Revisiting (R)CCA Security and Replay Protection

Christian Badertscher, Ueli Maurer, Christopher Portmann, **Guilherme Rito**

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Introduction

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Problem However, they often do not match the exact requirements of their applications.

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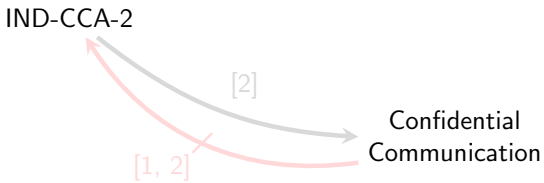

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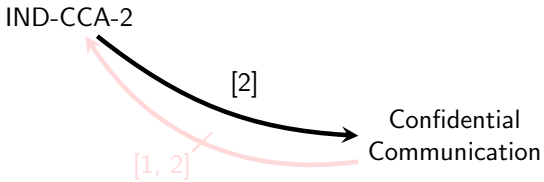

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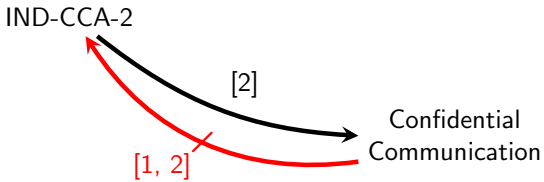

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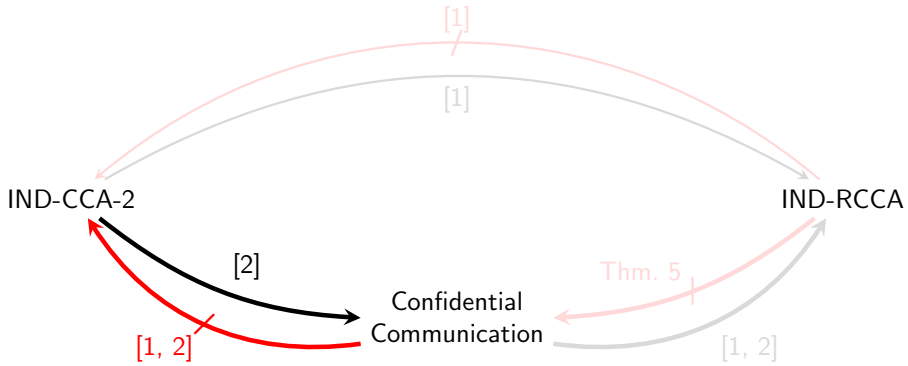

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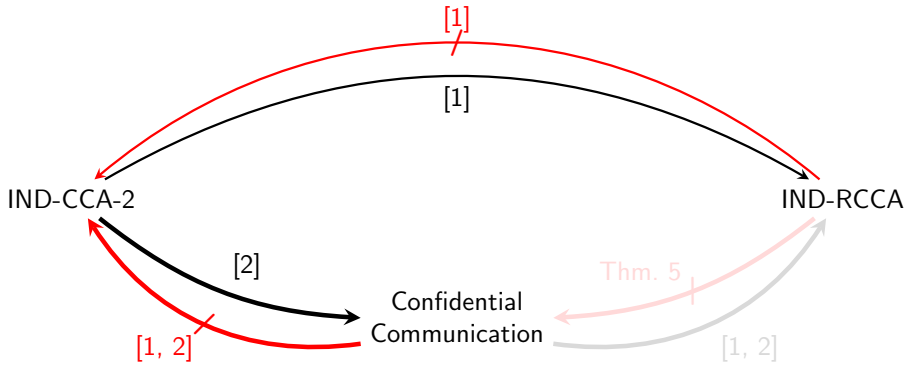

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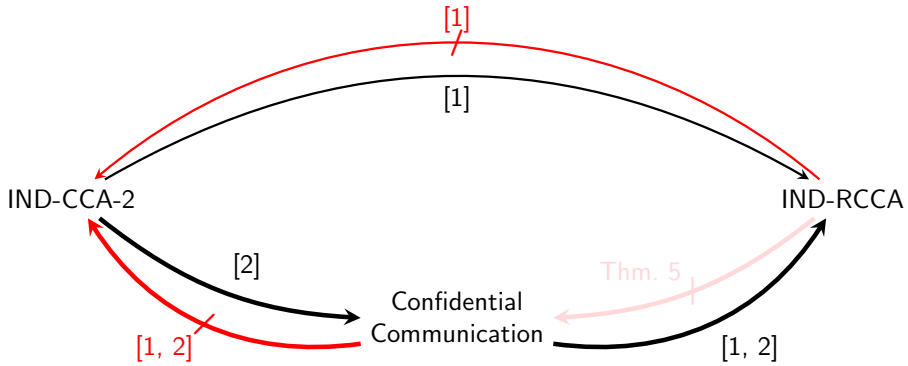

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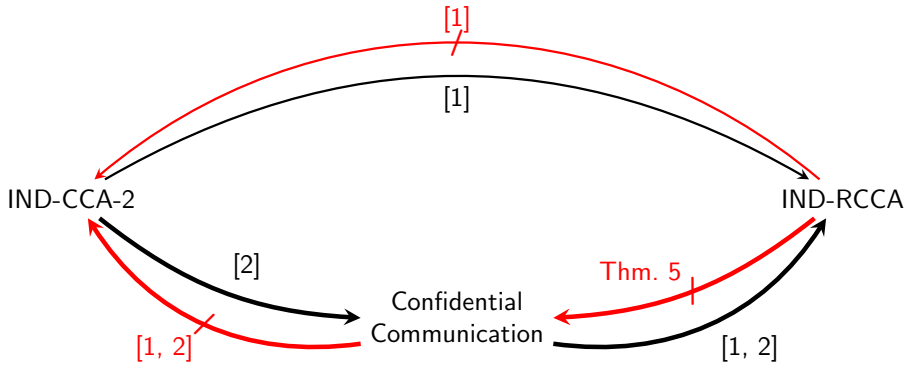

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Identify technical inconsistencies with intermediate notions (IND-pd-RCCA, IND-sd-RCCA):

- Not implied by IND-CCA-2 for probabilistic decryption
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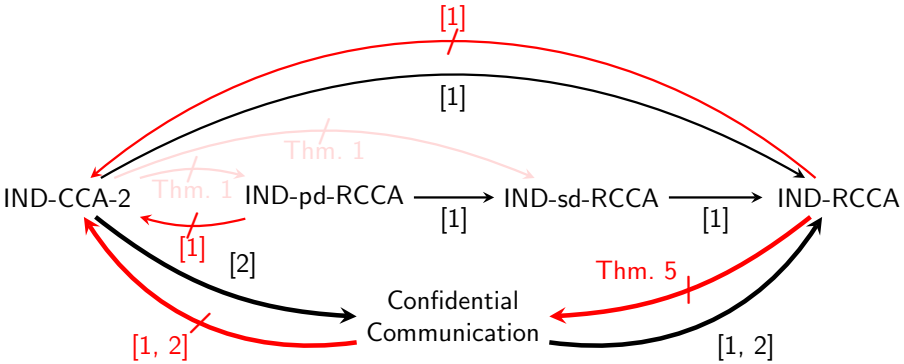

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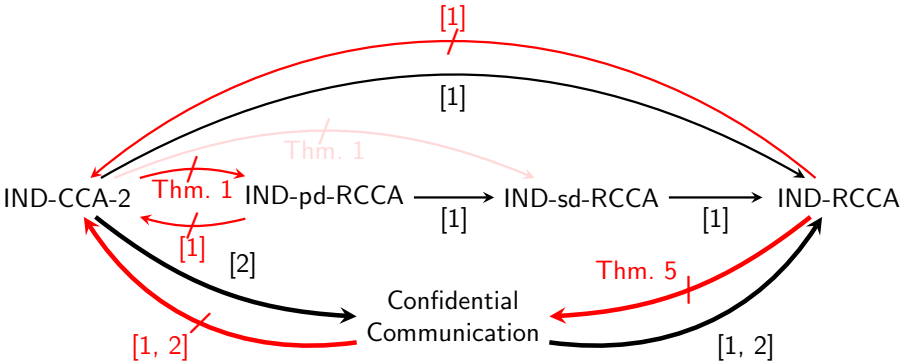

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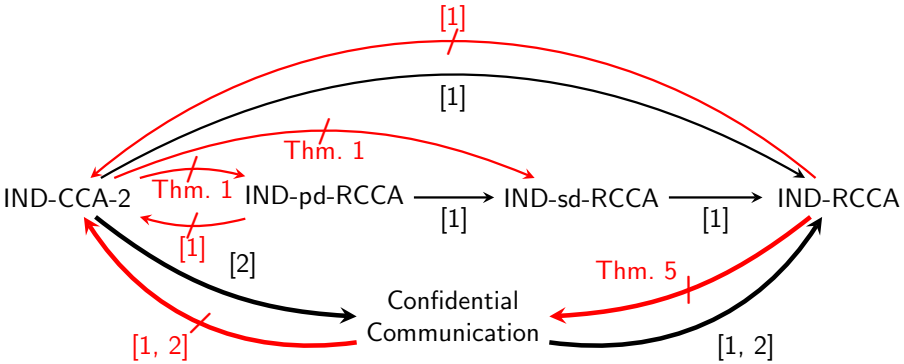

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- Systematic approach for characterizing security using a composable framework:
  - Define applications of PKE schemes as benchmarks (i.e. composable notions):
    - Benchmark 1:
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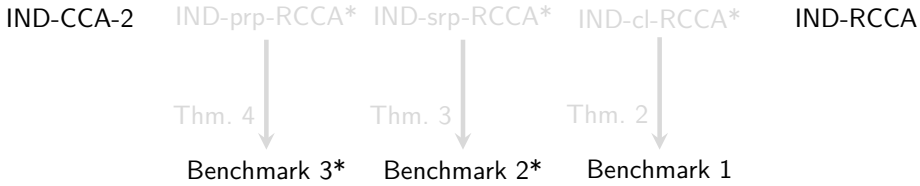

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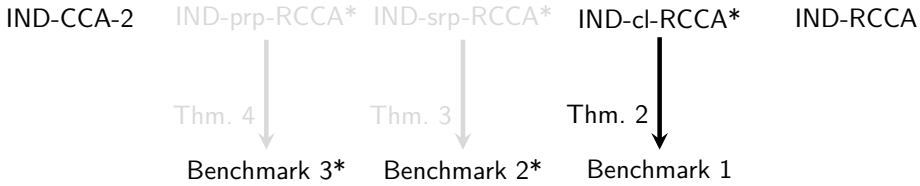

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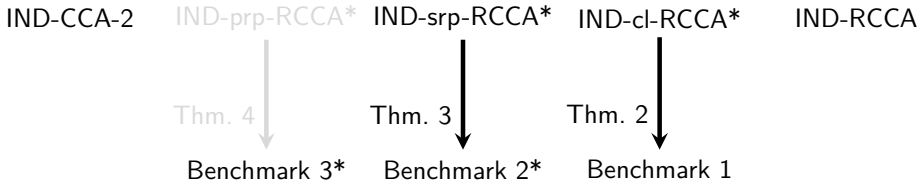

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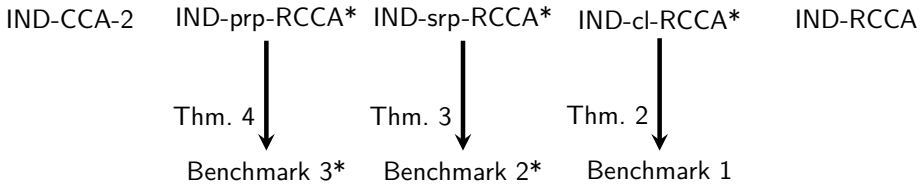

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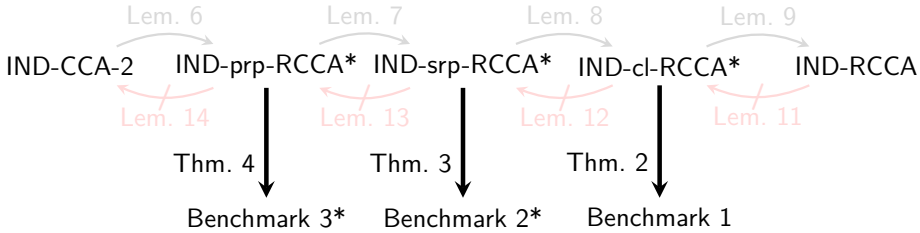

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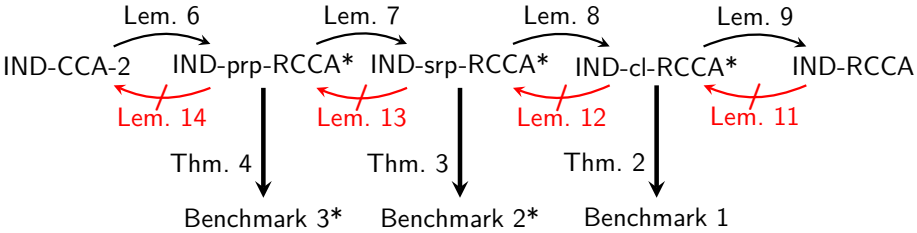

Preliminaries

Preliminaries - PKE

Definition (PKE scheme; Correctness)

A Public Key Encryption (PKE) scheme Π is a triple $\Pi = (G, E, D)$ of Probabilistic Polynomial-Time Algorithms (PPTs);

Correctness For any PPT adversary $\mathbf{A}$:

$$\Pr\left[\begin{array}{c|c} (\mathrm{pk}, \mathrm{sk}) \leftarrow G(1^k) & D_{\mathrm{sk}}(E_{\mathrm{pk}}(m)) \neq m \\ m \leftarrow \mathbf{A}(1^k, \mathrm{pk}) & \end{array}\right]$$

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PKE scheme $\Pi = (G, E, D)$ is IND-X secure if no PPT $\mathbf{D}$ distinguishes systems $\mathbf{G}_0^{\Pi\text{-IND-X}}$ and $\mathbf{G}_1^{\Pi\text{-IND-X}}$ (specified ahead) with non-negligible advantage (in the security parameter k).

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First decryption stage: On input $(\mathtt{ciphertext}, c)$, send $D_{\mathtt{sk}}(c)$ to $\mathbf{D}$.

Challenge stage: On input $(\mathtt{test\ messages}, m_0, m_1)$, send $c^* = E_{\mathtt{pk}}(m_b)$ to $\mathbf{D}$.

Second decryption stage: On input $(\mathtt{ciphertext}, c)$, send $\mathbf{D}$:

$$\text{reply} = \begin{cases} \mathtt{test}, & \text{if } P_X(\mathtt{pk}, \mathtt{sk}, (m_0, m_1), b, c^*, c) = 1 \\ m = D_{\mathtt{sk}}(c), & \text{otherwise,} \end{cases}$$

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where P_X is a predicate defined by X.

Preliminaries - PKE

Definition (Generic Game-Based Security Notion X)

For $b \in \{0,1\}$, $\mathbf{G}_b^{\Pi\text{-IND-X}}$ is as follows:

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Examples of P_X predicates:

IND-CCA-2: $P_{\text{CCA-2}}(\cdot, \cdot, \cdot, \cdot, c^*, c) := (c^* = c)$;

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Preliminaries

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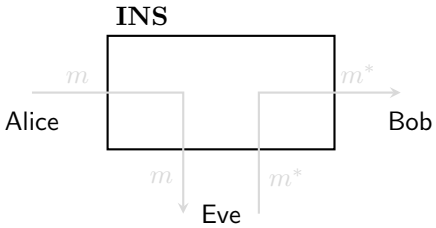

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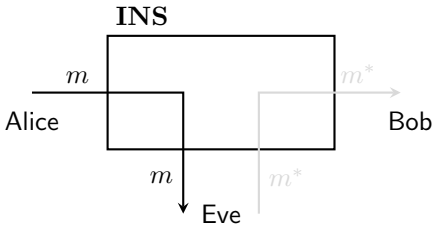

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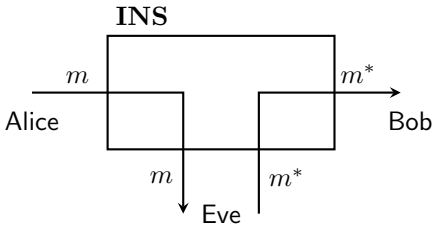

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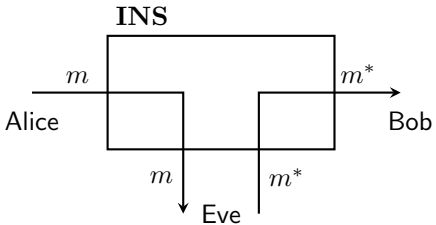

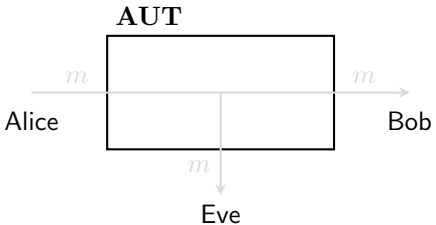

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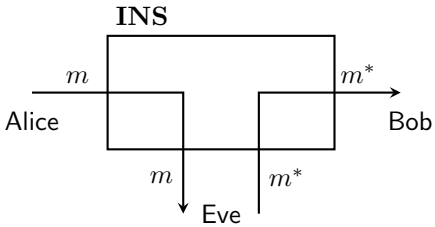

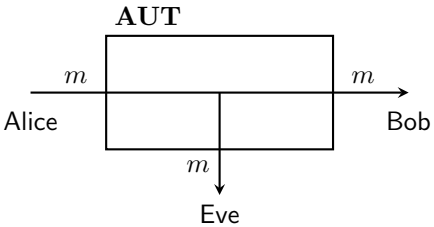

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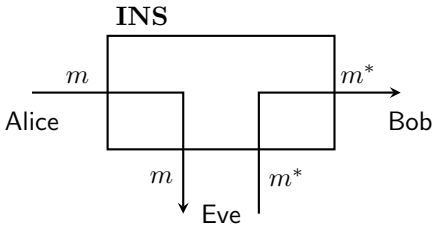

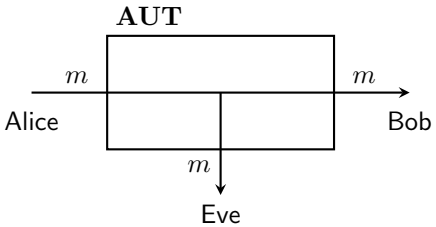

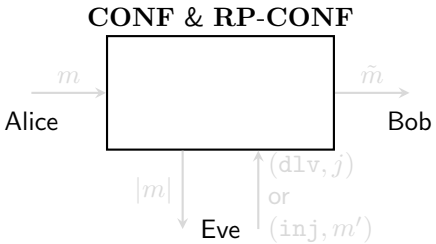

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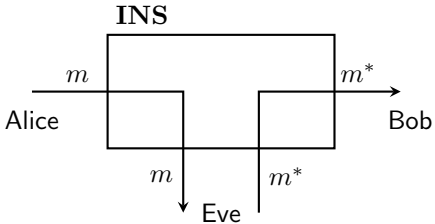

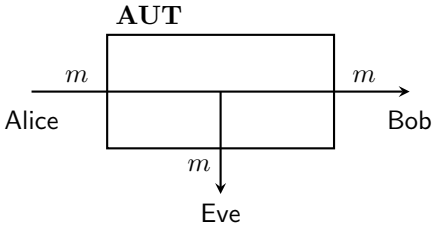

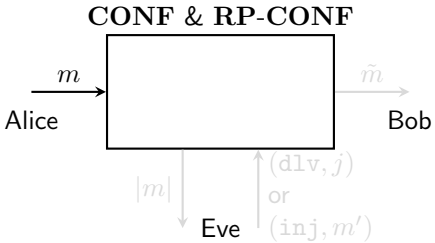

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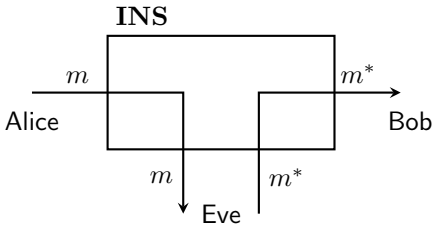

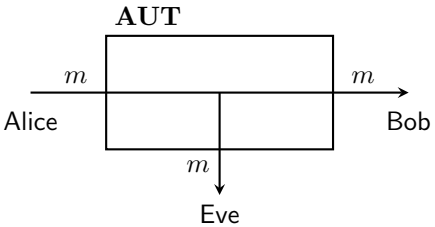

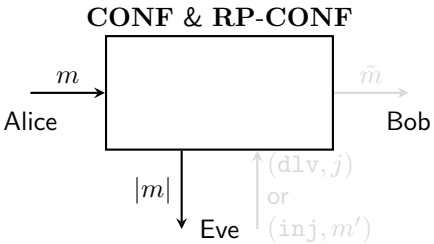

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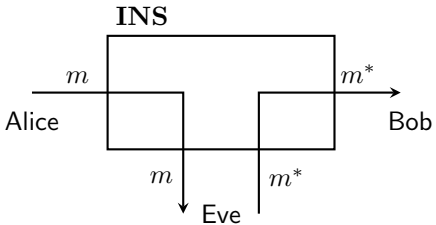

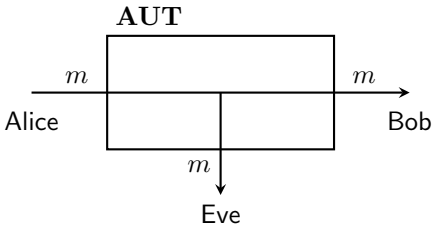

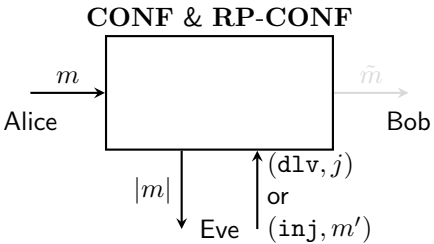

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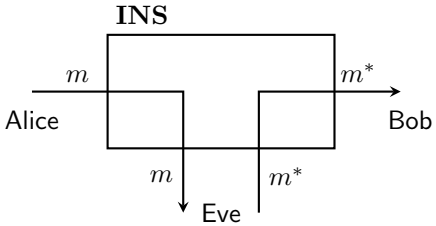

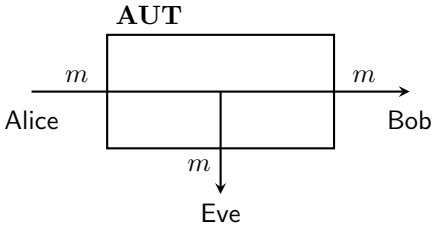

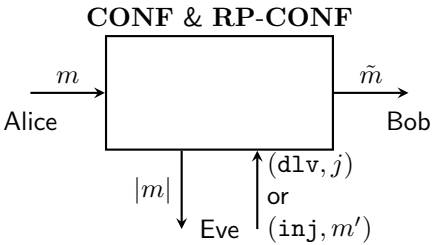

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- **CONF** channels allow for replays:
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Figure: Real and ideal systems for construction of confidential channel.

Benchmark 1 achieved if real and ideal worlds are indistinguishable.

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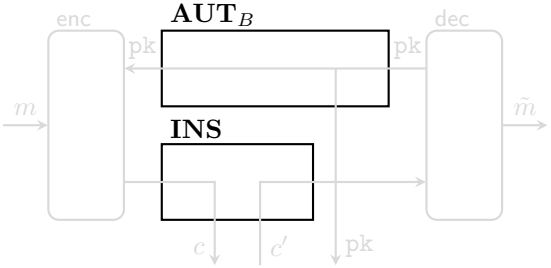

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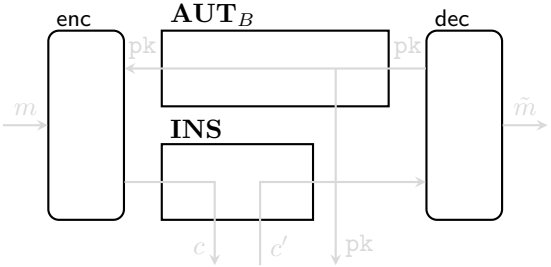

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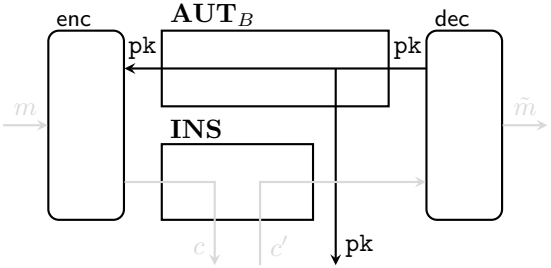

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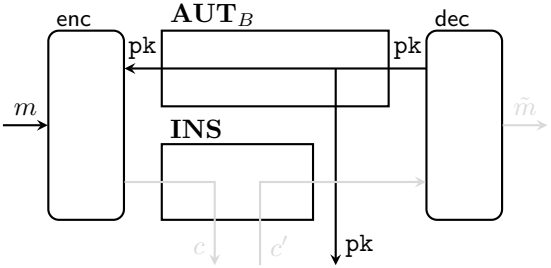

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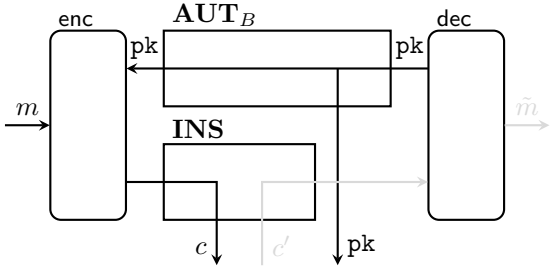

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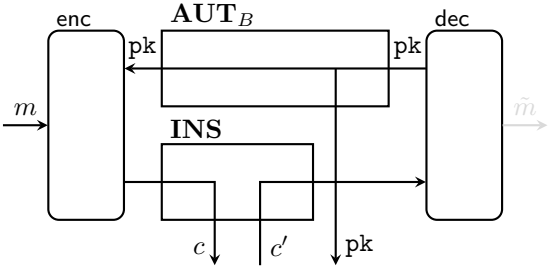

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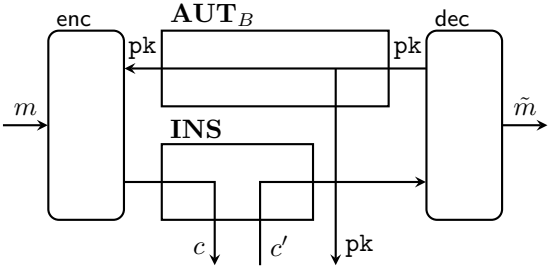

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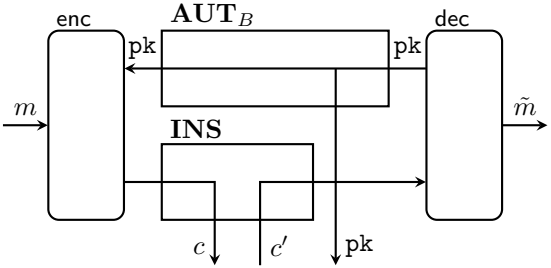

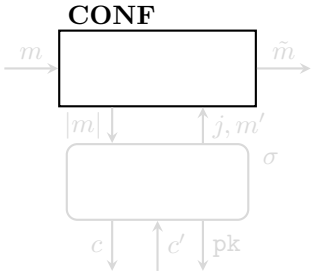

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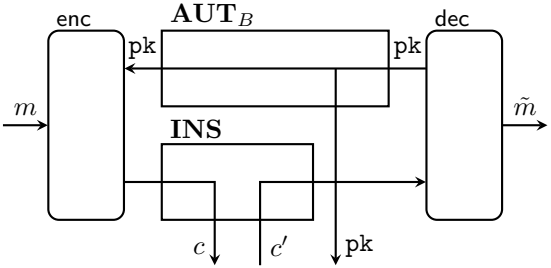

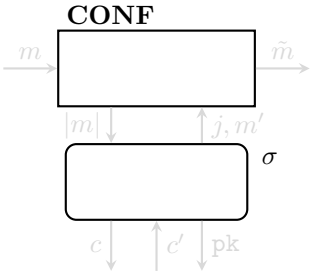

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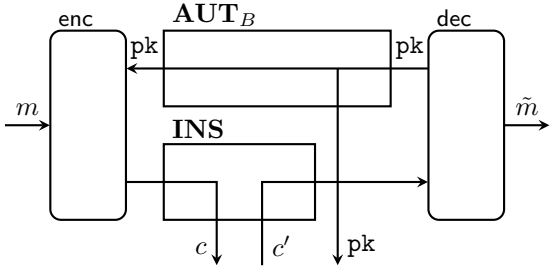

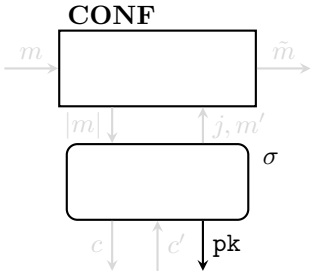

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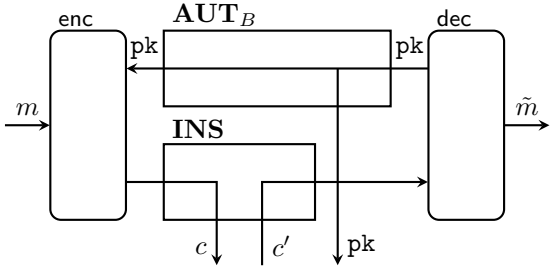

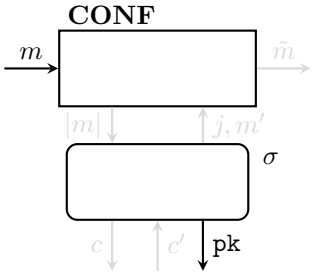

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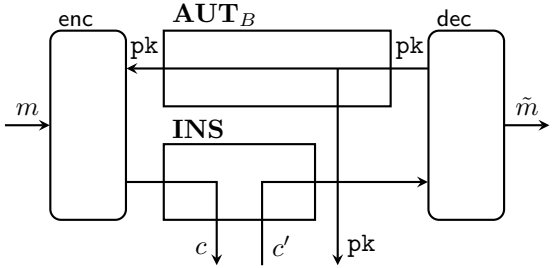

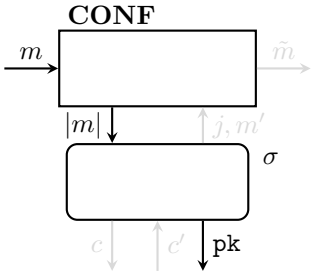

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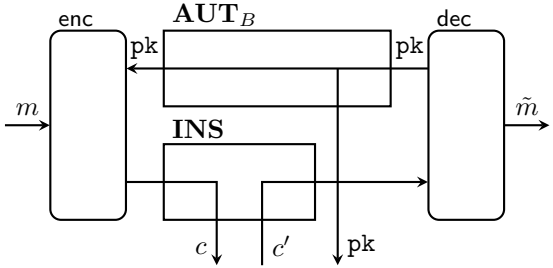

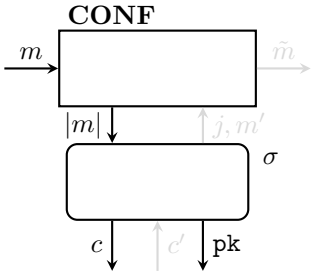

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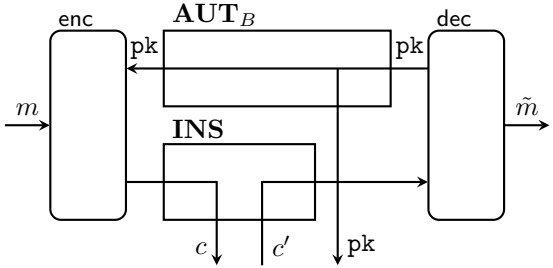

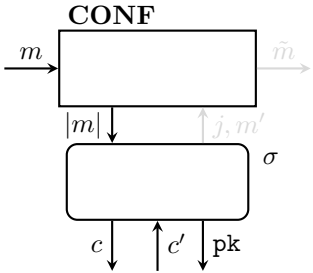

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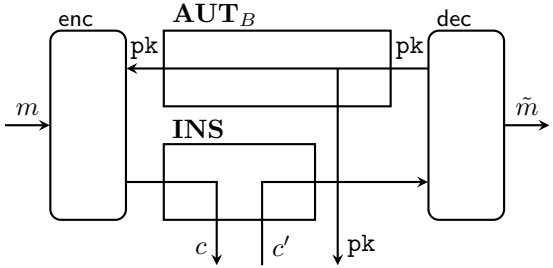

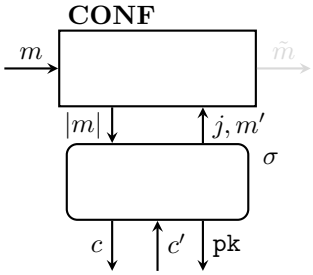

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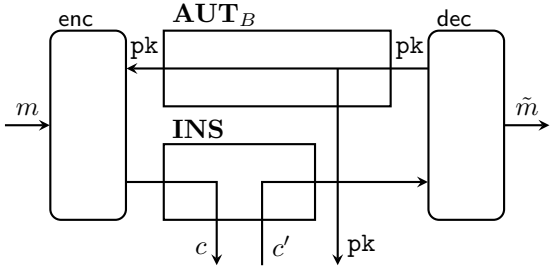

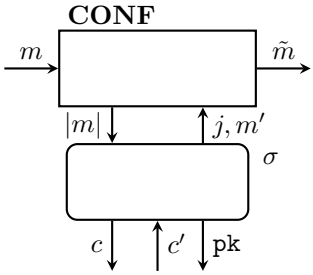

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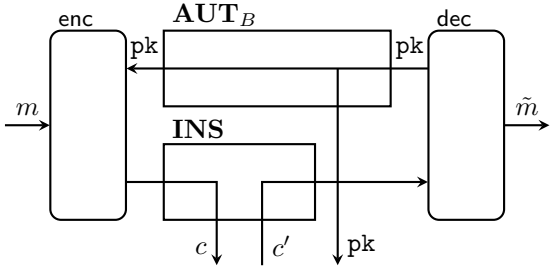

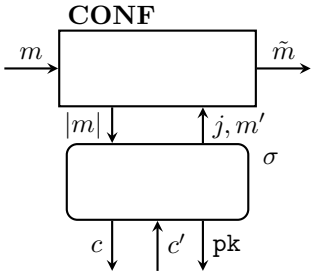

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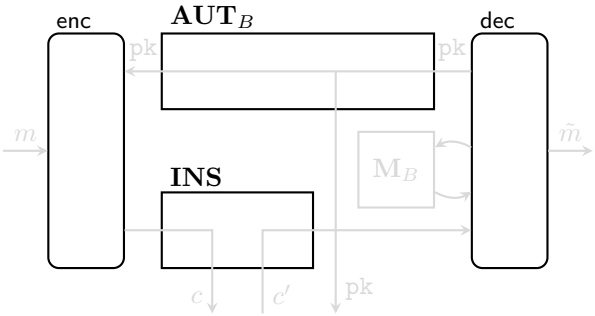

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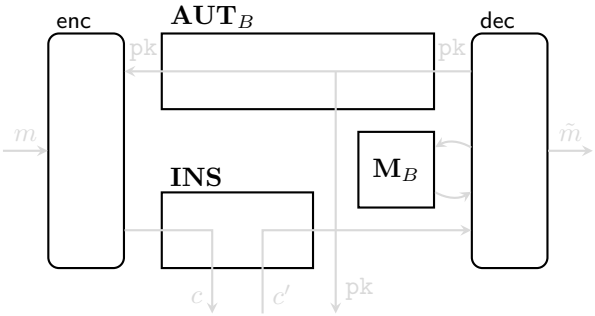

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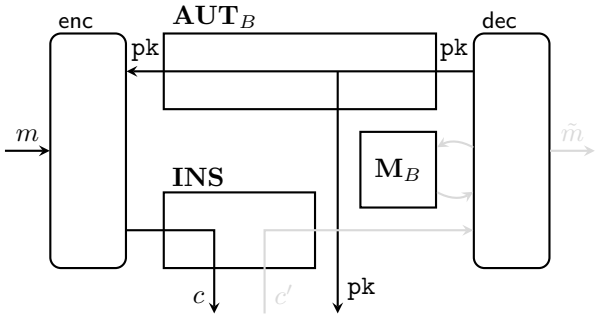

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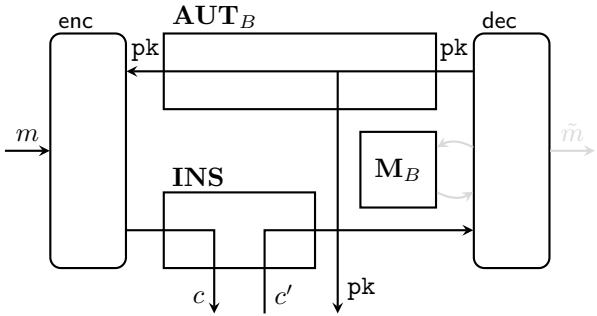

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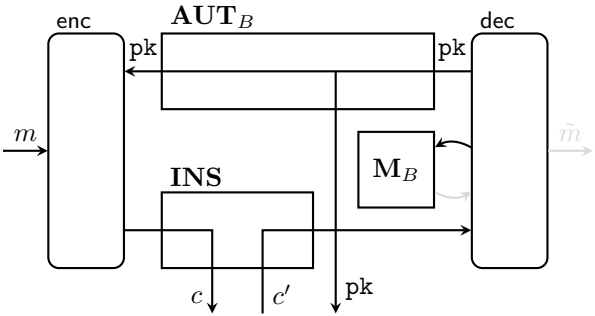

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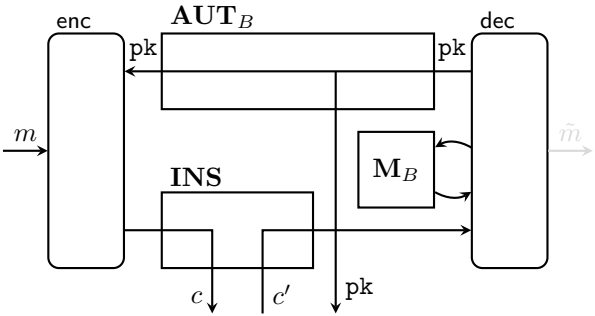

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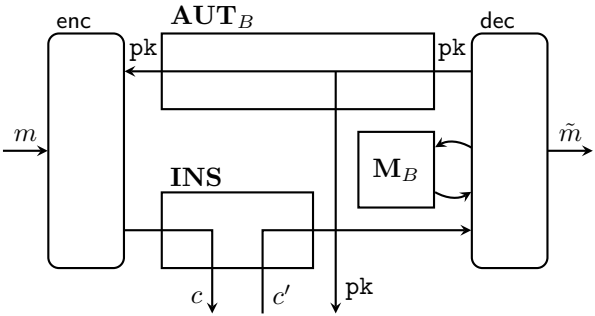

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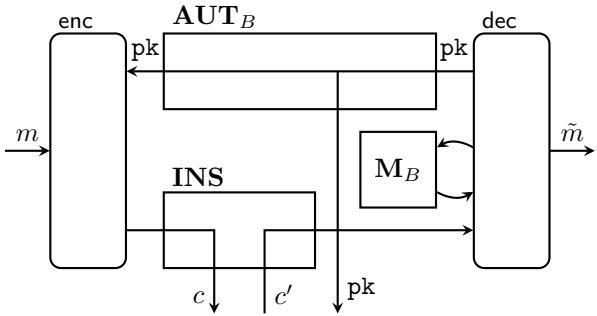

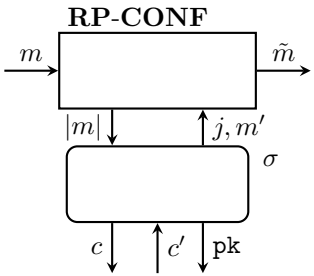

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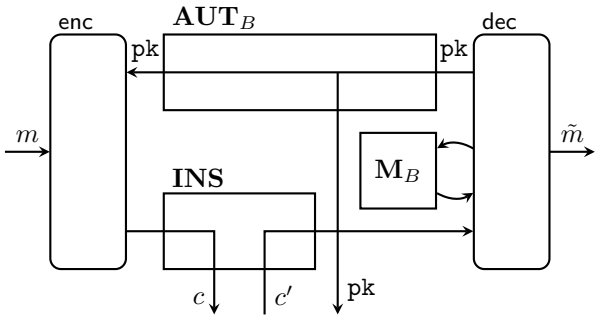

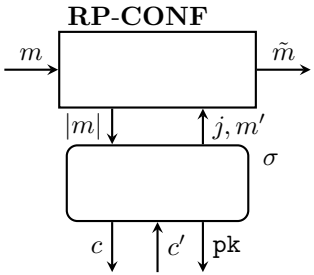

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Recall: $P_{\mathsf{RCCA}}(\cdot, \mathtt{sk}, (m_0, m_1), \cdot, \cdot, c) := (D_{\mathtt{sk}}(c) \in \{m_0, m_1\})$.

- $\mathbf{CONF}$ channel requires non-malleability
- Eve can only
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- Malleable PKE scheme can be RCCA secure:
  - Binary message space $\Longrightarrow$ second decryption stage queries are "useless";
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Achieving Benchmark 1

Achieving Benchmark 1: IND-cl-RCCA

PKE scheme $\Pi = (G, E, D)$ is IND-cl-RCCA secure if **there is an efficiently computable predicate** $v(\mathtt{pk}, \mathtt{sk}, c^*, c)$ such that no PPT $\mathbf{D}$ distinguishes systems $\mathbf{G}_0^{\Pi\text{-IND-cl-RCCA}}$ and $\mathbf{G}_1^{\Pi\text{-IND-cl-RCCA}}$ with non-negligible advantage.

$$P_{\text{IND-cl-RCCA}}(\mathtt{pk}, \mathtt{sk}, (m_0, m_1), b, c^*, c) = \begin{cases} 1, & v(\mathtt{pk}, \mathtt{sk}, c^*, c) = 1 \ \wedge m_b = D_{\mathtt{sk}}(c) \\ 0, & \text{otherwise.} \end{cases}$$

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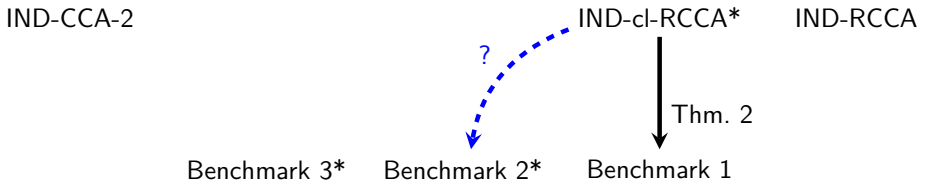
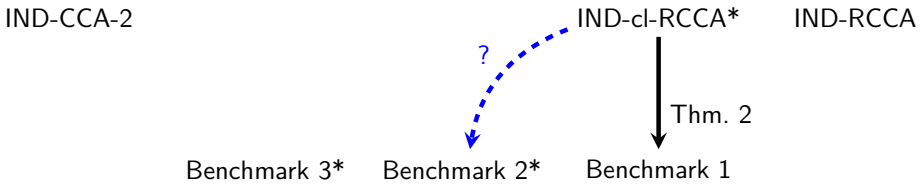


Does IND-cl-RCCA capture replay-protection?

Achieving Benchmark 2



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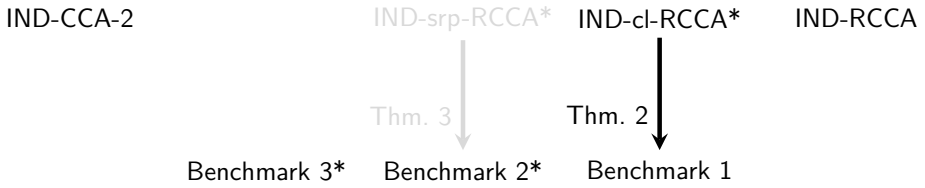

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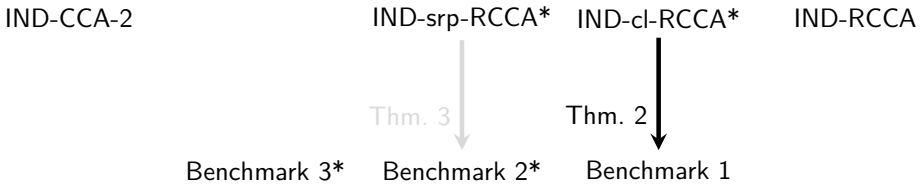

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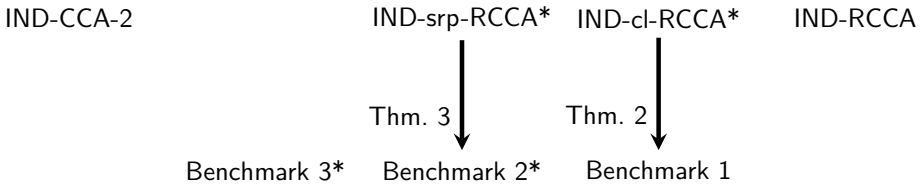

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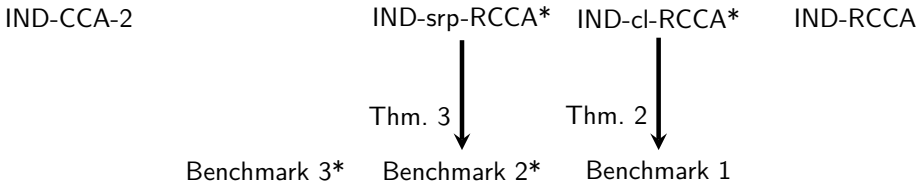

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Achieving Benchmark 3

Achieving Benchmark 3: IND-prp-RCCA

IND-prp-RCCA defined similarly to IND-srp-RCCA.

Main difference: predicate v is not given the secret key.

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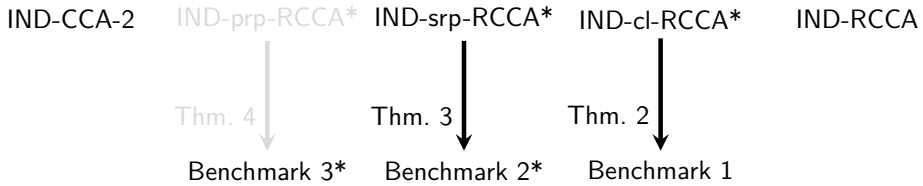

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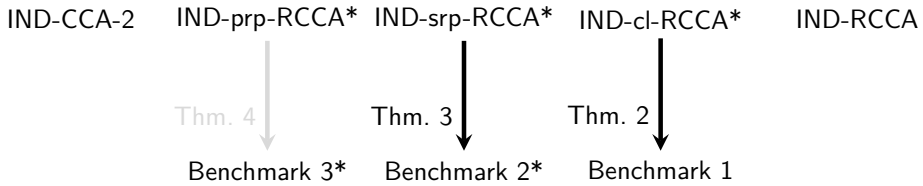

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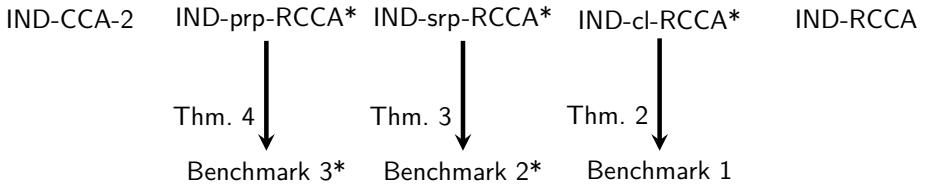

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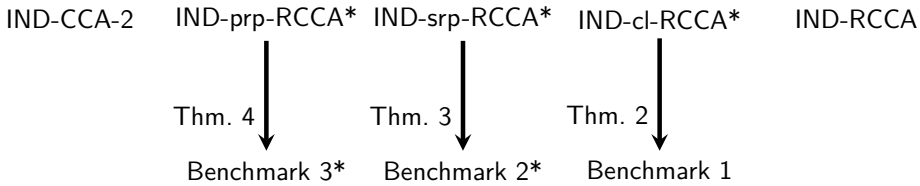
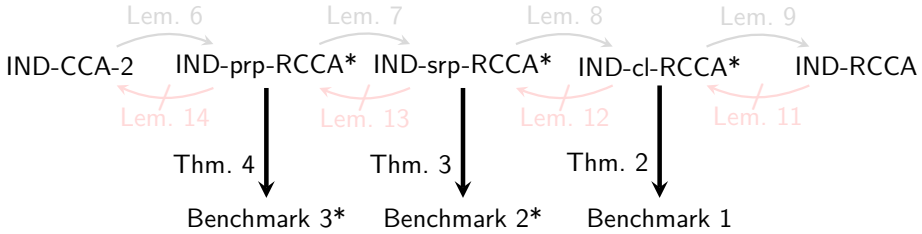
Achieving Benchmark 3: IND-prp-RCCA



Predicate v is used by rp for replay detection.

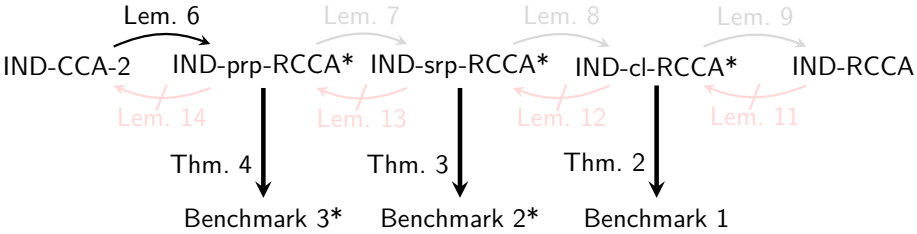
Relations Between Notions

Figure: Relations between security notions. Security notions introduced in this paper are marked with *.



Relations Between Notions

Figure: Relations between security notions. Security notions introduced in this paper are marked with *.



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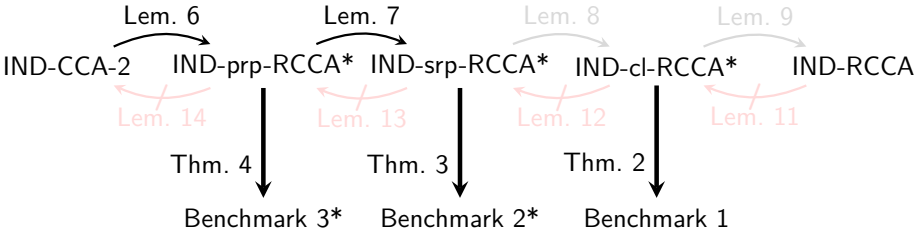

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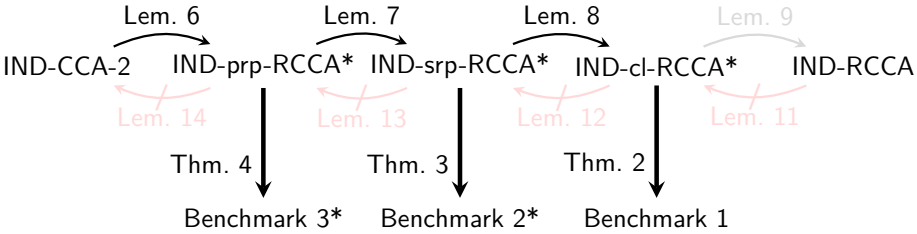

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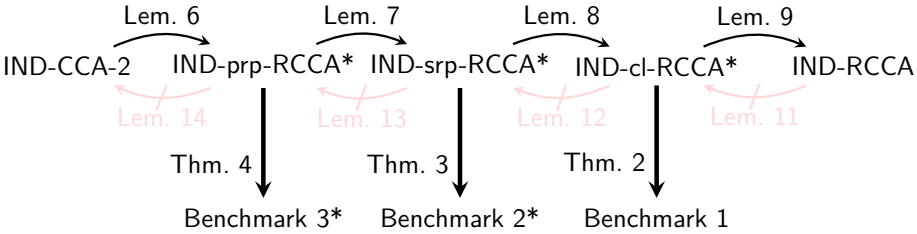

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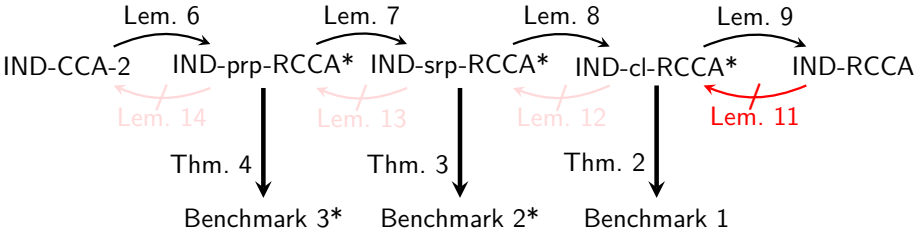

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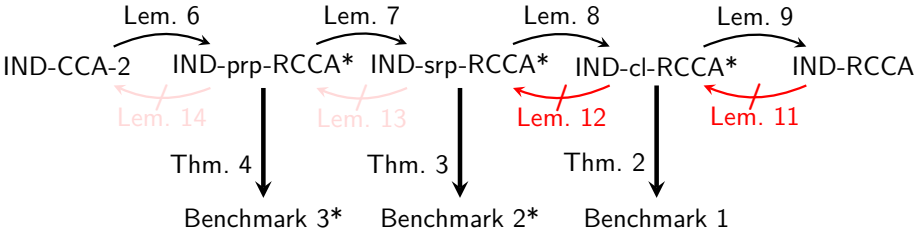

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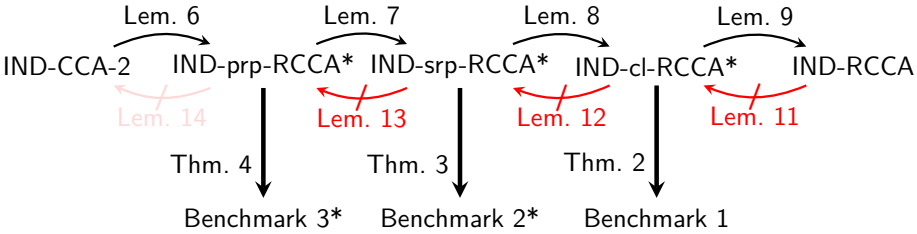

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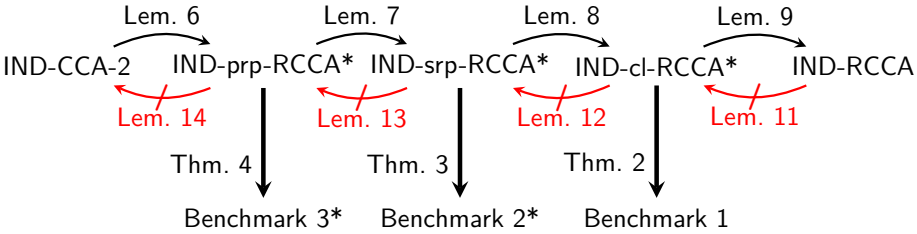

Thank You!

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