Topic 2.1 - Symmetric Encryption

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1. Basis of Symmetric key
2. Stream Ciphers
3. RC4
4. Block Ciphers
5. DES
6. AES

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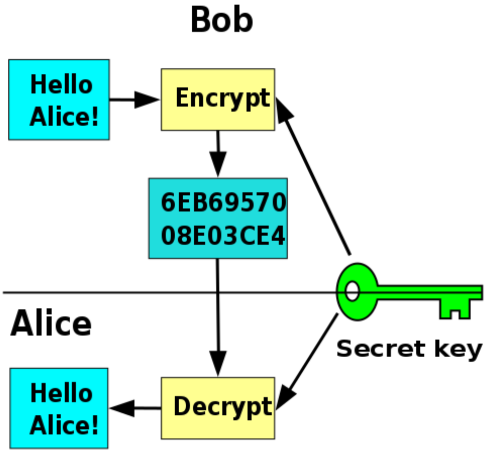
Basis I

- The key used to encrypt and decrypt are **the same**
- Then who knows the key, knows the message
- The key should be known by sender and receiver
- 2 approaches:
  - Stream ciphers: digits encrypted 1 at a time
  - Block ciphers: encryption of fixed group of bits, called blocks

Basis II


Bob
Hello Alice!
Encrypt
6EB69570
08E03CE4
Secret key
Alice
Hello Alice!
Decrypt

1 Basis of Symmetric key

2 Stream Ciphers

3 RC4

4 Block Ciphers

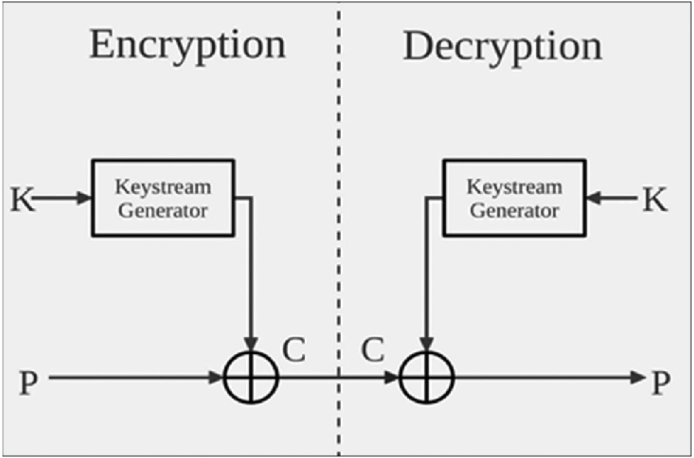
5 DES

6 AES

Stream Ciphers I

- Plaintext digits are combined with a pseudorandom cipher digit stream (keystream)
- Each plaintext digit is encrypted one at a time with the corresponding digit of the keystream, to give a digit of the ciphertext stream
- A digit is typically a bit and the combining operation an XOR
- Examples:
  - **Vernam's cipher**
  - **RC4**
  - Rabbit
  - Salsa20
  - CHACHA

Stream Ciphers II



Vernams cipher I

- Gilbert Vernam invented it in 1917 while working at AT&T
- The key is the same length as the message
- The key is XORed with the message.

Vernams cipher II

- $Enc(K, M) = M \bigoplus K = C$
- $Dec(K, C) = C \bigoplus K = M \bigoplus K \bigoplus K = M$

$\bigoplus$	0	1
0	0	1
1	1	0

```
  M   00101101          C   10001111
  K   10100010          K   10100010
⊕ ------------        ⊕ ------------
  C   10001111          M   00101101
```

- CARE: $M \bigoplus C = M \bigoplus M \bigoplus K = K$

Vernams cipher III

- Does it remind you in something seen so far?
- Do you think that this algorithm is secure?

Vernams cipher IV

- Does it remind you in something seen so far?
- Yes, it's a One Time Pad (OTP)
- Do you think that this algorithm is secure?
- Yes, it is secure and was demonstrated in 1949 by Claude E. Shannon (one of the fathers of the modern cryptography. But only secure if, and only if:
  - The key is truly random
  - Only sender and receiver knows the key
  - The key is not reused
  - The key is destroyed after use
- So why it is not used today?

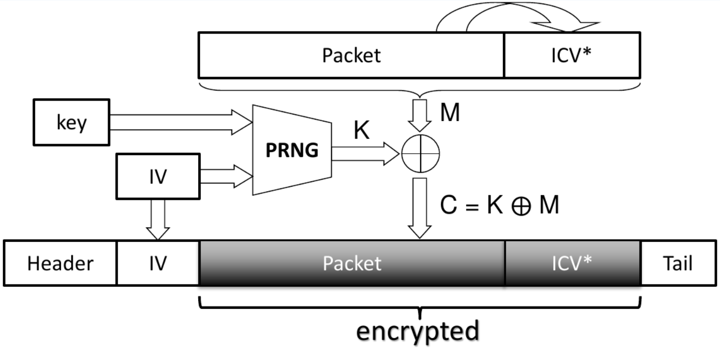
Vernams cipher V

- So why it is not used today?
- The key (keystream) is as long as the message
- Very difficult to distribute and manage the keys
- To send a message of 1GB you need to share a 1GB key

Stream Ciphers security I

- Instead of a key of the same length of the message, a stream cipher makes use of a key of e.g. 64, 128, 256 bits.
- Based on this key, it generates a pseudorandom keystream (e.g. using IV)
- The keystream is now pseudorandom and so is not truly random
- So, the proof of security associated with the OTP no longer holds
- However, we can consider "secure" if keystream:
  - is as random as possible
  - has large period
  - NOT reused

Stream Ciphers security II



- A PRNG can be a hash function
- Do not reuse IVs to increase randomness
- ICV: Integrity Check Value (for data integrity and proof of decryption)

Stream Ciphers security III

IN SUM:

- They are secure?
- They have not been studied in depth to conclude that they are secure
- Block ciphers are more studied, better studied and prefered today

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What is RC4 I

- Stream cipher designed in 1987 by Ron Rivest
- 2 parts:
  - KSA: Key Scheduling Algorithm
  - PRGA: PseudoRandom Generator Algorithm
- Multiple vulnerabilities have been discovered
- Keys from 40-128 bits
- No specified way to use IV
- Many real systems using RC4 have been attacked
- Used in:
  - Secure Socket Layer (SSL)/ Transport Layer Security (TLS) protocols
  - IEEE 802.11 wireless LAN standard
  - WEP

How it works? I

- 4 steps:
  - Initialize the arrays
  - Run KSA on them
  - Run PRGA on KSA output to generate keystream
  - XOR data with keystream

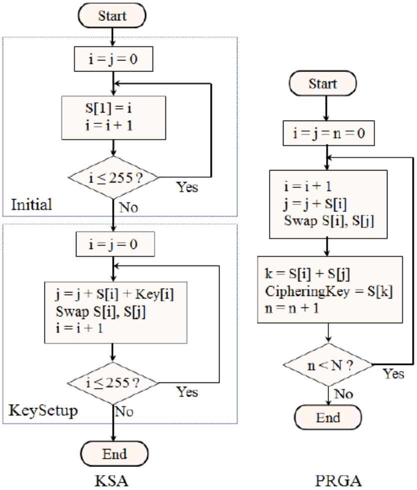
How it works? II

How RC4 works? (Spanish)

OR

Page 48 of the book *Network Security Essentials: Applications and Standards (Fourth edition)*

How it works? III



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Concepts

- Padding
- IVs

Padding

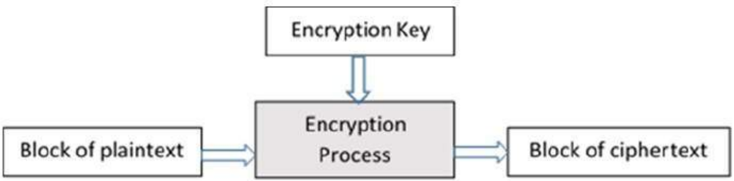
- If the last message block is not complete, a bit string is appended such that:
  - It has the minimum possible length
  - It doesn't introduce any ambiguity in decryption

IVs

- They are block of bits used to randomize the encryption
- Thanks to it we can produce distinct ciphertexts even if the same plaintext is encrypted multiple times
- IV usually does not need to be secret
- Not recommended to reuse IV with the same key

Block Ciphers I

- Process plaintext in blocks of **n** bits
- Produces a block of ciphertext of equal size for each plaintext block
- Examples:
  - DES: k = 64 bits
  - 3DES: k = 64 bits
  - AES: k = 128, 192, 256 bits

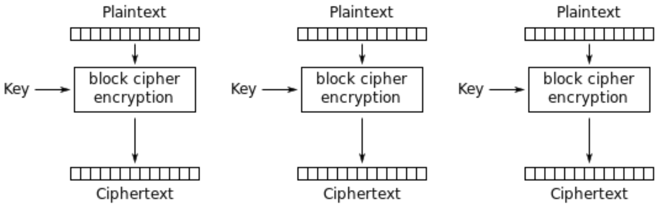


Block Ciphers II

- Stream ciphers can be used for encryption only
- However, block ciphers can be used for:
  - Stream ciphers
  - PRNG
  - Hash functions
  - MACs (Message Authentication Codes)
- Block ciphers also have modes of operation:
  - Electronic Code Book (ECB)
  - Cipher Block Chaining (CBC)
  - Cipher Feedback (CFB)
  - Output Feedback (OFB)
  - Counter Mode (CTR)

ECB I

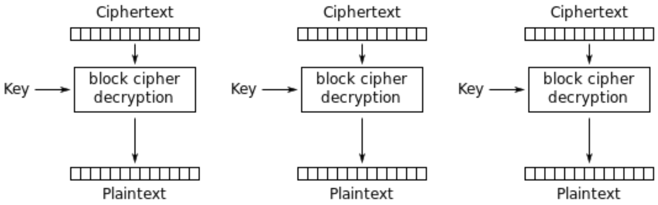
- ECB Encryption:
  $c_i = Enc(k, m_i)$



Electronic Codebook (ECB) mode encryption

ECB II

- ECB Decryption:
  $m_i = Dec(k, c_i)$



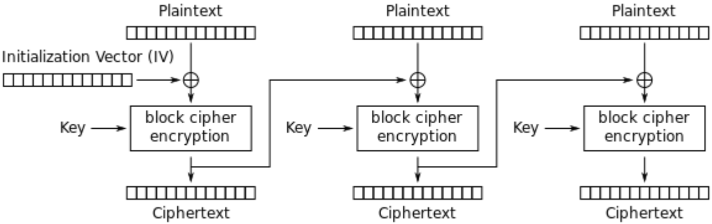
Electronic Codebook (ECB) mode decryption

ECB III

- Required padding
- $m_1 = m_2 \rightarrow c_1 = c_2$
- Not recommended for use in cryptographic protocols
- Encryption -> Parallelizable
- Decryption -> Parallelizable

CBC I

- CBC Encryption:
  $c_0 = iv$
  $c_i = Enc(k, m_i \bigoplus c_{i-1})$



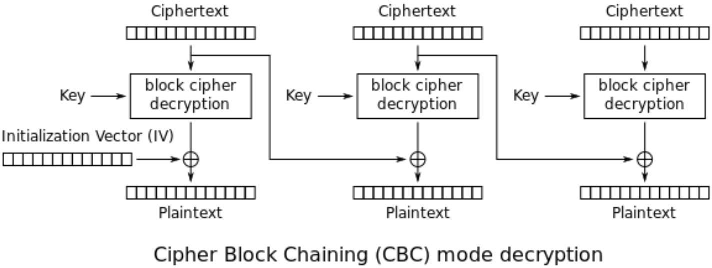
Cipher Block Chaining (CBC) mode encryption

CBC II

- CBC Decryption:

  $c_0 = iv$

  $m_i = Dec(c_i) \bigoplus c_{i-1}$

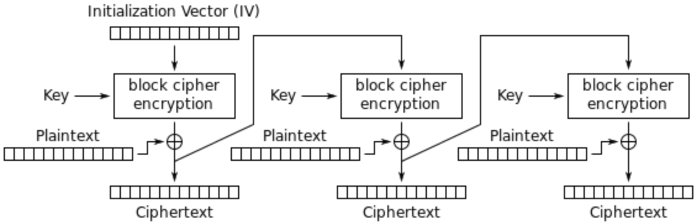


CBC III

- Required padding
- Required IV
- Each ciphertext requires the last processed plaintext
- Encryption -> Not Parallelizable
- Decryption -> Parallelizable

CFB I

- CFB Encryption:
  $c_0 = iv$
  $c_i = Enc(k, c_{i-1}) \bigoplus m_i$



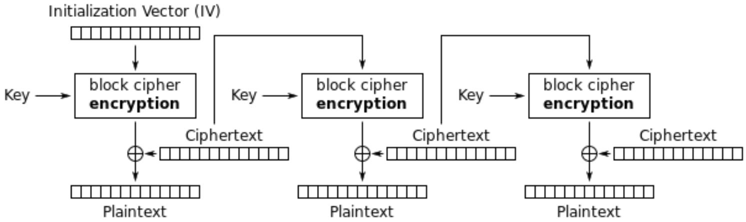
Cipher Feedback (CFB) mode encryption

CFB II

- CFB Decryption:

  $c_0 = iv$

  $m_i = \mathbf{Enc}(c_{i-1}) \bigoplus c_i$



Cipher Feedback (CFB) mode decryption

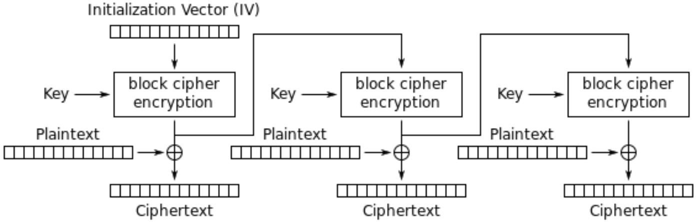
CFB III

- Not necessary padding
- Required IV
- Similar CBC
- Encryption and Decryption uses the same function
- Encryption -> Not Parallelizable
- Decryption -> Parallelizable

OFB I

- OFB Encryption:

$$r_0 = iv$$
$$r_i = Enc(k, r_{i-1})$$
$$c_i = m_i \bigoplus r_i$$



Output Feedback (OFB) mode encryption

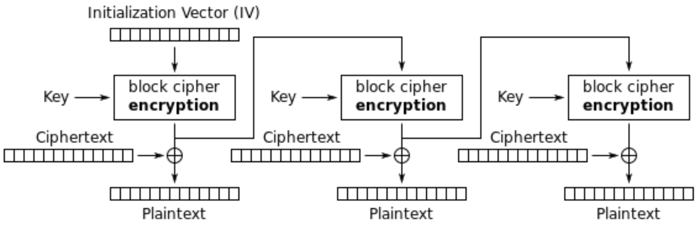
OFB II

- OFB Decryption:

$r_0 = iv$

$r_i = Enc(k, r_{i-1})$

$m_i = c_i \bigoplus r_i$



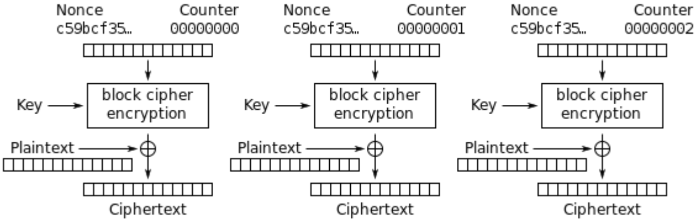
Output Feedback (OFB) mode decryption

OFB III

- Not necessary padding
- Required IV
- Encryption and Decryption uses the same function
- Encryption -> Not Parallelizable
- Decryption -> Not Parallelizable

CTR I

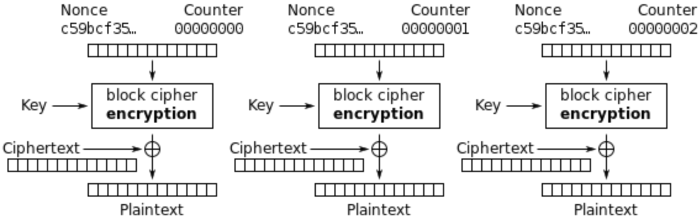
- CTR Encryption:
  $r_i = Enc(k, iv + i)$
  $c_i = m_i \bigoplus r_i$



Counter (CTR) mode encryption

CTR II

- CTR Decryption:
  $r_i = Enc(k, iv + i)$
  $m_i = c_i \bigoplus r_i$

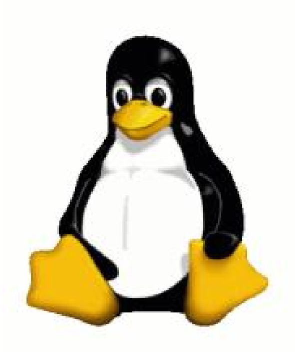


Counter (CTR) mode decryption

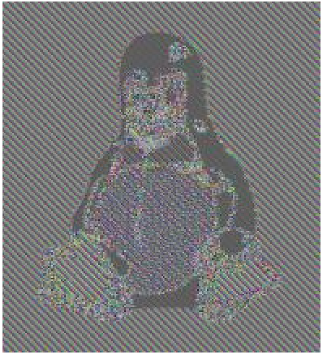
CTR III

- Not necessary padding
- Required IV
- Public nonce and "counter" to increase randomness
- Encryption and Decryption uses the same function
- Encryption -> Parallelizable
- Decryption -> Parallelizable

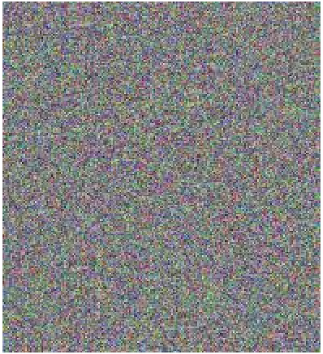
Operation Mode Comparison I



(a) Our god Tux



(b) Tux in ECB



(c) Tux in other modes

Operation Mode Comparison II

- CFB, OFB and CTR require only the encryption box (even for decryption)
- CTR and ECB are parallelizable
- Only ECB and CBC require padding of the last incomplete block

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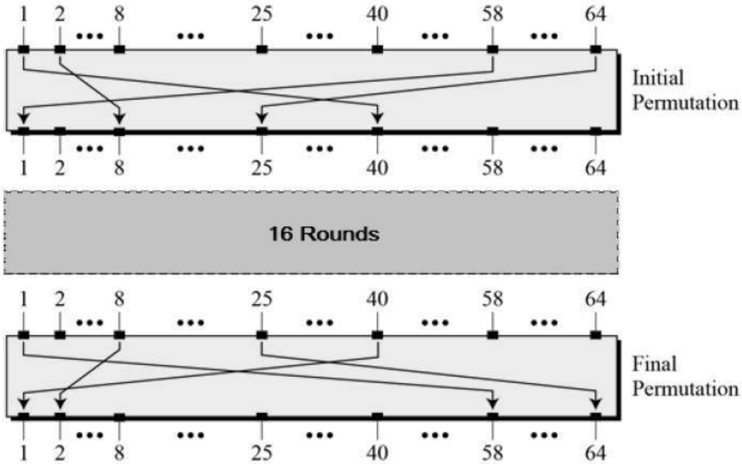
DES

- DES or Data Encryption Standard
- Symmetric key algorithm to encrypt data
- Developed in the 1970s at IBM
- In 1998 Electronic Frontier Foundation built a computer that broke DES in 3 days
- Block cipher of 64 bits (b4 bits per block)
- 56 bits key
- We can use any mode of operation

How DES works I

1. Initial permutation
2. 16 rounds of of Feistel functions
3. Final permutation (inverse of the initial)

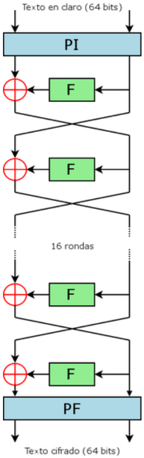
How DES works II



How DES works III

- In the 16 rounds:

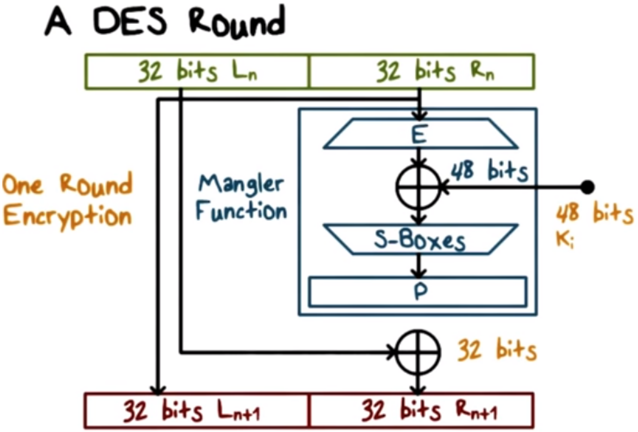
How DES works IV



How DES works V

- The feistel (F) function:

How DES works VI



How DES works VII

- In order to decrypt you have to do the process in reverse order!

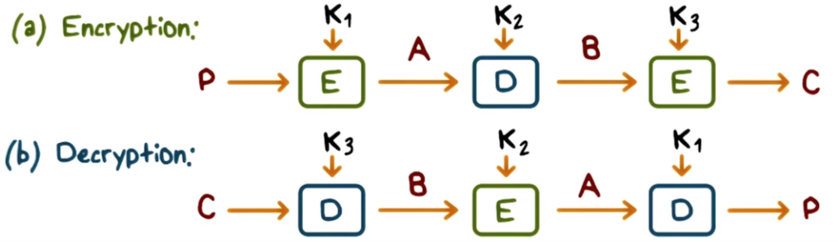
How DES works?

DES Security

- DES is not used today
- Many attacks to the algorithm:
  - Brute Force Attack (trying every combination 2^{64} possible keys)
  - Differential Cryptanalysis (To break the 16 rounds, 2^{49} chosen texts)
  - Linear Cryptanalysis (2^{43} known plaintexts)
- For these reasons DES was imporoved in 1998 to 3DES
- *Differential Cryptanalysis: It studies how differences in information input can affect the resultant difference at the output*
- *Linear Cryptanalysis: It studies the probabilistic linear relations between parity bits of the plaintext, the ciphertext, and the secret key*

3-DES

- Using 3 times DES:
- 3 keys: 3 different (k = 168 bits) or k1 = k3 (k = 112 bits)



1 Basis of Symmetric key

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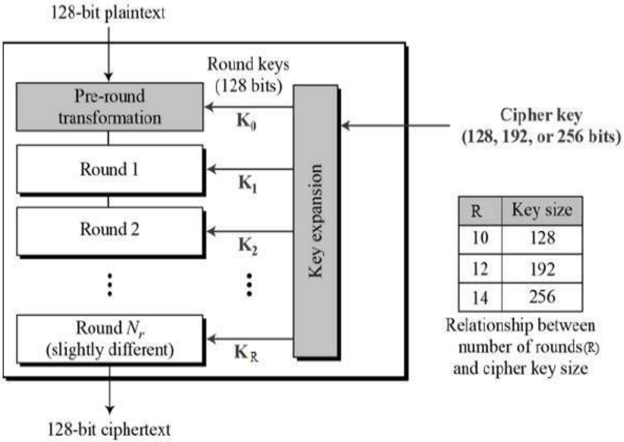
AES

- AES or Advanced Encryption Standard
- Symmetric key algorithm to encrypt data
- Developed in 2001 by NIST (National Institute of Standards Technology)
- Block cipher of 128 bits (128 blocks per bit)
- 128/192/256 bits key
- we can use any mode of operation

How AES works? I

- Algorithm description:
  1. KeyExpansion
  2. Pre-round transformation: AddRoundKey
  3. 9, 11 or 13 rounds (depending on key length 128, 192 or 256)
     1. SubBytes
     2. ShiftRows
     3. MixColumns
     4. AddRoundKey
  4. Final round:
     1. SubBytes
     2. ShiftRows
     3. AddRoundKey

How AES works? II

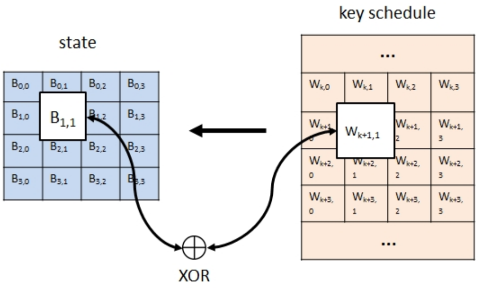


R	Key size
10	128
12	192
14	256

Relationship between number of rounds(R) and cipher key size

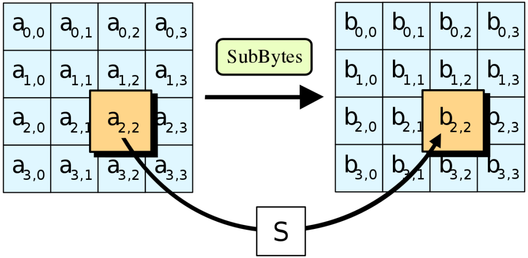
How AES works? III

- AddRoundKey



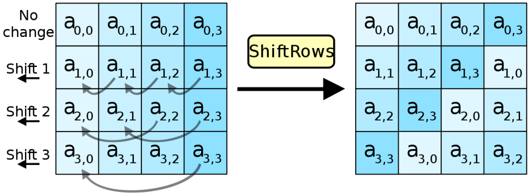
How AES works? IV

- SubBytes



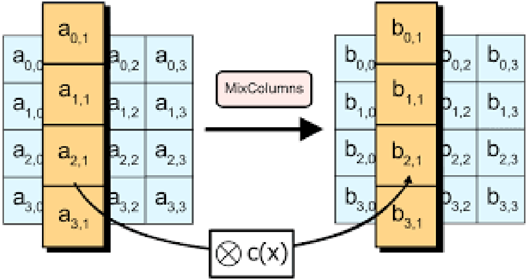
How AES works? V

- ShiftRows

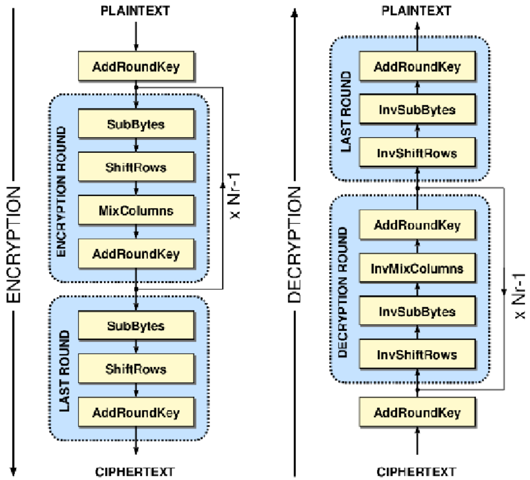


How AES works? VI

- MixColumns



How AES works? VII



How AES works? VIII

How AES works?

AES Security

- There are Side-channel attacks
- There are no known practical cryptanalytic attacks
- Today we can consider AES secure
- *side-channel attack: Is an attack based on information gained from the implementation of a computer system, rather than weaknesses in the implemented algorithm itself. This information can be timing information, power consumption, electromagnetic leaks or even sound*

The END!