Computer and Network Security: Block Modes

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Outline

- **Modern Cryptography**
  - Overview
  - **Confidentiality**
    - Background: Definition, Crypto-analysis, One Time Pads
    - Symmetric key encryption, **Block modes**
    - Asymmetric key encryption
  - Integrity (includes Authentication)
    - Hashes, MAC, Digital signature

Recap

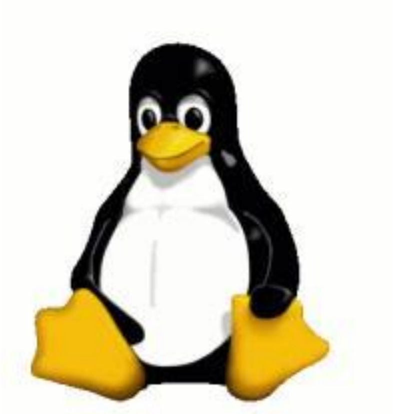
- Block Cipher operates on a block of plain/cipher text
- Examples: DES, 3-DES and AES
  - Confusion and Diffusion
  - Terms: Substitute, Permute, Mangle, Mix, Add-roundkey, Rounds
- How to encrypt a variable length message larger than block size?

Modes of Operation

- Specifies how an encryption algorithm is used in practice
- We have
  - Message divided into B1, B2, B3, ……. blocks (block length = n)
  - If message not a multiple of n?
    - For some modes, pad message before encryption to make it multiple of n
      - E.g. add 1 followed by zeros
    - Unpad after decryption
  - Key k
  - Block cipher algorithm like AES or DES

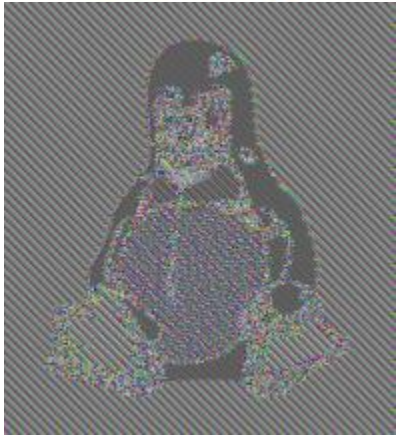
Electronic Code Book (ECB)

$$C_i = E_k(B_i) \text{ and } B_i = D_k(C_i)$$



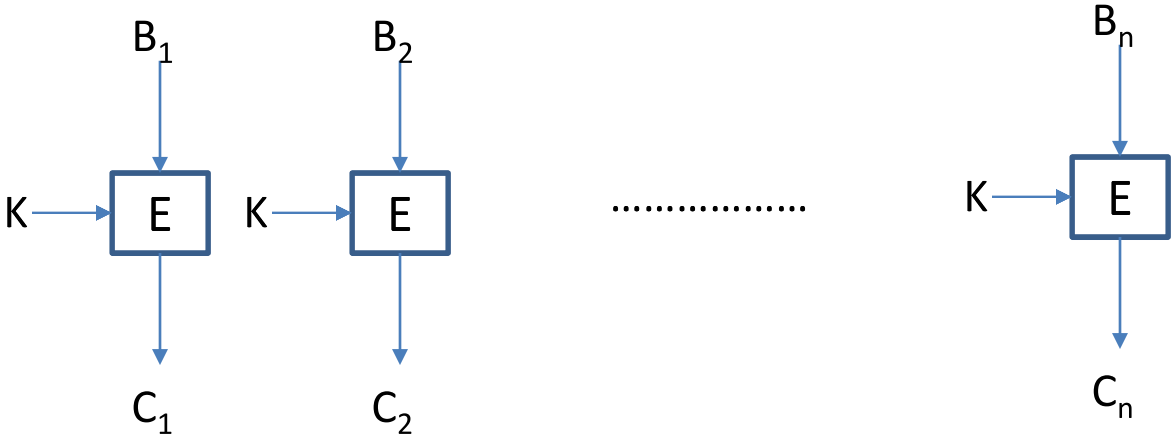
+ Simple
+ Tolerates losses
- May reveal patterns
- Can rearrange blocks to advantage

- ECB not used in practice
  - Good for encrypting random data like keys



ECB encoded image

Block Diagram



Example

Block1	Block2	Block3	Block4	Block5	Block6	Block7	Block8
Kamesw	ari	Pr	ofessor	I IT	Bombay	5	1,235.50
Bharga	v	Pr	ofessor	I IT	Bombay	5	1,235.50
Bhaska	R	Pr	ofessor	I IT	Bombay	8	1,175.00
Lakshm	I	Pr	ofessor	I IT	Bombay	8	9,775.00

- Can determine set of employees with identical salaries (last two blocks)
- Set of employees with same salary in 10,000’s range
- Change salary (copy last but one block of higher salary person to own)

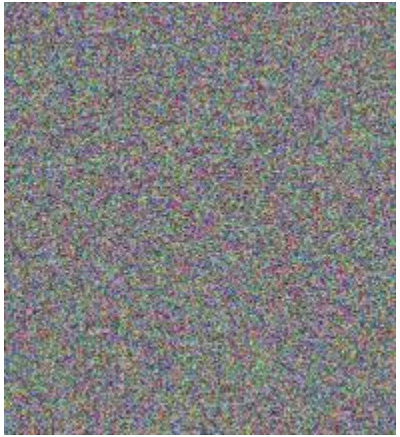
Cipher Block Chaining (CBC)

$$C_i = E_k(B_i \oplus C_{i-1}) \text{ and } B_i = D_k(C_i) \oplus C_{i-1}$$

- C_o: initialization vector (IV)
  – Has to be random each time. Why?
- Transmit IV with ciphertext

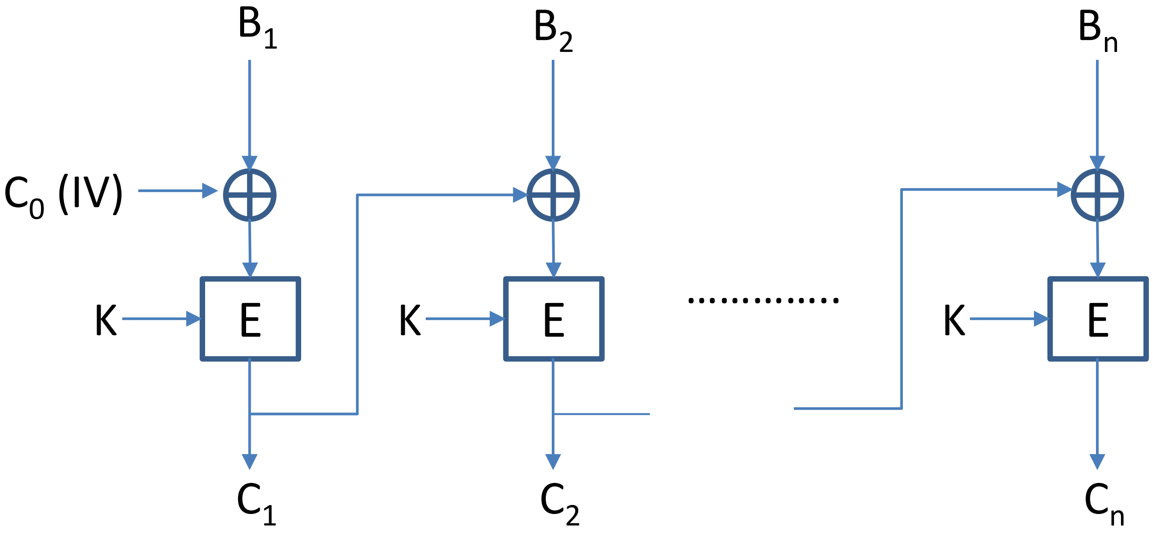
+ Does not reveal patterns

+ Decryption can happen in parallel (if all cipher text is available)



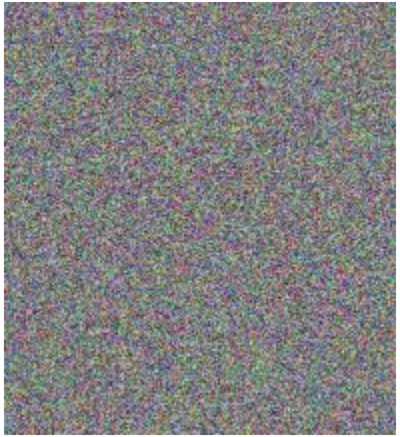
Non ECB mode

Block Diagram



$$C_i = E_k(B_i \oplus C_{i-1}) \text{ and } B_i = D_k(C_i) \oplus C_{i-1}$$

- Encryption needs to be in sequence
- Loss tolerance?
  - C_i is lost, i and i+1 blocks are lost
- Can modify blocks to advantage



Non ECB mode

Example

Block1	Block2	Block3	Block4	Block5	Block6	Block7	Block8
Kamesw	ari	Pr	ofessor	I IT	Bombay	5	1,235.50
Kamesw	ari	Pr	ofessor	I IT	Zxc%#FR	7	1,235.50

$$C_i = E_k(B_i \oplus C_{i-1}) \text{ and } B_i = D_k(C_i) \oplus C_{i-1}$$

Flip penultimate bit of C6

Maps to M7 xor 00….10

5 maps to 101; 7 maps to 111

M6 garbled due to tampering with C6

Cipher Feedback Mode (CFB)

$$C_i = E_k(C_{i-1}) \oplus B_i \text{ and } B_i = E_k(C_{i-1}) \oplus C_i$$

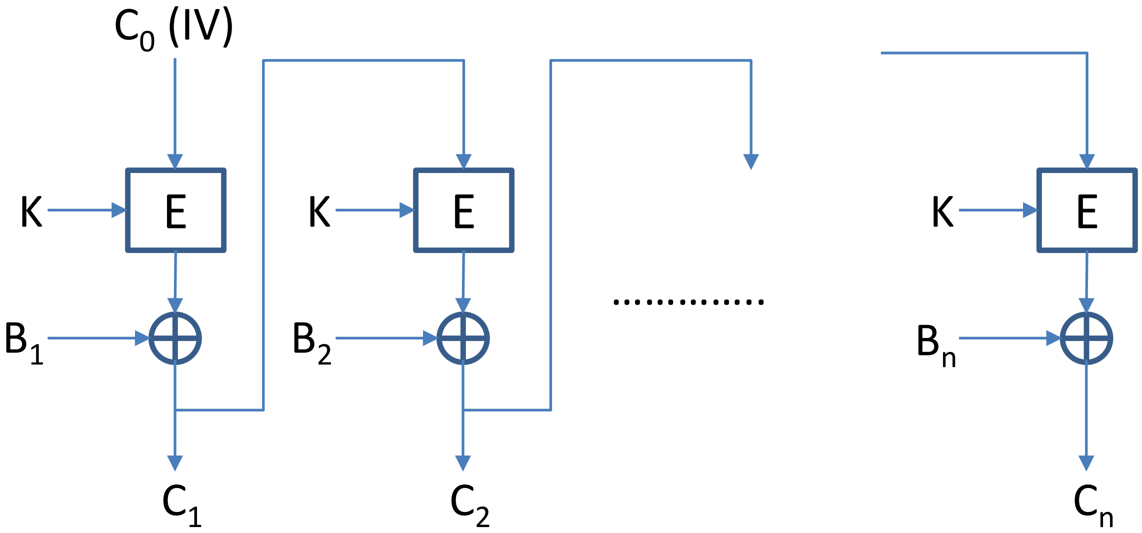
Transmit C_0 (IV, random) with ciphertext

+ Involves no decryption
    + If decryption is a slower operation, CFB better than CBC
+ Decryption can be in parallel

- Encryption needs to be in sequence

- Can modify plain text but it will garble next block

Block Diagram



Stream Ciphers

- Operate on a stream of plain/cipher text, one symbol at a time
  - Similar to one time pads (xor plain text with random bits)
- Key is not random bits. Why?
- Key (fixed bits) is input to a pseudo random generator that outputs arbitrarily long random bits

- “Any one who considers arithmetical methods of producing random digits is, of course, in a state of sin. “ -- **John von Neumann**
- PRG(K) not truly random but goal is computationally secure
  - Attacker can’t distinguish pseudo random pad from truly random pad.
- E(K,M) = PRG(K,IV) xor M
- Example: RC4 stream cipher (has vulnerabilities)
- Block ciphers can turn into stream ciphers. How?

Output Feedback Mode (OFB)

$$V_i = E_k(V_{i-1}) \text{ and } C_i = V_i \oplus B_i \text{ and } B_i = V_i \oplus C_i$$

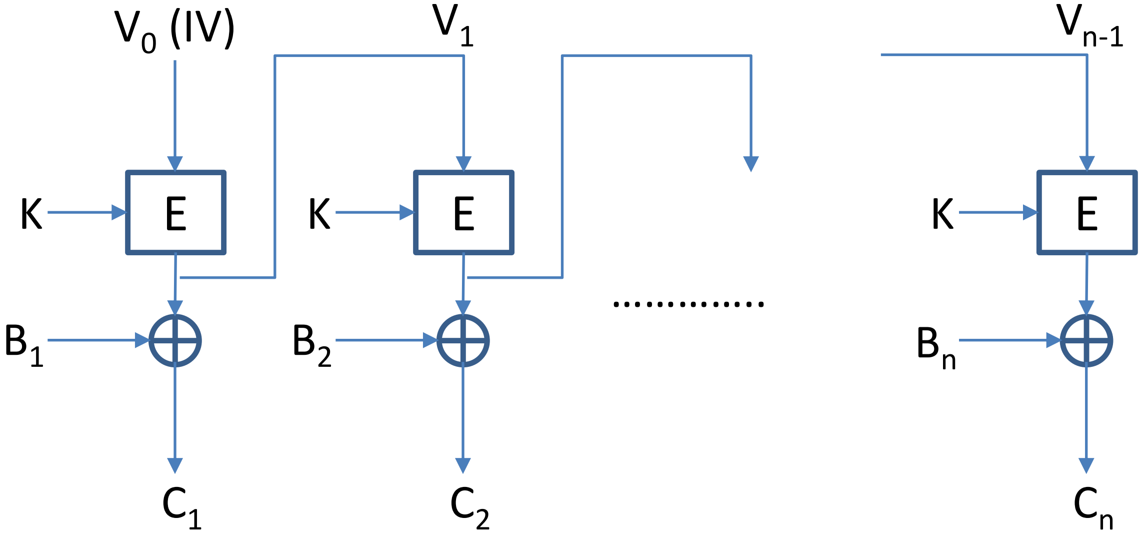
- V_i's can be generated before hand
  - Initialization vector V_0; random each time
  - Similar to a one time pad
  - Transmit IV with ciphertext

+ Tolerates losses

+ Encryption/Decryption can happen in parallel

- Can modify plaintext (no garbling also)

Block Diagram

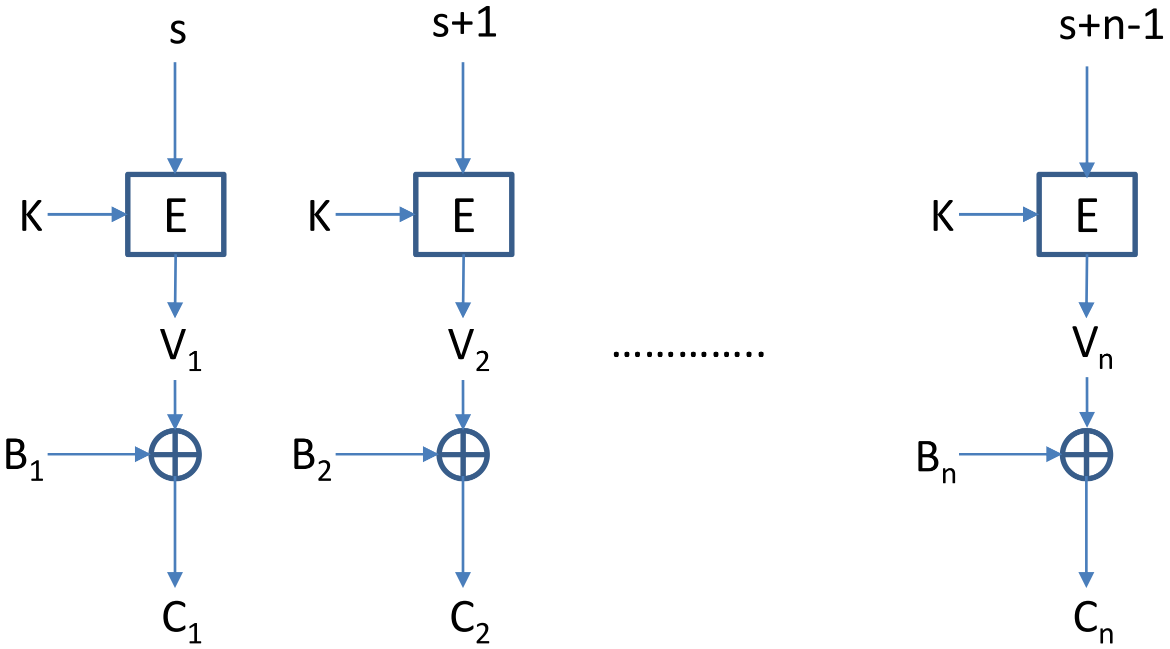


Counter Mode (CTR)

$$V_i = E_k(s+i-1),\ C_i = V_i \oplus B_i \text{ and } B_i = V_i \oplus C_i$$

- Very similar to OFB, except can decrypt at any point rather than from beginning
  - i.e. Pad (V_i) can be generated in parallel
- Gaining popularity over CBC
- s has to be random each time
- Transmit s with ciphertext

Block Diagram



Note: OFB, CTR are stream ciphers. CFB can also be converted into stream cipher, albeit its more complex

Summary

- Symmetric key algorithms like DES, AES are great, but usage as important
  - ECB highlights the drawbacks
- CBC, CFB, OFB, CTR other alternatives
  - Some positives and negatives
  - Still subject to tampering
- Integrity (to be covered) essential to protect against tampering of ciphertext