Ask Your Cryptographer if Context-Committing AEAD Is Right for You

Mihir Bellare, John Chan, Paul Grubbs, Viet Tung Hoang,
Sanketh Menda, Julia Len, Thomas Ristenpart, and Phillip Rogaway

Authenticated Encryption with Associated Data (AEAD)

Sender

Recipient

Authenticated Encryption with Associated Data (AEAD)

Context:

- Key K
- Nonce N (e.g., random IV or counter)
- Associated data A (e.g., network header)

K, **N**, **A**

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Shared out of band.

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Standardized
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2. ChaCha20/Poly1305
3. AES-GCM-SIV

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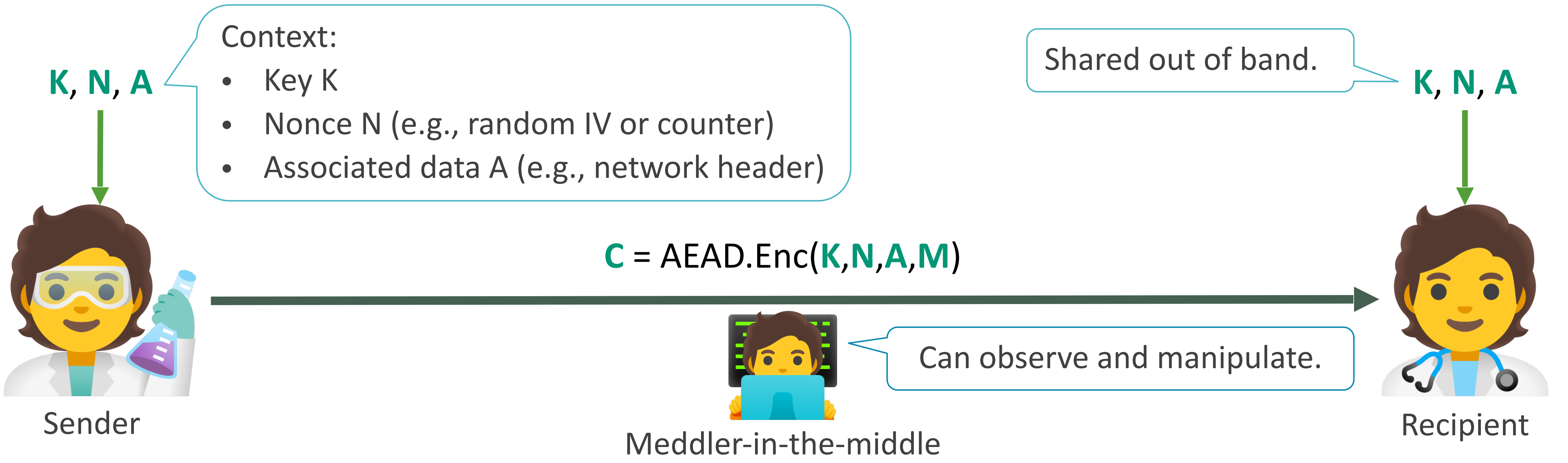

Standardized

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Provably Secure

1. Confidentiality
2. Authenticity

Recent Attacks on AEAD

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Fast Message Franking:
From Invisible Salamanders to Encryptment*

Yevgeniy Dodis[1], Paul Grubbs[2,†], Thomas Ristenpart[2], Joanne Woodage[3,†]

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Abstract

Message franking enables cryptographically verifiable reporting of abusive content in end-to-end encrypted messaging. Grubbs, Lu, and Ristenpart recently formalized the needed underlying primitive, what they call compactly committing authenticated encryption (AE), and analyzed the security of a number of approaches. But all known secure schemes are still slow compared to the fastest standard AE schemes. For this reason Facebook Messenger uses AES-GCM for franking of attachments such as images or videos.

We show how to break Facebook's attachment franking scheme: a malicious user can send an objectionable image to a recipient but that recipient cannot report it as abuse. The core problem stems from use of fast but non-committing AE, and so we build the fastest compactly committing AE schemes to date. To do so we introduce a new primitive, called encryptment, which captures the essential properties needed. We prove that, unfortunately, schemes with performance profile similar to AES-GCM won't work. Instead, we show how to efficiently transform Merkle-Damgärd-style hash functions into secure encryptments, and how to efficiently build compactly committing AE from encryptment. Ultimately our main construction allows franking using just a single computation of SHA-256 or SHA-3. Encryptment proves useful for a variety of other applications, such as remotely keyed AE and concealments, and our results imply the first single-pass schemes in these settings as well.

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By Sophie Schmieg September 7, 2020 No Comments

By now, many people have run across the Invisible Salamander paper about the interesting property of AES-GCM, that allows an attacker to construct a ciphertext that will decrypt with a valid tag under two different keys, provided both keys are known to the attacker. On some level, finding properties like this isn't too surprising: AES-GCM was designed to be an AEAD, and nowhere in the AEAD definition does it state anything about what attackers with access to the keys can do, since the usual assumption is that attackers don't have that access, since any Alice-Bob-Message model would be meaningless in that scenario.

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How to Abuse and Fix Authenticated Encryption Without Key Commitment

Ange Albertini[1], Thai Duong[1], Shay Gueron[2,3], Stefan Kölbl[1], Atul Luykx[1], and Sophie Schmieg[1]

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The vast majority of applications should default to using authenticated encryption (AE) [BN00, KY00], a well-studied primitive which avoids the pitfalls of unauthenticated SKE with relatively small performance overhead. AE schemes are used in widely adopted protocols like TLS [Res18], standard-

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Partitioning Oracle Attacks

Julia Len   Paul Grubbs   Thomas Ristenpart

Cornell Tech

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We introduce partitioning oracle attacks, a new type of CCA. These are similar to previous attacks considered in the password-authenticated key exchange (PAKE) literature [11, 72, 98]; we provide a unifying attack framework that transcends PAKE and show partitioning oracle attacks that exploit weaknesses in widely used non-committing AEAD schemes. Briefly, a partitioning oracle arises when an adversary can: (1) efficiently craft ciphertexts that suc-

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These attacks work in new threat models!

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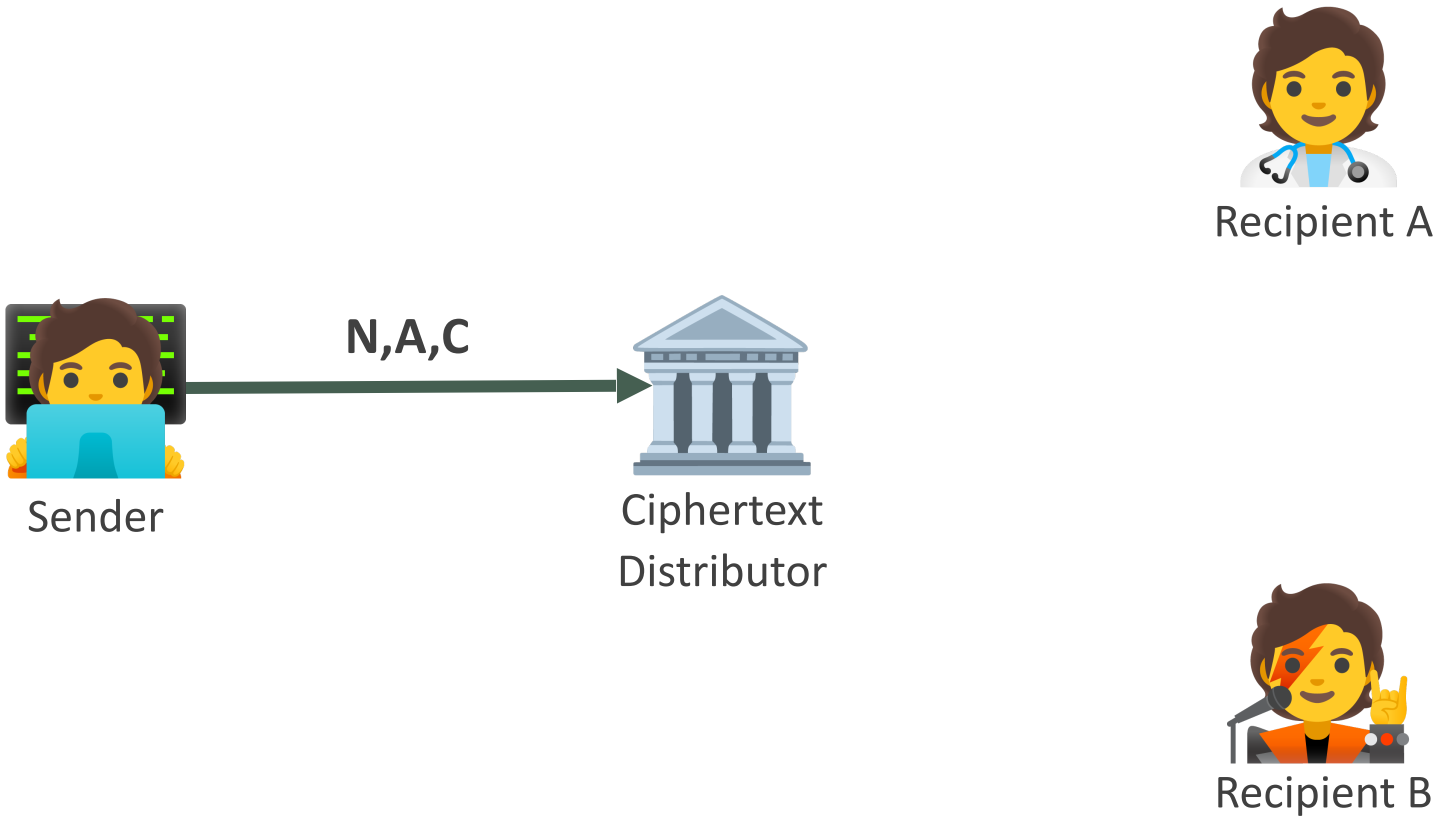

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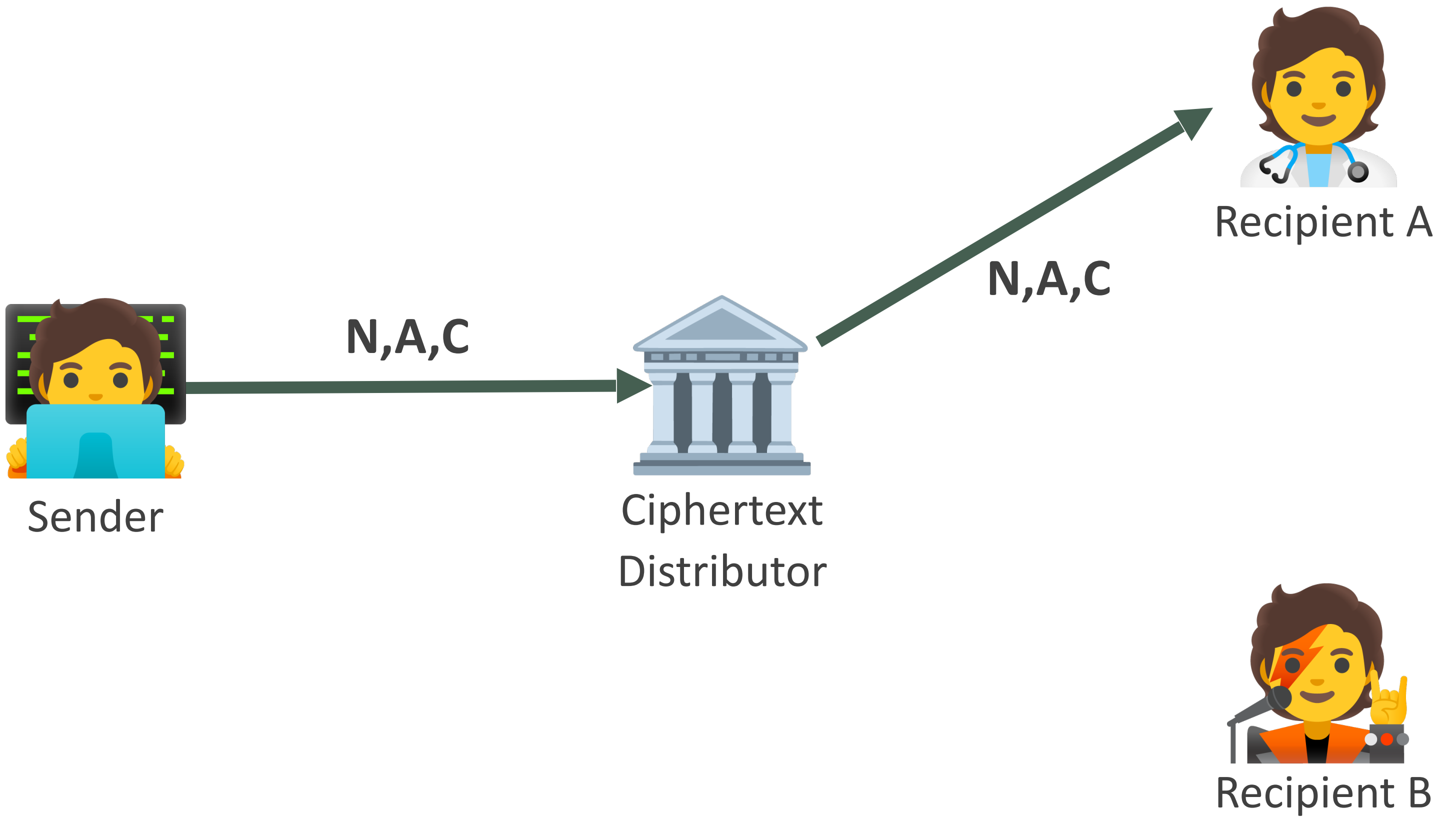

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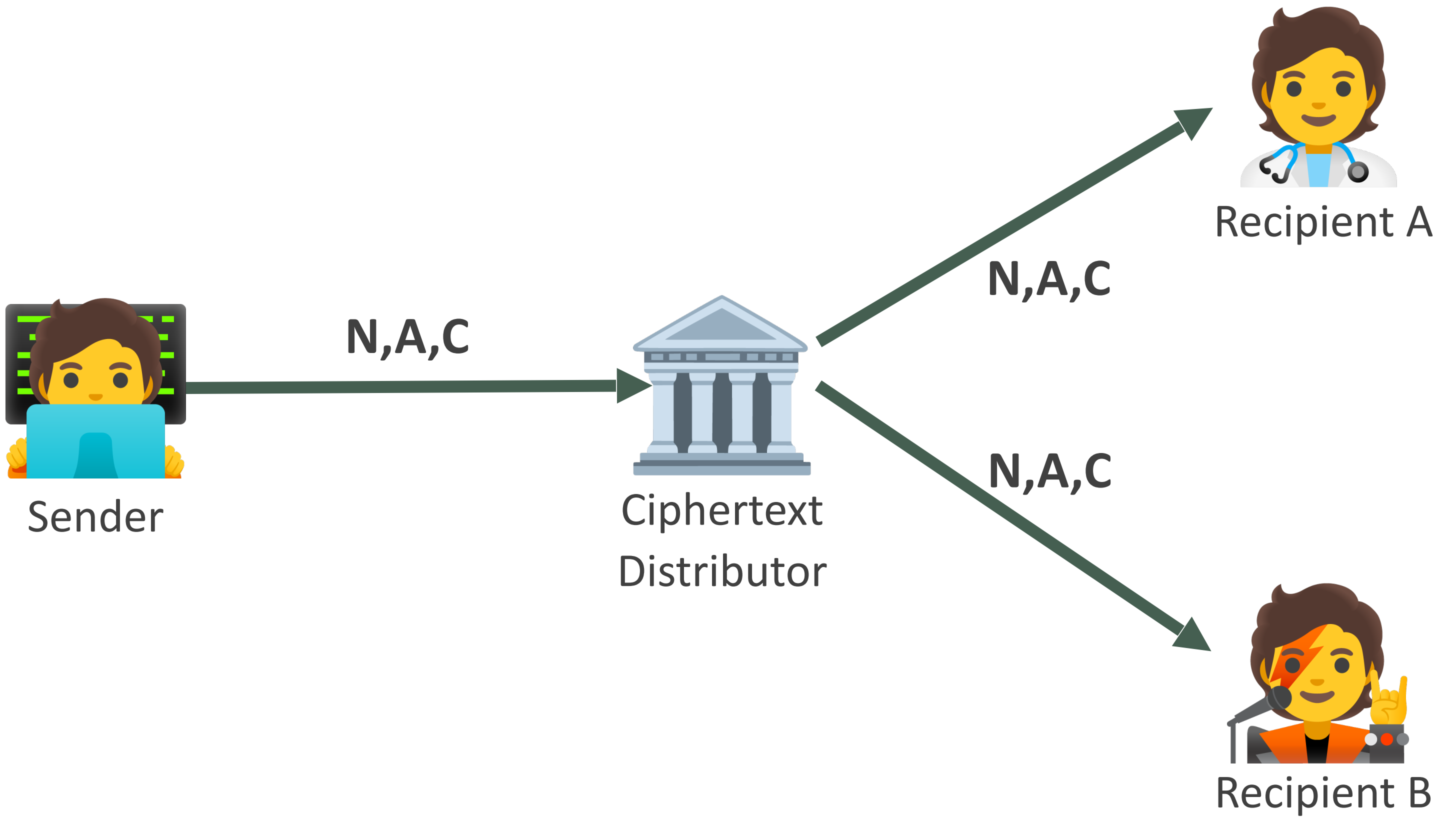

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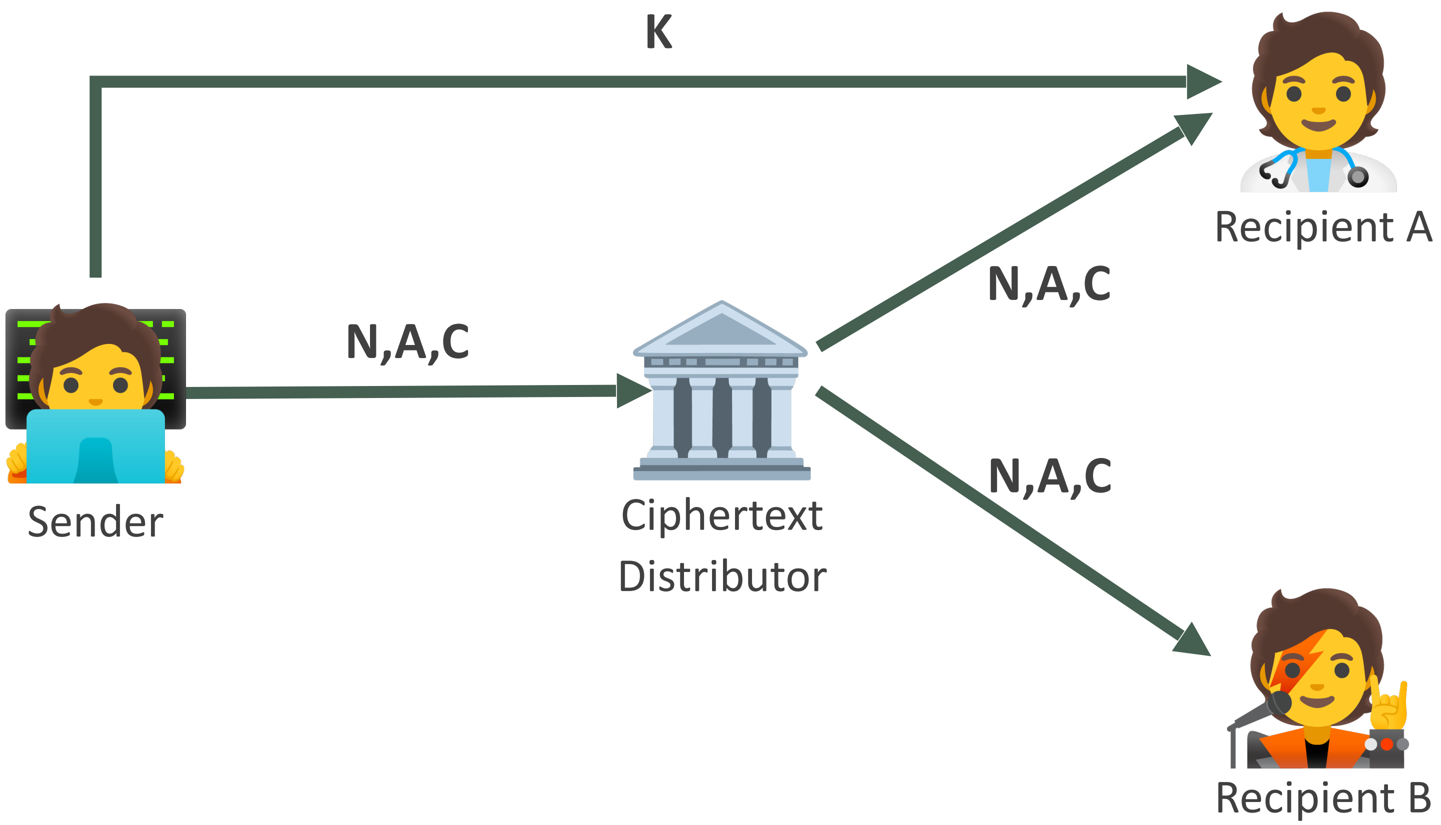

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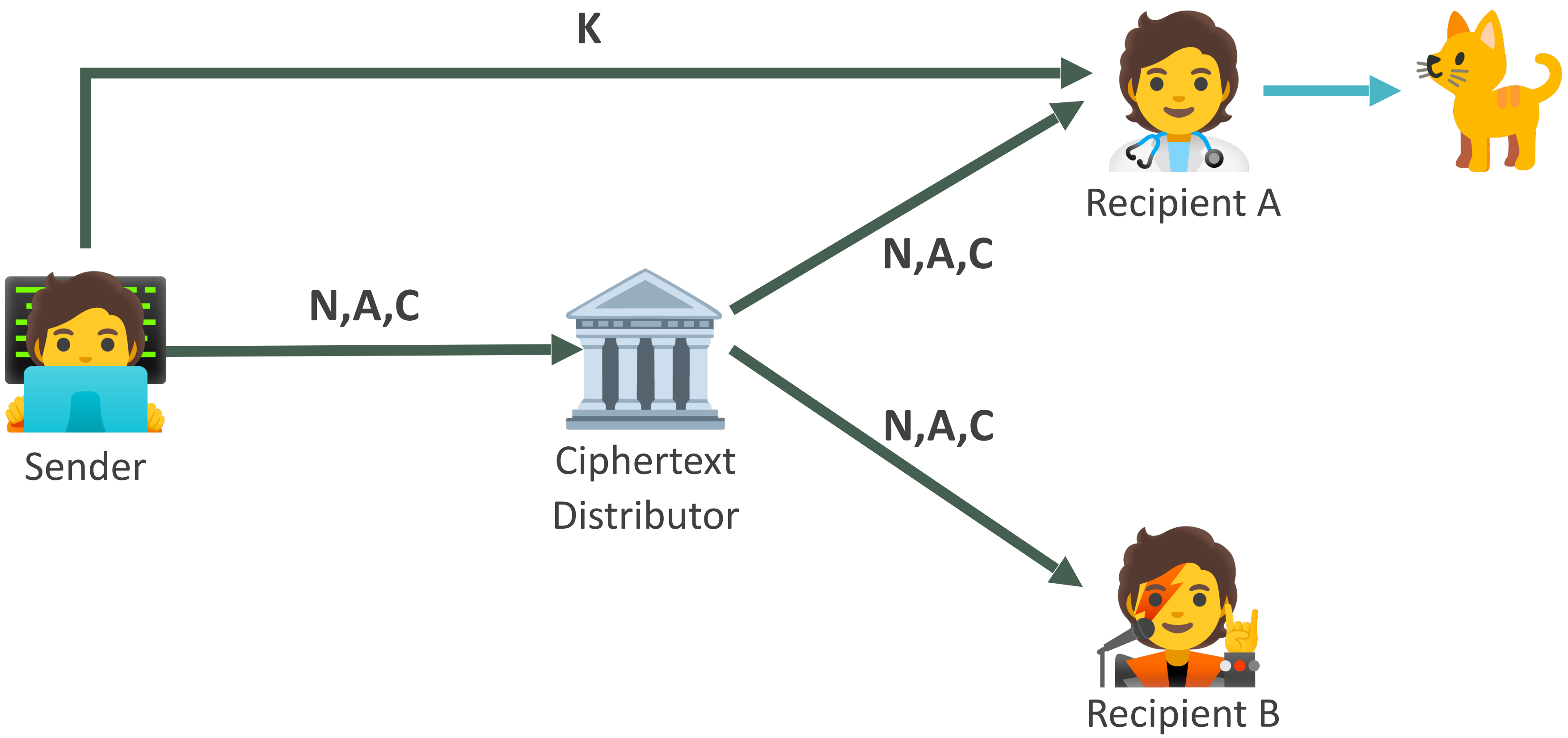

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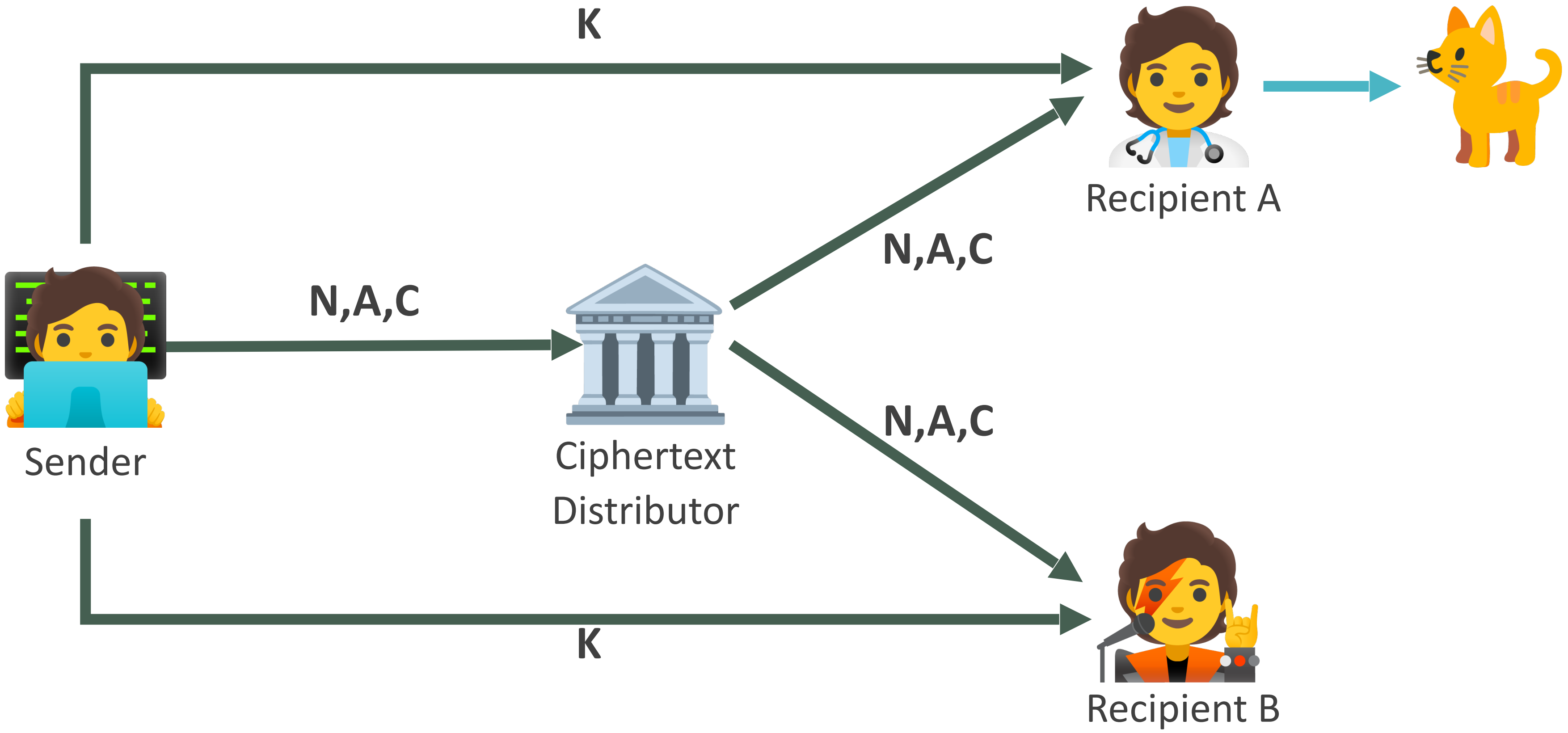

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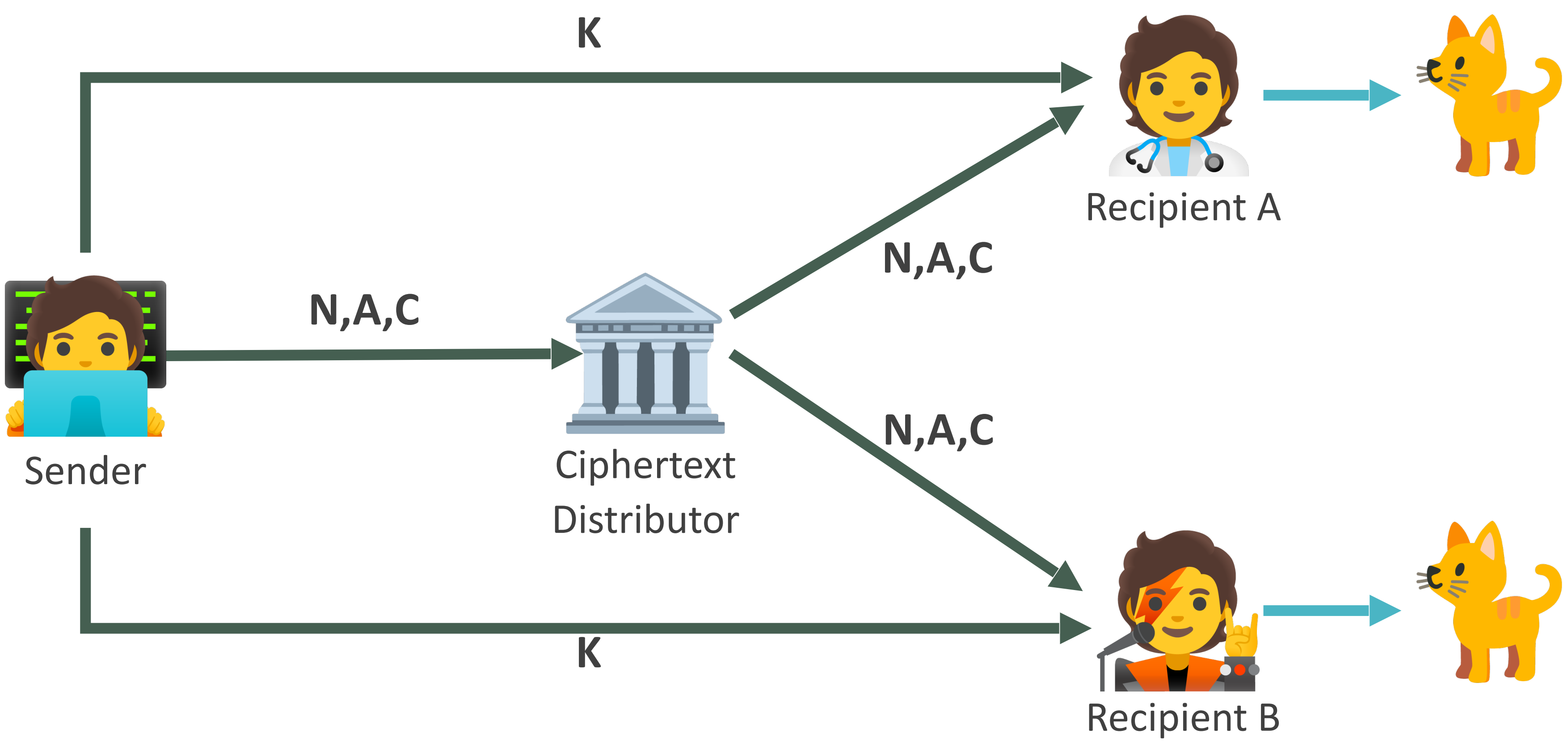

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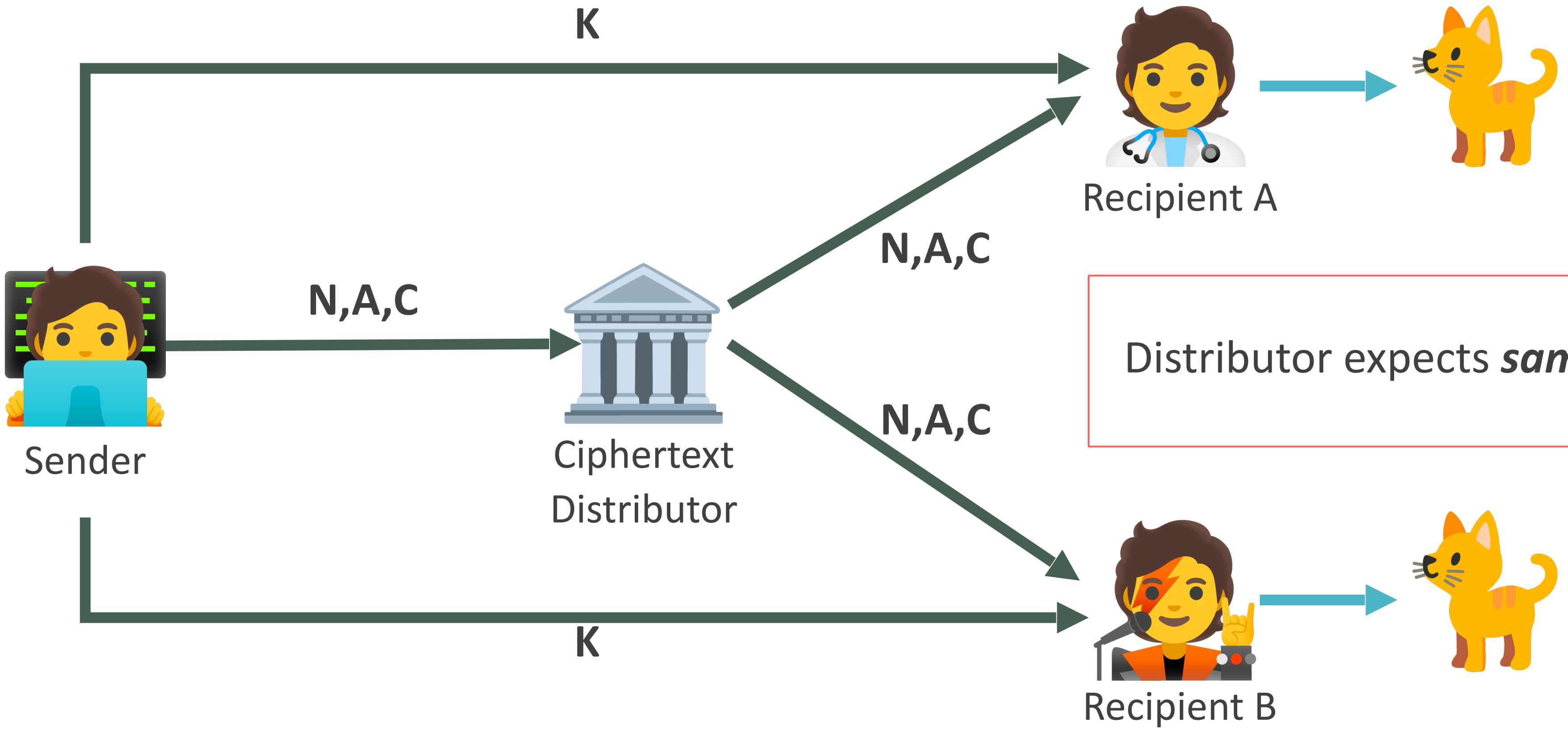

Distributor expects ***same plaintext received***

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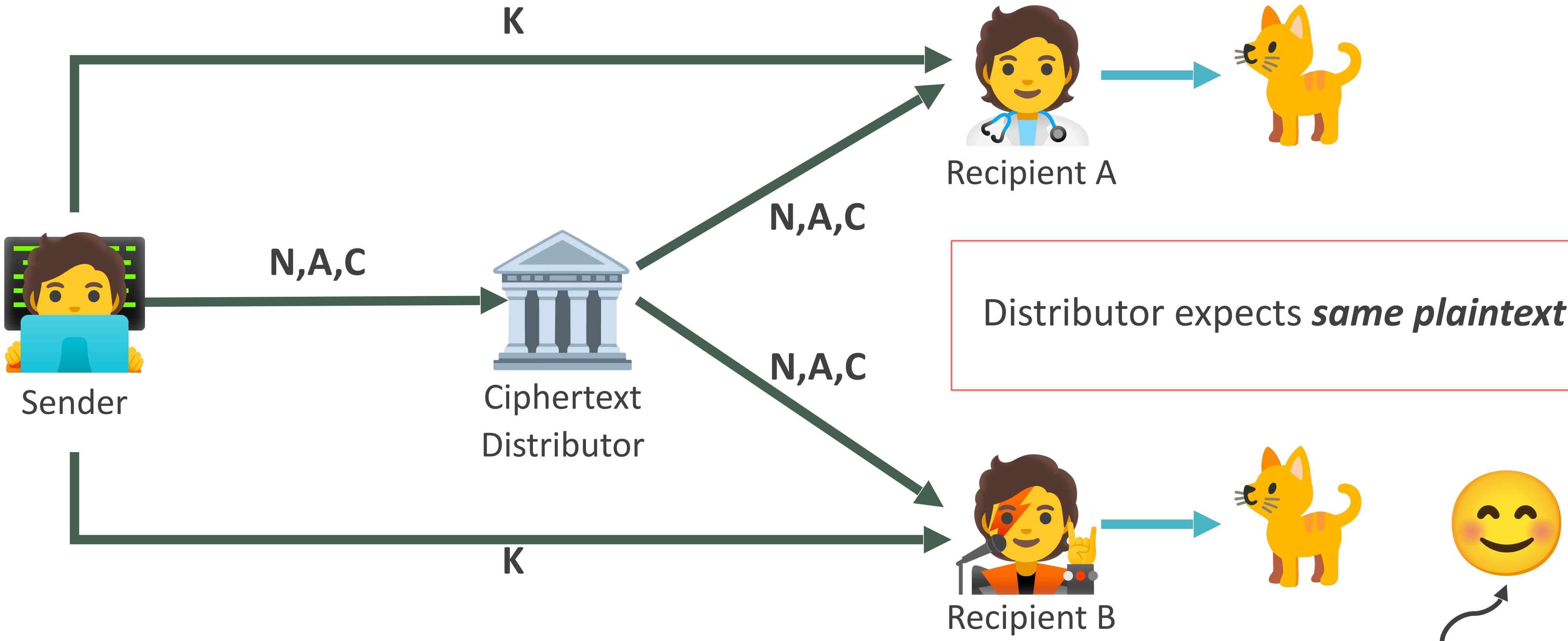

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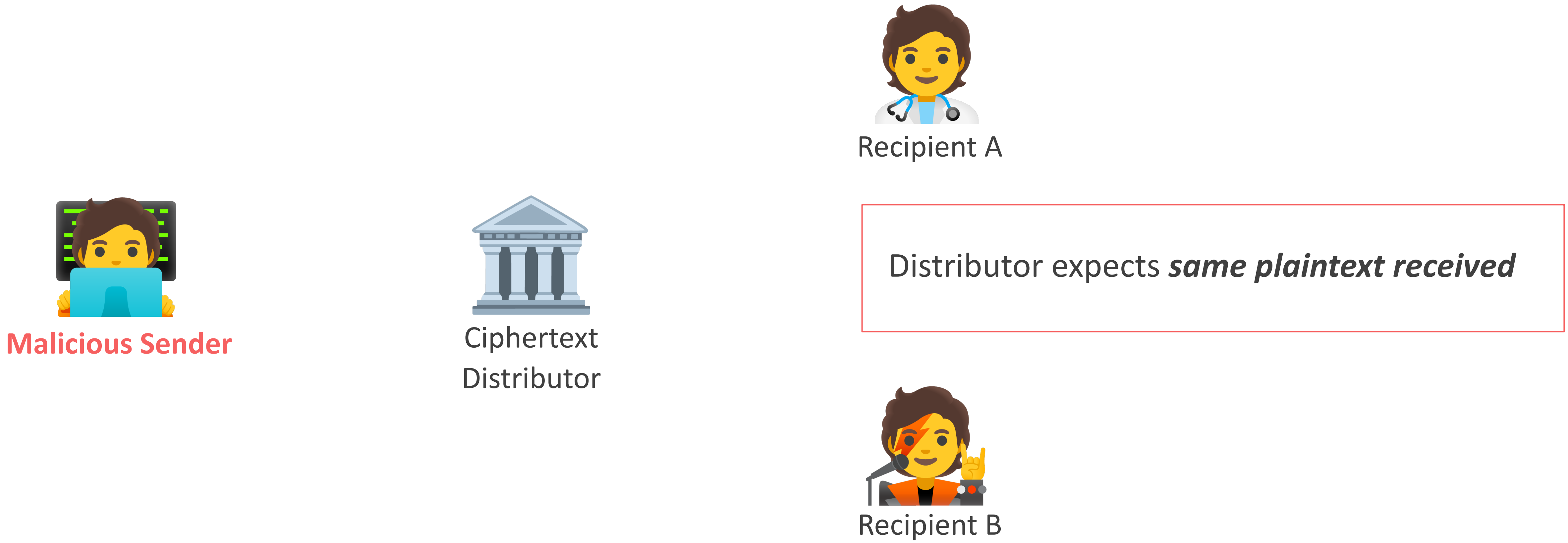

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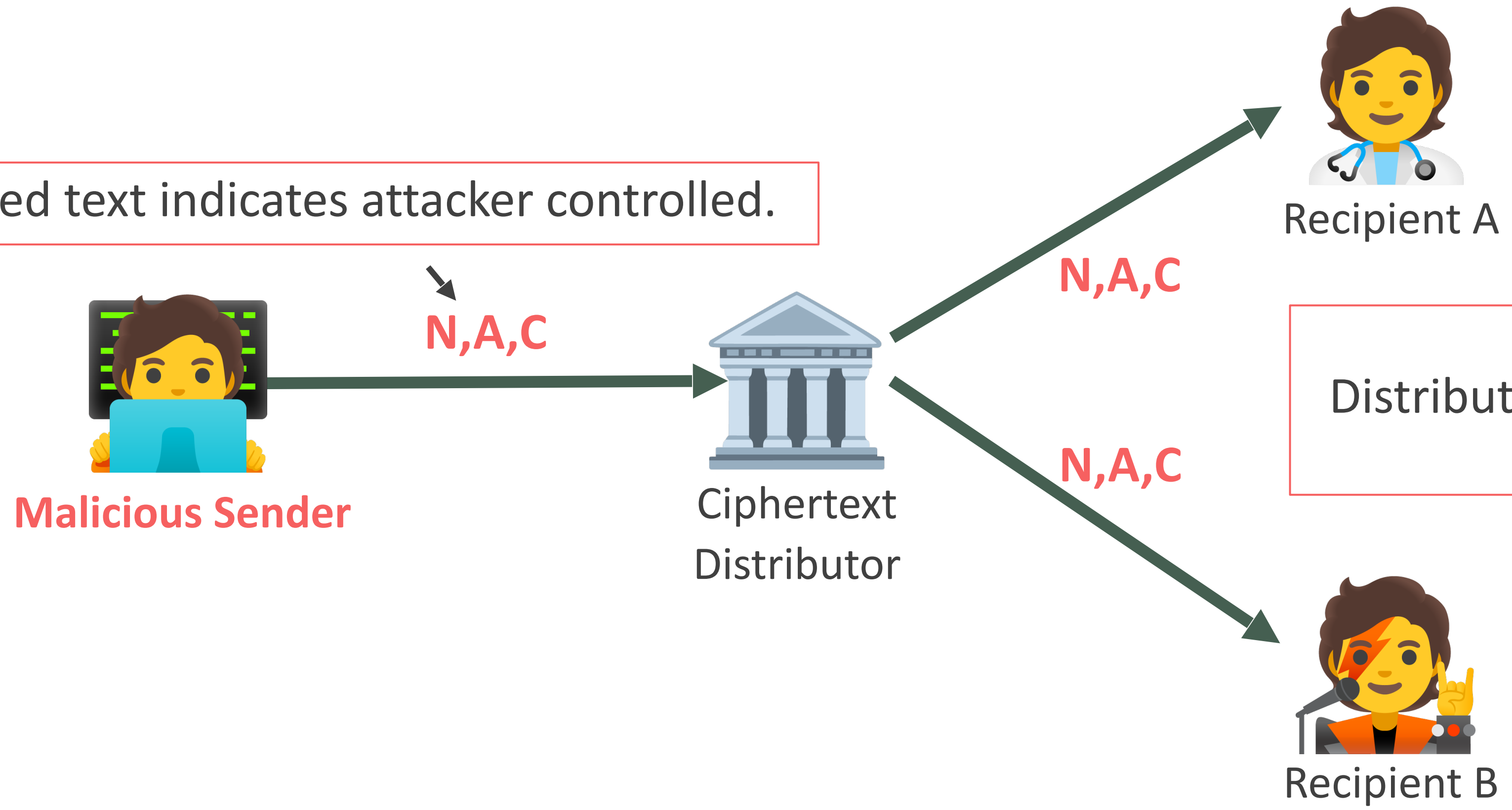
Red text indicates attacker controlled.



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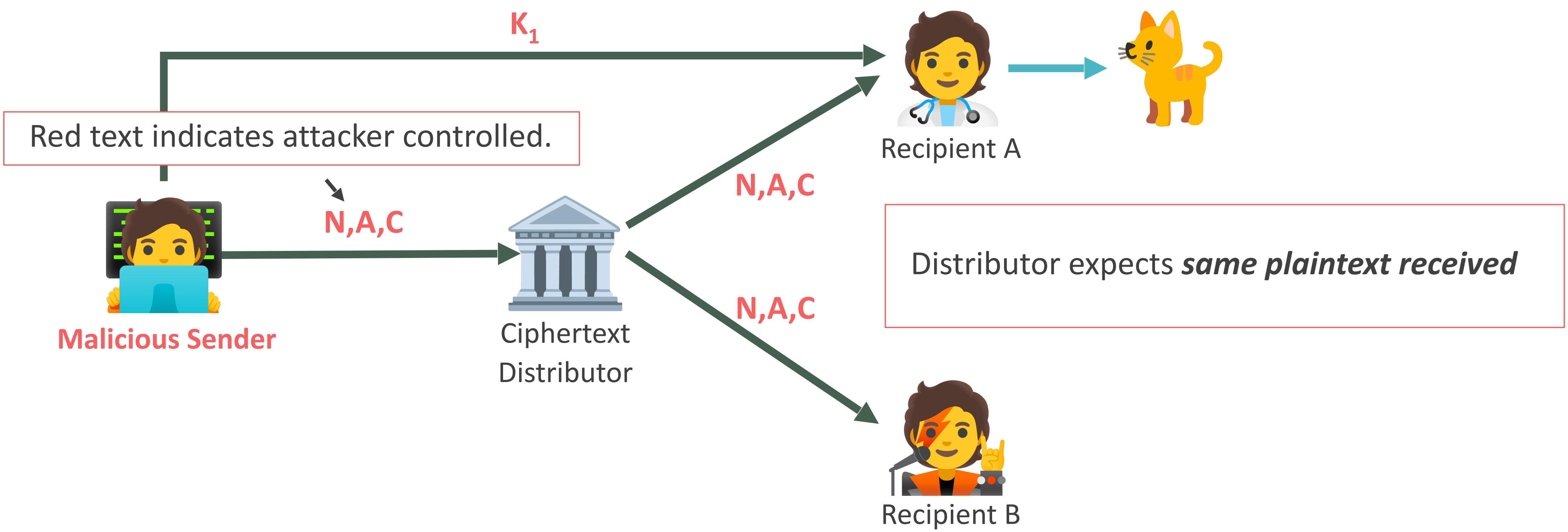

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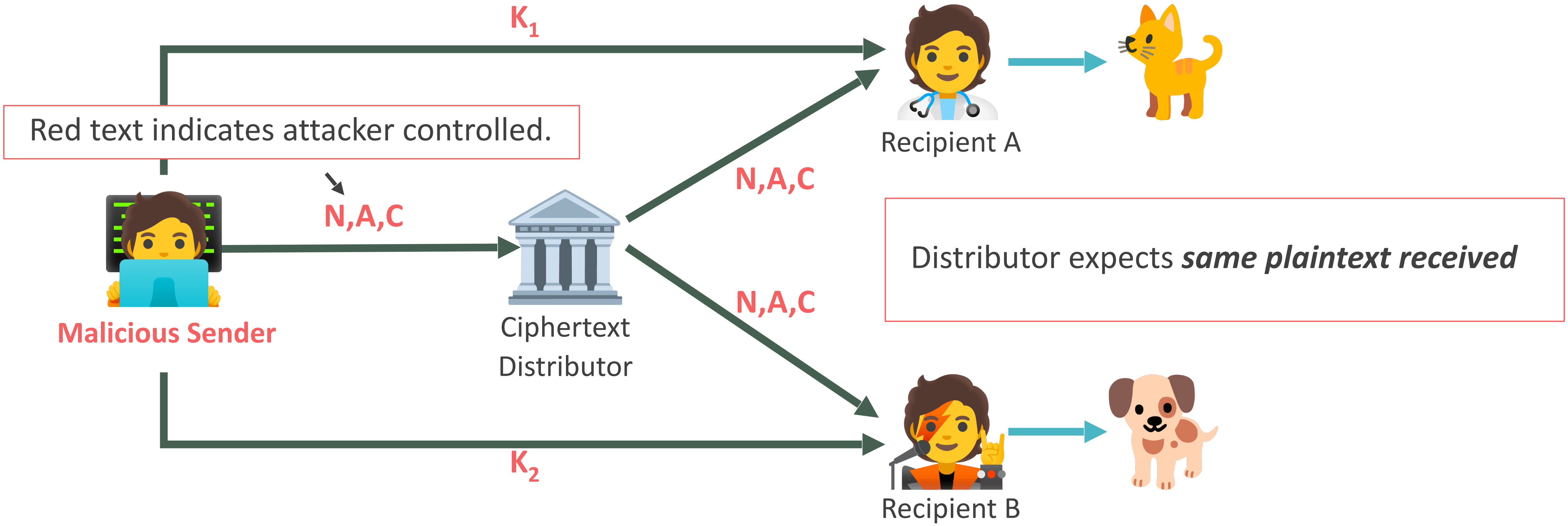

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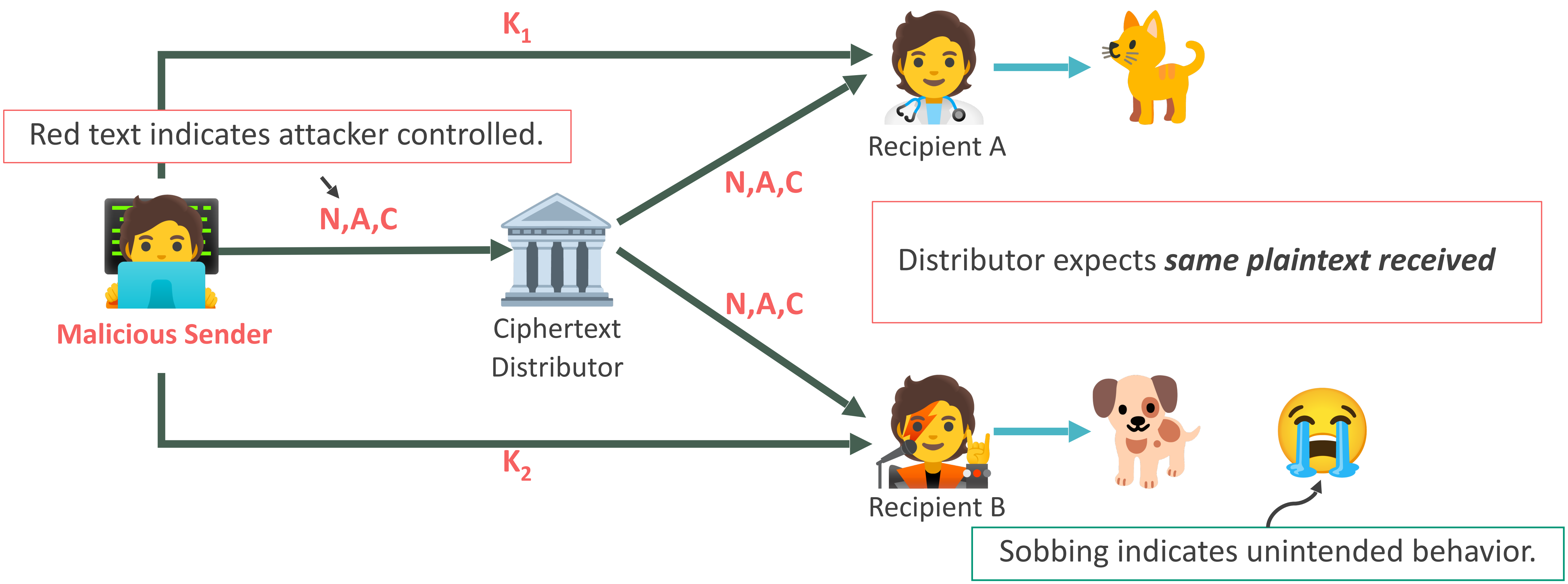

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In-use AEAD schemes are not *key committing* [FOR17, GLR17]

For AEAD = XXX computationally efficient to find

$K_1 \neq K_2$ and N, A, C

such that decryption

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Attacks are fast and practically damaging

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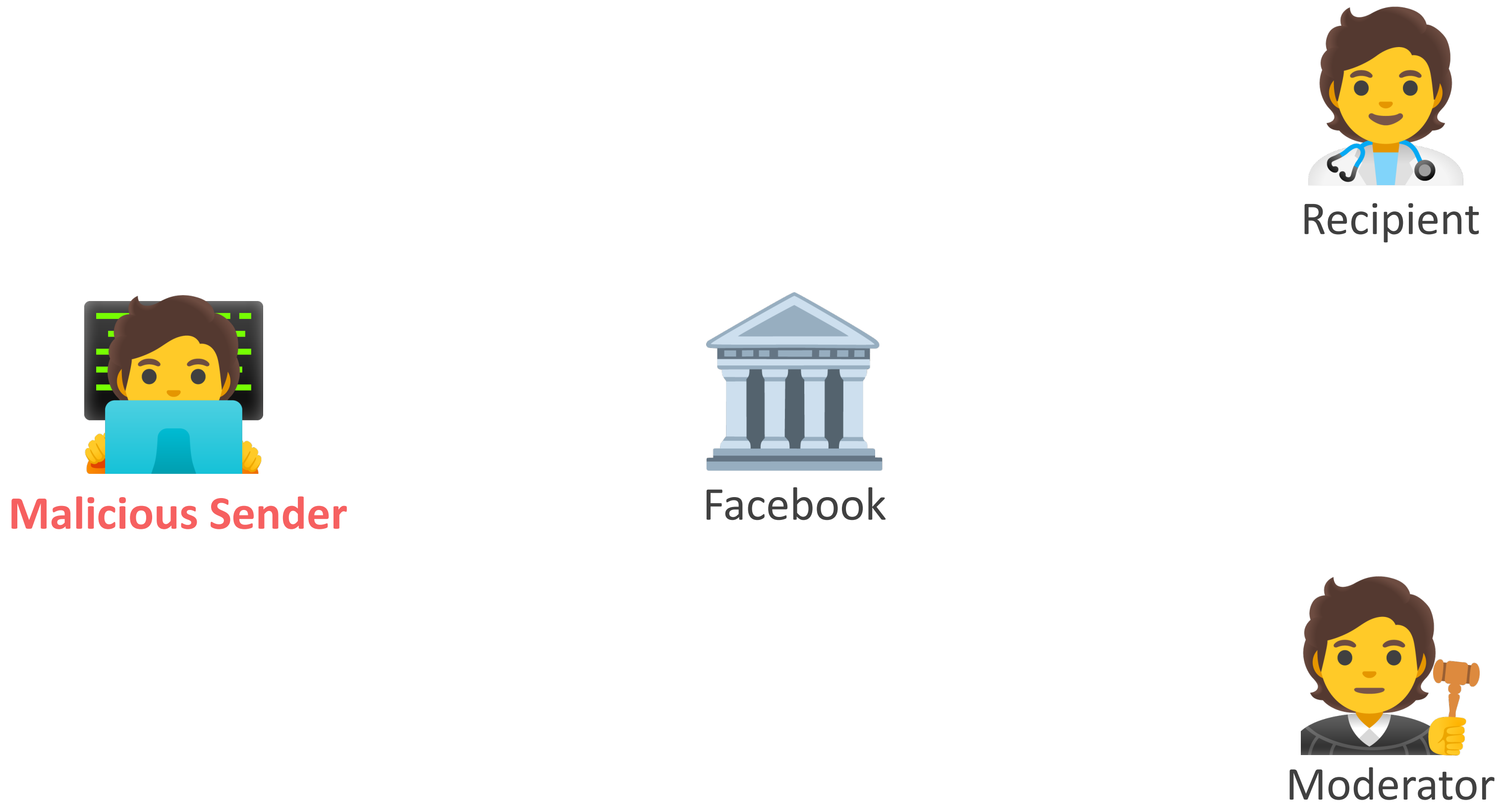

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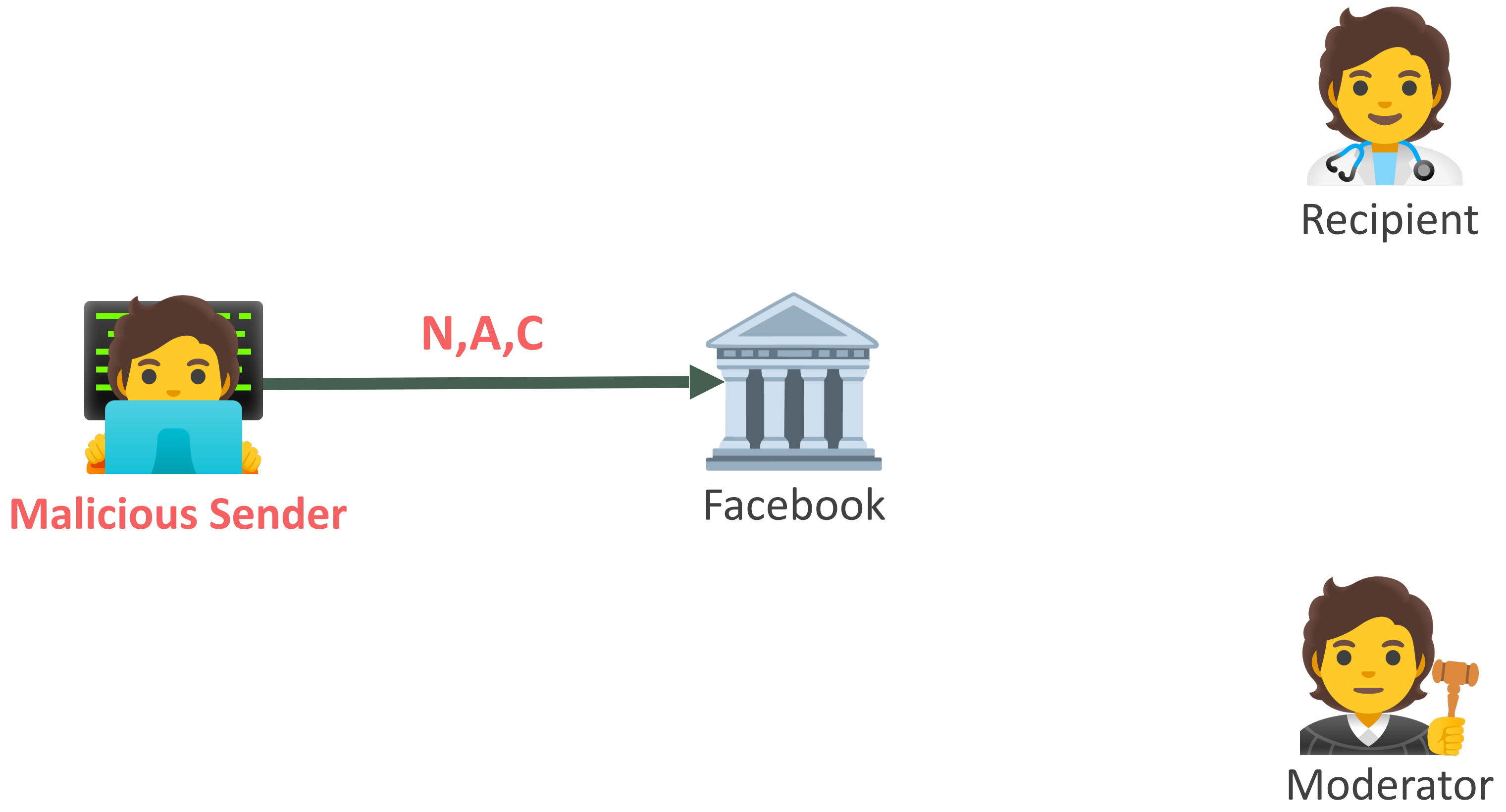

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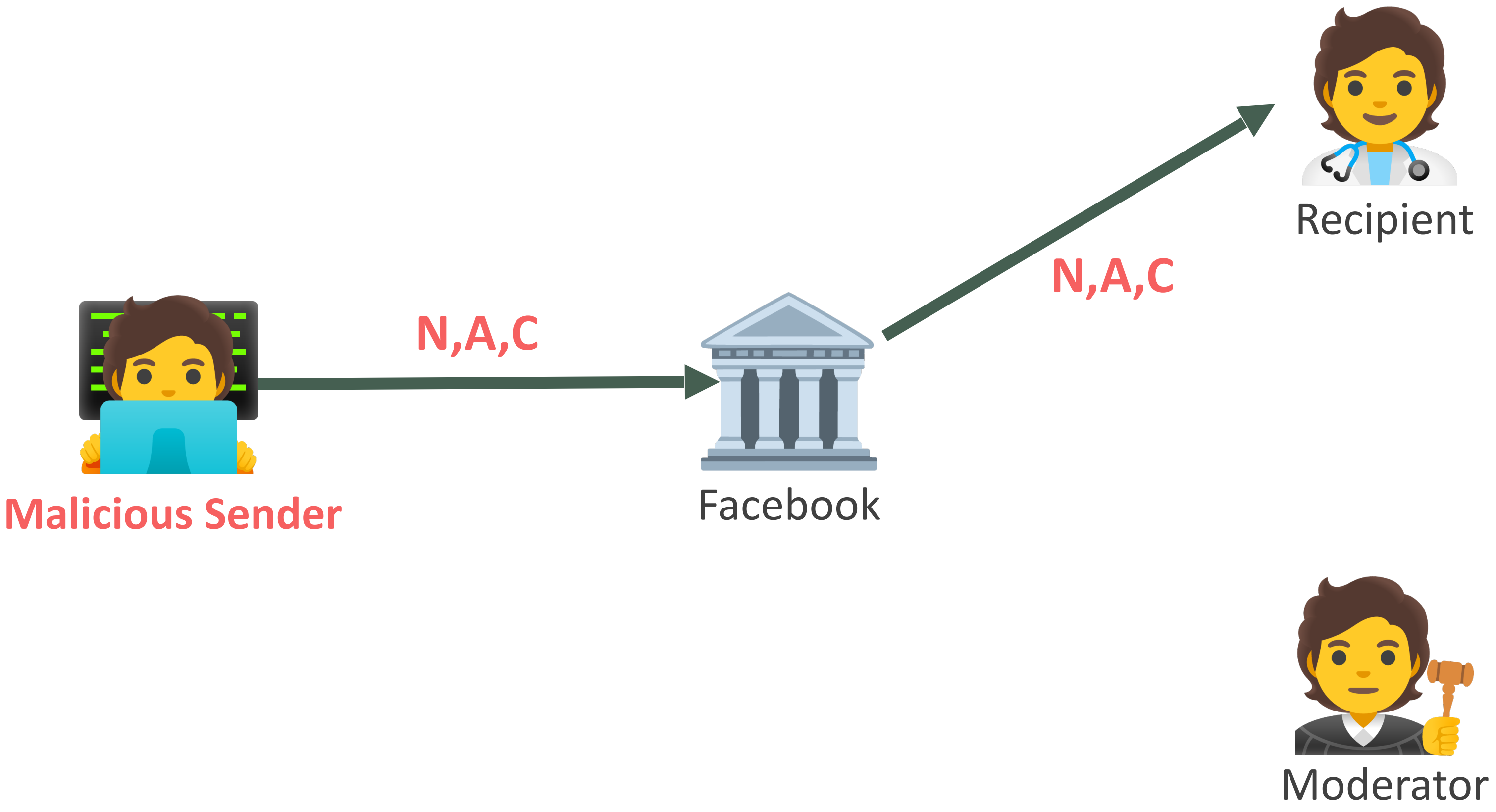

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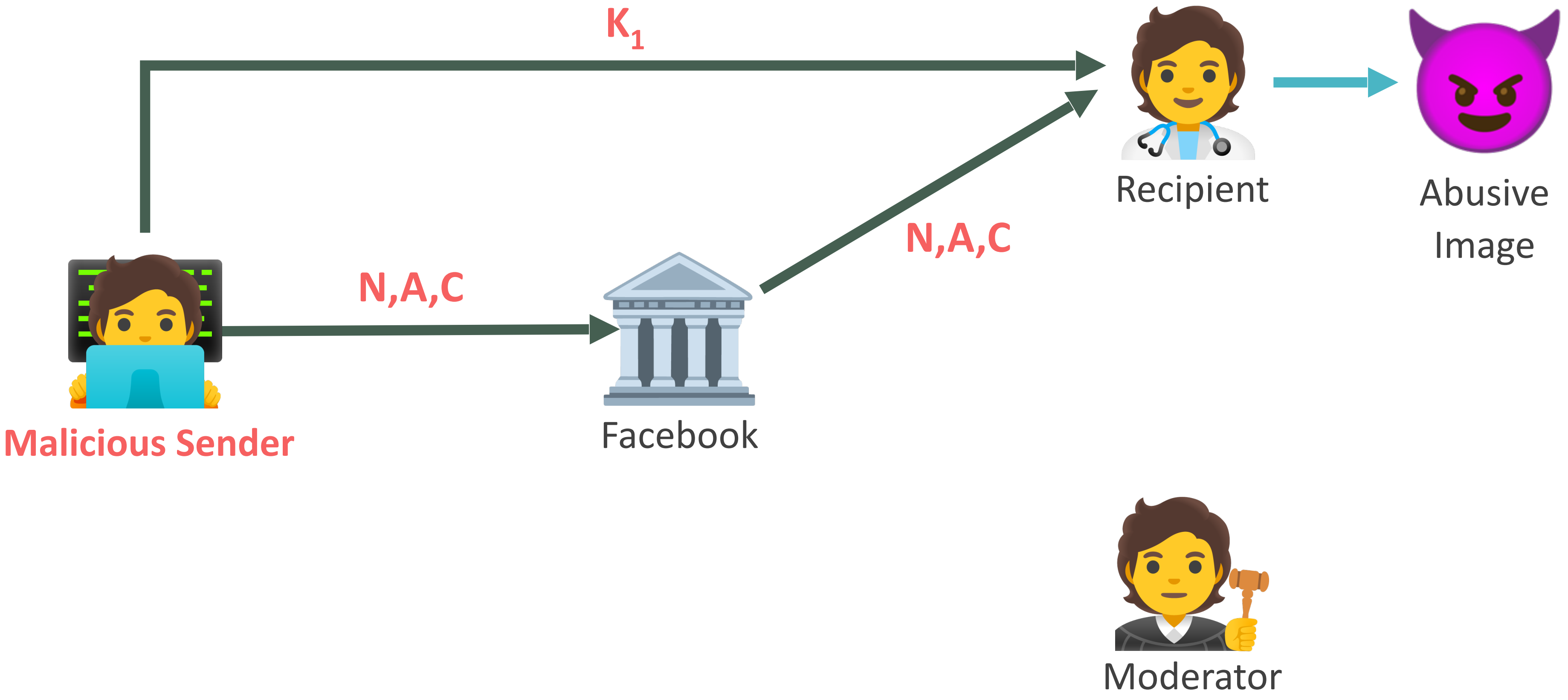

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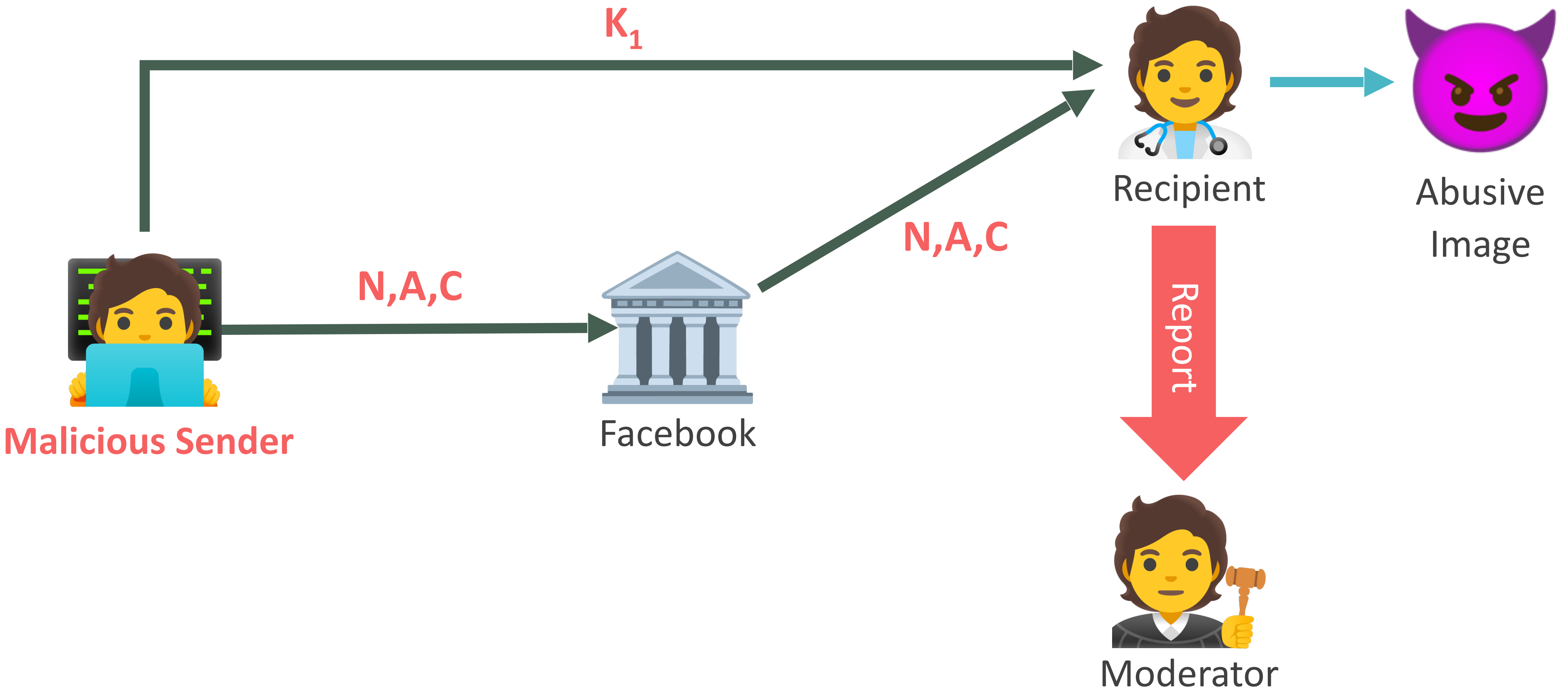

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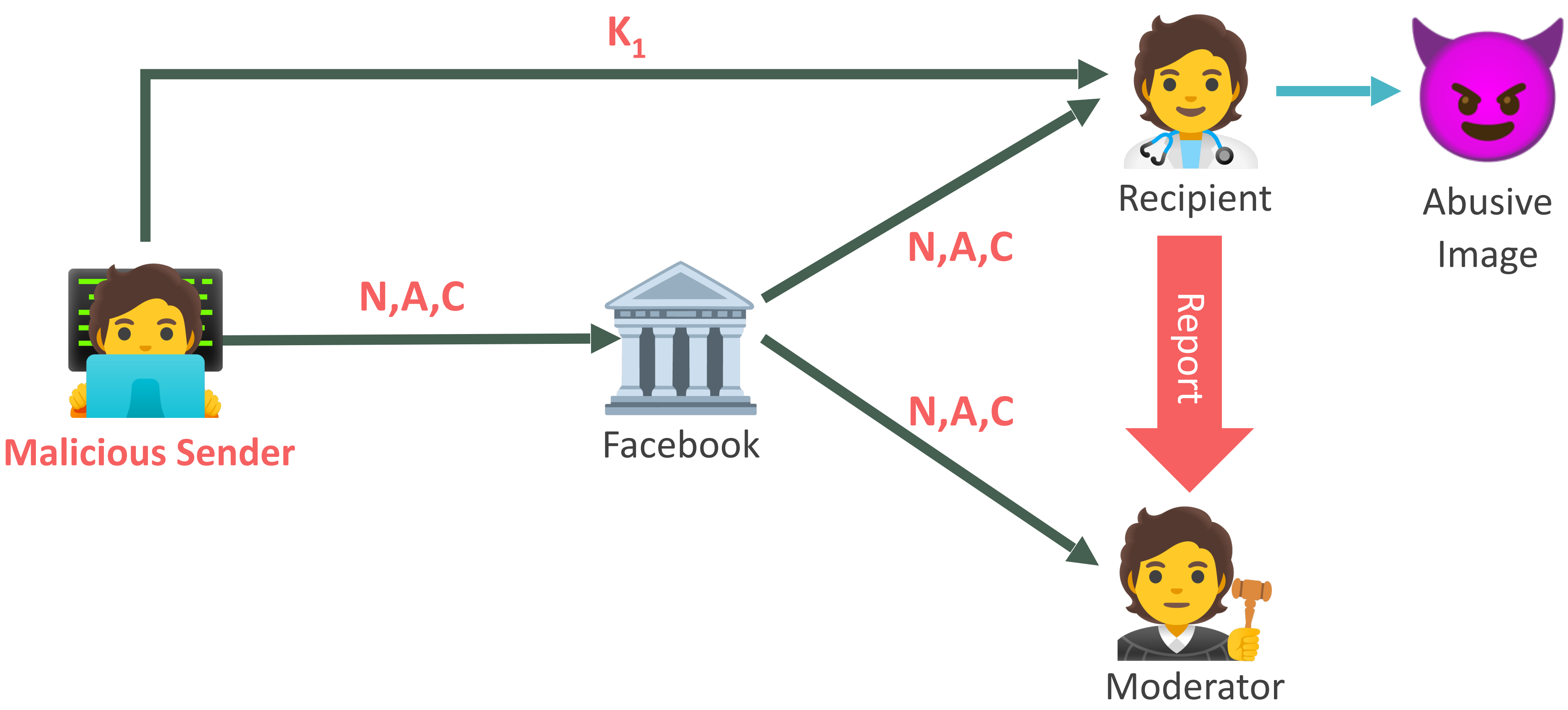

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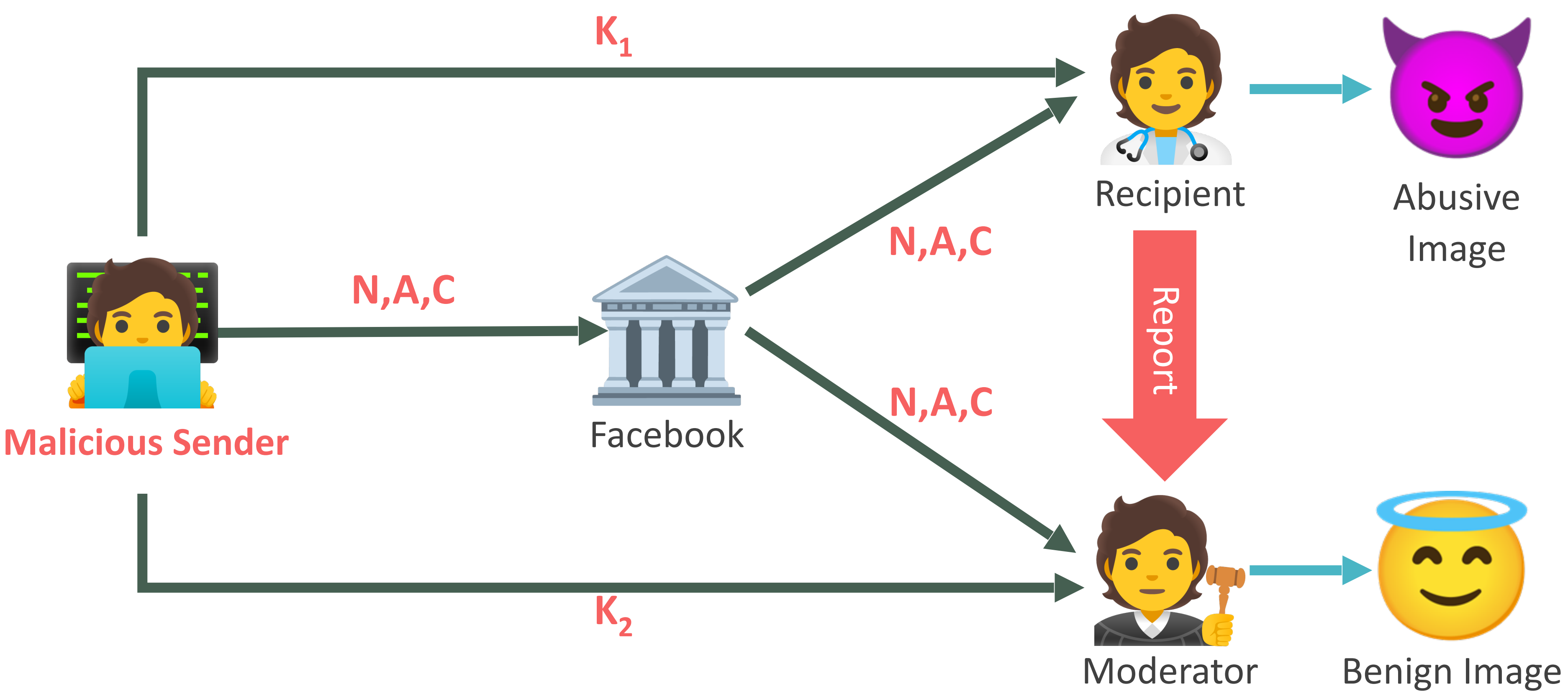

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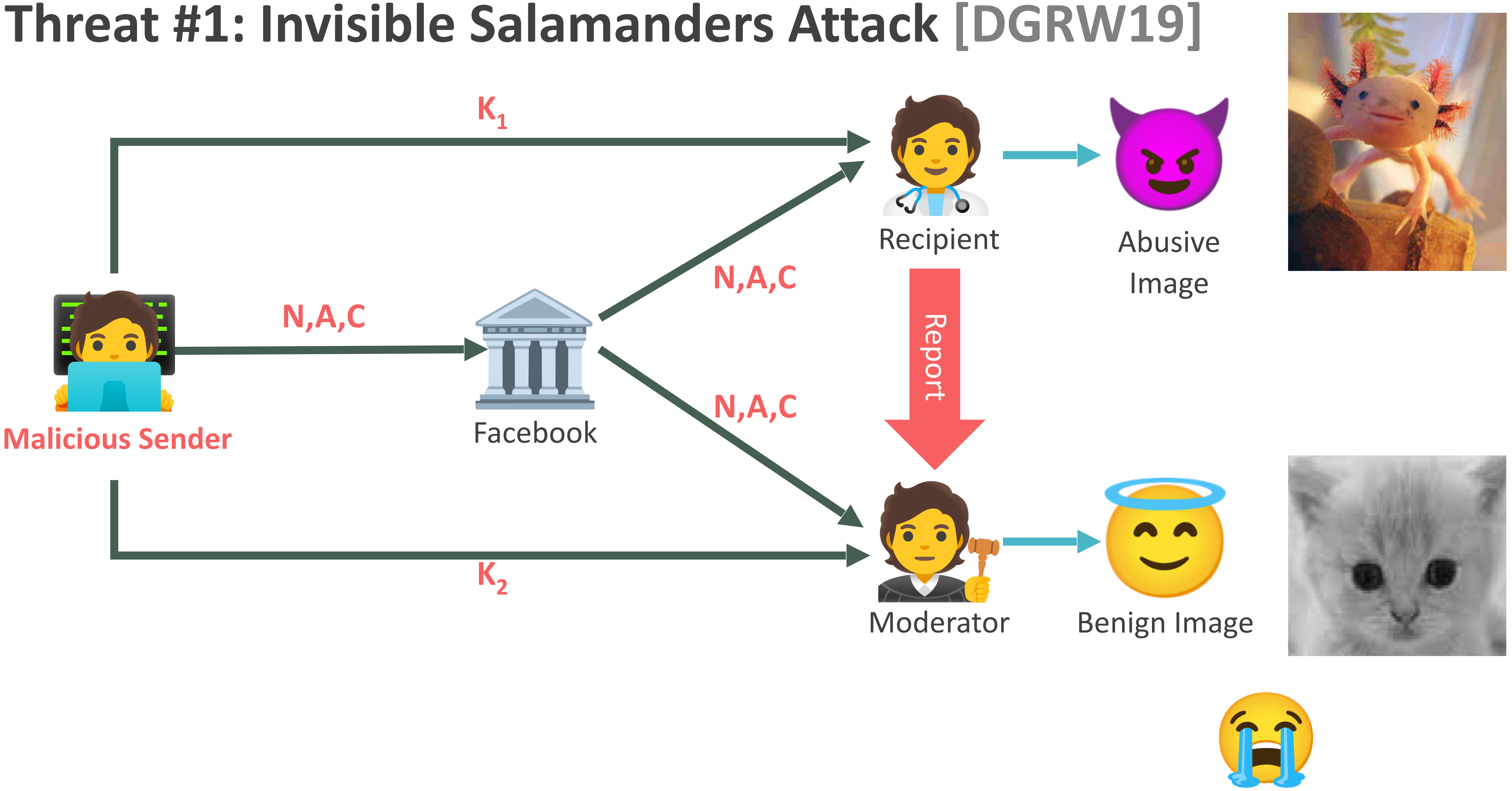

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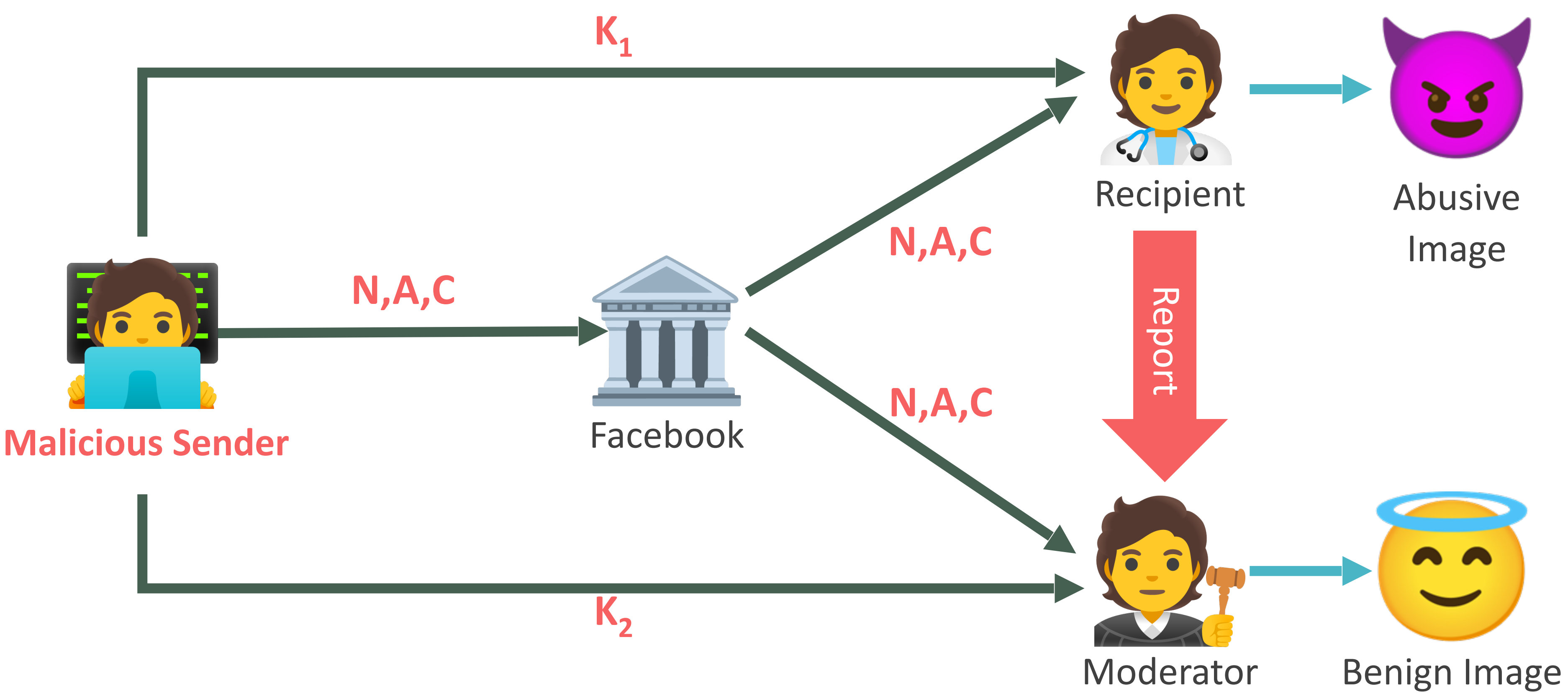


Multi-recipient integrity vulnerabilities also found in

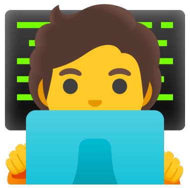
- AWS Encryption SDK
- pre-release product reviewed at Google

[ADGKLS20]

Threat #2: Partitioning oracle attacks [LGR20]

Server uses password to decrypt ciphertexts

password



Malicious Client

Server

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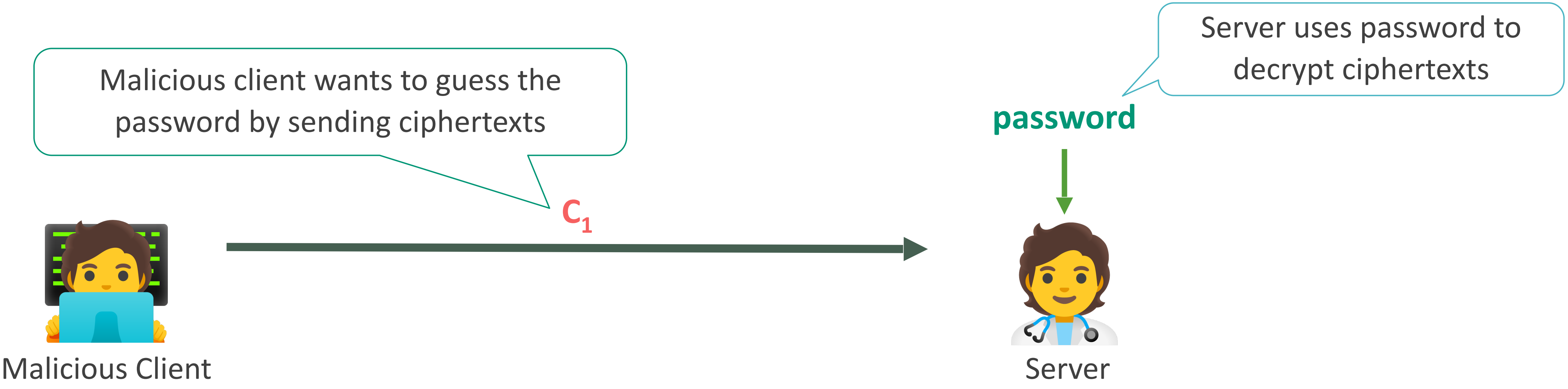

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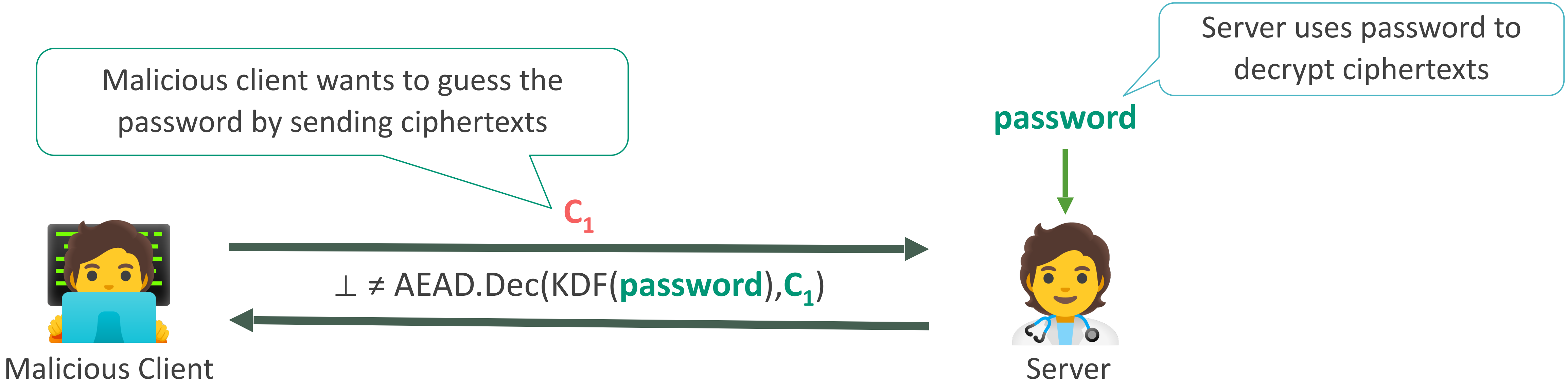

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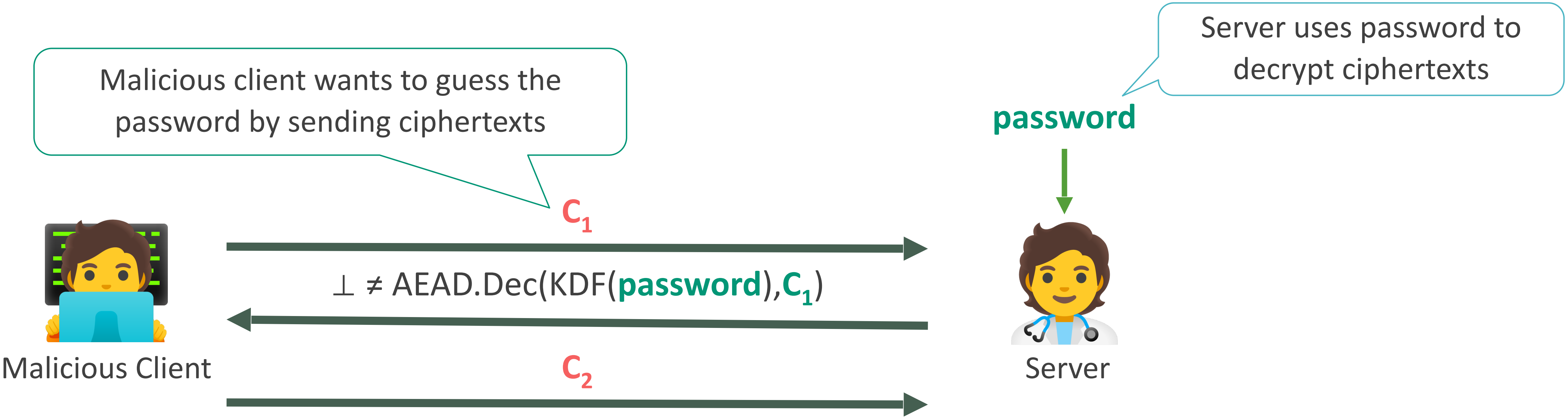

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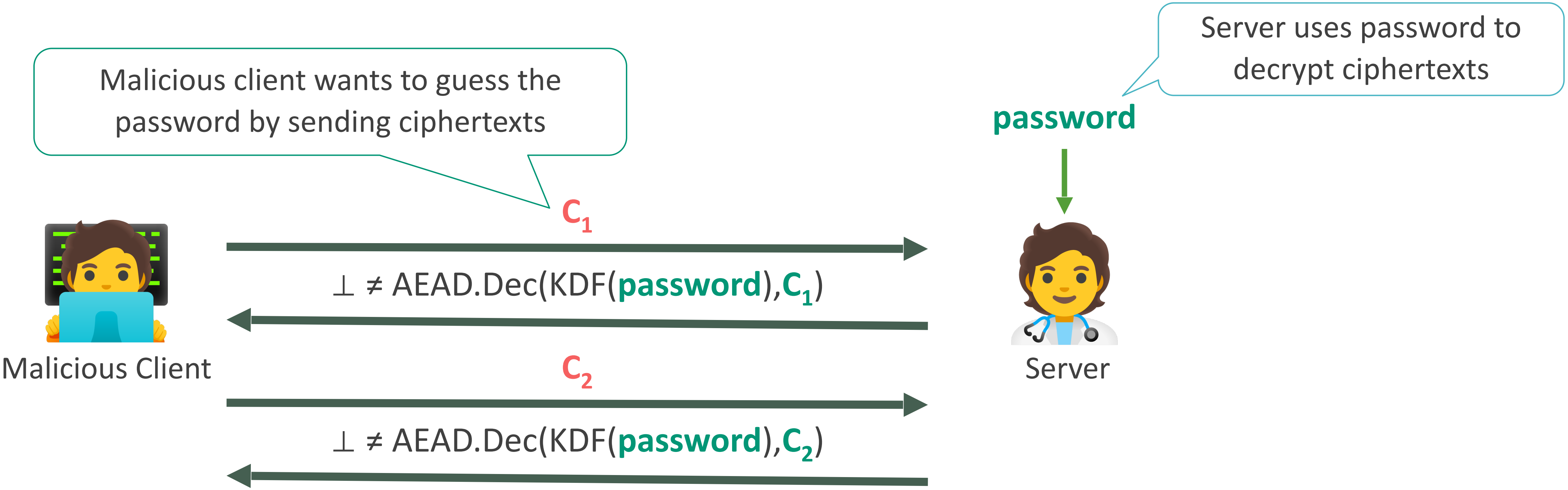

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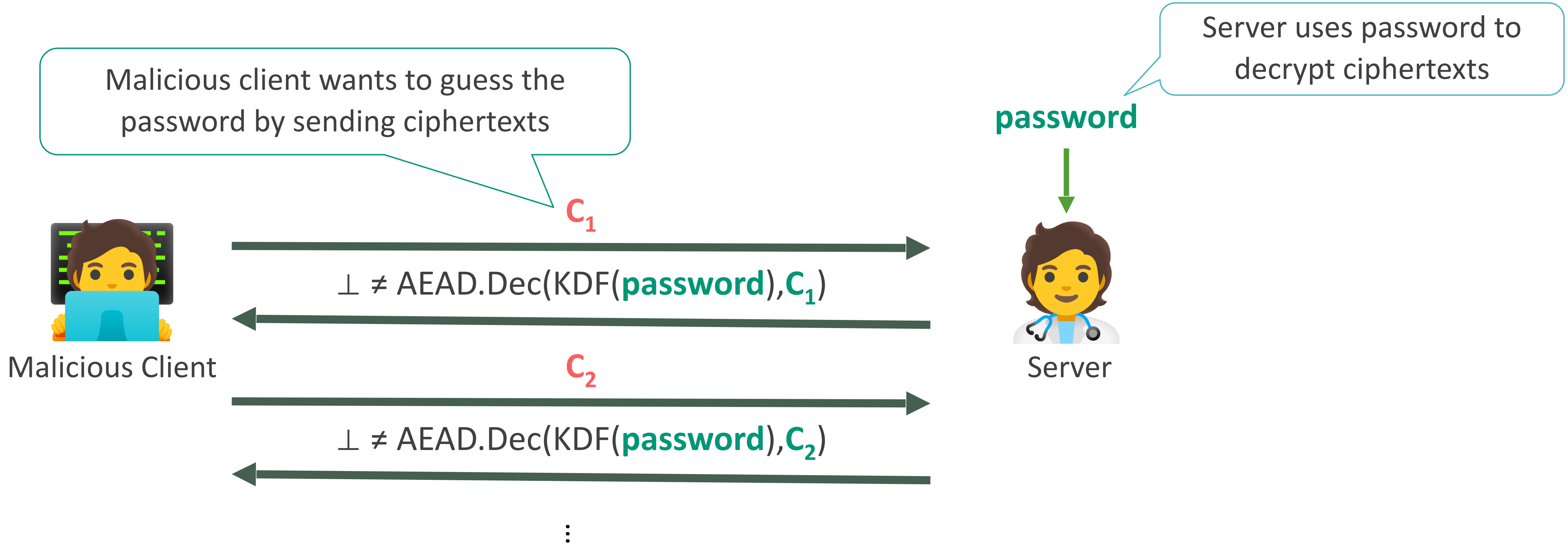

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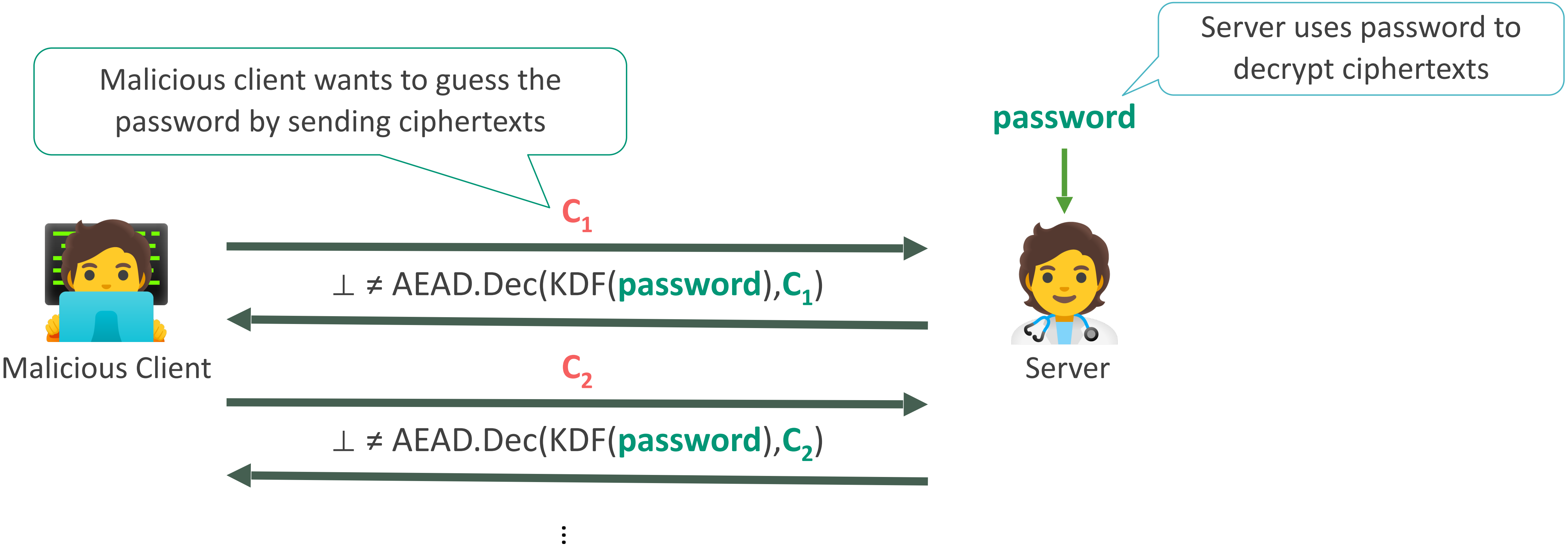

Security expected: one ciphertext = one guess

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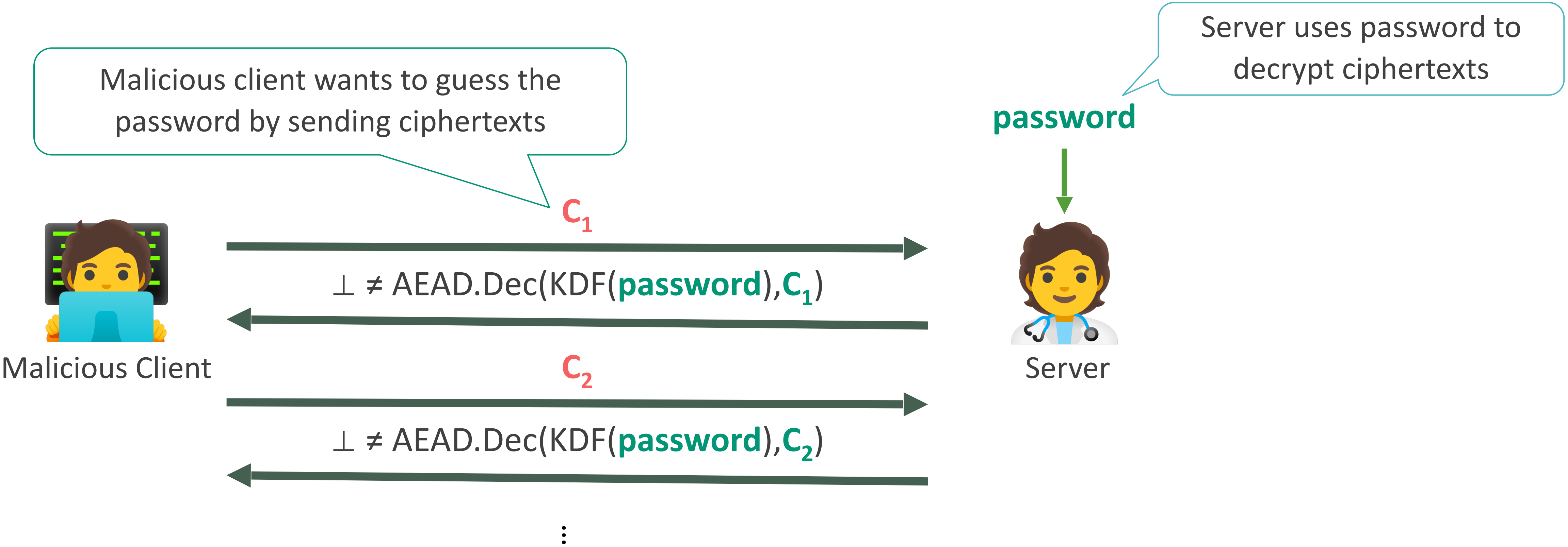

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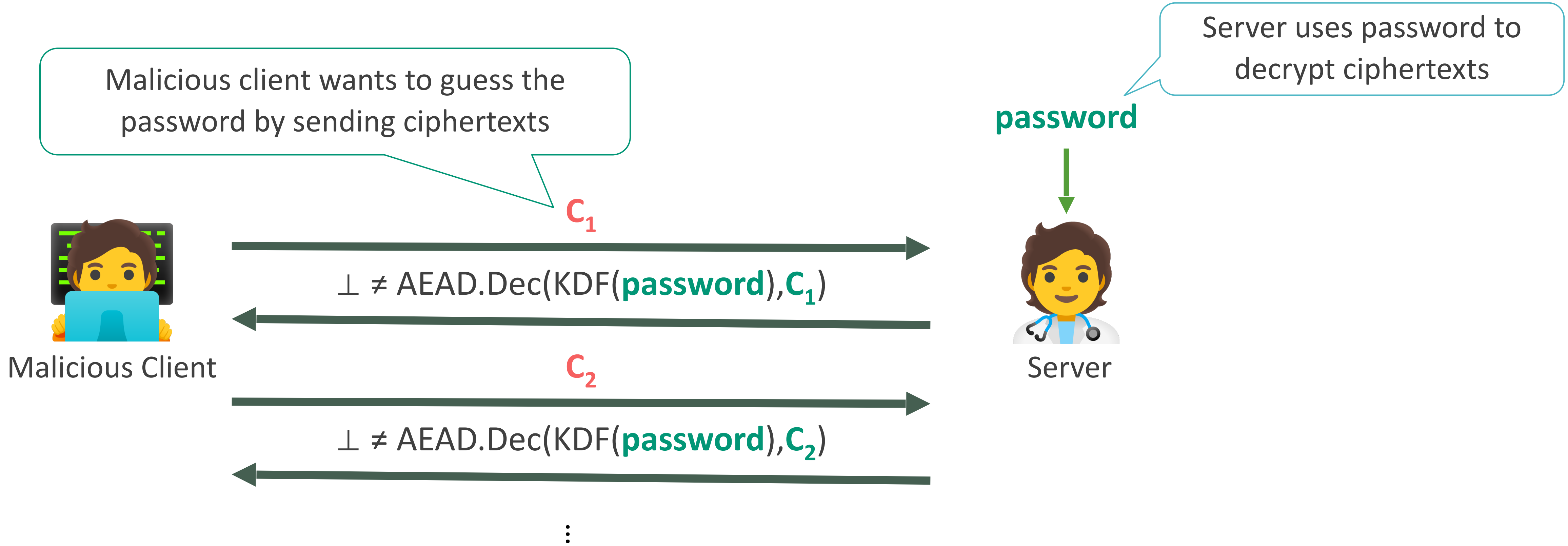

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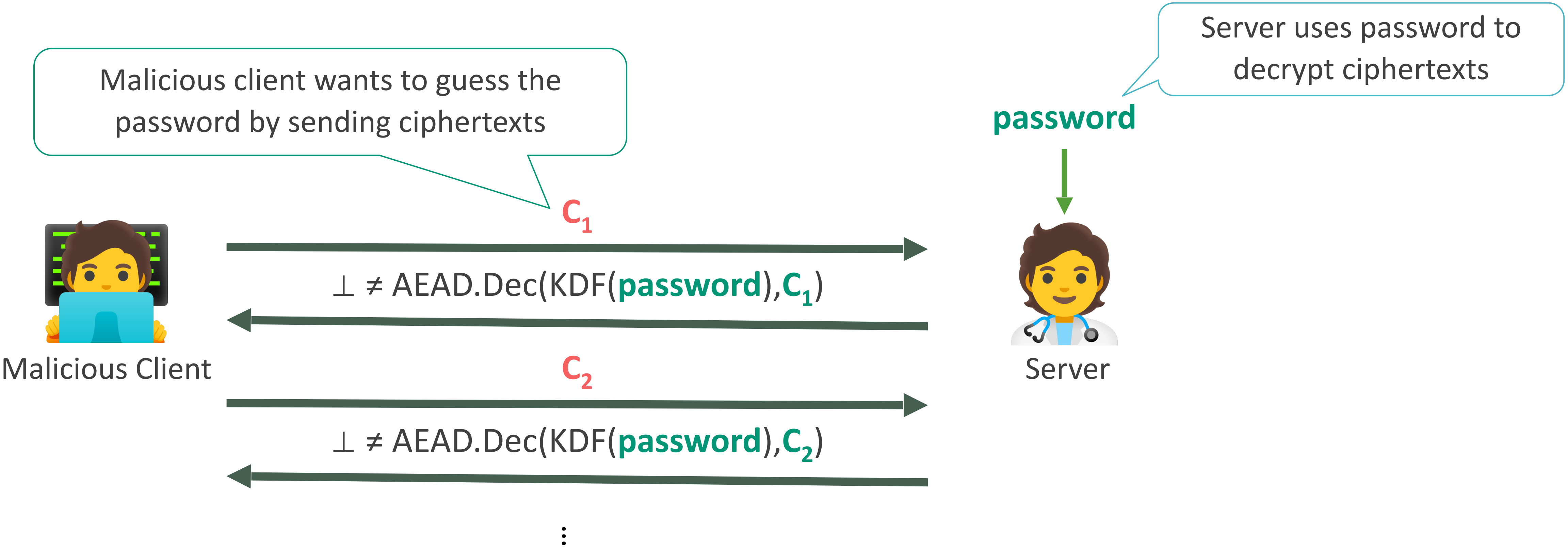

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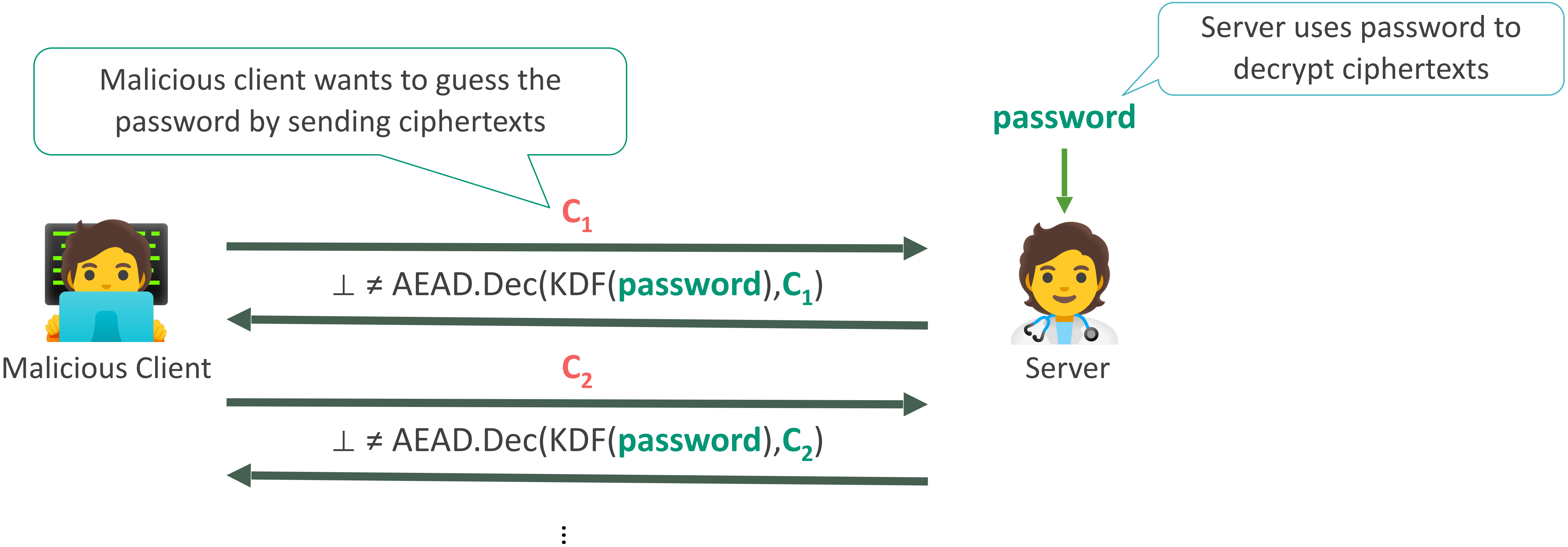

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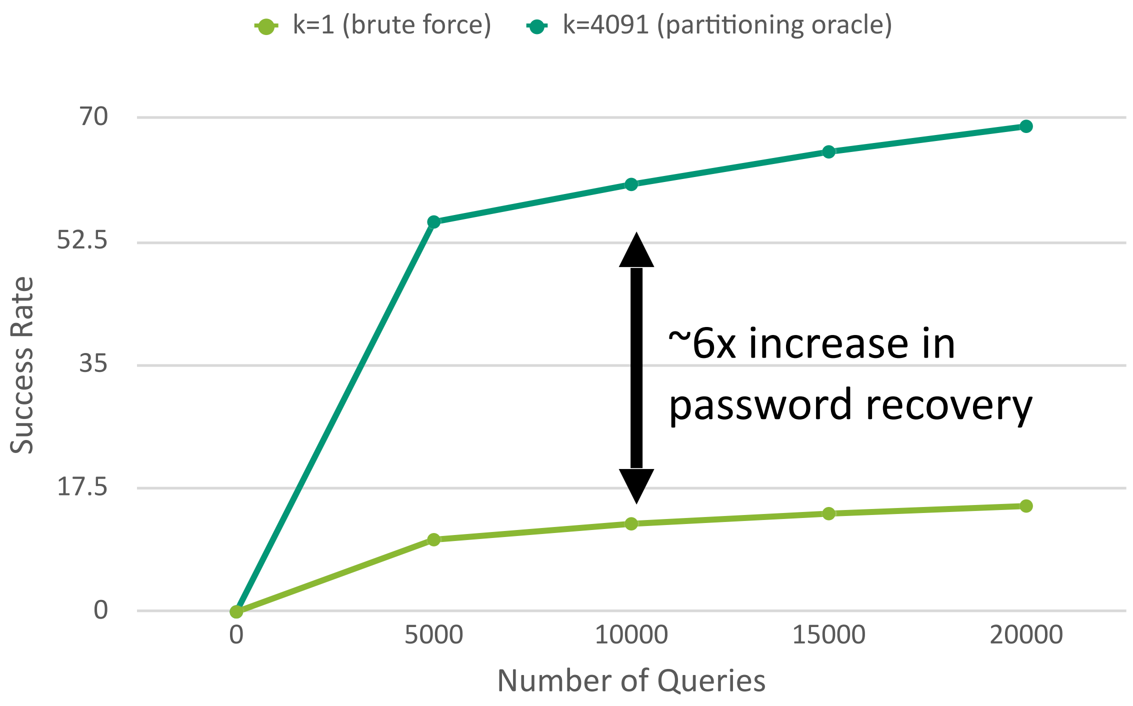

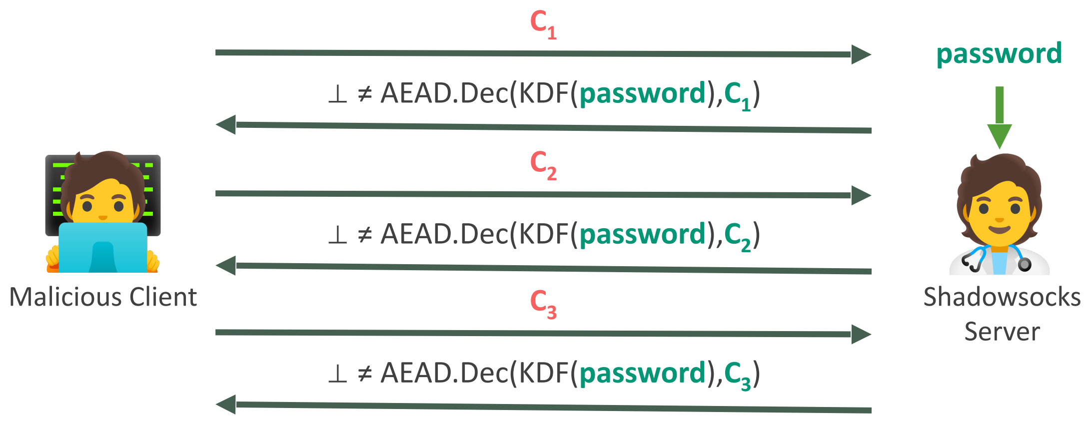

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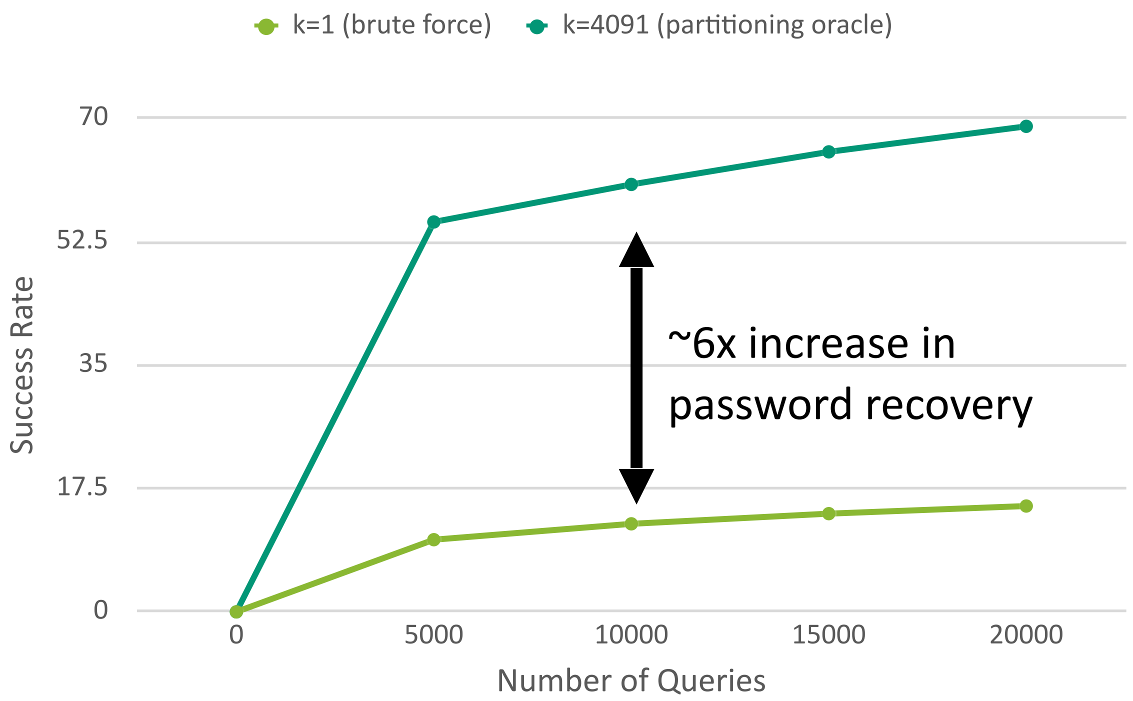

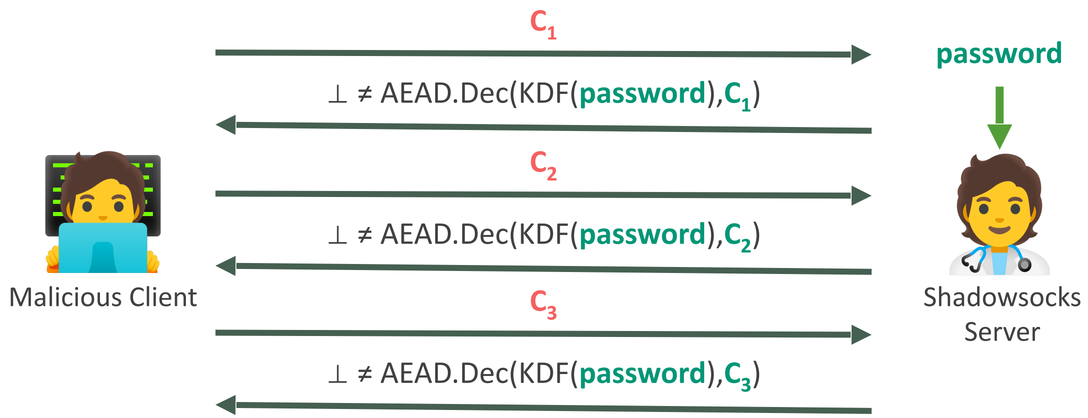

Partitioning oracle vulnerabilities also found in

- early, non-compliant OPAQUE implementations
- other open-source libraries

Summary of Vulnerabilities

Application	Attack	Impact	Citation
Facebook Messenger abuse reporting	Multi-recipient integrity	Makes it impossible to report specifically crafted images.	[GLR17] [DGRW19]
AWS Encryption SDK multi-recipient sending	Multi-recipient integrity	Can send different messages to different recipients.	[ADGKLS20]
…	…	…	…
Shadowsocks UDP	Partitioning oracle	Faster password guessing	[LGR20]
Non-compliant OPAQUE implementations	Partitioning oracle	Faster password guessing	[LGR20]
…	…	…	…

[GLR17] Paul Grubbs, Jiahui Lu, and Thomas Ristenpart. Message franking via committing authenticated encryption. ia.cr/2017/664
[LGR20] Julia Len, Paul Grubbs, and Thomas Ristenpart. Partitioning Oracle Attacks. ia.cr/2020/1491
[DGRW19] Yevgeniy Dodis, Paul Grubbs, Thomas Ristenpart, and Joanne Woodage. Fast message franking: From invisible salamanders to encryptment. ia.cr/2019/016
[ADGKLS20] Ange Albertini, Thai Duong, Shay Gueron, Stefan Kölbl, Atul Luykx, and Sophie Schmieg. How to Abuse and Fix Authenticated Encryption Without Key Commitment. ia.cr/2020/1456

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… they exploit **lack of key commitment**

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We could standardize these or other key-committing solutions

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4.3.3. Key commitment

Definition. An AEAD algorithm guarantees that it is difficult to find a tuple of the nonce, associated data, and ciphertext such that it can be decrypted correctly with more than one key.

Synonyms. Key-robustness, key collision resistance.

Further reading. [FOR17], [LGR21], [GLR17]

draft-irtf-cfrg-aead-properties-01

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Topics for discussion include:

- The security and efficiency of current NIST modes
- Additional security features (e.g., misuse-resistance, key commitment, etc.) that would be desirable in a new encryption technique

The Third NIST Workshop on Block Cipher Modes of Operation
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But we fear this is **short-sighted**

NIST modes

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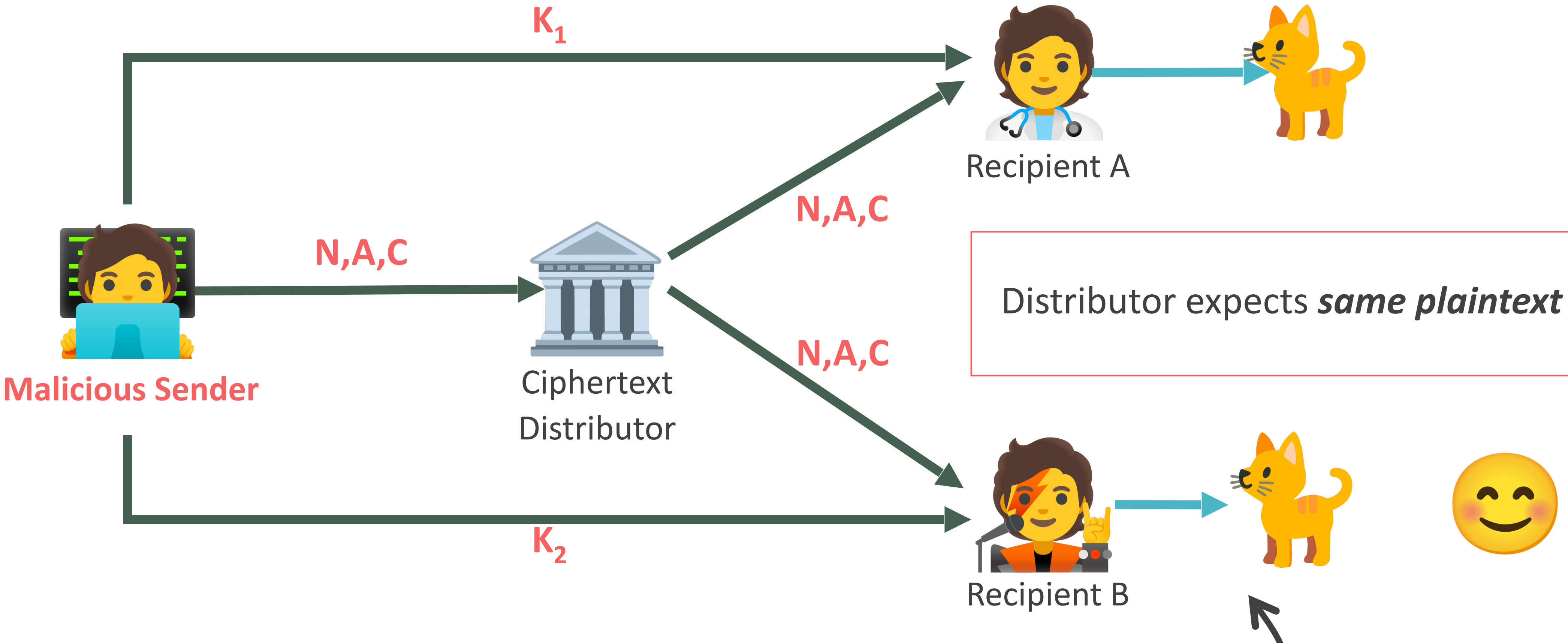
Revisiting Multi-Recipient Integrity [BT22,CR22,MLGR23]



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If $K_1 = K_2$, both get same plaintext

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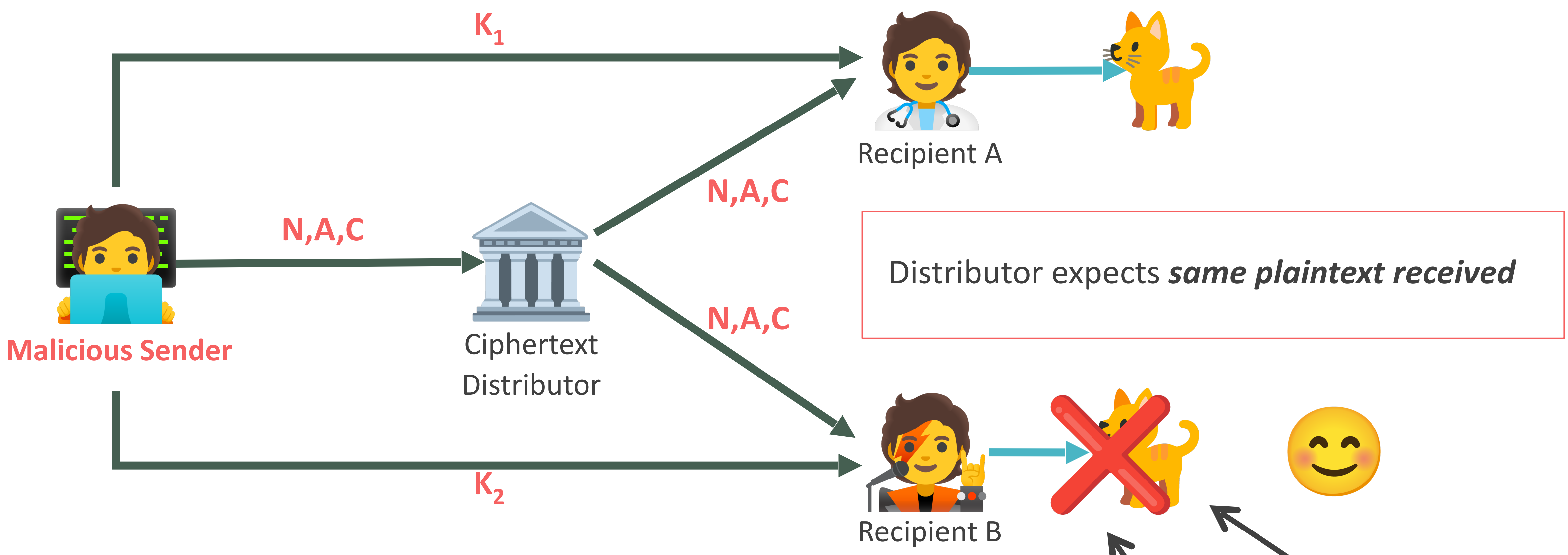

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If $K_1 \neq K_2$, and key commitment, one gets error

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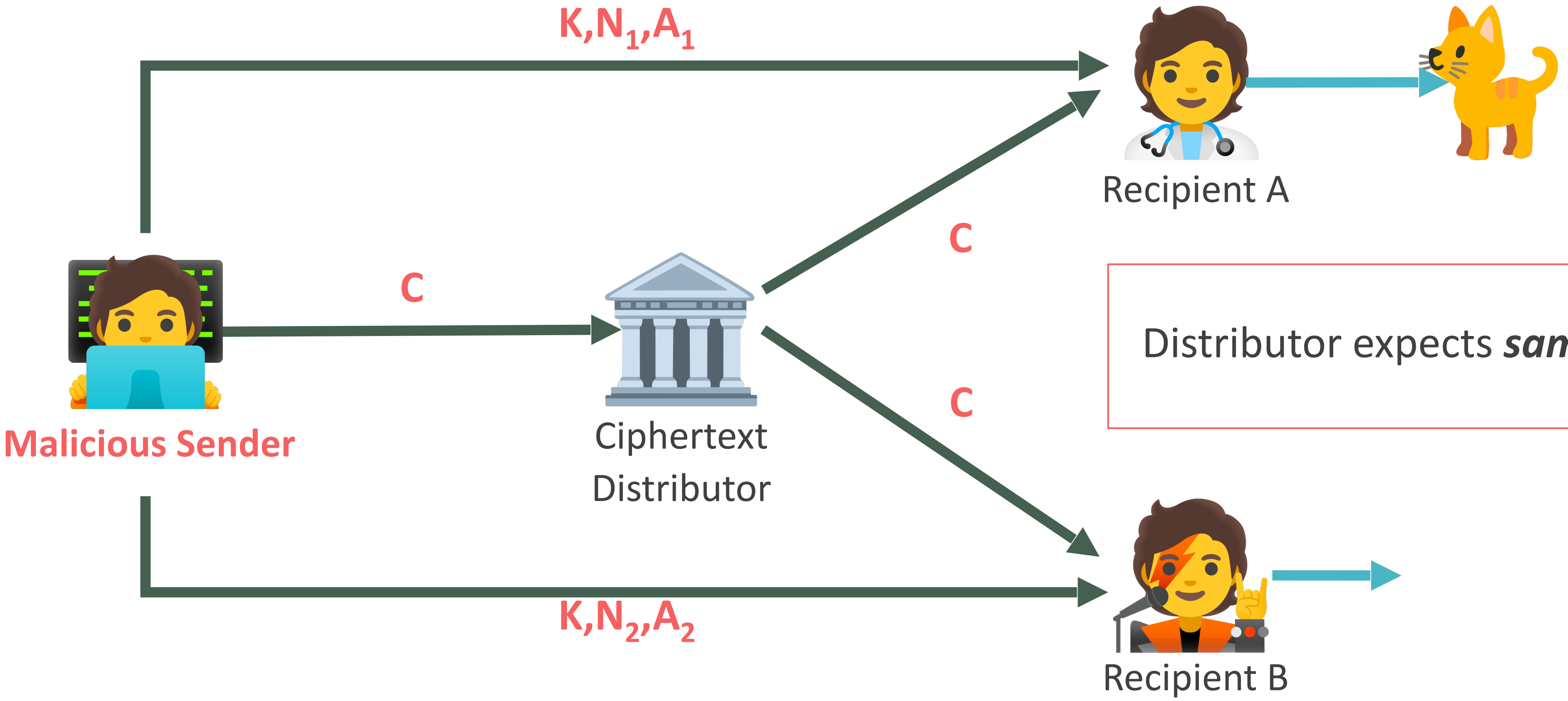

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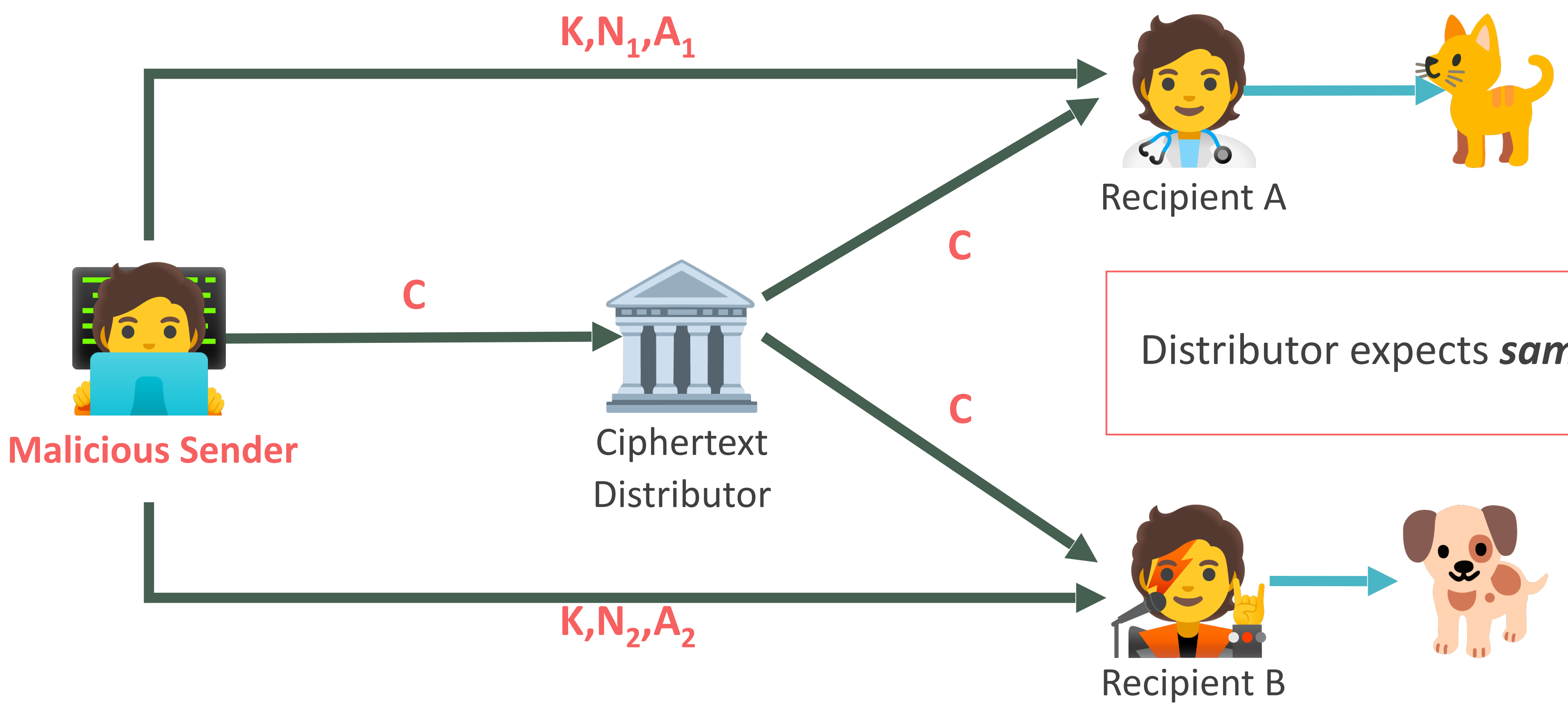

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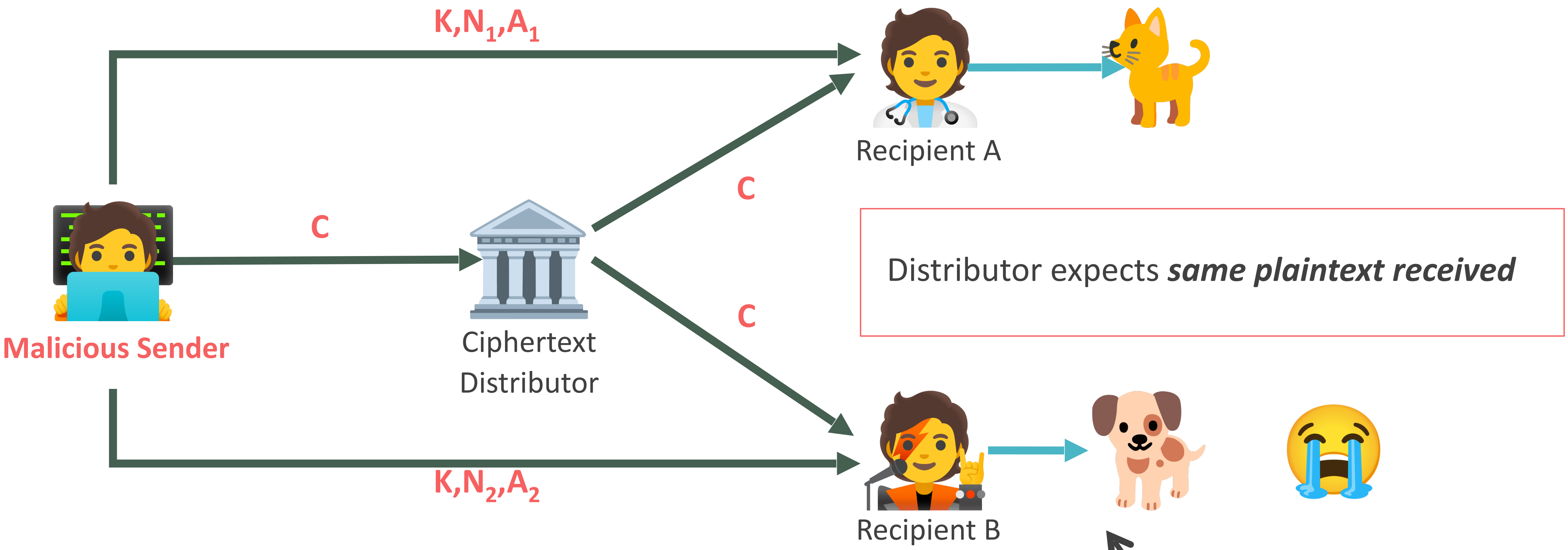

If **keys are same** but **N and A differ**,
even with key commitment, get different plaintexts

In-use AEAD schemes are not *context committing*

For AEAD = XXX computationally efficient to find

$$(K_1, N_1, A_1) \neq (K_2, N_2, A_2) \quad \text{and} \quad C$$

such that decryption

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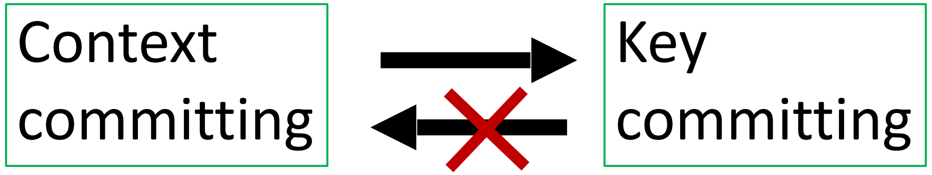

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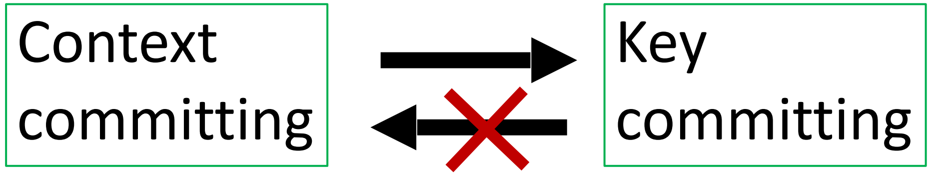

Large space of definitions **[BT22, CR22, MLGR23]**

Analogous to hash functions:

collision resistance ~ context commitment

preimage resistance ~ context discovery

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XXX	Key Committing Attack?	Context Committing Attack?
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ChaCha20 /Poly1305	[LGR20]	
AES-GCM-SIV	[Sch20, LGR20]	
AES-OCB3	[ADGKLS20]	
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Padding Zeros		[BH22]
Key hashing		[MGLR23]

Key commitment countermeasures don’t ensure context commitment (applies to: Padding Zeros, Key hashing)

Committing Encryption Timeline

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[FOR17, GLR17]

2017

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Future

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Duplex-style that use a single pass of hash function

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- \+ Simple, single primitive
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- – Not parallelizable

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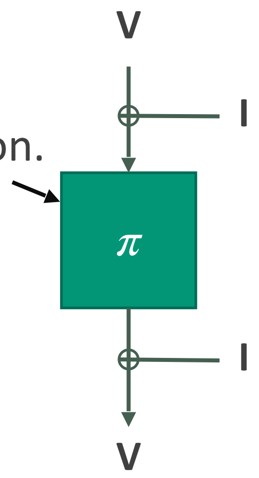
Wide permutation like Keccak or Ascon.



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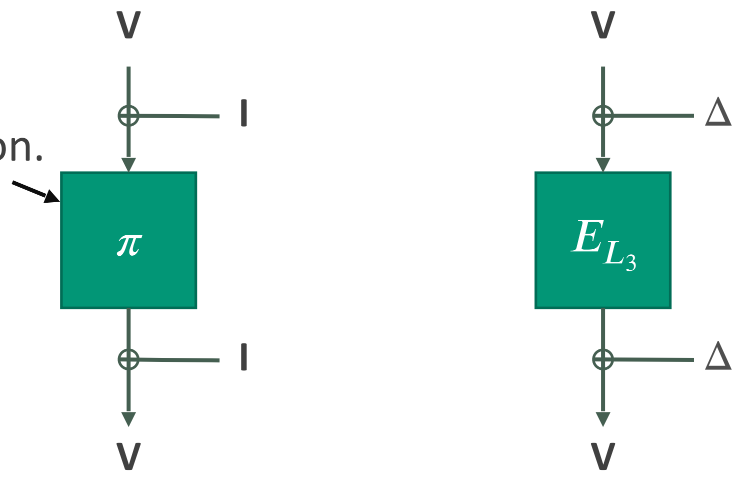

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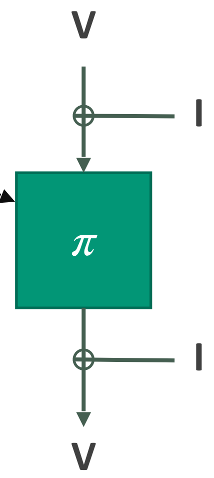

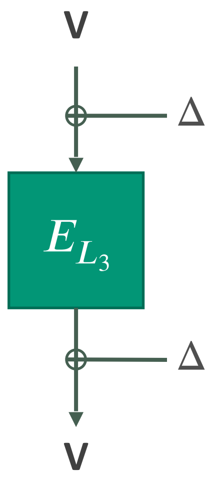

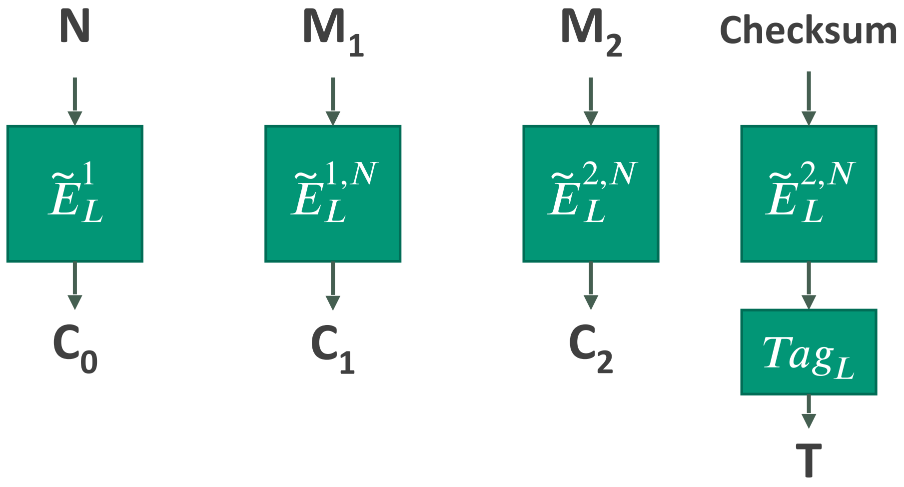

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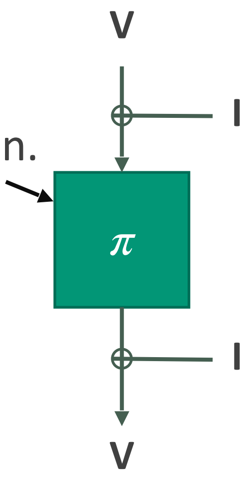

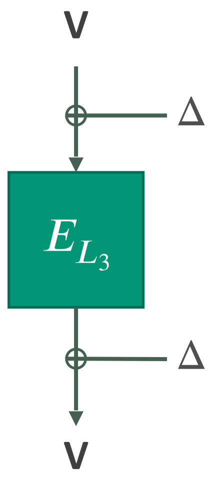

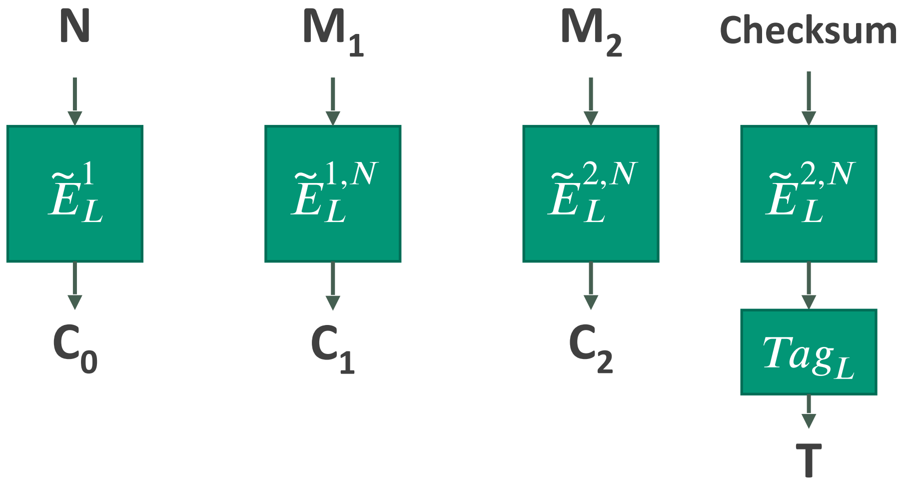

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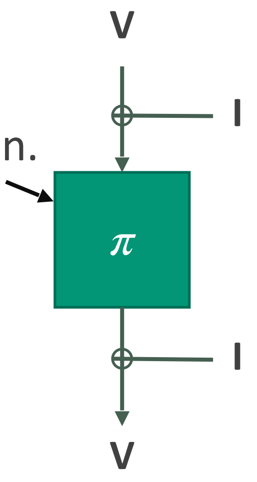

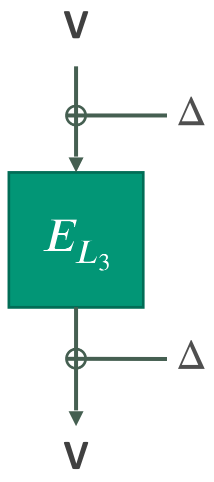

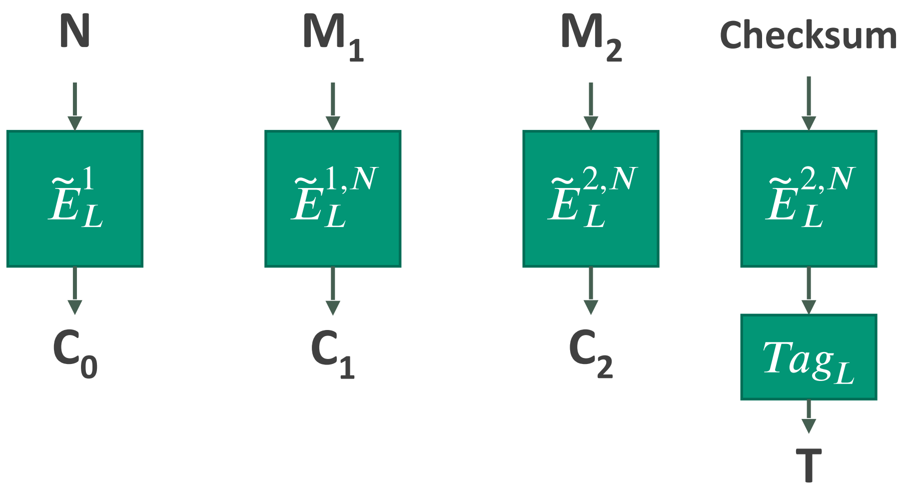

$$E(I, V) = \pi(V \oplus I) \oplus I$$

$$\widetilde{E}_L^T(V) = E\big(L_3,\ V \oplus \Delta\big) \oplus \Delta$$

$$\Delta = \mathrm{Offset}(L_1, L_2)$$

Even-Mansour block cipher [EM97]

XE/XEX inspired tweakable block cipher [R04]

OCB inspired authenticated encryption [RBB03]

HN4 inspired nonce-hiding [BNT19]

+ Simple, single primitive
+ Optimal length ciphertexts
+ Maximally parallelizable

Is context committing AEAD right for you?

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Yes

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Yes

1. Future-proof against potential context commitment attacks.

Is context committing AEAD right for you?

Yes

1. Future-proof against potential context commitment attacks.
2. Minimal performance overhead over a key committing scheme.

Next Steps

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Build context committing AEAD schemes.

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Standardize a few canonical context committing AEAD schemes.

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Thank you! 💙

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Thank you! 💙

Emoji in figures from Noto Emoji.

Thanks to my co-authors and the Cornell Security Seminar for feedback.

References

[EM97] Shimon Even and Yishay Mansour. A construction of a cipher from a single pseudorandom permutation. https://doi.org/10.1007/s001459900025

[RBB03] Phillip Rogaway, Mihir Bellare, and John Black. OCB: A Block-Cipher Mode of Operation for Efficient Authenticated Encryption. https://www.cs.ucdavis.edu/~rogaway/papers/ocb-full.pdf

[R04] Phillip Rogaway. Efficient Instantiations of Tweakable Blockciphers and Refinements to Modes OCB and PMAC. https://www.cs.ucdavis.edu/~rogaway/papers/offsets.pdf

[BDPA11] Guido Bertoni, Joan Daemen, Michaël Peeters, and Gilles Van Assche. Duplexing the sponge: single-pass authenticated encryption and other applications. ia.cr/2011/499

[FOR17] Pooya Farshim, Claudio Orlandi, and Răzvan Roşie. Security of Symmetric Primitives under Incorrect Usage of Keys. ia.cr/2017/288

[GLR17] Paul Grubbs, Jiahui Lu, and Thomas Ristenpart. Message franking via committing authenticated encryption. ia.cr/2017/664

[DGRW19] Yevgeniy Dodis, Paul Grubbs, Thomas Ristenpart, and Joanne Woodage. Fast message franking: From invisible salamanders to encryptment. ia.cr/2019/016

References

[BNT19] Mihir Bellare, Ruth Ng, and Björn Tackmann. Nonces are Noticed: AEAD Revisited. ia.cr/2019/624

[LGR20] Julia Len, Paul Grubbs, and Thomas Ristenpart. Partitioning Oracle Attacks. ia.cr/2020/1491

[ADGKLS20] Ange Albertini, Thai Duong, Shay Gueron, Stefan Kölbl, Atul Luykx, and Sophie Schmieg. How to Abuse and Fix Authenticated Encryption Without Key Commitment. ia.cr/2020/1456

[BH22] Mihir Bellare and Viet Tung Hoang. Efficient schemes for committing authenticated encryption. ia.cr/2022/268

[CR22] John Chan and Phillip Rogaway. On committing authenticated-encryption. ia.cr/2022/1260

[MLGR23] Sanketh Menda, Julia Len, Paul Grubbs, and Thomas Ristenpart. Context Discovery and Commitment Attacks: How to Break CCM, EAX, SIV, and More. preprint.link/ec23

[BHLMR23] Mihir Bellare, Viet Tung Hoang, Julia Len, Sanketh Menda, Thomas Ristenpart. In preparation.