Multi-Client Functional Encryption with Public Inputs and Strong Security

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Talk is given by: Robert Schädlich[1]

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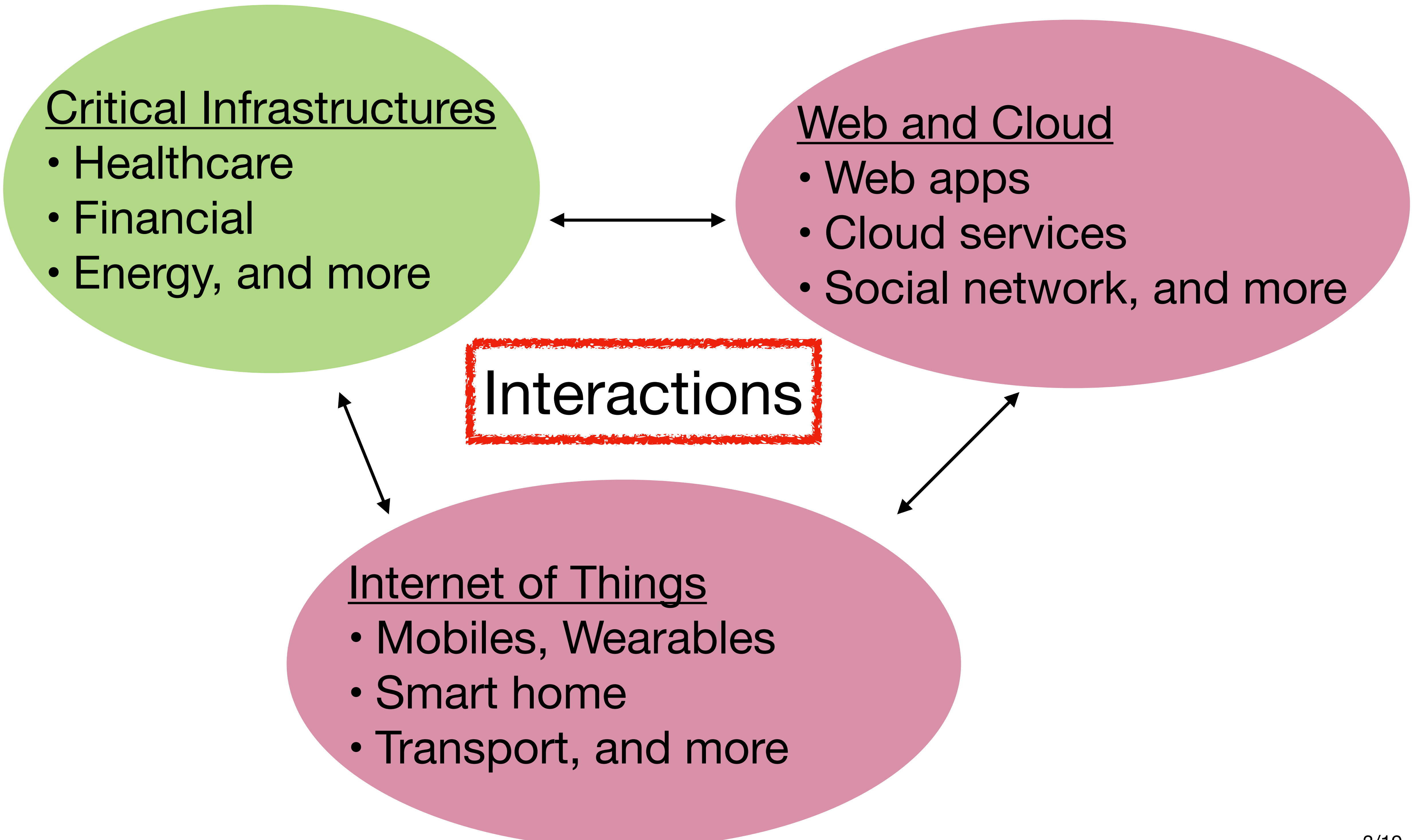
Outline

1. Motivation: Multiple Senders in Functional Encryption
2. Related Works
   a. Fine-Grained Access Control in Functional Encryption
   b. Revisiting Existing Security Notions
3. Our Contributions
4. Technical Highlights: Achieving Adaptive Security
5. Conclusion

Evolution of Information

Multiple sources, Complex Ecosystems



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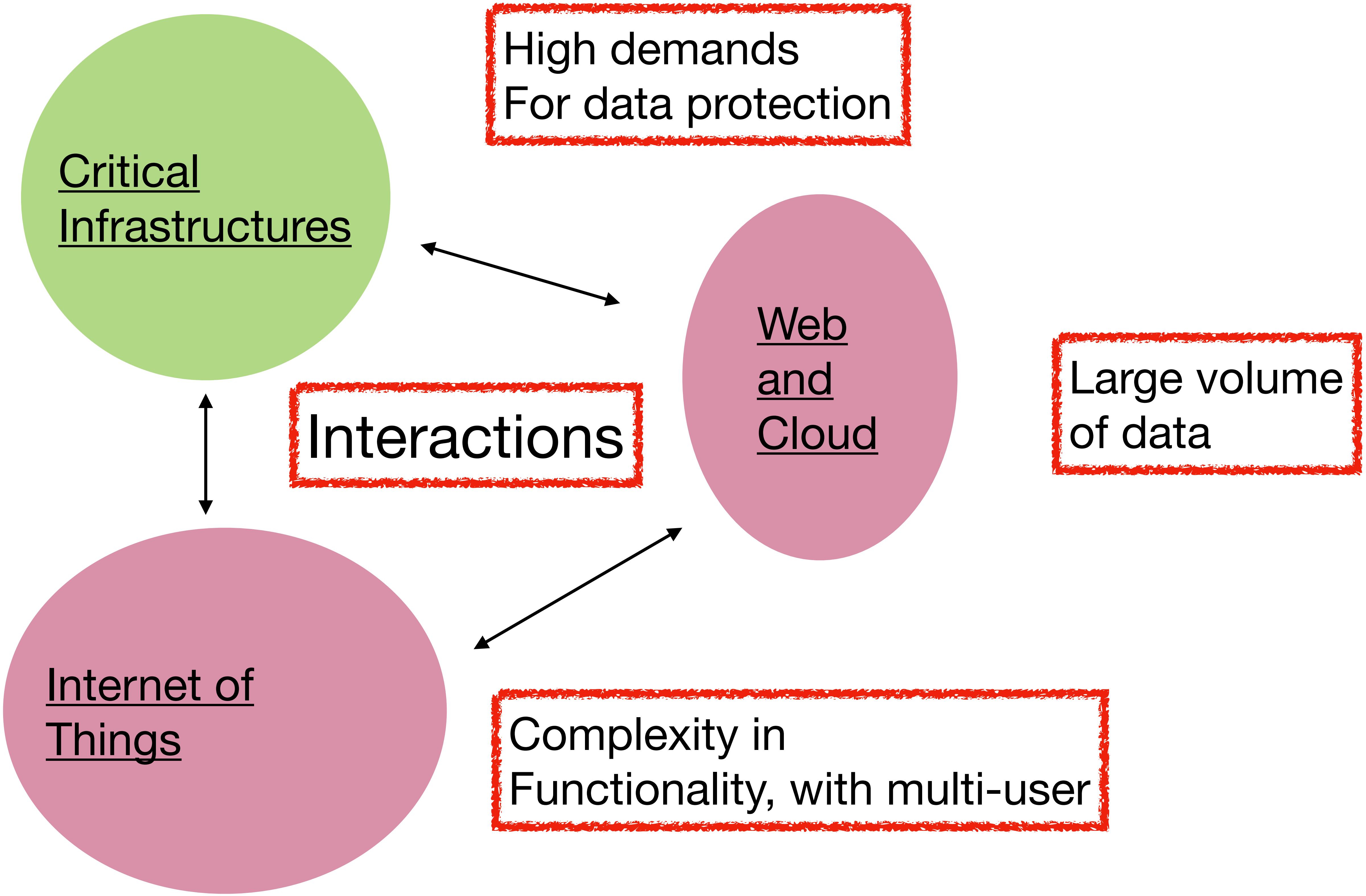


Evolution of Information

Multiple sources, Complex Ecosystems

Evolution of Information

Multiple sources, Complex Ecosystems

“Cryptographically”:
- Authentication
- Confidentiality
- Data Integrity

Critical Infrastructures

Web and Cloud

Interactions

+ Multiple Users

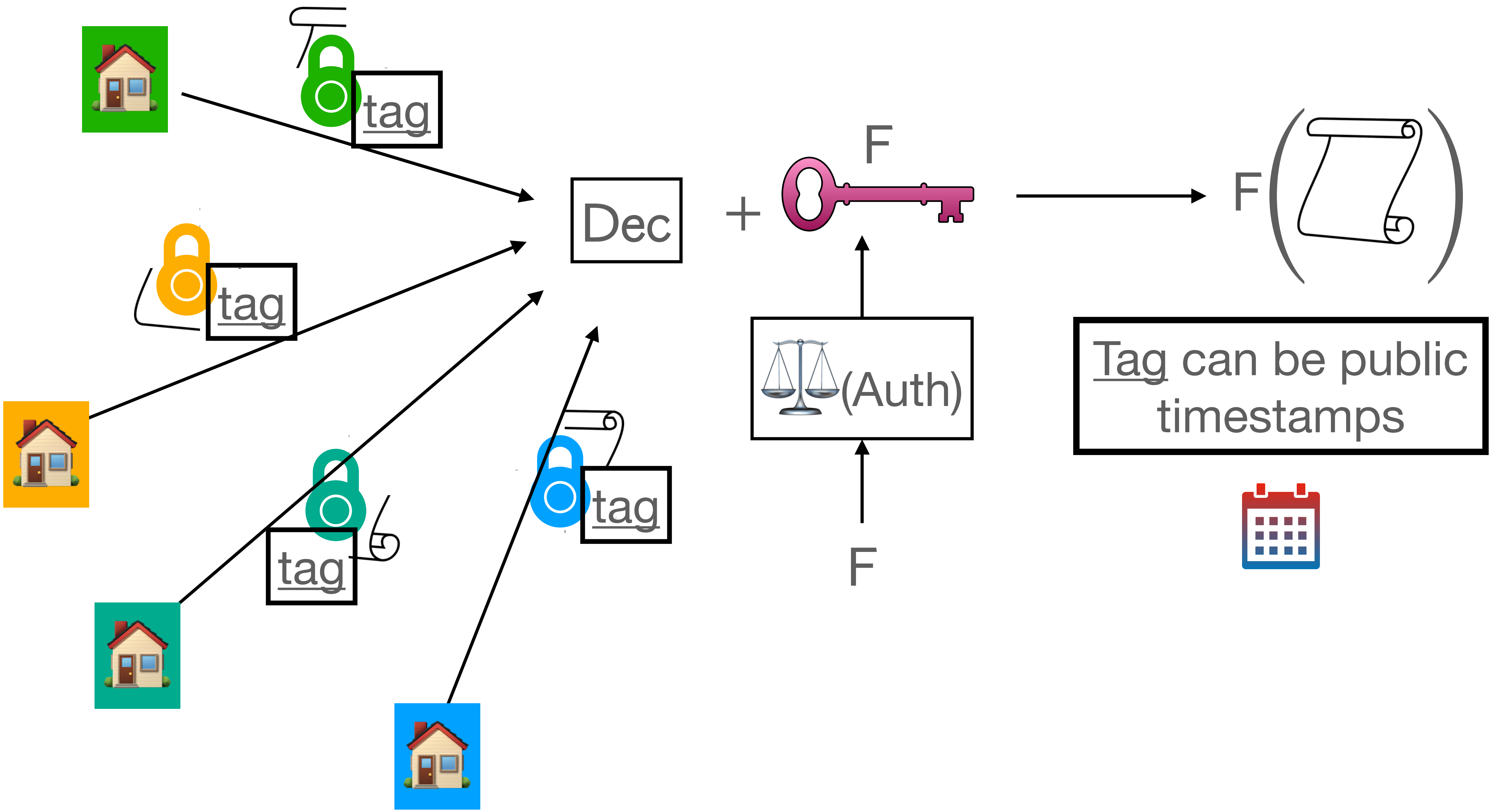
+ Fine-Grained Analysis

Internet of Things

One potential approach:

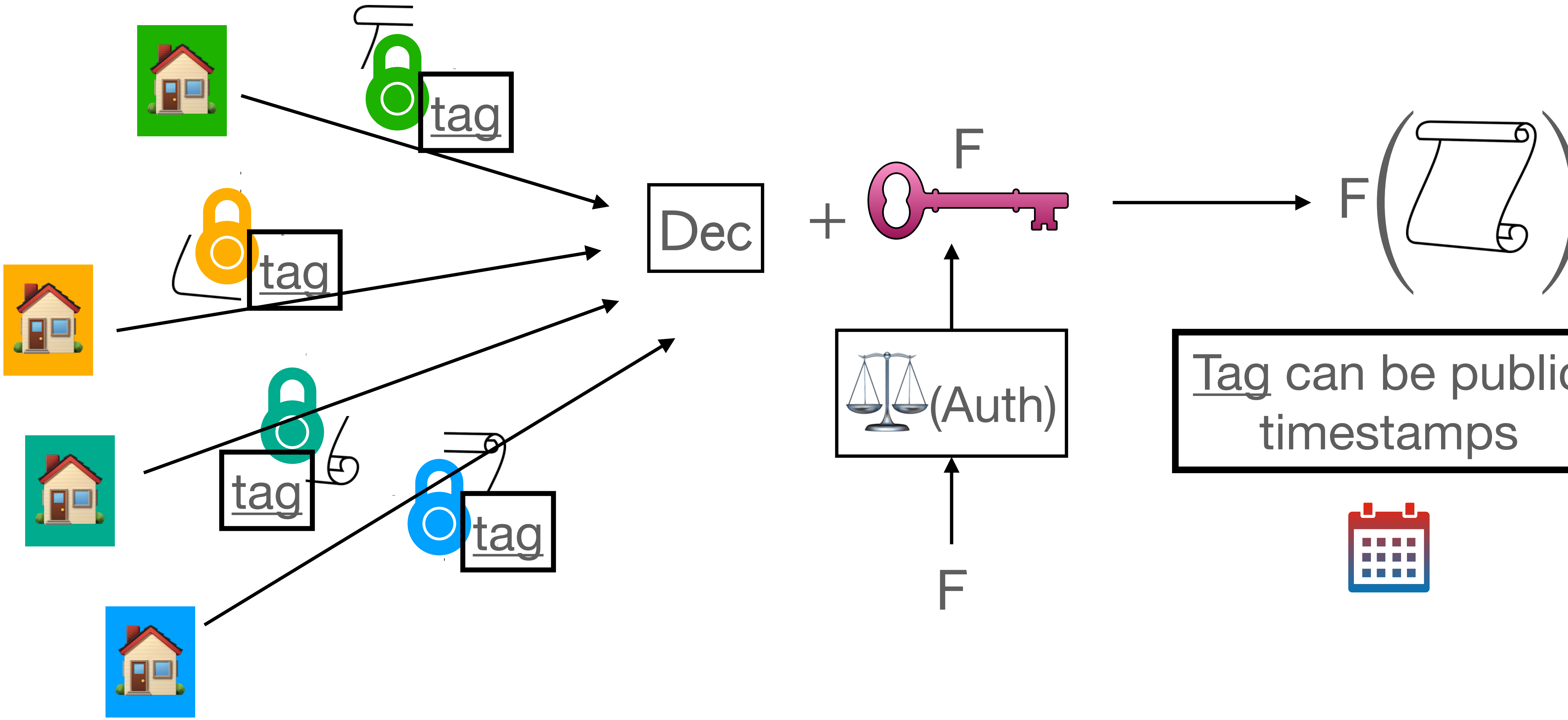
Sensitive Data are Encrypted
+ Fine-Grained Decryption

Multi-Client Functional Encryption (MCFE) [GGG+14,CDGPP18]



MCFE [GGG+14,CDGPP18]

How to Encrypt?



Tag can be public
timestamps

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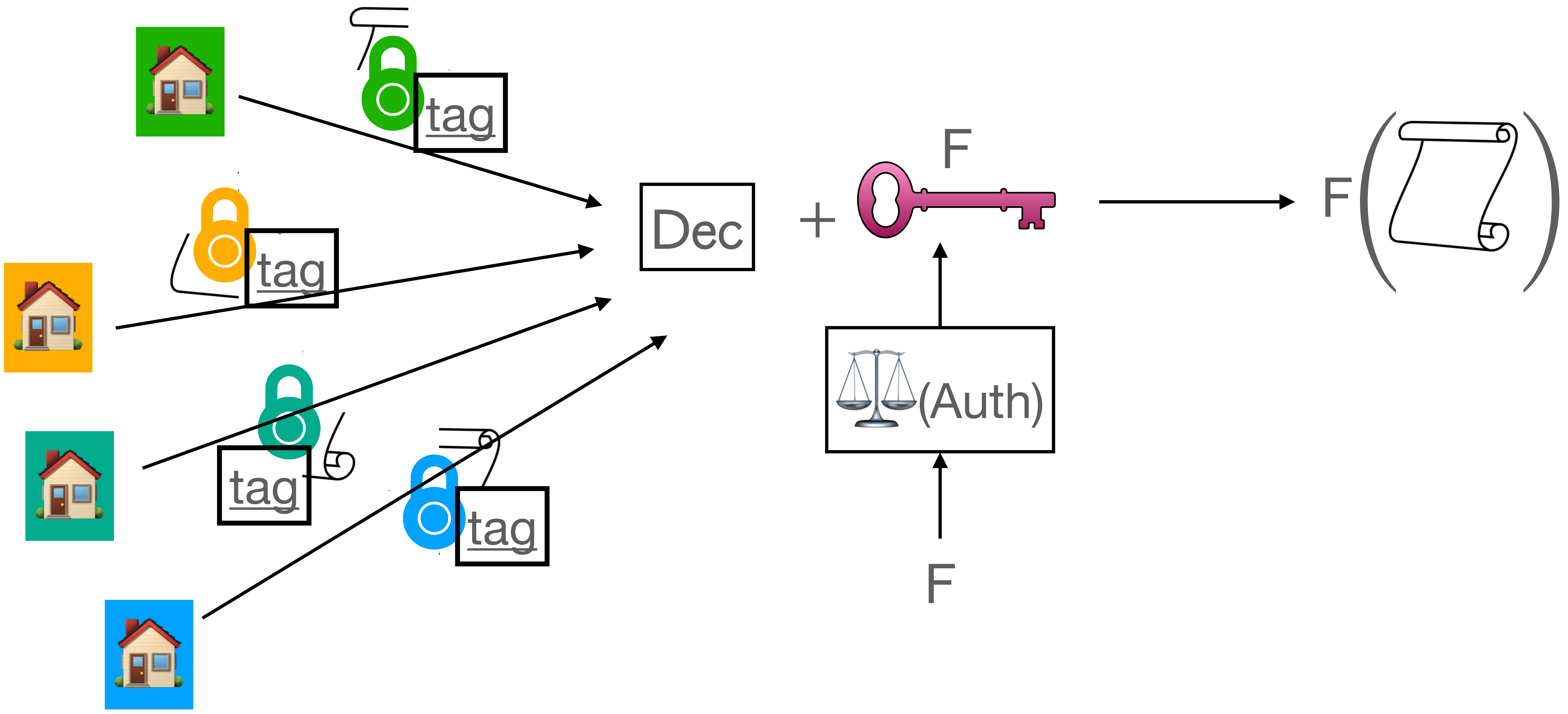

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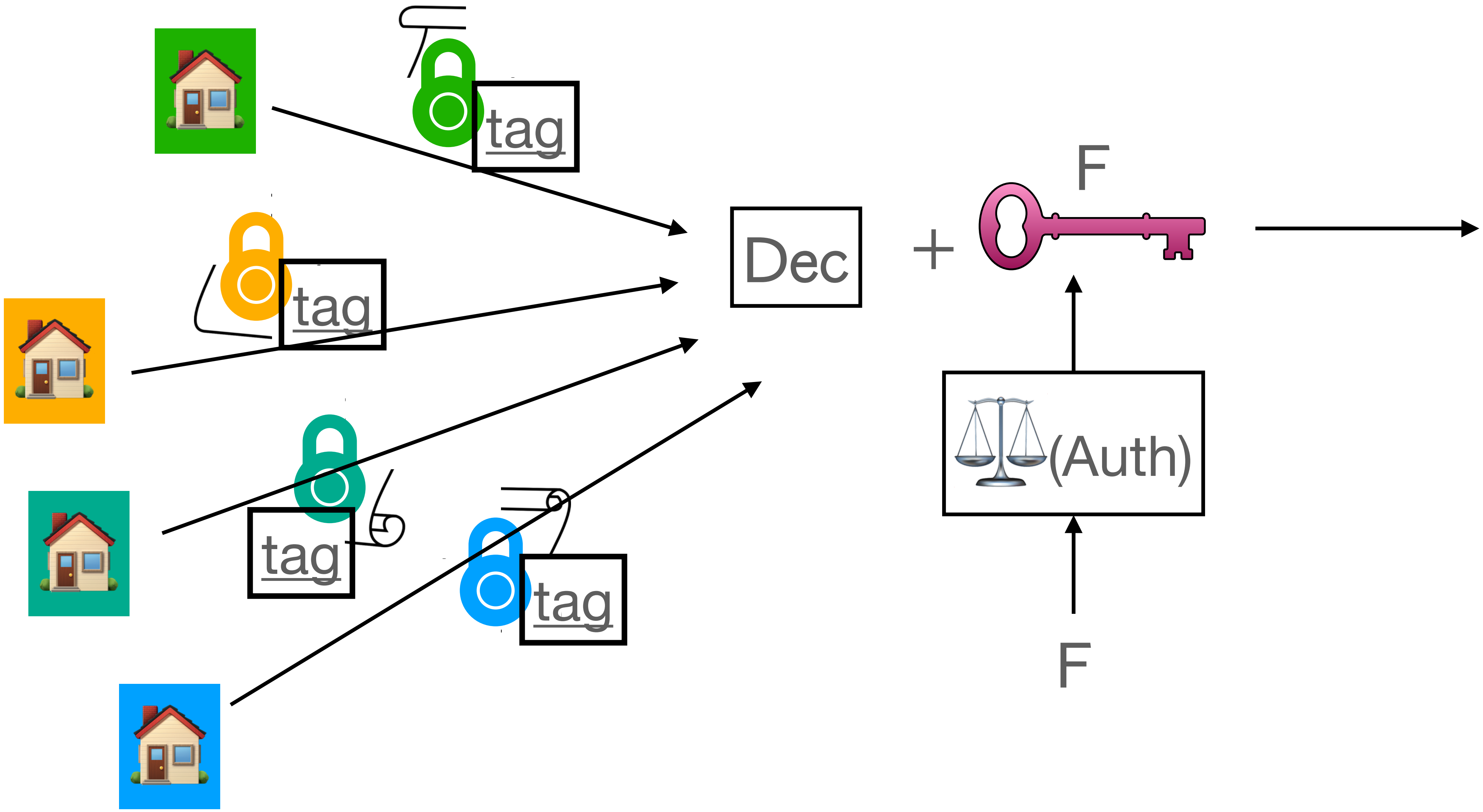

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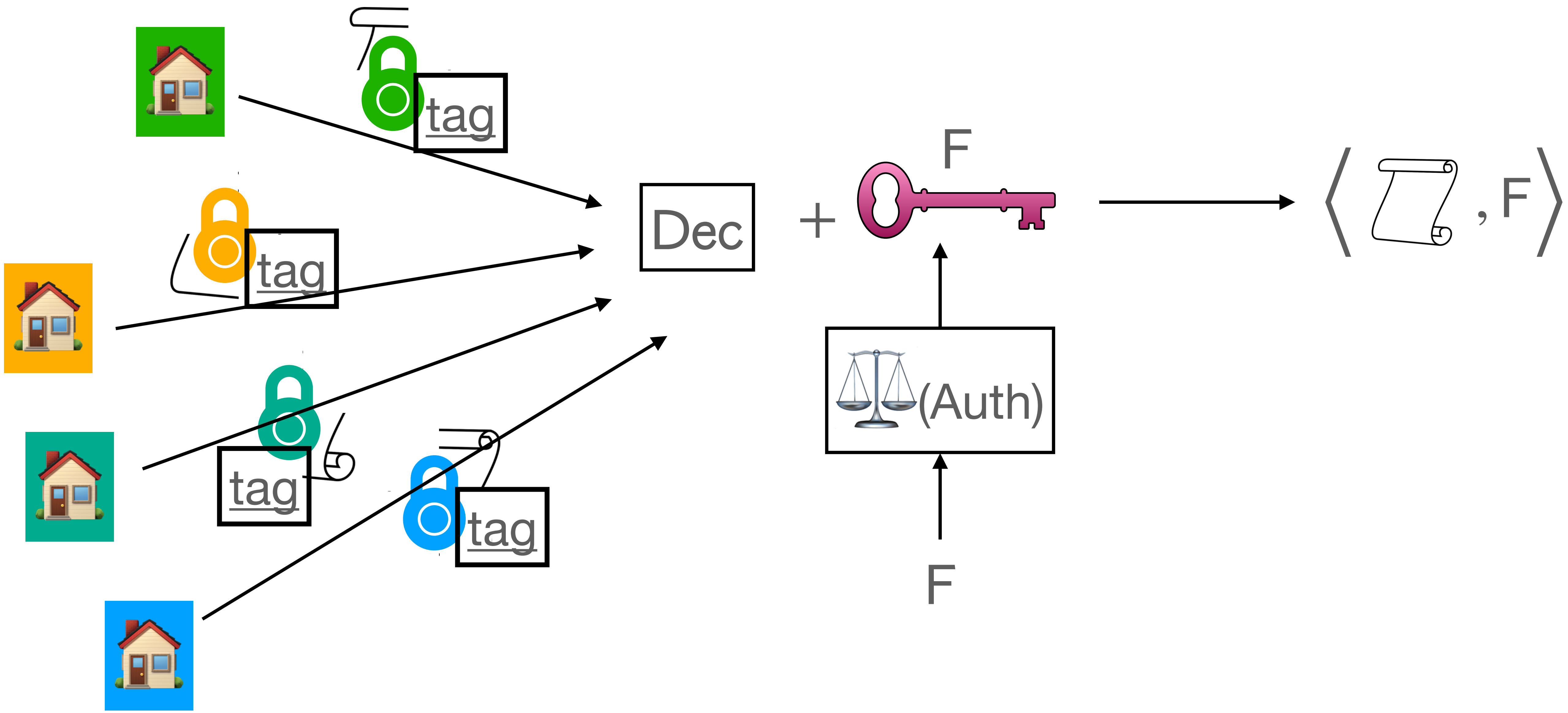

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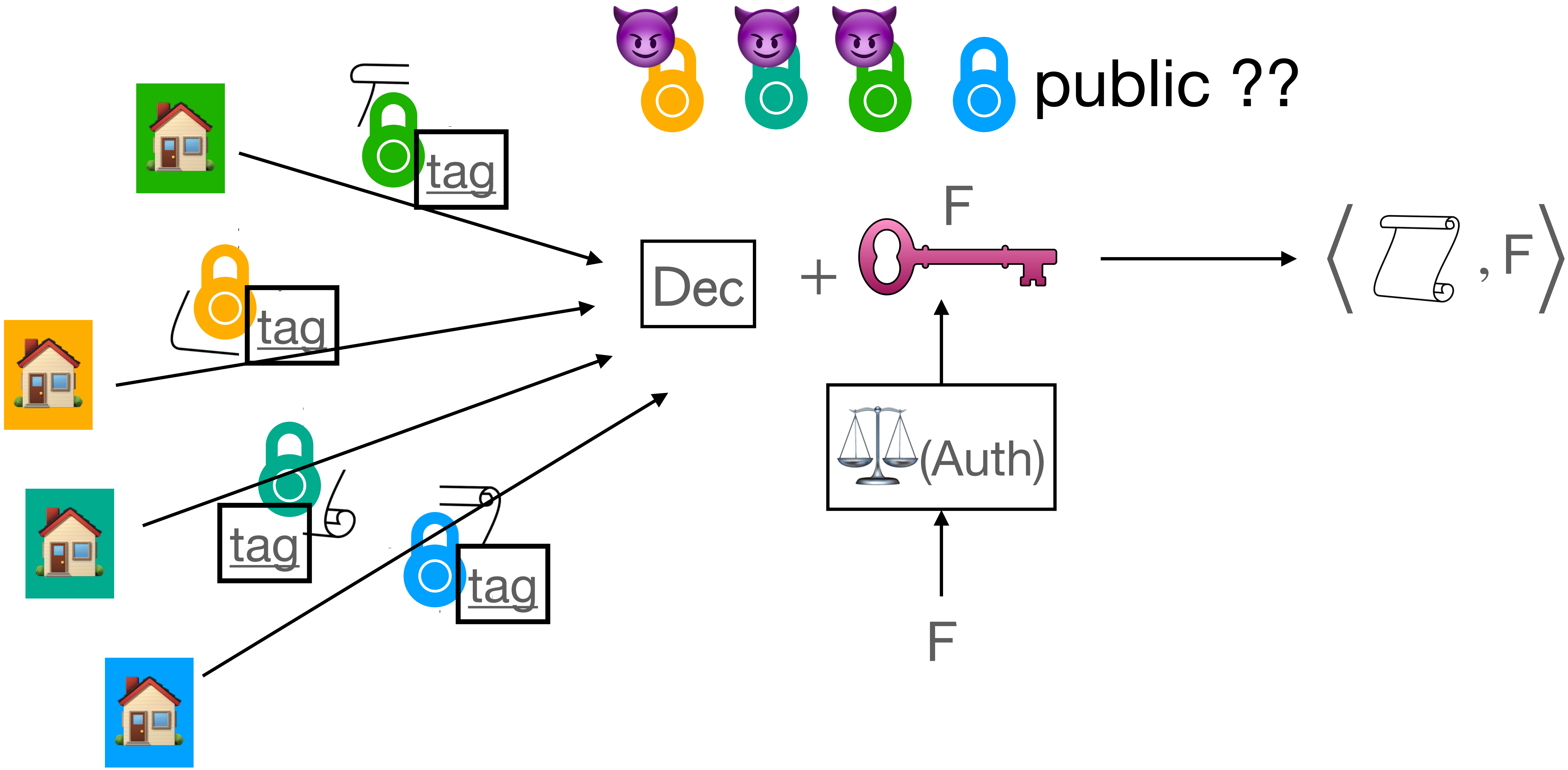

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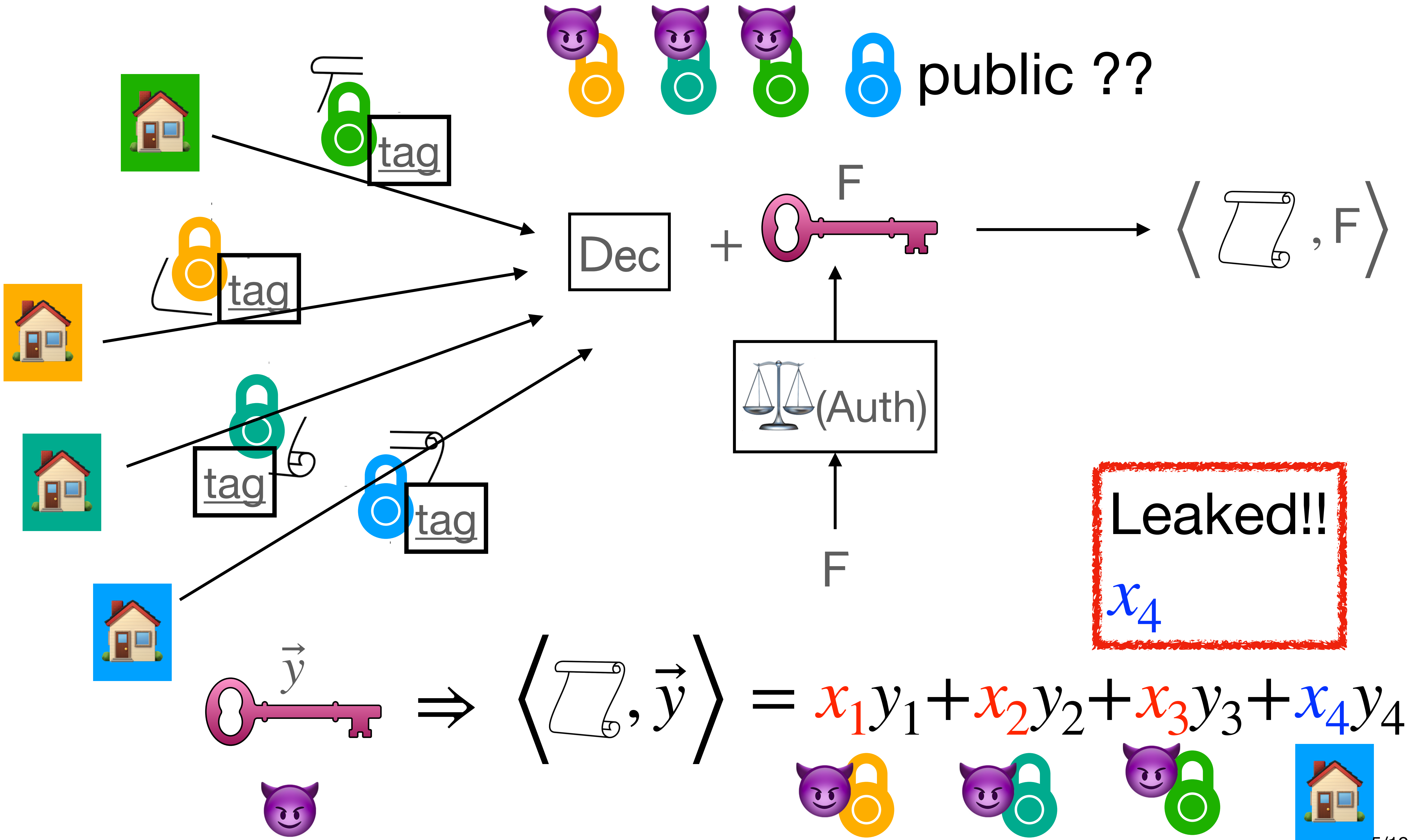
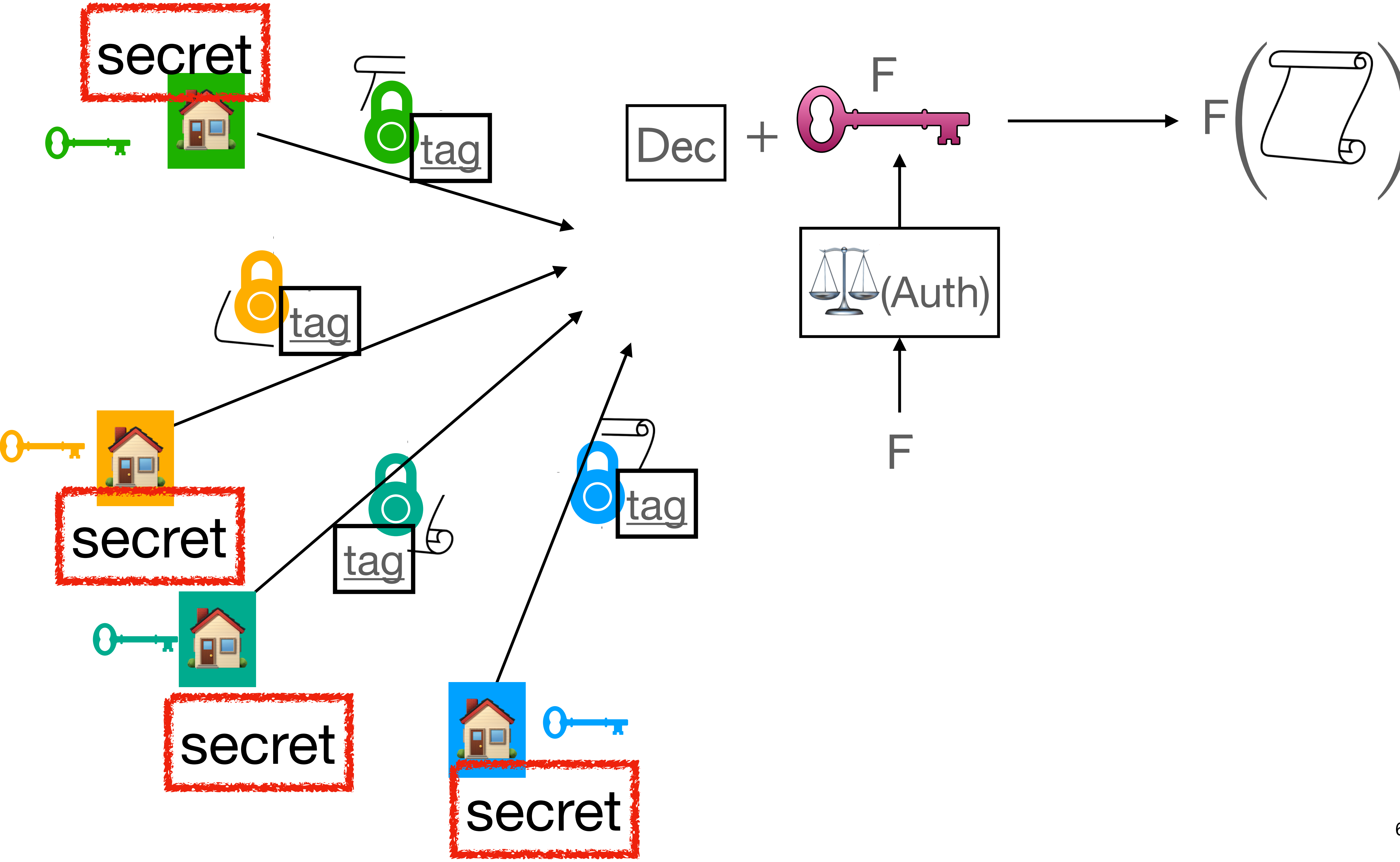


$$\vec{y} \Rightarrow \langle \;\cdot\;, \vec{y} \rangle = x_1 y_1 + x_2 y_2 + x_3 y_3 + x_4 y_4$$

Changes in Model

MCFE [GGG+14,CDGPP18] - Secret Encryption Keys



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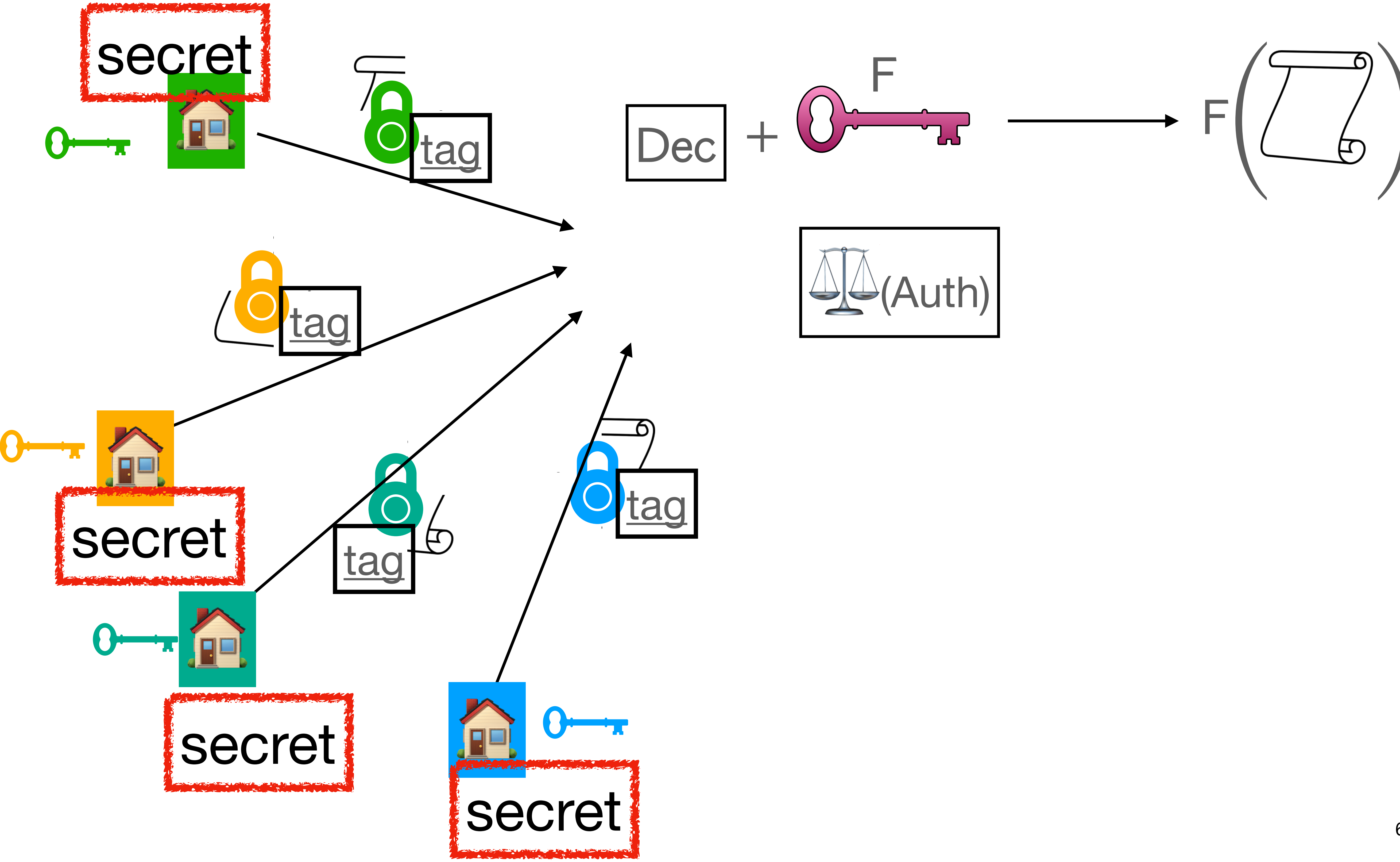

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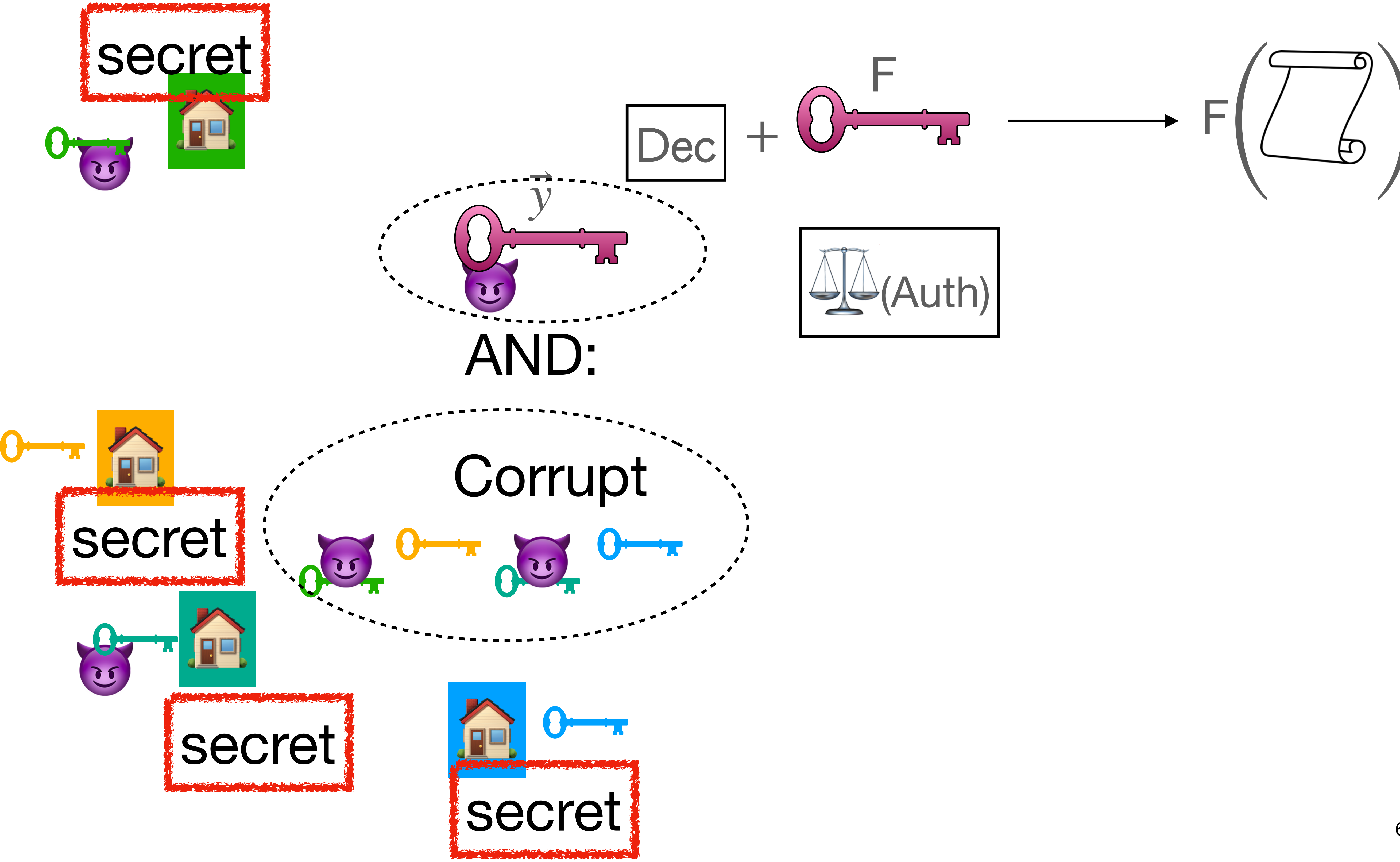

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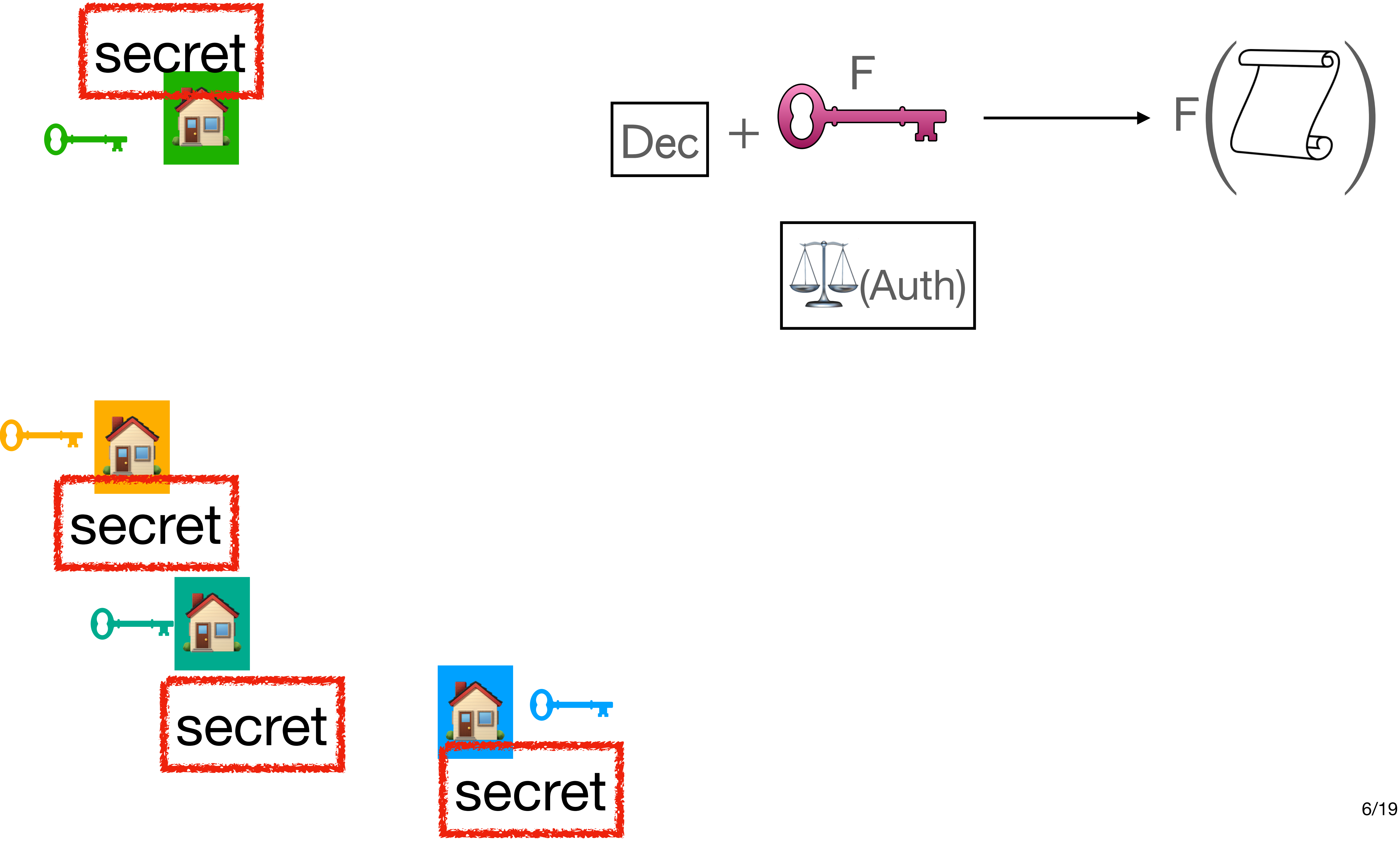

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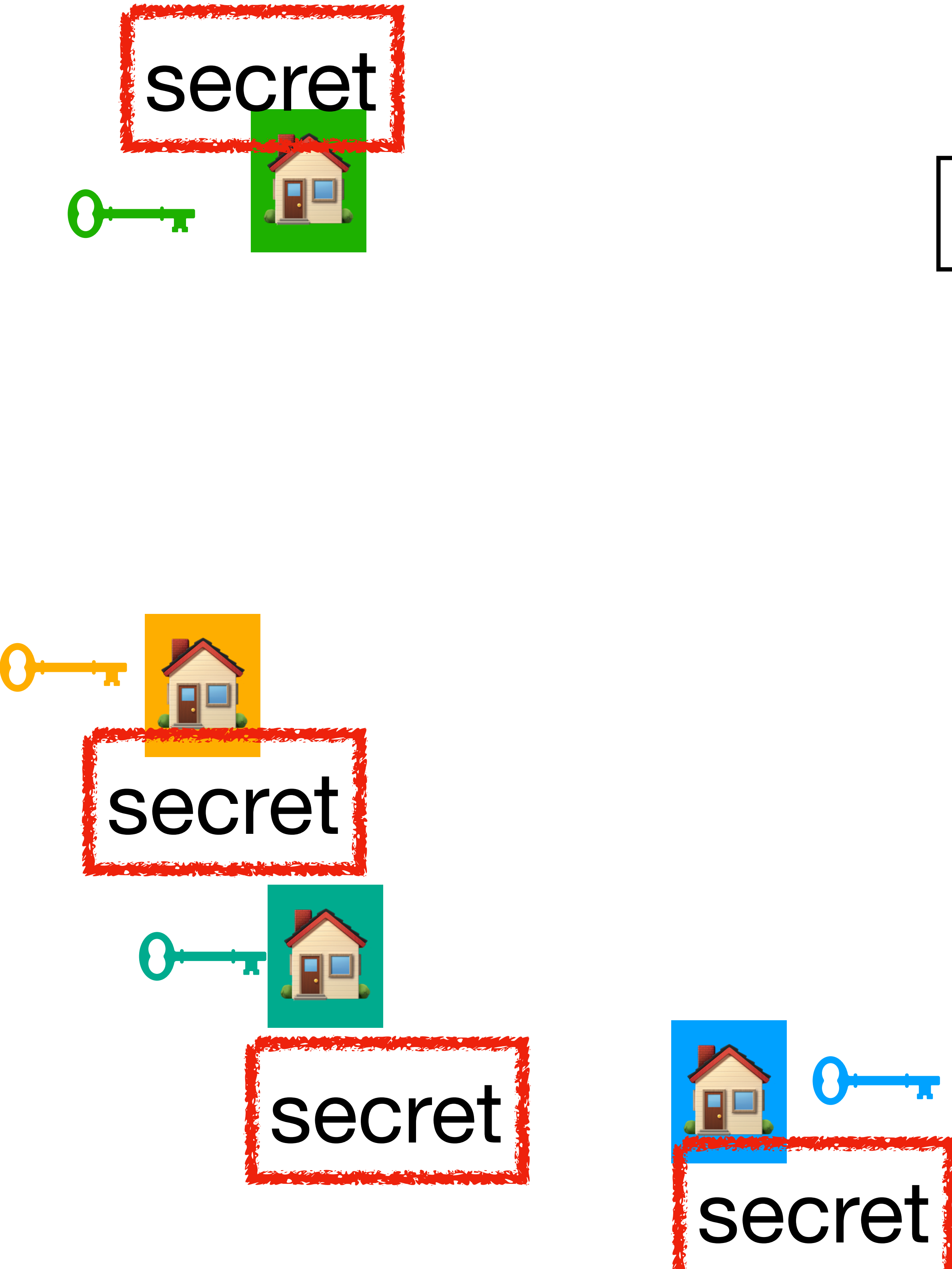

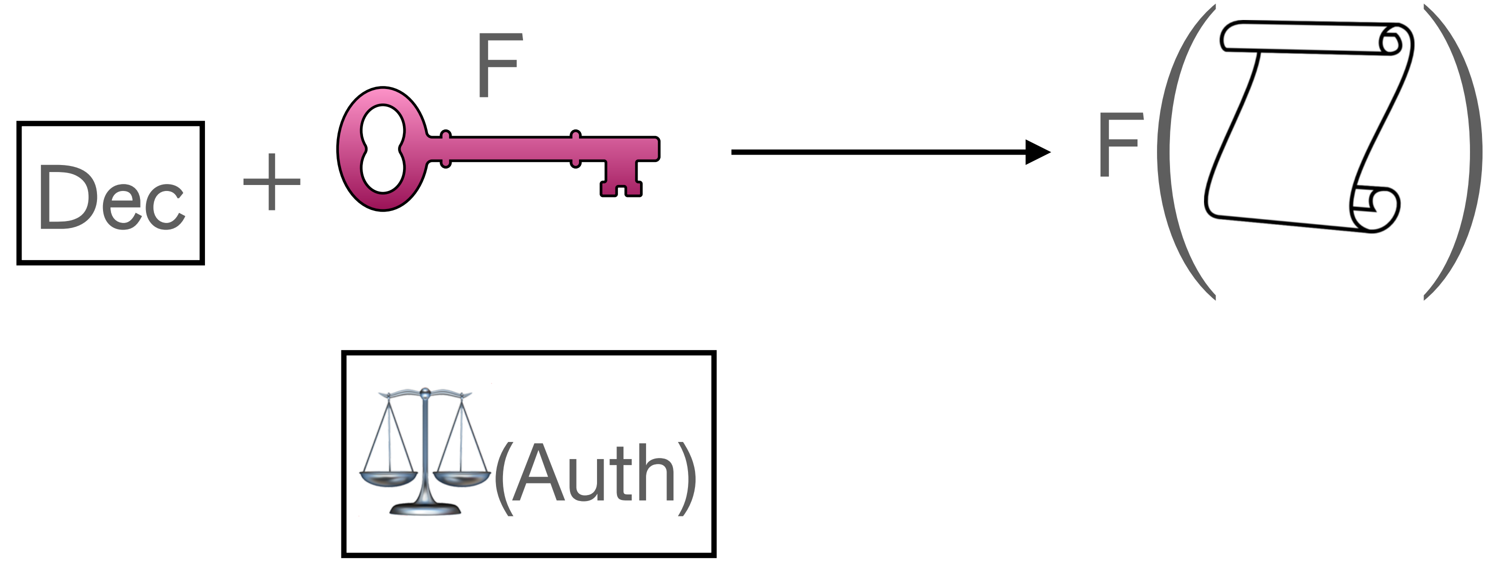

[GGG+14,CDGPP18]
“vanilla” syntax

F( ) :

Parse Att, =

If Pol(Att) = True then

Else “Nothing”

Changes in Model

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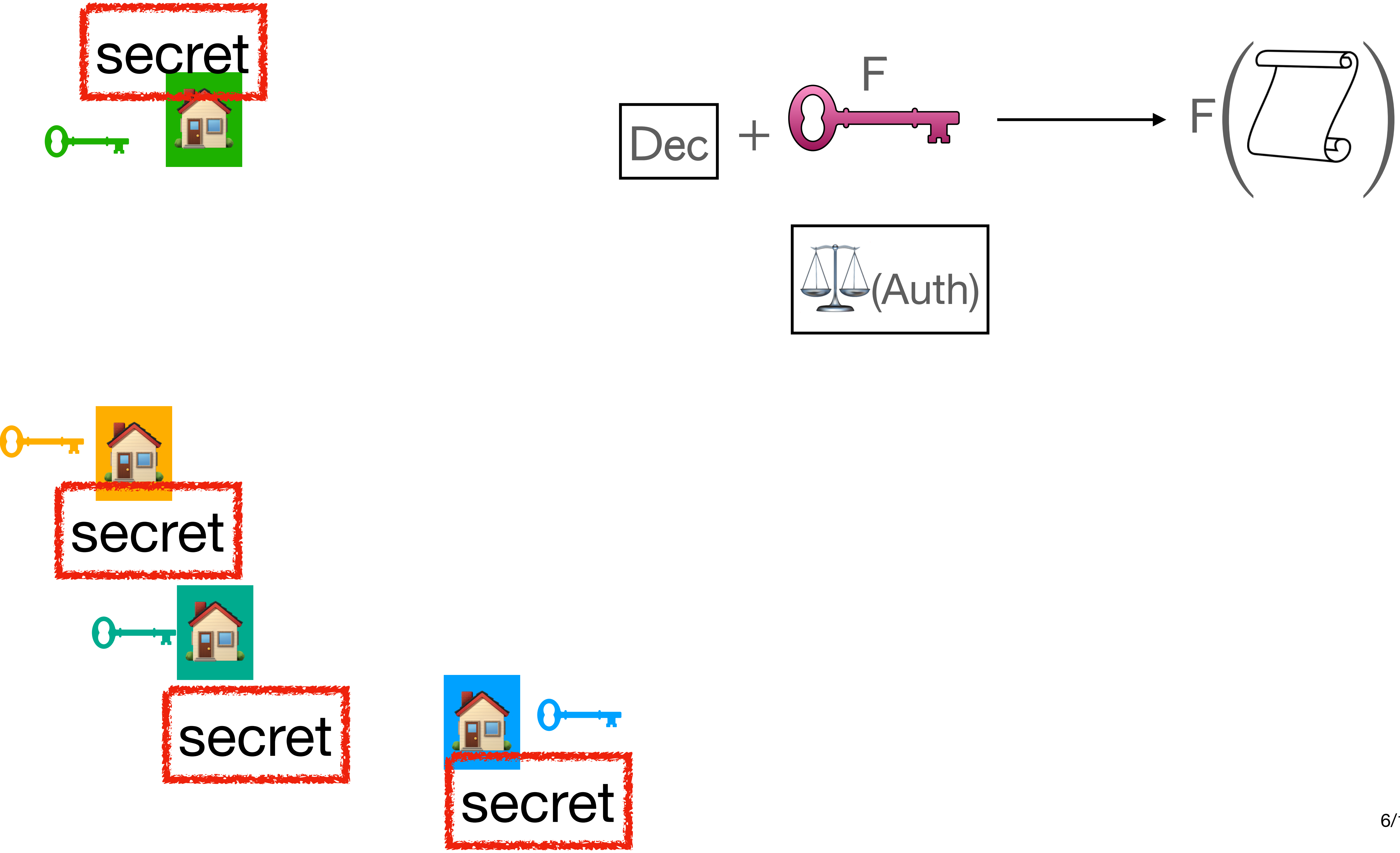

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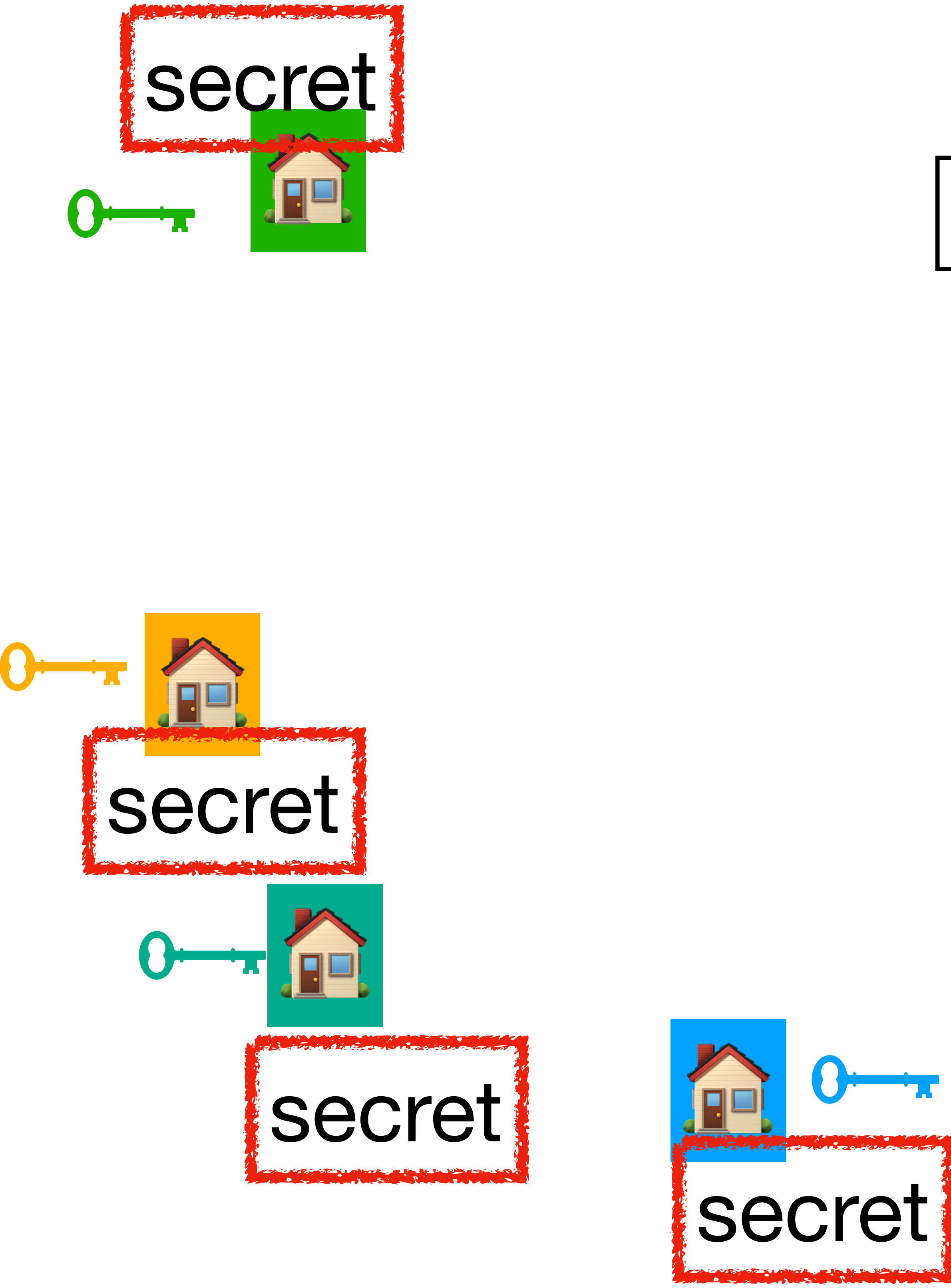
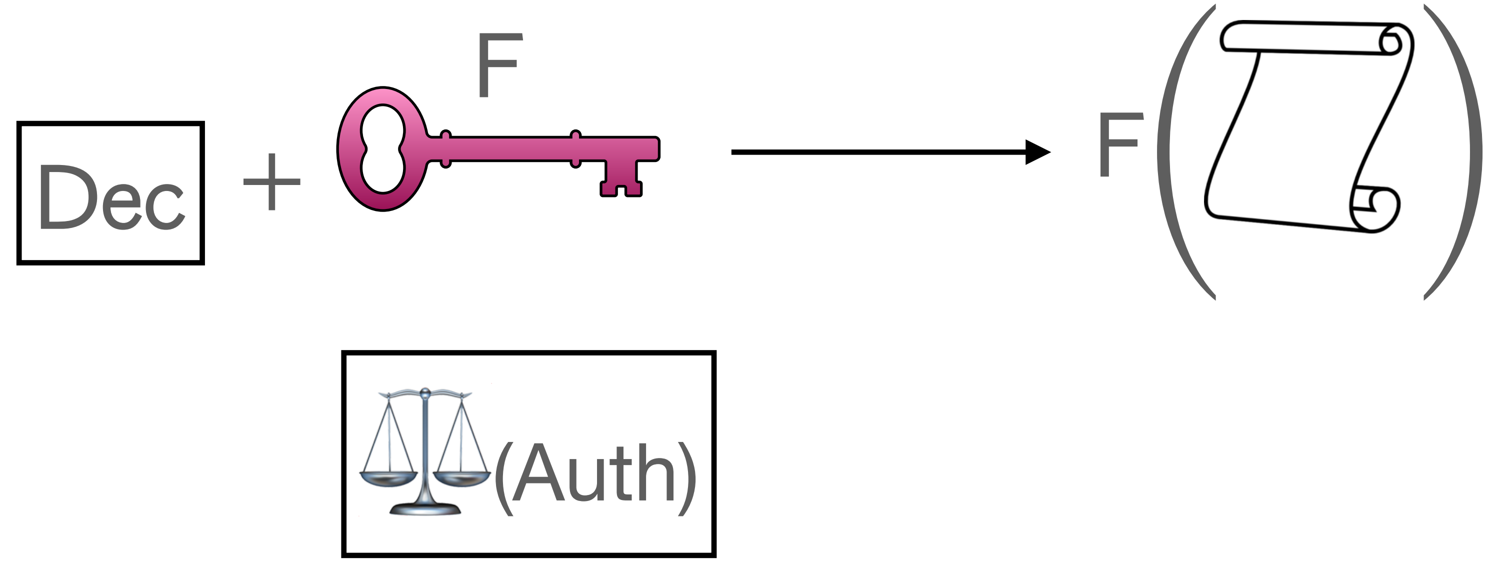




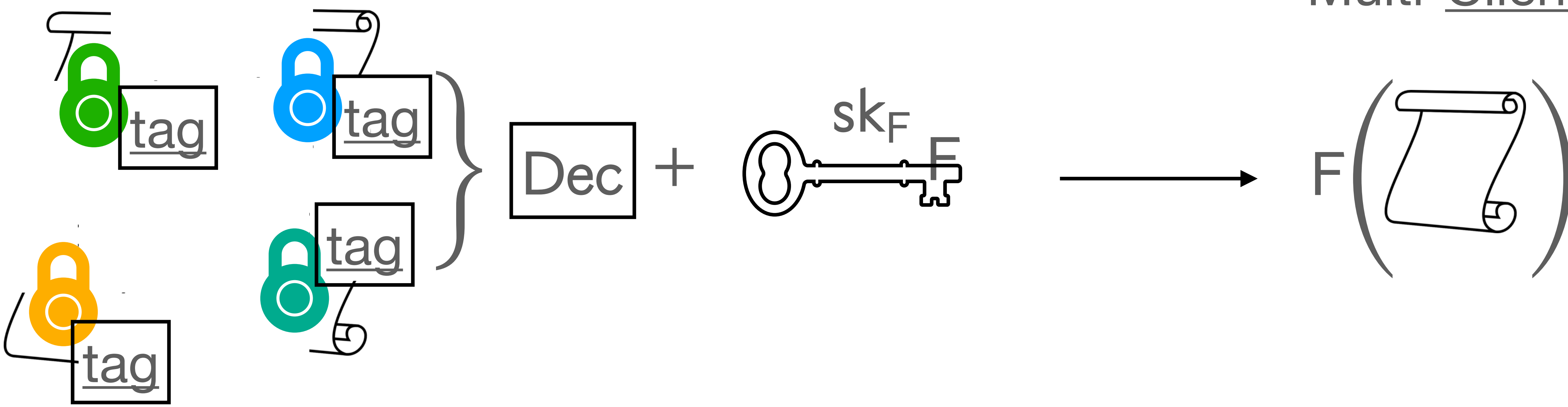
🤔**Syntactical:**

NOT allow public-Att

Motivation - Usage of Keys

MCFE [GGG+14, GKL+13,CDGPP18]

Multi-Client



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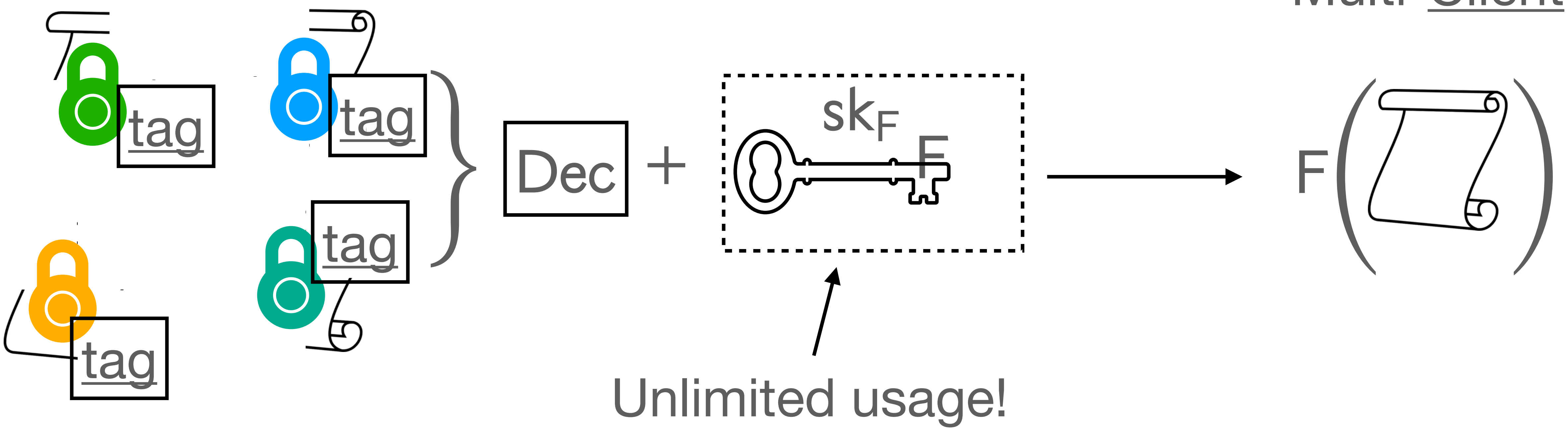

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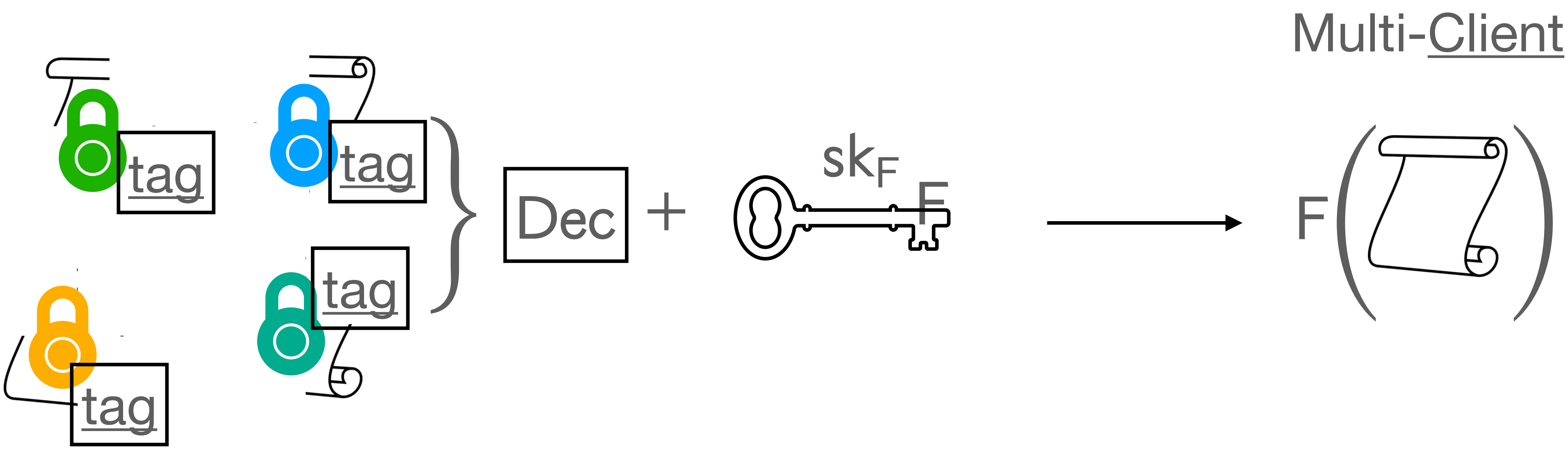

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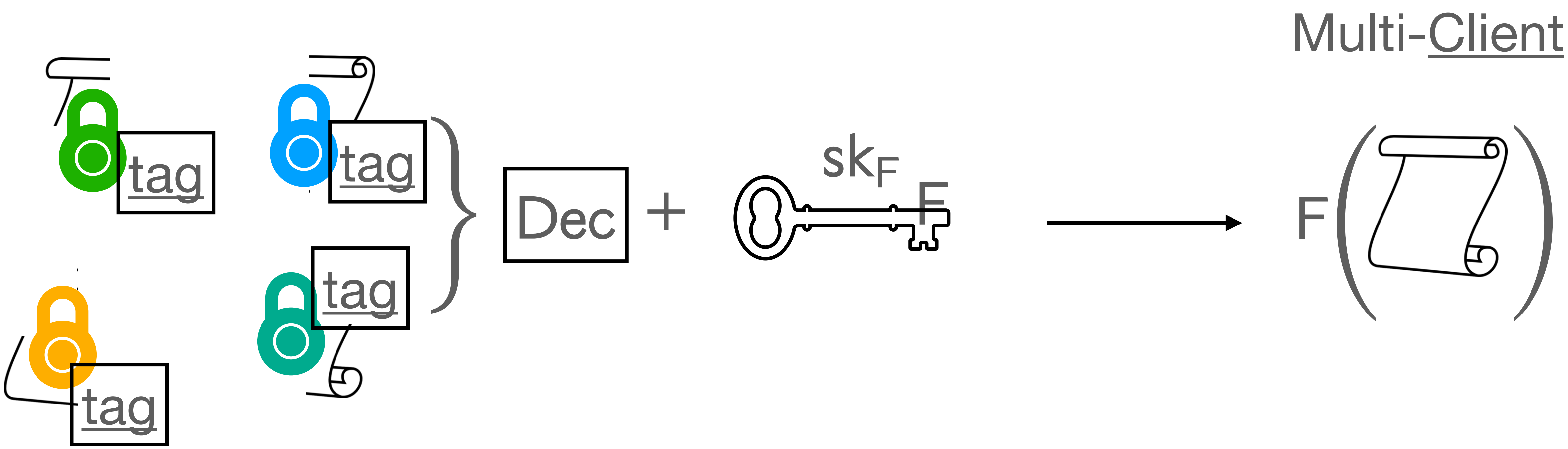


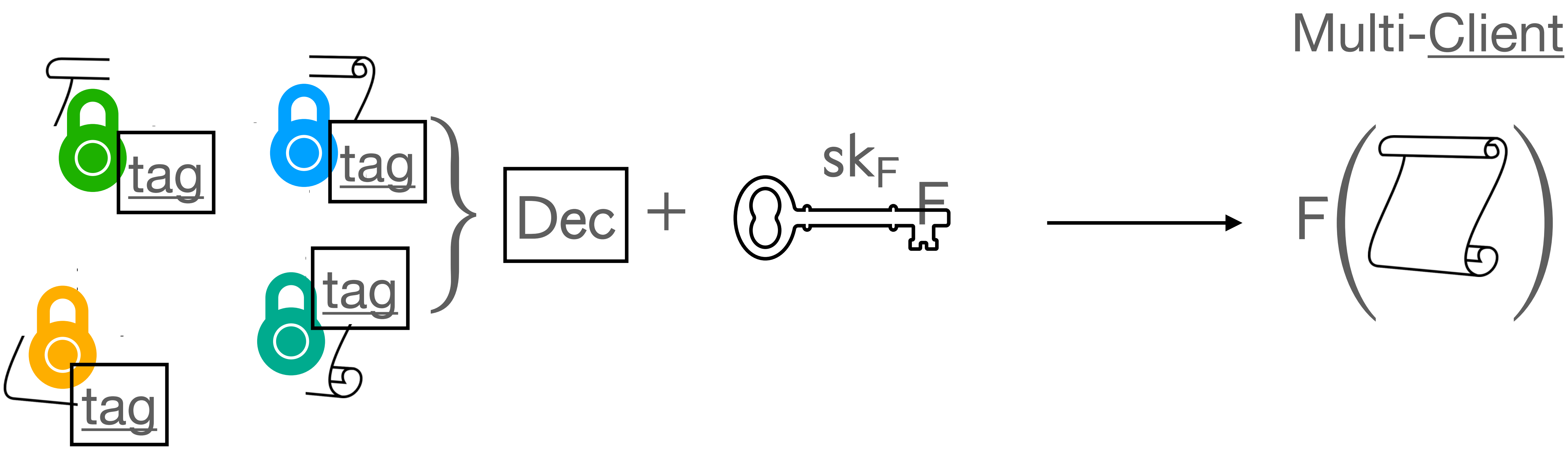
[ACGU20]: control keys
In *Multi-Input* FE [GGG+14]

Secret Encryption Keys

Only one encryptor

Motivation - Usage of Keys

MCFE [GGG+14, GKL+13,CDGPP18]



🤔Efficiency

Related Works

Multi-Client with Fine-Grained Access Control [NPP22]

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✓ **First definitions for MCFE with key control**

Related Works

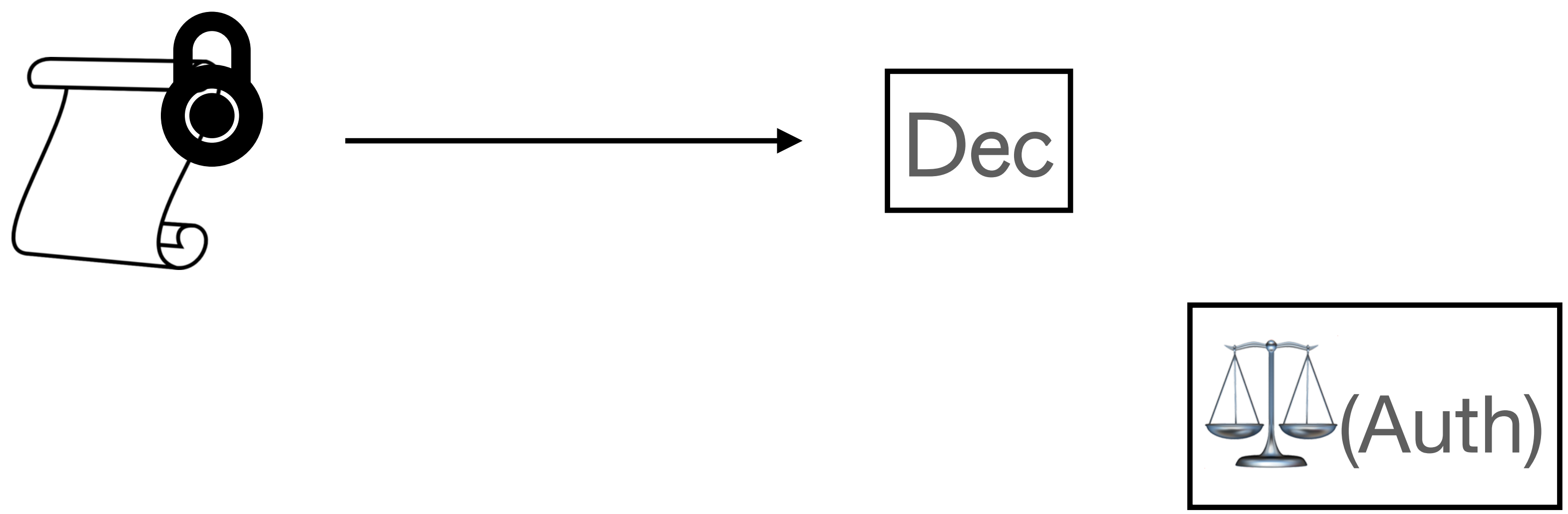
Multi-Client with Fine-Grained Access Control [NPP22]

✓ First definitions for MCFE with key control

✓ Concrete MCFE for scalar Inner Products with Linear Secret Sharing for key controlling

Motivation - Security Model

How do we define a “secure” FE ?



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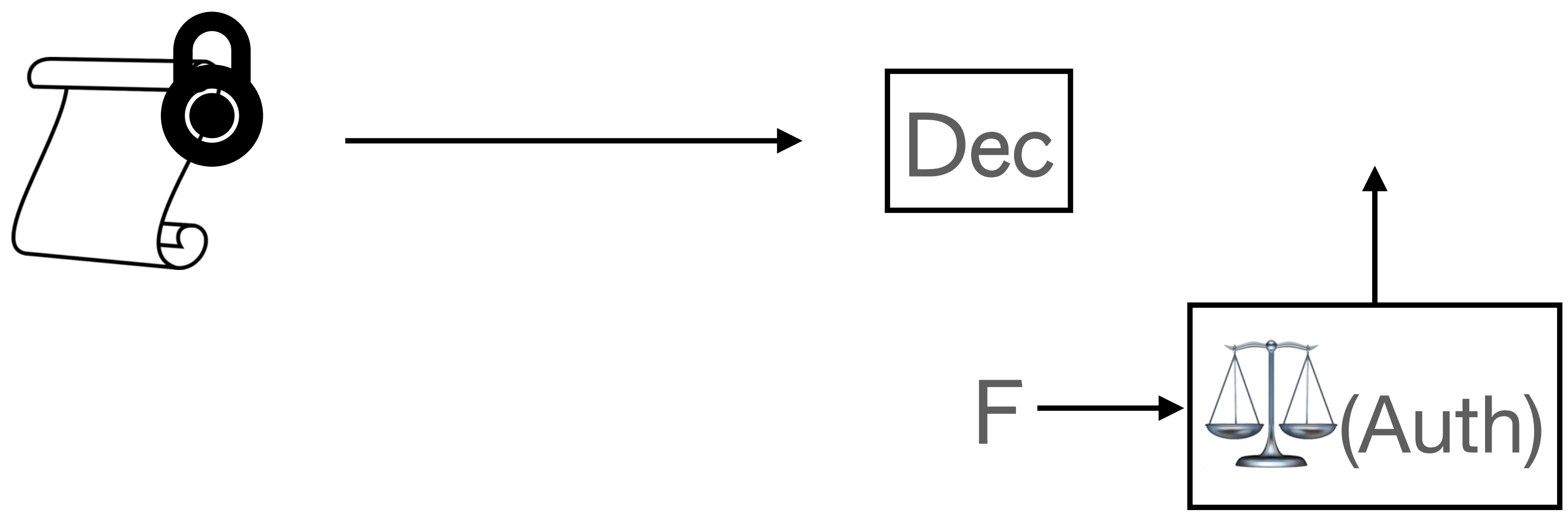

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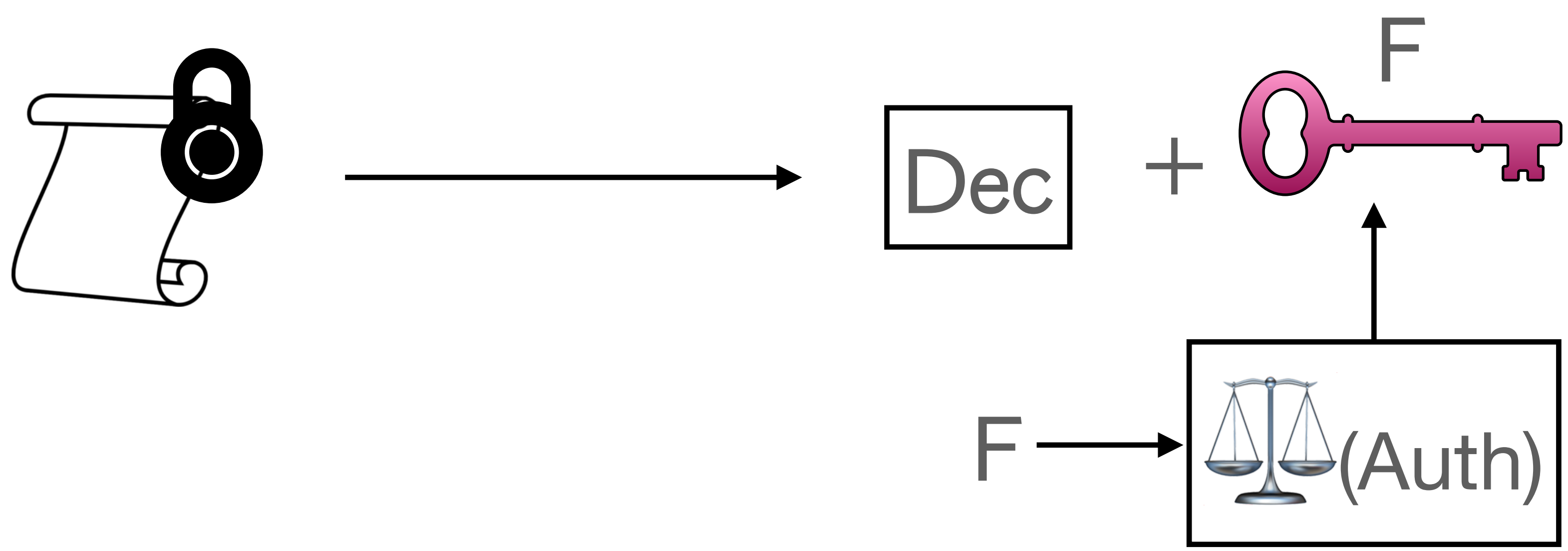

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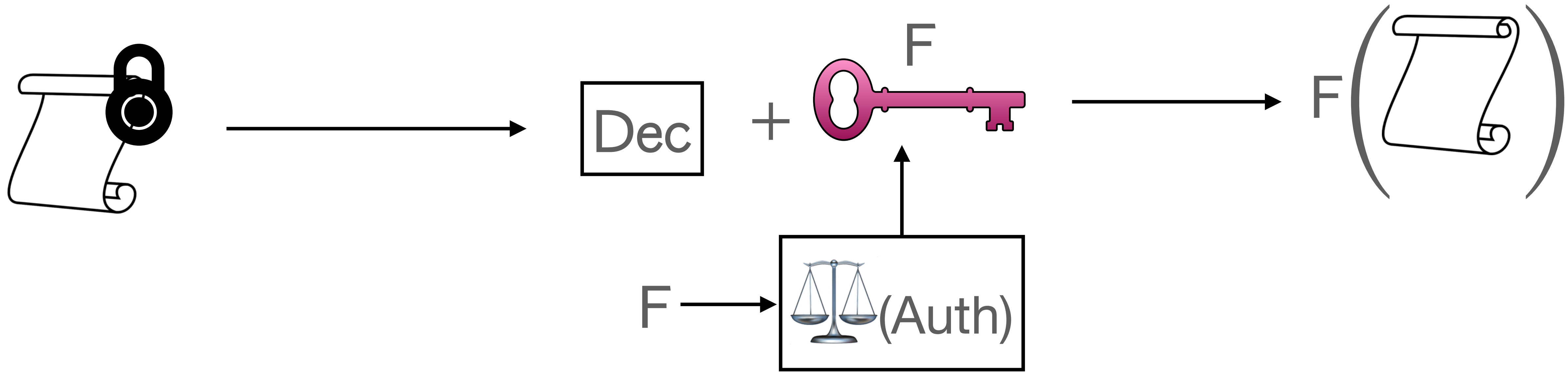

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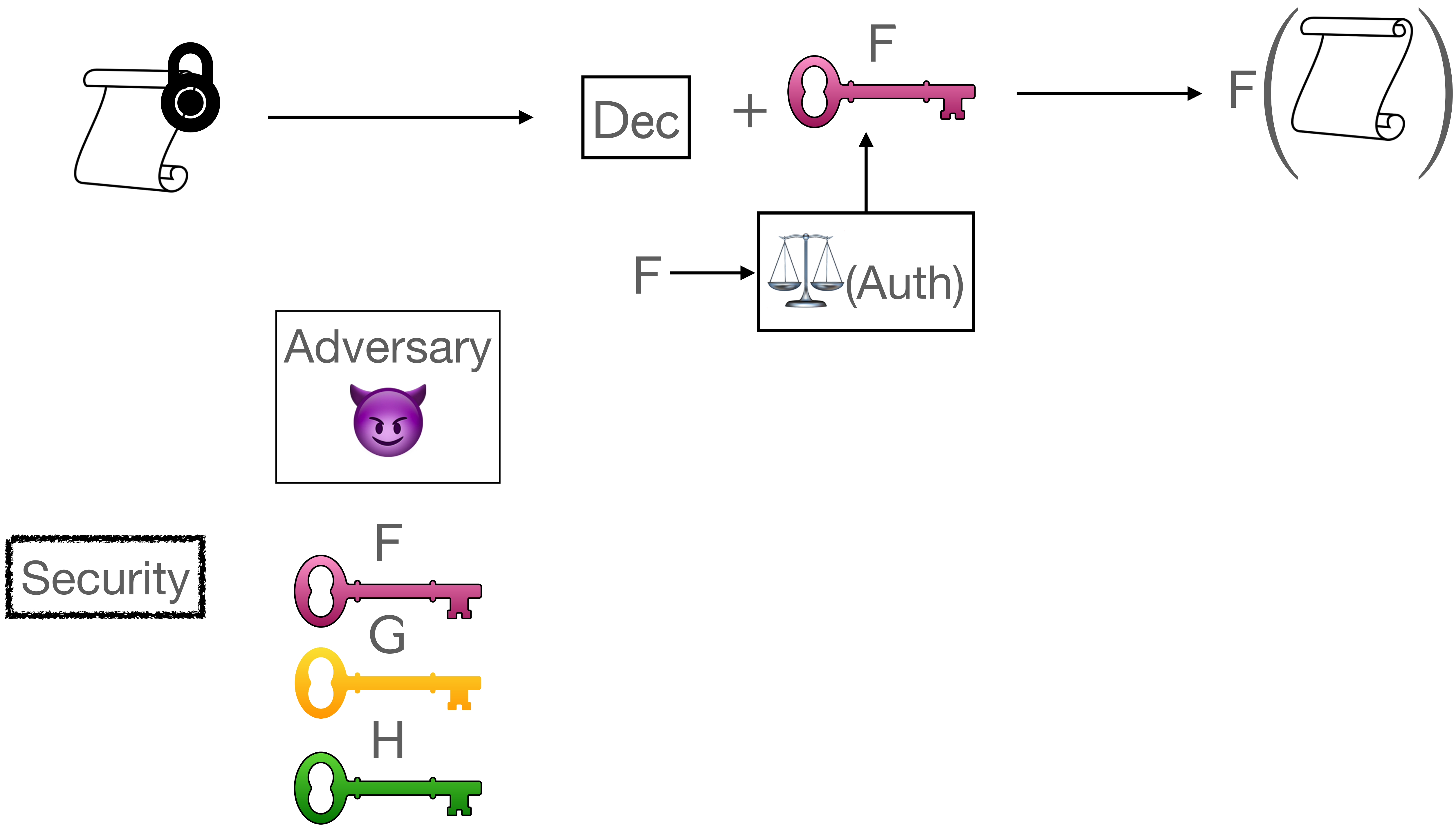

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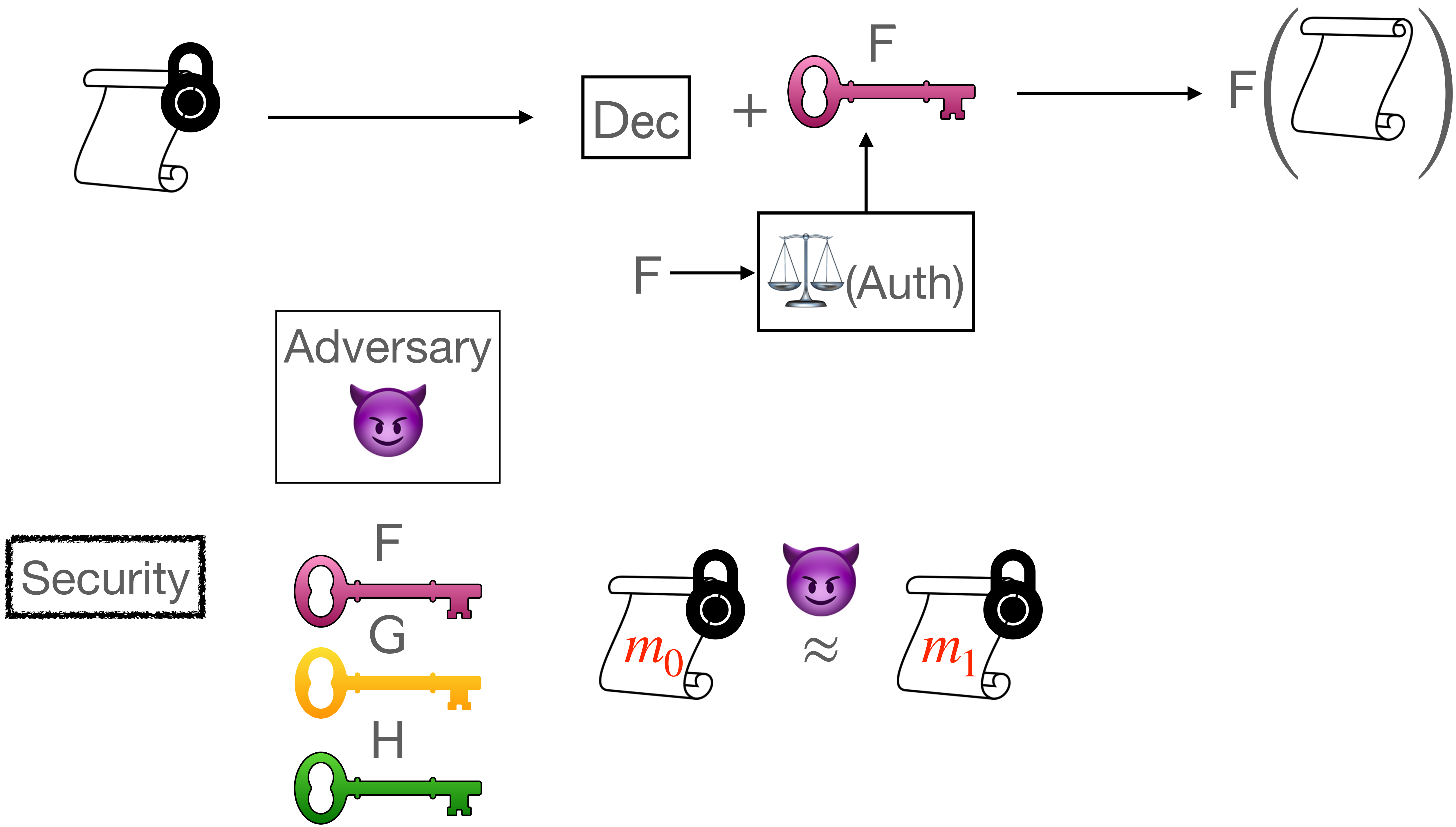

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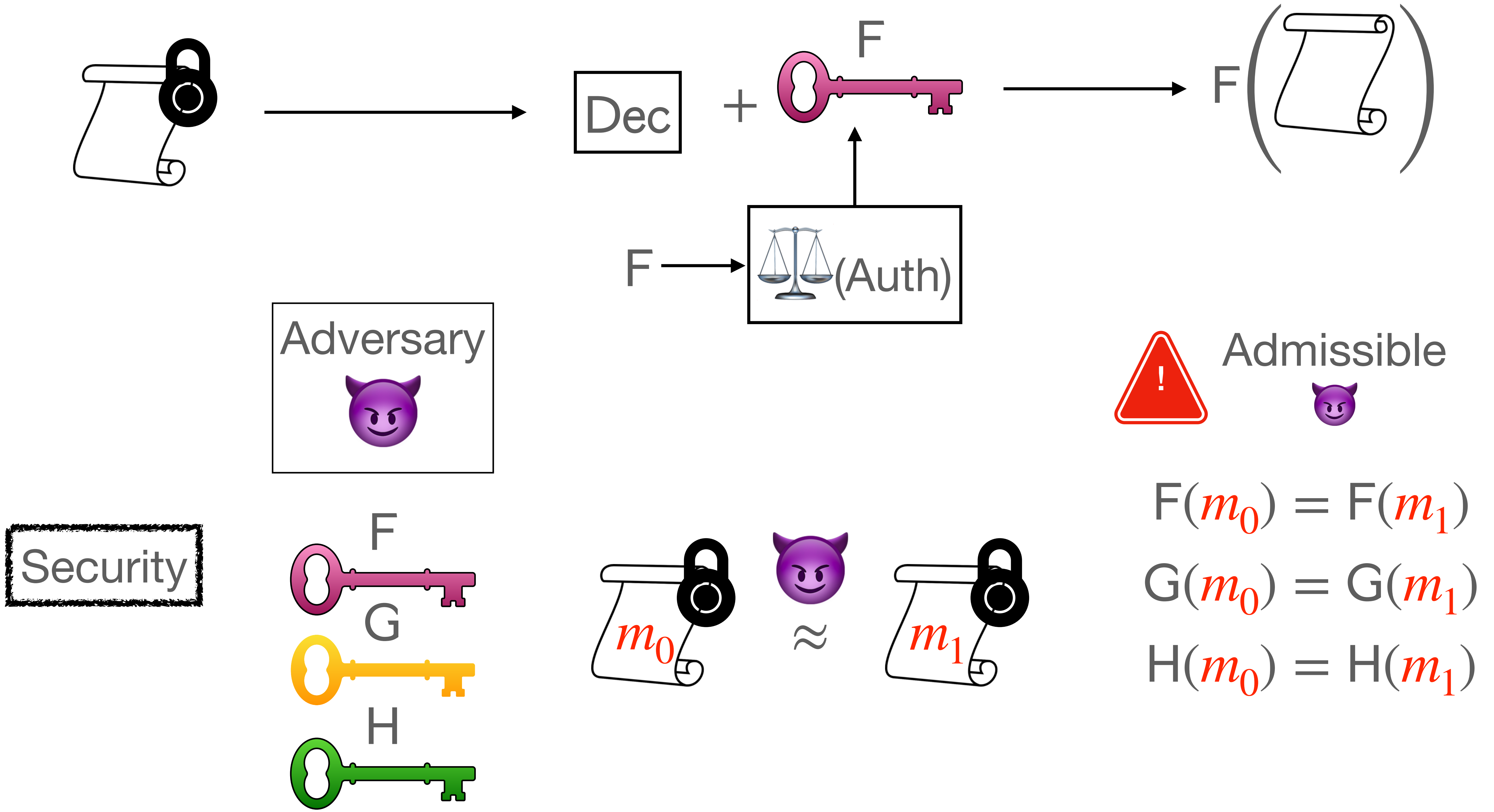

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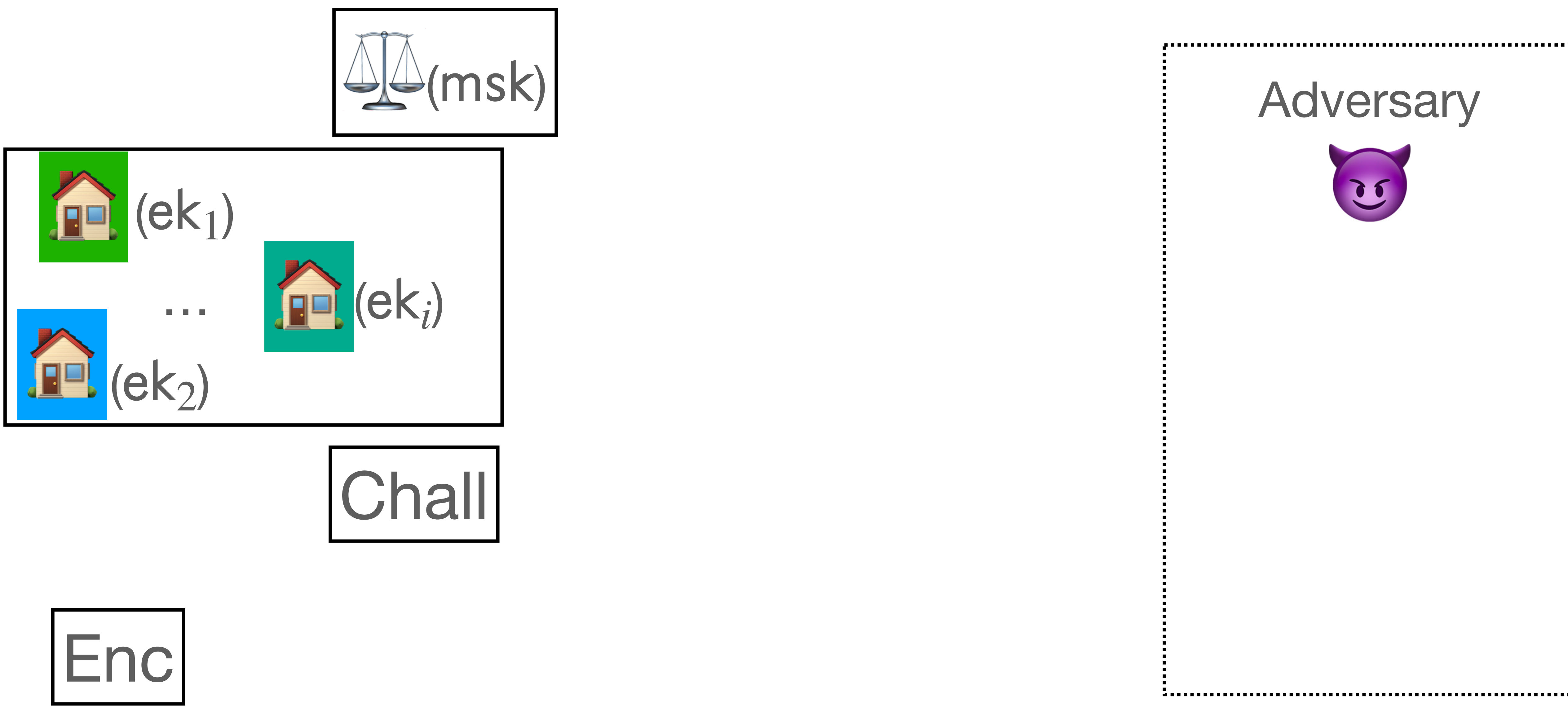
How do we define a “secure” MCFE ?

Challenger: $b \xleftarrow{\$} \{0,1\}$



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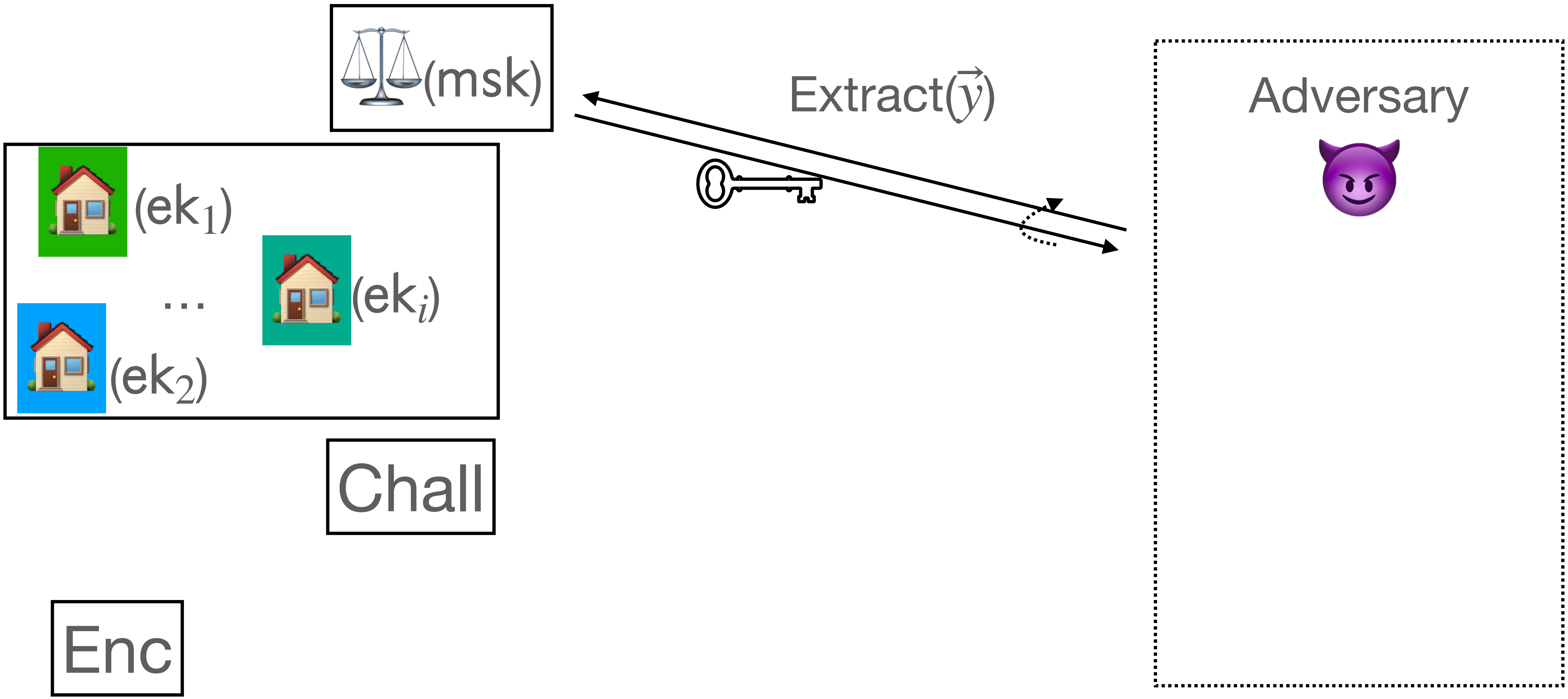

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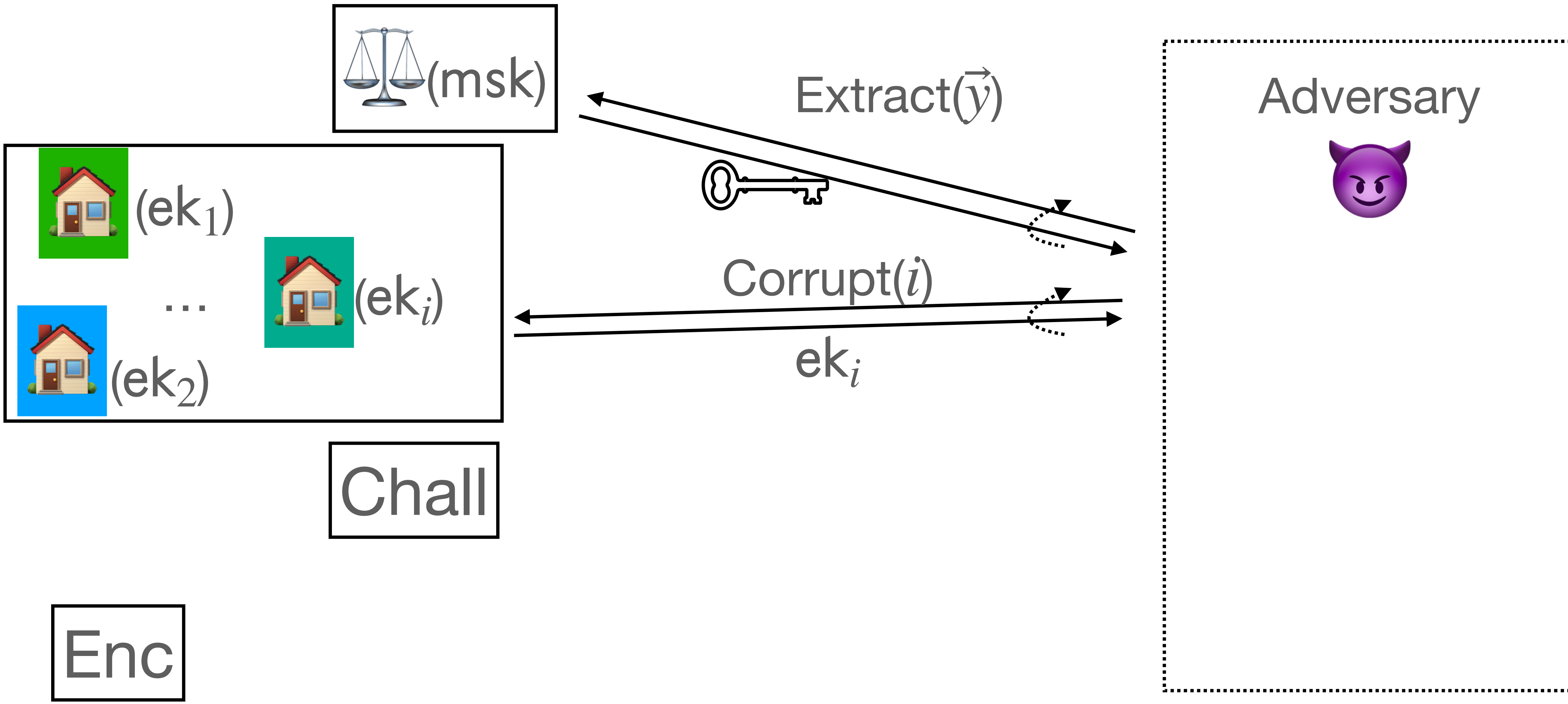

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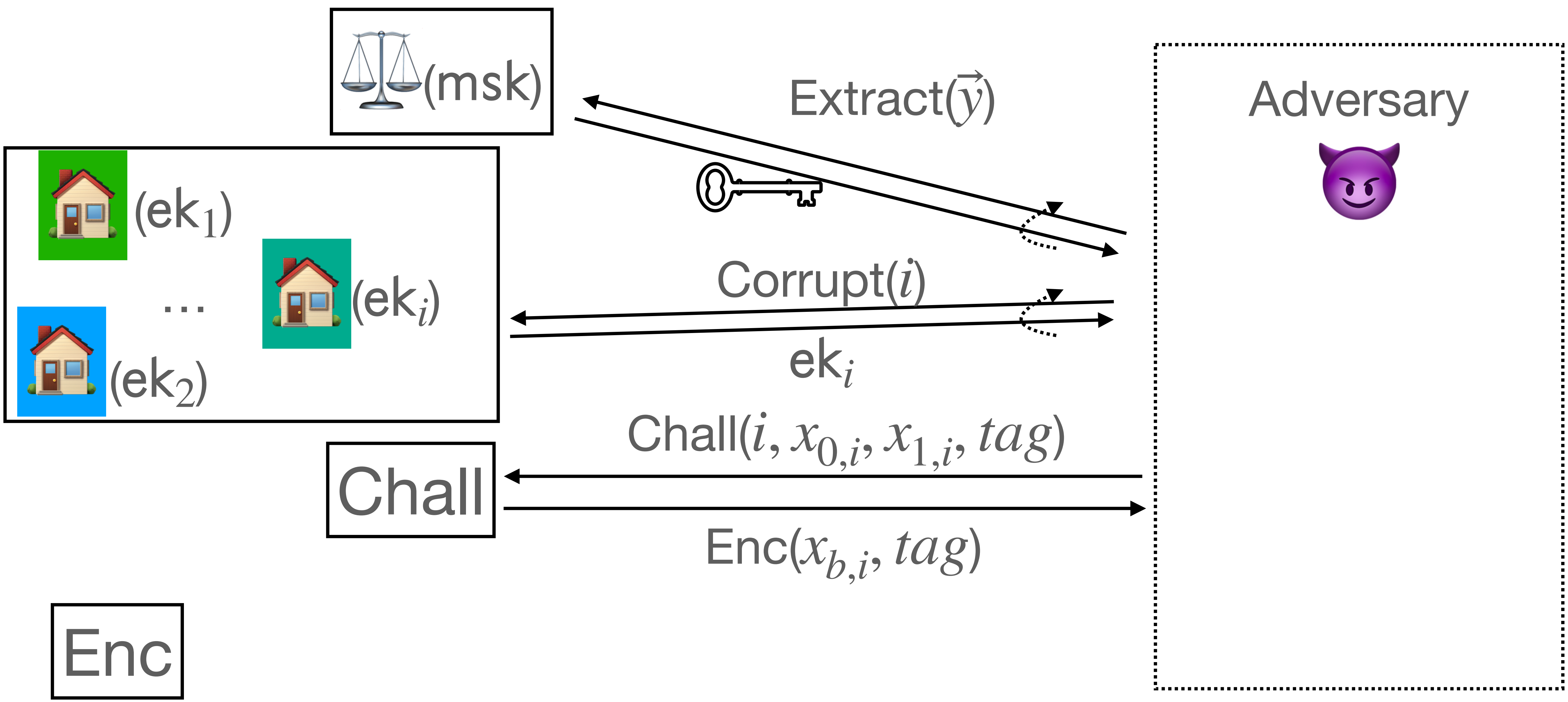

Secret Keys: $\boxed{\text{Enc}}$ +1 chall security ⇒ multi-chall security

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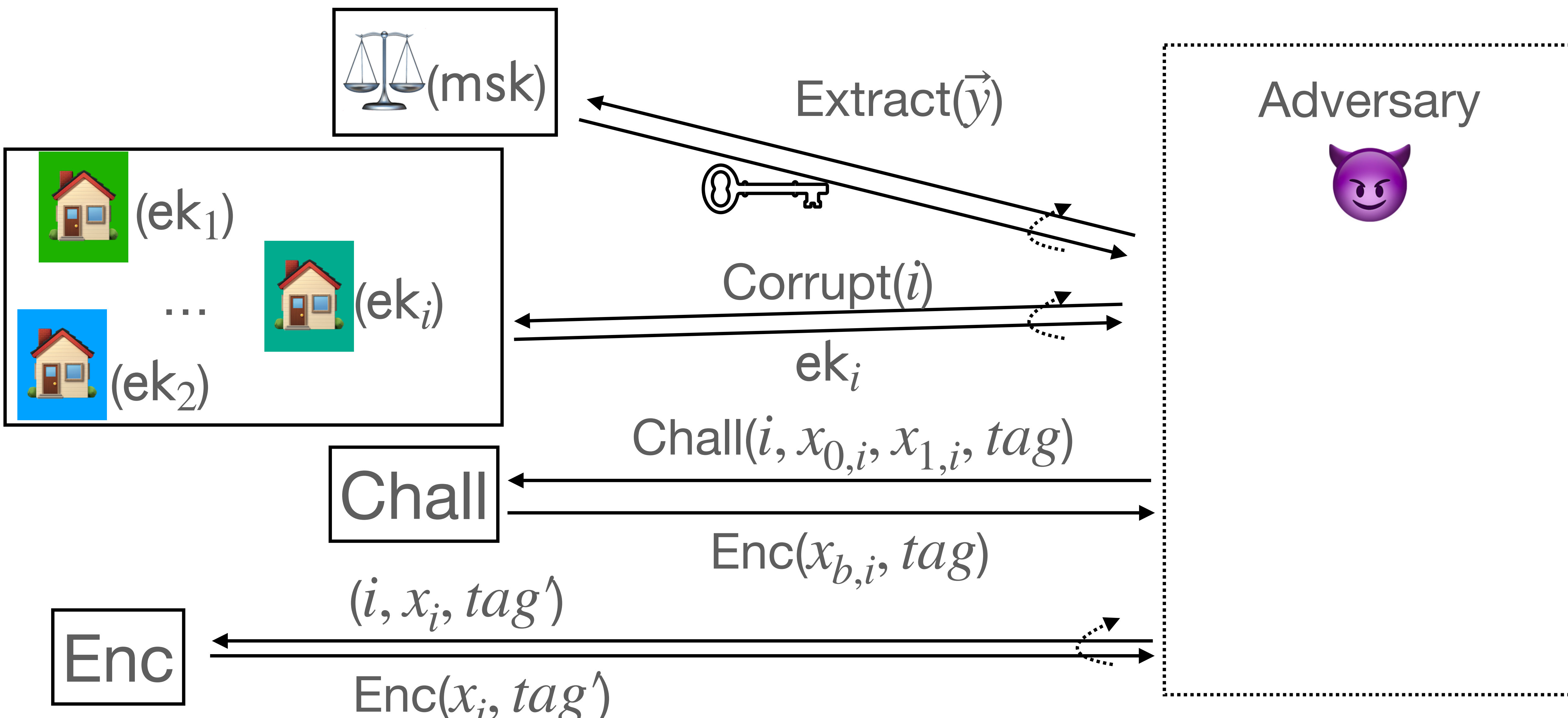

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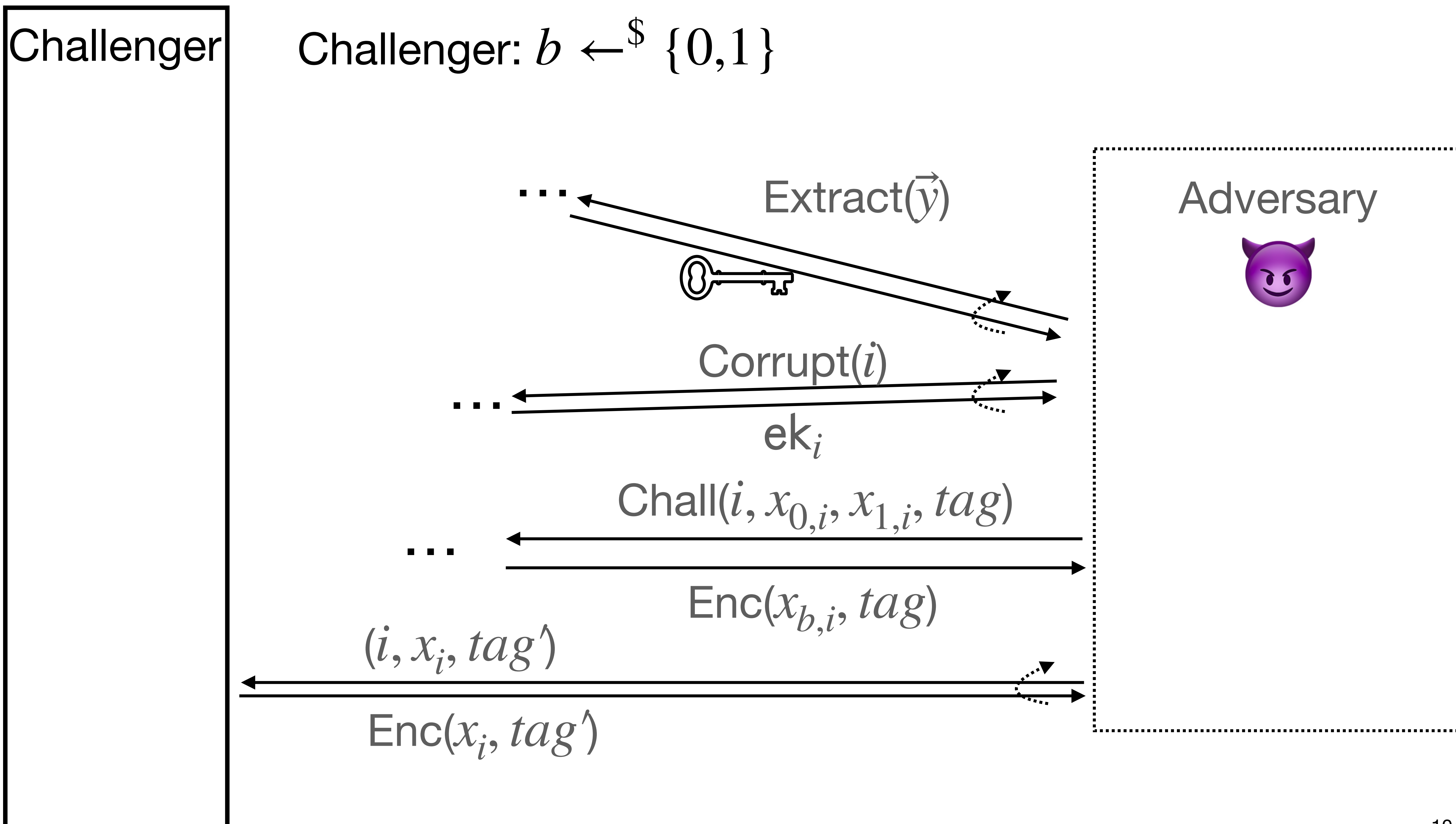

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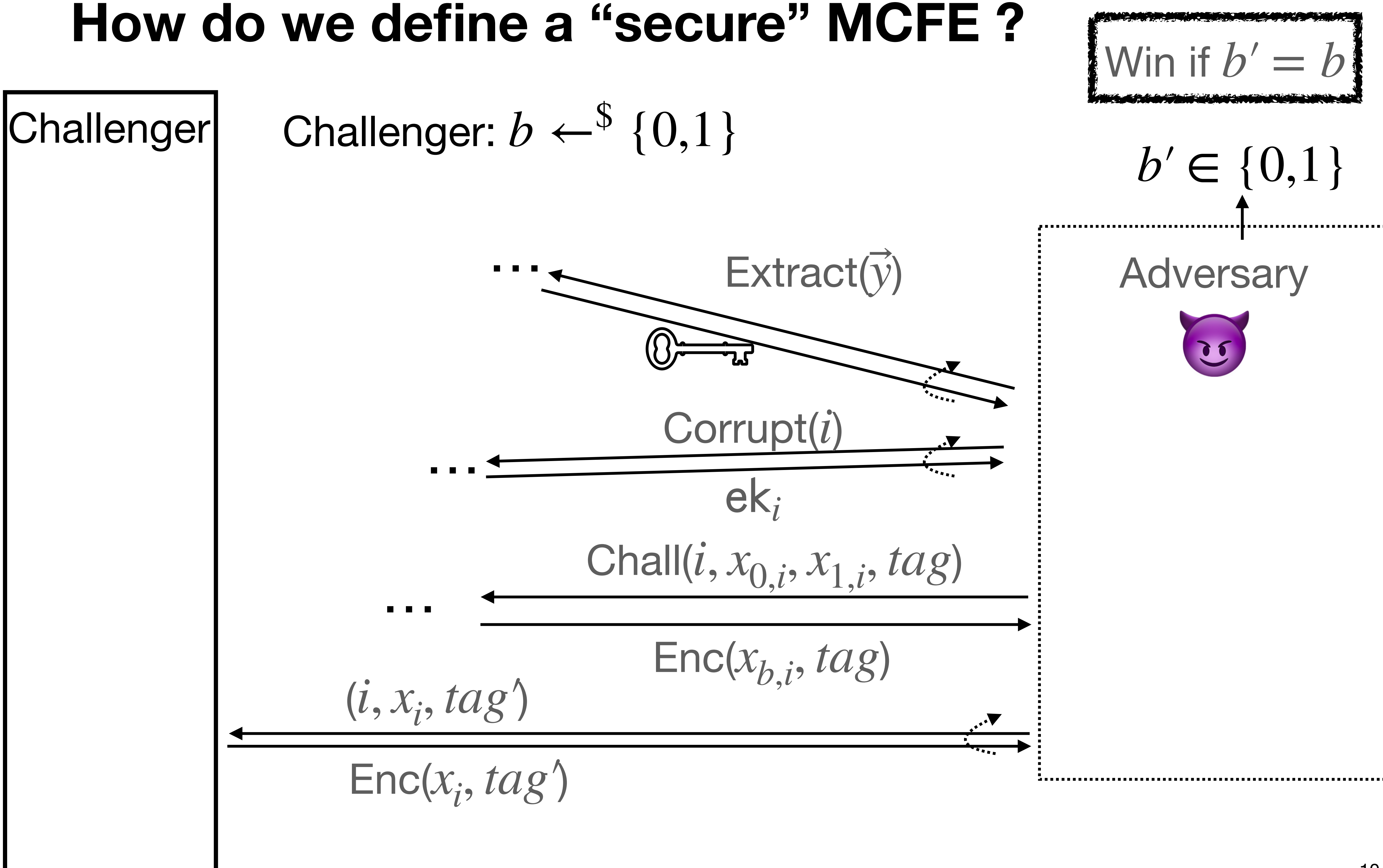

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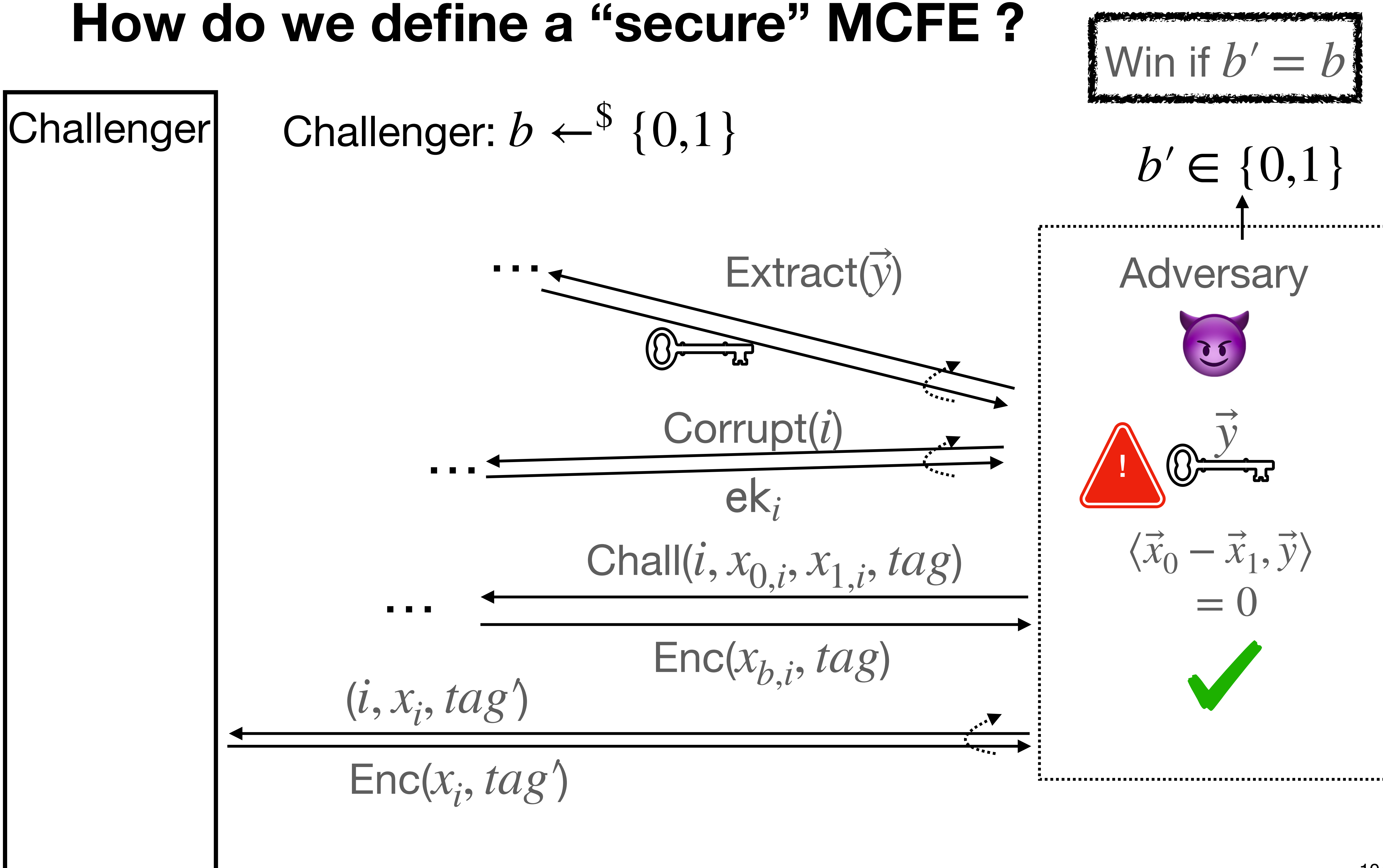

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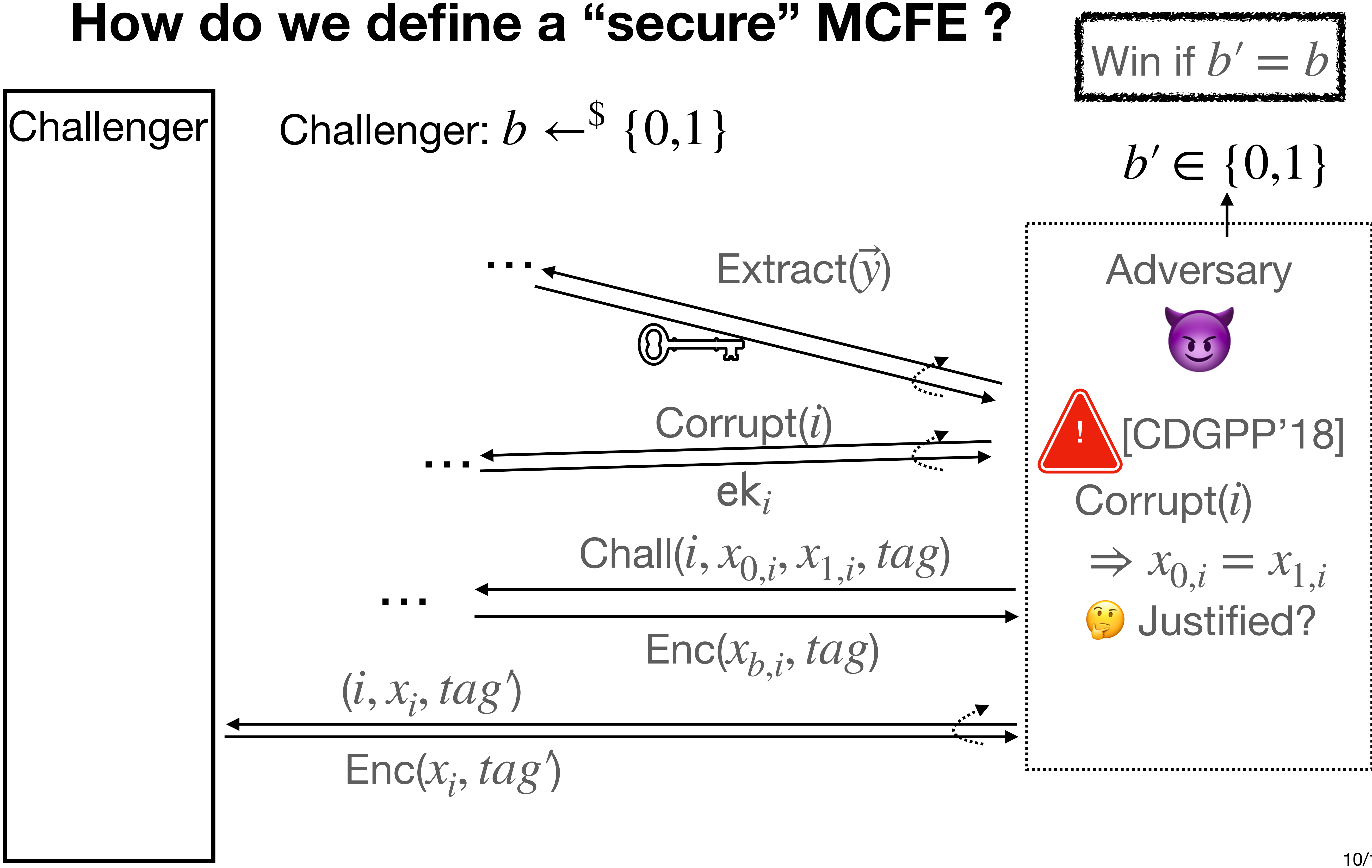

Motivation - Security Model

A“secure” MCFE - the case of Inner Products

Adversary 😈

⚠️ [CDGPP’18]

Corrupt(i)

$\Rightarrow x_{0,i} = x_{1,i}$

🤔 Justified?

Motivation - Security Model

A“secure” MCFE - the case of Inner Products

[CDGPP’18]

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—> Follow-ups with same constraint: [ABKW19],[ABG19],[LT19], [CDG+20],[AGT21],[SV23]

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🤔 Justified?

From [CDGPP18]:

MCFE is Secret Encryption Keys

$\Rightarrow$ Usually deterministic

$\Rightarrow$ $\boxed{\text{Corrupt}(i) \Rightarrow x_{0,i} = x_{1,i}}$

Motivation - Security Model

A“secure” MCFE - the case of Inner Products

[CDGPP’18]

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⚠️ [CDGPP'18]

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🤔 Justified?

✗

🤔Modeling Problem:

Why can't we do better?

(*I.e.*, weaker condition

$\Rightarrow$ considering stronger attacker

$\Rightarrow$ stronger security guarantee)

Related Works

Improved Security Notion for (D)MCFE

Optimal Security Notion for Decentralized Multi-Client Functional Encryption [NPP'23]

Computing scalar inner products:

F(·) =

$$\langle \cdot , param \rangle$$

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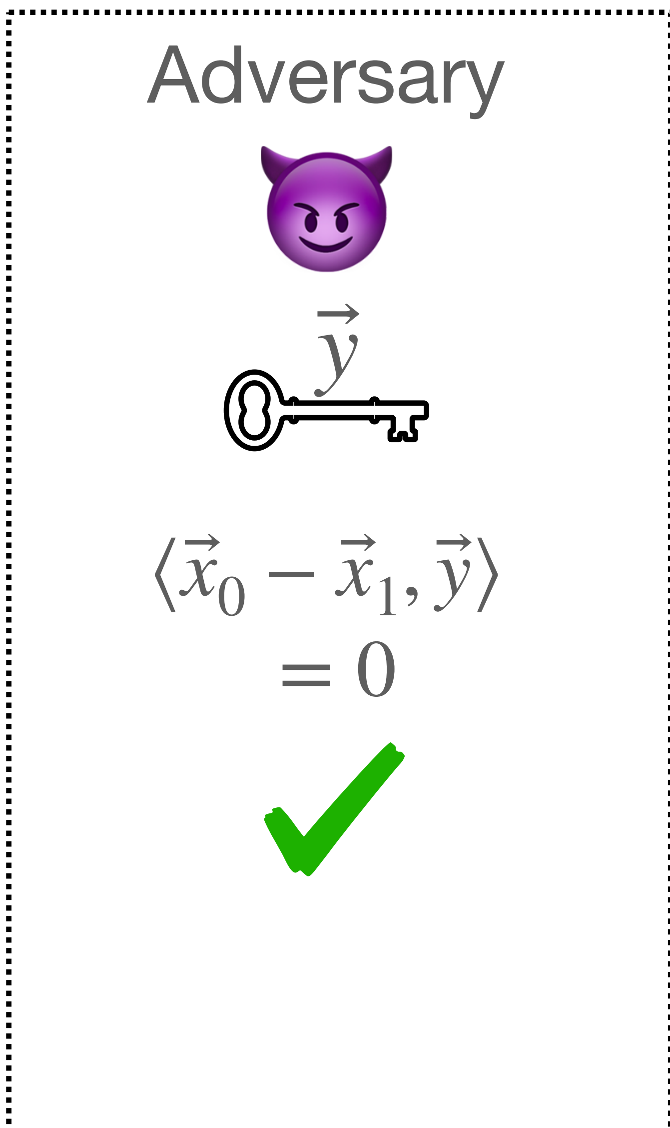

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or $y_i = 0$

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Adversary 😈

Corrupt(i)

$\Rightarrow x_{0,i} = x_{1,i}$

or $y_i = 0$

+ Optimality proof : this is the *least* we require 🎉

Computing scalar inner products:

F(·) =

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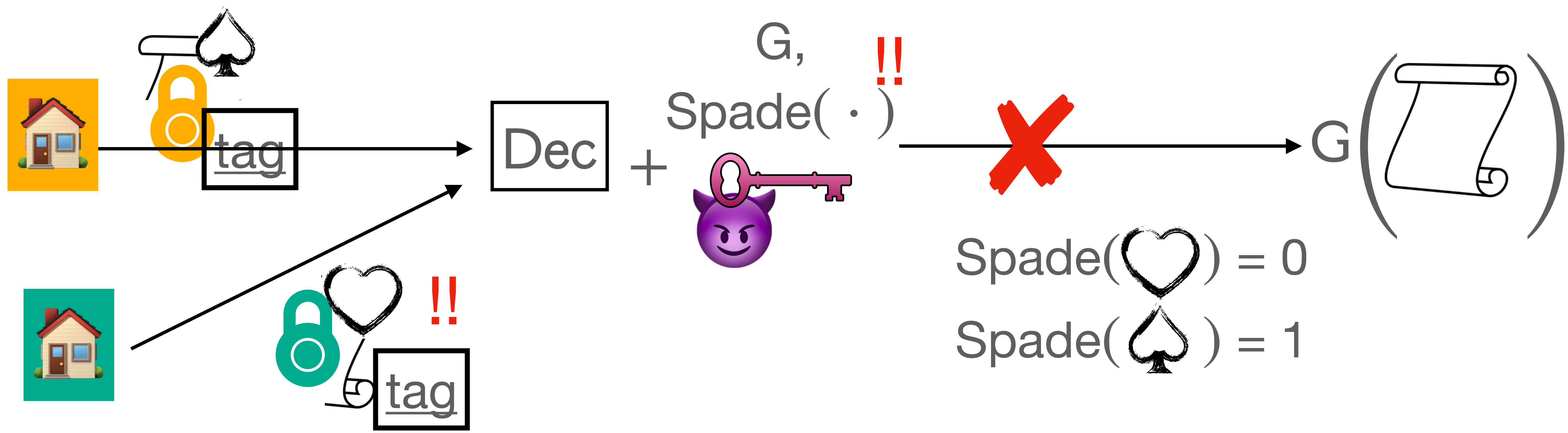
Research Question - Combining All Together

Controlling Keys (*as per* [NPP22]) in the Optimal Setting (*as per* [NPP23])



🤔 **public-key FE [BSW11], secret-key MCFE [GGG+14, CDG+18]**

Syntactical Problem:

NOT allow public-Att

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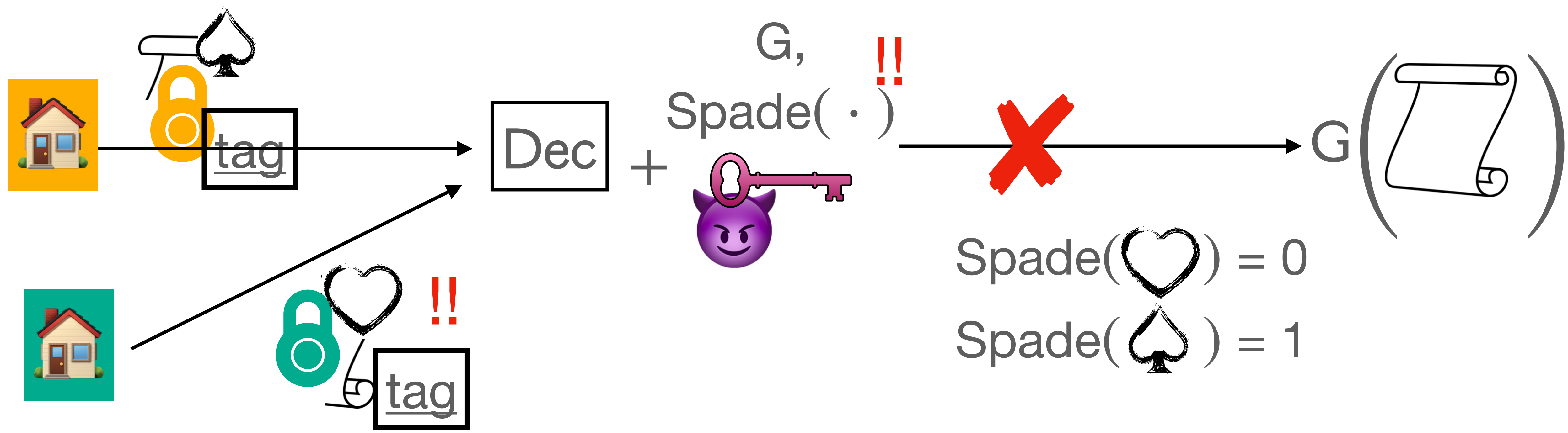


Tag, ♤, ♡ : can be public

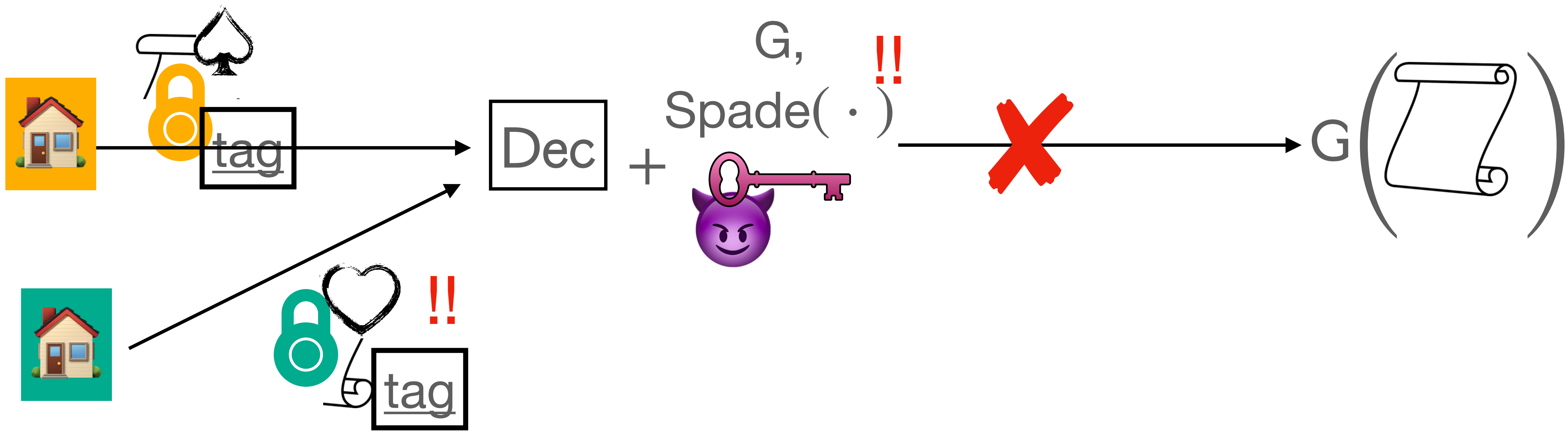
🤔 **<u>public-key FE [BSW11], secret-key MCFE [GGG+14, CDG+18]</u>**

<u>Syntactical Problem:</u>

NOT allow public-Att

Our Result

Controlling Keys in the Optimal Setting



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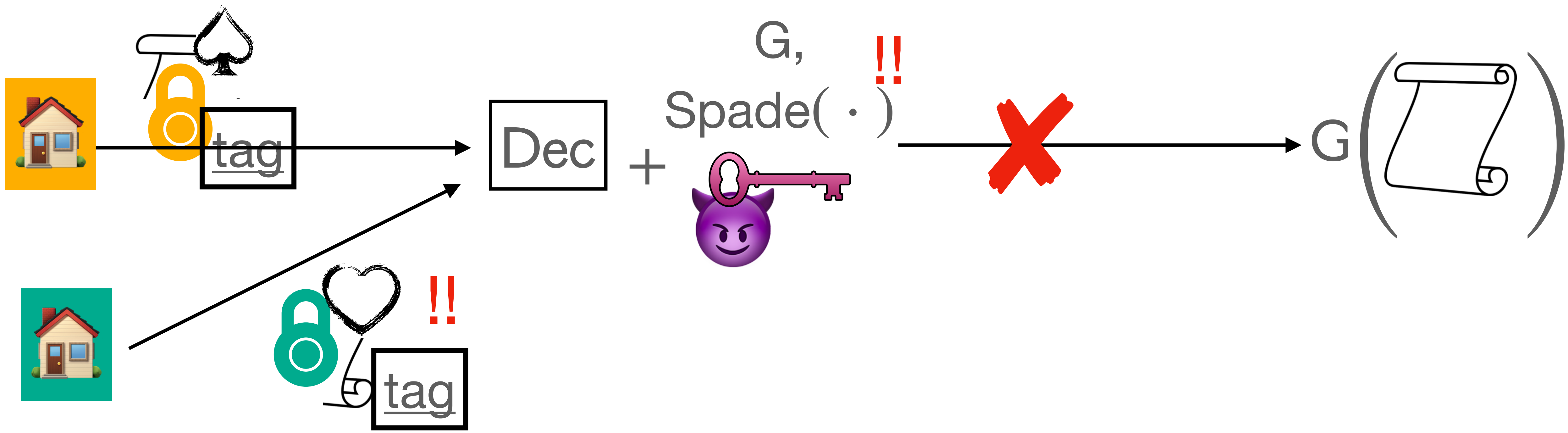

Refine Syntax of MCFE:

With public-inputs

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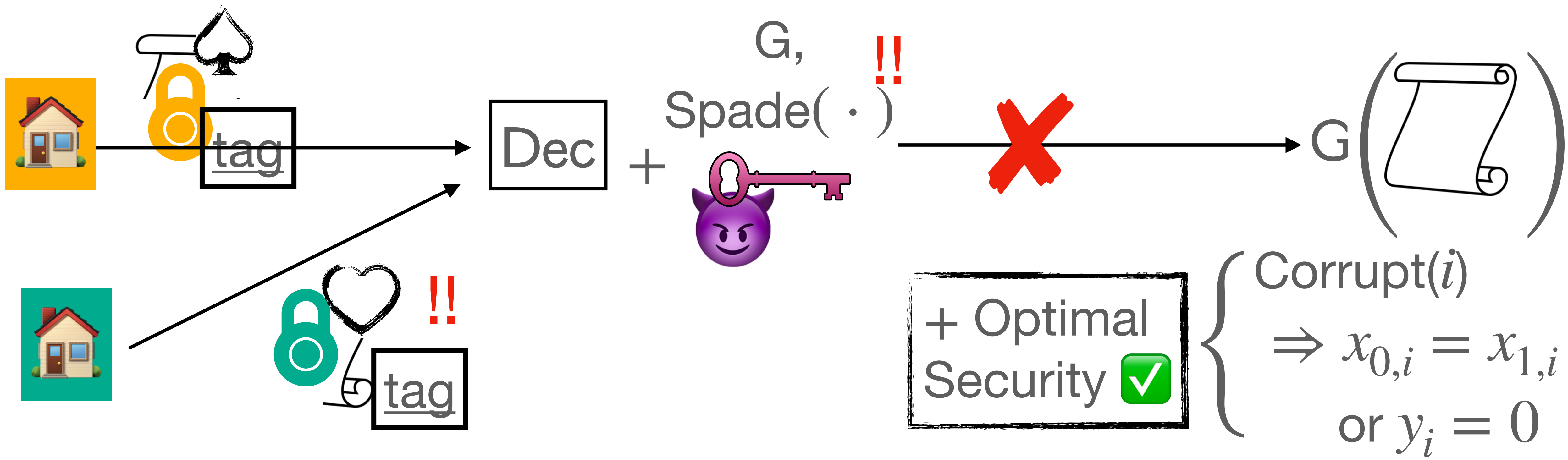

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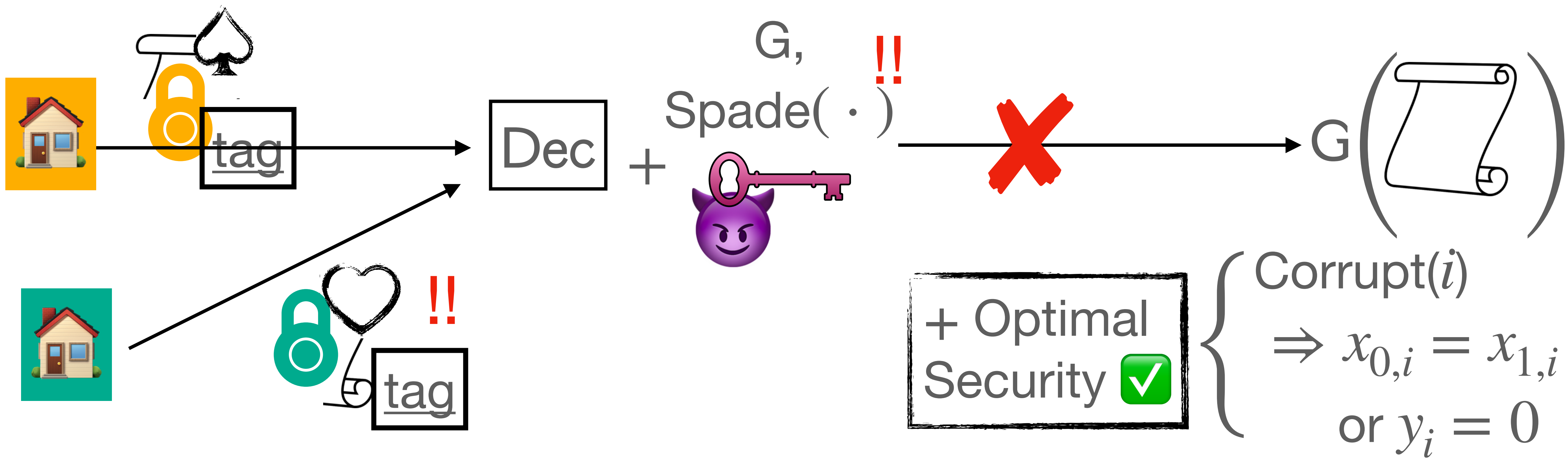

<u>Refine Syntax of MCFE:</u>

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<u>Identify Implications:</u>

MCFE + optimal security

$\Rightarrow$ public-key FE

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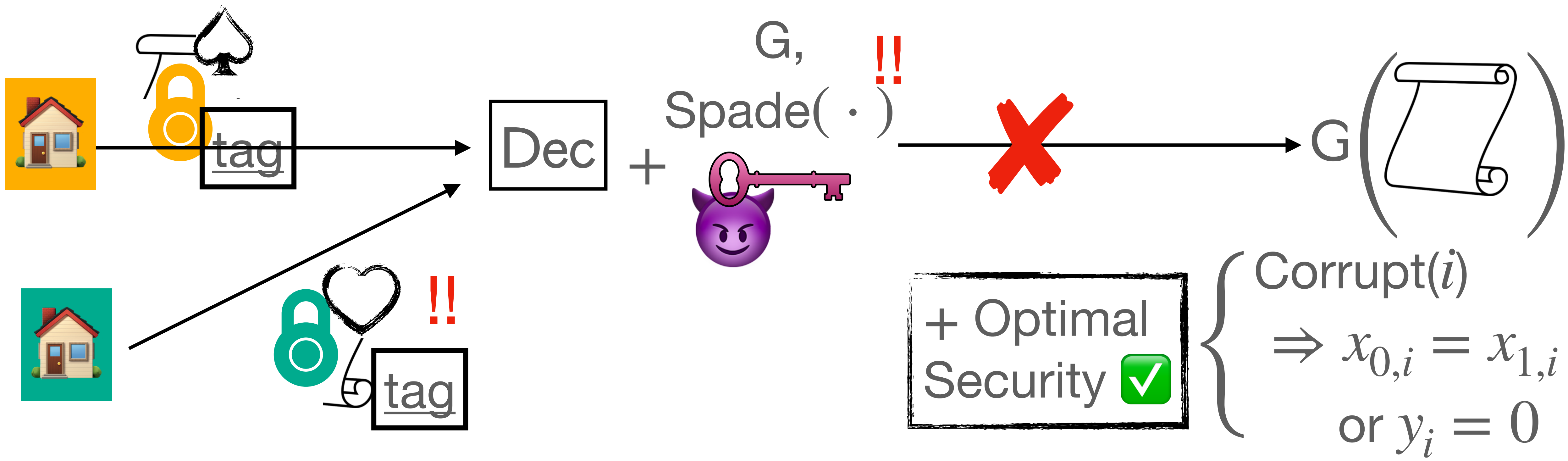

✓ **Refine Syntax of MCFE:**
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✓ **Identify Implications:**
MCFE + optimal security

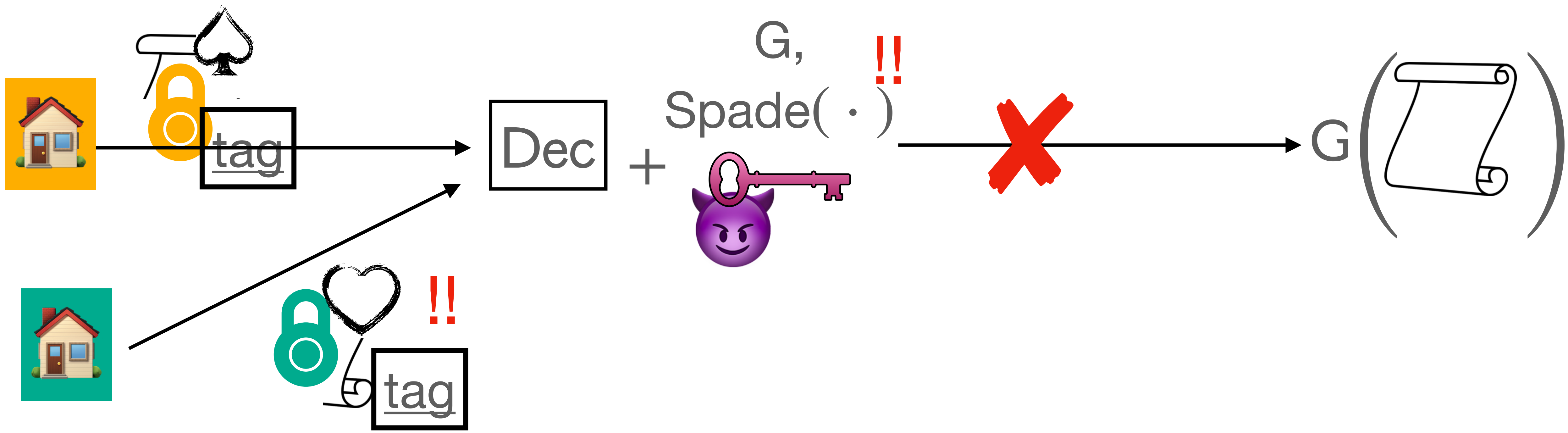
$\Rightarrow$ public-key FE

$\Longrightarrow$

Key-Policy
Attribute-based
Encryption,
Public- or private-att 🎉

Our Result

Controlling Keys in the Optimal Setting



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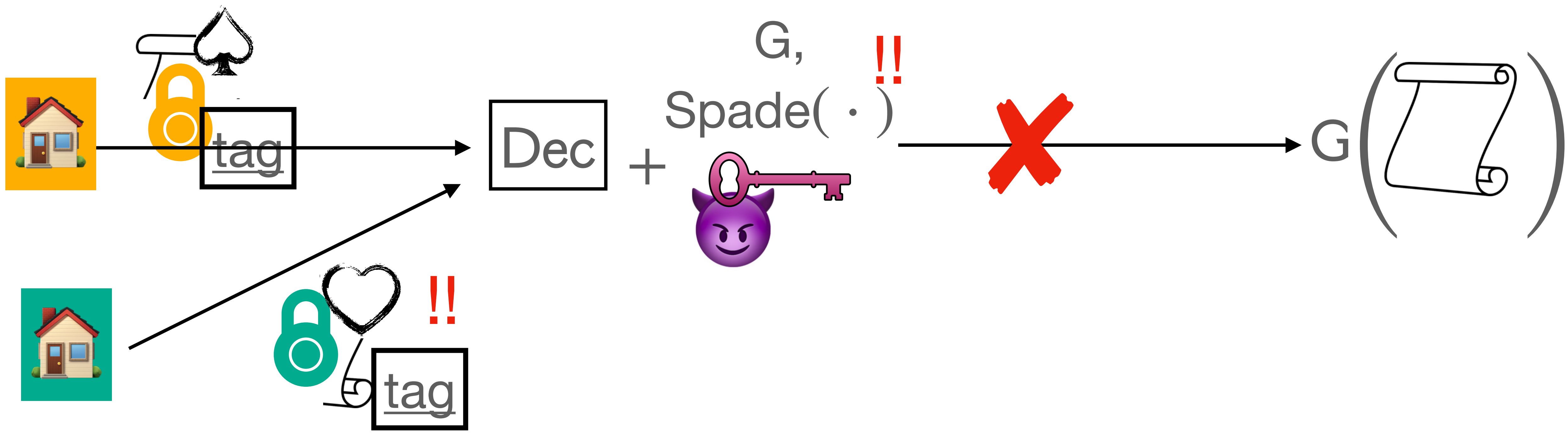
$\Longrightarrow$

Key-Policy
Attribute-based
Encryption,
Public- or private-att 🎉

Our Result

Controlling Keys in the Optimal Setting



Refine Syntax of MCFE:

With public-inputs

Identify Implications:

MCFE + optimal security

⇒ public-key FE

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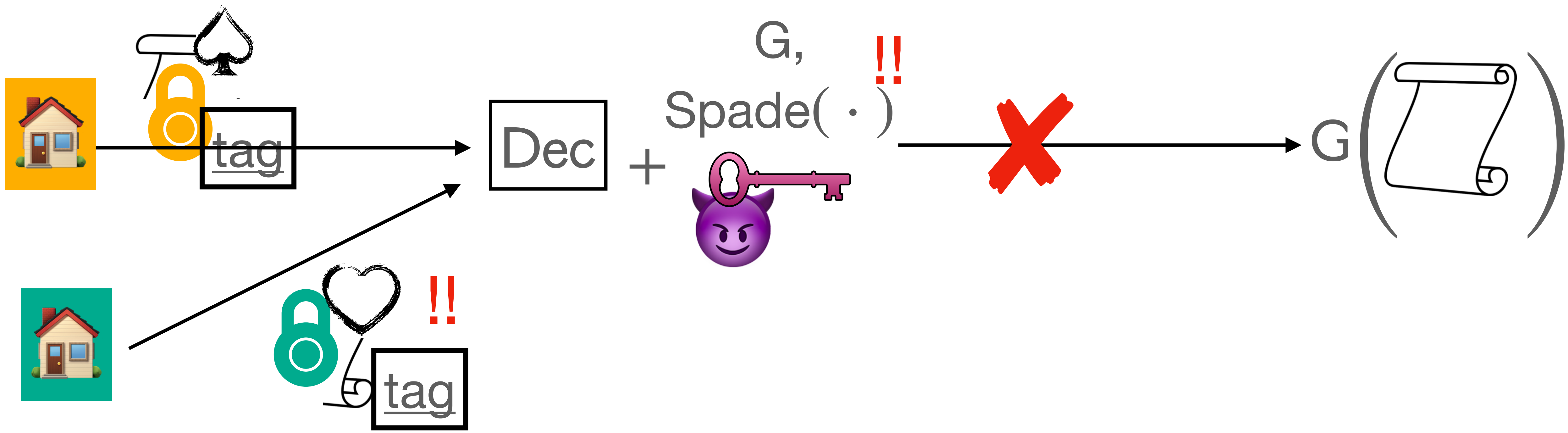

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Concret MCFE for Inner Products from Pairings in ROM, Stronger Security improving [NPP22,NPP23,ATY23]

Recall: The Admissibility from [NPP23]

Concrete conditions for IP, MCFE, one subvector/client

For all $(x_{0,i}, x_{1,i})_i$,

for all $\vec{y}$

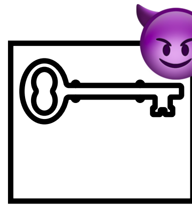
👼 honest i: $\boxed{x_{0,i}}$ $\boxed{x_{1,i}}$

😈 corrupted i: $x_{0,i}$ $x_{1,i}$

$$\vec{y} = \left(y_i \right)_i$$

(1) $$\sum_{\text{👼 honest } i} \left\langle \boxed{x_{0,i}}, y_i \right\rangle = \sum_{\text{👼 honest } i} \left\langle \boxed{x_{1,i}}, y_i \right\rangle$$

MCFE

(2)  😈(ek) $\left\langle x_{0,i}, y_i \right\rangle = \left\langle x_{1,i}, y_i \right\rangle$

On Security: Admissiblity All Over Again

Implications of Pub-Inputs & Strong Admissibility

🥳Our Work!

MCFE: Pub-Inputs,
Allowing repetitions $\vec{x}_i$

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#clients
$n = 1$

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Strong Admissiblity:

(ek) $\left\langle \vec{x}_0 , \vec{y} \right\rangle = \left\langle \vec{x}_1 , \vec{y} \right\rangle$

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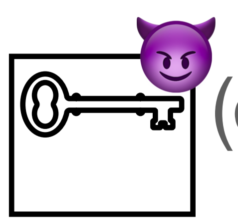
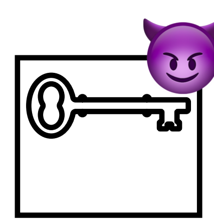
(ek) $\left\langle \vec{x}_0 , \vec{y} \right\rangle = \left\langle \vec{x}_1 , \vec{y} \right\rangle$

+ Static Corruption (ek)

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Strong Admissiblity:

Admissibility in Public-key FE !!

(ek) $\left\langle \vec{x}_0, \vec{y} \right\rangle = \left\langle \vec{x}_1, \vec{y} \right\rangle$

+ Static Corruption (ek)

Becomes pk !!

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Implications of Pub-Inputs & Strong Admissibility

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MCFE: Pub-Inputs, Allowing repetitions $\vec{x}_i$ $\Rightarrow$ Public-key FE With Pub-Inputs

On Security: Admissiblity All Over Again

Implications of Pub-Inputs & Strong Admissibility

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MCFE: Pub-Inputs,
Allowing repetitions $\vec{x}_i$

$\Rightarrow$

Public-key FE
With Pub-Inputs

Access control in
Public inputs

Covering syntactically
Non-pol/att-hiding
ABE !!

On Security: Admissiblity All Over Again

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MCFE: Pub-Inputs, Allowing repetitions $\vec{x}_i$ $\Rightarrow$ Public-key FE With Pub-Inputs

$\Downarrow$

Public-key ABE With or w/out Hiding properties

On Security: Admissiblity All Over Again

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<u>MCFE</u>: Pub-Inputs,
Allowing repetitions $\vec{x}_i$

$\Rightarrow$

<u>Public-key FE</u>
With Pub-Inputs

Fix one tag for all Enc

$\Downarrow$

<u>Public-key ABE</u>
With or w/out
Hiding properties

Repetitions on $\vec{x}_i$
Covers basic MIFE

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Implications of Pub-Inputs & Strong Admissibility

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<u>MCFE</u>: Pub-Inputs, Allowing repetitions $\vec{x}_i$ $\Rightarrow$ <u>Public-key FE</u> With Pub-Inputs

$\Downarrow$

<u>MIFE:</u> "vanilla" Same functions on $\vec{x}_i$

$\Downarrow$

<u>Public-key ABE</u> With or w/out Hiding properties

New Techniques: Dual Paring Vector Spaces with Complexity Leveraging

In a nutshell: With Formal Changes, Guesses are Free

Selective

simulator : guess $(\vec{x}_i^{(0)}, \vec{x}_i^{(1)})$ from 😈

$$\mathrm{View}_0^{sel} \equiv \mathrm{View}_1^{sel} \equiv \ldots \equiv \underline{\mathrm{View}_k^{sel}}$$

$\leftarrow$

$\vec{x}_i^{(0)}, \vec{x}_i^{(1)}$

$\leftarrow$

$\cdots$

$\rightarrow$

Adversary 😈

Start $\Rightarrow$ Guessing Challenges $\vec{x}_i^{(0)}, \vec{x}_i^{(1)}$

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In $\underline{\text{View}_k^{sel}}$: Some critical step in the proof

$\longleftarrow$

$\vec{x}_i^{(0)}, \vec{x}_i^{(1)}$

$\longleftarrow$

…

$\longrightarrow$

Adversary

😈

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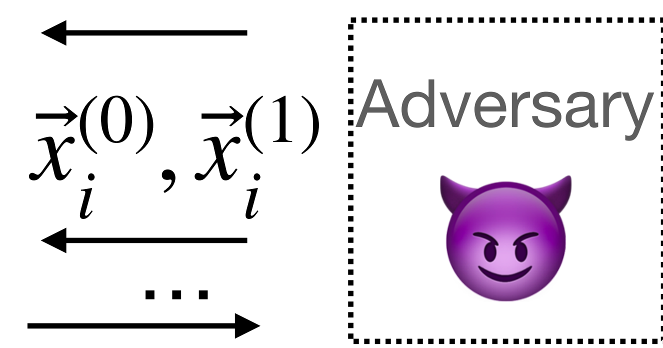

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All is <u>formal</u> basis changes in *Dual Pairing Vector Spaces*

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Perfectly Perfectly Perfectly

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Adversary
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$$0 \leq \mathit{diff}(\mathsf{View}_0^{sel}; \mathsf{View}_k^{sel}) \leq \sum_i \mathit{diff}(\mathsf{View}_i^{sel}; \mathsf{View}_{i+1}^{sel}) = 0$$

<u>Selective</u>

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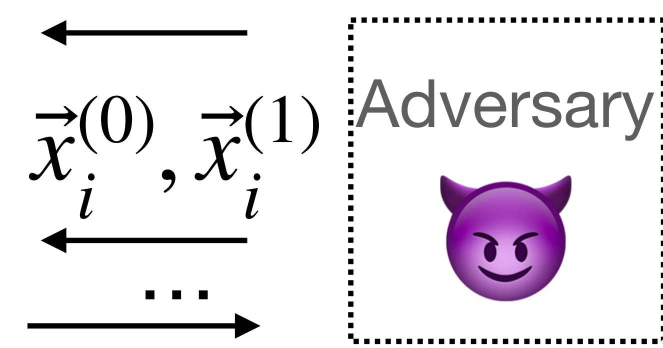

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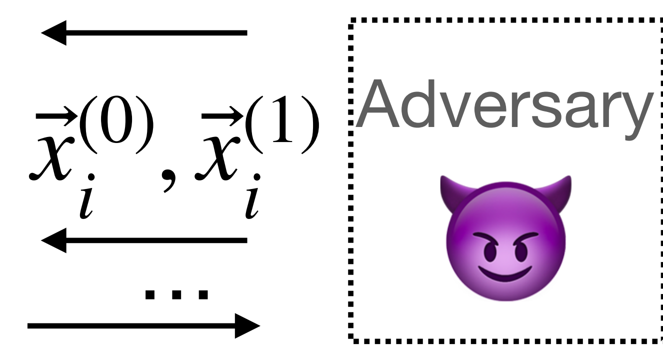

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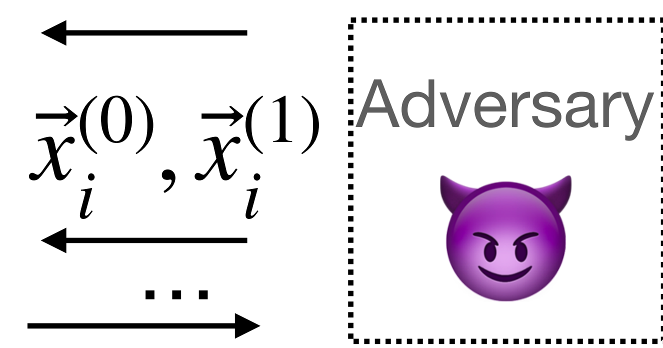

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Our Results:

- Definitional framework of MCFE with public inputs
- Implications from *secret-key* MCFE to *public-key* FE/KP-ABE
- Constructions with sub-vectors *per* client and strong security

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