Blockchain 101

1# Security Fundamental Concepts

About me

- My name is Miguel Garcia
- My background is on intrusion-tolerant systems
- I am a cryptocurrency skeptic, but I am a Blockchain enthusiast (however, I don't think it solves all the problems in the world)

About Blockchain101

- This is not a course on cryptocurrencies, I will not teach you how to become a bitcoin millionaire or create a mining pool.
- This course is a about the blockchain technology – which happens to be the core of the Bitcoin.
- It should provide you theoretical and practical knowledge about Blockchain.

Blockchain101: contents

1. Security Fundamental Concepts
2. Secure Distributed Systems
3. Blockchain in a Nutshell
4. Assembling the pieces: Blockchain prototype

Blockchain core parts

Blockchain technology has three key parts:

- **Security**
  - Cryptography
  - Fault-tolerance
- **Structure**
  - Ledger
- **Network**
  - P2P

Security Properties

A system is said secure if it guarantees the following properties

- Confidentiality
- Integrity
- Authenticity
- Availability

Security Properties

Confidentiality:

- Only authorized people can see the data

- Imagine that we have Bob, Alice and Trent
- Bob sends as letter to Alice and only Alice should read the text
- Therefore, we need to ensure that Trent cannot read the text

Security Properties

Integrity:

- Data cannot be modified without authorization or undetected.

- Imagine that we have Bob, Alice and Trent
- Bob sends as letter to Alice
- Trent takes the letter and change some words
- The data should avoid this modification OR Alice should be able to detect this modification

Security Properties

Authentication:

- The one that sends data can prove that he or she is the author of the data

- Bob sends as letter to Alice
- Alice knows that Bob sent the letter
- Trent cannot send a letter to Alice saying that he is Bob

Security Properties

Availability:

- Data or services should be always available

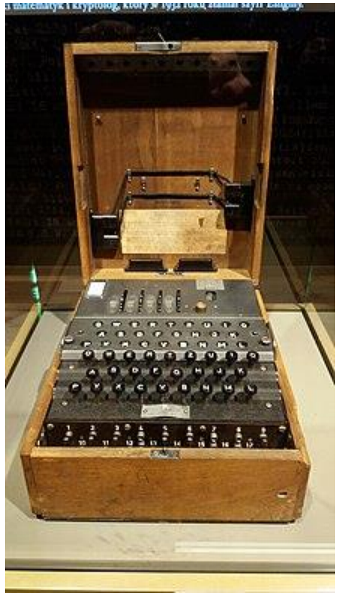
How can we guarantee these properties?

Cryptography

- Long time ago, Cryptography was synonym of encryption
- The idea was to send text messages that adversaries couldn't read
- The main classical ciphers were based on **transposition**:
    - *Hello world* ➡ *ehlol owrdl*
- And **substitution**:
    - *Hello world* ➡ *Ijmmp xpsme*
- A more advanced cipher was the Caeser Cipher, that applied **substitution** cipher based on a fixed number of shifts

Cryptography

- During the WWII the **Enigma Machine** was one of the weapons of the Nazis that could communicate without the allies discover the meaning of the messages
- Thanks to **Allan Turing** that cracked the Enigma Machine it was possible to uncover the encoded messages and defeat the Nazis



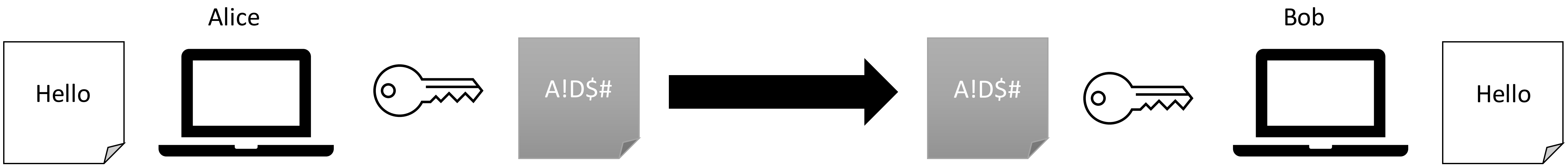
Cryptography (computer era)

Terminology

Method	Function	Output
Encrypt	*E(Clear Message, Key)*	Ciphered Message
Decrypt	*D(Ciphered Message, Key)*	Clear Message
Hash	*H(Message)*	Message Digest
Sign	*S(Message)*	Signture
Validate	*V(Signature)*	Boolean (true or false)

Symetric-key Cryptography

- Symetric-key cryptography uses the same key to encrypt and decrypt
- Therefore, is also called secret-key or shared-key cryptography



Symetric-key Cryptography

Properties:

- **E(K,M) = c** , then **D(K,c) = M**
- **D(K, (E(K,M)) = M**

Attributes:

- Given **E(K,M) is infeasible to find M without K**
- Given **E(K,M)=c is infeasible to find K**

Symetric-key Cryptography

E (Key, Data) = ciphered data

Encrypt

Variable size **key**	VByCFfclNy+OXk96fA3PpnlG03Rgm+rItxLTN8N0hXY+BuSpYwpjEItbFhgUE33RN0qlxLbIB0FnH/xqs9yWn6h7GlZlEo/cpSNlpfU7Ezd 7XWTjtt2JlpHidIvBGYhAkpA5OhWp8GgryVB+..........
Input **data**: text, bytes	This a clear text message
Ciphered data: bytes	ASDadkasERLDLASck495$%!"#

Symetric-key Cryptography

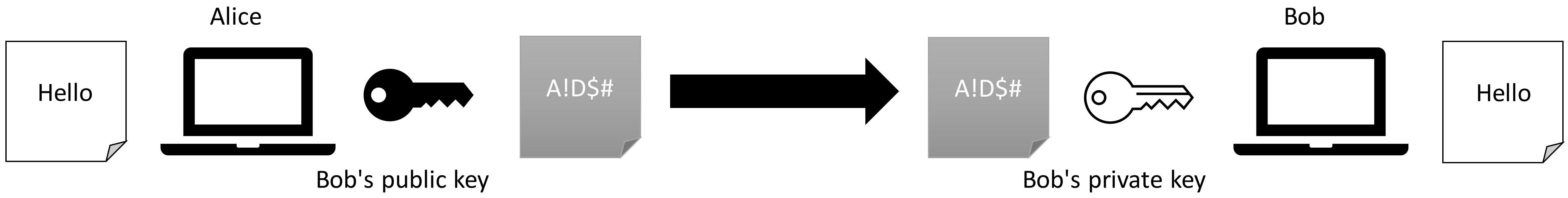
D(Key, Ciphered data) = data

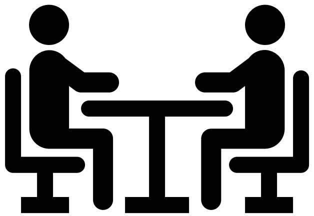
Decrypt

Variable size **key**	VByCFfclNy+OXk96fA3PpnlG03Rgm+rItxLTN8N0hXY+BuSpYwpjEItbFhgUE33RN0qlxLbIB0FnH/xqs9yWn6h7GlZlEo/cpSNlpfU7Ezd7XWTjtt2JlpHidIvBGYhAkpA5OhWp8GgryVB+..........
Input **data**: bytes	ASDadkasERLDLASck495$%!"#
Clear data: text, bytes	This a clear text message

Asymetric Cryptography

- Asymetric-key cryptography uses two keys
- Public key is used to encrypt and private key to decrypt
- Alice uses Bob' public key to encrypt, Bob uses its private key to decrypt





Discussion slide

Could we use the private key to encrypt and the public key to decrypt?

Asymetric Cryptography

Properties:

- **E(Ku,M) = c** , then **D(Kp,c) = M**
- **D(Ku, (E(Kp,M)) = M**

Attributes:

- Given **E(Ku,M) is infeasible to find M without Kp**

Asymetric-key Cryptography

E (Public Key, Data) = ciphered data

Encrypt

Variable size **key**

VByCFfclNy+OXk96fA3PpnlG03Rgm+rItxLTN8N0hXY+BuSpYwpjEItbFhgUE33RN0qlxLbIB0FnH/xqs9yWn6h7Gl ZlEo/cpSNlpfU7Ezd7XWTjtt2JlpHidIvBGYhAkpA5OhWp8GgryVB+……….

Input **data**: text, bytes

This a clear text message

Ciphered data: bytes

ASDadkasERLDLASck495$%!"#

Asymetric-key Cryptography

D(Private Key, Ciphered data) = data

Decrypt

Variable size **<u>key</u>**

ASDldoweifkf++33$32llapjrlçajERKFJas´++r+a#$$klasdçaspjpamkasligellasllERASllfiElfELasṕro4lc-.fo39$$332ças004#"o23''0400lliff//flaslrpprp+asçept.....

Input **<u>data</u>**: bytes

ASDadkasERLDLASck495$%!"#

<u>Clear data</u>: text, bytes

This a clear text message

Cryptography properties

Confusion:

- The adversary **should not** detect changes in the ciphered text if we change one symbol in the clear text.
- Therefore, it should be a complex relation between the clear text and the ciphered text

Cryptography properties

Diffusion:

- The clear text information should be spread all over the ciphered text
- Therefore, an attacker must collect a lot of ciphered text data to figure out how the cipher works

Symetric-key vs Asymetric-key Cryptography

Symetric-key Cryptography:

- The security relies on the shared key, once is lost the security is broken
- Key distribution: (n (n-1) / 2) keys for n participants
- 10 participants need 45 keys, one key for each pair of participants

Asymetric-key Cryptography :

- There is no need for key distribution, the public key is public so anyone can use it to encrypt data
- The security relies on the protection of the private key
- Is slower than symetric-key cryptography

Meeting point slide

- To guarantee confidentiality, we need cryptography
- In particular, by using secret-key or public-key cryptography
- Secret-key cryptography uses one shared key to encrypt and decrypt
- Public-key cryptography uses the destination public key to encrypt, and destination private key to decrypt – only the private-key owner can decrypt the message
- Symetric-key cryptography = Secret-key cryptography
- Asymetric-key cryptography = Public-key cryptography

We already know how to guarantee confidentiality.

How can we guarantee authenticity and integrity?

Digital Signatures

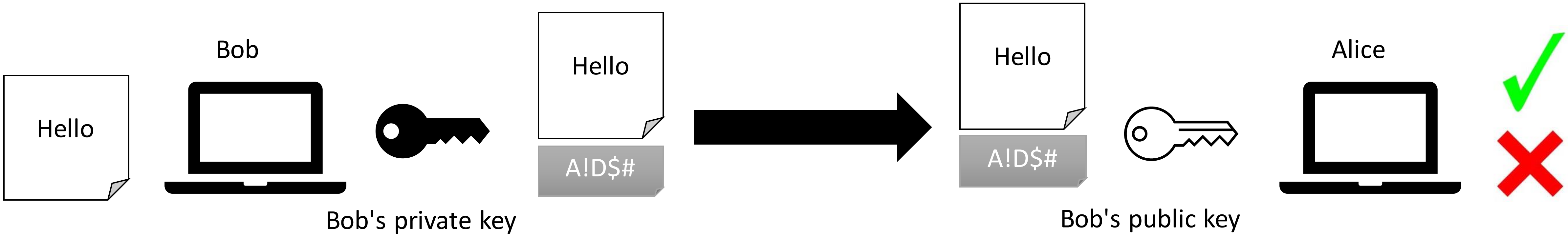
- Digital signatures are very similar to asymetric-key cryptography, however, **instead of using public key to ecnrypt we use private key to sign**
- **Very important:** Signing a message is not the same as encrypting a message
- **Another important note**: it is assumed that only the owner has access to the private key
- **Signatures** (alone) do not provide confidentiality but **provide authenticity and integrity** (and other properties)

Digital Signatures extra properties

- **Authenticity**: who signed the message is uniquely identifiable by his/her signature.
- **Tamperproof:** who signed, signed deliberatily
- **Integrity:** A valid signature guarantees that a message is not modified without being noticed
- **No-reuse:** A signture, or part of it, is not reusable in another message
- **No-repudiation:** the signer cannot deny his/her signature

Digital Signatures

- Sender: **sign(M, Kp) = S** (signture)
- Sender: sends message and signature
- Receiver: **verify(M, S, Ku) = true or false**



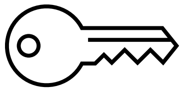
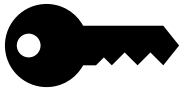
Digital Signatures: RSA

A Method for Obtaining Digital Signatures and Public-Key Cryptosystems

R.L. Rivest, A. Shamir, and L. Adleman*

- It was published in 1978 by Rivest,, Shamir and adleman (RSA)
- RSA can be used for both cipher and signatures
- It is the most used algorithm on the web.
- É muito utilizado em aplicações de comércio electrónico

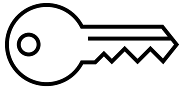
Digital Signatures:
RSA: Key generation

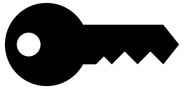
- Public Key: *(n, e)* 
- Private Key: *d* 

- **Step 1**: Choose two large prime numbers *p* and *q*

Digital Signatures:
RSA: Key generation

- Public Key: *(n, e)*
- Private Key: *d*





A prime number is a natural number greater than 1 that is not a product of two smaller natural numbers.

- **Step 1**: Choose two large **prime** numbers *p* and *q*

Digital Signatures:
RSA: Key generation

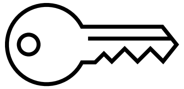
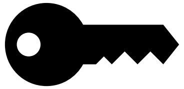
- Public Key: *(n, e)*
- Private Key: *d*

A prime number is a natural number greater than 1 that is not a product of two smaller natural numbers.

- **Step 1**: Choose two large **prime** numbers *p* and *q*

$$p = 43$$
$$q = 47$$

Digital Signatures:
RSA: Key generation

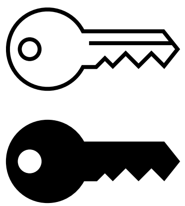
- Public Key: *(n, e)* 
- Private Key: *d* 

- **Step 2**: Compute n = p x q

n = 43 x 47
n = 2021

Digital Signatures: RSA: Key generation

- Public Key: *(n, e)*
- Private Key: *d*



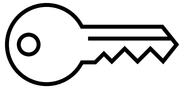
Euler's phi function is the number of integers k in the range $1 \leq k \leq n$ for which the greatest common divisor gcd(n, k) is equal to 1

- **Step 3**: Compute $\phi(n)$

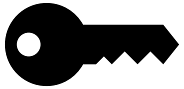
$$\phi(n) = \phi(p-1)(q-1)$$

Digital Signatures:
RSA: Key generation

- Public Key: *(n, e)*



- Private Key: *d*



- **Step 3**: Compute ϕ(n)

$$\phi(n) = \phi(p-1)(q-1)$$
$$\phi(2021) = (43-1)(47-1)$$

Digital Signatures: RSA: Key generation

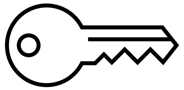
- Public Key: *(n, e)*
- Private Key: *d*

- **Step 3**: Compute ϕ(n)

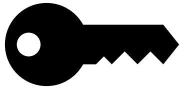
$$\phi(n) = \phi(p-1)(q-1)$$
$$\phi(2021) = (43-1)(47-1)$$
$$\phi(2021)=1932$$

Digital Signatures:
RSA: Key generation

- Public Key: *(n, e)*



- Private Key: *d*



The greatest common divisor (gcd) of two integers is the largest positive integer that divides each of the integers.
For example, the gcd of 8 and 12 is 4

- **Step 4**: Select *e, e is the public exponent*

Such that $e \in \{ 1, \ldots , \phi(n-1) \}$

$\gcd(e, 1932) = 1$

For example: $e = 155$

Digital Signatures: RSA: Key generation

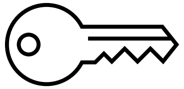
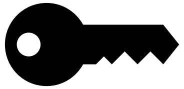
- Public Key: *(n, e)*
- Private Key: *d*

This equation can be solved using the Extended Euclidean Algorithm (see references)

- **Step 5**: Compute private key *d*

$$d \times e \equiv 1 \bmod \phi(n)$$
$$d \times 155 \equiv 1 \bmod 1932$$
$$d = 1583$$

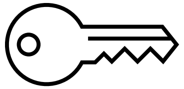
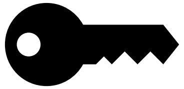
Digital Signatures:
RSA: Sign

- Now Bob wants to send a signed message to Alice
- **Bob's Public Key:** (2021,155) 
- **Bob's Private Key:** 1583 

- The message $m \in \{ 1, \ldots , n\text{-}1 \}$, e.g., $m = 411$

> Remember that we are using small prime numbers for the sake of simplicity.
> n-1 should accommodate any messages with larger prime numbers.

Digital Signatures:
RSA: Sign

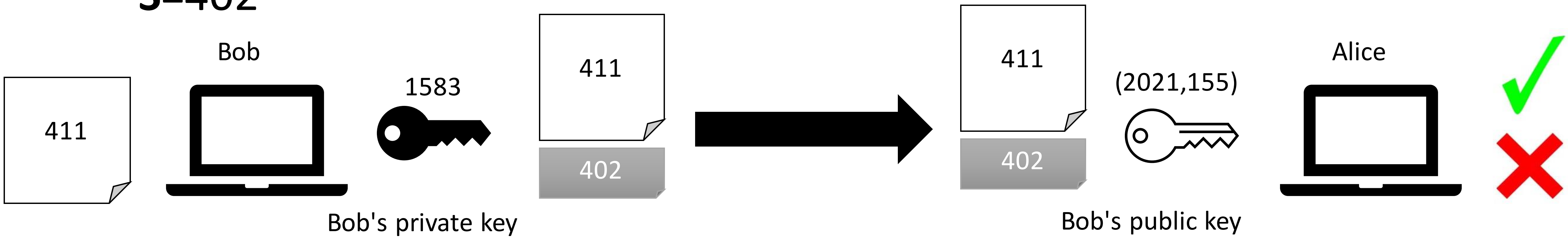
- Now Bob wants to send a signed message to Alice
- **Bob's Public Key:** (2021,155) 
- **Bob's Private Key:** 1583 
- **M:** 411

Signature algorithm

$$S = 411^{1583} \bmod 2021$$
$$S=402$$

Digital Signatures: RSA: Sending M

- Now Bob wants to send a signed message to Alice
- **Bob's Public Key:** (2021,155)
- **Bob's Private Key:** 1583
- **M:** 411
- **S**=402



Digital Signatures:
RSA: Validating S

- Now Bob wants to send a signed message to Alice
- **Bob's Public Key:** (2021,155)
- **Bob's Private Key:** 1583
- **M:** 411
- **S**=402

Validating algorithm

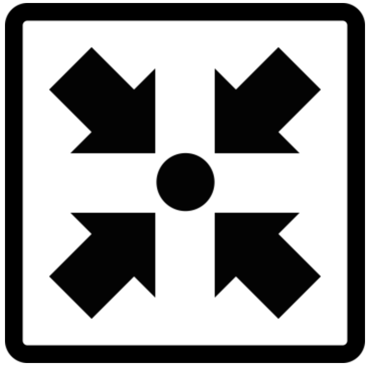
$M' = 402^{155} \bmod 2021$

$M'=402$

If $M'=M$, return *true*

If $M'!=M$, return *false*

Meeting point slide



- Signatures provide message authenticity and integrity
- Only the owner of the private key can sign a message
- Anyone with his/her public key can verify the message
- The signature depends on the data, therefore a signature cannot be used to other data/messages
  - It is not the same as a human handwritten signture
- The sender needs to send the signature and the message
- The receiver needs to use the public key, the signature and the message to validate the integrity and authenticity

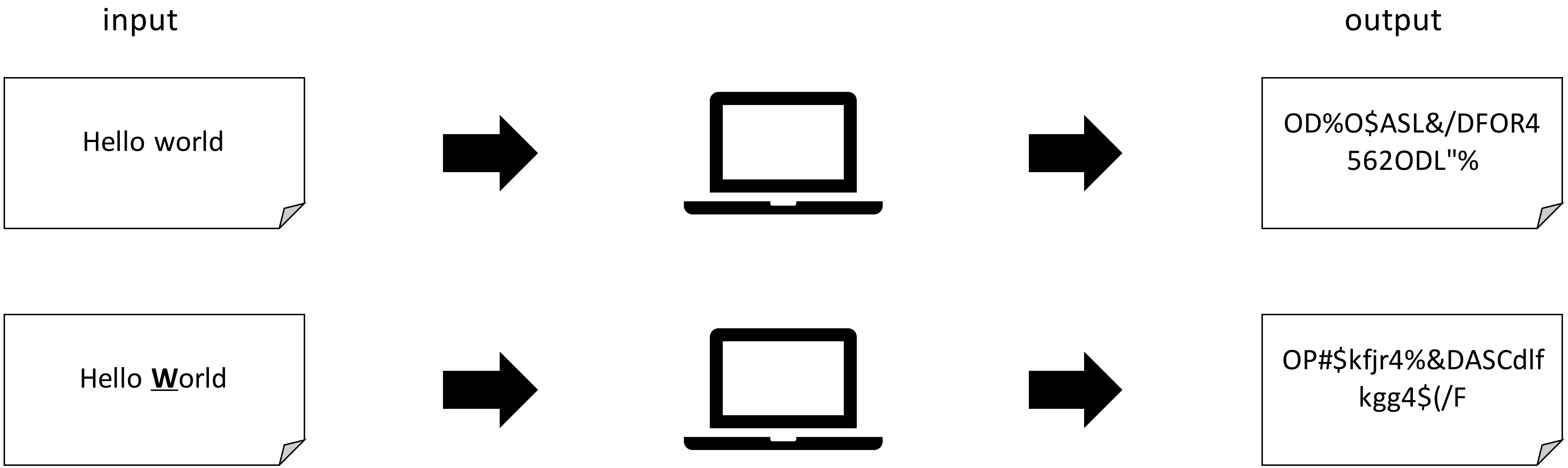
Signtures guarantee integrity and authentication.

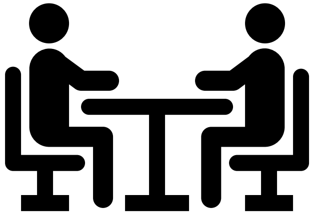
Can we guarantee integrity with a simple solution?

Hash Function

- Hash functions also provide integrity
- They are cheaper – but don't provide authenticity
- A Hash function receives as an input an arbitrary size and outputs a fixed sized string
- The most important feature of these functions is that they are deterministic
- In other words, for the same input they produce always the same ouput

Hash Function





Discussion slide

Can you think of a hash function solution?

Cryptographic Hash Function

- It is a one-way function; it is infeasible to find the inverse function of the hash function
- If you change one bit in the input the output should change drastically (this is called the avalanche effect)

- A few important properties that these functions guarantee:
  - Given M it should be easy to compute H(M) = *hash*
  - Given the *hash* it is infeasible to find M
  - It is hard to find M' and M such that H(M') = H(M)

Cryptographic Hash Function: SHA256

- The SHA (Secure Hash Algorithm) is cryptographic hash function.
- A cryptographic hash is like a signature for a data set, or like the fingerprints of the data.
- SHA256 algorithm generates an almost-unique, **fixed size** 256-bit (32-byte) hash.
- It is suitable for checking integrity of your data, challenge hash authentication, anti-tamper, digital signatures, blockchain.

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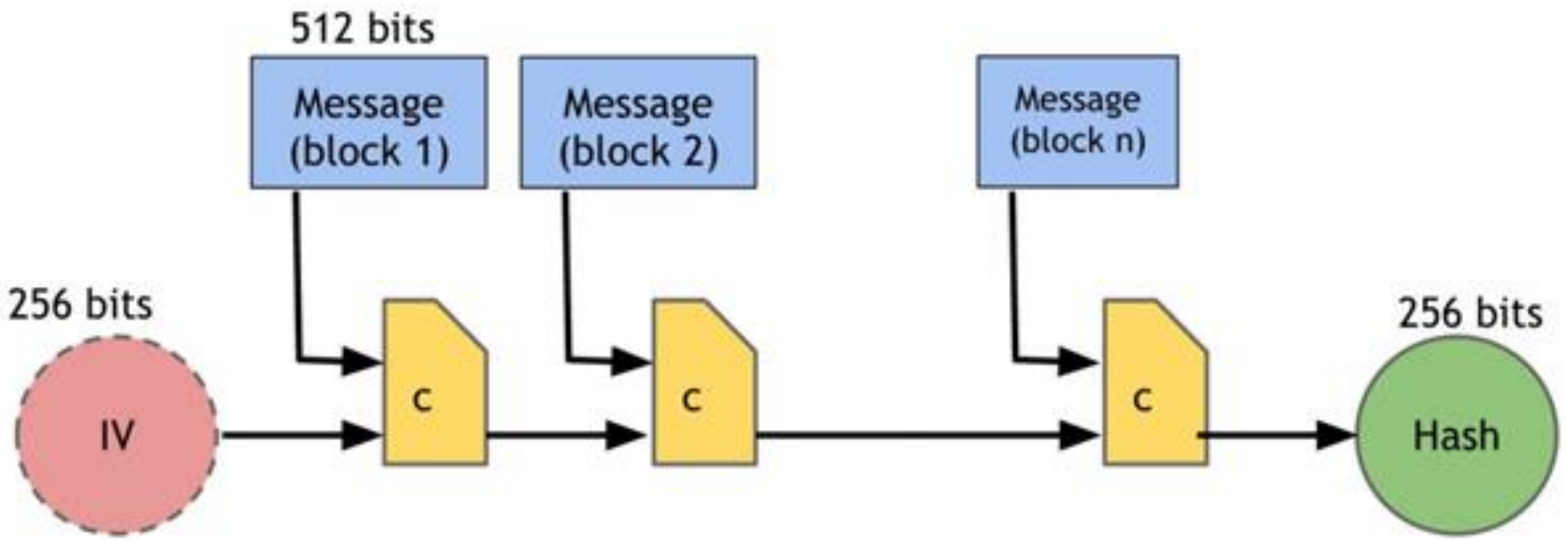
- It is suitable for checking integrity of your data, challenge hash authentication, anti-tamper, digital signatures, blockchain.

MD5 is no longer secure!

Cryptographic Hash Function: SHA256

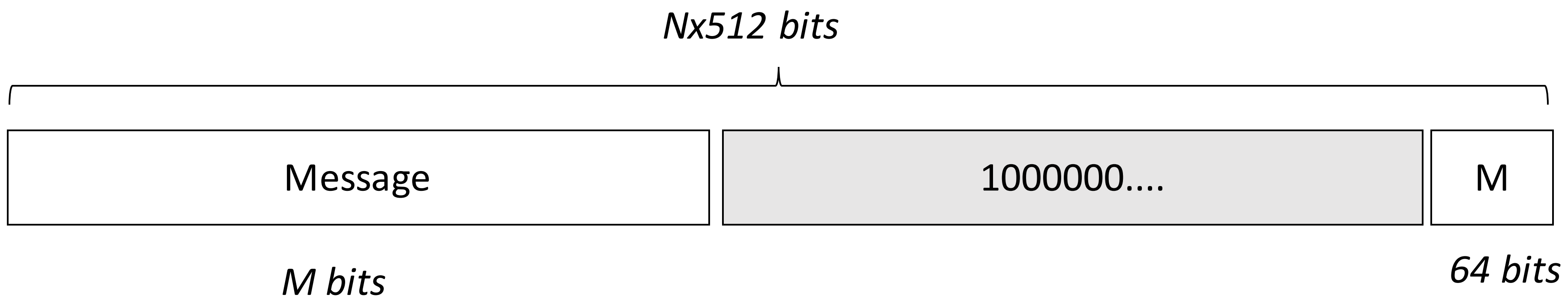
- Input: any size
- Block: 512 bits
- Output: 256 bits
- Rounds: 64



Cryptographic Hash Function: SHA256

- **Step1** add the padding to the input message

M + P + 64 = n x 512
M = length of original message
P = padded bits



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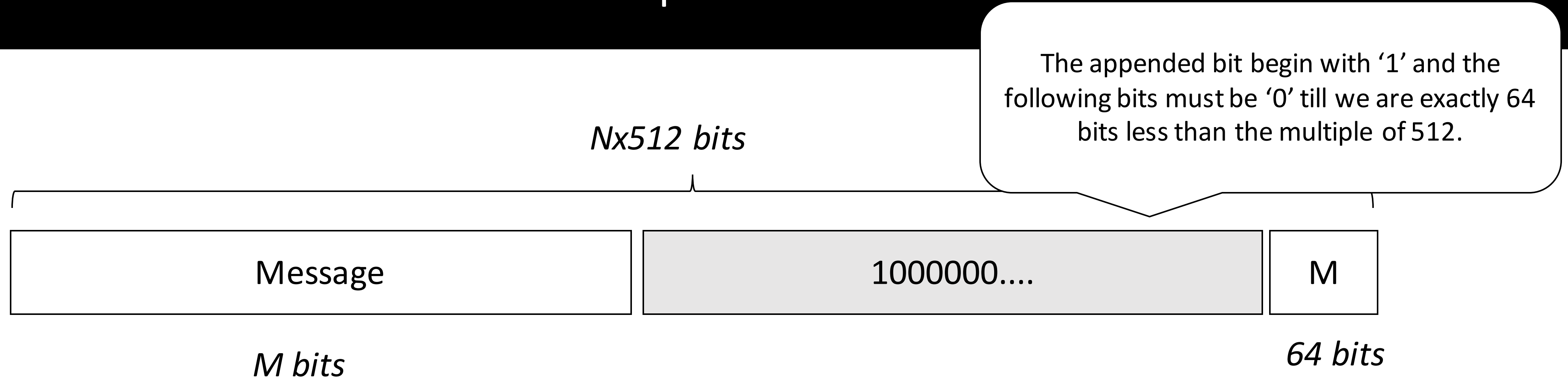

Cryptographic Hash Function: SHA256

- **Step1** add the padding to the input message

$$M + P + 64 = n \times 512$$

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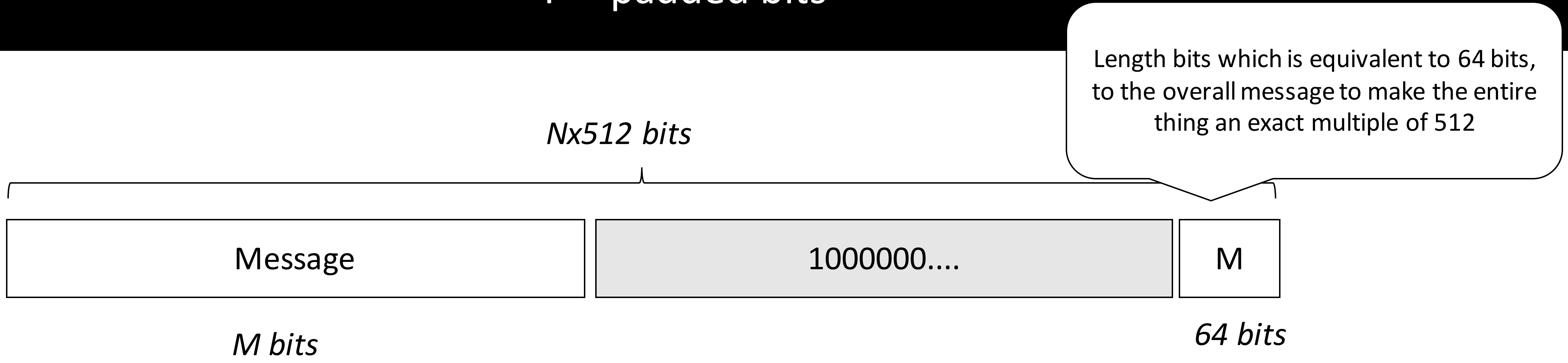
P = padded bits



Cryptographic Hash Function: SHA256

- **Step2** Initialize the buffers

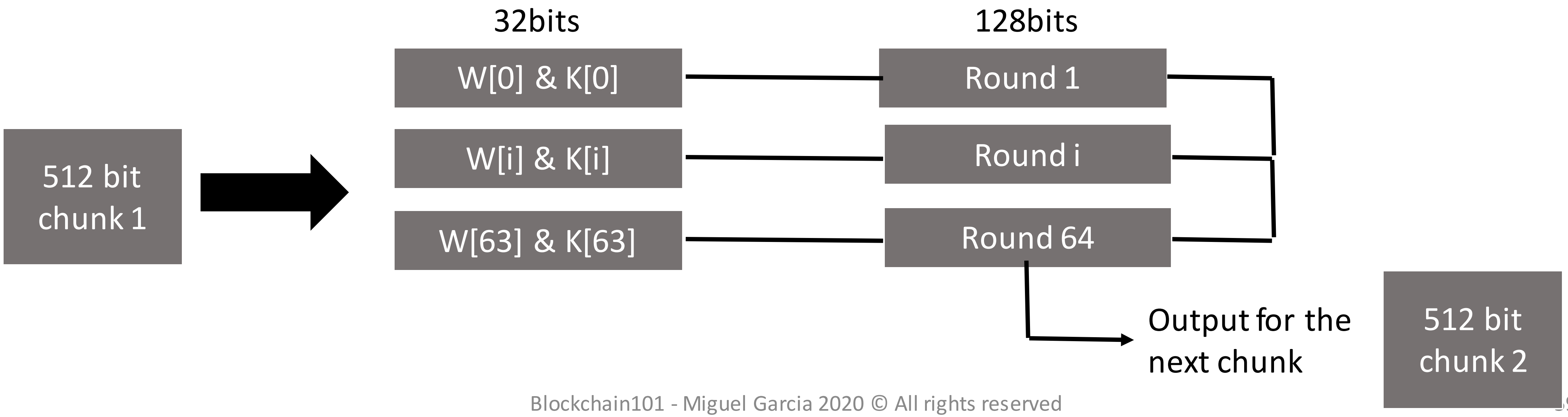
a = 0x6a09e667
b = 0xbb67ae85
c = 0x3c6ef372
d = 0xa54ff53a
e = 0x510e527f
f = 0x9b05688c
g = 0x1f83d9ab
h = 0x5be0cd19

```
k[0..63] :=
   0x428a2f98, 0x71374491, 0xb5c0fbcf, 0xe9b5dba5, 0x3956c25b, 0x59f111f1, 0x923f82a4, 0xab1c5ed5,
   0xd807aa98, 0x12835b01, 0x243185be, 0x550c7dc3, 0x72be5d74, 0x80deb1fe, 0x9bdc06a7, 0xc19bf174,
   0xe49b69c1, 0xefbe4786, 0x0fc19dc6, 0x240ca1cc, 0x2de92c6f, 0x4a7484aa, 0x5cb0a9dc, 0x76f988da,
   0x983e5152, 0xa831c66d, 0xb00327c8, 0xbf597fc7, 0xc6e00bf3, 0xd5a79147, 0x06ca6351, 0x14292967,
   0x27b70a85, 0x2e1b2138, 0x4d2c6dfc, 0x53380d13, 0x650a7354, 0x766a0abb, 0x81c2c92e, 0x92722c85,
   0xa2bfe8a1, 0xa81a664b, 0xc24b8b70, 0xc76c51a3, 0xd192e819, 0xd6990624, 0xf40e3585, 0x106aa070,
   0x19a4c116, 0x1e376c08, 0x2748774c, 0x34b0bcb5, 0x391c0cb3, 0x4ed8aa4a, 0x5b9cca4f, 0x682e6ff3,
   0x748f82ee, 0x78a5636f, 0x84c87814, 0x8cc70208, 0x90befffa, 0xa4506ceb, 0xbef9a3f7, 0xc67178f2
```

Cryptographic Hash Function: SHA256

- **Step3** Compression function

The entire message (n x 512 bits long) is divided into *n* chunks of 512 bits.
Each of these 512 bits, are then put through 64 rounds of operations.
The output is the input for the chunk



Cryptographic Hash Function: SHA256

- **Step3** Com

$W(i) = W^{i-16} + \sigma^0 + W^{i-7} + \sigma^1$

where:

σ^0 = $(W^{i-15}\ ROTR^7(x))$ XOR $(W^{i-15}\ ROTR^{18}(x))$ XOR $(W^{i-15}\ SHR^3(x))$

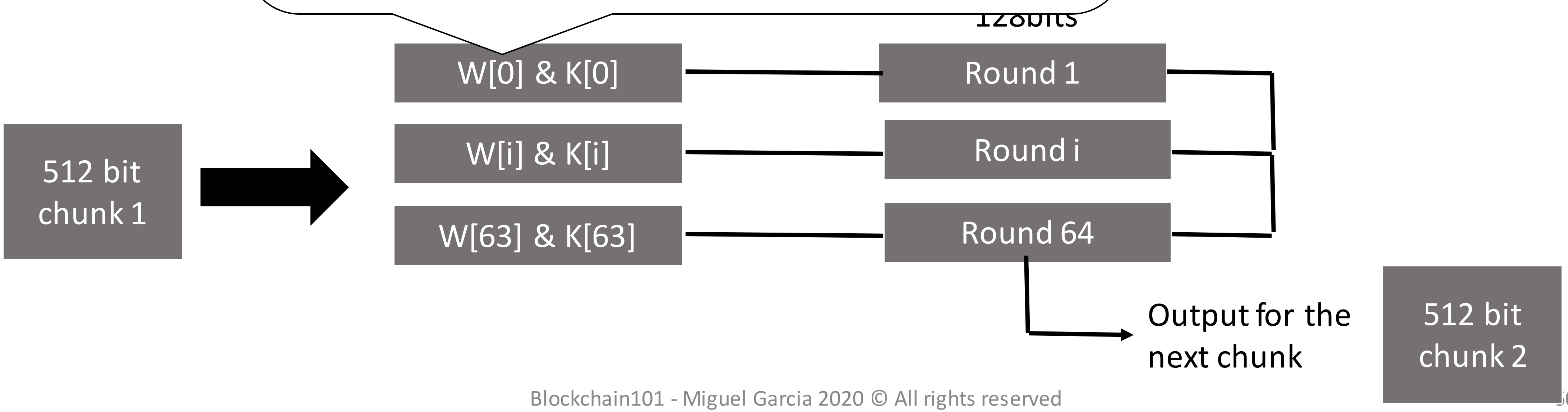
σ^1 = $(W^{i-2}\ ROTR^{17}(x))$ XOR $(W^{i-2}\ ROTR^{19}(x))$ XOR $(W^{i-2}\ SHR^{10}(x))$

$ROTR^n(x)$ = Circular right rotation of 'x' by 'n' bits

$SHR^n(x)$ = Circular right shift of 'x' by 'n' bits

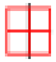
T … nks of 512 bits.

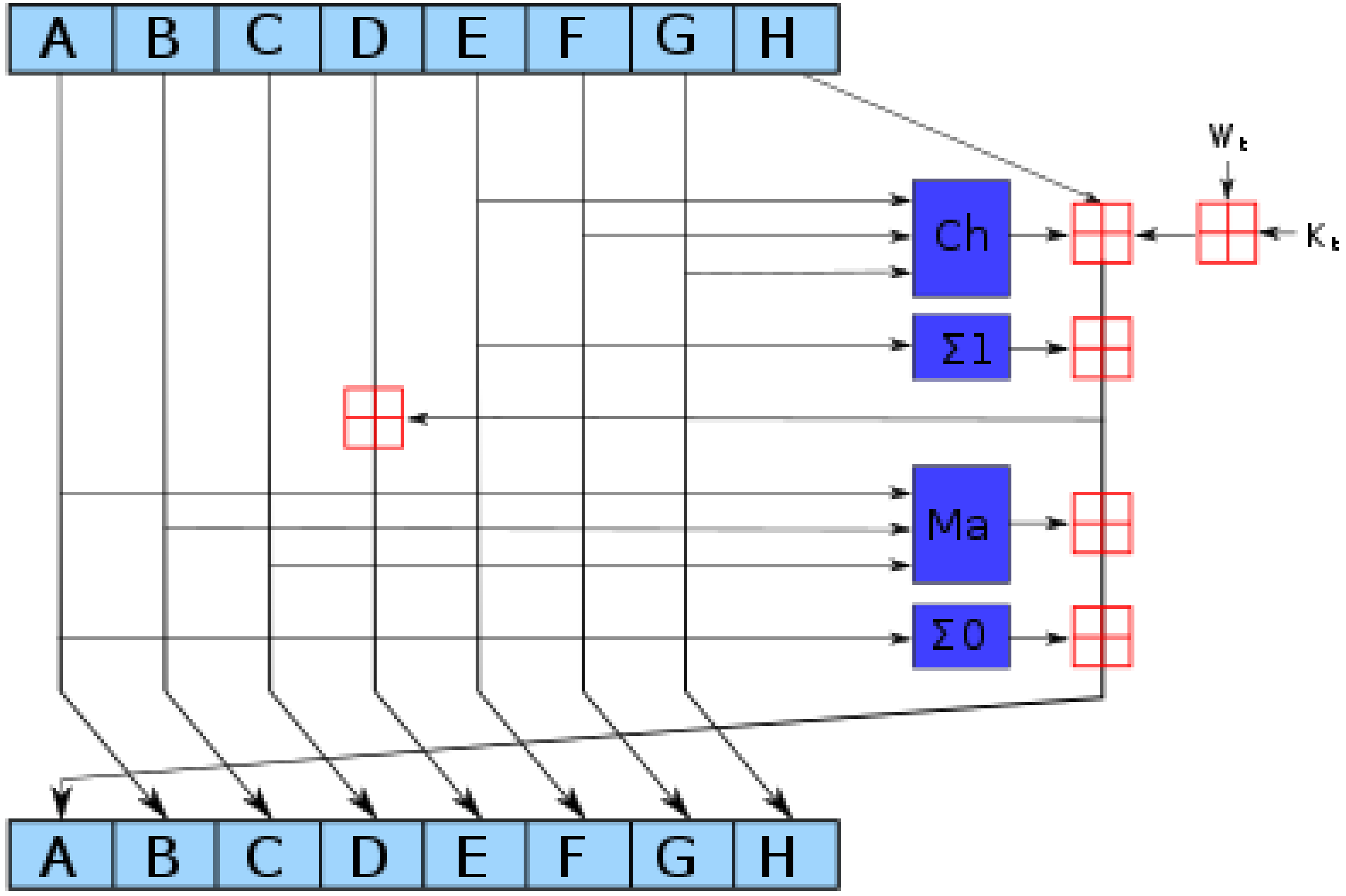
… of operations.



Cryptographic Hash Function: SHA256

- **Step3** Compression function

Ch(E, F, G) = (E AND F) XOR ((NOT E) AND G)
Ma(A, B, C) = (A AND B) XOR (A AND C) XOR (B AND C)
∑(A) = (A >>> 2) XOR (A >>> 13) XOR (A >>> 22)
∑(E) = (E >>> 6) XOR (E >>> 11) XOR (E >>> 25)
 = addition modulo 2

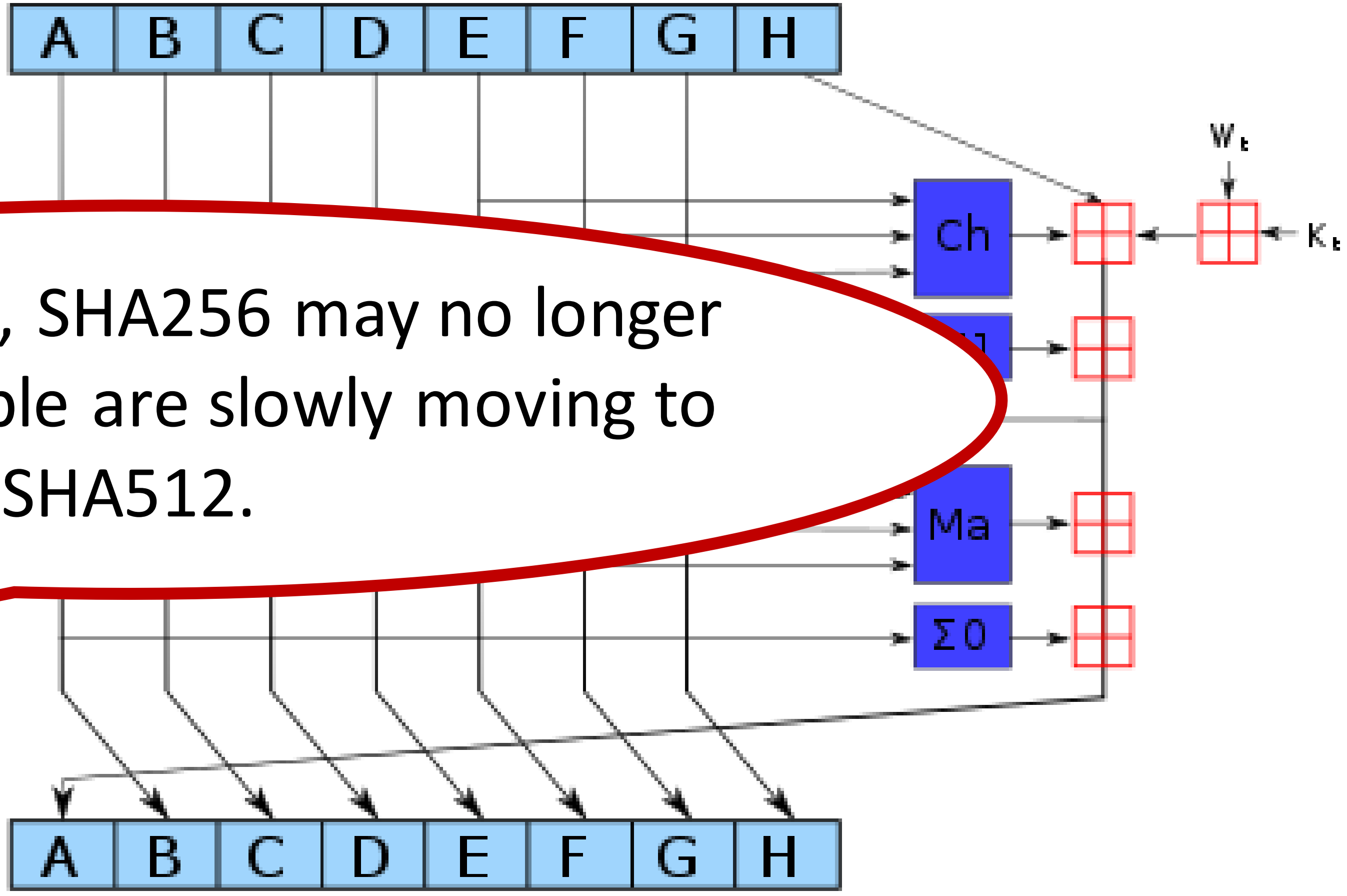


Cryptographic Hash Function: SHA256

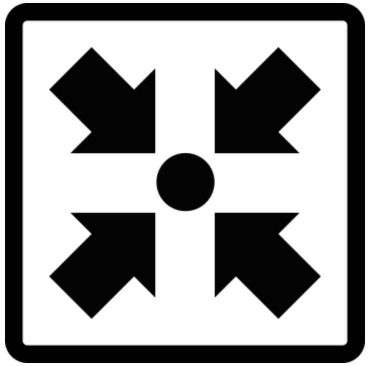
- **Step3** Compression function

Ch(E, F, G) = (E AN
Ma(A, B, C) = (A
∑(A) = (A >>
∑(E) = (E >>> 6) X
⊞ = addition modulo 2

In a near future, SHA256 may no longer be secure. People are slowly moving to SHA512.



Meeting point slide



- Cryptographic hash functions are one-way functions
  - This means it (should be) is impossible to find the input based on the output
- They are also deterministic
  - This means that for the same input the output is always the same
- The hash function output has a fixed size output, the input can have any size
- It guarantees integrity, it can be used – with caution – to encrypt data

Coding time

- Python overview
  - Basic structures
- Signature example: RSA
- Hash function example: SHA256

