Registered (Inner-Product) Functional Encryption

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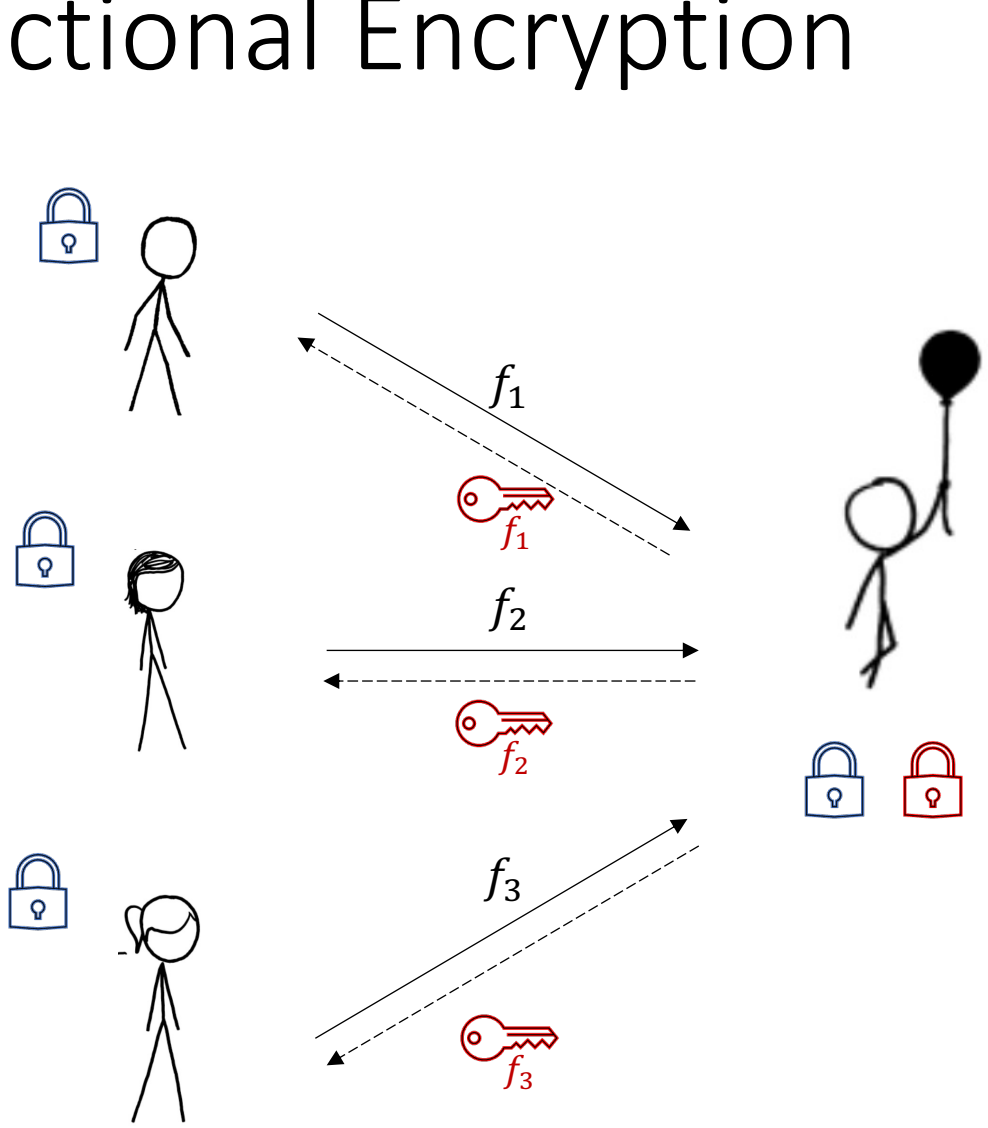
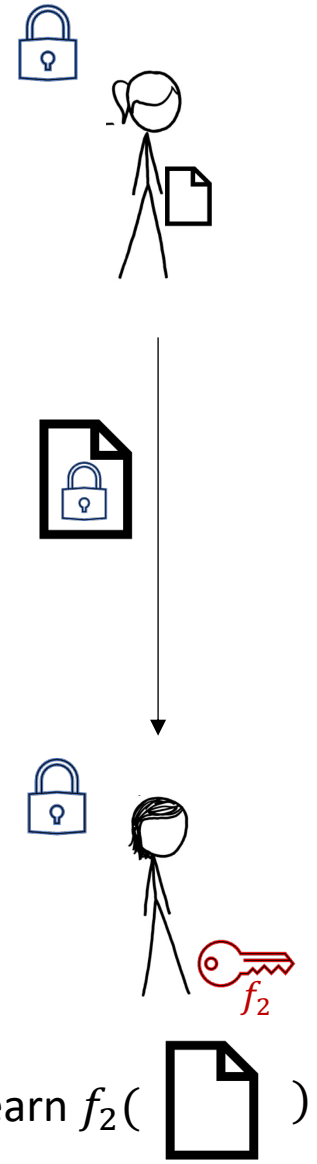
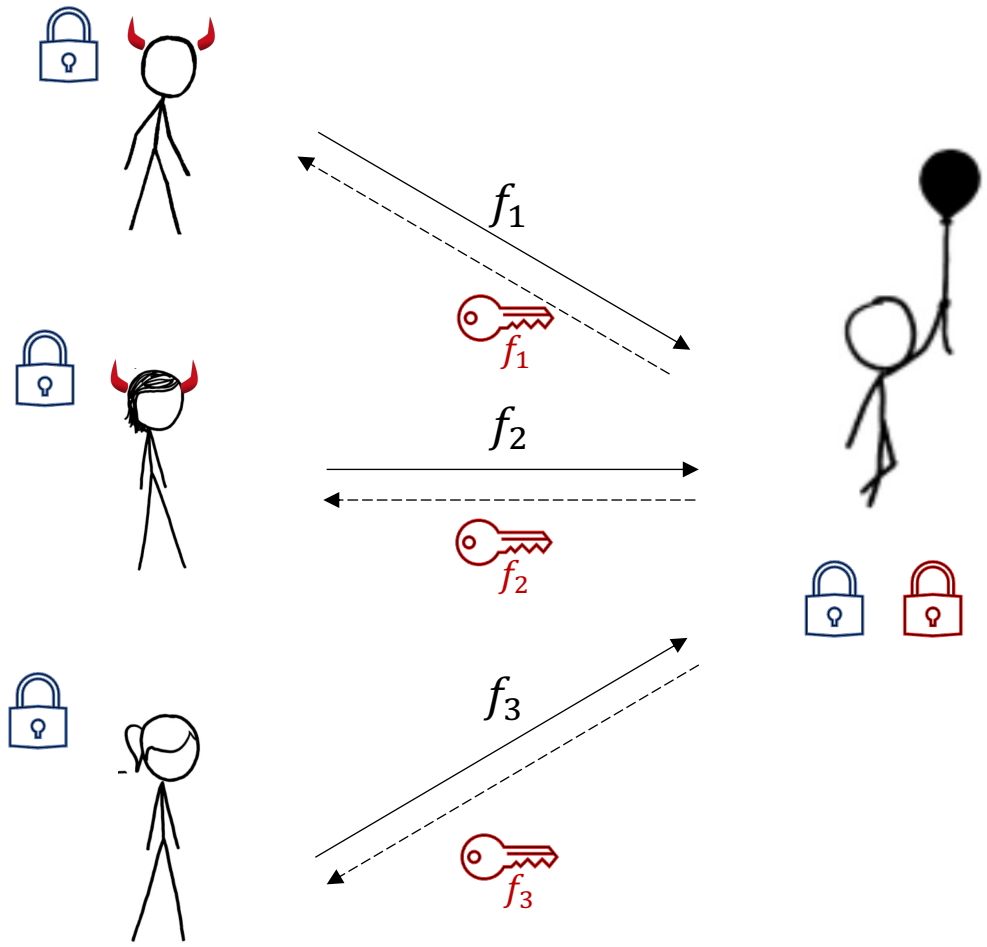
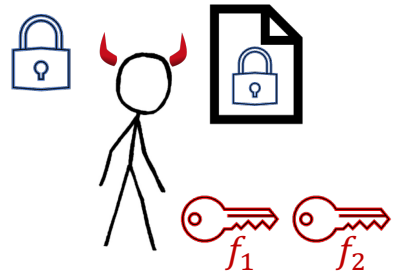
Functional Encryption





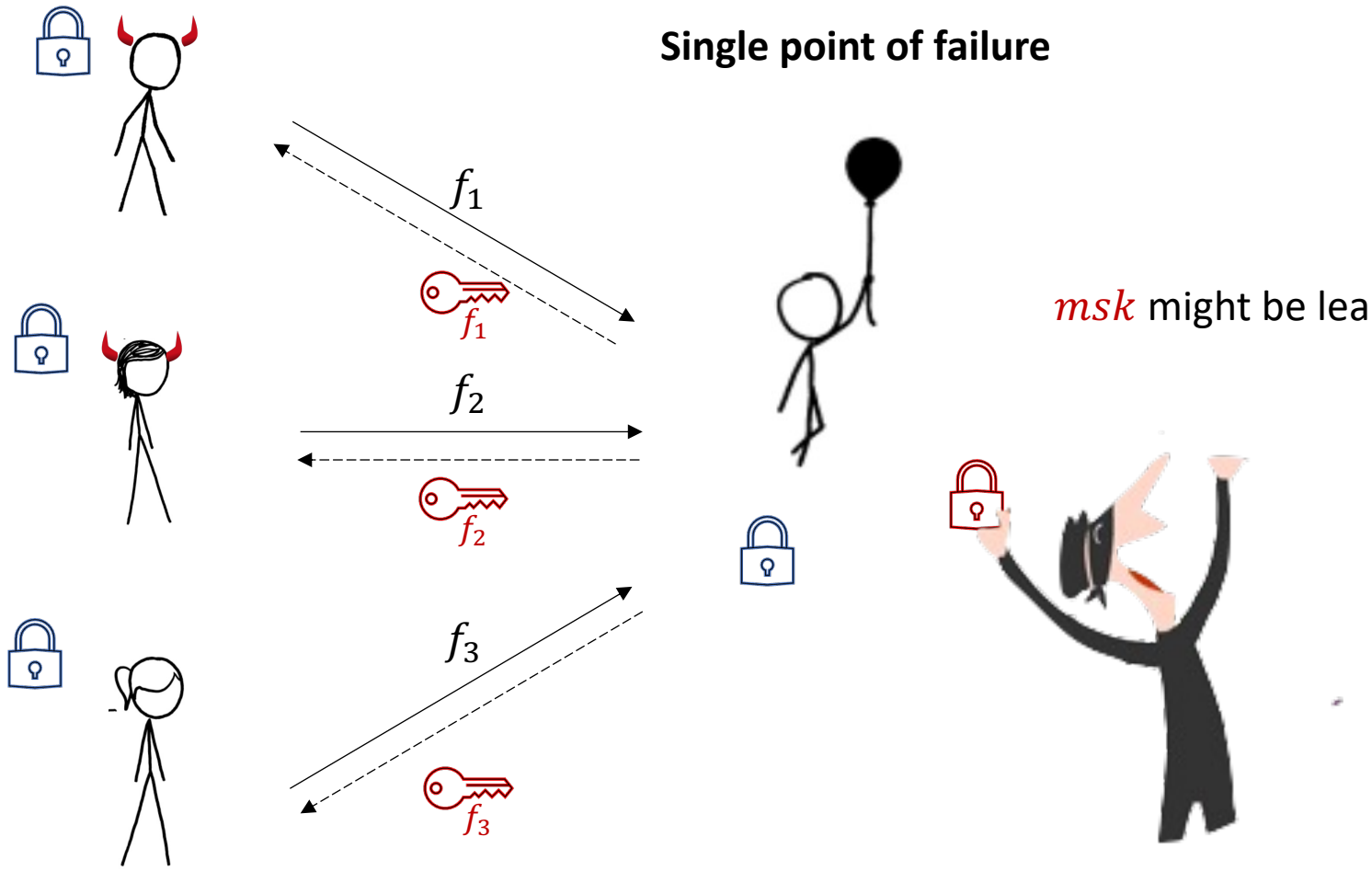
Functional Encryption





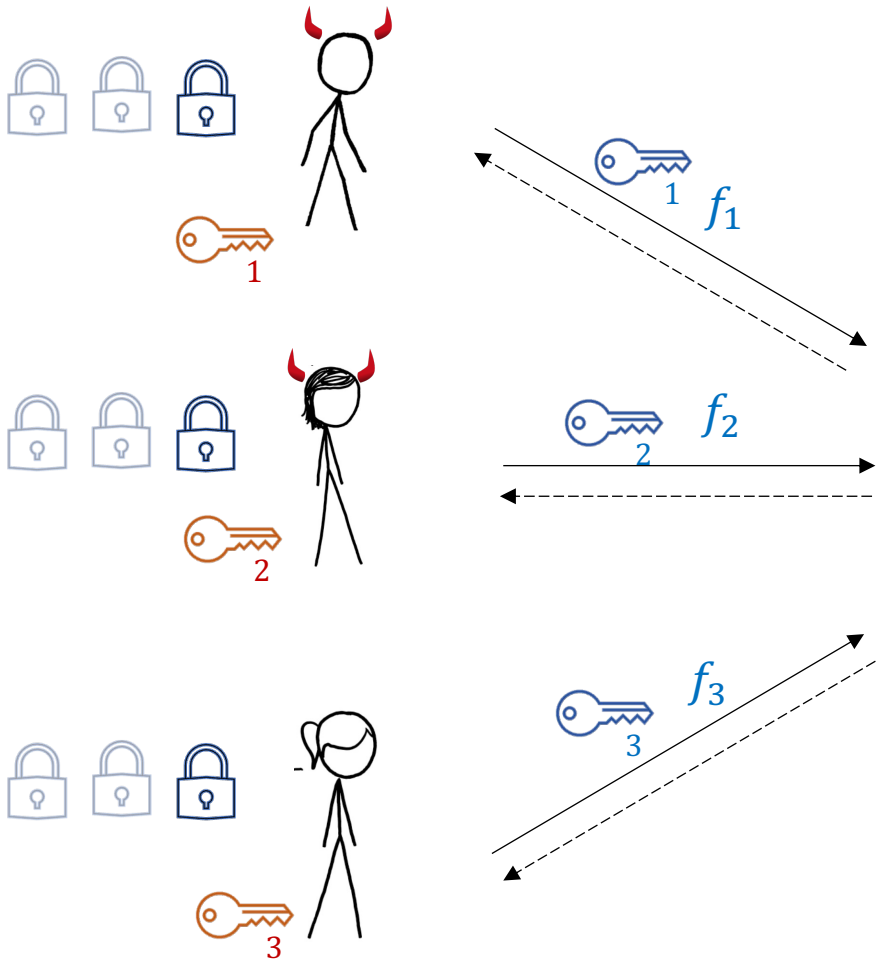
Cannot learn $f_{\neq 1,2}$()

Key-Escrow Problem



msk might be leaked

Registered Functional Encryption



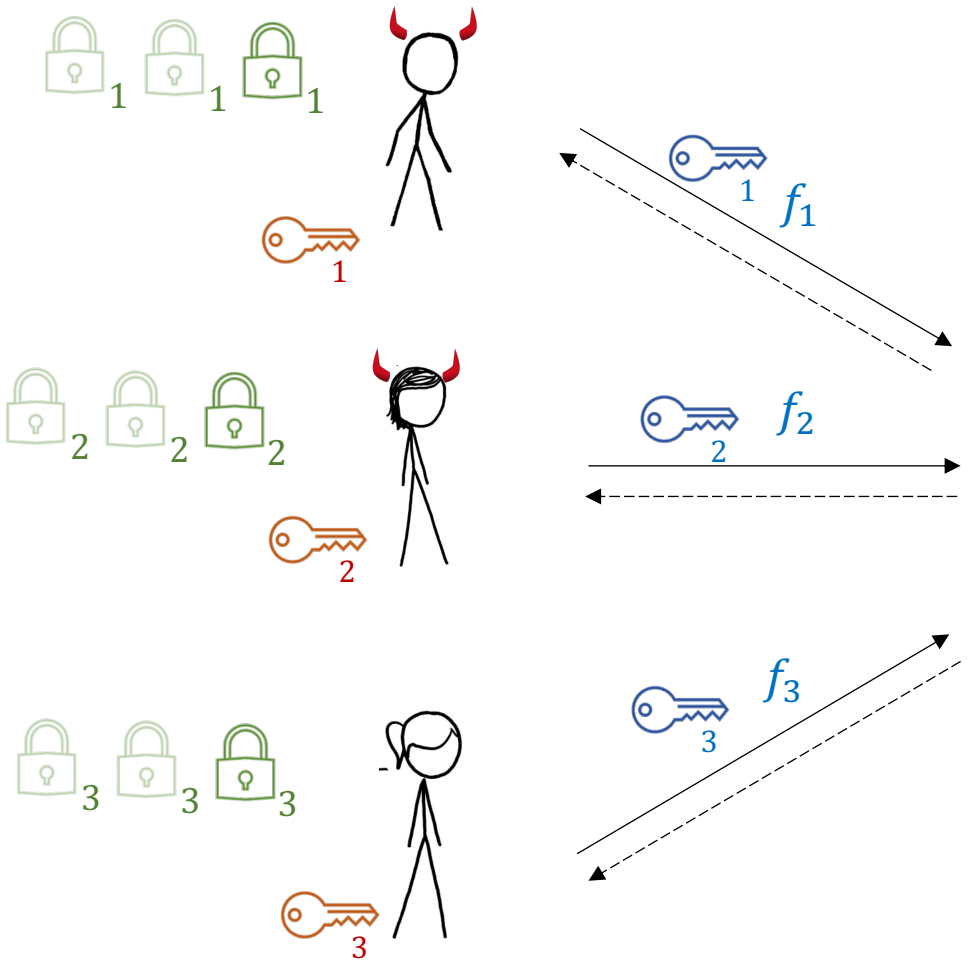
Key Curator

mpk is updated periodically

can be malformed

Trivial solution

Registered Functional Encryption



Key Curator

mpk is updated periodically

hks_i produced at each update connecting mpk and 

Requirements:

$L = \#\text{Users}$

$|crs|, |hks_i|, |mpk|$
= **polylog** in L

Keygen and registration run in **polylog** time in L

$\#\text{Updates} = O(logL)$

Our Contributions

- *Registered (attribute-hiding) Inner Product Encryption*
  from prime order groups in the bilinear GGM. Recasted in RFE as:

$$f_{\mathbf{x}}(m, \mathbf{y}) = \begin{cases} m & \text{if } \langle \mathbf{x}, \mathbf{y} \rangle = 0 \\ \perp & \text{otherwise} \end{cases}$$

- *Registered Functional Encryption*
  from iO and SSB hash functions for generic functionalities and large universe of users

Similar blueprint of [HLWW22] Registered Attribute-Based Encryption

Comparison with [HLWW22] RABE:

- *Our RIPE*

PROS:

- Large function space: n-size vectors
- Strong attribute-hiding:
  - CPA-2-sided security

CONS:

- Inner-Product
- Pairings of prime order + GGM

- *[HLWW22] RABE*

CONS:

- Small attribute space
- Attributes in clear

PROS:

- LSSS policies
- Pairings of composite order

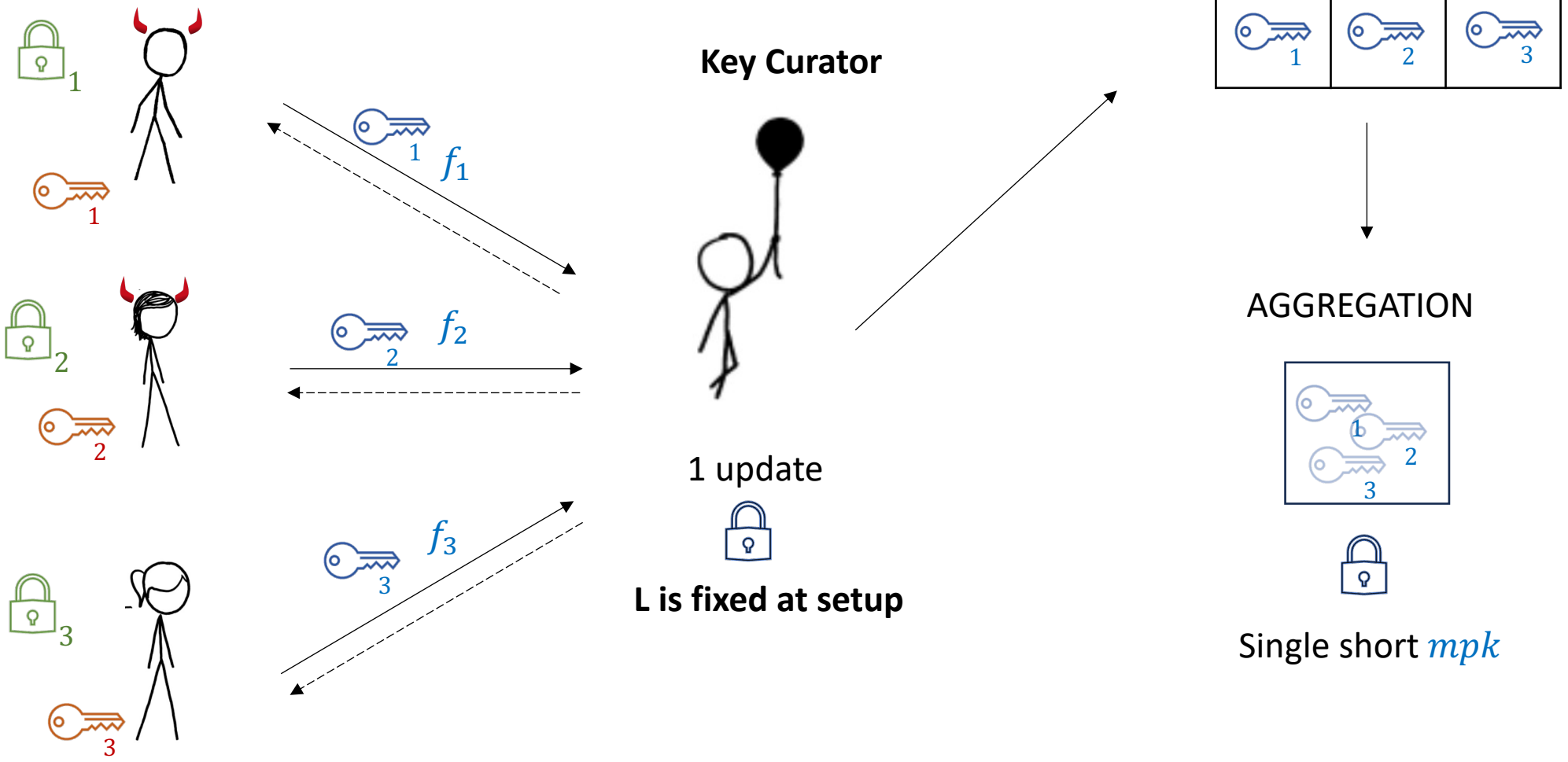
Both CONs:

- Require a bounded number of users
- CRS, Kgen and registration runtime dependent on L

Comparison with [HLWW22] RABE:

Reference	Type	CRS size	Keygen runtime	Registration key runtime	Master public key size	Helper dec. key size	# Updates	Unbounded users	BB	Assumptions
[GHMR18]	IBE	$O(1)$	$O(1)$	$\mathsf{poly}(\log L)$	$\mathsf{poly}(\log L)$	$\mathsf{poly}(\log L)$	$O(\log L)$	✓	✗	iO + SSB
[GHMR18]	IBE	$O(1)$	$O(1)$	$O(L)$	$\mathsf{poly}(\log L)$	$\mathsf{poly}(\log L)$	$O(\log L)$	✓	✗	CDH/LWE
[GHM+19]	Anon. IBE	$O(1)$	$O(1)$	$\mathsf{poly}(\log L)$	$\mathsf{poly}(\log L)$	$\mathsf{poly}(\log L)$	$O(\log L)$	✓	✗	CDH/LWE
[GV20]	IBE	$O(1)$	$O(1)$	$\mathsf{poly}(\log L)$	$\mathsf{poly}(\log L)$	$\mathsf{poly}(\log L)$	$O(\log L)$	✓	✗	CDH/LWE
[CES21]	IBE	$O(1)$	$O(1)$	$\mathsf{poly}(\log L)$	$O(\sqrt{L})$	$\mathsf{poly}(\log L)$	$O(\log L)$	✓	✗	CDH/LWE
[GKMR22]	IBE $O(1)$-size ciphertexts	$O(\sqrt{L})$	$O(\sqrt{L})$	$O(\sqrt{L})$	$O(\sqrt{L})$	$O(\sqrt{L})$	$O(\sqrt{L})$	✗	✓	Pairings of Prime Order
[GKMR22]	IBE $O(\log L)$-size ciphertexts	$O(\sqrt{L})$	$O(\sqrt{L})$	$O(\sqrt{L}\log L)$	$O(\sqrt{L}\log L)$	$O(\log L)$	$O(\log L)$	✗	✓	Pairings of Prime Order
[DKL+23]	IBE	$\mathsf{poly}(\log L)$	$\mathsf{poly}(\log L)$	$O(L)$	$\mathsf{poly}(\log L)$	$\mathsf{poly}(\log L)$	$O(\log L)$	✓	✓	LWE
[HLWW22]	ABE small attribute space $\mathcal{U}$ LSSS policies	$L^2 \cdot \mathsf{poly}(\lvert\mathcal{U}\rvert, \log L)$	$L \cdot \mathsf{poly}(\lvert\mathcal{U}\rvert, \log L)$	$L \cdot \mathsf{poly}(\lvert\mathcal{U}\rvert, \log L)$	$\lvert\mathcal{U}\rvert \cdot \mathsf{poly}(\log L)$	$\lvert\mathcal{U}\rvert \cdot \mathsf{poly}(\log L)$	$O(\log L)$	✗	✓	Pairings of Composite Order
[HLWW22]	ABE large attribute space $\mathcal{U}$ arbitrary policies	$O(1)$	$O(1)$	$O(L)$	$O(1)$	$O(1)$	$O(\log L)$	✓	✗	iO + SSB
Ours §6	Inner-Product PE large function space $\mathcal{F}$ n-size vectors	$n \cdot L^2 \cdot \mathsf{poly}(\log L)$	$L \cdot \mathsf{poly}(\log L)$	$n \cdot L^2 \cdot \mathsf{poly}(\log L)$	$n \cdot \mathsf{poly}(\log L)$	$n \cdot \mathsf{poly}(\log L)$	$O(\log L)$	✗	✓	Pairings of Prime Order + GGM
Ours §B	FE large function space $\mathcal{F}$ arbitrary functions	$O(1)$	$O(1)$	$O(L)$	$O(1)$	$O(1)$	$O(\log L)$	✓	✗	iO + SSB

Slotted RFE



Slightly modified compiler of [HLWW22] to make L independent with log updates

Slotted RIPE (Single slot)

CRS

- Prime order q:

  $\mathcal{G} = \mathbb{G}_1, \mathbb{G}_2, \mathbb{G}_T, q, g_1, g_2, e$

- General params:

  $h = g_1^{\boldsymbol{\beta}} \qquad Z = e(g_1, g_2)^{\boldsymbol{\alpha}}$

- Slot-specific:

  $A = g_2^{\boldsymbol{t}} \qquad B = g_2^{\boldsymbol{\alpha}} A^{\boldsymbol{\beta}} = g^{\boldsymbol{\alpha}+\boldsymbol{\beta}\boldsymbol{t}}$

- Key-specific:

  $U_w = g_1^{\boldsymbol{u_w}}$ for each $w \in [n+1]$

Key registration

$pk = U_{n+1}^{-\boldsymbol{sk}} \quad \boldsymbol{x} = (x_1, \ldots, x_n)$

Key aggregation:

$$pk \cdot \prod_{w=1}^{n} U_w^{-x_w}$$

Slotted RIPE (Single slot)

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$U_w = g_1^{\boldsymbol{u_w}}$ $\quad h = g_1^{\boldsymbol{\beta}}$

Enc $(m, \boldsymbol{y} = (y_1, \dots, y_n))$**:**

$$C_1 = m \cdot Z^{\boldsymbol{s}}$$

$$C_2 = g_1^{\boldsymbol{s}}$$

$$C_{3,w} = h^{y_w \cdot \boldsymbol{r}+\boldsymbol{s}} \cdot U_w^{-z}, \forall w \in [n]$$

$$C_{3,n+1} = h^{\boldsymbol{s}} \cdot U_{n+1}^{-z}$$

$$C_{3,n+2} = h^{\boldsymbol{s}} \cdot (pk \prod_{w=1}^{n} U_w^{-x_w})^{-z}$$

Dec $(C_1, C_2, C_{3,w}, C_{3,n+1}, sk, \boldsymbol{x})$**:**

$$m = \frac{C_1}{e(C_2, B)} \cdot e(h^s, A)$$

$$h^s = \left(C_{3,n+2} \cdot C_{3,n+1}^{sk} \cdot \prod_{w=1}^{n} C_{3,w}^{x_w}\right)^{(1+sk+\sum x_w)^{-1}}$$

Slotted RIPE (Single slot)

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$\prod_{w=1}^{n} C_{3,w}^{x_w} = \prod_{w=1}^{n} h^{x_w (y_w \cdot r)}$ $\quad \prod_{w=1}^{n} h^{x_w s}$ $\quad \prod_{w=1}^{n} U_w^{-z \cdot x_w}$

$C_{3,n+1}^{sk} = h^{s \cdot sk}$ $\quad U_{n+1}^{-z \cdot sk}$

$C_{3,n+2} = h^{\boldsymbol{s}}$ $\quad U_{n+1}^{z \cdot sk}$ $\quad \prod_{w=1}^{n} U_w^{z \cdot x_w}$

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Slotted RIPE (2 slots) IDEA:

CRS Generation:

A_1, B_1 $\quad$ A_2, B_2

$\{U_{w,1}\}$ $\quad$ $\{U_{w,2}\}$

$\{U_{w,1} \cdot U_{w,2}\}$

Key Generation:

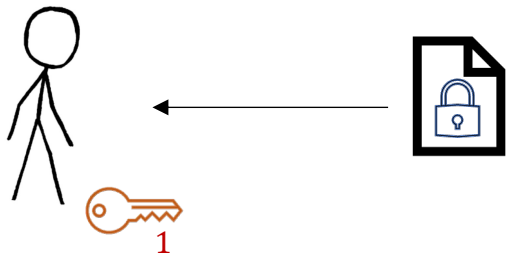
$pk_1 = U_{n+1}^{-sk_1}$ $\quad$ $\boldsymbol{x_1} = (x_{1,1}, \ldots, x_{n,1})$

$pk_2 = U_{n+1}^{-sk_2}$ $\quad$ $\boldsymbol{x_2} = (x_{1,2}, \ldots, x_{n,2})$

Key Aggregation:

$$pk_1 \cdot pk_2 \cdot \prod U_{w,1}^{x_{w,1}} \prod U_{w,2}^{x_{w,2}}$$

Slotted RIPE (2 slots)



$$\prod_{w\in[n]} C_{3,w}^{x_{w,1}} = \prod_{w\in[n]} h^{(y_w\cdot r+s)\cdot x_{w,1}} \cdot \prod_{w=1}^{n} U_{w,1}^{-z\cdot x_{w,1}} \cdot \boxed{\prod_{w=1}^{n} U_{w,2}^{-z\cdot x_{w,1}}}$$

$$C_{3,n+1}^{\mathsf{sk}_1} = h^{s\cdot \mathsf{sk}_1} \cdot U_{n+1,1}^{-z\cdot \mathsf{sk}_1} \cdot \boxed{U_{n+1,2}^{-z\cdot \mathsf{sk}_1}}$$

$$C_{3,n+2} = h^{s} \cdot U_{n+1,1}^{z\cdot \mathsf{sk}_1} \cdot \boxed{U_{n+1,2}^{z\cdot \mathsf{sk}_2}} \cdot \prod_{w=1}^{n} U_{w,1}^{z\cdot x_{w,1}} \boxed{\prod_{w=1}^{n} U_{w,2}^{z\cdot x_{w,2}}}$$

Slotted RIPE (2 slots)

CRS Generation:

A_1, B_1 A_2, B_2

$\{W_{1,2,w} = A_1^{u_{2,w}}\}$ $\{W_{2,1,w} = A_2^{u_{1,w}}\}$

$\{U_{w,1} = g^{u_{1,w}}\}$ $\{U_{w,2} = g^{u_{2,w}}\}$

$\{U_{w,1} \cdot U_{w,2}\}$

Key Generation:

$pk_1 = U_{n+1}^{-sk_1}$ $\boldsymbol{x_1} = (x_{1,1}, \ldots, x_{n,1})$ $\{W_{2,1,w}^{sk_1}\}$

$pk_2 = U_{n+1}^{-sk_2}$ $\boldsymbol{x_2} = (x_{1,2}, \ldots, x_{n,2})$ $\{W_{1,2,w}^{sk_2}\}$

Key Aggregation:

$pk_1 \cdot pk_2 \cdot \prod U_{w,1}^{x_{w,1}} \prod U_{w,2}^{x_{w,2}}$

$W_{2,1,n+1}^{sk_1} \cdot W_{1,2,n+1}^{sk_2}$

Slotted RIPE (2 slots)

A_1, B_1

$\{U_{w,1} \cdot U_{w,2}\}$ $\quad h \quad Z$ $\quad pk_1 \cdot pk_2 \cdot \prod U_{w,1}^{x_{w,1}} \prod U_{w,2}^{x_{w,2}}$ $\quad _1$

$W_{2,1,n+1}^{sk_1} \cdot W_{1,2,n+1}^{sk_2}$

$$\prod_{w\in[n]} C_{3,w}^{x_{w,1}} = \prod_{w\in[n]} h^{(y_w\cdot r+s)\cdot x_{w,1}} \cdot \prod_{w=1}^{n} U_{w,1}^{-z\cdot x_{w,1}} \cdot \boxed{\prod_{w=1}^{n} U_{w,2}^{-z\cdot x_{w,1}}}$$

$$C_{3,n+1}^{\mathsf{sk}_1} = h^{s\cdot \mathsf{sk}_1} \cdot U_{n+1,1}^{-z\cdot \mathsf{sk}_1} \cdot \boxed{U_{n+1,2}^{-z\cdot \mathsf{sk}_1}}$$

$$C_{3,n+2} = h^{s} \cdot U_{n+1,1}^{z\cdot \mathsf{sk}_1} \cdot \boxed{U_{n+1,2}^{z\cdot \mathsf{sk}_2}} \cdot \prod_{w=1}^{n} U_{w,1}^{z\cdot x_{w,1}} \boxed{\prod_{w=1}^{n} U_{w,2}^{z\cdot x_{w,2}}}$$

$C_4 = g_1^z$

Slotted RIPE (2 slots)

$\{W_{1,2,w} = A_1^{u_{2,w}/\gamma}\}$ $\{W_{2,1,w} = A_2^{u_{1,w}/\gamma}\}$

A_1, B_1

$\{U_{w,1} \cdot U_{w,2}\}$

$\Gamma = g_1^{\gamma}$

h

Z

$pk_1 \cdot pk_2 \cdot \prod U_{w,1}^{x_{w,1}} \prod U_{w,2}^{x_{w,2}}$

$_1$

$W_{2,1,n+1}^{sk_1} \cdot W_{1,2,n+1}^{sk_2}$

$$\prod_{w\in[n]} C_{3,w}^{x_{w,1}} = \prod_{w\in[n]} h^{(y_w\cdot r+s)\cdot x_{w,1}} \cdot \prod_{w=1}^{n} U_{w,1}^{-z\cdot x_{w,1}} \cdot \boxed{\prod_{w=1}^{n} U_{w,2}^{-z\cdot x_{w,1}}}$$

$$C_{3,n+1}^{\mathsf{sk}_1} = h^{s\cdot \mathsf{sk}_1} \cdot U_{n+1,1}^{-z\cdot \mathsf{sk}_1} \cdot \boxed{U_{n+1,2}^{-z\cdot \mathsf{sk}_1}}$$

$$C_{3,n+2} = h^{s} \cdot U_{n+1,1}^{z\cdot \mathsf{sk}_1} \cdot \boxed{U_{n+1,2}^{z\cdot \mathsf{sk}_2}} \cdot \prod_{w=1}^{n} U_{w,1}^{z\cdot x_{w,1}} \boxed{\prod_{w=1}^{n} U_{w,2}^{z\cdot x_{w,2}}}$$

$C_4 = \Gamma^z$

Slotted RIPE (2 slots)

$\{W_{1,2,w} = A_1^{u_{2,w}/\gamma}\}$ $\{W_{2,1,w} = A_2^{u_{1,w}/\gamma}\}$

A_1, B_1

$\{U_{w,1} \cdot U_{w,2}\}$

$\Gamma = g_1^{\gamma}$

h

Z

$pk_1 \cdot pk_2 \cdot \prod U_{w,1}^{x_{w,1}} \prod U_{w,2}^{x_{w,2}}$

$_1$

$W_{2,1,n+1}^{sk_1} \cdot W_{1,2,n+1}^{sk_2}$

$$\prod_{w\in[n]} C_{3,w}^{x_{w,1}} = \prod_{w\in[n]} h^{(y_w\cdot r+s)\cdot x_{w,1}} \cdot \prod_{w=1}^{n} U_{w,1}^{-z\cdot x_{w,1}} \cdot \prod_{w=1}^{n} U_{w,2}^{-z\cdot x_{w,1}}$$

$$C_{3,n+1}^{\mathsf{sk}_1} = h^{s\cdot \mathsf{sk}_1} \cdot U_{n+1,1}^{-z\cdot \mathsf{sk}_1} \cdot U_{n+1,2}^{-z\cdot \mathsf{sk}_1}$$

$$C_{3,n+2} = h^{s} \cdot U_{n+1,1}^{z\cdot \mathsf{sk}_1} \cdot U_{n+1,2}^{z\cdot \mathsf{sk}_2} \cdot \prod_{w=1}^{n} U_{w,1}^{z\cdot x_{w,1}} \prod_{w=1}^{n} U_{w,2}^{z\cdot x_{w,2}}$$

$C_4 = \Gamma^z$

Conclusions

- Registered RFE Definition
- Registered IPE from parings in the GGM
- Registered RFE for P/poly and unbounded users from iO and SSB hash functions
- Open problems
  - RFE from any compact and polynomially-hard FE
  - RFE for specialized function classes from weaker assumptions
  - Prove our pairing-based RIPE in the standard model

Thank you for your attention!

https://ia.cr/2023/395