Crypto 0x01 - 在家輕鬆學 AES

by oalieno

目錄

Introduction to AES

AES 是什麼

- Advanced Encryption Standard (AES)，2001 年選出的加密標準
- 對稱式密碼 (Symmetric Cipher)
  - 加密解密使用相同金鑰
- 區塊密碼 (Block Cipher)
  - 輸入輸出長度固定

對稱式密碼 vs 非對稱式密碼

加密密鑰 e = 解密密鑰 d → **對稱式密碼**

e 跟 d 不一定要相同
只要我們能輕易的由 e 推算出 d

AES

加密密鑰 e ≠ 解密密鑰 d → **非對稱式密碼**

我們無法輕易的由 e 推算出 d

RSA

Block Cipher

16 bytes 明文

密鑰  **加密**

16 bytes 密文

- **輸入輸出長度固定**
- 以 AES 為例
- 輸入明文 16 bytes
- 輸出密文 16 bytes
- 密鑰長度有 16, 24, 32 bytes 三種

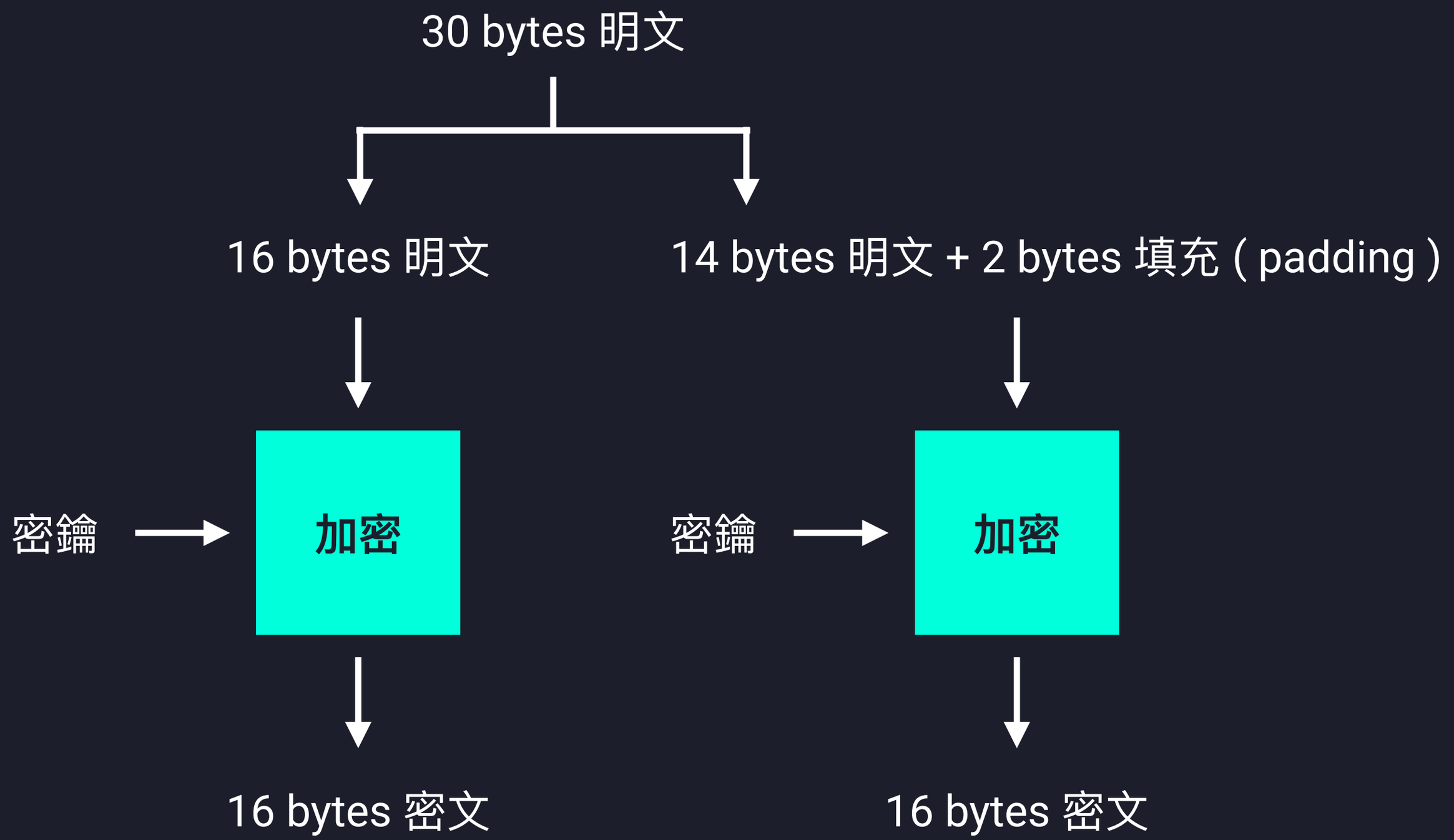
最常見

Block Cipher

我要加密的明文不是 16 bytes 怎麼辦？

切成很多個 16 bytes

Block Cipher



Get Your Hands Dirty

Get Your Hands Dirty - python

https://pycryptodome.readthedocs.io/en/latest/

使用 pycryptodome 套件

```python
#!/usr/bin/env python3
from Crypto.Cipher import AES

key = 'A' * 16
aes = AES.new(key, AES.MODE_ECB)

# AES 加密 ( ECB MODE )
print(aes.encrypt('C' * 16)) # b'\xbf\x1ej>.\xc2\xdb_\x9a1&\x17\xee\xfc\x95S'

# AES 解密 ( ECB MODE )
print(aes.decrypt(b'\xbf\x1ej>.\xc2\xdb_\x9a1&\x17\xee\xfc\x95S')) # b'CCCCCCCCCCCCCCCC'
```

Block Cipher Mode

Block Cipher Mode

- AES 是 Block Cipher，輸入輸出長度固定
- 所以要加密**任意長度**的明文，需要一些額外加工
- 一些常見的加工模式：ECB, CBC, CFB, OFB, CTR...
- 有 AEAD 的模式：CCM, GCM, OCB...

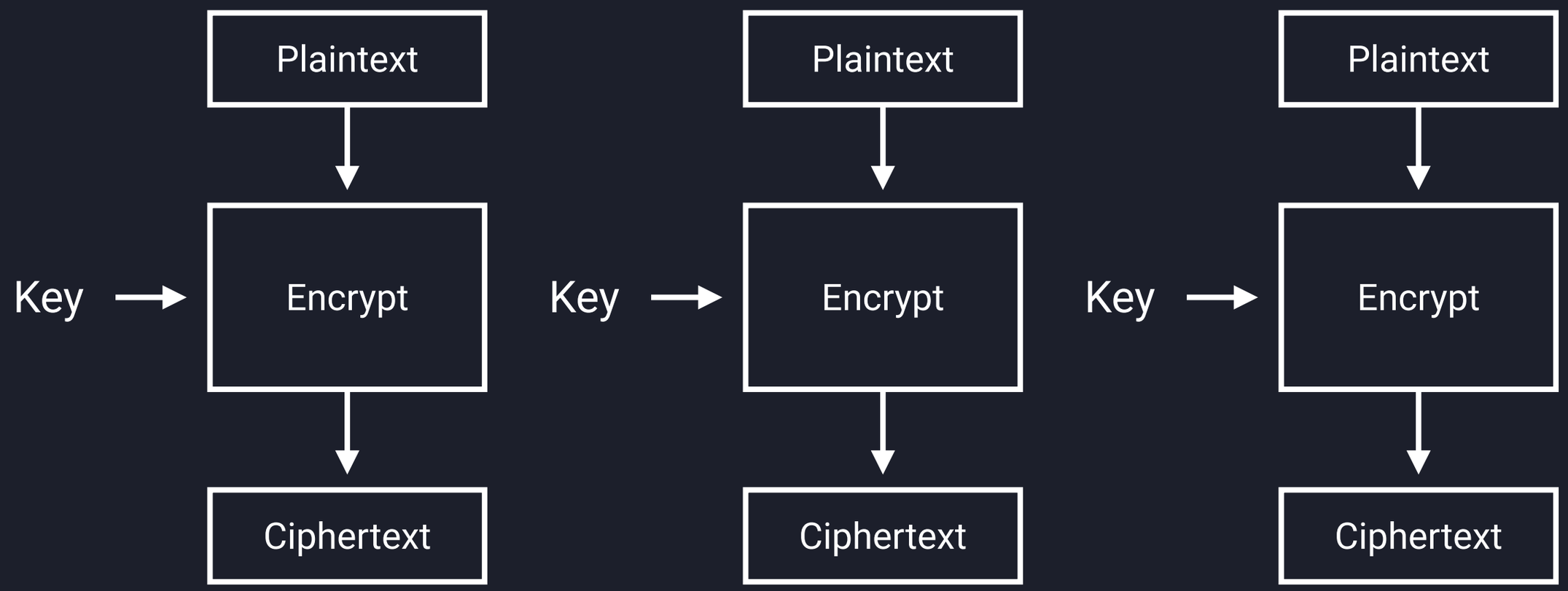
Authenticated **E**ncryption with **A**ssociated **D**ata

Authenticated Encryption with Associated Data

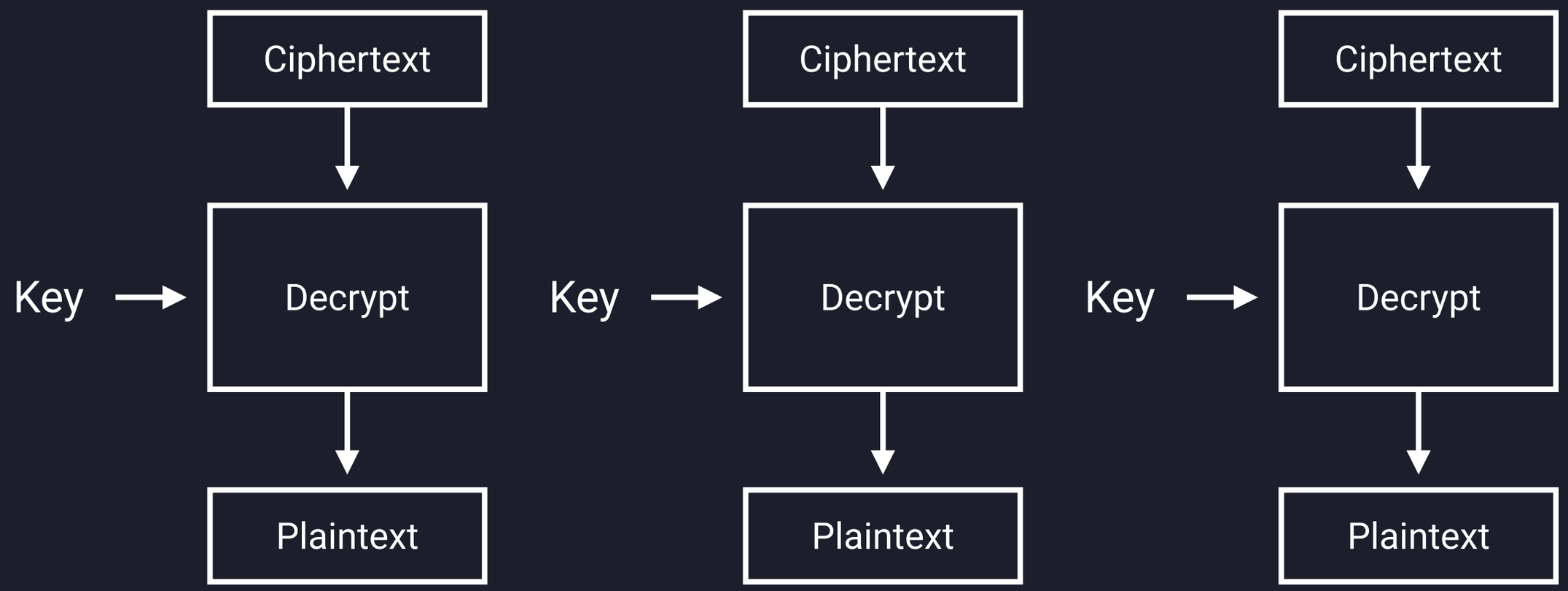
- Authenticated Encryption (AE)
  - 會多計算一個 MAC (Message Authentication Code)
- Associated Data (AD)
  - 可以連同一些沒加密的資料一起做 Authentication
  - 比如一些不需要加密的 Header Information

ECB Mode

ECB Mode Encryption



ECB Mode Decryption

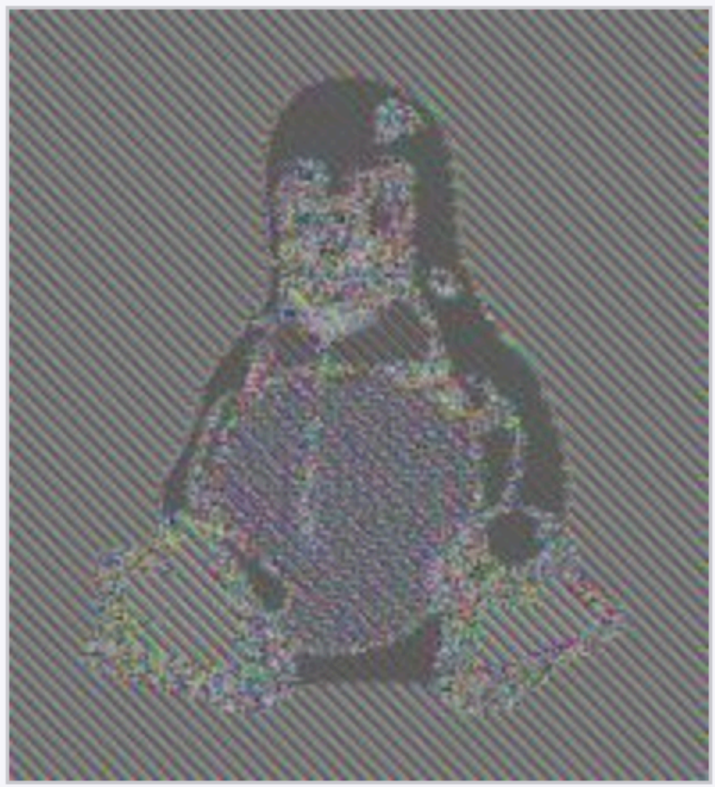


ECB Mode

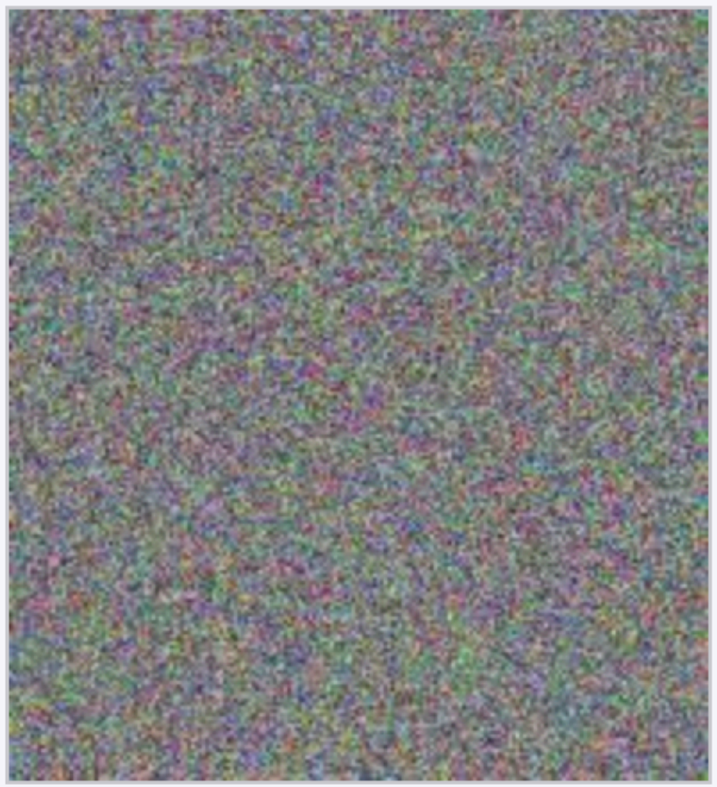
https://en.wikipedia.org/wiki/Block_cipher_mode_of_operation

ECB 模式的缺點：相同的明文區塊會加密出相同的密文區塊

Original image



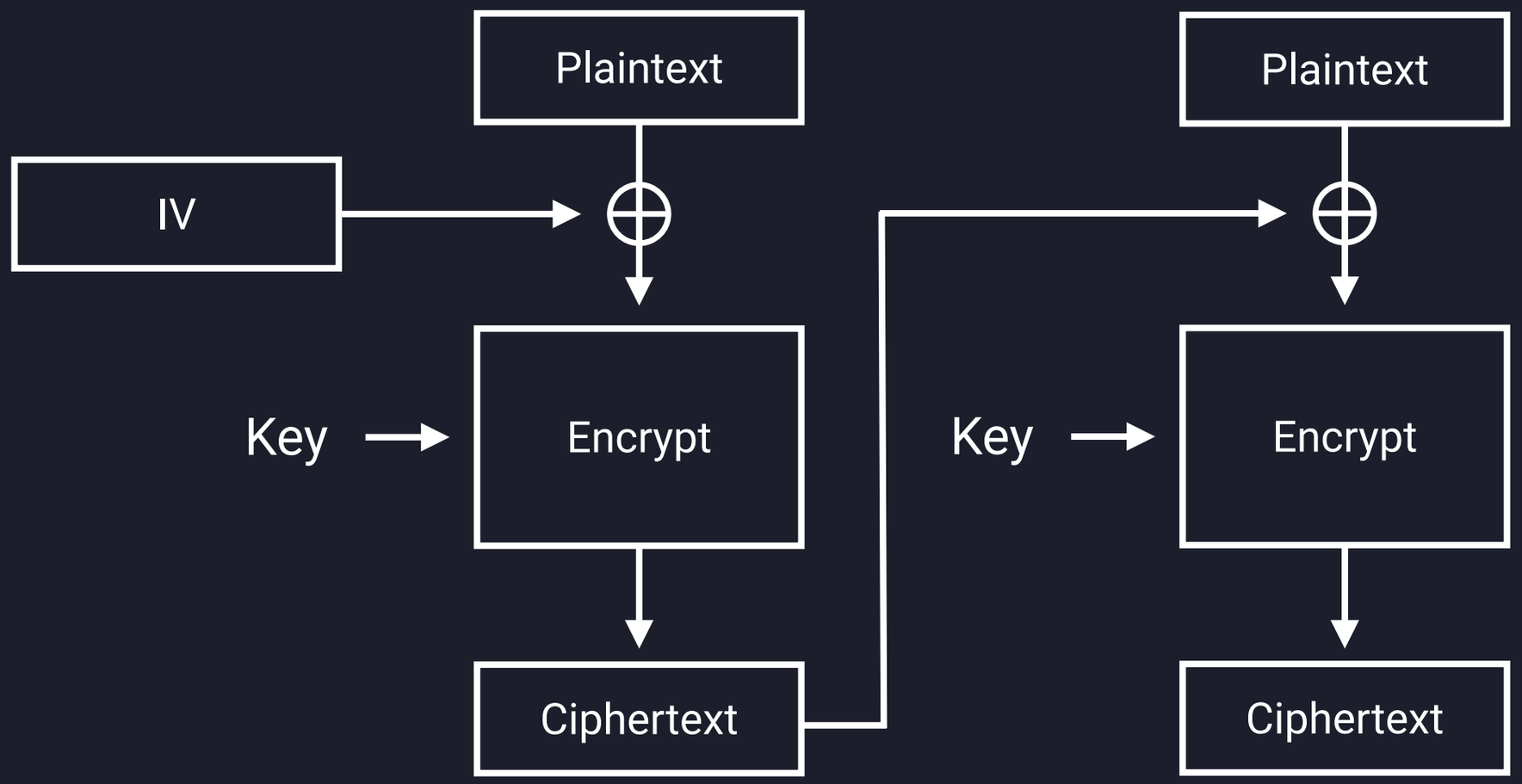
Encrypted using ECB mode



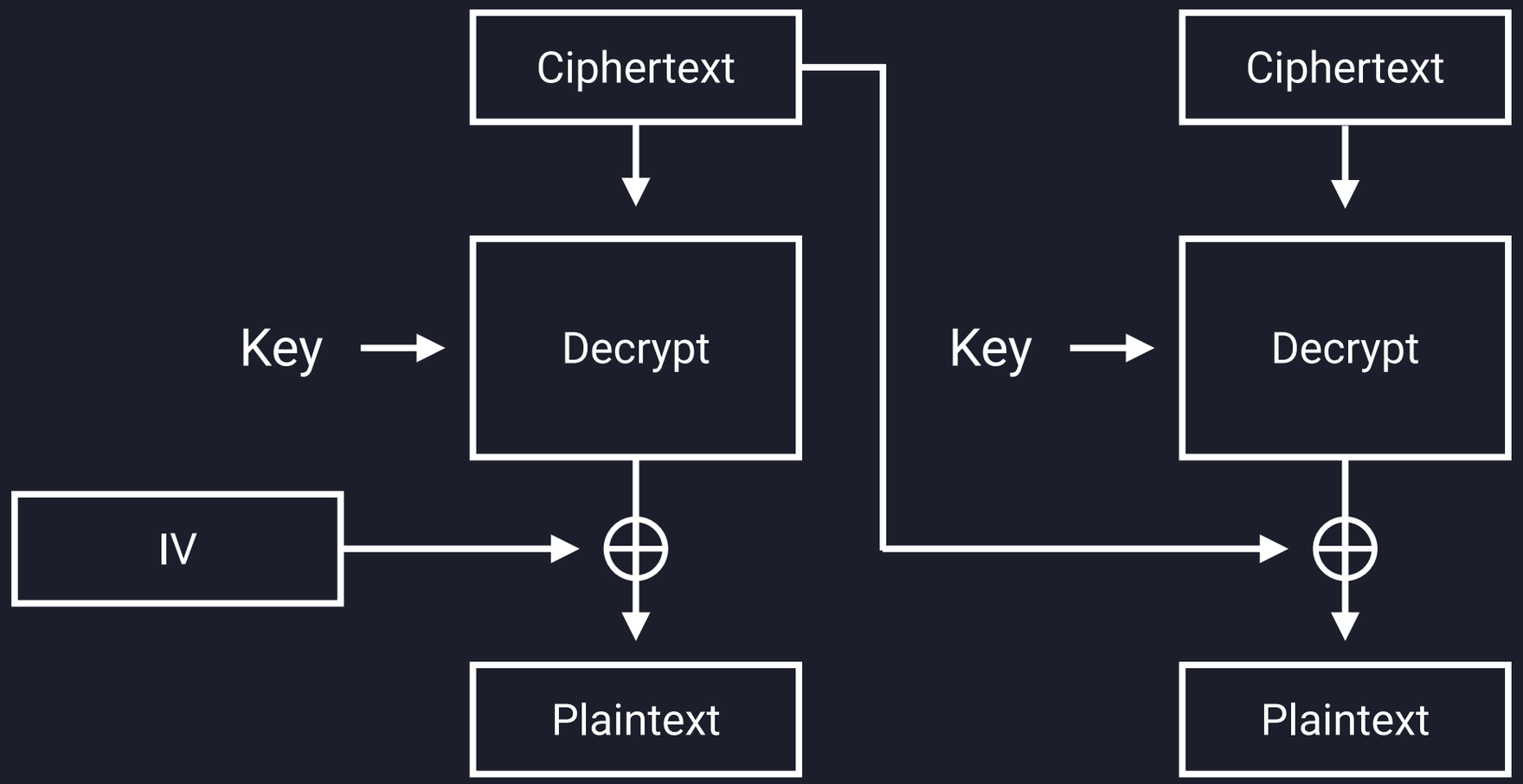
Modes other than ECB result in pseudo-randomness

CBC Mode

CBC Mode Encryption



CBC Mode Decryption

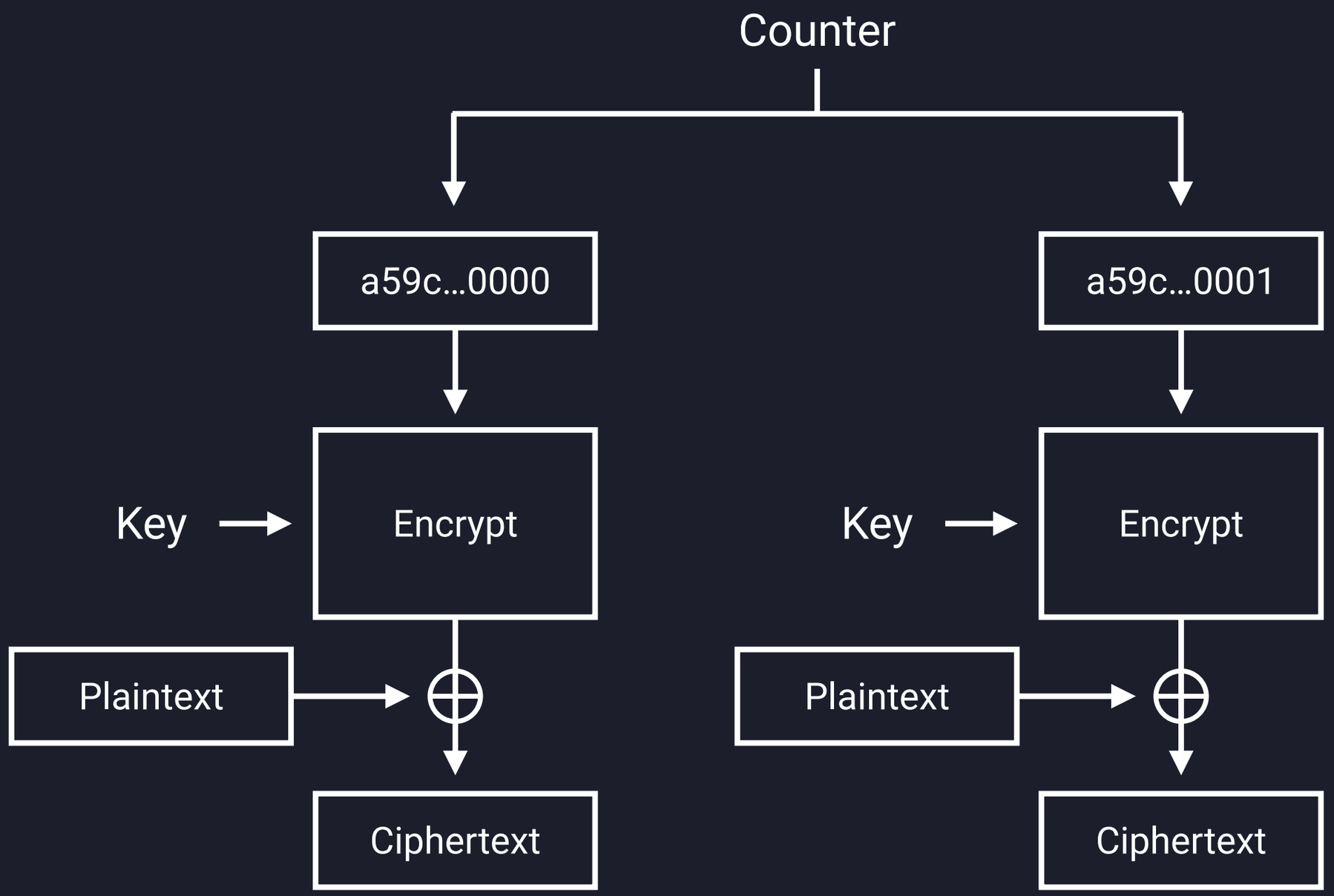


CBC Mode

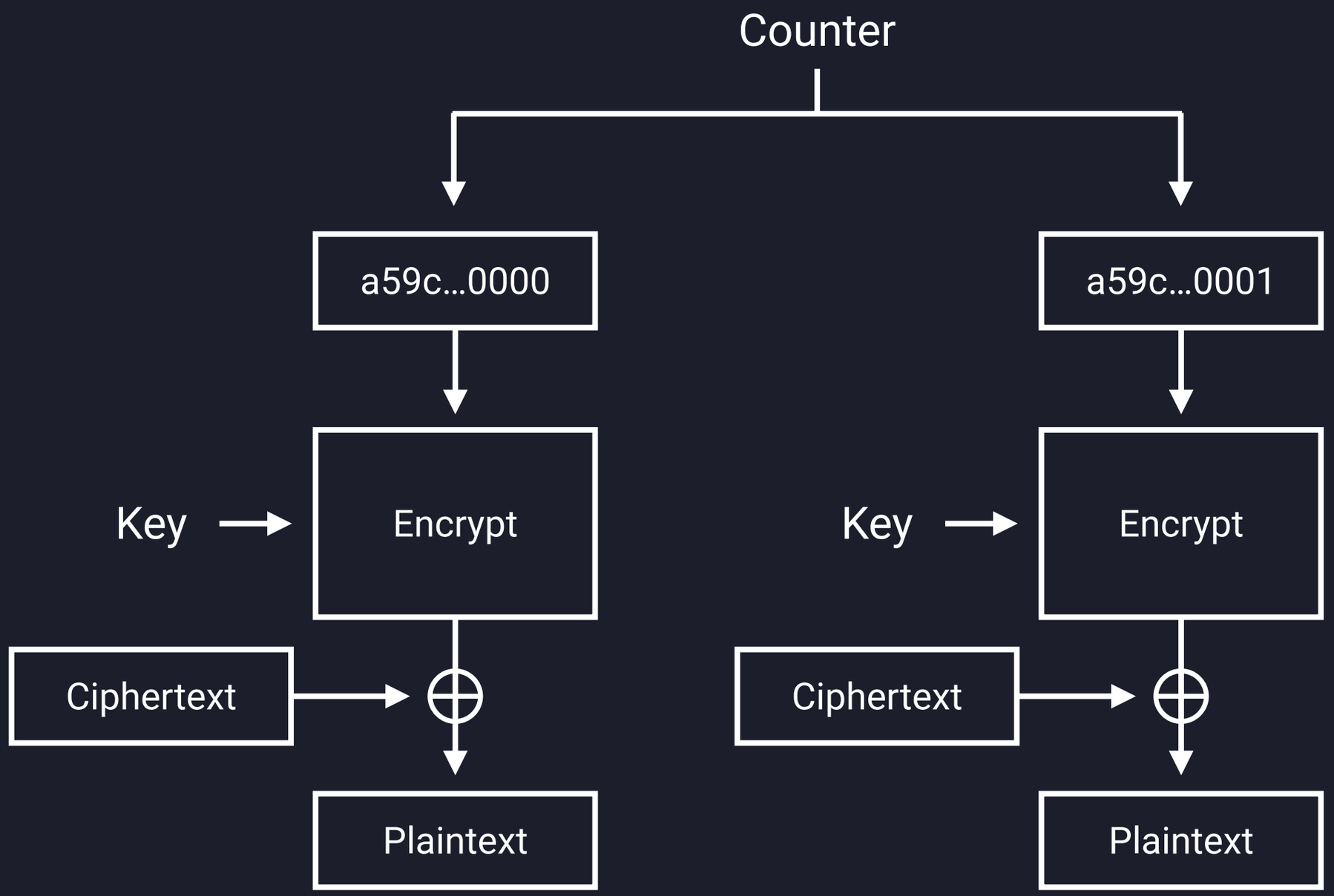
- 每塊密文都依賴前面所有的明文
- 相同的區塊明文會加密出不同的區塊密文
- 有一個初始化向量 (Initial Vector)，簡稱 IV

CTR Mode

CTR Mode Encryption



CTR Mode Decryption



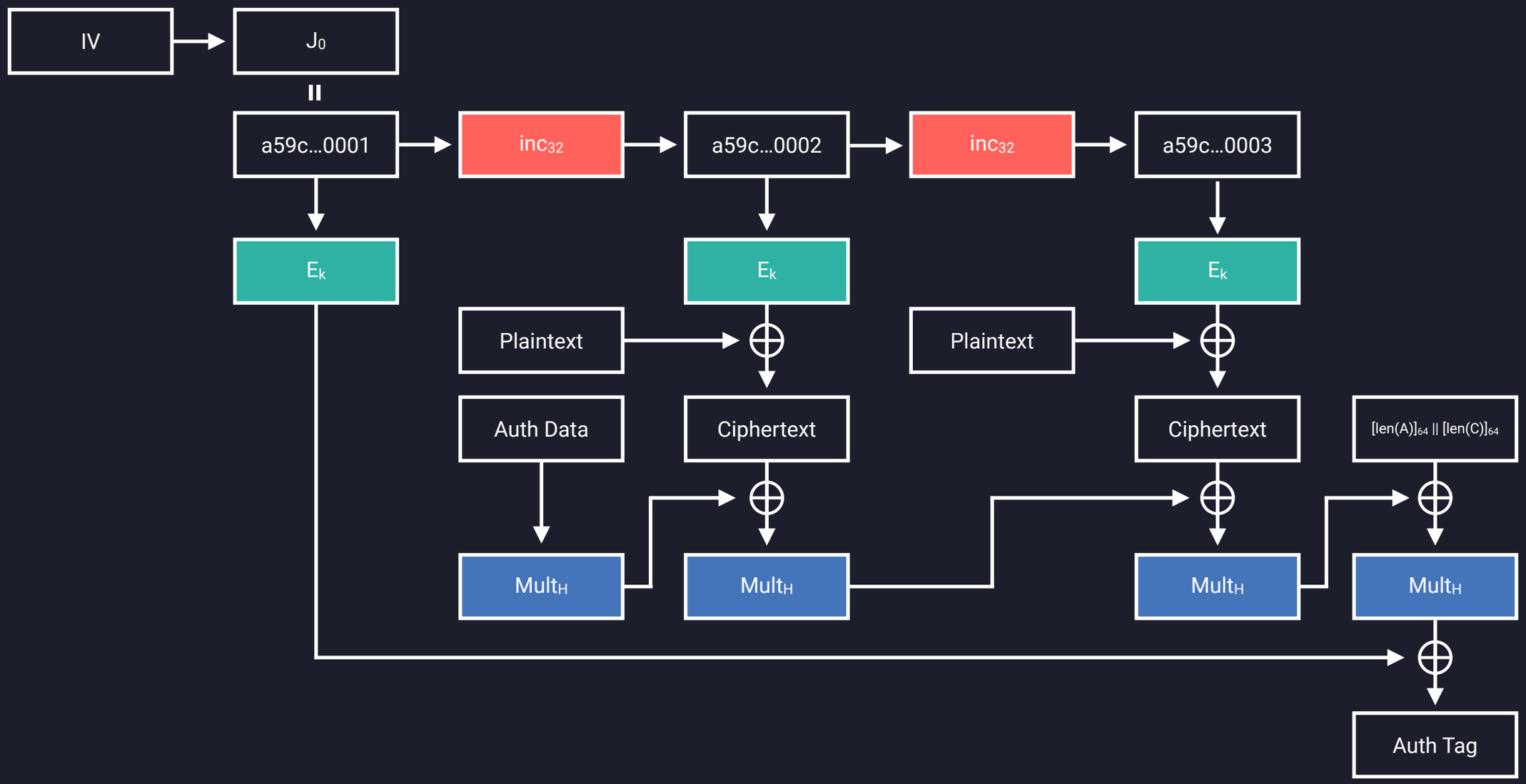
CTR Mode

- 利用 AES 去產生 xor key 然後做 xor cipher
- 加密和解密都是用 AES Encryption，因為要產生相同的 xor key
- Counter 會初始一個隨機數字，每次加一
- Block 之間沒有互相依賴，可平行運算

GCM Mode

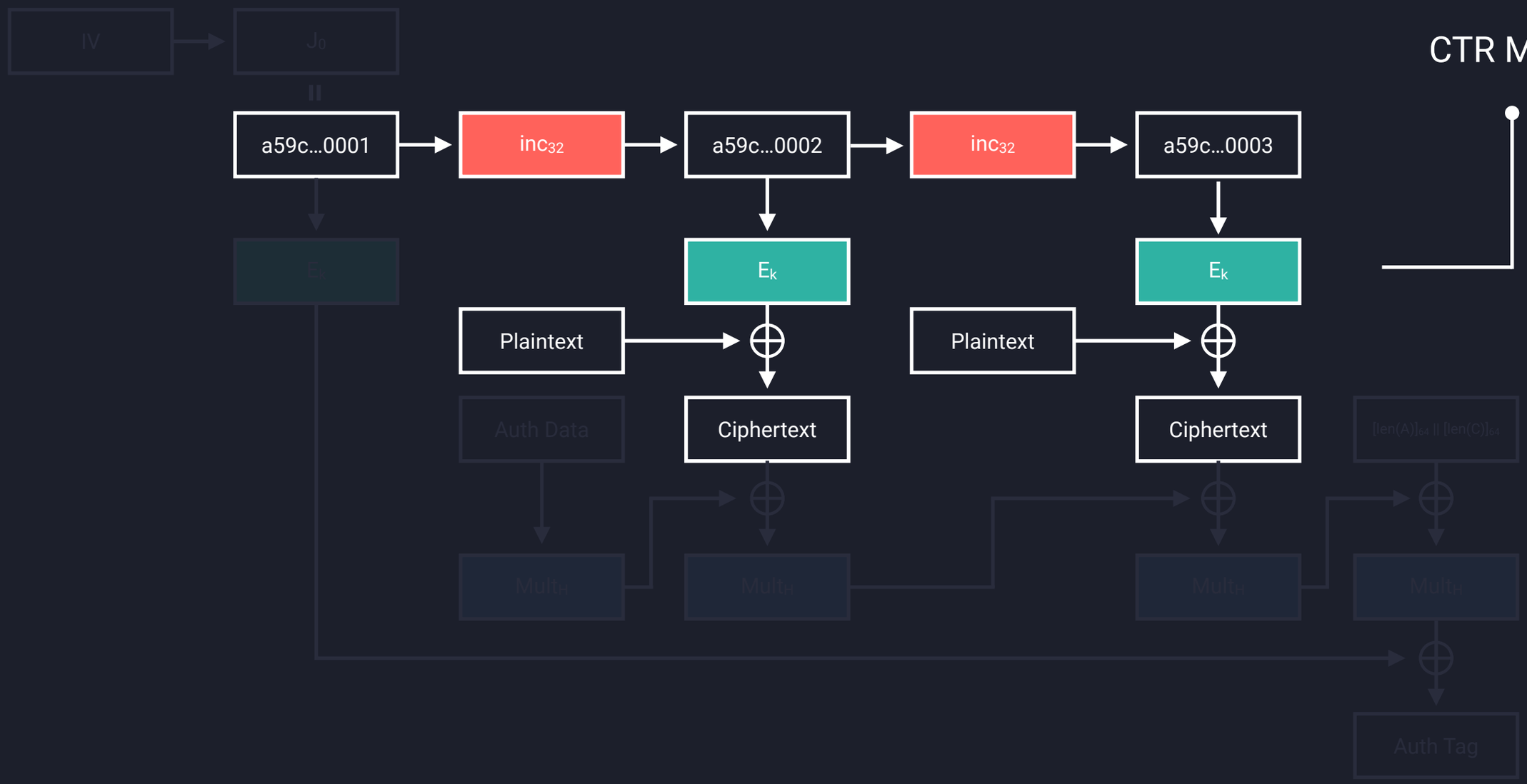
GCM Mode Encryption

https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf



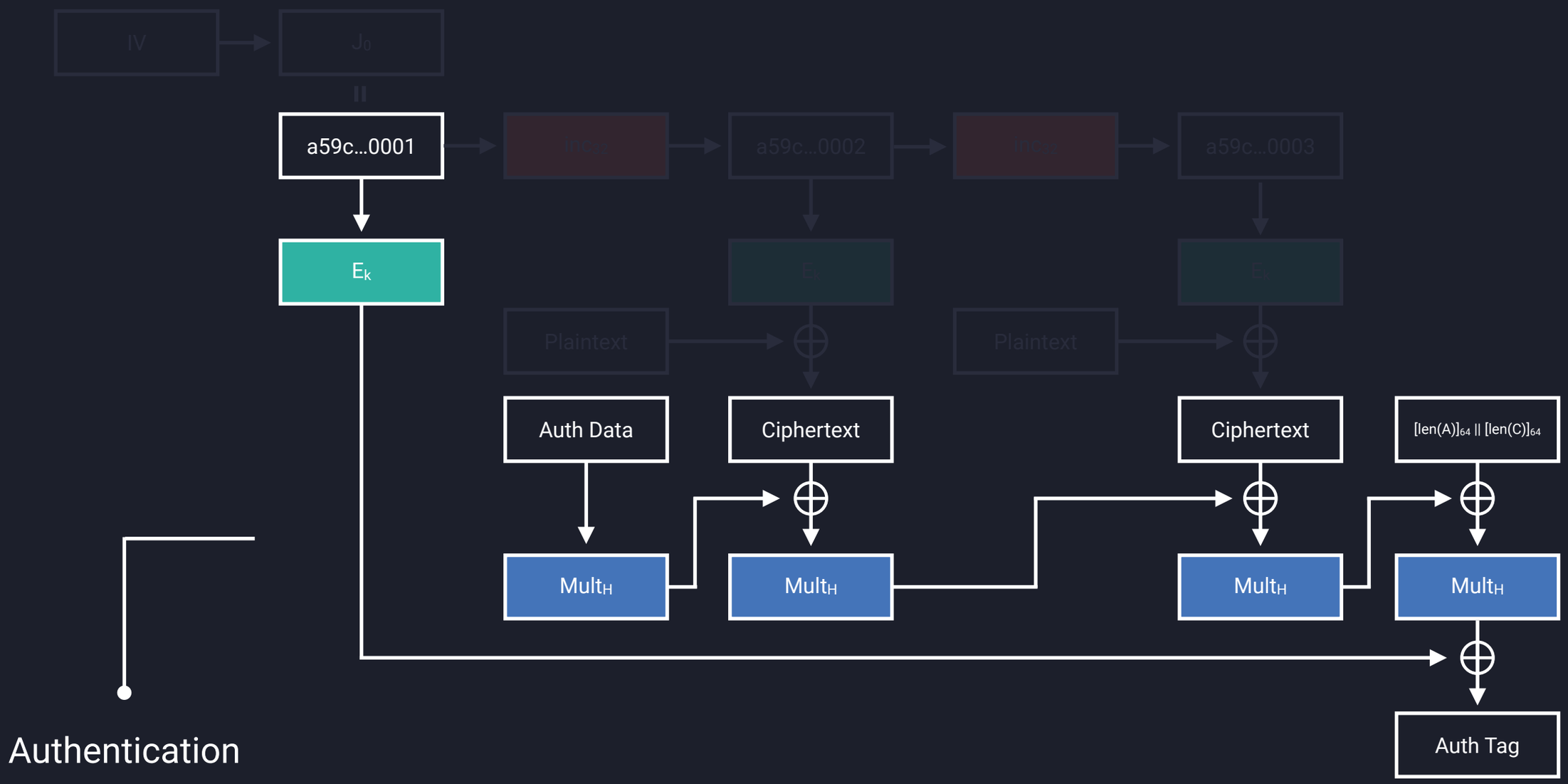
GCM Mode Encryption

https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf



GCM Mode Encryption

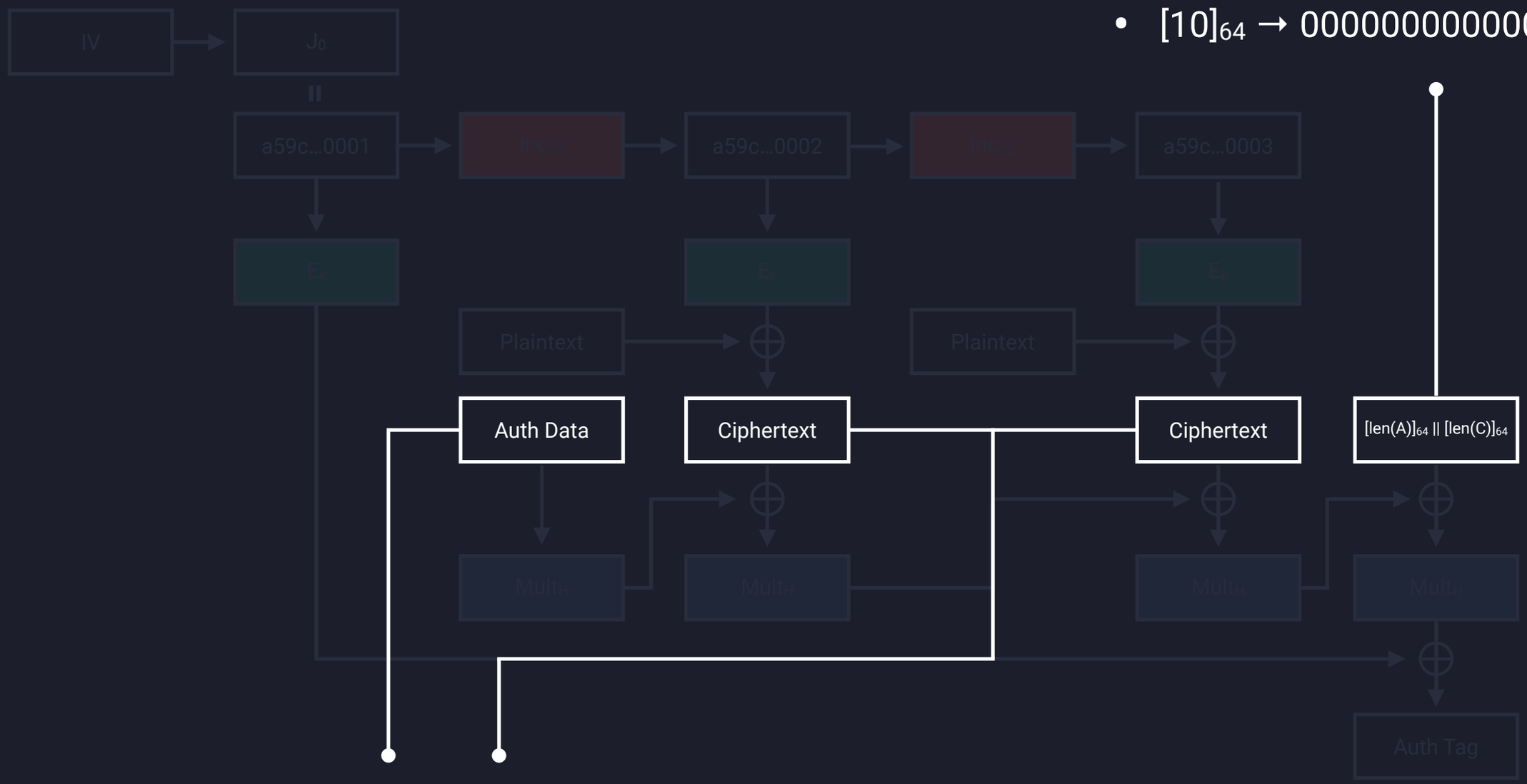
https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf



GCM Mode Encryption

https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf

- len 是 bitlen
- $[10]_{64}$ → 000000000000000a



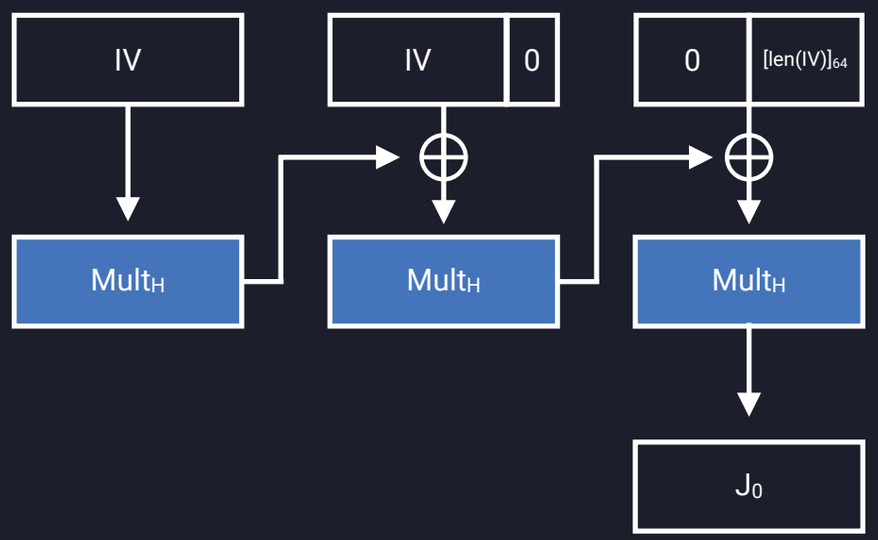
不是 16 bytes 的倍數會在後面補 \x00

GCM Mode Encryption

https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf

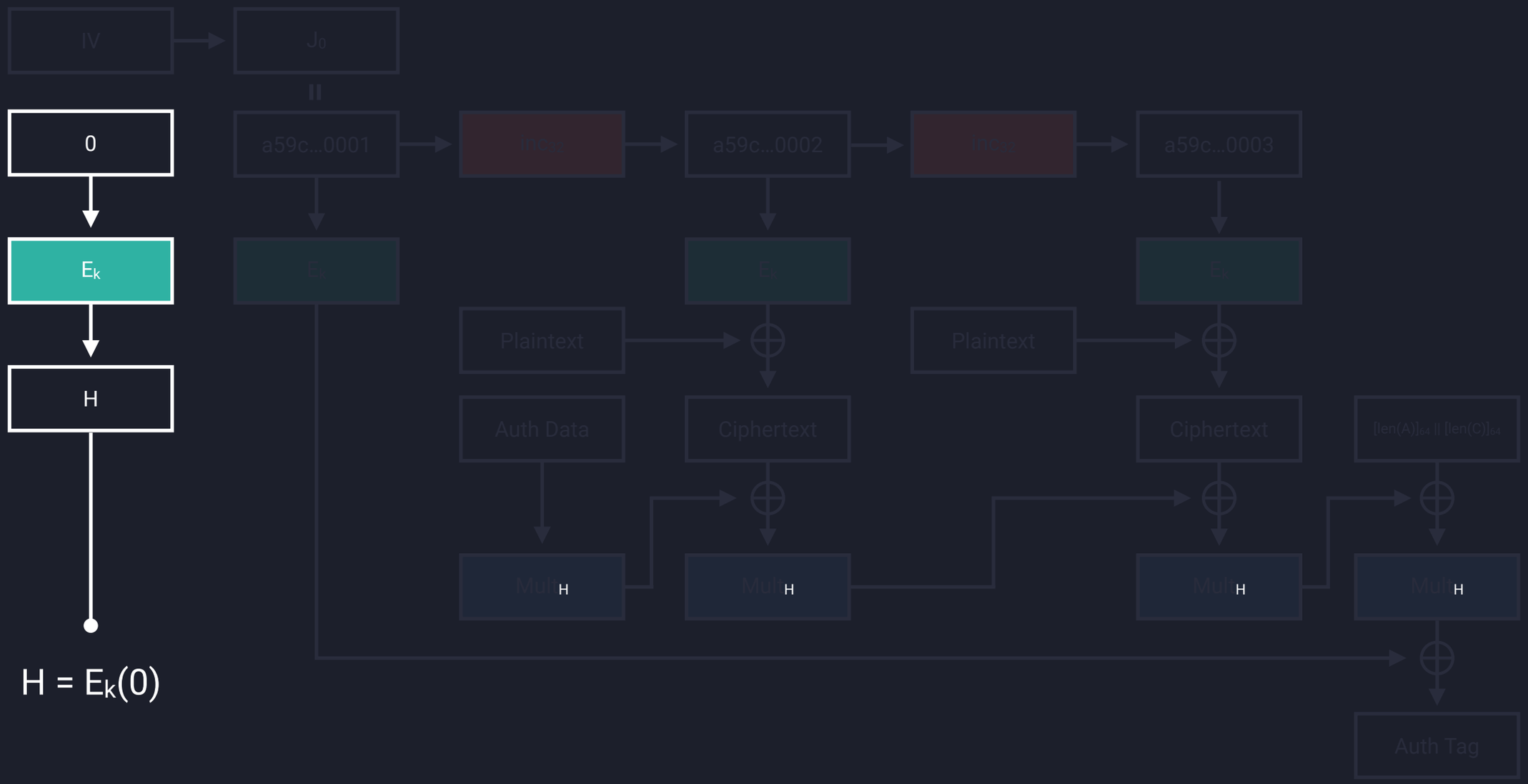
如果 len(IV) = 96

如果 len(IV) ≠ 96



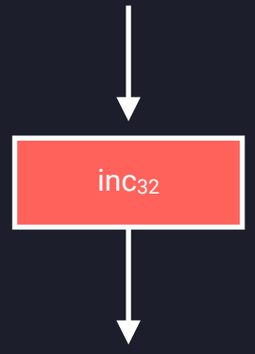
GCM Mode Encryption

https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf



GCM Mode Encryption

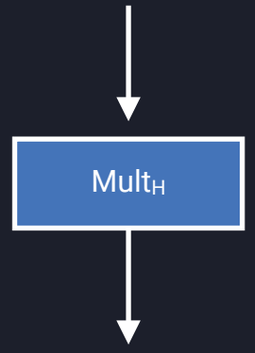
https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf



- 低位 32 bits 加一 modulo 2^{32}
- 剩下的高位不動

GCM Mode Encryption

https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf



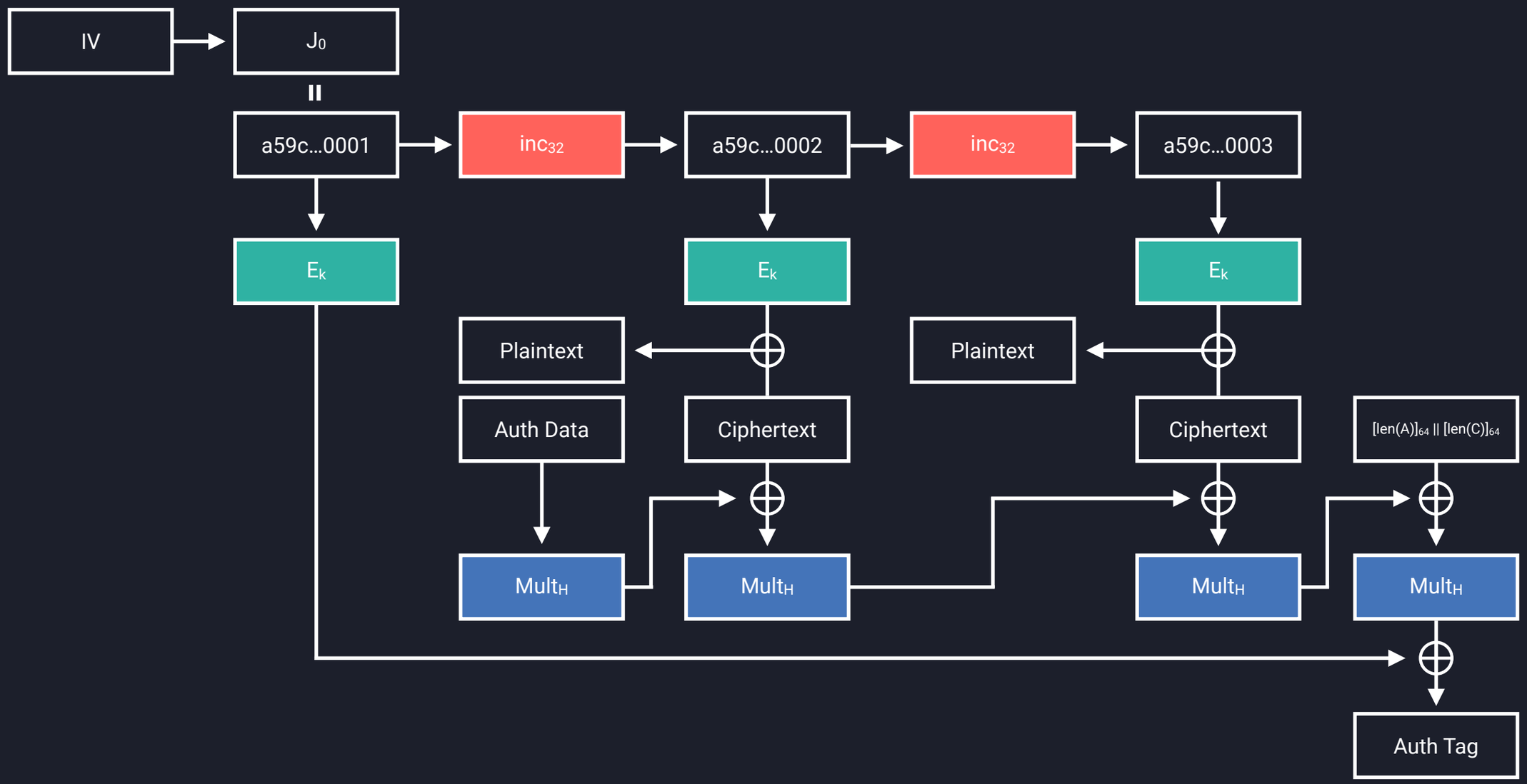
- $Mult_H$ 是在 GF(2^{128}) 下乘上 H
- GF(2^{128}) 的 reduction modulus 是 $x^{128} + x^7 + x^2 + x + 1$
- 從 bytes 轉成 GF(2^{128}) 下的元素
  - u is the variable of the polynomial
  - $x_0x_1...x_{127} \rightarrow x_0 + x_1u + ... + x_{127}u^{127}$
  - '\x00...\x00\x01\x02' → $x^{119}+x^{126}$

Galois Field

- Galois Field (GF) 或叫 Finite Field
- GF(2^{128}) 裡面的元素可以表示成一個 degree = 127 的多項式
- 加法和乘法就是做多項式的加法和除法 modulo 一個 degree = 128 的 irreducible polynomial
  - GCM Mode 用的 GF(2^{128}) 是 modulo $x^{128} + x^7 + x^2 + x + 1$

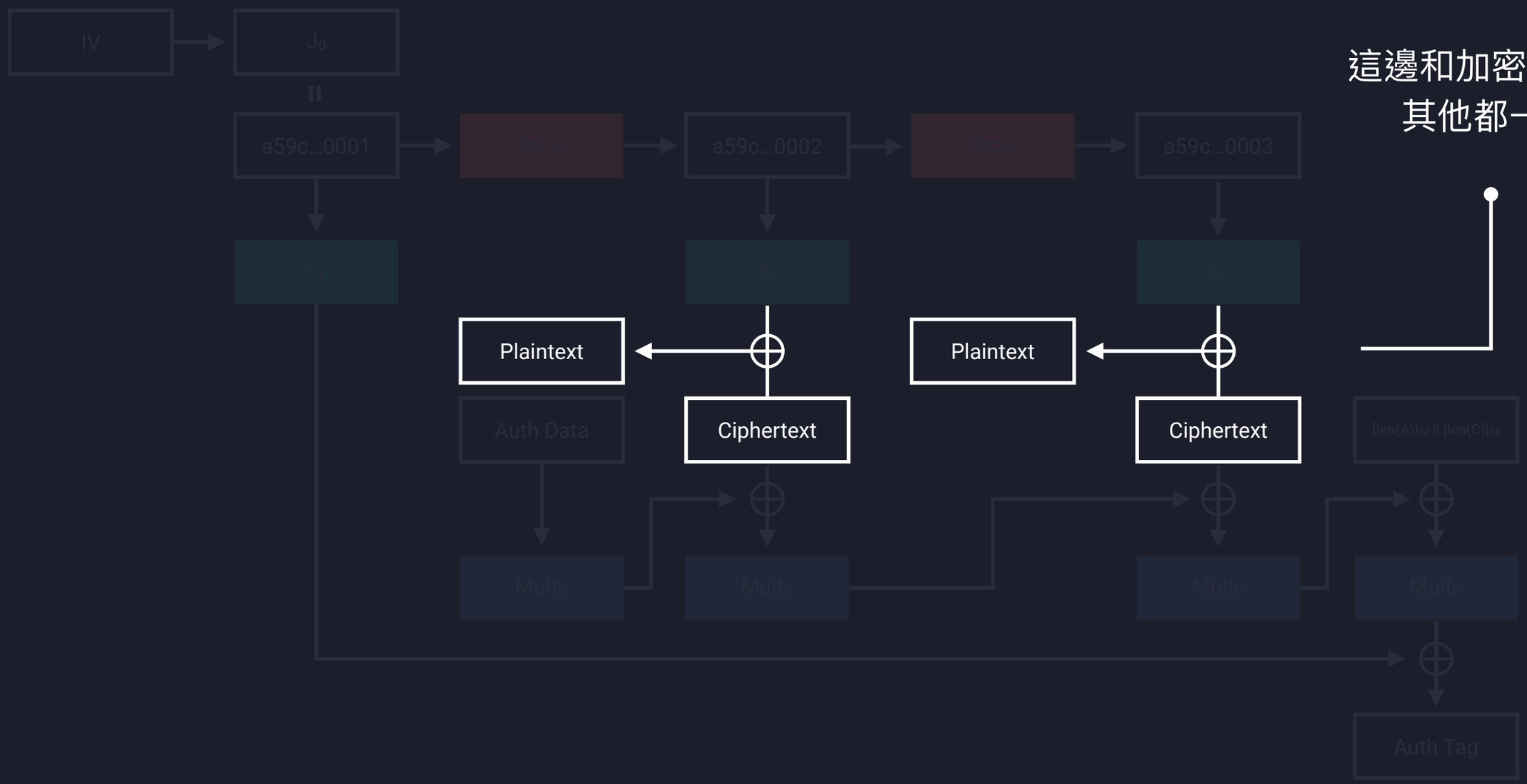
GCM Mode Decryption

https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf



GCM Mode Decryption

https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-38d.pdf

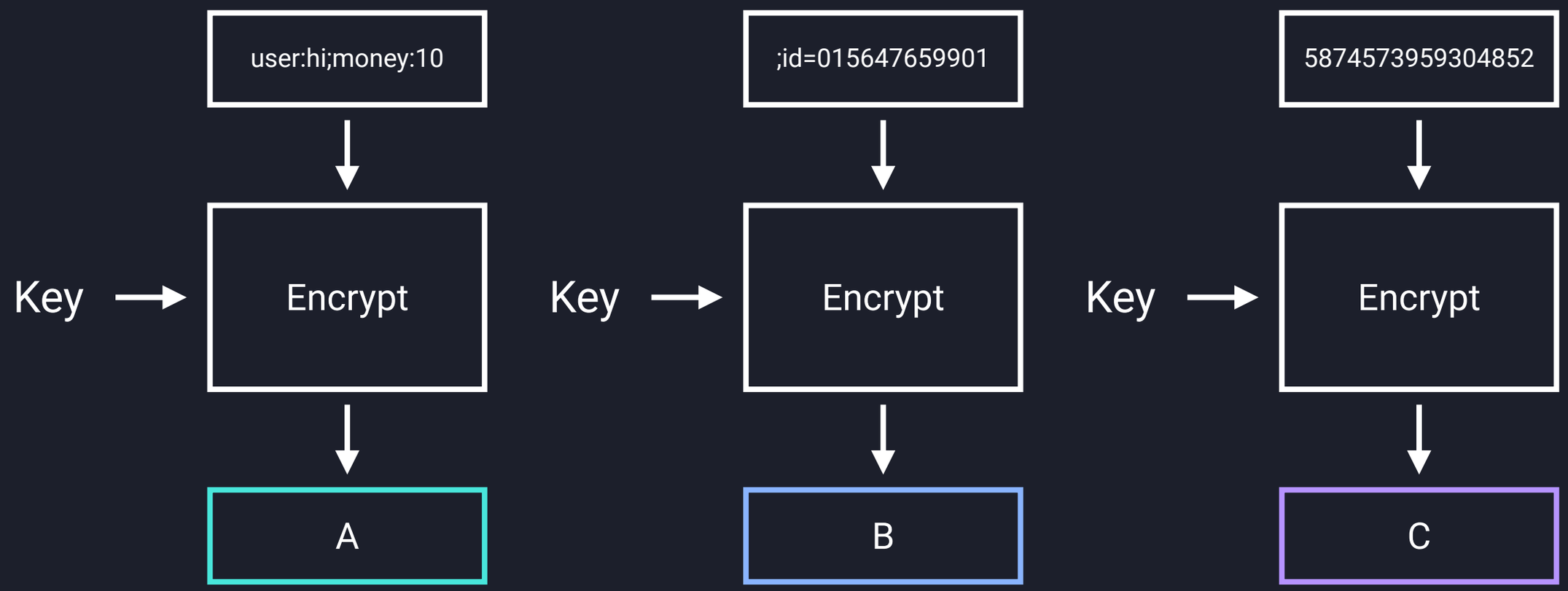


這邊和加密時顛倒
其他都一樣

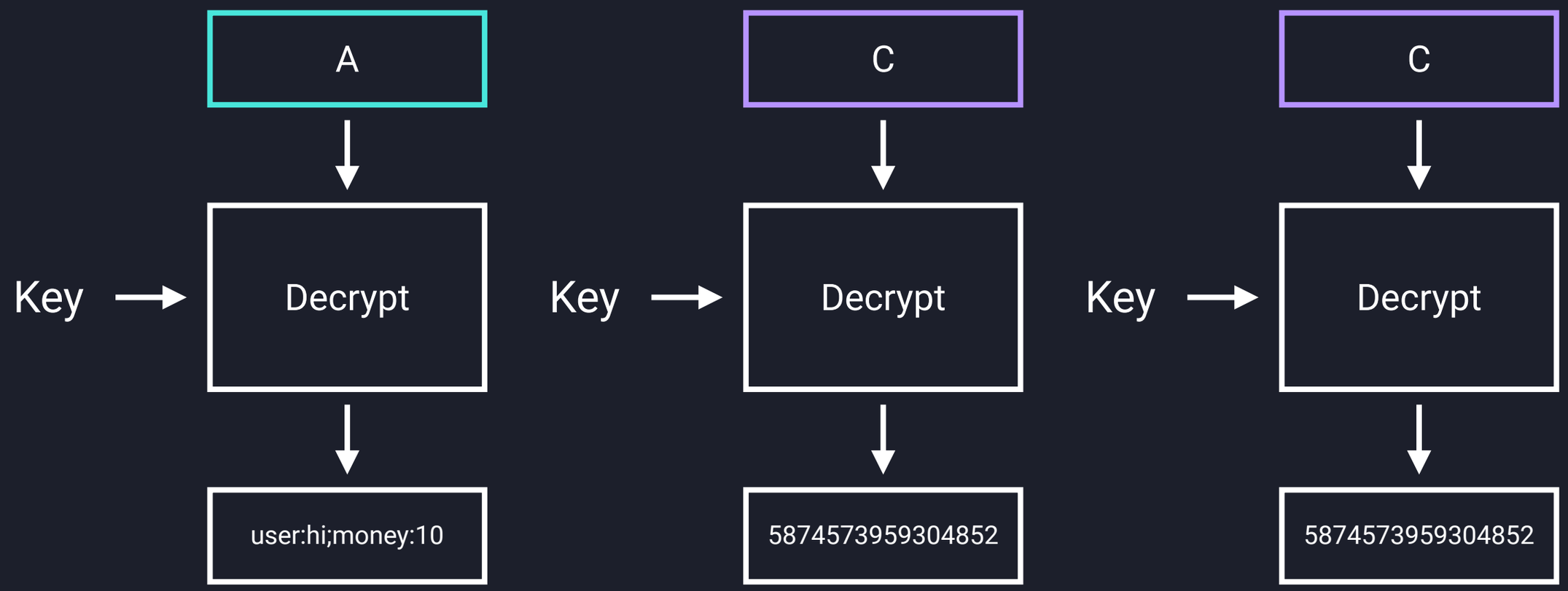
Attack Scenarios

ECB Mode / Cut & Paste

ECB Mode / Cut & Paste



ECB Mode / Cut & Paste



錢錢變多了~

ECB Mode / Prepend Oracle Attack

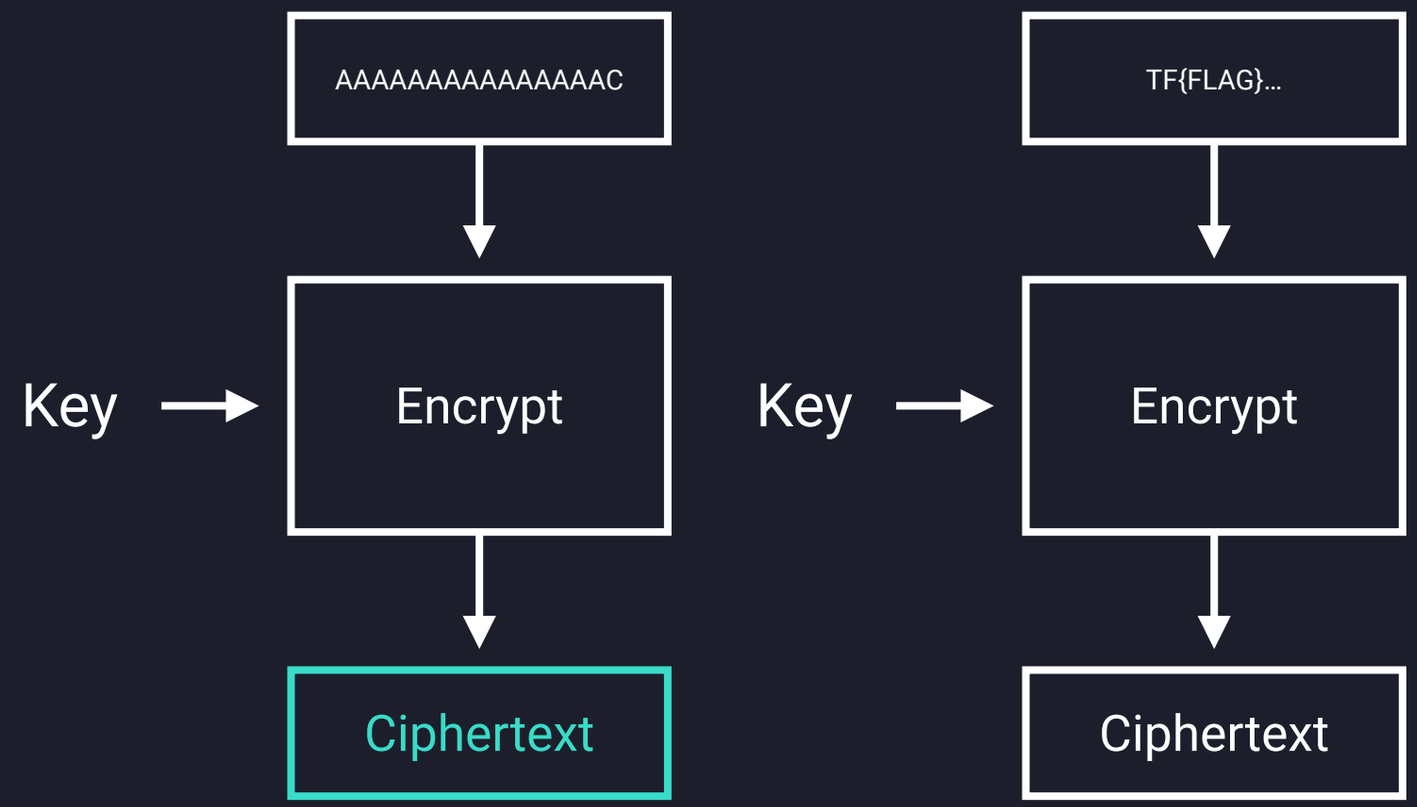
The Oracle

- 使用 AES ECB Mode
- 伺服器將我們的明文 prepend 在 flag 前面作加密

```
def oracle(plain):
    aes = AES.new(KEY, AES.MODE_ECB)
    return aes.encrypt(plain + flag)
```

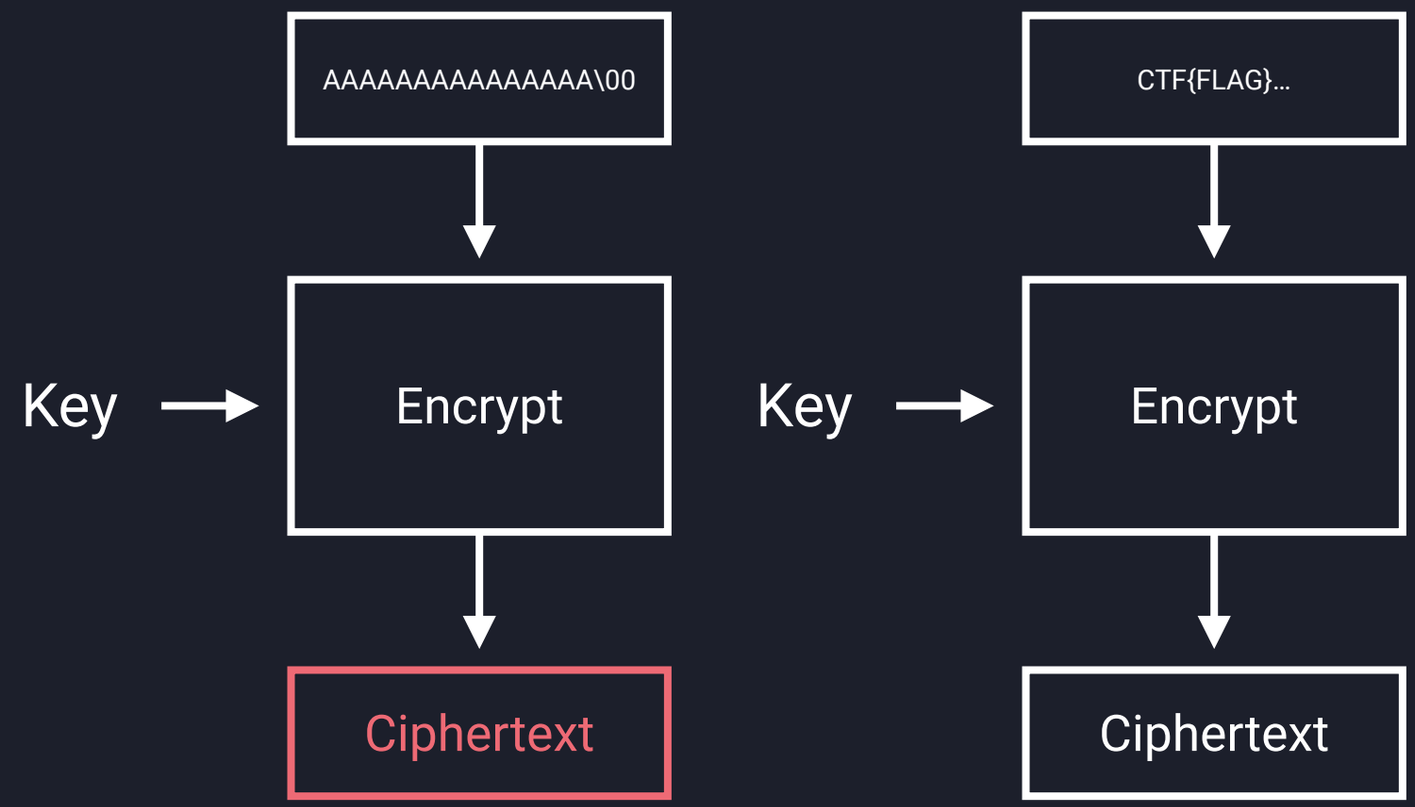
找 flag[0]

先塞 15 個垃圾
讓 flag 的第一個字元掉進來



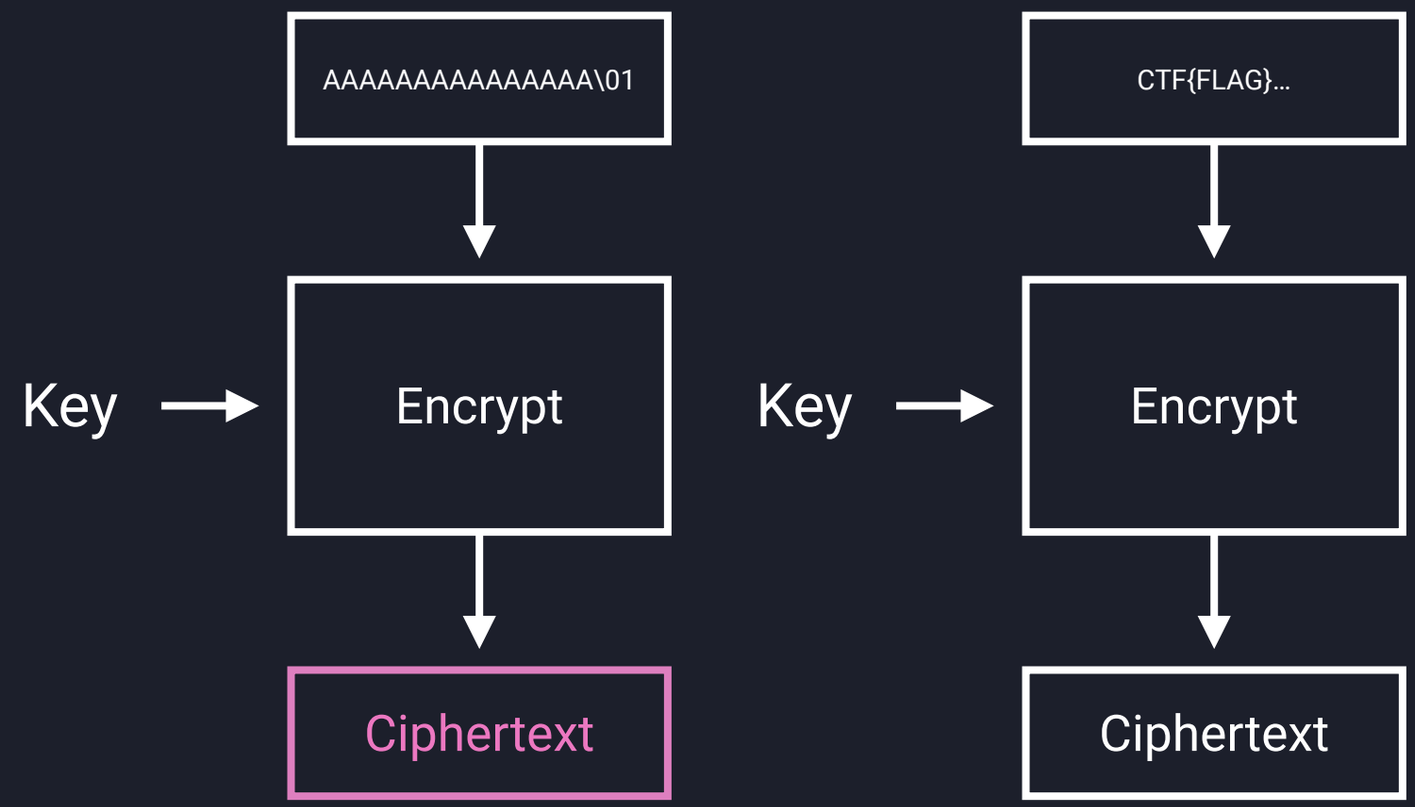
找 flag[0]

塞 15 個一樣的垃圾 +
爆搜最後一個 byte



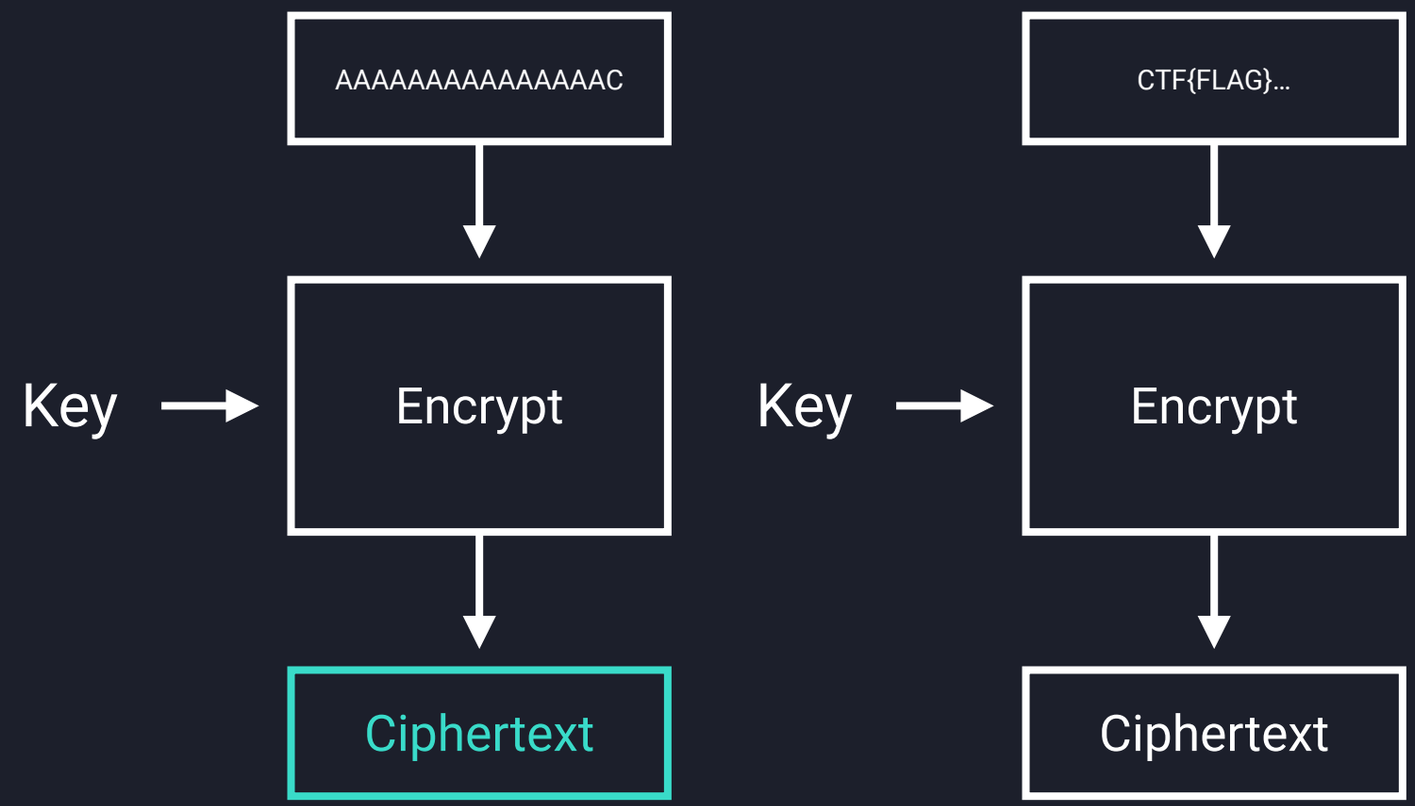
找 flag[0]

塞 15 個一樣的垃圾 +
爆搜最後一個 byte



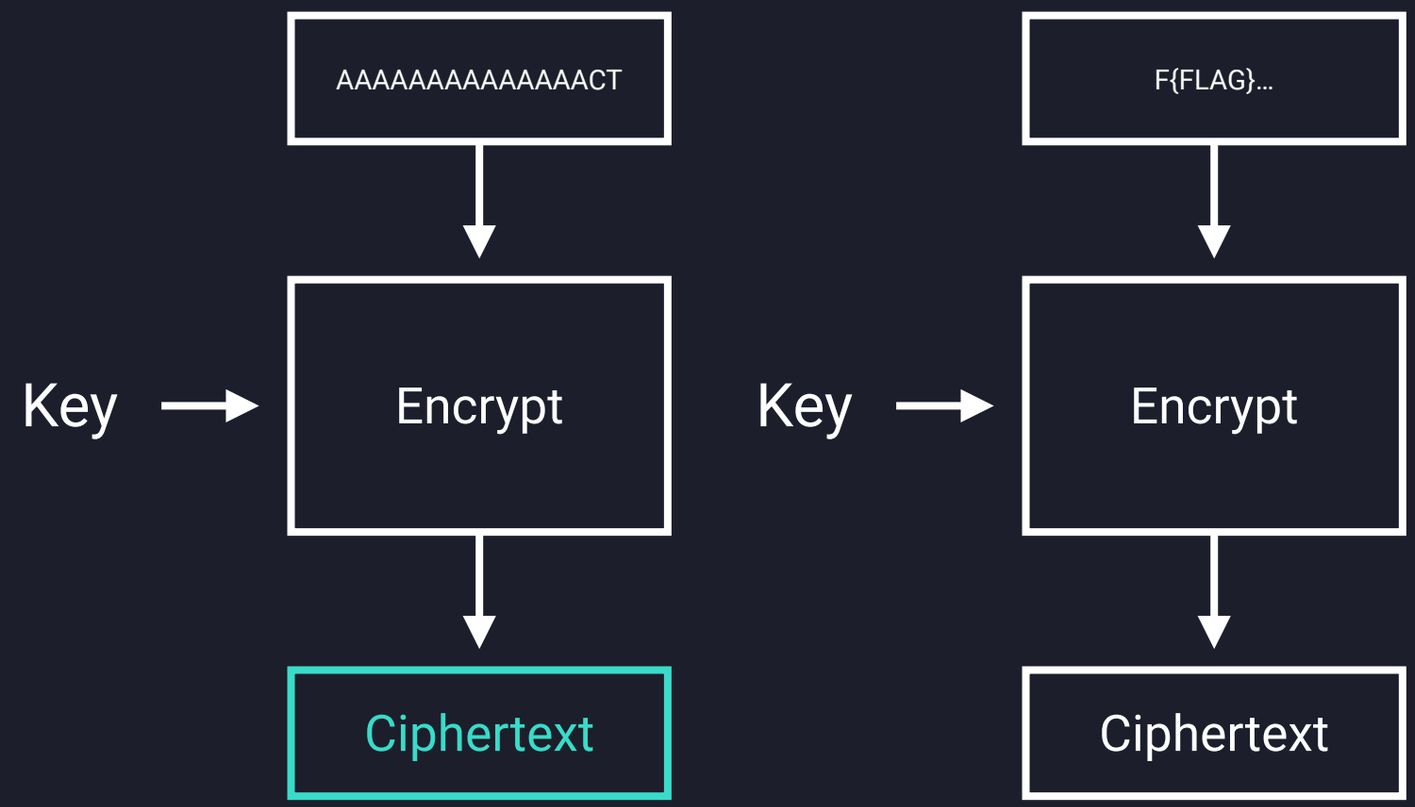
找 flag[0]

找到了 flag 的第一個 byte



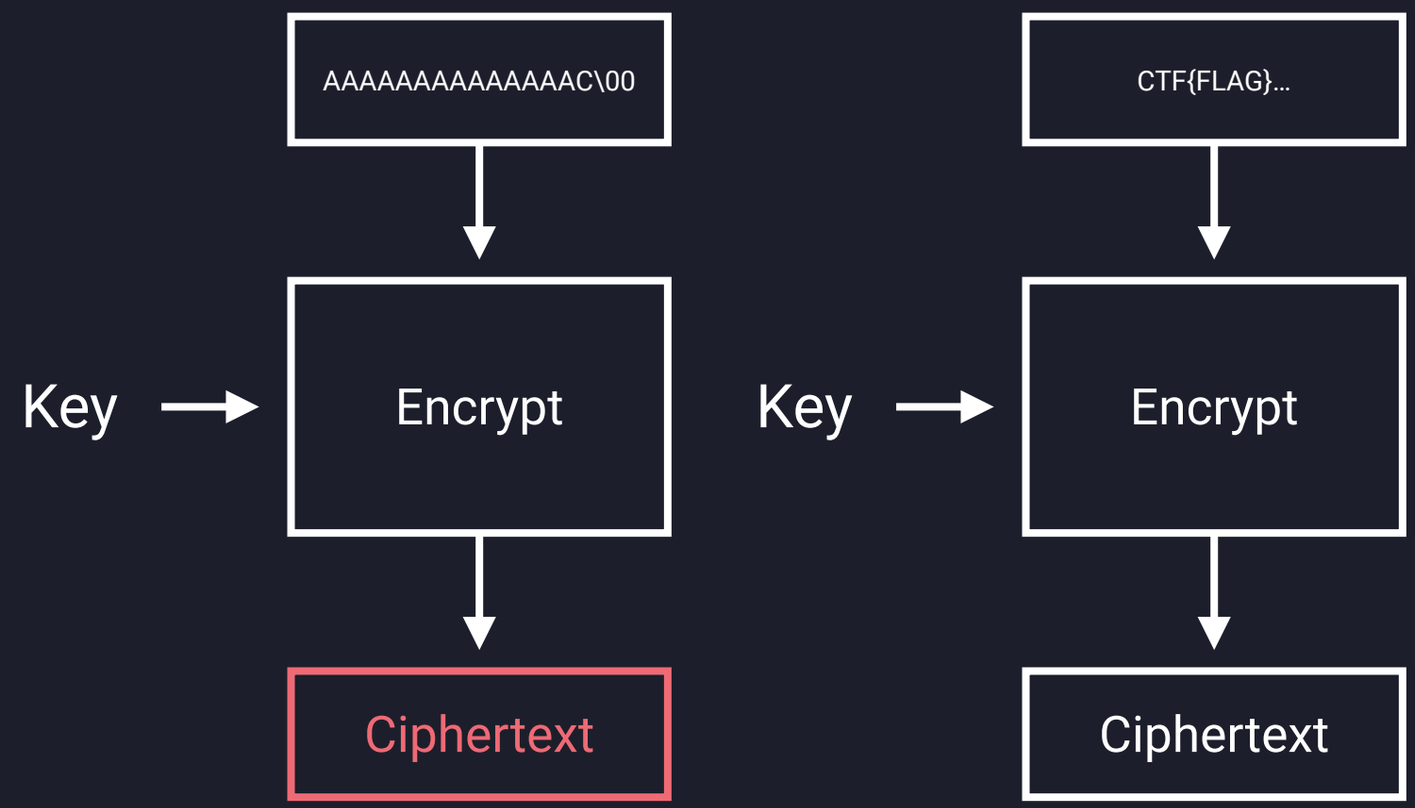
找 flag[1]

先塞 14 個垃圾
讓 flag 的前兩個字元掉進來



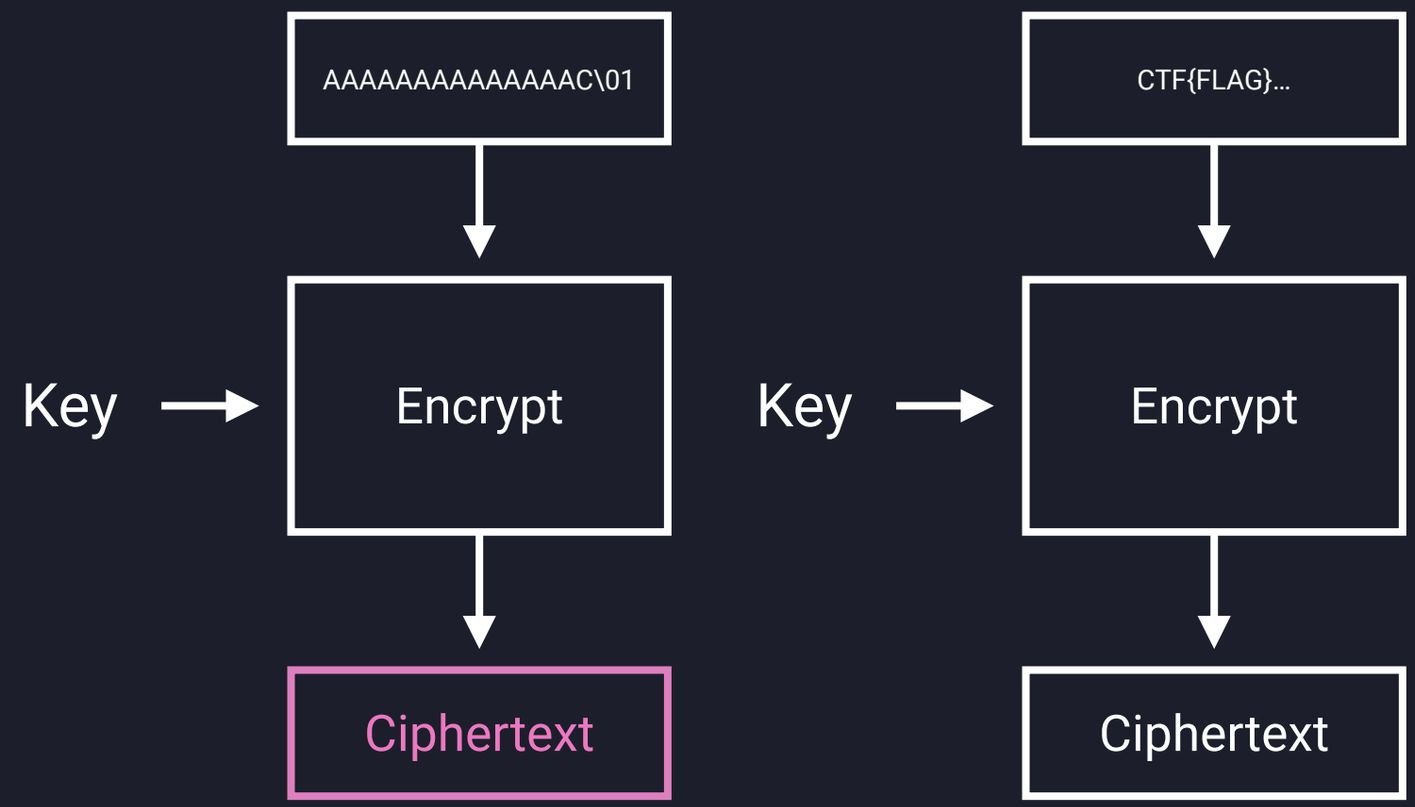
找 flag[1]

塞 14 個一樣的垃圾 +
已知的 flag 第一個 byte +
爆搜最後一個 byte



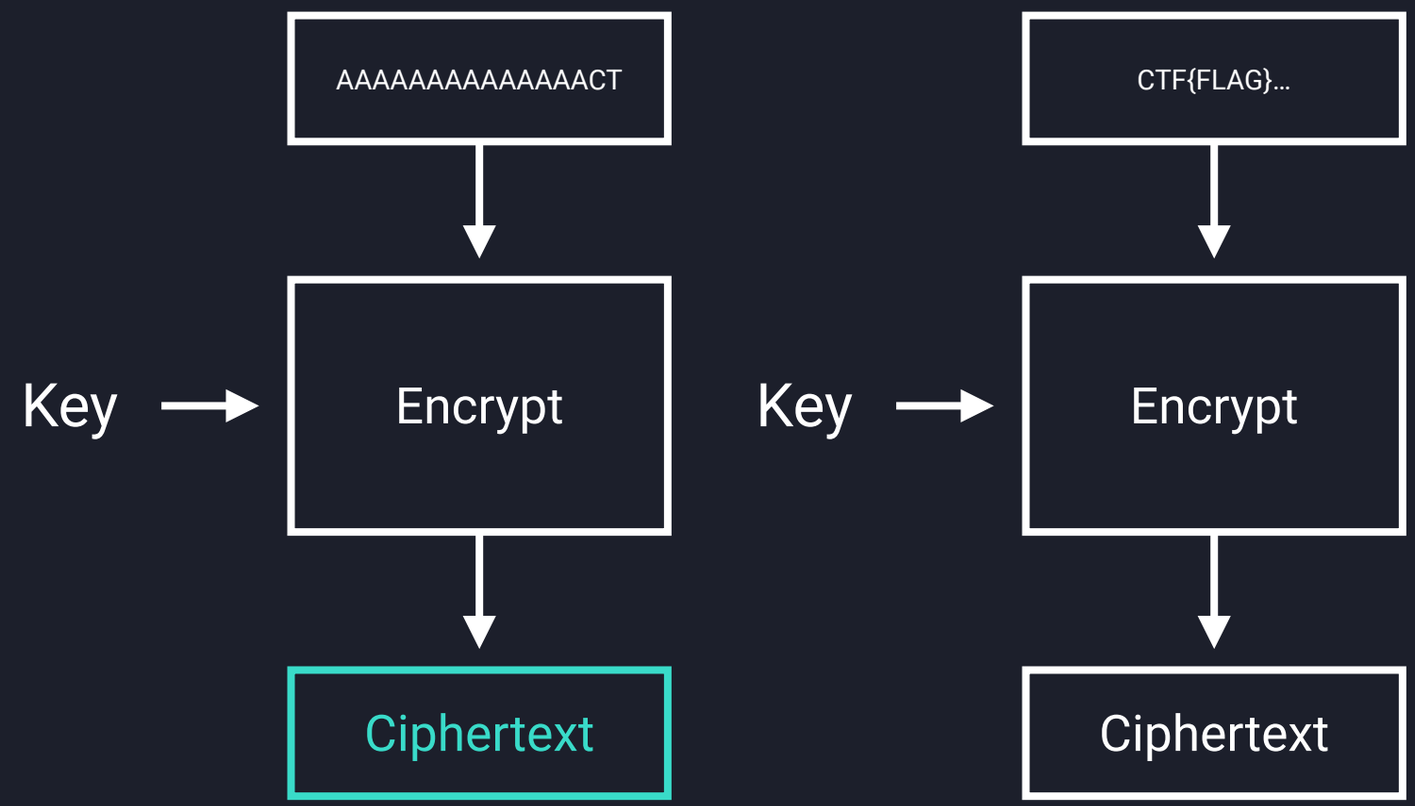
找 flag[1]

塞 14 個一樣的垃圾 +
已知的 flag 第一個 byte +
爆搜最後一個 byte



找 flag[1]

找到了 flag 的第二個 byte



Finally

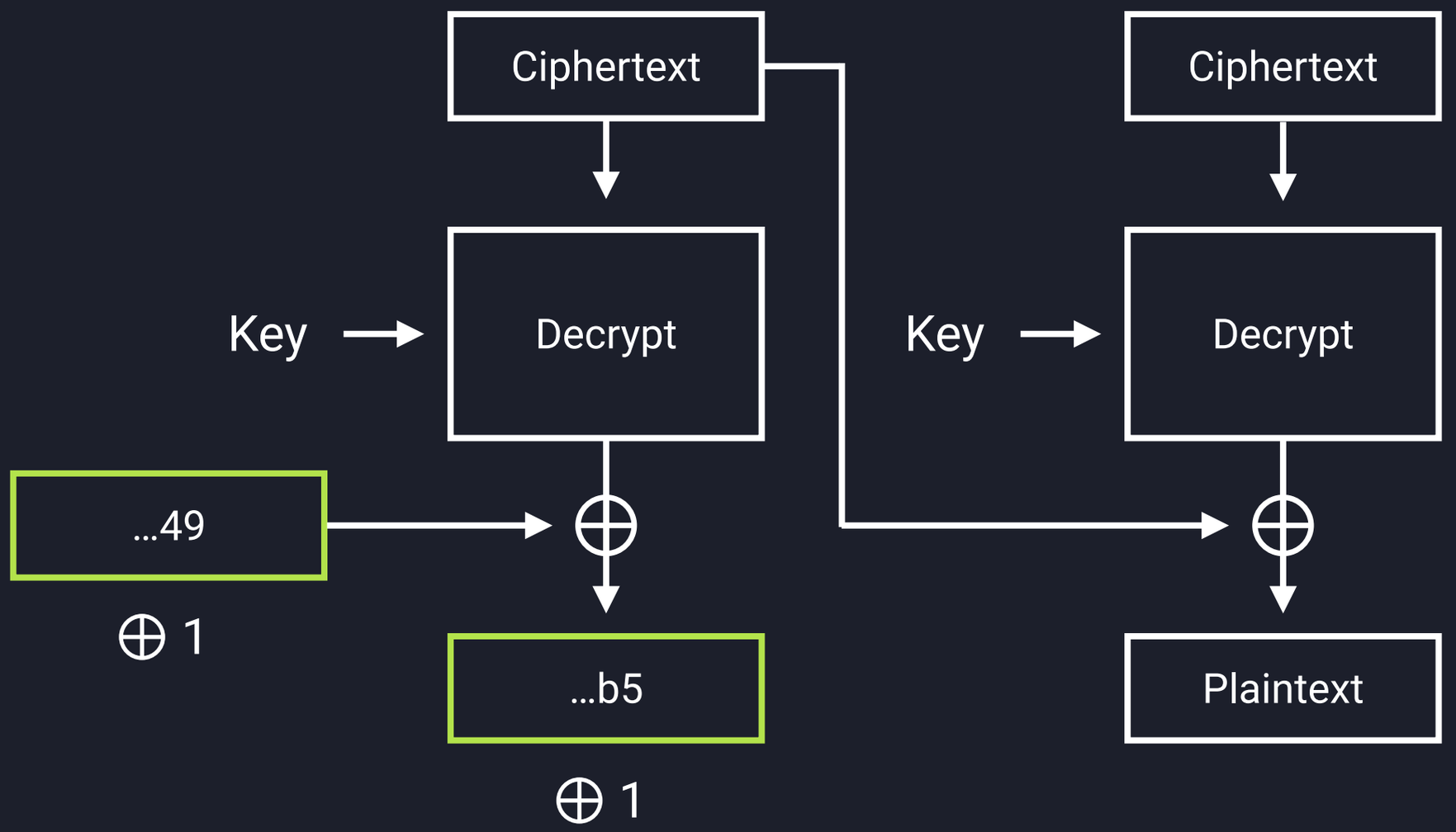
- 這樣一直做下去就能解密出 flag 的所有字元了
- 最多需要做 len(flag) * 257 次

CTF Challenges

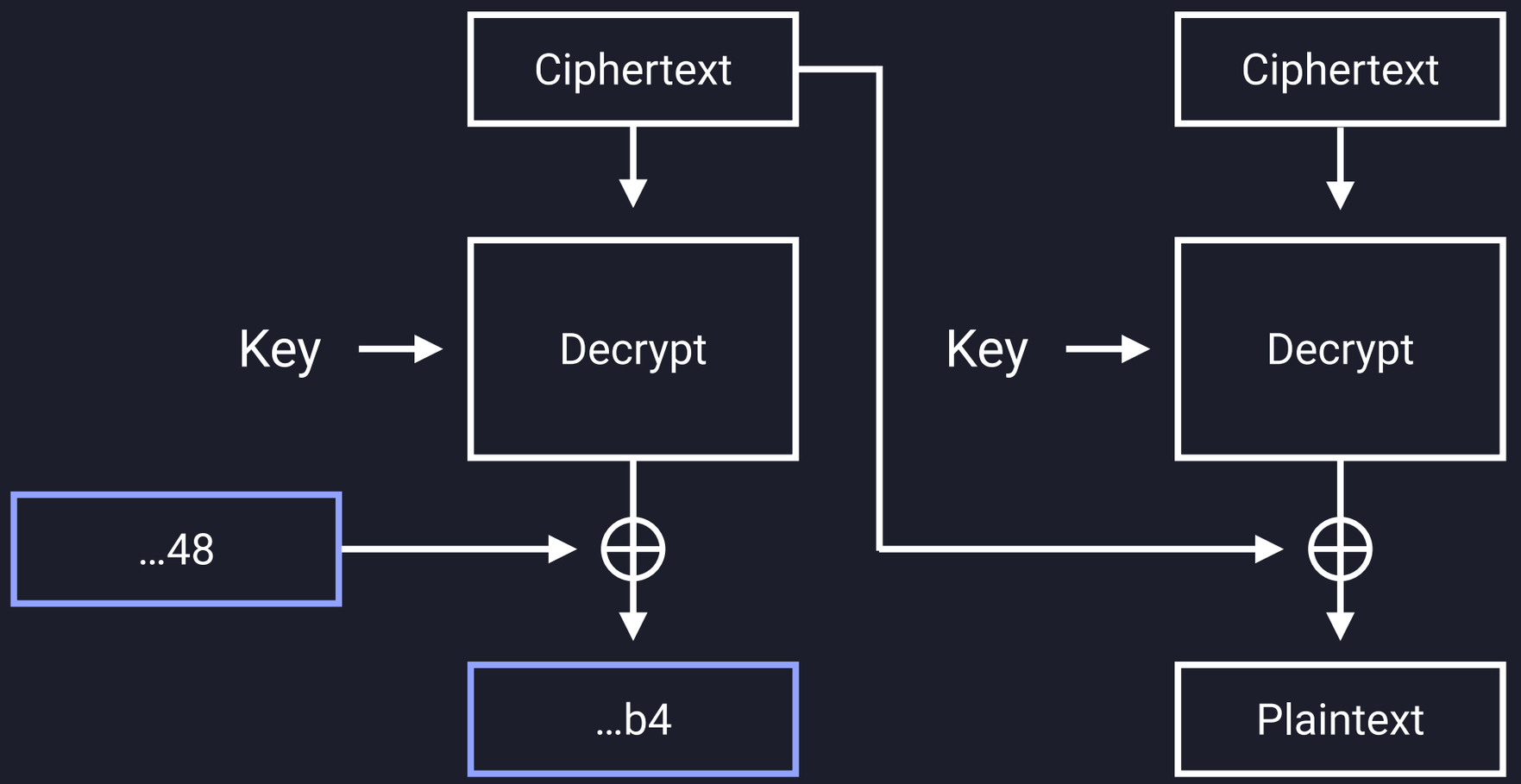
- **UTCTF 2020 - Random ECB**
- **TUCTF 2018 - AESential Lesson**
- **cryptohack.org - ECB Oracle**

CBC Mode / Bit-Flipping Attack

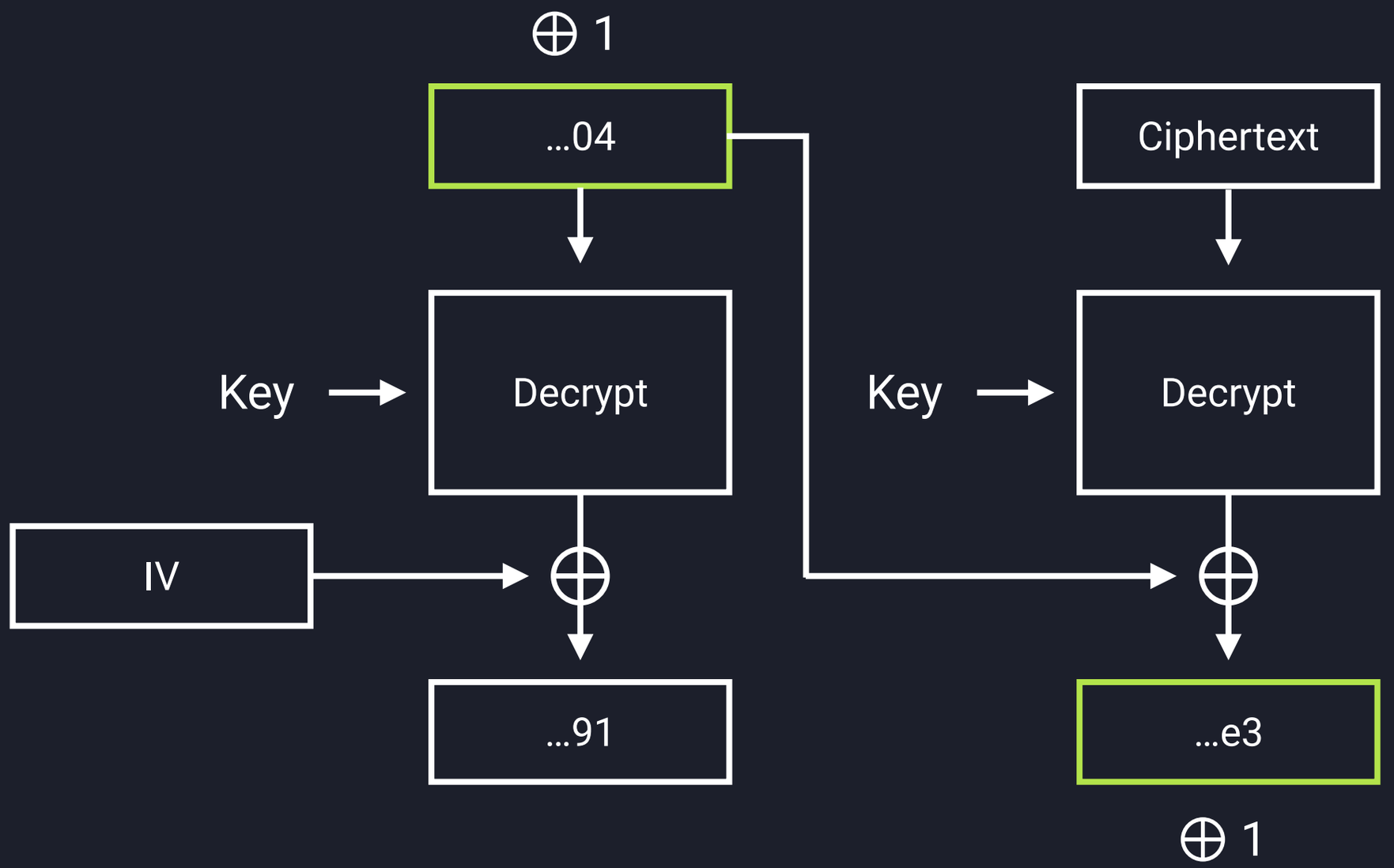
CBC Mode / Bit-Flipping Attack



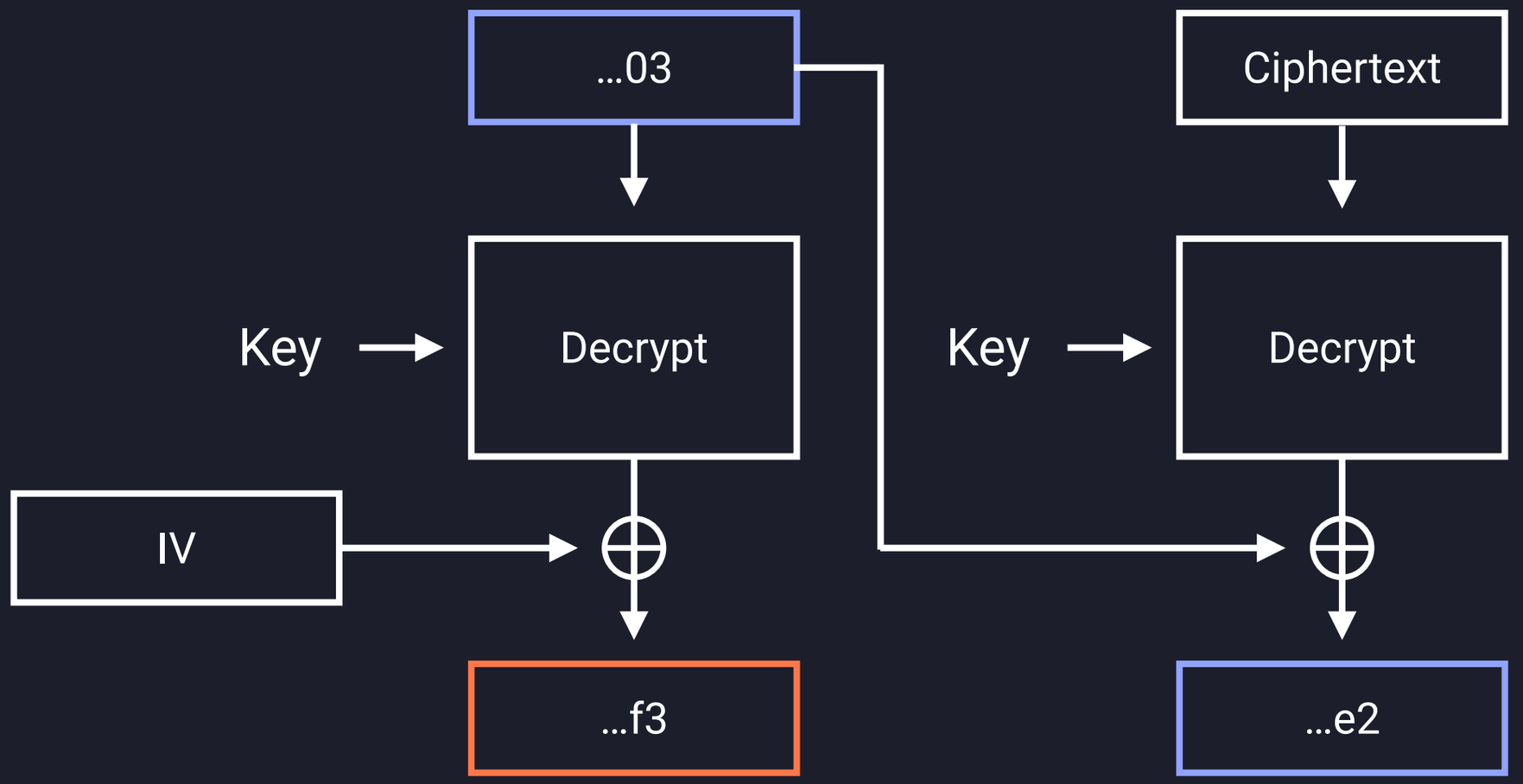
CBC Mode / Bit-Flipping Attack



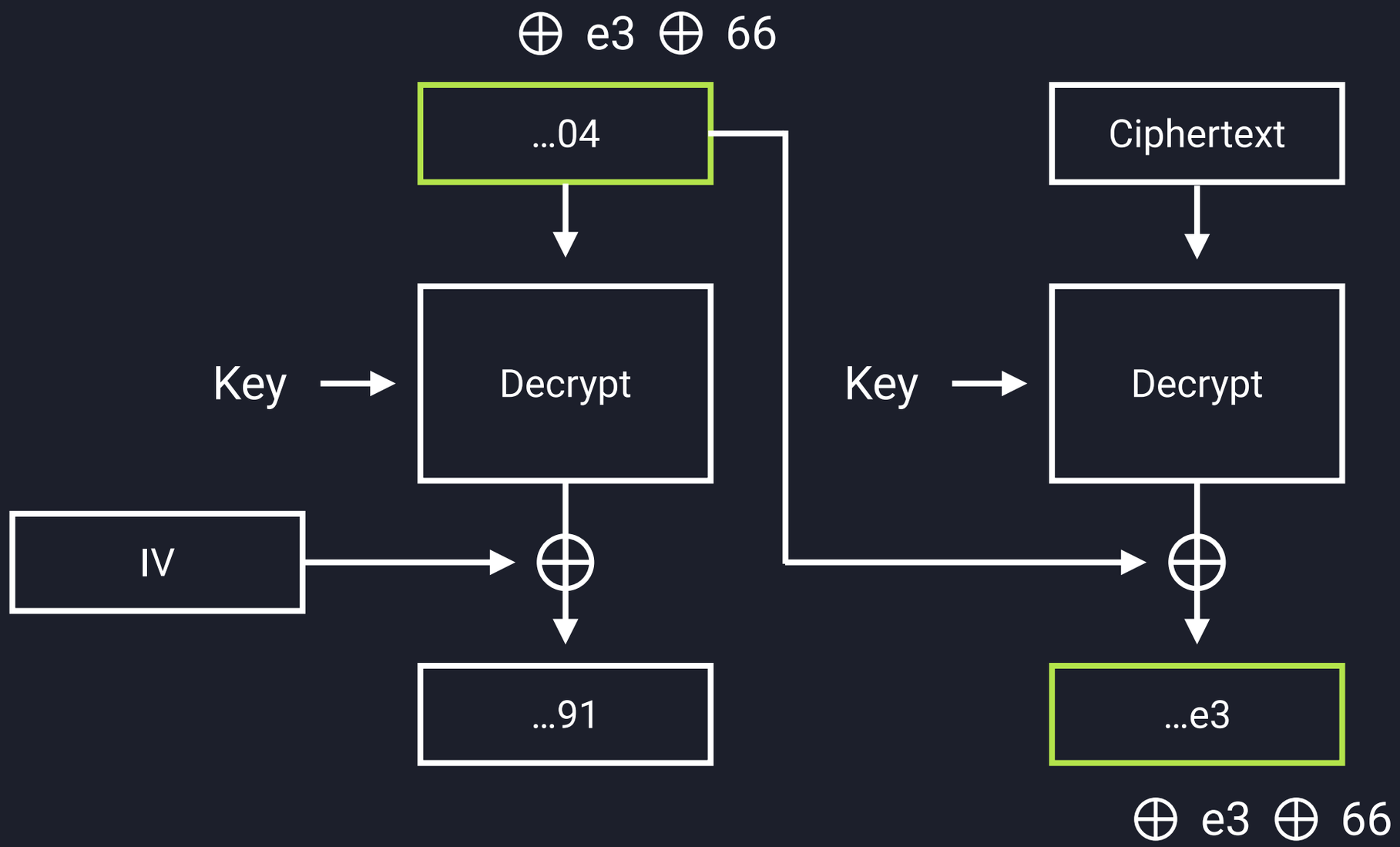
CBC Mode / Bit-Flipping Attack



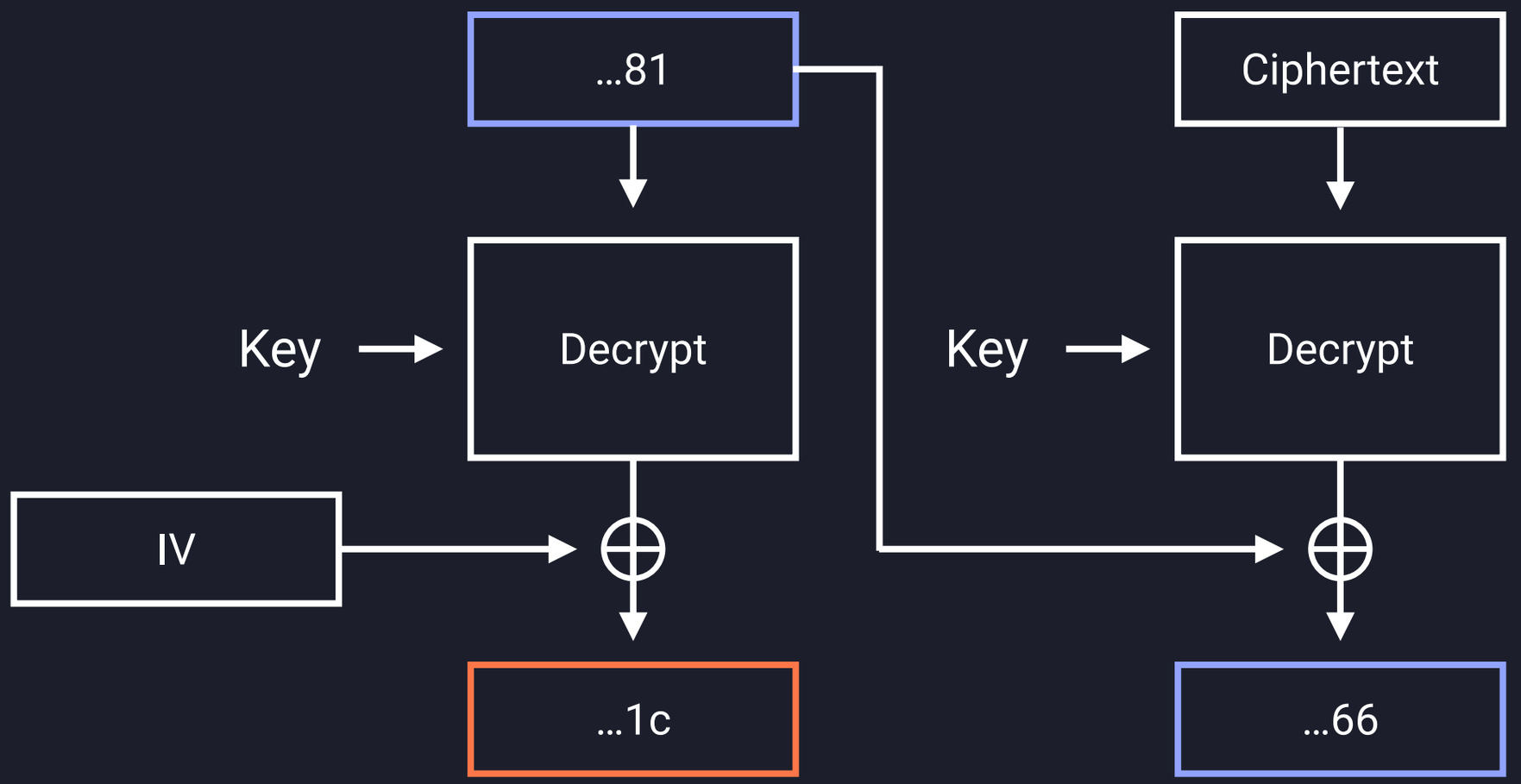
CBC Mode / Bit-Flipping Attack



CBC Mode / Bit-Flipping Attack



CBC Mode / Bit-Flipping Attack



將解密的明文改成我們指定的 0x66

CBC Mode / Bit-Flipping Attack

- 透過修改 IV 和 Ciphertext 來控制 Plaintext
- 其他 CFB, OFB, CTR 也存在相同的攻擊方式

CTF Challenges

- **AIS3 preexam 2018 - EFAIL**
- **AIS3 preexam 2018 - BLIND**
- **AceBear CTF - CNVService**
- **Teaser Dragon CTF 2018 - AES-128-TSB**

CBC Mode / Padding Oracle Attack

The Oracle

- 使用 AES CBC Mode 配上 PKCS#7 Padding Scheme
- 伺服器能幫我們解密訊息
- 如果解密出來的訊息 Padding 錯誤會噴錯

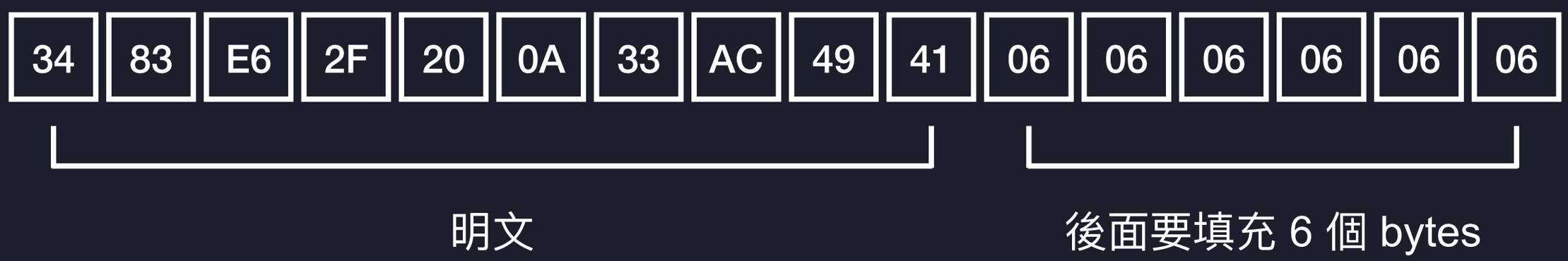
```
def unpad(data):
    if not all([x == data[-1] for x in data[-data[-1]:]]):
        raise ValueError
    return data[:-data[-1]]

def oracle(cipher):
    aes = AES.new(KEY, AES.MODE_CBC)
    try:
        plain = unpad(aes.decrypt(cipher))
    except ValueError:
        return False
    return True
```

PKCS#7

PKCS#7 : Cryptographic Message Syntax

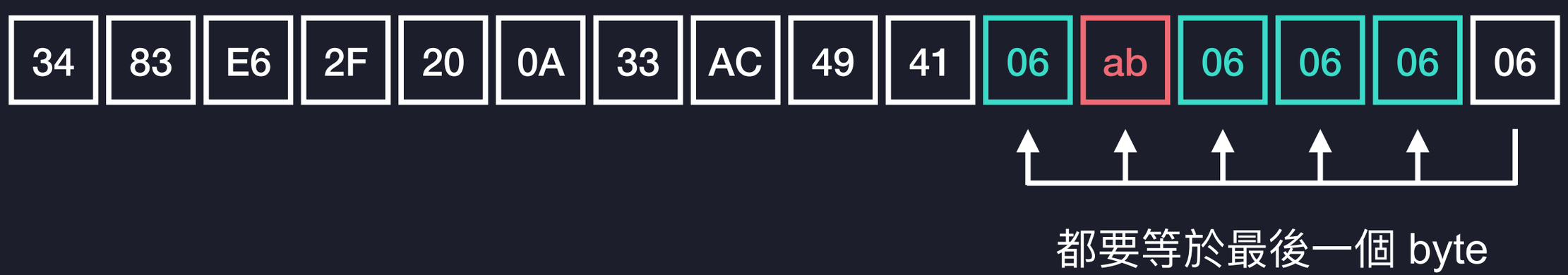
https://tools.ietf.org/html/rfc2315

- 這個標準裡面定義了一種 Padding 的格式
  - 要填充 5 個 bytes 就填充 5 個 0x05
  - 要填充 2 個 bytes 就填充 2 個 0x02



Padding 錯誤

- 怎麼樣會 Padding 錯誤？
- 抓最後一個 byte 就可以知道 Padding 長度

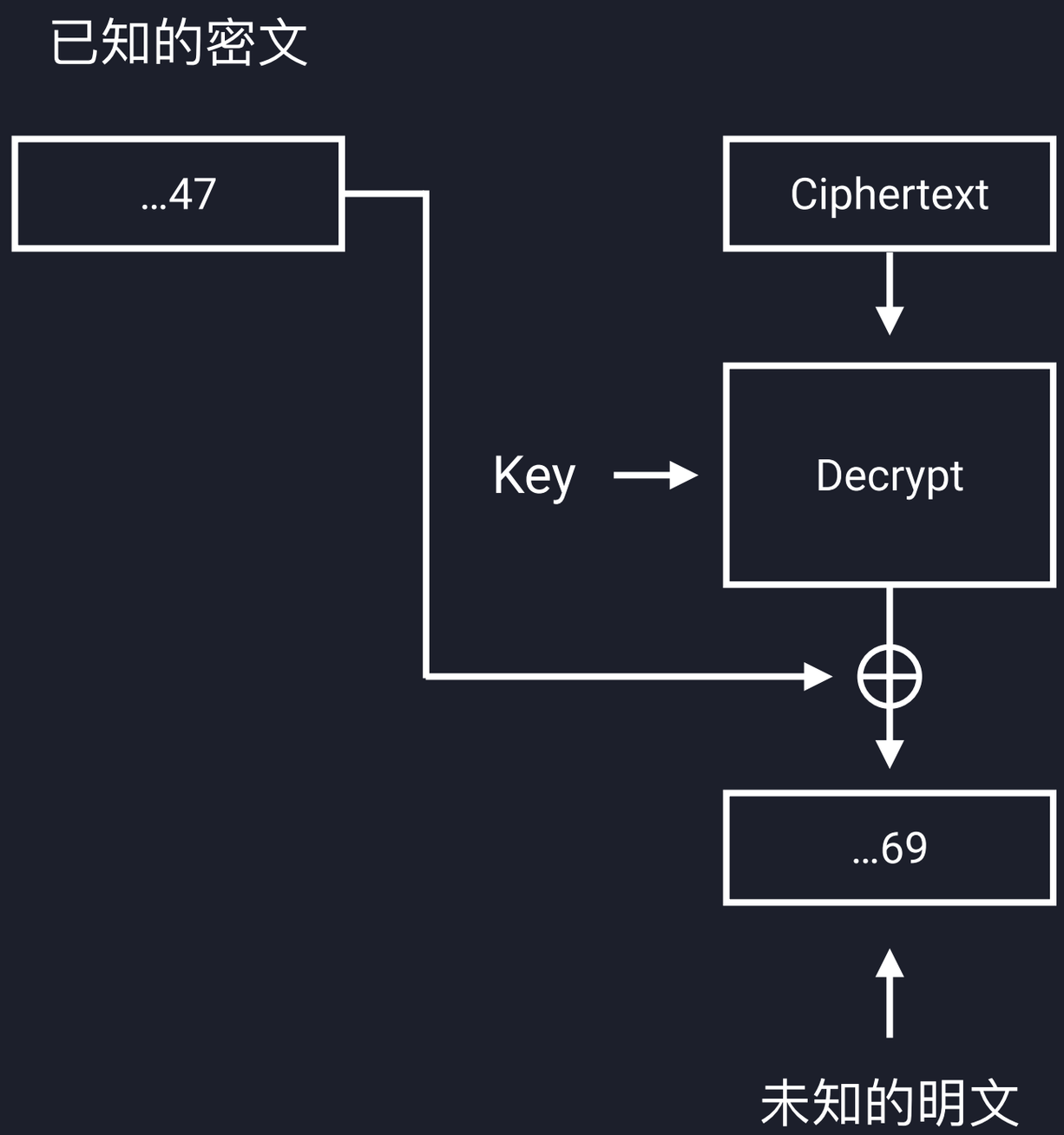


Python Implementation

```
def pad(data):
    p = 16 - len(data) % 16
    return data + bytes([p]) * p

def unpad(data):
    if not all([x == data[-1] for x in data[-data[-1]:]]):
        raise ValueError
    return data[:-data[-1]]
```

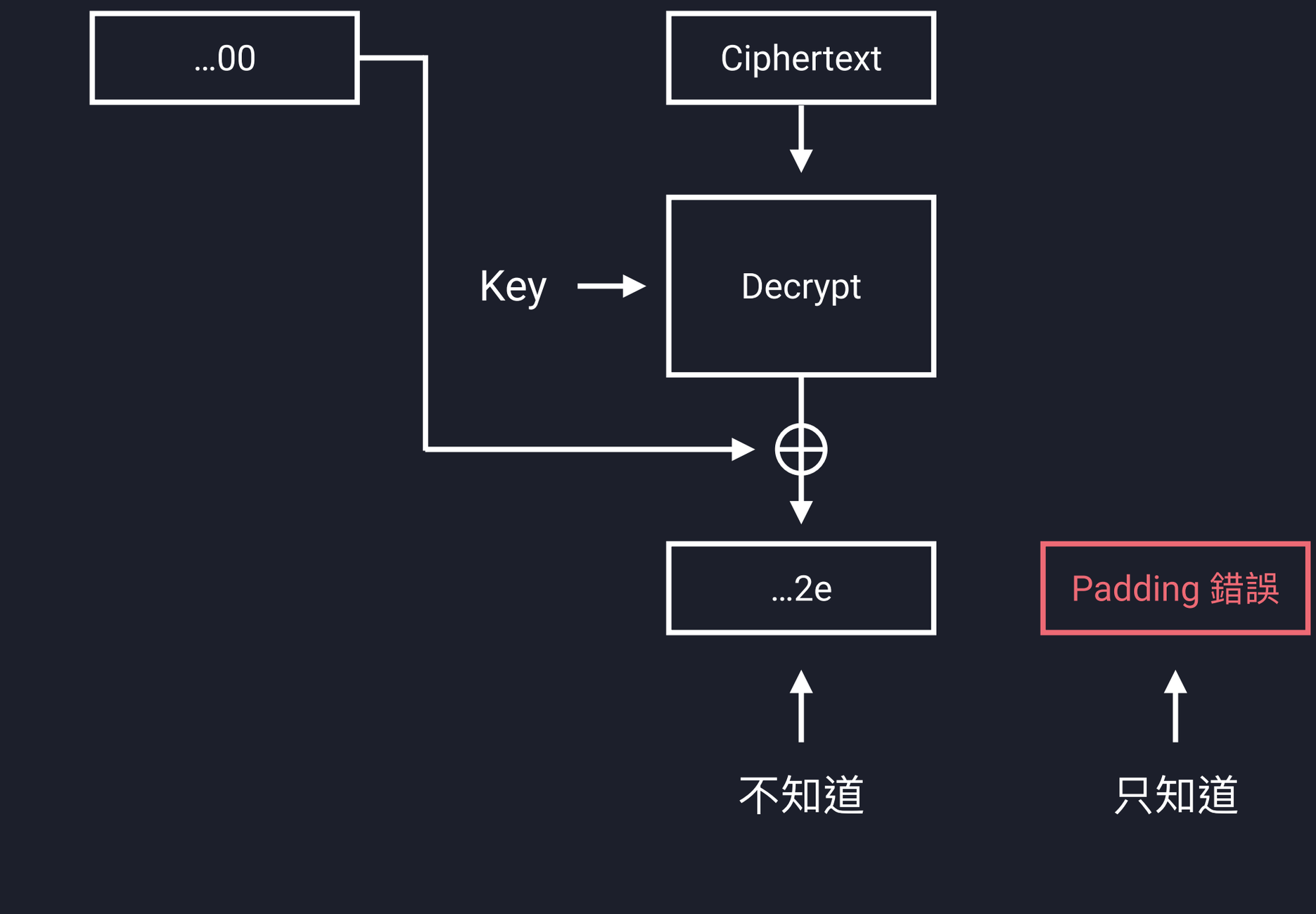
解 plaintext[-1]

Padding Oracle Attack



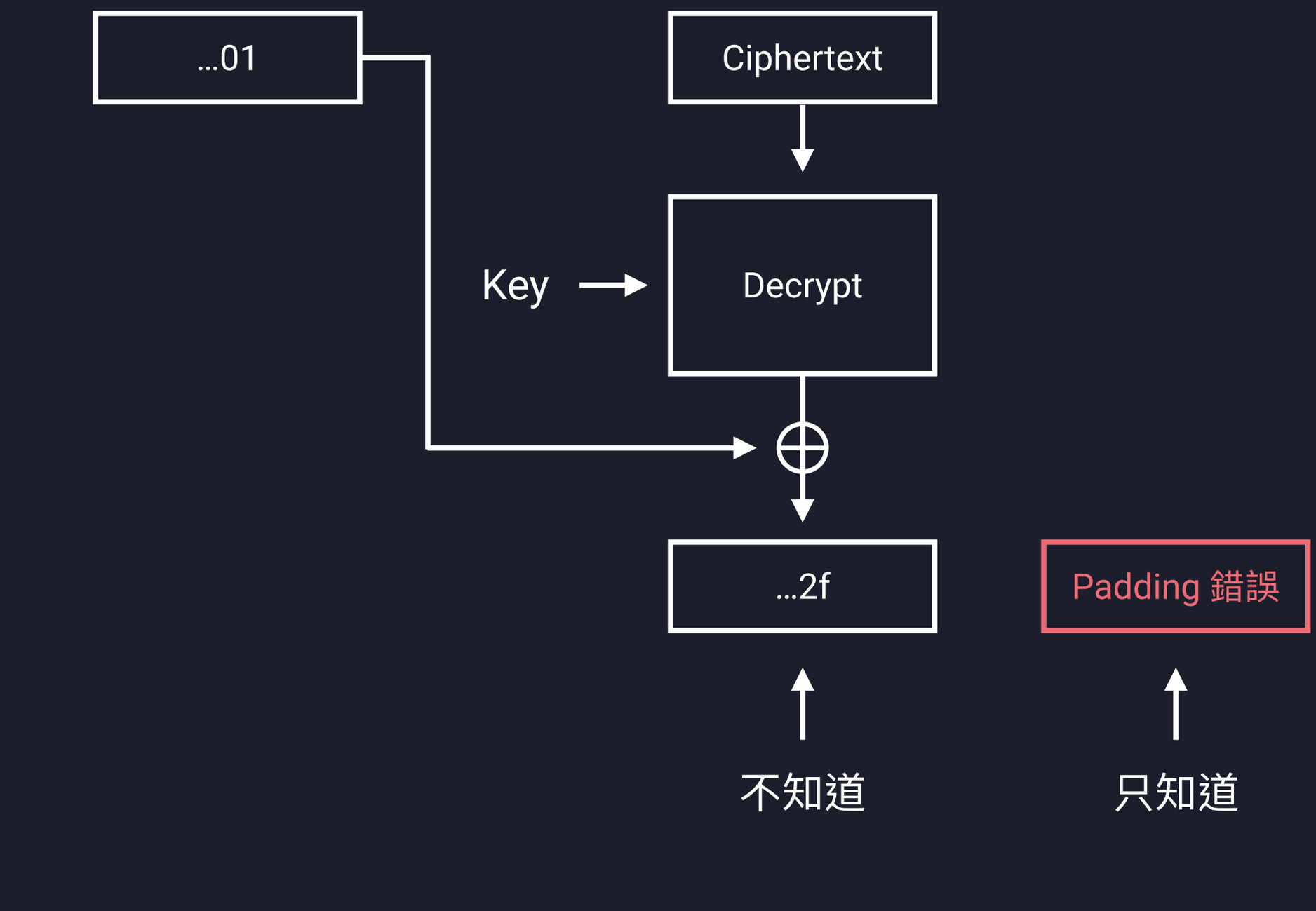
Padding Oracle Attack

暴力嘗試最後一個 byte



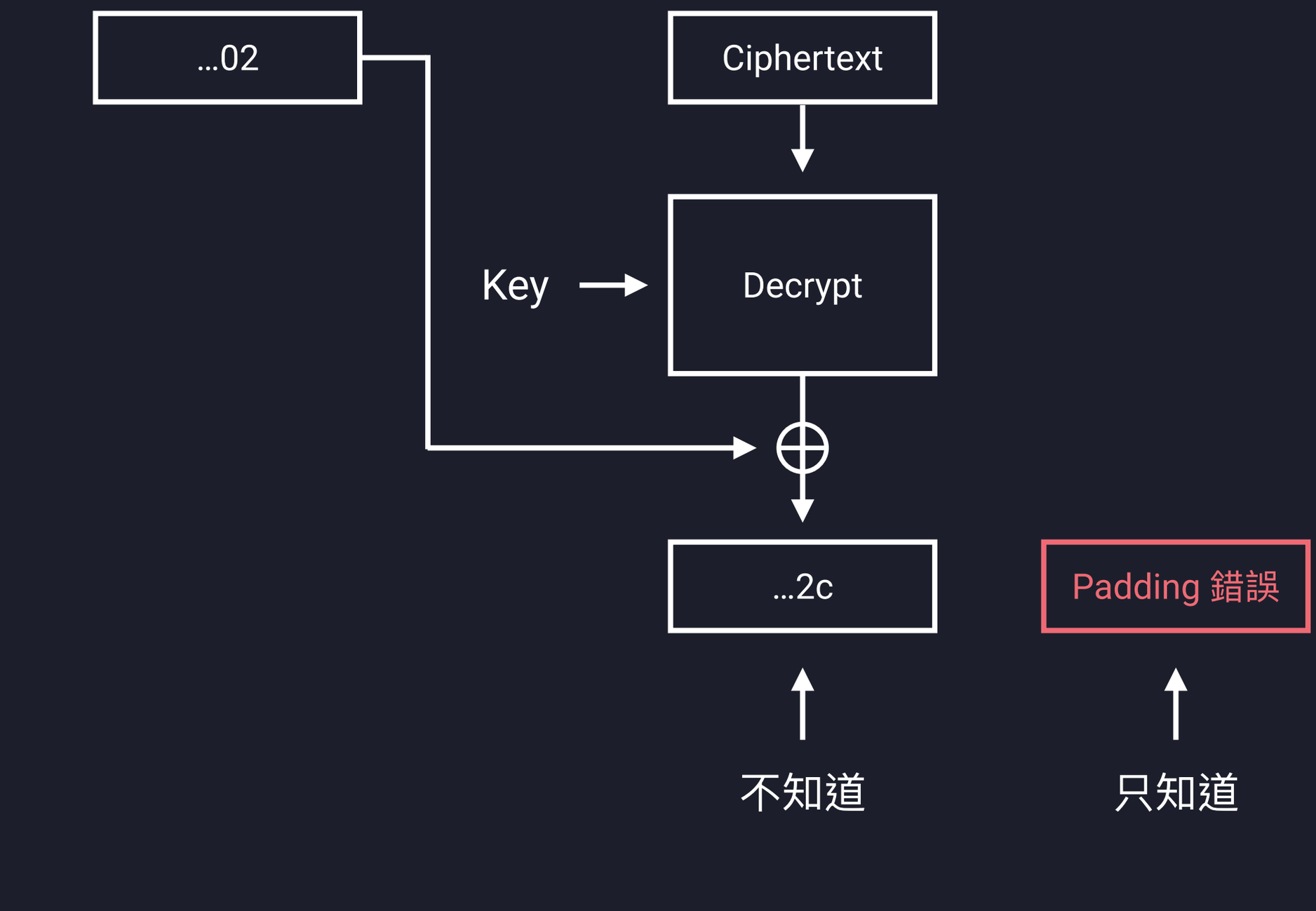
Padding Oracle Attack

暴力嘗試最後一個 byte



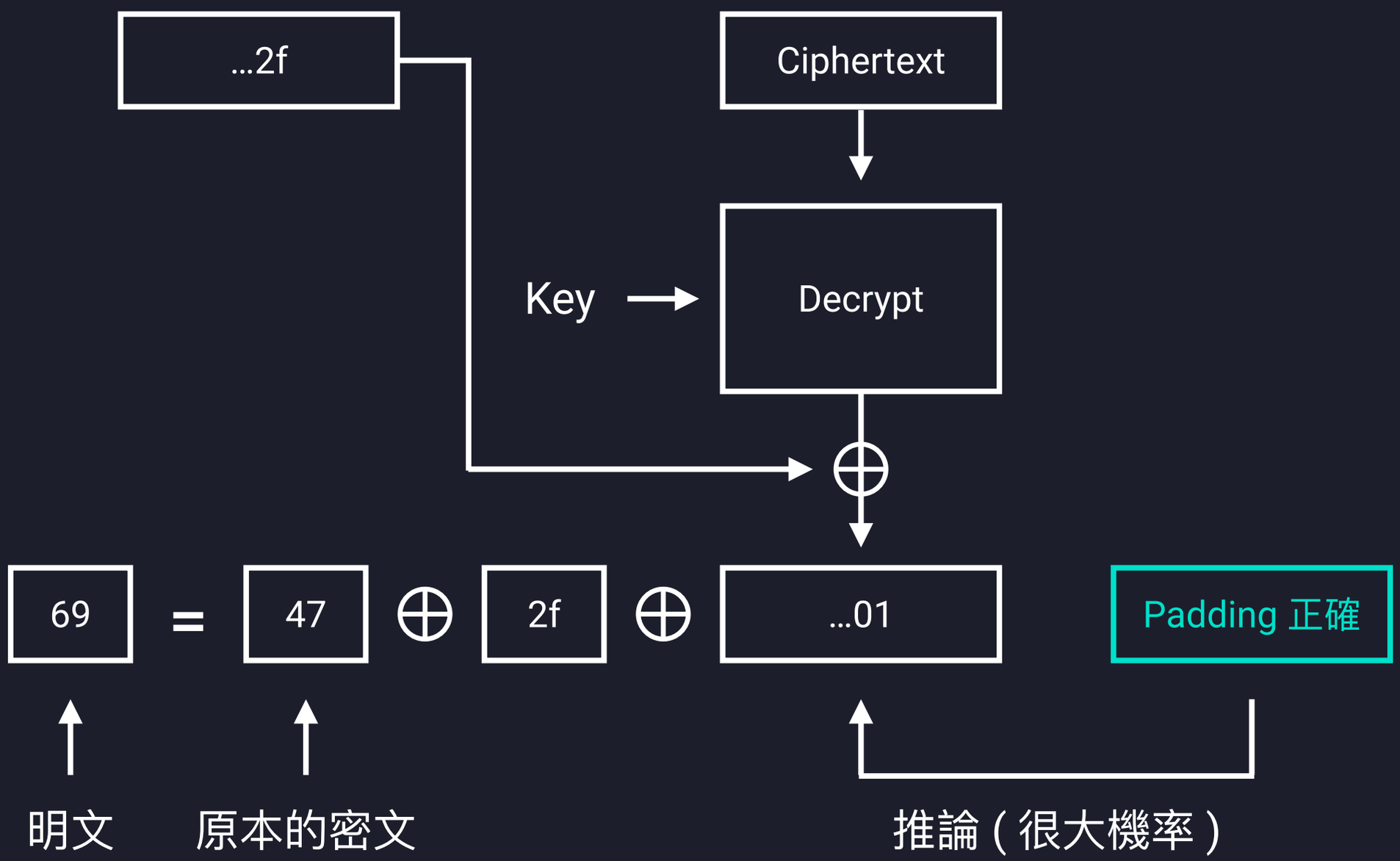
Padding Oracle Attack

暴力嘗試最後一個 byte



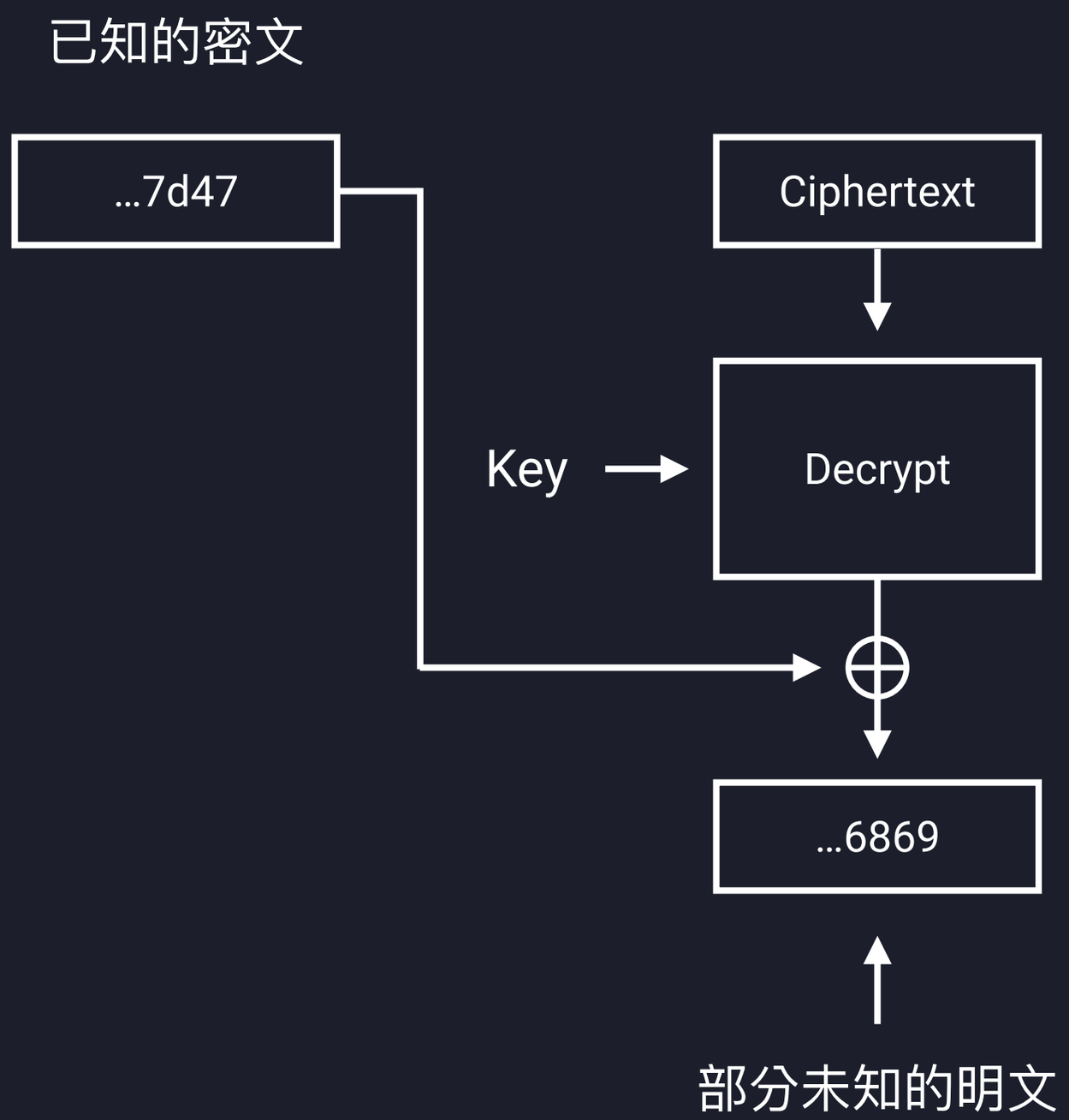
Padding Oracle Attack

暴力嘗試最後一個 byte



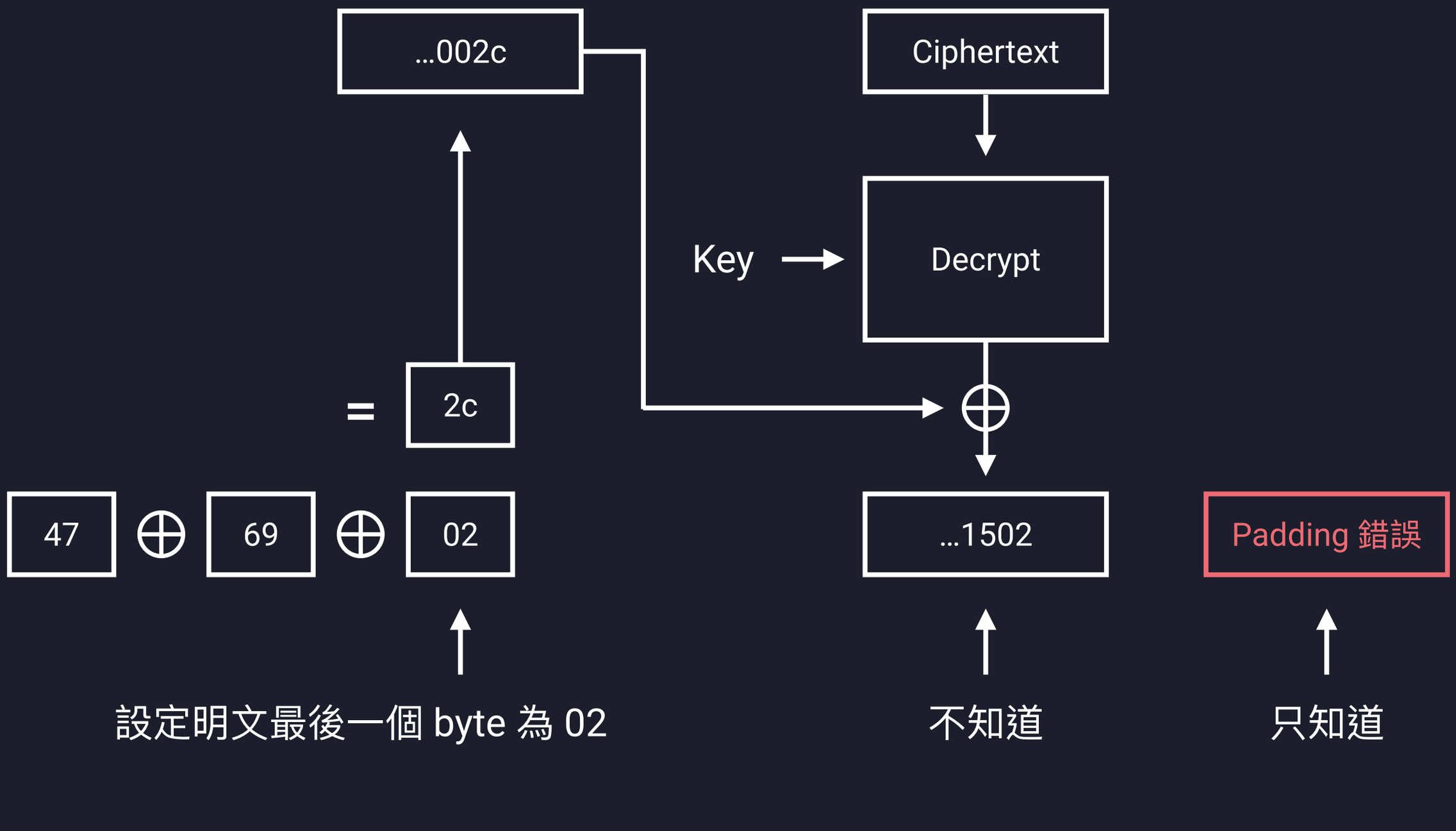
解 plaintext[-2]

Padding Oracle Attack



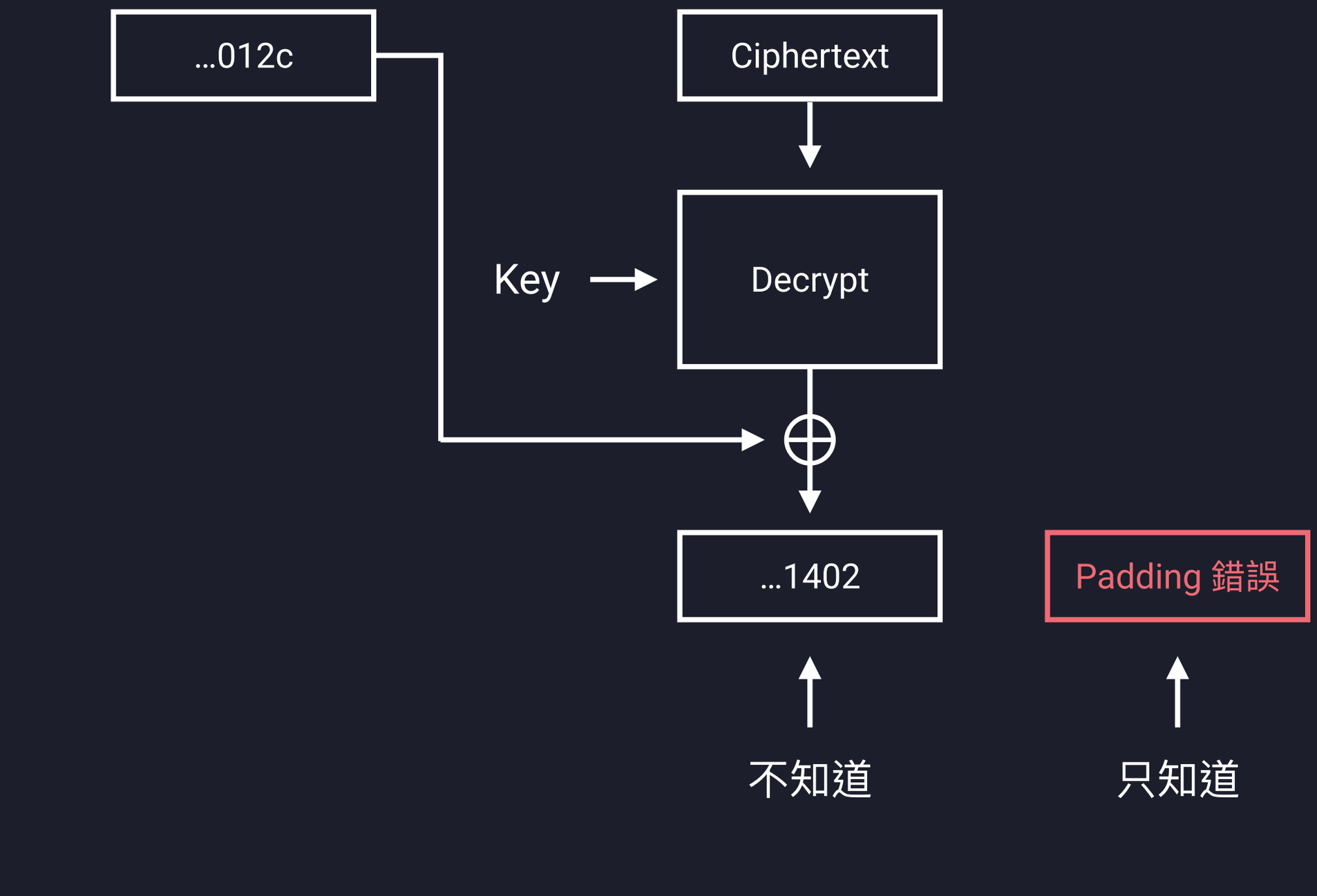
Padding Oracle Attack

暴力嘗試倒數第二個 byte



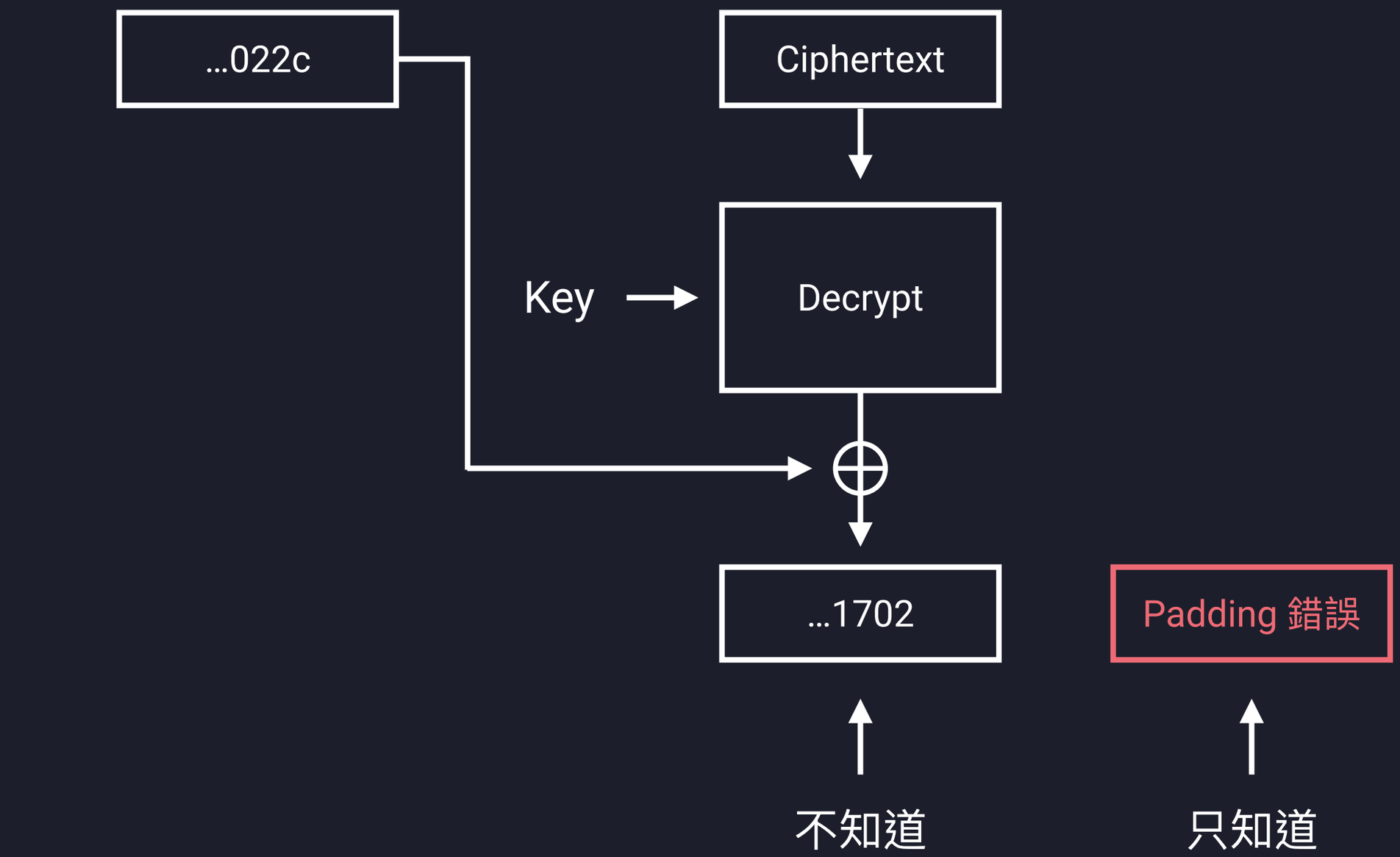
Padding Oracle Attack

暴力嘗試倒數第二個 byte



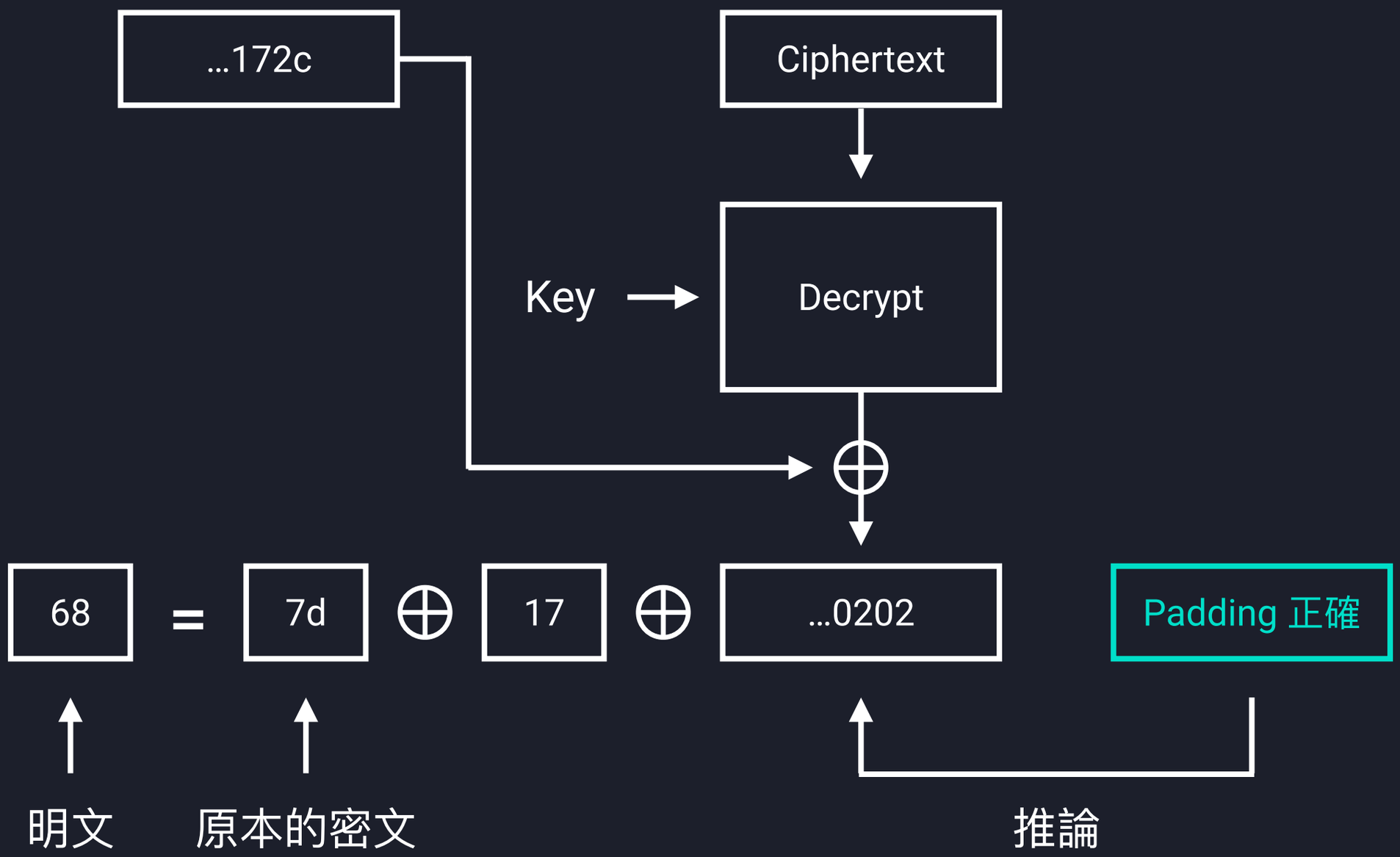
Padding Oracle Attack

暴力嘗試倒數第二個 byte



Padding Oracle Attack

暴力嘗試倒數第二個 byte



Summary

- 總共有三層迴圈
  - 猜 0 - 255 直到猜出一個 byte
  - 一次解出一個 byte 直到解完一個 block
  - 一次解出一個 block 直到解完所有 blocks
- 解出一個 block 最多需要 4096 次嘗試

CTF Challenges

原汁原味 padding oracle attack :

- CSAW CTF 2016 Quals - Neo
- HITCON CTF 2016 Quals - Hackpad
- BAMBOOFOX CTF 2018 - mini-padding

padding 相關攻擊技巧 :

- HITCON CTF 2017 Quals - Secret Server
- HITCON CTF 2017 Quals - Secret Server Revenge
- BAMBOOFOX CTF 2018 - baby-lea-revenge
- BAMBOOFOX CTF 2018 - baby-lea-impossible

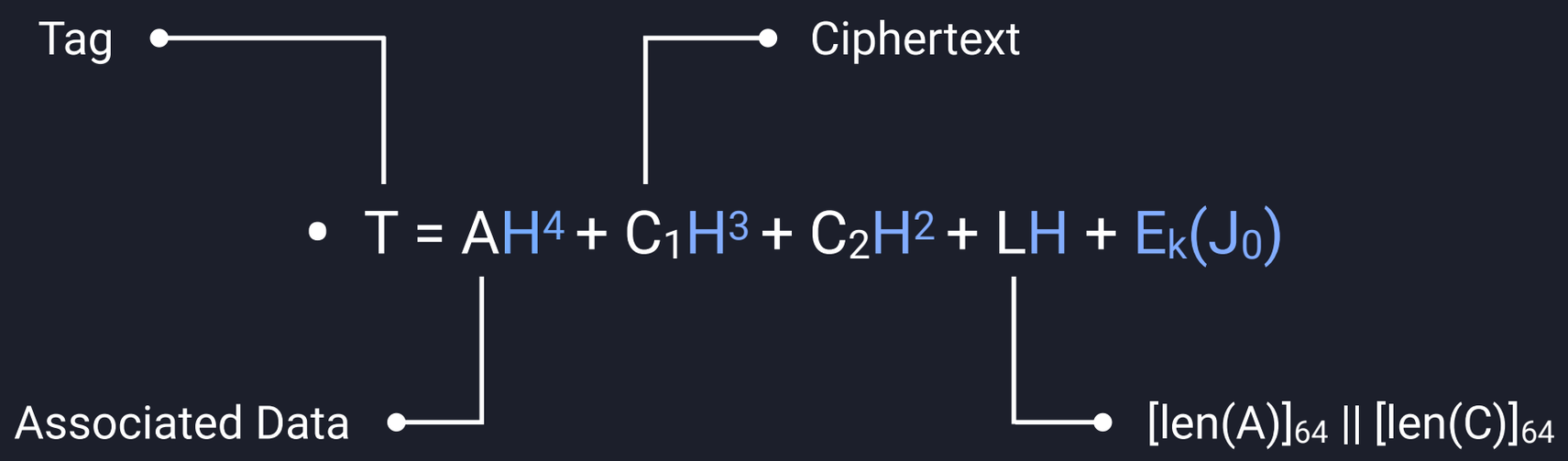
GCM Mode / Forbidden Attack

GCM Mode / Forbidden Attack

- 又叫 Nonce Repeating Attack
- 也就是當 IV 重複用的情況
- 假設可以拿到任意明文加密的結果
- 這個攻擊可以做到**偽造簽章**

GCM Mode / Forbidden Attack

- 在 Authentication 中做的 xor 就是 GF(2^{128}) 中的加法
- Tag 可以表示成在 GF(2^{128}) 中的式子如下



未知的只有藍色的部分

GCM Mode / Forbidden Attack

- 做兩次加密拿到兩個 Tag
- 兩個相減後只剩 H 未知，解方程式求根可得 H
- 有 H 帶回原式可得 $E_k(J_0)$ 就可以偽造 Tag 了

- $T_1 = A_1H^4 + C_{11}H^3 + C_{12}H^2 + L_1H + E_k(J_0)$
- $T_2 = A_2H^4 + C_{21}H^3 + C_{22}H^2 + L_2H + E_k(J_0)$
- $T_1 - T_2 = (A_1 - A_2)H^4 + (C_{11} - C_{21})H^3 + (C_{12} - C_{22})H^2 + (L_1 - L_2)H$

CTF Challenges

- **UTCTF 2020 - Galois**
- **VolgaCTF 2018 Quals - Forbidden**