Using Cryptography to Protect Integrity

Thierry Sans

Overview

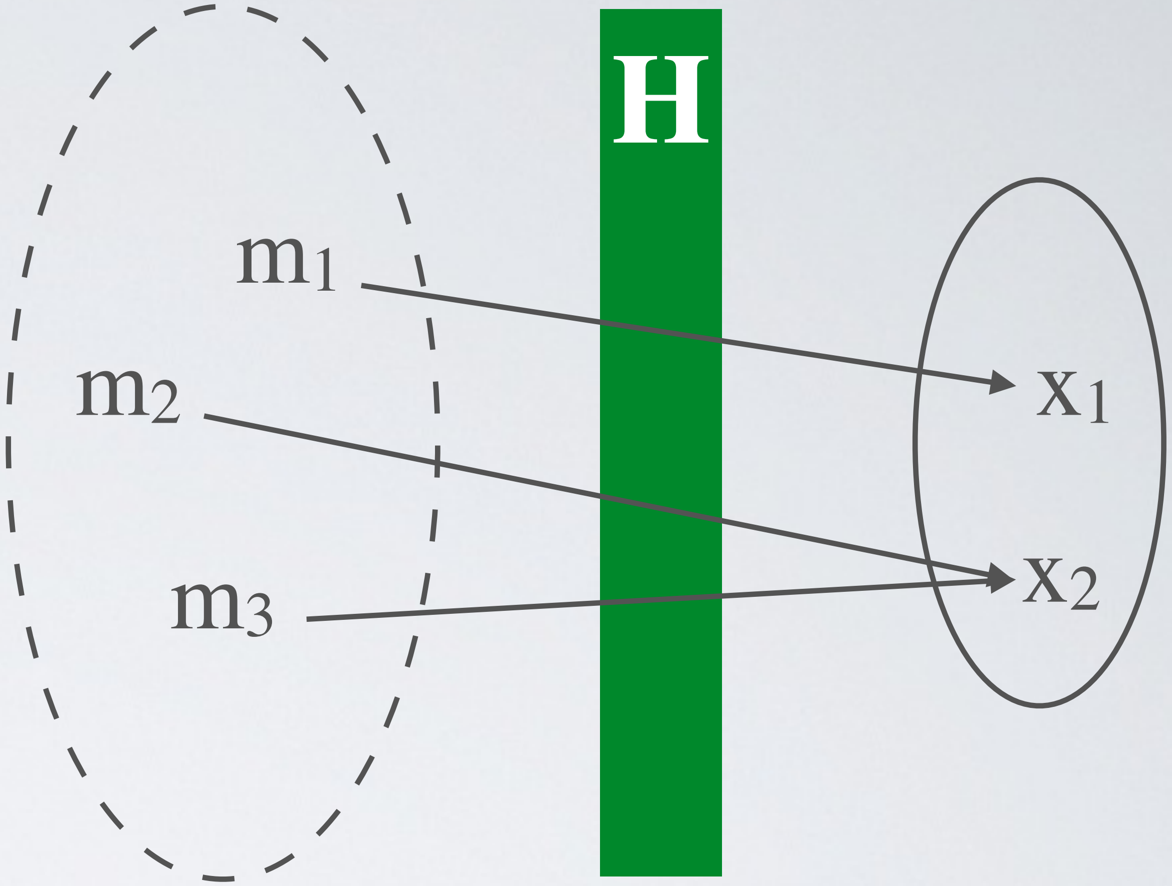
- One new tool in the cryptography toolbox:
  Hash Functions

- Using Symmetric Encryption :
  Message Authentication Code
  and **Authenticated Encryption**

- Using Asymmetric Encryption :
  Digital Signatures

Cryptographic Hash Functions

Cryptographic Hashing



$H(m) = x$ is a hash function if

- H is one-way function
- m is a message of any length
- x is a message digest of a fixed length

➡ H is a lossy compression function
necessarily there exists x, m_1 and m_2 | $H(m_1) = H(m_2) = x$

Computational Complexity

- Given H and m, computing x is **easy** (polynomial or linear)
- Given H and x, computing m is **hard** (exponential)

➡ H is **not invertible**

Preimage Resistance and Collision Resistance

PR - Preimage Resistance (a.k.a One Way)

- given H and x, hard to find m
  e.g. password storage

2PR - Second Preimage Resistance (a.k.a Weak Collision Resistance)

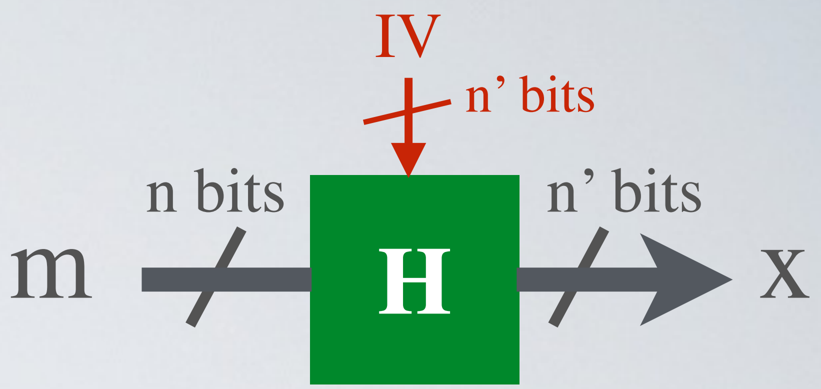
- given H, m and x, hard to find m' such that $H(m) = H(m') = x$
  e.g. virus identification

CR - Collision Resistance (a.k.a Strong Collision Resistance)

- given H, hard to find m and m' such that $H(m) = H(m') = x$
  e.g. digital signatures

CR → 2PR and CR → PR

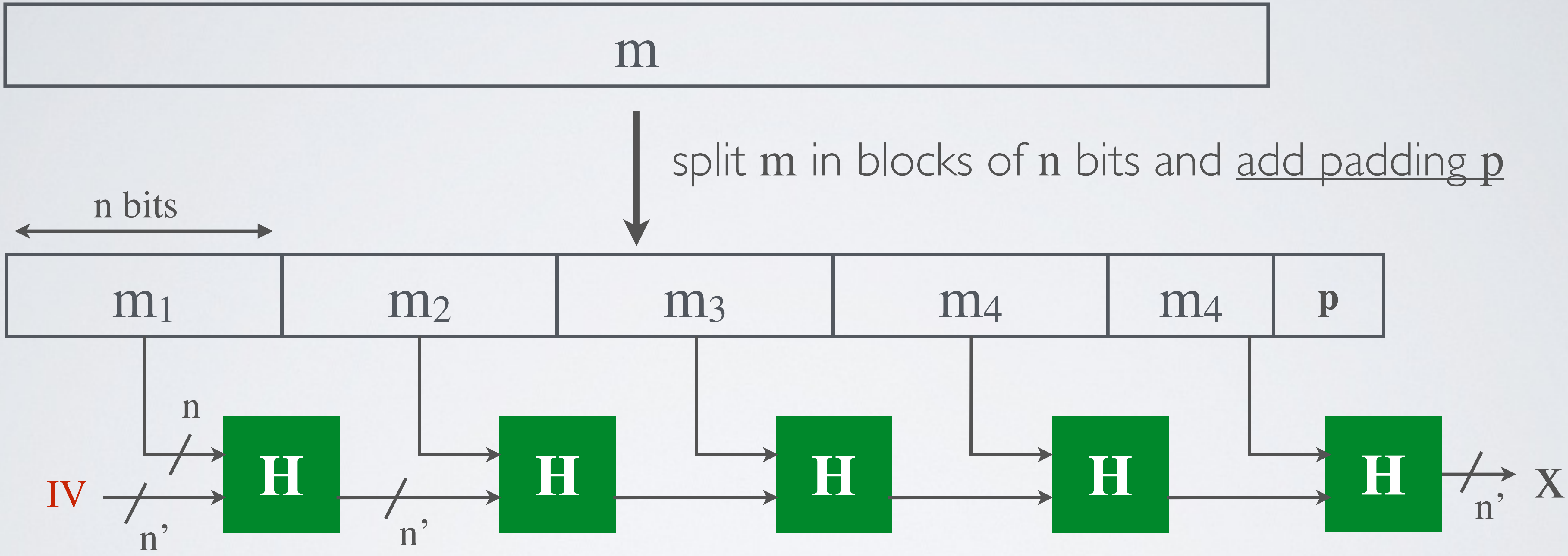
Common Hash Functions



Name	MD5	SHA-1	SHA-2				SHA-3 (Keccak)			
Variant			SHA-224	SHA-256	SHA-384	SHA-512	SHA3-224	SHA3-256	SHA3-384	SHA3-512
Year	1992	1993	2001				2012			
Designer	Rivest	NSA	NSA				Guido Bertoni, Joan Daemen, Michaël Peeters, and Gilles Van Assche			
Input n bits	512	512	512	512	1024	1024	1152	1088	832	576
Output n' bits	128	160	224	256	384	512	224	256	384	512
Construction	Merkle–Damgård						Sponge			
Speed cycle/byte	6.8	11.4	15.8		17.7		12.5			
Considered Broken	**yes**	**yes**	**no**				**no**			

How to hash long messages ?

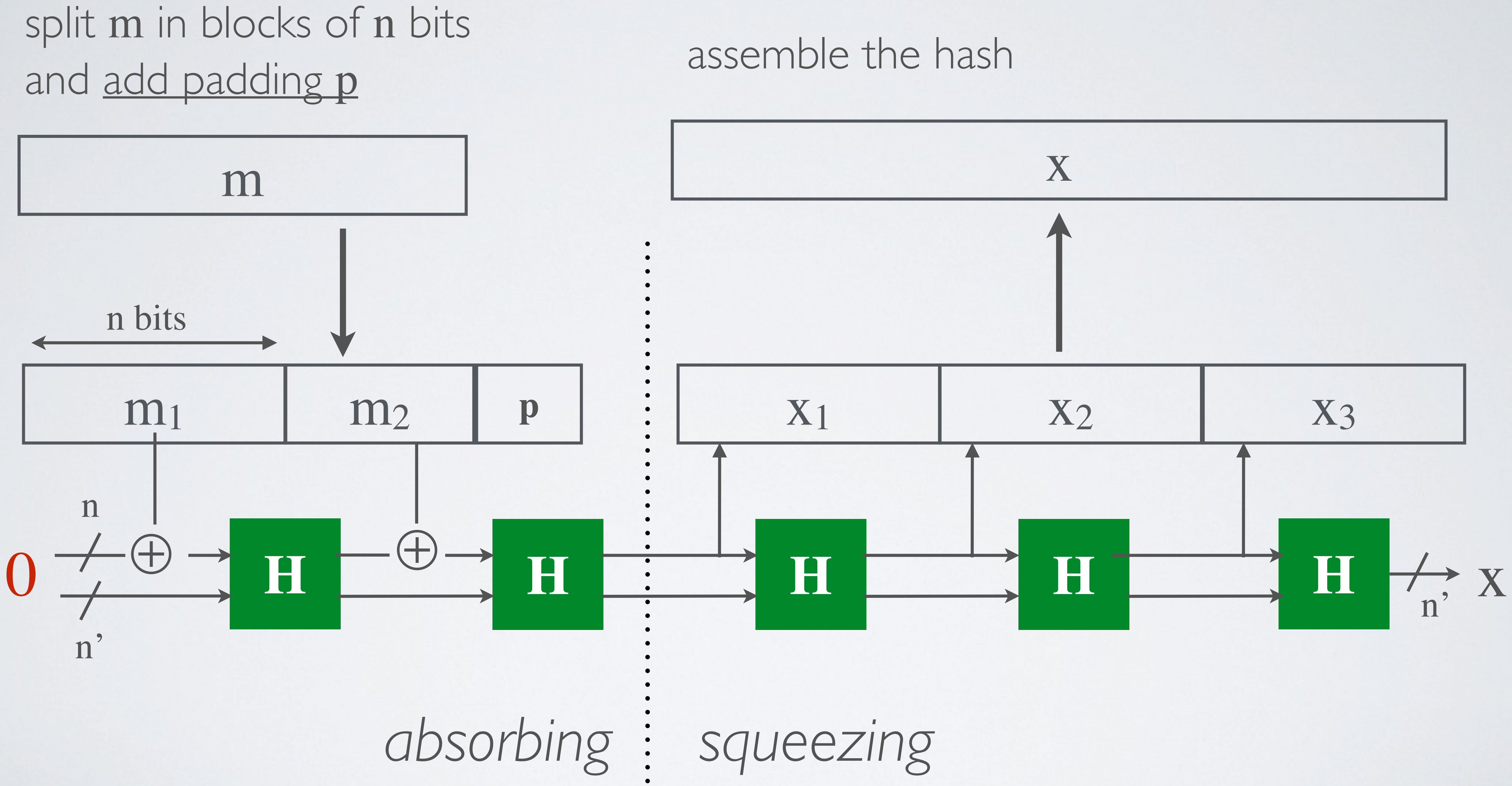
Merkle–Damgård construction (MD5, SHA-1 and SHA-2)



Property : if **H** is CR then Merkel-Damgard is CR

How to hash long messages ?

Sponge construction (SHA-3)



Property : if H is CR then Sponge is CR

Brute-forcing a hash function

CR - Collision Resistance

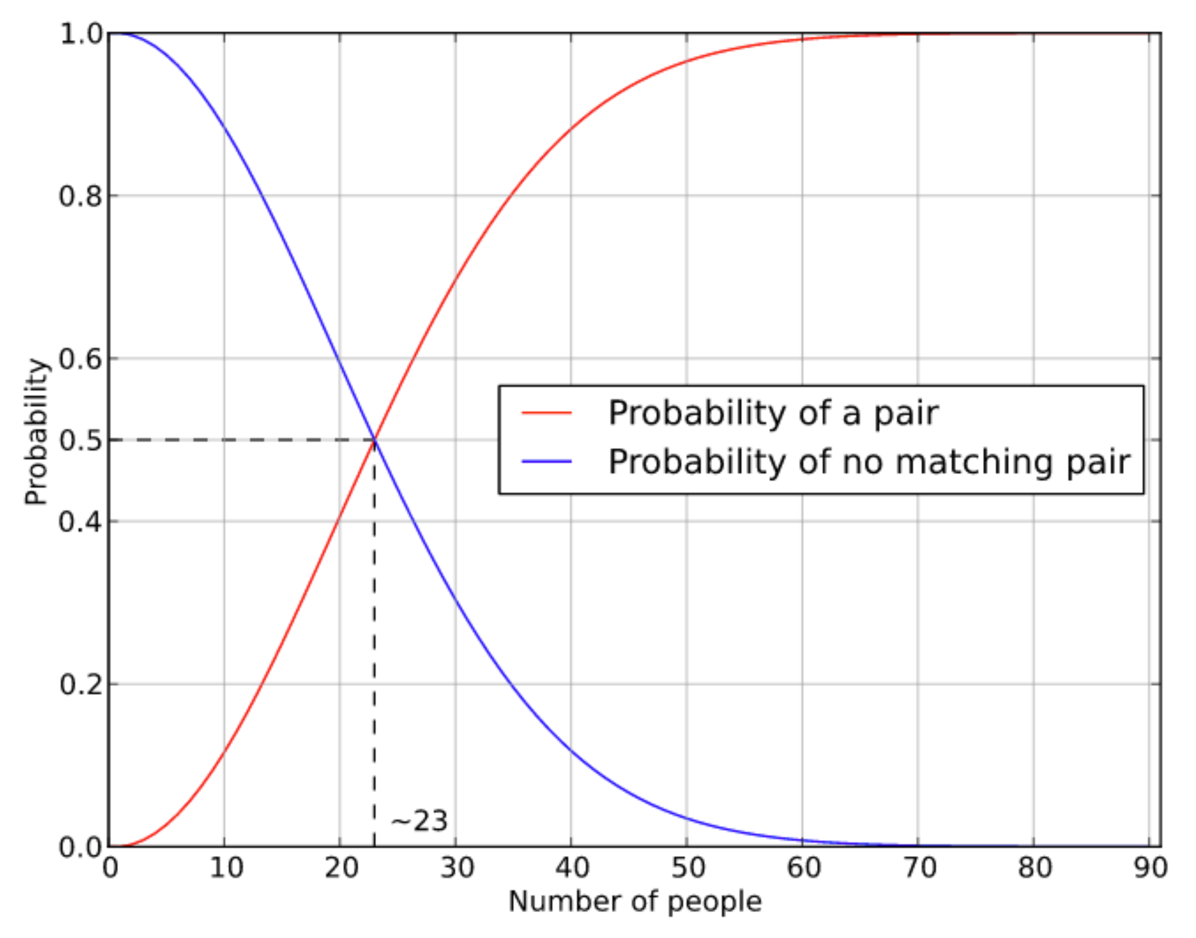
➡ given H, hard to find m and m' such that $H(m) = H(m') = x$

Given a hash function H of n bits output

- There are 2^n hashes
- Given a specific hash, an attacker will find the corresponding input in ~~2^{n-1} tries~~

Birthday Paradox

“There are 50% chance that 2 people have the same birthday in a room of 23 people”



N-bits security

➡ Given a hash function **H** of **n** bits output,

a collision can be found in around $\mathbf{2^{n/2}}$ evaluations

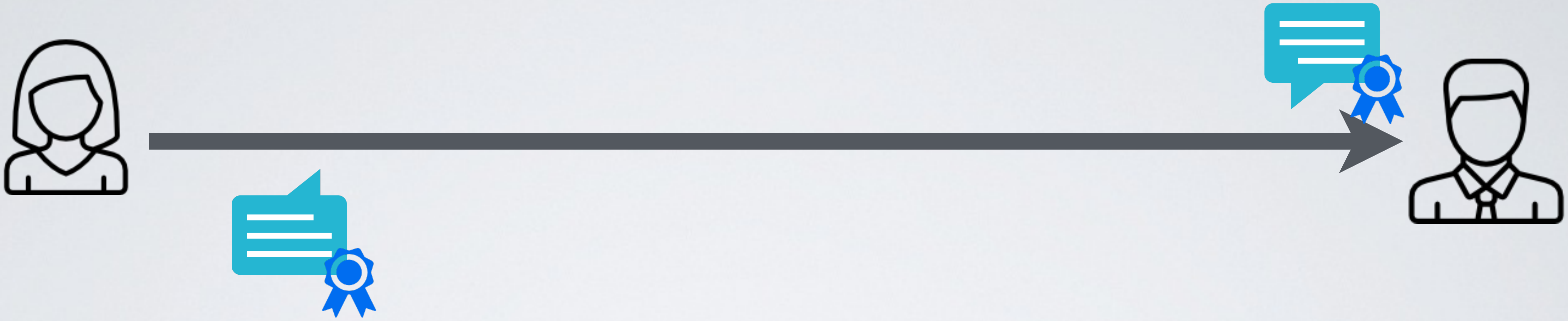
e.g SHA-256 is 128 bits security

Broken hash functions beyond the birthday paradox

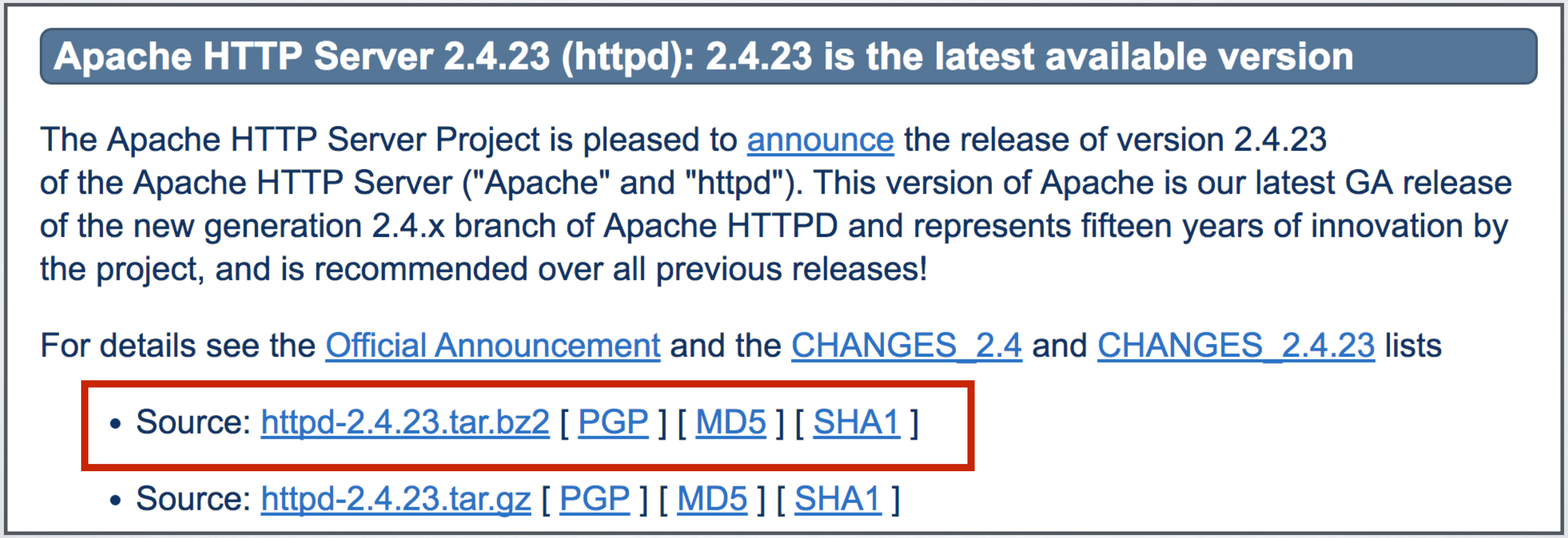
	Year	Collision
MD5	2013	2^{24} evaluations (2^{39} with prefix)
SHA-1	2015	2^{57} evaluations

Message Authentication Code

Hashing



$m \| H(m)$



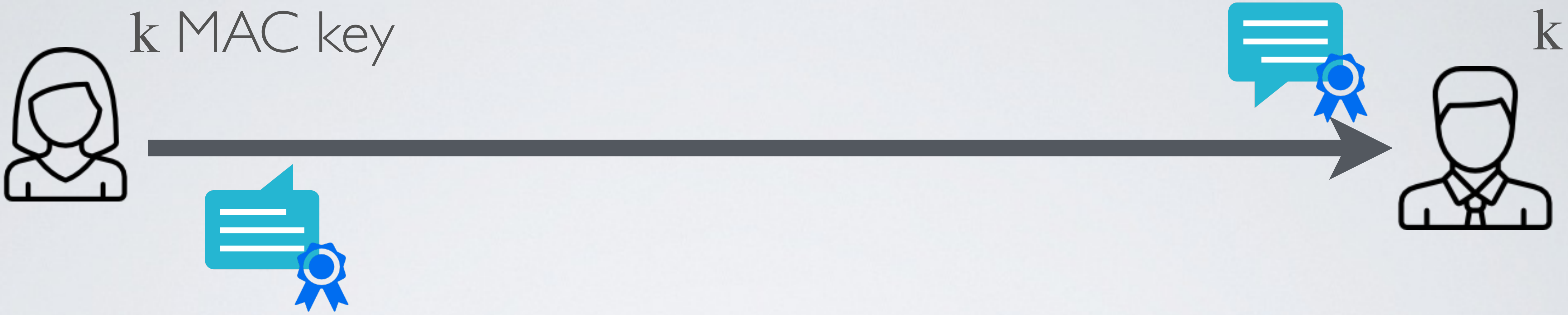
Apache HTTP Server 2.4.23 (httpd): 2.4.23 is the latest available version

The Apache HTTP Server Project is pleased to announce the release of version 2.4.23 of the Apache HTTP Server ("Apache" and "httpd"). This version of Apache is our latest GA release of the new generation 2.4.x branch of Apache HTTPD and represents fifteen years of innovation by the project, and is recommended over all previous releases!

For details see the Official Announcement and the CHANGES_2.4 and CHANGES_2.4.23 lists

- Source: httpd-2.4.23.tar.bz2 [PGP] [MD5] [SHA1]
- Source: httpd-2.4.23.tar.gz [PGP] [MD5] [SHA1]

MAC - Message Authentication Code



k MAC key

k

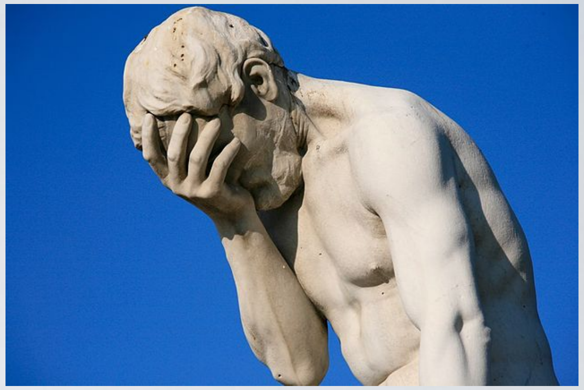
$$m \,\|\, \mathrm{MAC}_k(m)$$

Alice an Bob share a key **k**

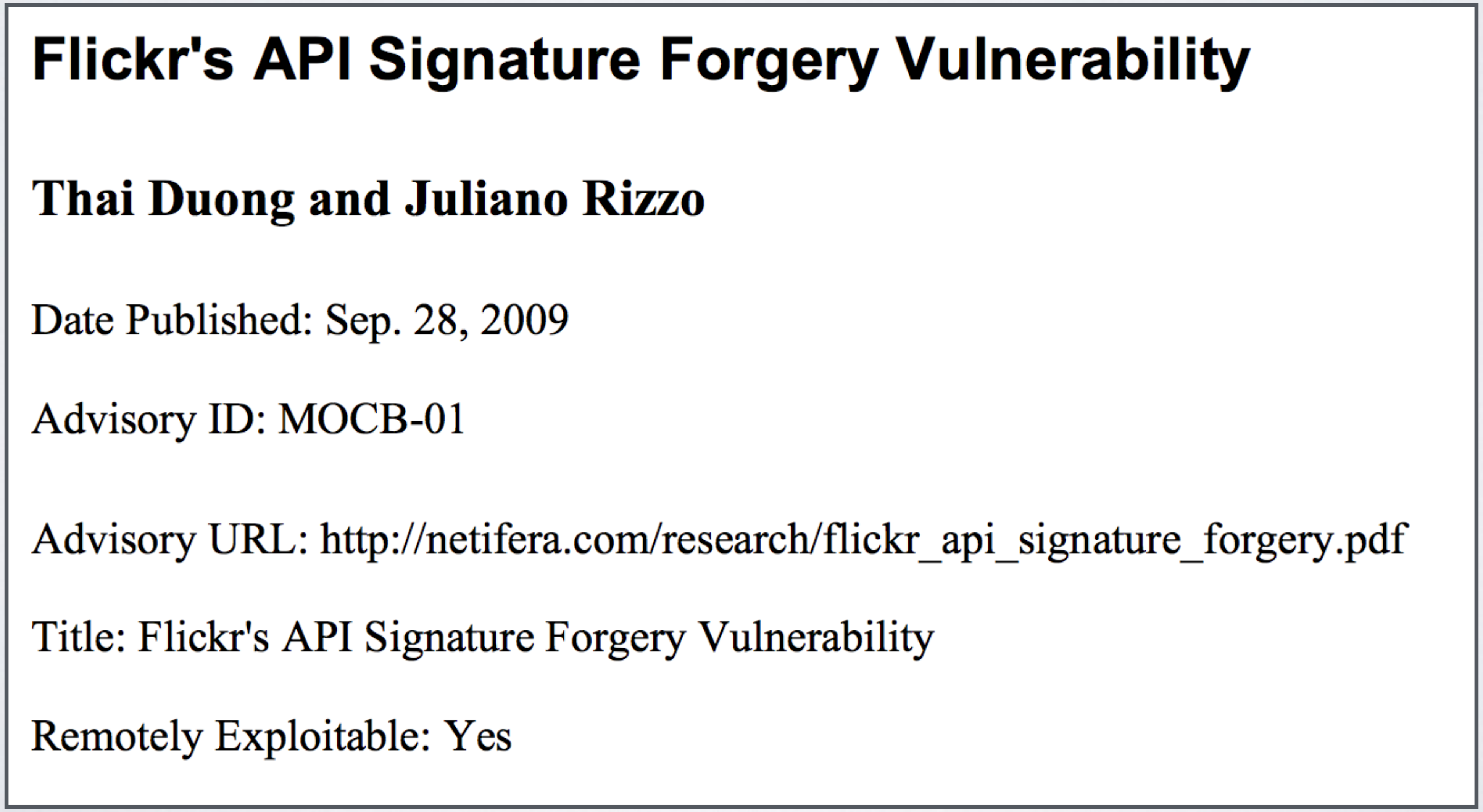
➡ HMAC - use a hash function on the message and the key

$$\mathrm{MAC}_k(m) = H(\xcancel{k \,\|}\, m)$$

Length Extension Attack



Vulnerable : All Merkle–Damgård-based hash functions
so MD5, SHA-1 and SHA-2 (but not SHA-3)



Flickr's API Signature Forgery Vulnerability

Thai Duong and Juliano Rizzo

Date Published: Sep. 28, 2009

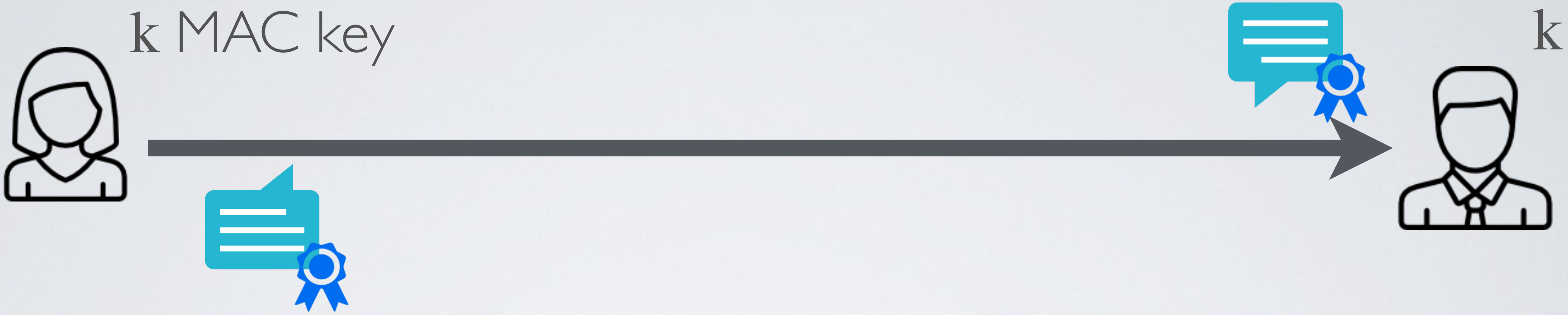
Advisory ID: MOCB-01

Advisory URL: http://netifera.com/research/flickr_api_signature_forgery.pdf

Title: Flickr's API Signature Forgery Vulnerability

Remotely Exploitable: Yes

Good HMAC



k MAC key

k

$$m \parallel MAC_k(m)$$

Alice an Bob share a key k

- ➡ Option 1 : envelope method

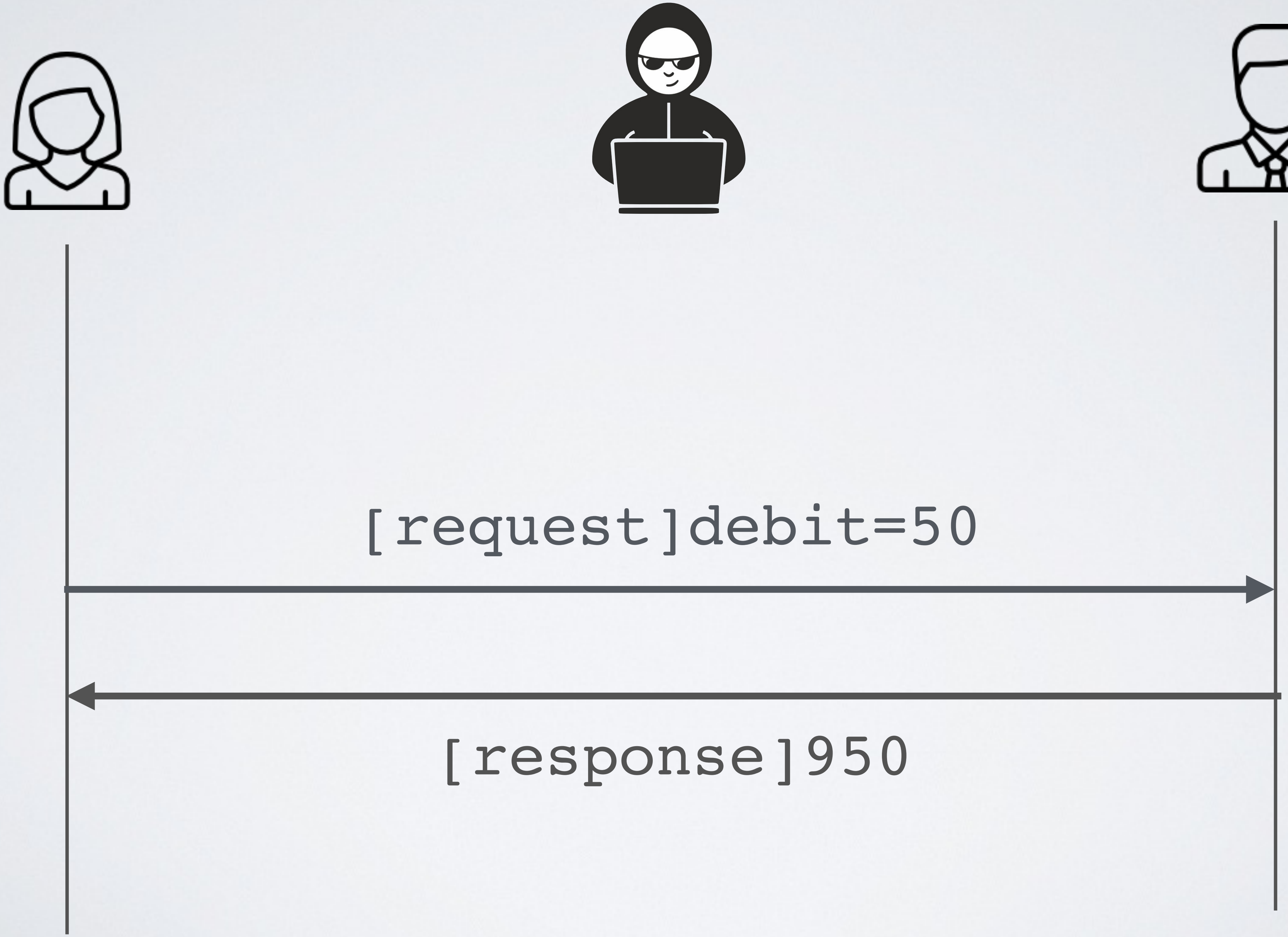
$$MAC_k(m) = H(k \parallel m \parallel k)$$

- ➡ Option 2 : padding method (i.e. HMAC standard)

$$HMAC_k(m) = H((k \oplus opad) \parallel H((k \oplus ipad) \parallel m))$$

Authenticated Encryption

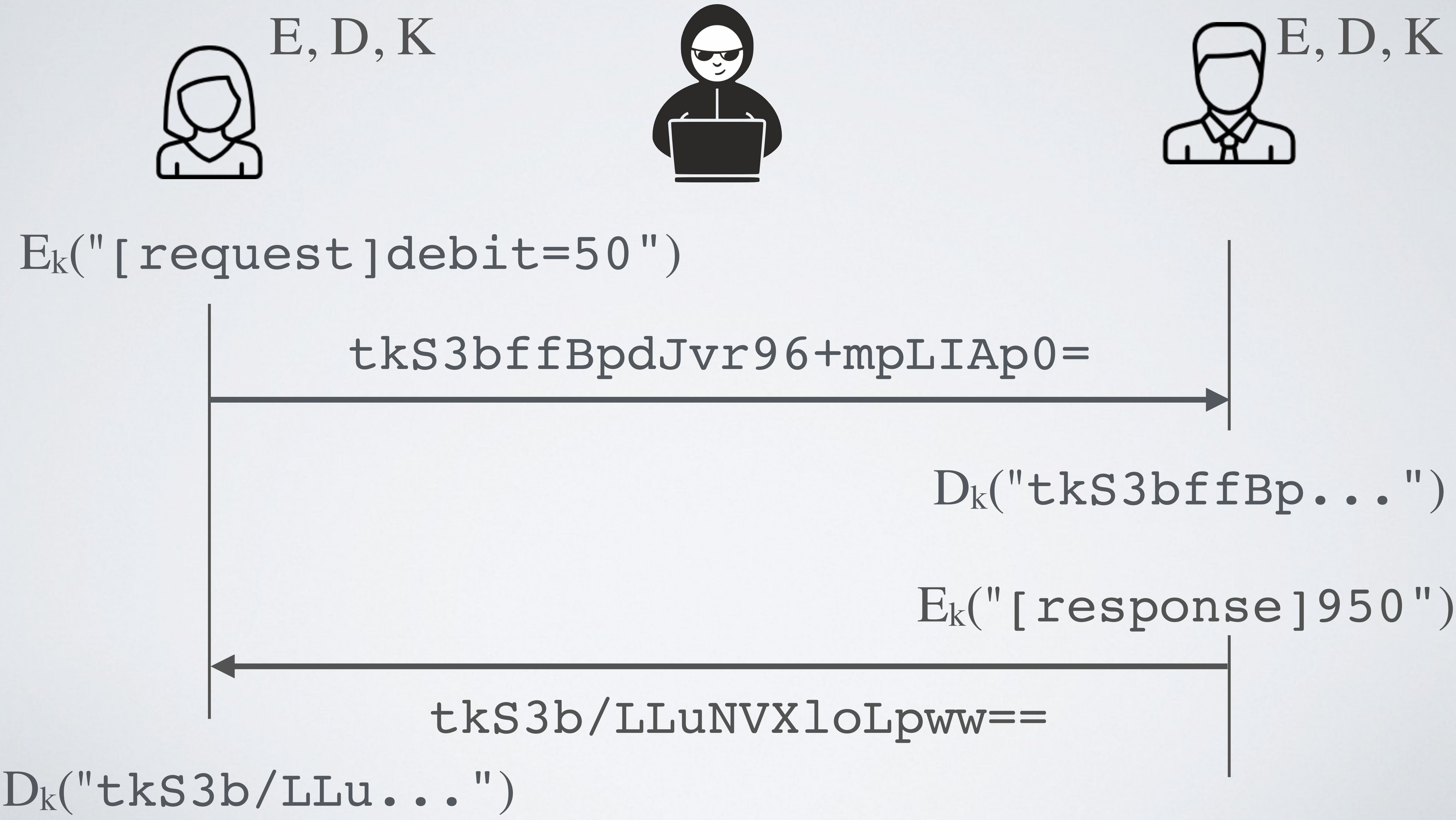
Example



`[request]debit=50`

`[response]950`

Ensuring confidentiality with encryption



E, D, K

E, D, K

E_k(`"[request]debit=50"`)

`tkS3bffBpdJvr96+mpLIAp0=`

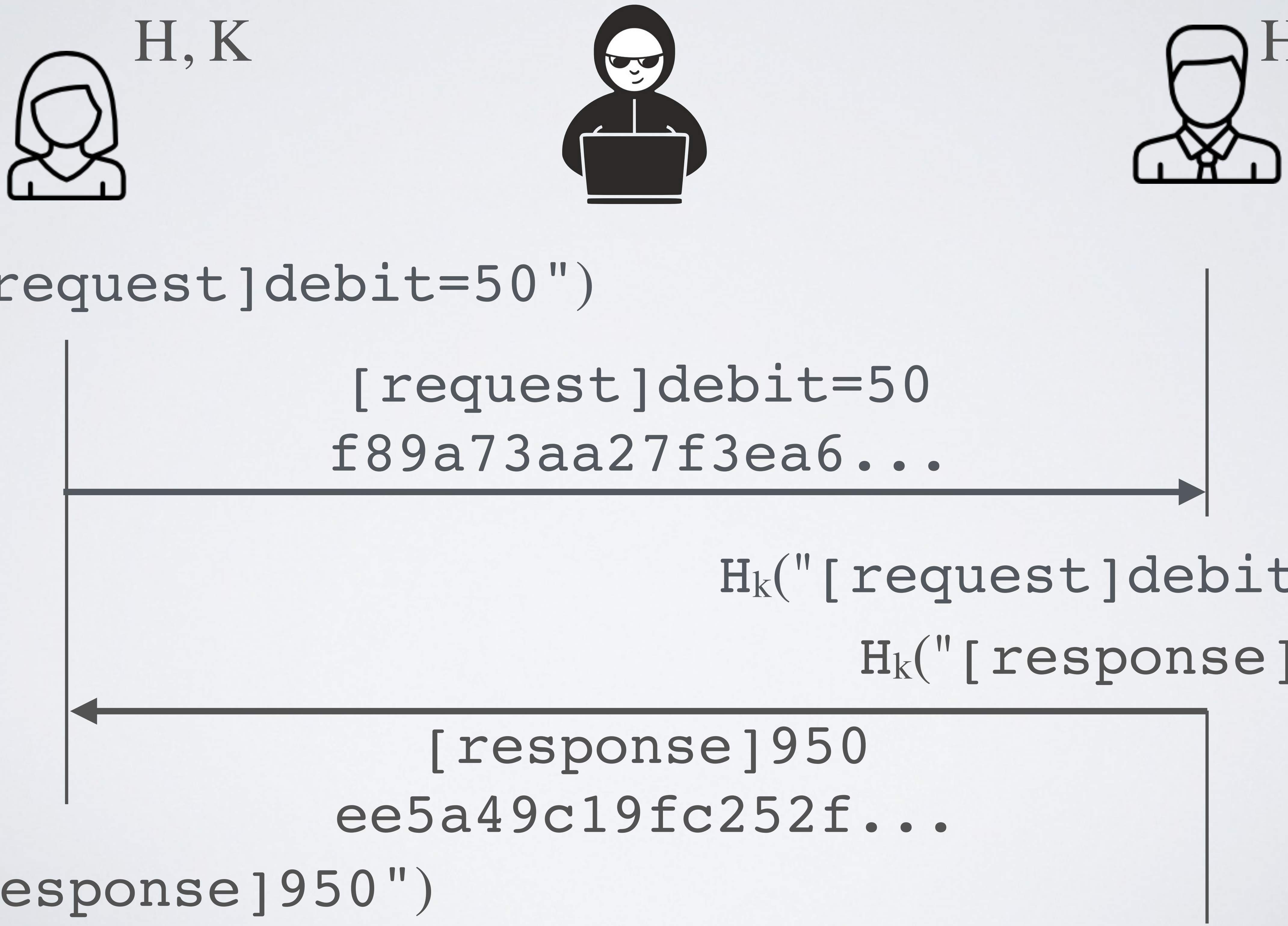
D_k(`"tkS3bffBp..."`)

E_k(`"[response]950"`)

`tkS3b/LLuNVXloLpww==`

D_k(`"tkS3b/LLu..."`)

Ensuring integrity with an HMAC



H, K

H, K

H_k("[request]debit=50")

[request]debit=50

f89a73aa27f3ea6...

H_k("[request]debit=50")

H_k("[response]950")

[response]950

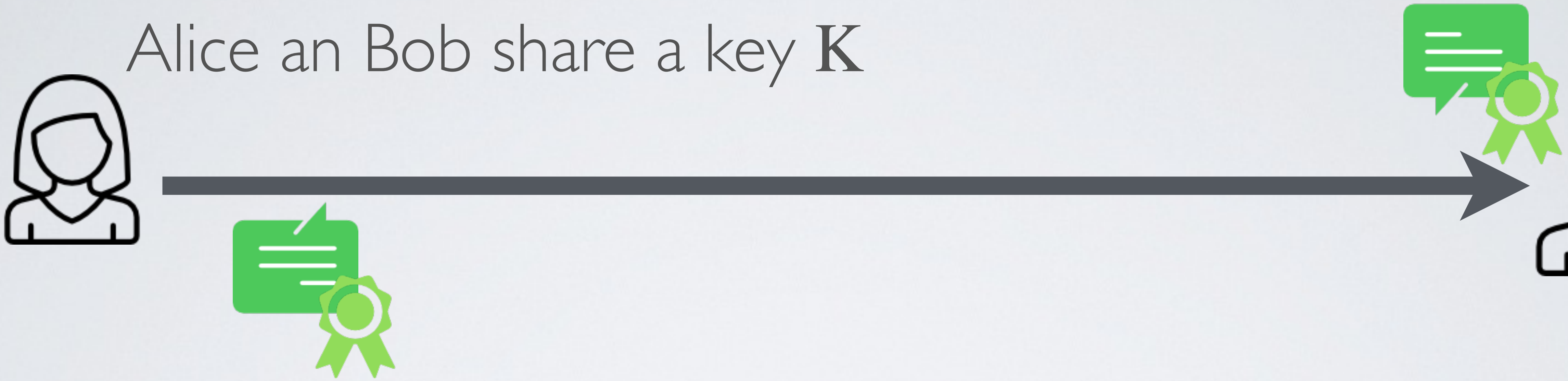
ee5a49c19fc252f...

H_k("[response]950")

Security mechanisms

	Encryption	MAC	Authenticated Encryption
Confidentiality	✓	✗	✓
Integrity	✗	✓	✓

Authenticated Encryption (2013)

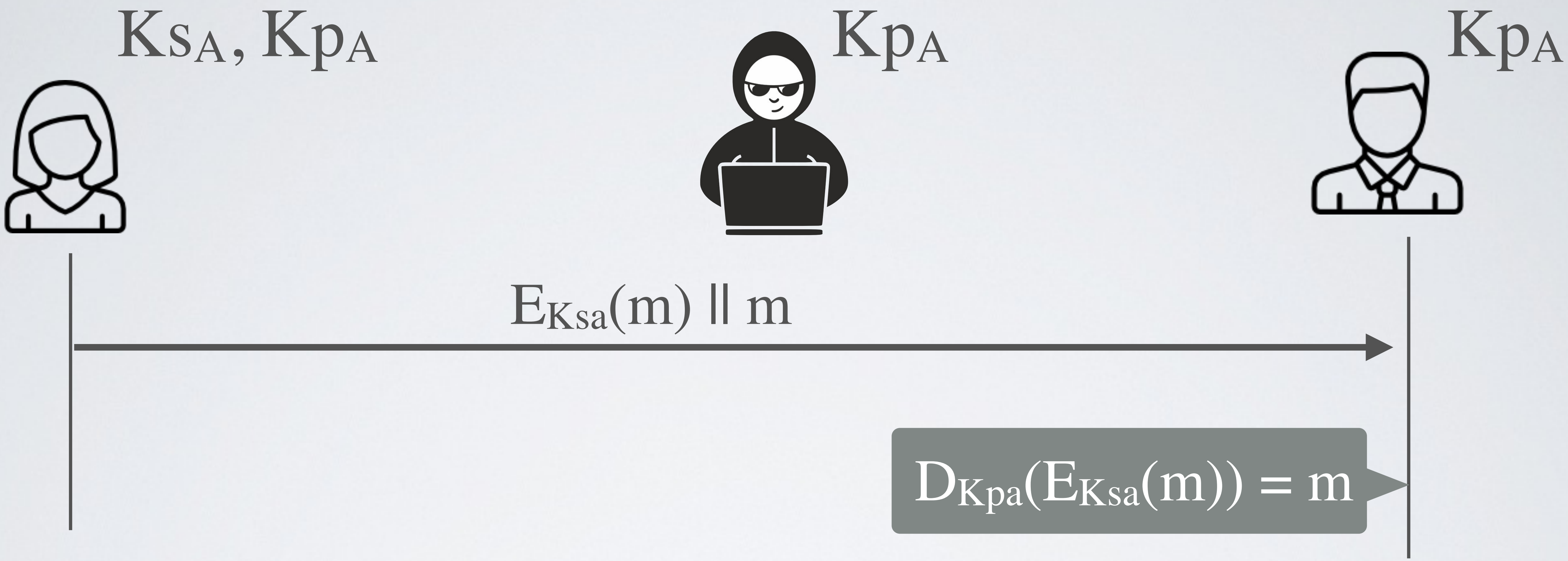


Alice an Bob share a key **K**

Encrypt-and-MAC (E&M)	$AE_k(m) = E_K(m) \parallel H_K(m)$	*SSH*
MAC-then-Encrypt (MtE)	$AE_k(m) = E_K(m \parallel H_K(m))$	*SSL*
Encrypt-then-MAC (EtM)	$AE_k(m) = E_K(m) \parallel H_K(E_K(m))$	*AES-GCM*

Digital Signatures

Asymmetric encryption for **integrity**



K_{sA}, K_{pA}

K_{pA}

K_{pA}

$E_{Ksa}(m) \mathbin{\|} m$

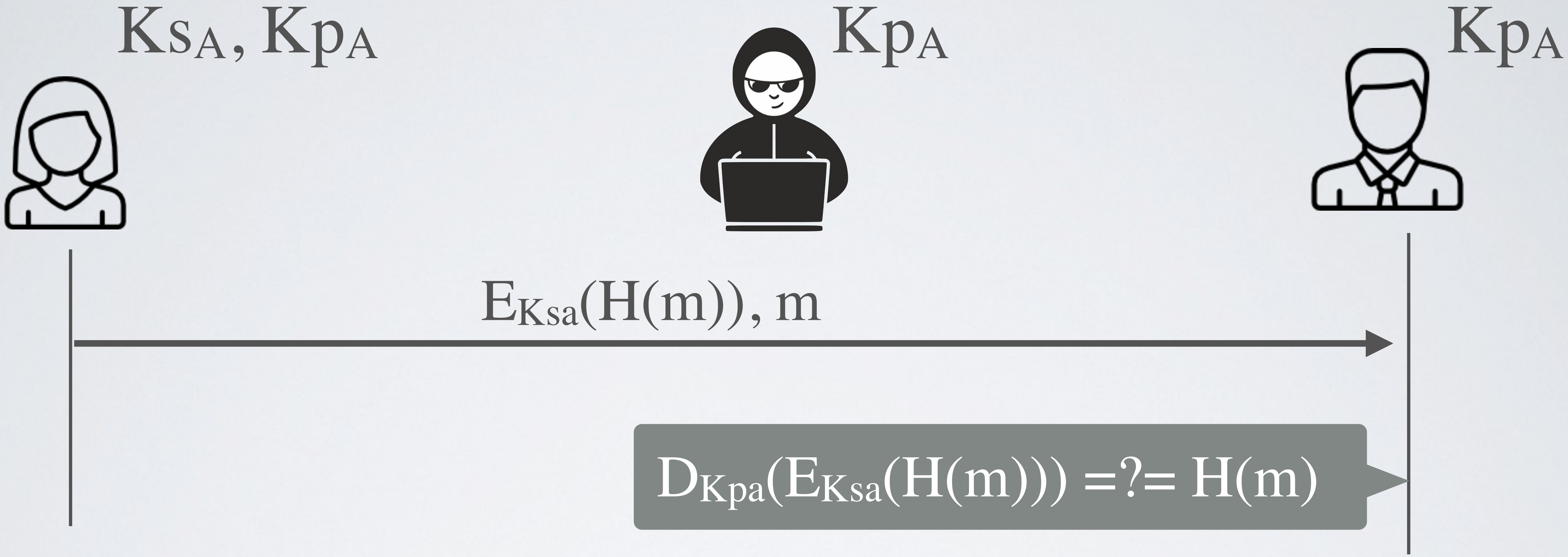
$D_{Kpa}(E_{Ksa}(m)) = m$

Alice encrypts a message $\mathbf{m}$ with her private key K_{sA}

➡ Everybody can decrypt $\mathbf{m}$ using Alice's public key K_{pA}

✓ Authentication with non-repudiation (a.k.a Digital Signature)

The Naive Approach of Digital Signatures



K_{sA}, K_{pA}

K_{pA}

K_{pA}

$E_{Ksa}(H(m))$, m

$D_{Kpa}(E_{Ksa}(H(m))) =?= H(m)$

1. Alice signs the message **m** by encrypting the hash of **m** with her private key **K_{sA}**
2. Alice sends the message **m** (in clear) and the encrypted hash to Bob
3. Bob decrypts **H(m)** using Alice's public key **K_{pA}** and verifies that it matches the hash of the message **m** received

Digital Signatures Schemes in Practice

The precursors

- *ElGamal signature*
- *Schnorr signature*

The standards

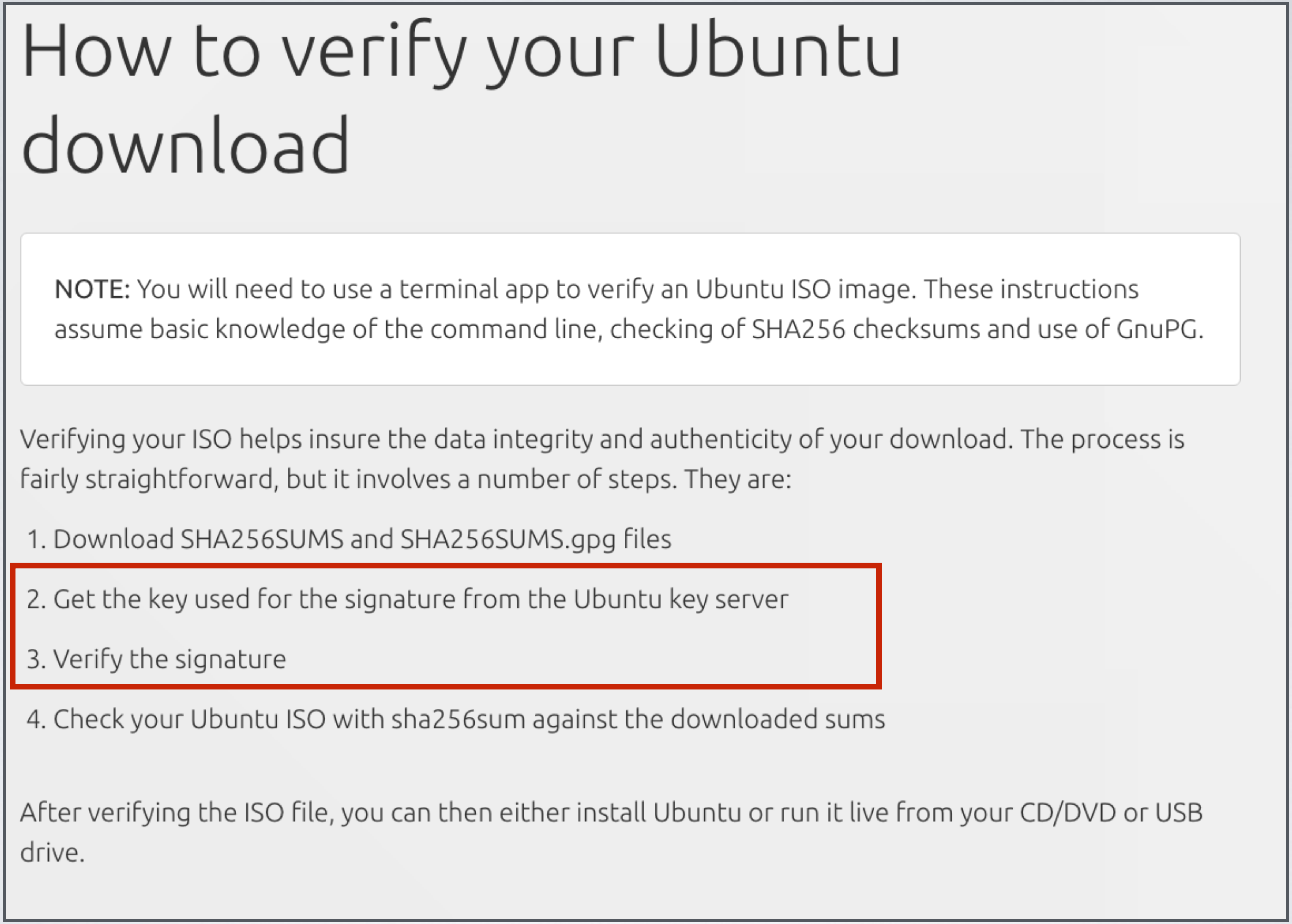
- *DSA - Digital Signature Algorithm* (RSA-based)
- *ECDSA - Elliptic Curve Digital Signature Algorithm* (ECC-based)

The newcomer

- *EdDSA - Edwards-curve Digital Signature Algorithm* (ECC-based)

Non-repudiation as a special case of integrity

	MAC	Digital Signature
Integrity	✓	✓
Non-repudiation	✗	✓



How to verify your Ubuntu download

NOTE: You will need to use a terminal app to verify an Ubuntu ISO image. These instructions assume basic knowledge of the command line, checking of SHA256 checksums and use of GnuPG.

Verifying your ISO helps insure the data integrity and authenticity of your download. The process is fairly straightforward, but it involves a number of steps. They are:

1. Download SHA256SUMS and SHA256SUMS.gpg files
2. Get the key used for the signature from the Ubuntu key server
3. Verify the signature
4. Check your Ubuntu ISO with sha256sum against the downloaded sums

After verifying the ISO file, you can then either install Ubuntu or run it live from your CD/DVD or USB drive.