Release of Unverified Plaintext: Tight Unified Model and Application to ANYDAE

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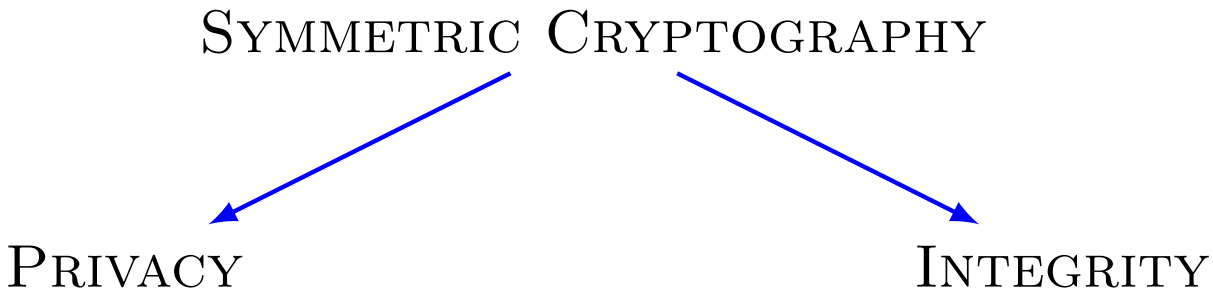
Outline of the Talk

- Definitions of AE and Security Notion.
- RUP Security.
- INT-RUP Attack on SUNDAE.
- MONDAE: An INT-RUP Secure Variant of SUNDAE.
- ANYDAE: Generic INT-RUP Design.
- TUESDAE: An Optimal Instantiation of ANYDAE.

Goal of Symmetric Cryptography



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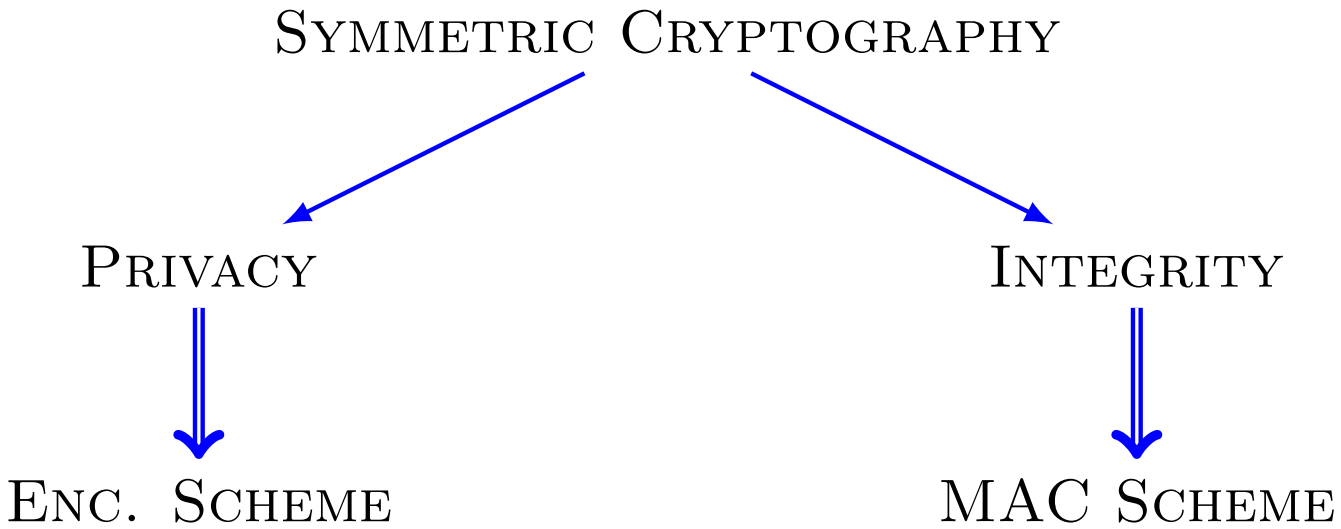

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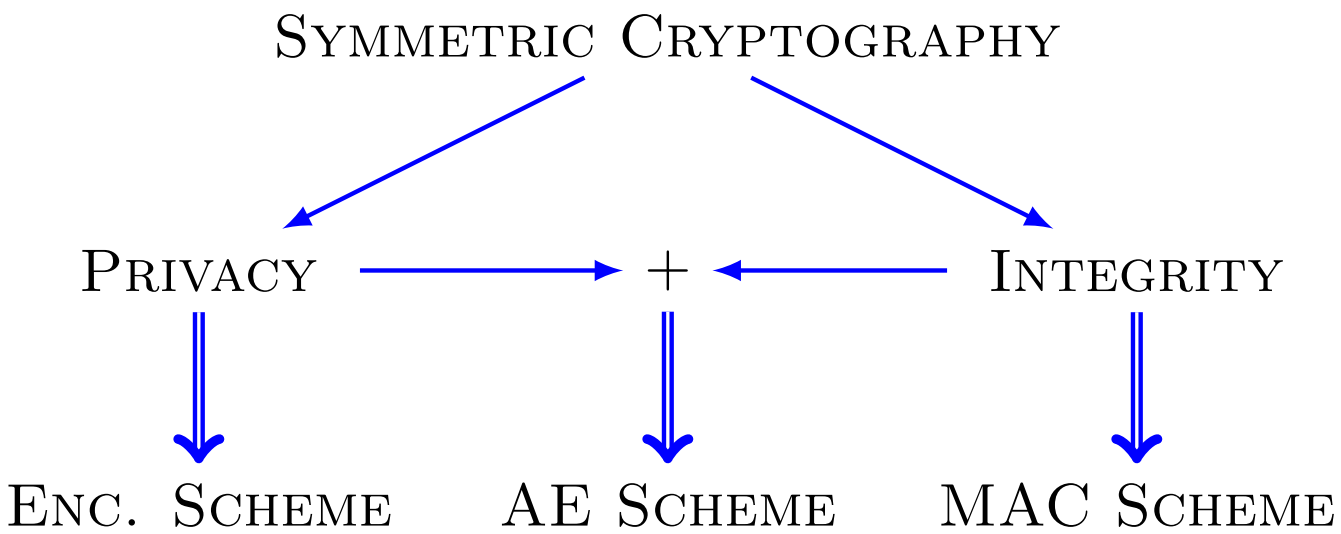

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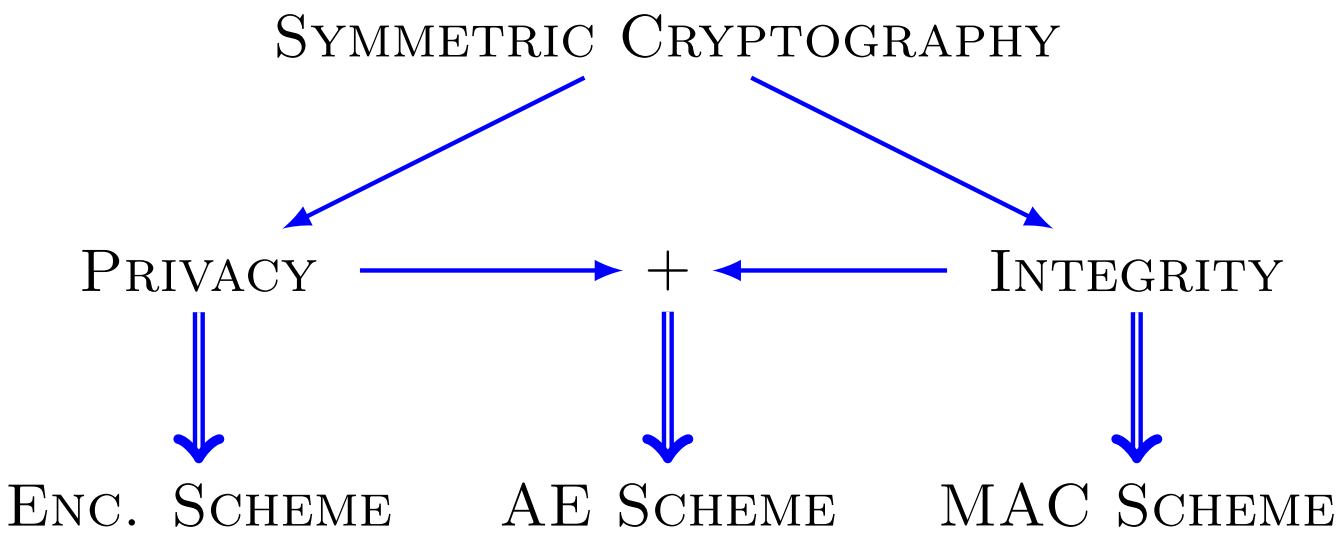
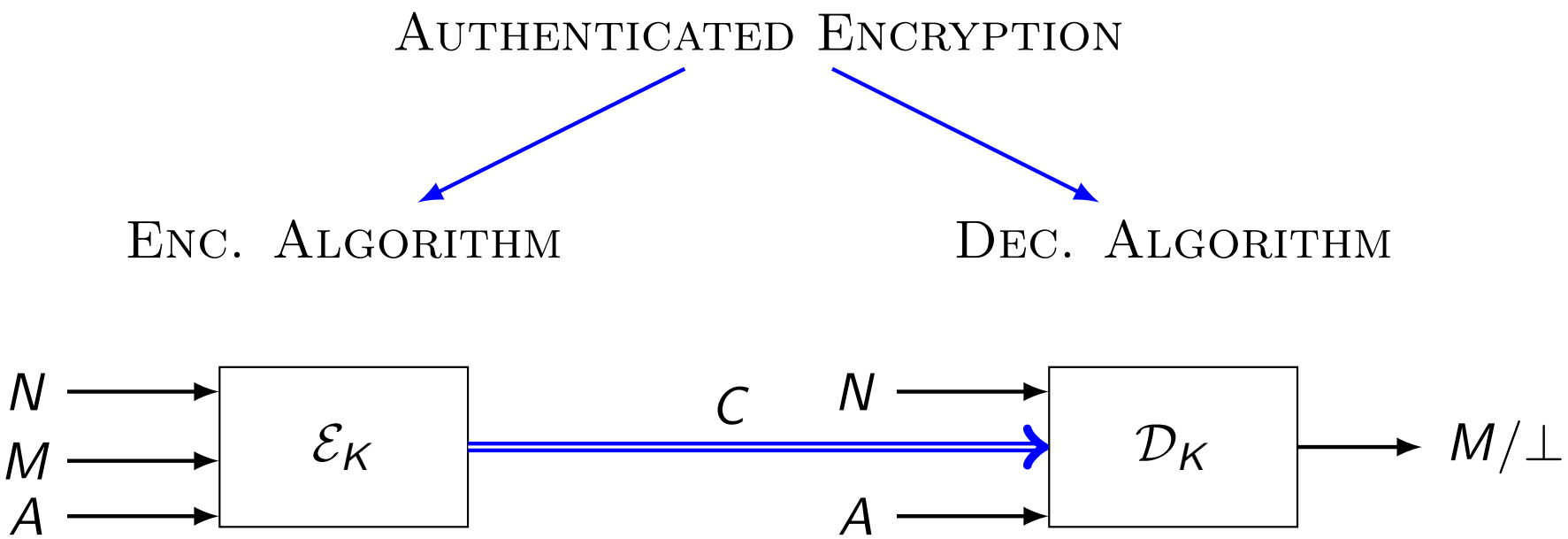
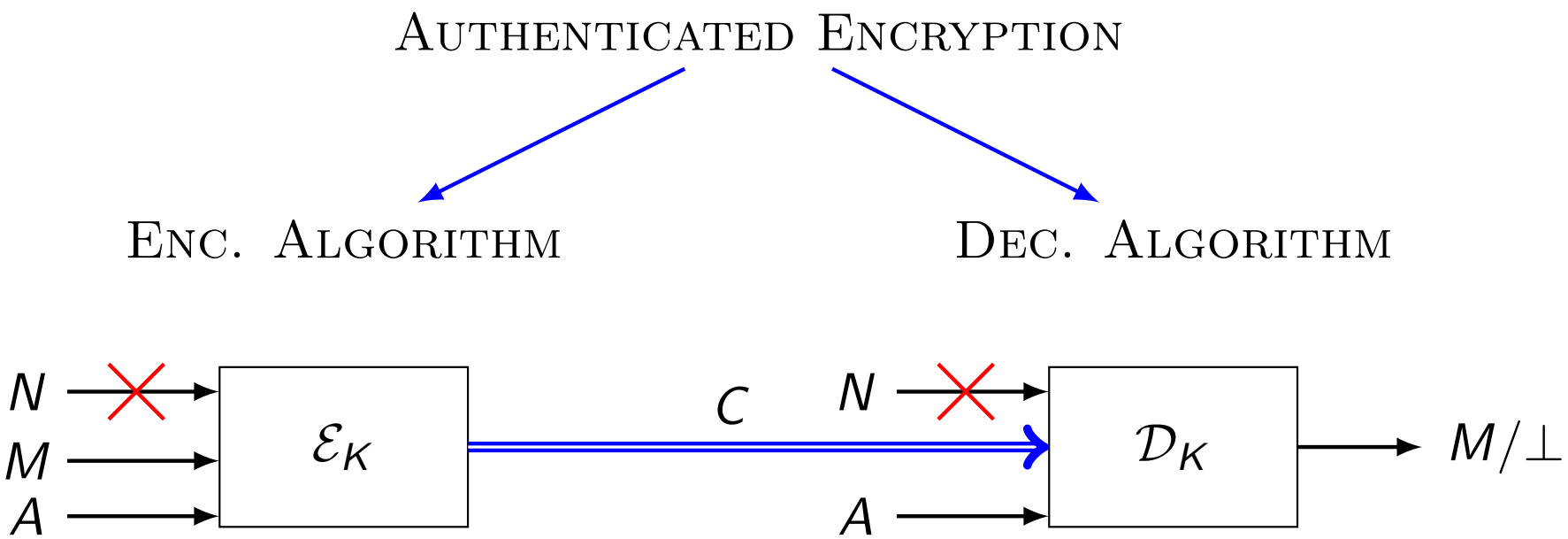


- Stateful AE (Nonce, Random IV or Arbitrary IV Based).
- Stateless AE.

Stateful Authenticated Encryption (AE)

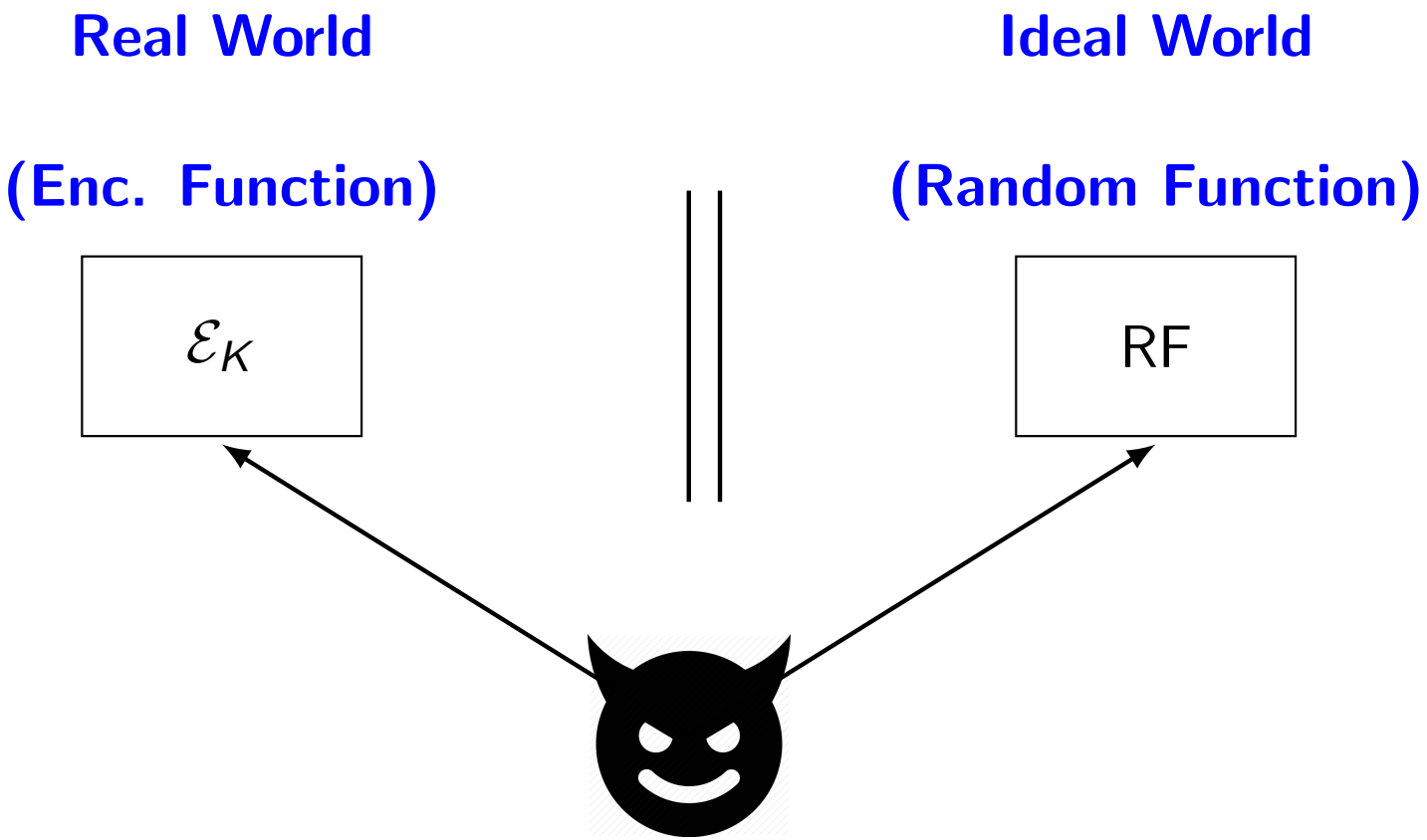


Stateless Authenticated Encryption (AE)



Security of AE

Privacy Requirement (IND-CPA).



Security of AE

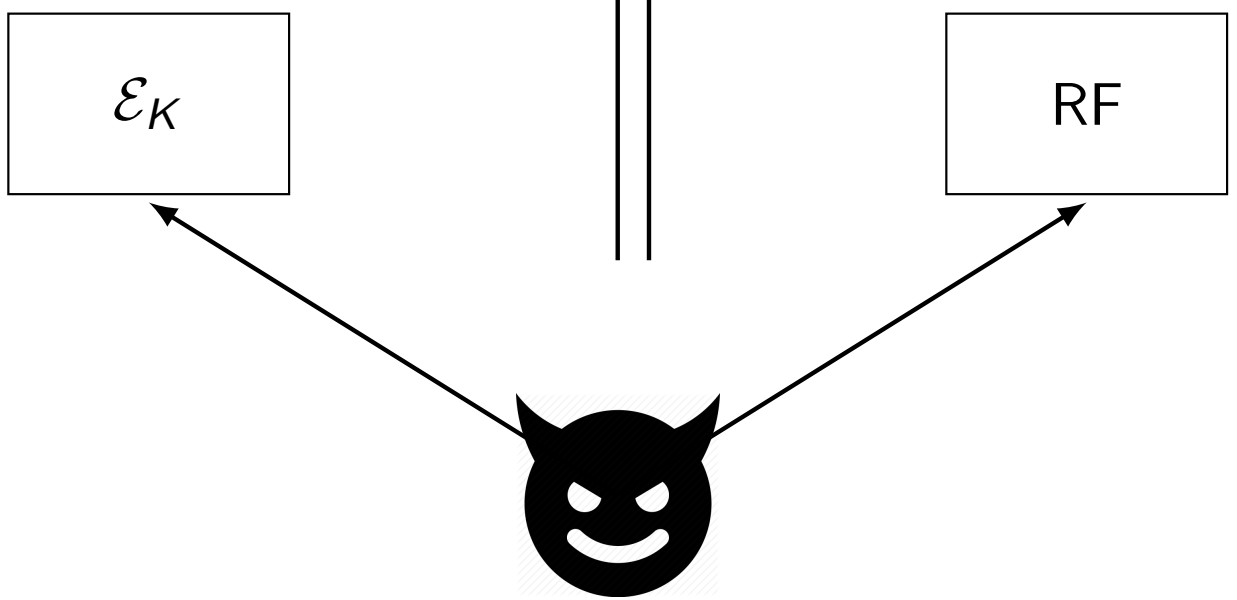
Privacy Requirement (IND-CPA).

Real World

(Enc. Function)

Ideal World

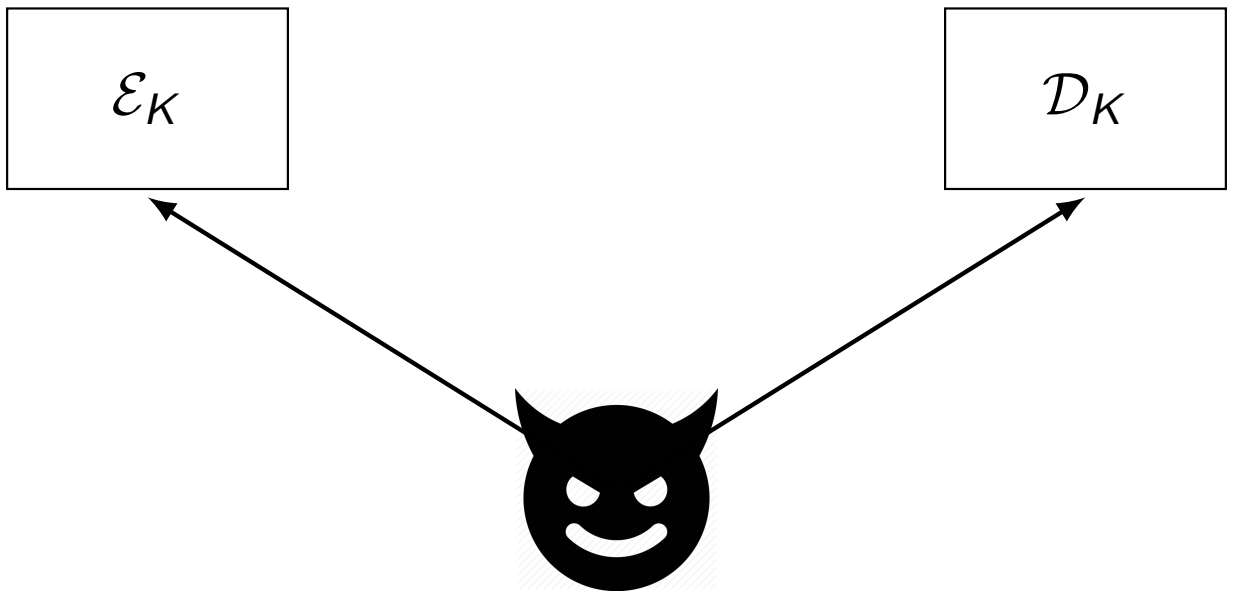
(Random Function)



For a secure AE, the distinguishing advantage is negligible.

Security of AE

Integrity Requirement (INT-CTXT).



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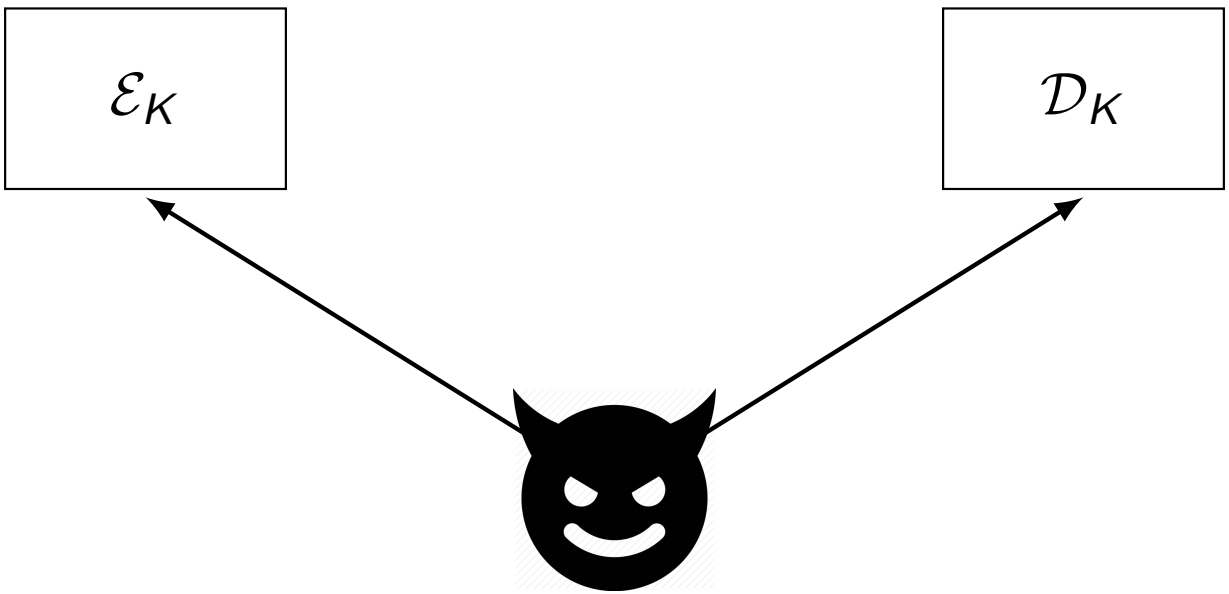

$\mathcal{A}$ forges if $\mathcal{A}$ can produce a non-trivial (N^*, A^*, C^*) tuple such that

$$\mathcal{D}_K(N^*, A^*, C^*) = M^*.$$

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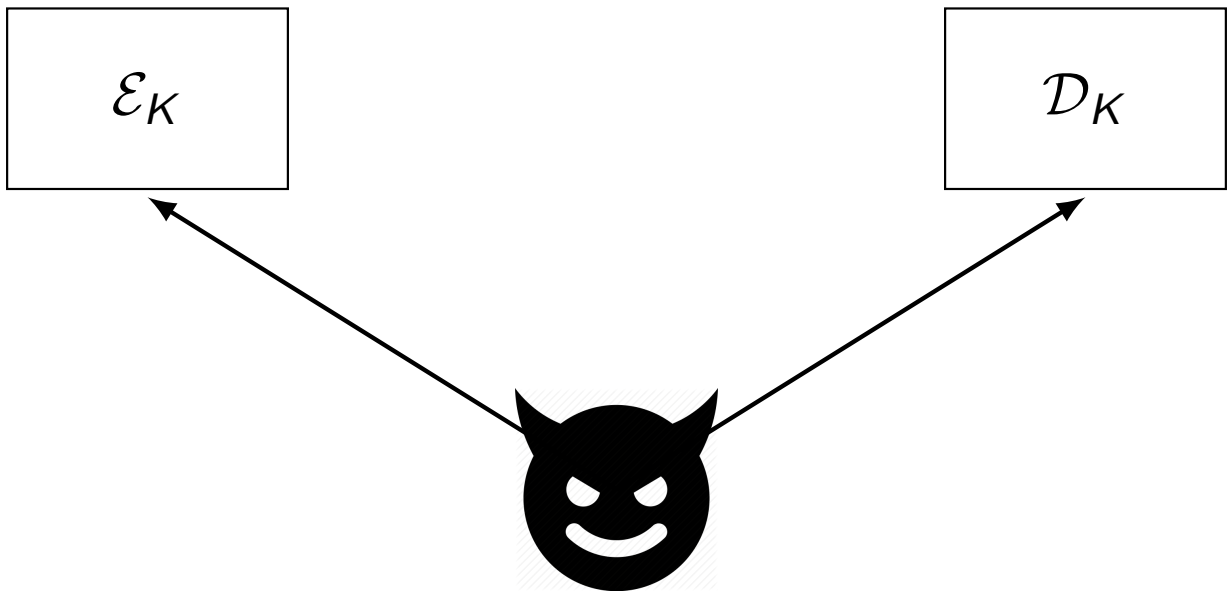

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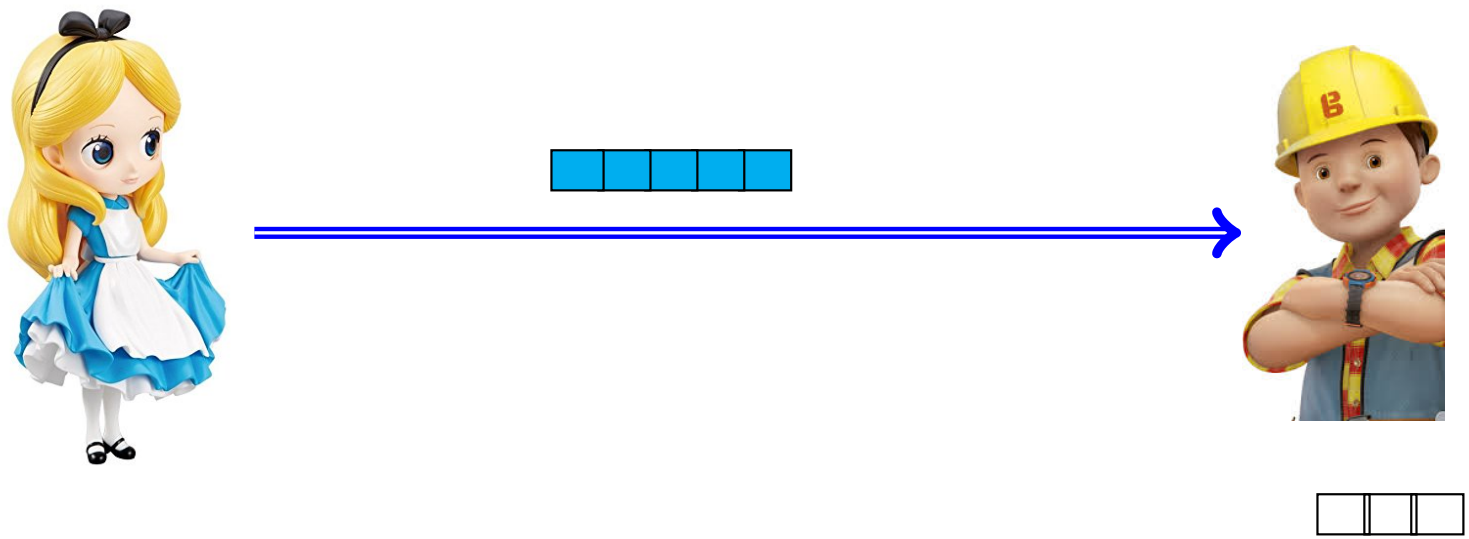
For a secure AE, the forging advantage is negligible.

Security of AE

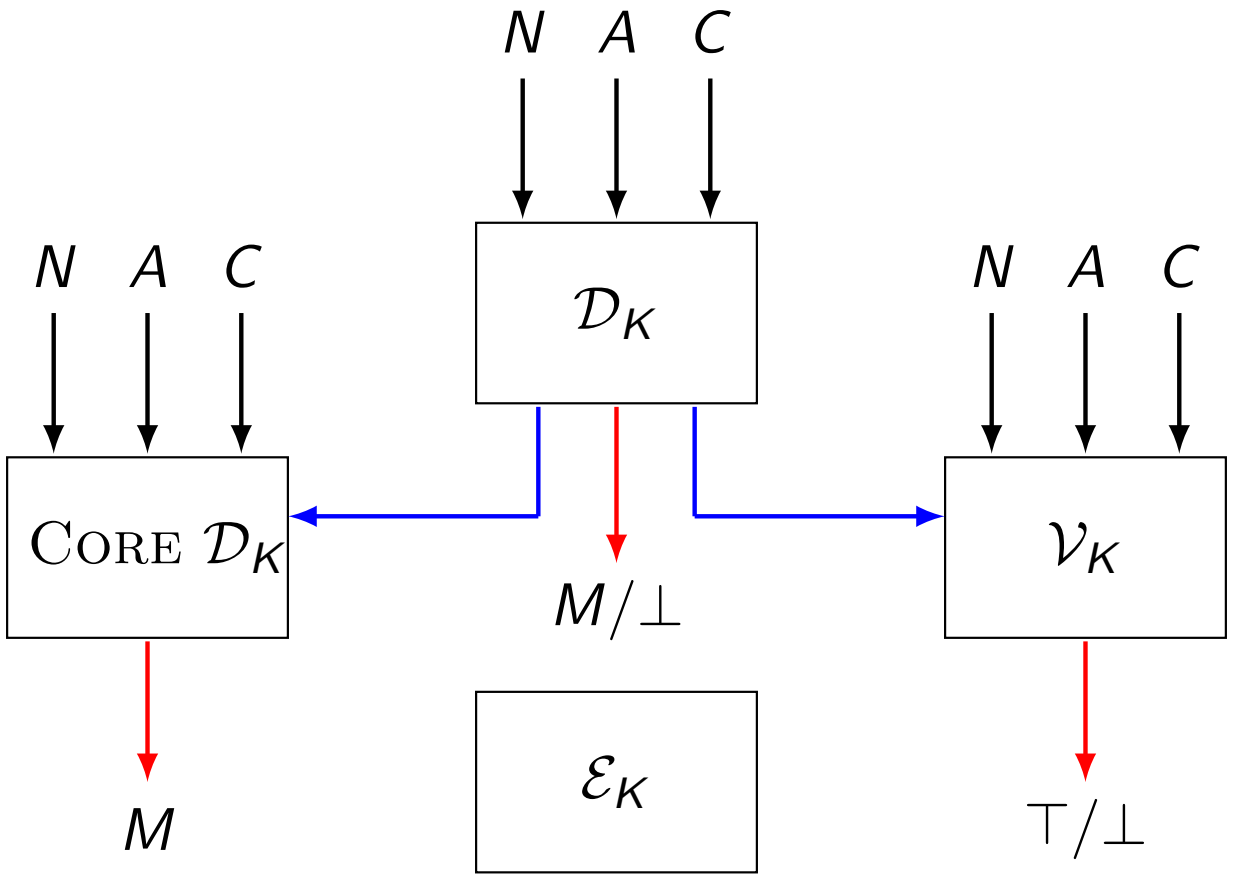
An AE scheme is secure in a conventional sense if it achieves IND-CPA and INT-CTXT security.

Release of Unverifiable Plaintext (RUP) Issue of AE

- Plaintext blocks can only be released after successful verification in the receiver end.
- But the buffer size in the receiving end is limited. As a result, it might not be able to hold the entire plaintext at once.
- **Receiver might have to release the plaintext before verifying.**



RUP Security Model



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Security of AE in RUP Model formalized by Andreeva et al. (ASIACRYPT 2014).

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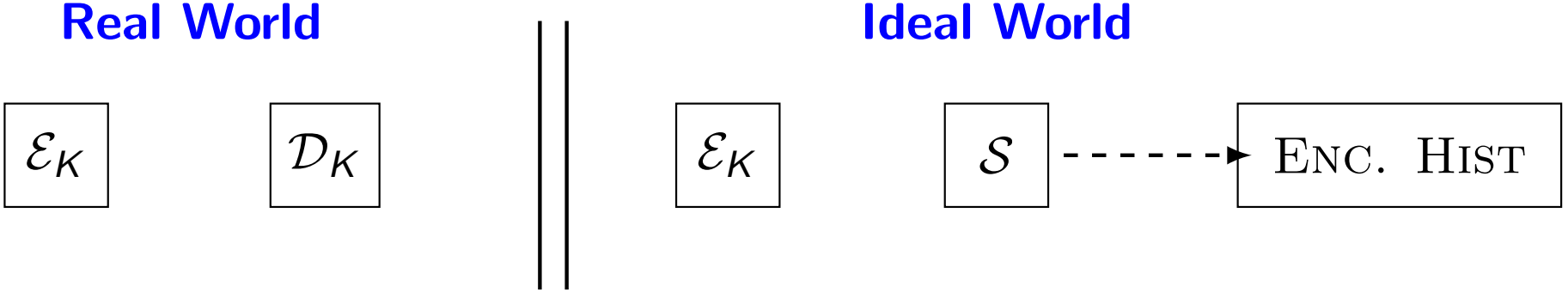
PA1 Notion.



RUP Security Model

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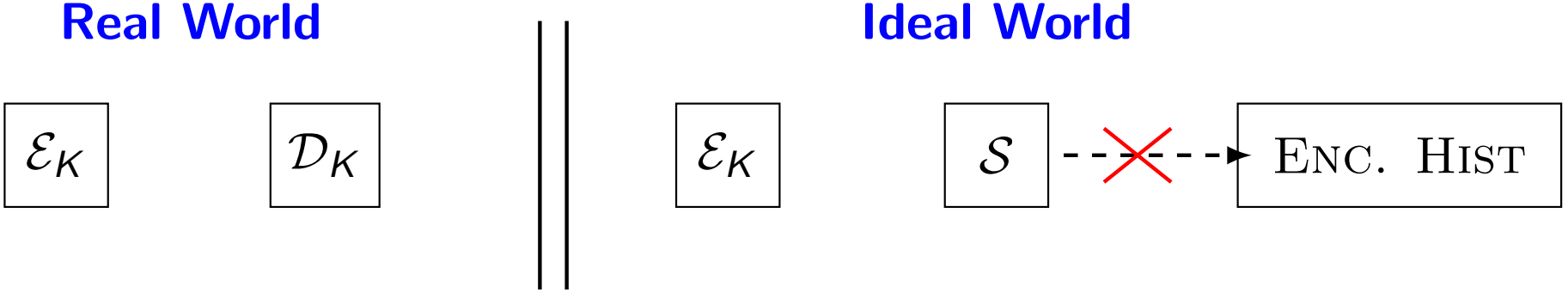
PA2 Notion.



RUP Secure AE

An AE scheme is RUP secure if it achieves IND-CPA and PA1 and INT-RUP security.

Different Variants of RUP Security

- Hoang et al. introduced RAE notion (EUROCRYPT 2015).
  - **Distinguish AE from a random injective function.**
- Hoang et al. introduced RAE_{sim} notion (EUROCRYPT 2015).
  - **Employs PA2 notion.**
- Barwell et al. introduced SAE notion (IMACC 2015).
  - **Refinement of RAE for nonce based AE.**
- Ashur et al. introduced RUPAE notion (CRYPTO 2017).
  - **Focuses on nonce based AE.**
  - **PA1 + INT-RUP with the ideal model decryption being a random function.**

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We need a security model in RUP scenario which allows

- Nonce Misuse.
- Single pass decryption feature.

AERUP Security Notion

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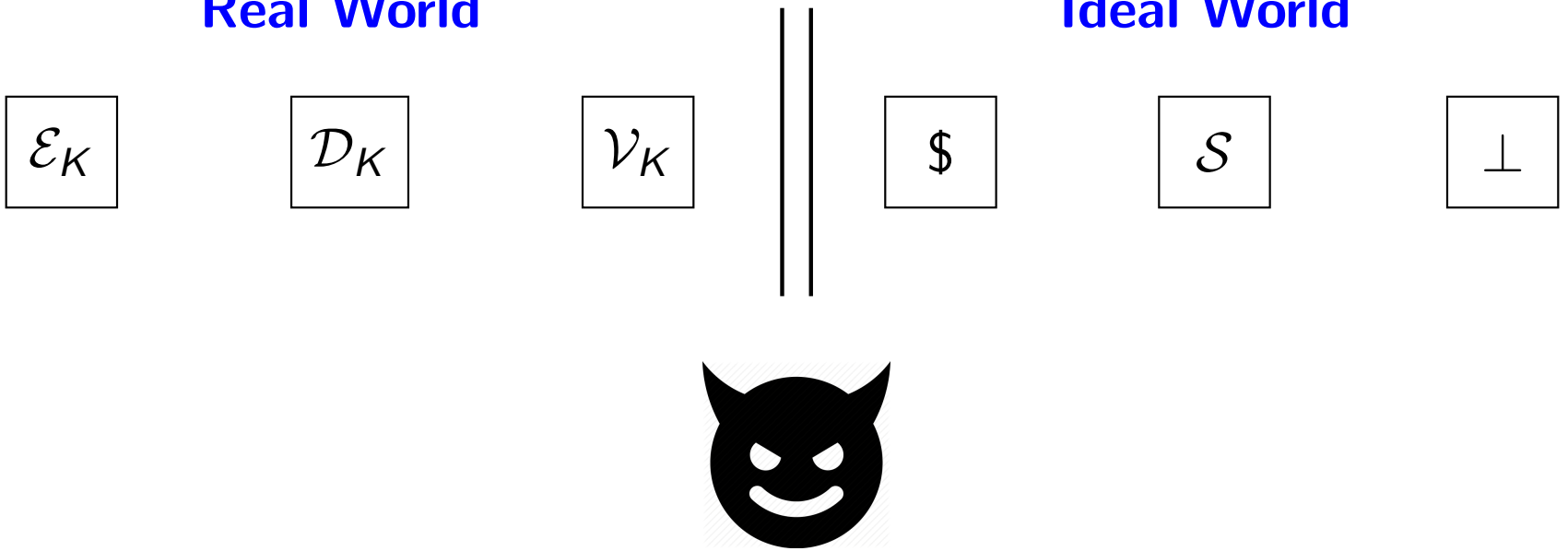
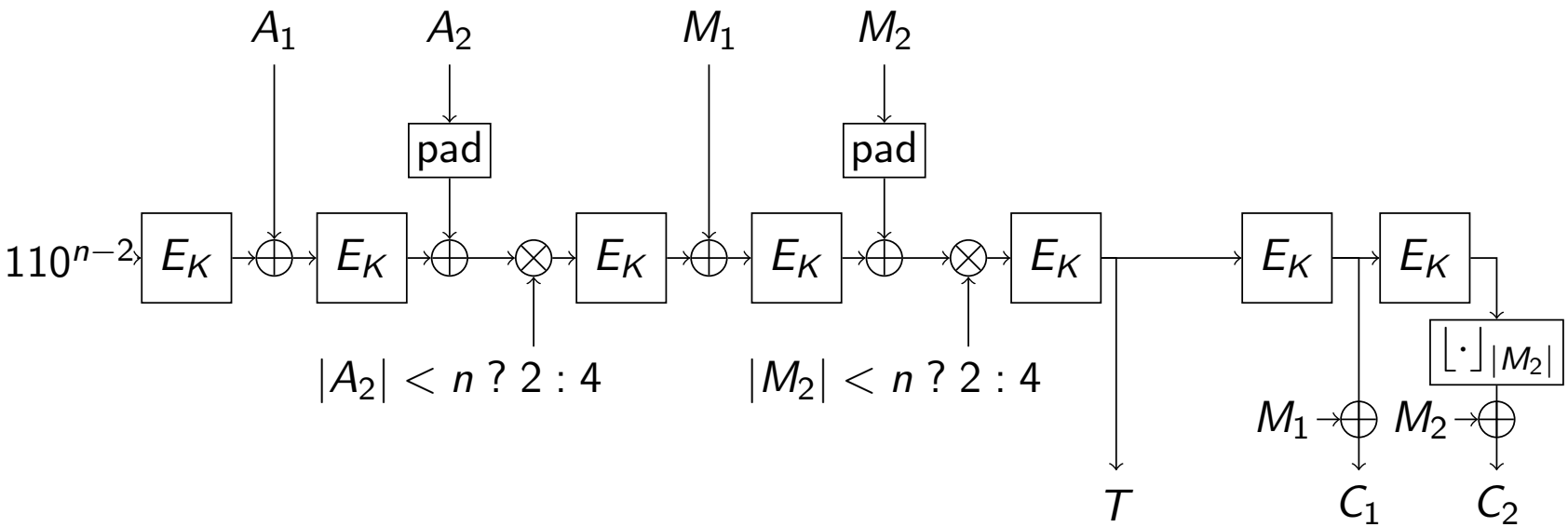
Real World **Ideal World**



AERUP $\iff$ AE + PA1 + INT-RUP.

SUNDAE [Banik et al., FSE 2019]



- Determinstic AE.

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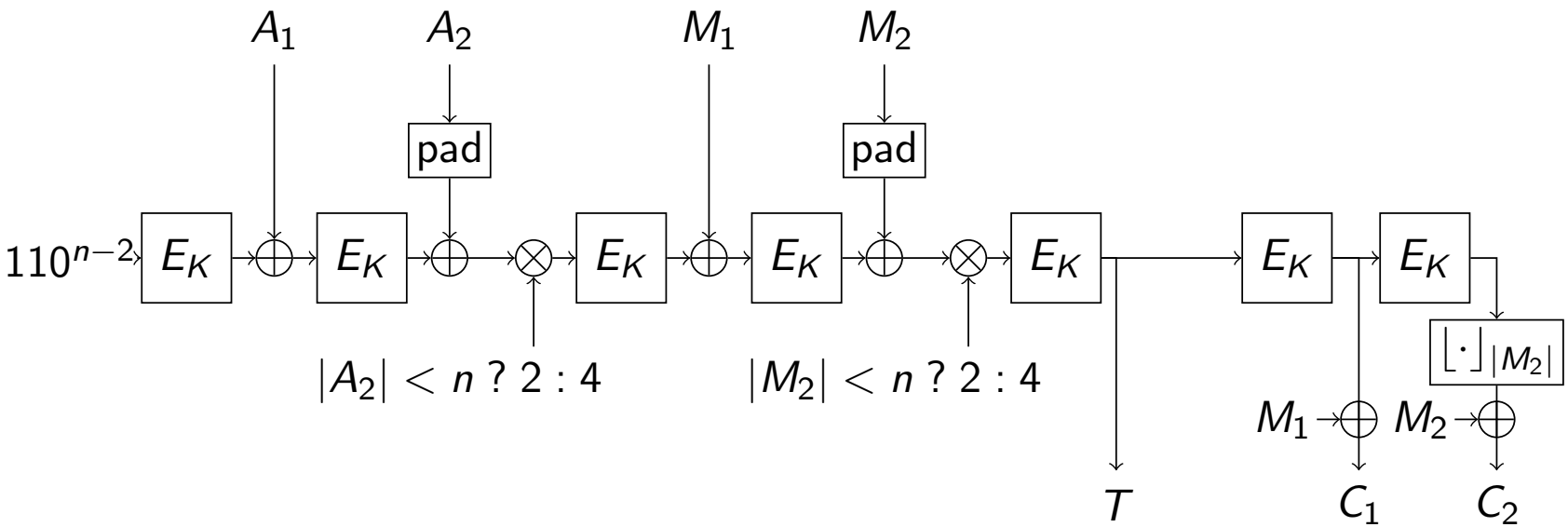

- Determinstic AE.
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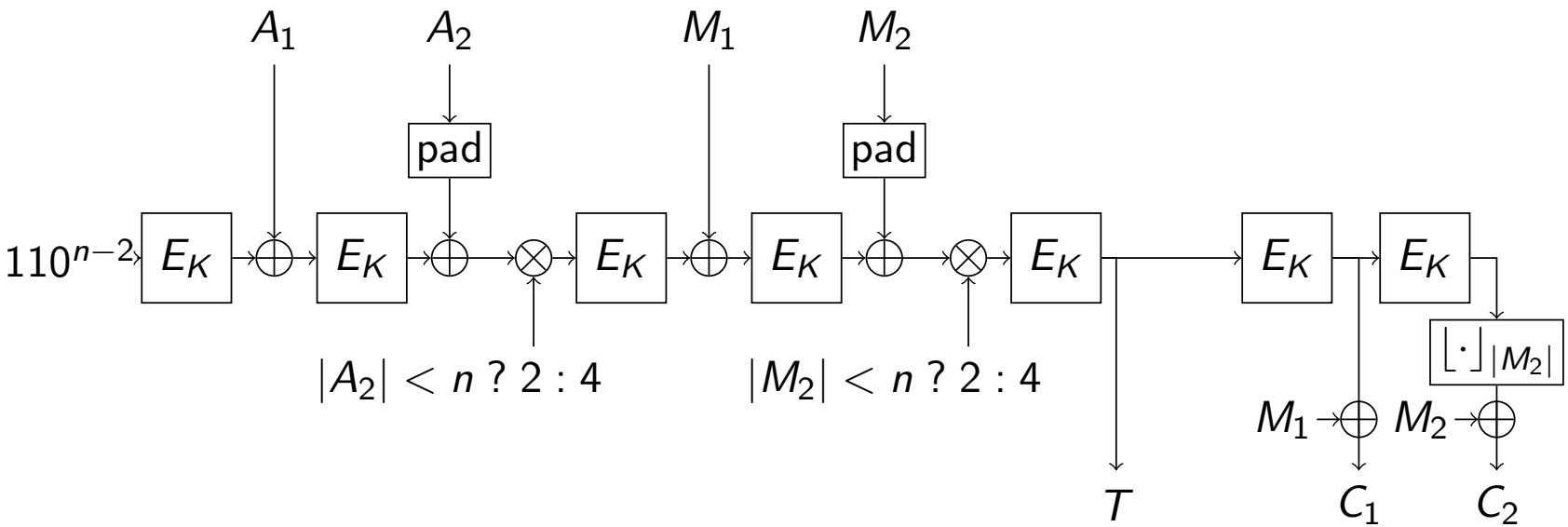

- Determinstic AE.
- Makes $a + 2m + 1$ BC invocations.
- One of the AE Candidates in NIST Lightweight Cryptography competition.

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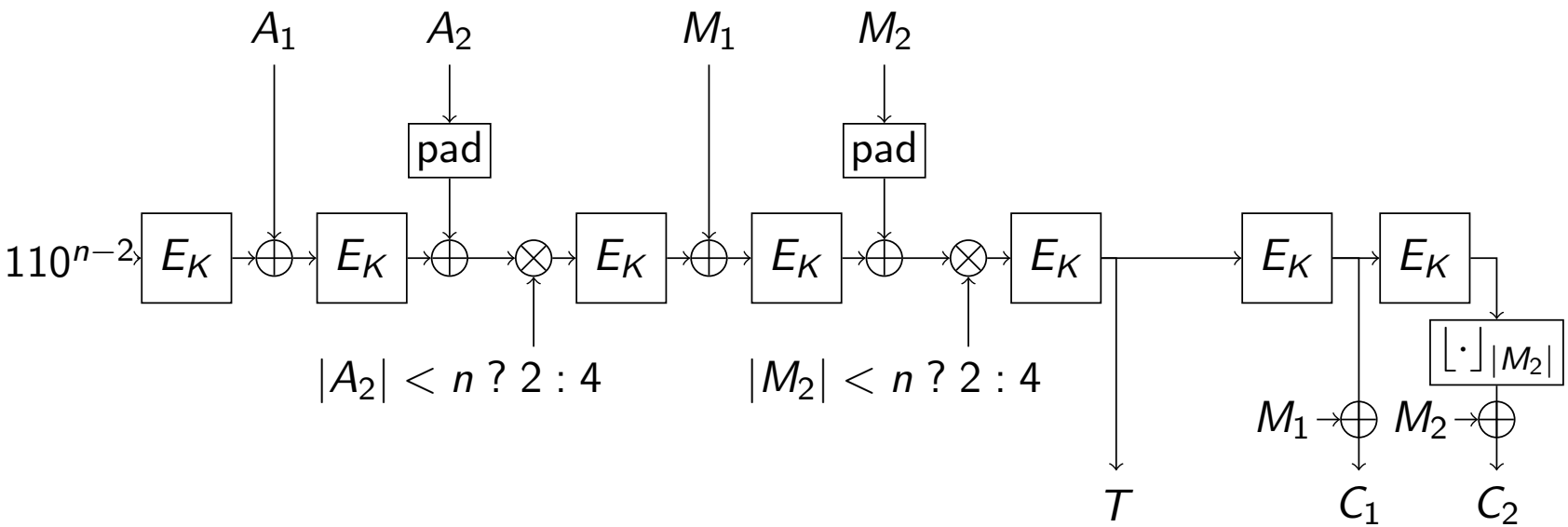

- SUNDAE is particularly efficient for short messages.

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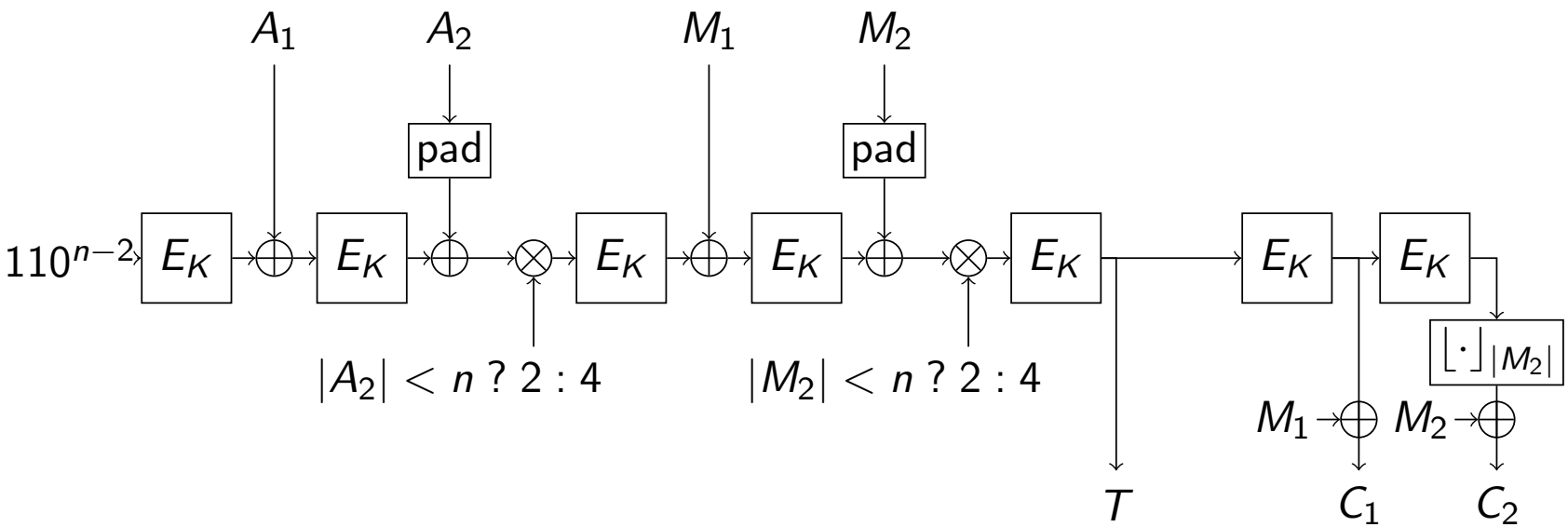

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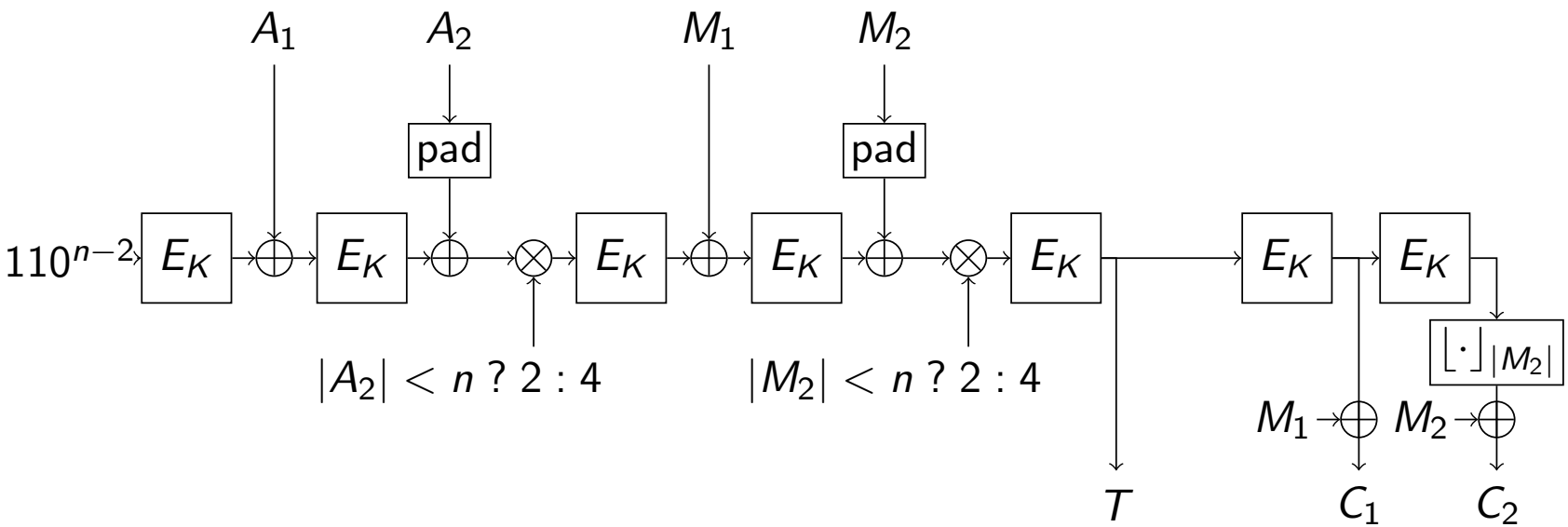
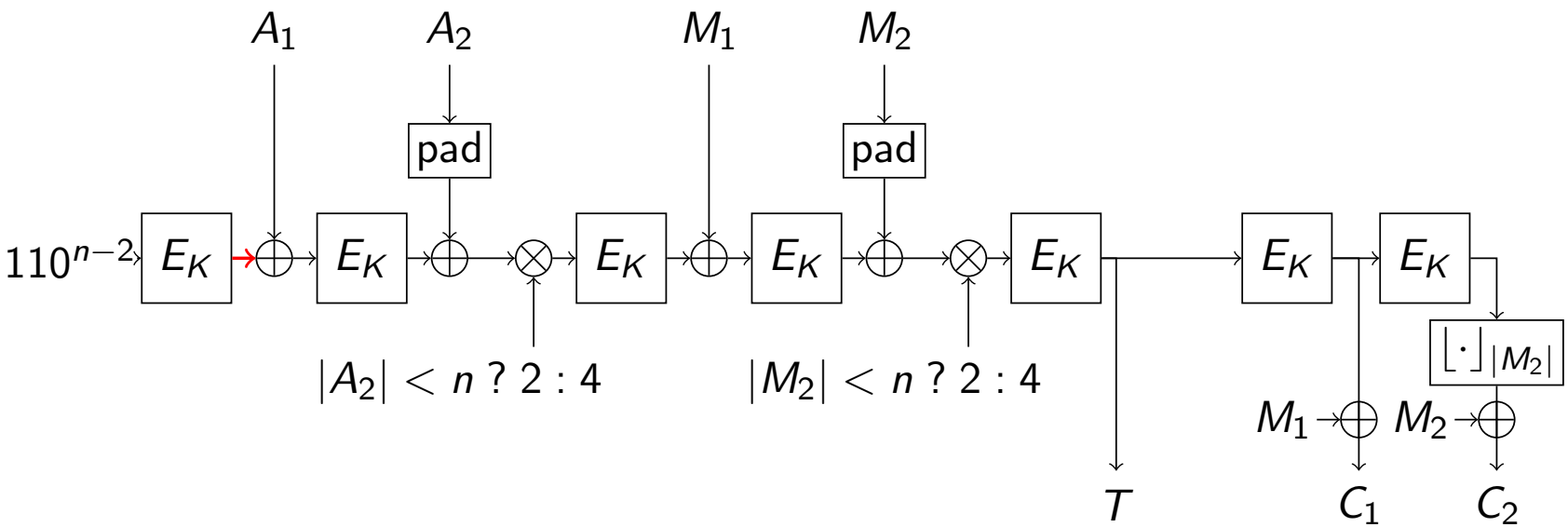


- SUNDAE is particularly efficient for short messages.
- State size as small as the block size.
- Offers good implementation characteristics both on lightweight and high-performance platforms.

SUNDAE is not RUP Secure: INT-RUP Insecurity



1. $\mathcal{A}$ makes query $\mathcal{D}_K(\epsilon, T_1, C_1[1])$, where $T_1 = 110^{n-2}$ and obtains $M_1[1]$.

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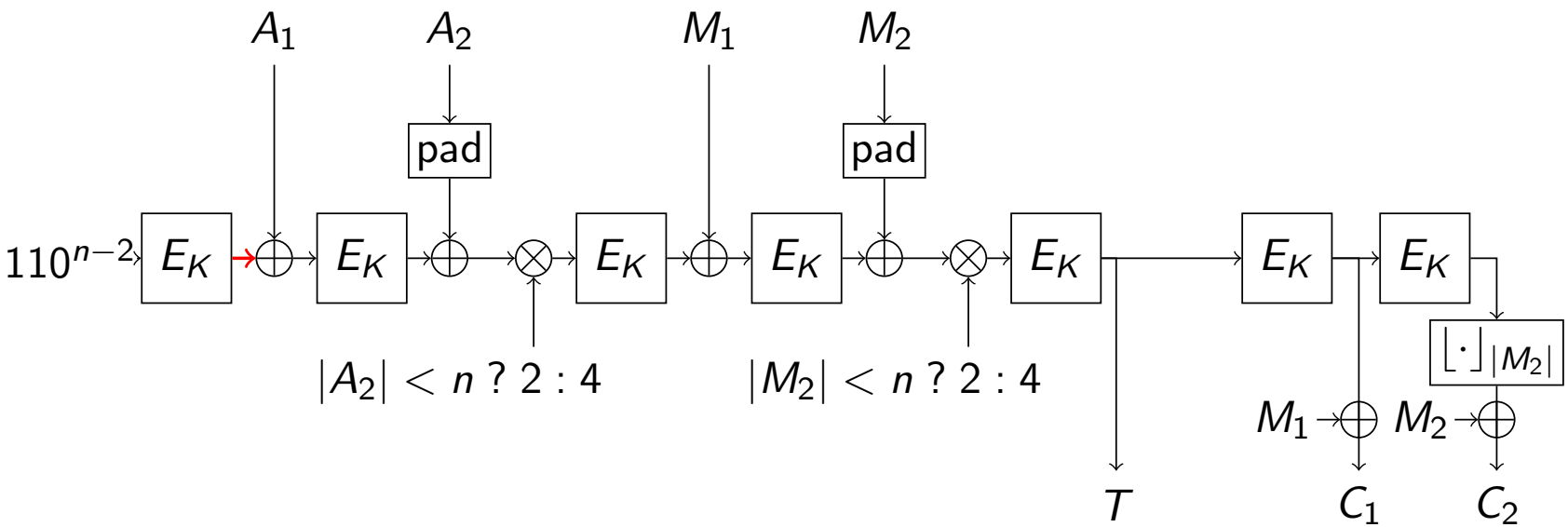

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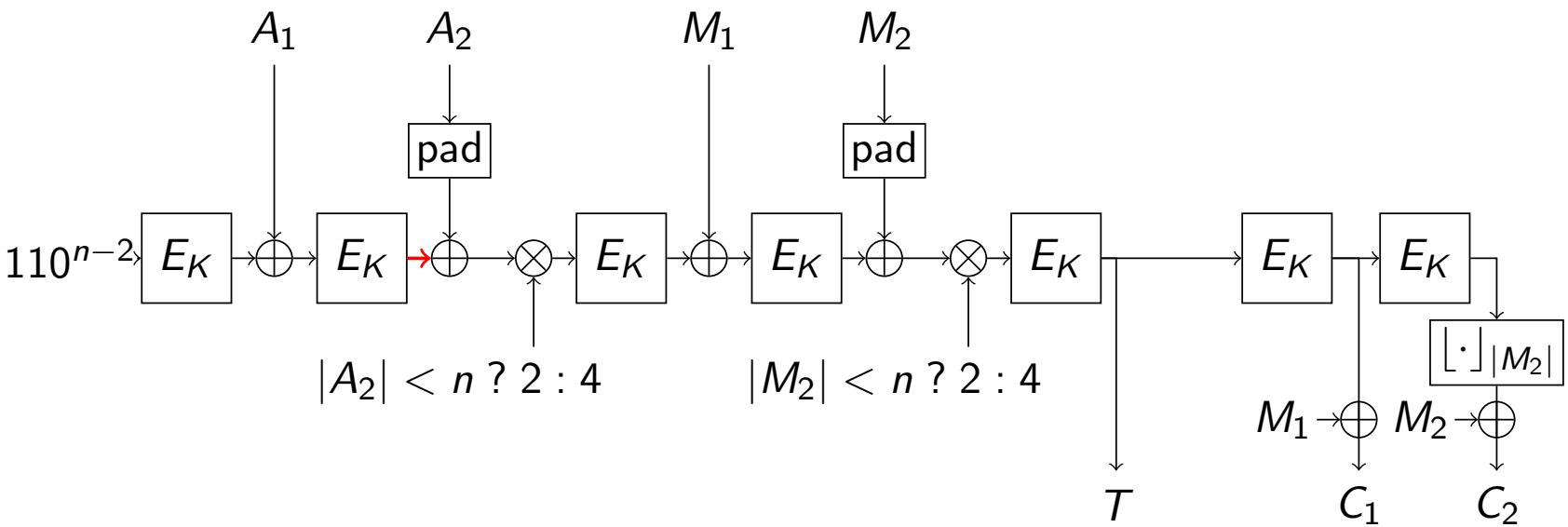

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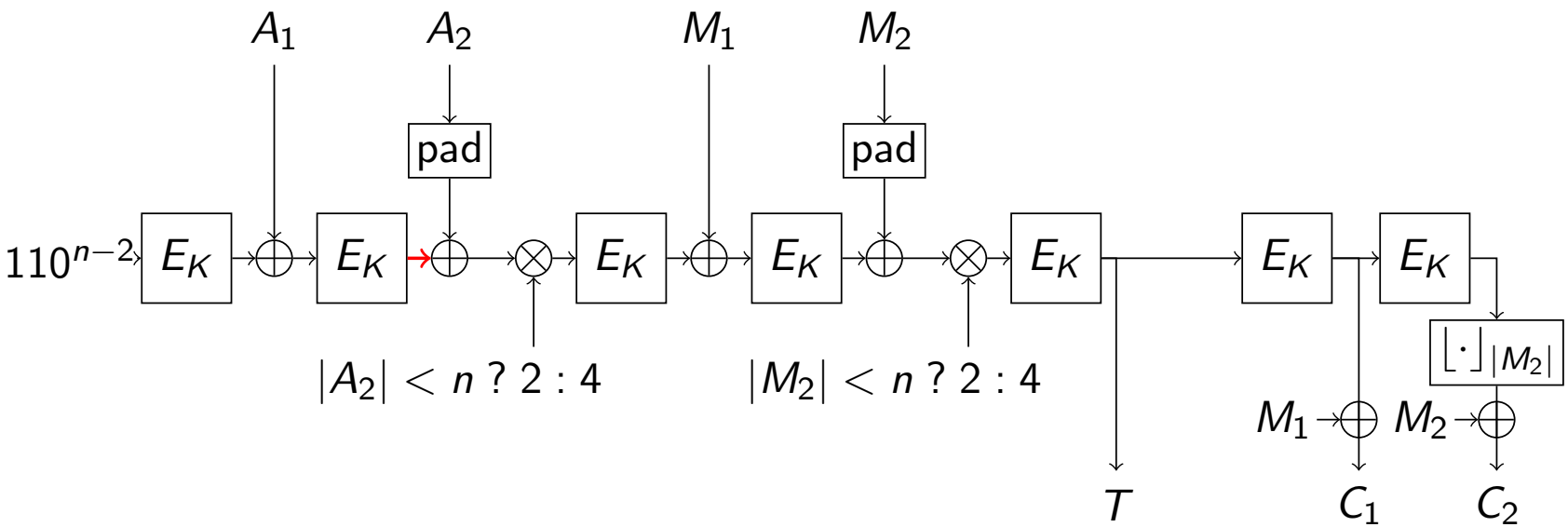

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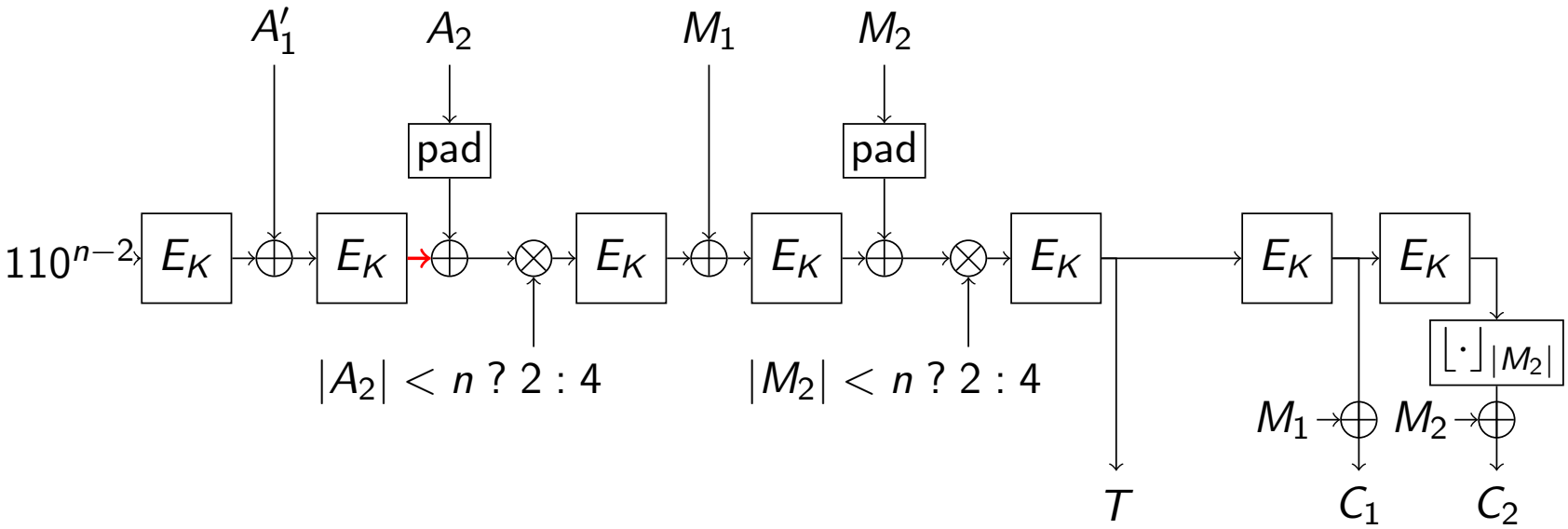

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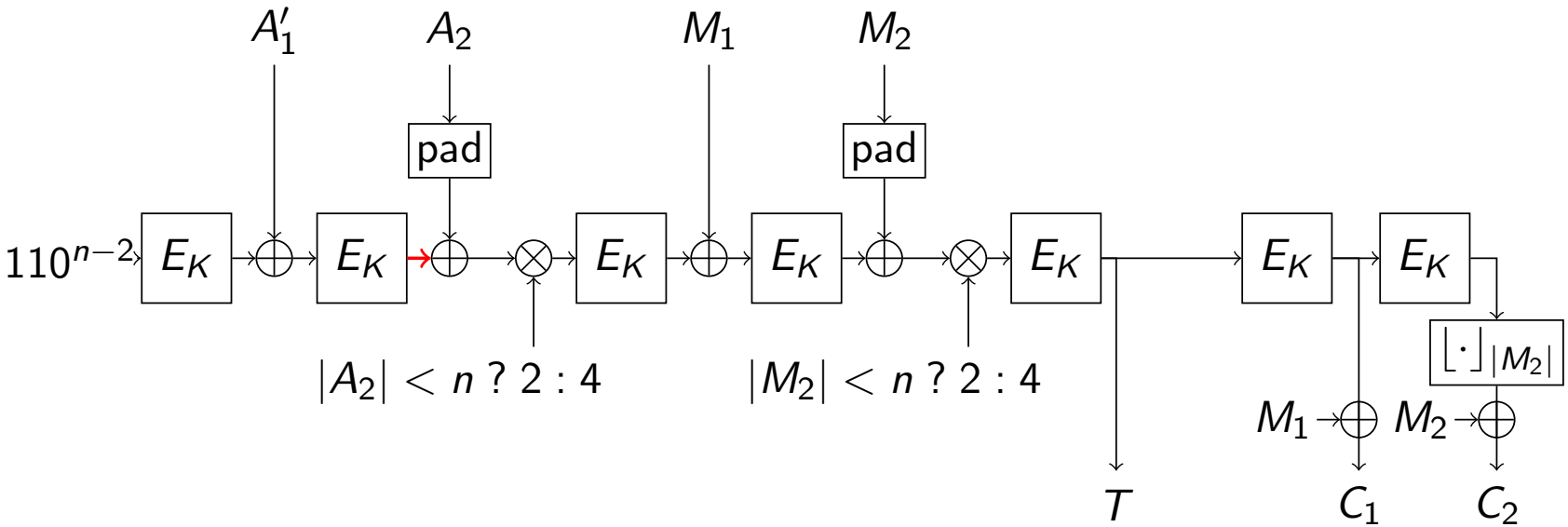

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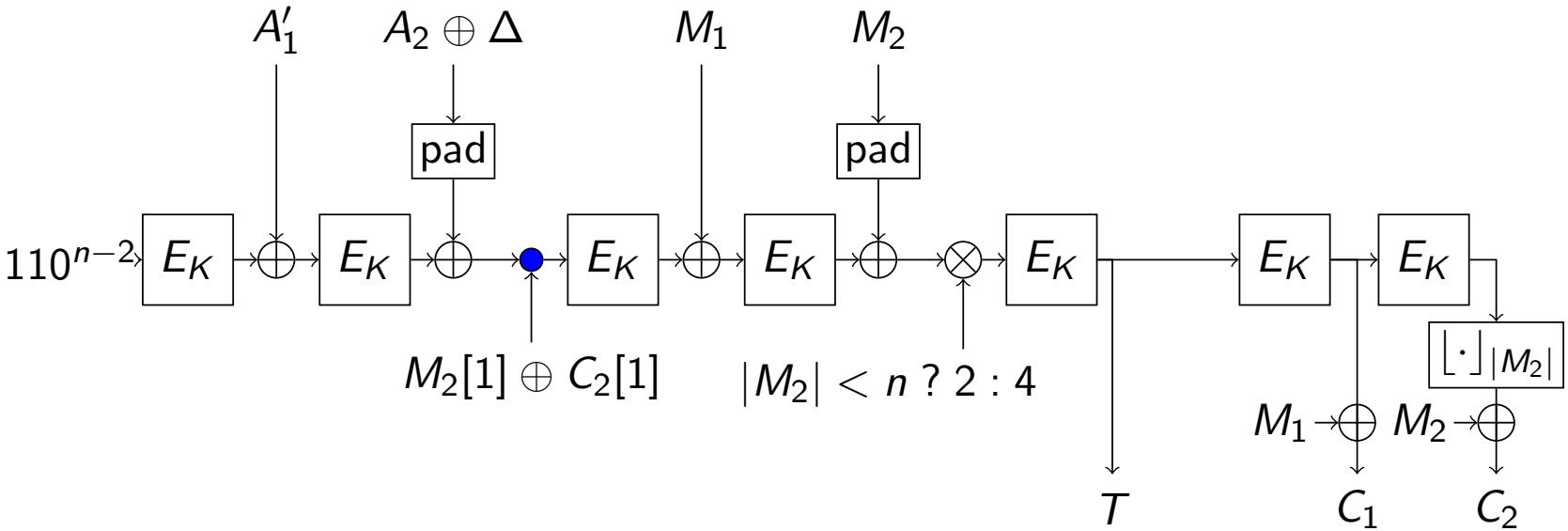

4. $\mathcal{A}$ makes query $\mathcal{E}_K(A'[1] \| (A[2] \oplus \Delta) \| A[3] \| \ldots \| A[a], M))$ and obtains (C, T), $\Delta = M_2[1] \oplus C_2[1] \oplus M_3[1] \oplus C_3[1]$.

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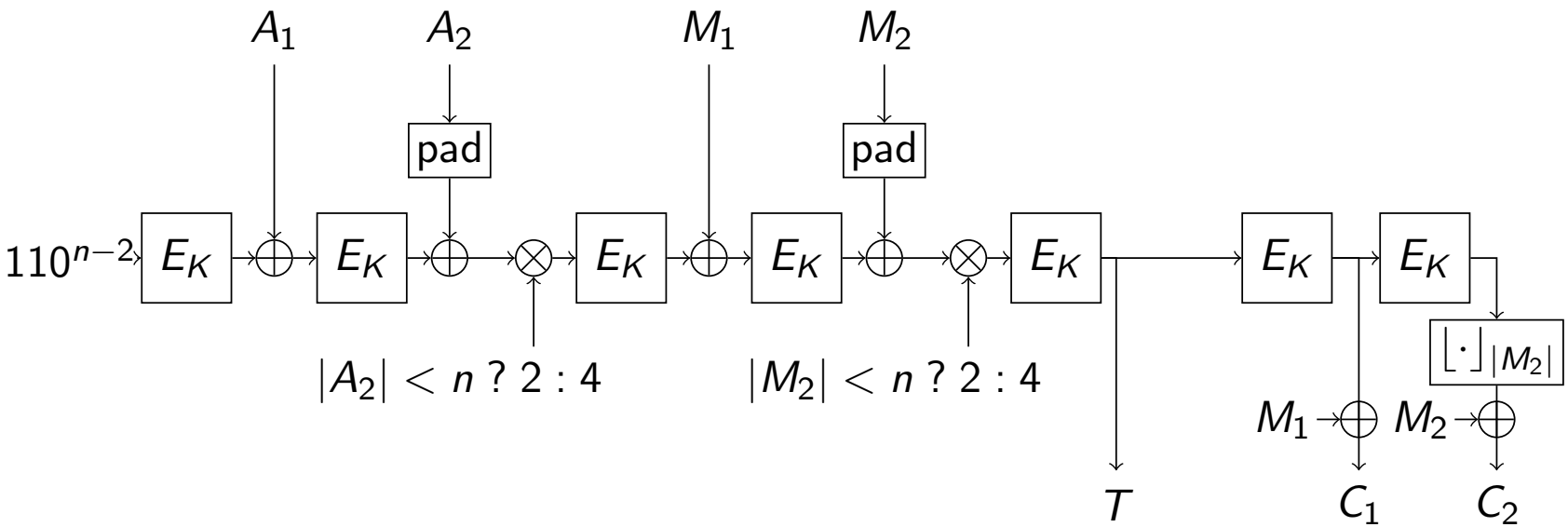

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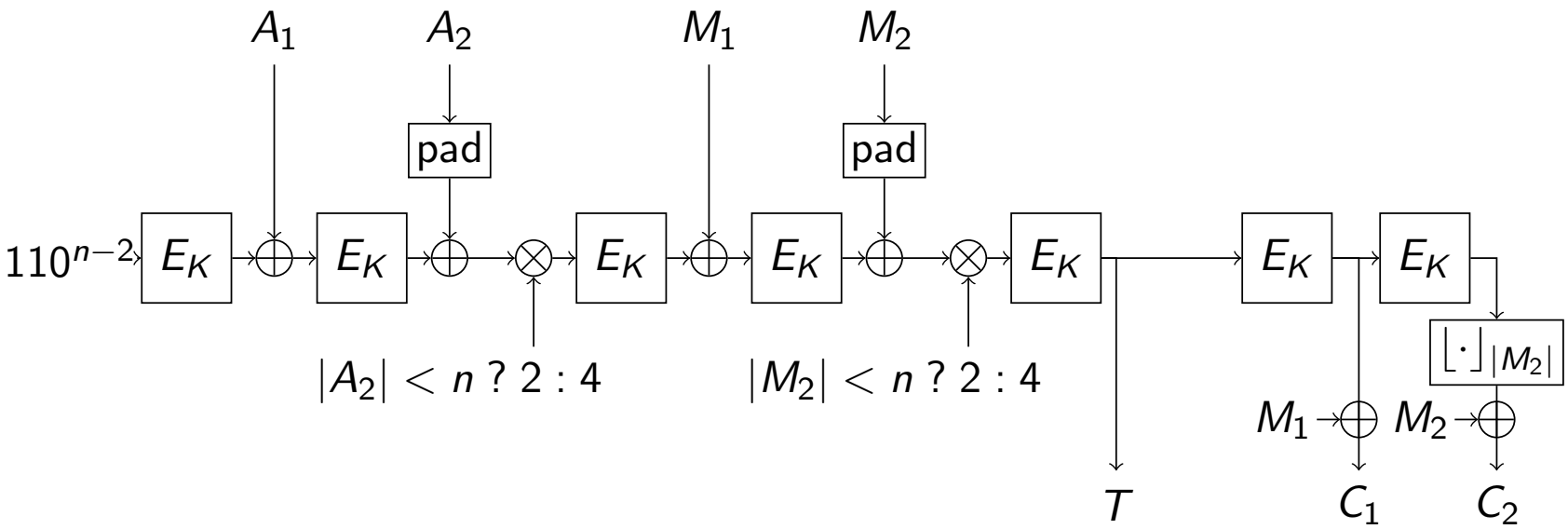

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SUNDAE is not INT-RUP Secure.

MONDAE: A RUP-Secure Variant of SUNDAE.

Remedy for INT-RUP Attack: MONDAE

Reason for INT-RUP attack on SUNDAE.

Adversary can learn $E_k(T)$ for any value of T.

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Can we make a small change to SUNDAE and make it RUP-Secure ?

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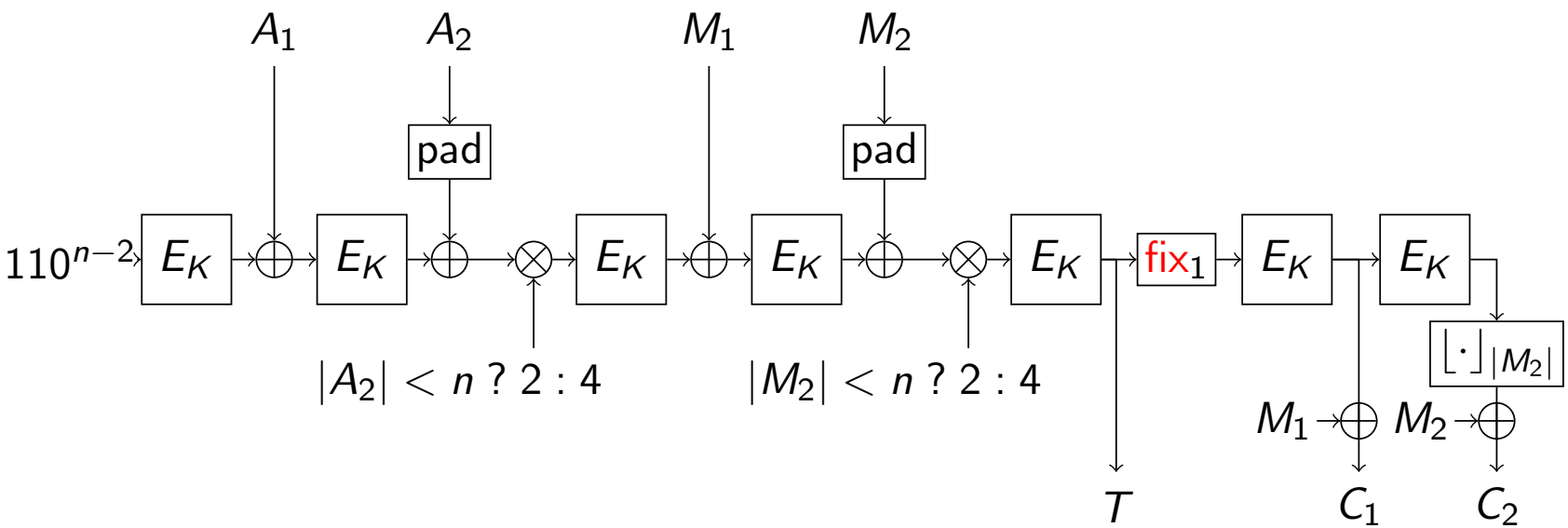
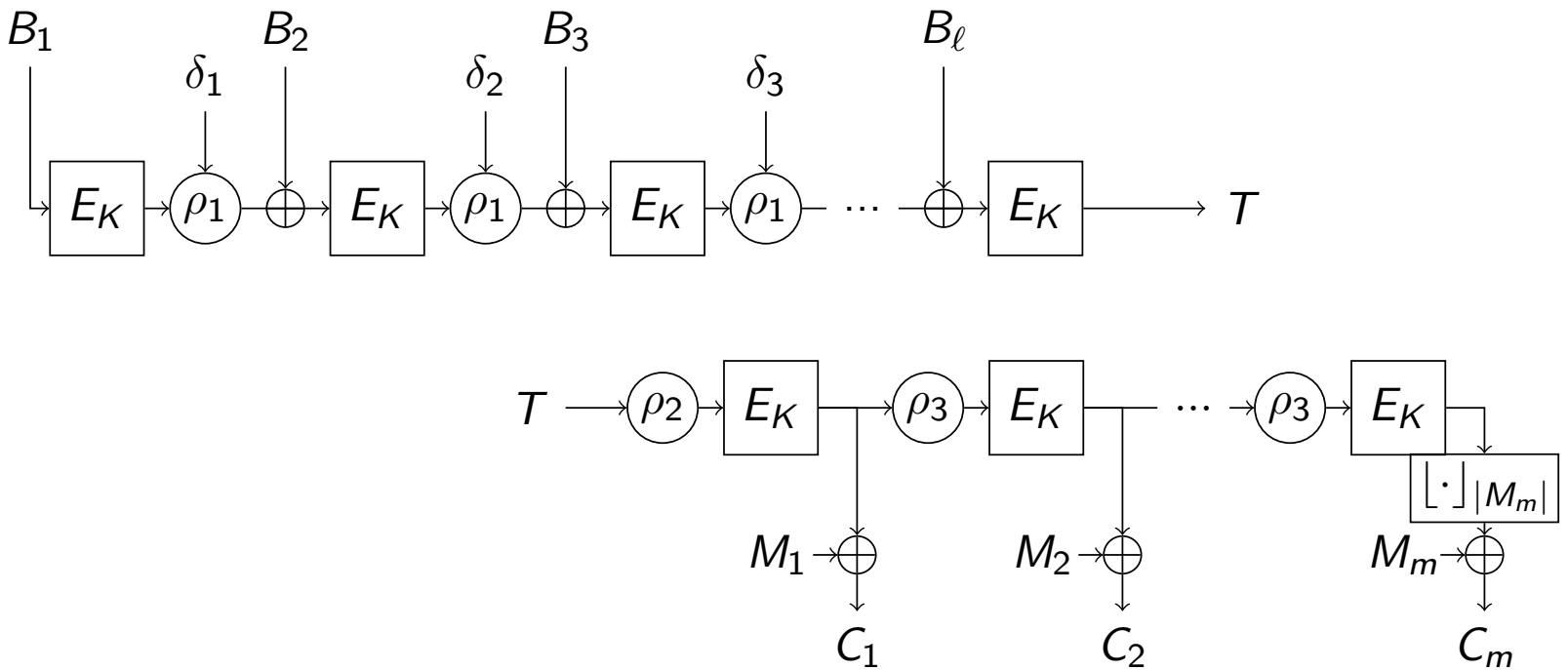


ANYDAE: A Generic RUP Secure AE

- $\mathsf{Fmt}(A, M) = ((B_1, \delta_1), \ldots, (B_{l-1}, \delta_{l-1}), B_l)$.
- $\rho_1(B_i, \delta_i) \to \{0,1\}^n$.
- $\rho_2, \rho_3 : \{0,1\}^n \to \{0,1\}^n$.



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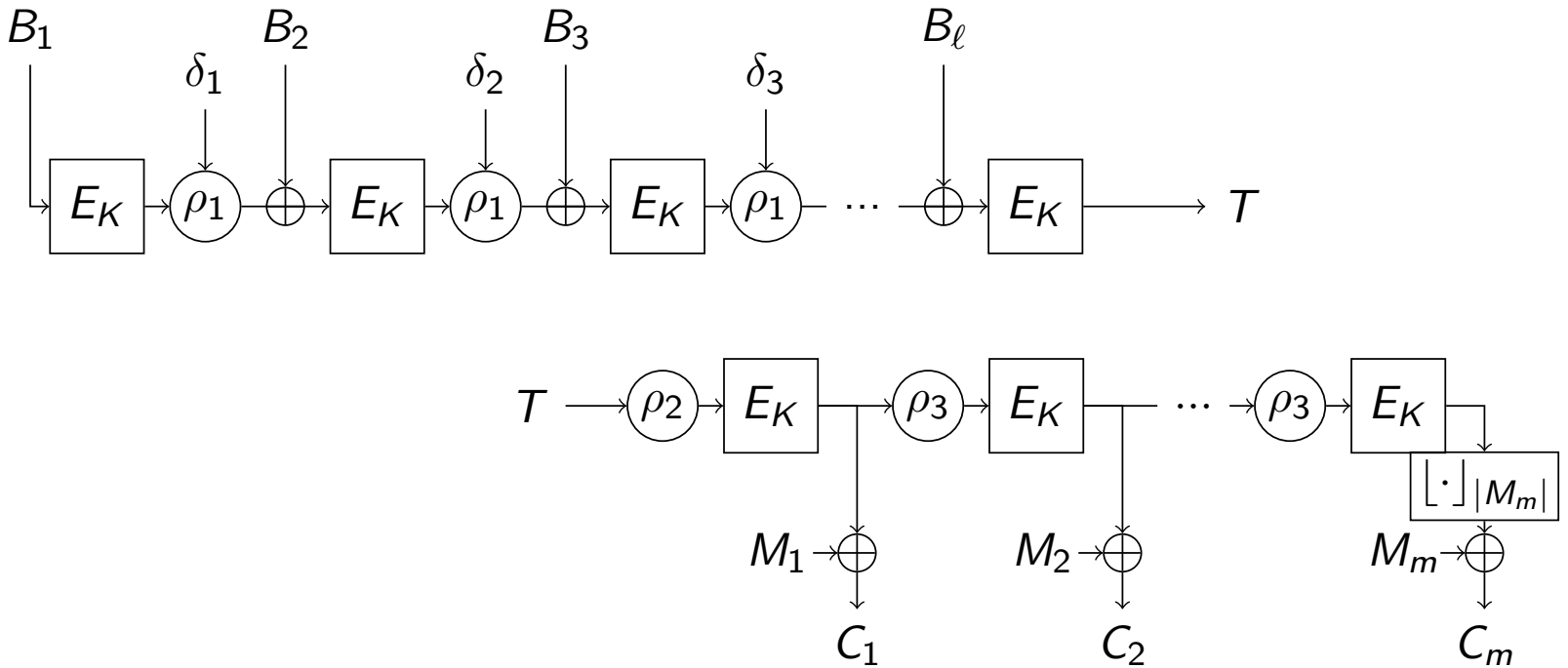

Is ANYDAE secure for any choice of Fmt, ρ_1, ρ_2 and ρ_3 function ?

Security of ANYDAE

$\mathcal{F}_1$ is the set of first block outputs of Fmt function.

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- If Fmt is injective and prefix free function.
- ρ_1 is ϵ_1 differential uniform and γ_1 regular function.
- ρ_2 is γ_2 regular and ρ_3 is γ_3 regular functions.
- $\mathcal{F}_1$ is disjoint from the range of ρ_2.
- $\Omega := |\mathcal{F}_1 \cap \mathrm{range}(\rho_3)|$.

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Security Result

$$\mathbf{Adv}_{\mathrm{ANYDAE}}(\sigma, q_d) \lesssim \frac{\sigma^2}{2^n} + \Omega\sigma \cdot \gamma_3 + \frac{q_d}{2^n}.$$

MONDAE and TUESDAE: Instantiations of ANYDAE

- MONDAE is an instantiation of ANYDAE where ρ_2 is fix_1 function.
- TUESDAE is a n-bit state DAE scheme and hence optimal instantiation of ANYDAE.
- MONDAE and TUESDAE are INT-RUP secure.
- TUESDAE makes optimal number of BC calls.
- This optimality comes at the cost of some additional multiplexers which could slightly increase the hardware area.

Thank You For Your Attention.