PKE and ABE with Collusion-Resistant Secure Key Leasing

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Portland State University

PKE with Secure Key Leasing

[AKN+23]

[APV23]

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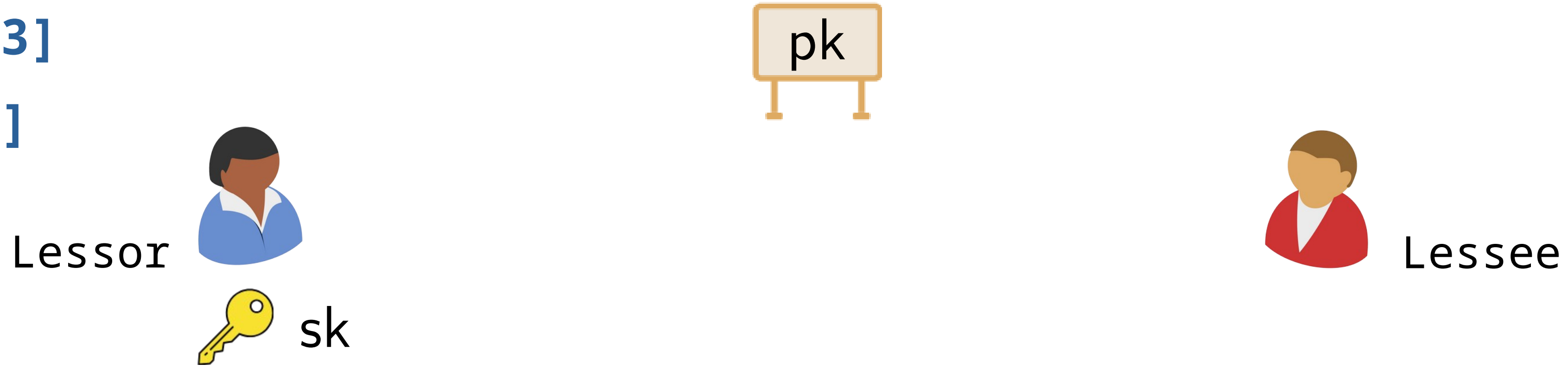

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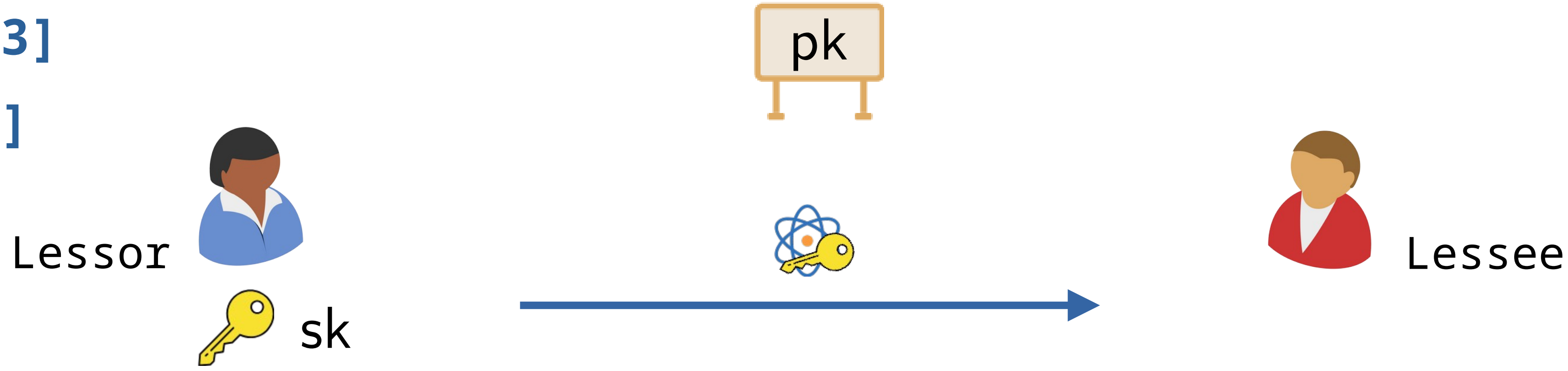

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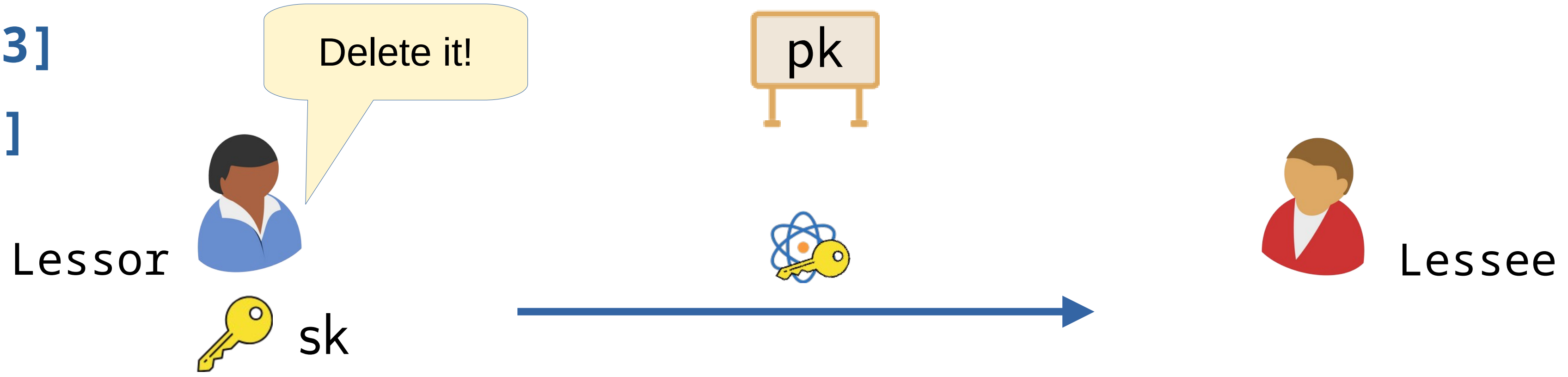

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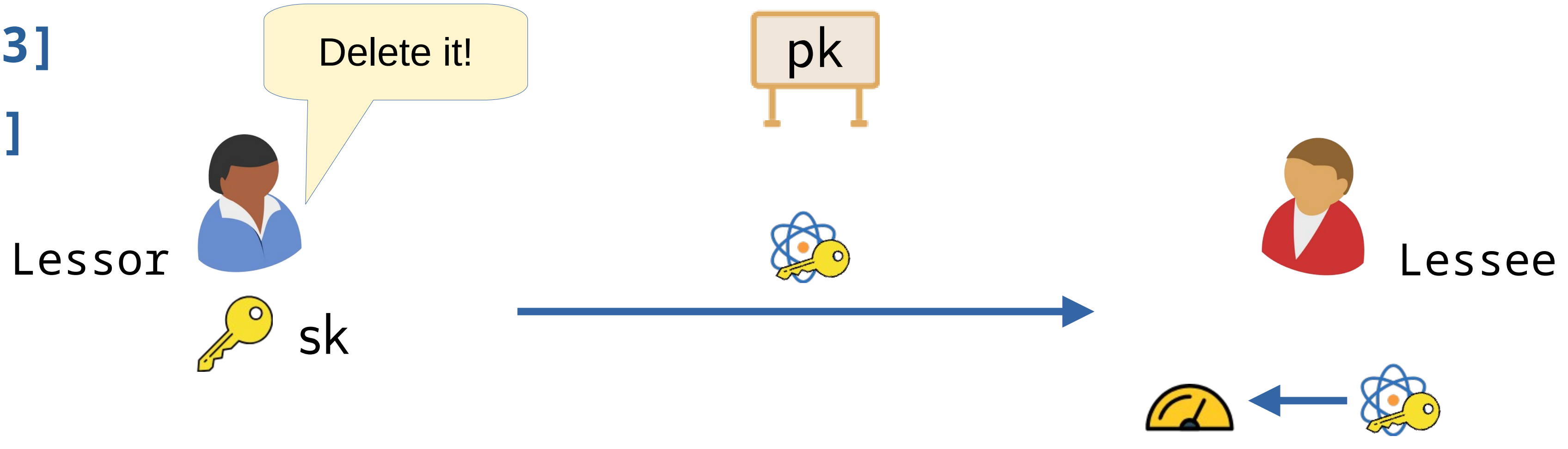

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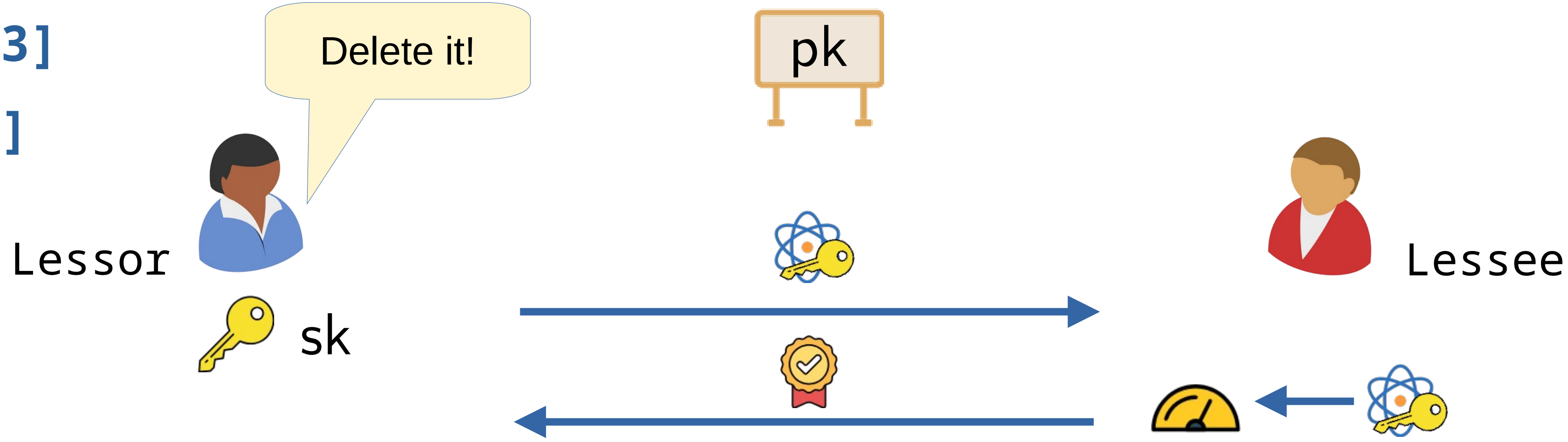

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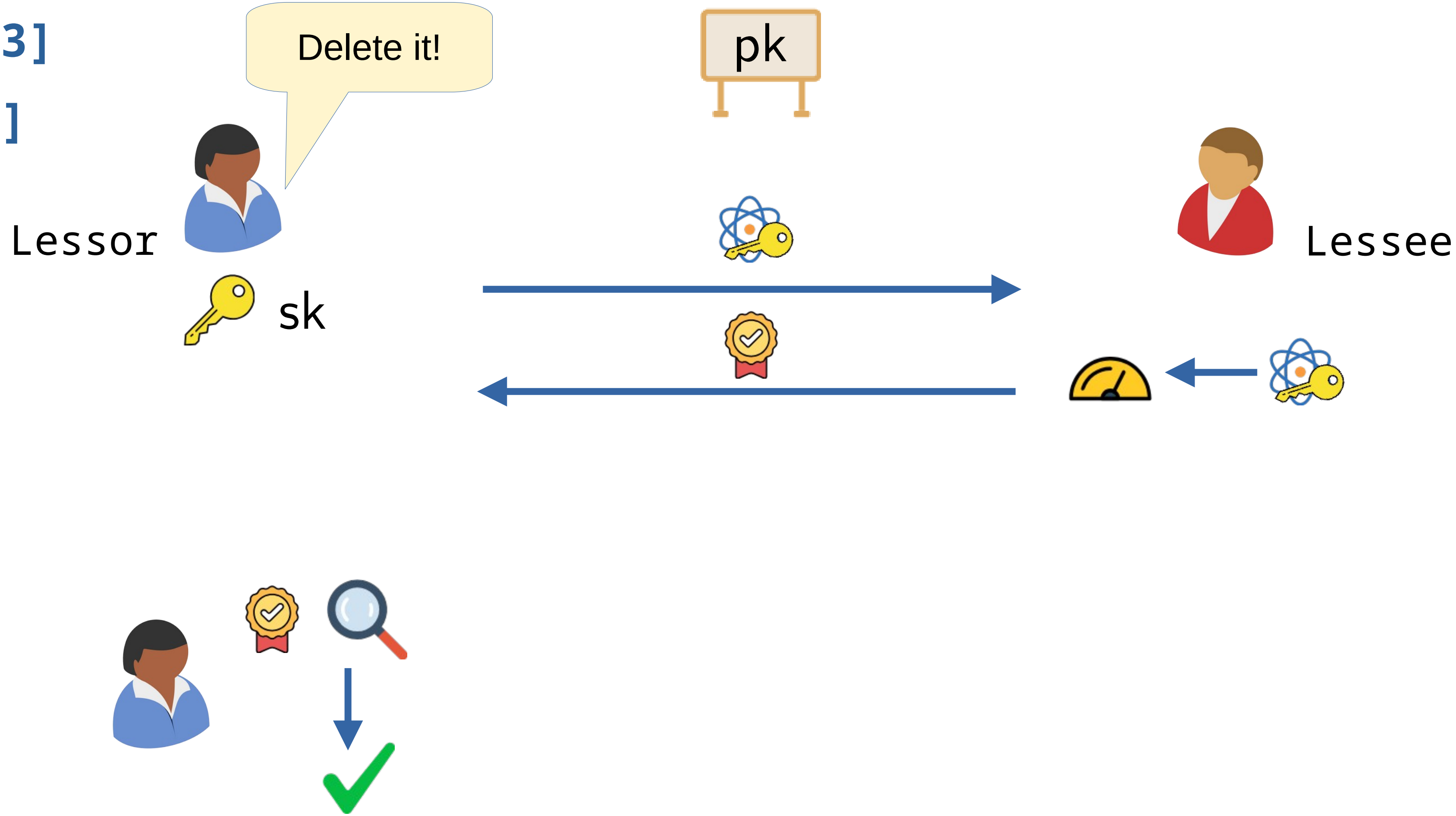

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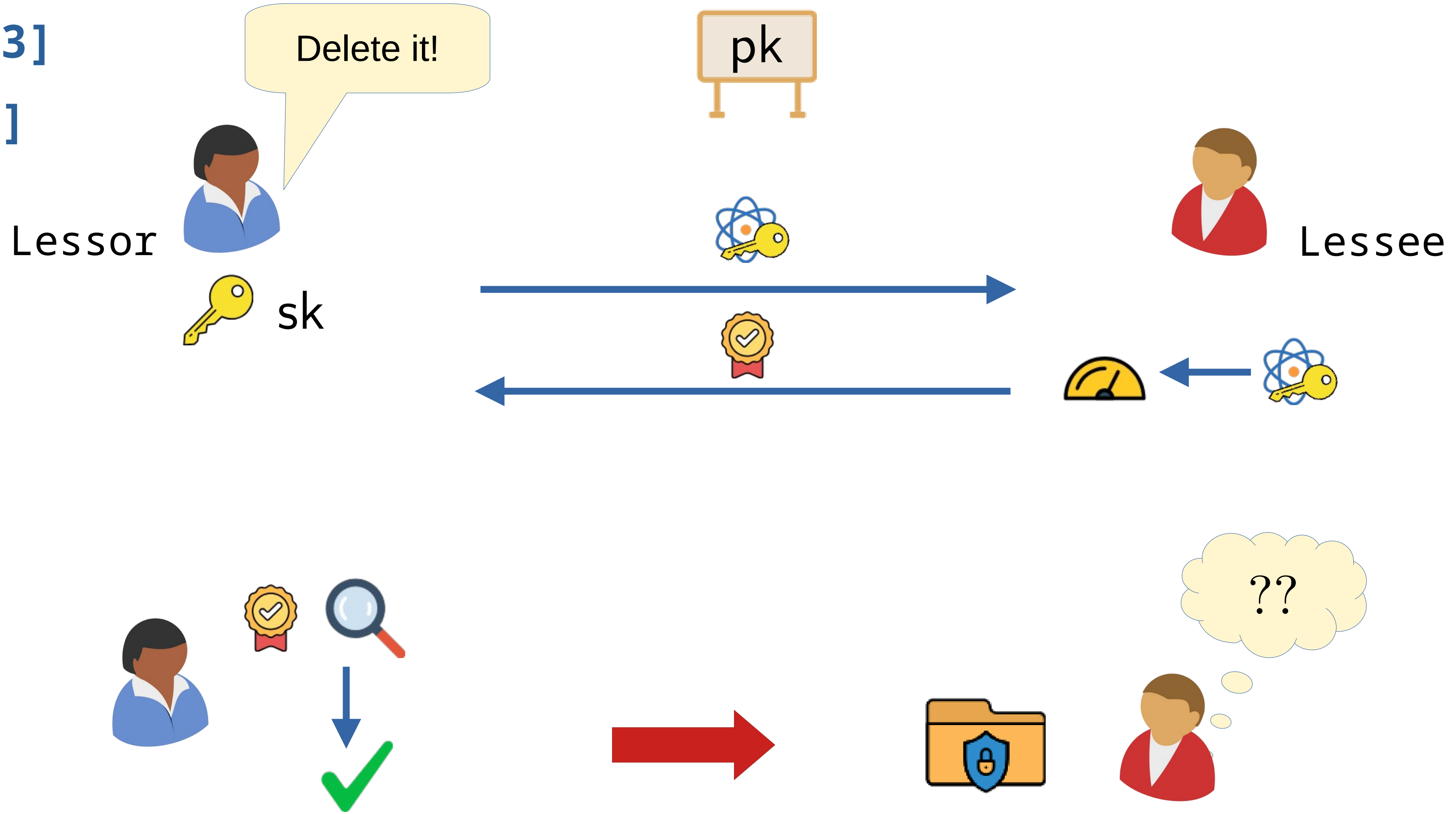

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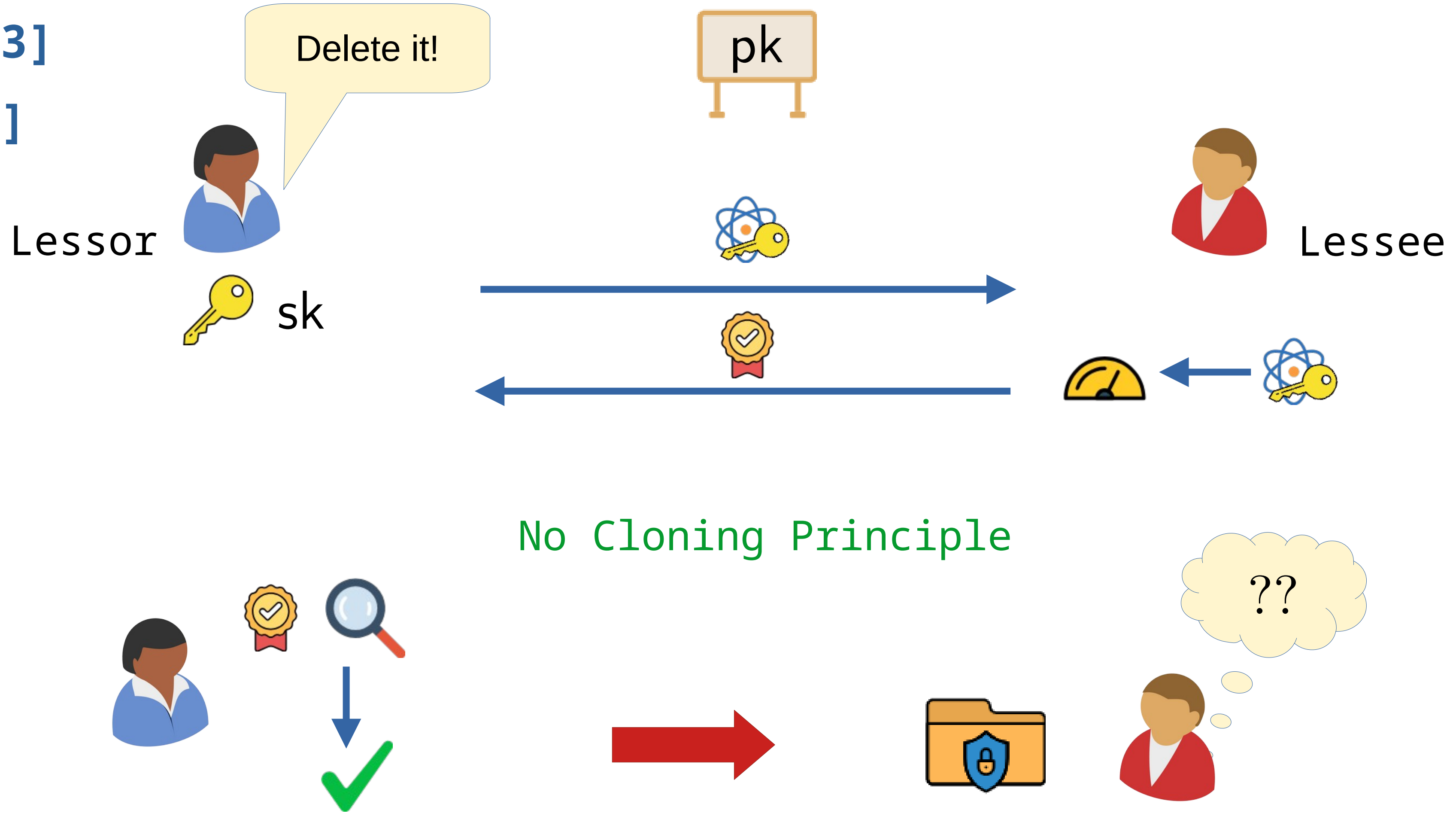

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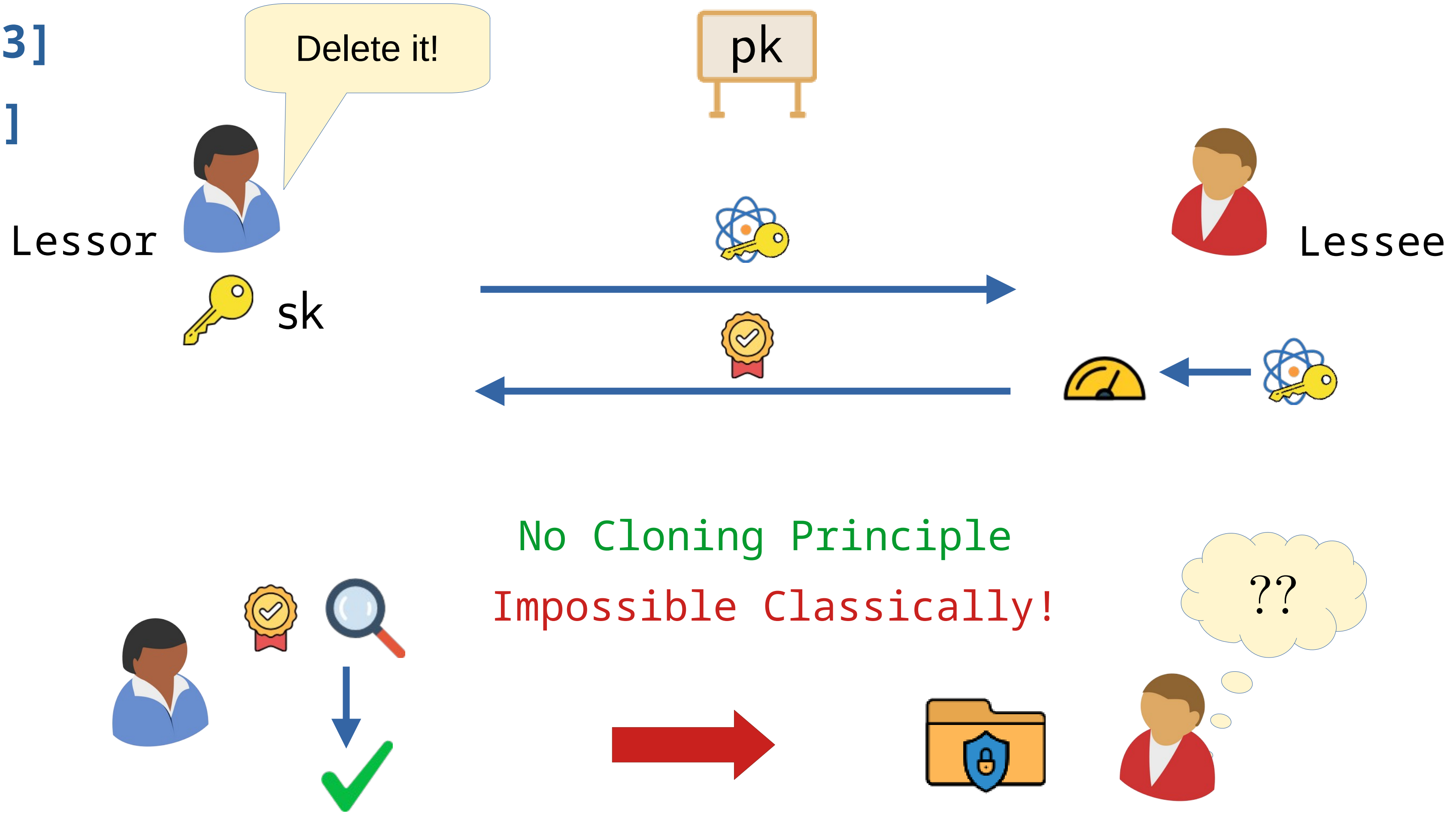

Collusion-Resistance

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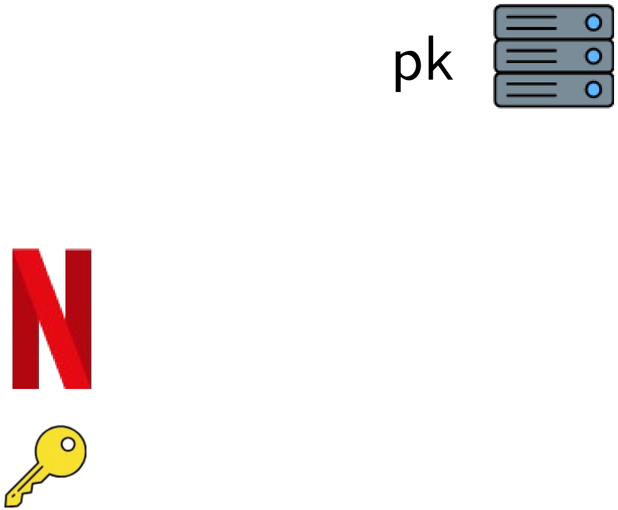

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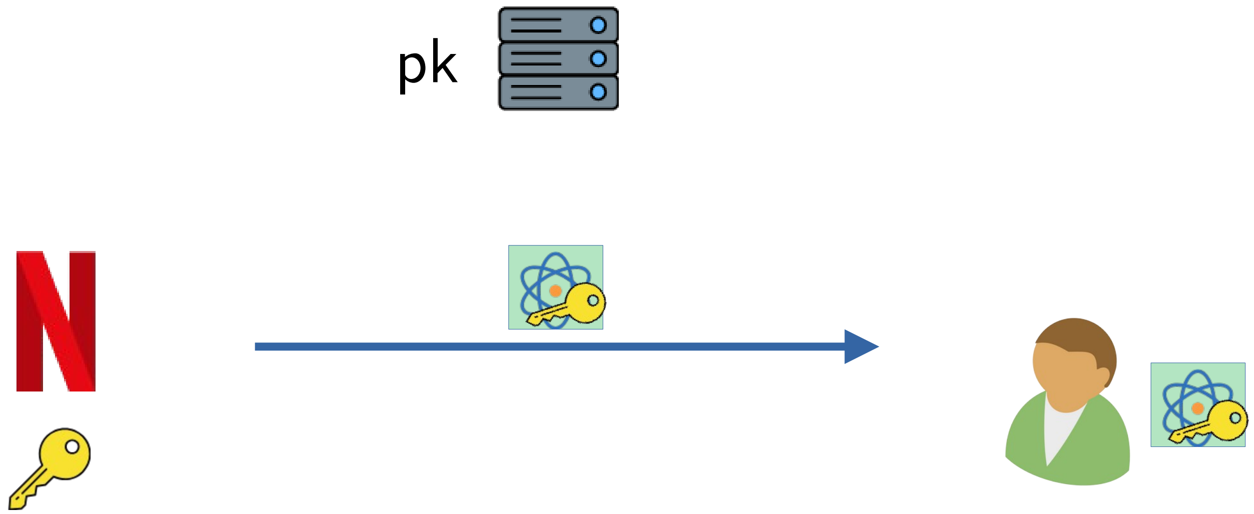

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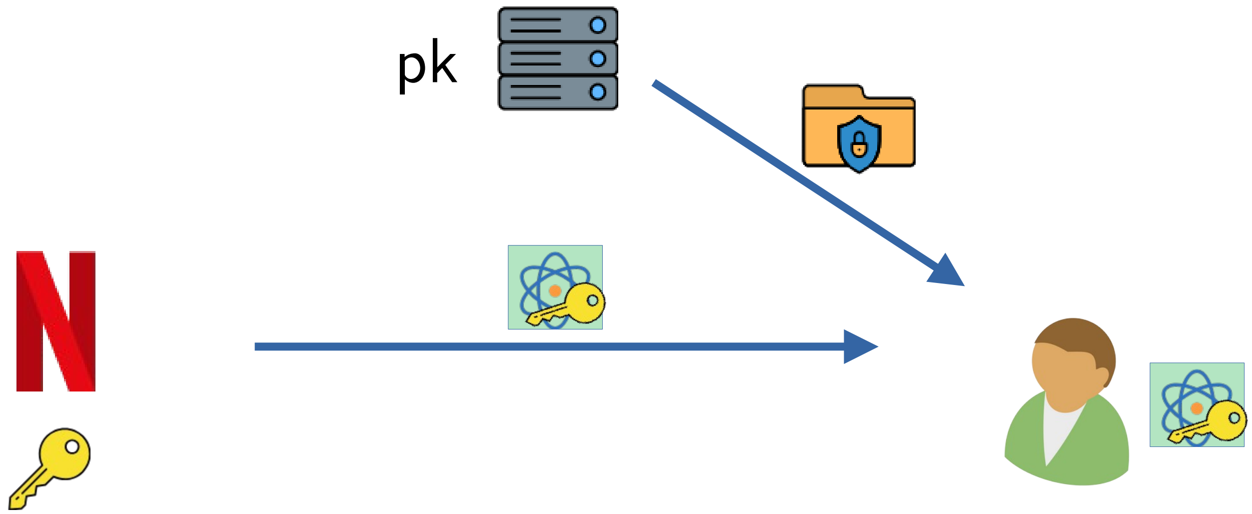

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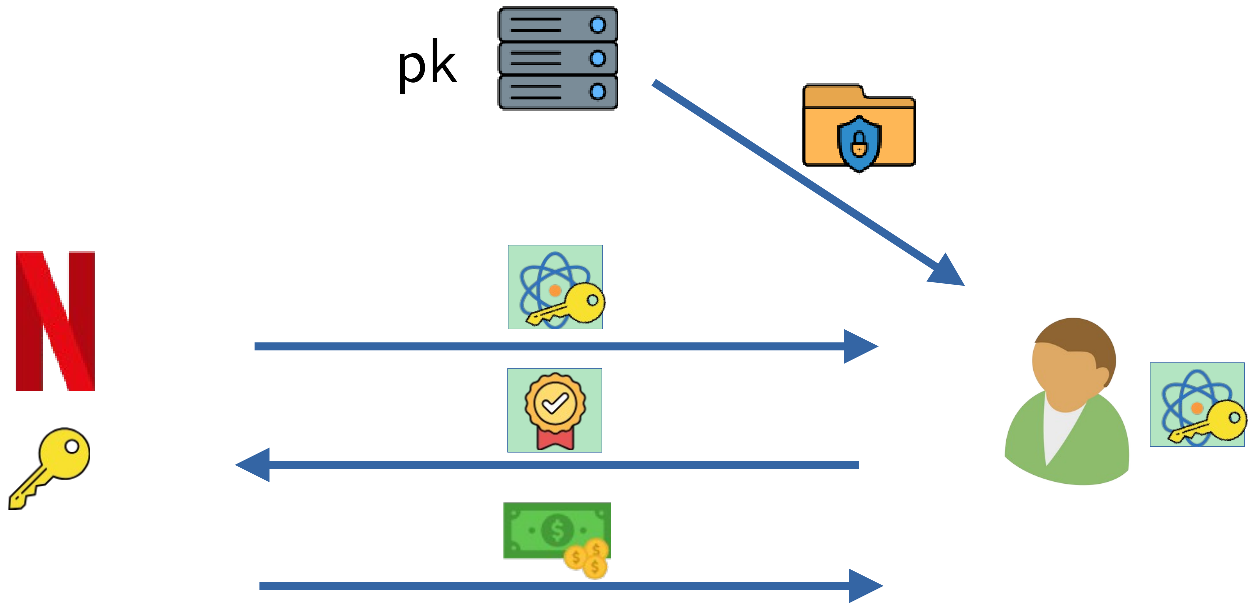

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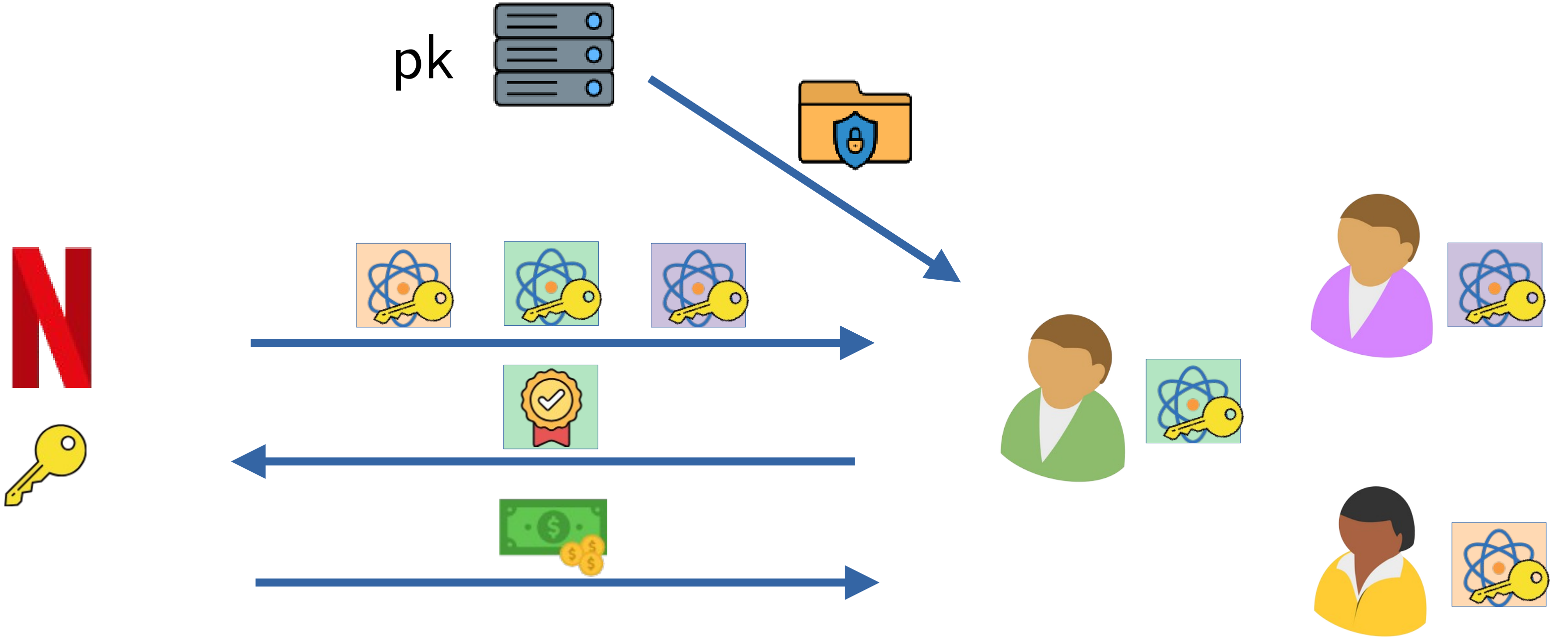

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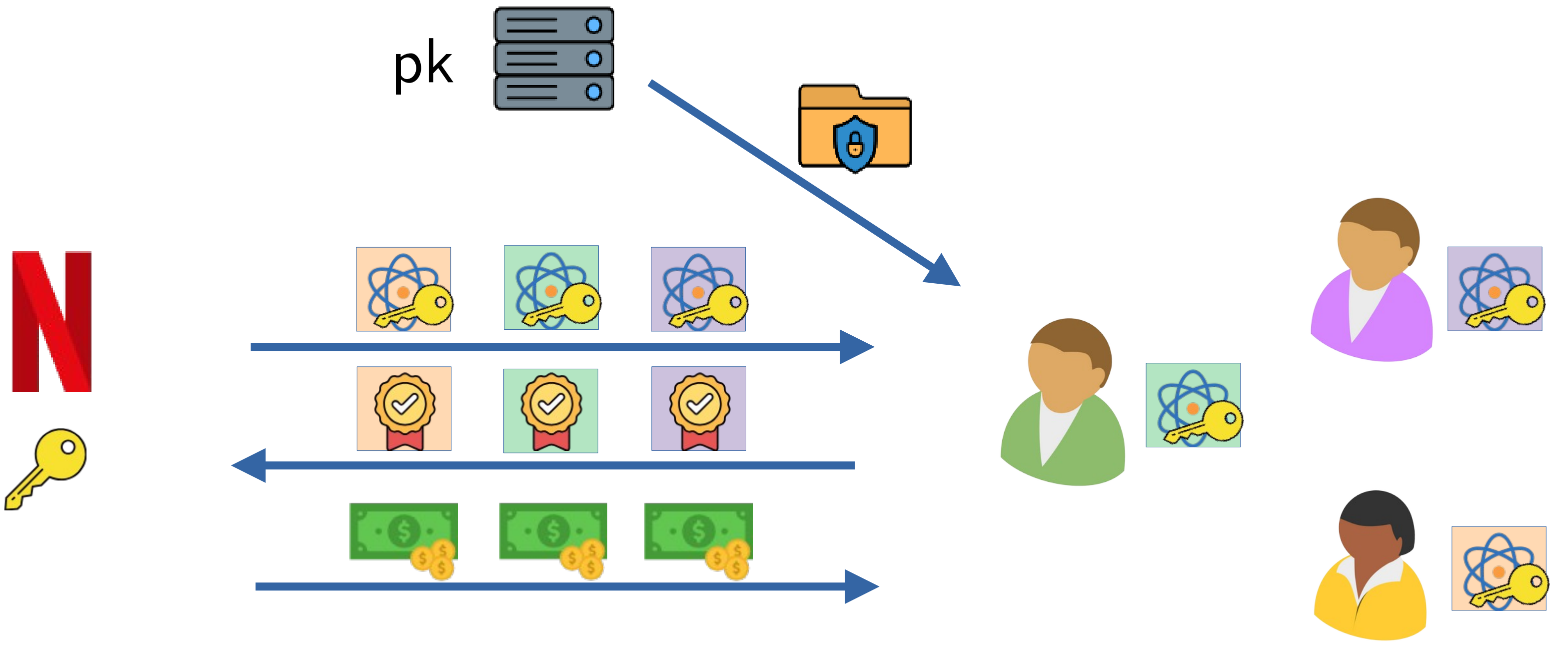

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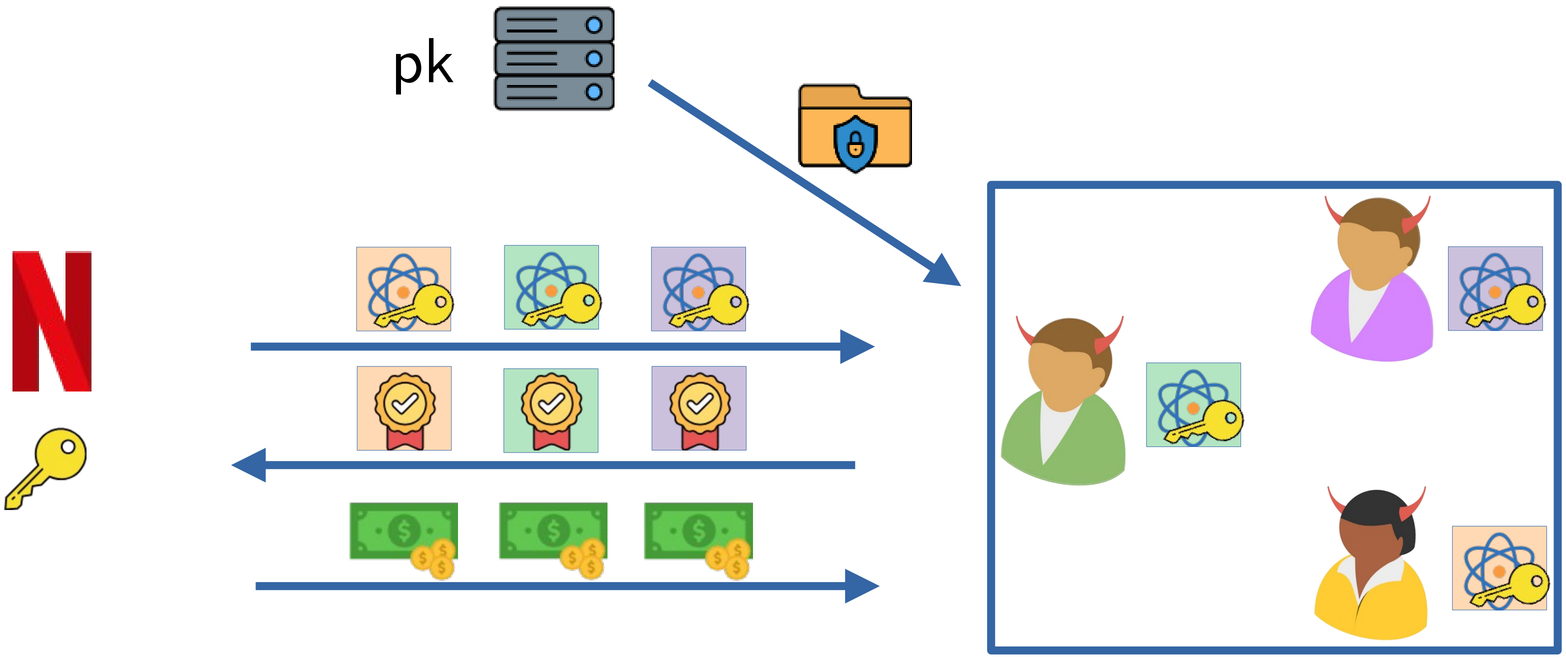

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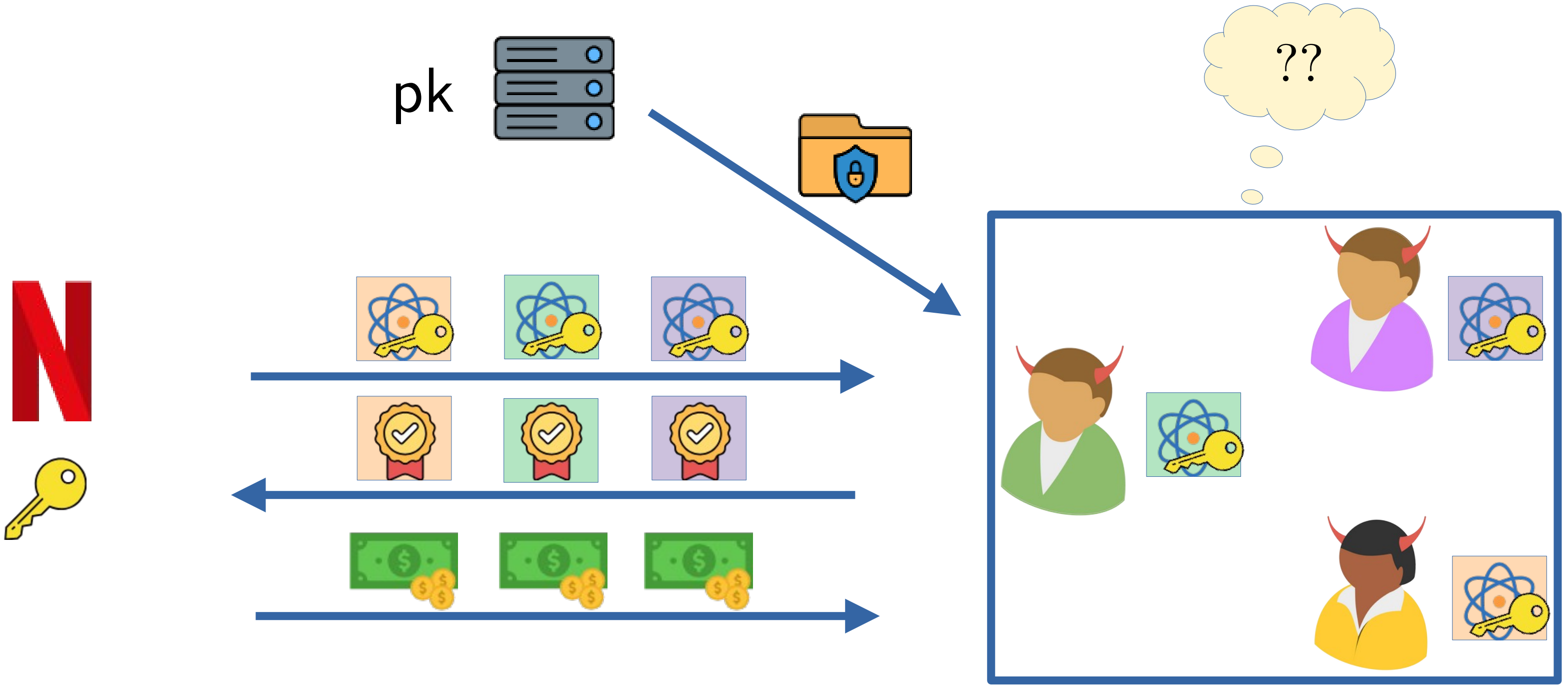

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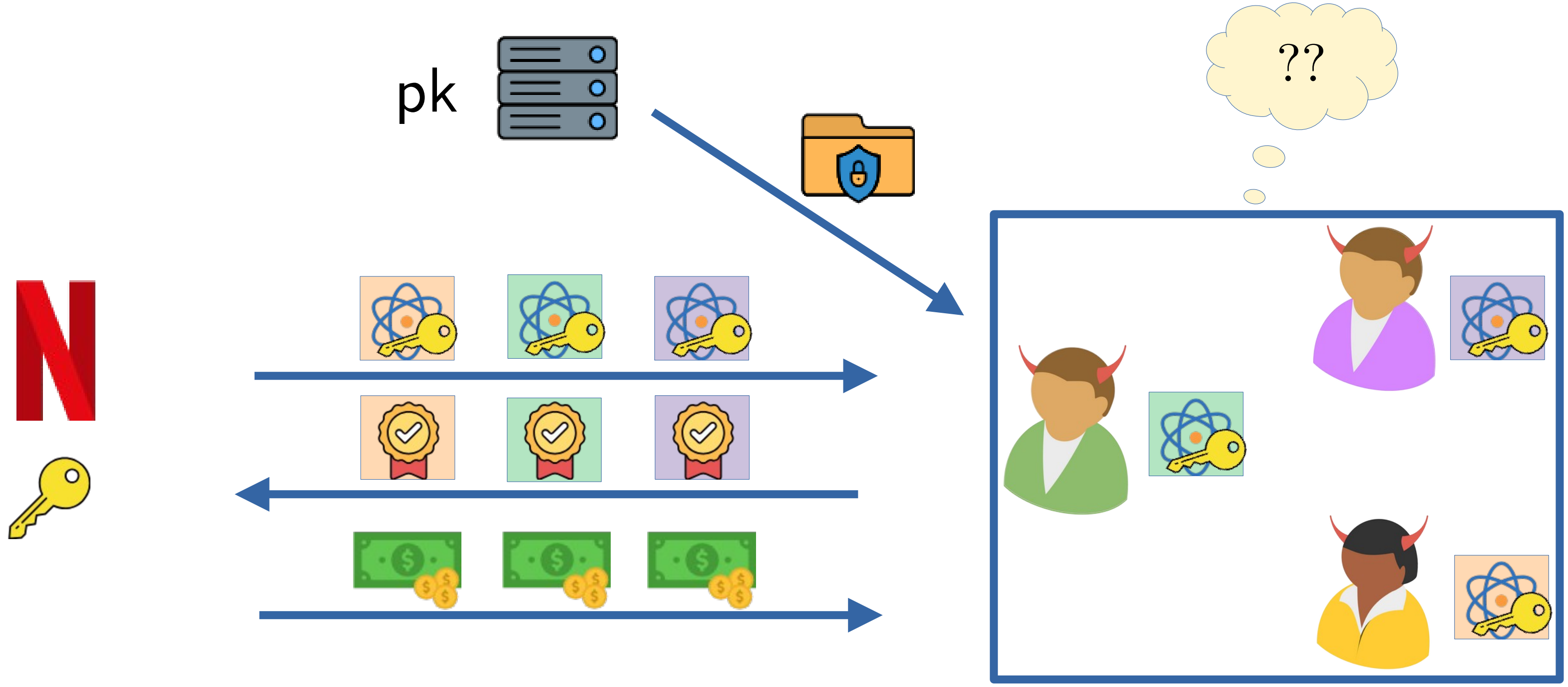

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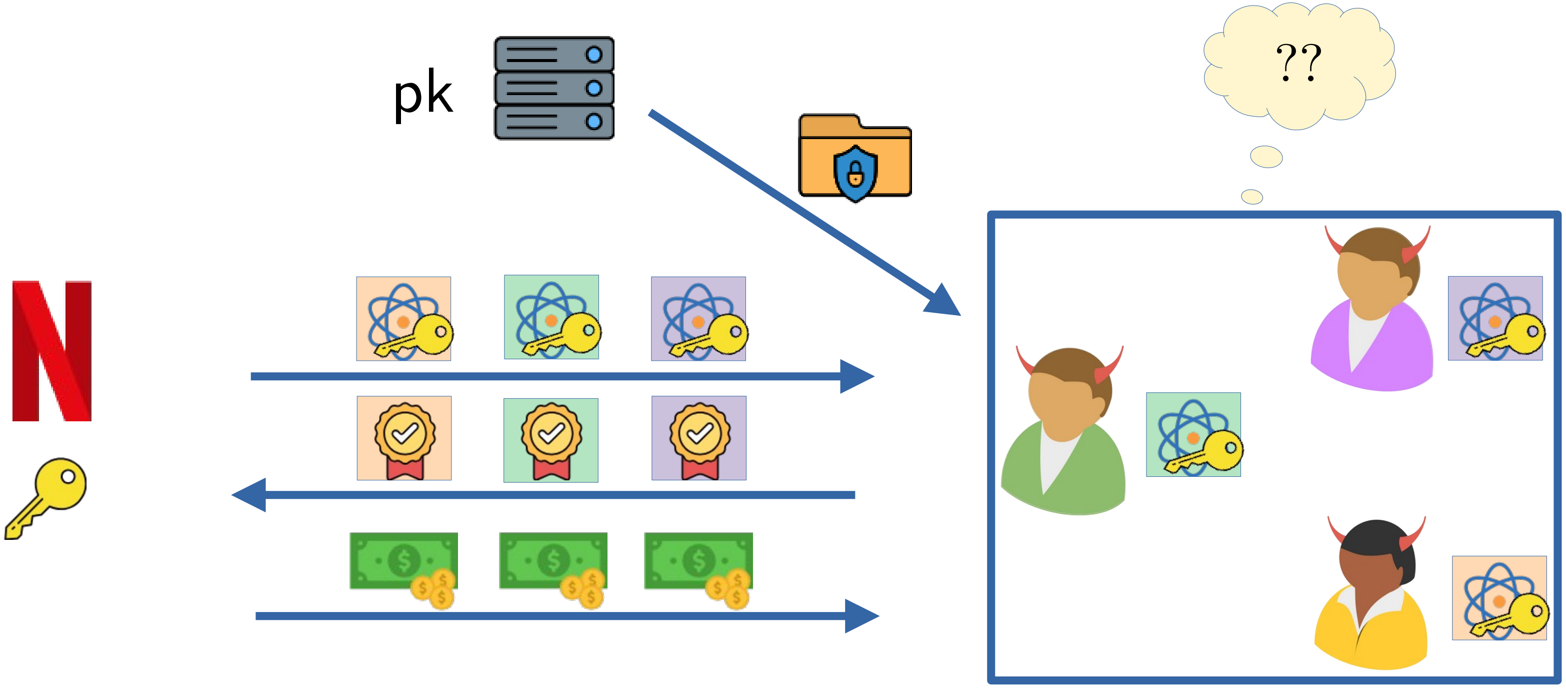

Unbounded Collusion-Resistance: Paramaters scale poly-logarithmically with the number of users.

Quantum Copy Protection

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[Aar09] Copy Protection

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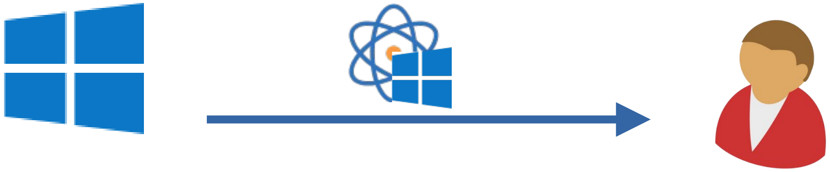

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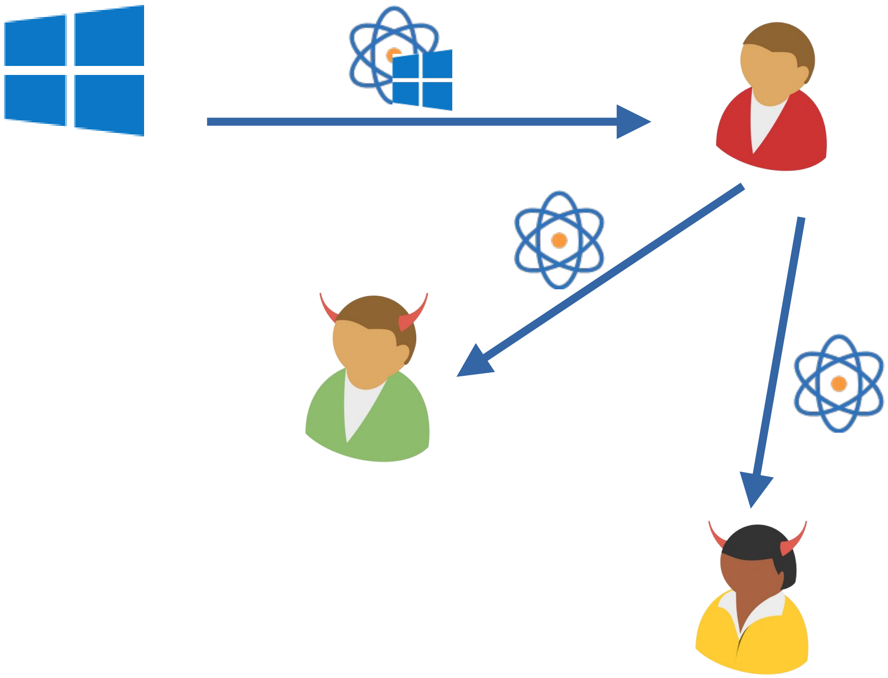

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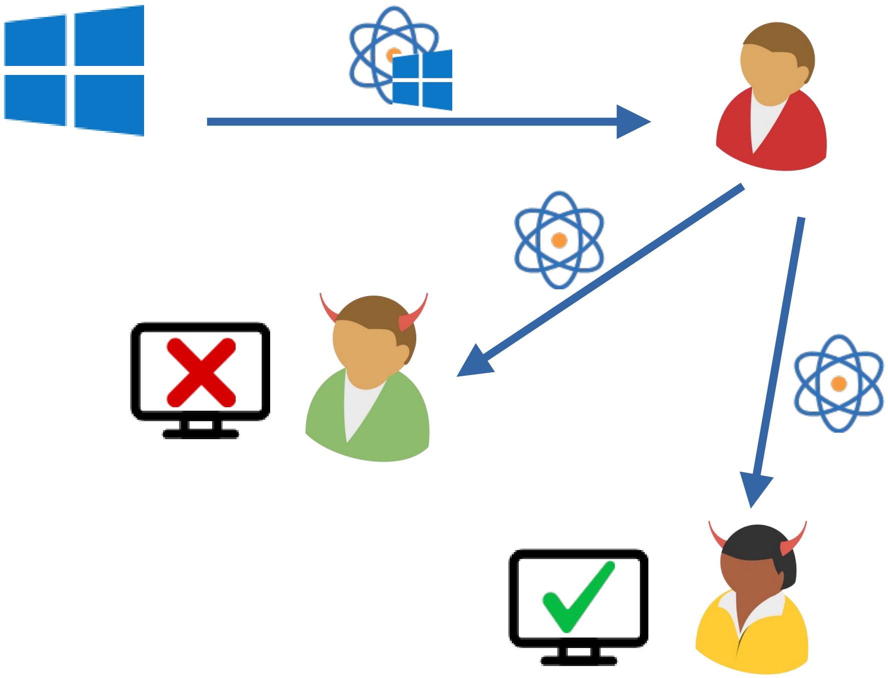

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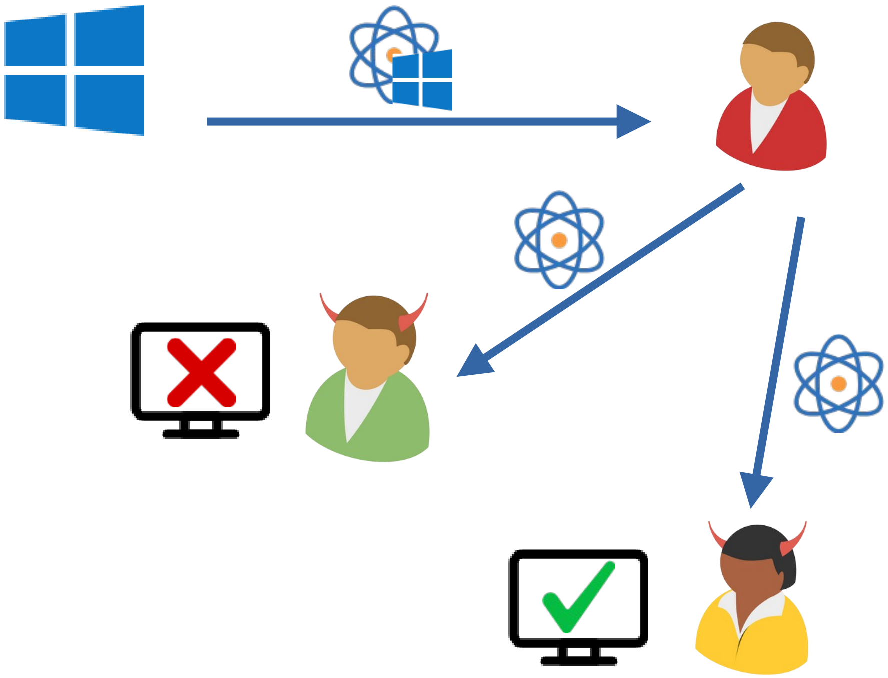

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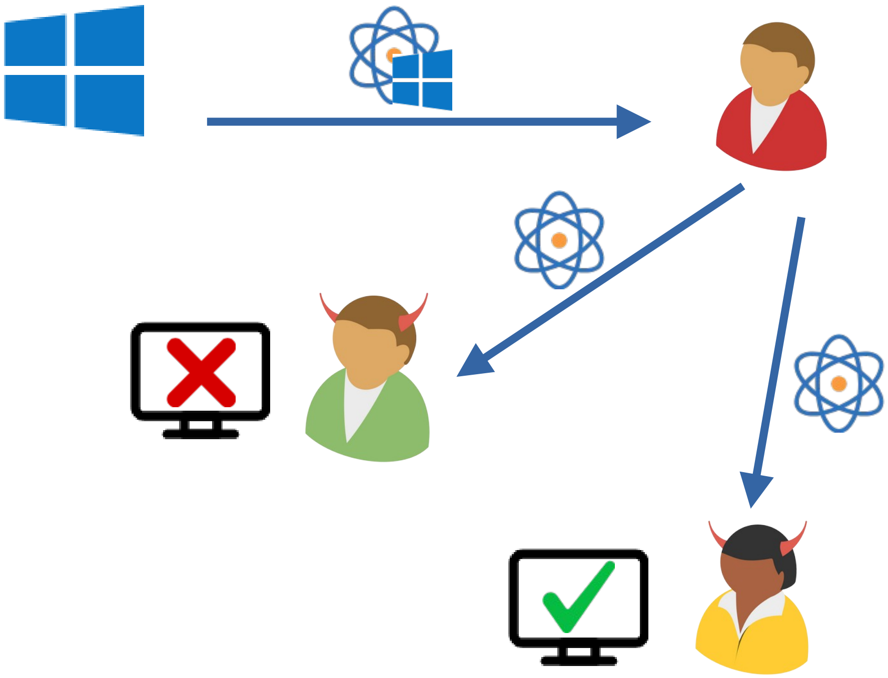

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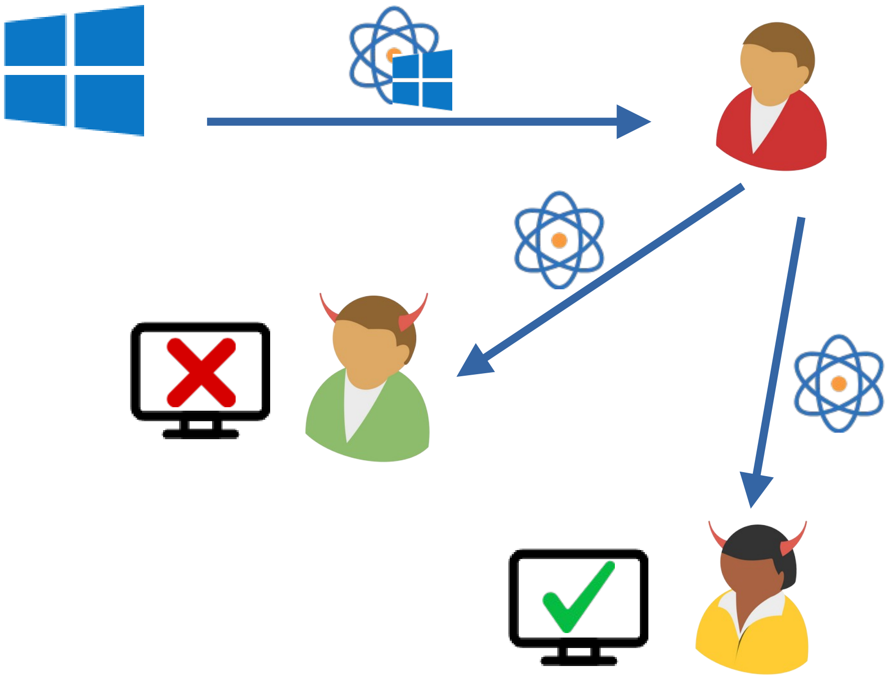

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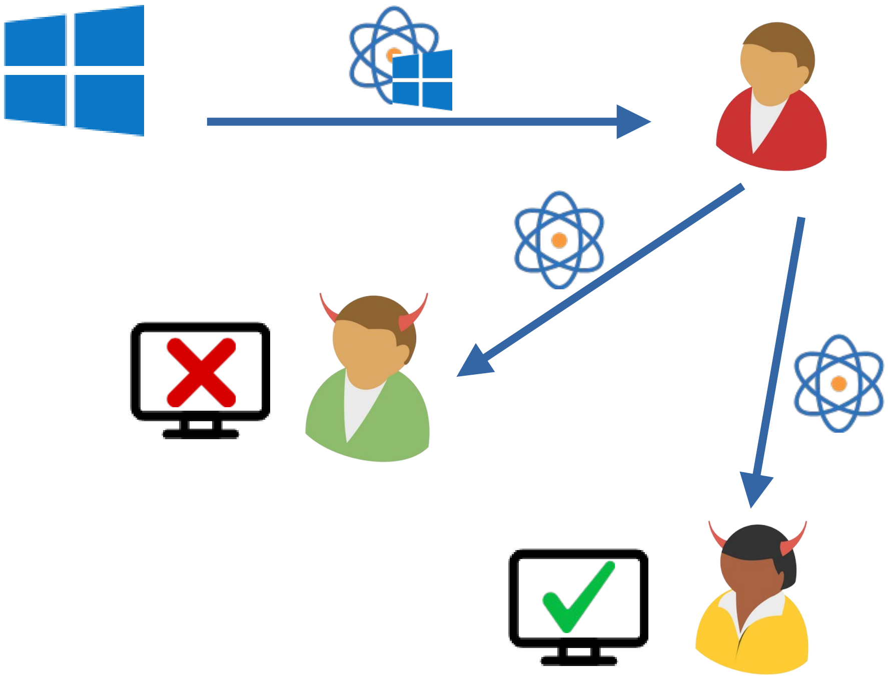

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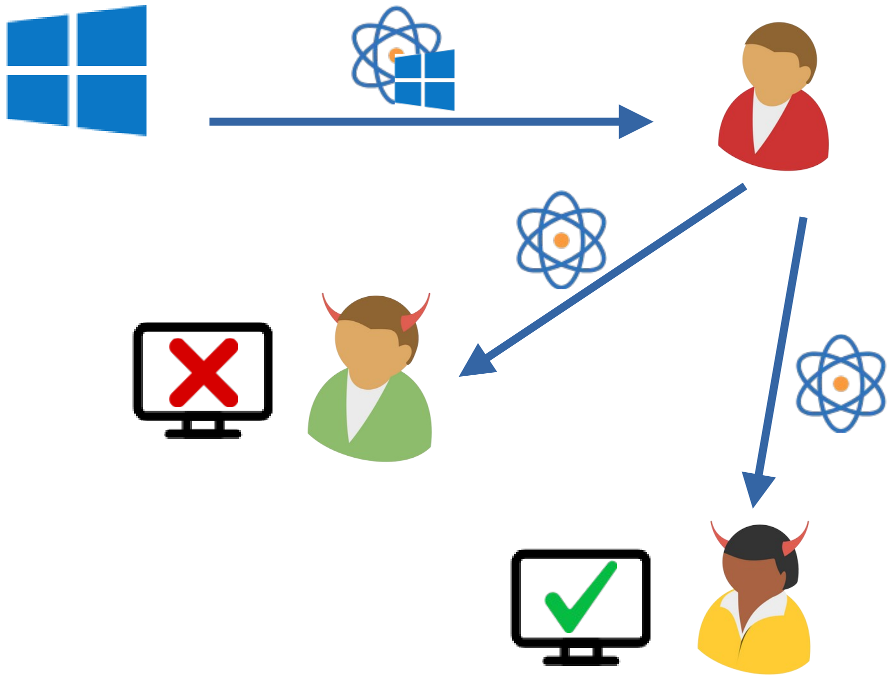

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- Collusion-resistant Constructions **[LLQZ22]**, **[ÇG24]**
- Constructions rely on iO.

Prior Work

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[AKN+23, APV23, AHH24, CGJL25, KMY25]:

- Various PKE-SKL Constructions
- Standard Assumptions

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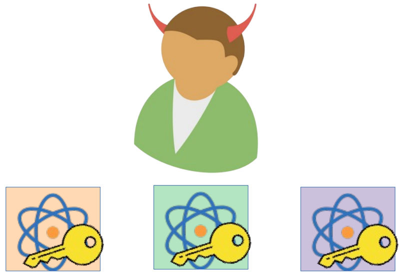

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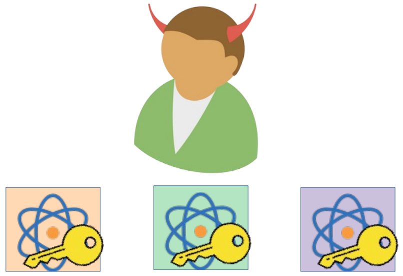

1) Correlate keys before deletion

Completely Broken with Collusions

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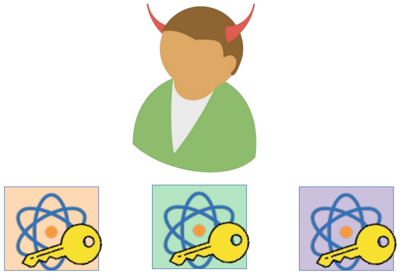

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1) Correlate keys before deletion
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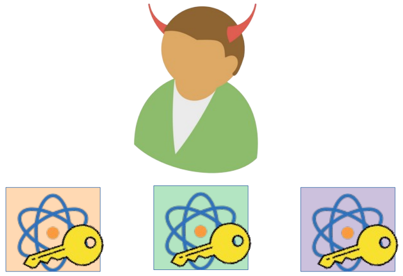

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2) Learn crucial classical info
3) Leave states undisturbed

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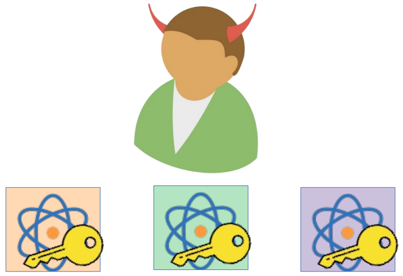

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⚠ Challenging Setting.

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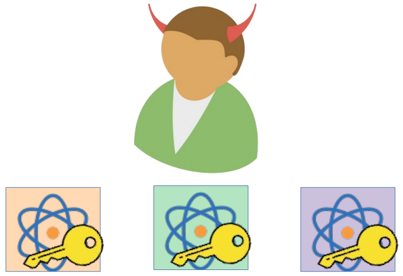

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Provable-Security even more so!

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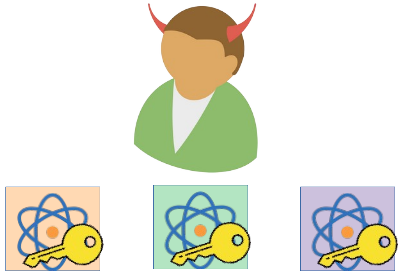

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[AKN+23, BGK+24]:

- (Bounded + Unbounded) Collusion-Resistant Constructions

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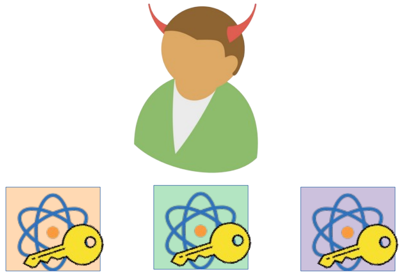

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⚠ Challenging Setting.
Provable-Security even more so!

[AKN+23, BGK+24]:

- (Bounded + Unbounded) Collusion-Resistant Constructions

⚠ Bounded is Inefficient. Unbounded rely on FE/IO (Strong! Post-Quantum?)

Our Contributions

[KNP25]:

Our Contributions

[KNP25]:

1) Collusion-Resistant Definition:

Our Contributions

[KNP25]:

1) Collusion-Resistant Definition: **PKE-CR-SKL**

Our Contributions

[KNP25]:

1) Collusion-Resistant Definition: PKE-CR-SKL

2)

Our Contributions

[KNP25]:

1) Collusion-Resistant Definition: **PKE-CR-SKL**

2) **LWE** → **PKE-CR-SKL**

Our Contributions

[KNP25]:

1) Collusion-Resistant Definition: PKE-CR-SKL

2) LWE → PKE-CR-SKL & ABE-CR-SKL

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3) New Techniques and Building Blocks:

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Our Contributions

[KNP25]:

1) Collusion-Resistant Definition: **PKE-CR-SKL**

2) **LWE** → **PKE-CR-SKL** & **ABE-CR-SKL**

3) New Techniques and Building Blocks: **SKE-CR-SKL**

4) **Multi-Input ABE** → Variant w/ Classical

Main Result

[KNP25]

Main Result

[KNP25]

PKE-CR-SKL

Main Result

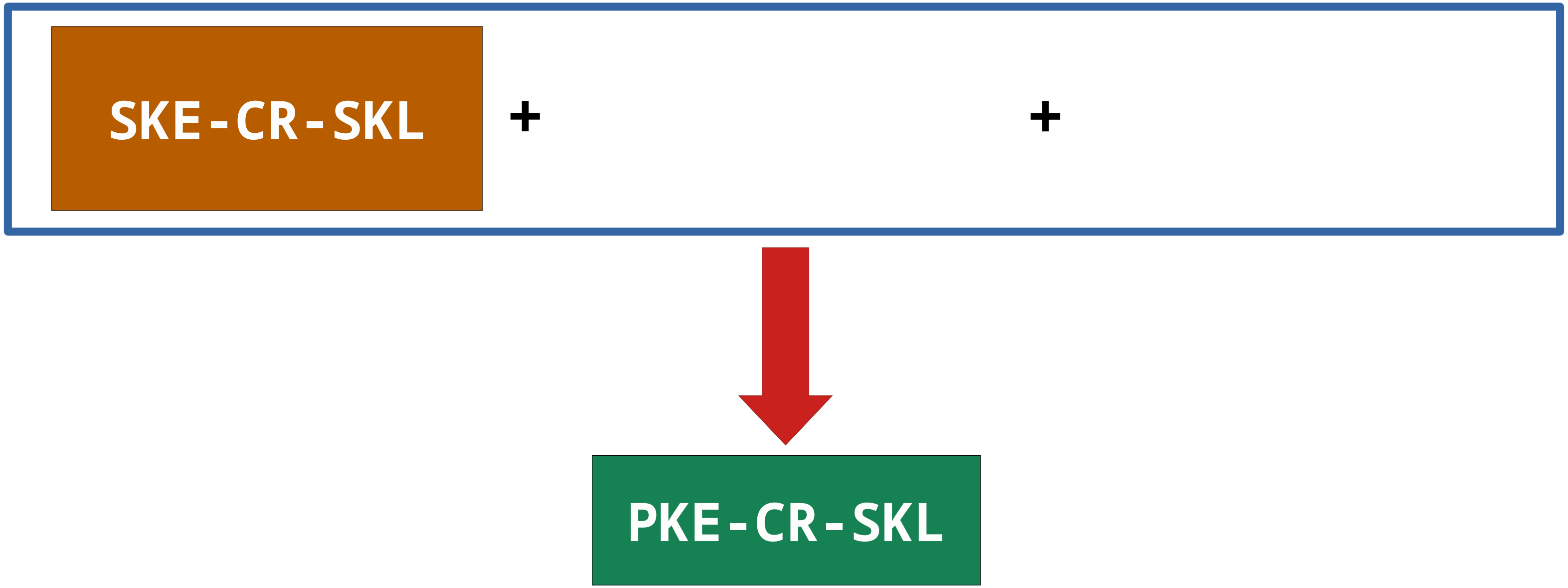
[KNP25]

+ +

PKE-CR-SKL

Main Result

[KNP25]



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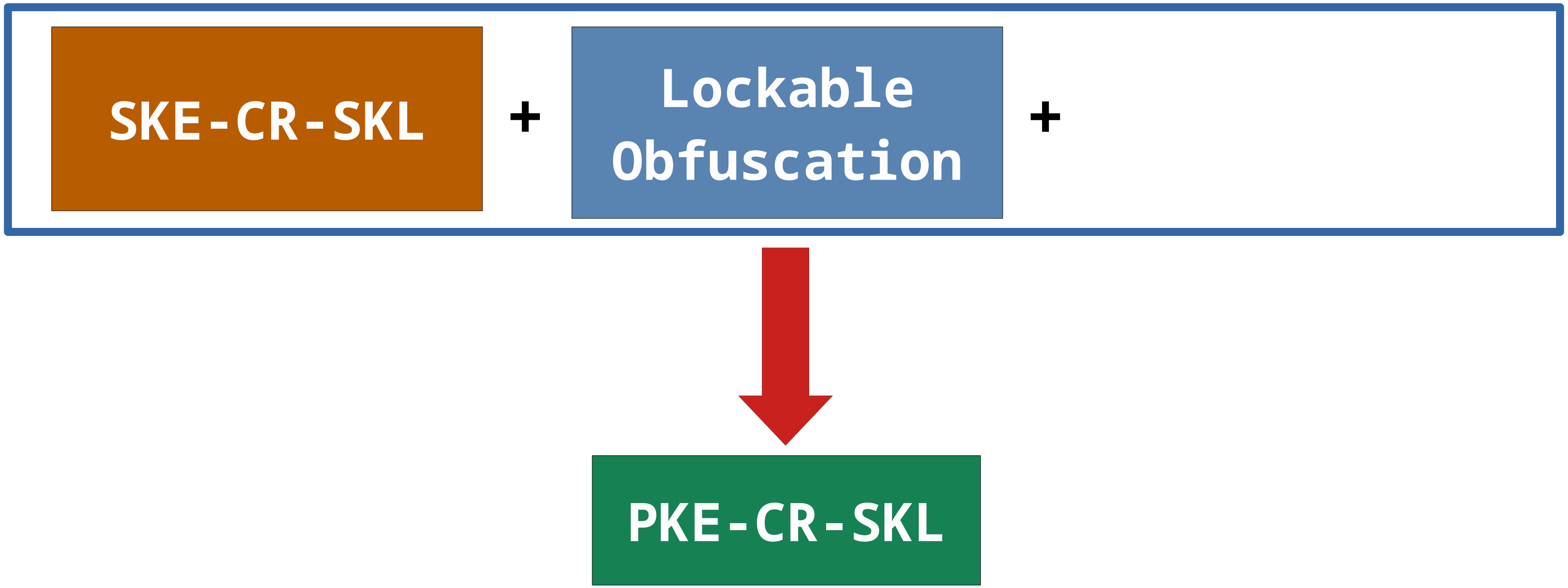

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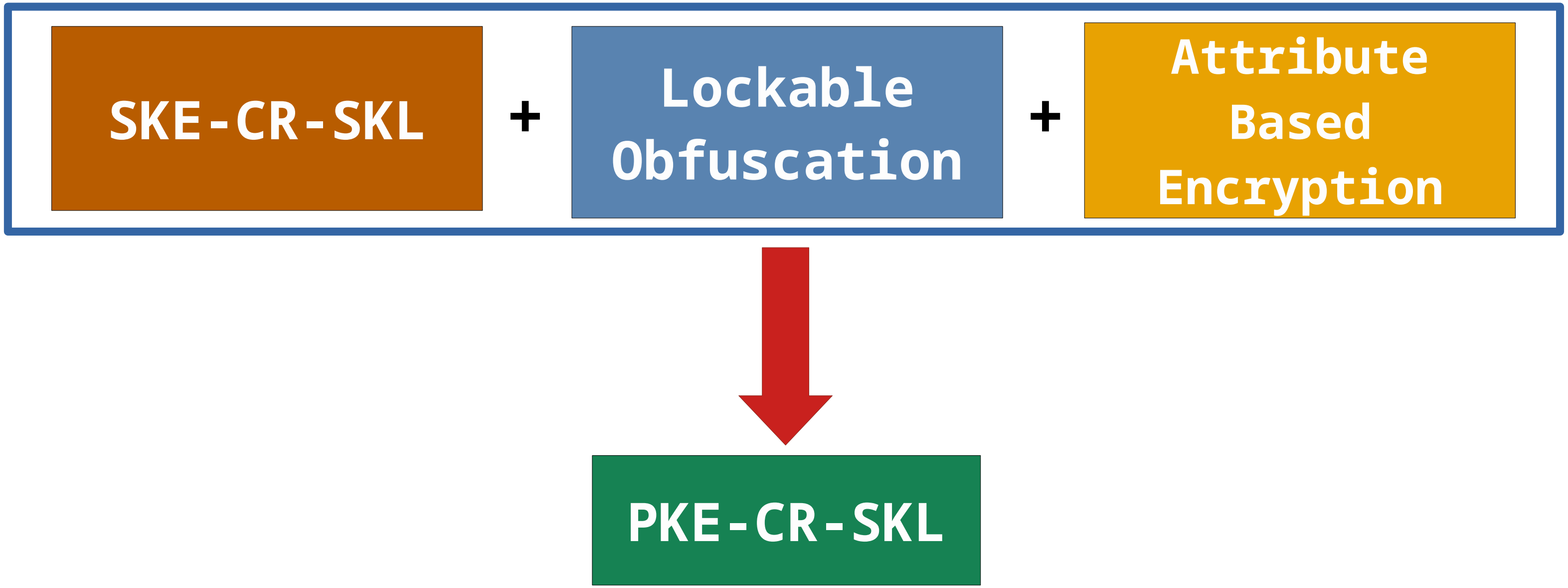

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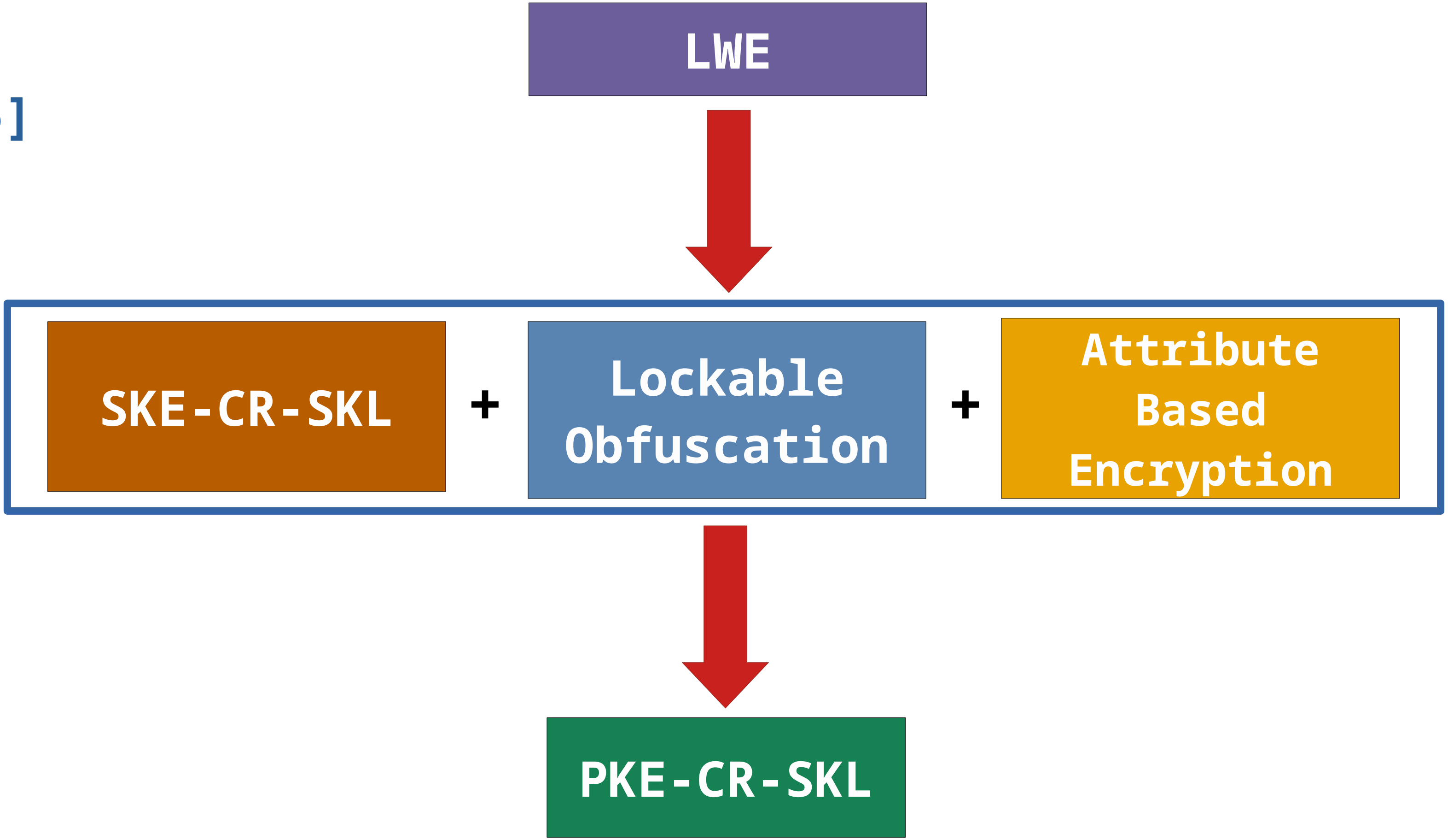

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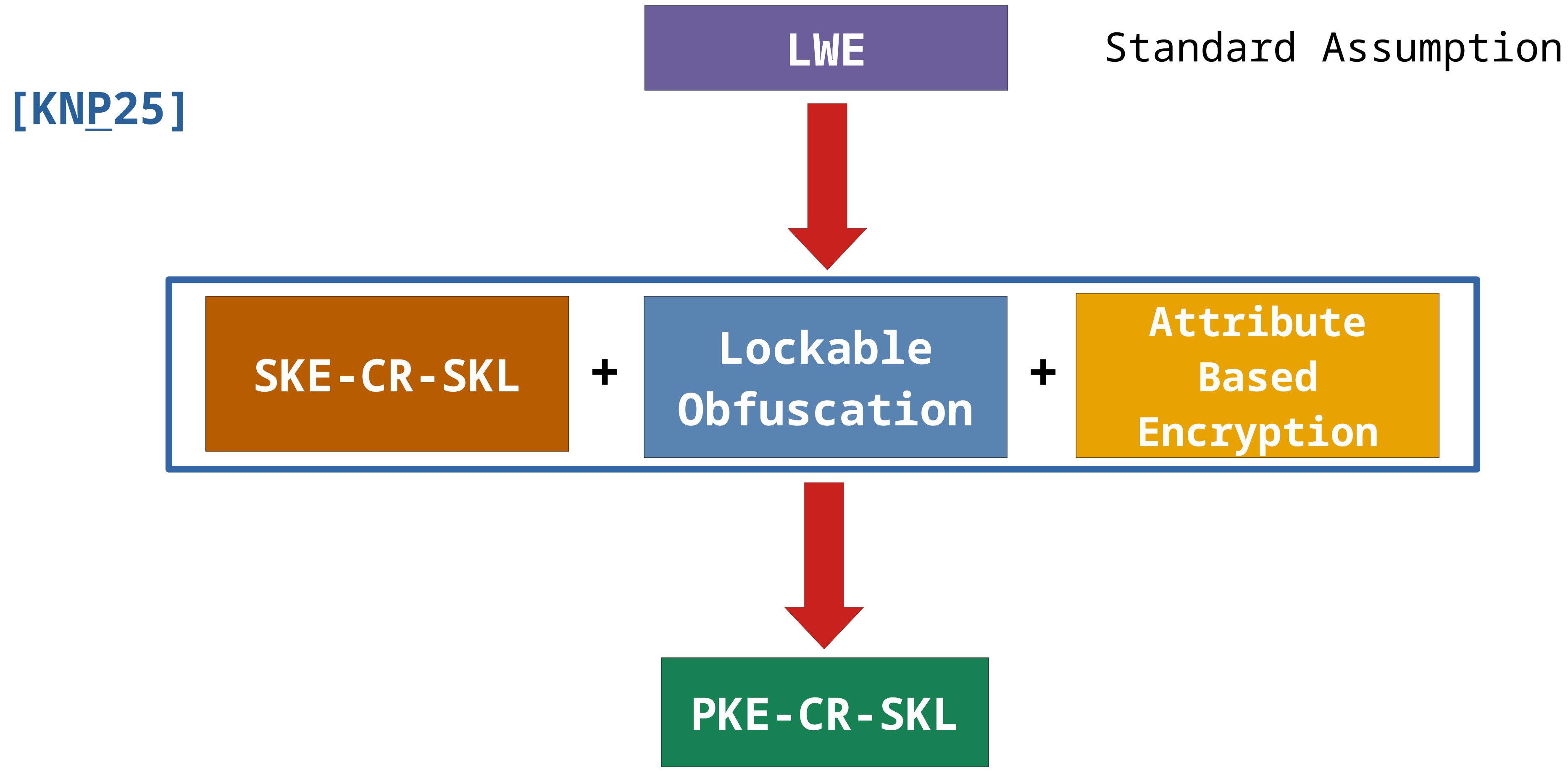
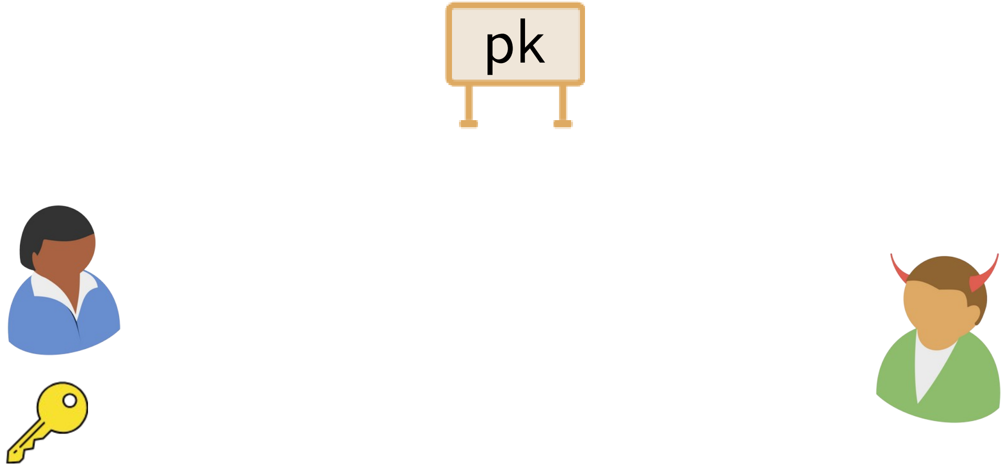

LWE
Standard Assumption
[KNP25]
SKE-CR-SKL
+
Lockable Obfuscation
+
Attribute Based Encryption
PKE-CR-SKL

PKE-CR-SKL and SKE-CR-SKL

PKE-CR-SKL and SKE-CR-SKL



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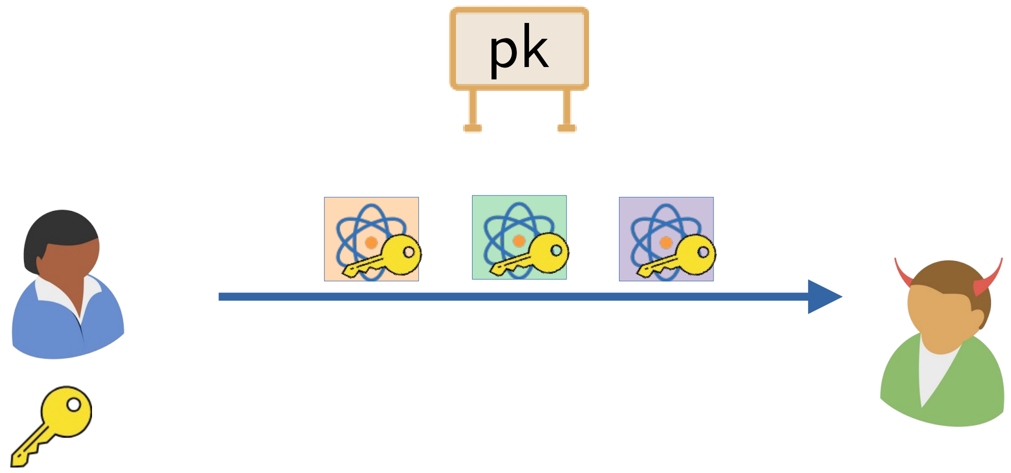

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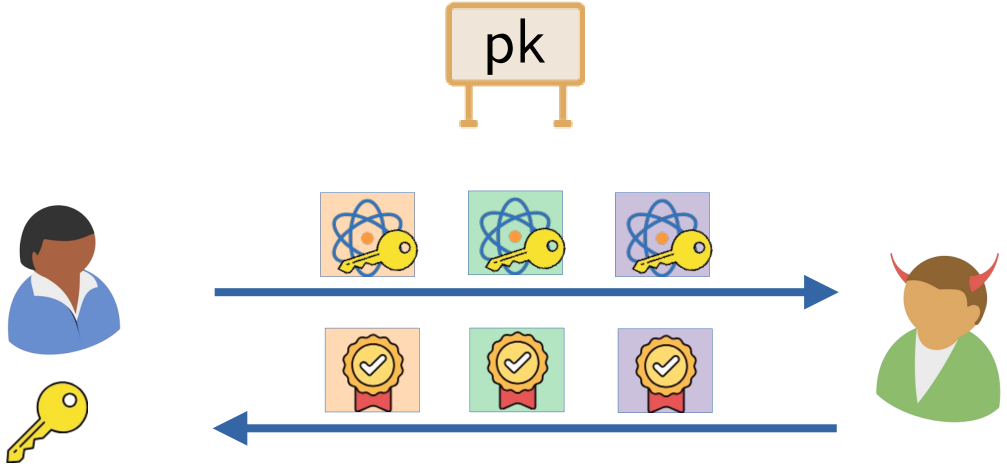

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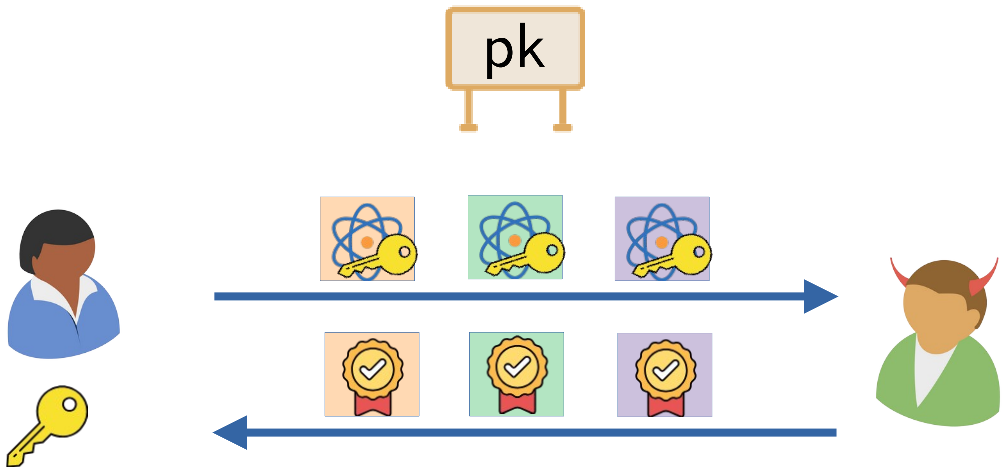

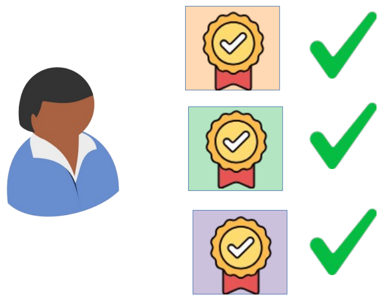

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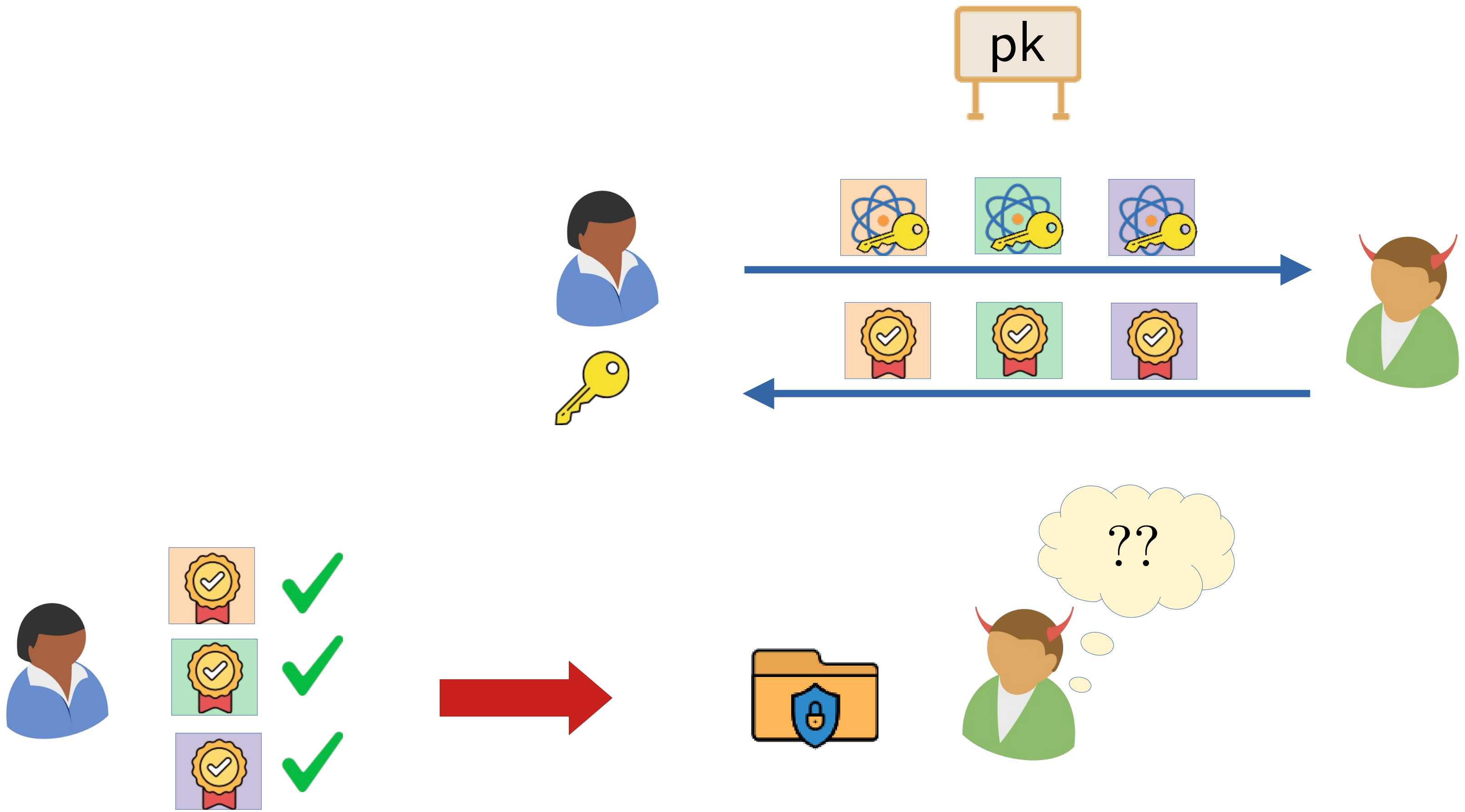
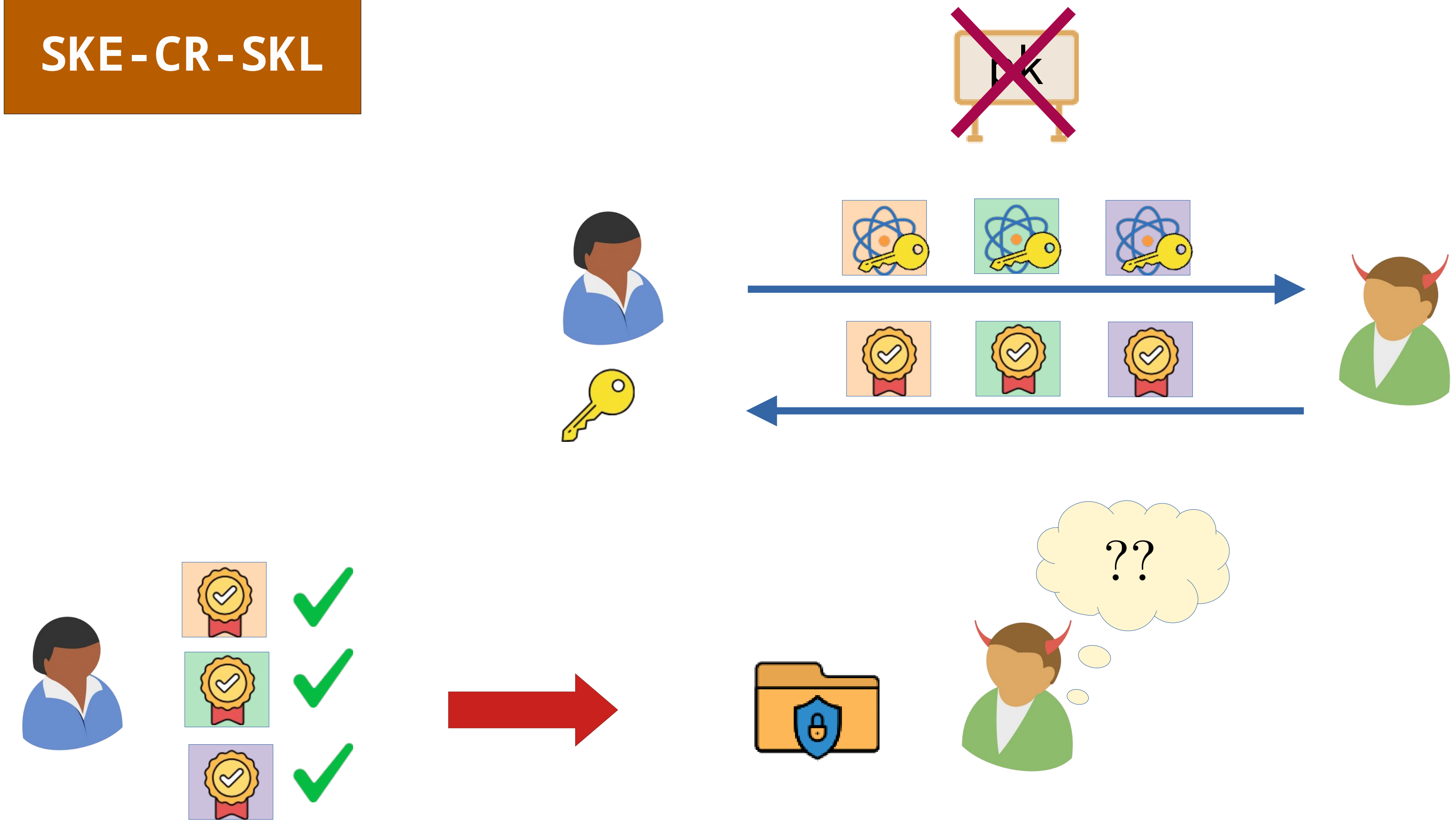


PKE-CR-SKL and SKE-CR-SKL

SKE-CR-SKL



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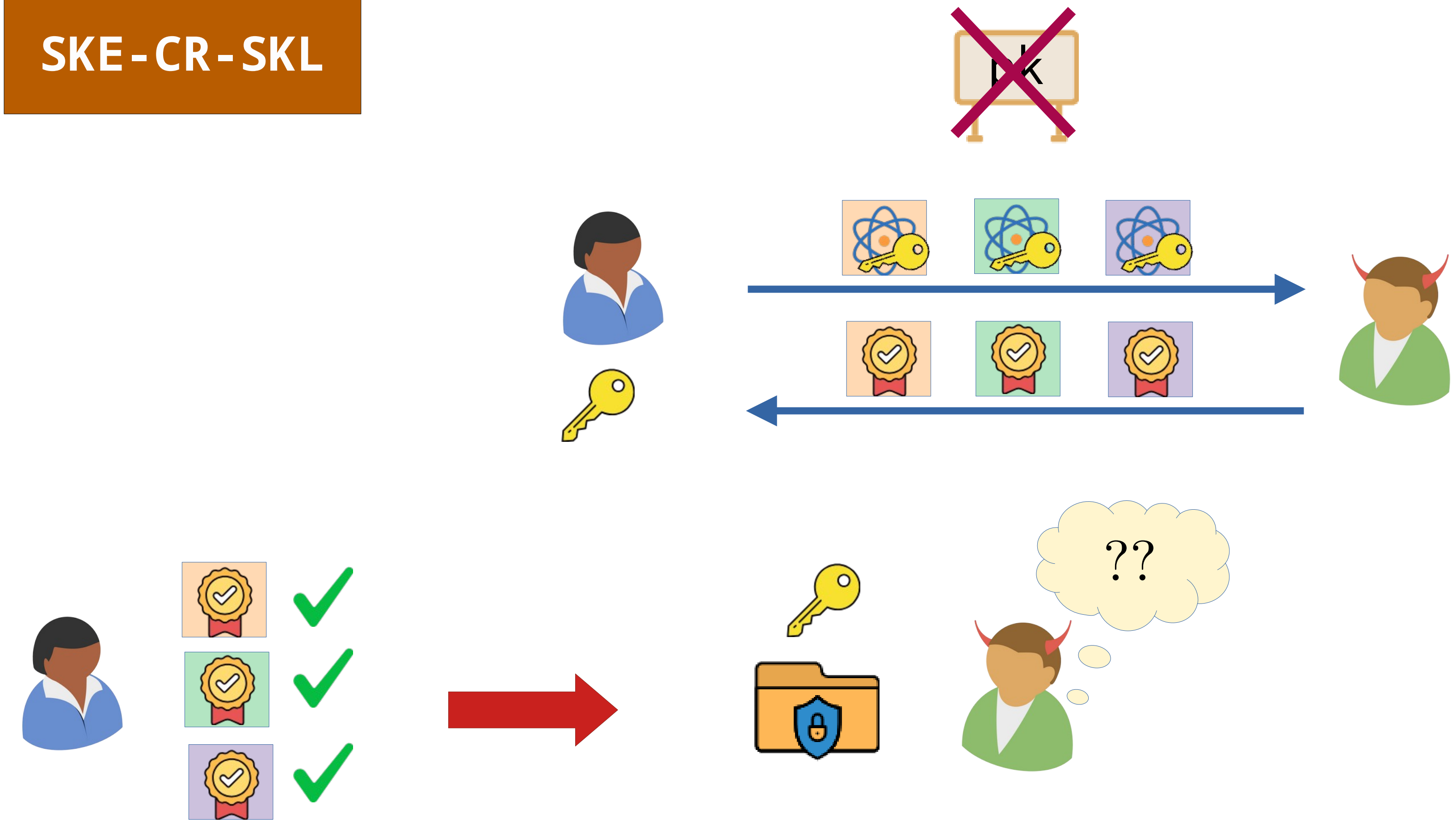

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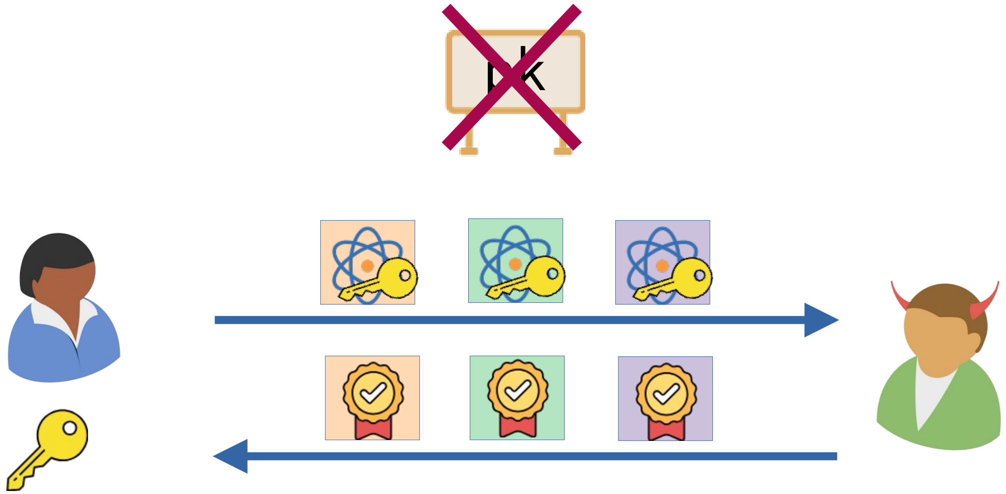

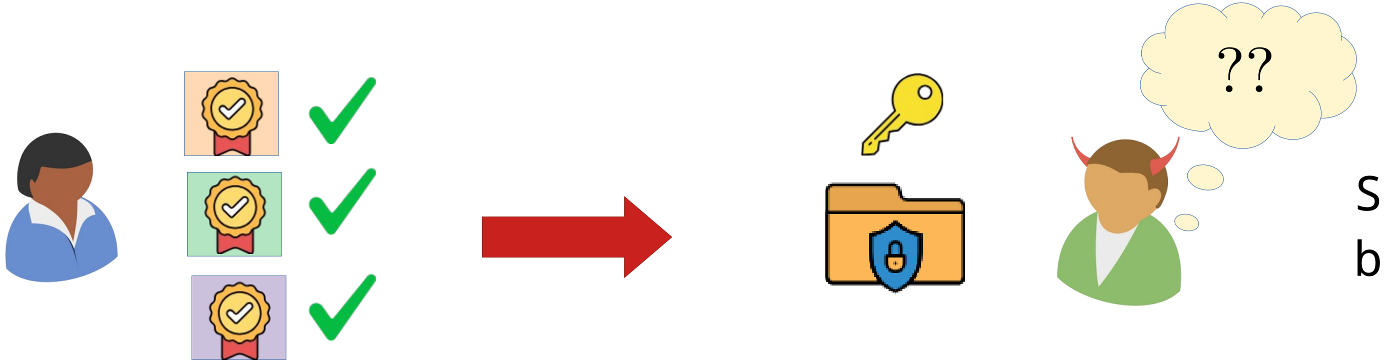

Sees no ciphertexts before returning!

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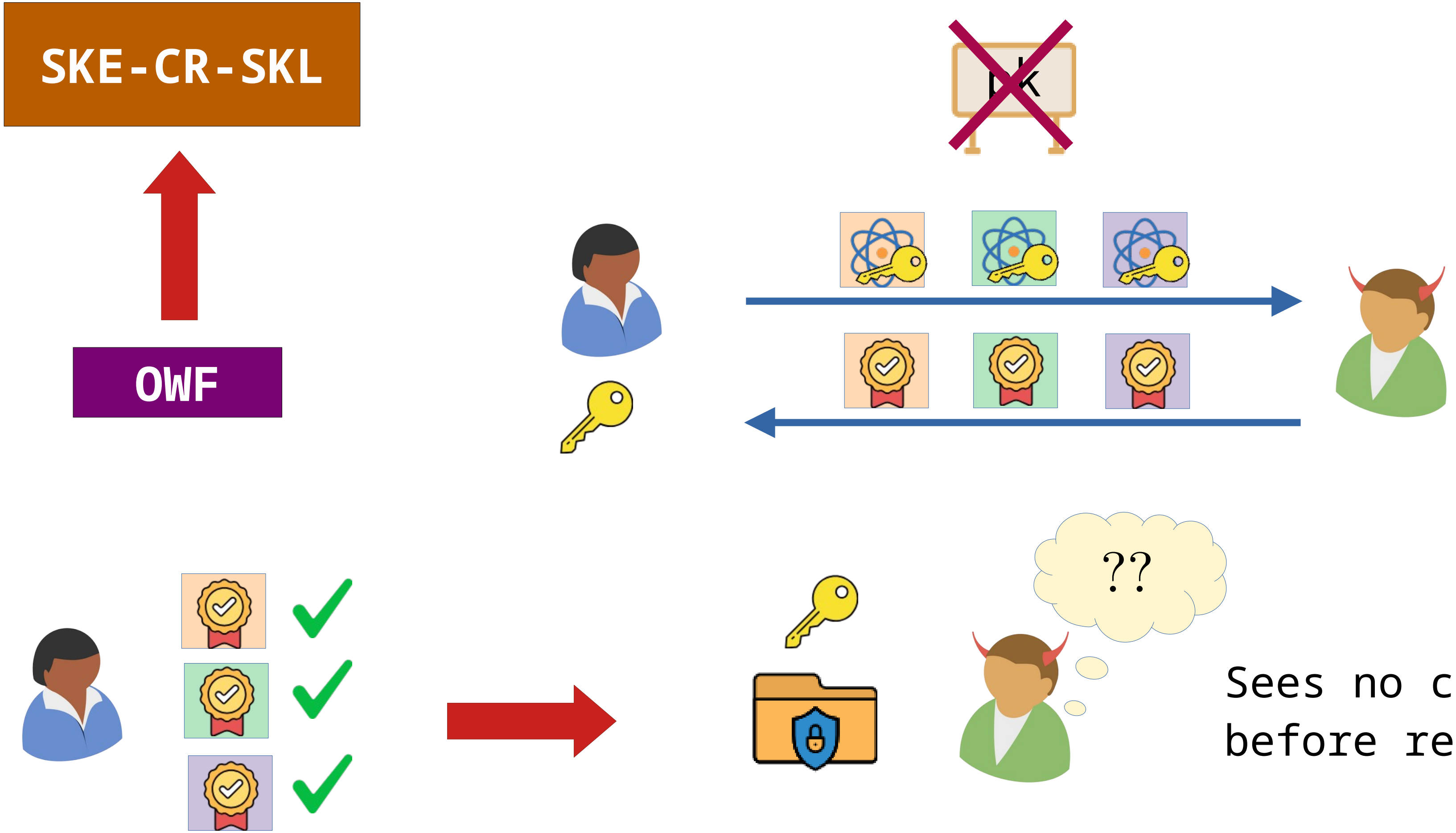

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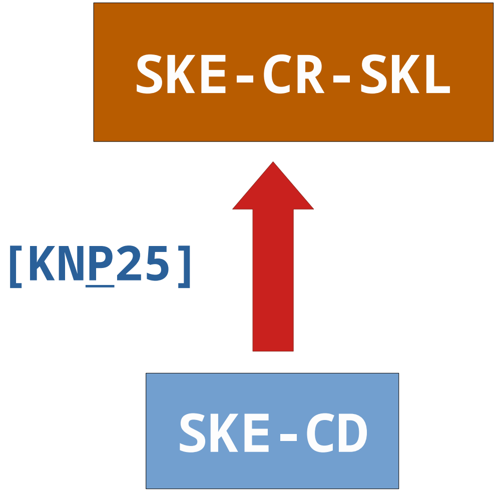

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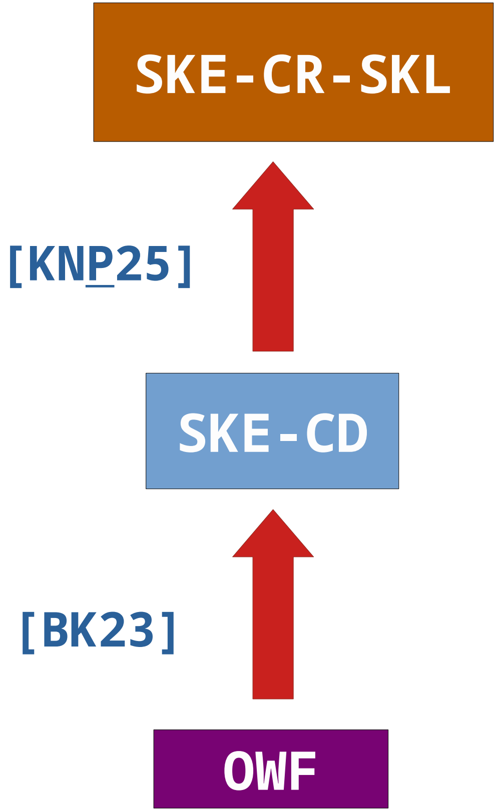

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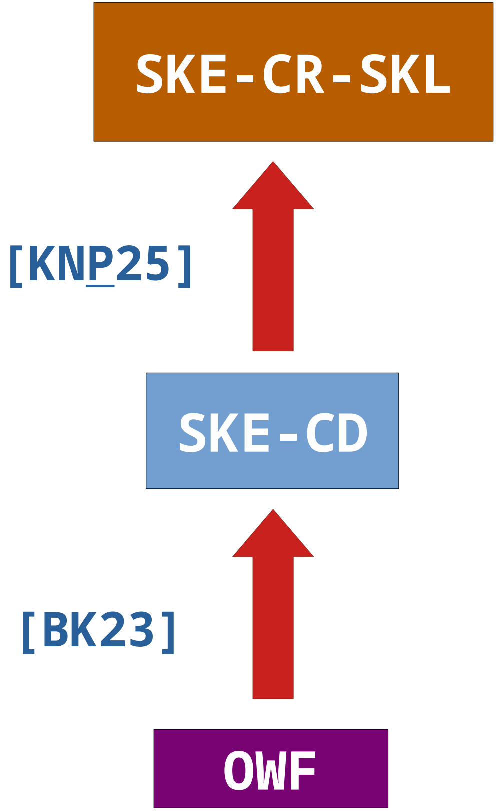
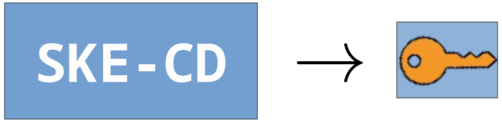
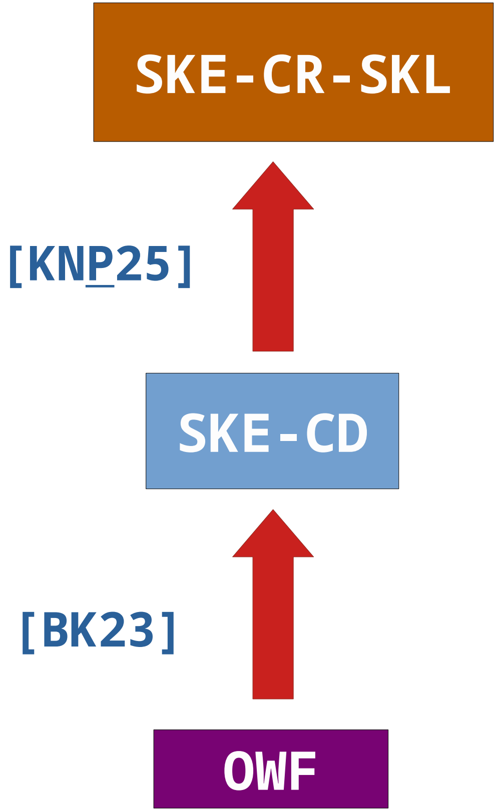
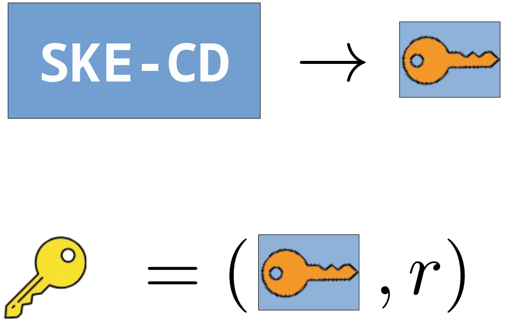




Constructing SKE-CR-SKL





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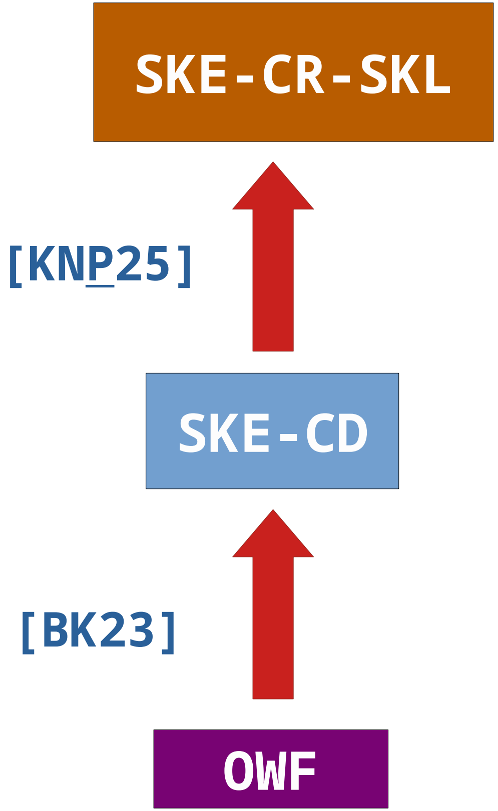
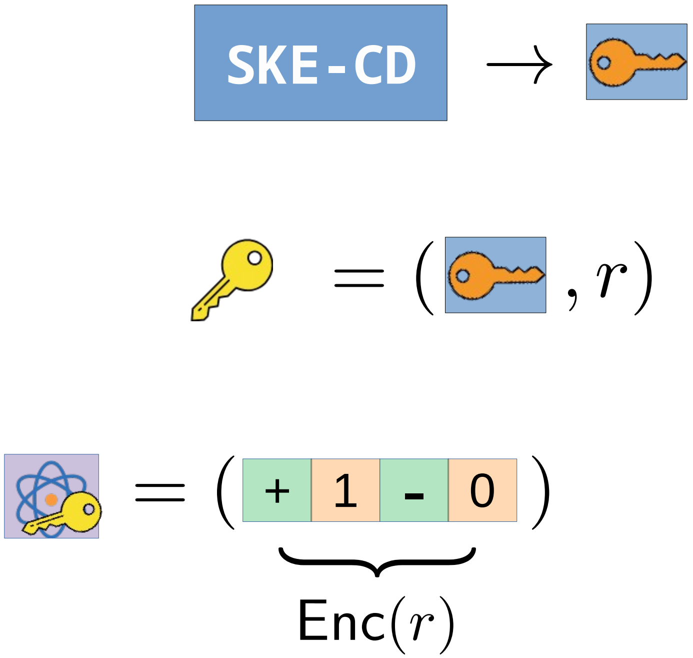
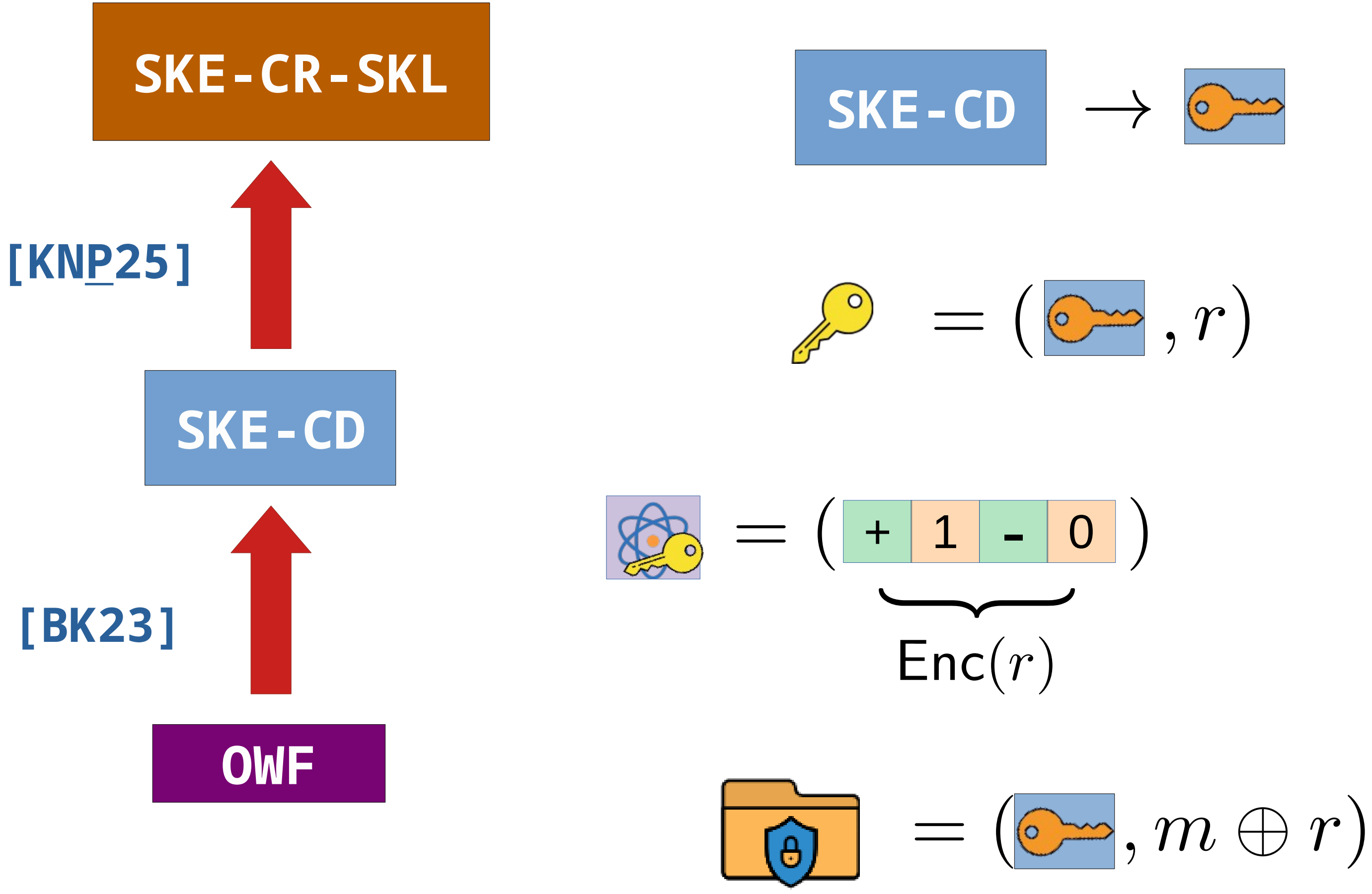




Constructing SKE-CR-SKL



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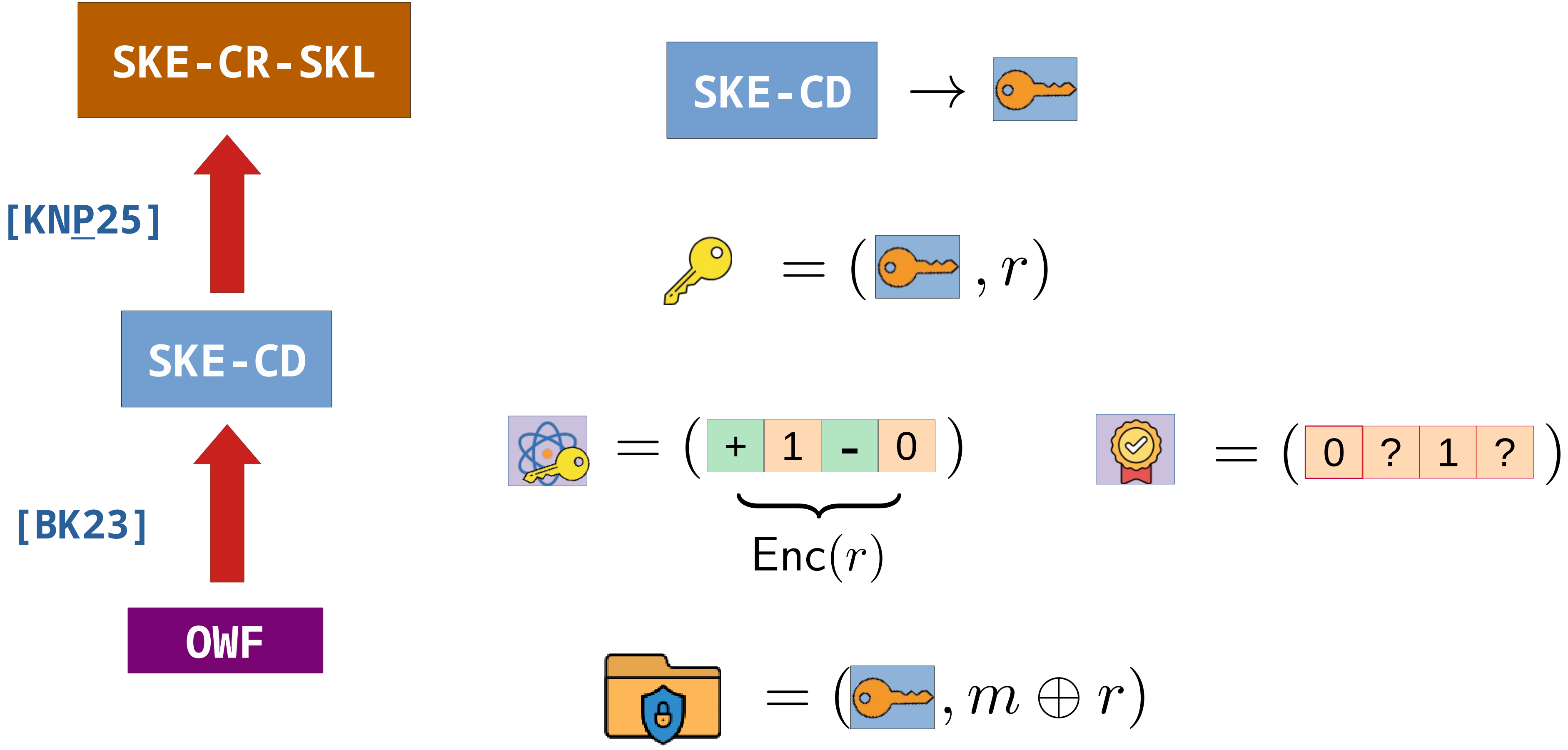
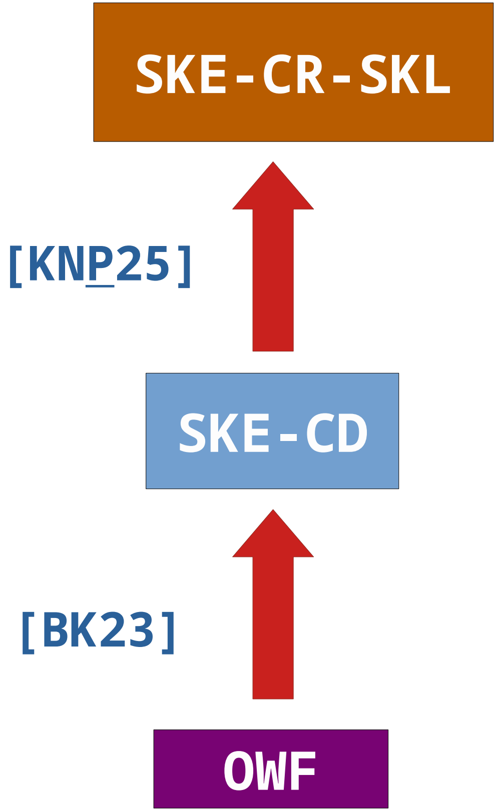
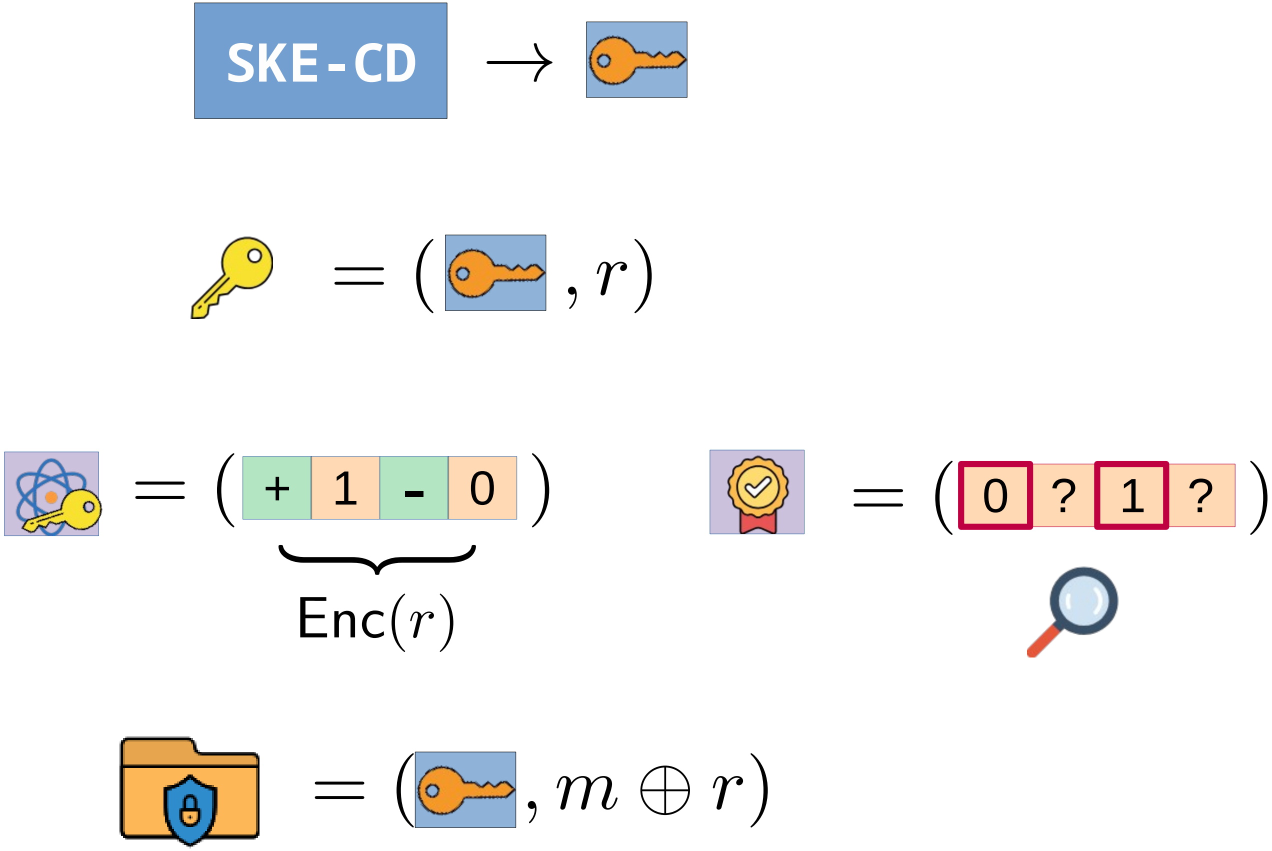


Constructing SKE-CR-SKL





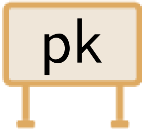
Building Block: ABE

Attribute Based Encryption

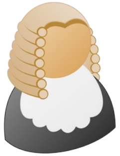
[GPS+06]

Building Block: ABE

Attribute Based Encryption



[GPS+06]

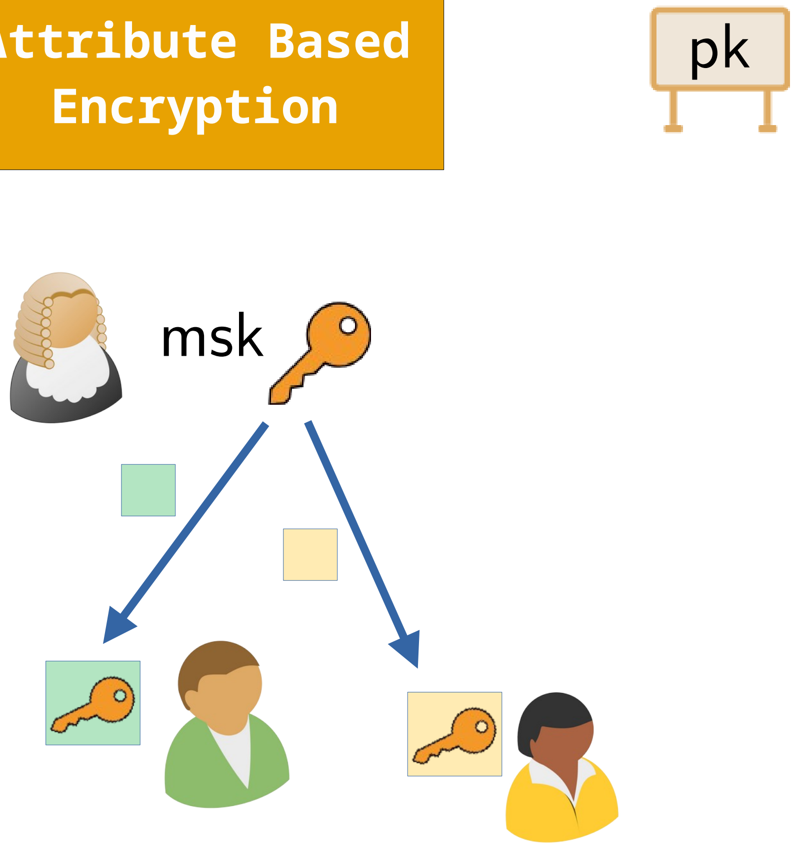


msk

Building Block: ABE

Attribute Based Encryption

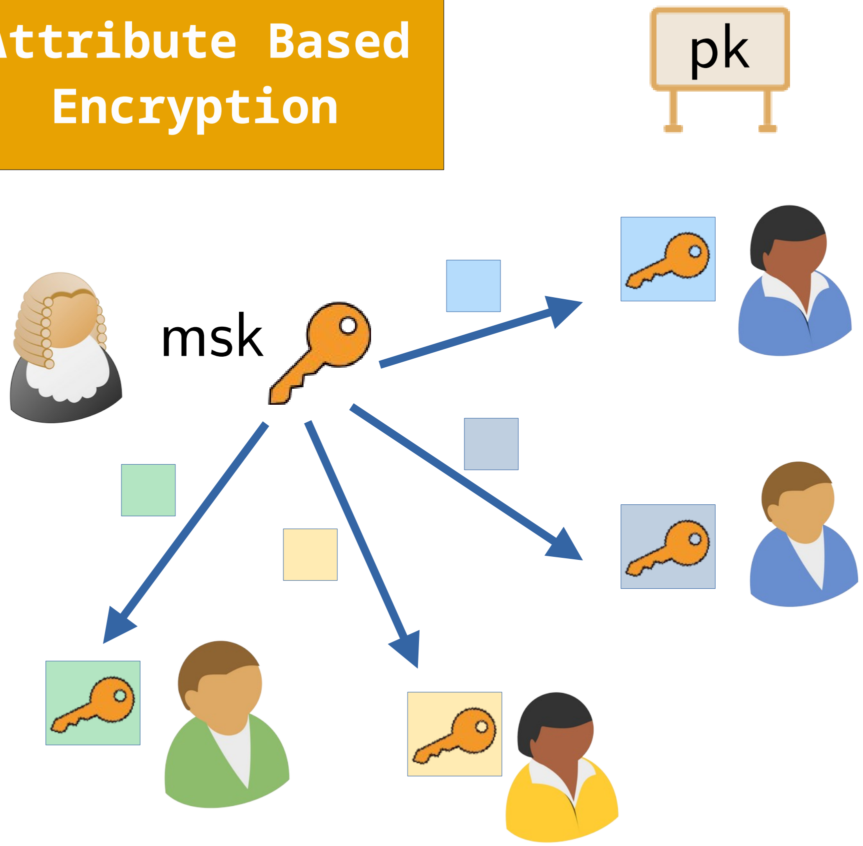
[GPS+06]



Building Block: ABE

Attribute Based Encryption

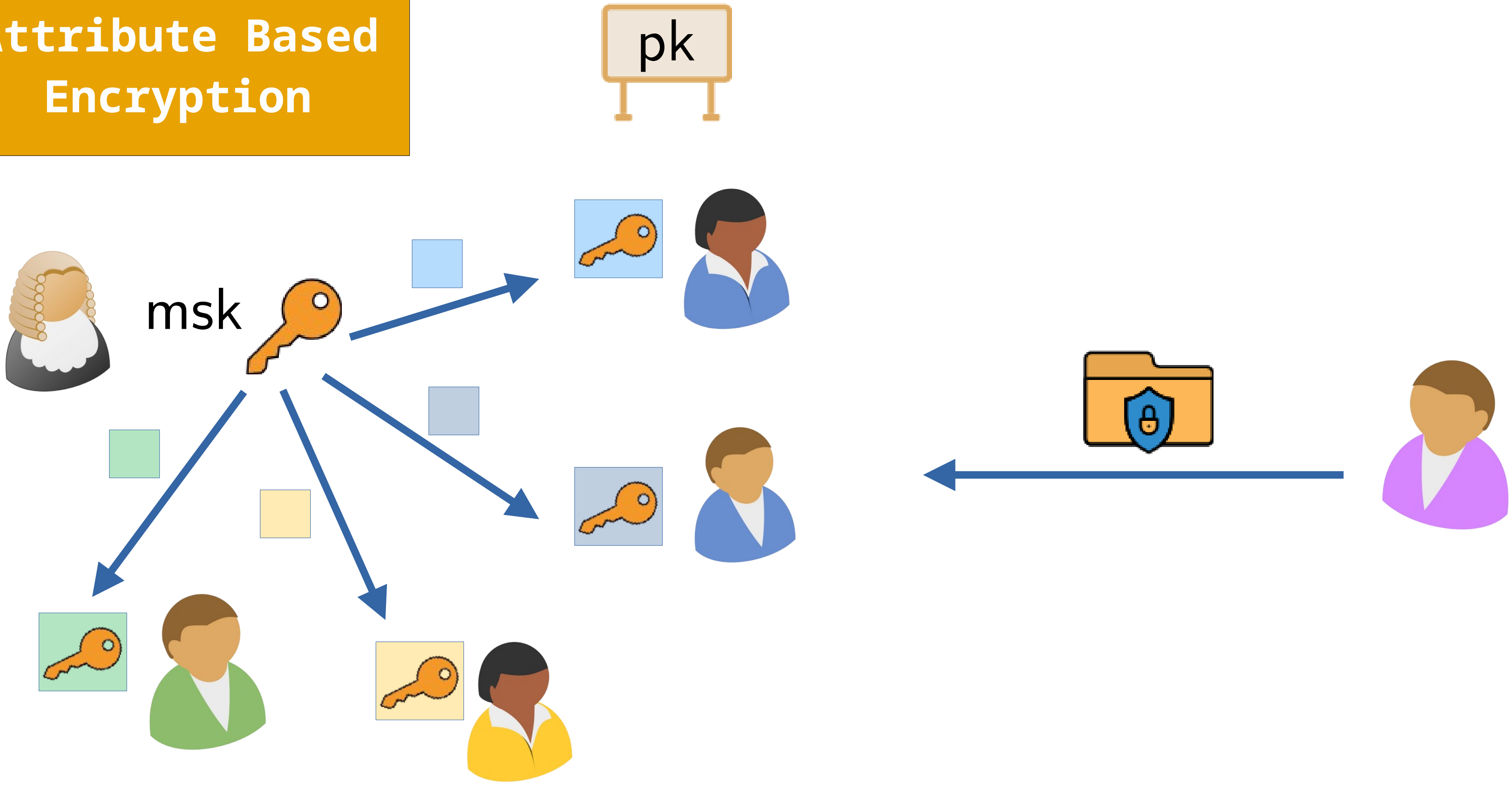
[GPS+06]



Building Block: ABE

Attribute Based Encryption

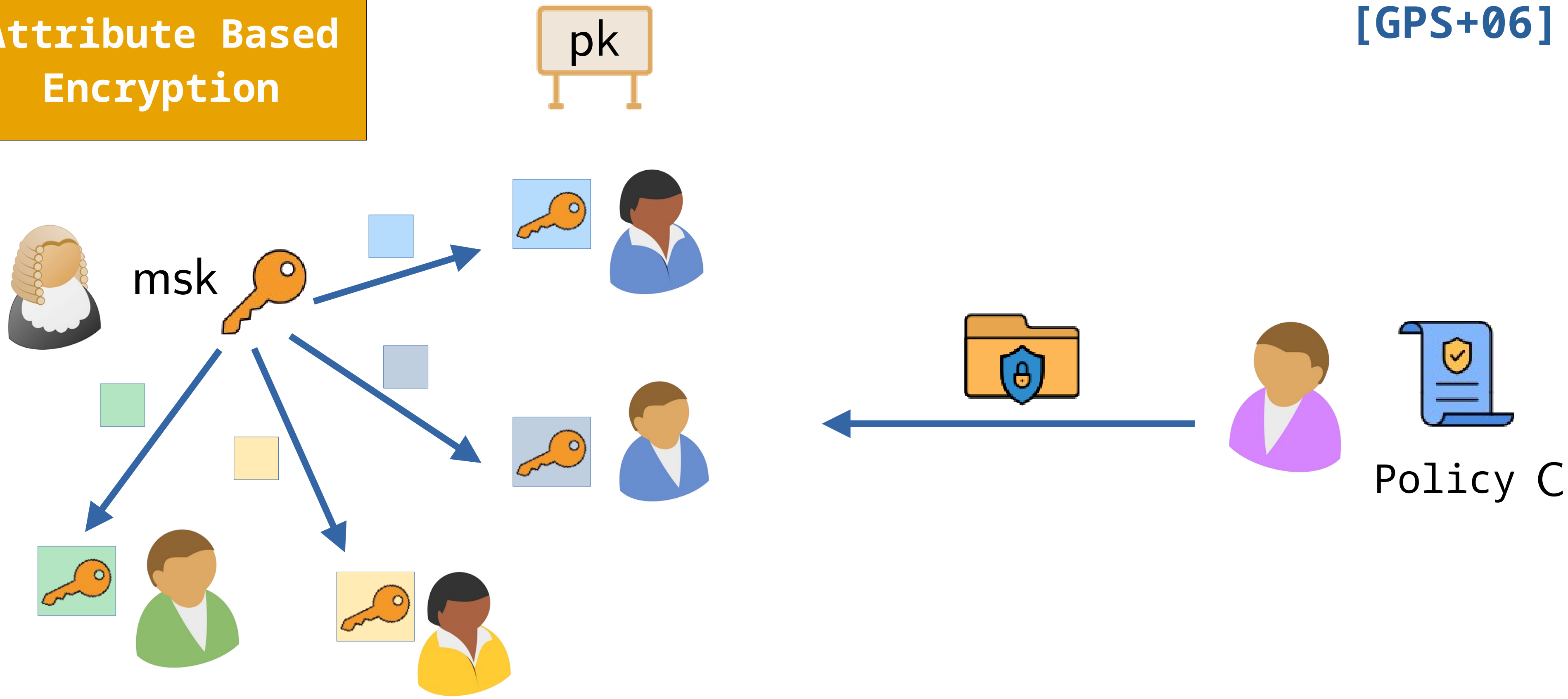
[GPS+06]



Building Block: ABE

Attribute Based Encryption

[GPS+06]



Building Block: ABE

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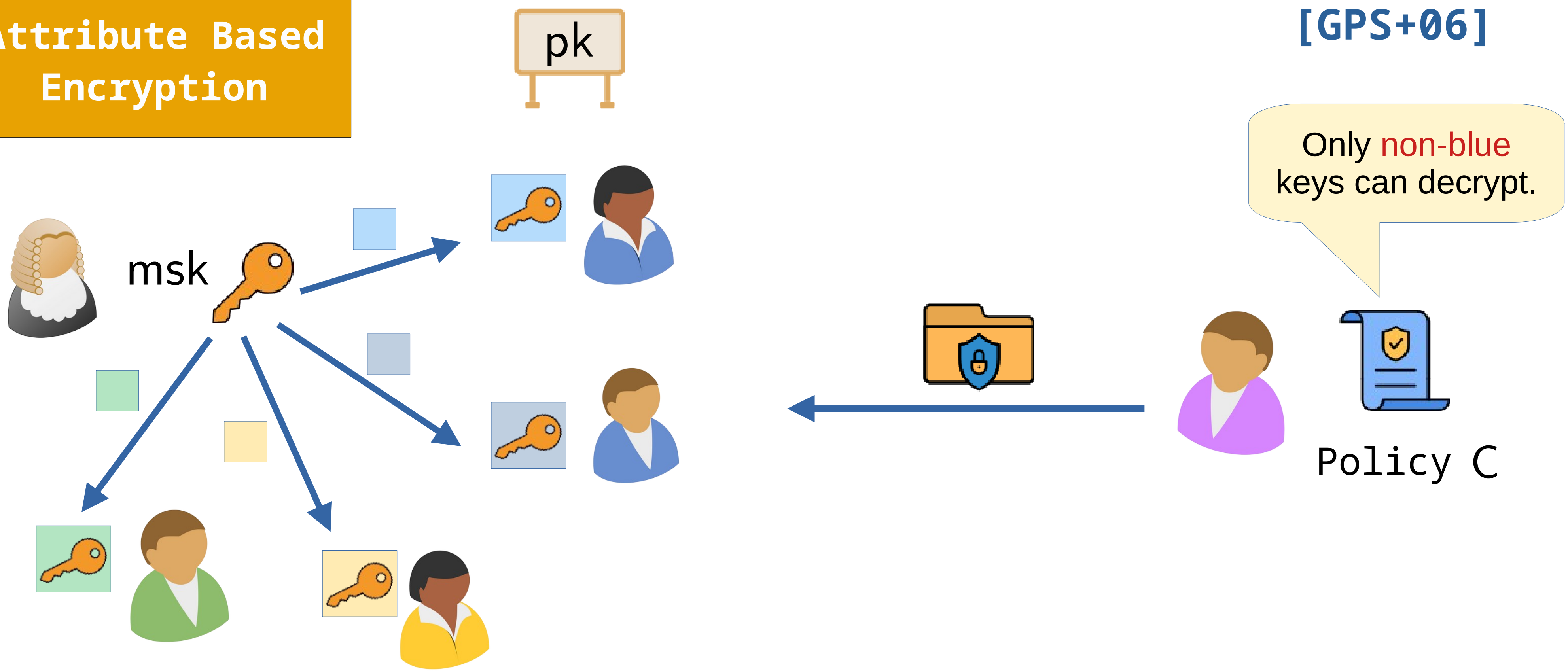
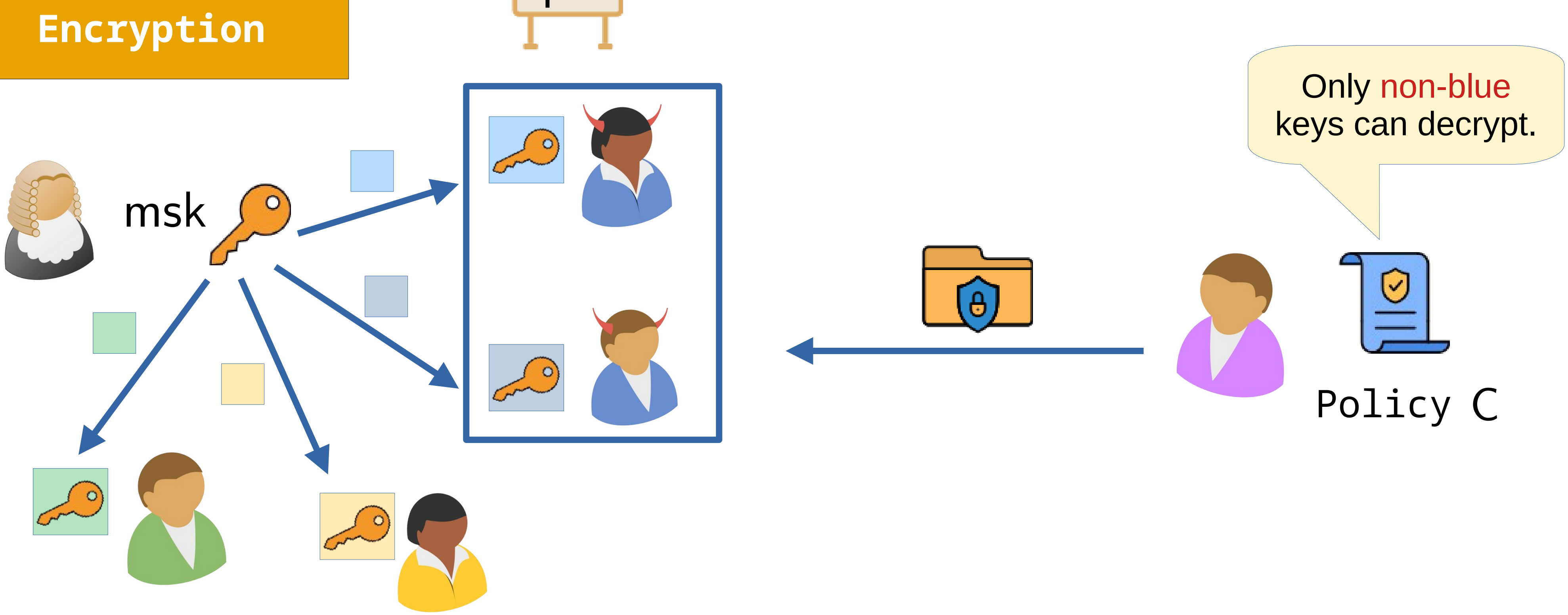
[GPS+06]



Building Block: ABE

Attribute Based Encryption

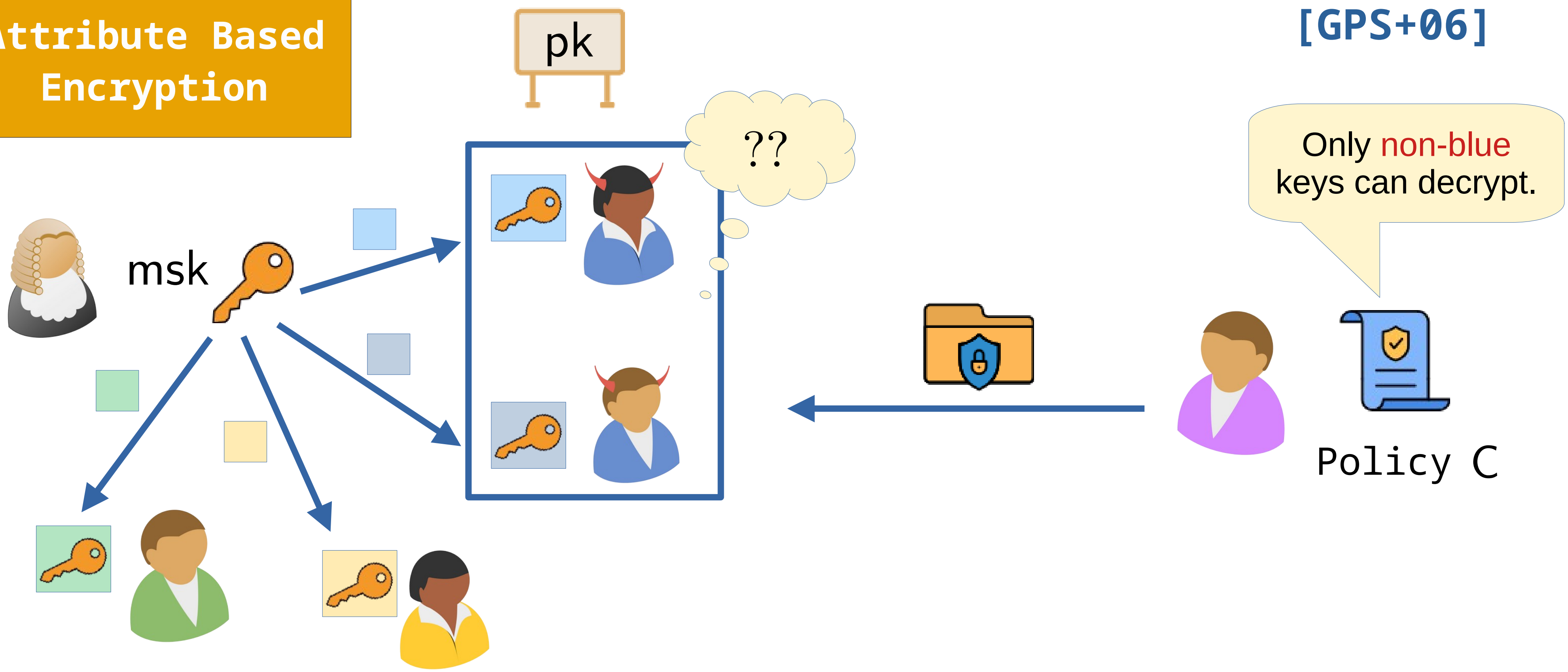
[GPS+06]



Building Block: ABE

Attribute Based Encryption

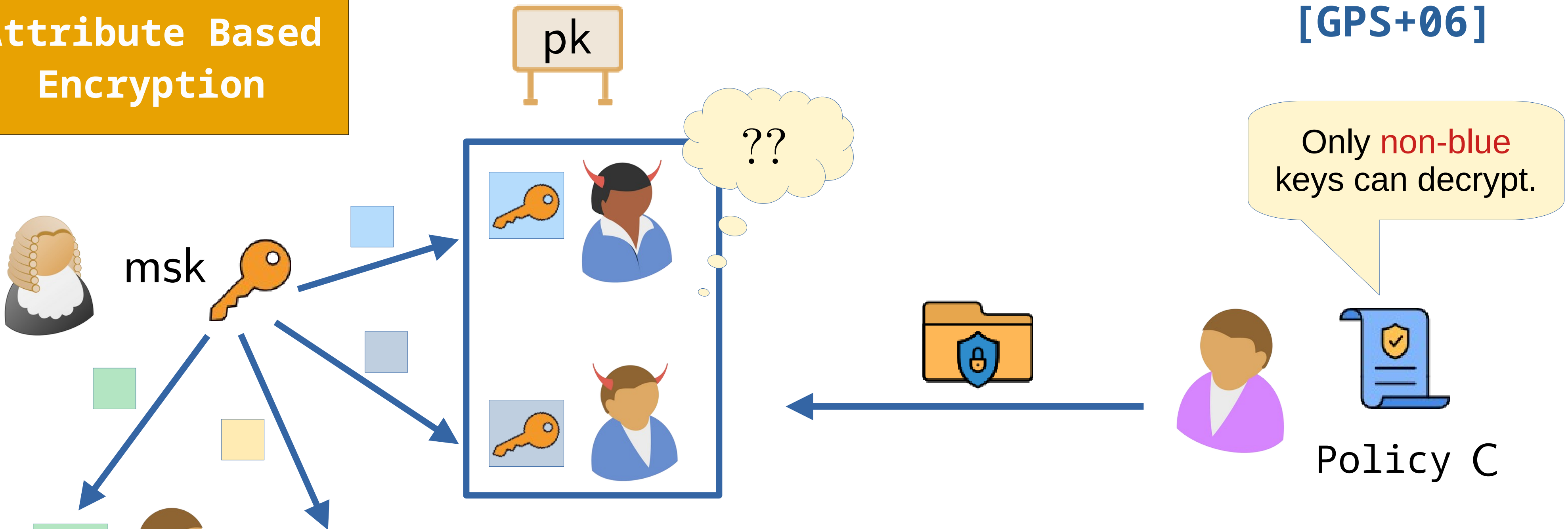
[GPS+06]



Building Block: ABE

Attribute Based Encryption

[GPS+06]



[KNP25]

$\sum |$  $\rangle$ Quantum Security of LWE-based ABE of [BGG+14].

Main Idea: Part I

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$$\mathsf{ske.dk} = \alpha_1|\square\rangle + \alpha_2|\square\rangle + \ldots + \alpha_N|\square\rangle$$

SKE-CR-SKL

Main Idea: Part I

$$\mathsf{ske.dk} = \alpha_1|\square\rangle + \alpha_2|\square\rangle + \ldots + \alpha_N|\square\rangle$$

SKE-CR-SKL

Classical Decryption Property

$$\mathsf{CDec}(\mathsf{ske.ct}, \square) = \mathsf{CDec}(\mathsf{ske.ct}, \square) = \ldots = \mathsf{CDec}(\mathsf{ske.ct}, \square) = \mathsf{m}$$

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SKE-CR-SKL

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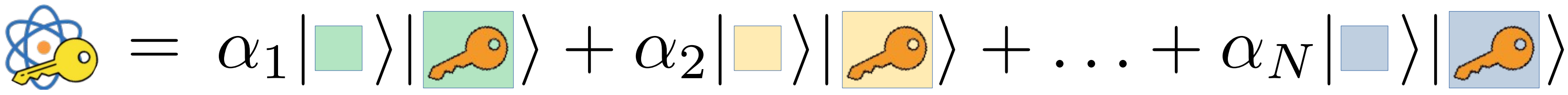

PKE-CR-SKL

Main Idea: Part I

$$\mathsf{ske.dk} = \alpha_1|\square\rangle + \alpha_2|\square\rangle + \ldots + \alpha_N|\square\rangle$$

SKE-CR-SKL

Classical Decryption Property

$$\mathsf{CDec}(\mathsf{ske.ct}, \square) = \mathsf{CDec}(\mathsf{ske.ct}, \square) = \ldots = \mathsf{CDec}(\mathsf{ske.ct}, \square) = \mathsf{m}$$

$$= \alpha_1|\square\rangle|\square\rangle + \alpha_2|\square\rangle|\square\rangle + \ldots + \alpha_N|\square\rangle|\square\rangle$$

PKE-CR-SKL

ABE Secret-Key

Main Idea: Part I

$$\text{ske.dk} = \alpha_1|\square\rangle + \alpha_2|\square\rangle + \ldots + \alpha_N|\square\rangle$$

SKE-CR-SKL

Classical Decryption Property

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$$= \alpha_1|\square\rangle|\square\rangle + \alpha_2|\square\rangle|\square\rangle + \ldots + \alpha_N|\square\rangle\underbrace{|\square\rangle}_{\text{ABE Secret-Key}}$$

PKE-CR-SKL

Main Idea: Part I

$\mathsf{ske.dk} = \alpha_1|\square\rangle + \alpha_2|\square\rangle + \ldots + \alpha_N|\square\rangle$ **SKE-CR-SKL**

Classical Decryption Property

$\mathsf{CDec}(\mathsf{ske.ct}, \square) = \mathsf{CDec}(\mathsf{ske.ct}, \square) = \ldots = \mathsf{CDec}(\mathsf{ske.ct}, \square) = \mathsf{m}$

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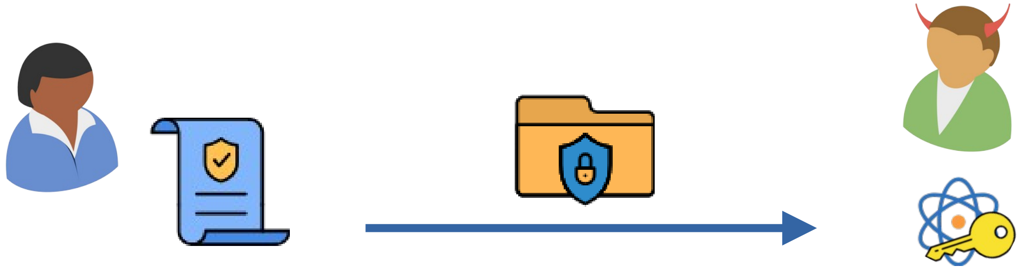
ABE Secret-Key



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SKE-CR-SKL

<u>Classical Decryption Property</u>

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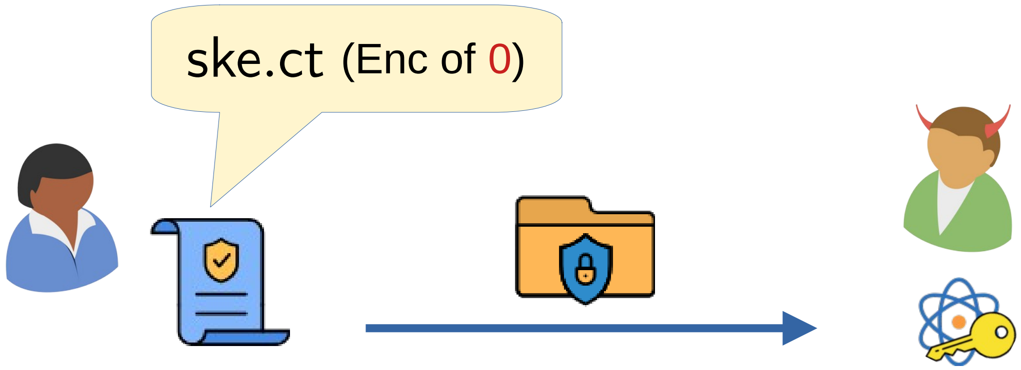
PKE-CR-SKL



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$\mathsf{ske.dk} = \alpha_1|\square\rangle + \alpha_2|\square\rangle + \ldots + \alpha_N|\square\rangle$ **SKE-CR-SKL**

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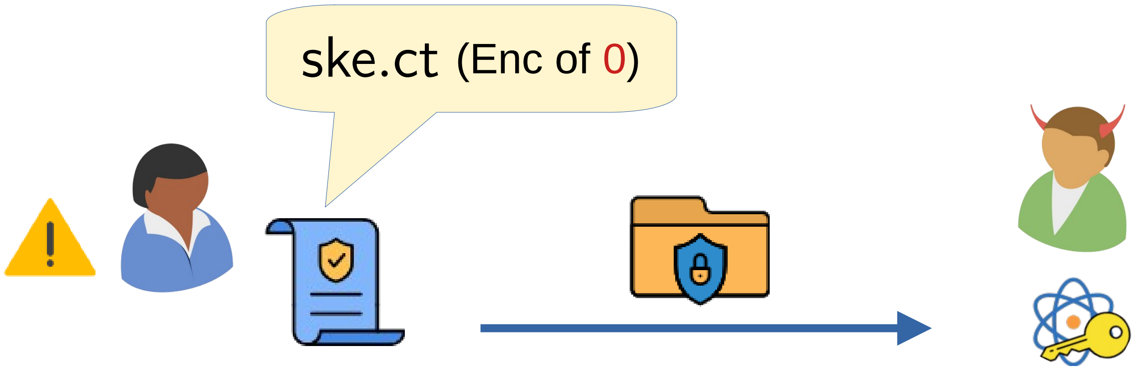
 $= \alpha_1|\square\rangle|\square\rangle + \alpha_2|\square\rangle|\square\rangle + \ldots + \alpha_N|\square\rangle|\square\rangle$ **PKE-CR-SKL**

ABE Secret-Key



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$$\mathsf{ske.dk} = \alpha_1|\square\rangle + \alpha_2|\square\rangle + \ldots + \alpha_N|\square\rangle$$

SKE-CR-SKL

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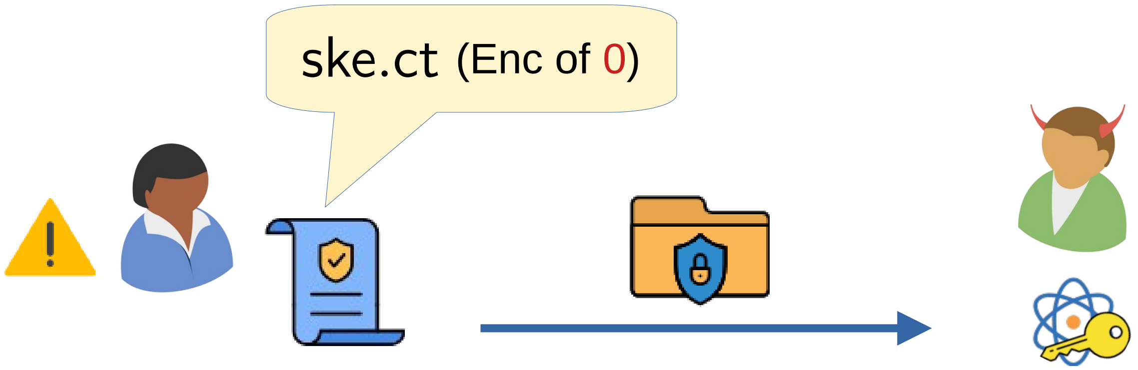
$$\mathsf{CDec}(\mathsf{ske.ct}, \square) = \mathsf{CDec}(\mathsf{ske.ct}, \square) = \ldots = \mathsf{CDec}(\mathsf{ske.ct}, \square) = \mathsf{m}$$

$$= \alpha_1|\square\rangle|\text{key}\rangle + \alpha_2|\square\rangle|\text{key}\rangle + \ldots + \alpha_N|\square\rangle|\text{key}\rangle$$

PKE-CR-SKL

ABE Secret-Key



satisfies policy if:

$$\mathsf{CDec}(\mathsf{ske.ct}, \square) = 0$$

Main Idea: Part II

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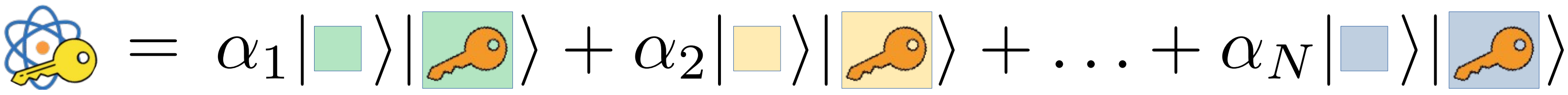

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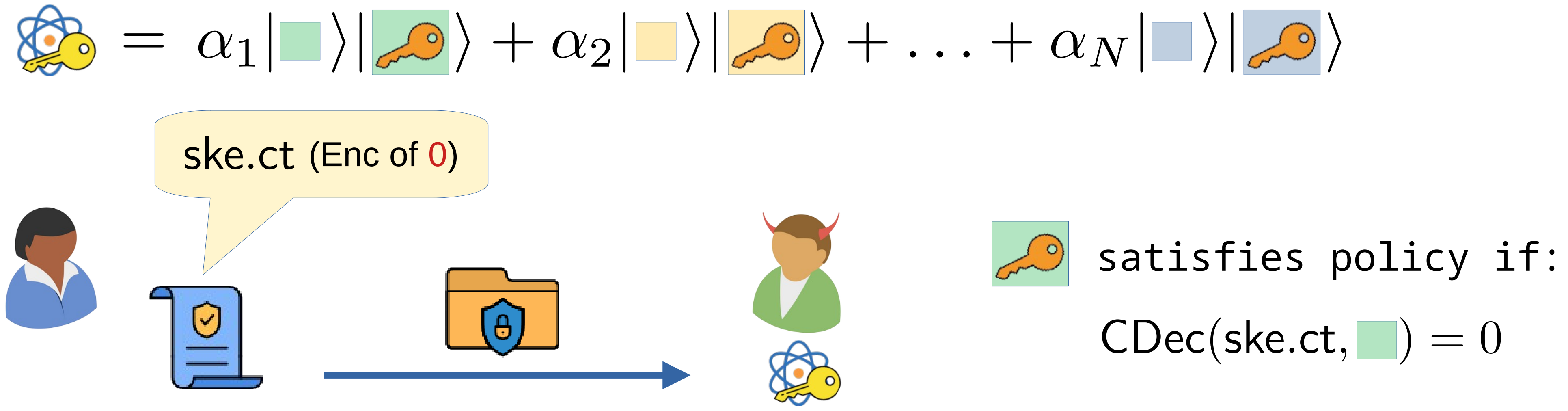

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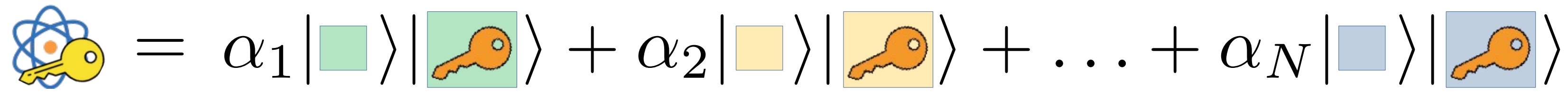

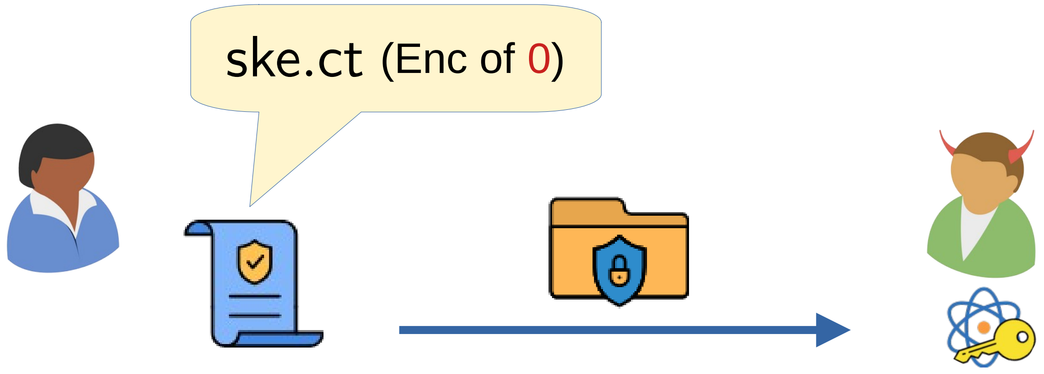

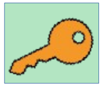

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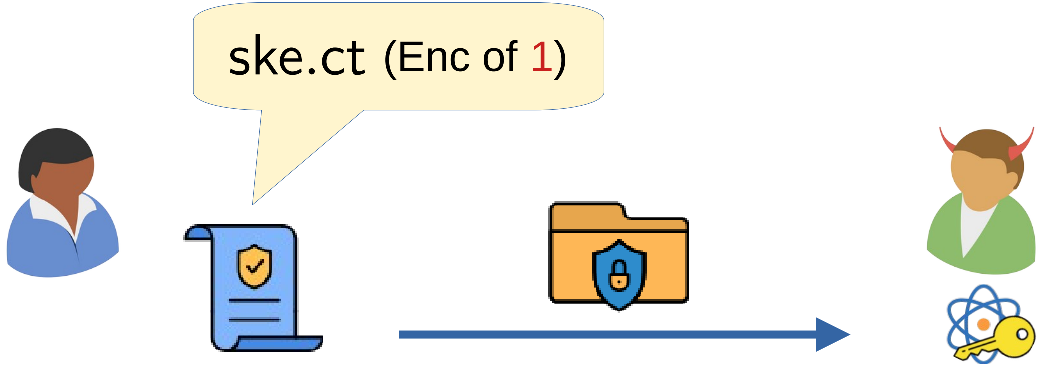

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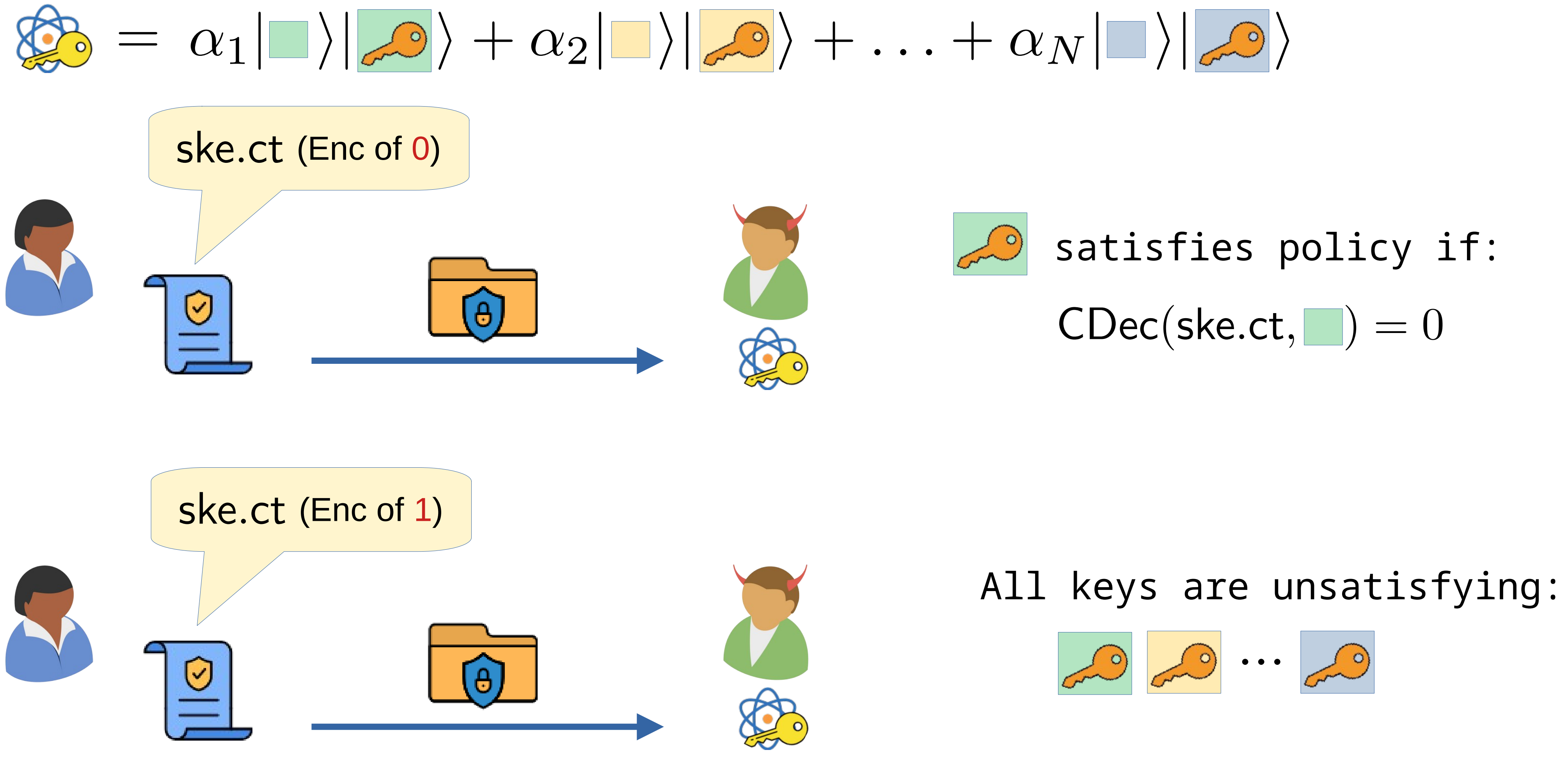

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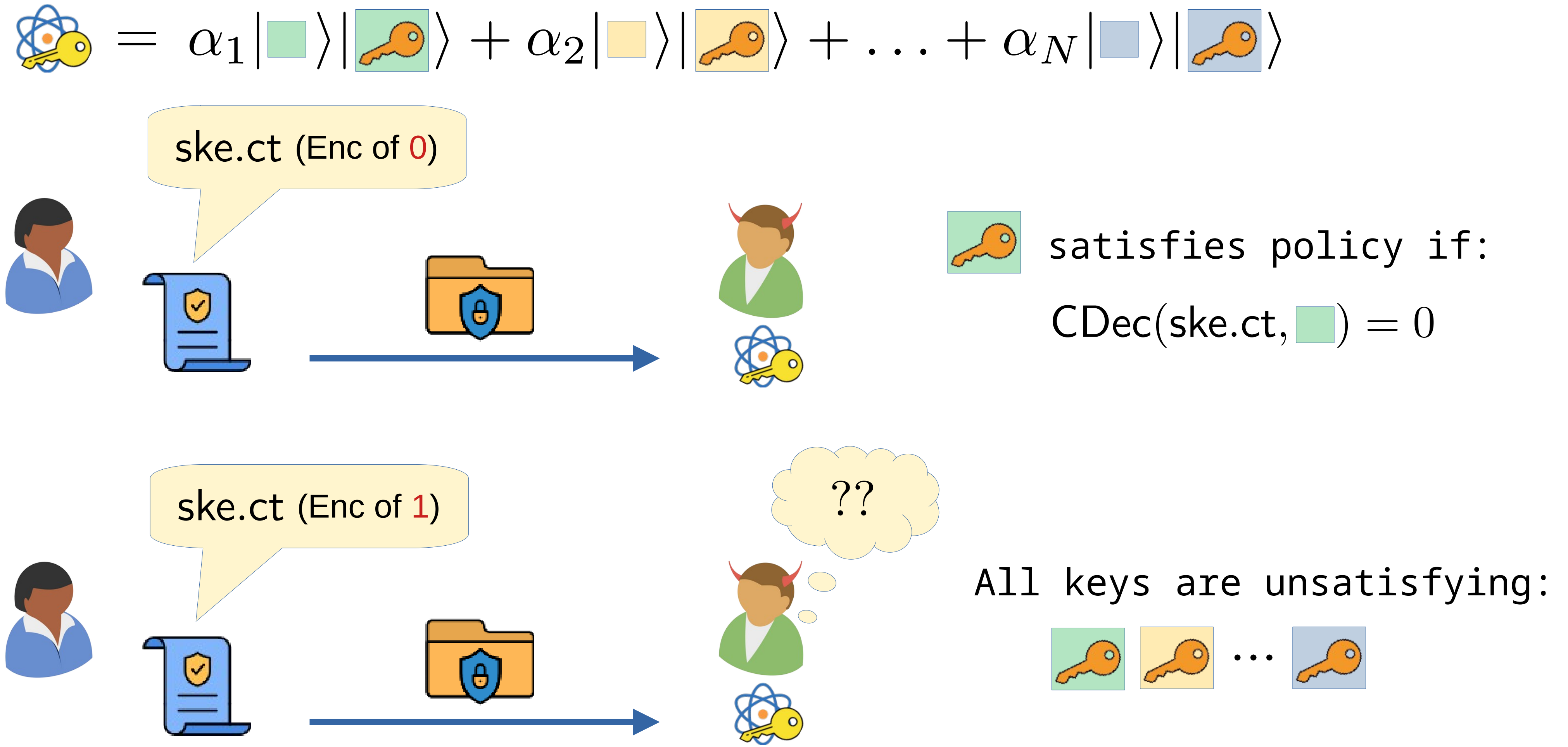

Main Idea: Part III

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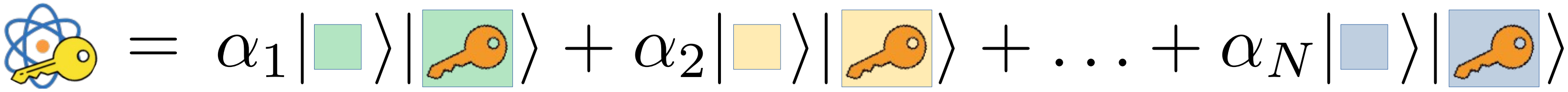

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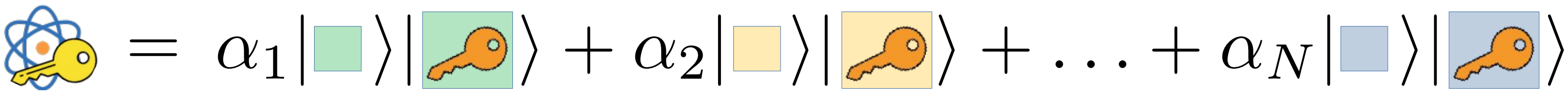

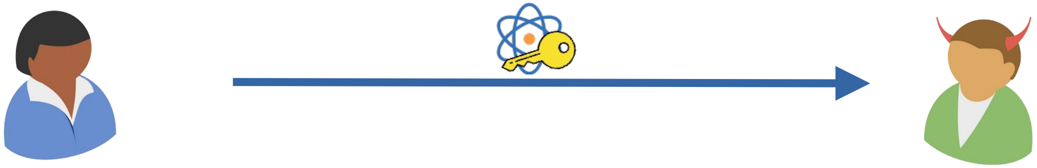

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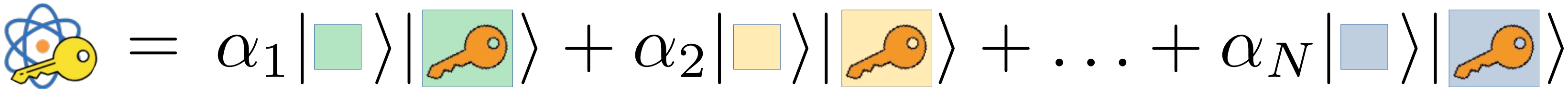

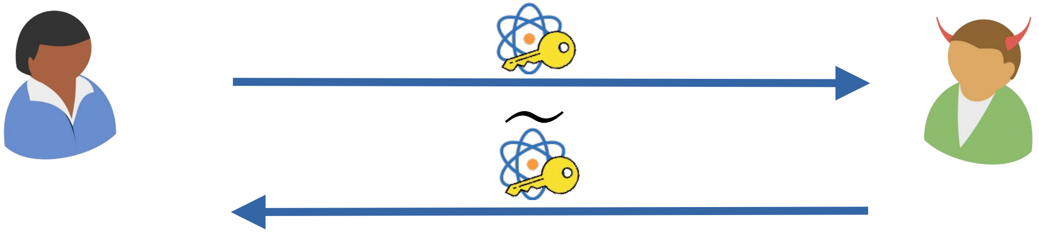

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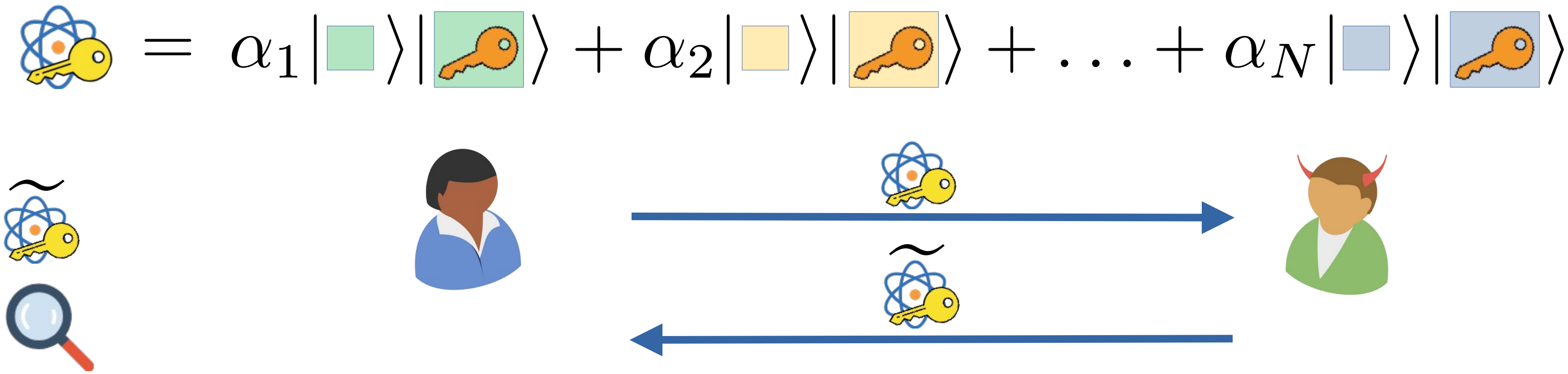

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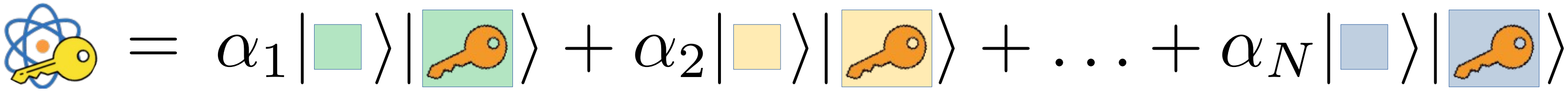
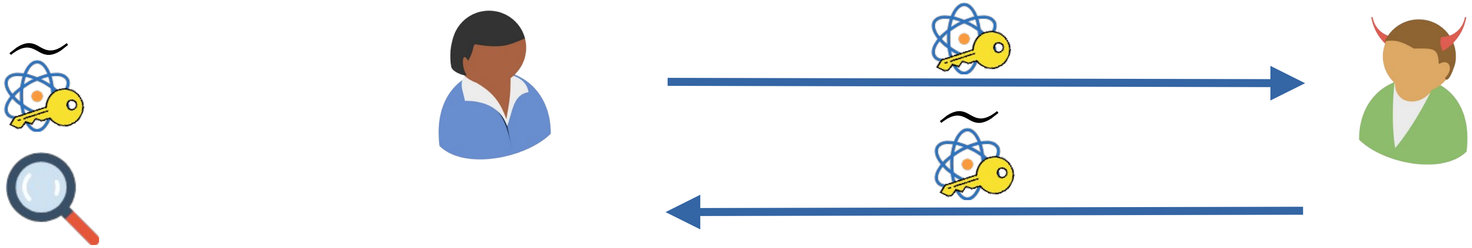
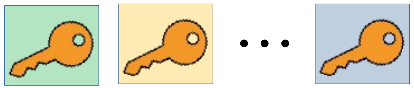




1. Uncompute ABE keys



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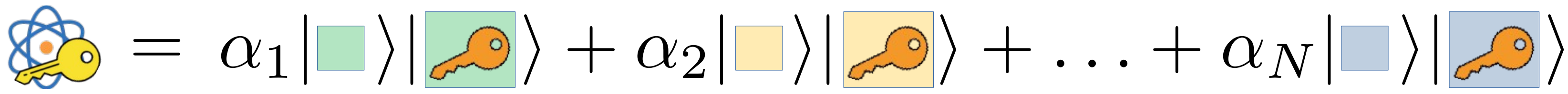

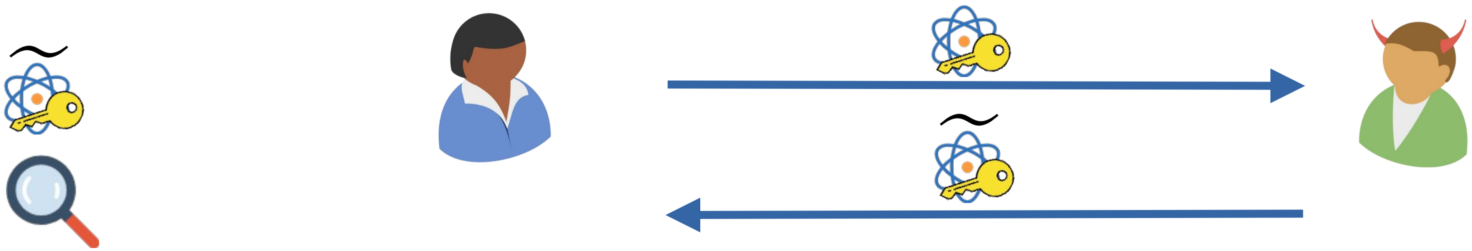

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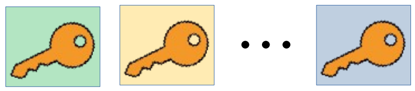
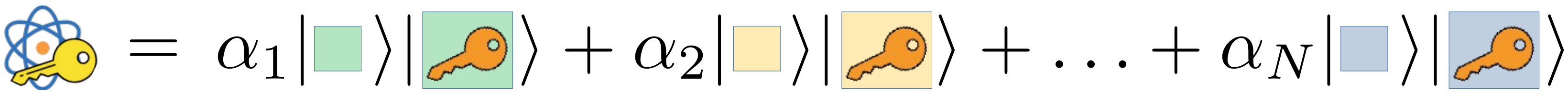
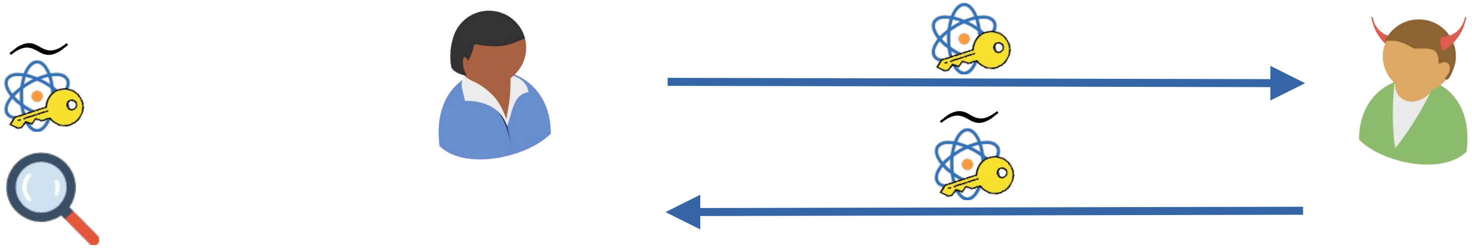


2. Verify $\mathsf{ske}.\widetilde{\mathsf{dk}}$.

Main Idea: Part III





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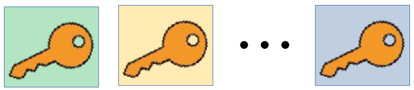

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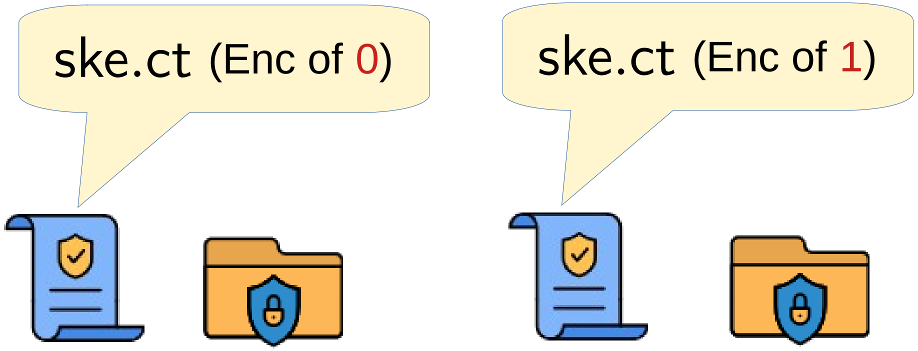

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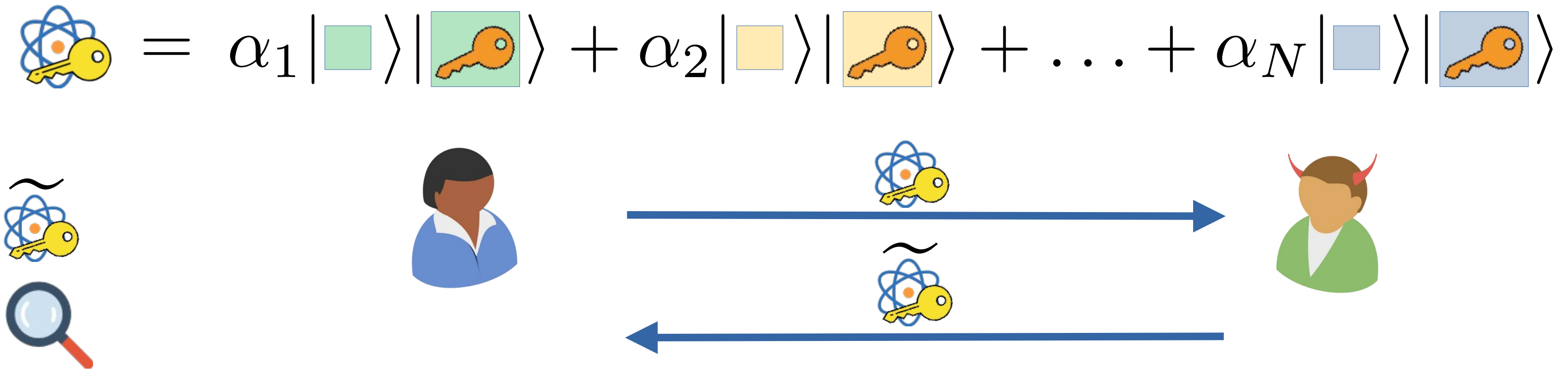

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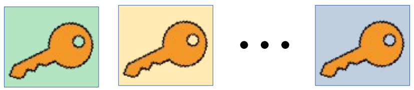

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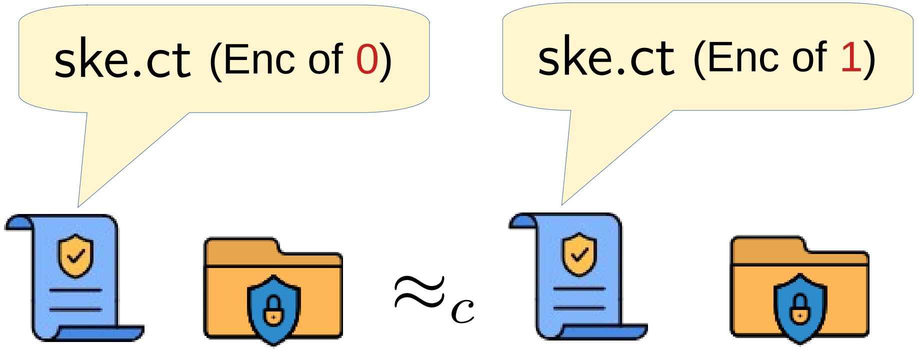
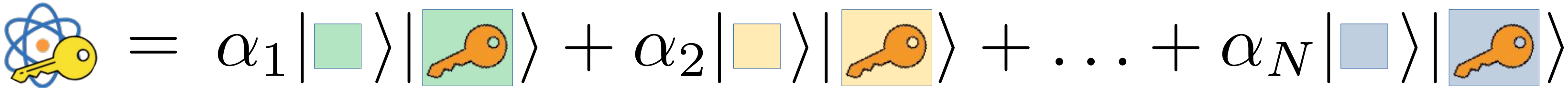
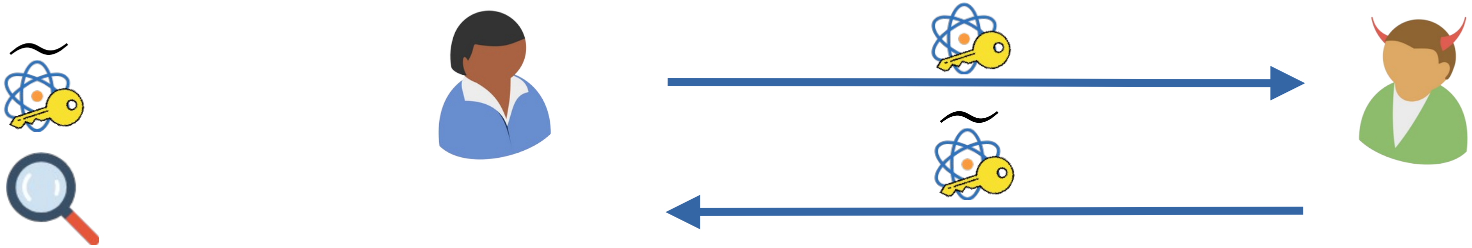


SKE-CR-SKL

Main Idea: Part III





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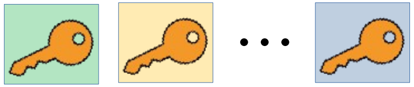

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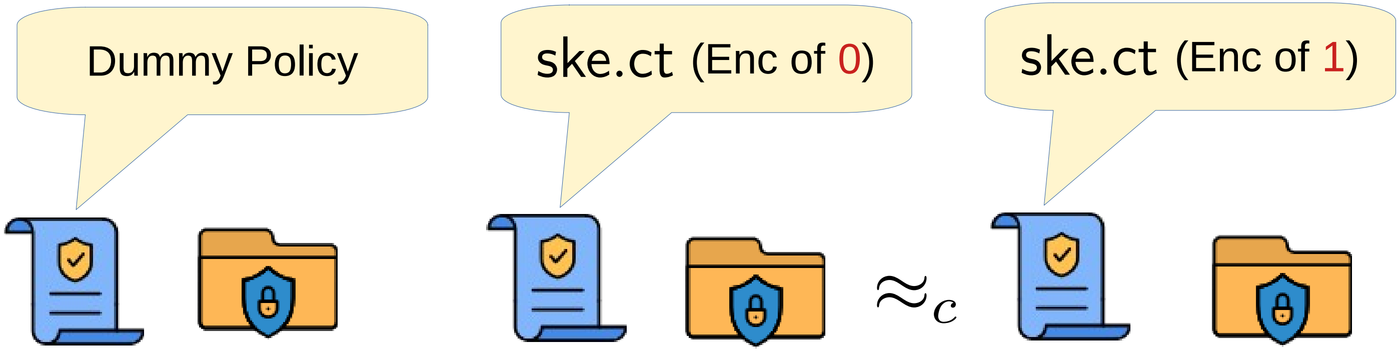
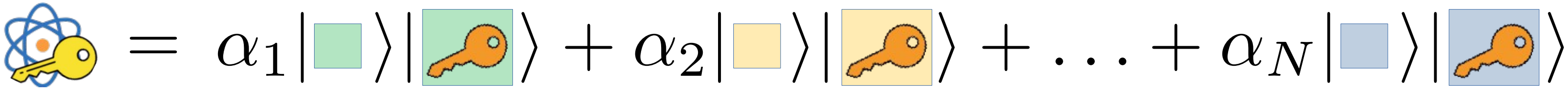
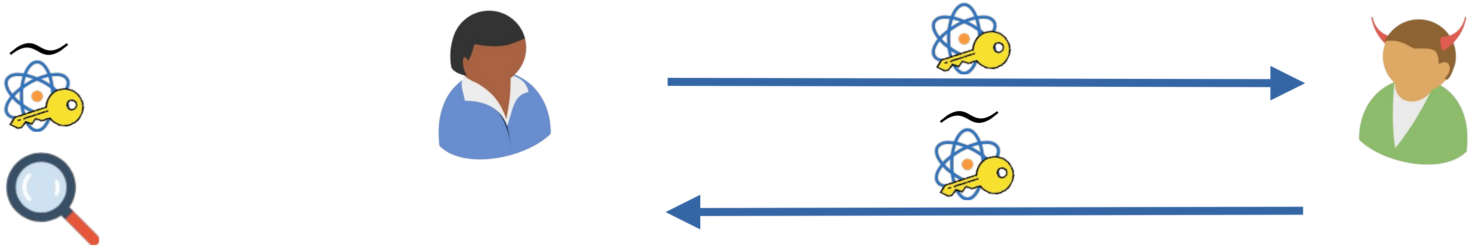


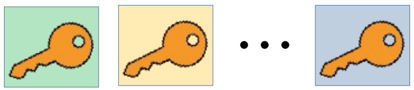
SKE-CR-SKL

Main Idea: Part III

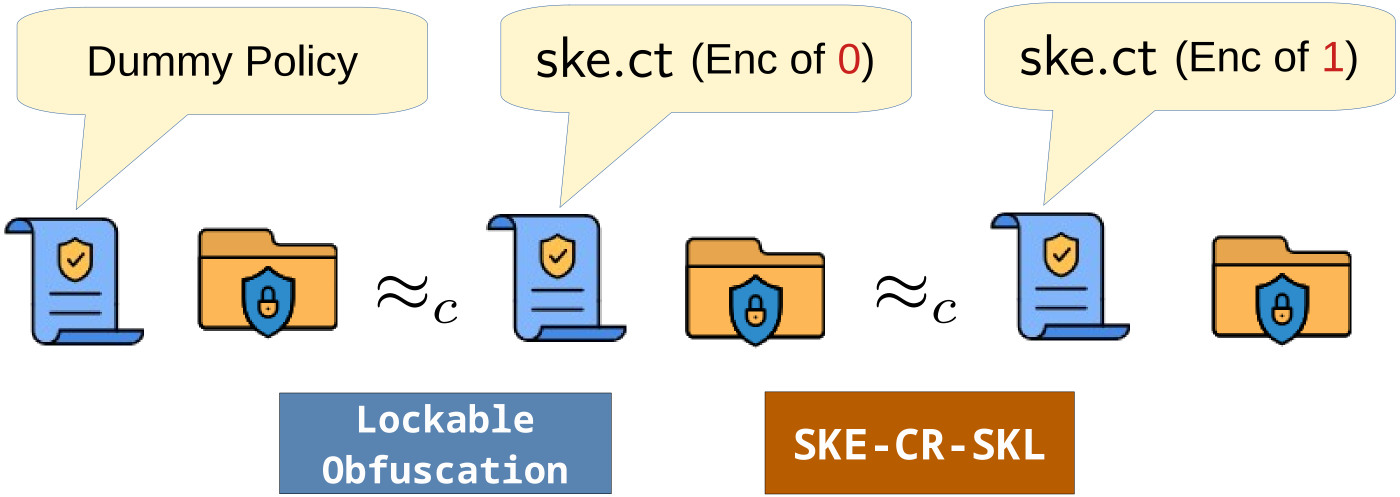




1. Uncompute ABE keys



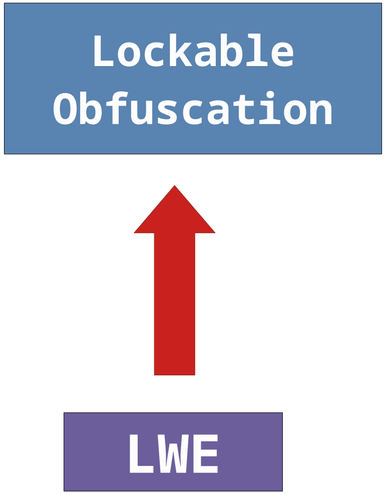
2. Verify $\widetilde{\text{ske.dk}}$.



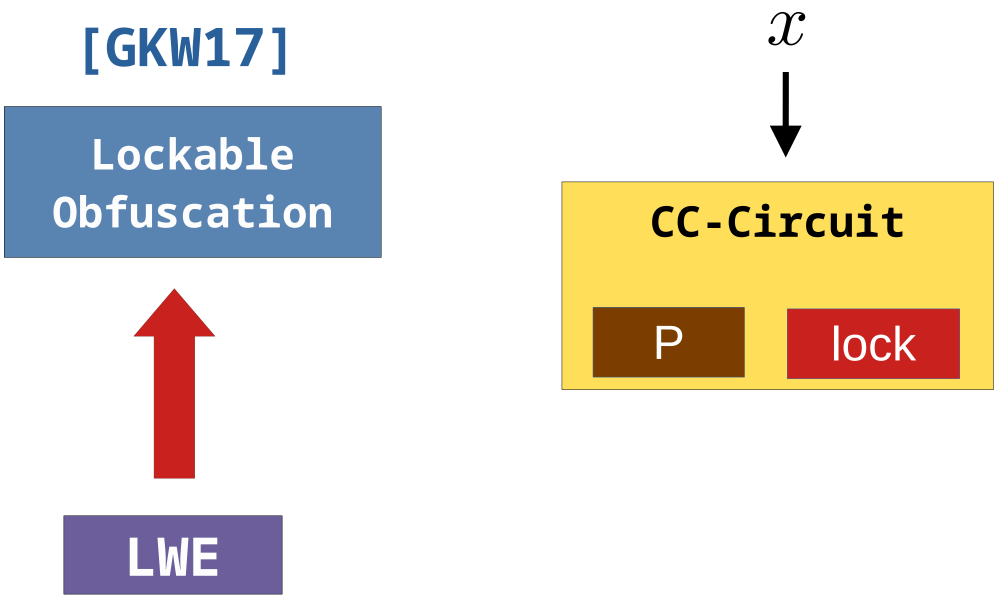
Main Idea: Part IV

Main Idea: Part IV

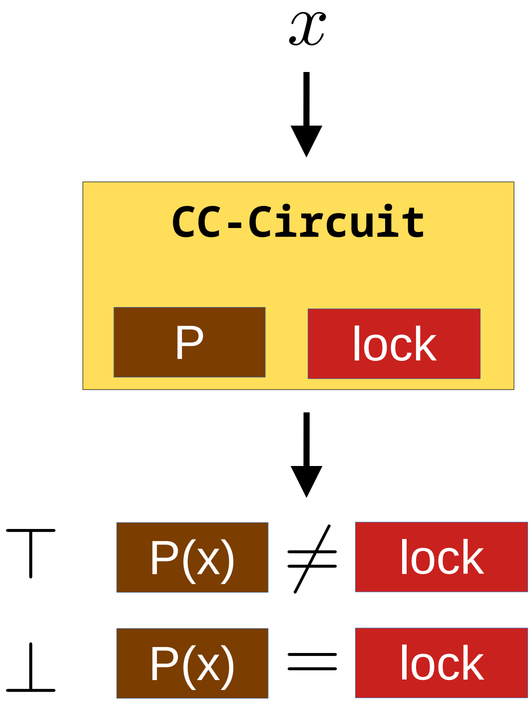
[GKW17]



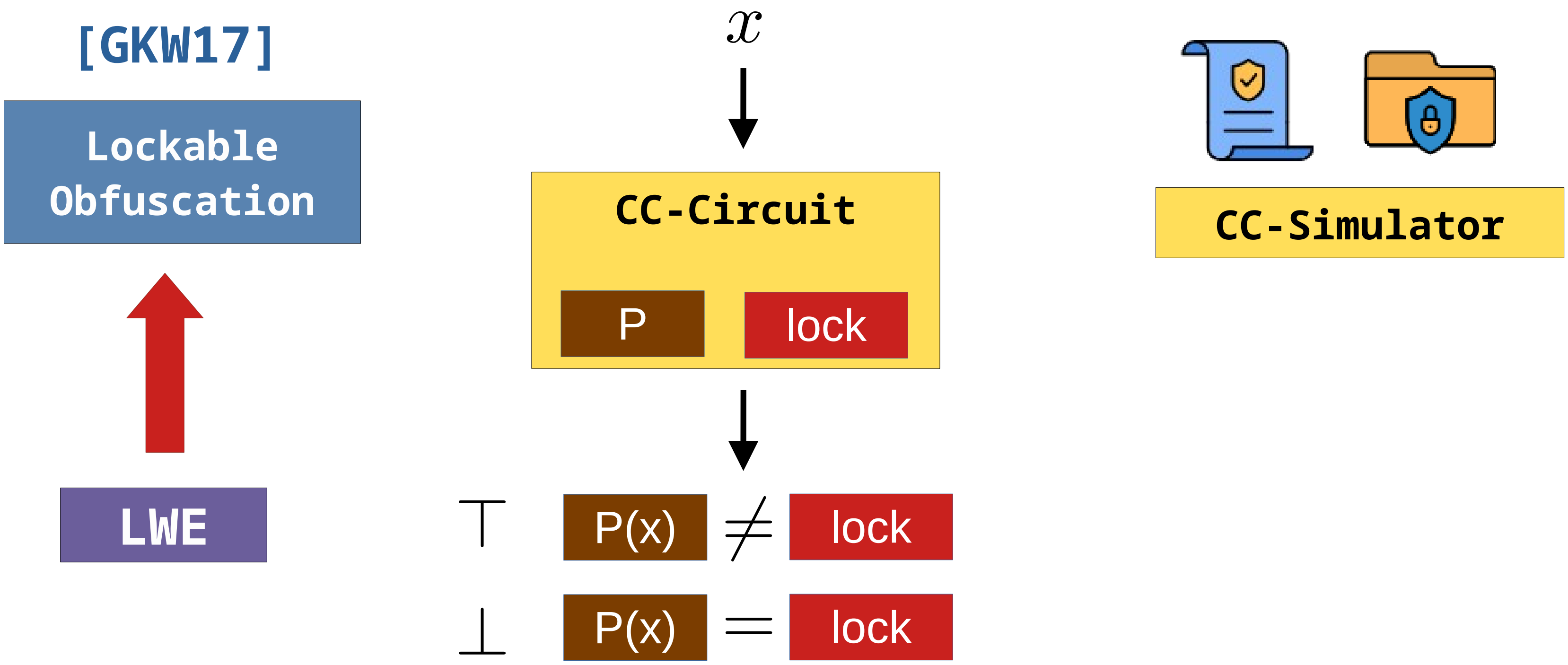
Main Idea: Part IV



Main Idea: Part IV



Main Idea: Part IV



Main Idea: Part IV

[GKW17]

Lockable Obfuscation

LWE

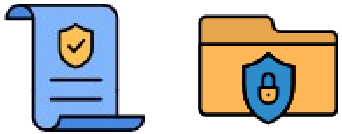
x

CC-Circuit

P lock

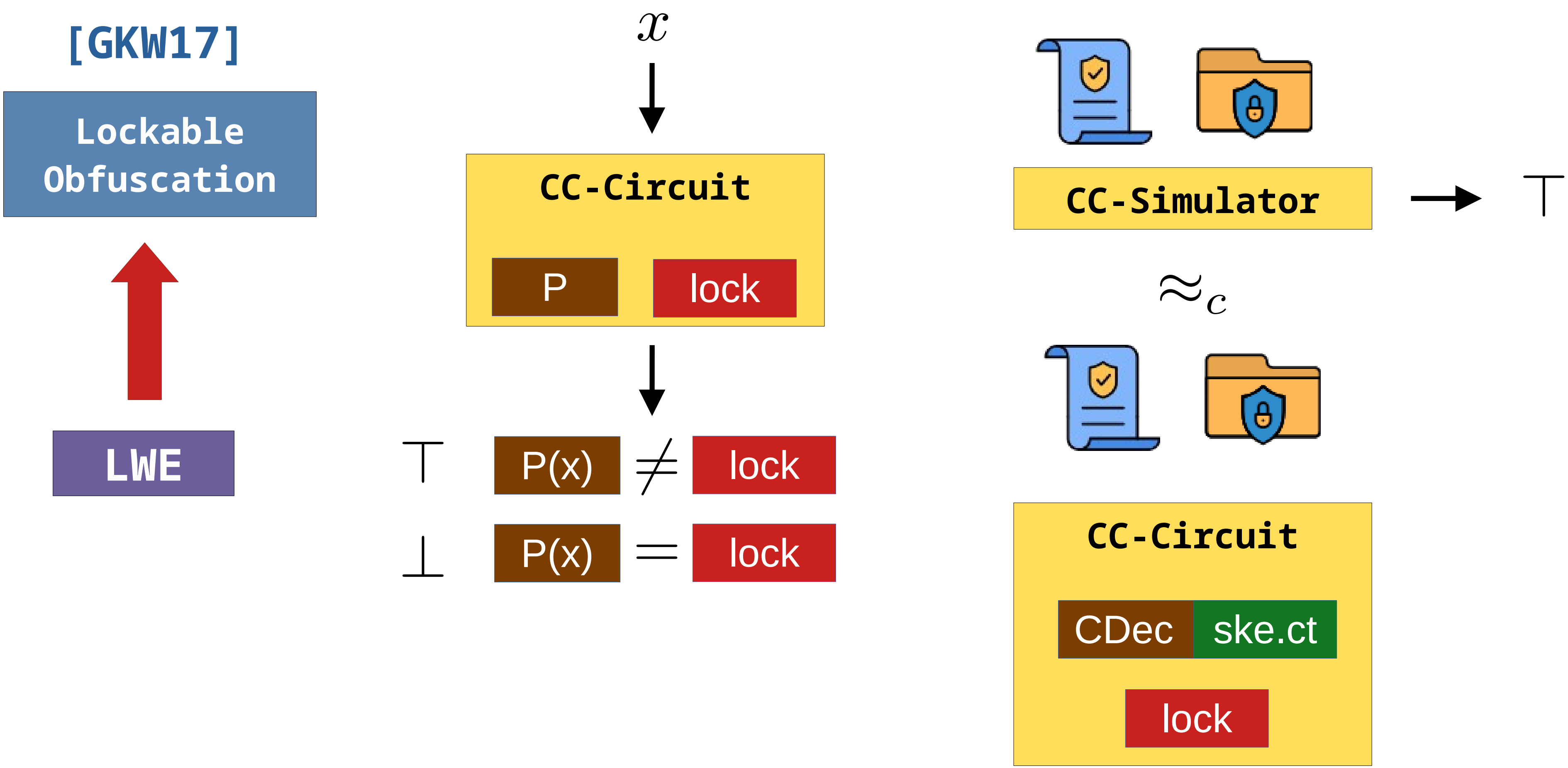
$\top$ P(x) $\neq$ lock

$\bot$ P(x) $=$ lock

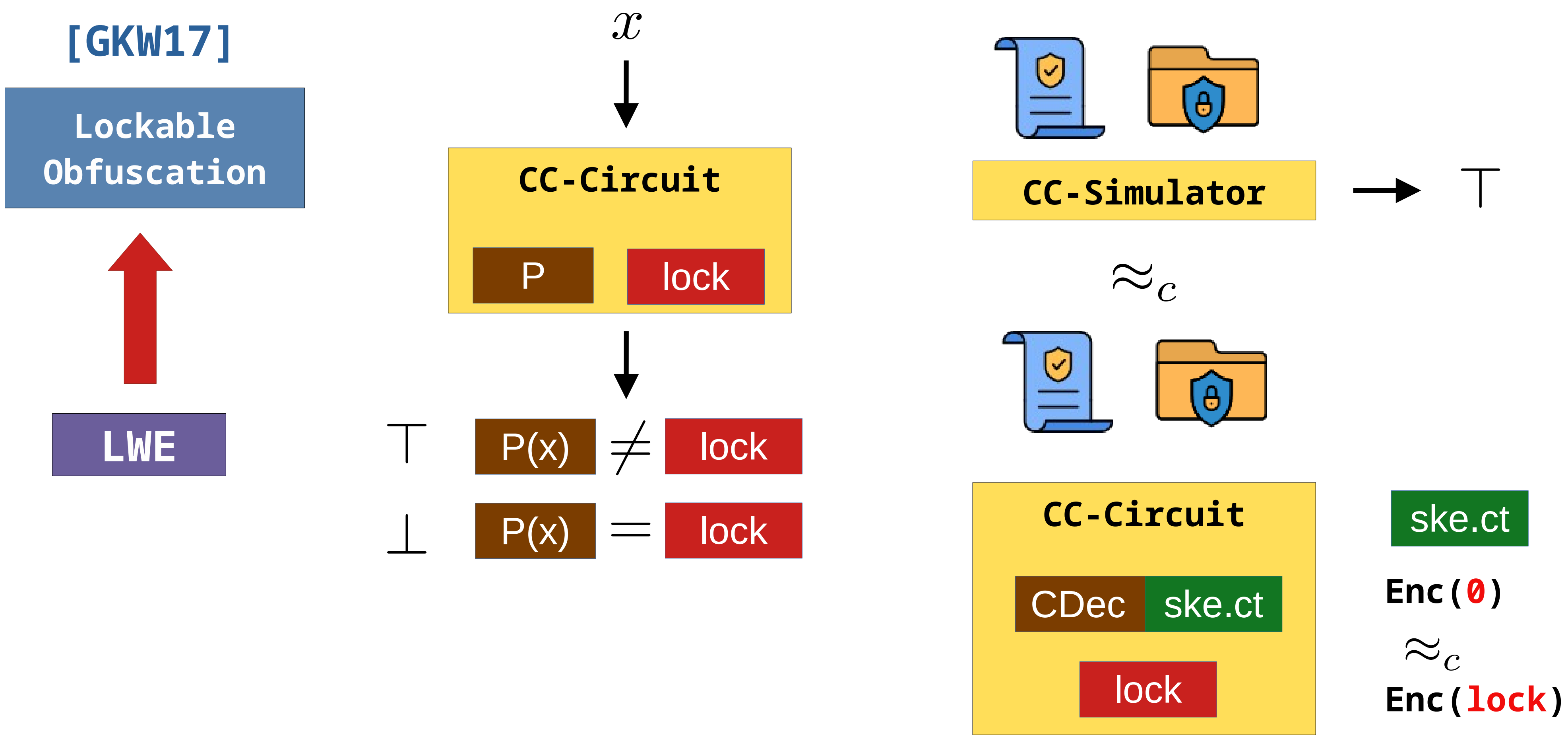


CC-Simulator $\rightarrow$ $\top$

Main Idea: Part IV



Main Idea: Part IV



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Thank You!