Reconsidering Generic Composition

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What is the correct way to build
an authenticated encryption scheme
from an encryption scheme and a MAC?

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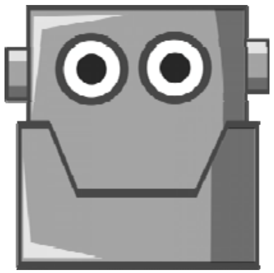
[Bellare-Namprempre – ASIACRYPT 2000]
Authenticated Encryption: Relations among Notions and Analysis of the Generic Composition Paradigm



Encrypt-and-MAC

Encrypt-then-MAC

MAC-then-Encrypt

always works if encryption IND-CPA secure and MAC unforgeable

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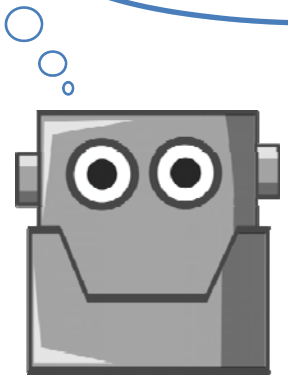

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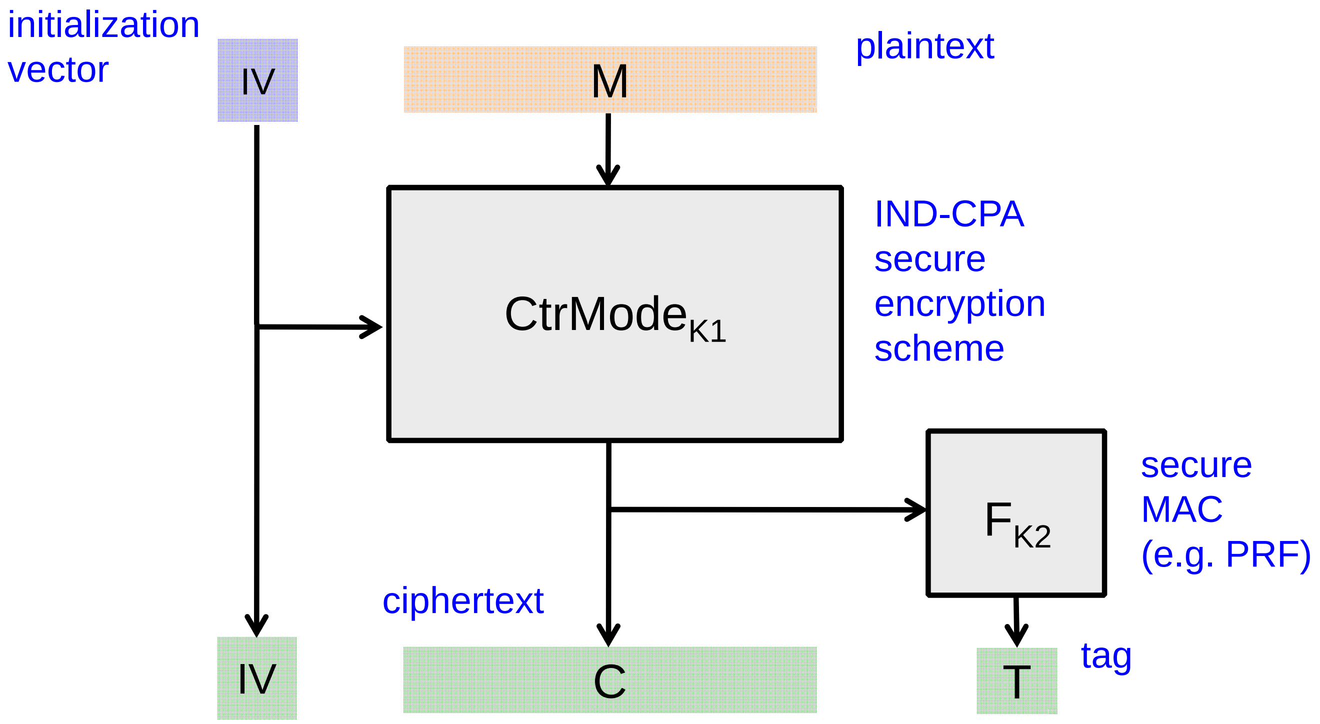
This summary of [BN] is incorrect.

Encrypt-then-MAC



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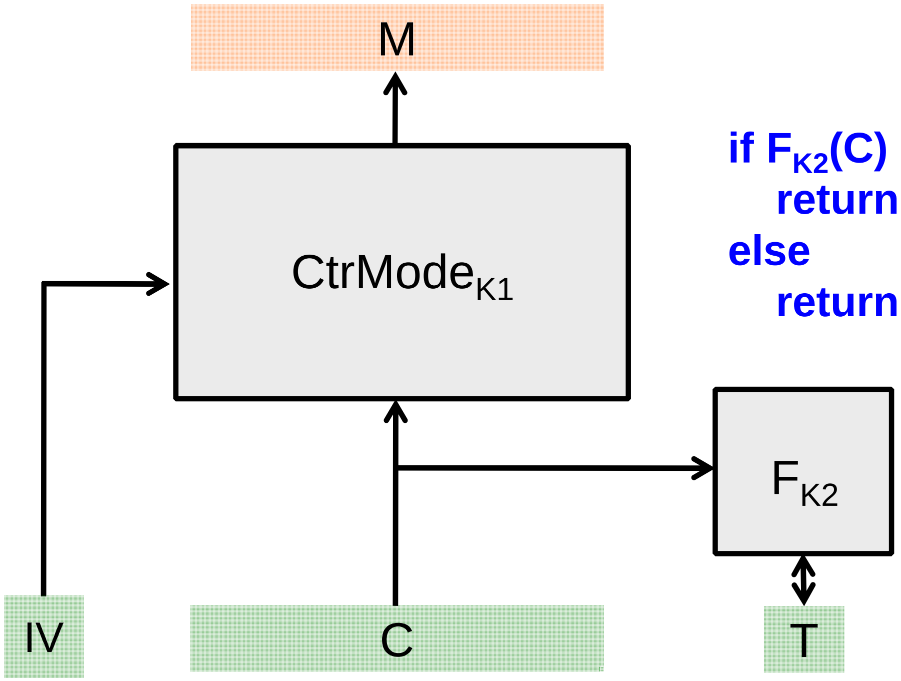
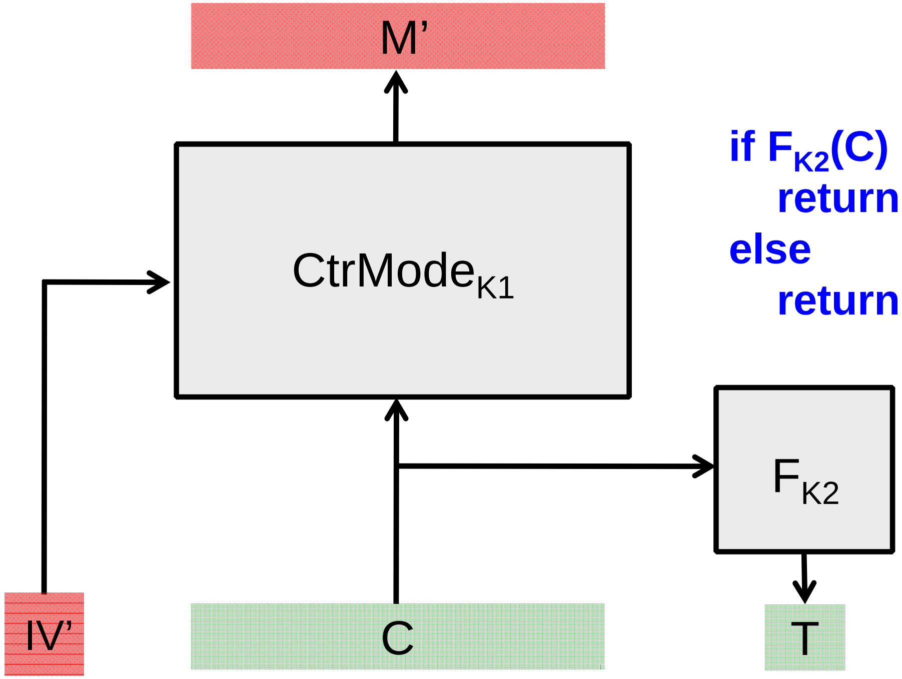


```
if $F_{K2}(C) = T$ then
    return $\text{Dec}_{K1}(IV,C)$
else
    return “invalid”
```

Encrypt-then-MAC



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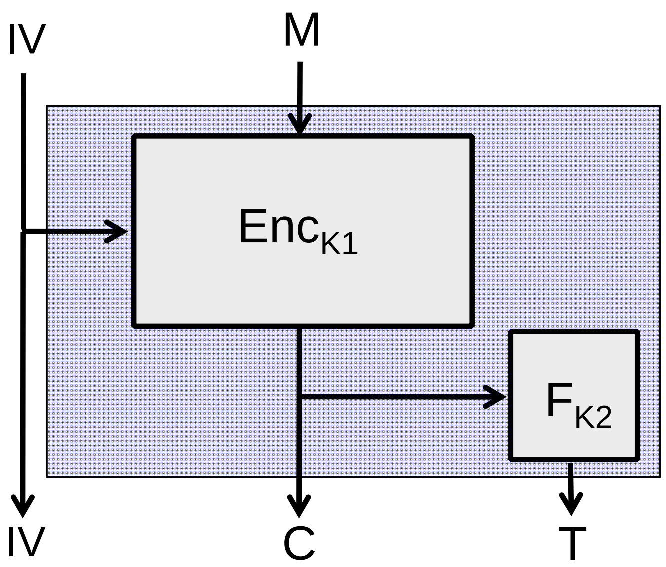
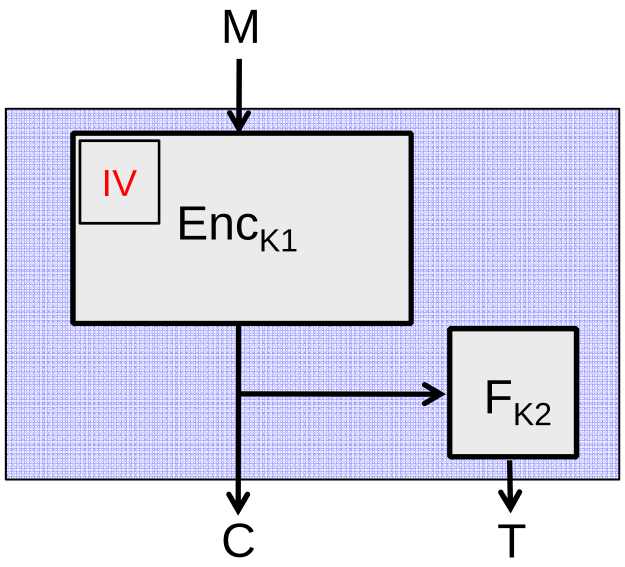
But… [BN] says… ???

“Encrypt-then-MAC” vs. Encrypt-then-MAC





IV-based AE scheme built from an **IV-based encryption** scheme and a MAC

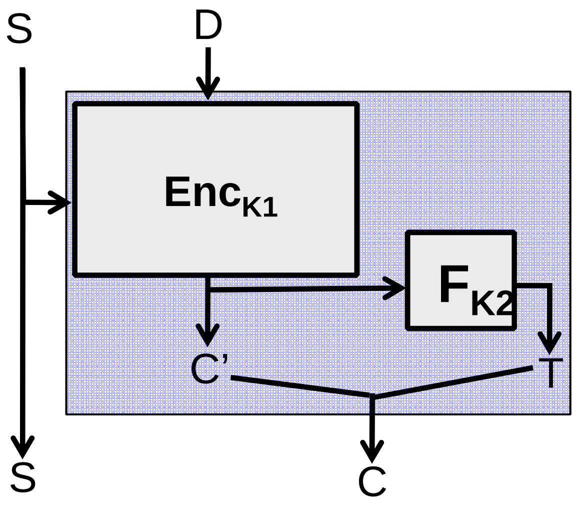
Probabilistic AE scheme built from a **probabilistic encryption** scheme and a MAC

[BN] is about this setting only.

Different starting primitives, different final primitives, different security

Incorrect summary of [BN], in practice

ISO/IEC 19772, Mechanism 5 (Encrypt-then-MAC)
Information Security – Security Techniques – Authenticated Encryption



S required to be a nonce (but not random)

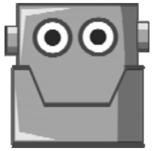
"Enc" = CBC, CTR, OFB, CFB blockcipher modes

-- not all have {0,1}* domains

-- some require S to be random for IND-CPA

S not covered by tag

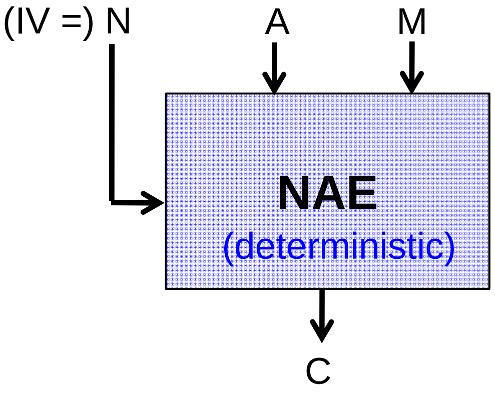
Appeals to [BN] to justify security of a nonce-based scheme
built from IV-based encryption.



“Okay, fine: EtM + secure prob. Enc + secure MAC = secure prob. AE”

The thing is…

1. Typical goal nowadays is **nonce-based AE with associated data (NAE),** not probabilistic AE



N= nonce (“number used once”, e.g. sequence number)

A = associated data, bound to plaintext/ciphertext, not private

M = plaintext, private

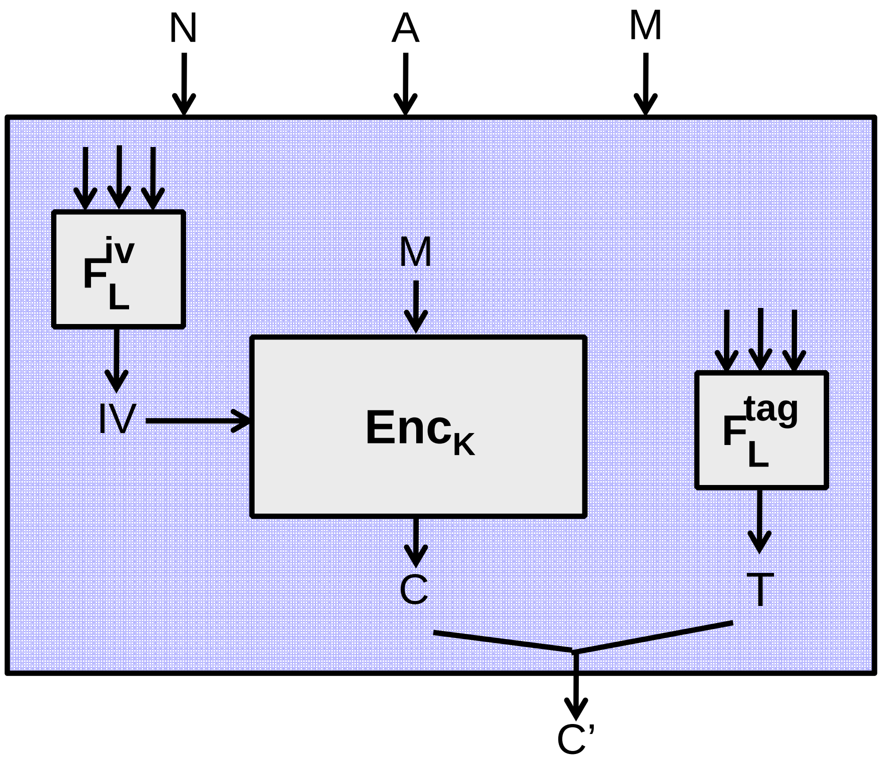
2. Standards and common crypto libraries **don’t provide probabilistic encryption** schemes, they provide **IV-based encryption**

```
int encrypt(unsigned char *plaintext,
            int plaintext_len,
            unsigned char *key,
            unsigned char *iv,
            unsigned char *ciphertext)
```

openSSL encryption API

What are the correct ways to compose
a secure IV-based encryption scheme
and a secure PRF in order to build
a nonce-based AE(AD) scheme?

Our basic NAE forms

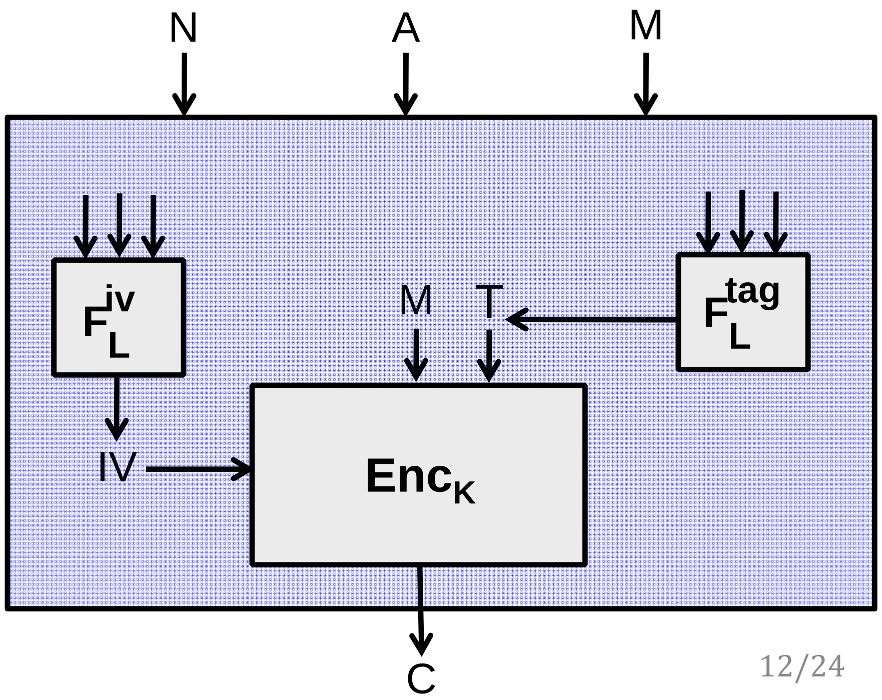


F^{iv} inputs: (N or □ , A or □, M or □)

F^{tag} inputs: (N or □ , A or □, M or □) "E&M"

or (N or □ , A or □, C or □) "EtM"

□ = "missing"



F^{iv} inputs: (N or □ , A or □, M or □)

F^{tag} inputs: (N or □ , A or □, M or □)

160 possible constructions analyzed, resulting in:

8 "favored" schemes --- generically secure, good security bounds

1 "transitional" scheme --- generically secure, inferior bound

3 "elusive" schemes --- despite LOADS of effort, unable to find proofs
using only IND$-CPA and PRF security of components,
unable to find counterexamples

All other schemes --- we find counterexamples (many trivial, some not)

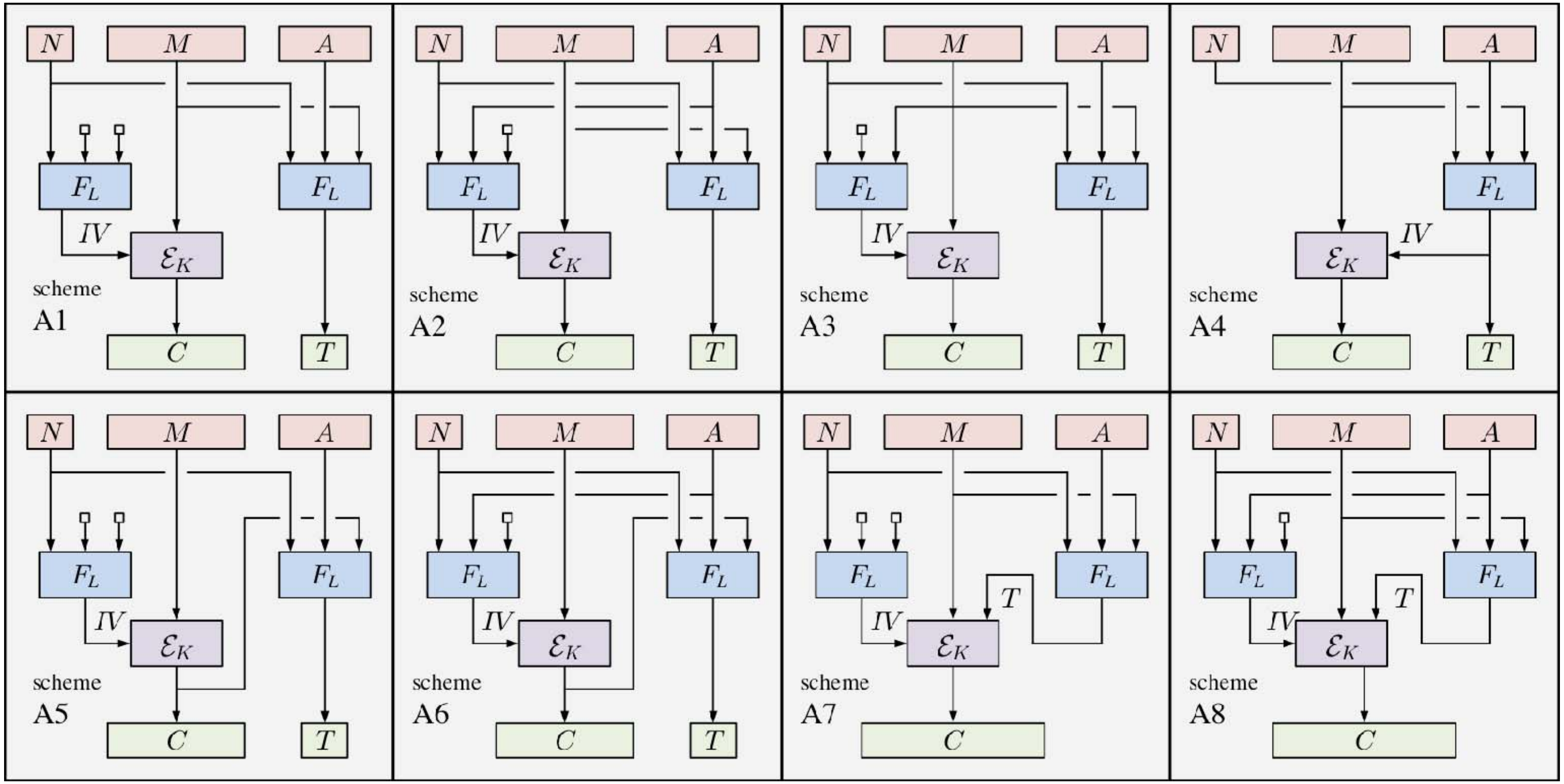
What security notion?

$$\mathbf{Adv}_{\Pi}^{\mathrm{nAE}}(\mathcal{A}) = \Pr\left[\mathcal{A}^{\mathcal{E}(\cdot,\cdot,\cdot),\,\mathcal{D}(\cdot,\cdot,\cdot)} \Rightarrow 1\right] - \Pr\left[\mathcal{A}^{\$(\cdot,\cdot,\cdot),\,\perp(\cdot,\cdot,\cdot)} \Rightarrow 1\right]$$

we target an "all-in-one" AE notion [RS06],
equivalent to IND$-CPA + INT-CTXT

The favored eight

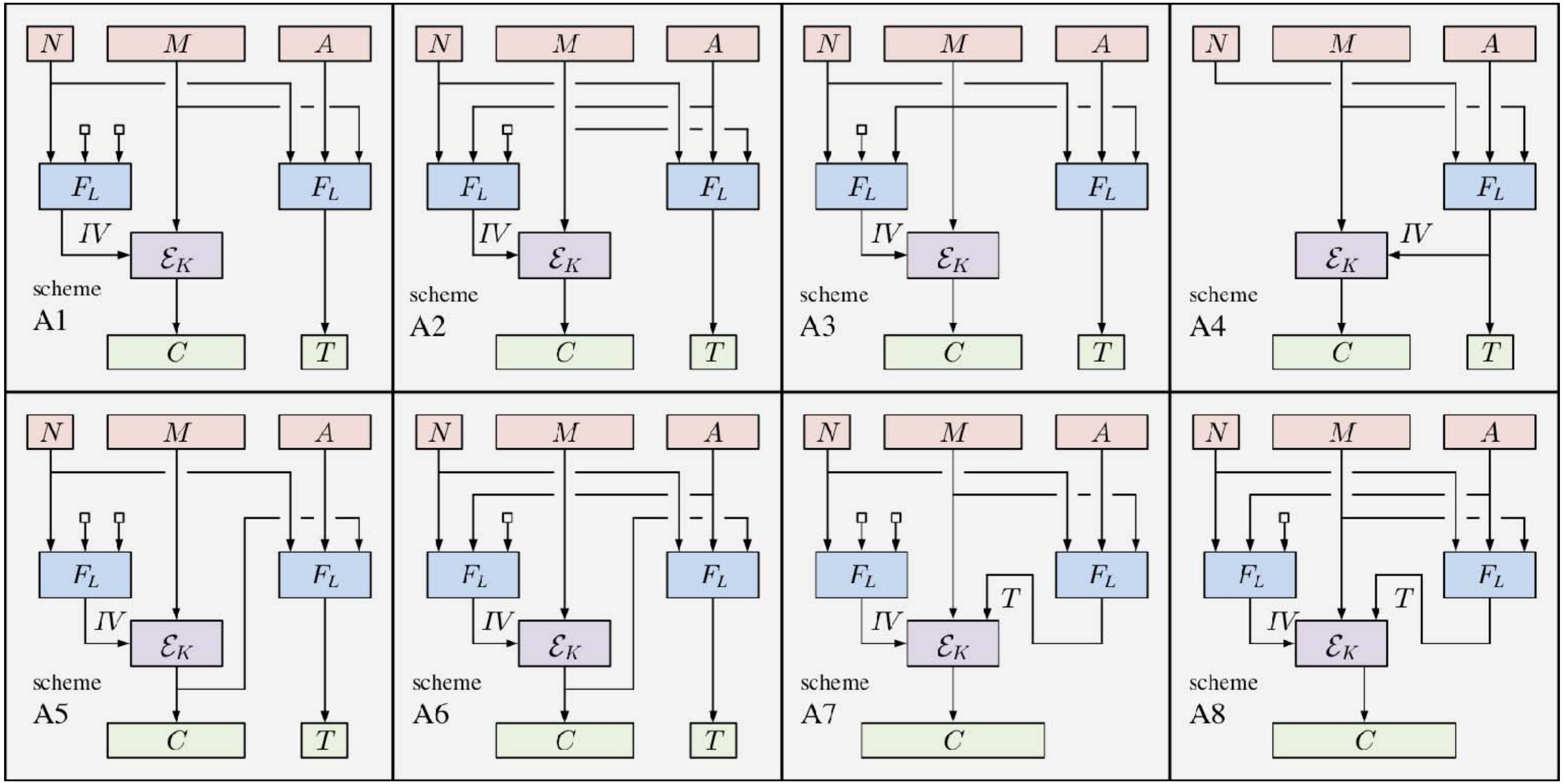
“E and M” “E and M” “E and M” SIV mode [RS06]



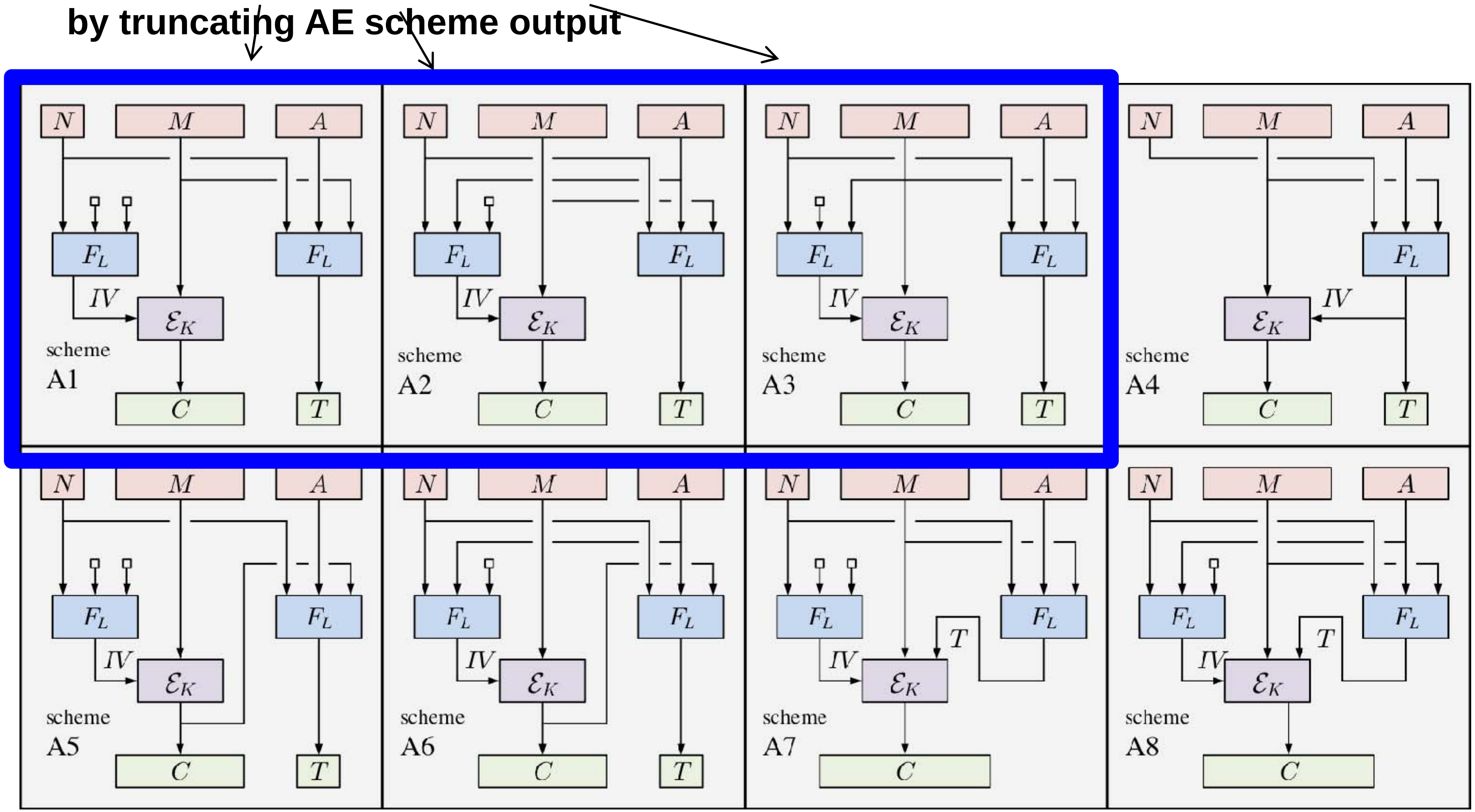
“E then M” “E then M” “M then E” “M then E”

The favored eight all have the same (good, tight) AE security.

Which should I use?



Encryption can compute C,T in parallel
Can truncate the tag
by truncating AE scheme output



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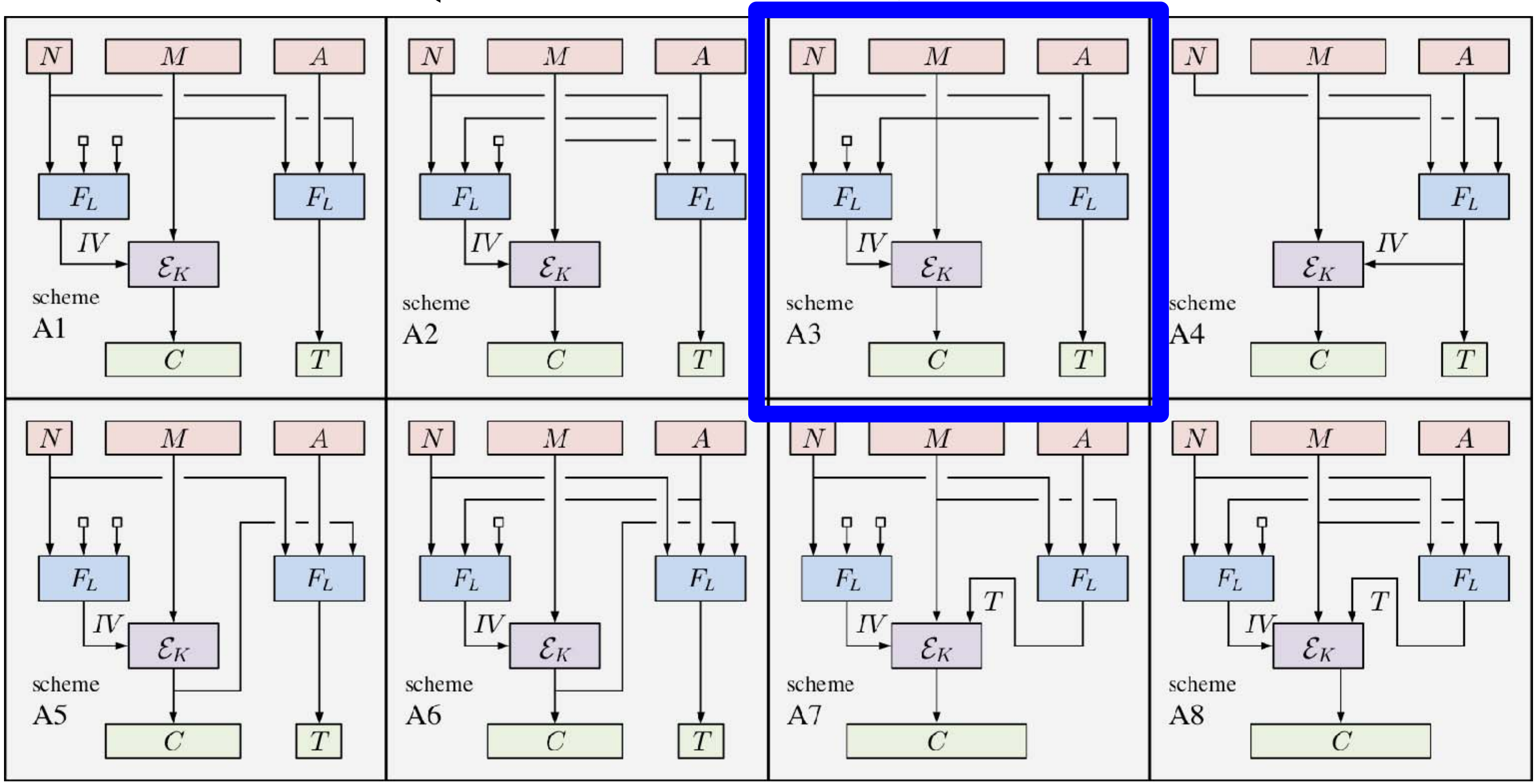
IV must be recoverable from C,T



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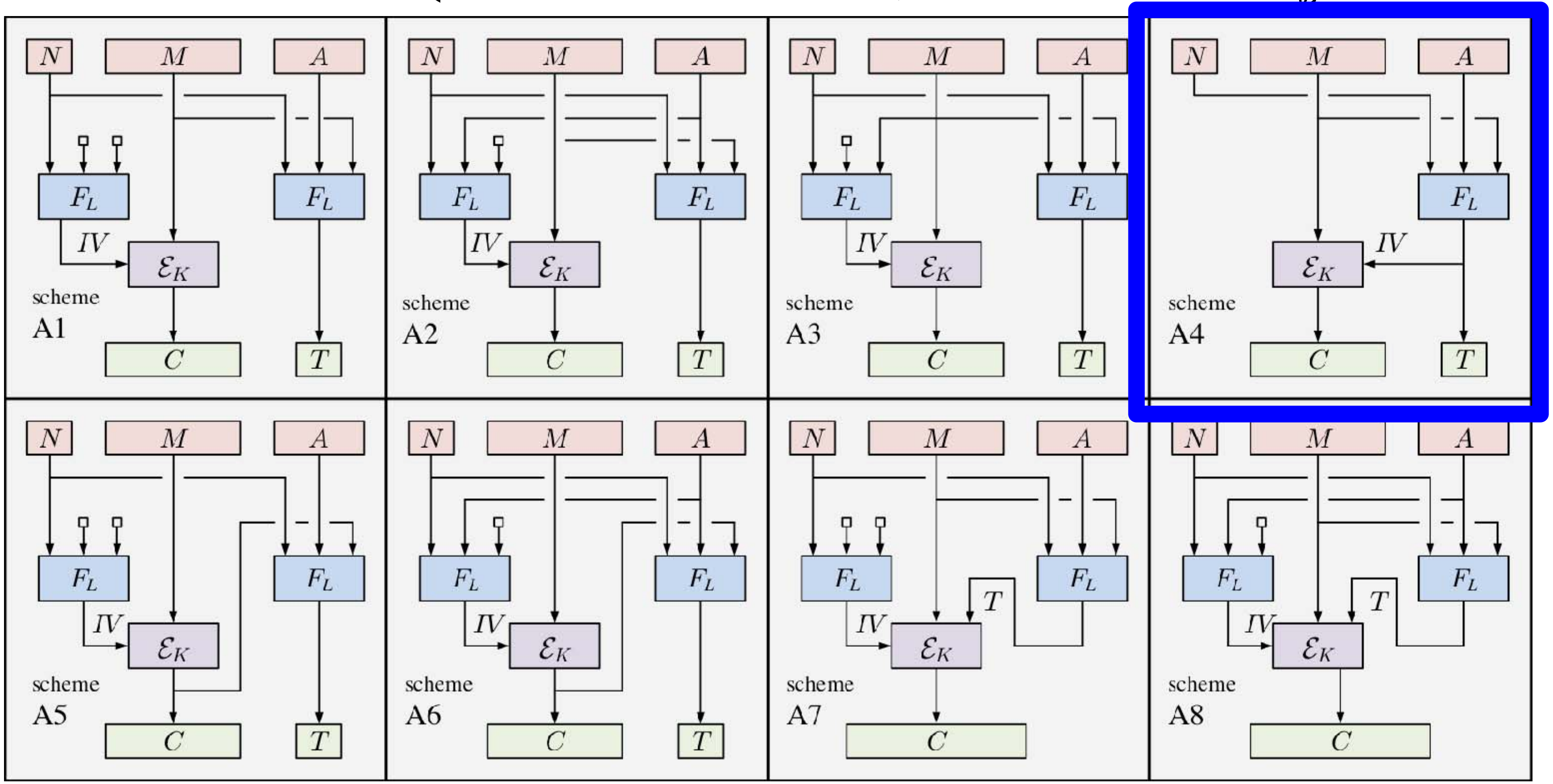

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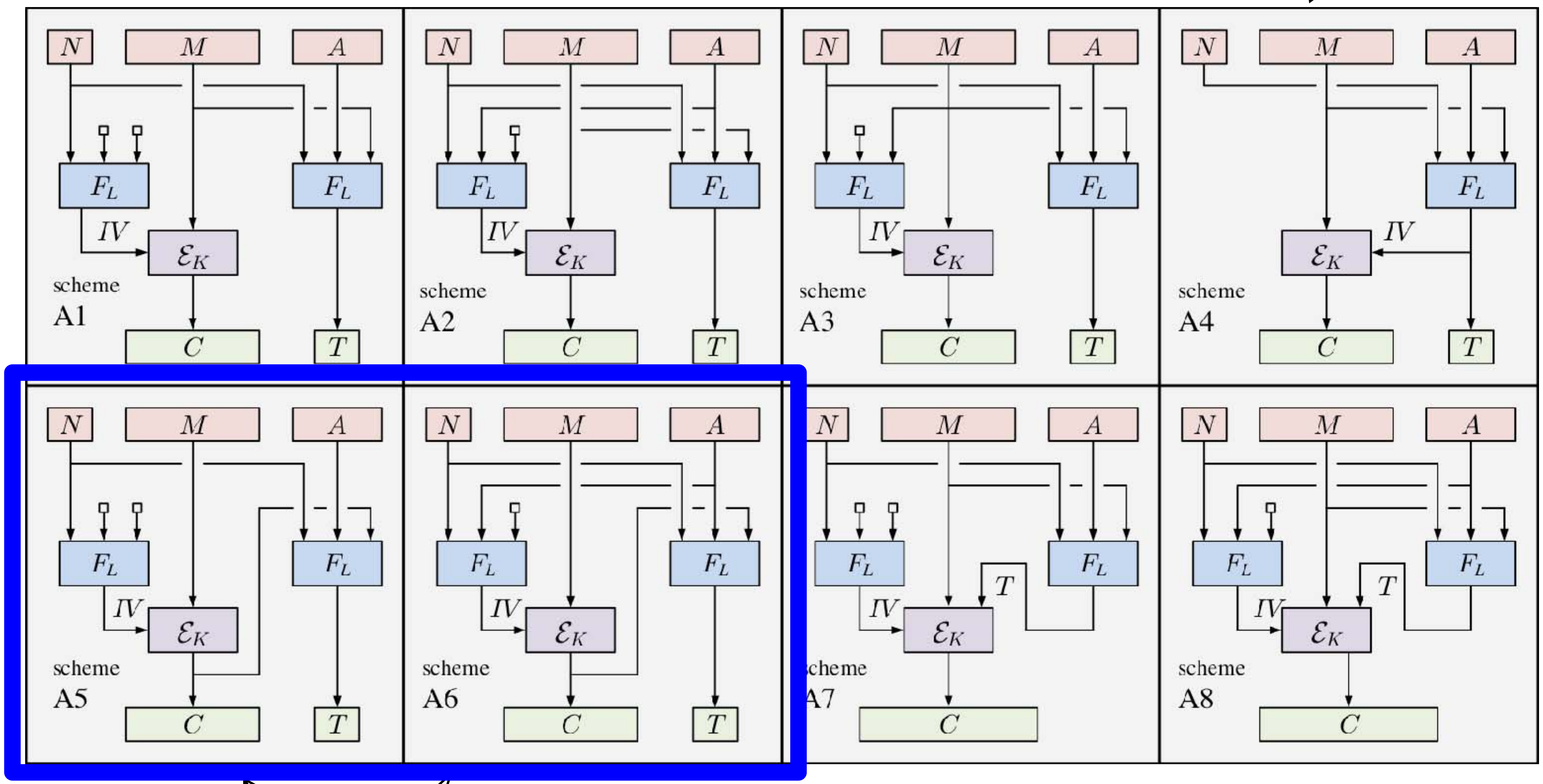

Decryption can compute M, check T in parallel
Can truncate

Encryption can compute C,T in parallel
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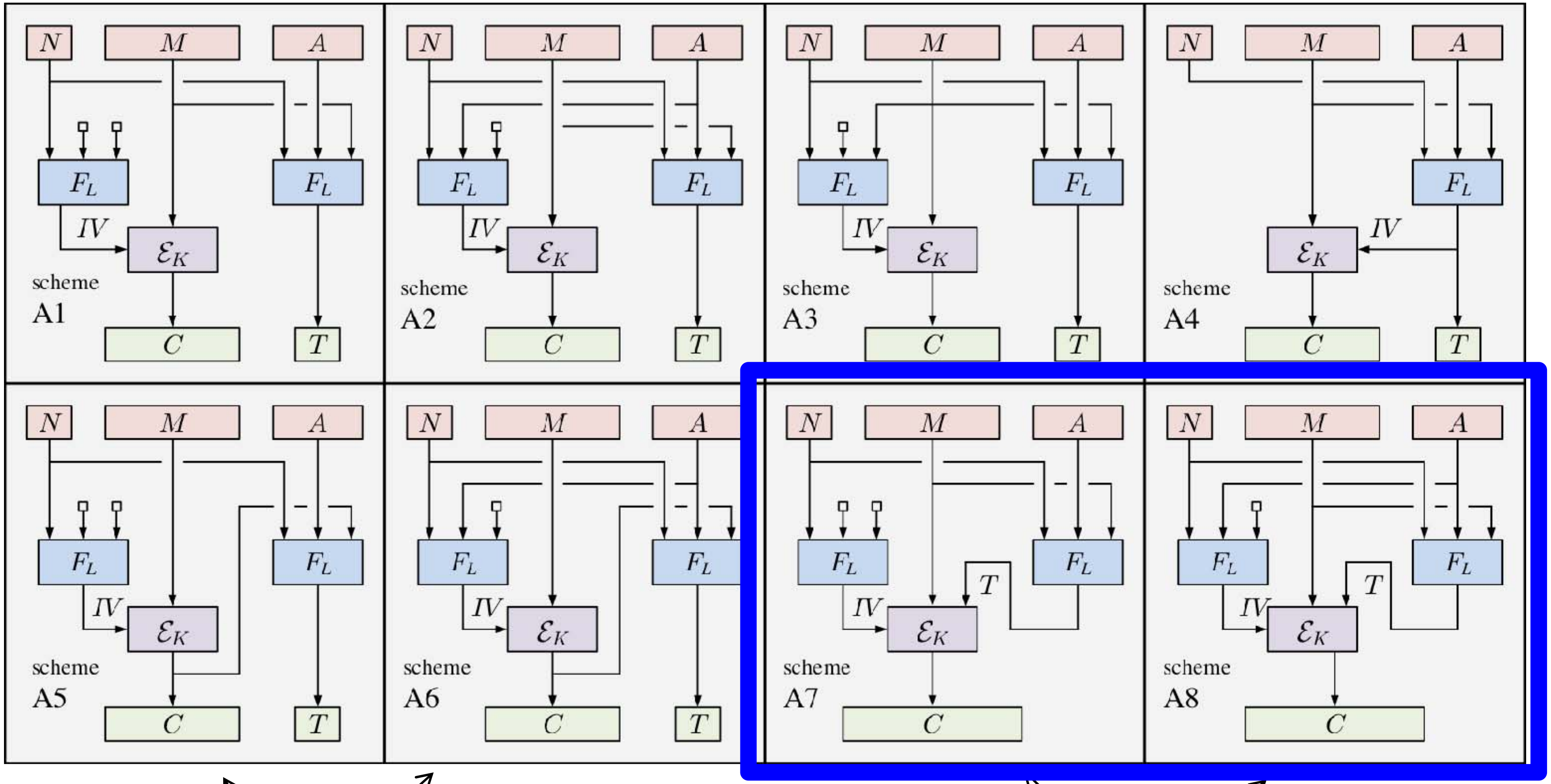
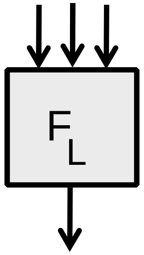


Decryption can compute M, check T in parallel
Can truncate

Cannot truncate
“MtE” style schemes have history
of problems in practice

What are these “vector input” PRFs?
Real PRFs (e.g. HMAC-SHA) take a string!



Can be instantiated in many ways. We use the **three-xor construction**.

$$F_{L1,L2,L3}(N,A,M) = f_{L1}(N) \oplus f_{L2}(A) \oplus f_{L3}(M)$$

$$F_{L1,L2,L3}(N,\square,M) = f_{L1}(N) \oplus 0^n \oplus f_{L3}(M)$$

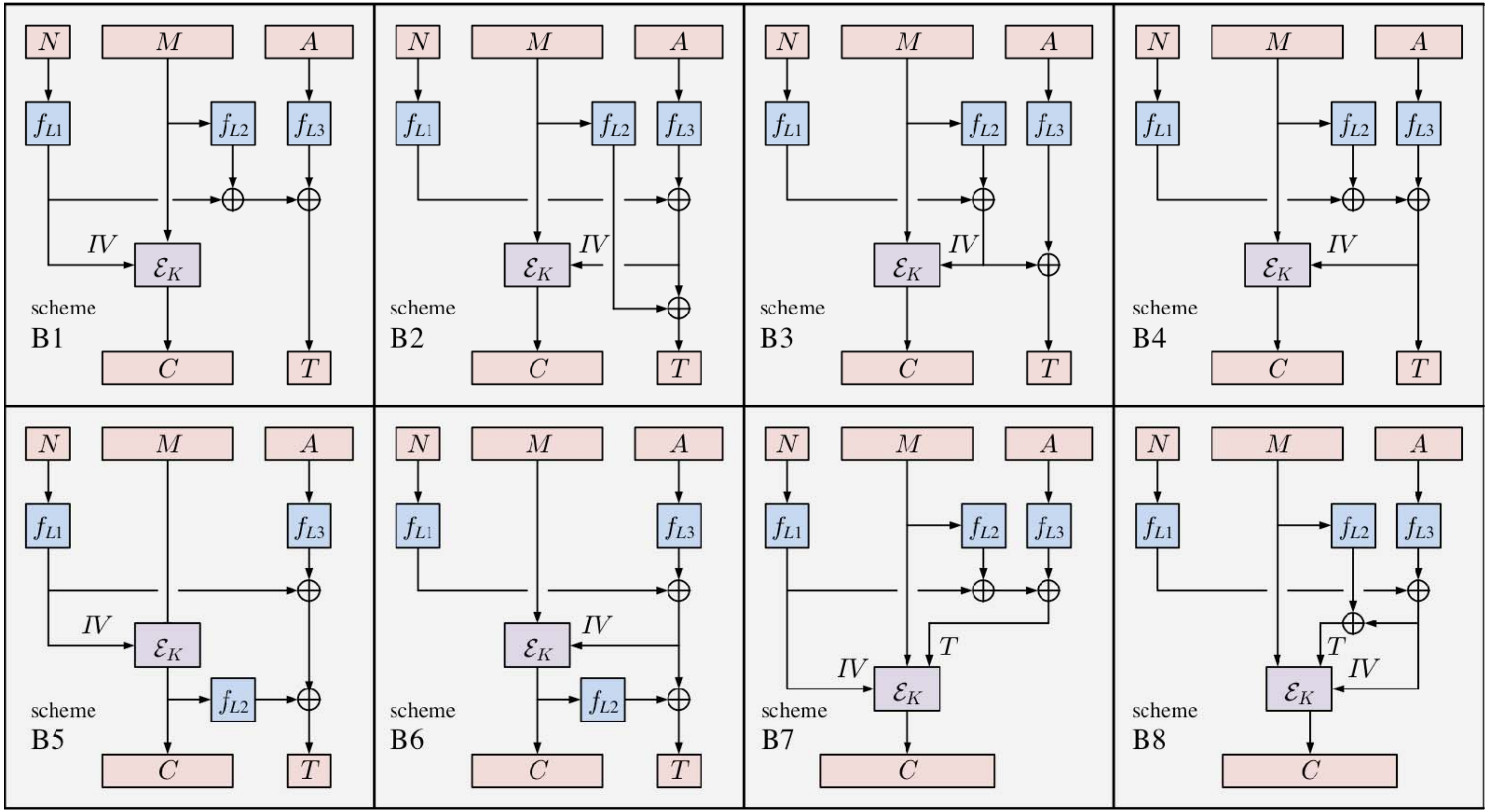
$$F_{L1,L2,L3}(\square,\square,M) = 0^n \oplus 0^n \oplus f_{L3}(M)$$

etc.

The favored eight, based on a string-input PRF

(using the three-XOR construction)

EAX2
[Bellare, R, Wagner'04]



Also in the paper

Building NAE from tidy **nonce-based encryption** and a PRF:
Three secure options, one elusive.

Proofs of security for elusive schemes under new “knowledge of tags” assumption

An ISO standard that uses [BN] to justify an NAE design = Broken

Discussion of “tidiness” as a syntactic property of deterministic encryption

High-level Summary

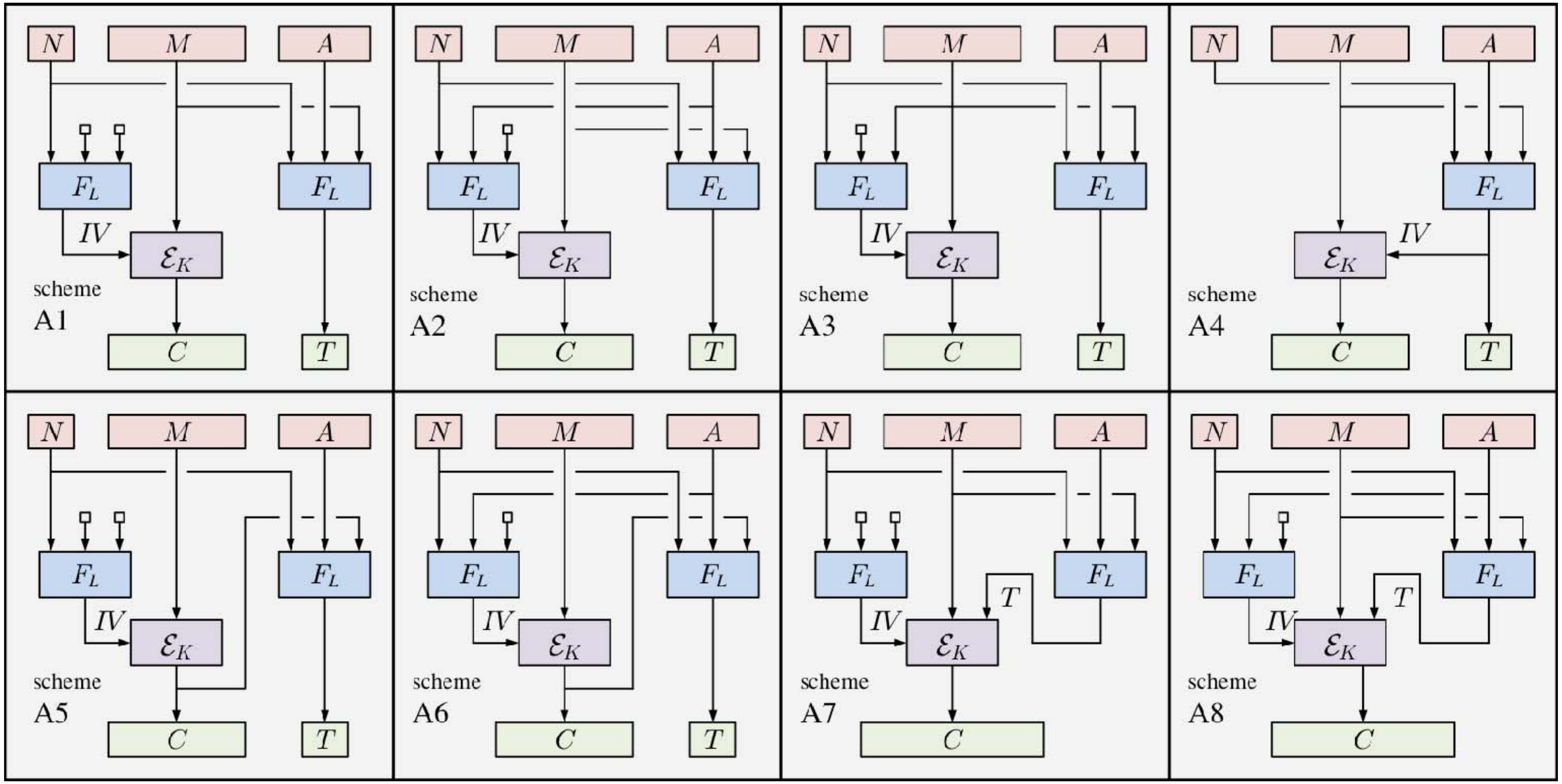
[BN] is fine, but people’s “understanding” of it over-generalizes,
leading to problems in practice

E&M, EtM, MtE taxonomy / security characterization is specific
to building probabilistic AE from probabilistic encryption

GC story is much more nuanced when building nonce-based AE

Thank you!

“E and M” “E and M” “E and M” SIV mode [RS06]



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--- END ---