Crypto I: Symmetric-Key Cryptography

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Slides modified from
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Administrivia

- Midterm
- Lab2

Overview

- Cryptography: **secure communication over insecure communication channels**
- Three goals
  - Confidentiality
  - Integrity
  - Authenticity

Brief history

- 2,000 years ago
  - Caesar Cypher: shift each letter forward by a fixed amount
  - Encode and decode by hand
- During World War I/II
  - Mechanical era: a mechanical device for encrypting messages (Enigma)
- After World War II
  - Modern cryptography: rely on mathematics and electronic computers

Modern cryptography

- Symmetric-key cryptography
  - The same secret key is used by both endpoints of a communication
- Public-key cryptography – Two endpoints use different keys

Perfect secrecy

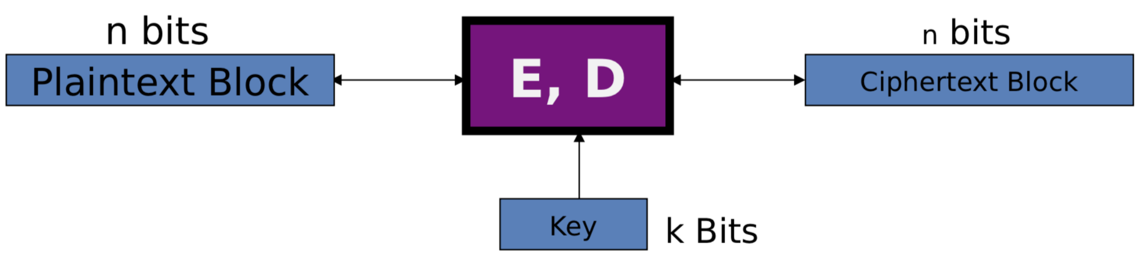
- Claude Shannon: the father of information theory
- Basic idea: ciphertext **C** should provide no "information" about plaintext **M**
- Have several equivalent formulations:
  - The two random variables **M** and **C** are independent
  - Knowing what values **C**/**M** takes does not change what one believes the distribution **M**/**C** is
  - Encrypting two different messages m_0 and m_1 results in exactly the same distribution

One-time pad

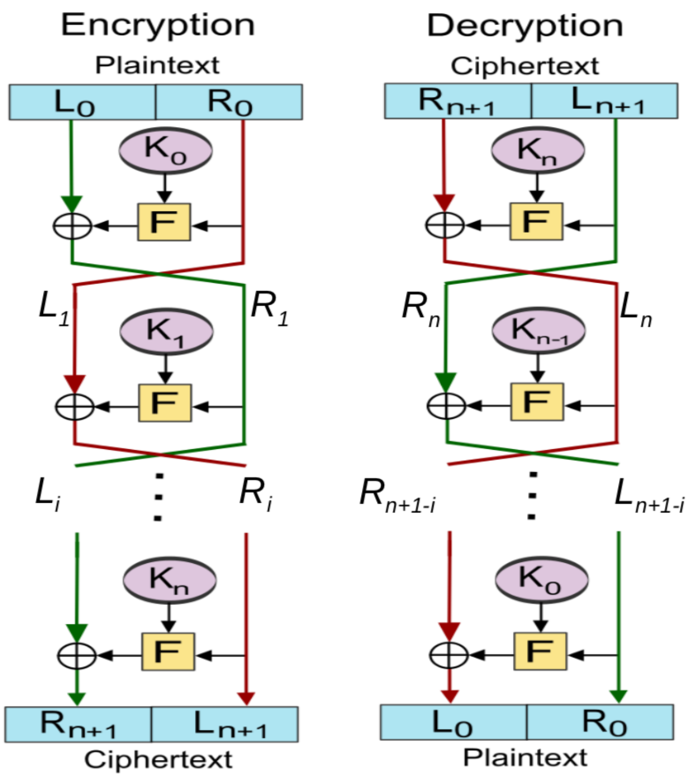
- **K**: random n-bit key
- **M**: n-bit message (plaintext)
- **C**: n-bit ciphertext
- Encryption: C = M xor K
- Decryption: M = C xor K
- To satisfy perfect secrecy **a key can only be used once** -> Impractical!

Block cipher

- Encrypt/Decrypt messages in fixed size blocks using the same secret key
  - k-bit secret key
  - n-bit plaintext/ciphertext



Feistel cipher



Encryption

Start with (L_0, R_0)

$L_{i+1}=R_i$

$R_{i+1}=L_i \text{ xor } F(R_i,K_i)$

Decryption

Start with (R_{n+1}, L_{n+1})

$R_i=L_{i+1}$

$L_i=R_{i+1} \text{ xor } F(L_{i+1},K_i)$

DES - Data Encryption Standard (1977)

- Feistel cipher
- Works on 64 bit block with 56 bit keys
- Developed by IBM (Lucifer) improved by NSA
- Brute force attack feasible in 1997

AES - Advanced Encryption Standard (1997)

- Rijndael cipher
  - Joan Daemen & Vincent Rijmen
- Block size 128 bits
- Key can be 128, 192, or 256 bits

Abstract block ciphers: PRPs and PRFs

- Pseudo Random Function (**PRF**): F: K × X → Y such that:
  - Exists "efficient" algorithm to evaluate F(k,x)
- Pseudo Random Permutation (**PRP**): E: K × X → X such that:
  1. Exists "efficient" algorithm to evaluate E(k,x)
  2. The func E(k,·) is one-to-one
  3. Exists "efficient" algorithm for inverse D(k,x)
- A block cipher is a PRP

Secure PRF and secure PRP

- A **PRF** $F: K \times X \rightarrow Y$ is secure if
  - $F(k, \cdot)$ is indistinguishable from a random function $f: X \rightarrow Y$
- A **PRP** $E: K \times X \rightarrow X$ is secure if
  - $E(k, \cdot)$ is indistinguishable from a random permutation $\pi: X \rightarrow X$

Take-away

- Block cipher approximates one-time pad by using a short key
    - Short secret -> long randomness
- Designing secure block cipher is not easy so
    - **DO NOT EVER TRY TO DESIGN YOUR OWN BLOCK CIPHER**
    - Just use AES, it's secure and fast, even has hardware support

Modes of Operation

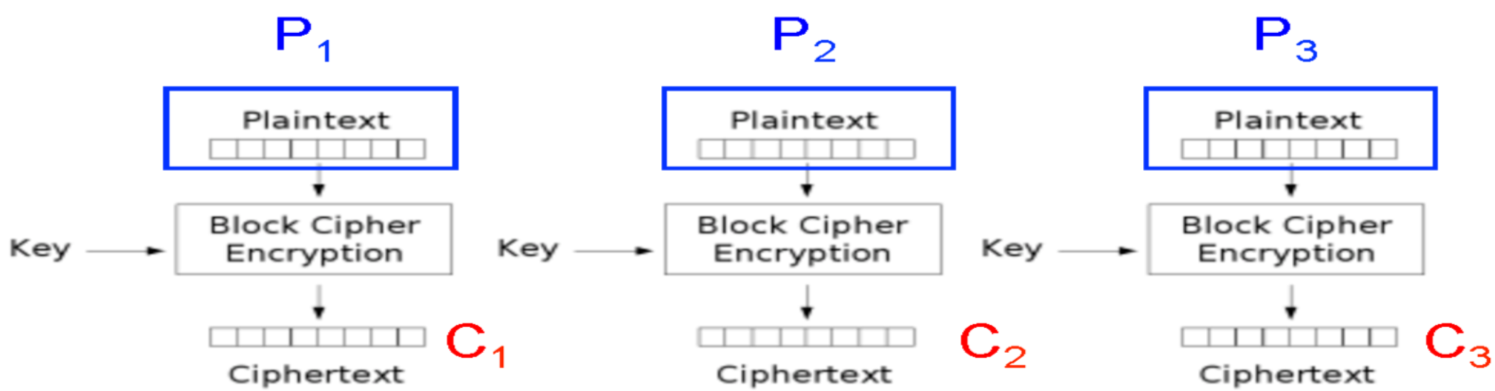
- Block ciphers encrypt fixed size blocks
- How to en/decrypt arbitrary amounts of data?
- NIST SP 800-38A defines 5 modes
    - **Block** and **stream** modes
    - Cover a wide variety of applications
    - Can be used with any block cipher

Electronic Code Book (ECB)

- Message is broken into independent blocks which are encrypted
- Each block is a value which is substituted, like a codebook
- Each block is encoded independently of the other blocks

ECB

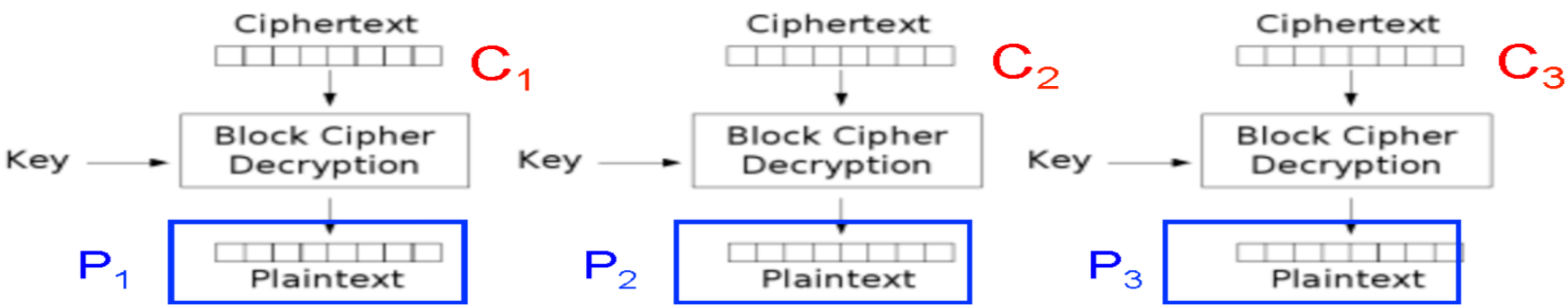
- Encryption



Electronic Codebook (ECB) mode encryption

ECB

- Decryption



Electronic Codebook (ECB) mode decryption

Problems of ECB

- Message repetitions may show in ciphertext
  - If aligned with message block
  - Particularly with data such graphics
  - Or with messages that change very little
- Breaks the requirement of **one-time**
- Not recommended

Example of ECB failure

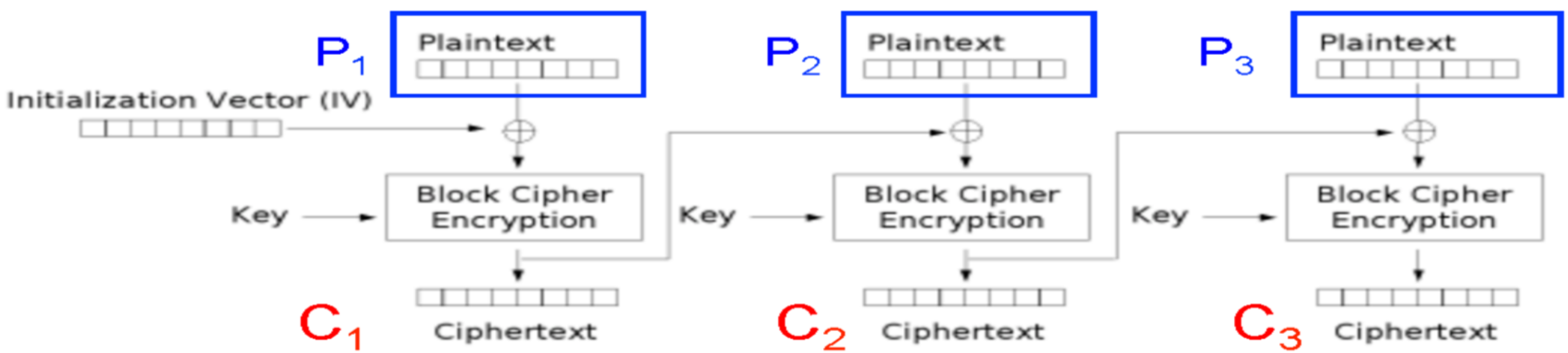
Original image

Example of ECB failure

Encrypted with ECB

Cipher Block Chaining (CBC)

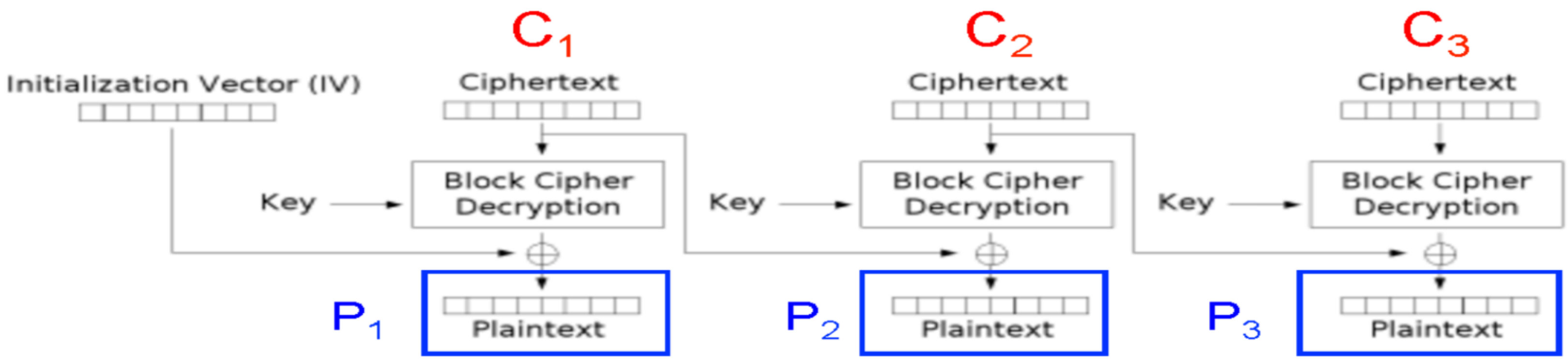
- Encryption



Cipher Block Chaining (CBC) mode encryption

ECB

- Decryption



Cipher Block Chaining (CBC) mode decryption

Advantages and Limitations of CBC

- Ciphertext block depends on *all* blocks before it
- Change to a block affects all following blocks
- Need Initialization Vector (IV)
    - Random numbers
    - Must be known to sender & receiver

Example of CBC

Original image

Example of CBC

Encrypted with CBC

Stream modes

- Block modes encrypt entire block
- May need to operate on smaller units
    - Real time data
- Convert block cipher into stream cipher
    - **Counter (CTR) mode**
- Use block cipher as PRNG (Pseudo Random Number Generator)

Counter (CTR)

- Encrypts counter value
- Need a different key & counter value for every plaintext block
  - O_i = EK(IV+i)
  - C_i = P_i xor O_i
- Uses: high-speed network encryption

Advantages and Limitations of CTR

- Efficiency
  - Can do parallel encryptions in h/w or s/w
  - Can preprocess in advance of need
  - Good for bursty high speed links
- Random access to encrypted data blocks
- Must ensure never reuse key/counter values, otherwise could break

For next class ...

- Crypto II: Asymmetric Key Cryptography