Network SECURITY

50.005 CSE

Natalie Agus
Information Systems Technology and Design
SUTD

IMPORTANT SECURITY PROPERTIES

Confidentiality

No one else, except sender and receiver should understand the messages exchanged (encryption)

Authentication

Sender and receiver should confirm the identity of one another

Message Integrity

Sender and receiver want messages exchanged to be unaltered in transit. Altered messages should be detected.

Availability

Communication link between sender and receiver should be available

Access

Communication link between sender and receiver should be accessible

POSSIBLE SECURITY ATTACKS

- **Eavesdrop** — Intercept messages
- **Alter messages** — Actively insert messages into connection
- **Impersonate** — Fake (**spoof**) source address in packet or any part of the packet
- **Denial of Service** — Prevent service from being used by others
- **Hijack** — Take over ongoing connection by removing sender or receiver unknowingly to either party

CRYPTOGRAPHY

Protects **confidentiality,** hence **preventing** attackers from **eavesdropping**

HOW?

```
plaintext:   abcdefghijklmnopqrstuvwxyz
ciphertext:  mnbvcxzasdfghjklpoiuytrewq
```

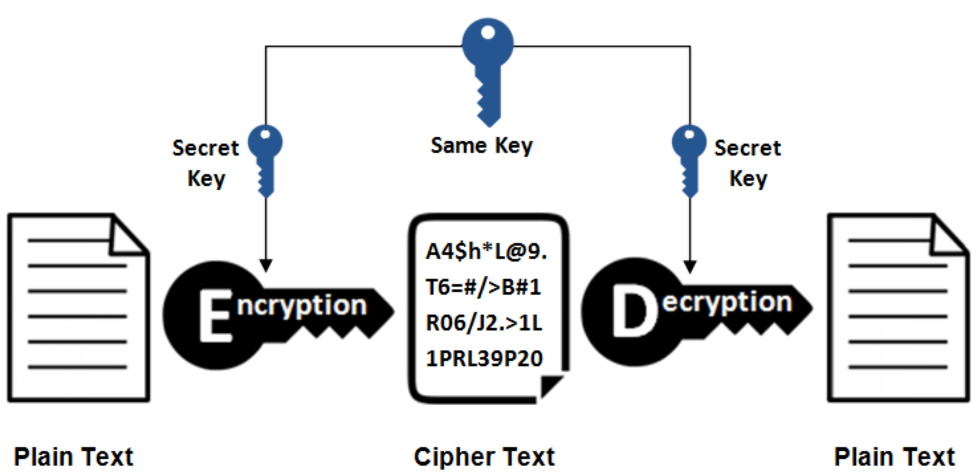
Naive attempt: Substitution Cipher

Mapping from a set of 26 letters to another set of 26 letters

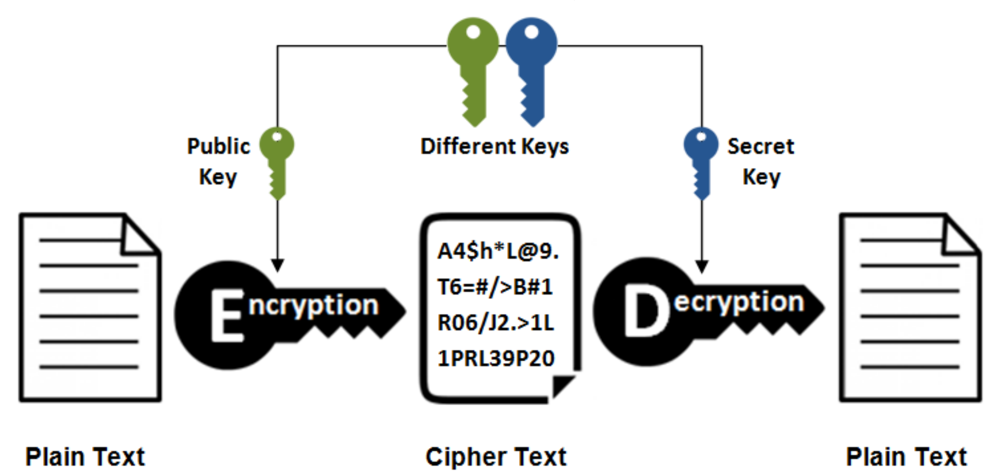
Disadvantage: the frequencies of the letters are not masked at all

CRYPTOGRAPHY

Protects **confidentiality,** hence
preventing attackers from **eavesdropping**
There's two good methods to encrypt and decrypt plaintext



Symmetric Key



Asymmetric Key

SYMMETRIC KEY CRYPTO

encryption and decryption both uses the **same** key

Data Encryption Standard (DES):

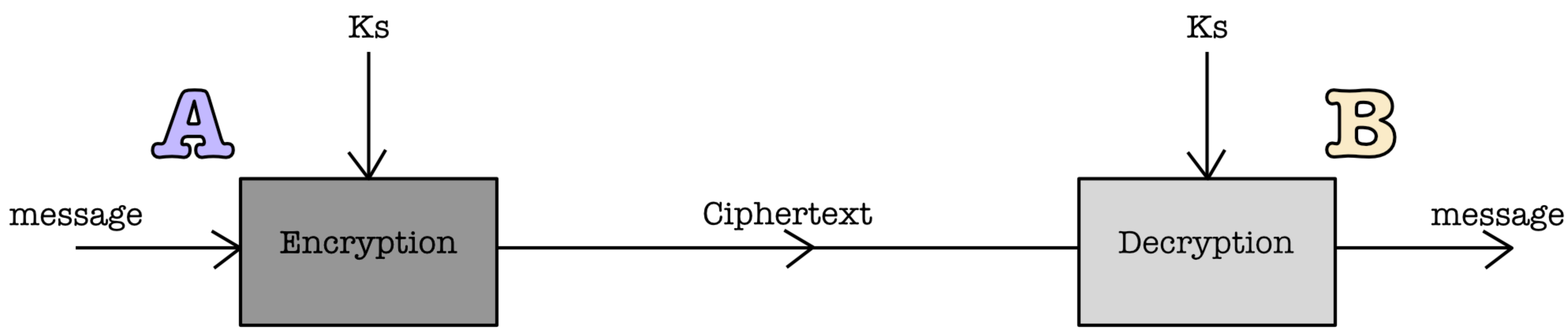
- An algorithm to perform symmetric key cryptography
- 56-bit symmetric key
- 64-bit plaintext input (padding may be needed)
- 16 rounds of encryption to produce 64-bit encrypted output
- It was US encryption standard in 1993
- Can be decrypted using brute force in less than a day
- 3-DES to make it *more secure*

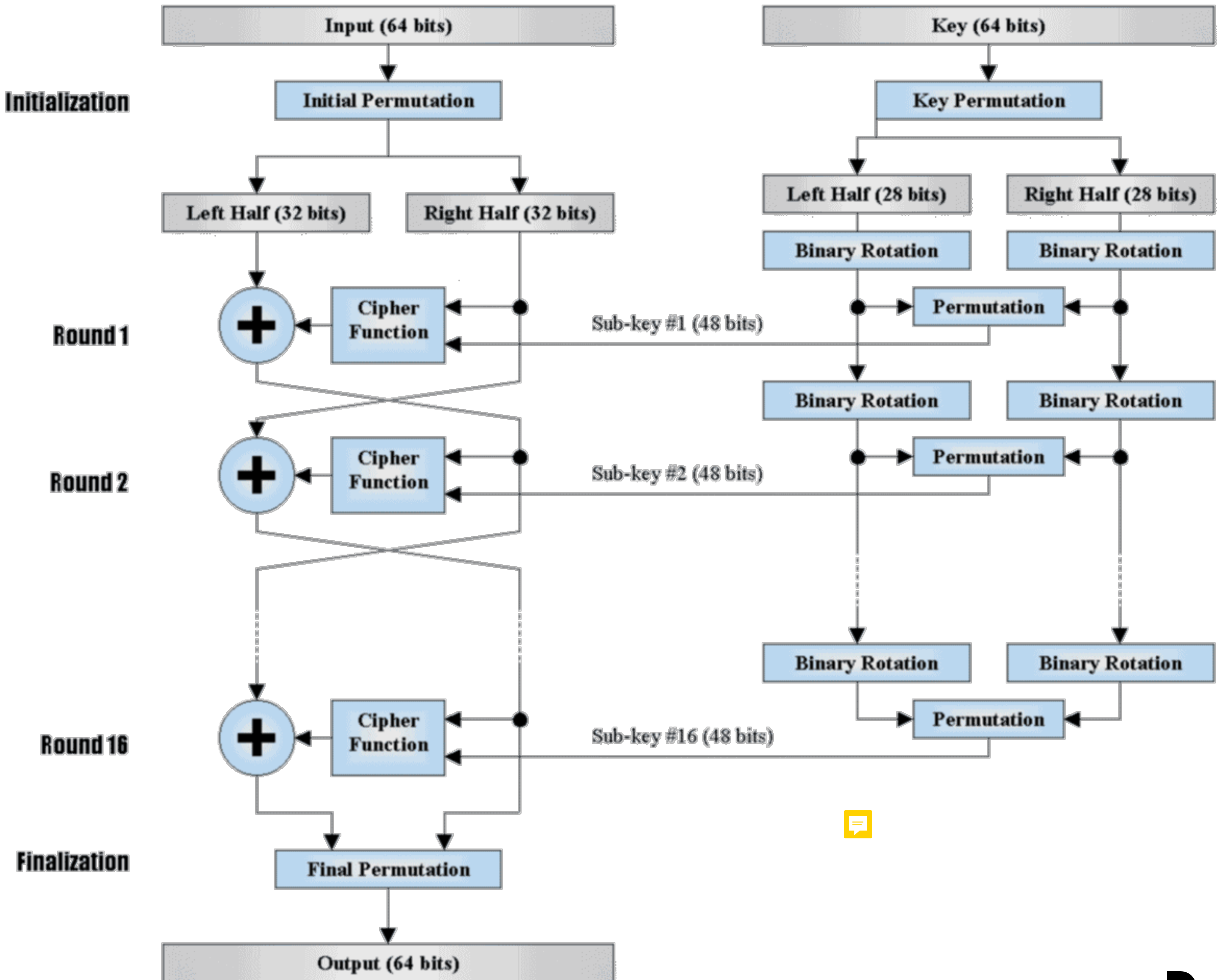
Advanced Encryption Standard (AES):

- A better algorithm to perform symmetric key cryptography
- 128, 192, or 256-bit symmetric key
- 128-bit plaintext input (padding may be needed)
- 10,12,14 rounds of encryption to produce 128-bit encrypted output
- Replaced DES in 2001,
- If 128-bit key is used, brute force decryption will take 1 billion *billion* years (yes, double billions right there), with a supercomputer

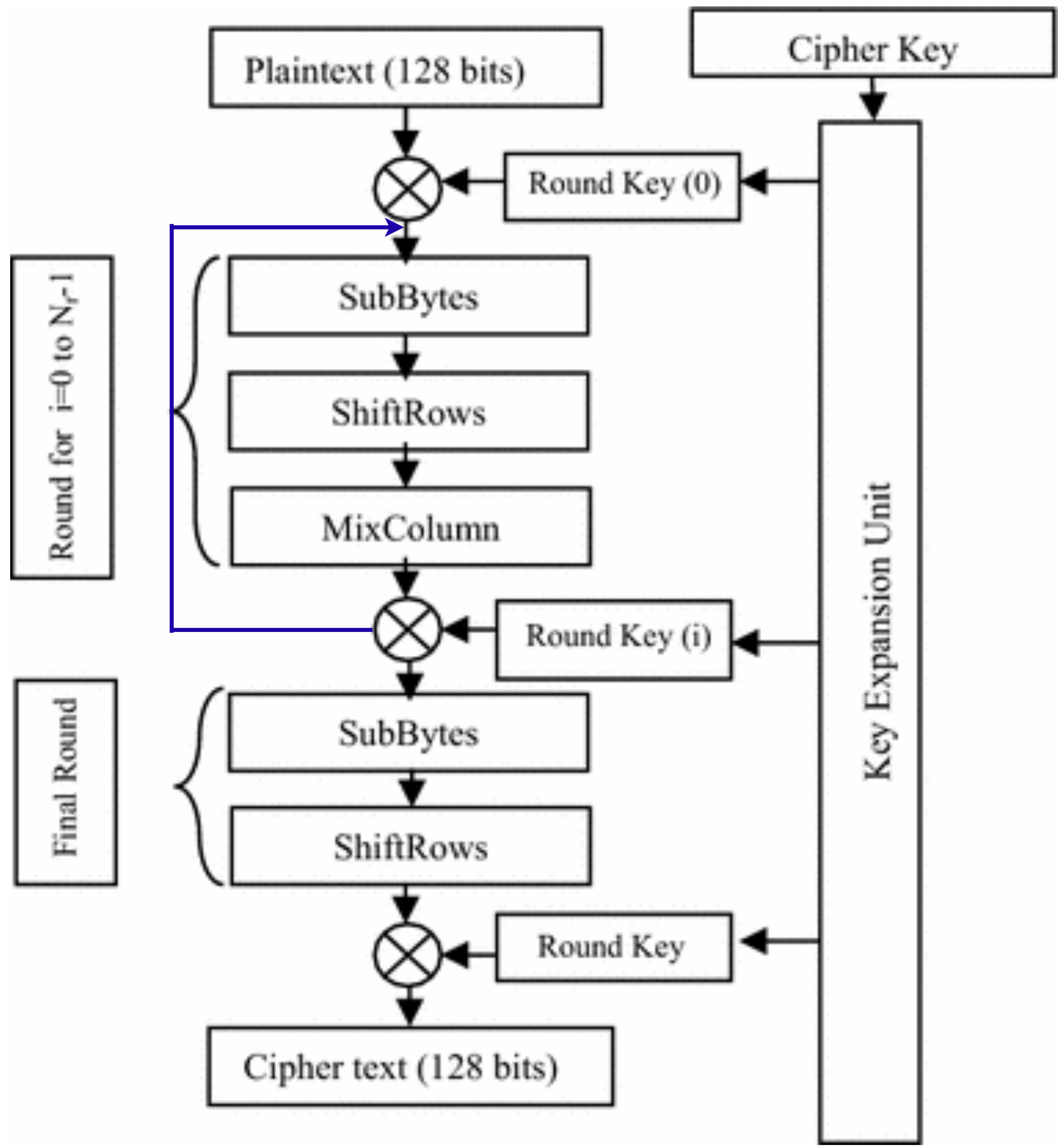
SYMMETRIC KEY CRYPTO

encryption and decryption both uses the **same** key




Input (64 bits)
Key (64 bits)
Initialization
Initial Permutation
Key Permutation
Left Half (32 bits)
Right Half (32 bits)
Left Half (28 bits)
Right Half (28 bits)
Binary Rotation
Binary Rotation
Round 1
Cipher Function
Permutation
Sub-key #1 (48 bits)
Binary Rotation
Binary Rotation
Round 2
Cipher Function
Permutation
Sub-key #2 (48 bits)
Binary Rotation
Binary Rotation
Round 16
Cipher Function
Permutation
Sub-key #16 (48 bits)
Finalization
Final Permutation
Output (64 bits)

D E S


Plaintext (128 bits)
Cipher Key
Round Key (0)
Round for i=0 to N_r-1
SubBytes
ShiftRows
MixColumn
Round Key (i)
Final Round
SubBytes
ShiftRows
Round Key
Cipher text (128 bits)
Key Expansion Unit

AES

PUBLIC KEY CRYPTO

a.k.a **asymmetric** key cryptography

Rivest–Shamir–Adleman (RSA) algorithm (1977):

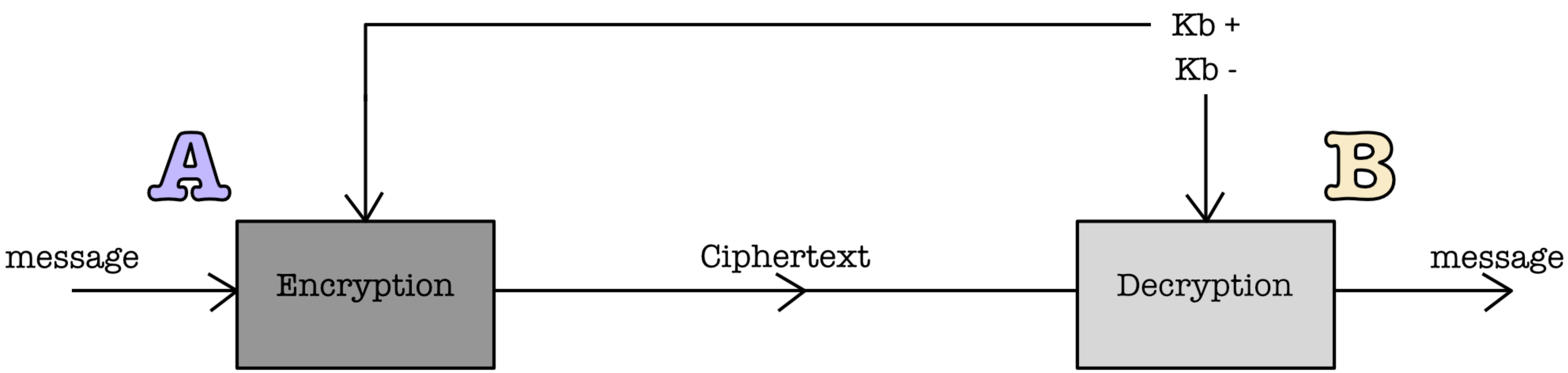
- Sender, receiver, do **not** share secret key
- **Public** encryption key **known to all**
- **Private** decryption key known only to receiver
- 1024 - 4096-bit asymmetric (public-private) key pair
- 1 round of encryption
- Input/output size: depends on key size

Two **important** requirements:

- Given **public** key, it is **impossible** to compute the private key
- Need a public-private key pair such that,
    - public(m) = encrypted message   –––––– **encryption**
    - private(encrypted message) = m   –––––– **decryption**

PUBLIC KEY CRYPTO

a.k.a **asymmetric** key cryptography



RSA MATH

Before that, some quick **modular arithmetic**

$$[(a \mod n) \pm (b \mod n)] \mod n = (a \pm b) \mod n$$

$$[(a \mod n) * (b \mod n)] \mod n = (a * b) \mod n$$

$$[(a \mod n)^d] \mod n = a^d \mod n$$

RSA MATH

...and some quick message-to-number translation:

- Computer translates between bit patterns to the character you can see on screen, e.g using **UTF-8 encoding**

- You can represent a message by a
- integer number (simple binary to dec translation)

- Thus **encrypting a message is equivalent to encrypting a number**

Dec	Symbol	Binary	Dec	Symbol	Binary
65	A	0100 0001	83	S	0101 0011
66	B	0100 0010	84	T	0101 0100
67	C	0100 0011	85	U	0101 0101
68	D	0100 0100	86	V	0101 0110
69	E	0100 0101	87	W	0101 0111
70	F	0100 0110	88	X	0101 1000
71	G	0100 0111	89	Y	0101 1001
72	H	0100 1000	90	Z	0101 1010
73	I	0100 1001	91	[	0101 1011
74	J	0100 1010	92	\	0101 1100
75	K	0100 1011	93	]	0101 1101
76	L	0100 1100	94	^	0101 1110
77	M	0100 1101	95	_	0101 1111
78	N	0100 1110	96	`	0110 0000
79	O	0100 1111	97	a	0110 0001
80	P	0101 0000	98	b	0110 0010
81	Q	0101 0001	99	c	0110 0011
82	R	0101 0010	100	d	0110 0100

RSA MATH

The RSA algorithm

1. Choose 2 large **prime** number : p & q (1024 bits each)
2. Compute:

$$n = pq,\ z = (p-1)(q-1)$$

relatively prime: dont share common divisor except 1
eg 9 and 16
but 11 and 22 are not

3. Choose e, where e<n, and e,z are relatively prime to one another
4. Choose d, where (ed-1) mod z = 0
5. **Public key, is (n,e):**

$$c = m^e \mod n$$

m = message (unencrypted), where **m must be < n**

c = encrypted message

6. **Private key, is (n,d):**

$$m = c^d \mod n$$

7. An important property:

$$if\ k = m^d \mod n,$$

$$k^e \mod n = m = c^d \mod n$$

$$\boxed{x^y \mod n = x^{(y \mod z)} \mod n \text{ for any } x, y}$$

RSA MATH

The RSA algorithm: example

(note this is an example, so we choose small numbers for ease of calculation.

1. Choose ~~2 la~~rge **prime** number : p=5 & q=7
2. Compute:

$$n = 5 * 7 = 35, z = (5 - 1)(7 - 1) = 24$$

3. Choose e = 5, where e<n, and e,z are relatively prime to one another
4. Choose d = 29, where (ed-1) mod z = 0
5. **Public key, is (n,e):**

$$c = 12^5 \mod 35 = 17$$

m = 00001100 (this is 12)
c = 00010001 (this is 17)

6. **Private key, is (n,d):**

$$m = 17^{29} \mod 35 = 12$$

7. An important property:

$$if\ k = m^d \mod n,$$

$$k^e \mod n = m = c^d \mod n$$

$$x^y \mod n = x^{(y \mod z)} \mod n \text{ for any } x, y$$

•

RSA MATH

The RSA algorithm: proof

$$c = m^e \mod n$$

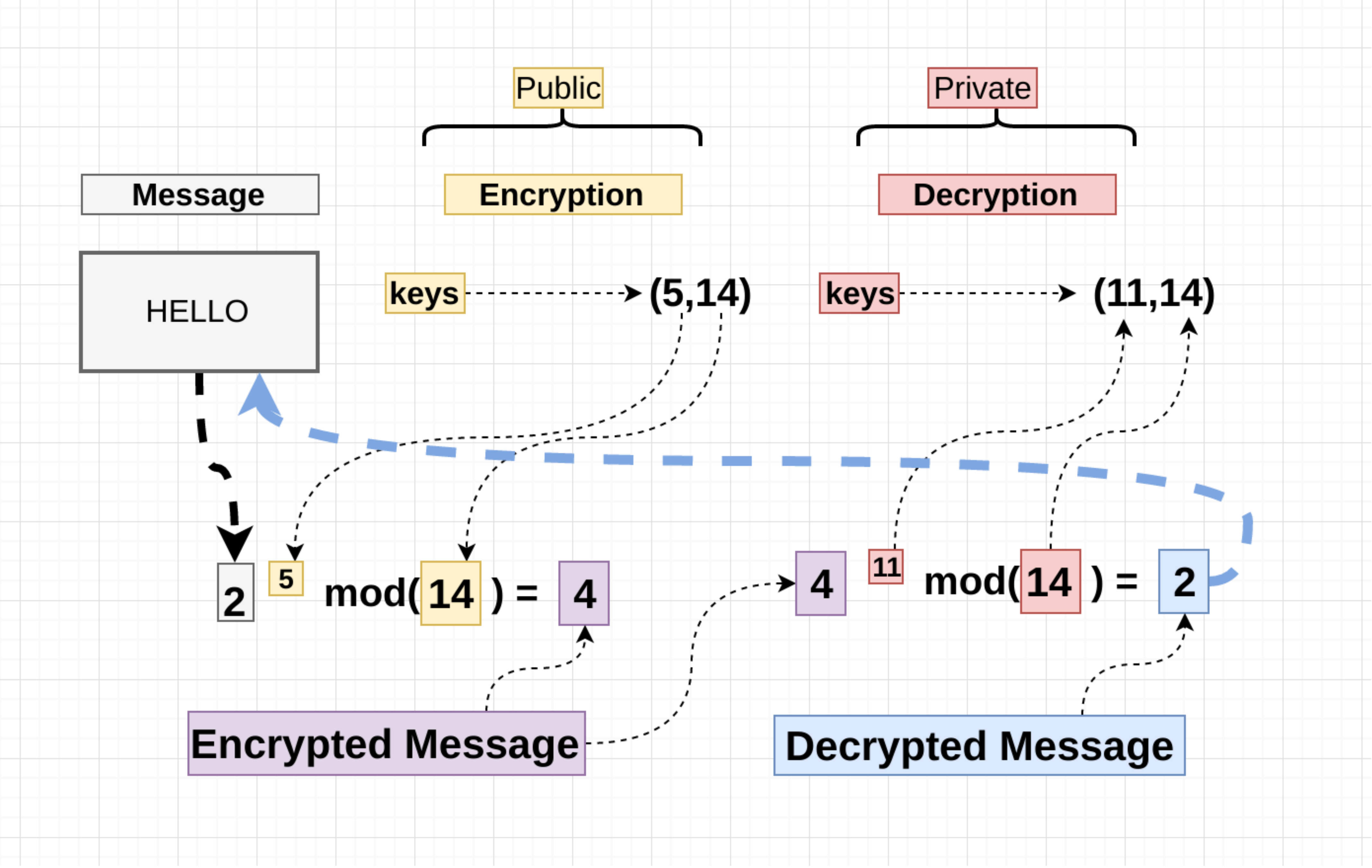
$$\begin{aligned} c^d \mod n &= (m^e \mod n)^d \mod n \\ &= m^{ed} \mod n \\ &= m^{(ed \mod z)} \mod n \\ &= m^1 \mod n \end{aligned}$$

–––––– Since m < n

$$\boxed{x^y \mod n = x^{(y \mod z)} \mod n \text{ for any } x, y}$$

RSA MATH

The RSA algorithm: another example



HOW SECURE IS RSA?

Very, very **secure** (1024 bit key above),
unless someone comes up with scalable quantum computers.

- Public key (n, e) is known to everybody. Private key (n, d) is only known to receiver
- **Essentially, need to guess the value of d**
- e is known and d is related to e : (ed-1) mod **z** = 0
- To find z, one has to know **p** and **q**
- p and q is related to n : n = p*q
- Hence, one has to be able to **perform prime factorization** of n to know p and q
- If n is sufficiently large, e.g: 1024 bits, it is hard to find the correct prime factors of n (exponential complexity).
- **To crack a simple 128-bit key, a supercomputer requires ~10^(39) seconds.** The universe is younger than that.

- The prime factorization problem falls under **NP**
- Note: with *possible scalable quantum computing*, Shor's algorithm can solve prime factorisation in polynomial time.

HOW *PRACTICAL* IS RSA?

Exponentiation in RSA is **computationally exhaustive.**
DES is 100x faster than RSA

- **USE <u>SESSION KEY</u>:**
    1. Use public-key cryptography to establish a secure connection, meaning that we know for sure who the host at the end of the network line is
    2. Generate **symmetric session key** and exchange between sender and receiver
    3. **Use this symmetric session key** (instead of the public key) for lots of subsequent communications throughout the session

APPLICATION OF CRYPTOGRAPHY

What kind of security properties can it give? And how does it defend against the attacks?

PROVIDES

- Authentication
- Availability
- Confidentiality
- Access
- Message Integrity

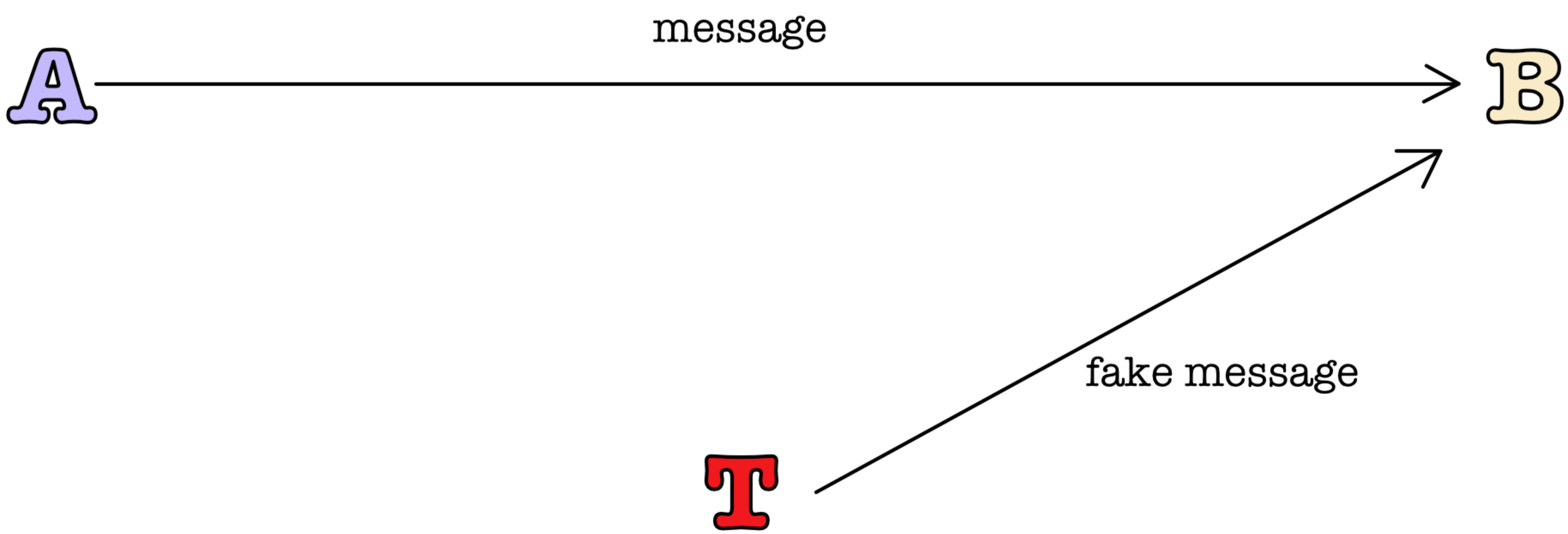
PREVENT

- Eavesdrop
- Alter messages
- Impersonate
- Denial of Service
- Hijack

1. PROVIDING AUTHENTICATION

Need: **prevent impersonation**

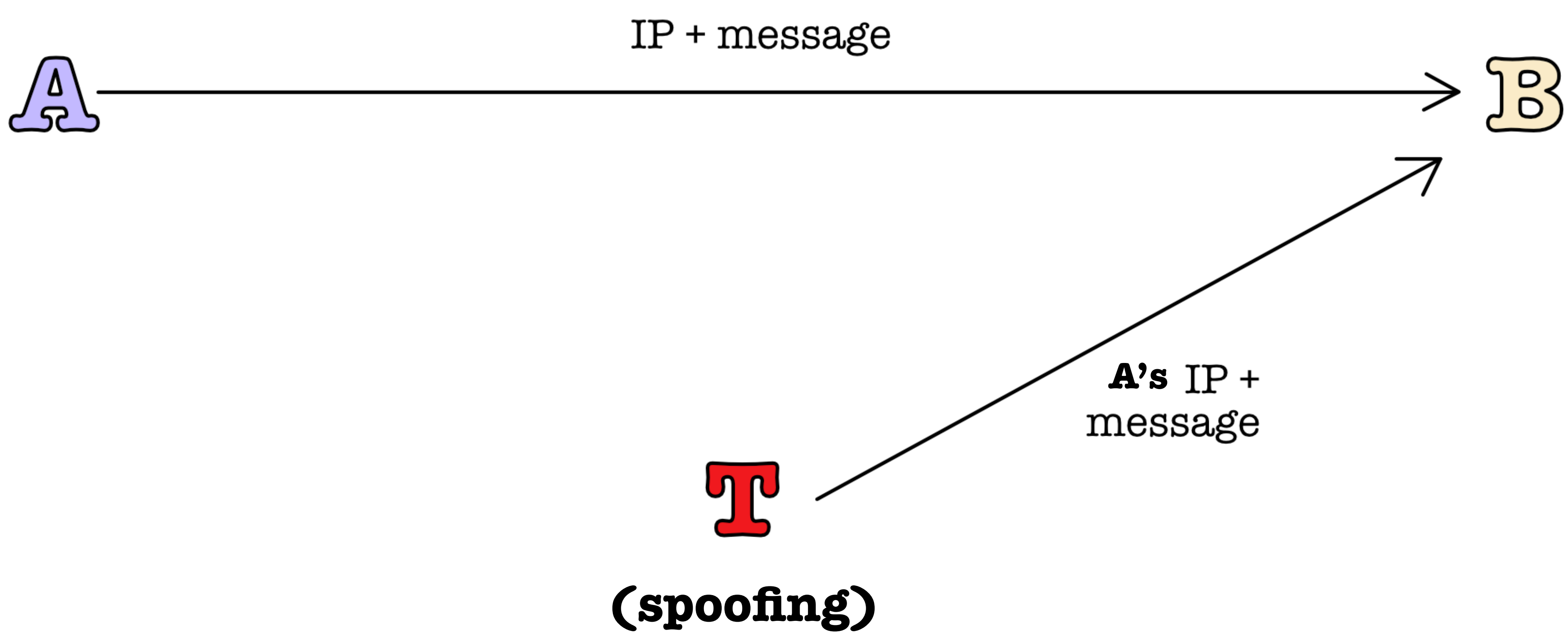
Lets consider this case without encryption first:



Without any encryption, B doesn't know who is the "real" A

1. PROVIDING AUTHENTICATION

Need: **prevent impersonation and spoofing**
Lets consider this case without encryption first:



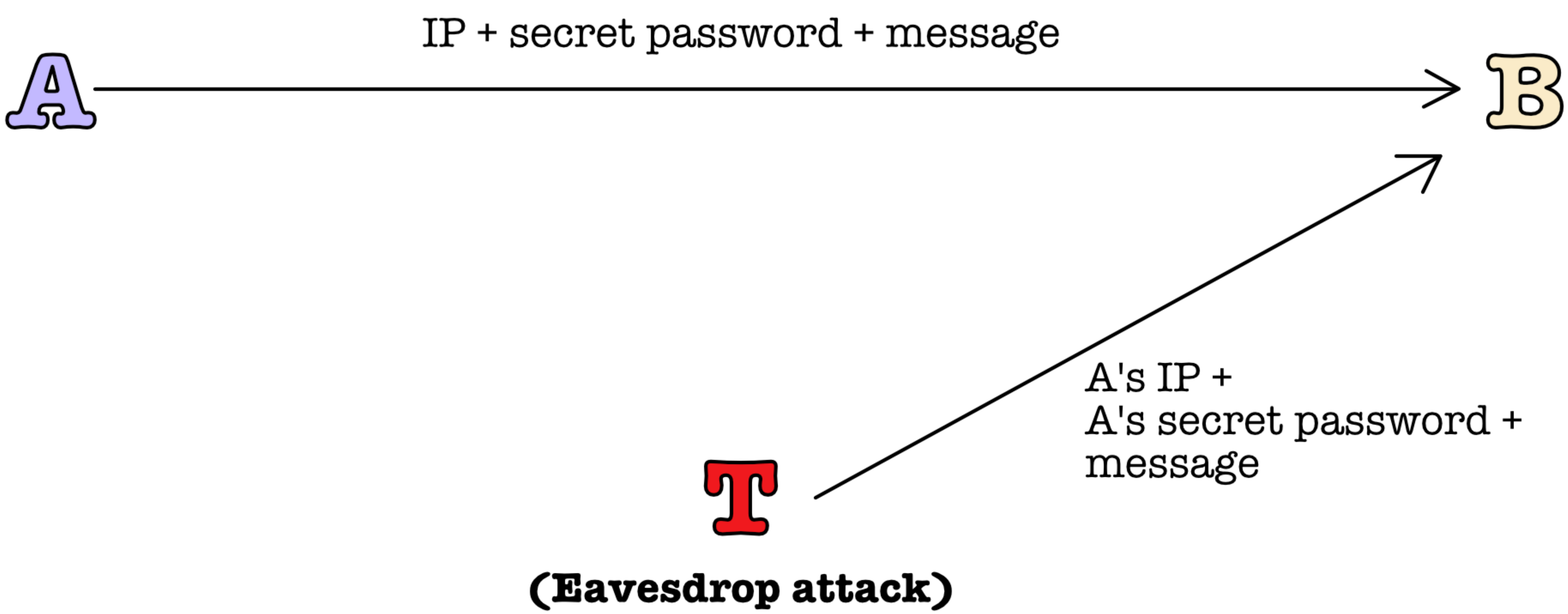
Without any encryption, B doesn't know who is the "real" A, even with IP address (IP is always changing depending on your network)

•

1. PROVIDING AUTHENTICATION

Need: **prevent impersonation, spoofing, and eavesdropping**

Lets consider this case without encryption first:

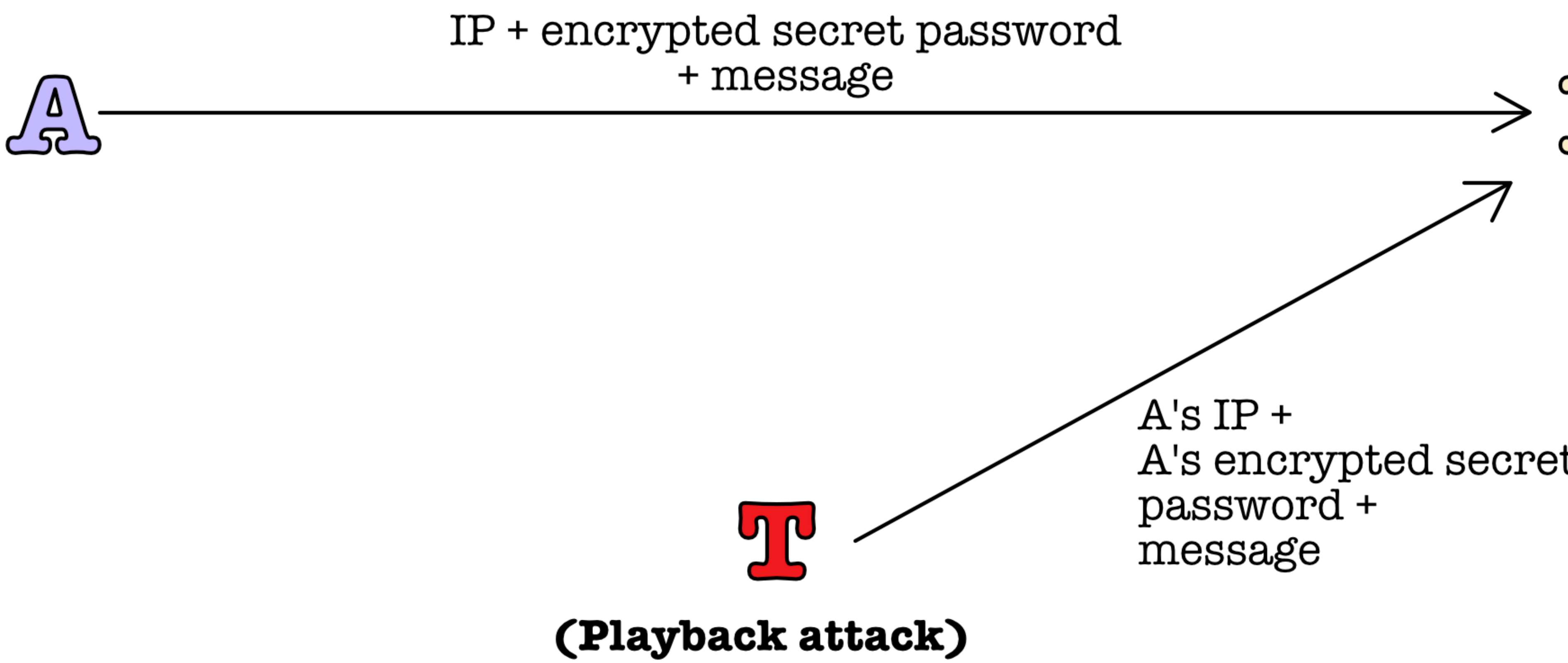


Without any encryption, B doesn't know who is the "real" A, even with IP address (IP is always changing depending on your network), and **nothing is secret in the internet**

1. PROVIDING AUTHENTICATION

Need: **prevent impersonation, spoofing, eavesdropping, and playback**

Some encryption is used here, but not enough

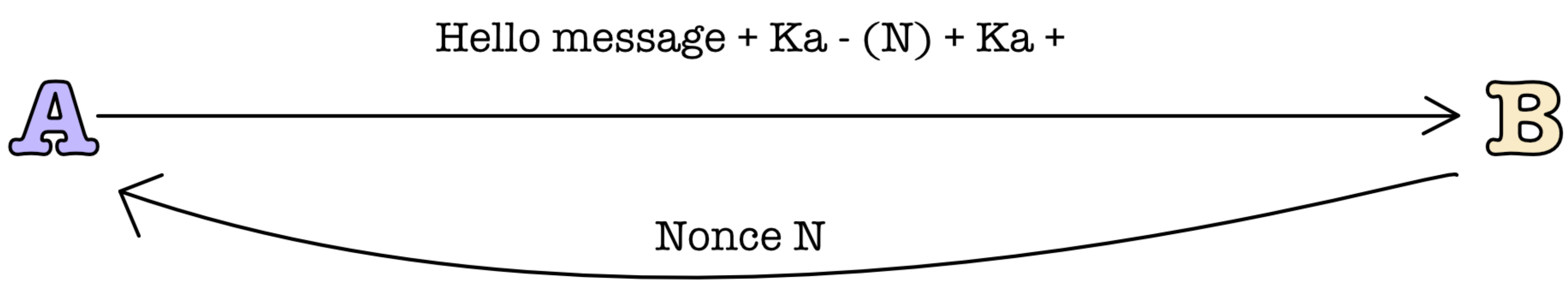


T can still just record and playback the "encrypted secret password". B cannot tell if its really A or T who is sending this.

1. PROVIDING AUTHENTICATION

Need: **prevent impersonation, spoofing, eavesdropping, and playback**

Attempt 1: Lets use encryption and nonce



Encrypting message with private key is called **digital signature**

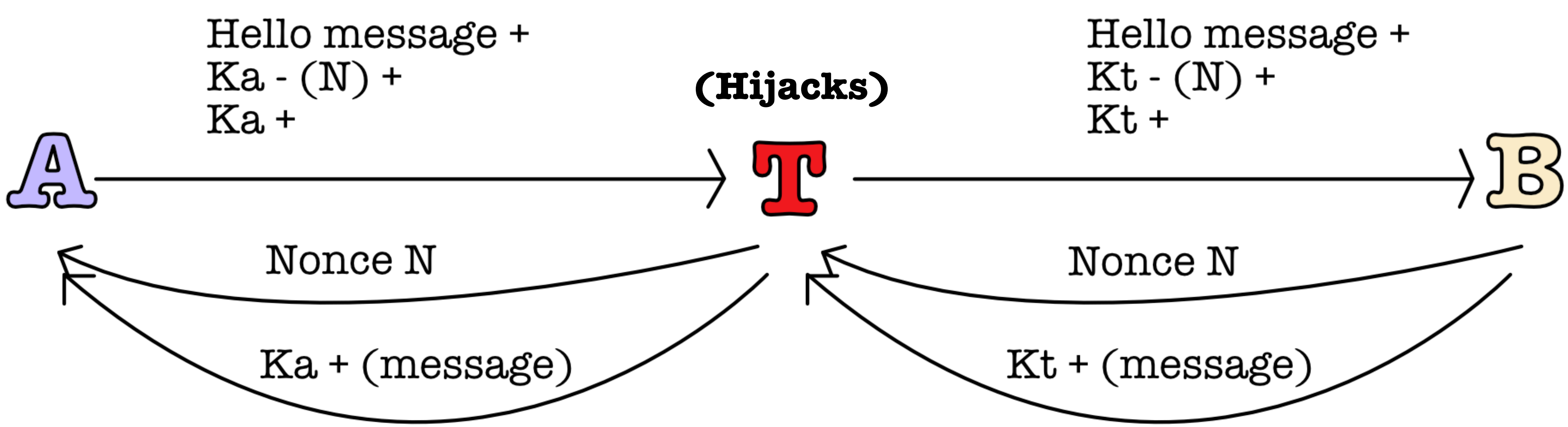
•

1. PROVIDING AUTHENTICATION

Need: **prevent impersonation, spoofing, eavesdropping, playback, and man in the middle attack**

Attempt 1: Lets use encryption and nonce

Failed by man-in-the-middle attack

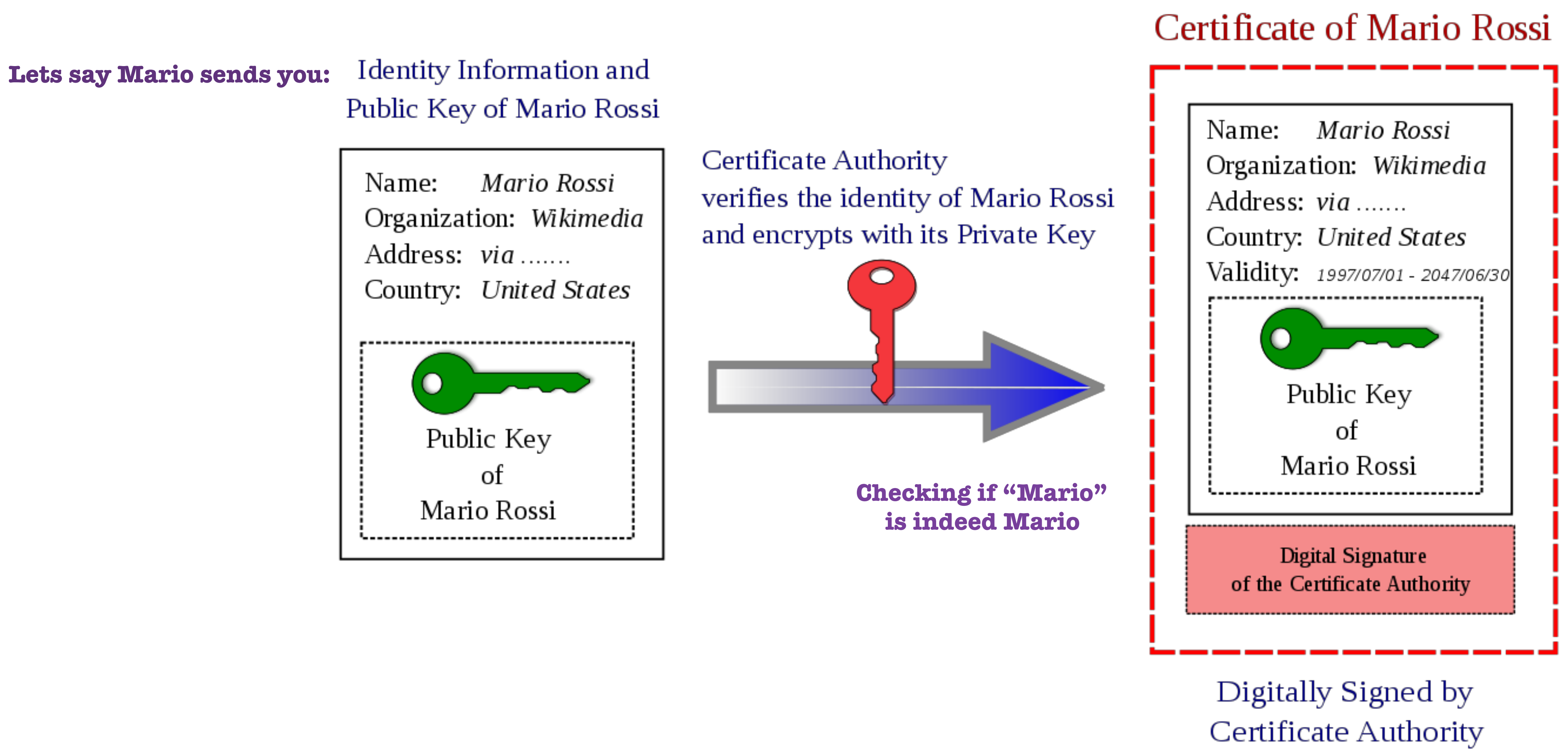


1. PROVIDING AUTHENTICATION

Need: **prevent impersonation, spoofing, eavesdropping, playback, and man in the middle attack**

Attempt 1: Lets use encryption and nonce
Result: Failed by man-in-the-middle attack

The loophole: B doesn't know whether A's public key he received indeed belongs to A
Solution: You need an **external party (called Certificate Authority: CA)** to verify that A's public key indeed **belongs to A**



1. PROVIDING AUTHENTICATION

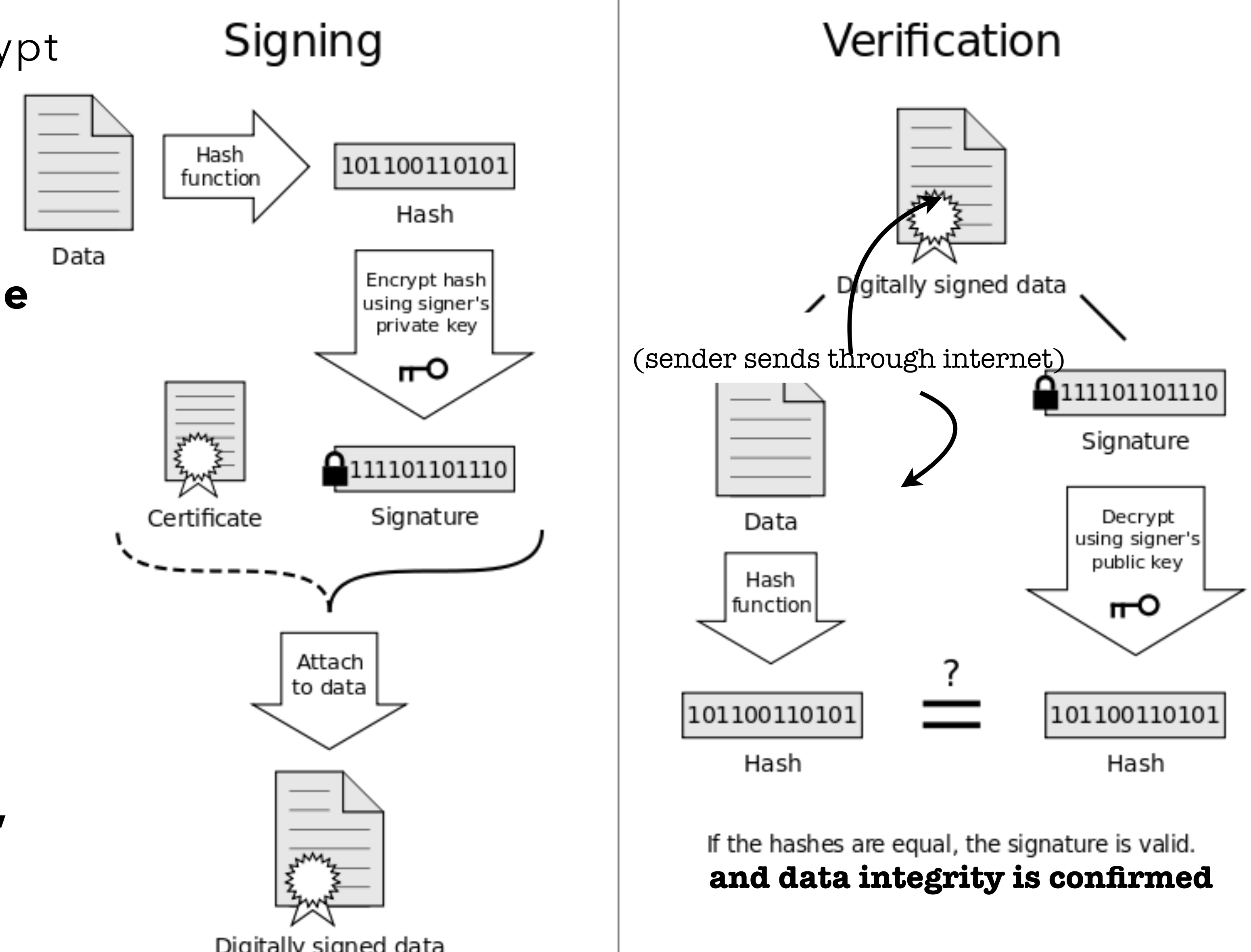
Practical usage using **message digest**

It is expensive to encrypt long messages using private key (RSA)

Solution: use message digest

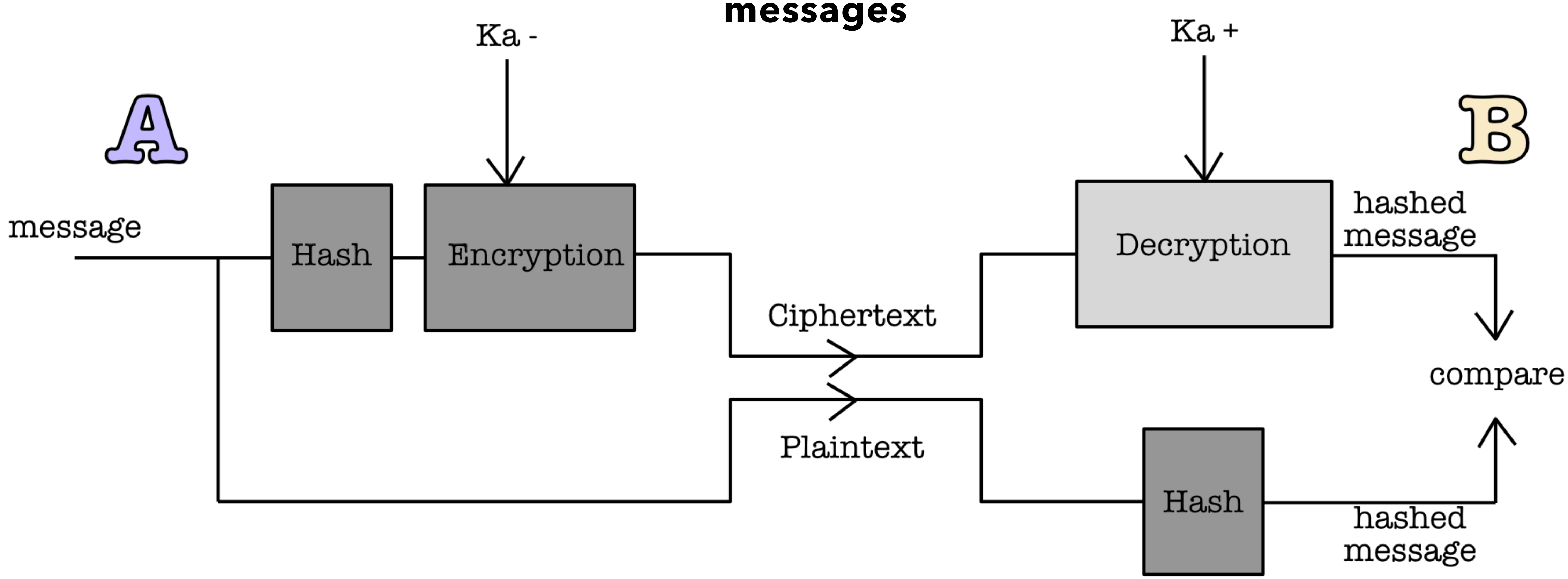
Message digest: Hash long (arbitrary sized) messages to produce a **fixed size *message digest***

Hash functions: MD5, SHA1



2. PROVIDING AUTHENTICATION AND MESSAGE INTEGRITY

Prevent impersonation, spoofing, eavesdropping, playback, and altering of messages



3. PROVIDING AUTHENTICATION, MESSAGE INTEGRITY, AND CONFIDENTIALITY

Eg: **secure e-mail, ssh, https**

Prevents prevent impersonation, spoofing, eavesdropping, playback and man-in-the-middle (hijacking)