Parallelizable and Authenticated Online Ciphers[1]

Atul Luykx

COSIC
KU Leuven and iMinds

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[1] Joint work with E. Andreeva, A. Bogdanov, B. Mennink, E. Tischhauser, and K. Yasuda.

Motivation: Authenticated Encryption

Authenticated Encryption (AE) = Privacy + Authenticity

1. Applications: SSH, IPsec, TLS, IEEE 802.11
2. CAESAR competition

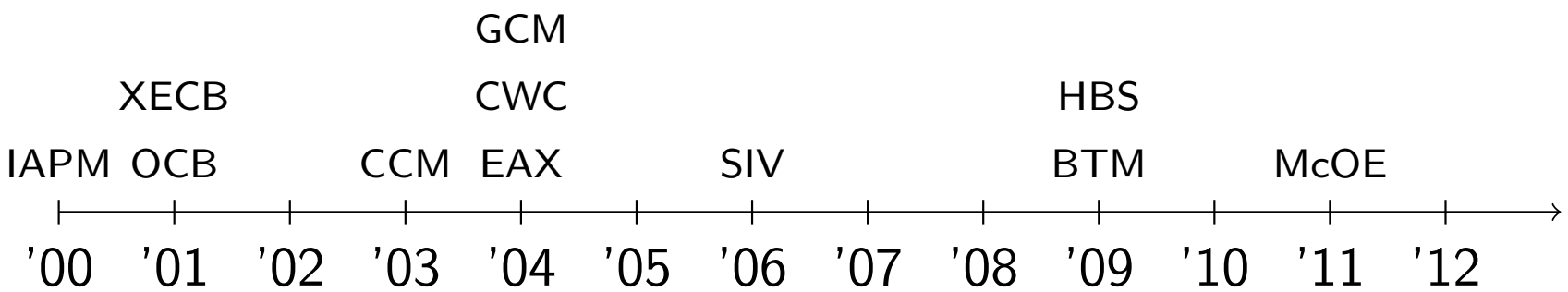

Figure : AE schemes

Motivation: Nonce Misuse

Authenticated Encryption (AE)

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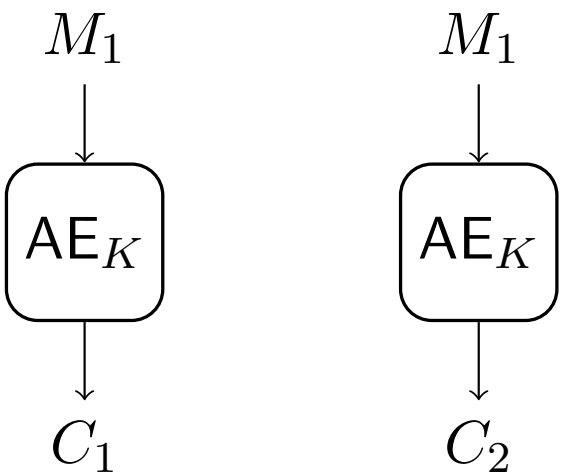

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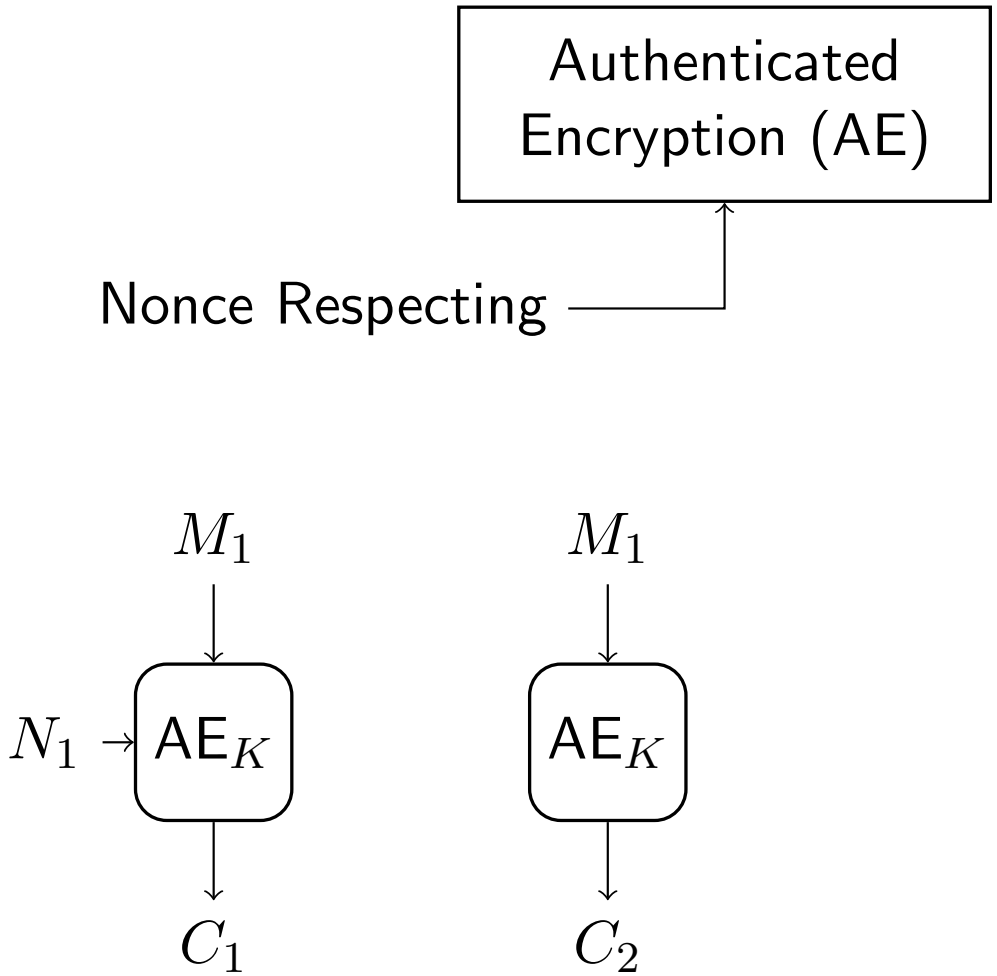

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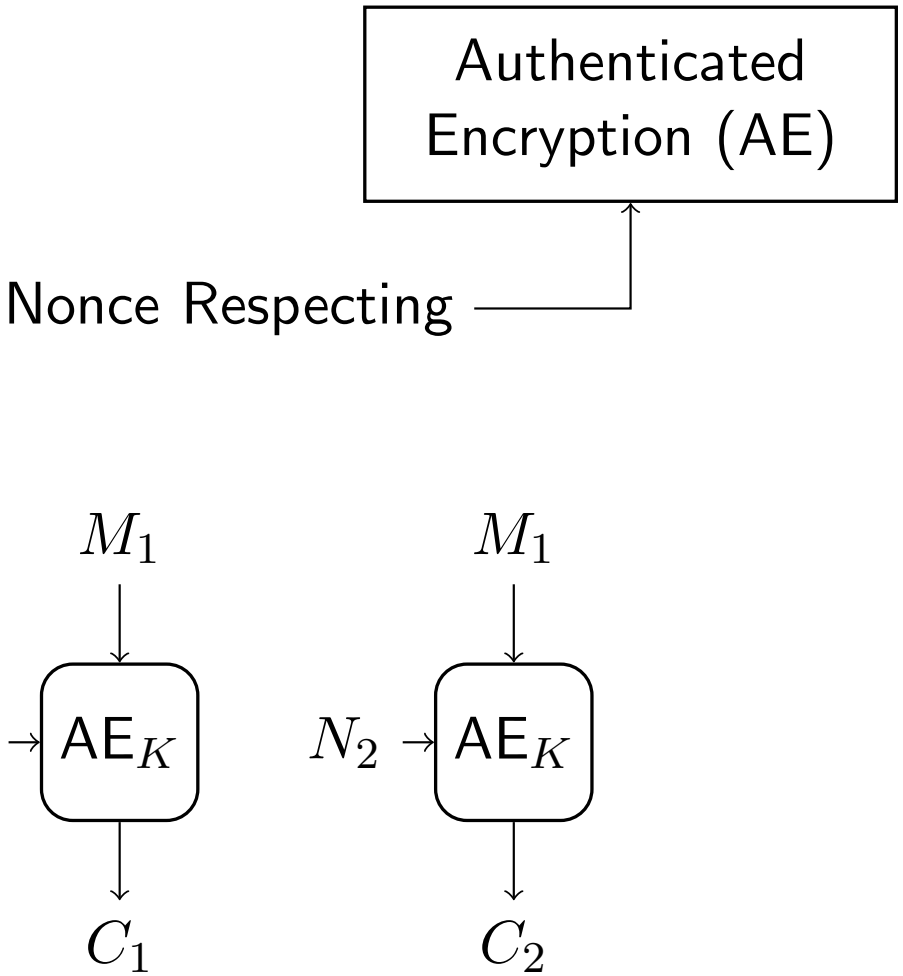

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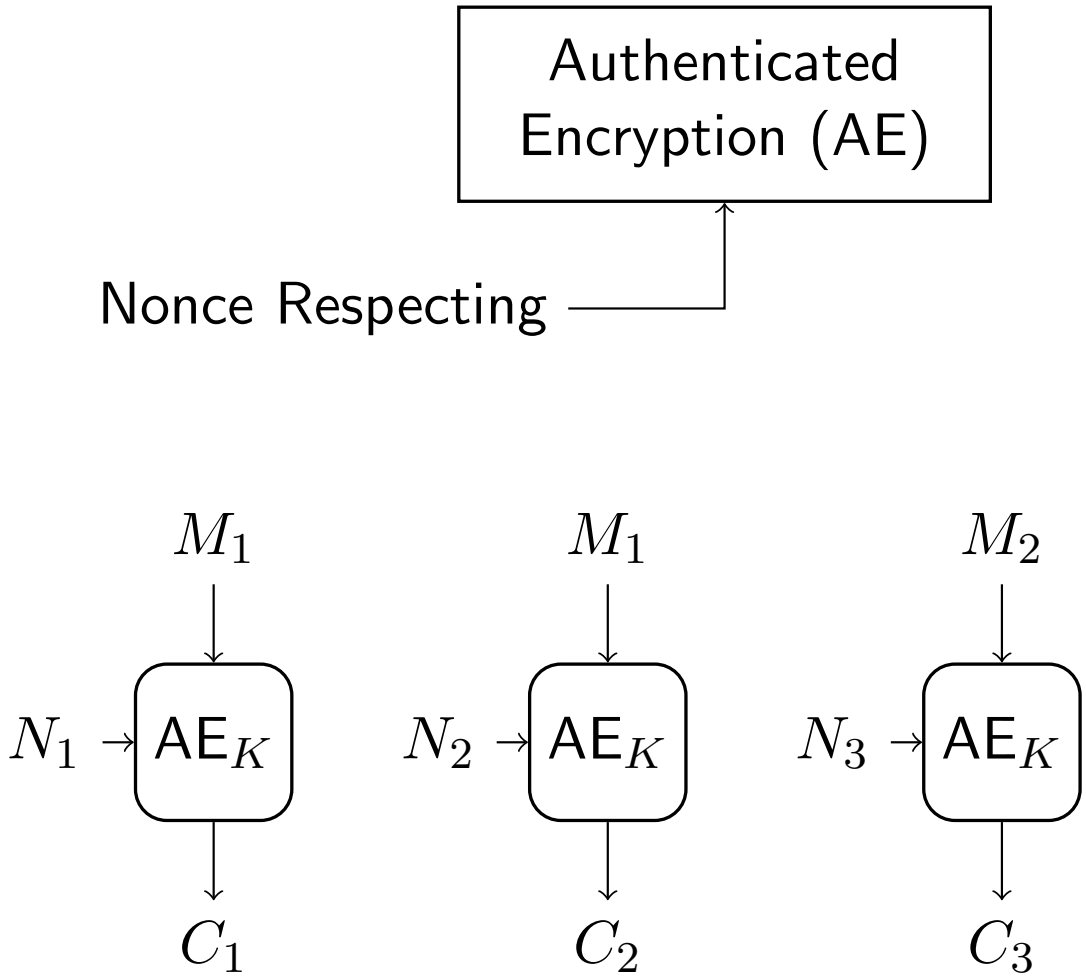

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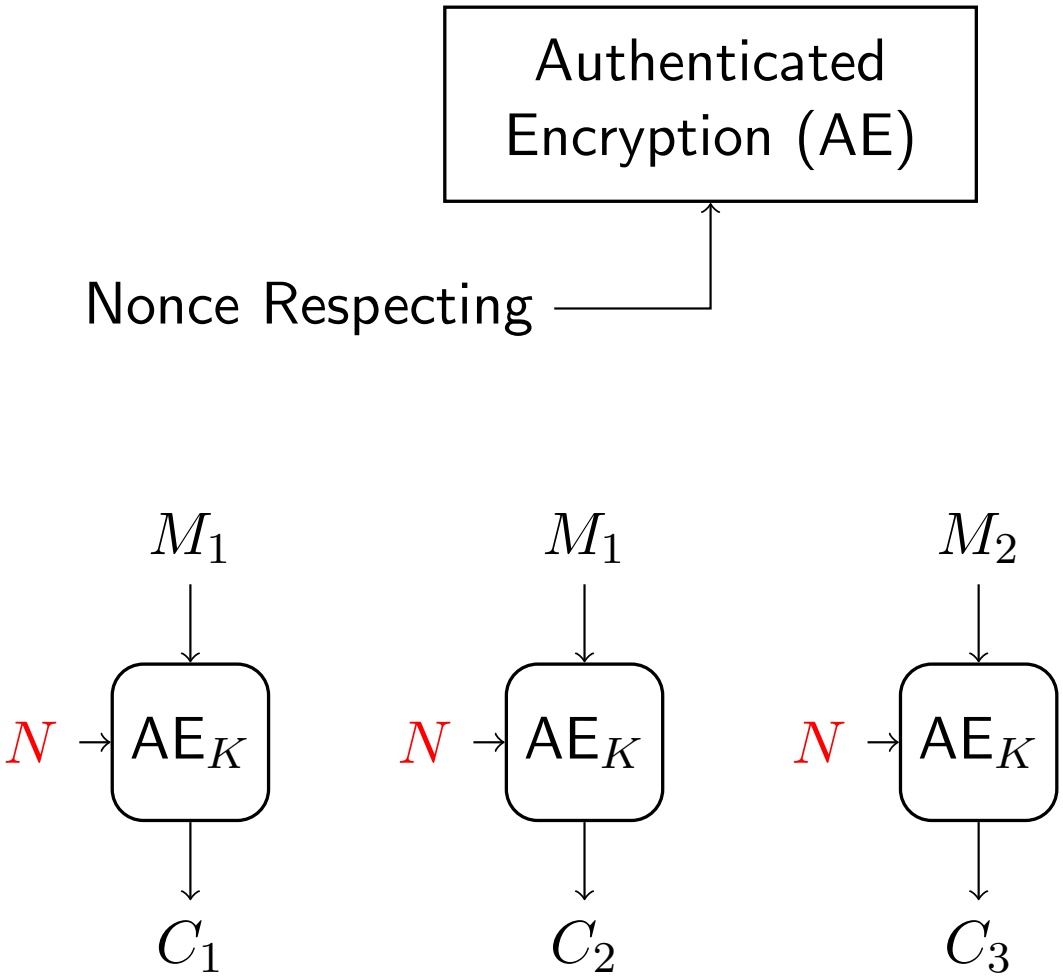

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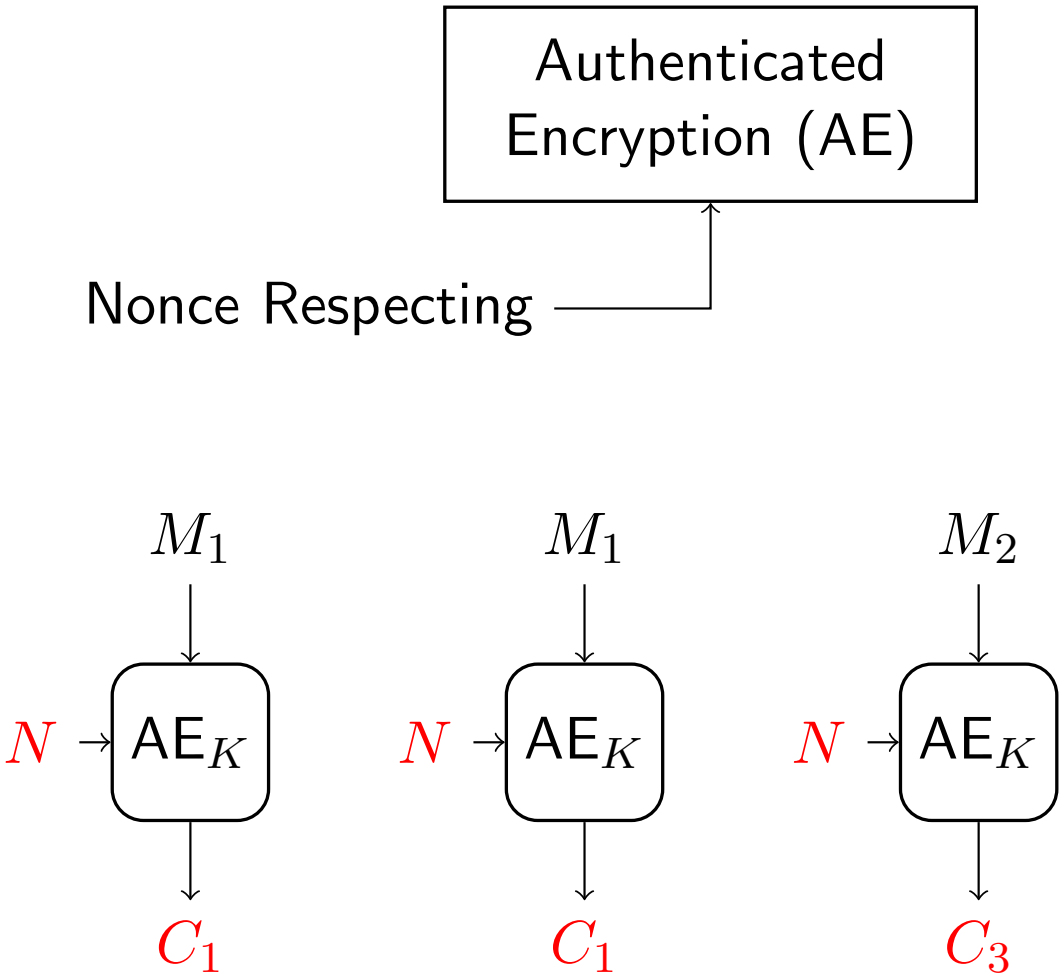

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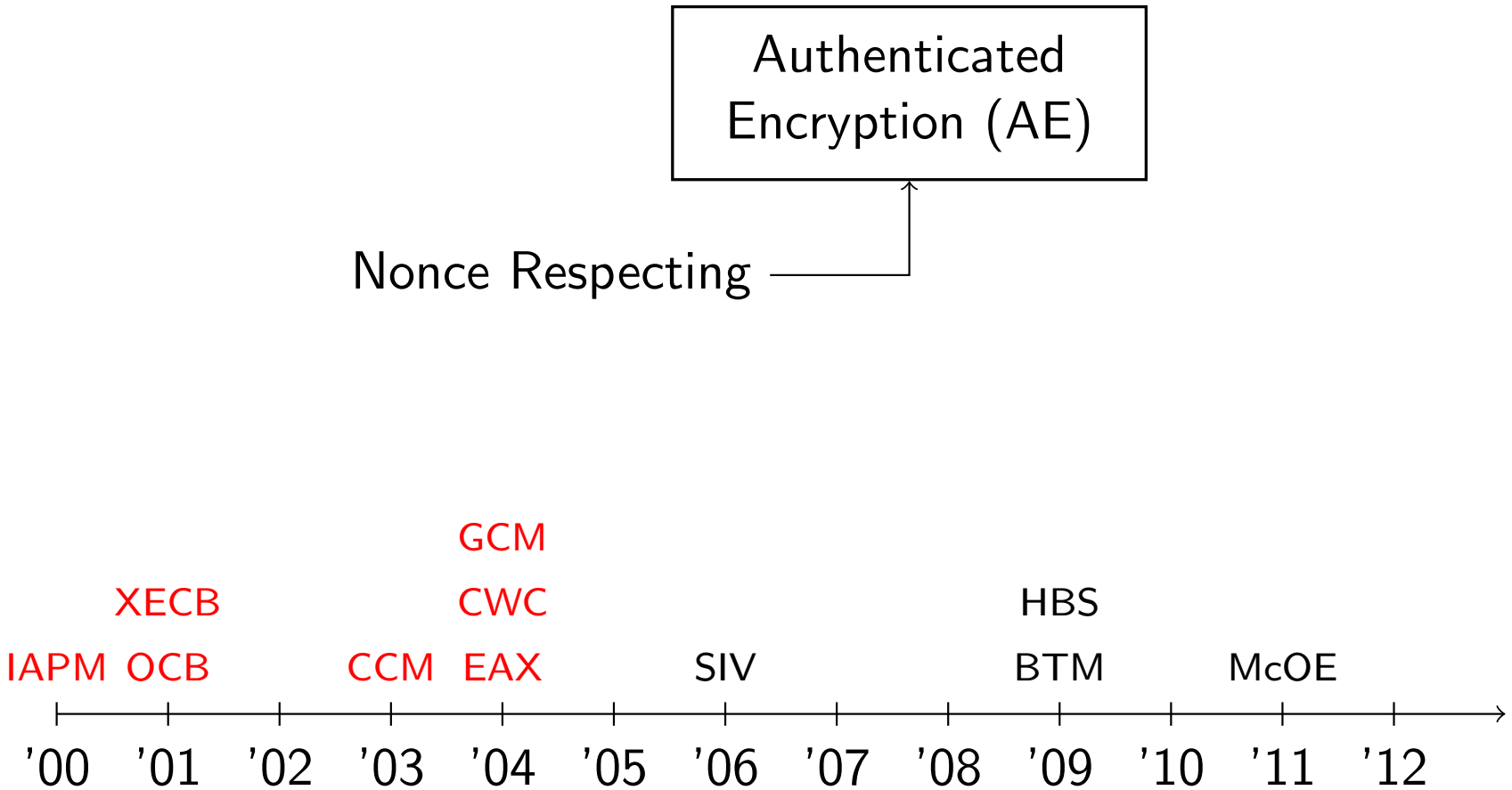

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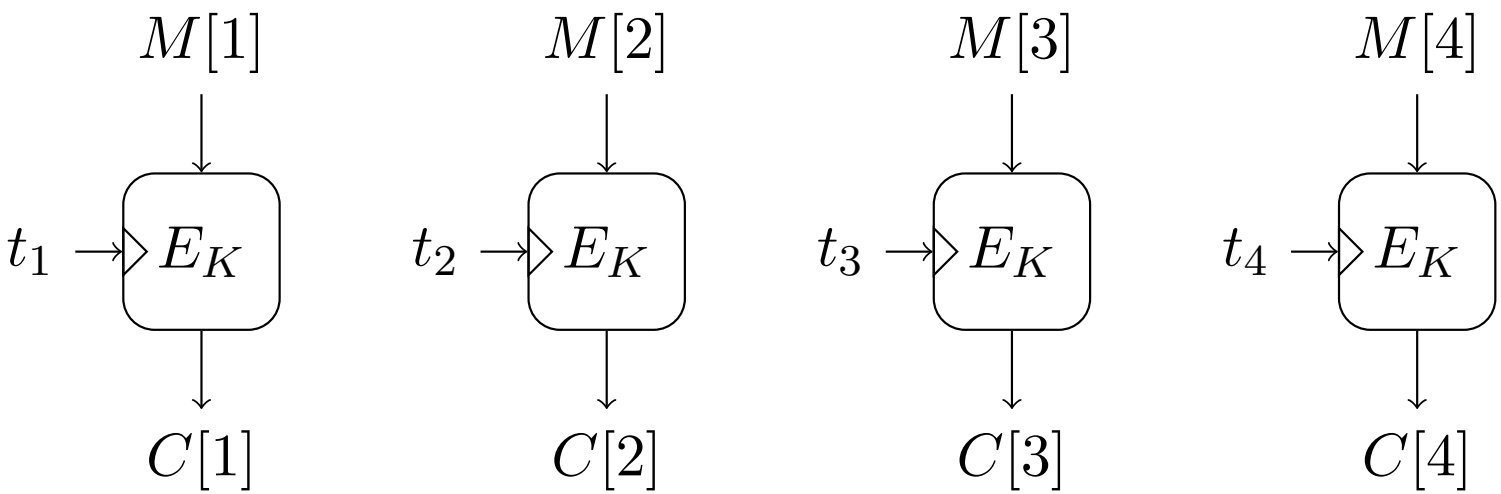

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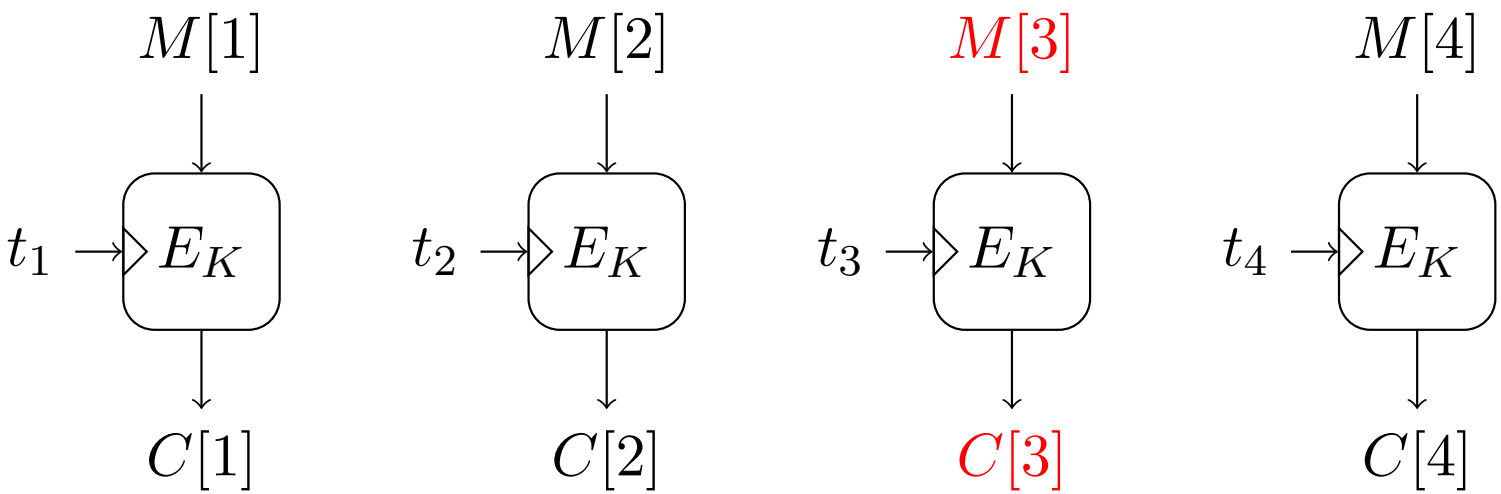

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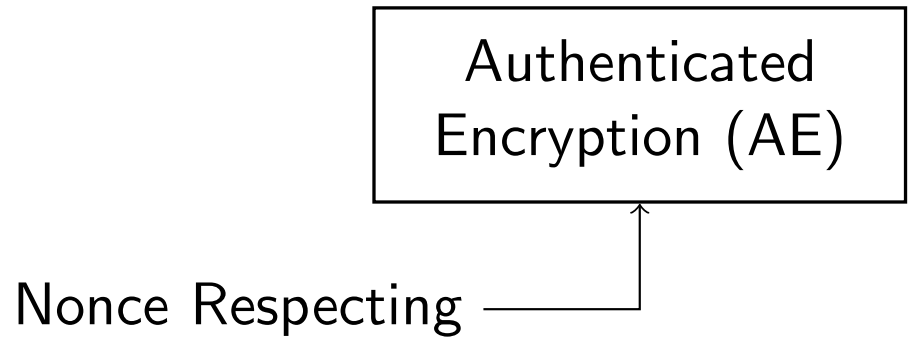

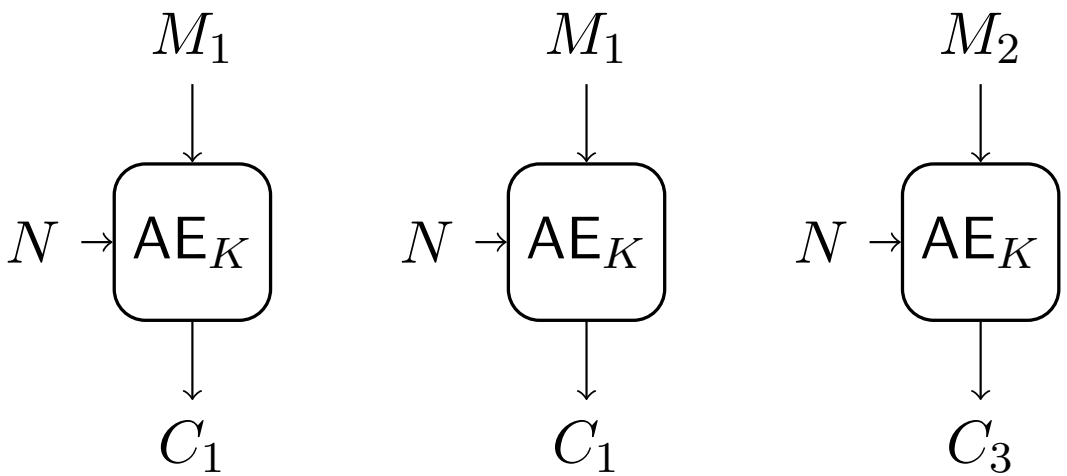

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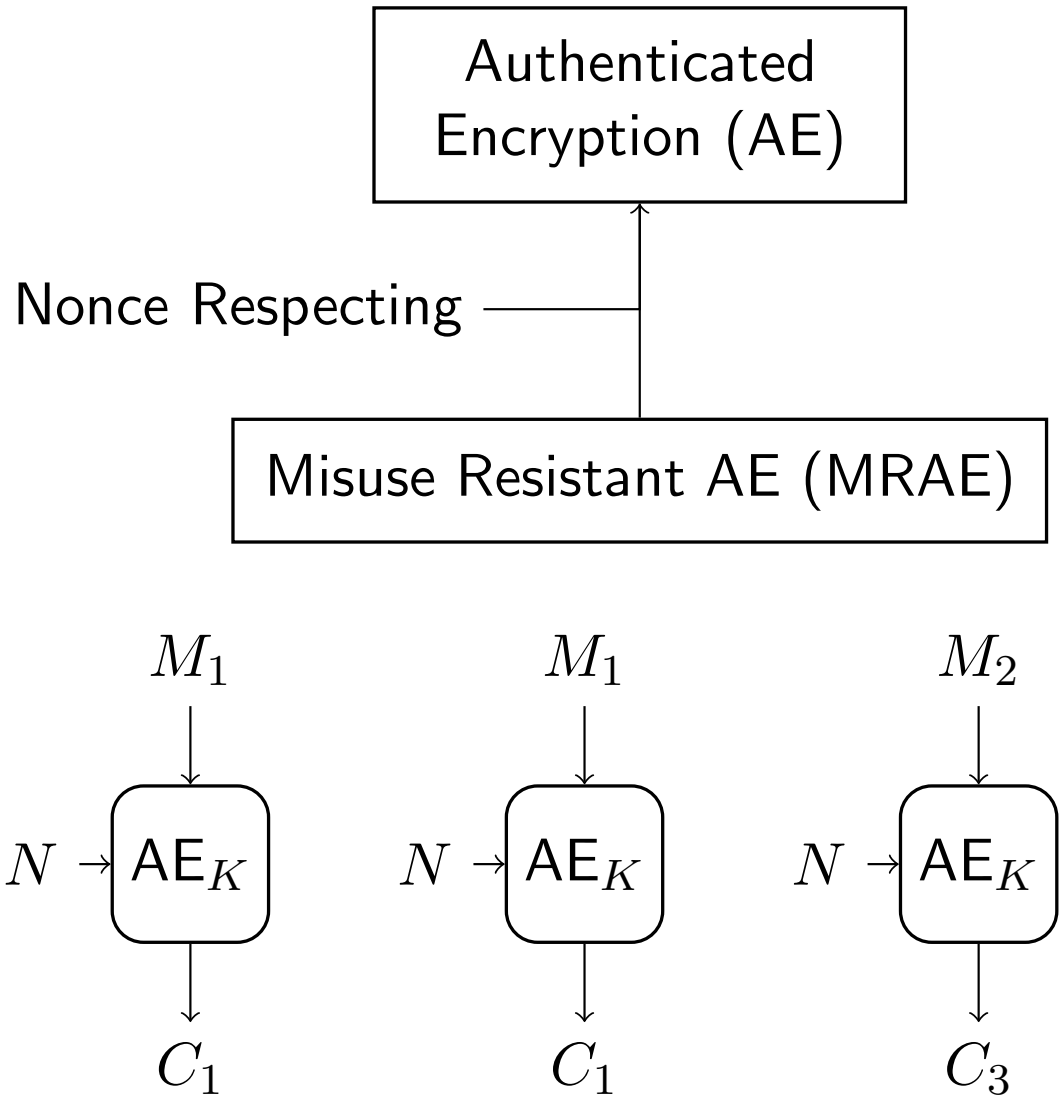
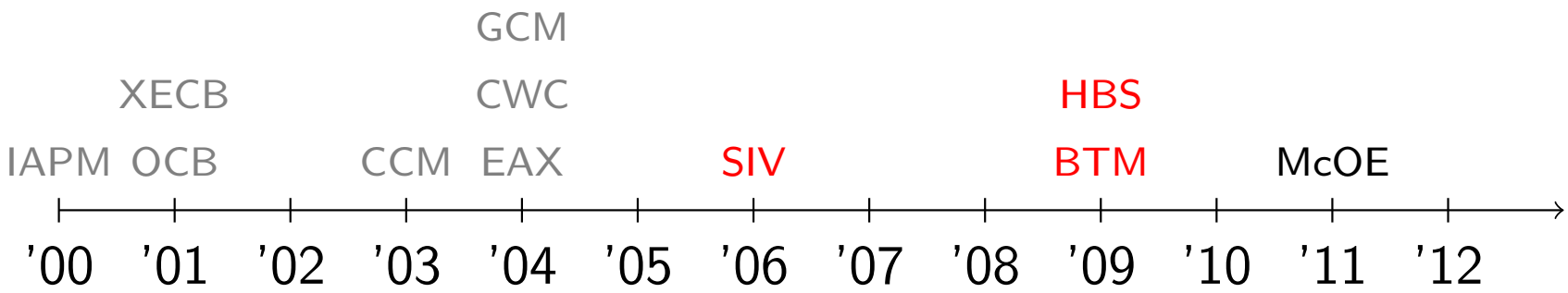


Motivation: Efficiency

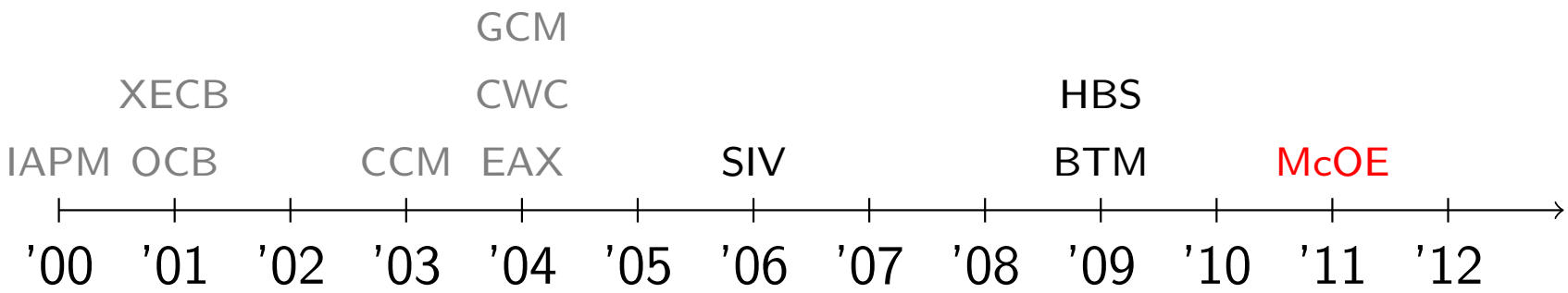


SIV, BTM, HBS:

1. High latency (receive full message before first output)
2. Storage issues (large internal state)

McOE: inherently sequential

Motivation: Efficiency



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Our desired AE scheme: COPA

Background: Cipher Definition

$$M \in \{0,1\}^*$$

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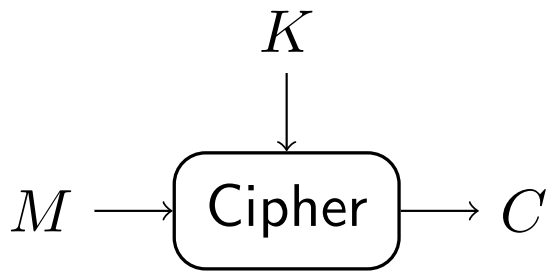

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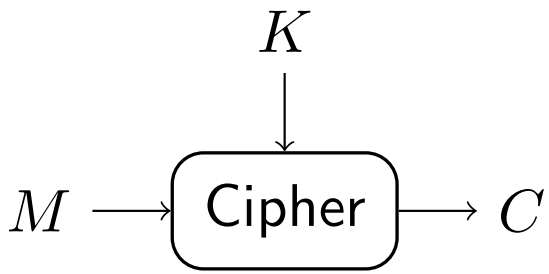

$|M| = |C|$

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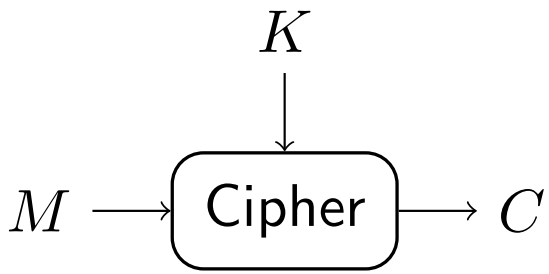

$|M| = |C|$

Cipher	vs	Encryption Scheme
Length-Preserving		Not Necessarily
Deterministic		Randomized, Stateful (nonce)
Indistinguishable from permutations		Indistinguishable from random bits

Background: Achieving AE via Ciphers

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Authentication

Cipher

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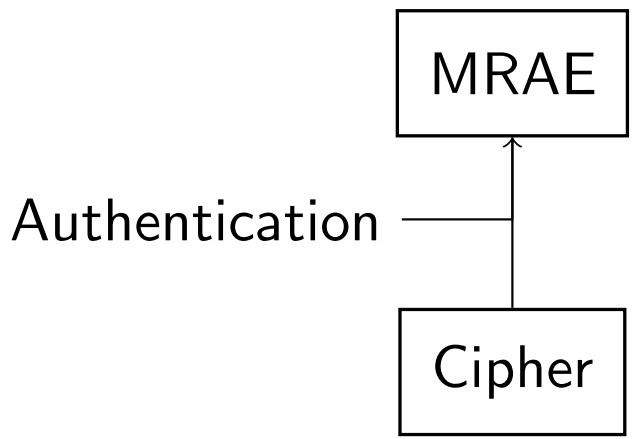

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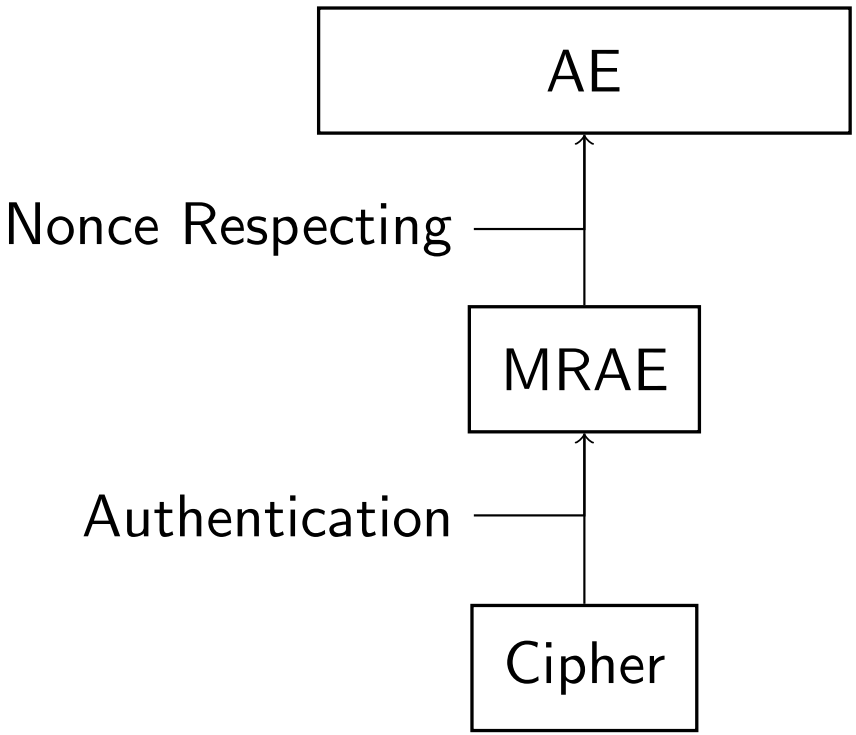

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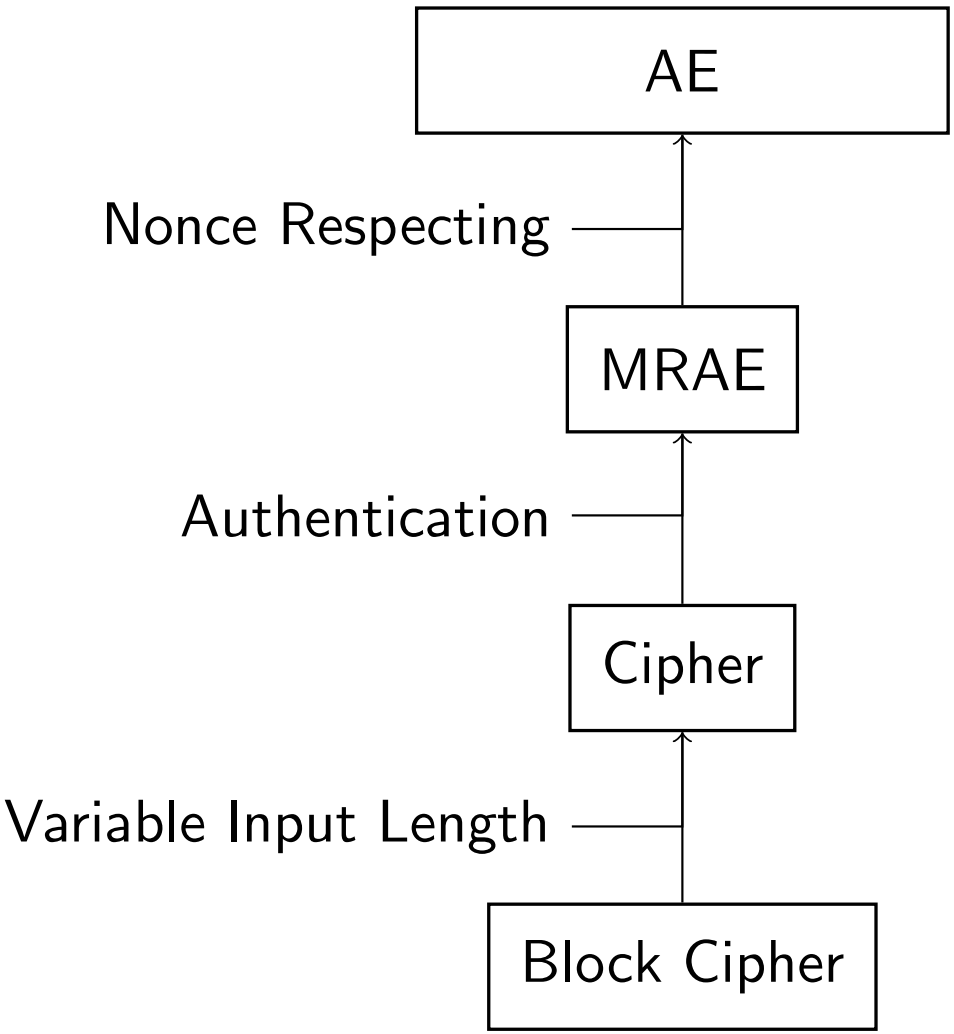

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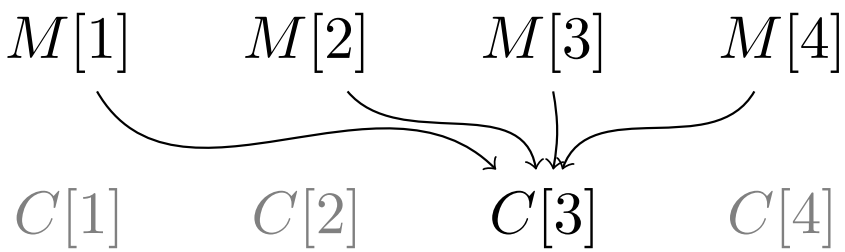

Dependency in a cipher.

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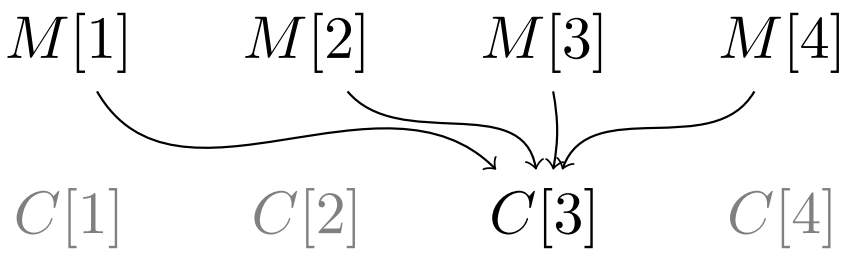

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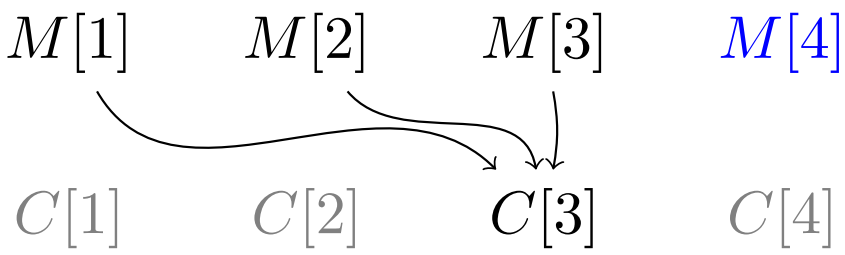
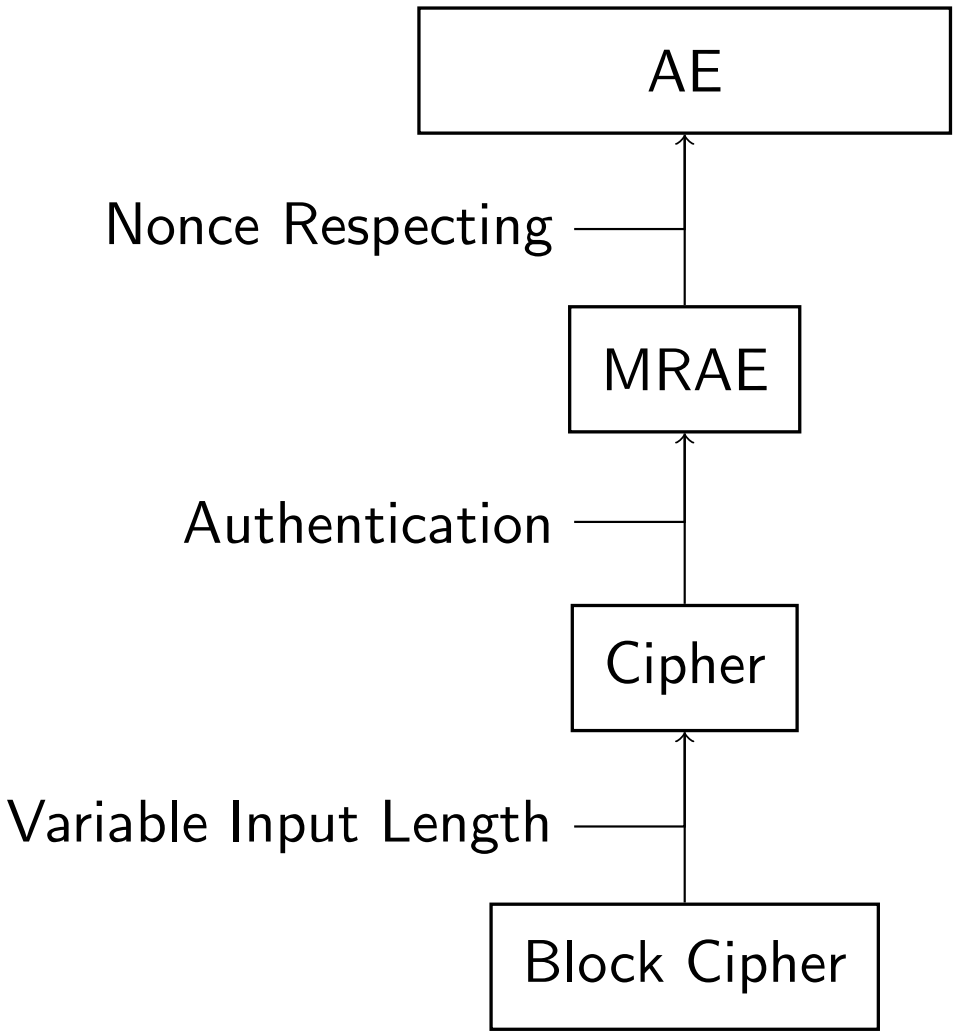


Dependency in an online cipher.

Background: Achieving AE Via Online Ciphers



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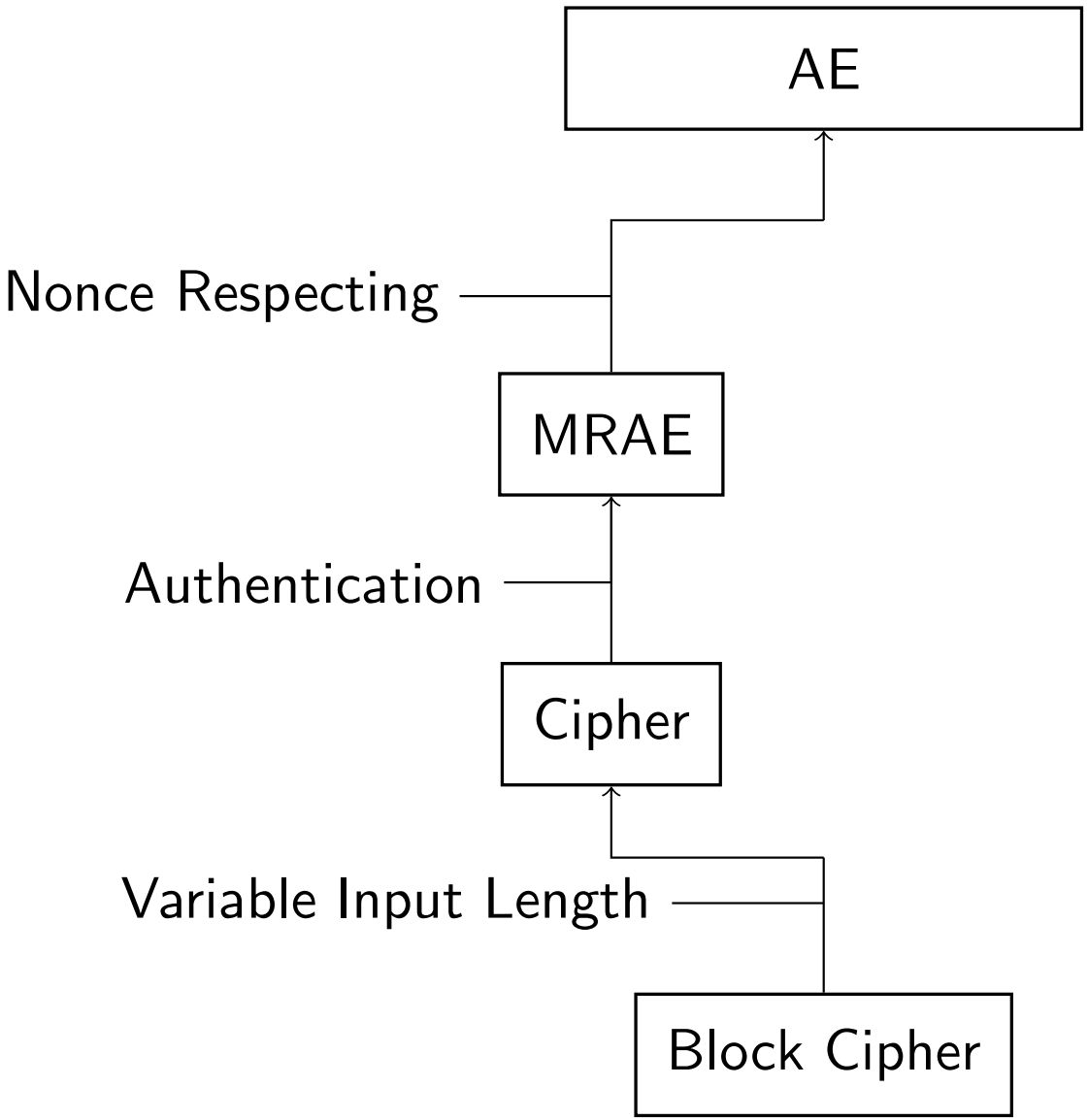

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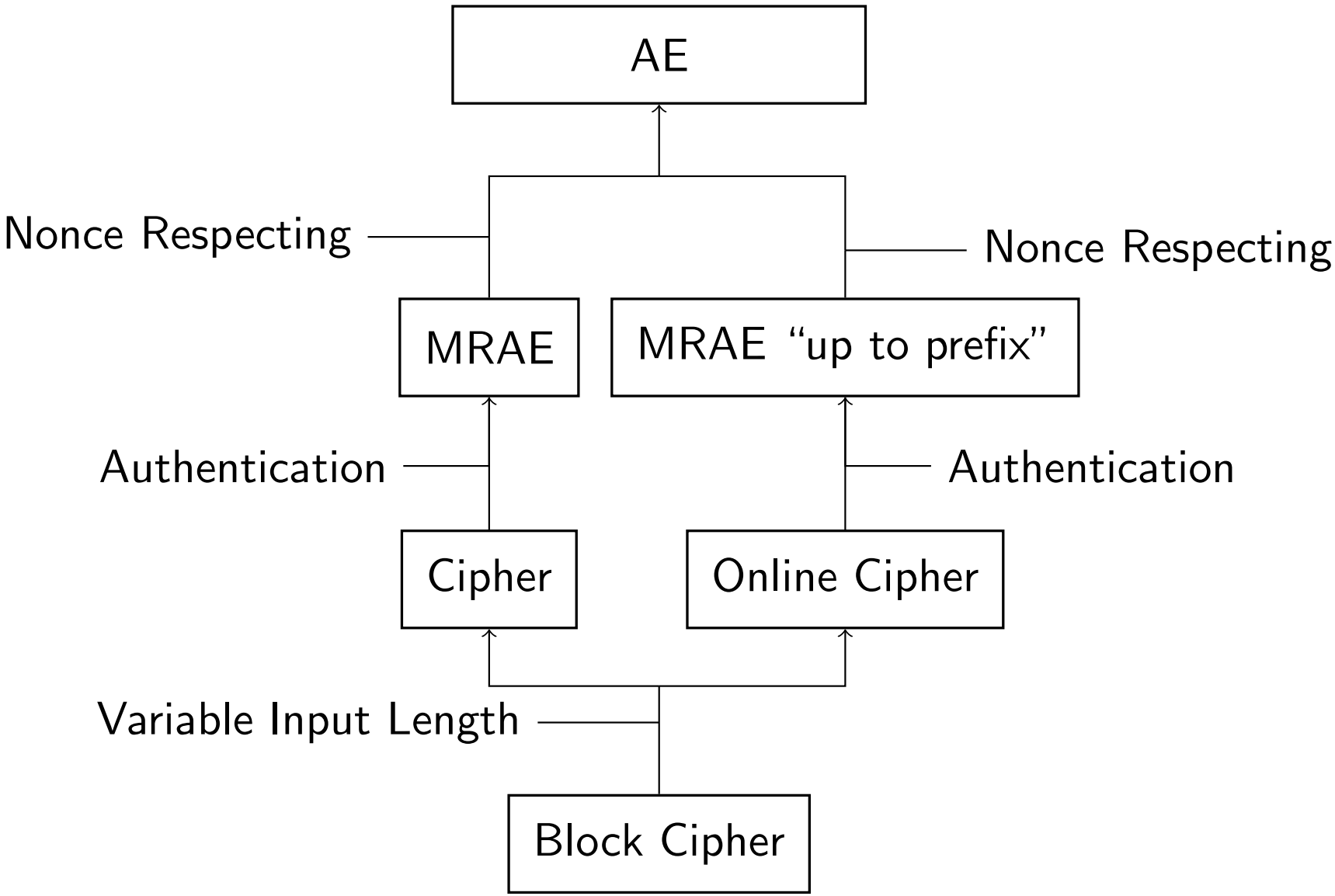

Existing Work

1. HCBC1, HCBC2 (BBKN, Crypto '01)
2. MHCBC, MCBC (Nandi, Indocrypt '08)
3. Rewritten with *tweakable block ciphers*: TC1, TC2, TC3 (Rogaway and Zhang, CT-RSA '11)
4. McOE family (FFL, FSE '12): TC3 with authentication

All schemes are inherently sequential.

Existing Work: TC3

$M[1]$ $M[2]$ $M[3]$ $M[4]$

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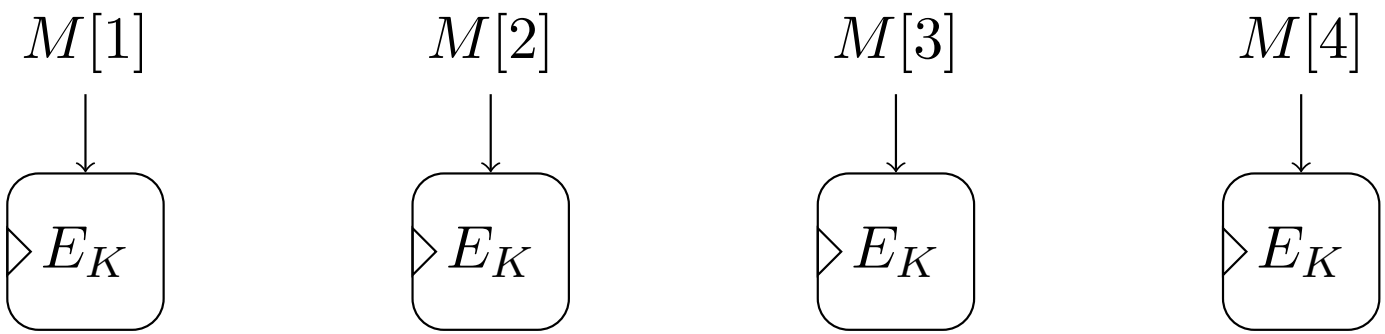

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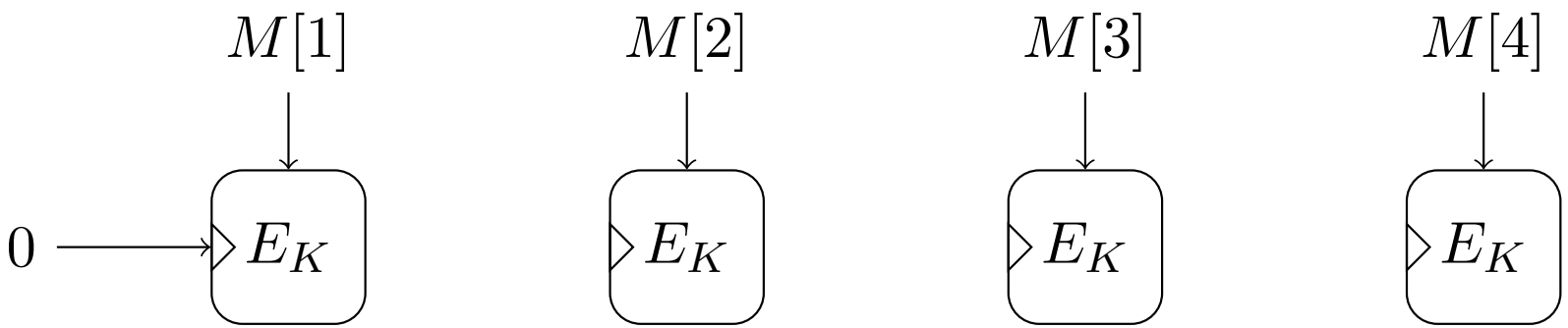

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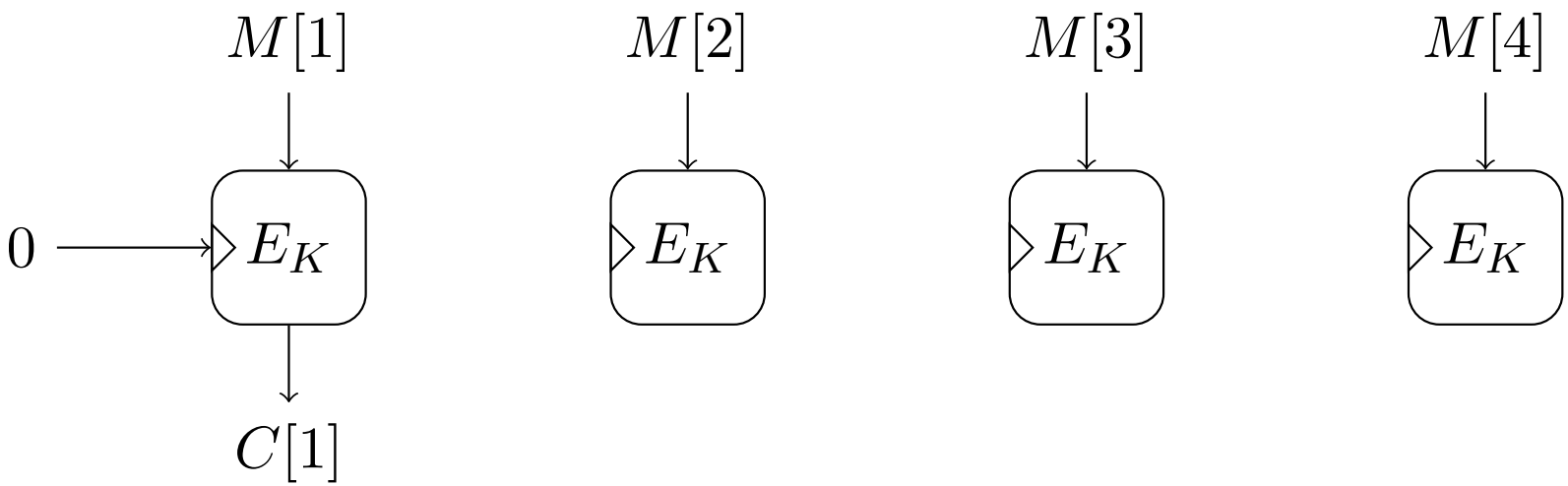

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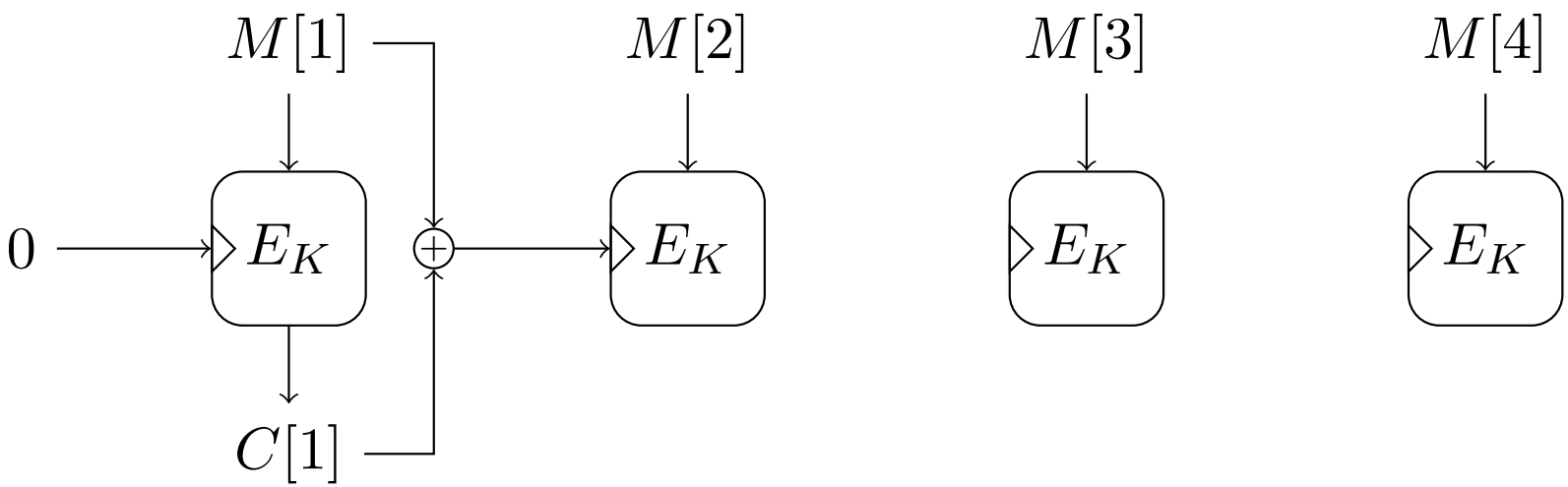

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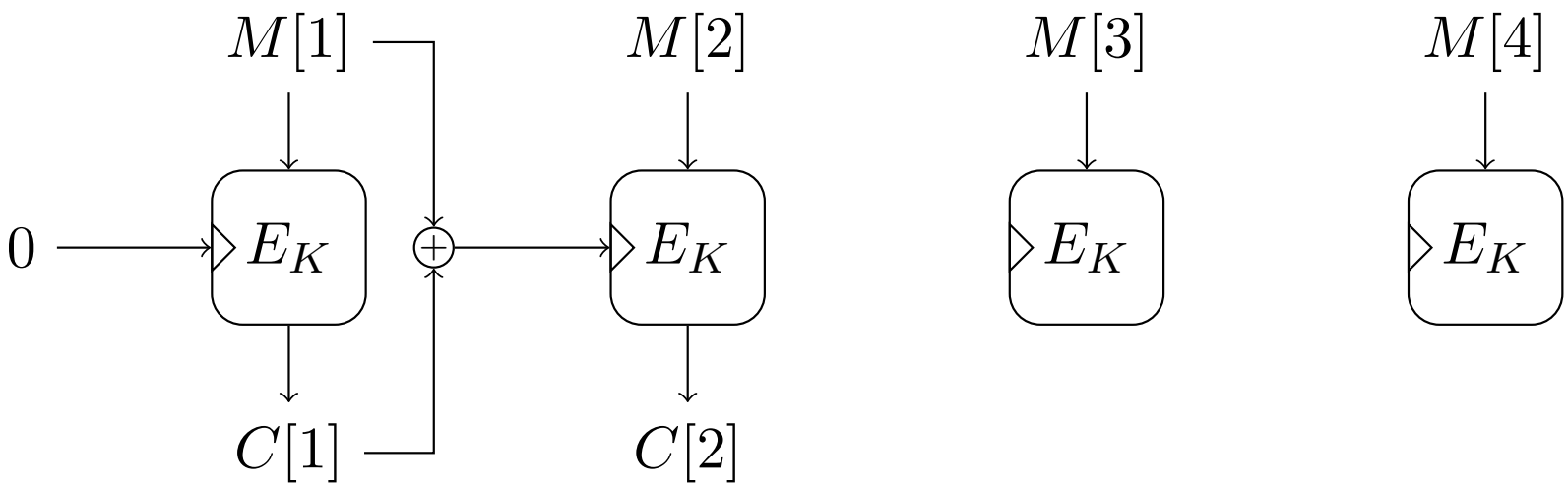

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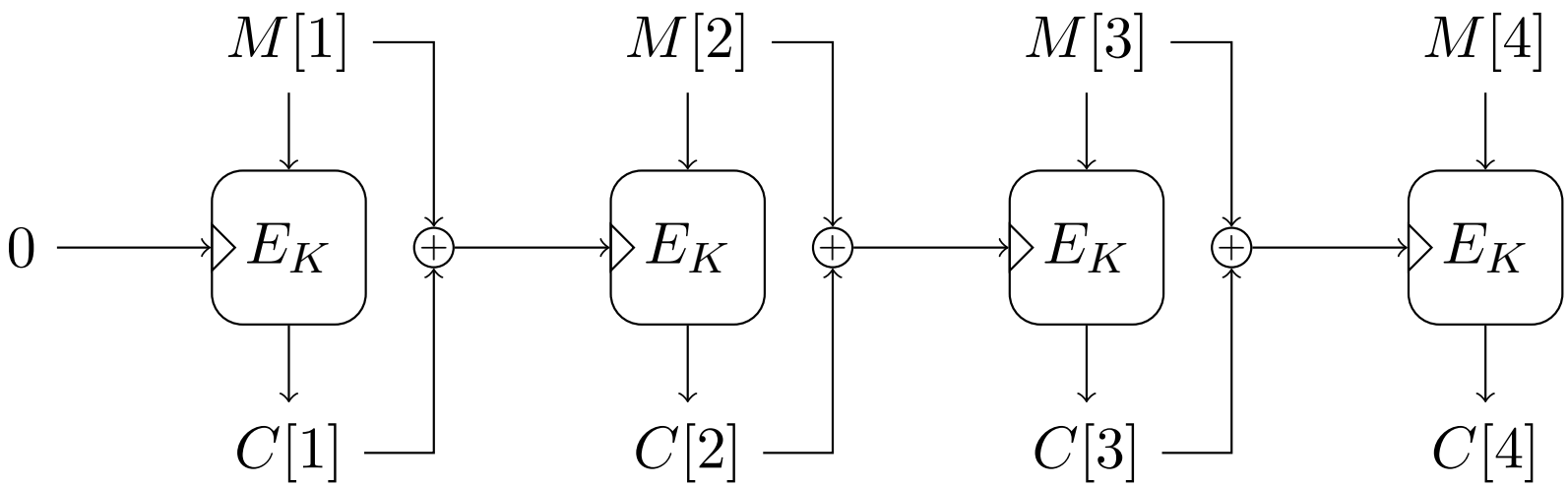
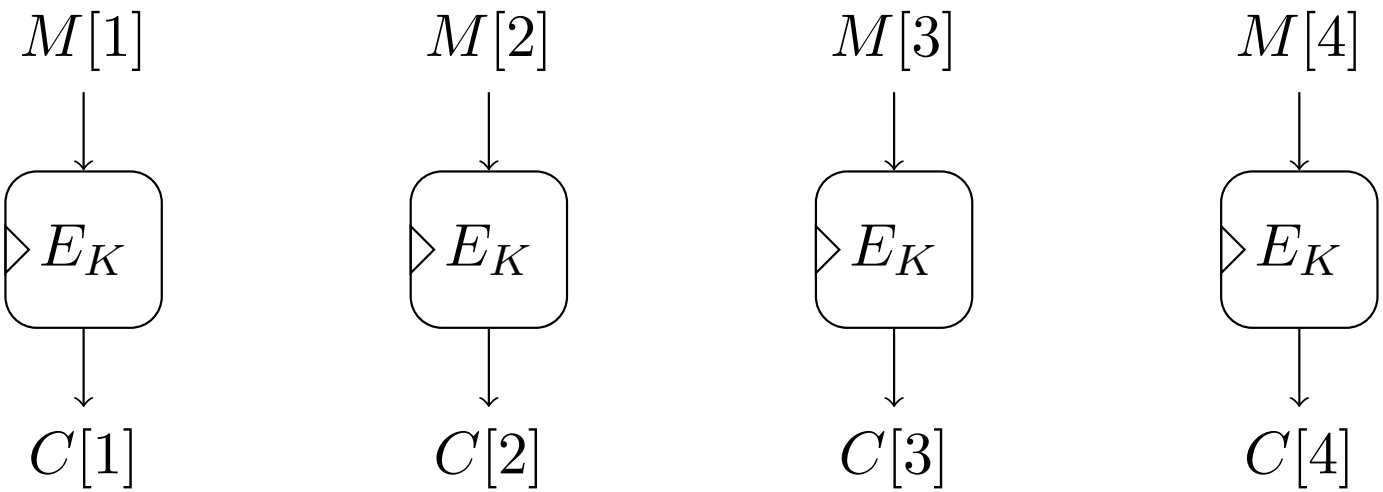


Achieving Parallelizability



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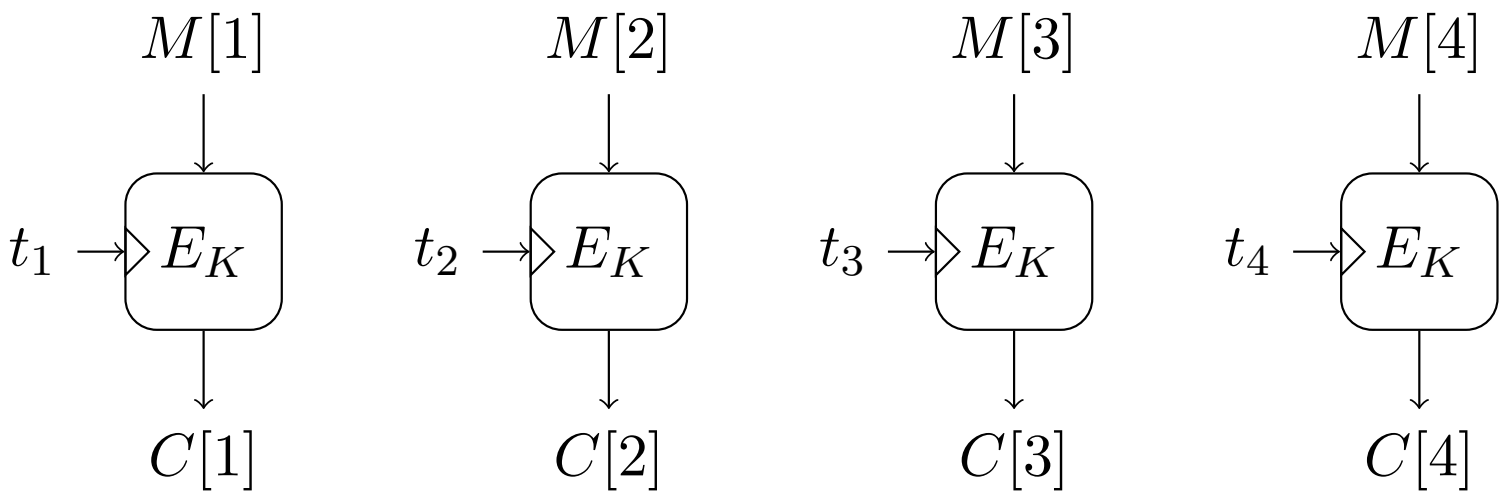

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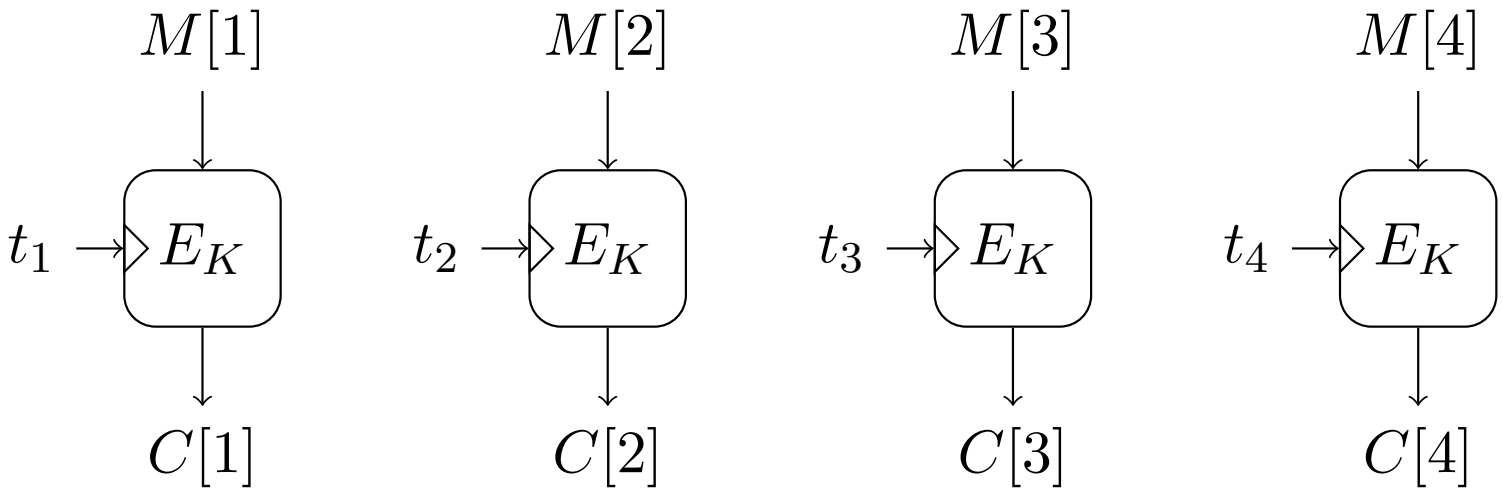

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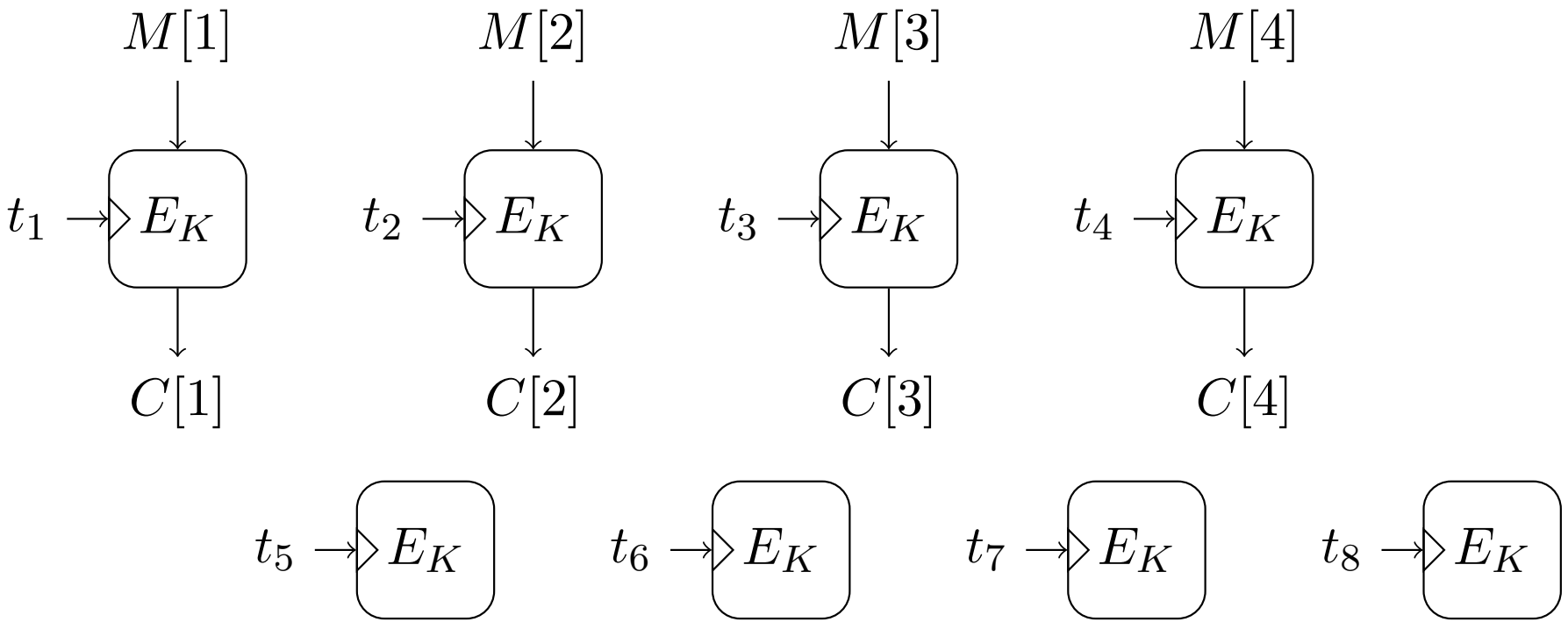

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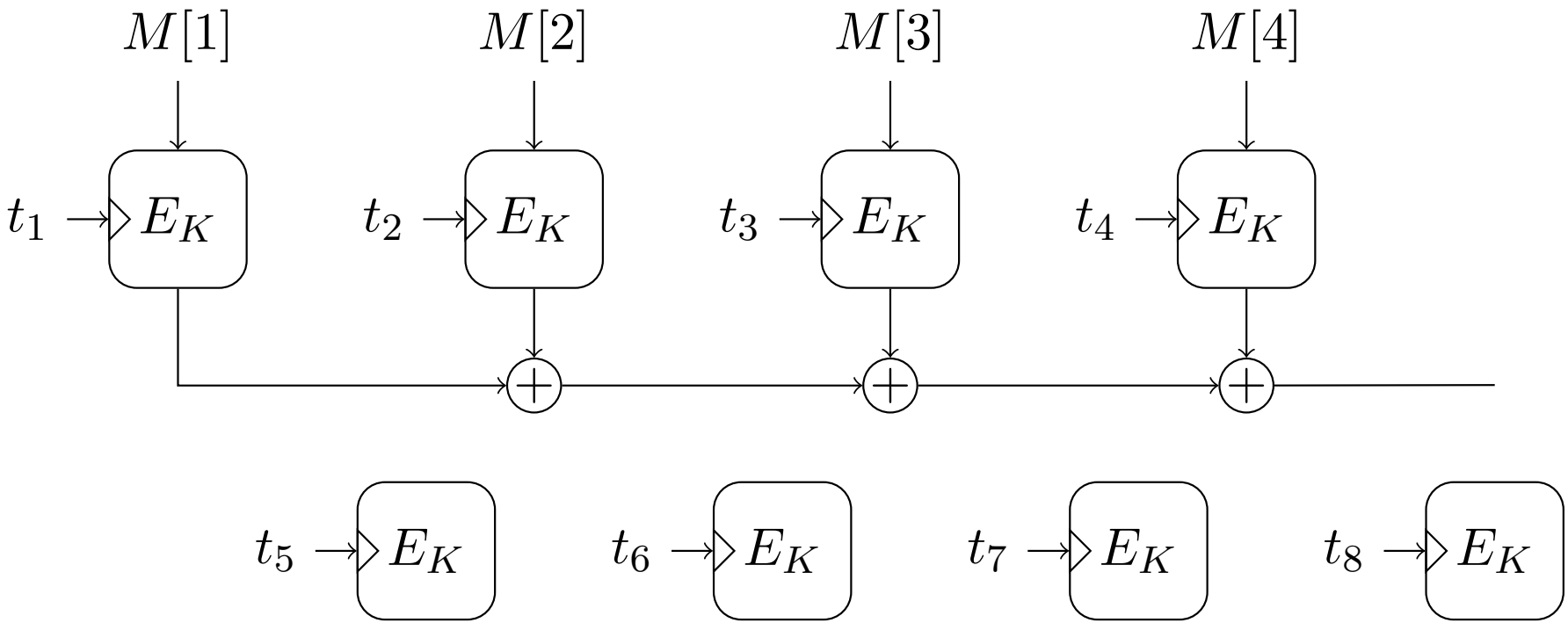

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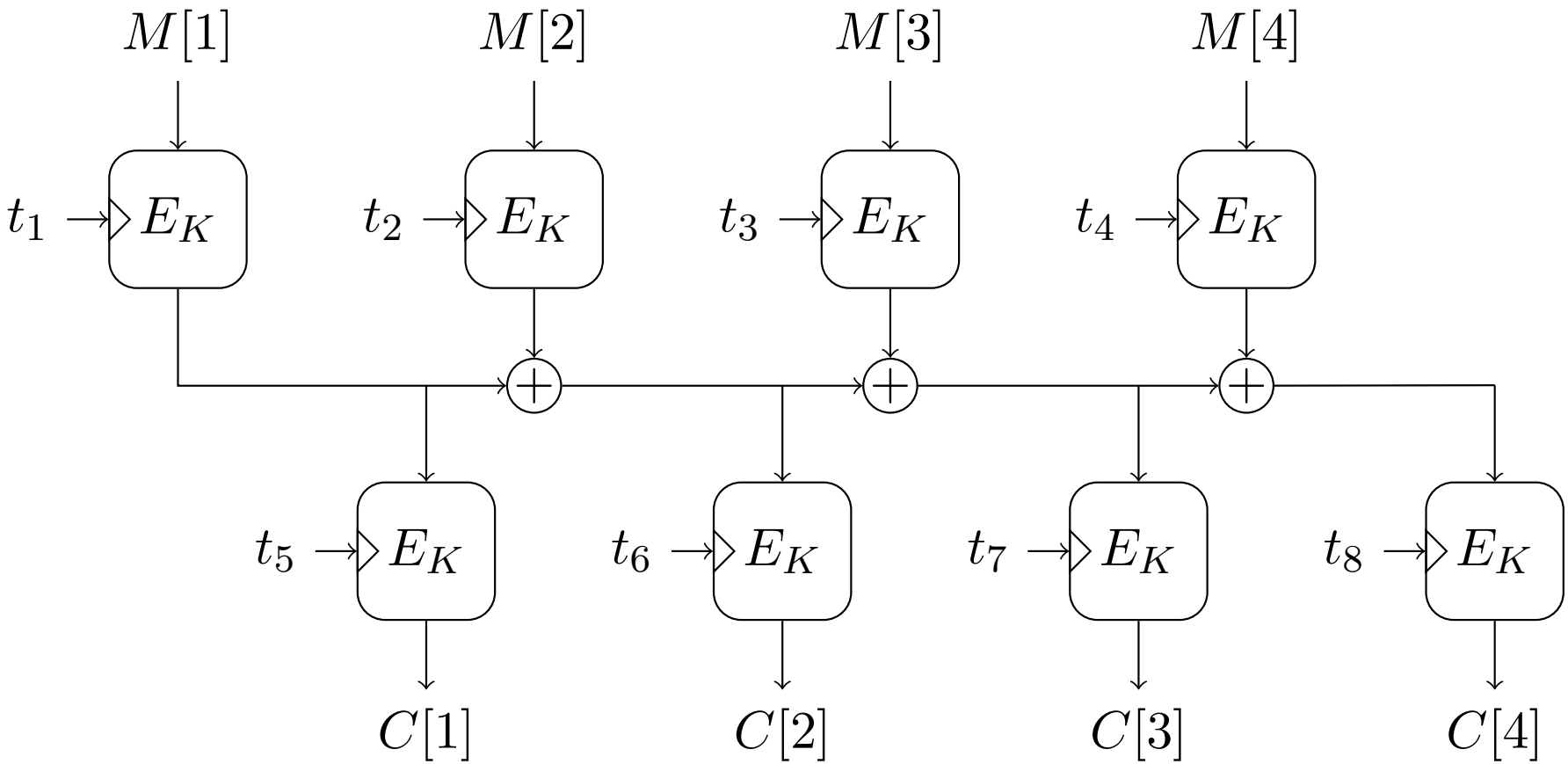
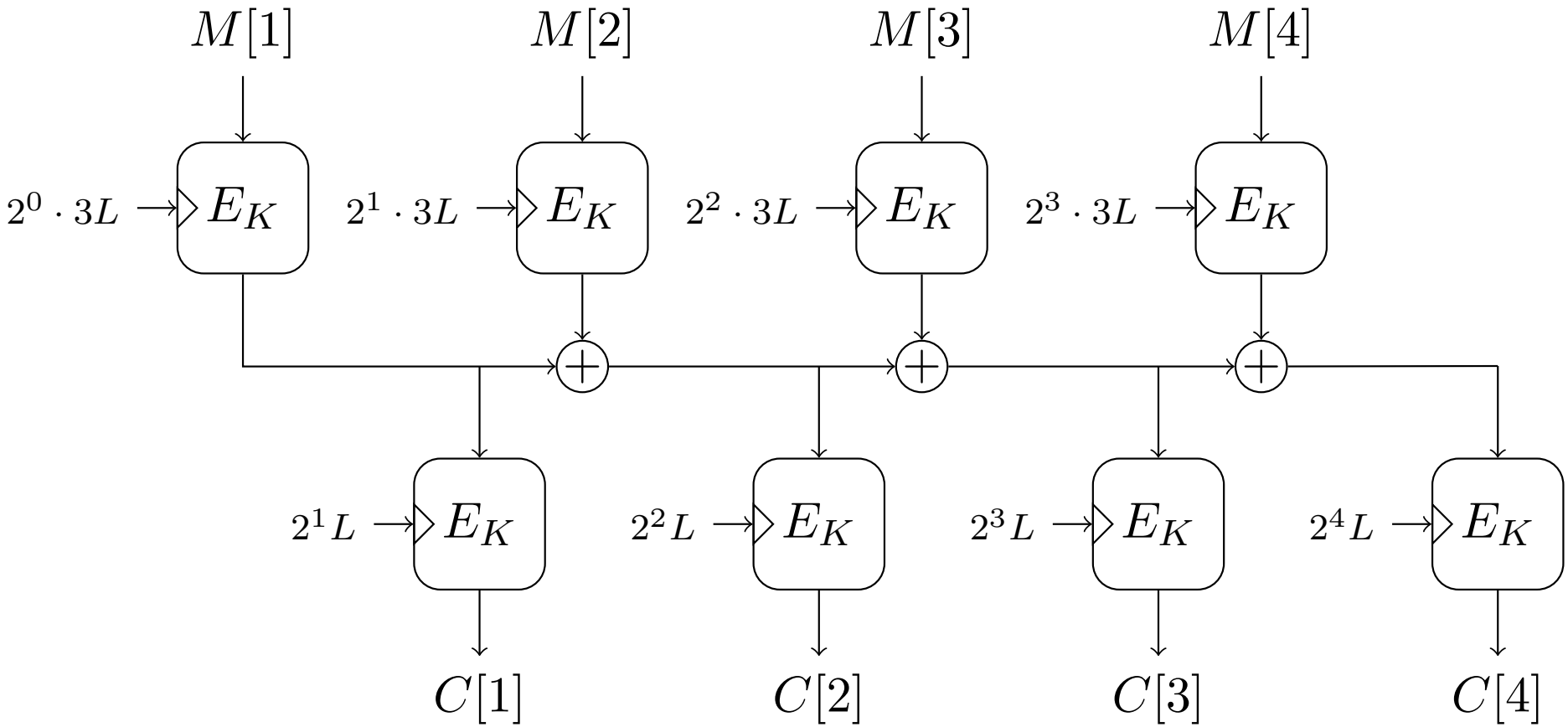
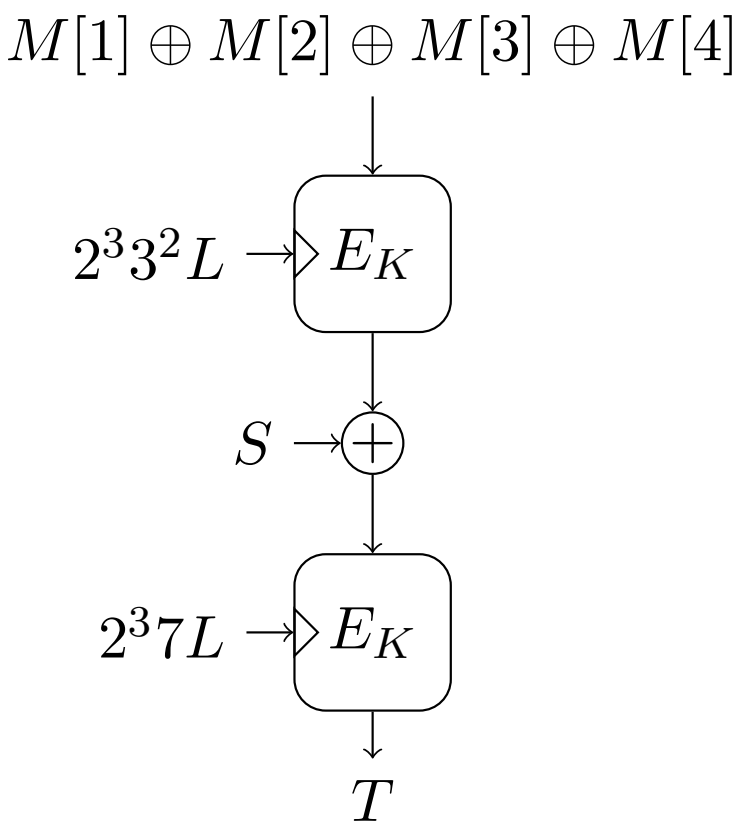


Our Online Cipher: COPE

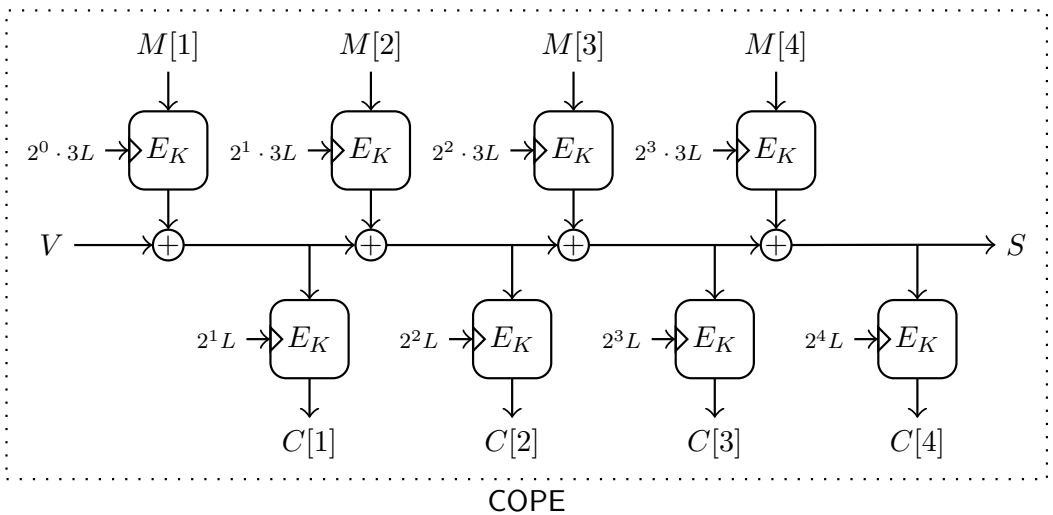


$$L := E_K(0)$$

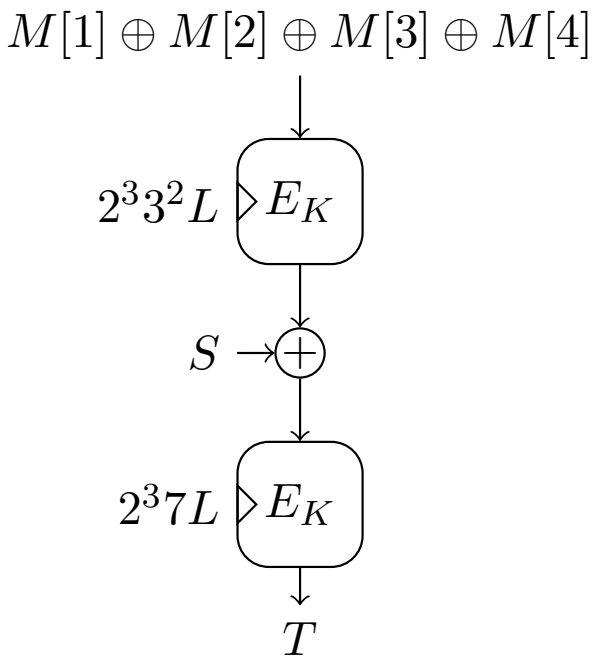
Adding Authenticity to COPE



Our Authenticated Online Cipher: COPA



COPE



Note: COPA also accepts associated data (while maintaining parallelizability)

Security

σ: total length of all queries in number of blocks
$a \approx 40, b \approx 4$

$$\mathbf{Adv}^{\mathrm{cpa}}_{\mathsf{COPE}}(t, \sigma) \leq \frac{a \cdot \sigma^2}{2^n} + \mathbf{Adv}^{\mathrm{prp}\pm 1}_{E}(t', b \cdot \sigma)$$

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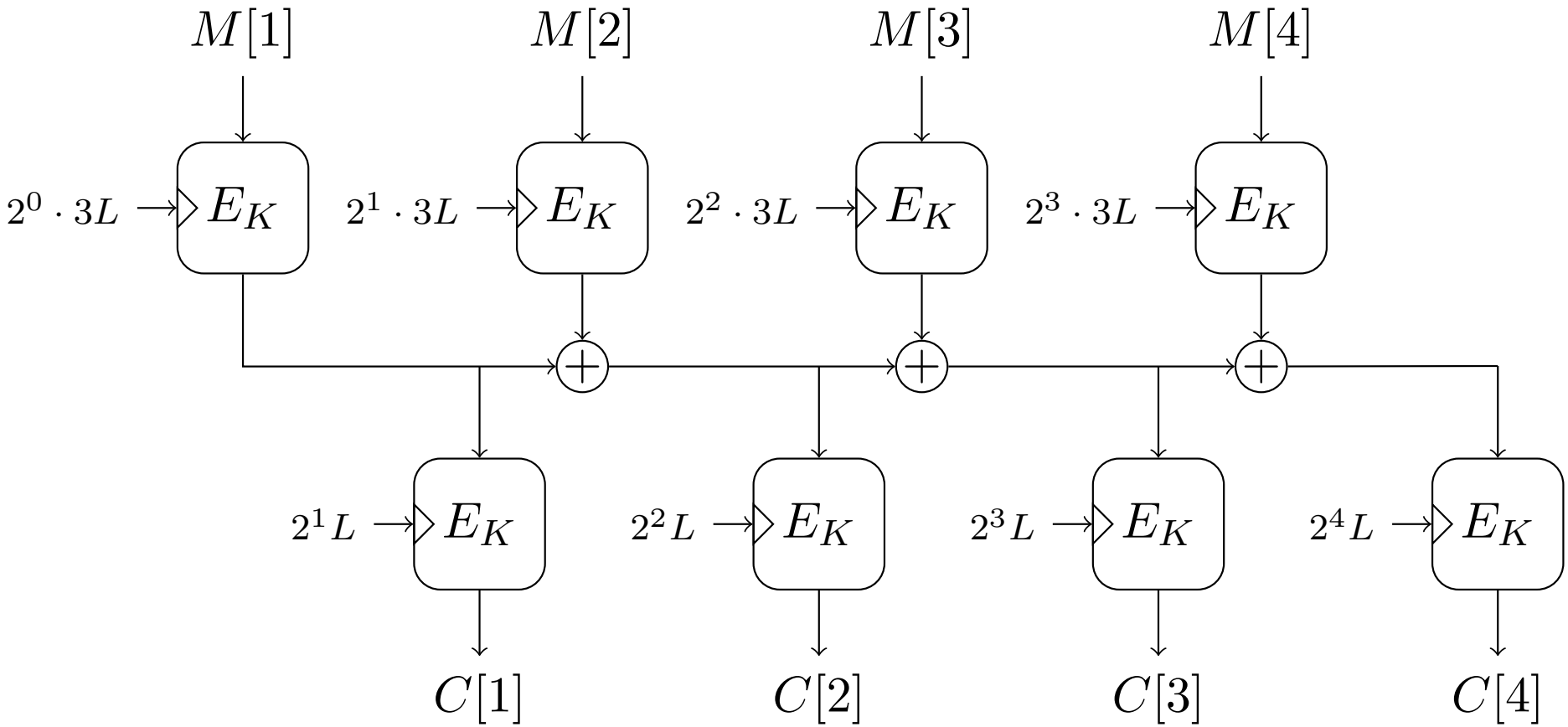
Security: Proof Idea



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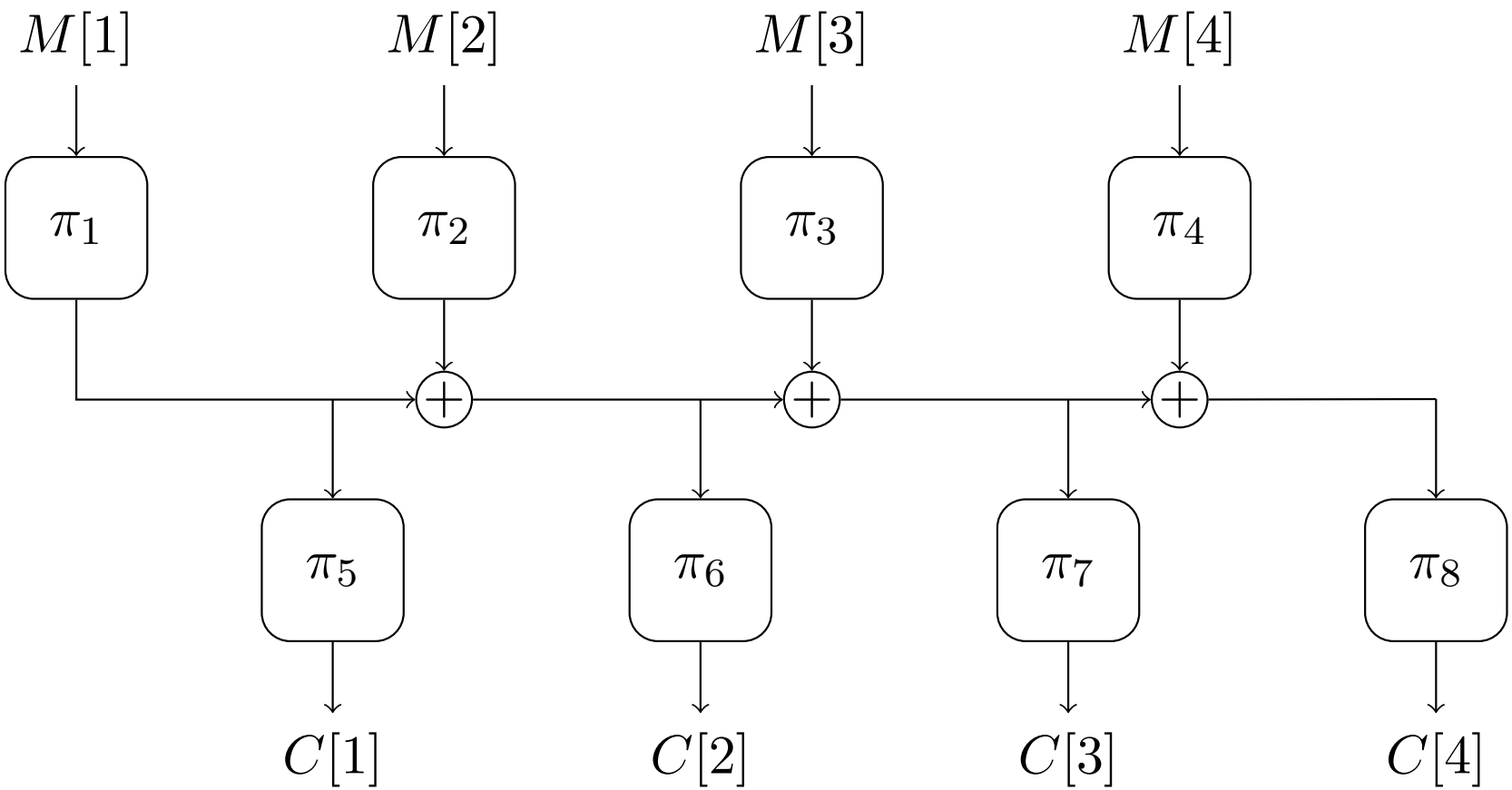

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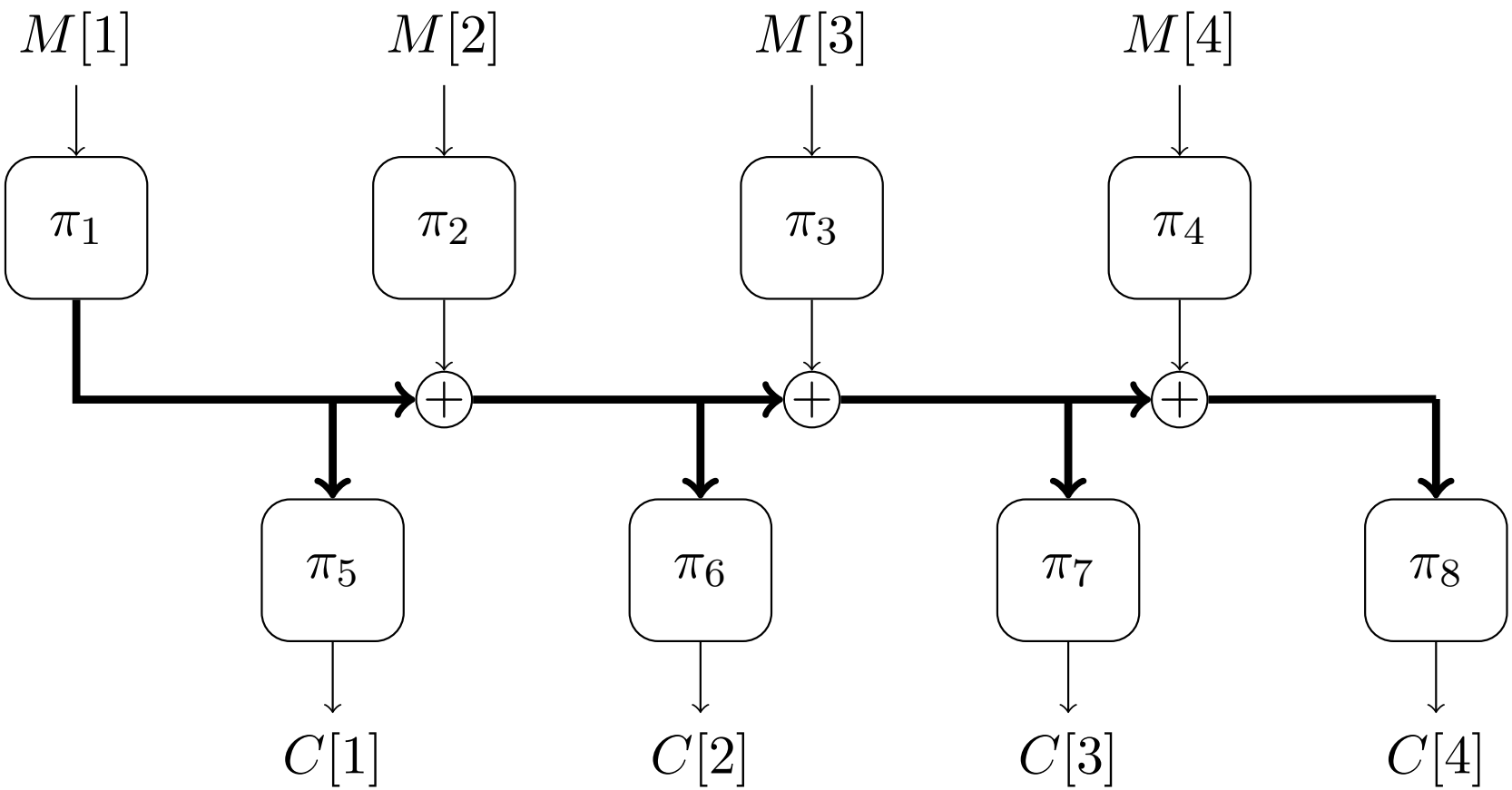
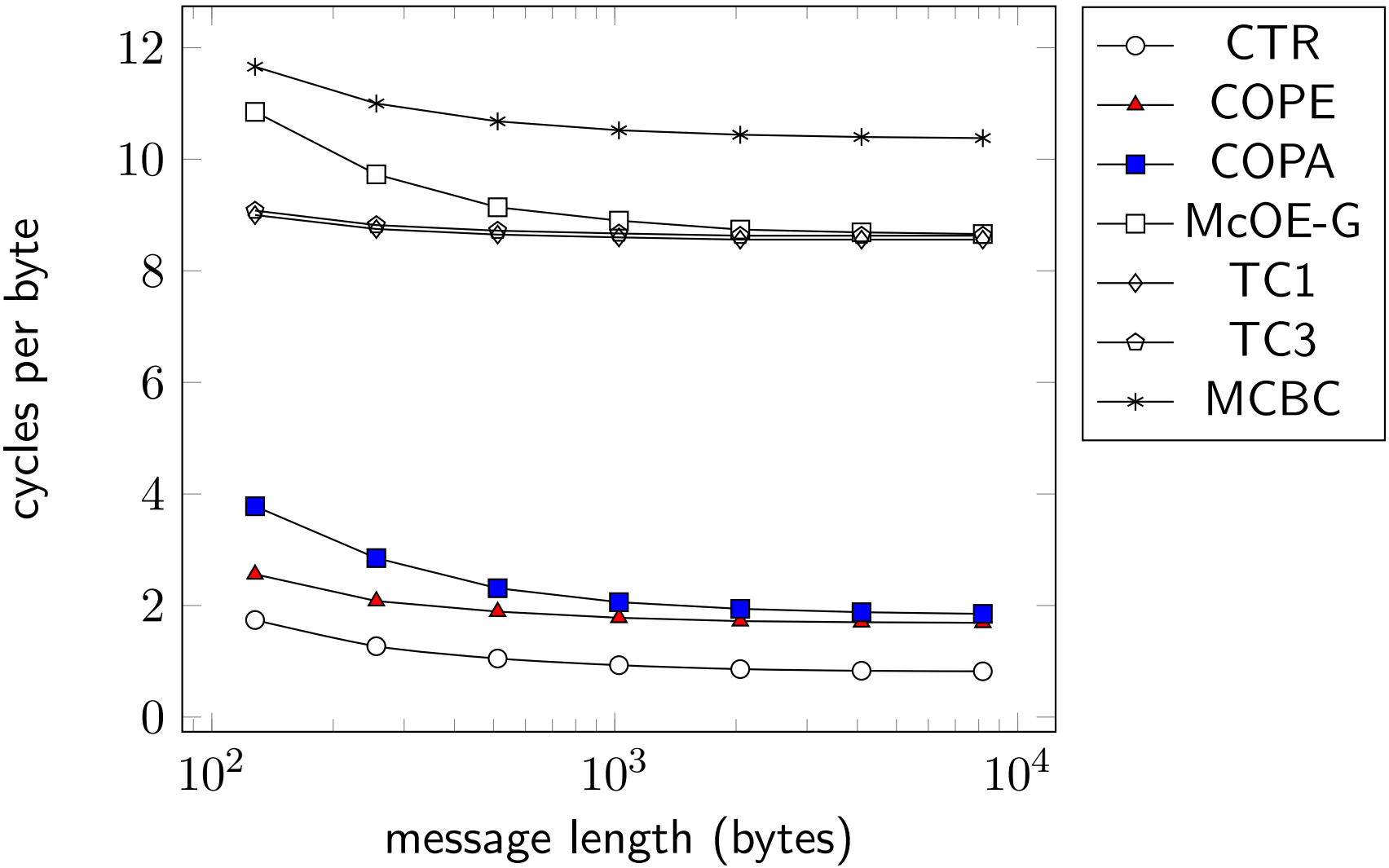


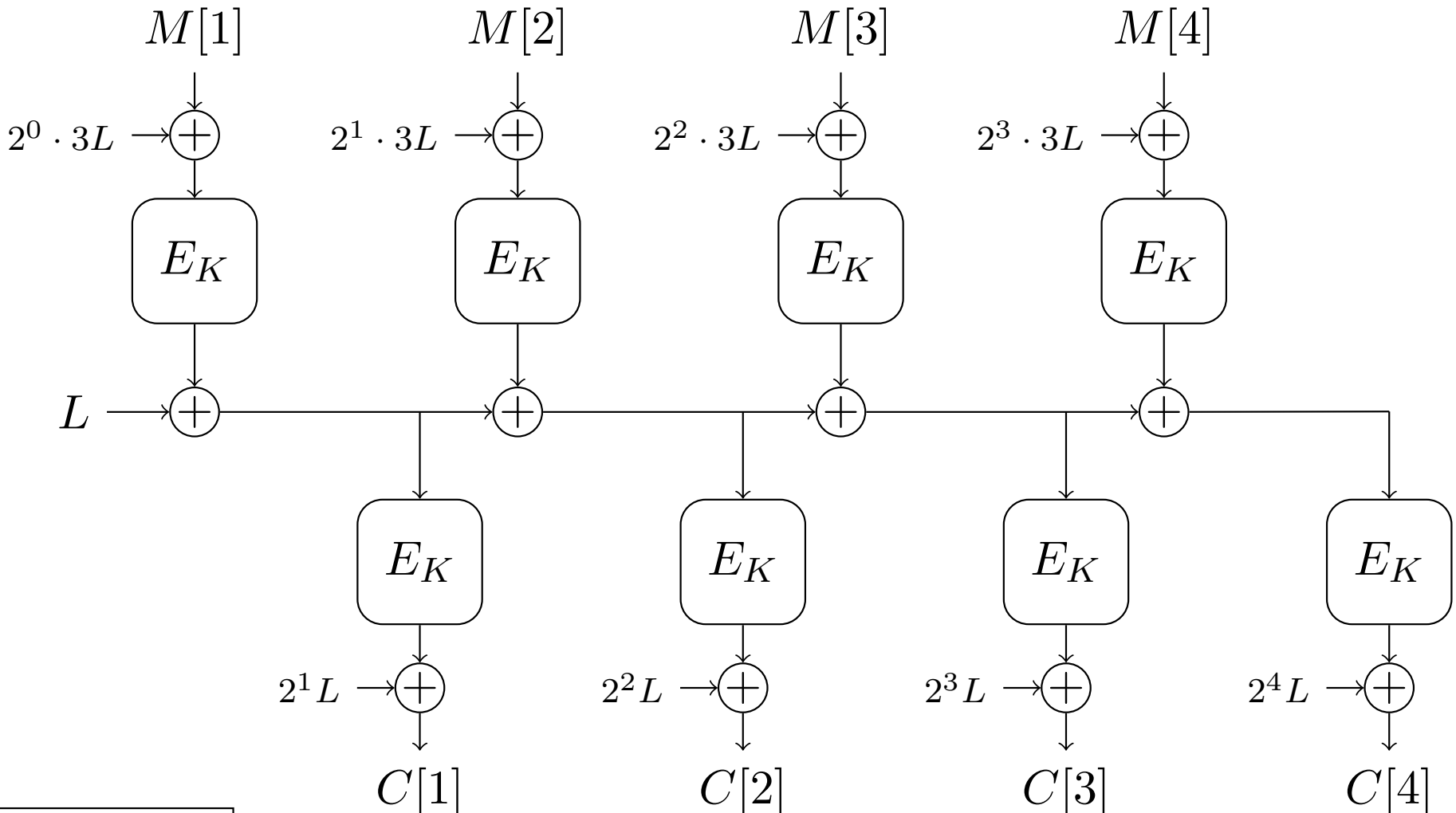
Results: Using AES-NI on Intel Sandy Bridge



Summary

1. COPE: first parallelizable, online cipher
2. COPA: misuse resistant authenticated encryption (with associated data)
   - efficient
   - security reduction to block cipher
   - CAESAR submission

COPE


$M[1]$
$M[2]$
$M[3]$
$M[4]$
$2^0 \cdot 3L$
$2^1 \cdot 3L$
$2^2 \cdot 3L$
$2^3 \cdot 3L$
E_K
L
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$2^2 L$
$2^3 L$
$2^4 L$
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$C[3]$
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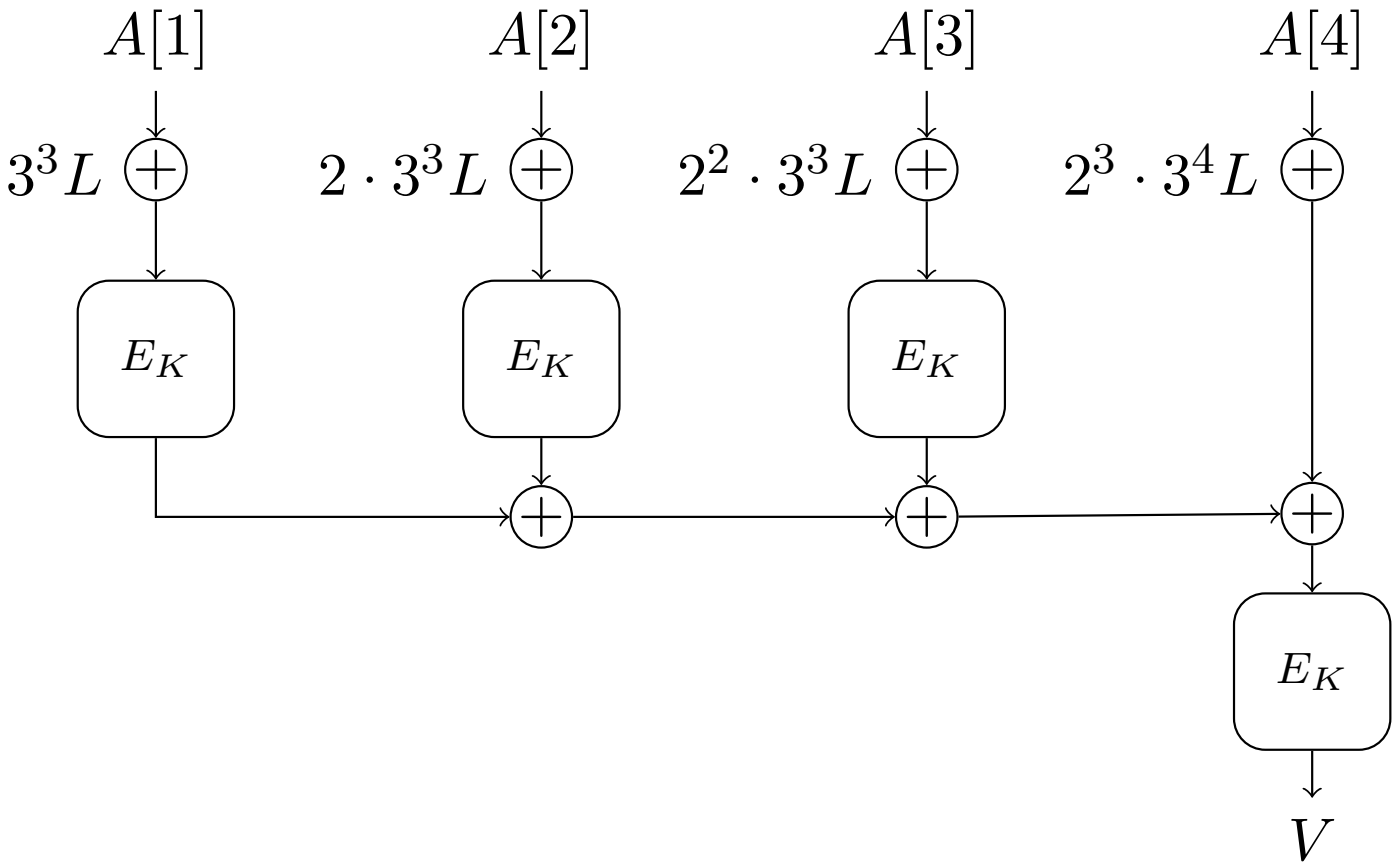
$L := E_K(0)$

Associated Data in COPA



Results

Table : Software performance of (authenticated) online ciphers based on the AES on the Intel Sandy Bridge platform (AES-NI). All numbers are given in cycles per byte (cpb).

	message length (bytes)						
Algorithm	128	256	512	1024	2048	4096	8192
CTR	1.74	1.27	1.05	0.93	0.86	0.83	0.82
TC1	9.00	8.75	8.65	8.60	8.56	8.56	8.56
TC3	9.08	8.82	8.72	8.67	8.63	8.63	8.62
MCBC	11.66	11.00	10.68	10.52	10.44	10.40	10.38
COPE	2.56	2.08	1.89	1.78	1.72	1.70	1.69
McOE-G	10.85	9.73	9.14	8.90	8.74	8.69	8.66
COPA	3.78	2.85	2.31	2.06	1.94	1.88	1.85