Compact Selective Opening Security From LWE

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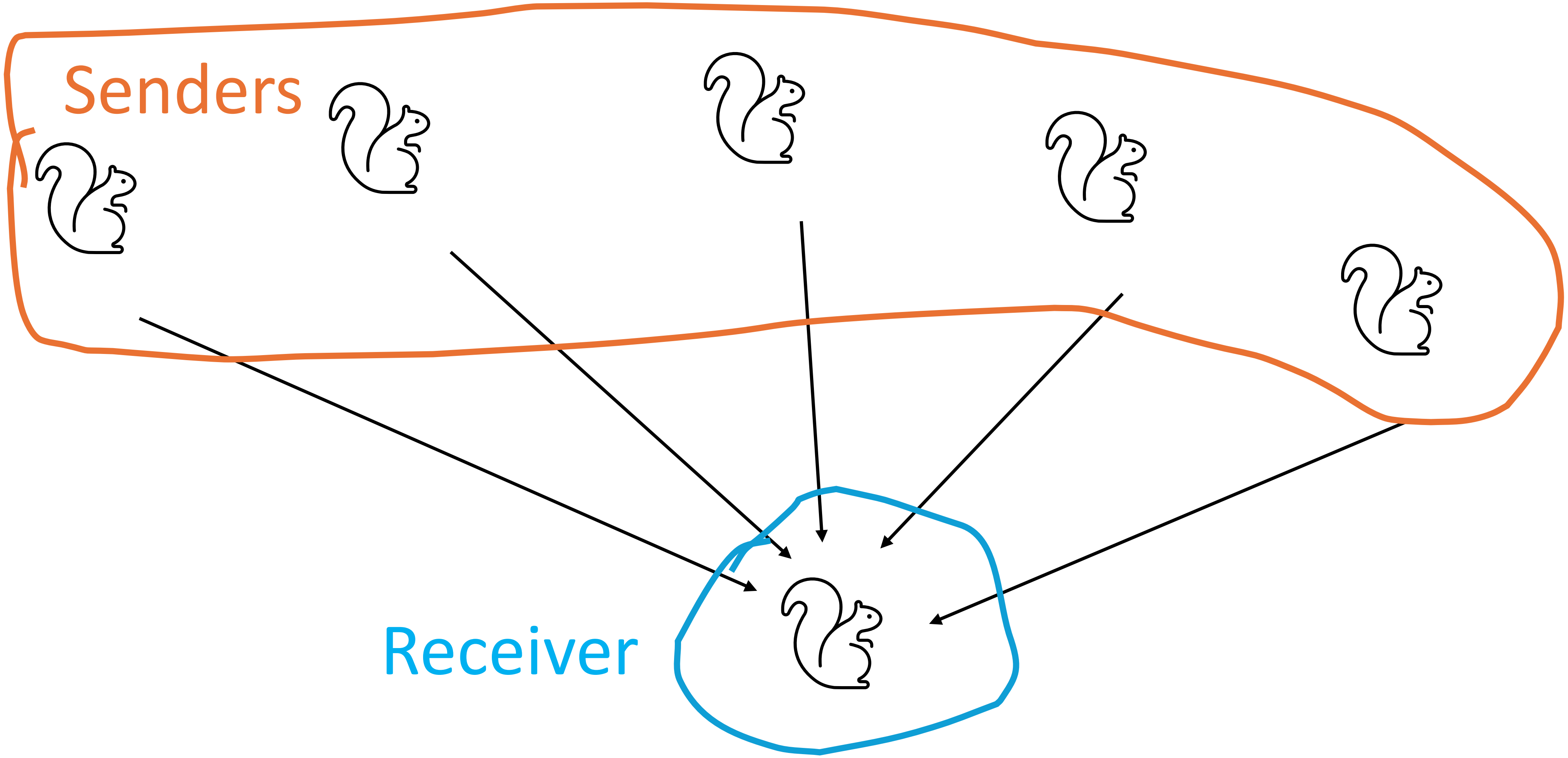
IND-Selective Opening-CPA Security [BHY09]



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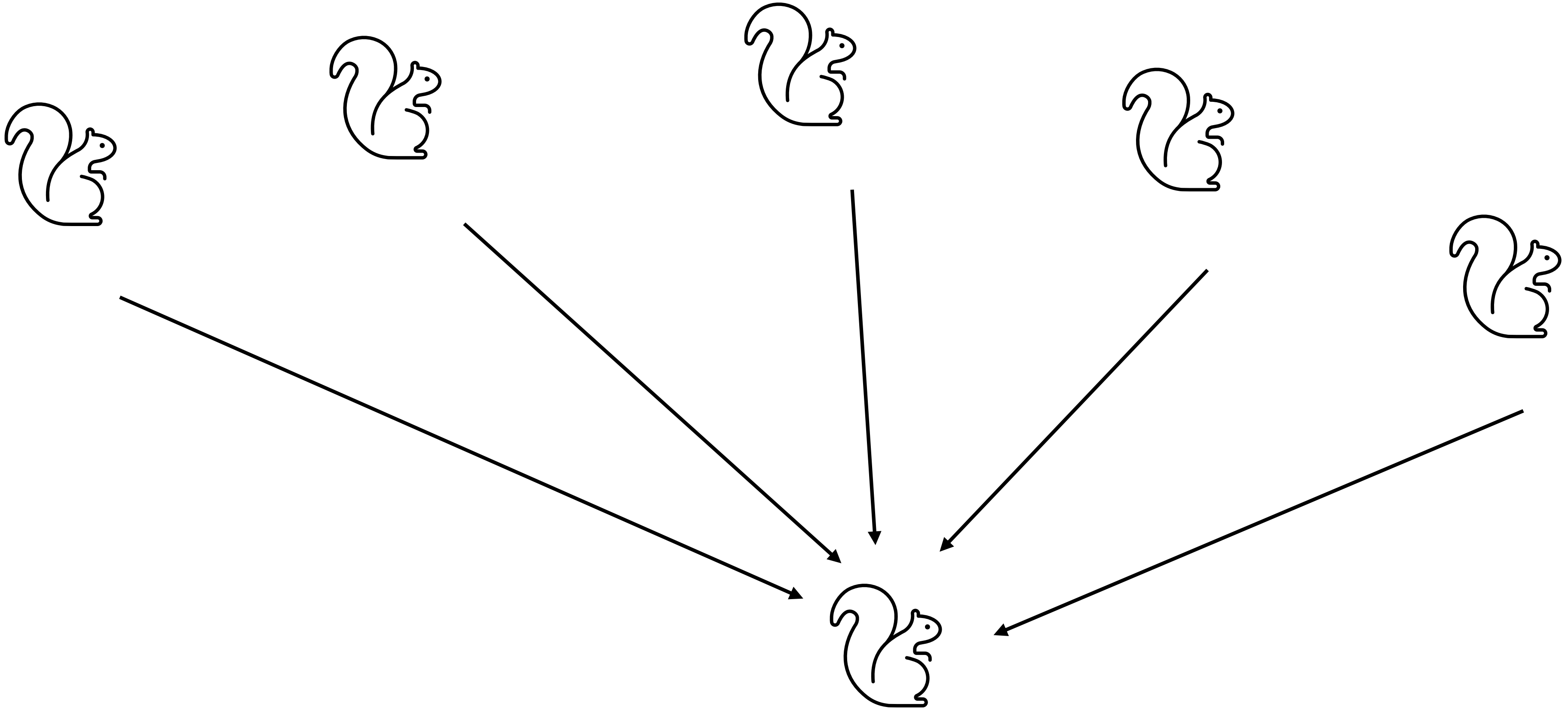

$pk, sk \leftarrow Setup(1^\lambda)$

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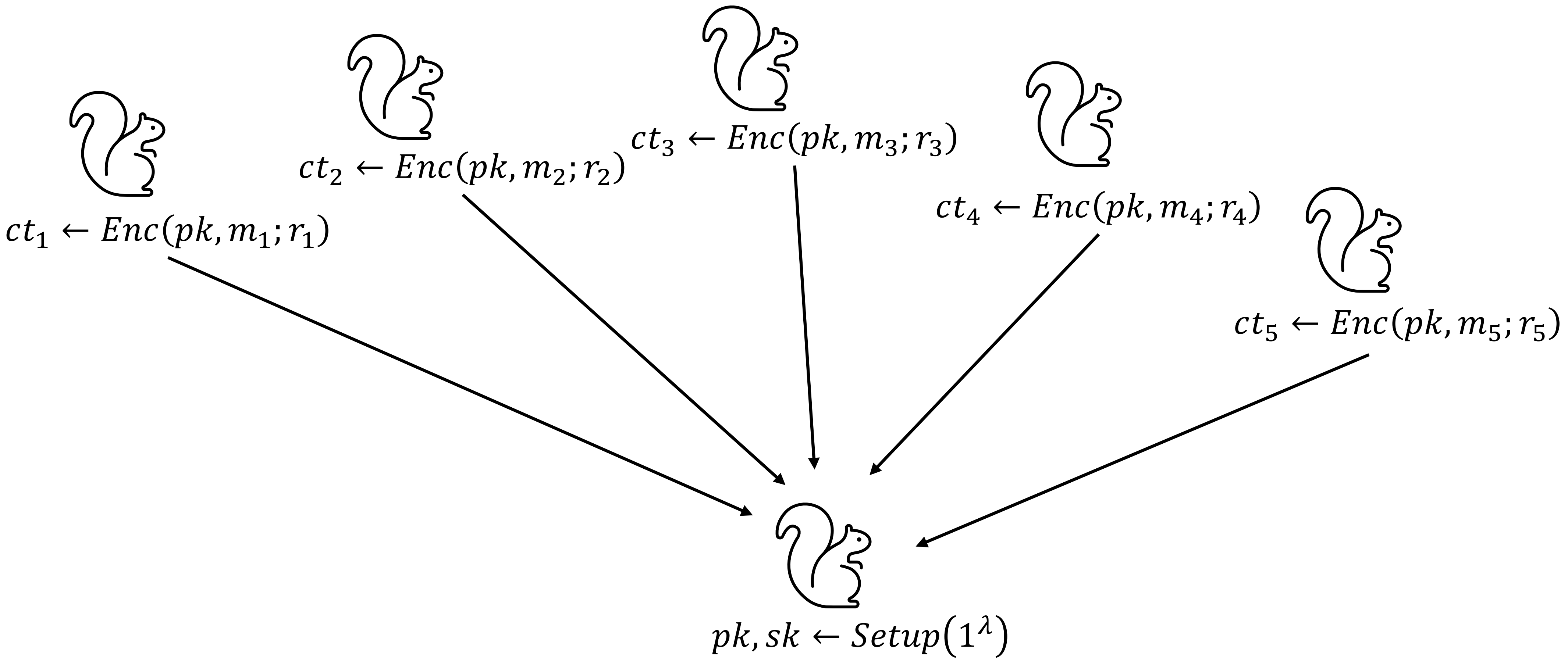

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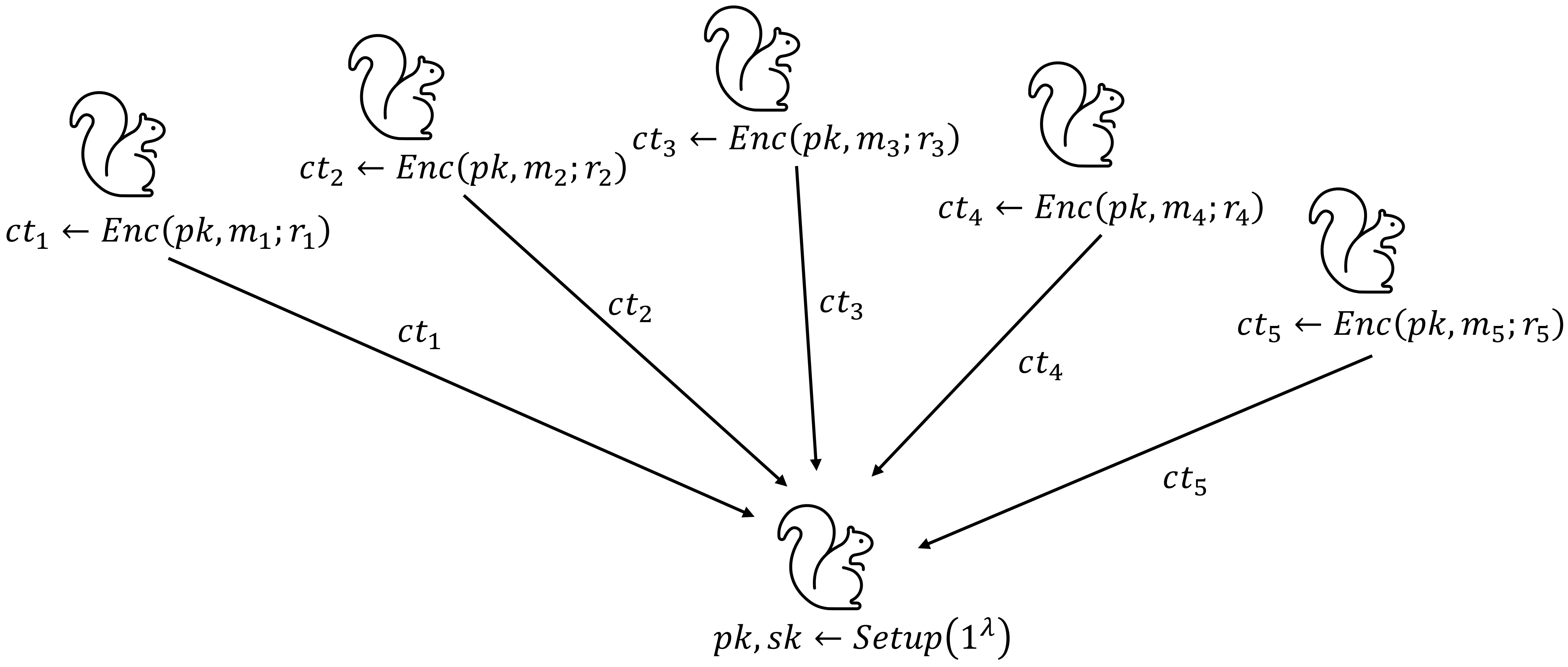

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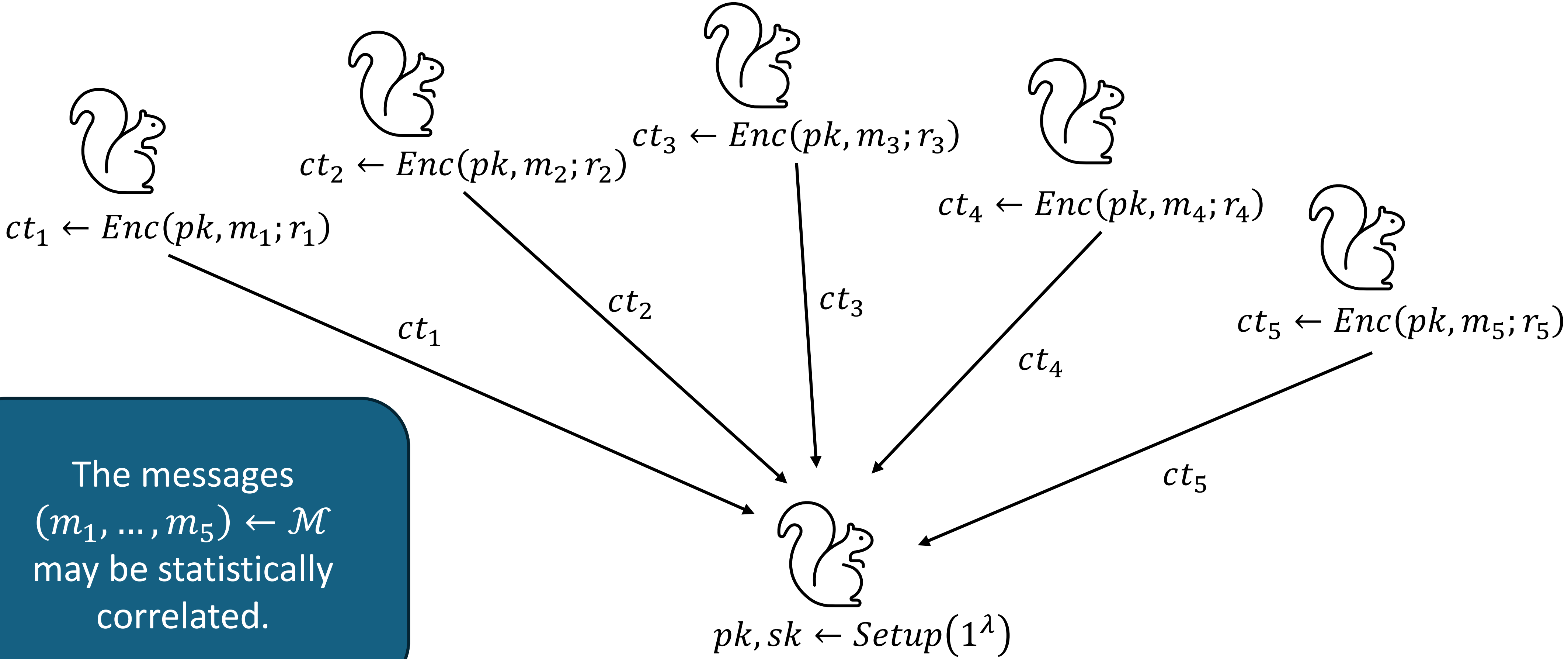

The messages $(m_1, \ldots, m_5) \leftarrow \mathcal{M}$ may be statistically correlated.

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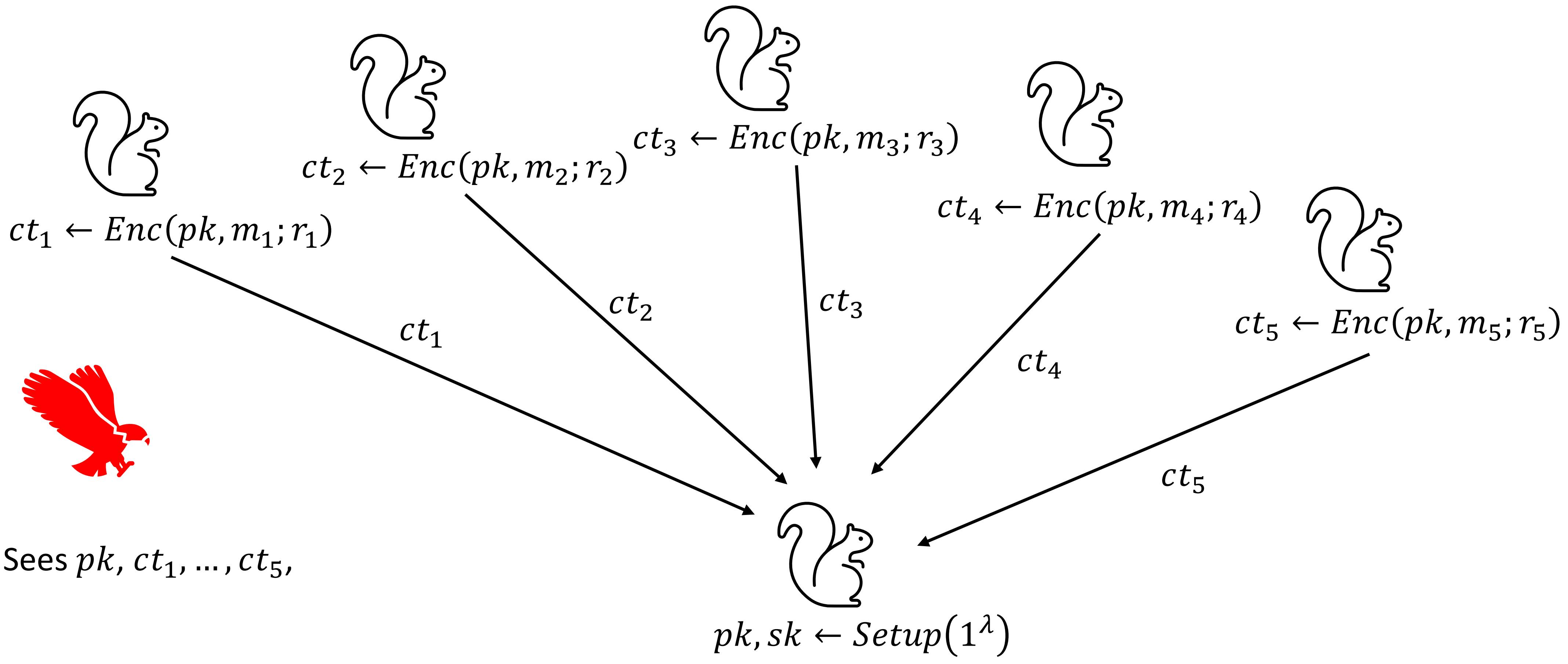

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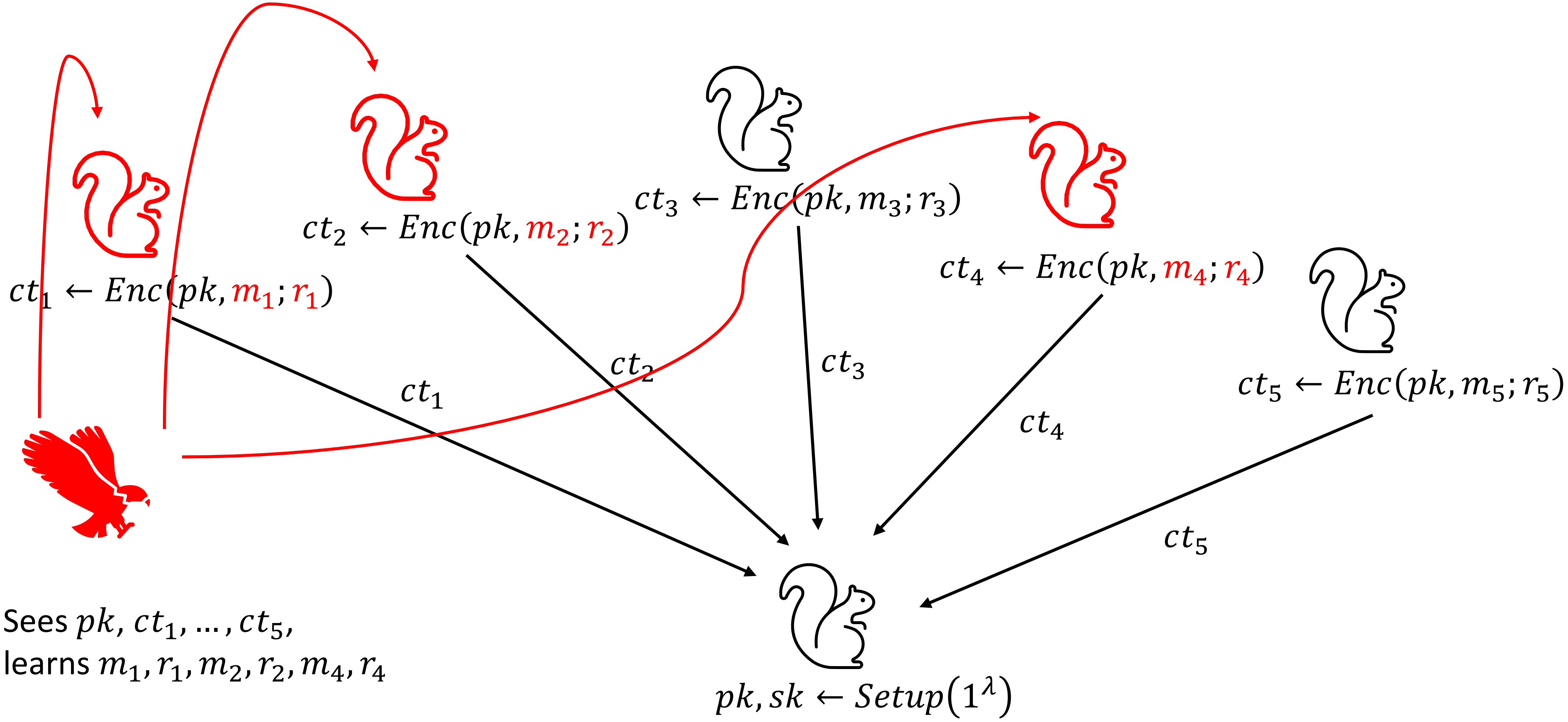

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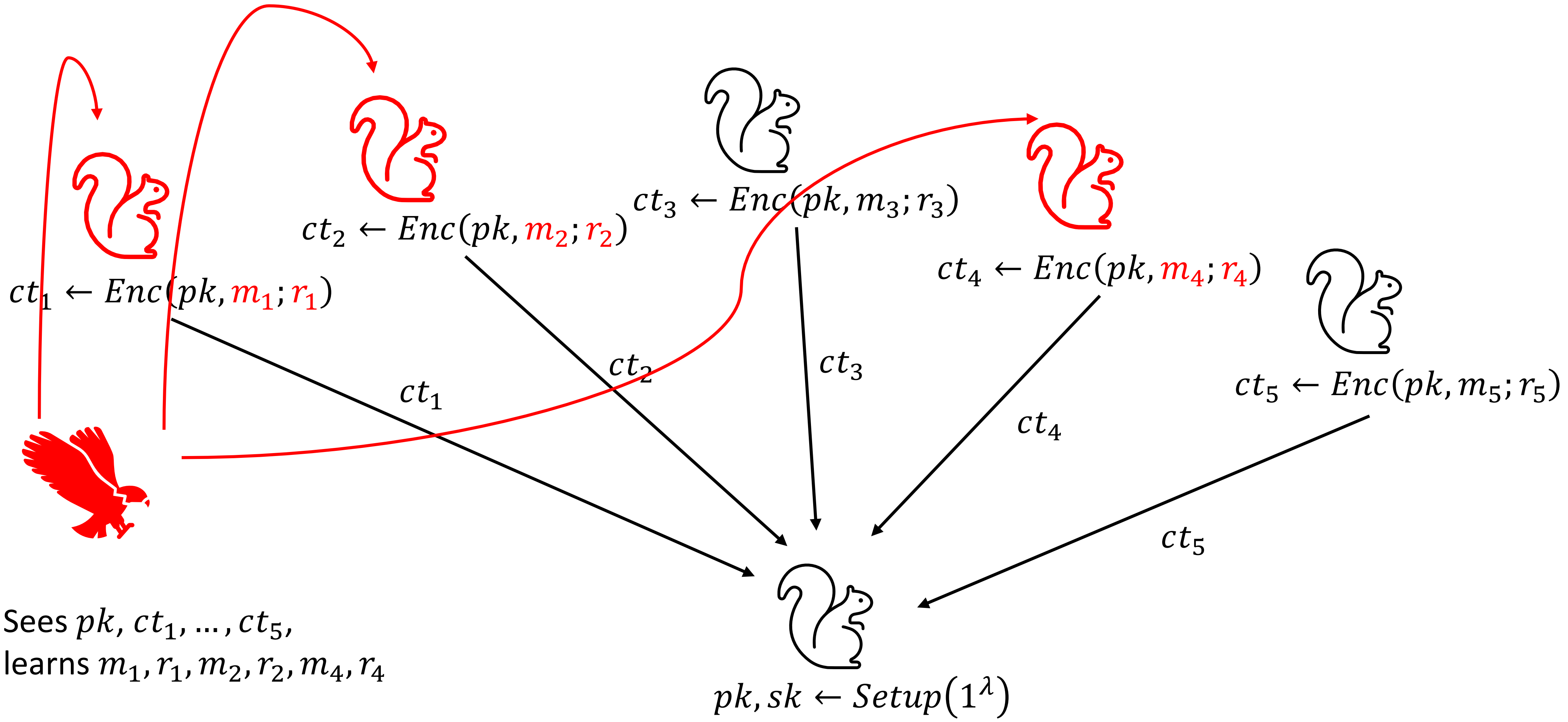
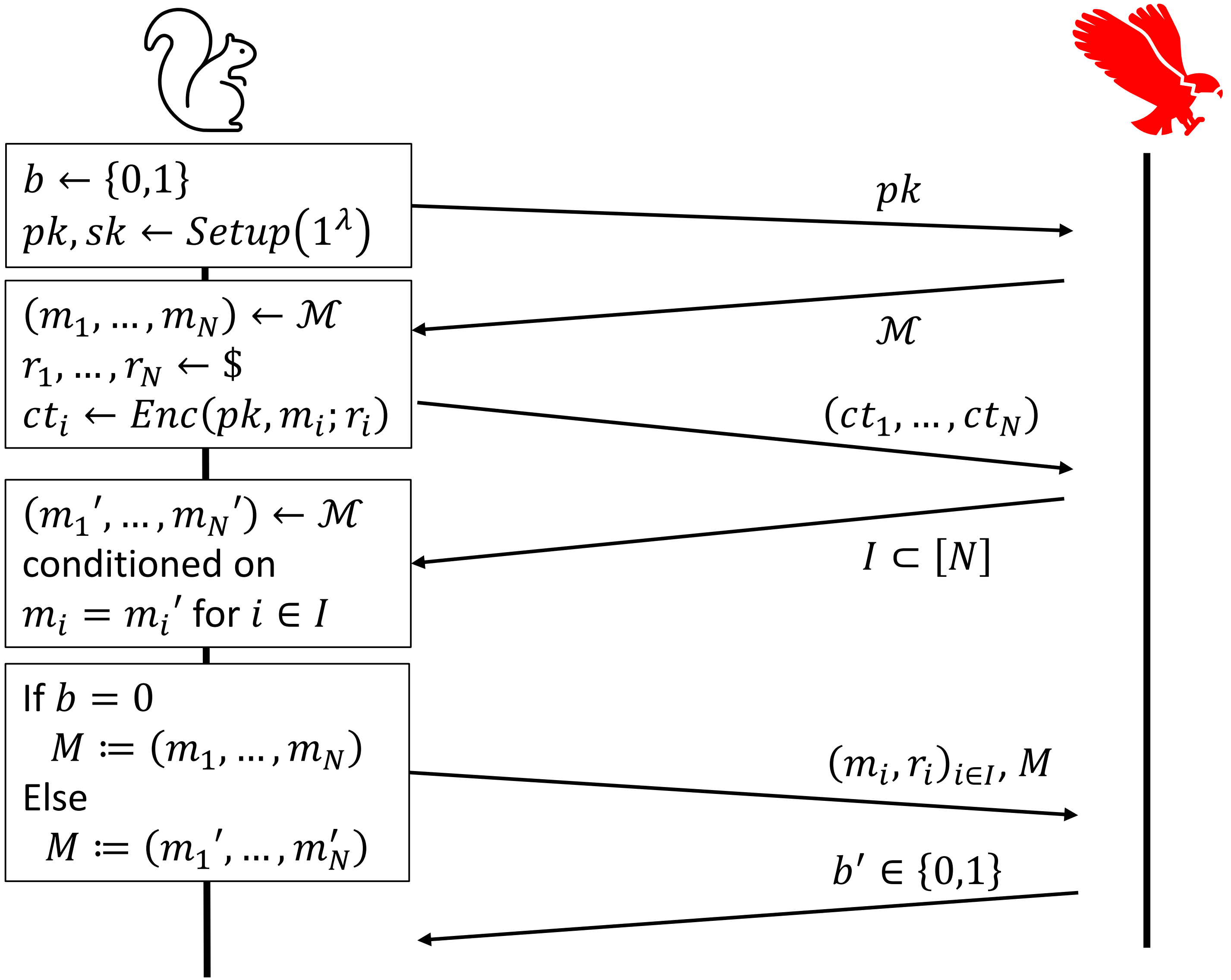
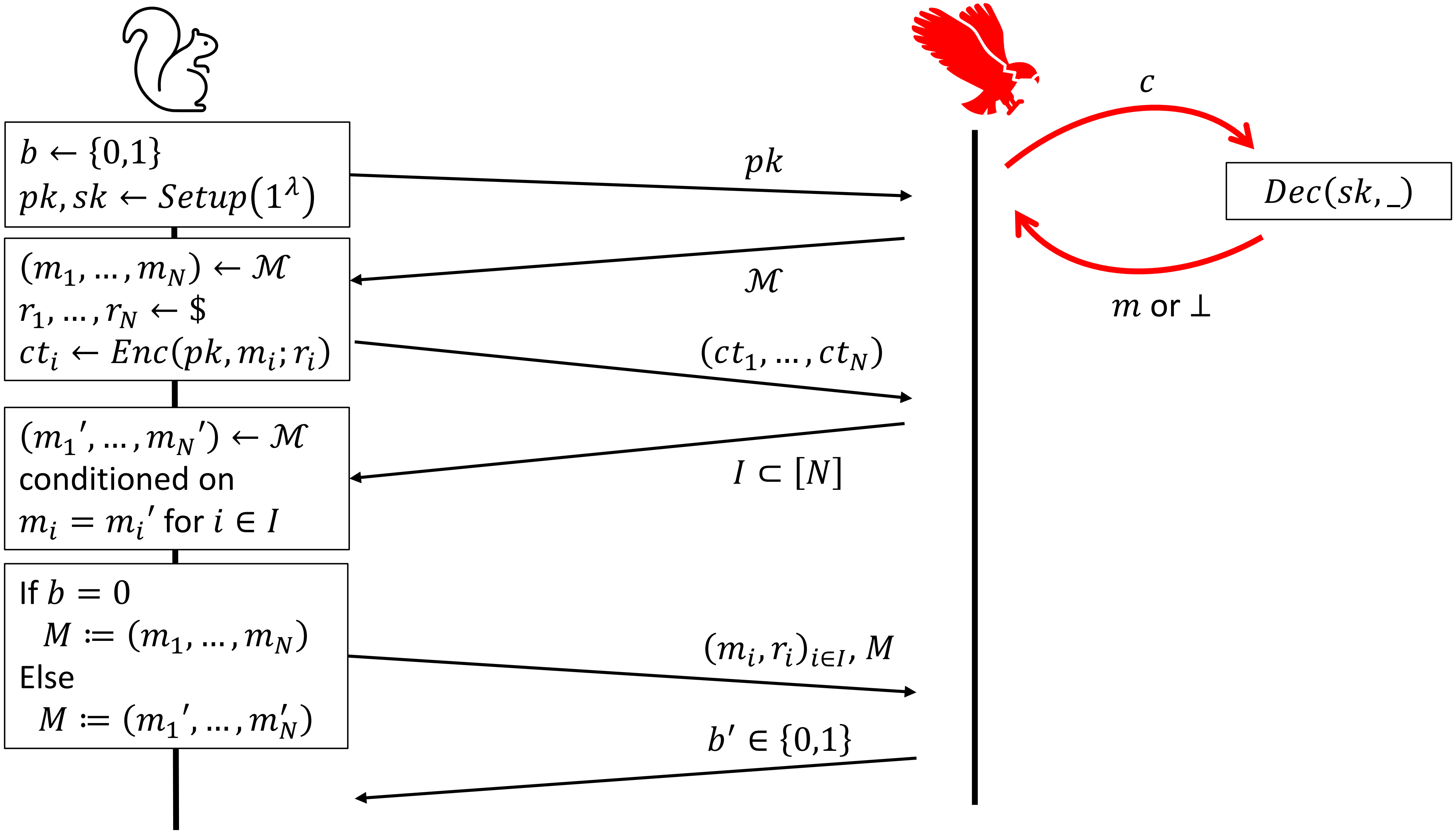


Security guarantee: Adversary does not learn any more about m_3, m_5 than what m_1, m_2, m_4 do trivially tell it.

IND-Selective Opening-CPA Security



IND-Selective Opening-CCA Security



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Our Result:

The first *compact* IND-so-CCA secure PKE scheme from LWE (and PRFs in **NC**1).

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Our Technique:

Use dual GSW FHE [GSW13] and a compression trick for messages.

Construction of IND-so-CCA PKE [Hof12]

In the standard model:

- A lossy trapdoor function LTF
- An all-but-many lossy trapdoor function ABM-LTF
- A universal family of hash functions H
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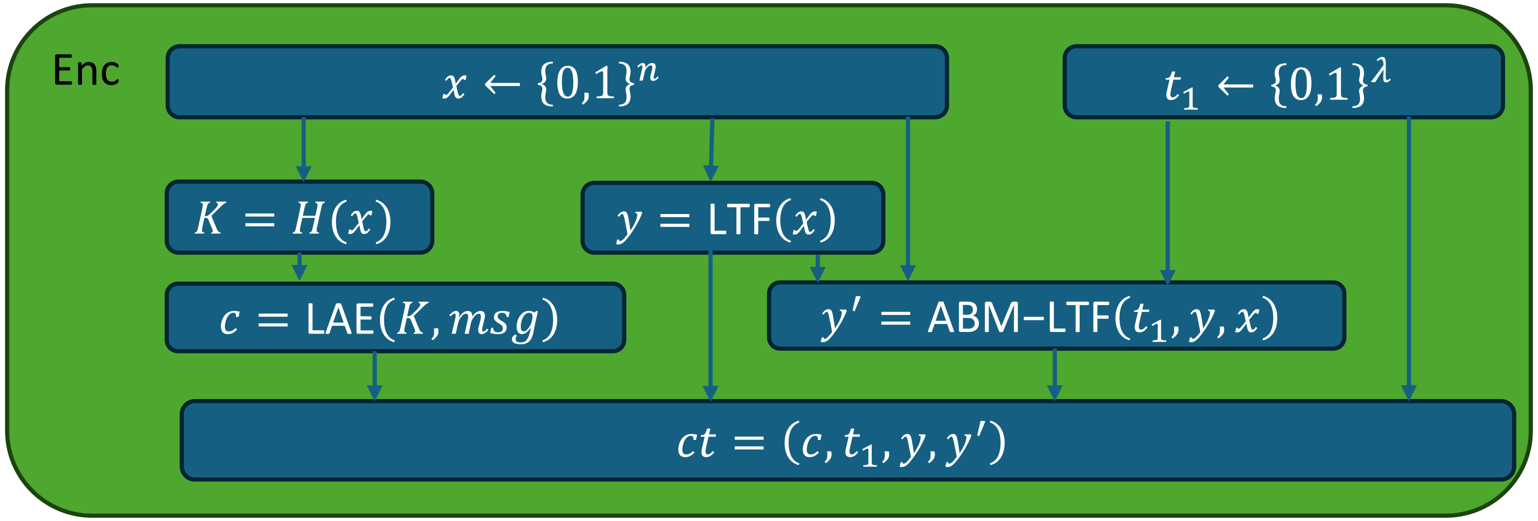

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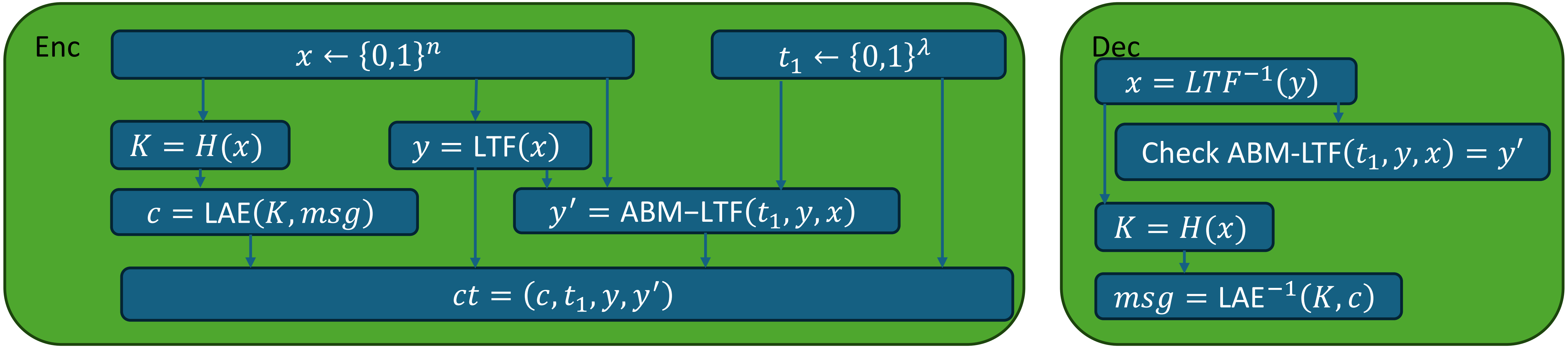

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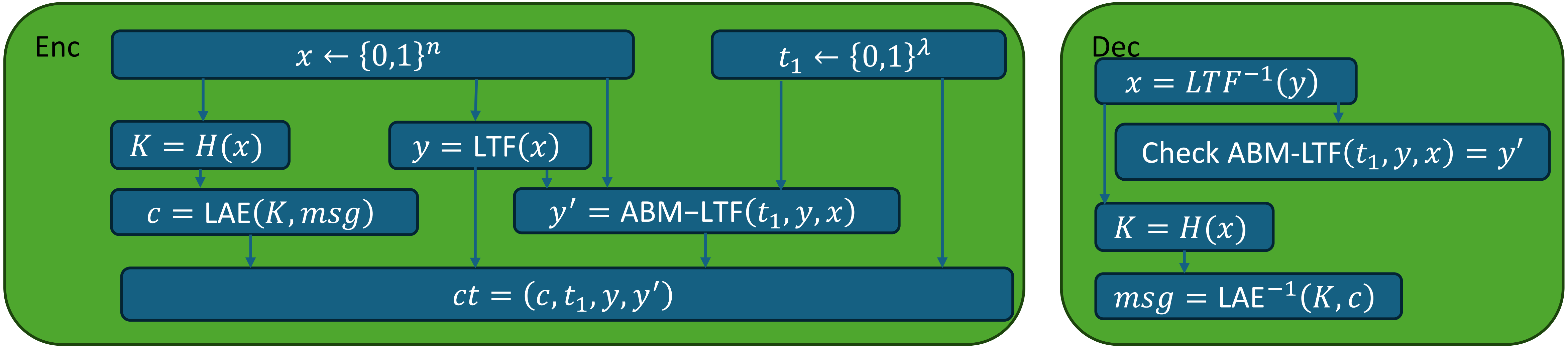

Construction of IND-so-CCA PKE [Hof12]

Build compactly from LWE (+PRFs).

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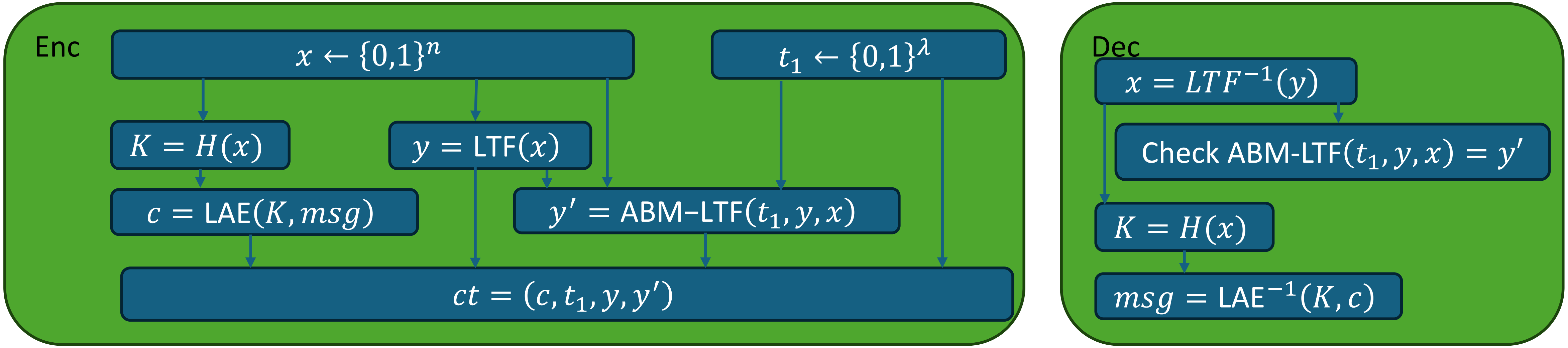
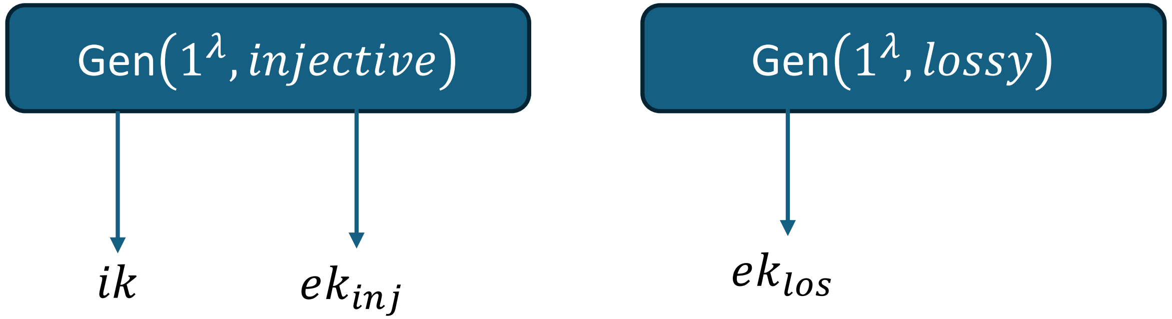


Compact Lossy Trapdoor Functions



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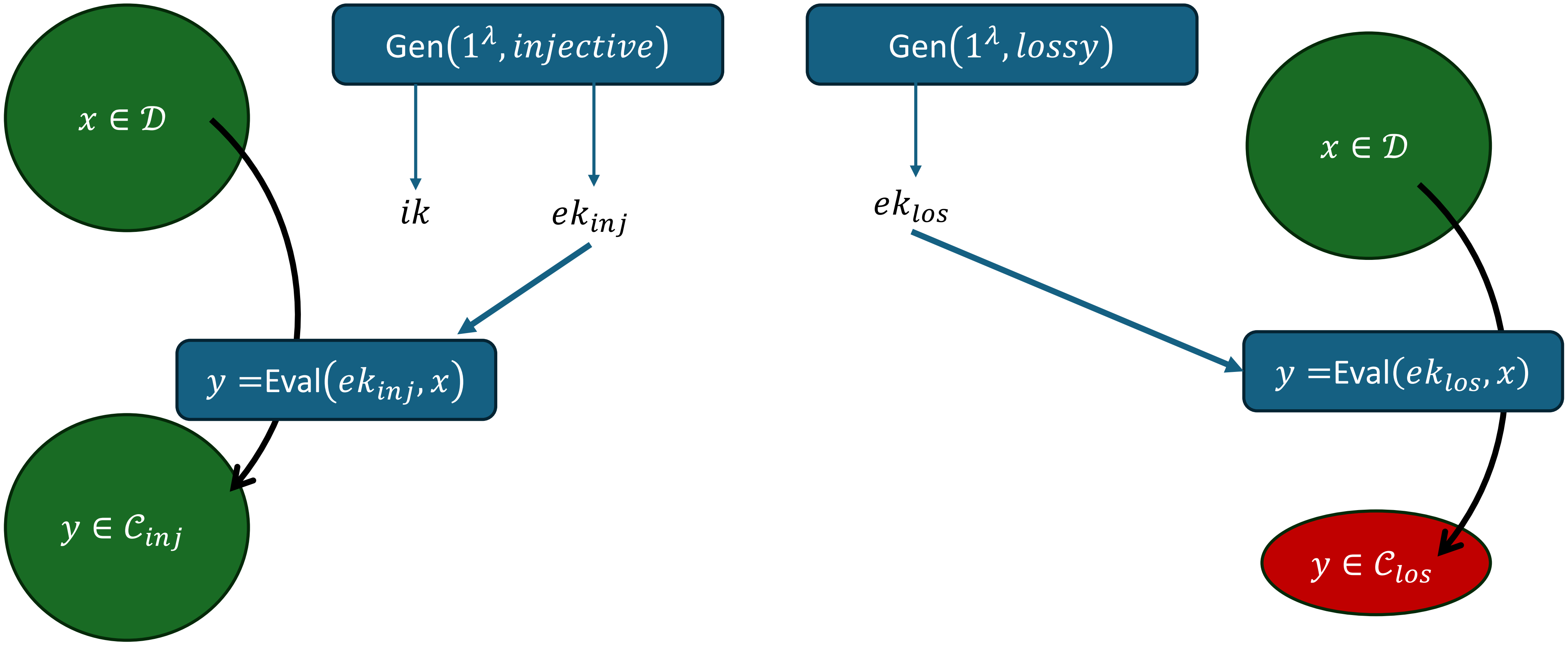

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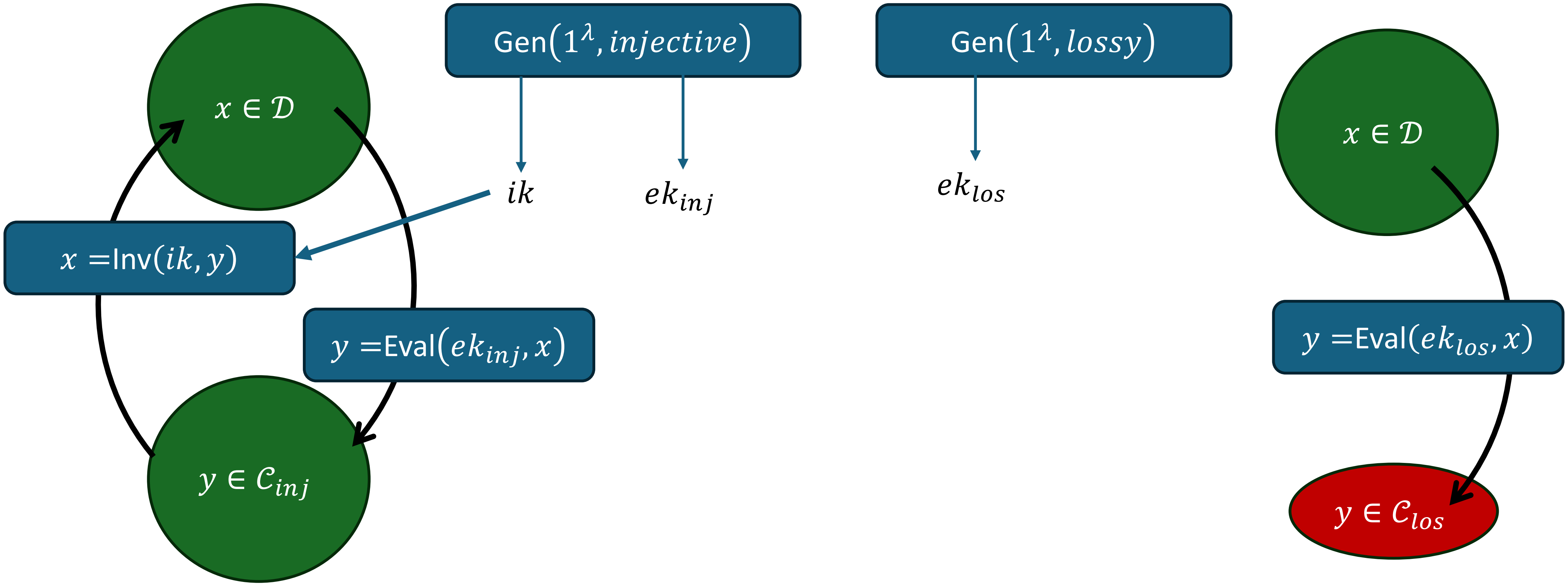

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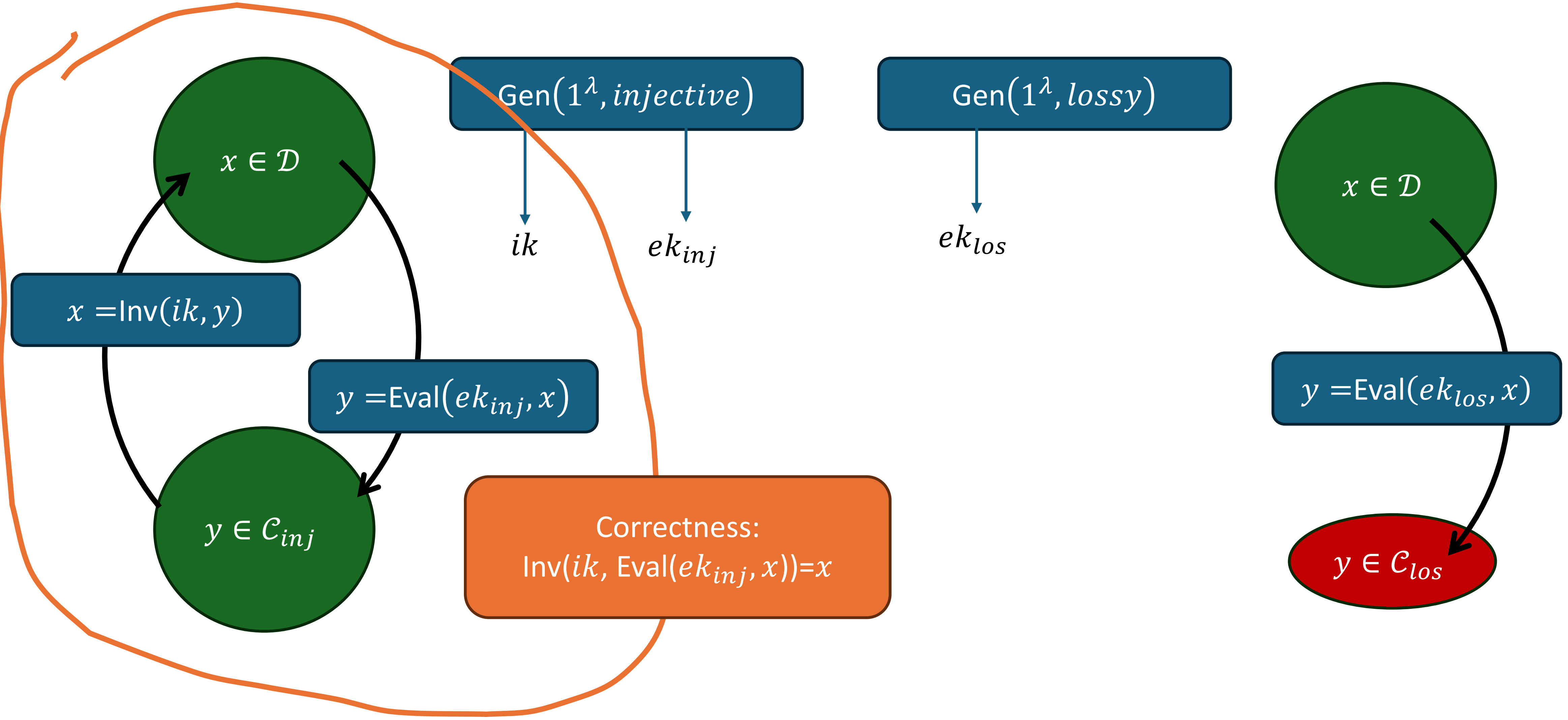

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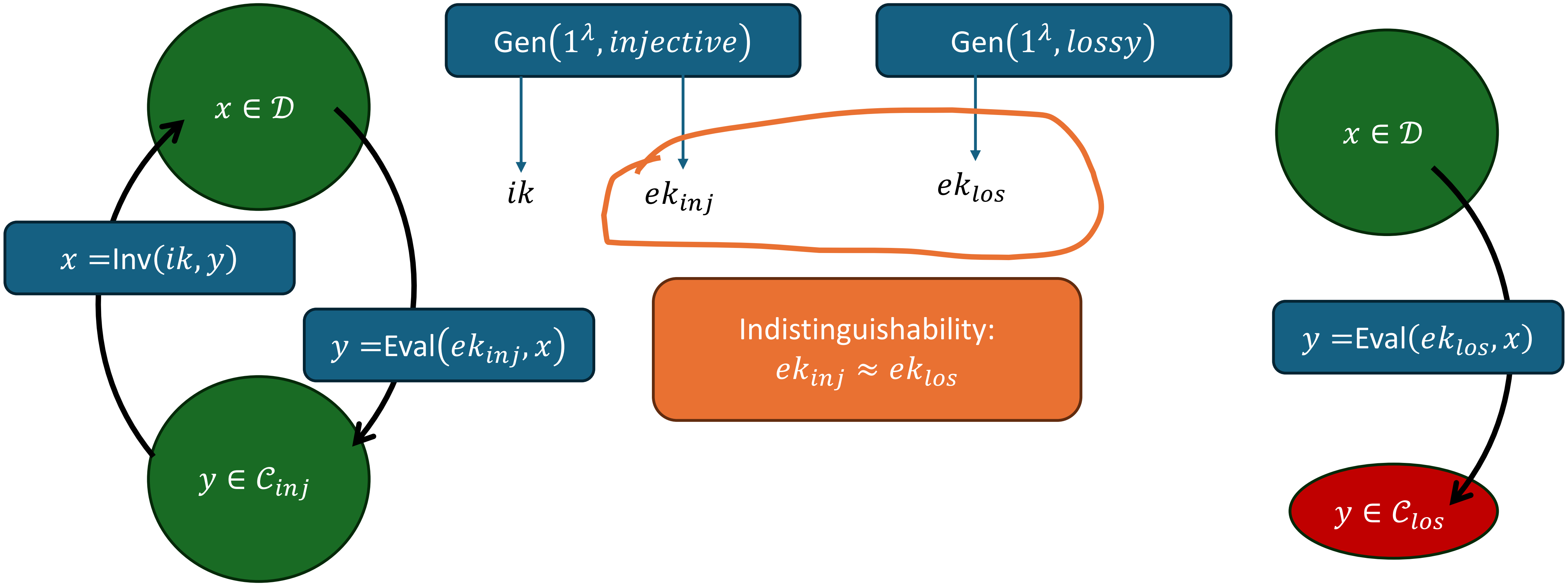

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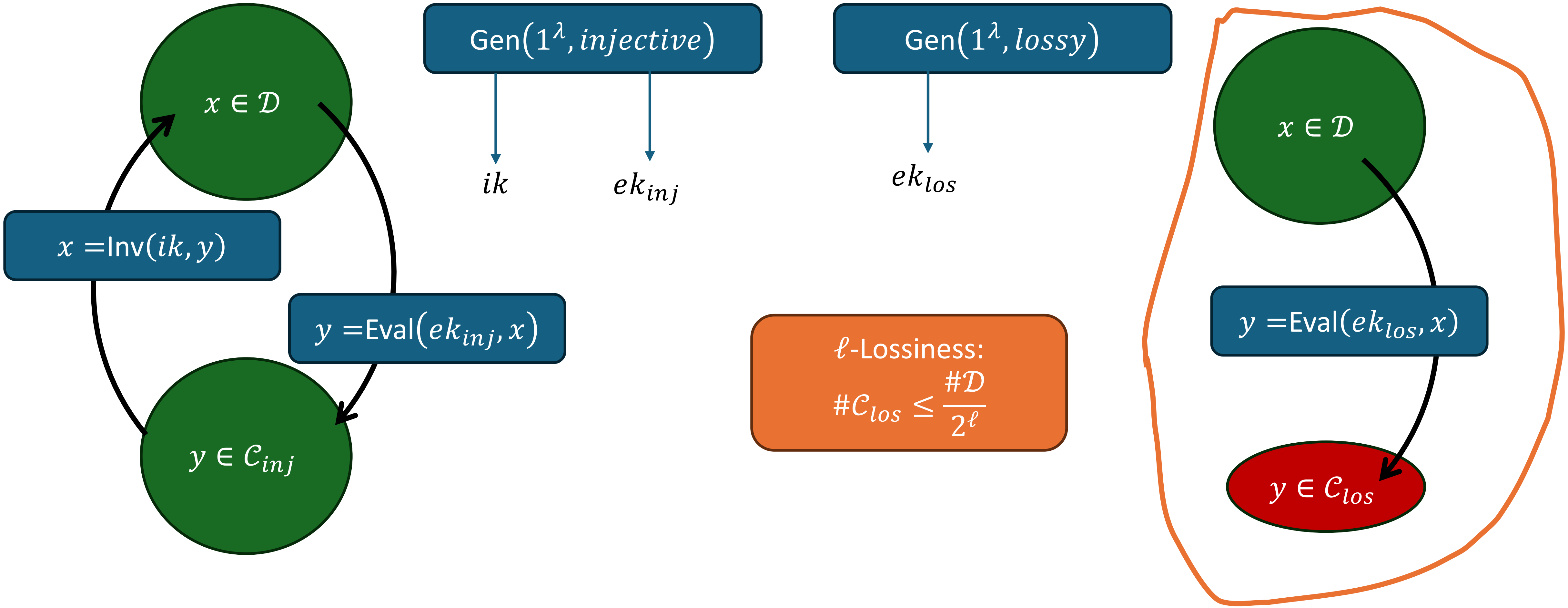

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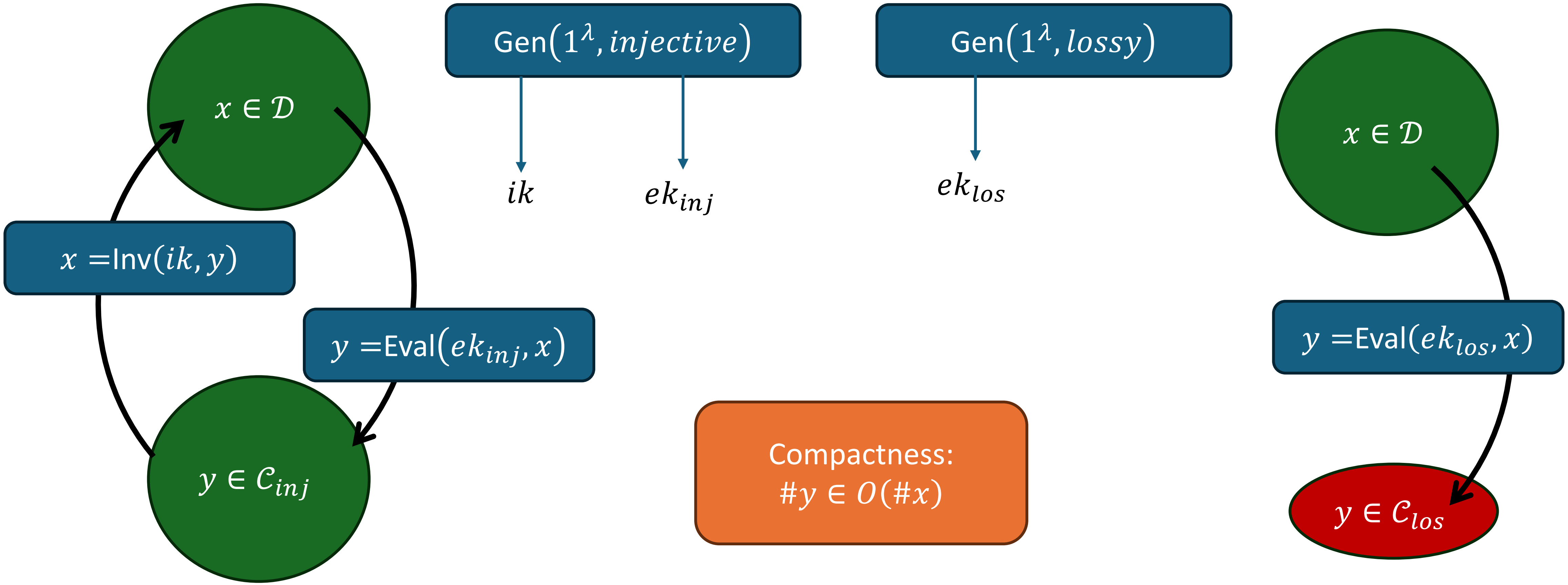

A Compact LTF from LWE

Generating Keys:

Draw an MP12-Trapdoor $(\mathbf{A}, td) \leftarrow GenTrap(u \times n)$,

$\mathbf{B} \leftarrow \mathbb{Z}_q^{m \times n}$,

$\mathbf{S} \leftarrow \mathbb{Z}_q^{n \times N}, \mathbf{E} \leftarrow \chi^{(m+u) \times N}$.

Output $ek \coloneqq \binom{\mathbf{A}}{\mathbf{B}} \cdot \mathbf{S} + \mathbf{E} + b \cdot \mathbf{G}$
and $ik \coloneqq (A, B, td)$ (if injective mode).

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$$\mathbf{G} = \begin{pmatrix} 1\ 2\ 4\ \ldots\ 2^{\log q} & \cdots & \\ \vdots & \ddots & \vdots \\ & \cdots & 1\ 2\ 4\ \ldots\ 2^{\log q} \end{pmatrix}$$

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Injective Mode: $b = 1$
Lossy Mode: $b = 0$

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Use Sg to extract $\frac{q}{p} \cdot x$.

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Low Rank

Short Entries

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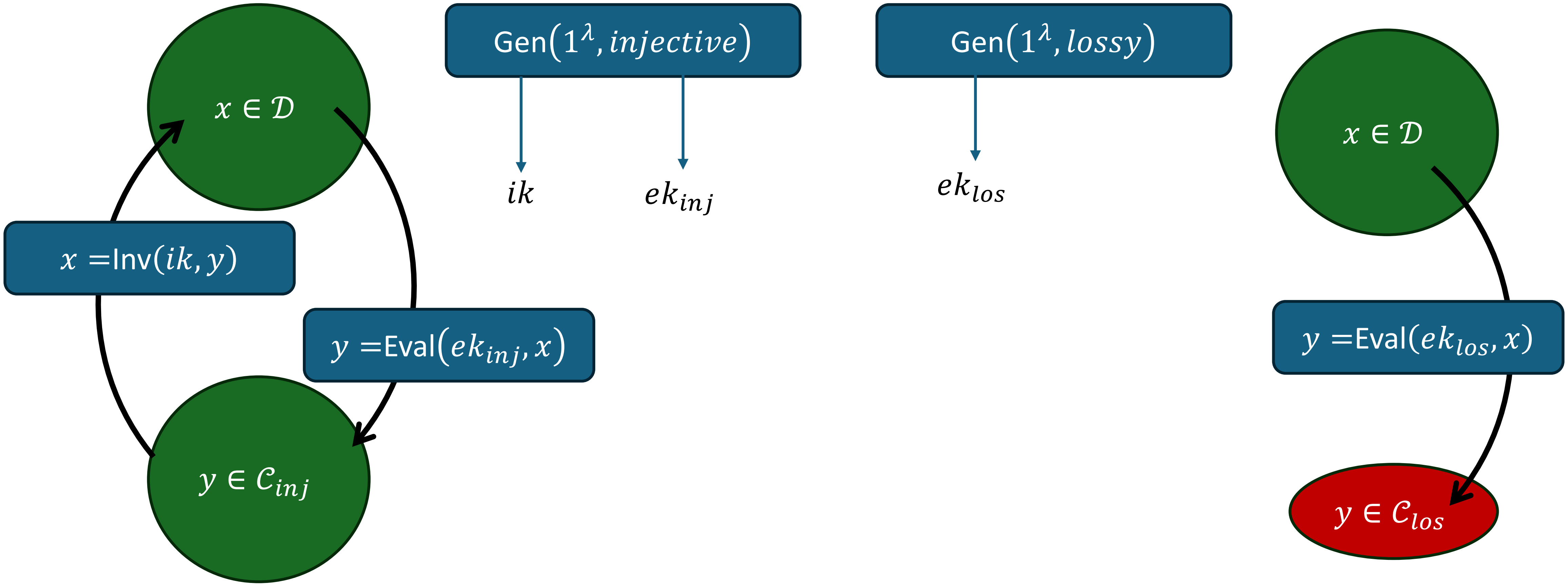
- ℓ-Lossiness: Counting argument.
- Compactness:

  Messages lie in $\mathbb{Z}_p^{m'}$.
  Ciphertexts lie in $\mathbb{Z}_q^{m+u}$.
  Choose $\log p \in \Omega(\log q)$ and $m' \in \Omega(m+u)$.

Lossy Trapdoor Function



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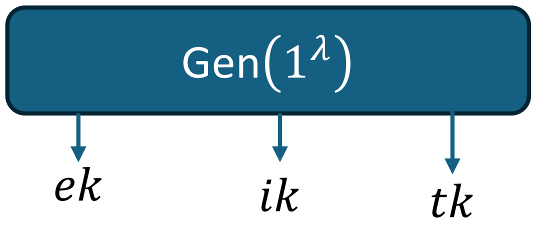

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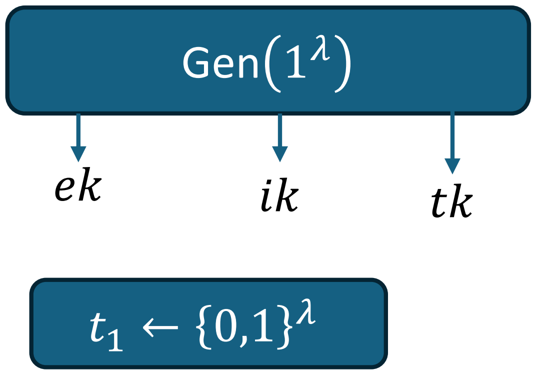

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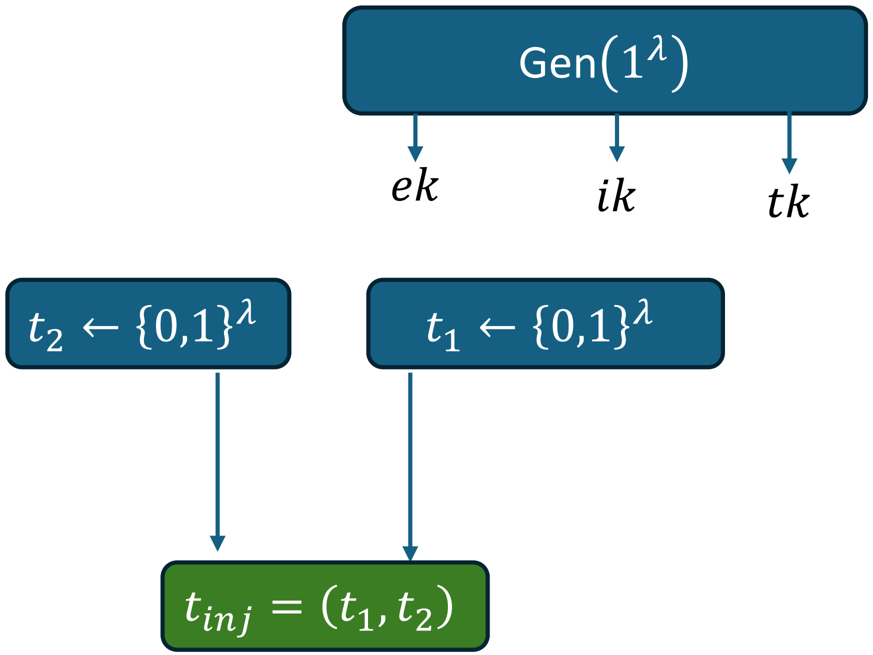

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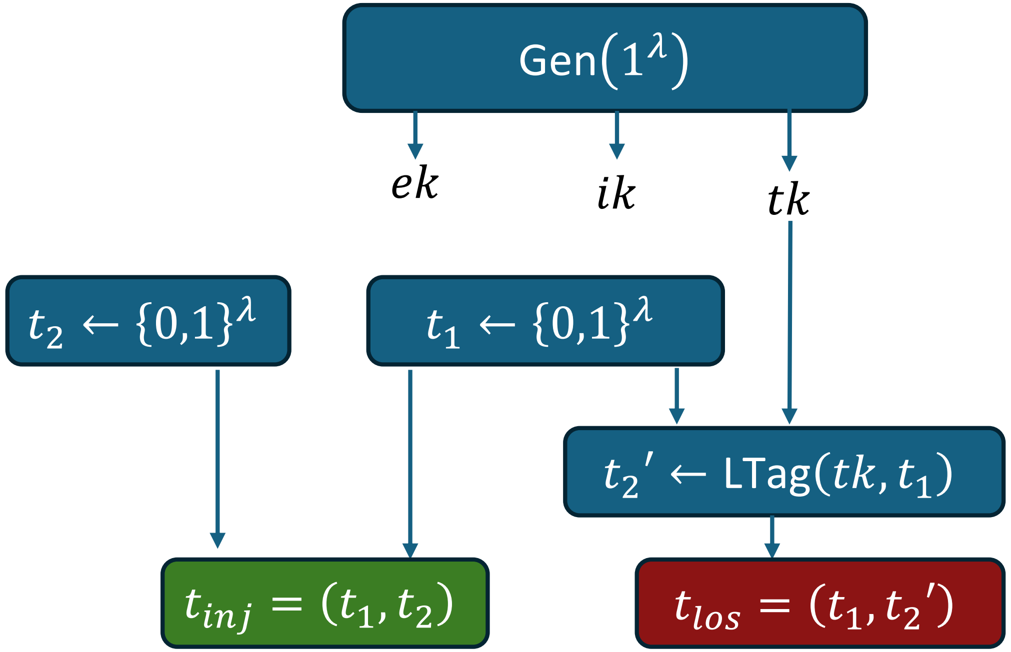

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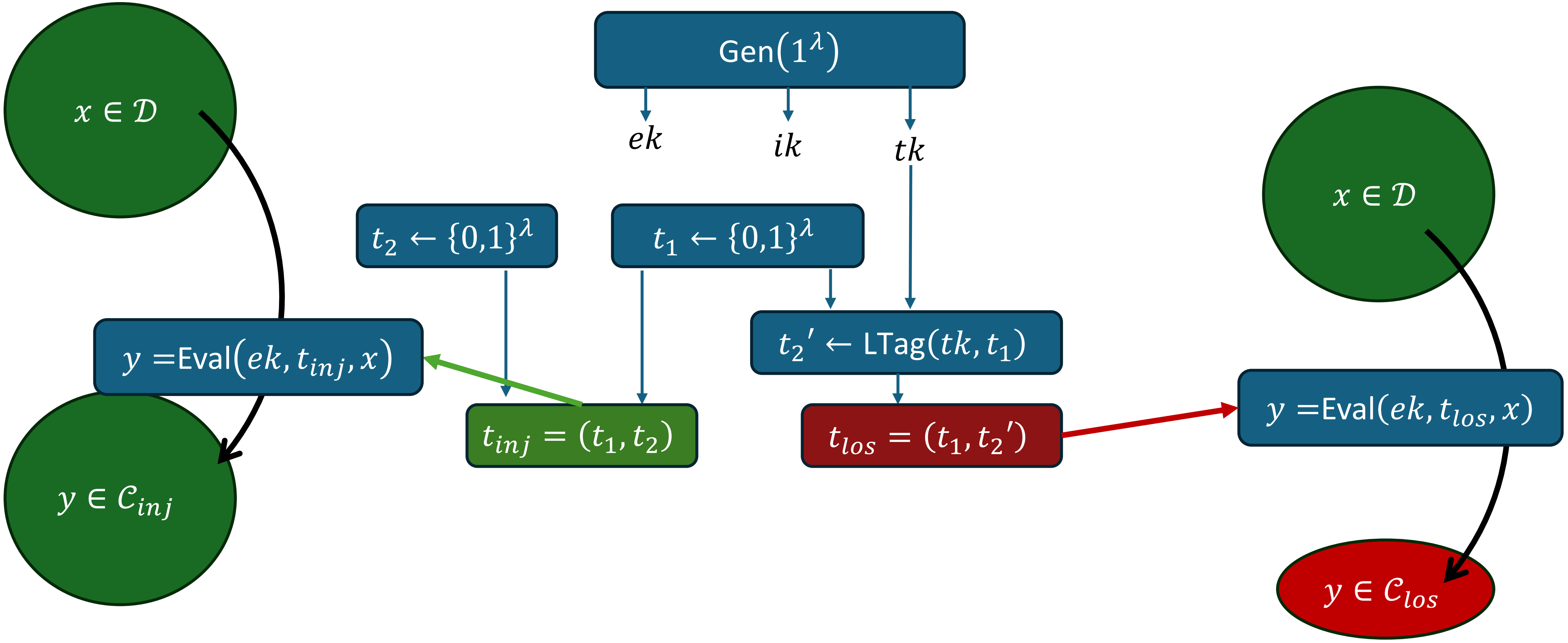

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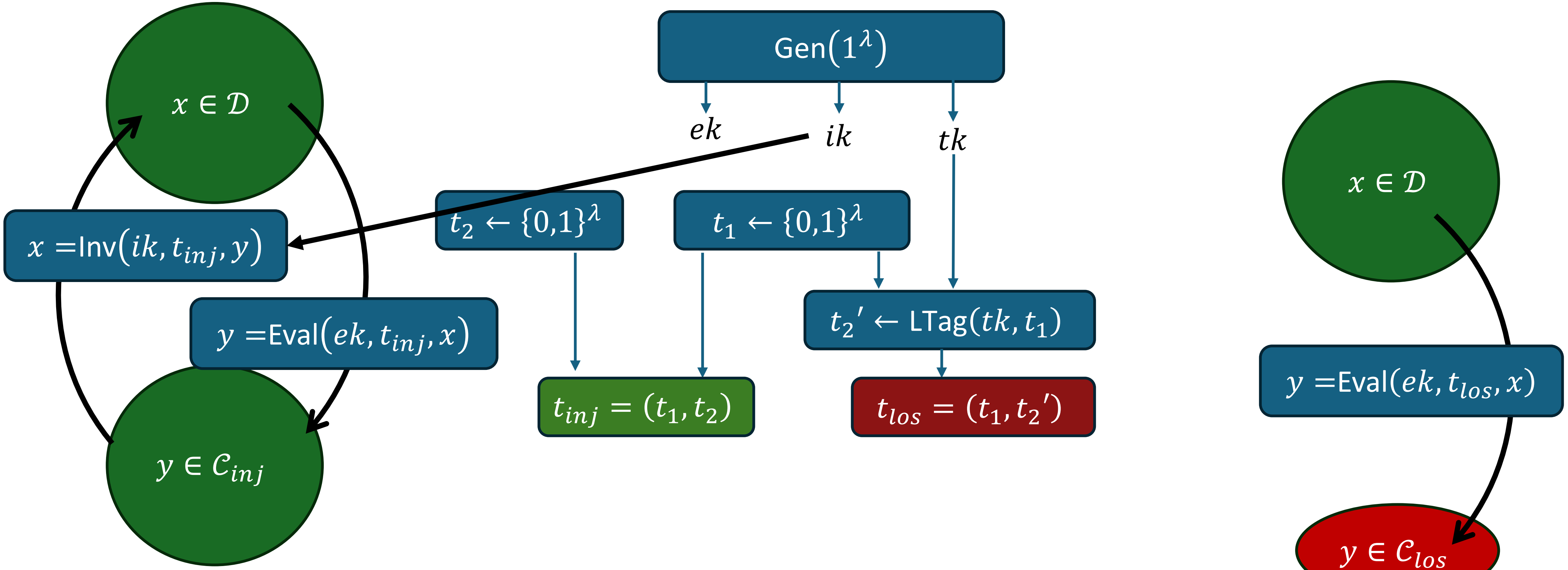

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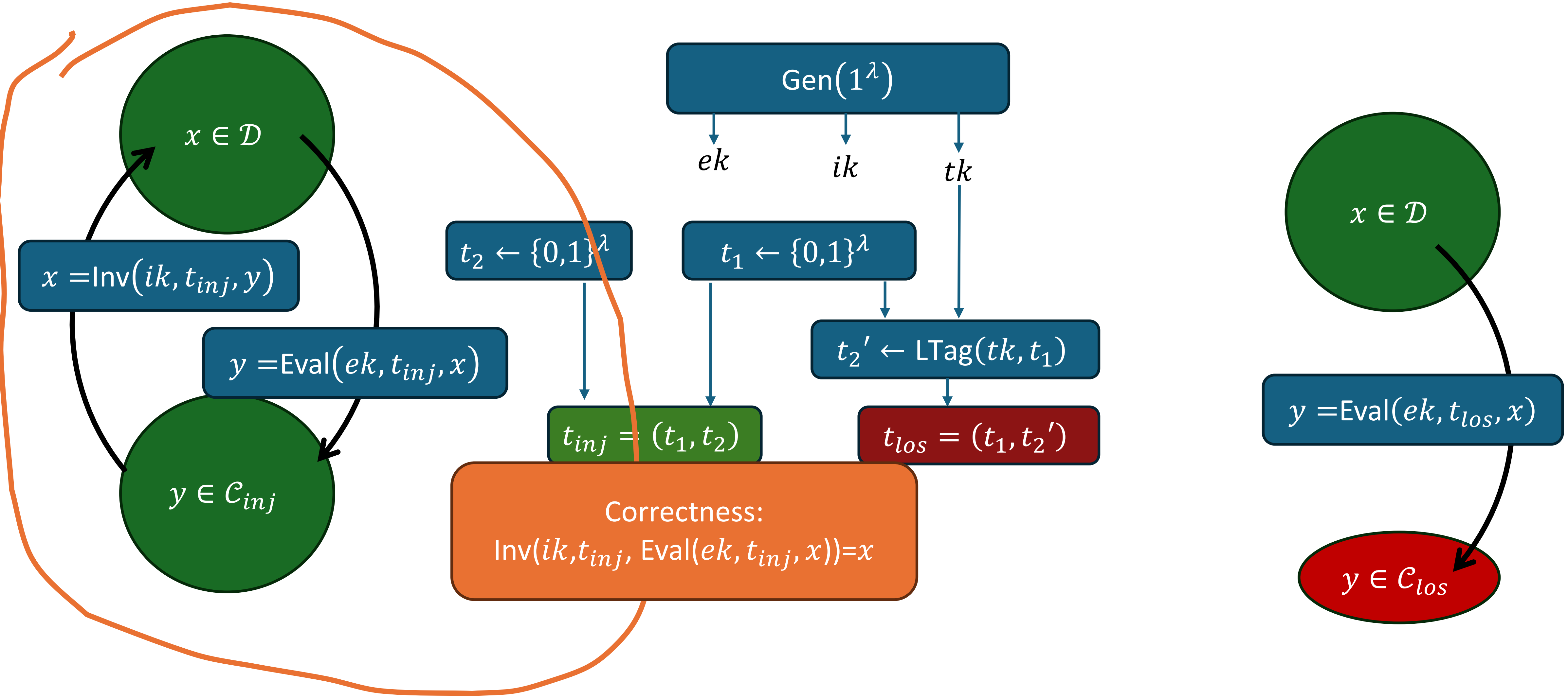

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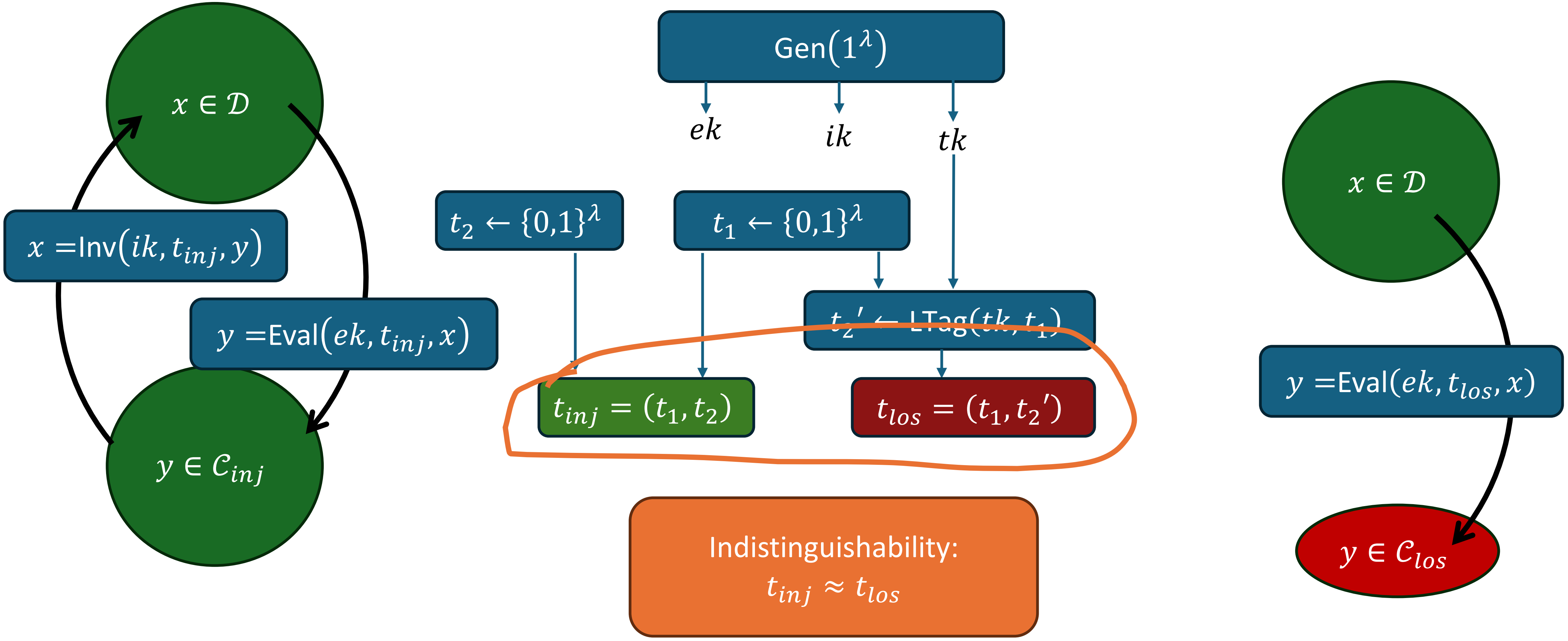

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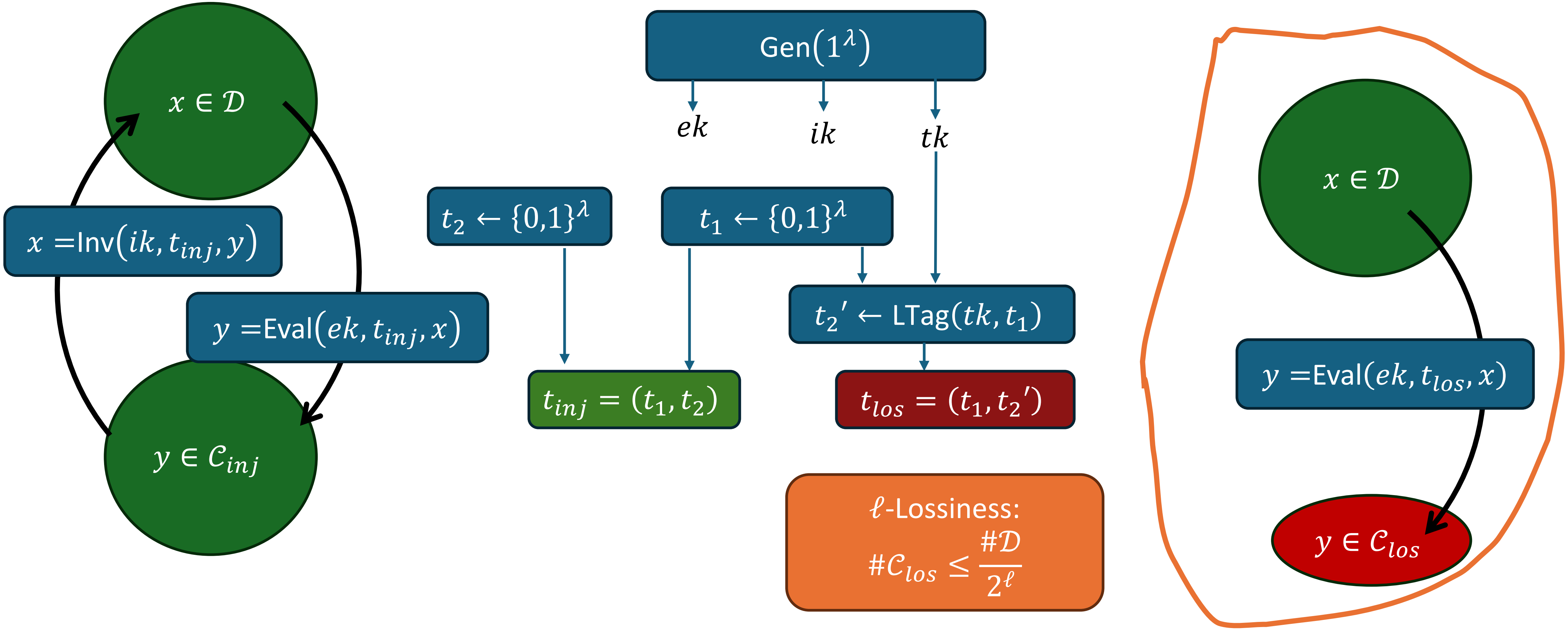

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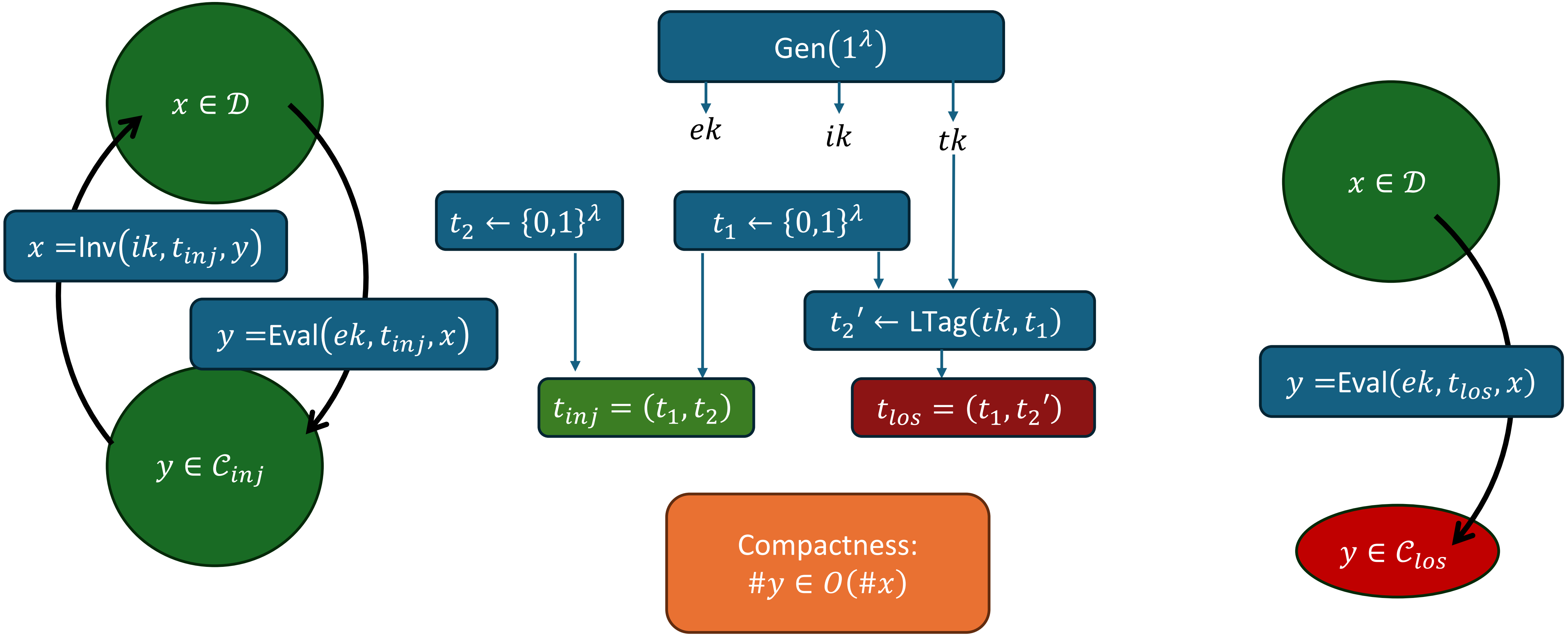

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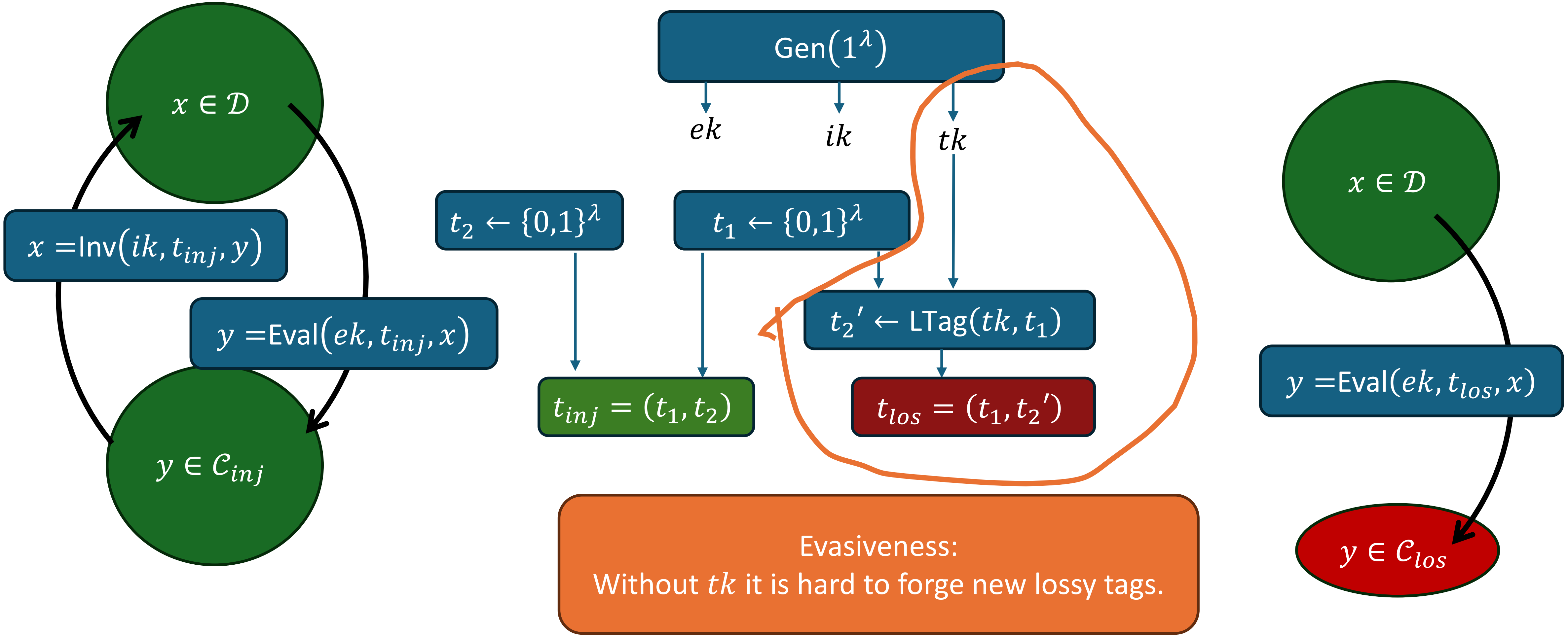

Compact ABM Lossy Trapdoor Functions

ABM-LTF = (Gen, Eval, Inv, LTag)

- Gen(1^λ) outputs ek and ik and tag key tk.
- LTag(tk, t_1) outputs t_2 s.t. (t_1, t_2) is lossy.
- Eval(ek, t_1, t_2, x) evaluates x to y.
- Inv(ik, t_1, t_2, y) extracts x if (t_1, t_2) is injective.

A Compact LTF from LWE

Generating Keys:

Draw a MP12-Trapdoor $(\mathbf{A}, td) \leftarrow GenTrap(u \times n)$,

$\mathbf{B} \leftarrow \mathbb{Z}_q^{m \times n}$,

$\mathbf{S} \leftarrow \mathbb{Z}_q^{n \times N}, \mathbf{E} \leftarrow \chi^{(m+u) \times N}$.

Output $ek \coloneqq \binom{\mathbf{A}}{\mathbf{B}} \cdot \mathbf{S} + \mathbf{E} + b \cdot \mathbf{G}$
and $ik \coloneqq (A, B, td)$ (if injective mode).

A Compact ABM-LTF from LWE

Fix $\mathsf{PRF} : \{0,1\}^\lambda \times \{0,1\}^\lambda \to \{0,1\}^\lambda$.
Generating Keys:

Draw a PRF key $k = (k_1, \dots, k_\lambda) \leftarrow \{0,1\}^\lambda$.

Draw an MP12-Trapdoor $(\mathbf{A}, td) \leftarrow GenTrap(u \times n)$,

$\mathbf{B} \leftarrow \mathbb{Z}_q^{m \times n}$,

$\mathbf{S}_1, \dots, \mathbf{S}_\lambda \leftarrow \mathbb{Z}_q^{n \times N}$, $\mathbf{E}_1, \dots, \mathbf{E}_\lambda \leftarrow \chi^{(m+u) \times N}$.

Output $\mathbf{C}_1 := \binom{\mathbf{A}}{\mathbf{B}} \cdot \mathbf{S}_1 + \mathbf{E}_1 + k_1 \cdot \mathbf{G}, \dots,$

$\mathbf{C}_\lambda := \binom{\mathbf{A}}{\mathbf{B}} \cdot \mathbf{S}_\lambda + \mathbf{E}_\lambda + k_\lambda \cdot \mathbf{G}$ as ek.

and $ik := (A, B, td)$ and $tk := k$.

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and $ik := (A, B, td)$ and $tk := k$.

$\mathbf{C}_1, \dots, \mathbf{C}_\lambda$ are dual GSW encryptions of $k_1 \dots, k_\lambda$.

A Compact ABM-LTF from LWE

Fix PRF : $\{0,1\}^\lambda \times \{0,1\}^\lambda \to \{0,1\}^\lambda$.
Generating Keys:

$$\mathbf{C}_i := \begin{pmatrix} \mathbf{A} \\ \mathbf{B} \end{pmatrix} \cdot \mathbf{S}_i + \mathbf{E}_i + k_i \cdot \mathbf{G} \qquad \text{for } i = 1, \ldots, \lambda$$

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Generating Lossy Tags:

$$\mathrm{Ltag}(tk = k, t_1) \text{ outputs } t_2 := \mathrm{PRF}(k, t_1).$$

A Compact ABM-LTF from LWE

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$$\mathbf{C}_i \coloneqq \binom{\mathbf{A}}{\mathbf{B}} \cdot \mathbf{S}_i + \mathbf{E}_i + k_i \cdot \mathbf{G} \qquad \text{for } i = 1, .., \lambda$$

Generating Lossy Tags:

Ltag$(tk = k, t_1)$ outputs $t_2 \coloneqq \mathsf{PRF}(k, t_1)$.

Evaluating x:

Eval(ek, t_1, t_2, x) uses FHE to evaluate the function

$$f(k) \coloneqq \begin{cases} x, & \text{if } \mathrm{PRF}(k, t_1) \neq t_2 \\ 0, & \text{if } \mathrm{PRF}(k, t_1) = t_2 \end{cases}$$

on $ek = (\mathbf{C}_1, \dots, \mathbf{C}_\lambda)$.

A Compact ABM-LTF from LWE

- Correctness
- Indistinguishability of injective and lossy tags
- Evasiveness of lossy Tags
- Compactness
- ℓ-Lossiness

A Compact ABM-LTF from LWE

- Correctness ✓
- Indistinguishability of injective and lossy tags ✓
- Evasiveness of lossy Tags ✓ (follows from pseudorandomness of PRF)
- Compactness ✓
- ℓ-Lossiness ✓

On Parameters

In theory, we get high lossiness and small ciphertext expansion.

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But in praxis, parameters turn out to be huge ☹

Problem: using FHE/PRF makes modulus large.

Possible solution:

Switch to (Q)ROM and use Fujisaki-Okamoto transformation [next talk, Pan&Zeng].

Summary

Our results:

- Compact ABM-LTFs from LWE (and PRFs in **NC**1).
- Compact IND-so-CCA PKE from LWE (and PRFs in **NC**1).
- Along the way: fix mistake in proof of [Hof12].

Our techniques:

- Use dual GSW FHE [GSW13].
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- Use dual GSW FHE [GSW13].
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Thank you for your Attention!