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Symmetric Crypto Systems

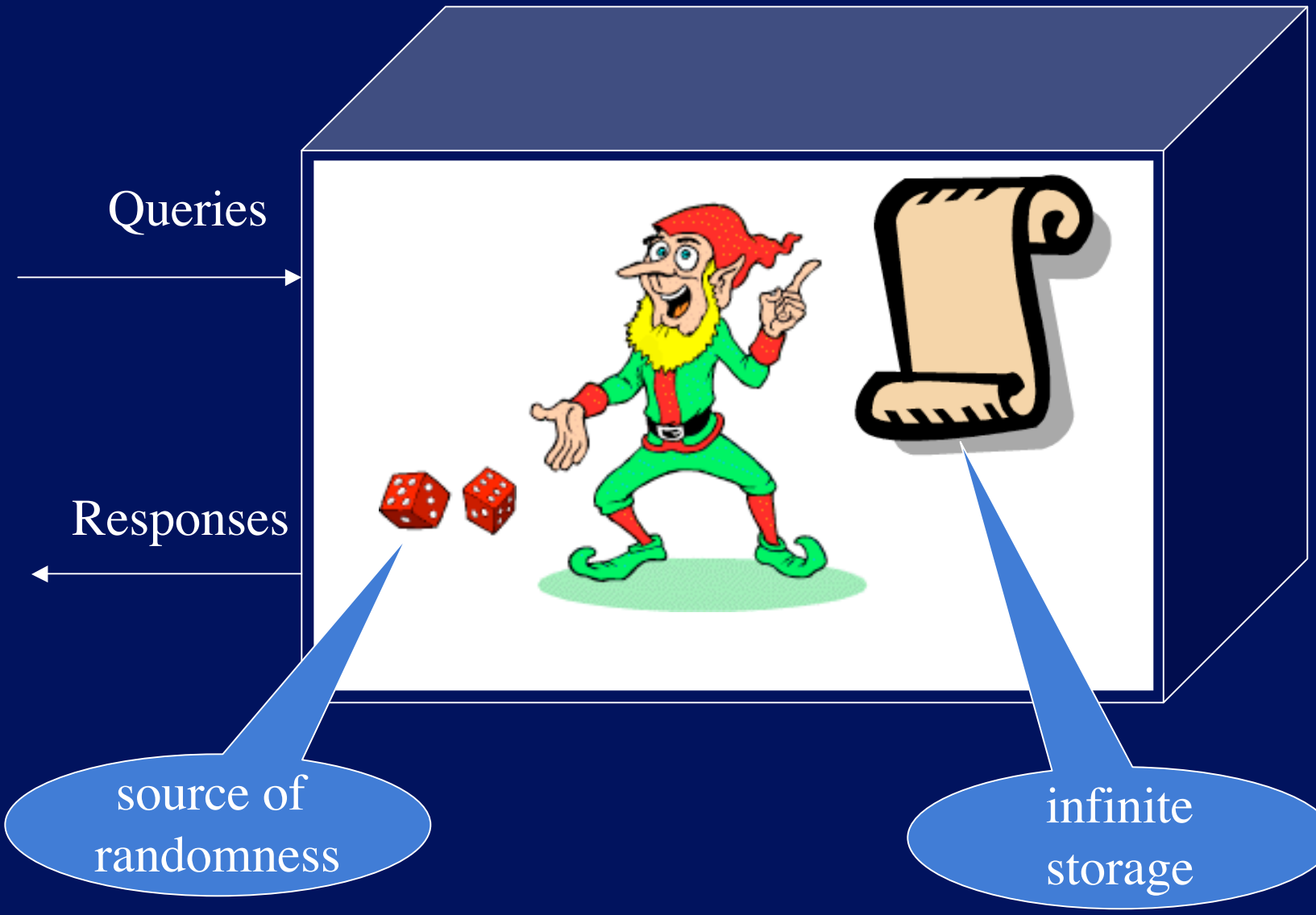
EECE 412

Session 4

Last Session Recap

- Historical background
  - Caesar and Vigenère ciphers
  - One-time pad
- The Random Oracle model
  - Random functions: hash functions
  - Random generators: stream ciphers
  - Random Permutations: block ciphers

What is Random Oracle Model?



Session Outline

- Substitution and transposition ciphers
- Block ciphers "under the hood"
- Modes of operation for block ciphers

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Substitution and transposition ciphers

Substitution Ciphers

Change characters in plaintext to produce ciphertext

Example: Vigenère Cipher

```
Plain   TO BE OR NOT TO BE  TH AT  IS  THE  QUESTION
Key     RE LA T I  ONS  RE LA  T I ON  SR ELA T I ONSREL
Cipher  KS ME HZ BBL   KS ME MPOG AJ  XSE J CSFLZSY
```

Transposition Cipher

Rearrange letters in plaintext to produce ciphertext

- Example (Rail-Fence Cipher)
  - Plaintext: `HELLO WORLD`
  - Rearrange as

    `HLOOL`

    `ELWRD`
  - Ciphertext: `HLOOLELWRD`
- a.k.a. permutation ciphers

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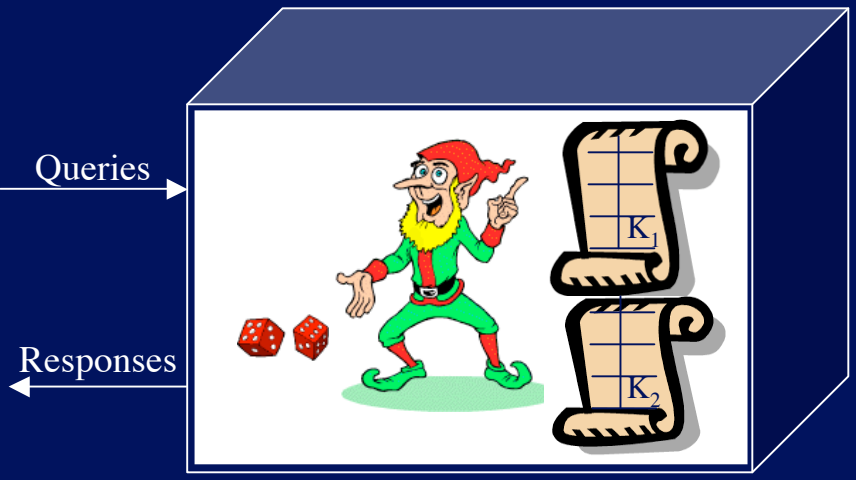
Block Ciphers "Under the Hood"

Random Permutation (Block Cipher)
as Random Oracle

- In
  - fixed size short string (plaintext) M,
    - DES -- 64 bits
  - Key K



- Out
  - same fixed size short string (ciphertext) C

Notation

- $C = \{ M \}_K$
- $M = \{ C \}_K$

Related Notes

- Main properties of block ciphers
  - invertible
  - confusing
  - Diffusing
- Main block ciphers
  - Data Encryption Standard (DES)
  - Advanced Encryption Standard (AES) a.k.a., Rijndael

SP-network

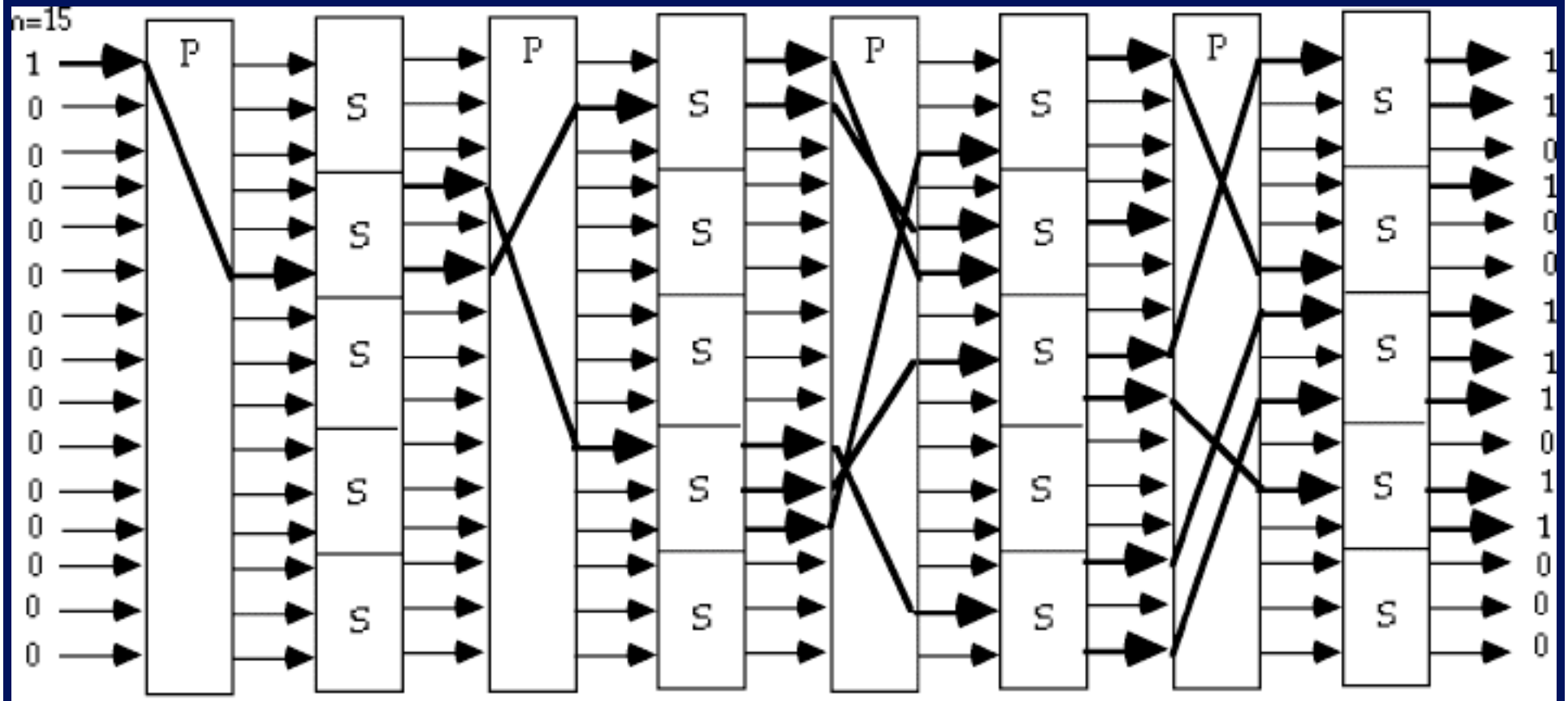


Fig 2.3 - Substitution-Permutation Network, with the Avalanche Characteristic

From lecture notes on "Cryptography and Computer Security" by Lawrie Brown

S-Boxes

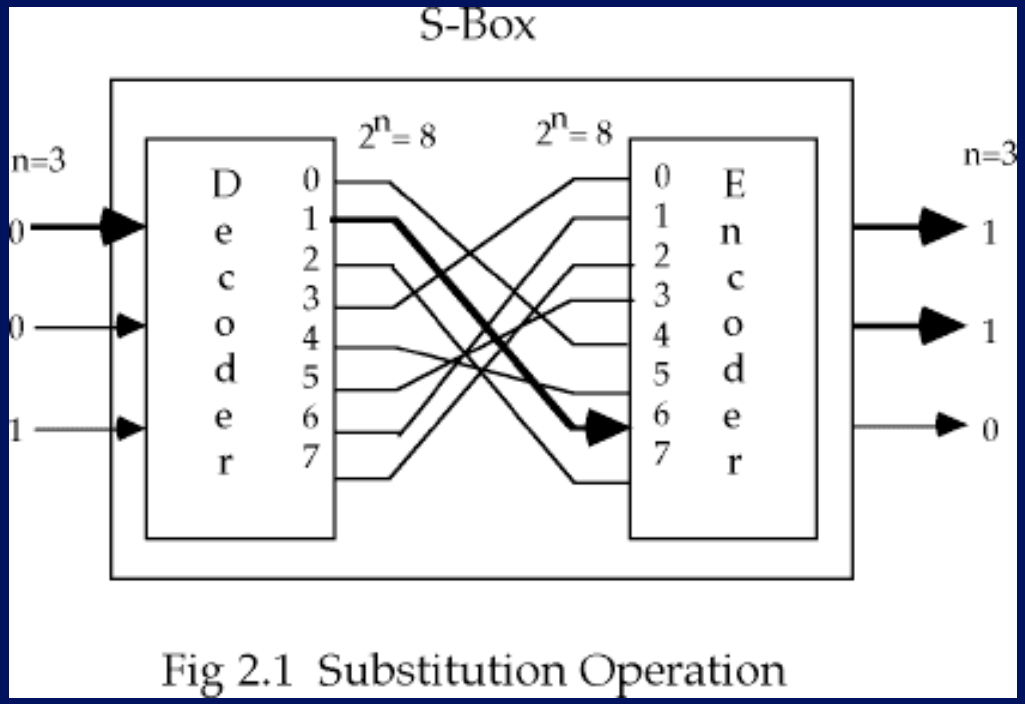


Fig 2.1 Substitution Operation

From lecture notes on "Cryptography and Computer Security" by Lawrie Brown

Main techniques for breaking S-boxes

- Linear cryptanalysis
- Differential cryptanalysis

Required properties of S-boxes

- each output bit will depend on every input bit
- changing one input bit will change about half of the output bits

P–Box

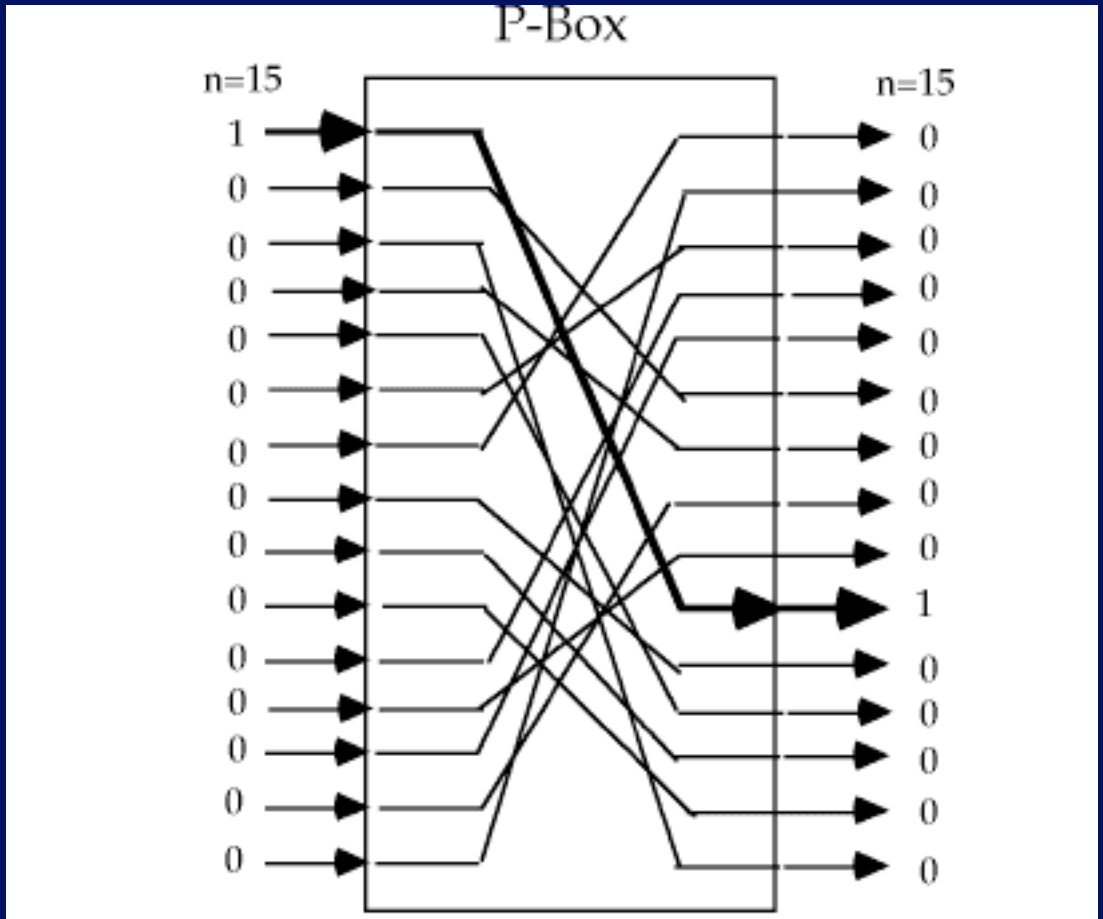


Fig 2.2 - Permutation or Transposition Function

From lecture notes on "Cryptography and Computer Security" by Lawrie Brown

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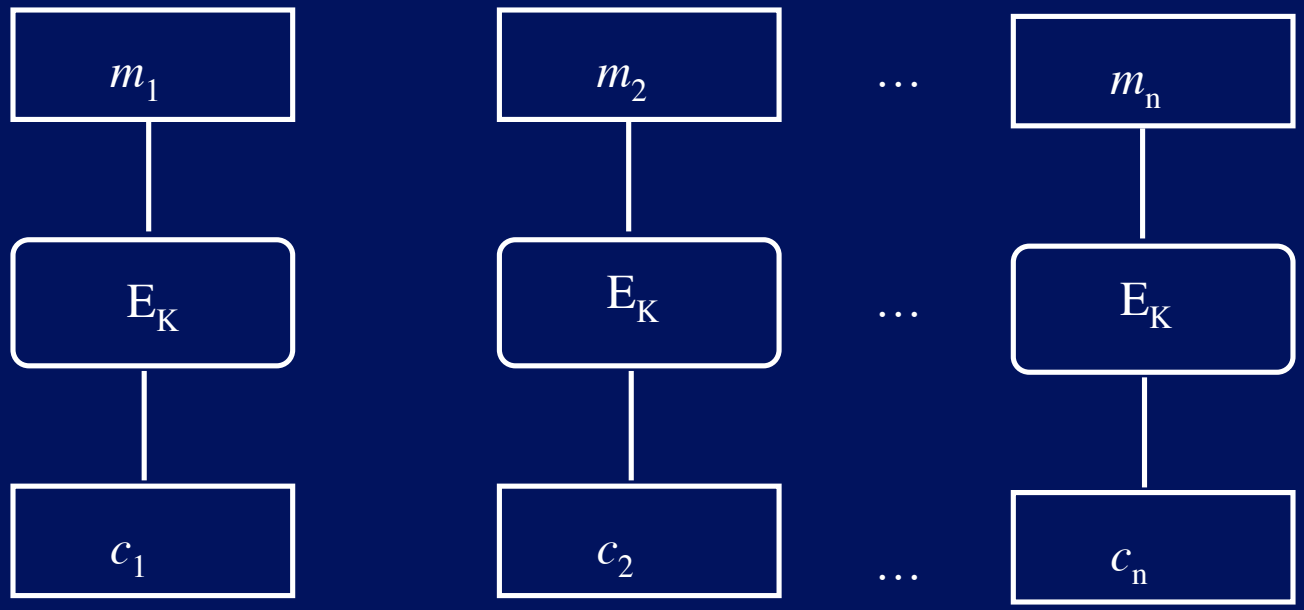
Modes of Operation

Electronic Code Book (ECB)

$M = m_1 \mid m_2 \mid \ldots \mid m_n$



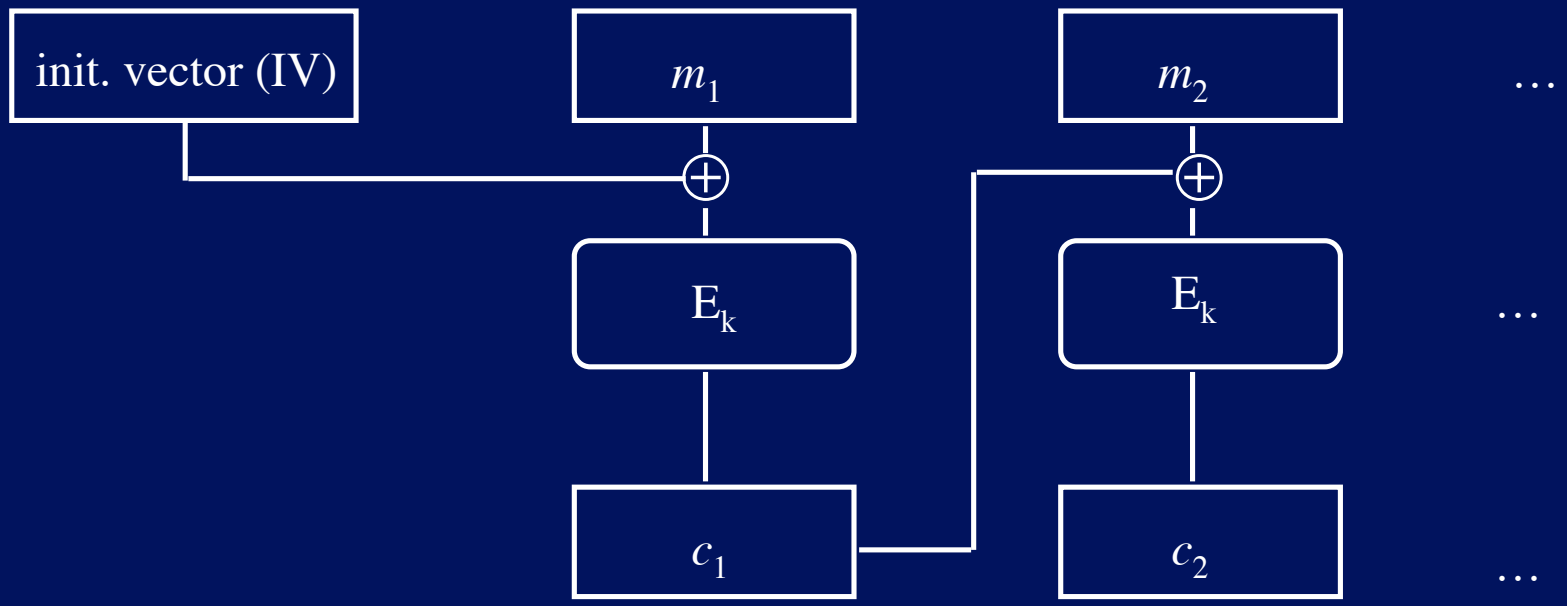
$C = c_1 \mid c_2 \mid \ldots \mid c_n$

Drawbacks

- Same message has same ciphertext
- Redundant/repetitive patterns will show through
- Subject to "cut-and-splice" attacks

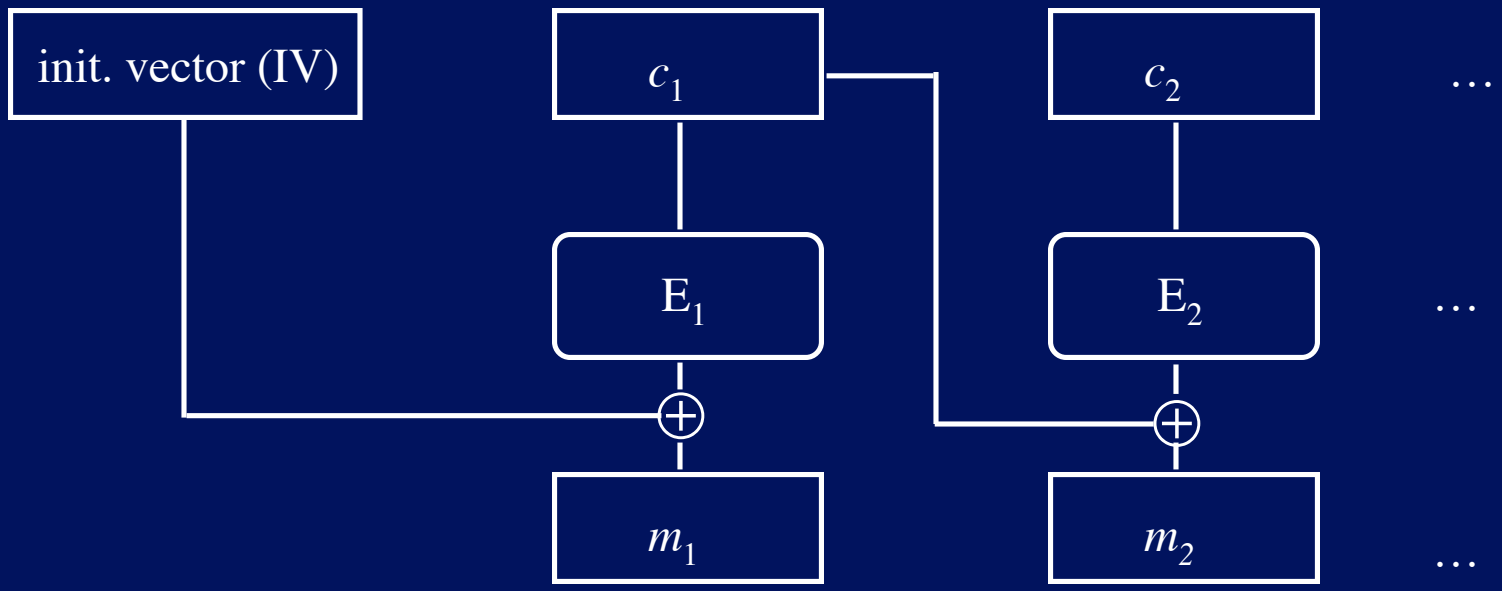
Cipher Block Chaining (CBC)

$M = m_1 \mid m_2 \mid \ldots \mid m_n$



$C = IV \mid c_1 \mid c_2 \mid \ldots \mid c_n$

Decryption with CBC

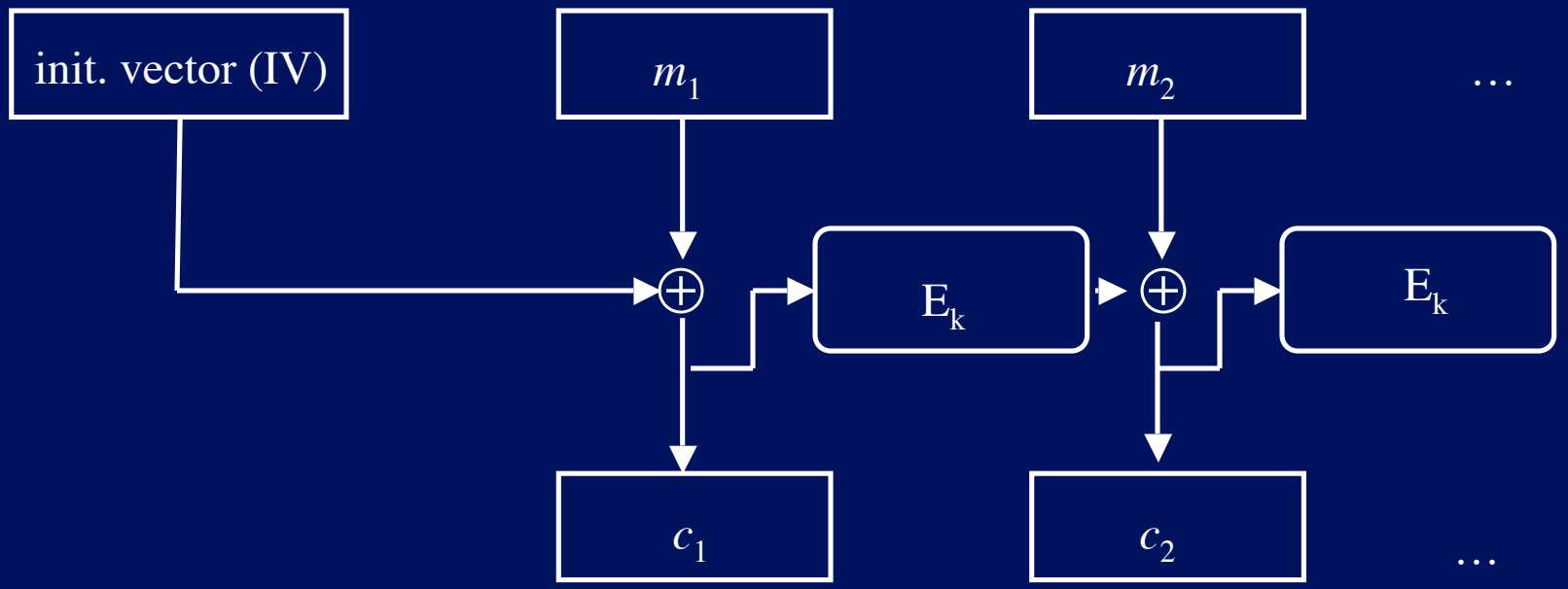


Output Feedback (OFB)

- $K_1 = \{IV\}_K$, $K_2=\{K_1\}_K$, … $K_i=\{K_{i-1}\}_K$ …
- Purpose: use block cipher as a stream cipher
- $C_i = \{m_i\}_{Ki}$, e.g., $c_i = m_i \oplus K_i$

Cipher Feedback (CFB) Mode

$M = m_1 \mid m_2 \mid \ldots \mid m_n$



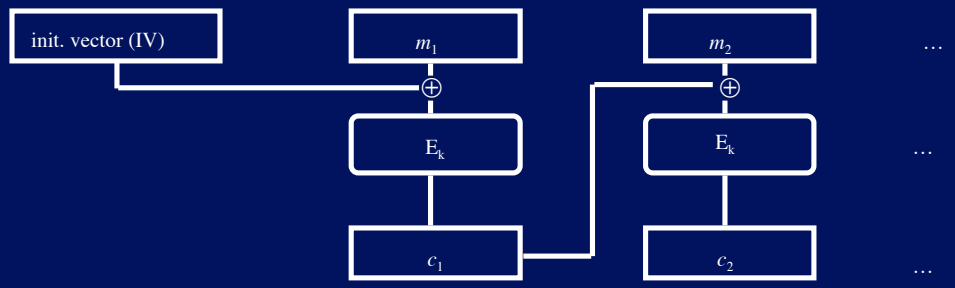
$C = IV \mid c_1 \mid c_2 \mid \ldots \mid c_n$

Counter Encryption

- Drawbacks of feedback modes
  - Hard to parallelize
    - CBC -- cannot precompute
    - OFB -- memory requirements
- $K_i = \{IV + i\}_K$

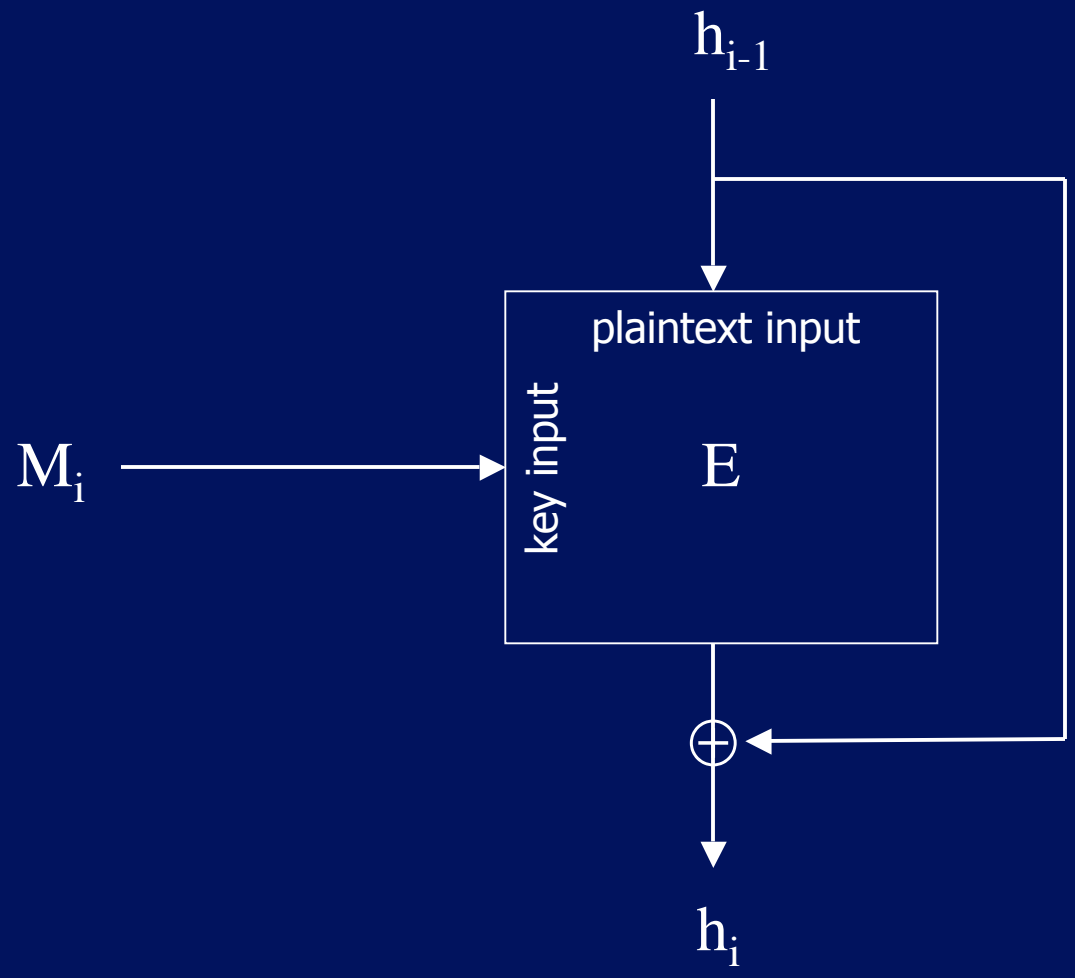
Message Authentication Code (MAC)

- Purpose
  - protect message integrity and authenticity
- How to do MAC with a block cipher?



- How to do MAC and encryption of a message?

Hash Function from a Block Cipher



h = H(M)

1. Easy to compute h from M
2. Hard to compute M from h
3. Hard to find another M' s.t. H(M) == H(M')

Common Hash Functions and Applications

- Common hash functions
  - (Message Digest) MD5 value 128b
  - (Secure Hash Algorithm) SHA-1 160b value
- Applications
  - MACs
    - $MAC_K(M) = H(K,M)$
    - $HMAC_K(M) = H(K \oplus A, H(K \oplus B, M))$
  - Time stamping service
  - key updating
    - $K_i = H(K_{i-1})$
    - Backward security
  - Autokeying
    - $K_{i+1} = H(K_i, M_{i1}, M_{i2}, \ldots)$
    - Forward security

Key Points

- Ciphers are either substitution, transposition (a.k.a., permutation), or product
- Any block cipher should confuse and defuse
- Block ciphers are implemented in SP-networks
- Stream ciphers and hash functions are commonly implemented with block ciphers
- Hash functions used for fingerprinting data, MAC, key updating, autokeying,