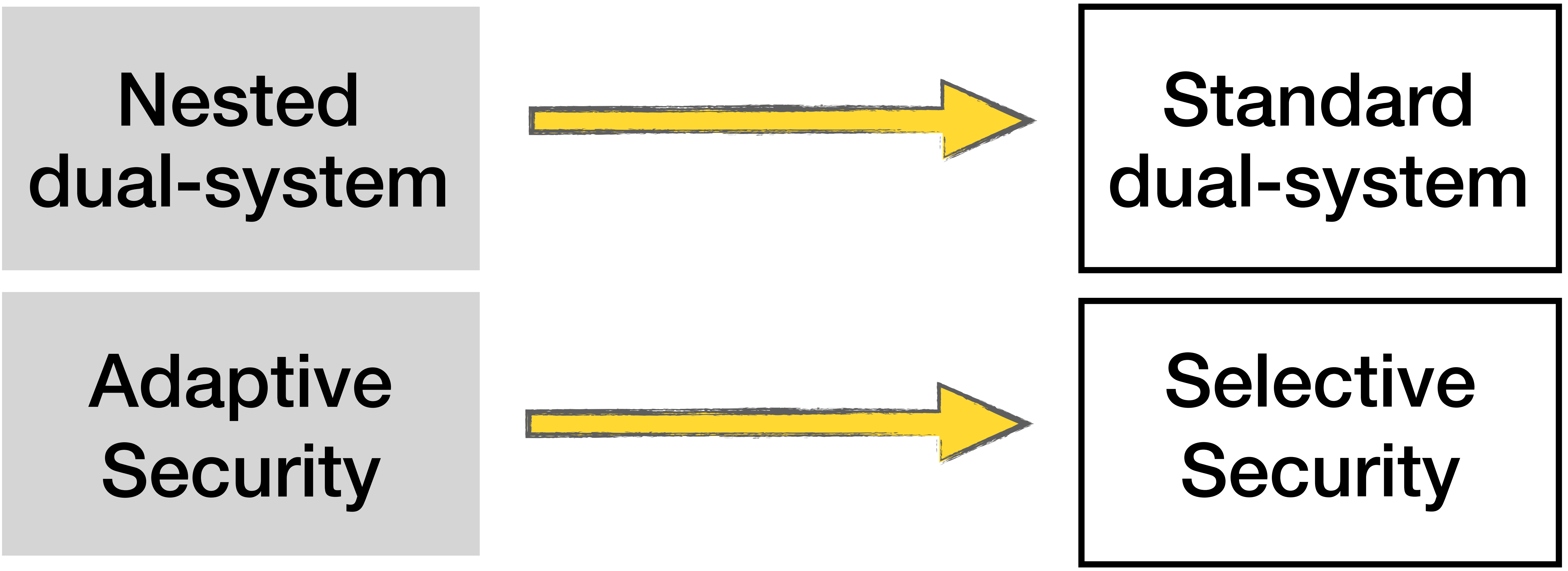
$$(s\mathbf{w} + \mathbf{x}) \cdot \mathbf{M}\mathbf{f}_i^\top - s(r_i\mathbf{w}_i\mathbf{M}\mathbf{f}_i^\top + \mathbf{w}\mathbf{M}\mathbf{f}_i^\top) + sr_i \sum_{j} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top) - sr_i \cdot u$$

$$= \mathbf{x}\mathbf{M}\mathbf{f}_i^\top \cancel{+ sr_i \sum_{j\neq i} (u_j + \mathbf{w}_j\mathbf{M}\mathbf{f}_j^\top)}$$

sReg-IPFE to sReg-QFE: Solution-1

$$iDec(ct_0, sk_i, hsk_i) \longrightarrow [1 \cdot \mathbf{xMf}^\top]_T$$

With fixed DLOG base



sReg-IPFE to sReg-QFE: Challenge-2

$iKey([\mathbf{Mf}^\top]_2)$

[Wee20]: “register” function over $\mathbb{G}_2$

sReg-IPFE to sReg-QFE: Challenge-2

$iKey([\mathbf{M}\mathbf{f}^\top]_2)$ [Wee20]: “register” function over $\mathbb{G}_2$

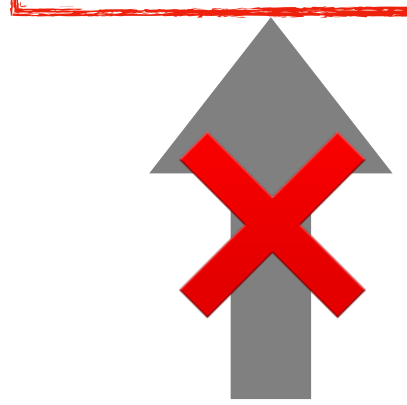
$icrs: [r_i, r_i\mathbf{w}_j]_2, \quad i \neq j$ Our Reg-IPFE: terms for hsk over $\mathbb{G}_2$

sReg-IPFE to sReg-QFE: Challenge-2

$$iKey([\mathbf{M}\mathbf{f}^\top]_2)$$

$$icrs : [r_i, r_i\mathbf{w}_j]_2, \quad i \neq j$$

$$ihsk_i : [\sum_{j \neq i} (r_i u_j + \boxed{r_i \mathbf{w}_j \mathbf{M}\mathbf{f}_j^\top})]_2$$



$$[r_i\mathbf{w}_j]_2, [\mathbf{M}\mathbf{f}_j^\top]_2$$

Cannot multiply them over $\mathbb{G}_2$

sReg-IPFE to sReg-QFE: Solution-2

$$[\mathbf{M}] = \begin{bmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{bmatrix} \xleftarrow{\text{Determine}} [\mathbf{A}_1]\ [\mathbf{A}_2]$$

sReg-IPFE to sReg-QFE: Solution-2

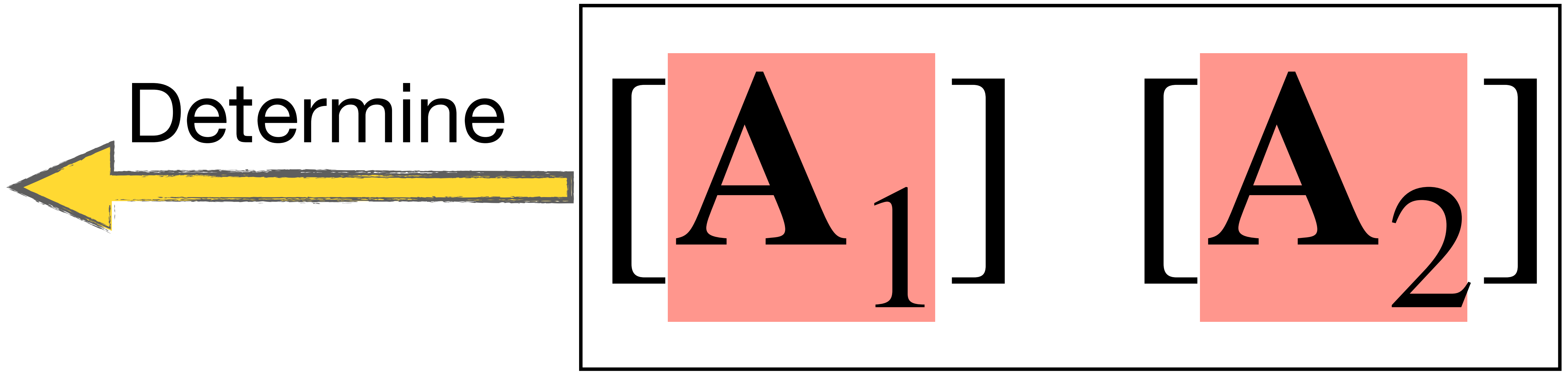
$$[\mathbf{M}] = \begin{bmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{bmatrix} \xleftarrow{\text{Determine}} [\mathbf{A}_1] \quad [\mathbf{A}_2]$$

For security: must be over group, to use MDDH

$$ct = \underbrace{[\boxed{\mathbf{s}_1\mathbf{A}_1} + \mathbf{x}_1]_1}_{\mathbf{y}_1}, \underbrace{[\boxed{\mathbf{s}_2\mathbf{A}_2} + \mathbf{x}_2]_2}_{\mathbf{y}_2}, \underbrace{iEnc(\mathbf{x})}_{ct_0};$$

sReg-IPFE to sReg-QFE: Solution-2

$$[\mathbf{M}] = \begin{bmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{bmatrix}$$

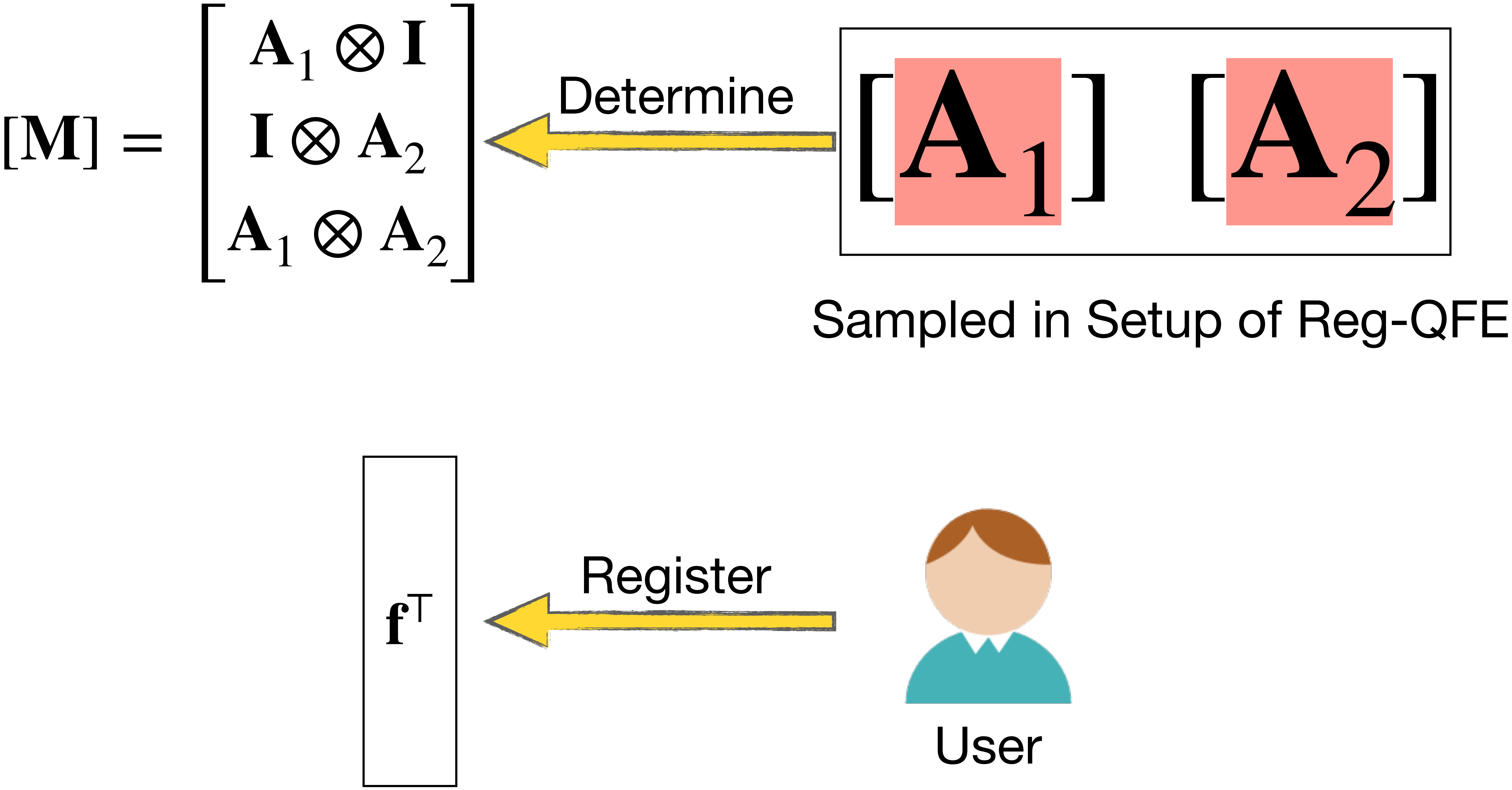


Determine

$[\mathbf{A}_1]$ $[\mathbf{A}_2]$

Sampled in Setup of Reg-QFE

sReg-IPFE to sReg-QFE: Solution-2



$$[\mathbf{M}] = \begin{bmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{bmatrix}$$

Determine

$$[\mathbf{A}_1] \quad [\mathbf{A}_2]$$

Sampled in Setup of Reg-QFE

$$\mathbf{f}^\top$$

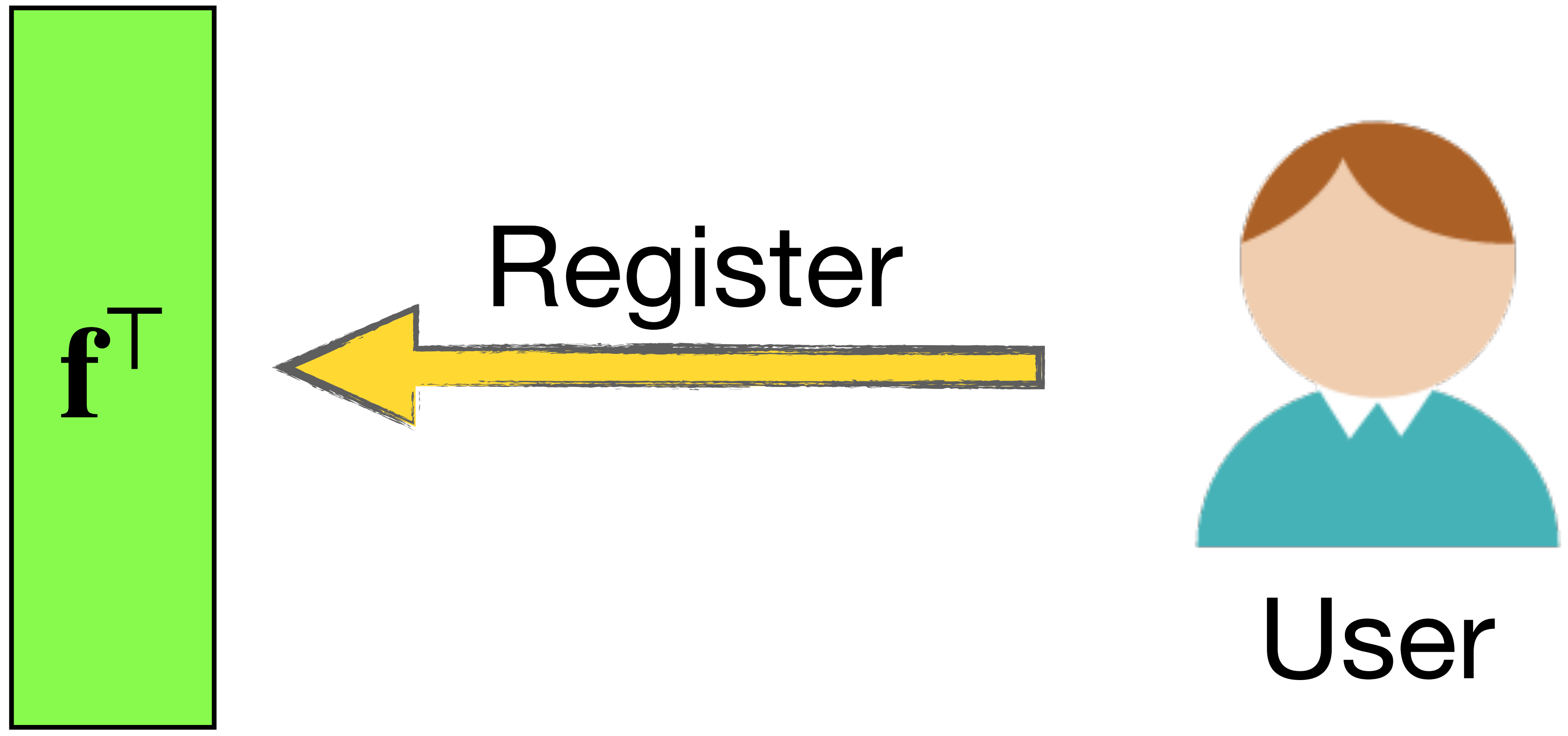
Register

User

sReg-IPFE to sReg-QFE: Solution-2

$$[\mathbf{M}] = \begin{bmatrix} \mathbf{A}_1 \otimes \mathbf{I} \\ \mathbf{I} \otimes \mathbf{A}_2 \\ \mathbf{A}_1 \otimes \mathbf{A}_2 \end{bmatrix} \xleftarrow{\text{Determine}} \boxed{[\mathbf{A}_1] \quad [\mathbf{A}_2]}$$

Sampled in Setup of Reg-QFE



Over $\mathbb{Z}_p$

sReg-IPFE to sReg-QFE: Solution-2

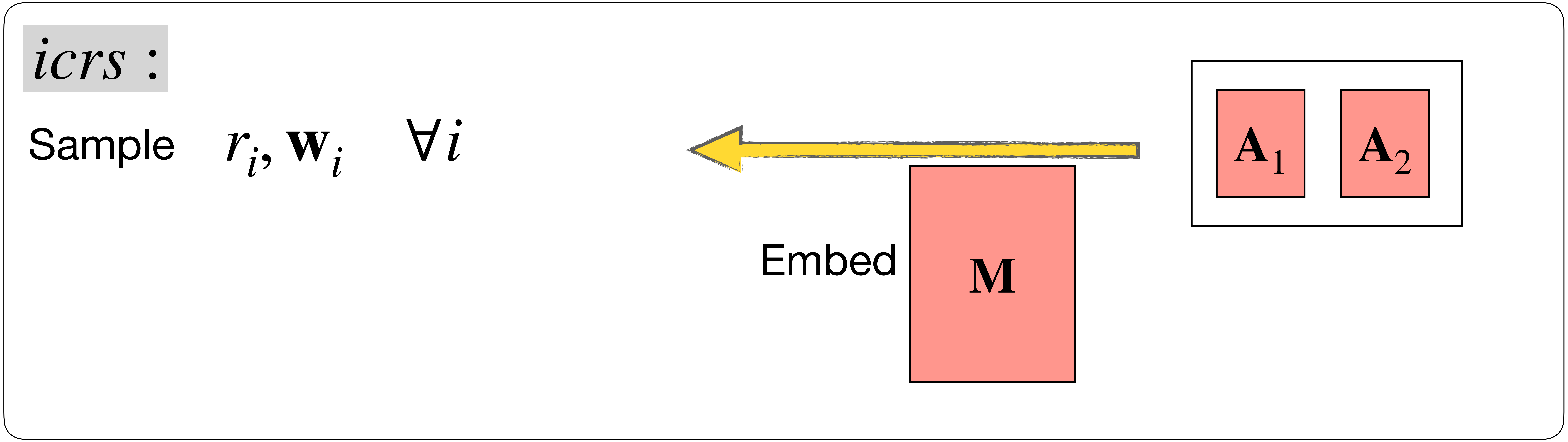
$icrs:$

Sample $r_i, \mathbf{w}_i \quad \forall i$

Sample: $\boxed{\mathbf{A}_1 \quad \mathbf{A}_2}$

Setup of Reg-QFE

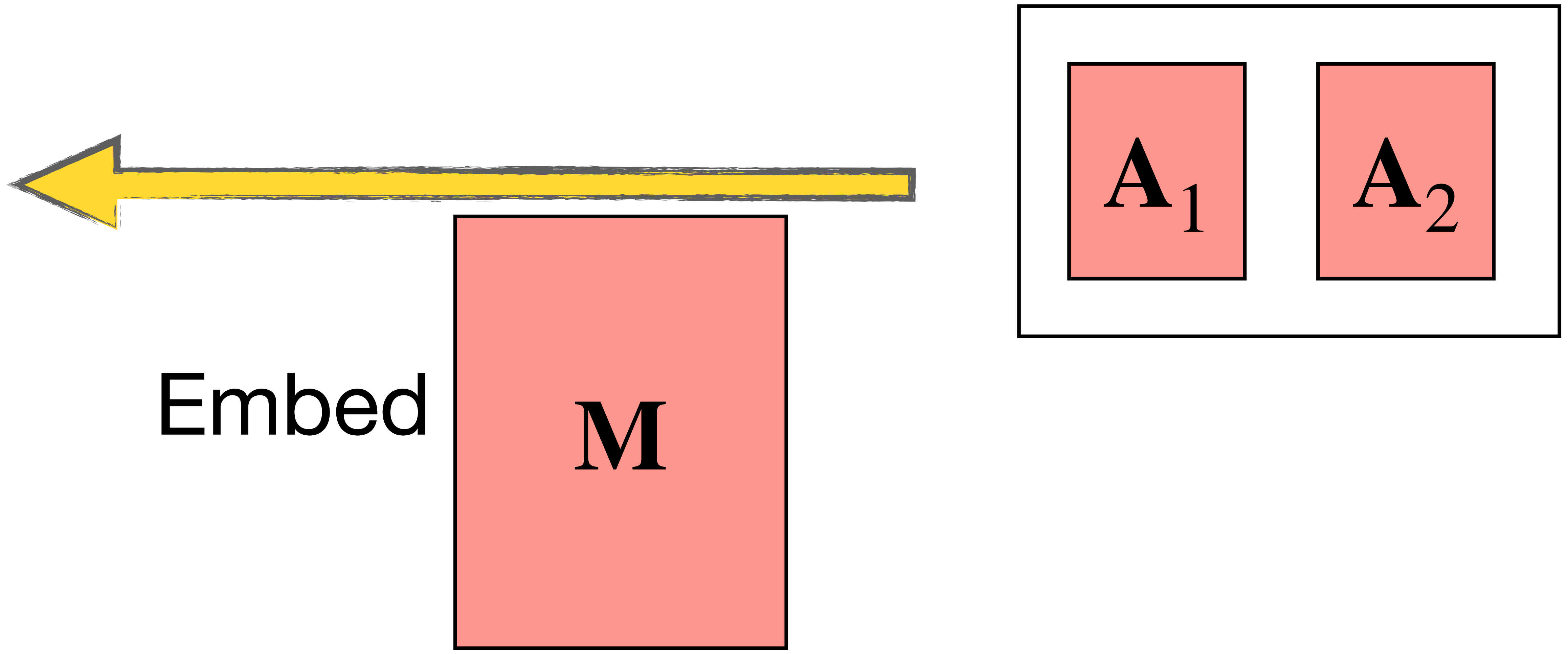
sReg-IPFE to sReg-QFE: Solution-2



Setup of Reg-QFE

sReg-IPFE to sReg-QFE: Solution-2

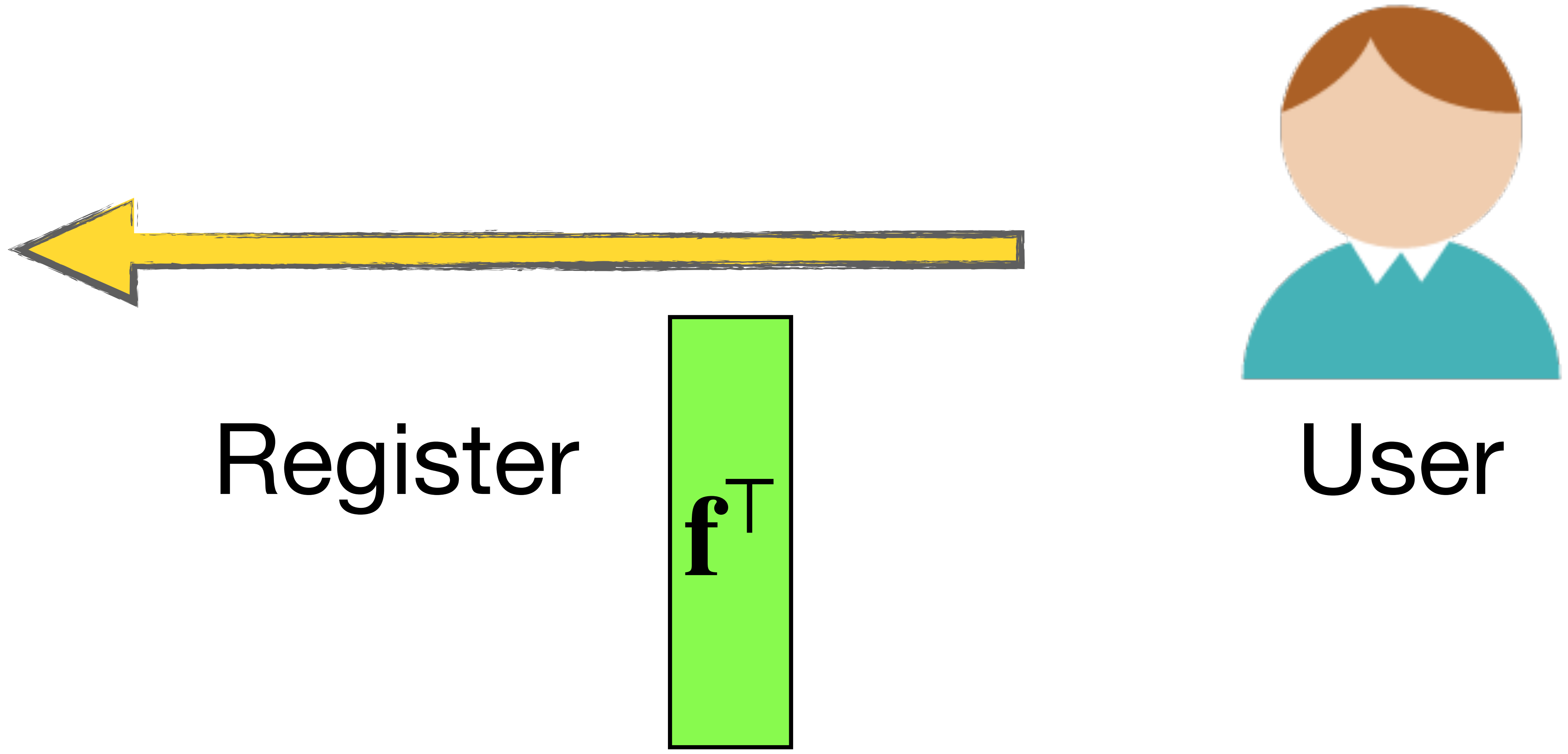
$icrs : [r_i, r_i \mathbf{w}_j \mathbf{M}]_2, \quad i \neq j$



Setup of Reg-QFE

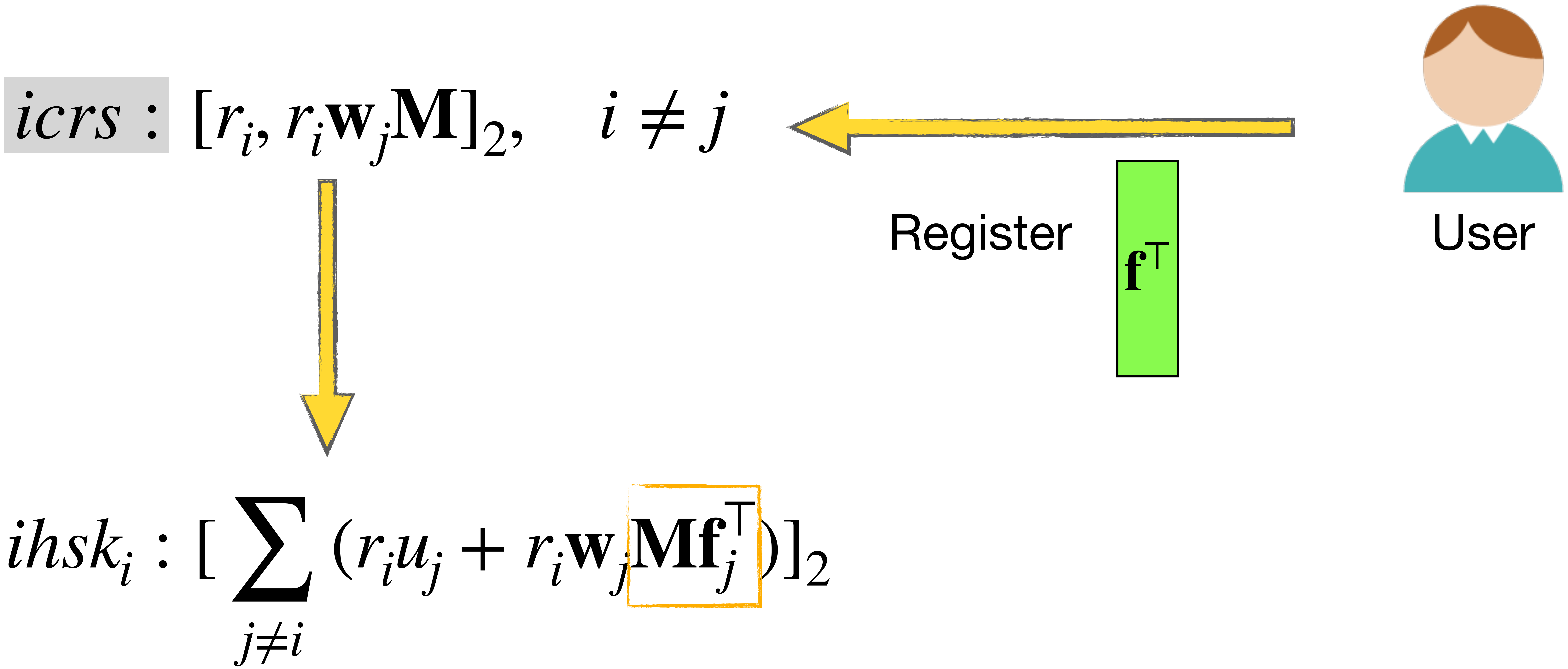
sReg-IPFE to sReg-QFE: Solution-2

$$icrs : [r_i, r_i\mathbf{w}_j\mathbf{M}]_2, \quad i \neq j$$



Register of Reg-QFE

sReg-IPFE to sReg-QFE: Solution-2



$icrs : [r_i, r_i\mathbf{w}_j\mathbf{M}]_2, \quad i \neq j$

Register

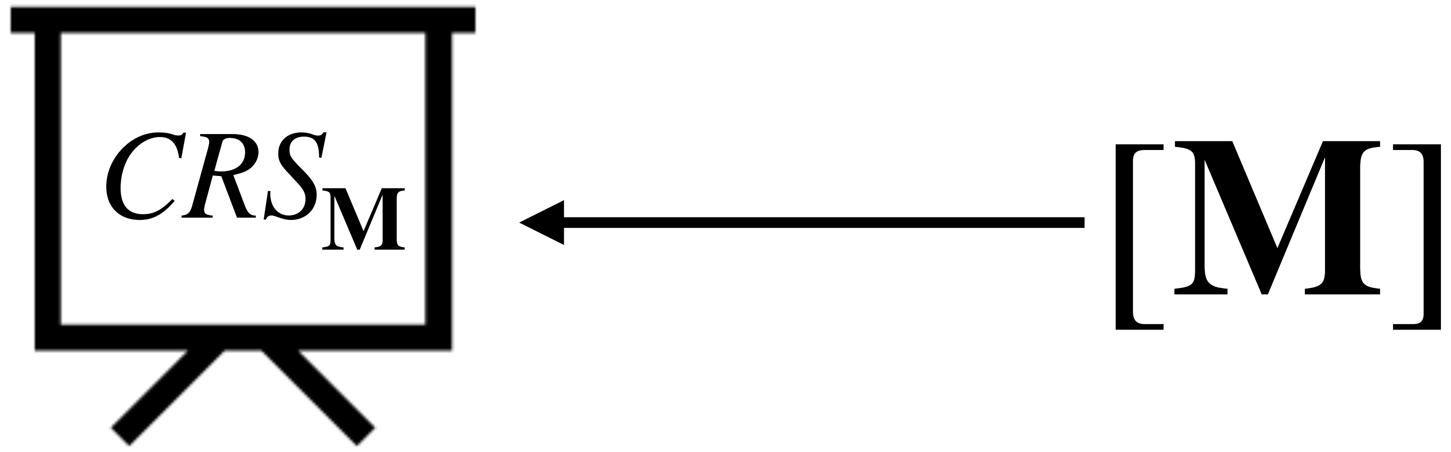
$\mathbf{f}^\top$

User

$$ihsk_i : [\sum_{j\neq i}(r_i u_j + r_i\mathbf{w}_j\boxed{\mathbf{M}\mathbf{f}_j^\top})]_2$$

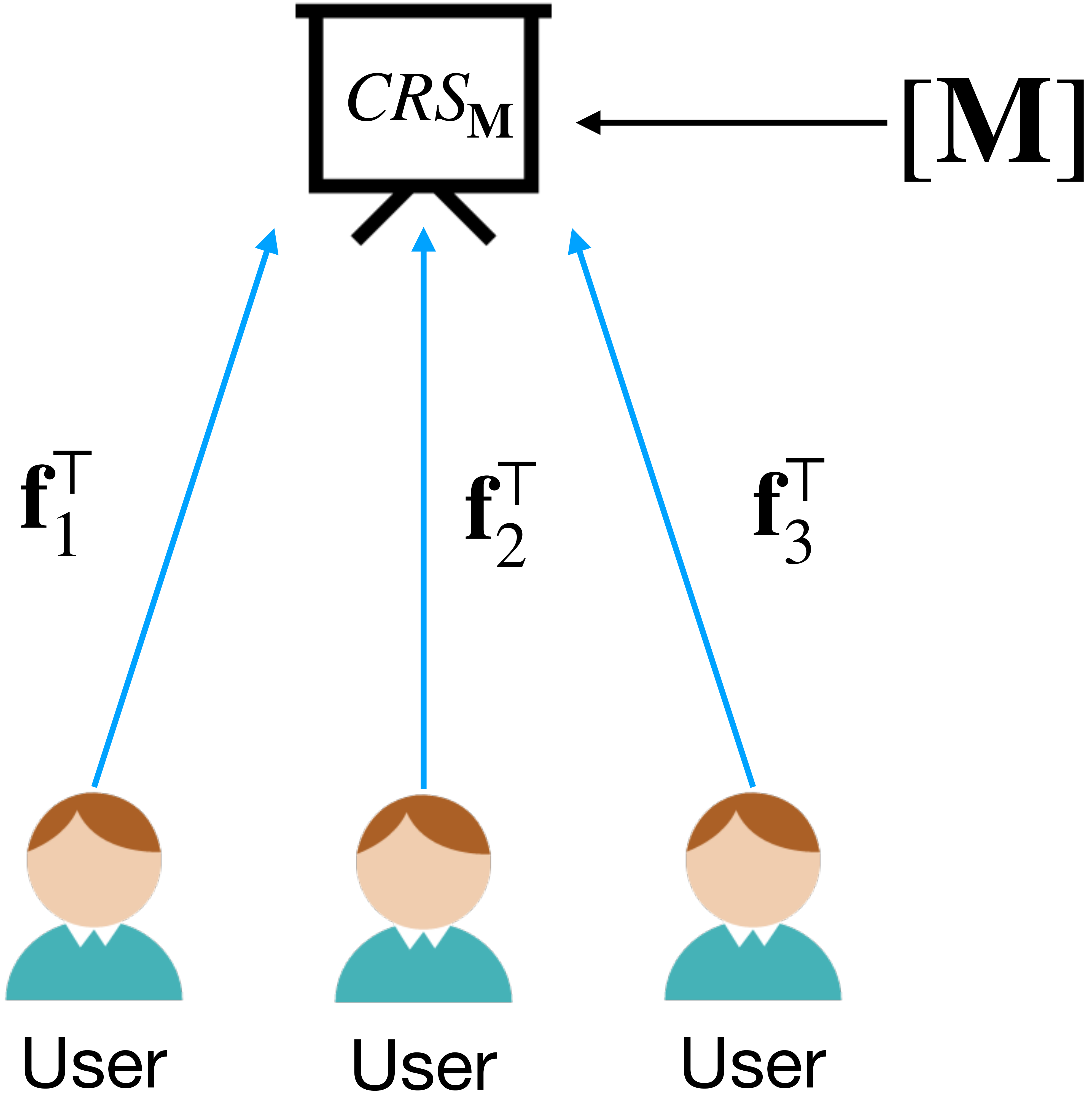
sReg-IPFE to sReg-QFE: Solution-2

New notion: Pre-constrained Reg-IPFE



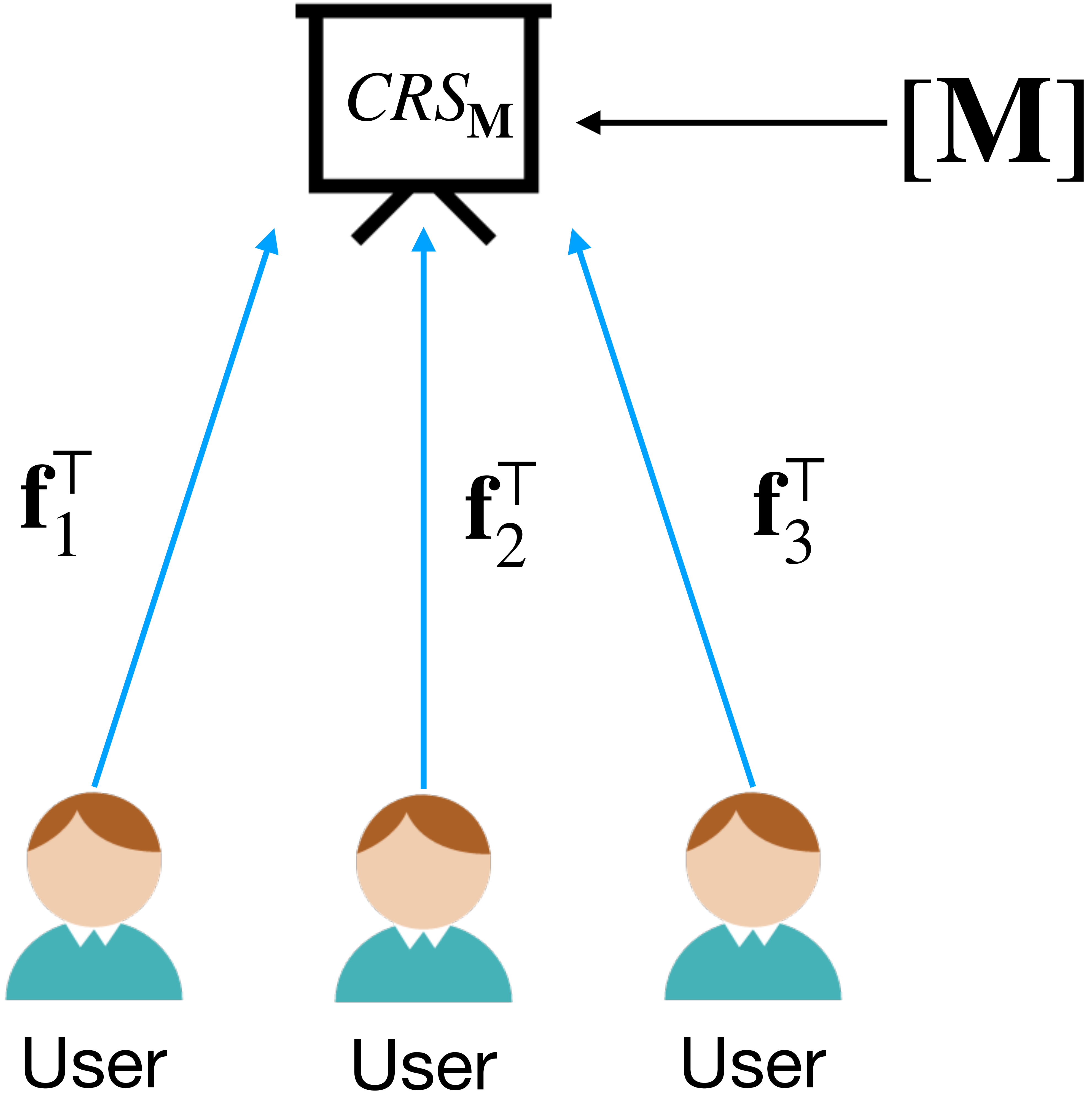
sReg-IPFE to sReg-QFE: Solution-2

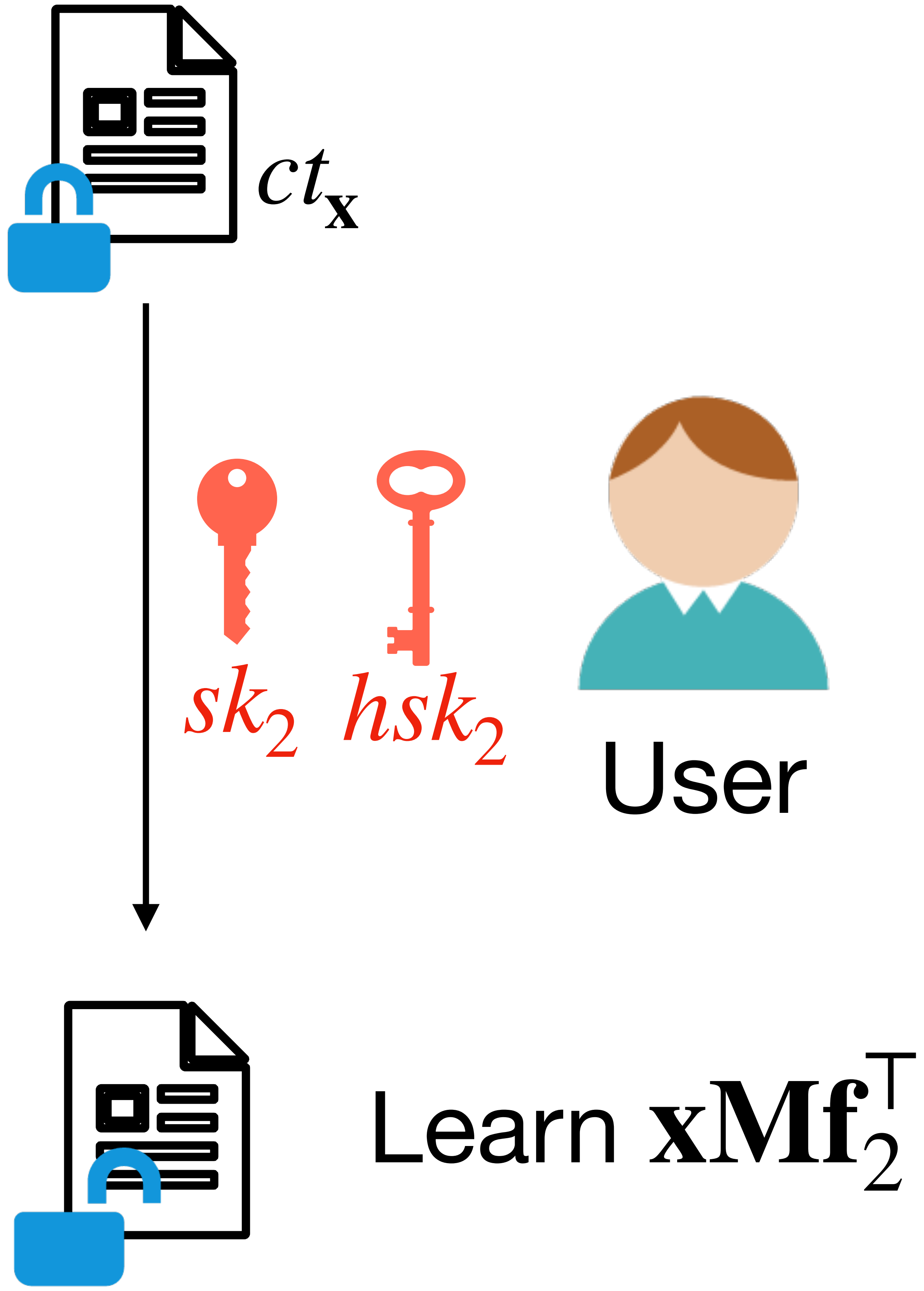
New notion: Pre-constrained Reg-IPFE



sReg-IPFE to sReg-QFE: Solution-2

New notion: Pre-constrained Reg-IPFE

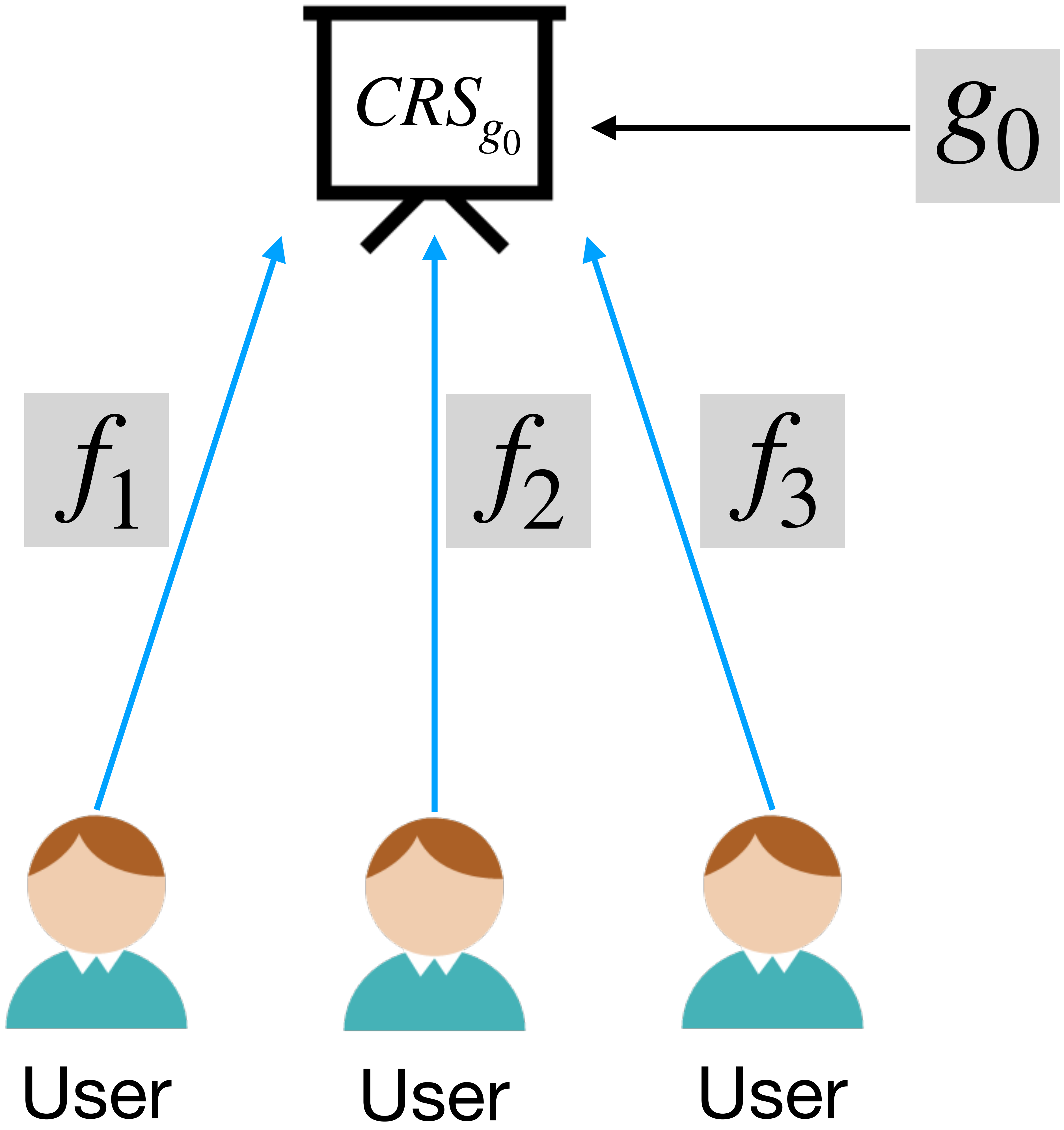


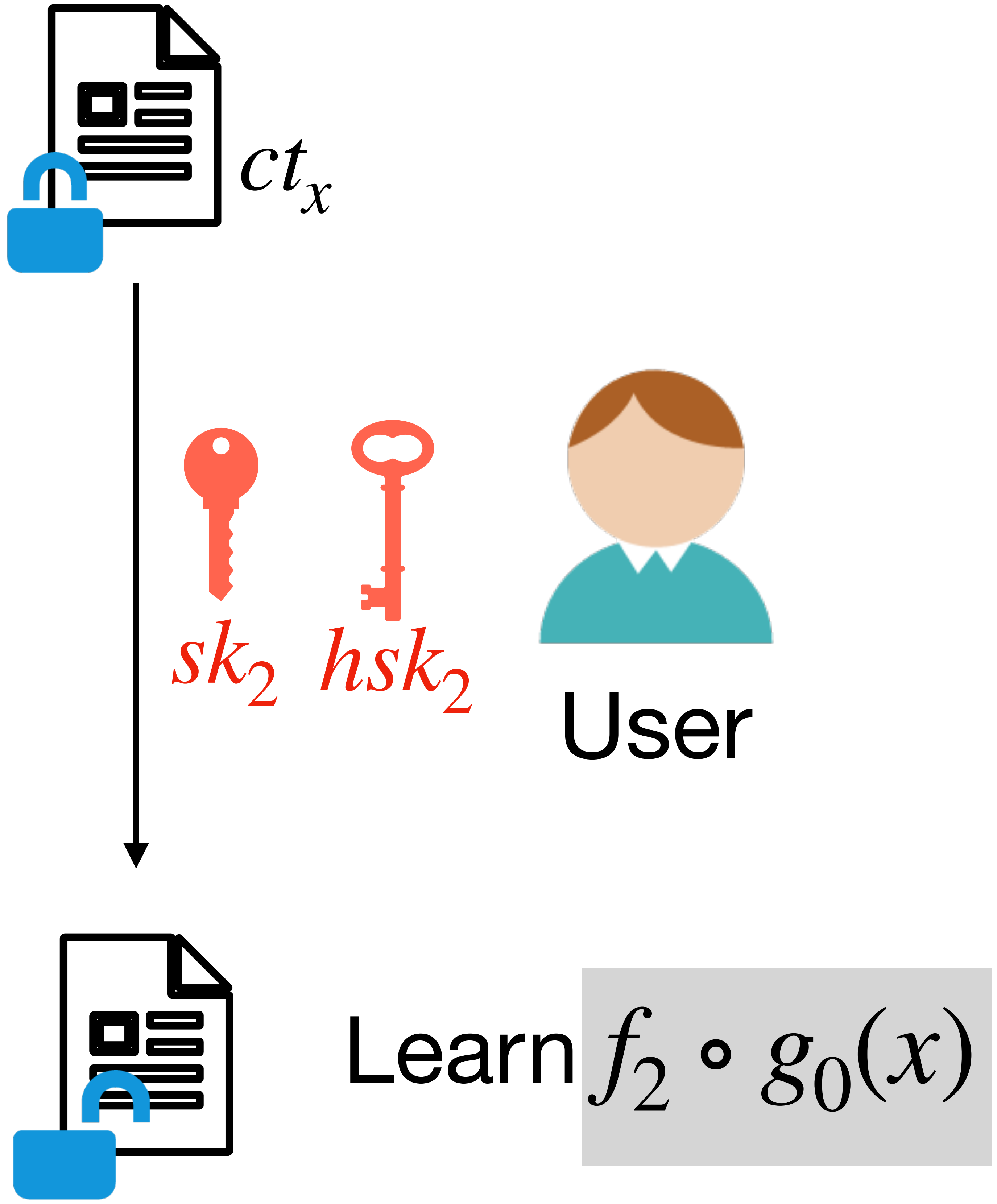


sReg-IPFE to sReg-QFE: Solution-2

New notion (more general): PReg-FE

$$\boxed{\begin{array}{l} G : X \to Y \\ F : Y \to Z \end{array}}$$





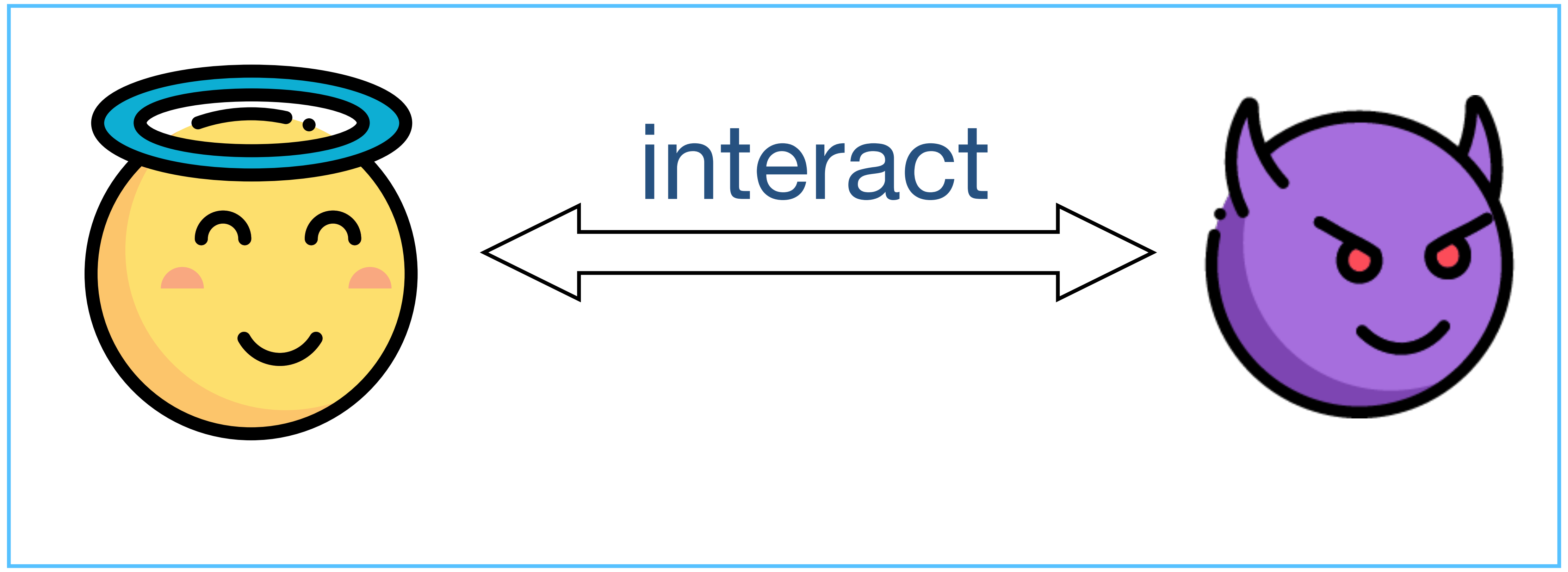
sReg-IPFE to sReg-QFE: Challenge-3

[Wee20]: use sel-SIM-security IPFE

sReg-IPFE to sReg-QFE: Challenge-3

[Wee20]: use sel-SIM-security IPFE

Real



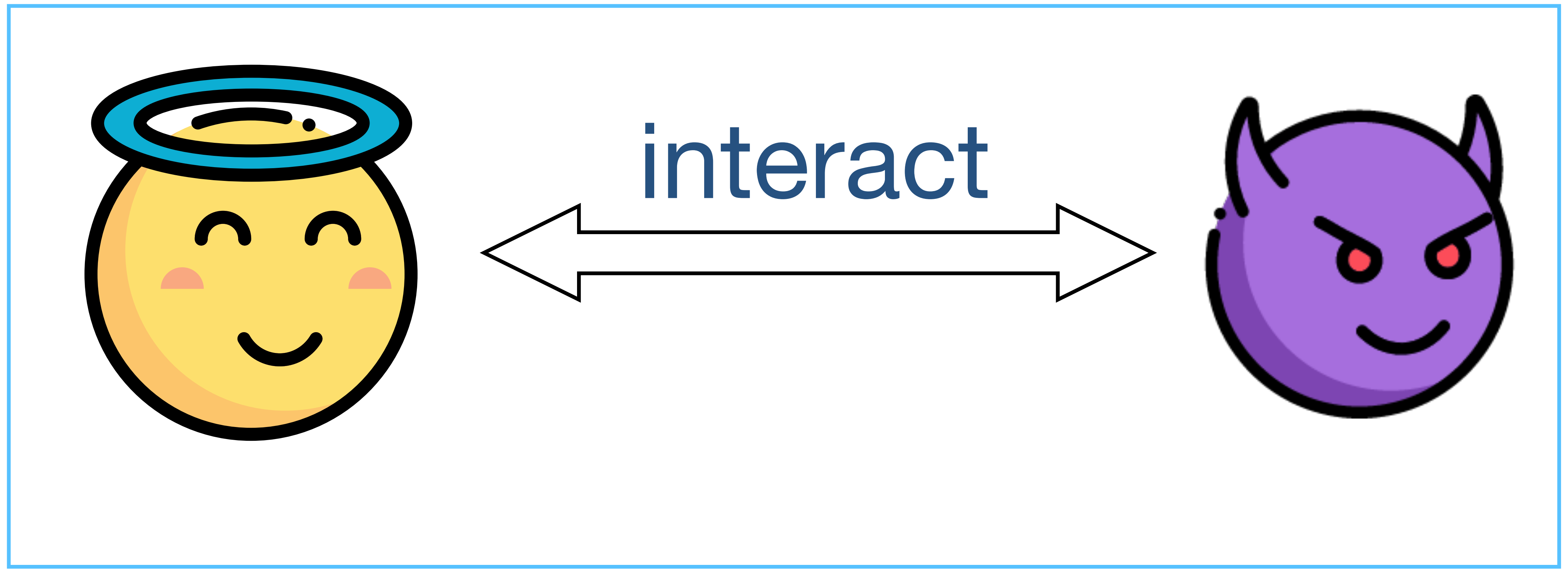
Corrupted $\mathbf{f}$: $sk \leftarrow \boxed{[\mathbf{M}\mathbf{f}^{\top}]_2}$

$ct \leftarrow \boxed{\mathbf{x}}$

sReg-IPFE to sReg-QFE: Challenge-3

[Wee20]: use sel-SIM-security IPFE

Simulator



Corrupted $\mathbf{f}$: $\widetilde{sk} \leftarrow \boxed{[\mathbf{x}\mathbf{M}\mathbf{f}^\top]_2}$

$\widetilde{ct} \leftarrow \cancel{\boxed{}}$

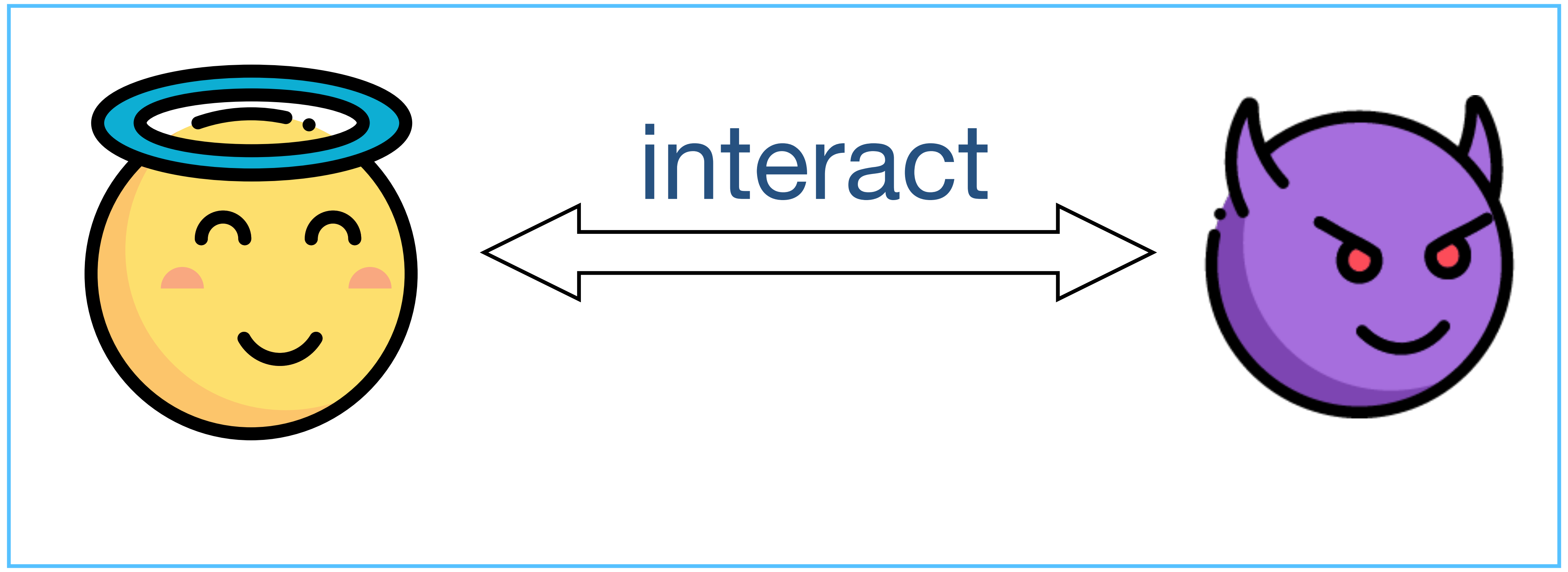
sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Real



$$crs \leftarrow \boxed{[\mathbf{M}]}$$

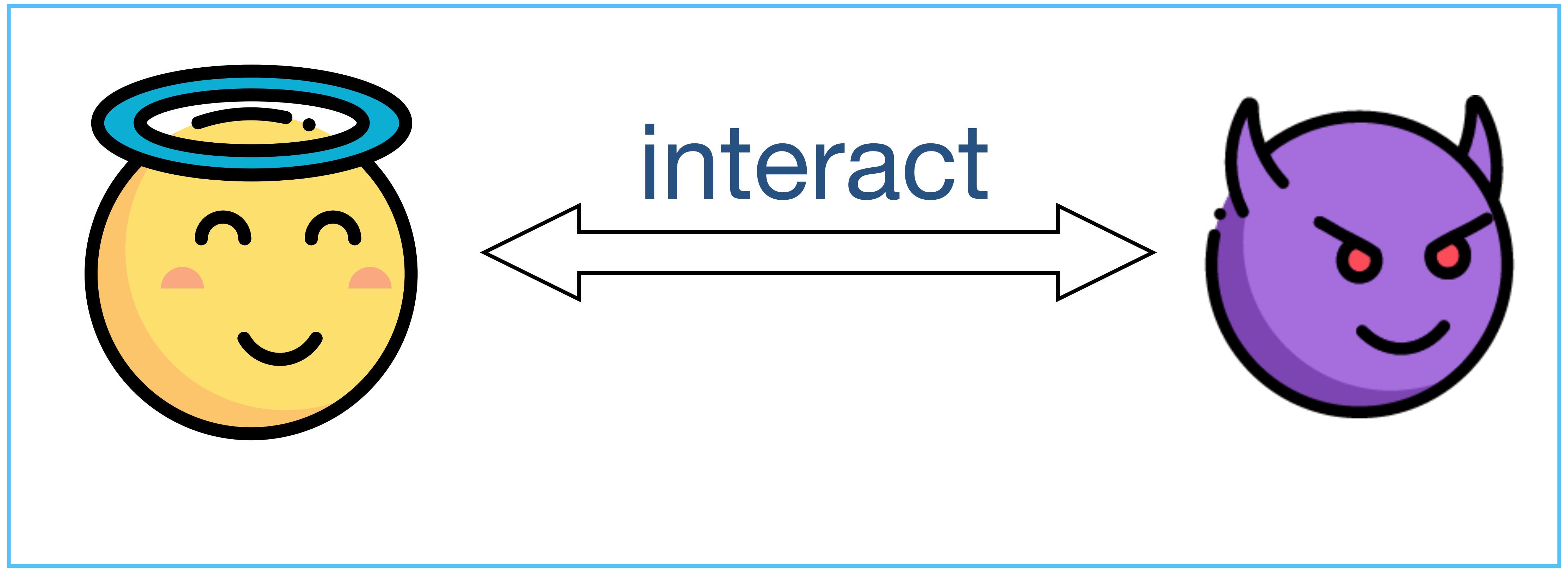
Corrupted & malicious $\mathbf{f}_i$: $$hsk_i \leftarrow \boxed{[\mathbf{M}\mathbf{f}_i^\top]_2}$$

$$ct \leftarrow \boxed{\mathbf{x}}$$

sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Simulator



$$\widetilde{crs} \leftarrow \boxed{[\mathbf{M}]}$$

Corrupted & malicious $\mathbf{f}_i$: $hsk_i \leftarrow \boxed{[\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2}$

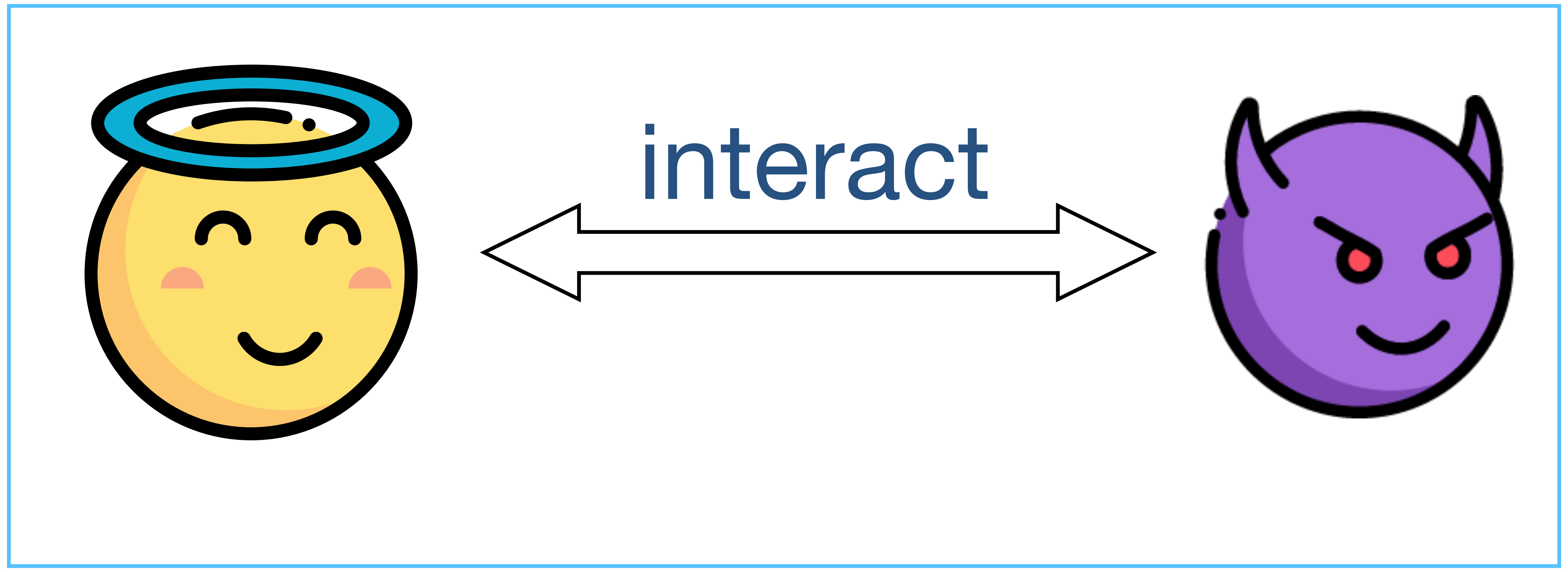
$$\widetilde{ct} \leftarrow \cancel{\boxed{}}$$

Idea from plain IPFE

sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Simulator



$\widetilde{crs} \leftarrow \boxed{[\mathbf{M}]}$

Corrupted & malicious $\mathbf{f}_i$: $hsk_i \leftarrow \boxed{[\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2}$

$\widetilde{ct} \leftarrow \cancel{\boxed{}}$

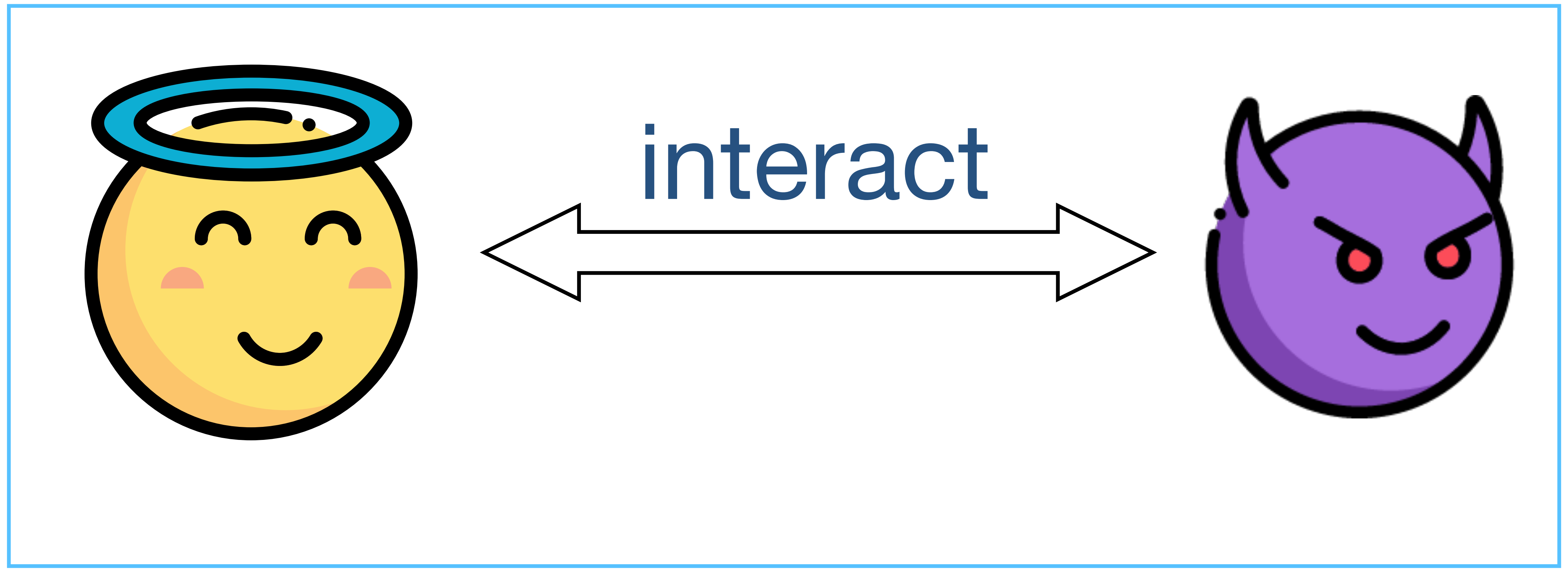
hsk are deterministic!

No chance to embed!

sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Simulator



Corrupted & malicious $\mathbf{f}_i$:

$\widetilde{crs} \leftarrow \boxed{[\mathbf{xMf}_i^\top]_2}$

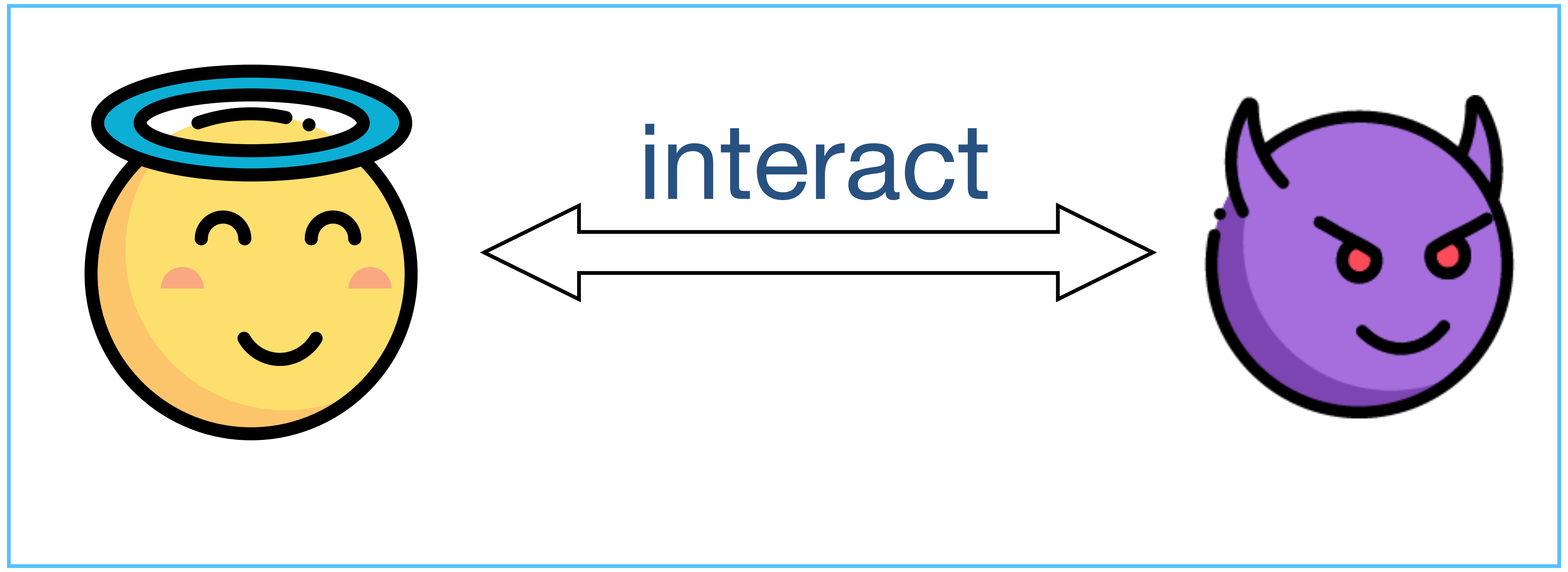
$hsk_i \leftarrow \boxed{[\mathbf{xMf}_i^\top]_2}$

$\widetilde{ct} \leftarrow \cancel{\boxed{}}$

sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Simulator



Corrupted & malicious $\mathbf{f}_i$:

$\widetilde{crs} \leftarrow \boxed{[\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2}$

$hsk_i \leftarrow \boxed{[\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2}$

$\widetilde{ct} \leftarrow \cancel{\boxed{}}$

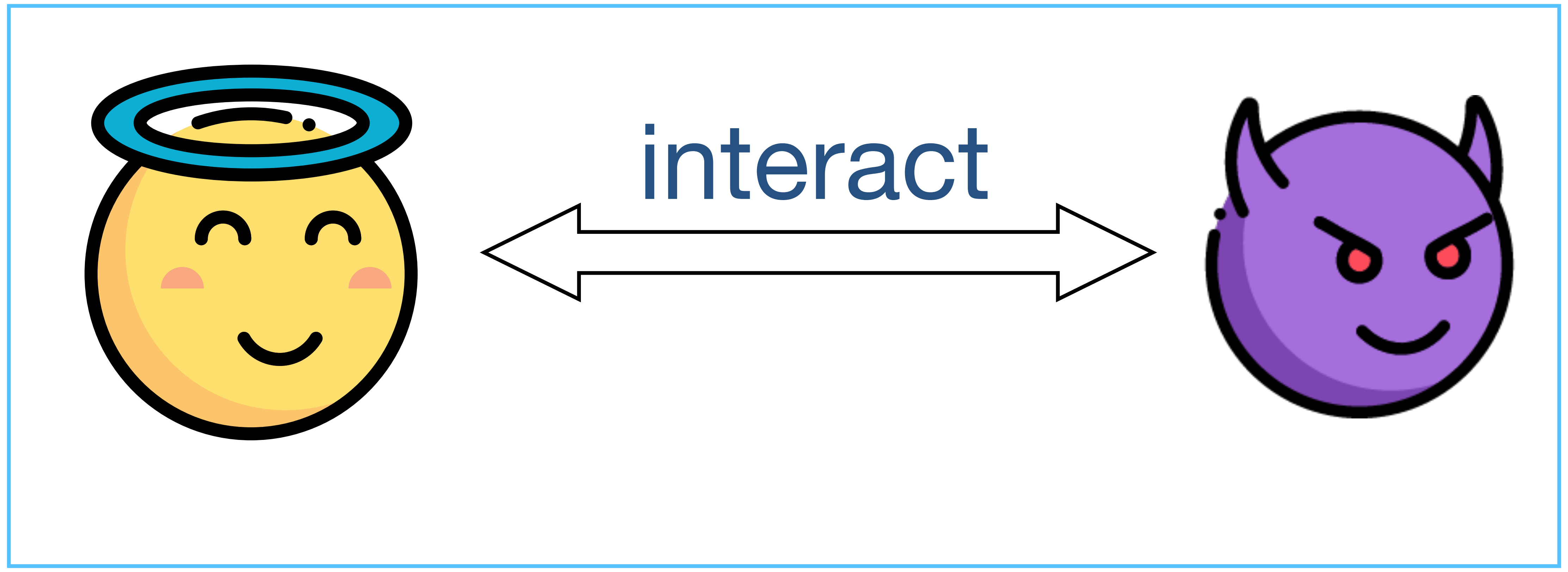
Claim at beginning:

- challenge $\mathbf{x}$
- corrupted & malicious set $\mathscr{C}, \mathscr{M}$
- functions $\mathbf{f}_i$

sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Simulator



Corrupted & malicious $\mathbf{f}_i$:

$\widetilde{crs} \leftarrow [\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2$

$hsk_i \leftarrow [\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2$

$\widetilde{ct} \leftarrow \cancel{\square}$

Claim at beginning:

challenge $\mathbf{x}$ Requirement of “selective”

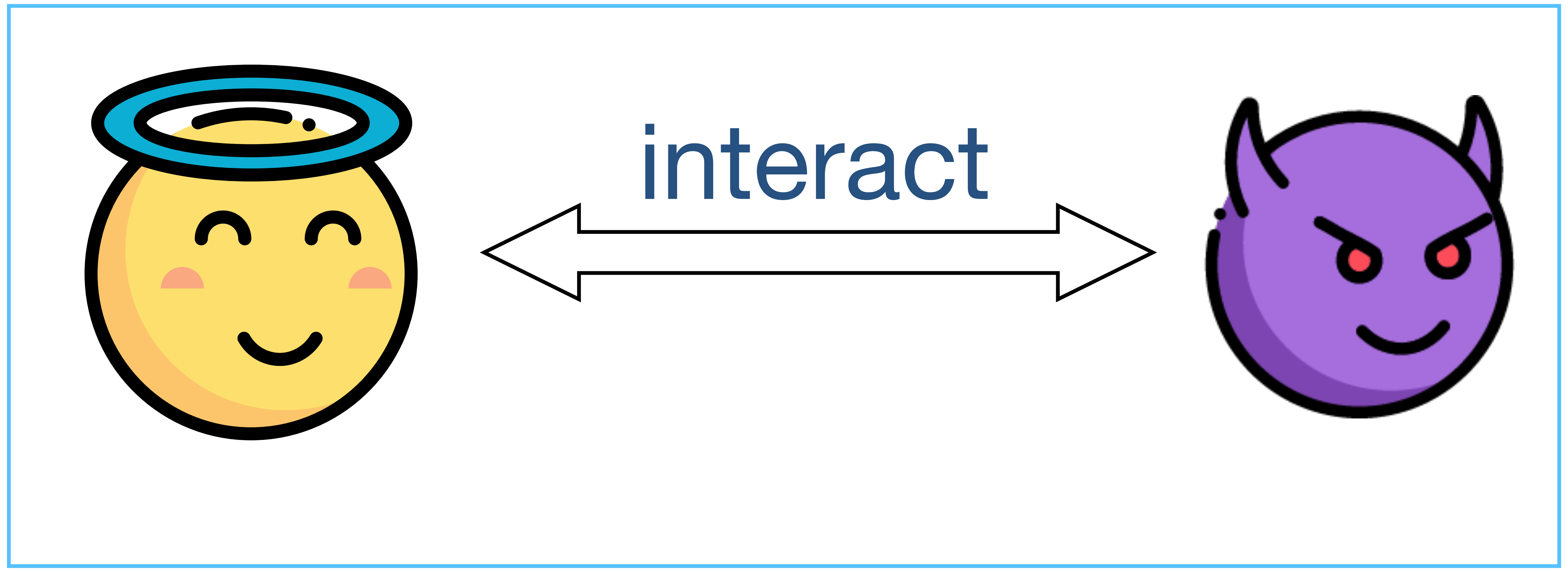
corrupted & malicious set $\mathscr{C}, \mathscr{M}$

functions $\mathbf{f}_i$

sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Simulator



Corrupted & malicious $\mathbf{f}_i$:

$\widetilde{crs} \leftarrow [\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2$

$hsk_i \leftarrow [\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2$

$\widetilde{ct} \leftarrow \cancel{\boxed{}}$

Claim at beginning:

challenge $\mathbf{x}$

corrupted & malicious set $\mathscr{C}, \mathscr{M}$

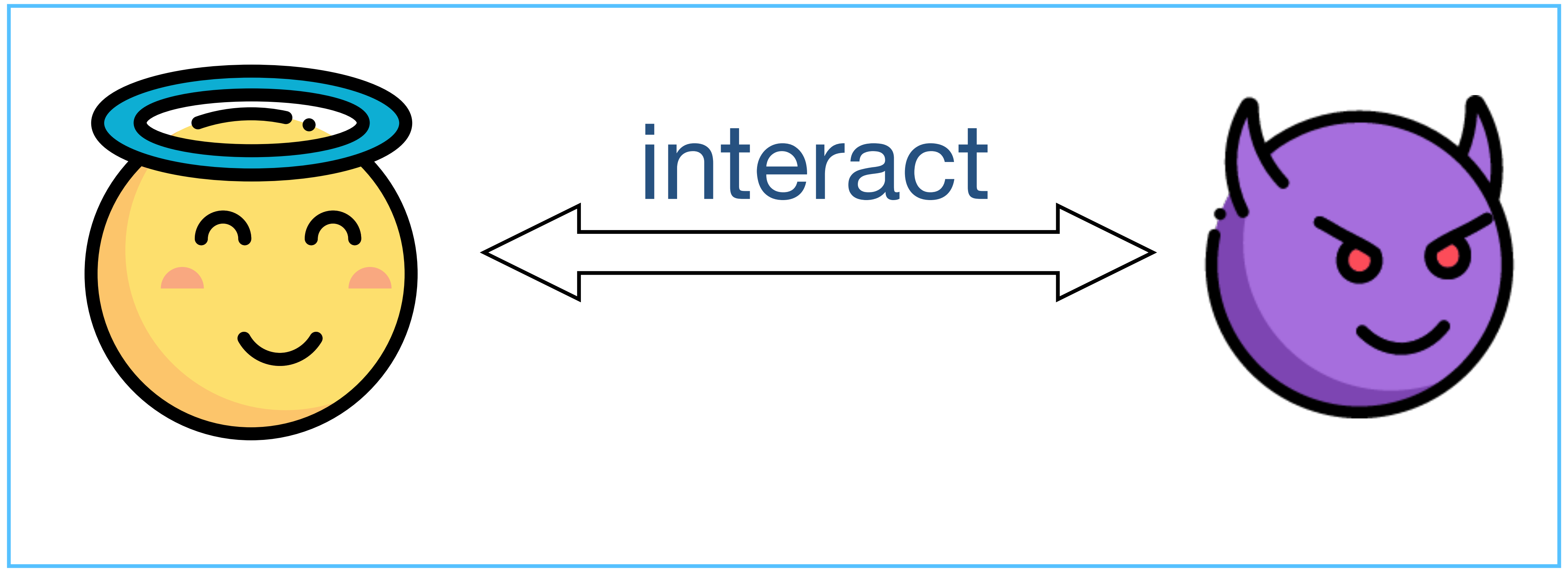
functions $\mathbf{f}_i$

Similar to “very selective” in [AMY19]

sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Simulator



Corrupted & malicious $\mathbf{f}_i$:

$\widetilde{crs} \leftarrow [\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2$

$hsk_i \leftarrow [\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2$

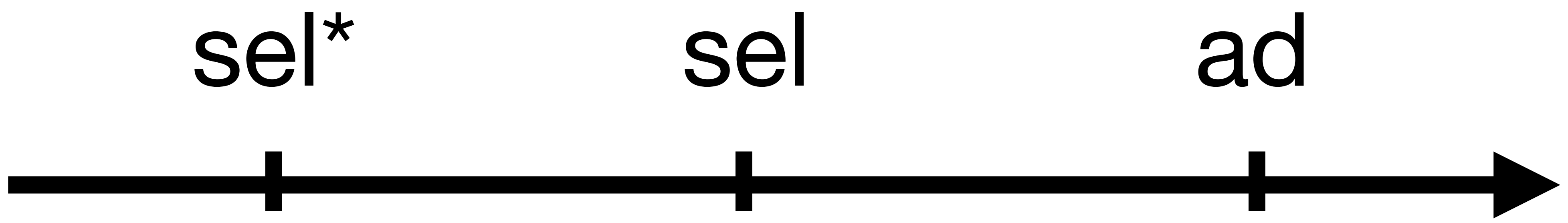
$\widetilde{ct} \leftarrow \cancel{\boxed{}}$

Claim at beginning:

challenge $\mathbf{x}$

corrupted & malicious set $\mathscr{C}, \mathscr{M}$

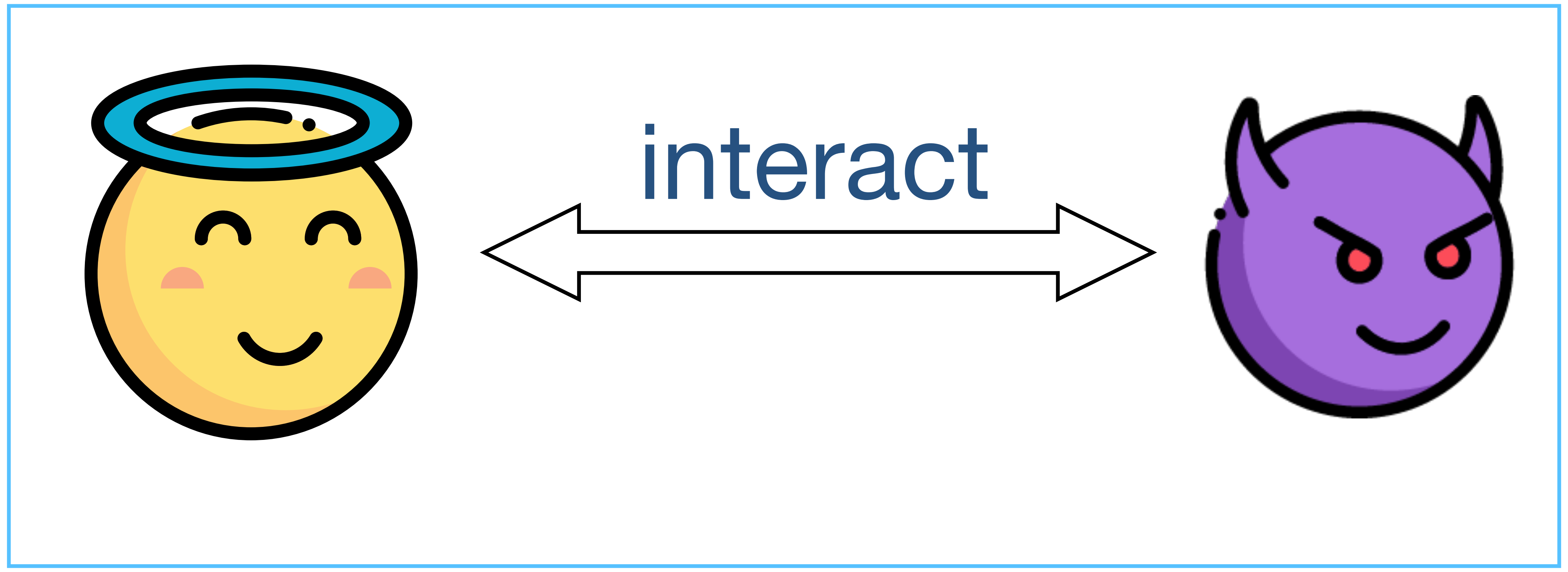
functions $\mathbf{f}_i$



sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Simulator



Corrupted & malicious $\mathbf{f}_i$:

$\widetilde{crs} \leftarrow \boxed{[\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2}$

$hsk_i \leftarrow \boxed{[\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2}$

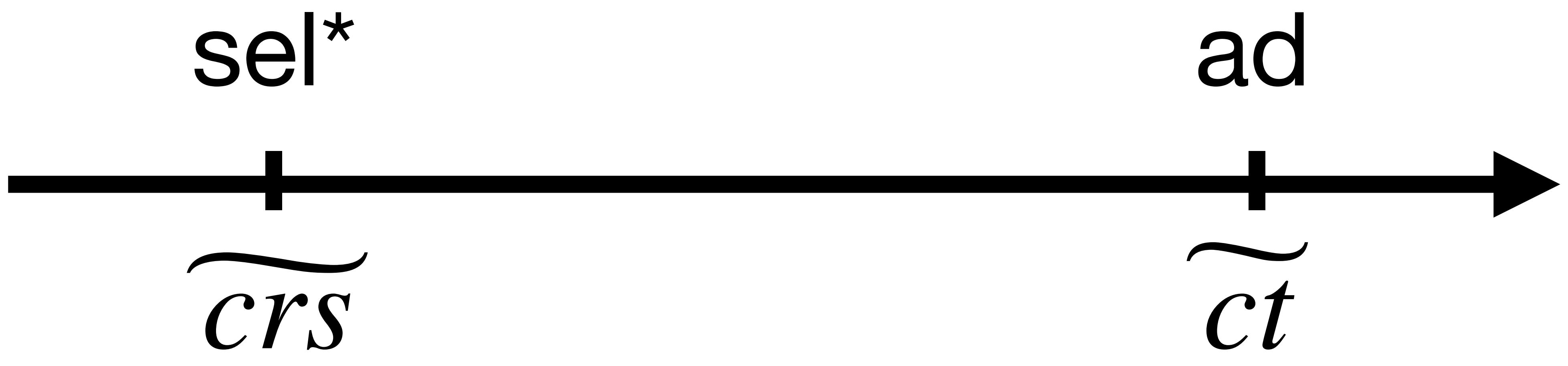
$\widetilde{ct} \leftarrow \cancel{\square}$

Claim at beginning:

challenge $\mathbf{x}$

corrupted & malicious set $\mathscr{C}, \mathscr{M}$

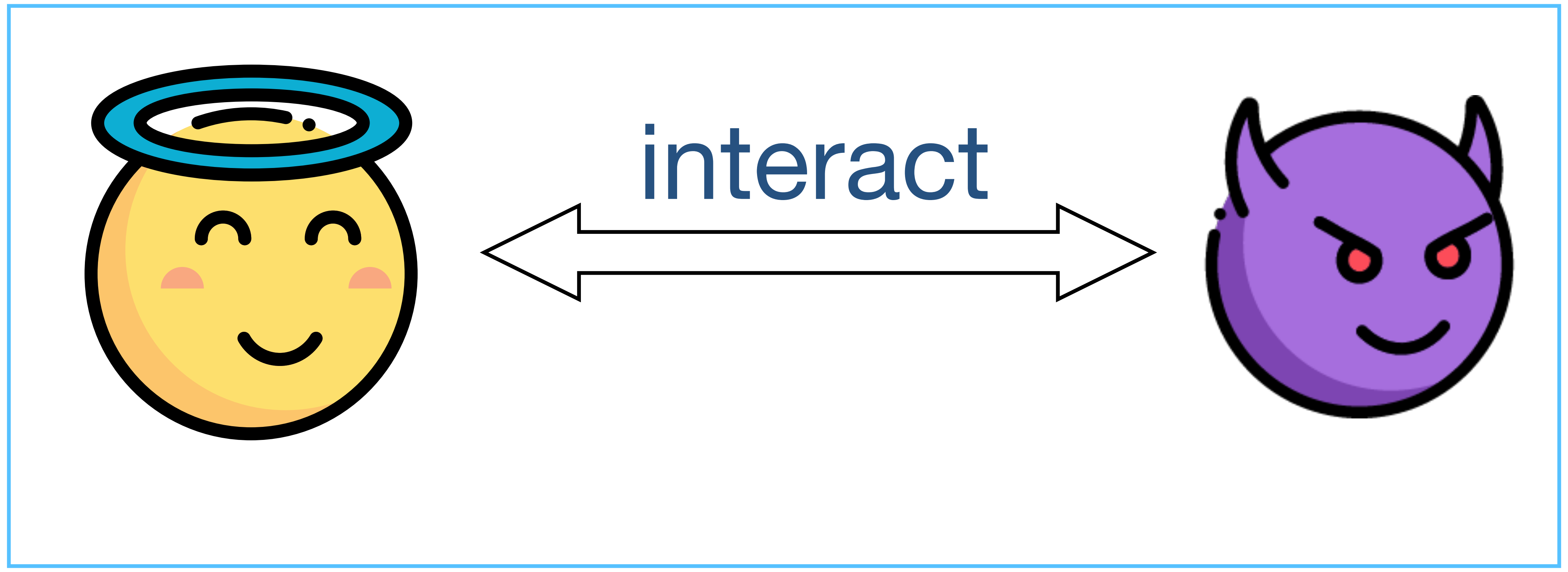
functions $\mathbf{f}_i$



sReg-IPFE to sReg-QFE: Challenge-3

First time consider SIM-security in registration

Simulator



Corrupted & malicious $\mathbf{f}_i$:

$\widetilde{crs} \leftarrow \boxed{[\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2}$

$hsk_i \leftarrow \boxed{[\mathbf{x}\mathbf{M}\mathbf{f}_i^\top]_2}$

$\widetilde{ct} \leftarrow \cancel{\boxed{}}$

Claim at beginning:

challenge $\mathbf{x}$

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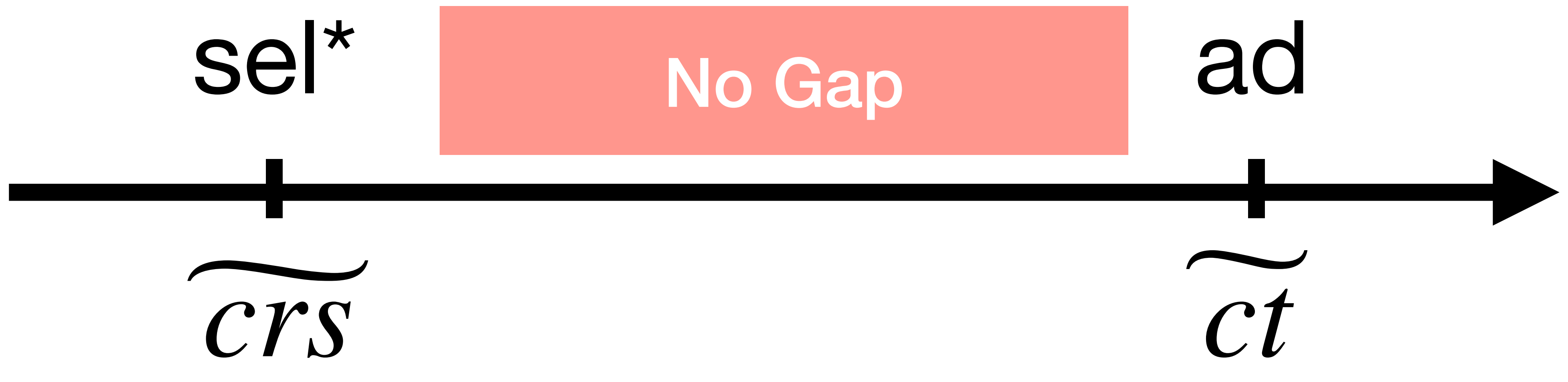
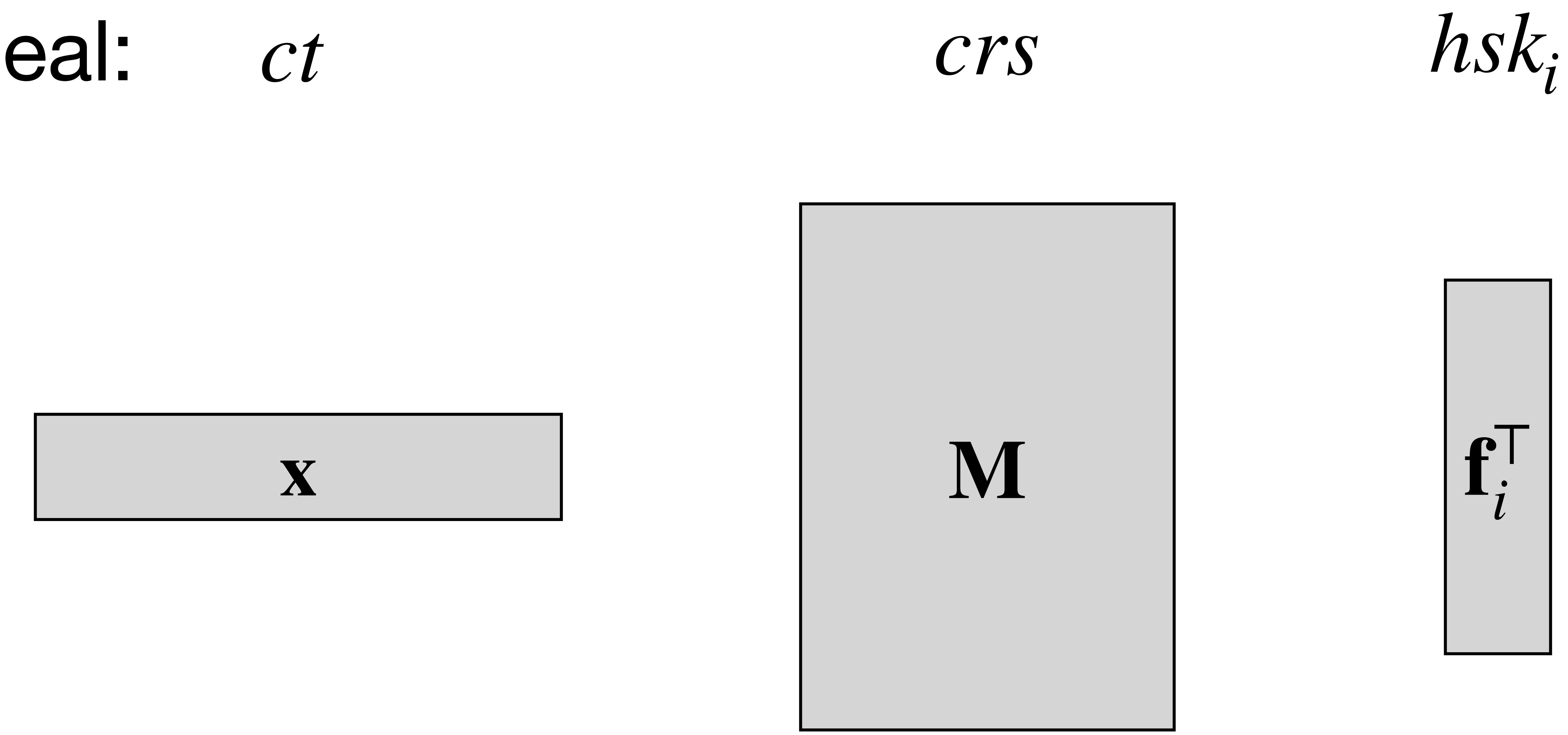


sReg-IPFE to sReg-QFE: Solution-3

To achieve sel*-SIM PReg-IPFE

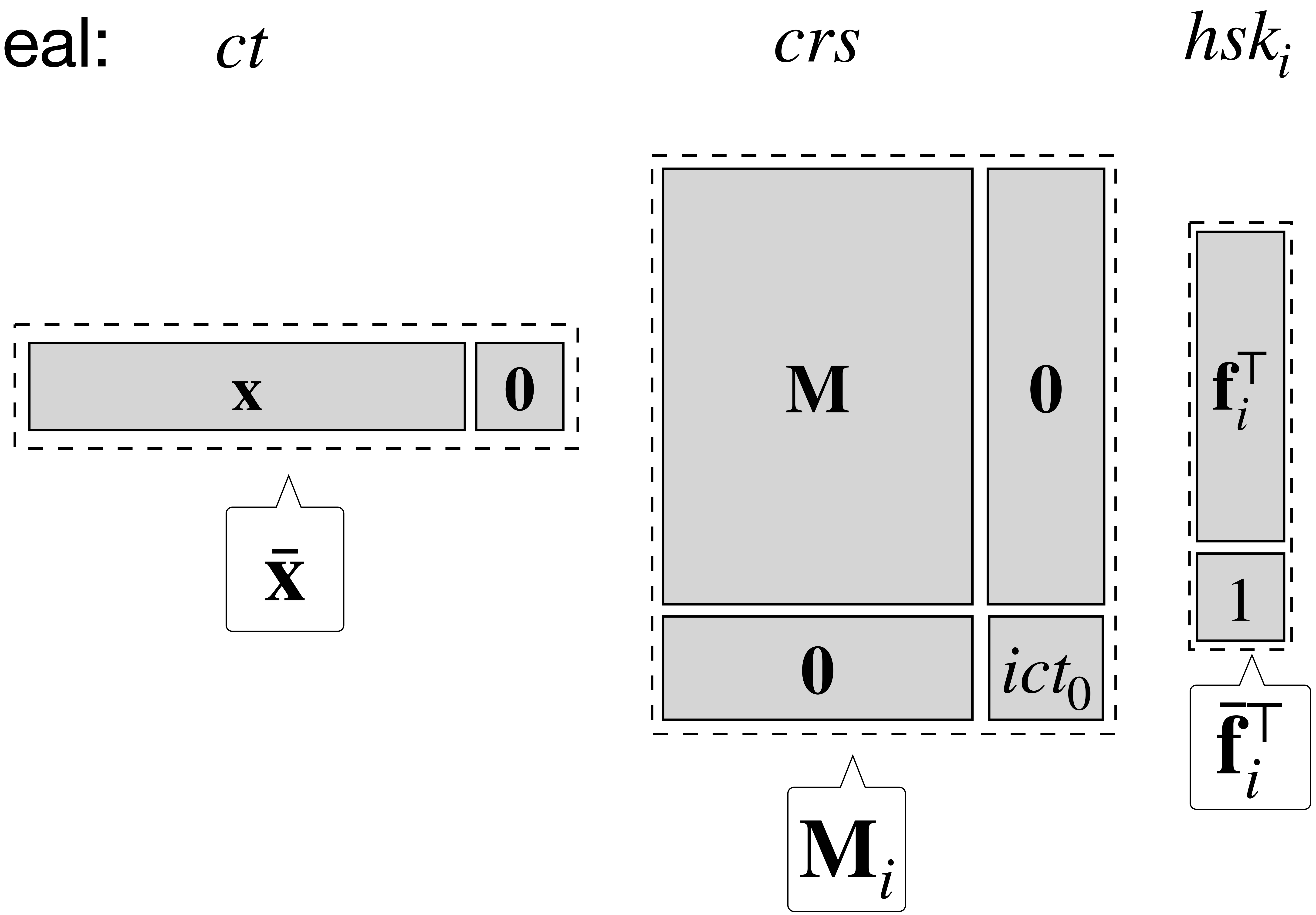
Real:



sReg-IPFE to sReg-QFE: Solution-3

To achieve sel*-SIM PReg-IPFE

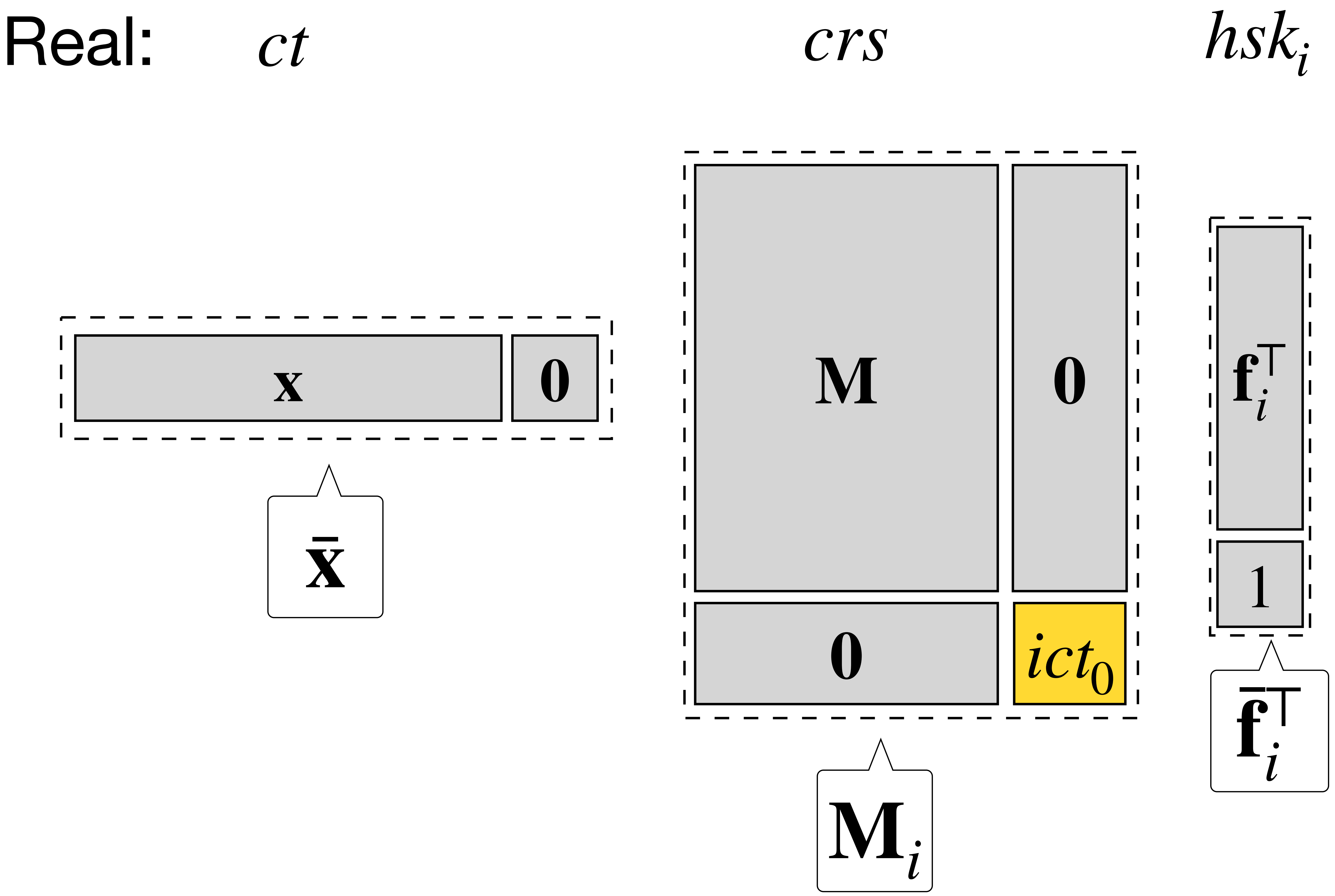
Real:



sReg-IPFE to sReg-QFE: Solution-3

To achieve sel*-SIM PReg-IPFE

Real:



With PKE:

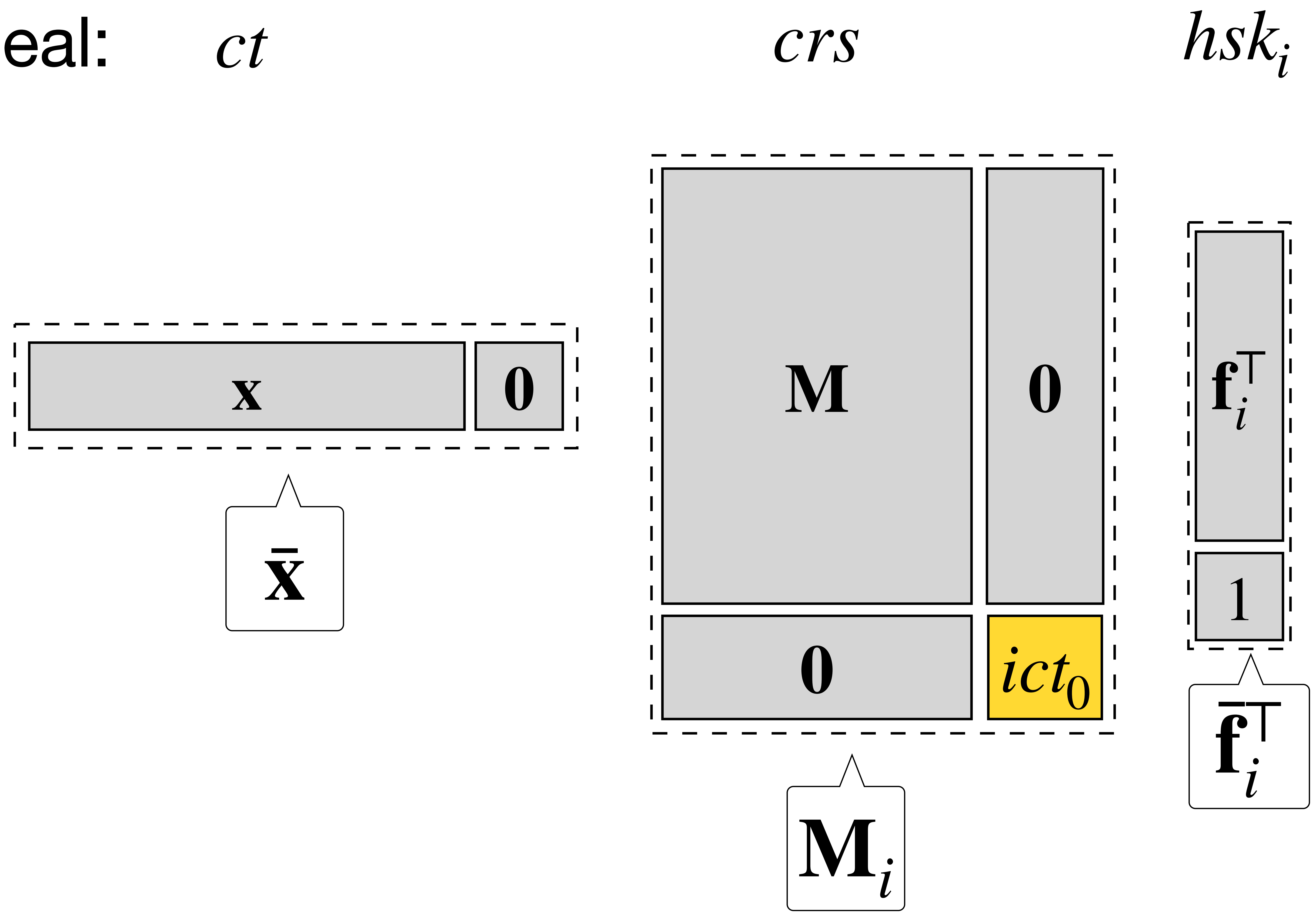
$(ipk, isk) \leftarrow iGen(1^\lambda)$

$ict_0 \leftarrow iEnc(0)$

sReg-IPFE to sReg-QFE: Solution-3

To achieve sel*-SIM PReg-IPFE

Real:



With PKE:

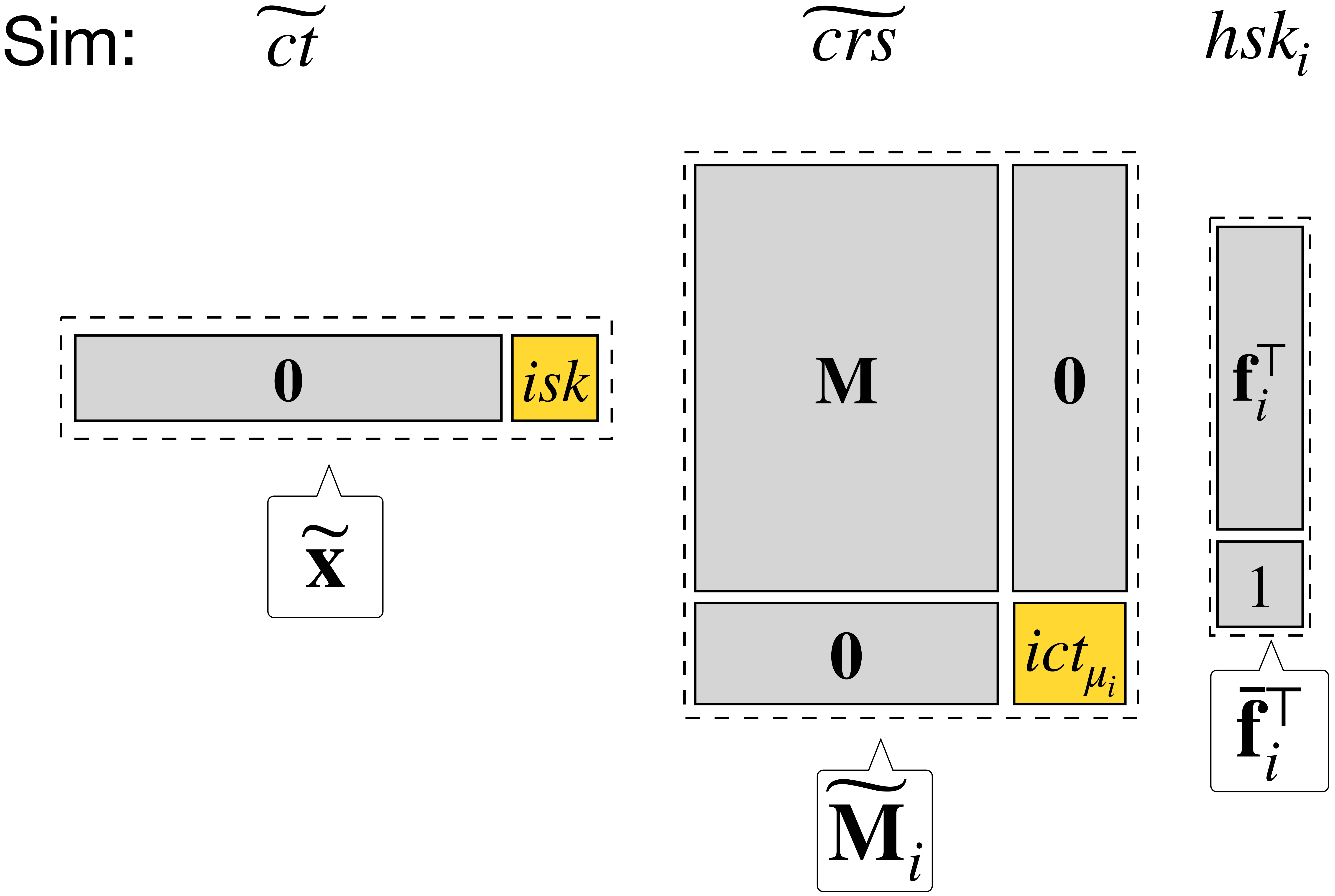
$$(ipk, isk) \leftarrow iGen(1^\lambda)$$

$$\boxed{ict_0} \leftarrow iEnc(0)$$

$$\bar{\mathbf{x}}\mathbf{M}_i\bar{\mathbf{f}}_i^\top = \mathbf{x}\mathbf{M}\mathbf{f}_i^\top$$

sReg-IPFE to sReg-QFE: Solution-3

To achieve sel*-SIM PReg-IPFE



With PKE:

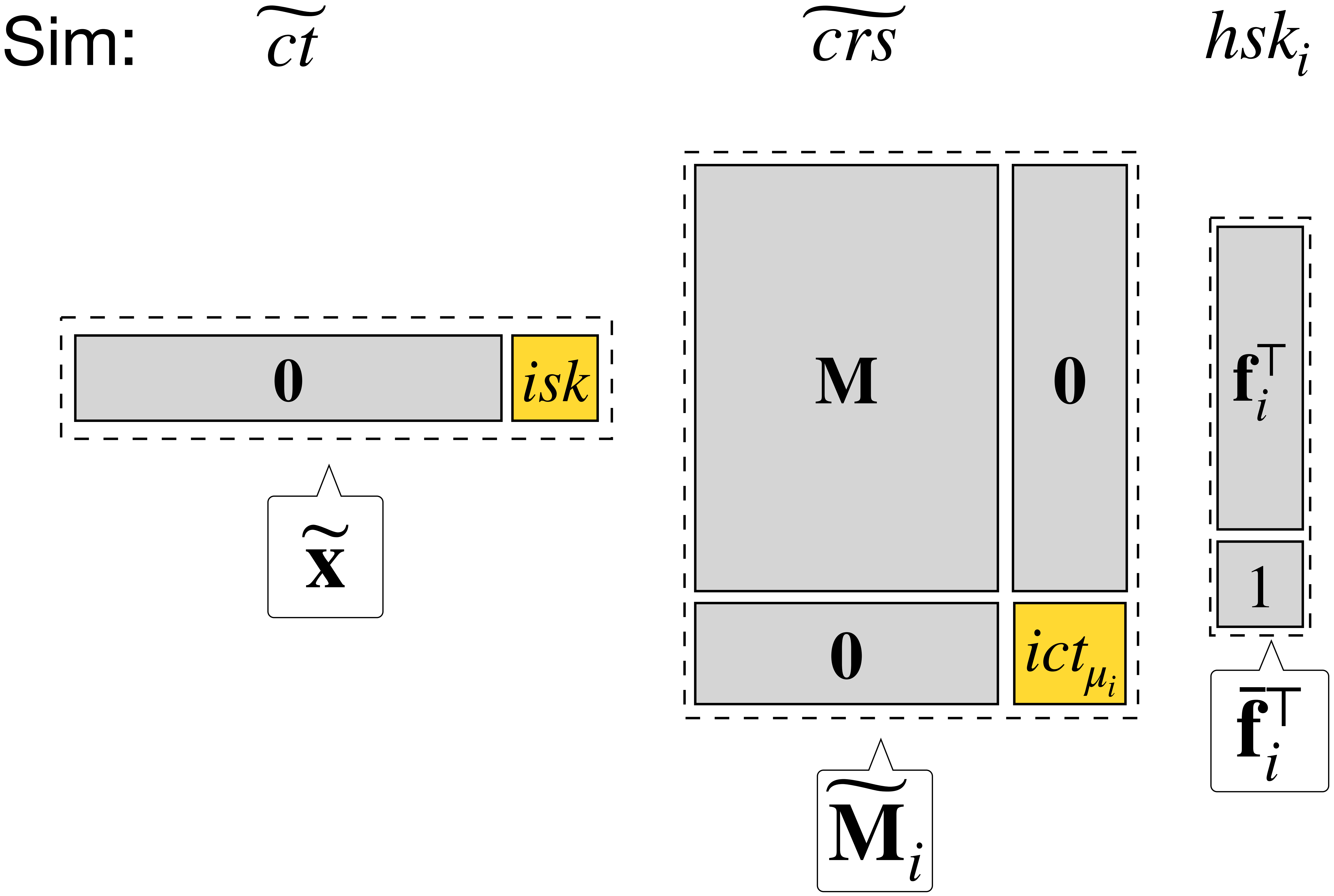
$(ipk, isk) \leftarrow iGen(1^\lambda)$

$ict_{\mu_i} \leftarrow iEnc(\mathbf{x}\mathbf{M}\mathbf{f}_i^\top)$

$i \in \mathscr{C} \cup \mathscr{M}$

sReg-IPFE to sReg-QFE: Solution-3

To achieve sel*-SIM PReg-IPFE



With PKE:

$(ipk, isk) \leftarrow iGen(1^\lambda)$

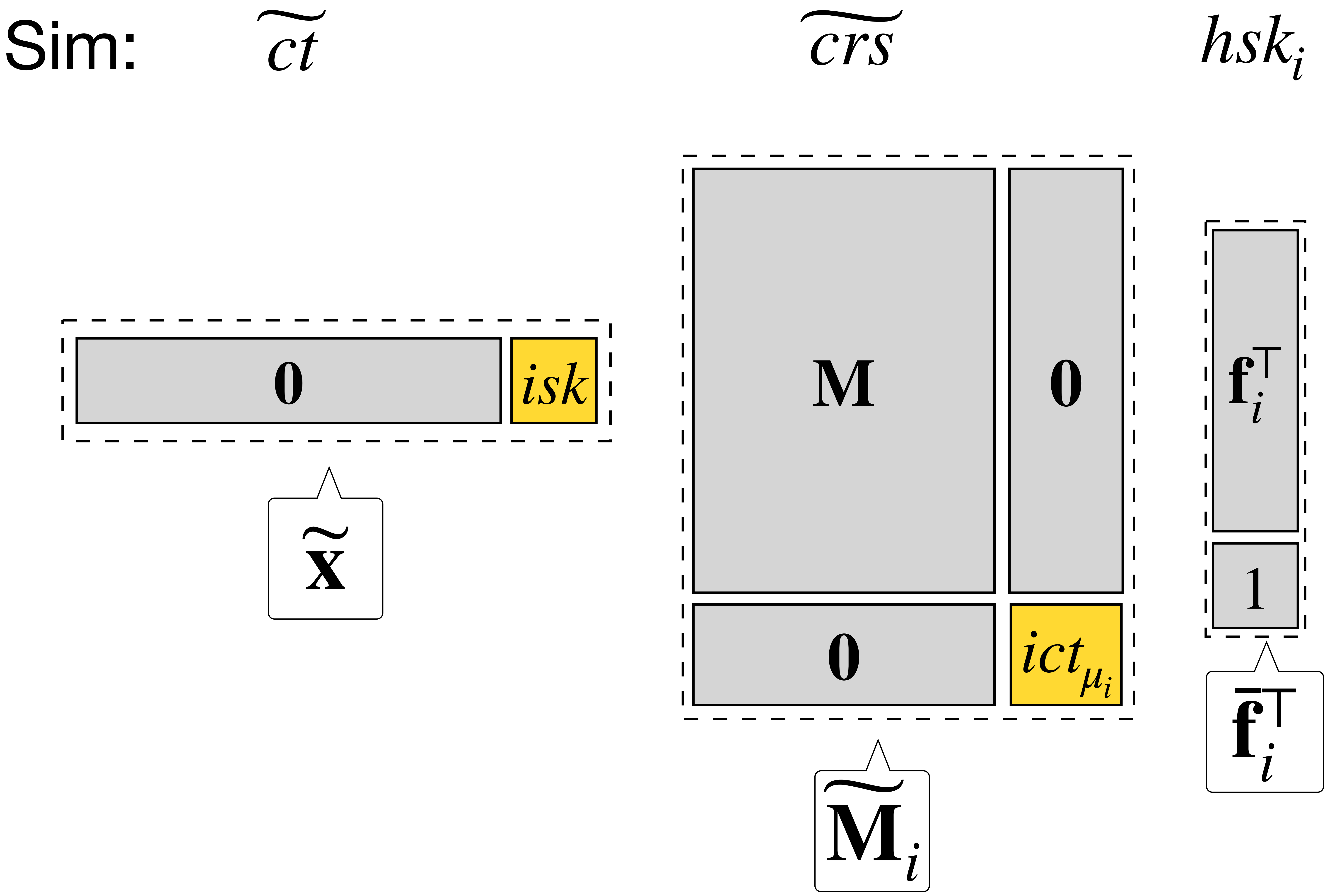
$ict_{\mu_i} \leftarrow iEnc(\mathbf{x}\mathbf{M}\mathbf{f}_i^\top)$

$i \in \mathscr{C} \cup \mathscr{M}$

$$\tilde{\mathbf{x}}\widetilde{\mathbf{M}}_i\bar{\mathbf{f}}_i^\top = < isk, ict_{\mu_i} >$$

sReg-IPFE to sReg-QFE: Solution-3

To achieve sel*-SIM PReg-IPFE



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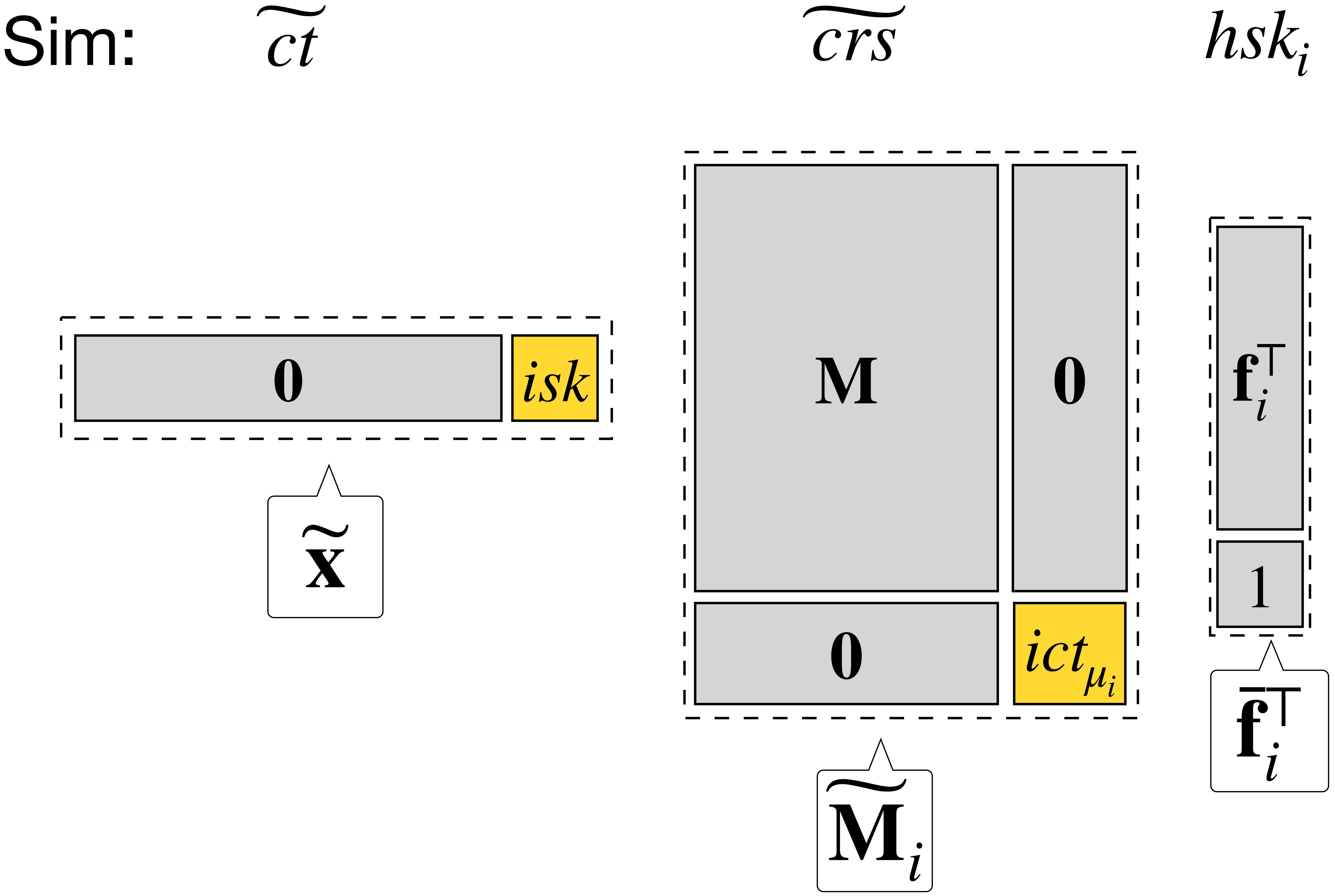

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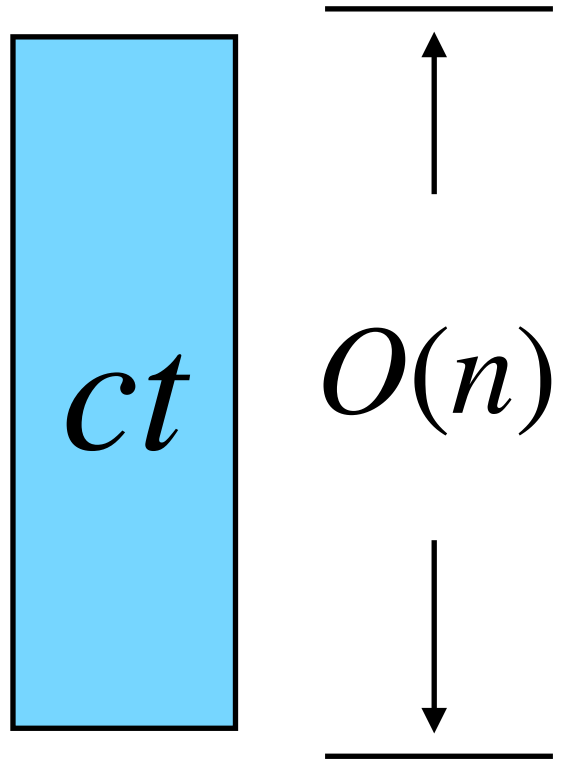
$$\tilde{\mathbf{x}}\widetilde{\mathbf{M}}_i\bar{\mathbf{f}}_i^\top = \boxed{< isk, ict_{\mu_i} > = \mathbf{x}\mathbf{M}\mathbf{f}_i^\top}$$

linear decryption

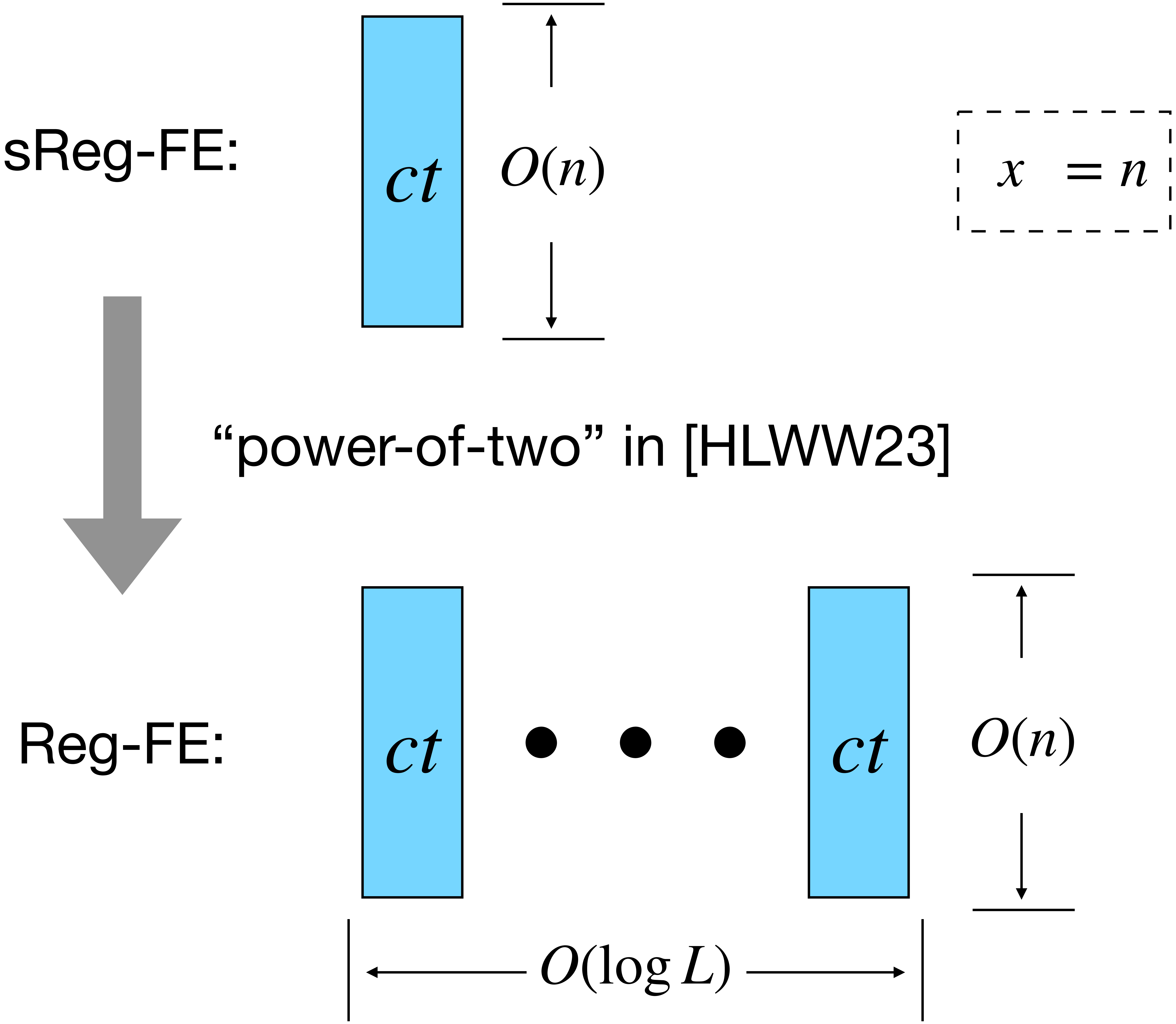
To Compact Ciphertext

sReg-FE:



$x \quad = n$

To Compact Ciphertext



sReg-FE: ct $O(n)$

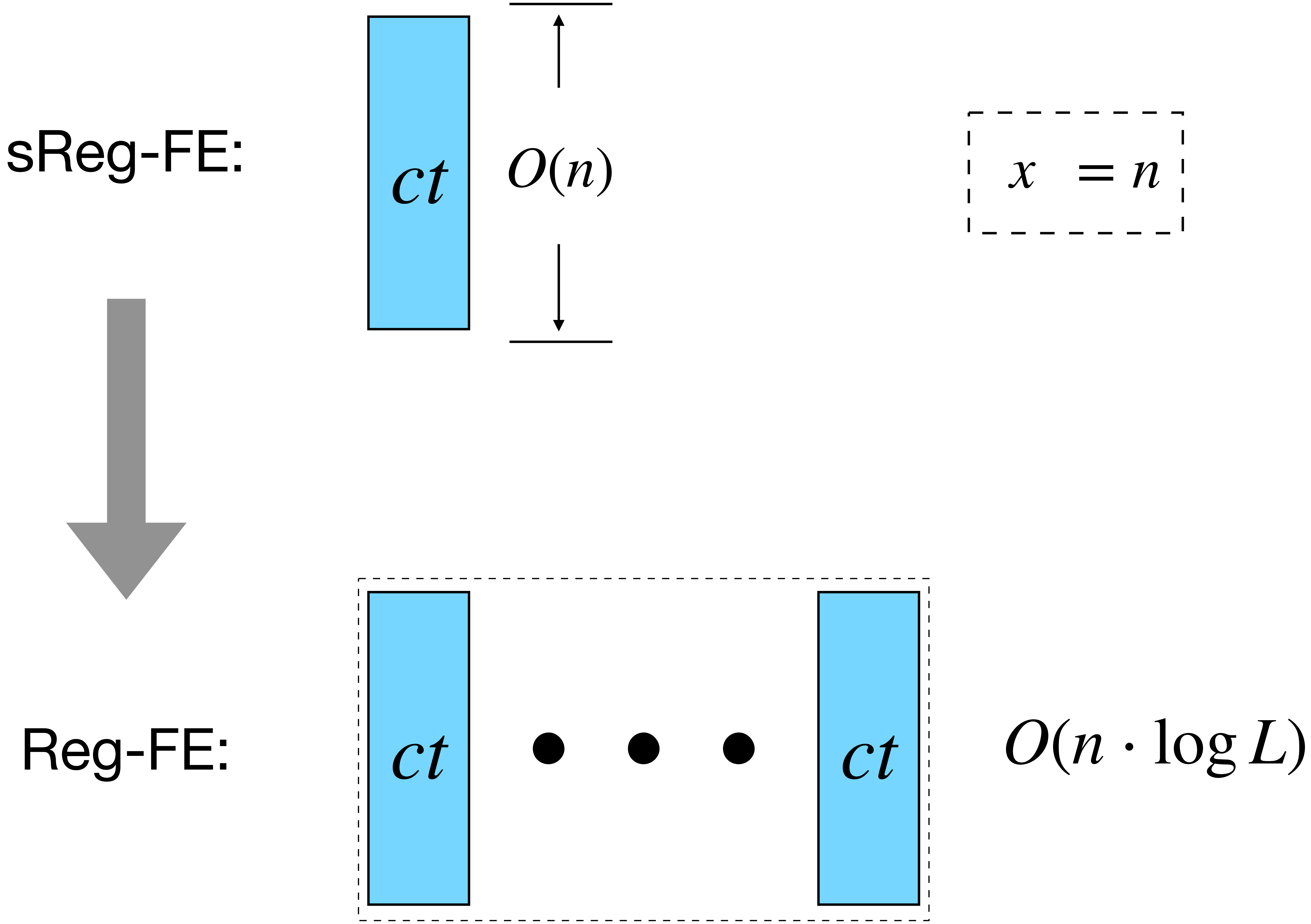
$x = n$

“power-of-two” in [HLWW23]

Reg-FE: ct ● ● ● ct $O(n)$

$O(\log L)$

To Compact Ciphertext



sReg-FE:

ct

$O(n)$

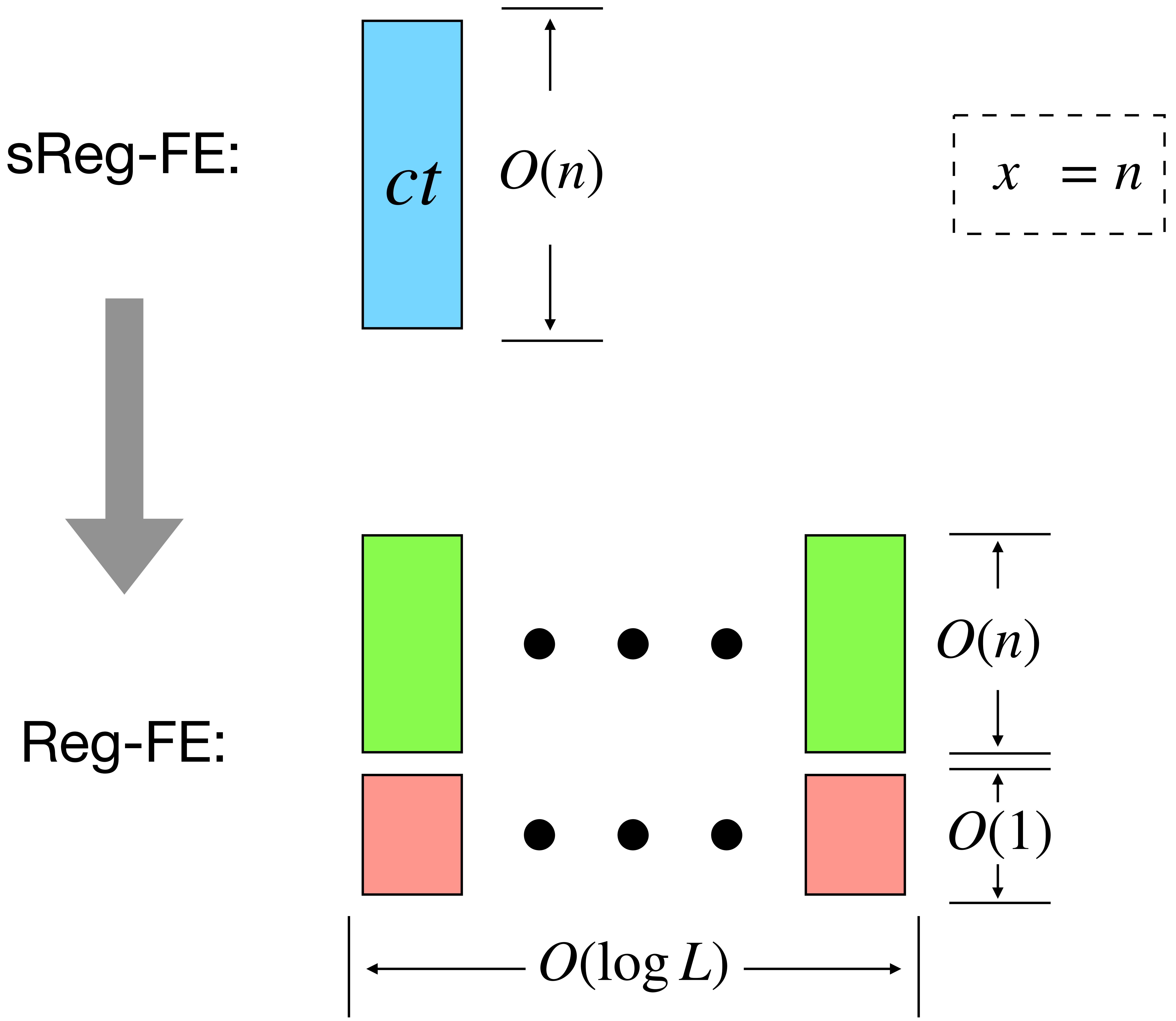
$x \ = n$

Reg-FE:

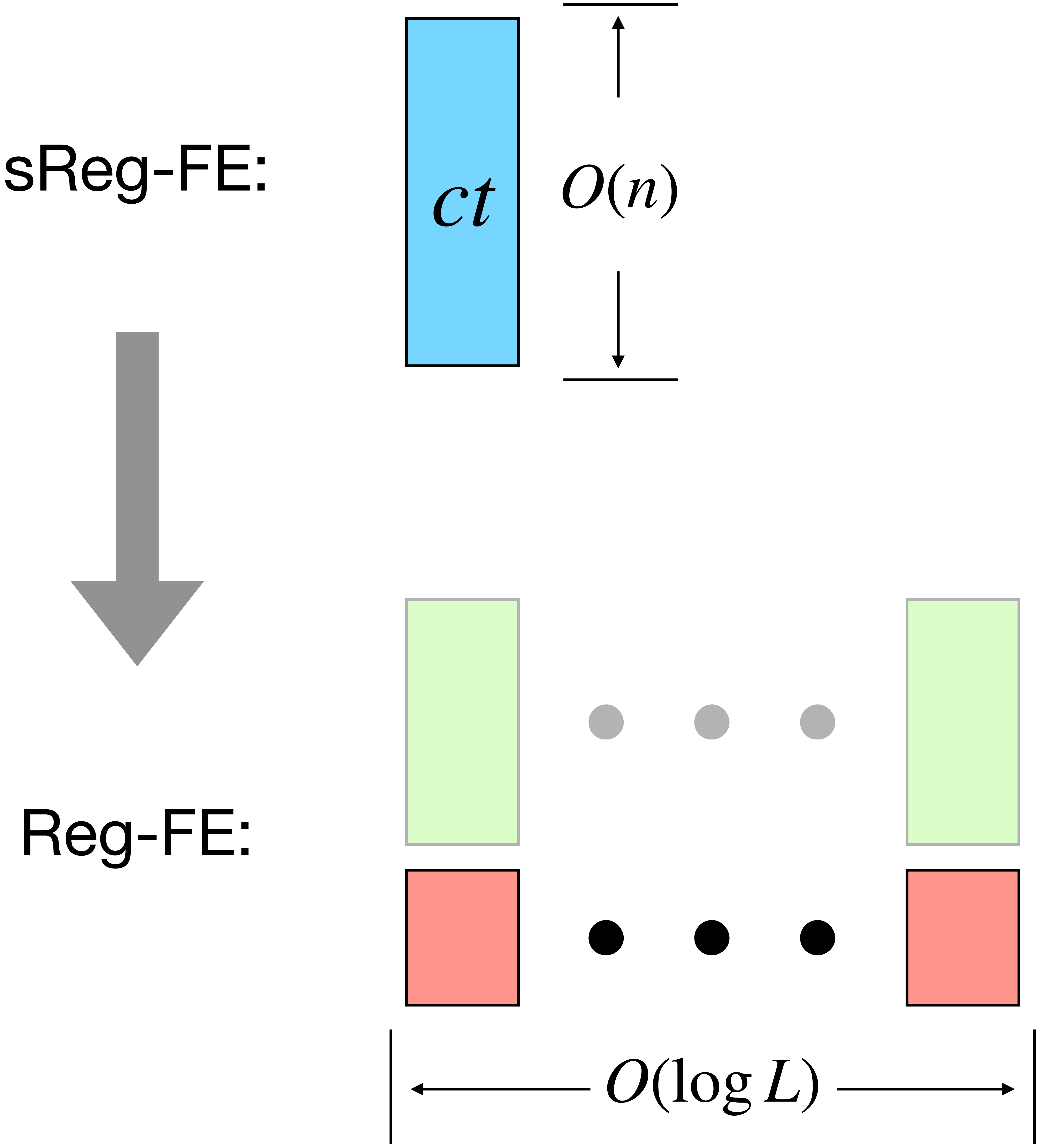
ct ● ● ● ct

$O(n \cdot \log L)$

To Compact Ciphertext



To Compact Ciphertext



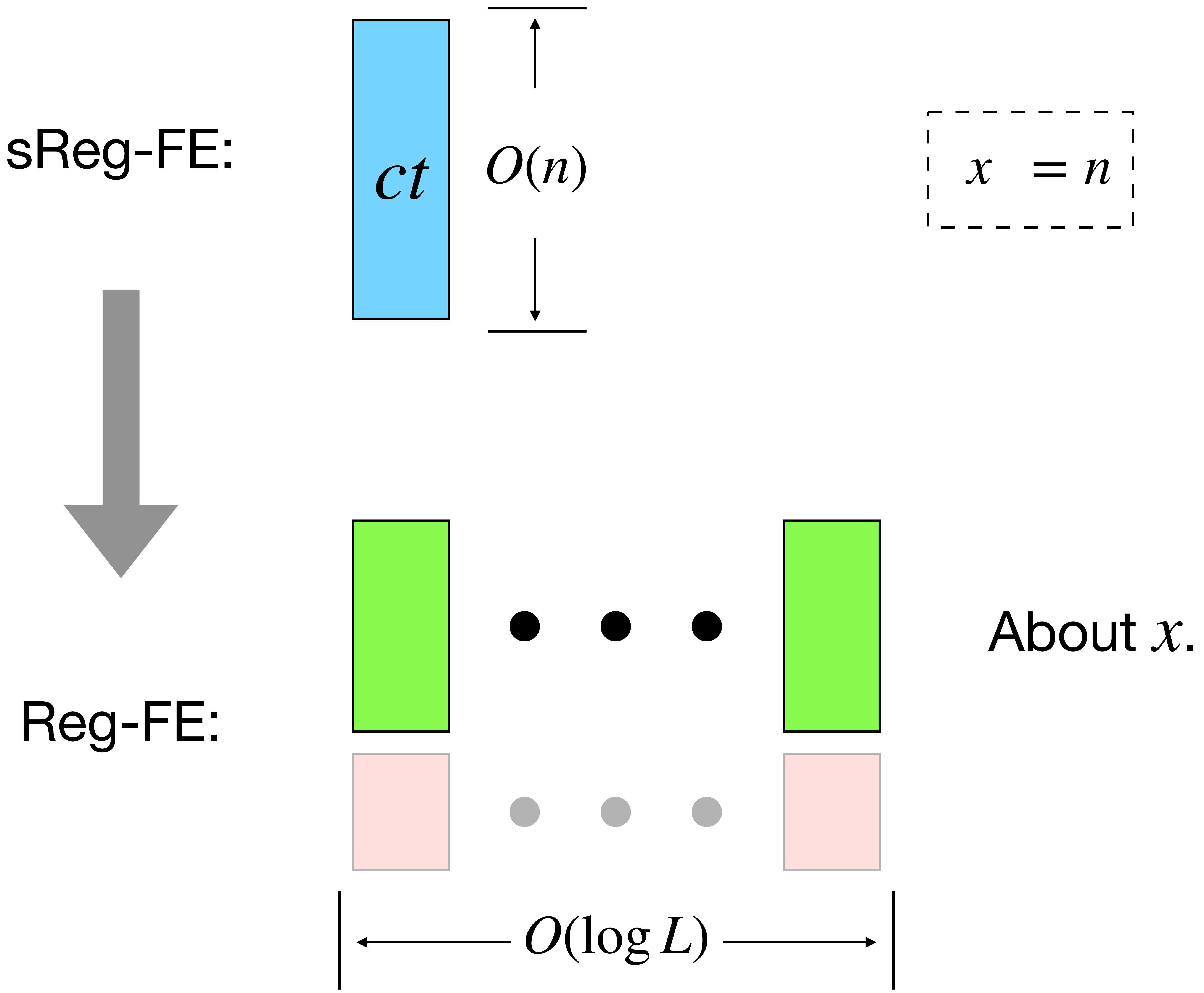
sReg-FE:

Reg-FE:

$x = n$

About users in sReg-FE instance.

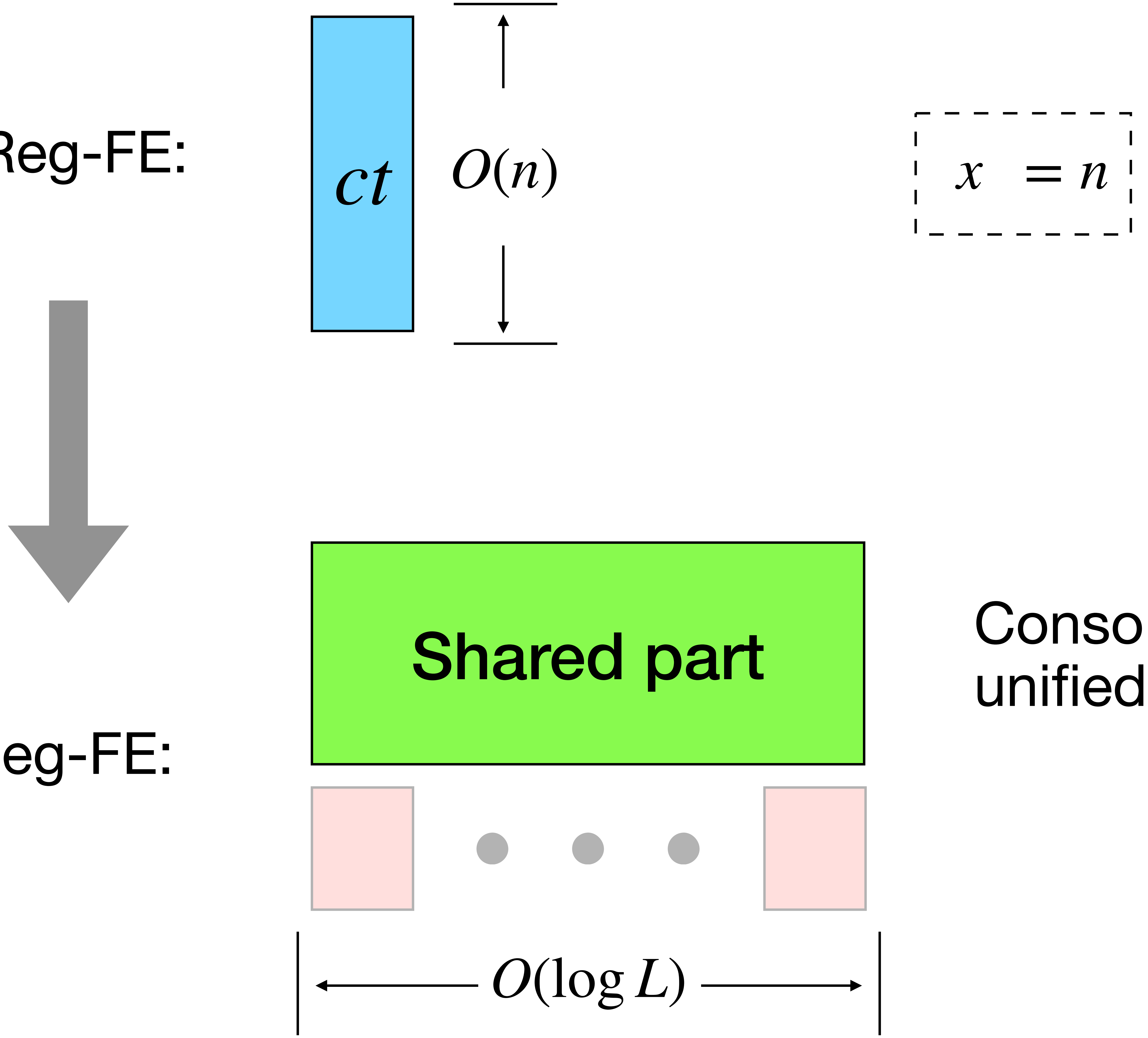
To Compact Ciphertext



To Compact Ciphertext

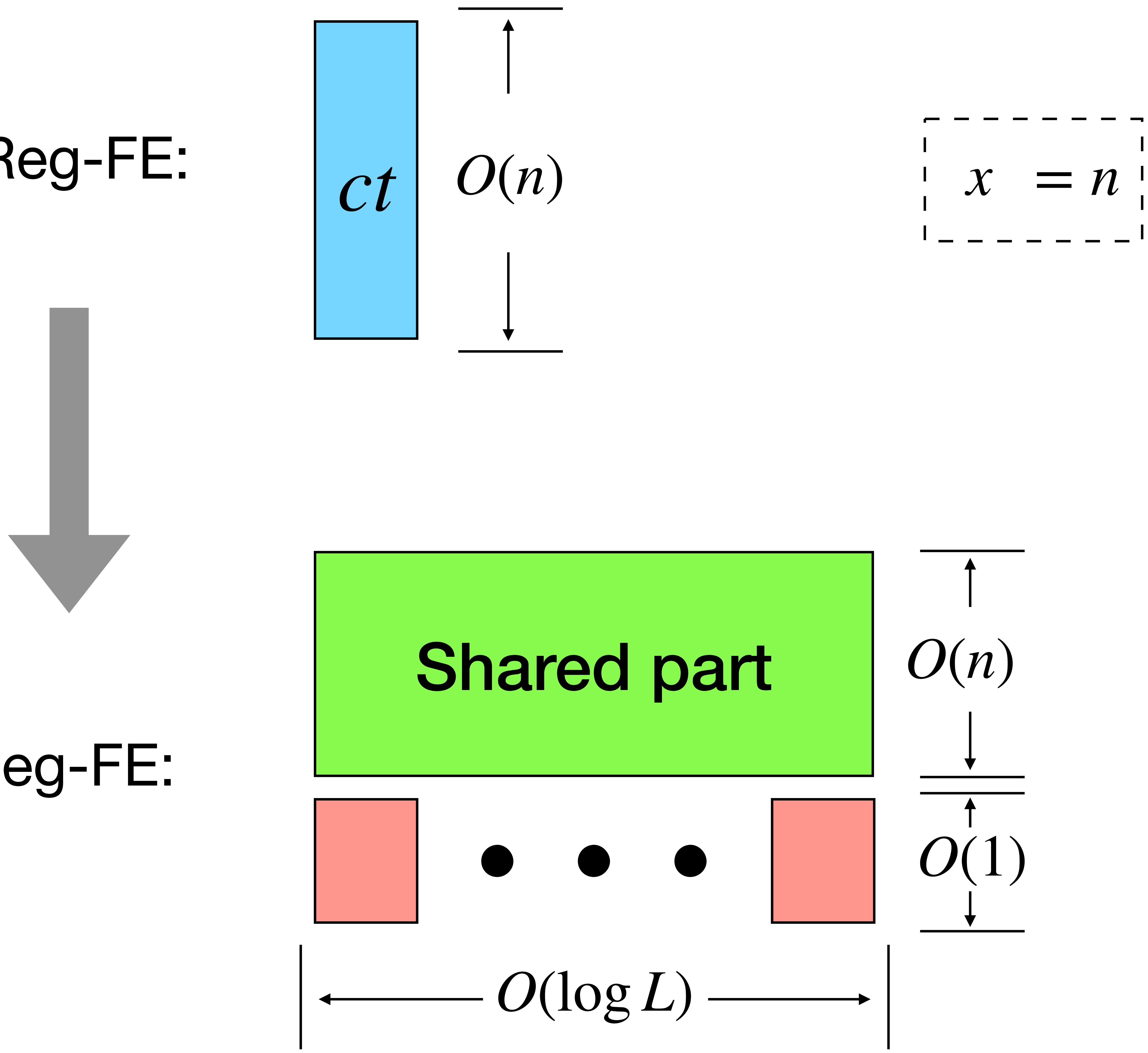
sReg-FE:

Reg-FE:



Consolidate them with a unified random coin.

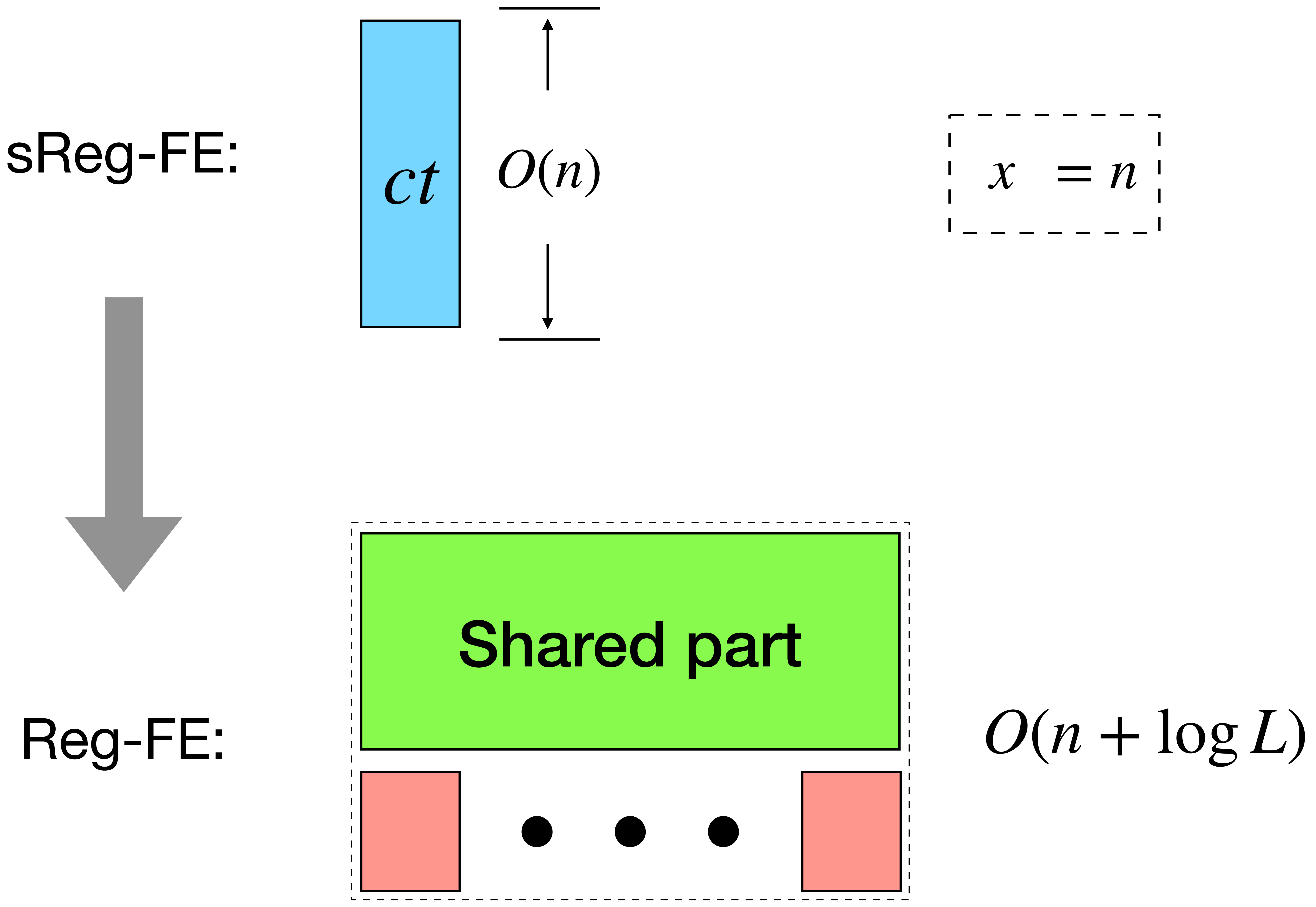
To Compact Ciphertext



sReg-FE:

Reg-FE:

To Compact Ciphertext



sReg-FE:

ct

$O(n)$

$x \quad = n$

Reg-FE:

Shared part

$O(n + \log L)$

Thanks for Your Listening

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