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On the Selective Opening Security of Practical Public-Key Encryption Schemes

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Selective-Opening Attacks

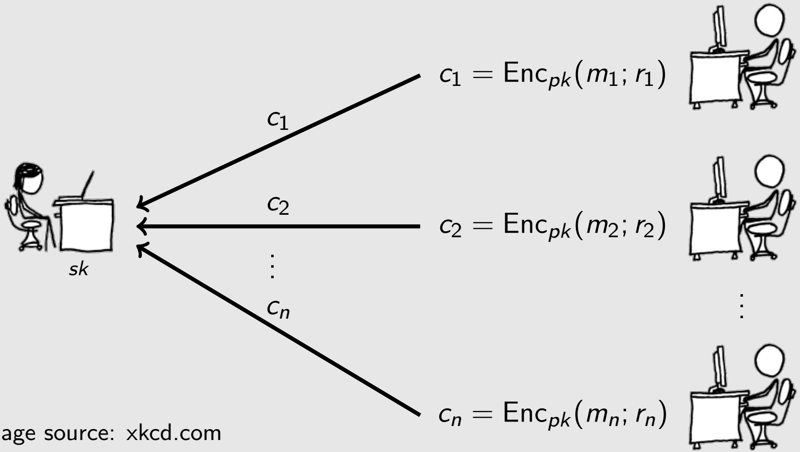

Image source: xkcd.com

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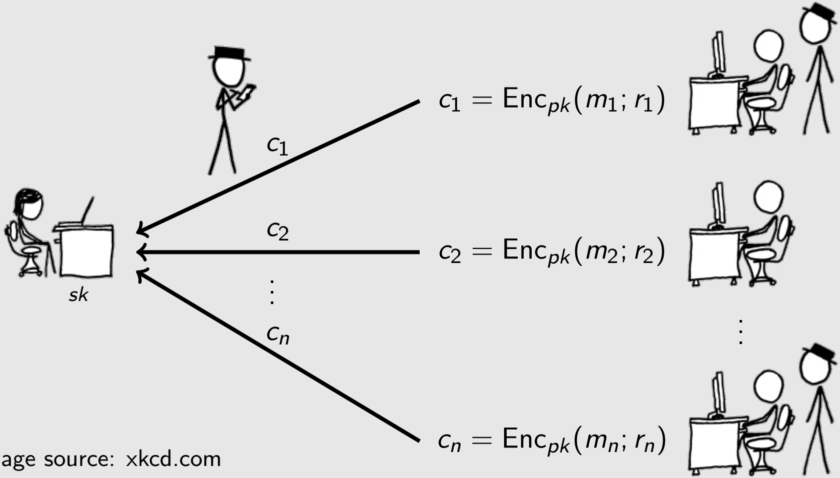

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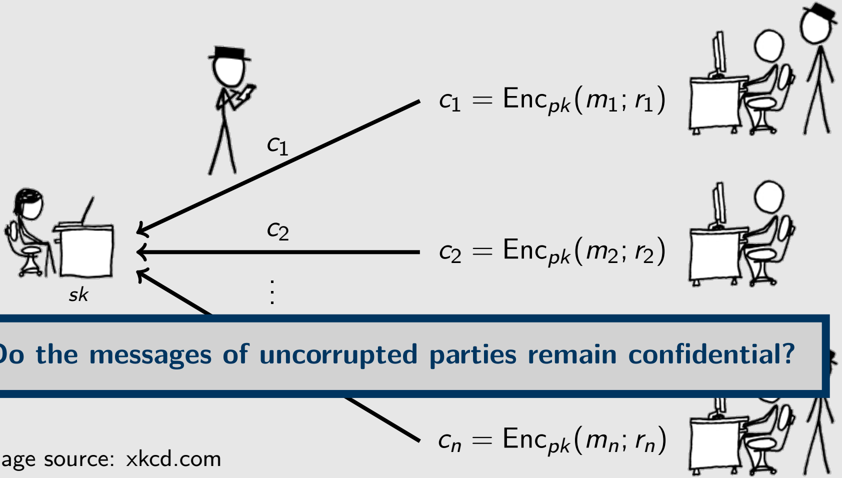

Do the messages of uncorrupted parties remain confidential?

Image source: xkcd.com

SIM-SO-CCA Security Definition [FHKW10]

real game

$\mathcal{A}$

$(pk, sk) \leftarrow \mathrm{Gen}(1^\kappa)$

pk →

$(m_1, \dots, m_n) \leftarrow \mathfrak{D}$

← $\mathfrak{D}$

choose distribution $\mathfrak{D}$

$(r_1, \dots, r_n) \overset{\$}{\leftarrow} \mathit{Coins}$

$c_i := \mathrm{Enc}_{pk}(m_i; r_i)$

$(c_1, \dots, c_n)$ →

← $\mathit{Open}(i)$

$\mathcal{I} := \mathcal{I} \cup \{i\}$

(m_i, r_i) →

← $\mathit{out}_{\mathcal{A}}$

compute output "$\mathit{out}_{\mathcal{A}}$"

Output:
$(m_1, \dots, m_n, \mathfrak{D}, \mathcal{I}, \mathit{out}_{\mathcal{A}})$

Dec oracle

← $c \notin \{c_1, \dots, c_n\}$

$\mathit{Dec}_{sk}(c)$ →

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$\mathcal{I} := \mathcal{I} \cup \{i\}$ — $\longleftarrow \mathit{Open}(i)$

(m_i, r_i) $\longrightarrow$

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<u>*Output*</u>:

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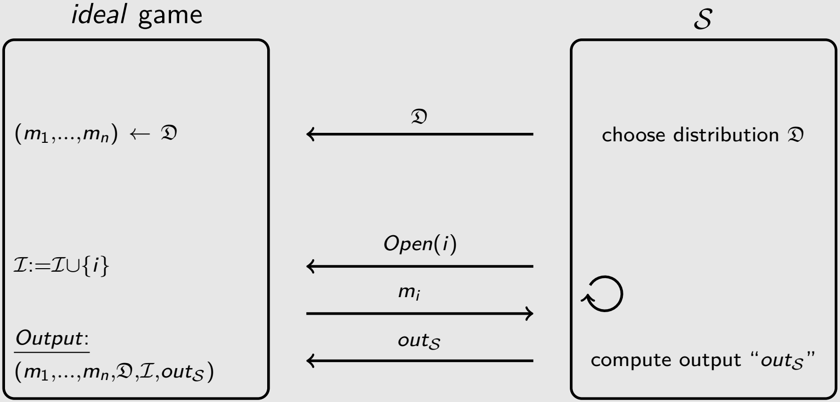

SIM-SO-CCA Security Definition [FHKW10]

Definition 1 (SIM-SO-CCA security)

A public key encryption scheme is SIM-SO-CCA secure if for every PPT adversary $\mathcal{A}$ there exists a PPT simulator $\mathcal{S} := \mathcal{S}(\mathcal{A})$ such that the distributions induced by

$\mathcal{A}$ run in the *real* game and $\mathcal{S}$ run in the *ideal* game

are computationally indistinguishable.

Selective Opening vs. Standard Security Notions

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  SIM implies IND, not known to be equivalent.

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- Existing SIM-SO-CCA schemes are very inefficient. [FHKW10], [Hof12], [LP15]

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- IND-SO-CCA stronger security notion than IND-CCA security. [HR14]
- Existing SIM-SO-CCA schemes are very inefficient. [FHKW10], [Hof12], [LP15]
- **This work:** Certain known constructions give SIM-SO-CCA security for free in the ROM.

Our Work

Part I:

PKE from any one-way PCA secure KEM

Part II:

PKE from OAEP for any partial-domain TP

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“Hashed KEM/DEM Approach”

Let $\mathsf{KEM} = (\mathsf{KGen}, \mathsf{Encap}, \mathsf{Decap})$ be a Key Encapsulation Mechanism, $\mathsf{MAC} = (\mathsf{Tag}, \mathsf{Vrfy})$ a Message Authentication Code and H a hash function. Consider the following PKE:

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$k \leftarrow \text{Decap}_{sk}(c^{(1)})$
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if $\text{Vrfy}_{k^{mac}}(c^{(2)}, c^{(3)}) = 1$
    Return $c^{(2)} \oplus k^{sym}$
else
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"Hashed KEM/DEM Approach"

Theorem 2 (SBZ02)

The given transformation achieves IND-CCA security in the ROM if KEM *is OW-PCA secure and* MAC *is sUF-OT-CMA.*

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- Use RSA KEM under RSA assumption
- Use DH KEM under strong DH assumption

Instantiation of DHIES

"Hashed KEM/DEM Approach"

Theorem 3 (This work)

The same transformation gives rise to a SIM-SO-CCA secure PKE in the ROM without additional assumptions.

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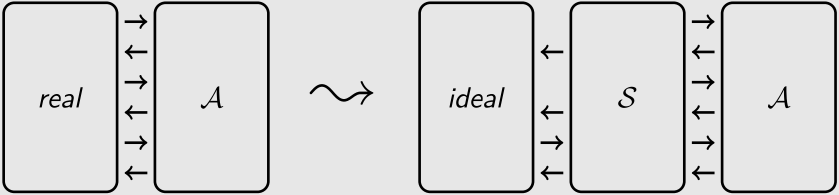
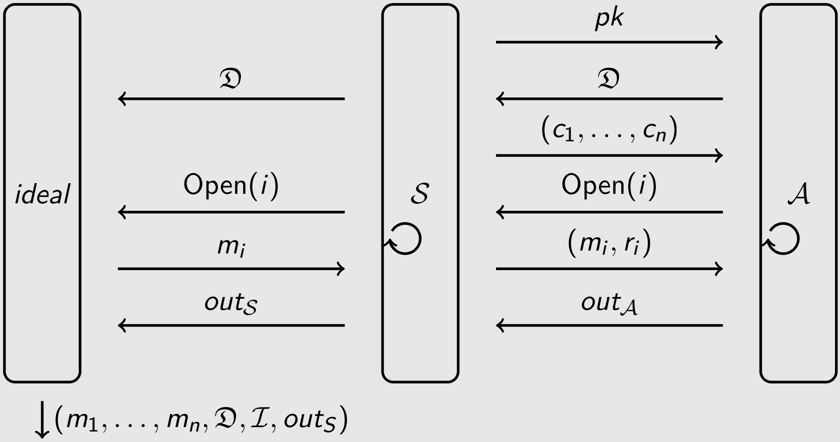
How to Prove SIM-SO-CCA Security



How to Construct a Simulator



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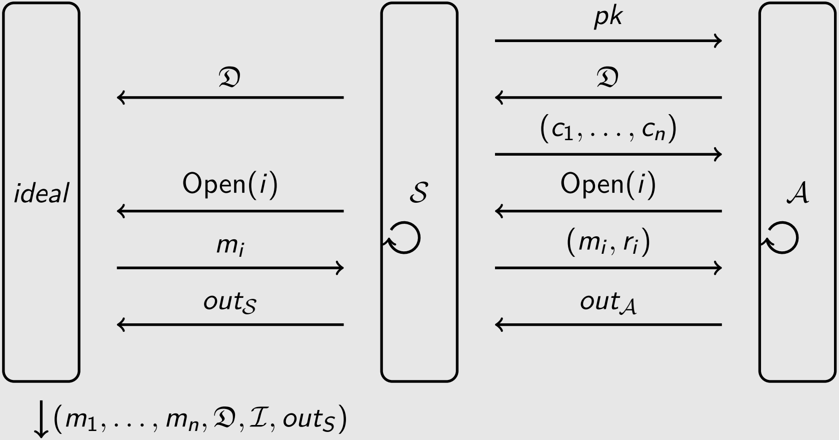

$\mathcal{A}$ is allowed to make additional **Hash** or **Dec** queries at any time!

Possible Tripping Hazards for a Simulator

- $\mathcal{S}$ must not make more opening queries than $\mathcal{A}$ to learn m_i.

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- $\mathcal{S}$ must not make more opening queries than $\mathcal{A}$ to learn m_i.
- $\mathcal{S}$ has to create non-committing "dummy"-encryptions that allow for later opening to any message.
- Answering Hash or Decryption queries is easy if $\mathcal{A}$ called Open(i) earlier.
- However, $\mathcal{S}$ has to answer Hash and Decryption queries without committing to m_i if $\mathcal{A}$ did not call Open(i) (yet).

Tweaking $\mathcal{A}$ in a Sequence of Games

G_0: *real* SIM-SO-CCA game.

$\underline{\mathsf{Enc}_{pk}(m_i)}$

$r_i \xleftarrow{\$} Coins$

$(k_i, c_i^{(1)}) \leftarrow \mathsf{Encap}_{pk}(r_i)$

$(k_i^{sym}, k_i^{mac}) \leftarrow H(k_i)$

$c_i^{(2)} := m_i \oplus k_i^{sym}$

$c_i^{(3)} := \mathsf{Tag}_{k_i^{mac}}(c_i^{(2)})$

Return $(c_i^{(1)}, c_i^{(2)}, c_i^{(3)})$

G_0

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G_0: *real* SIM-SO-CCA game.

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$$G_0 \approx_s G_1$$

statistical argument

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Assume $\mathcal{A}$ makes a valid $\mathrm{Dec}(c_i^{(1)}, \cdot, \cdot)$ query:

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Assume $\mathcal{A}$ makes a valid $\mathrm{Dec}(c_i^{(1)}, \cdot, \cdot)$ query:

Case 1:
$H(k_i)$ is not defined $\rightsquigarrow$ k_i^{mac} still uniform, use MAC security

Case 2:
$H(k_i)$ is defined

G_3

G_0

st...
ar...

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<u>Case 2:</u>
$H(k_i)$ is defined $\rightsquigarrow$ $\mathcal{A}$ decapsulated $c_i^{(1)}$, use KEM security

G_3

G_4

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$$G_0 \approx_s G_1 = G_2 \approx_c G_3$$

statistical argument ($G_0 \approx_s G_1$)

MAC security ($G_2 \approx_c G_3$)

Tweaking $\mathcal{A}$ in a Sequence of Games

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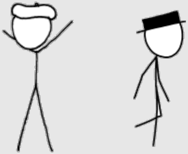

Image source: xkcd.com

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Thank you!

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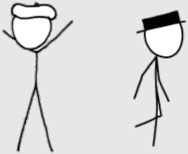

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