ΥΣ13 - Computer Security

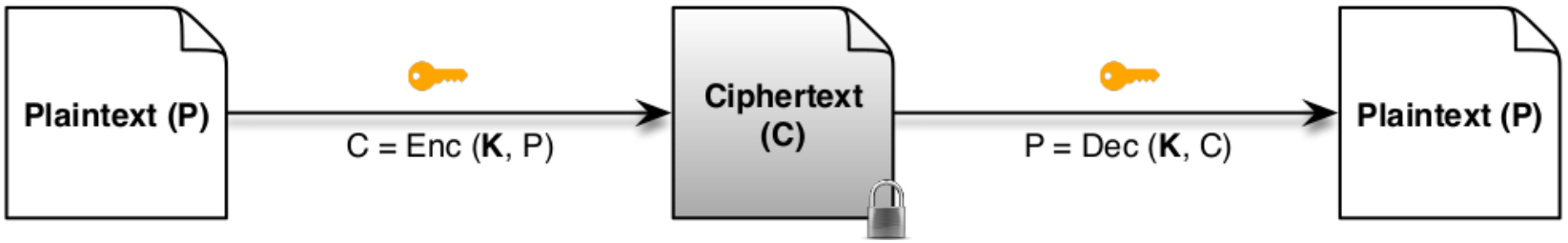
Symmetric Cryptography

Κώστας Χατζηκοκολάκης

Context

- **Goal**
  - Confidentiality
  - Alice wants to send a message *P* (plaintext) to Bob
  - Only Bob should be able to read it
- **Solution** : symmetric encryption
  - Share a key *K* with Bob
  - Only Alice and Bob should know the key
  - Alice constructs an (encrypted) message *C* (ciphertext) from *P*, *K*
  - Bob uses *K* to decrypt *C* and obtain *P*

Context



Correctness: $P = \mathrm{Dec}(K, \mathrm{Enc}(K, P)))$

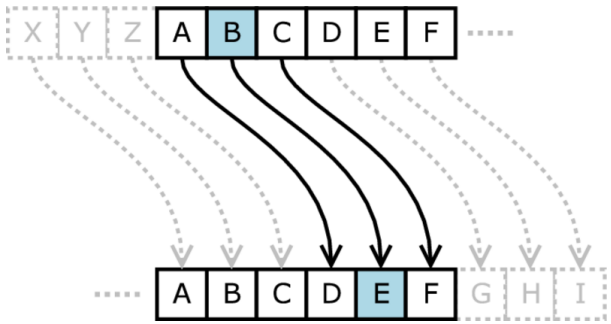
Context

Adversary model

- Knows everything except P, K
- Including all algorithms, protocols, conventions
  - **Important**: obscurity is not security
- Having all information public actually makes the system more secure

First attempt

- Caesar's cipher (50 BC)
  - Replace A$\rightarrow$D, B$\rightarrow$ E, . . .
  - In other words $C_i = P_i + K \mod 26$
  - $K = 4$ (or $K =$ "D") is the key



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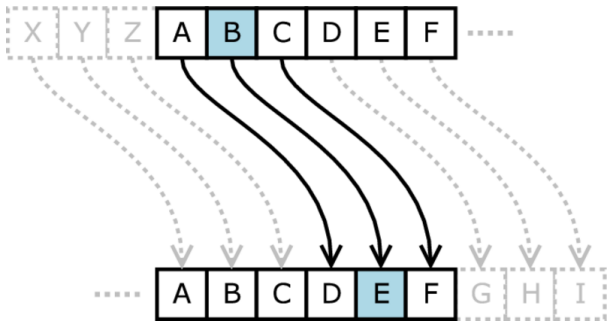

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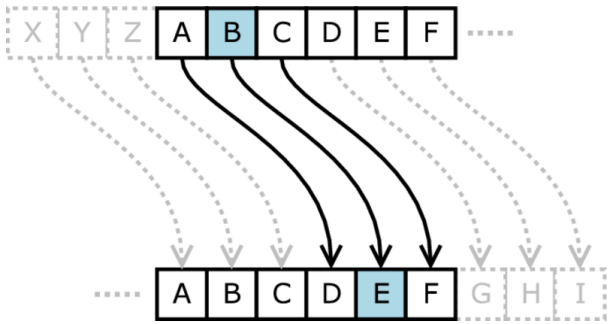
- ROT13
  - $K = 13$ (decrypt is the same as encrypt)
  - Win XP registry keys!



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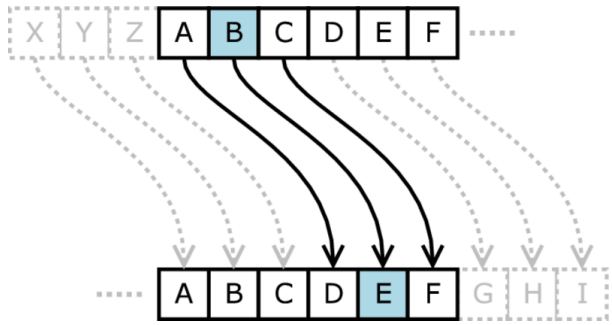
  - use a single permutation of the alphabet
  - How can we break this?



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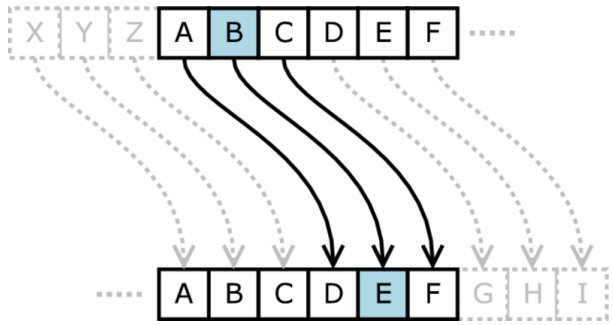

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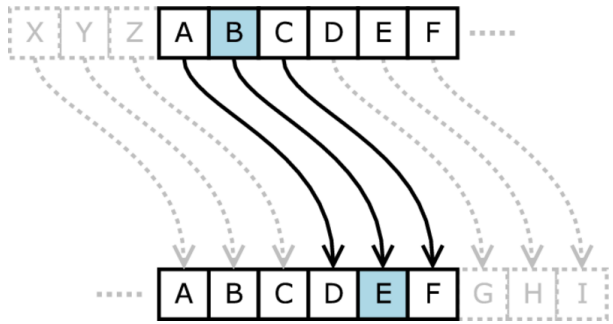

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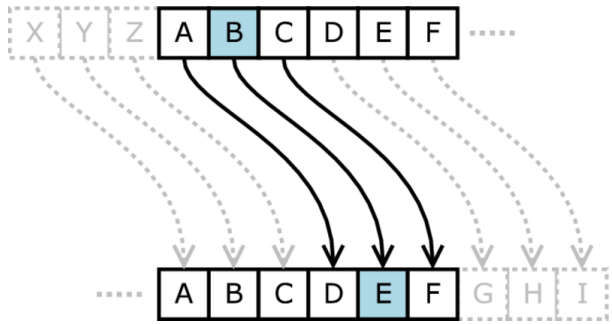

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- How can we do better?
  - Stream cipher : substitution depends on the character's position
  - Block cipher : encrypt many letters at once in a block

Vigenère cipher

An early stream cipher (1553)

- Idea
  - Key: **C**CCCCCCCCCCC… change to
  - Key: **WORD**WORDWORD…
- Frequency analysis much harder
  - Unbreakable for 300 years

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- Problem
  - Repeated patters at multiples of the keyword length
  - Find out the keyword length
  - Then?

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- Repeating key letters was problematic
- Solution?

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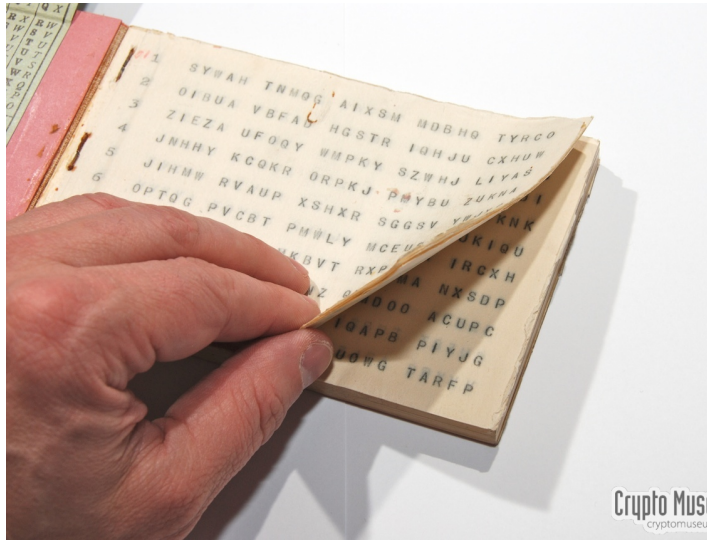

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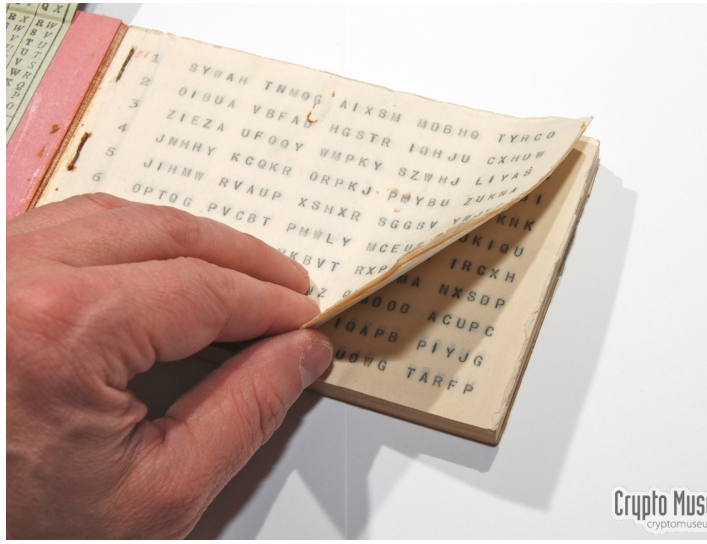

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- Why “one time”?
- Drawbacks?

Playfair Cipher

An early block cipher (1854)

- Key: 5x5 permutation of all letters (I/J combined)
- Encrypt pairs of letters (blocksize: 2 letters)

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R	S	T	O	N
B	C	D	F	G
H	I	K	Q	U
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- Much better than Vigenère
  - But how much better?
  - Change a single letter of plaintext?

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  - Stream : key $\rightarrow$ long keystream
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- Good real cipher
  - indistinguishable from a suitable oracle
  - given certain abilities of the adversary

How can we create a good block cipher?

Principles

- Confusion
  - Drastic (non-linear) change to the input
  - Basic tool : substitution
  - Inverible function $\{0,1\}^n \rightarrow \{0,1\}^n$ (permutation of $\{0,1\}^n$)

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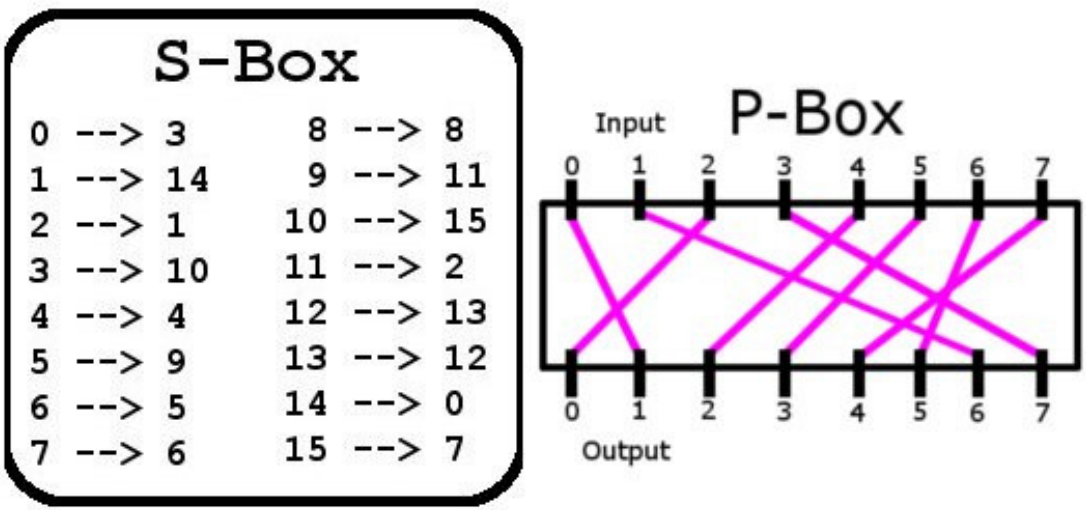
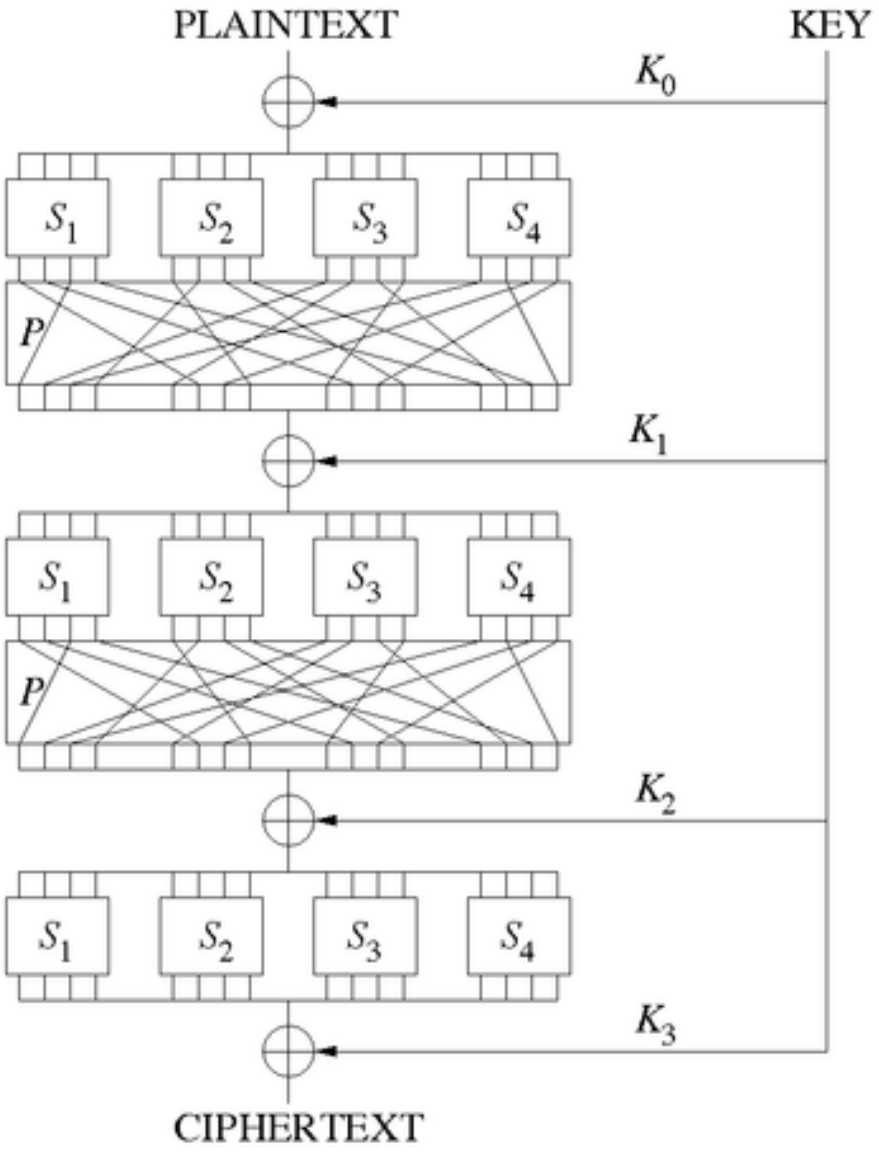
- Diffusion
  - changing a single character of the input will change many characters of the output.
  - Basic tool : permutation of bits

How can we create a good block cipher?

- Substitution (confusion)
- Permutation (diffusion)

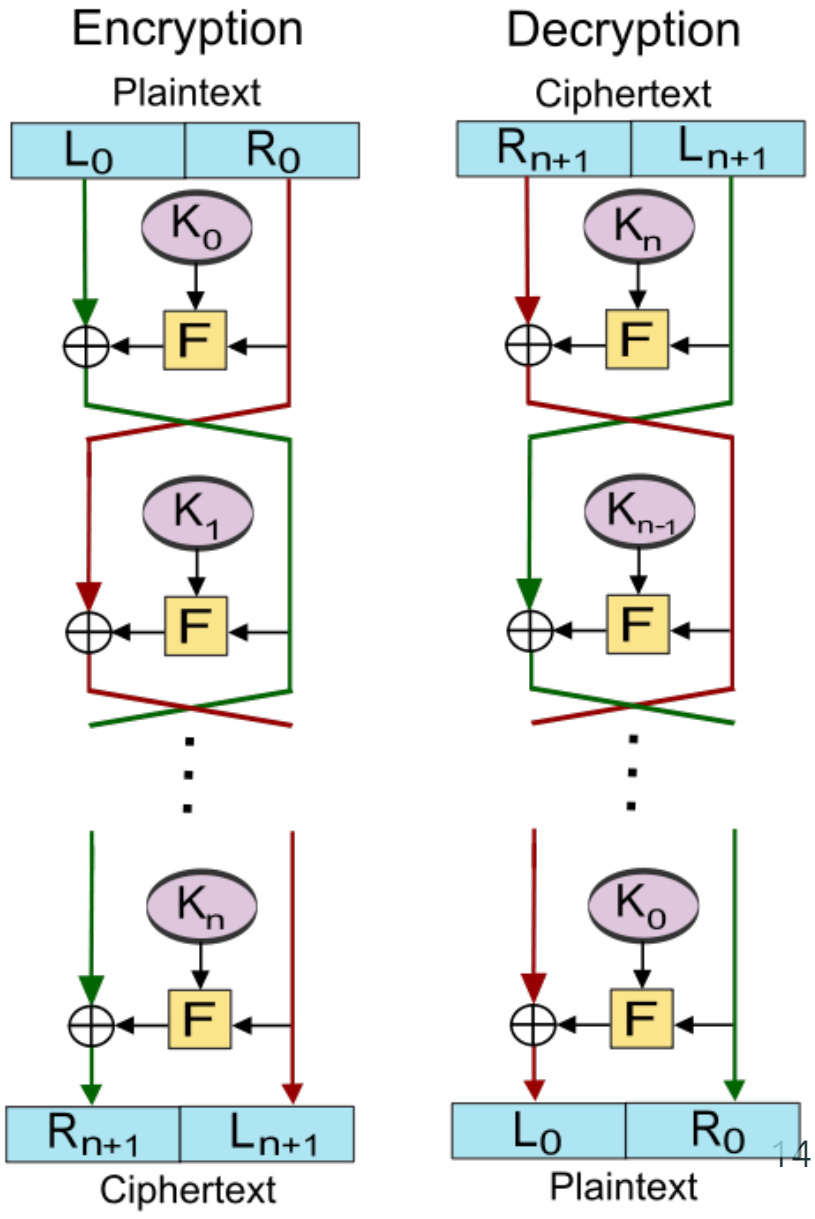


Substitution–permutation network



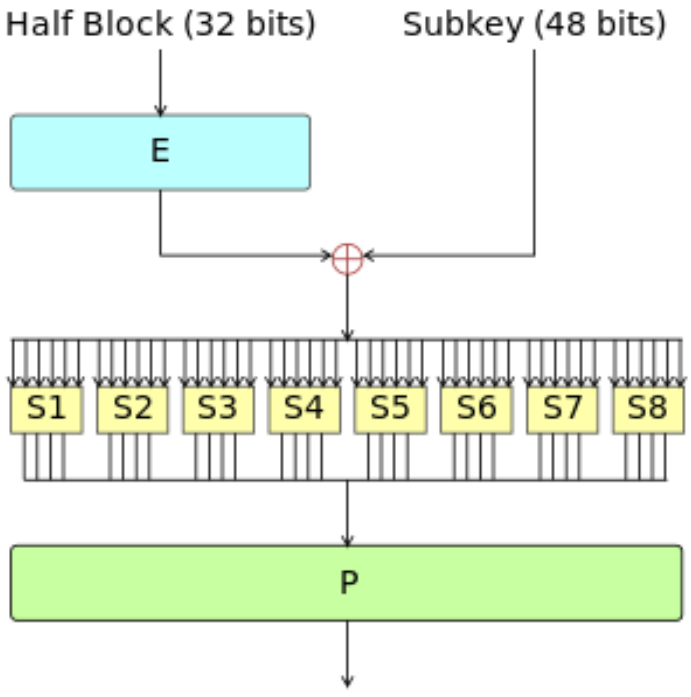
Feistel cipher

- No need for invertible *F*!
- IF *F* is a random function then
  - indist. from random permutation
  - 3 rounds: chosen plaintext
  - 4 rounds: chosen plaintext/ciphertext



Data Encryption Standard (DES)

- IBM, 1975
- Feistel cipher
- 56bit keys
- 64bit block size



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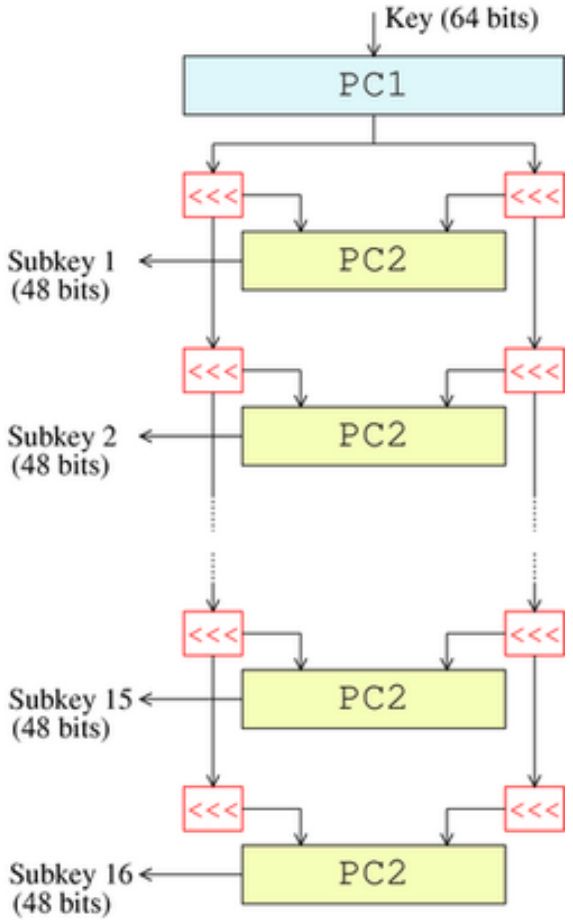

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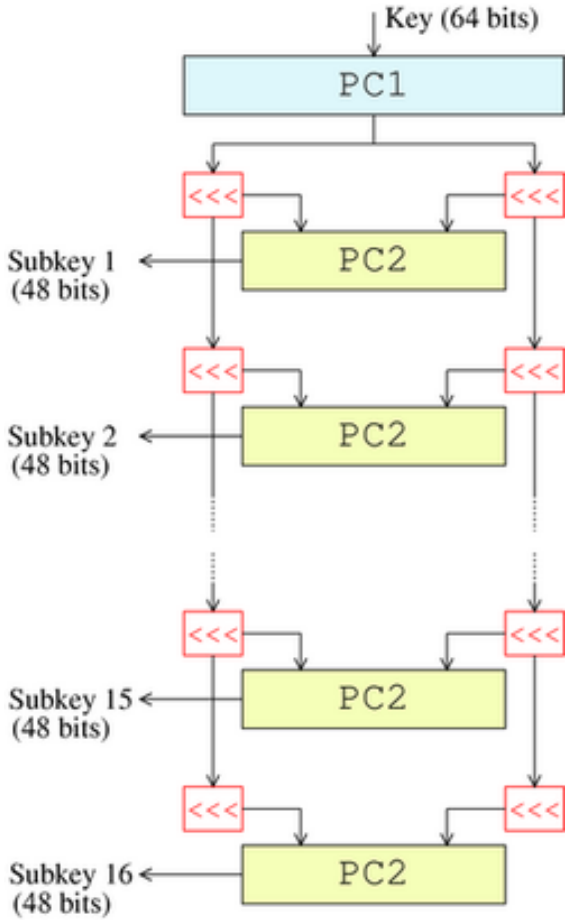
- Weaknesses
  - Brute force (< day)
  - Linear cryptanalysis



Advanced Encryption Standard (AES)

- NIST, 2001
  - Key: 128, 192, 256 bits
  - Block: 128
  - 64bit block size
- SP-network: multiple rounds of
  - Substitution
    - SubBytes
  - Permutation
    - MixColums
    - ShiftRows
- No known practical attack

$$\begin{bmatrix} b_0 & b_4 & b_8 & b_{12} \\ b_1 & b_5 & b_9 & b_{13} \\ b_2 & b_6 & b_{10} & b_{14} \\ b_3 & b_7 & b_{11} & b_{15} \end{bmatrix}$$

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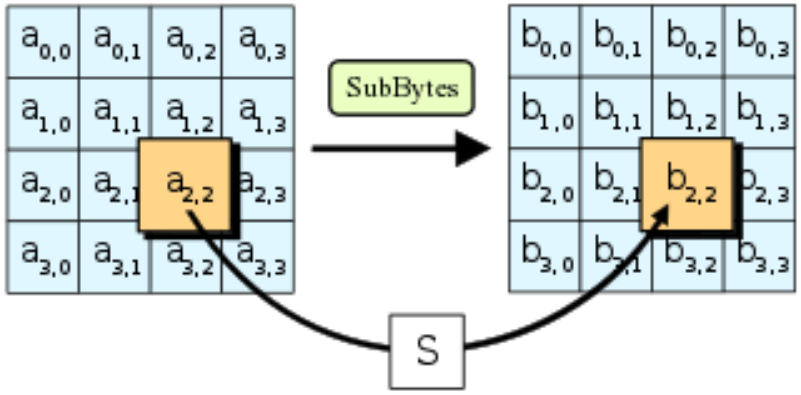

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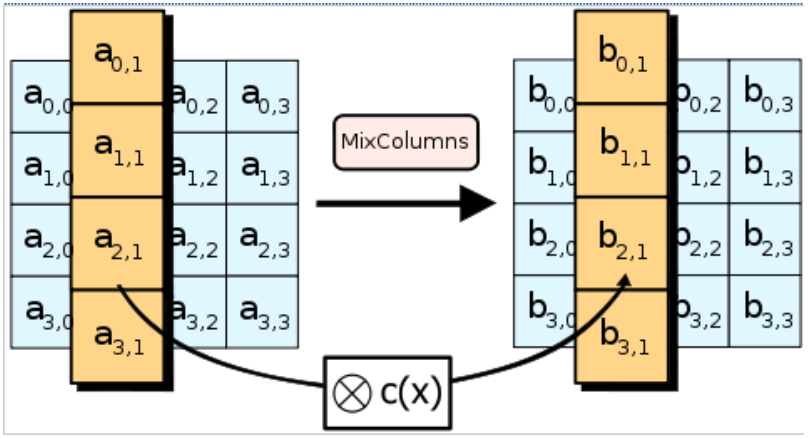

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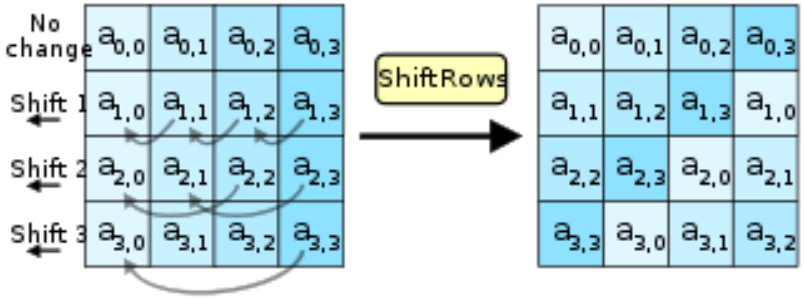

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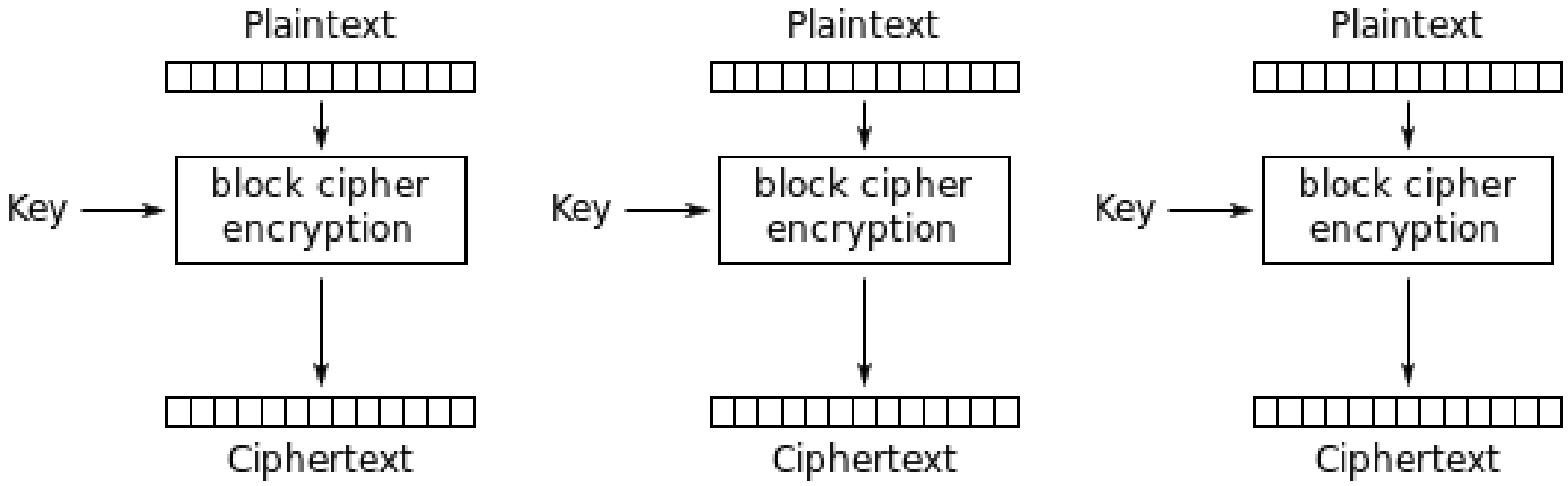

Electronic Codebook (ECB) mode encryption

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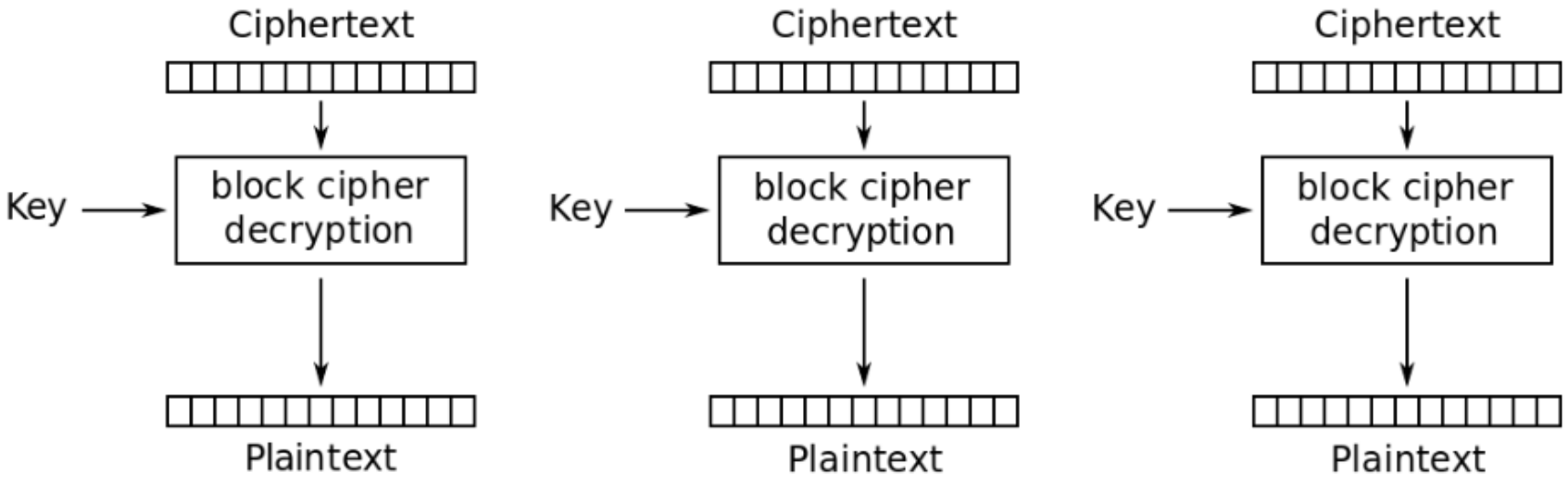
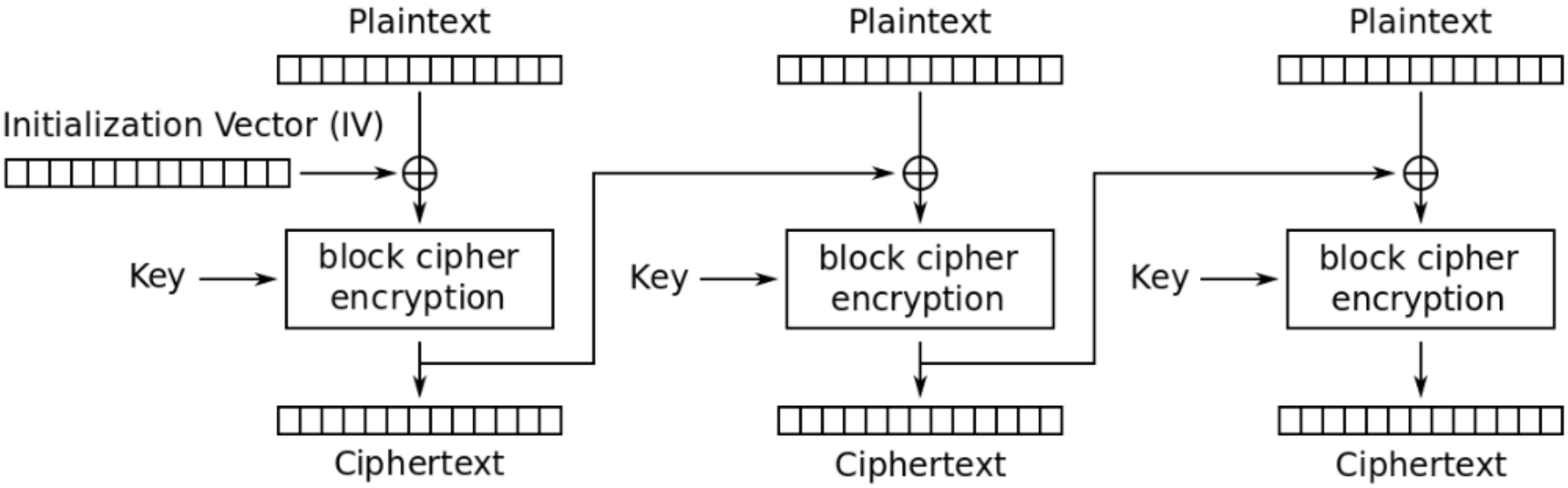


Electronic Codebook (ECB) mode decryption

Mode of operation



Cipher Block Chaining (CBC) mode encryption

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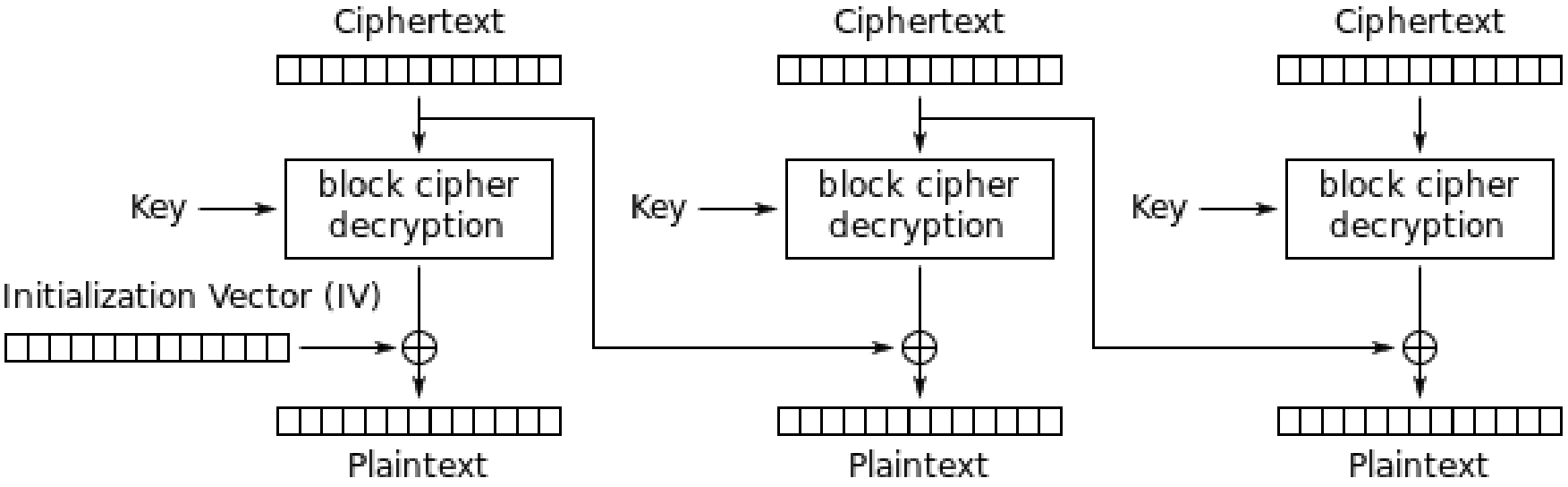

Cipher Block Chaining (CBC) mode decryption

References

- Ross Anderson, Security Engineering, Sections 5.1 - 5.5
- `https://blog.filippo.io/the-ecb-penguin/`