# CSE467: Computer Security

## 5-1. Symmetric-key Encryption (2)

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# Notice: Homework #1



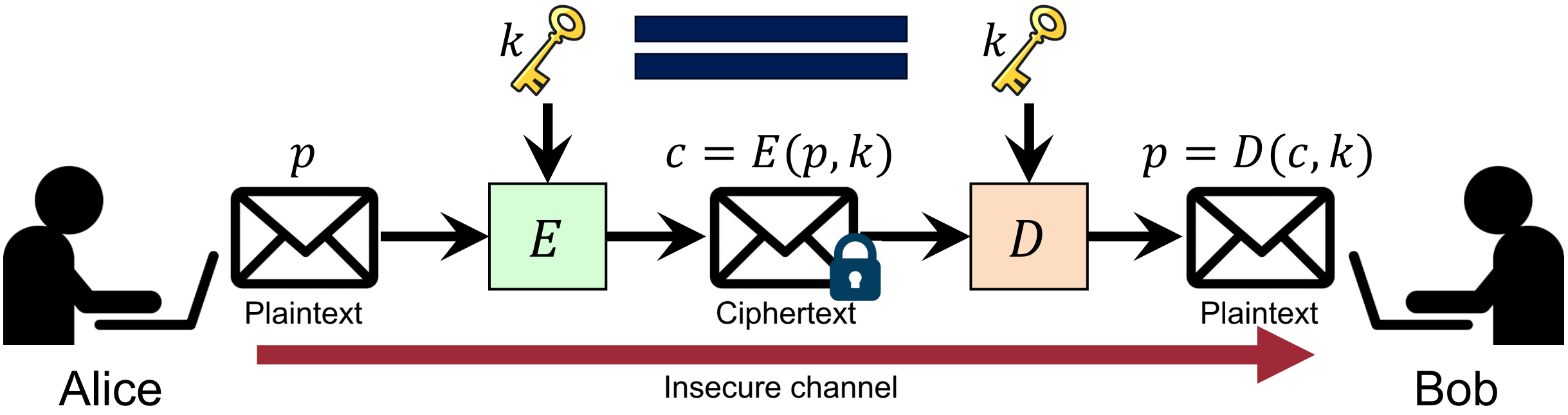
- Programming assignment
- Will be noticed within today! (Please refer to the course homepage)
- Due: Sep 21, 11:59 PM

- Implementing encryption, decryption, signing program for the RSA cryptosystem

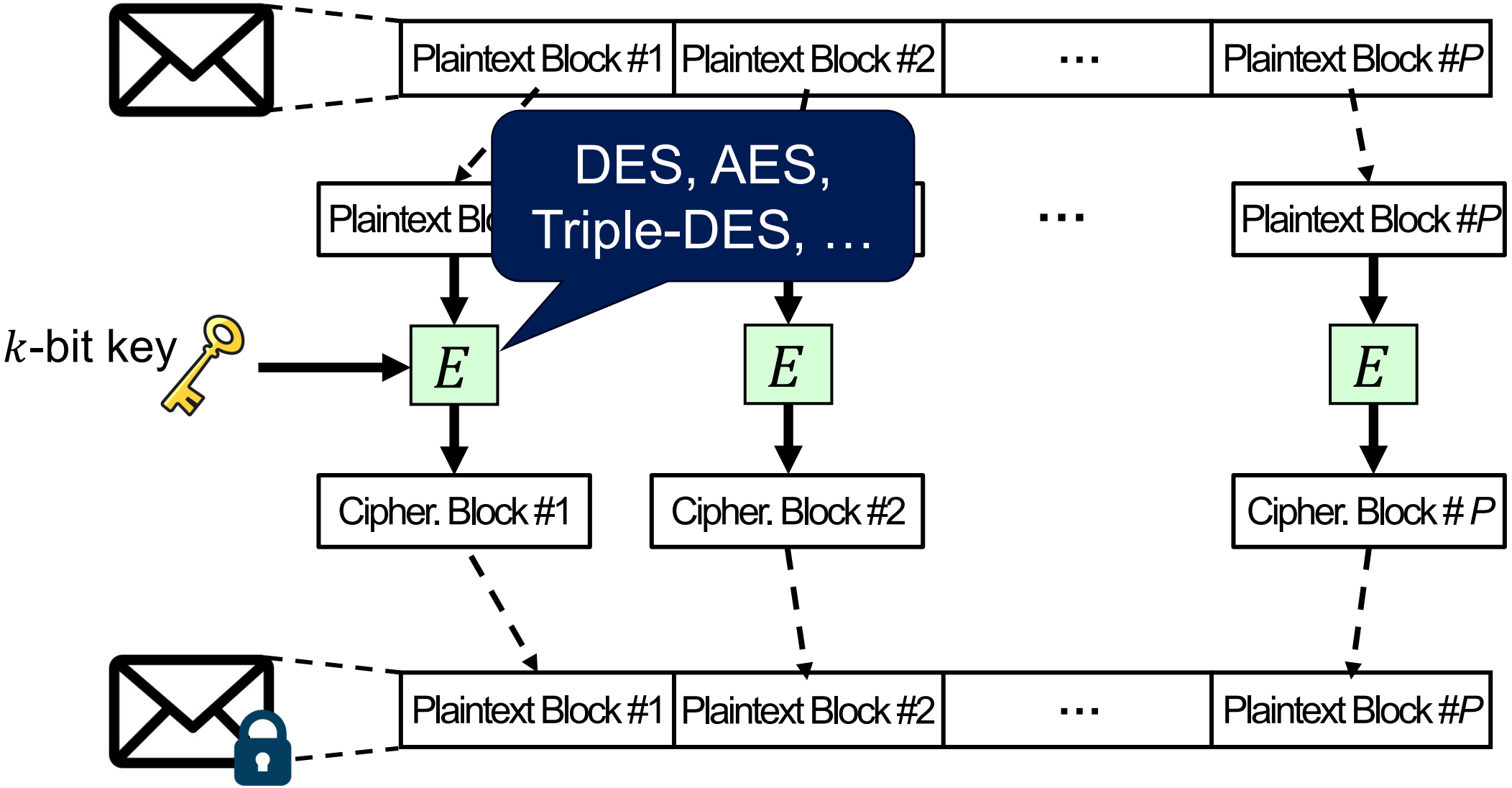
- Late submission will be assessed a penalty of 10% per day.

# Recap: Symmetric-key Encryption

- **Symmetric**: the encryption and decryption keys *are the same*



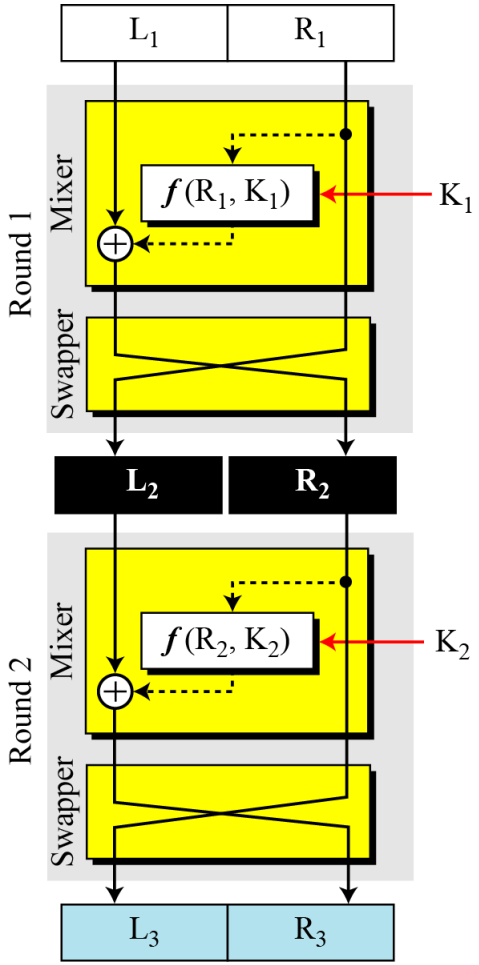
# Recap: Block Cipher



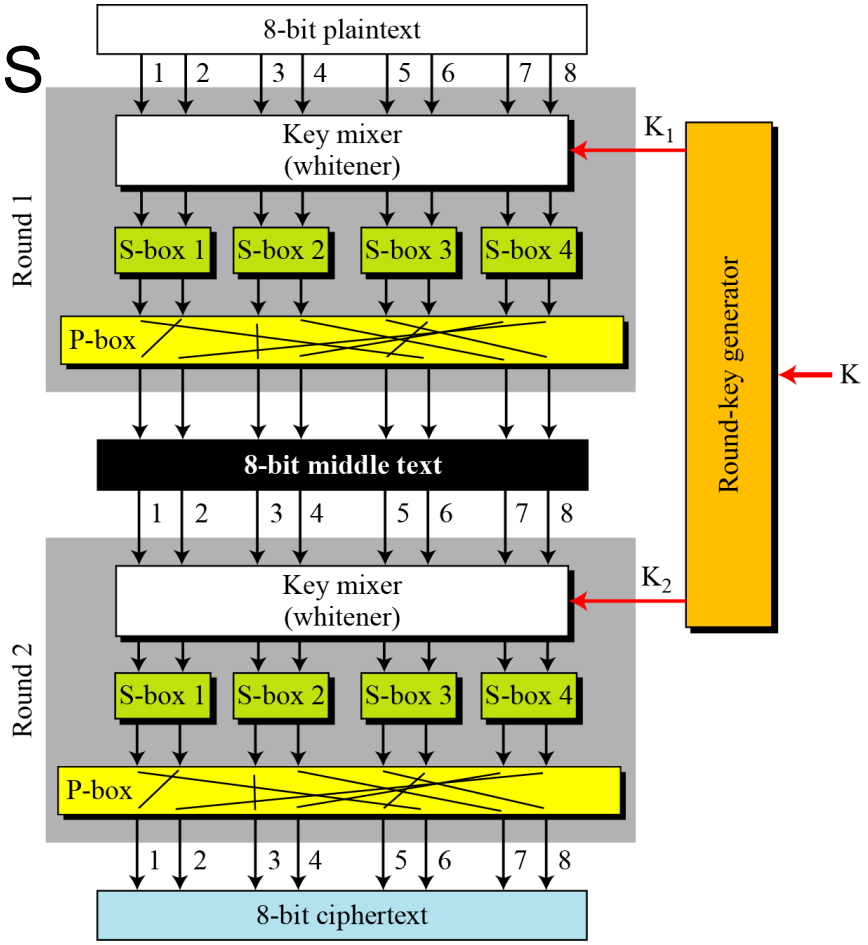
# Recap: Two Classes of Block Ciphers



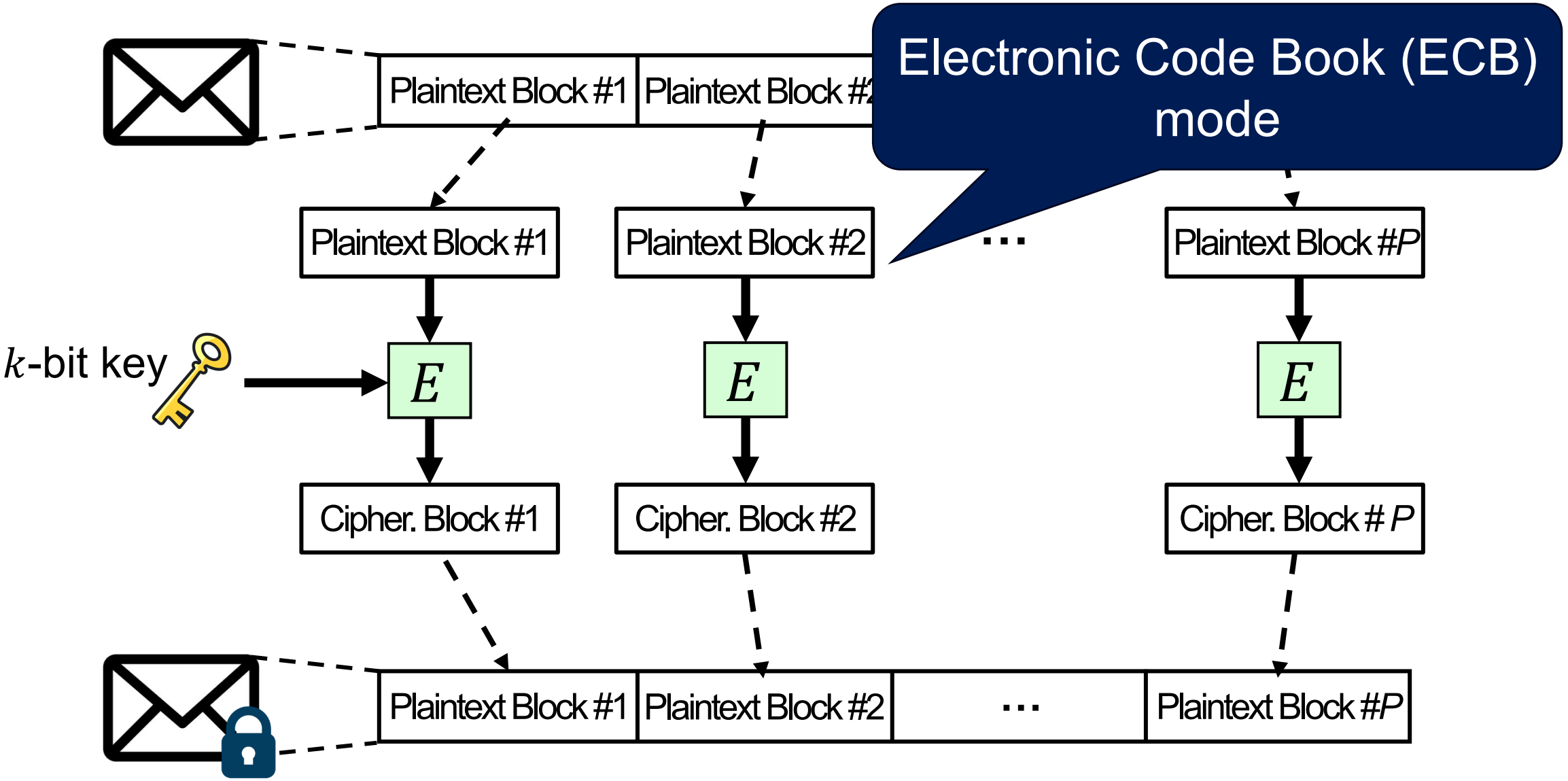
- **Feistel ciphers**
  - E.g., DES



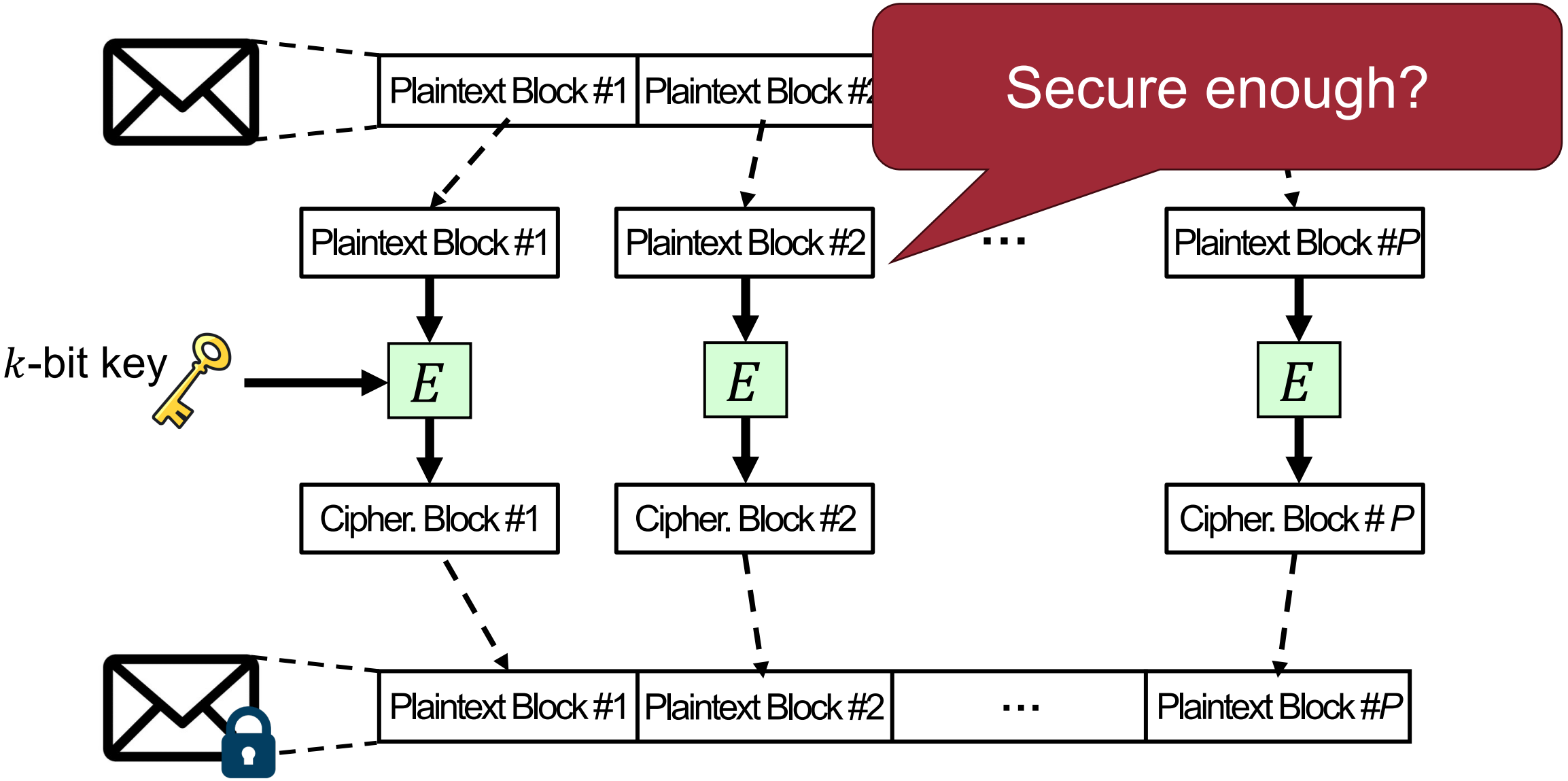

- **Substitution-permutation (SP) ciphers**
  - E.g., AES



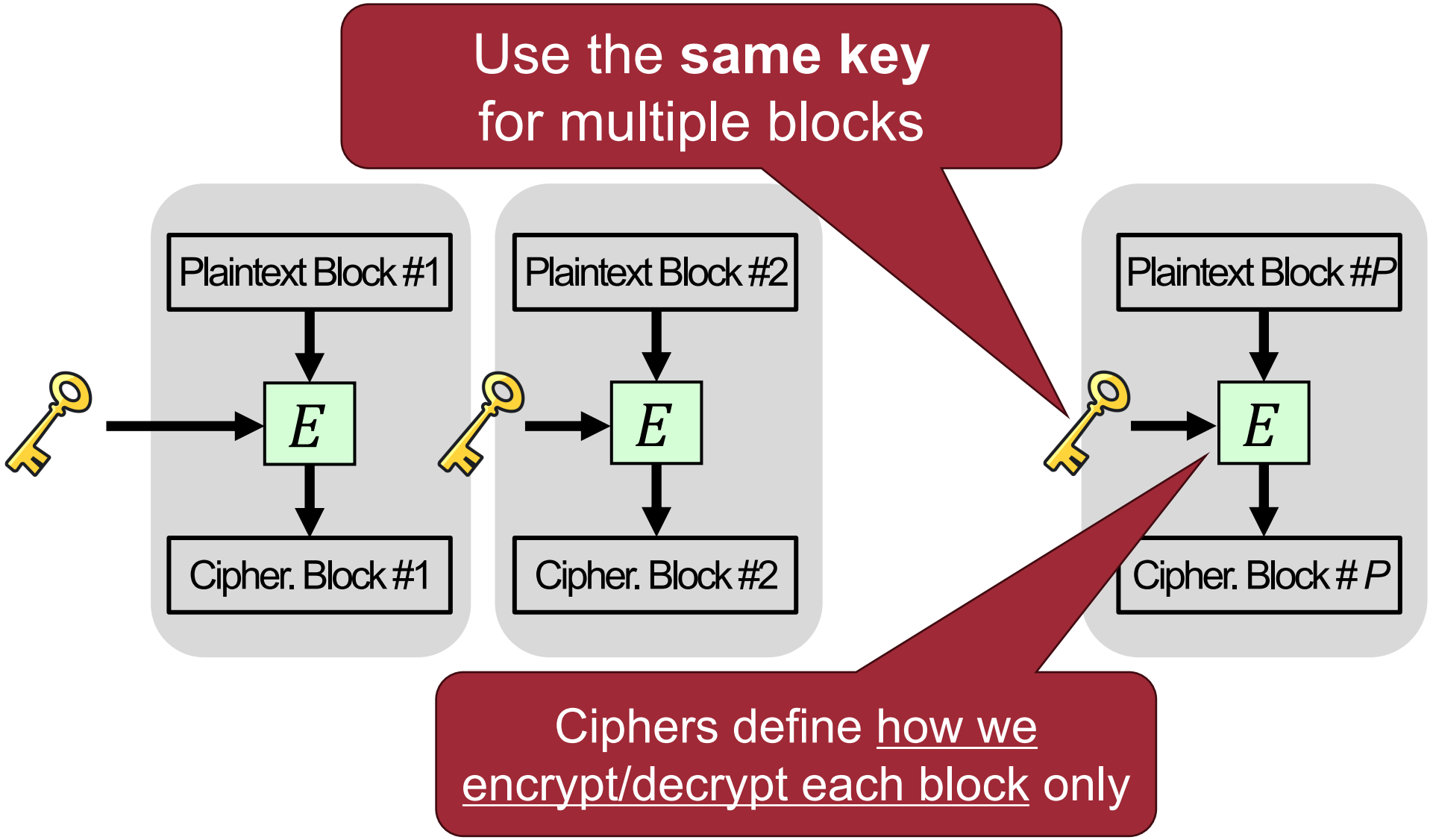
# Practical Use of Block Cipher



# Practical Use of Block Cipher



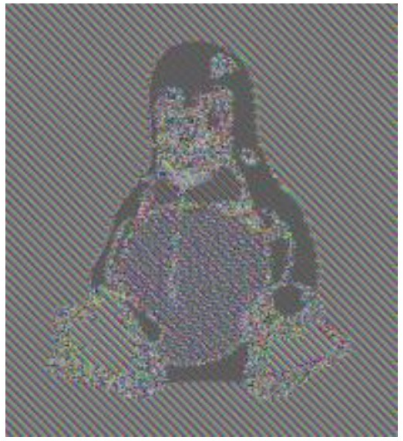
# Problems for ECB mode



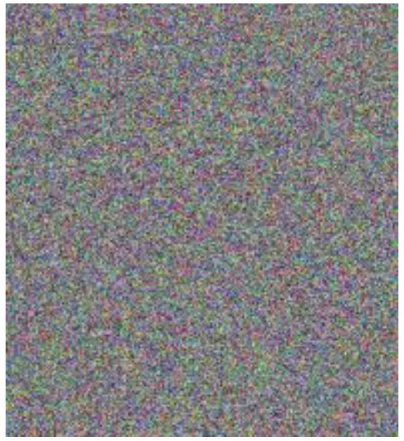
# Problems for ECB mode

- Identical plaintext blocks → identical ciphertext blocks

**Plaintext**



**Ciphertext of the Naive block cipher**



**Ciphertext we want!**

How to generate different ciphertexts for the same plaintext?

# Block Cipher Modes of Operation



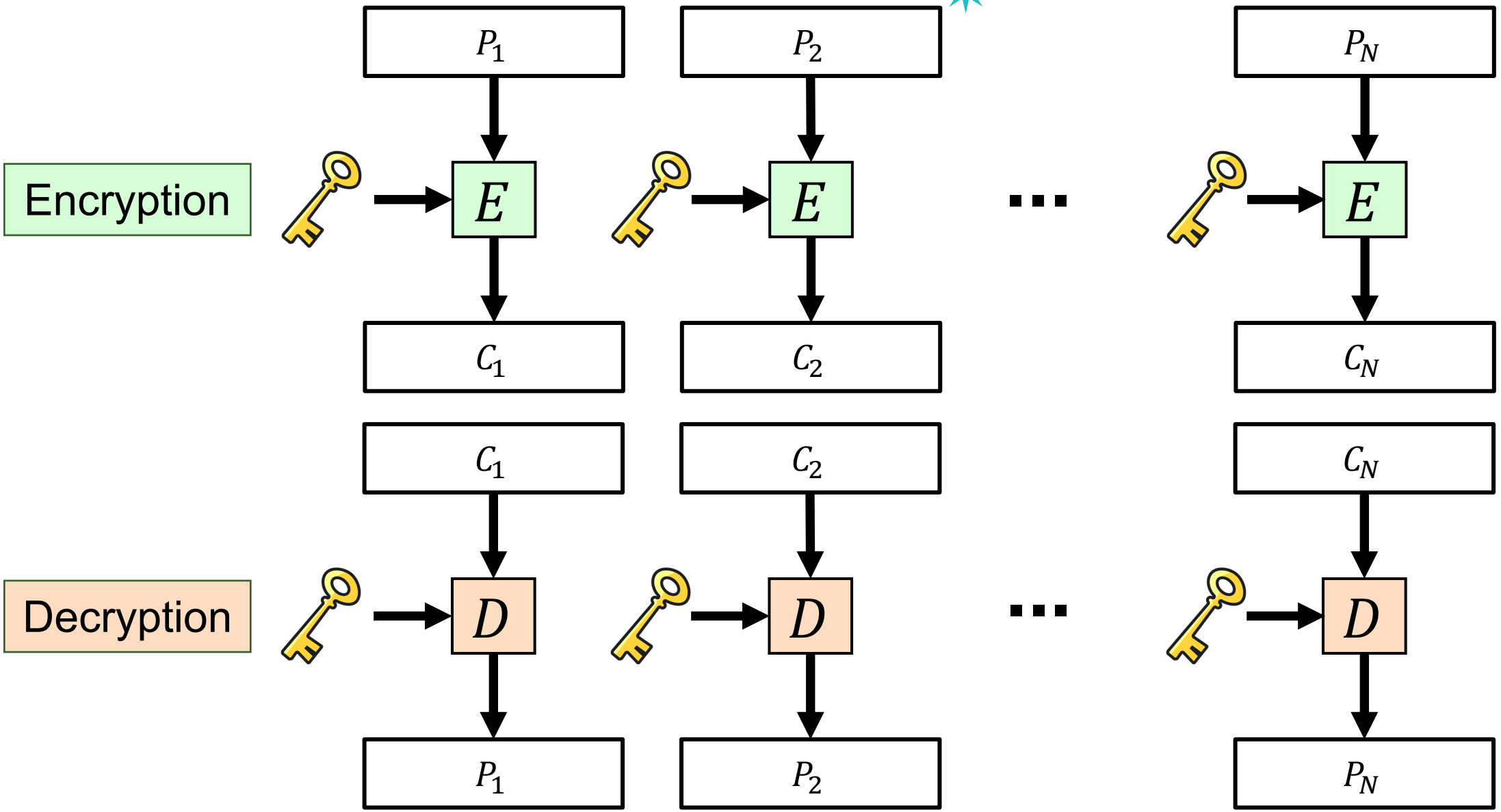
- Determine **how to repeatedly apply a single-block operation** to a sequence of blocks? => Modes of operation!
- Different modes of operations
  - ECB: Electronic Code Book (The naïve one we've just discussed)
  - CBC: Cipher Block Chaining
  - CFB: Cipher FeedBack
  - OFB: Output FeedBack
  - CTR: CounTeR mode

Block cipher mode

Shell Command

```
$ openssl enc -aes-128-cfb -e -in plain.bin -out cipher.bin -K
```

# ECB: Electronic Code Book



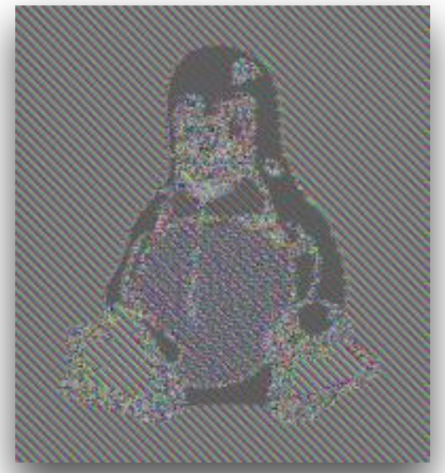
# ECB: Electronic Code Book



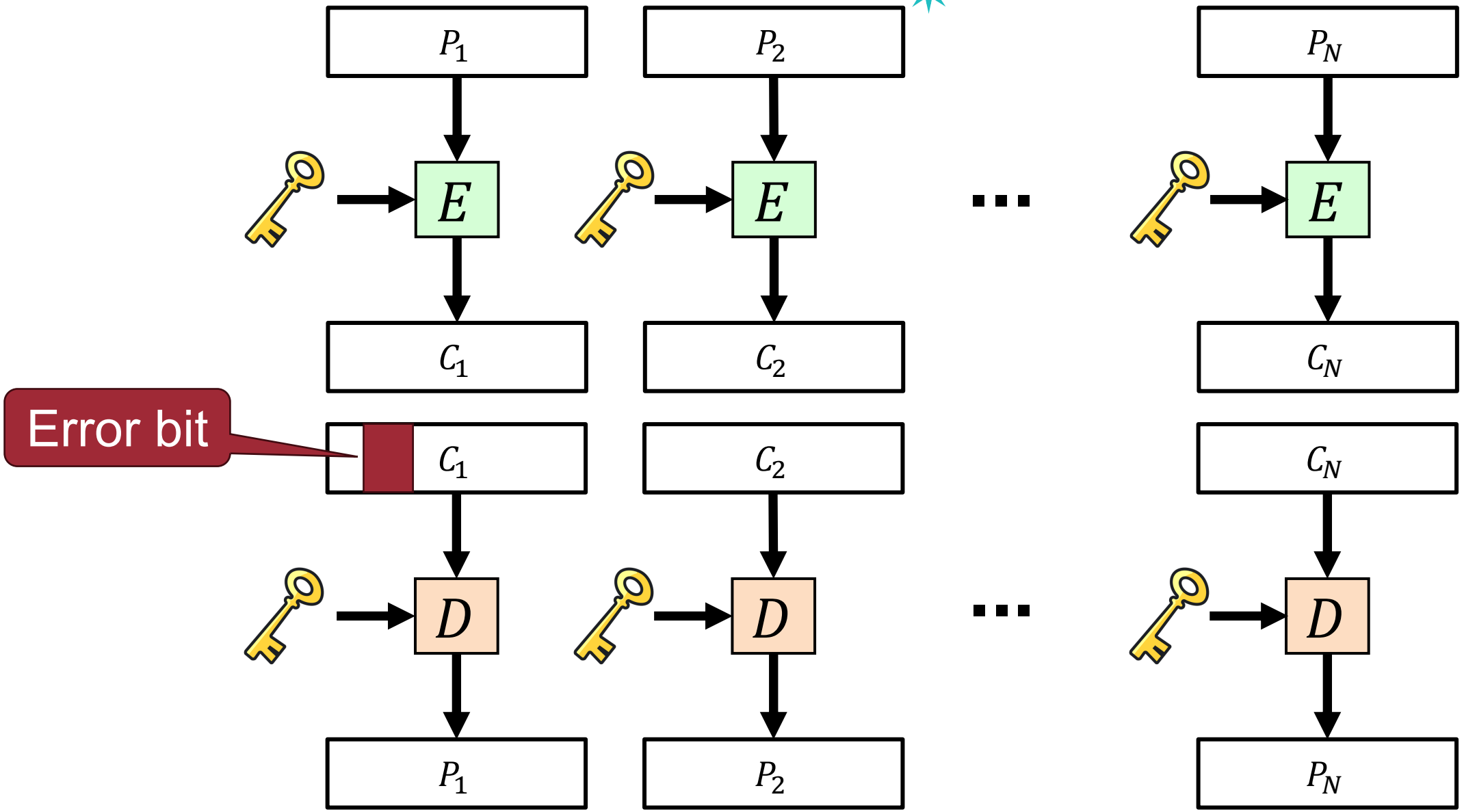
- Each block is encoded independently of the other blocks

- Advantages
  - Simple and efficient (i.e., parallelizable) to compute
  - The error does not have any effects on the other blocks

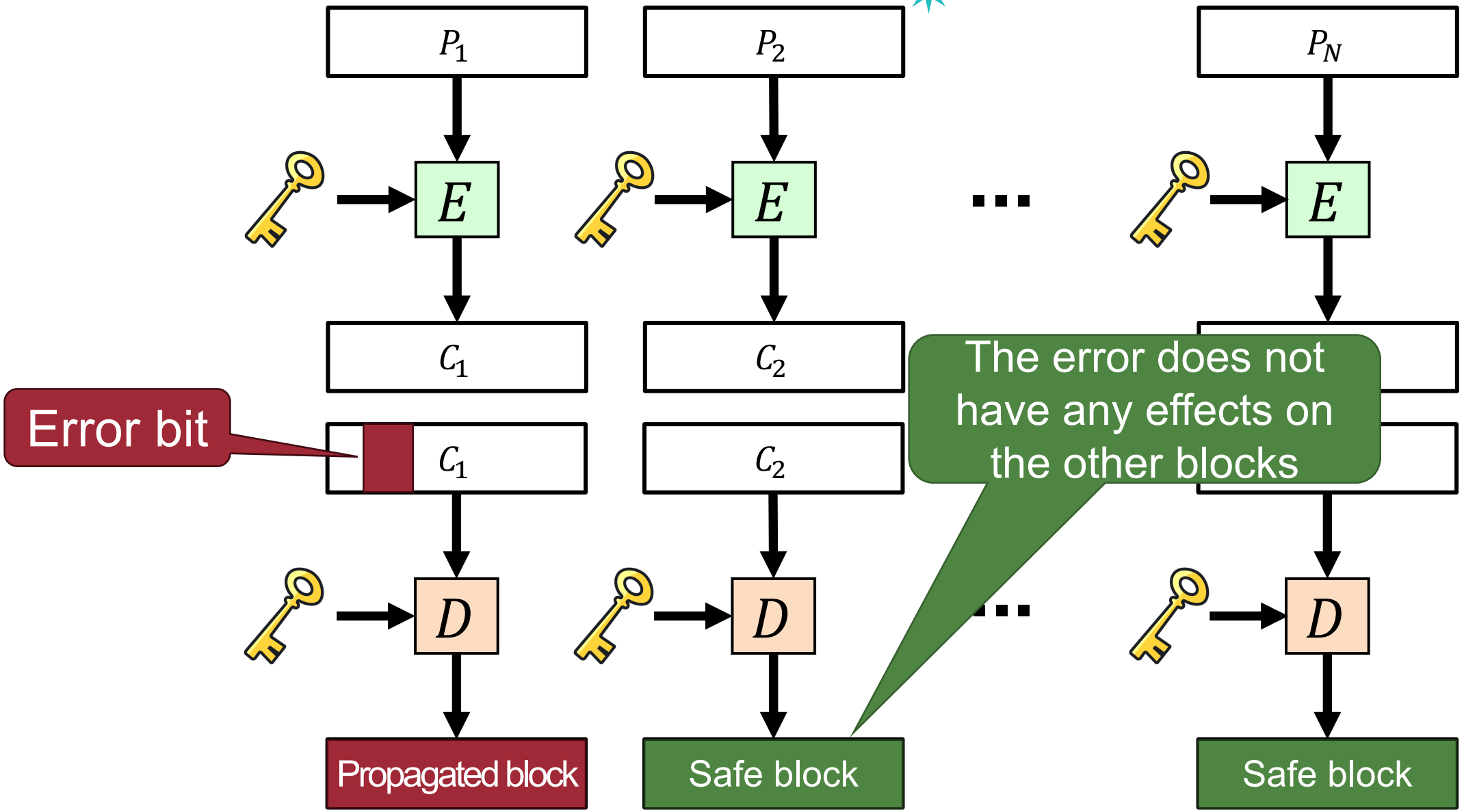
- Disadvantages
  - Same plaintext always corresponds to same ciphertext



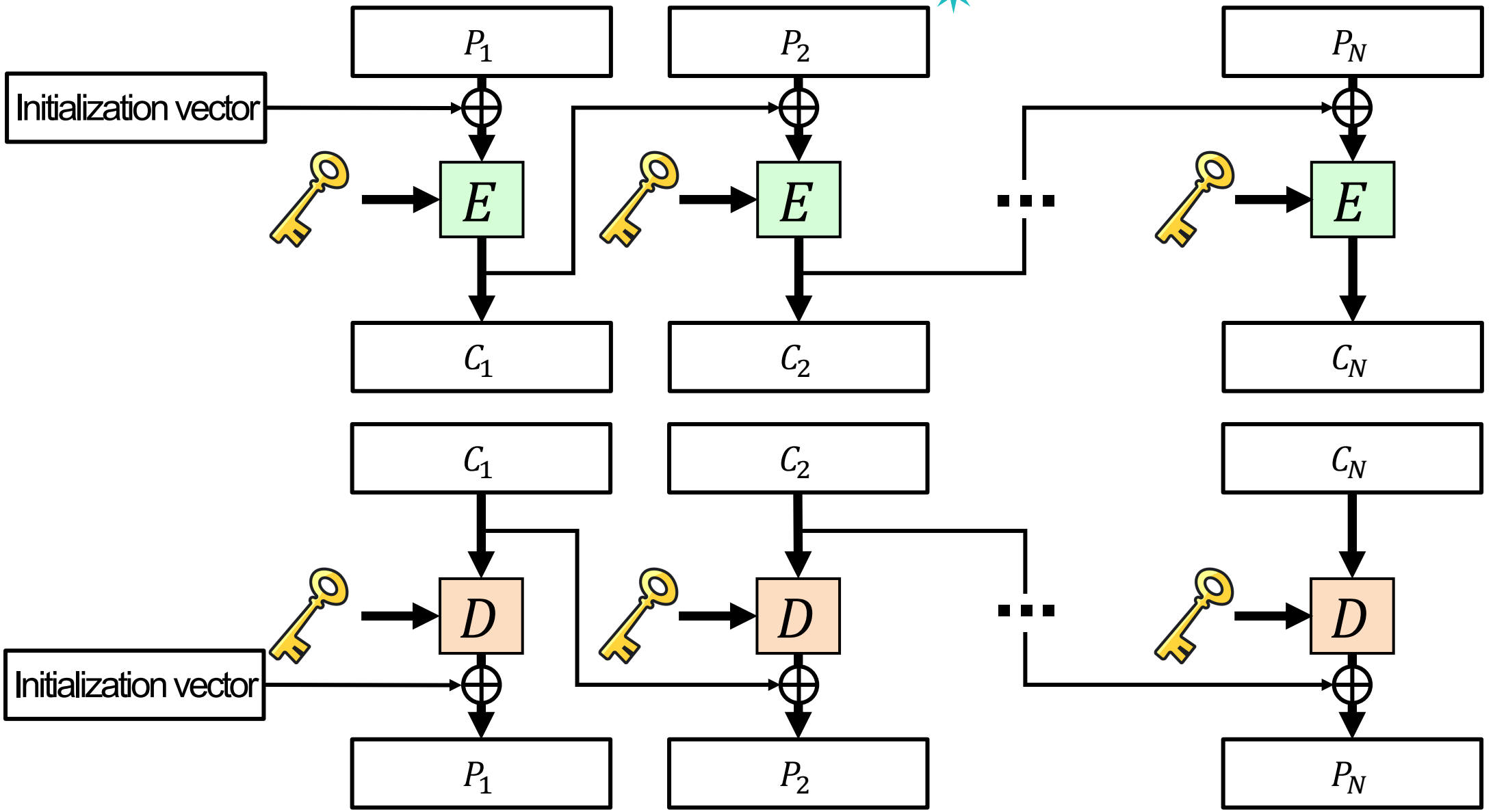
# Error Propagation in ECB



# Error Propagation in ECB



# CBC: Cipher Block Chaining



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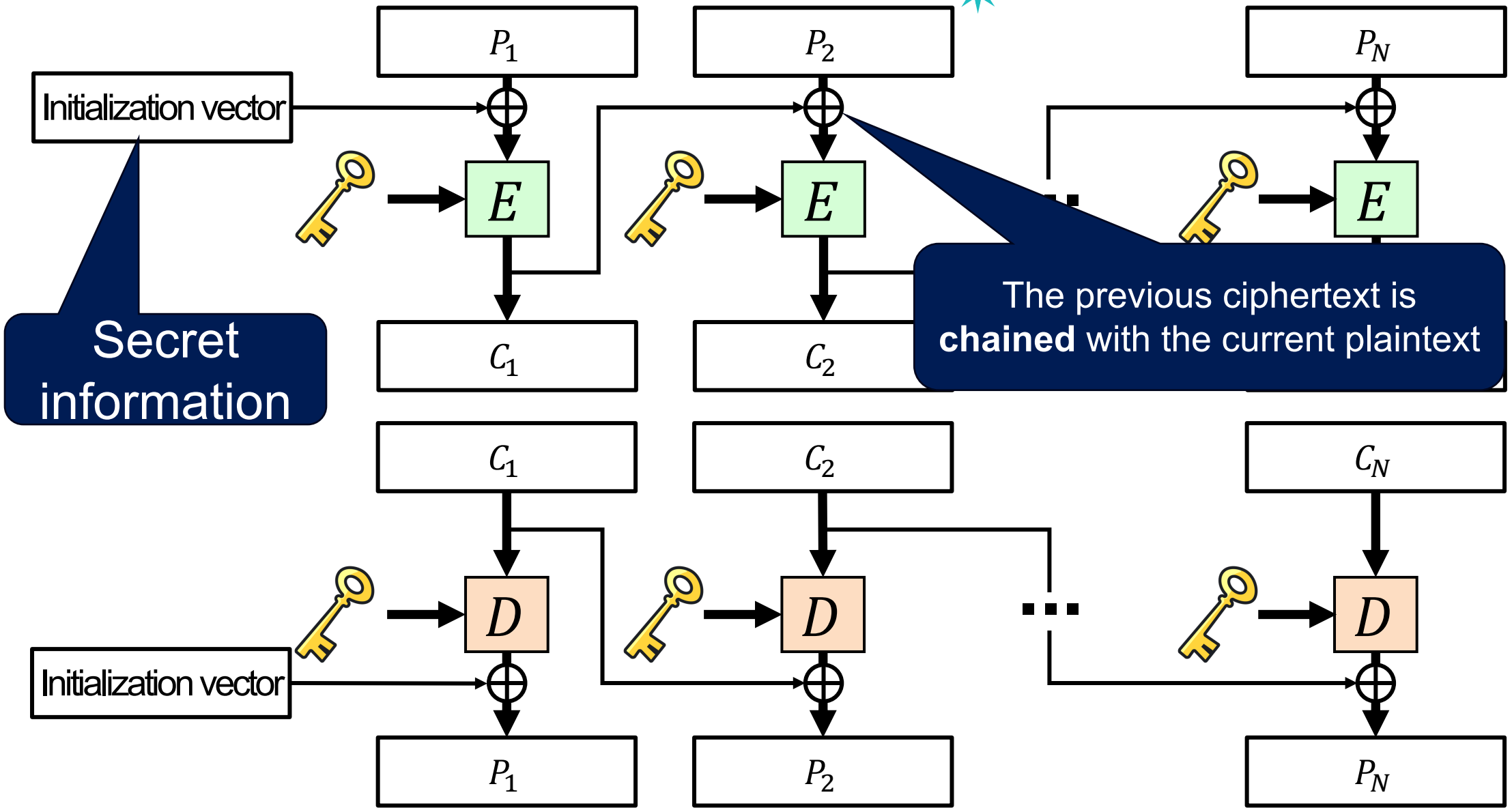


# CBC: Cipher Block Chaining

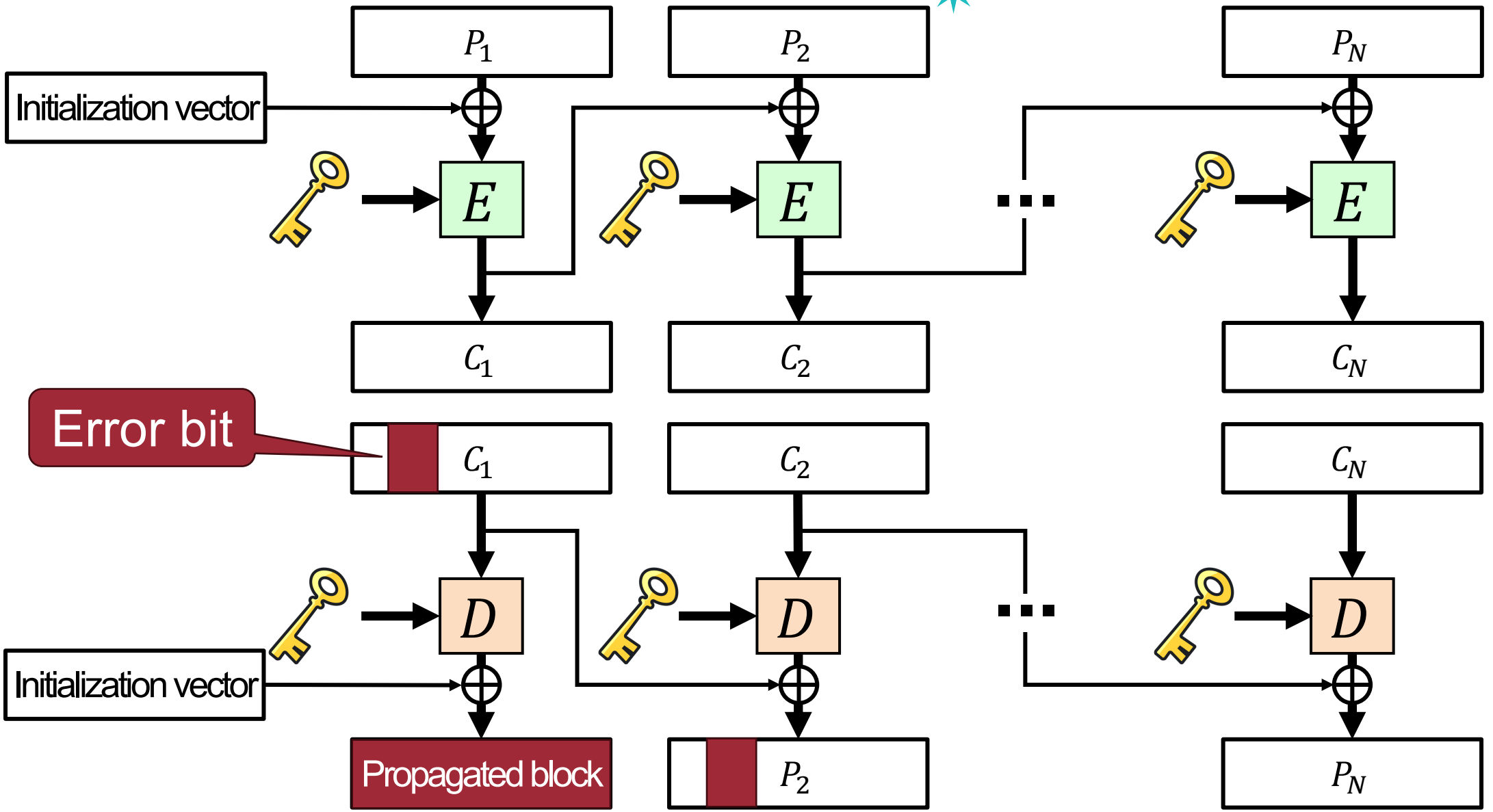


- Each previous cipher block is chained with current plaintext block

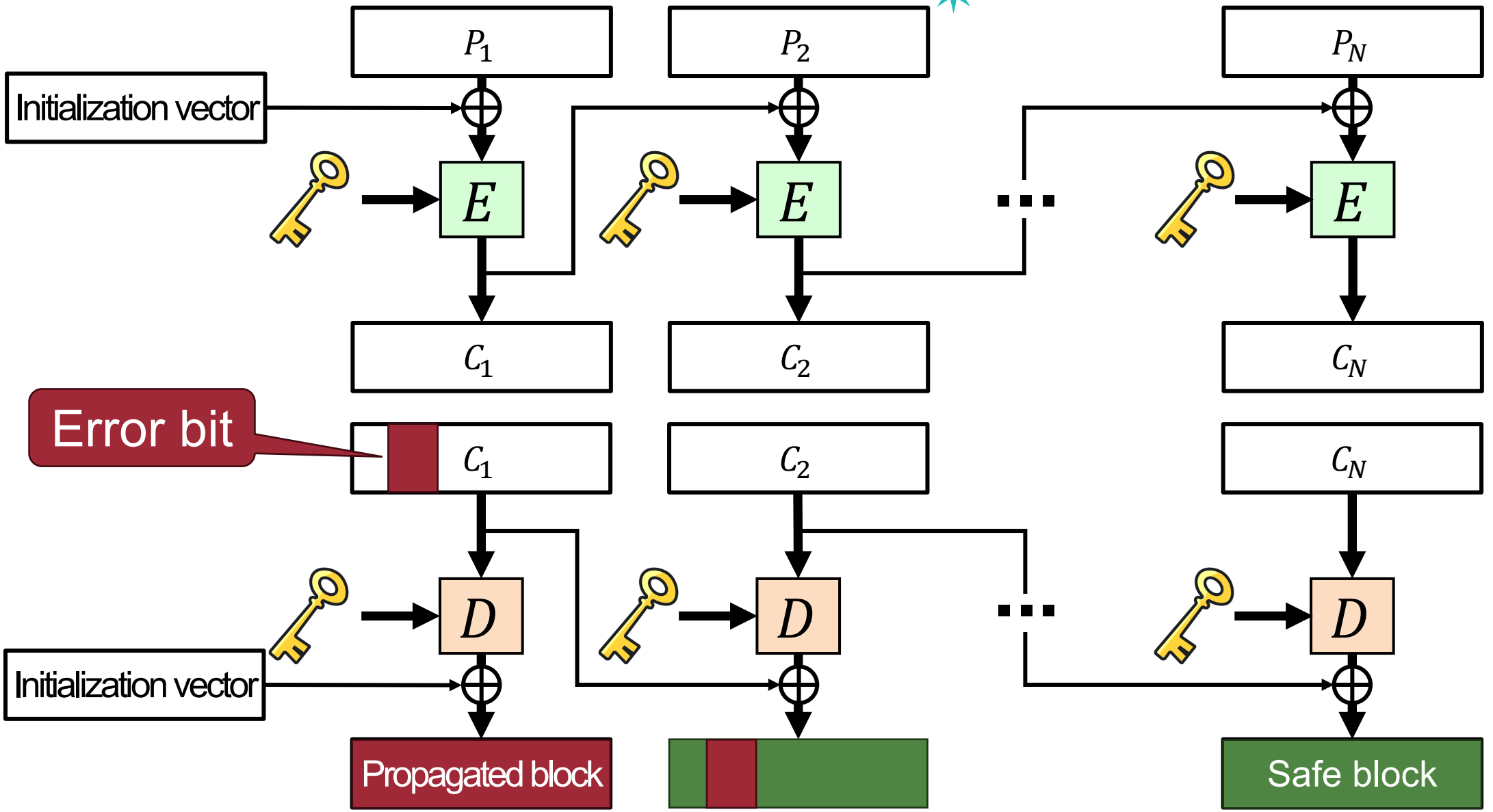
- Advantages
  - Does not reveal any patterns the plaintext may have

- Disadvantages
  - Cannot parallelize encryption (How about the decryption process?)
  - An error affects one other block (Toggles only one bit in the next block)

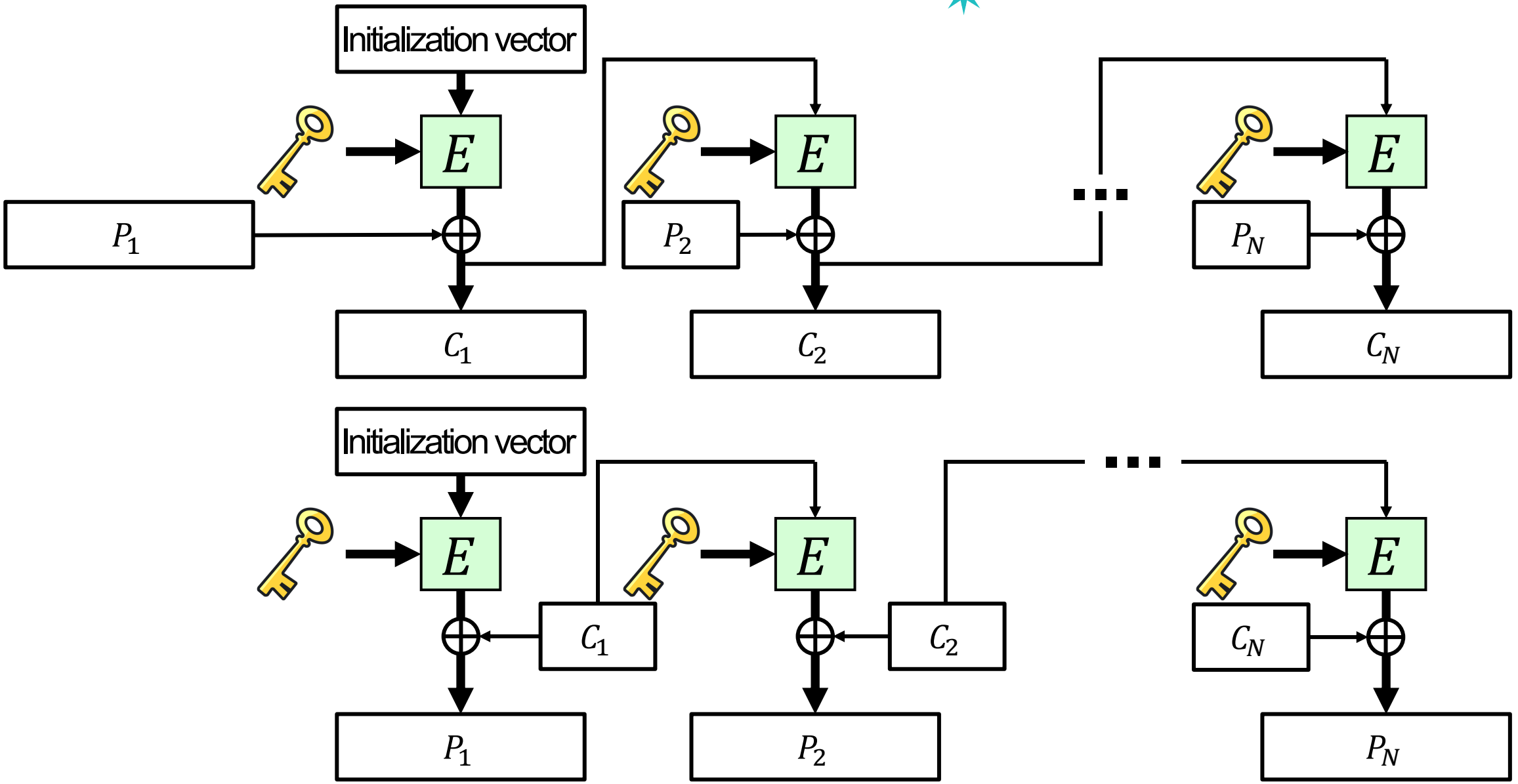
# Error Propagation in CBC



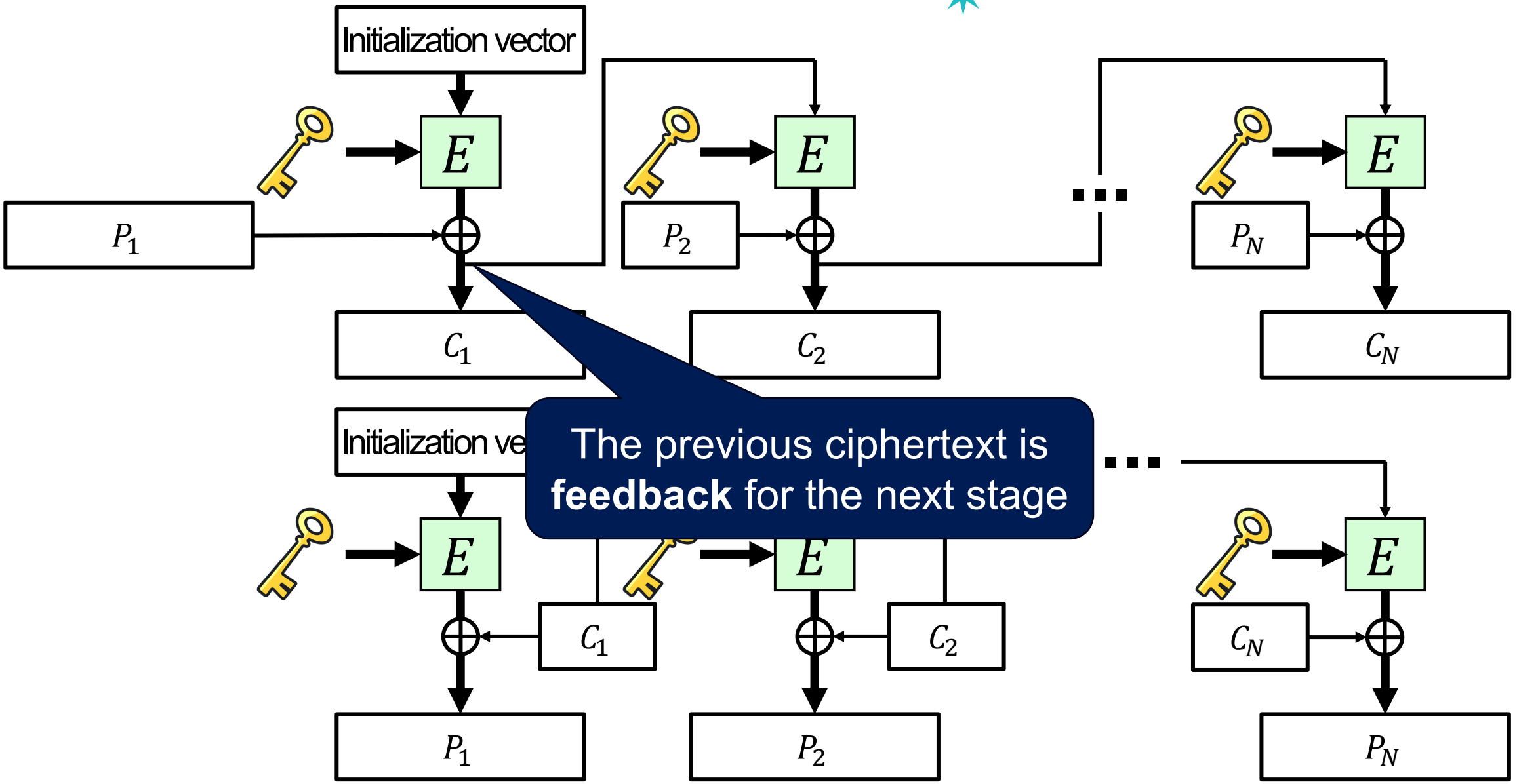
# Error Propagation in CBC



# CFB: Cipher Feedback



# CFB: Cipher Feedback



# CFB: Cipher Feedback

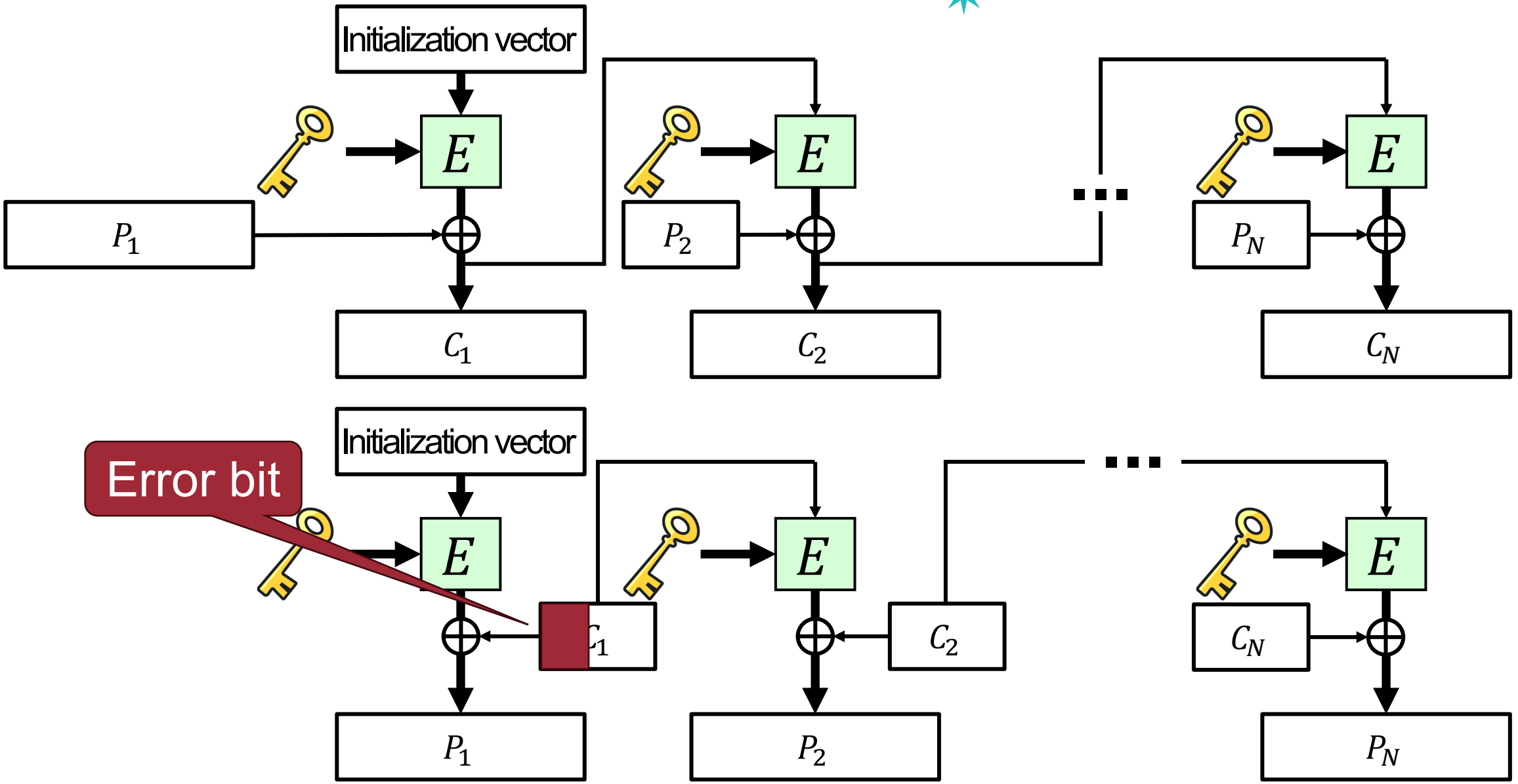


- Each previous cipher block is feedback for the next stage

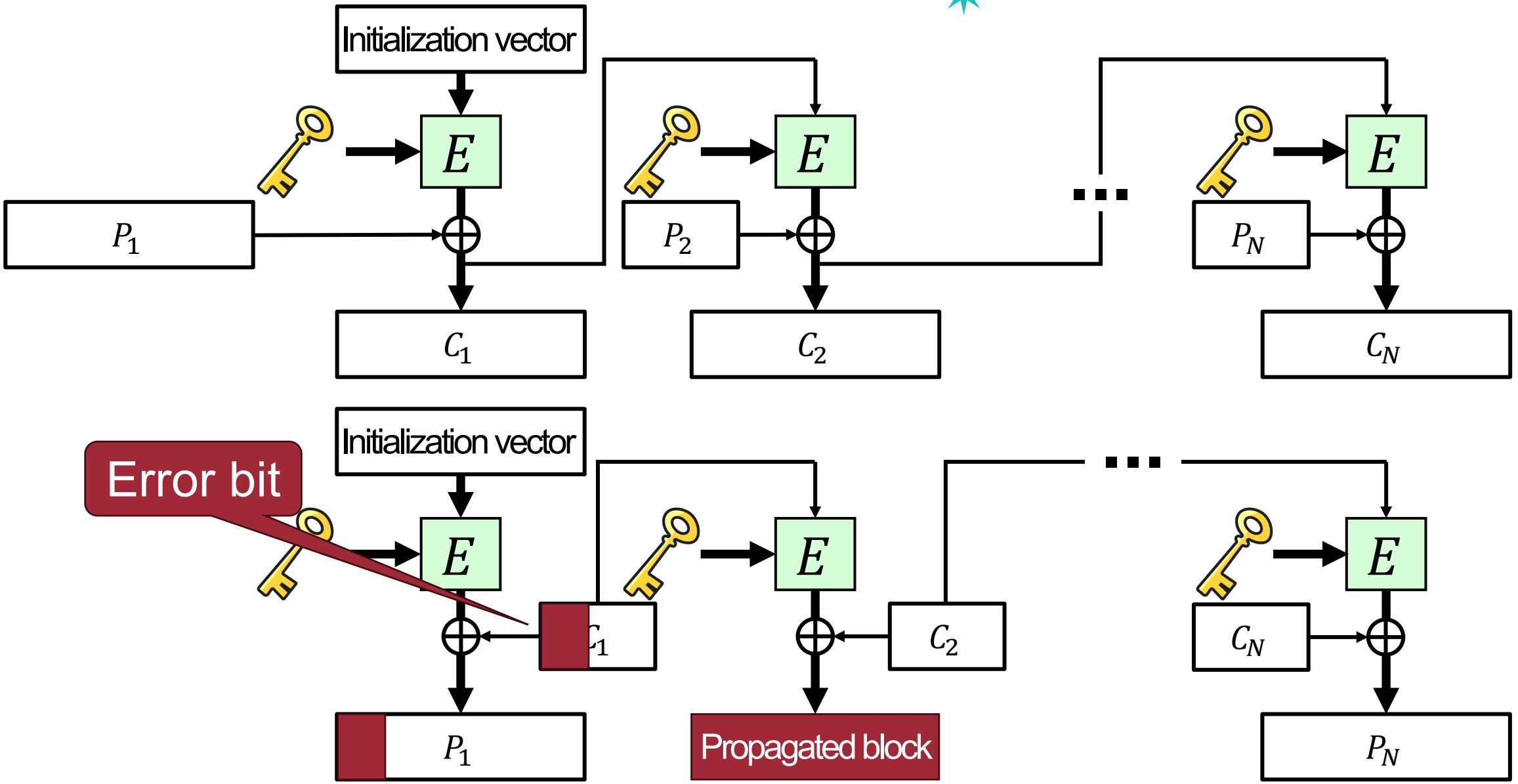
- Advantages
  - Does not reveal any patterns the plaintext may have
  - Does not use a decryption algorithm (The implementation is efficient)

- Disadvantages
  - Cannot parallelize encryption (How about the decryption process?)
  - An error affects one other block

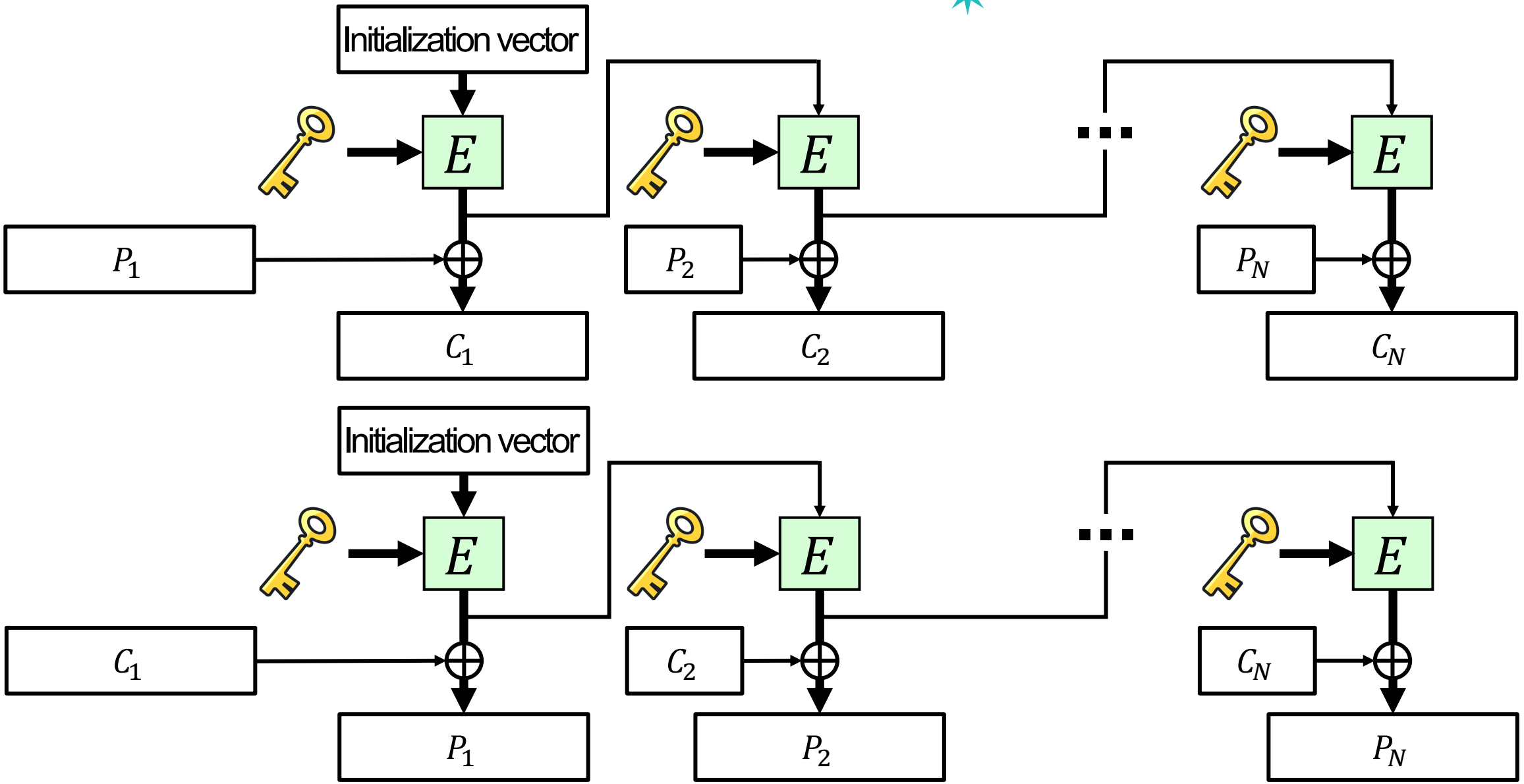
# Error Propagation in CFB



# Error Propagation in CFB



# OFB: Output Feedback



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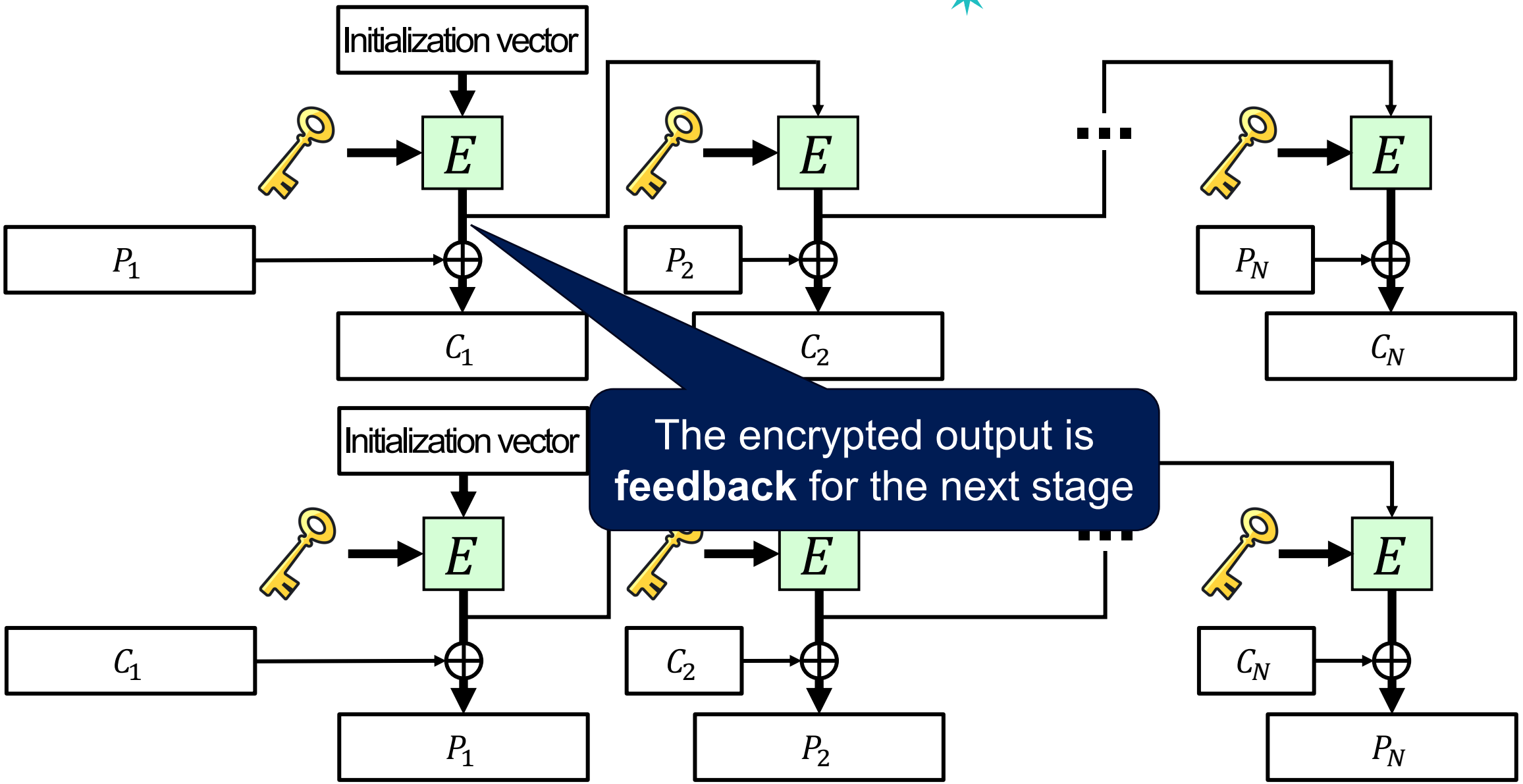


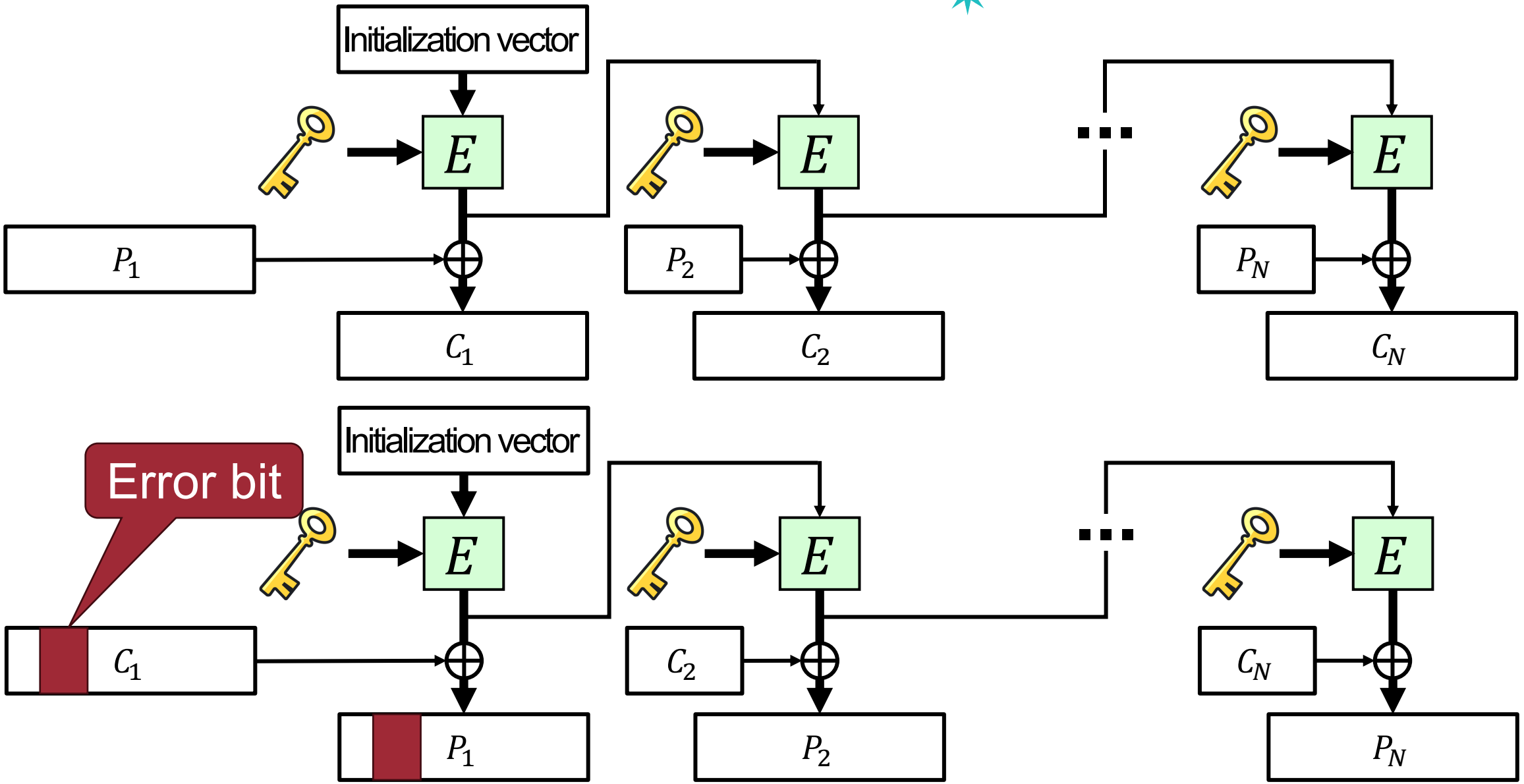
# OFB: Output Feedback



- Each encrypted output is feed back for next stage

- Advantages
  - Does not reveal any patterns the plaintext may have
  - Does not use a decryption algorithm (+ Use the same structure for both encryption and decryption)
  - An error has no effect on other blocks (+ Error of one bit in ciphertext affects only one bit in the plaintext block)

# Error Propagation in OFB



# OFB: Output Feedback



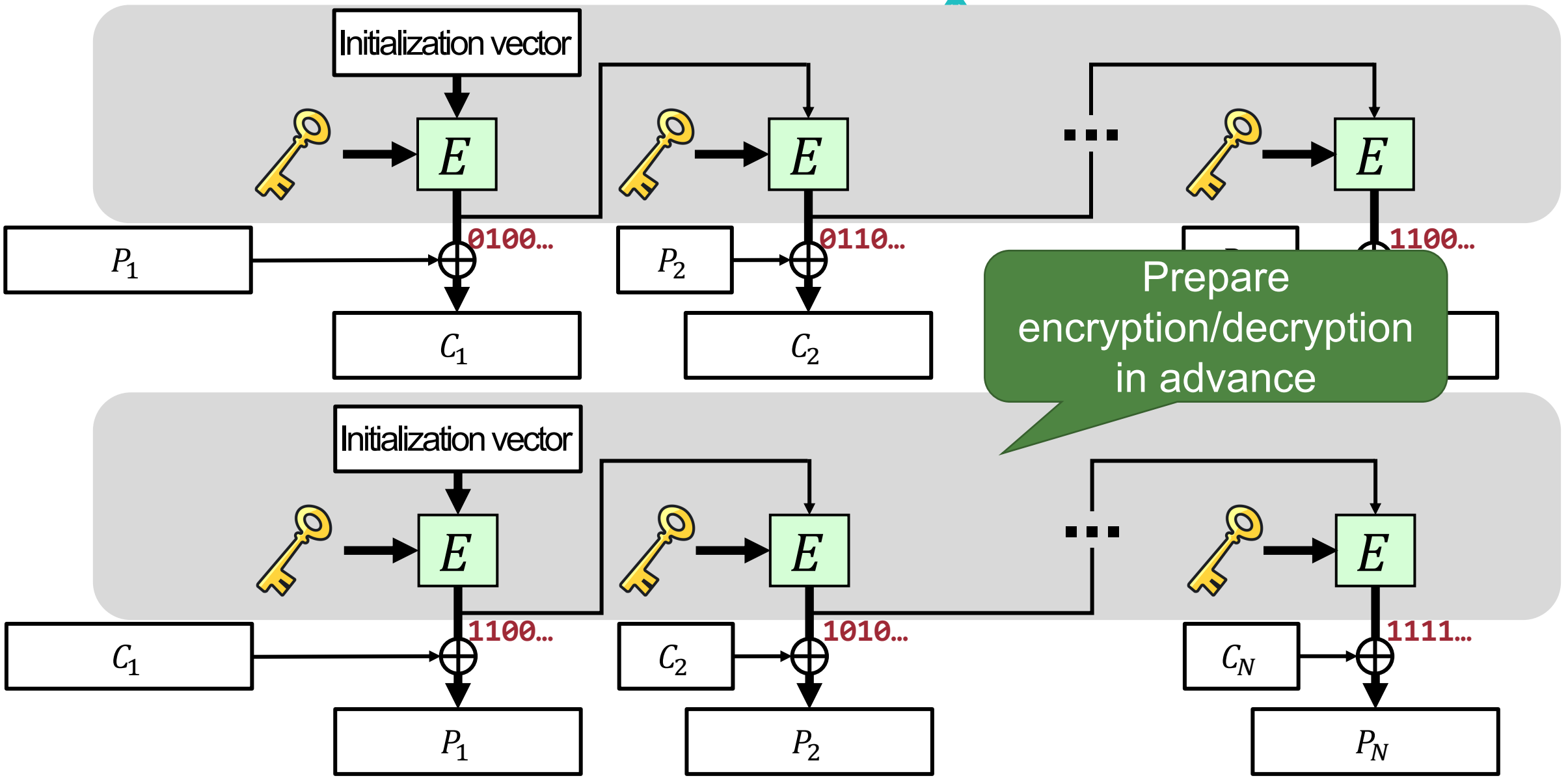
- Each encrypted output is feed back for next stage

- Advantages
  - Does not reveal any patterns the plaintext may have
  - Does not use a decryption algorithm (+ Use the same structure for both encryption and decryption )
  - An error has no effect on other blocks (+ Error of one bit in ciphertext affects only one bit in the plaintext block)

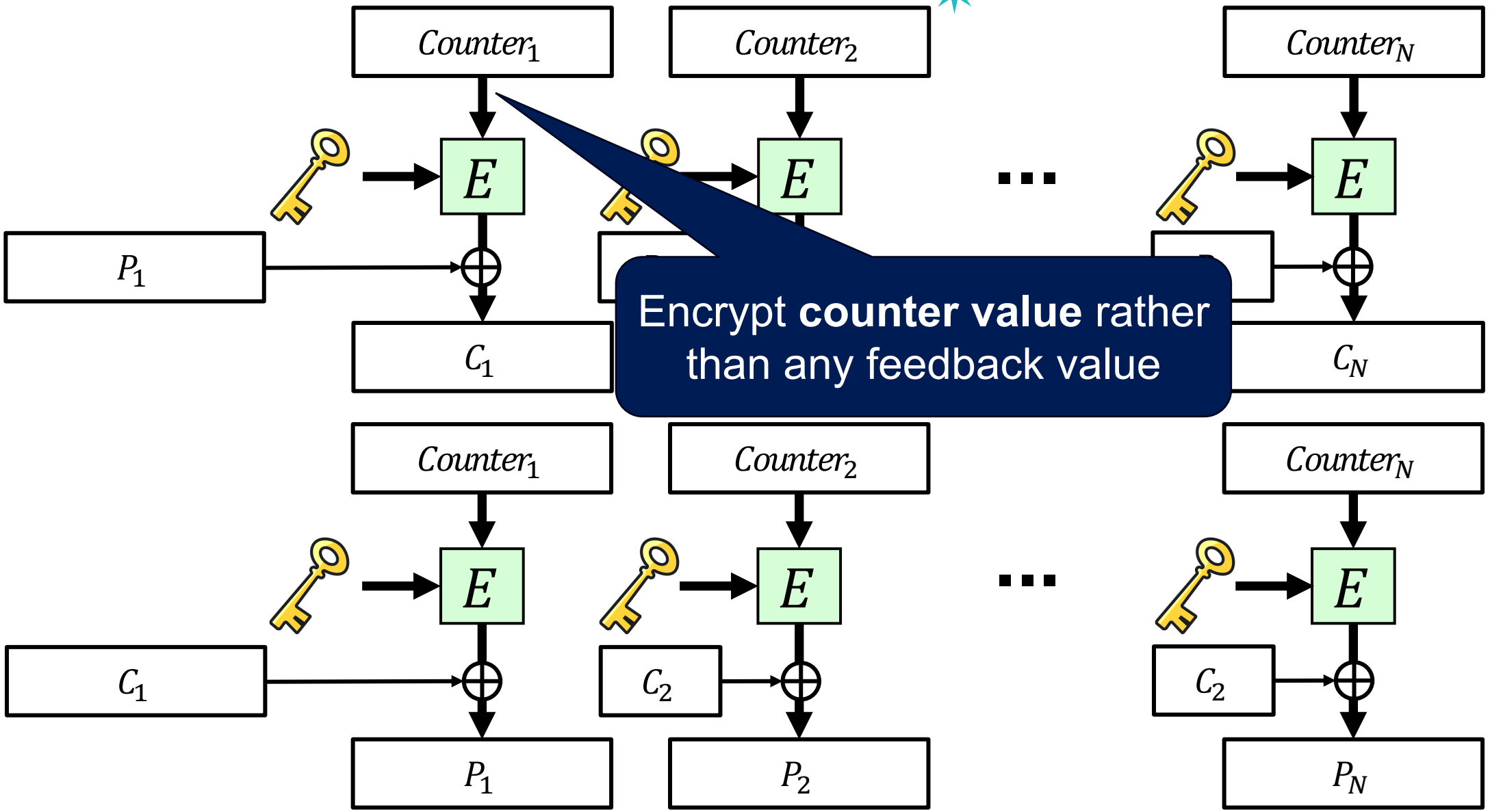
- Disadvantages
  - Cannot parallelize encryption and decryption

However, we can overcome this disadvantage by preparing encryption/decryption in advance

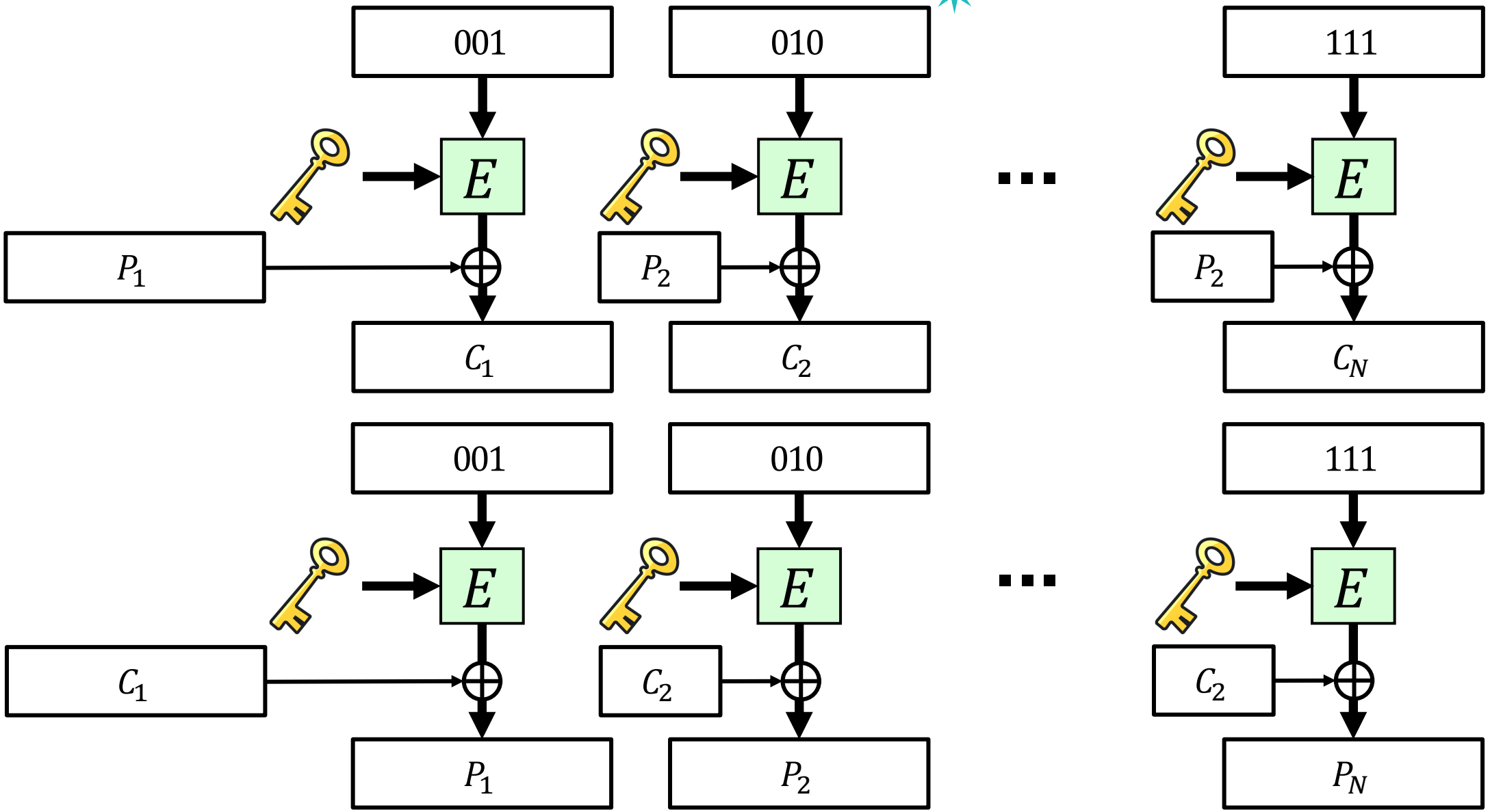
# Boost Up OFB Mode



# CTR: Counter Mode



# CTR: Counter Mode



# OFB: Output Feedback



- Encrypt **counter value** rather than any feedback value

- Advantages
  - Does not reveal any patterns the plaintext may have
  - Can do parallel encryption/decryption in H/W or S/W (+ can preprocess in advance of need)
  - Does not use a decryption algorithm (+ Use the same structure for both encryption and decryption )
  - An error has no effect on other blocks (+ Error of one bit in ciphertext affects only one bit in the plaintext block)

- Disadvantages
  - Must ensure never reuse key/counter values, otherwise could break

# Summary



- Symmetric-key cryptography: the same key for encryption and decryption
- Block cipher: basic building block of many cipher schemes
  - DES, Triple-DES, AES
- Block cipher mode of operations
  - ECB: Electronic Code Book
  - CBC: Cipher Block Chaining
  - CFB: Cipher FeedBack
  - OFB: Output FeedBack
  - CTR: CounTeR mode

# Question?