INSTITUTO POLITÉCNICO NACIONAL
ESCUELA SUPERIOR DE CÓMPUTO

Cryptography

"Advanced Encryption Standard (AES)"

Abstract

Implementation in Python of AES Cipher using 5 different modes of operation for two different bmp images, one with just 2 colors and the other with too much variation of color pixel by pixel.

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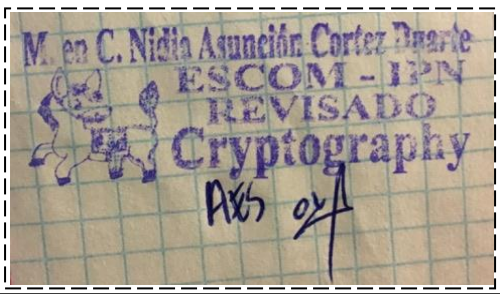
November 2017



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Introduction:

AES Cipher is a symmetric block cipher capable of encrypt blocks of 128 bits (16 bytes or characters), it has a security of 128 bits because the key to encrypt/decrypt the information has 128 bits of length. This cipher, receive arrays of 16 bytes (it doesn't matter if we are talking about plaintext, images, wav files, etc.). [1]

It is formed by 4 different functions in regular rounds (9) and 3 of those 4 functions in the last round, on Figure 1 is shown the general process of AES.

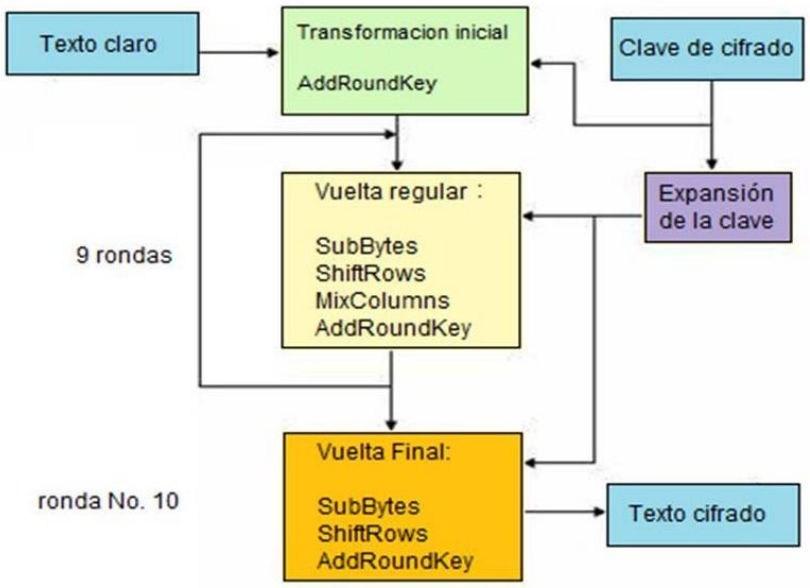


Figure 1. General Diagram of AES

In this cipher, the plaintext is represented by a matrix as such as the key (it has its own process of expansion to select a new key for the next rounds).

As we can observe, the 4 different functions are:

- **AddRoundKey:** XOR operation byte by byte between key and plaintext.
- **SubBytes:** Substitute each byte of the matrix following the S-box.
- **ShiftRows:** Make a left-rotation of n – bytes (with n from 0 to number of rows – 1).
- **MixColumns:** Multiply the matrix obtained by the first 3 functions with the key in GF (2^8).

Although these 4 functions seems to be very simple, just 3 of them really are, because MixColumns function is very hard if we do it manually, because a multiplication of 2 matrixes in GF (2^8) is not too simple. This procedure will be explained better on "Literature Review" section.

This cipher works with bytes (I already mentioned that) written in hexadeximal, that's why GF (2^8), each byte is composed by 8 bits, but we need only 4 bits to represent from 0 to F and then, we have to have 2 *characters* on each position of the matrix.

On Figure 2, we can observe AddRoundKey function.

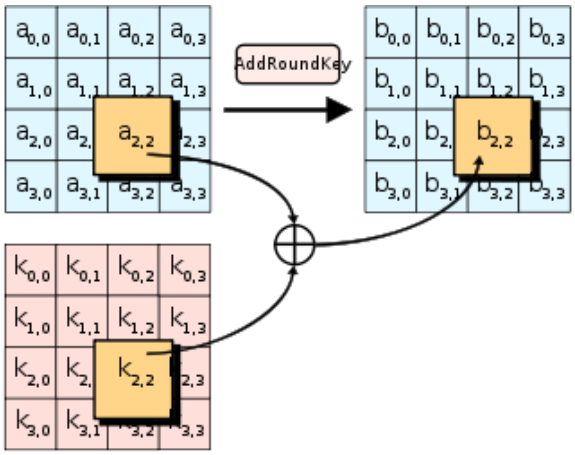


Figure 2. AddRoundKey Function

As you can see, we made and XOR between $a_{2,2}$ and $k_{2,2}$ to obtain $b_{2,2}$. The next function (SubBytes) is shown on Figure 3.

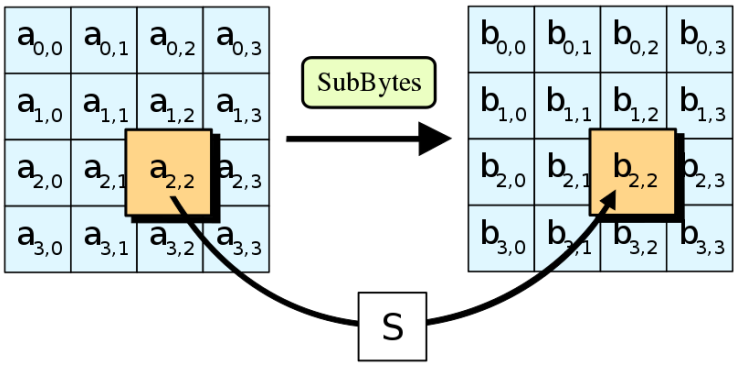


Figure 3. SubBytes Function

On Figure 4, is shown ShiftRows Function.

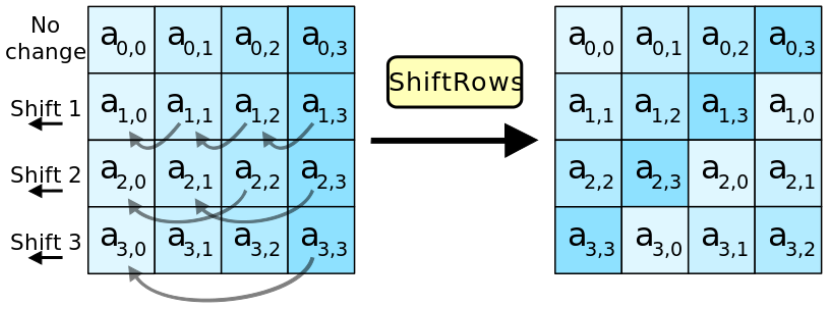


Figure 4. ShiftRows Function

The last function, MixColums, is shown on Figure 5.

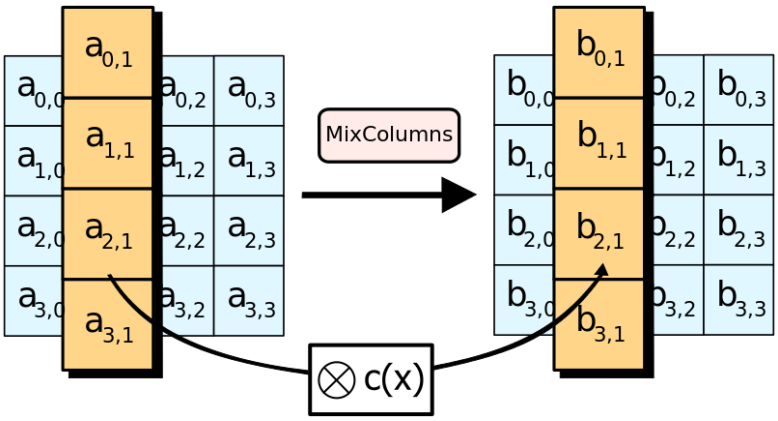


Figure 5. MixColumns Function

On the next section, I will explain the idea of MixColumns function supported by multiplication in GF (2^8).

Literature review:

In order to explain what and how MixColumns does, is important to know what is GF (2^8). GF (2^8) is known as ***finite binary fields of extension 8***, it means that here, applies the same idea that in the first practice, we are operating from 0 to 2^8. Every number in this ***finite field*** could be represented as a polynomial expression as such as the following example of the representation of number 814_{10}:

Binary	Hexadecimal	Polynomial expression
1000 1110	8E	$x^7 + x^3 + x^2 + x^1$

Maybe it is difficult to observe why we obtained that mathematical expression for that number, but is not. As we can already have said it, we need to use 8 bits to represent every number due to the extension of our field. To obtain the polynomial expression we need to name bit by bit every bit on the number, that's why the most significant bit will be x^7, but if we have a zero in that place, it will be the same as $0 \cdot x^7 = 0$. The bit next to the right will be x^6 so, successively.

Now, we know what GF (2^8) means, then, we need to know how to work on it, addition will be the same operation as an XOR, like the following table:

A	B	A + B = C
0	0	0
0	1	1
1	0	1
1	1	0

As we can observe, is very simple, if we have just 1 bit on, the result will be 1, in other case, the result will be 0. Addition is very simple, now, complexity will increase in multiplication in GF (2^8). In the following example, the multiplication will be between **1010 1101 * 1110 1111 = AD * EF**

$$x^7 + x^5 + x^3 + x^2 + 1$$
$$\underline{x^7 + x^6 + x^5 + x^3 + x^2 + x^1 + 1}$$
$$x^7 + x^5 + x^3 + x^2 + 1$$
$$x^8 + x^6 + x^4 + x^3 + x^1$$
$$x^9 + x^7 + x^5 + x^4 + x^2$$
$$x^{10} + x^8 + x^6 + x^5 + x^3$$
$$x^{12} + x^{10} + x^8 + x^7 + x^5$$
$$x^{13} + x^{11} + x^9 + x^8 + x^6$$
$$\underline{x^{14} + x^{12} + x^{10} + x^9 + x^7}$$
$$x^{14} + x^{13} + x^{11} + x^{10} + x^9 + x^6 + x^4 + x^3 + x^1 + 1$$

Now, we can observe that we have exponents bigger than 7 (the biggest possible exponent), so, what we need to do is to make a polynomial reduction with a simple division as the next example with a special polynomial: 1001 1011

$$x^7 + x^4 + x^3 + x^1 + 1 \,\big|\, \overline{x^{14} + x^{13} + x^{11} + x^{10} + x^9 + x^6 + x^4 + x^3 + x^1 + 1}$$

The result of that expression is: $\mathbf{x^7 + x^6 + x^5 + x^4 + x^2 + 1}$

MixColumns function works in that way, multiplying 2 matrixes (the corresponding key for each round and the plaintext) in GF (2^8), that's why, the important thing here was to understand how GF (2^8) works and how do we need to reduce a polynomial expression.

Remember that multiplication of matrixes A * B = C is explained below:

$(A_{1,1} * B_{1,1}) + (A_{1,2} * B_{2,1}) + \ldots + (A_{1,n} * B_{n,1}) = C_{1,1}$

$(A_{2,1} * B_{1,1}) + (A_{2,2} * B_{2,1}) + \ldots + (A_{2,n} * B_{n,1}) = C_{2,1}$

As you can observe, the multiplication of 2 matrixes is an addition of a lot of multiplications of 2 numbers (as such as multiplication in GF (2^8)). On Figure 6, you can see a graphic example of multiplication of 2 matrixes.

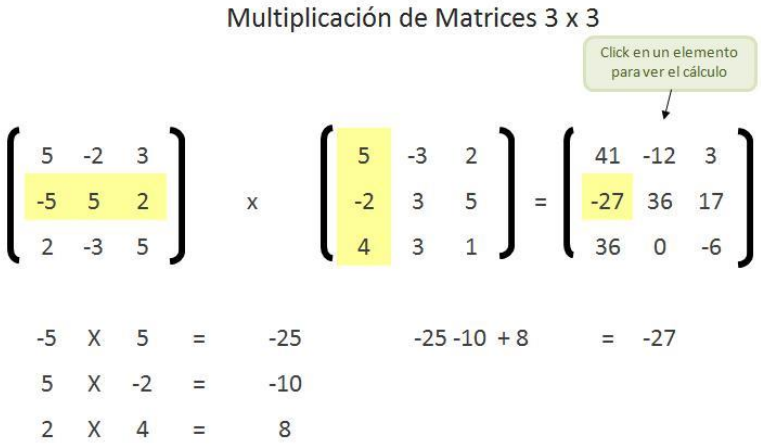
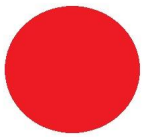
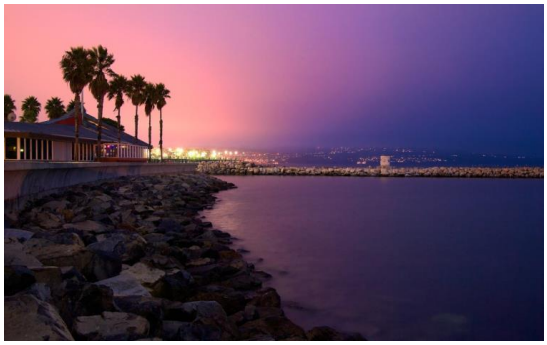
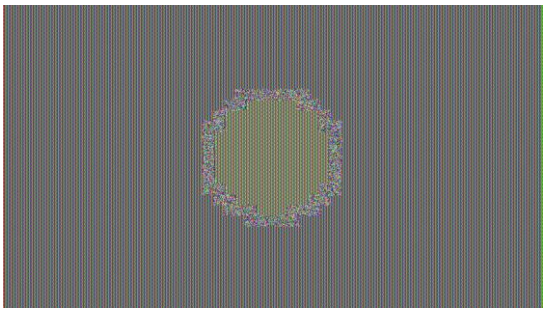
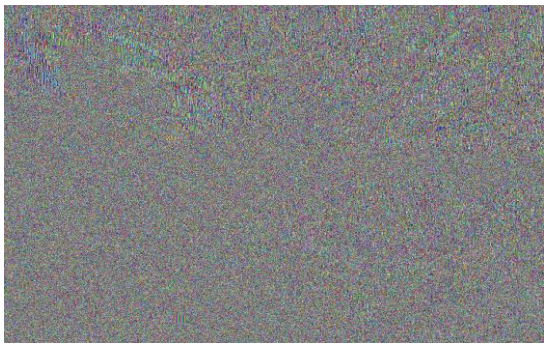
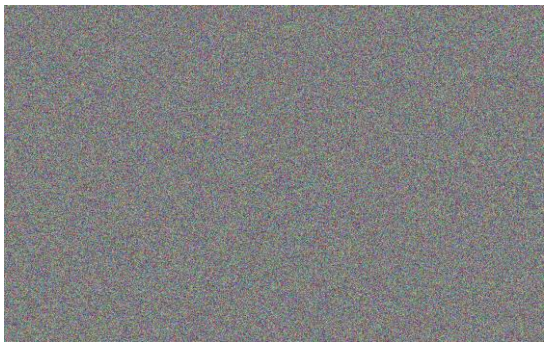
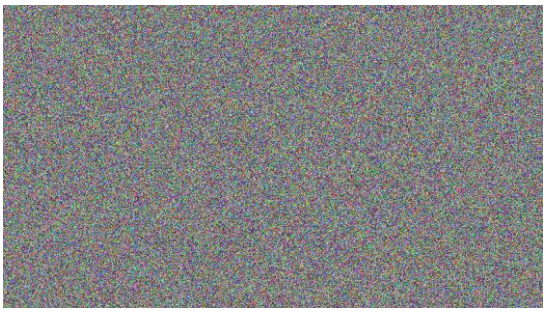
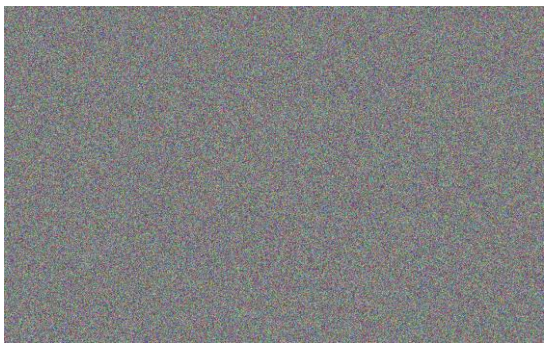


Figure 6. Example of Matrix Multiplication

The next tables represent the differences between AES and DES Cipher, encrypting 2 different images, one of them is Japan's Flag (only 2 colors), and the other is a landscape (too much variation of color).

DES	Japan	Paisaje
Plaintext		
Electronic Codebook		
Cipher Block Chaining		
Output Feedback		

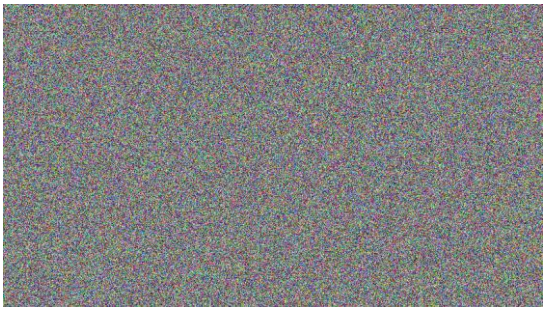
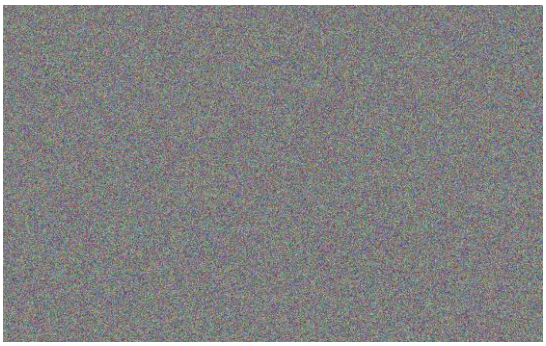
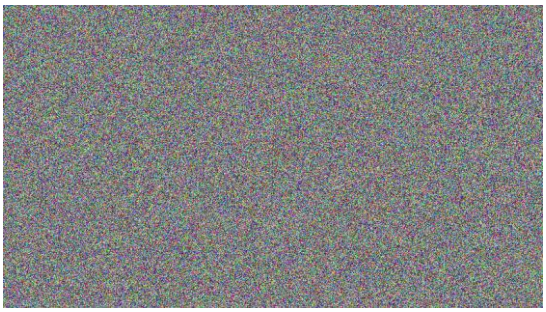
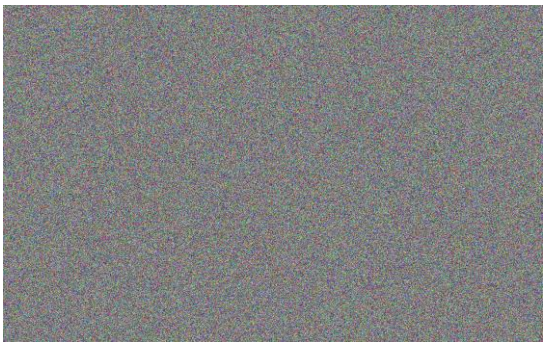
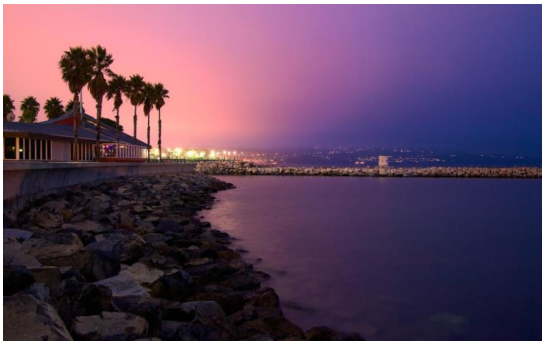
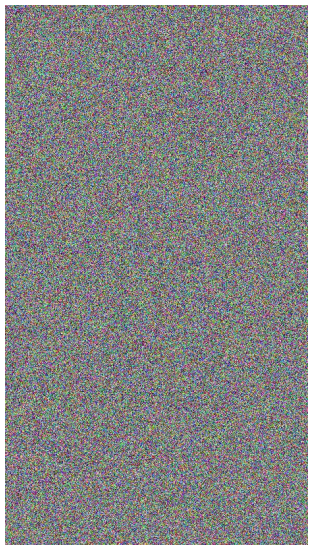
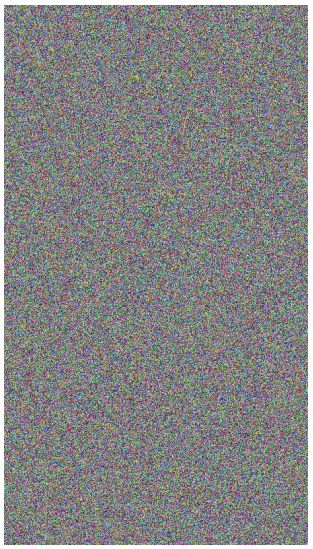
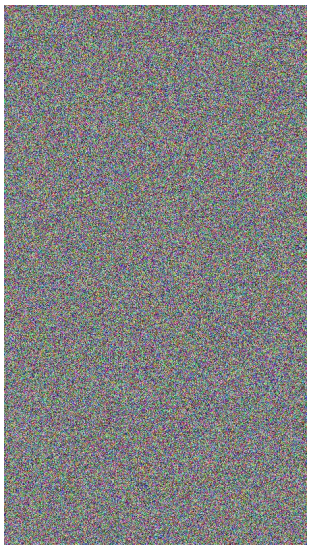
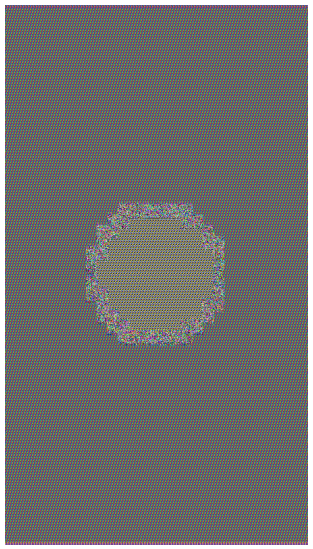
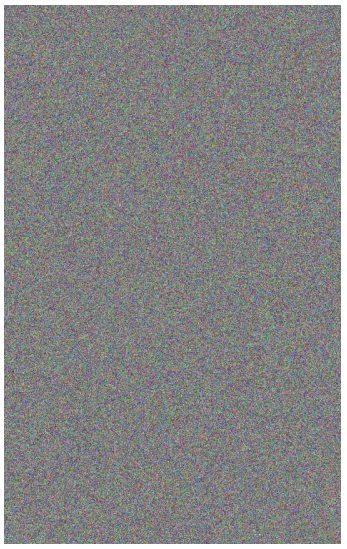
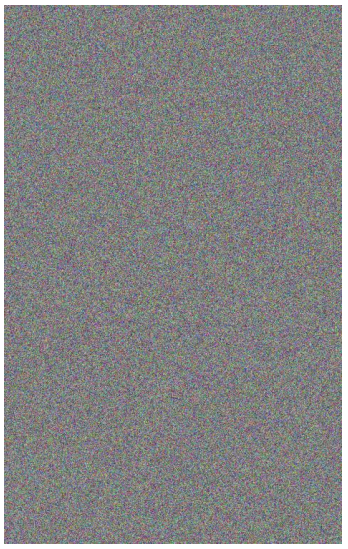
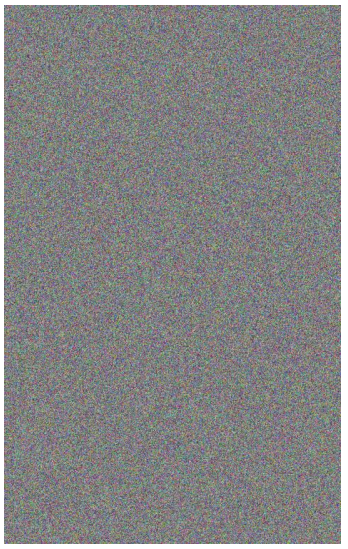
Cipher Feedback		
Counter		

Table 1. Encryption examples with DES Cipher

The next table represents the same both example images but encrypting now with AES Cipher with its 128 bits of security that is the length of the encryption key.

AES	Japan	Paisaje
Plaintext		

Cipher Feedback	Output Feedback	Cipher Block Chaining	Electronic Codebook
			
			

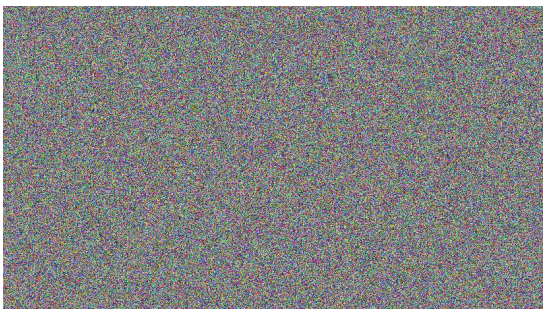
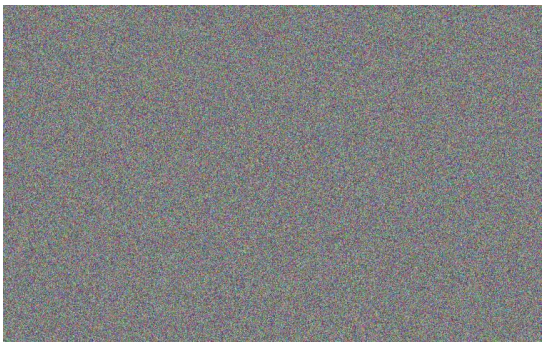
Counter		

Table 2. Encryption examples with AES Cipher

As we can see on those tables, there's not a big difference between these two ciphers at least in ECB mode, because the only change is the color and maybe a little distortion in both. For this practice, python facilitates the implementation of the algorithm with 5 different modes of operation and its Crypto Package.

Software (libraries, packages, tools):

Packages [2]:

- Crypto: A collection of cryptographic modules implementing various algorithms and protocols.

Sub - packages [2]:

- Cipher: Used for the following objects and/or methods
  - AES [3]: Cipher object
  - Encrypt: Method used to encrypt data with key and parameters set at initialization
  - Decrypt: Method used to decrypt data with key and parameters set at initialization

Tools:

- Sublime Text 3 [4]
- Python 3.6 [5]

Procedure:

The algorithm used for this practice is really simple, it is explained now:

Algorithm for AES encryption

- Introduce the name of the original image to encrypt.
- Introduce the name of the encrypted image.
- Select the option "encrypt".
- Select one of the 5 modes of operation (ECB, CBC, CFB, OFB or CTR).

- For ECB and CTR:
    - Introduce the key of 128 bits (16 characters).
- For CBC, CFB and OFB
    - Introduce the key of 128 bits (16 characters).
    - Introduce the initialization vector (16 characters).

Algorithm for AES decryption

- Introduce the name of the encrypted image to decrypt.
- Introduce the name of the decrypted image.
- Select the option “decrypt”.
- Select one of the 5 modes of operation (ECB, CBC, CFB, OFB or CTR).
- For ECB and CTR:
    - Introduce the same key used to encrypt the image.
- For CBC, CFB and OFB
    - Introduce the same key used to encrypt the image.
    - Introduce the same initialization vector used to encrypt the image (16 characters).

On Figure 7, it can be observed the first 2 options for AES.

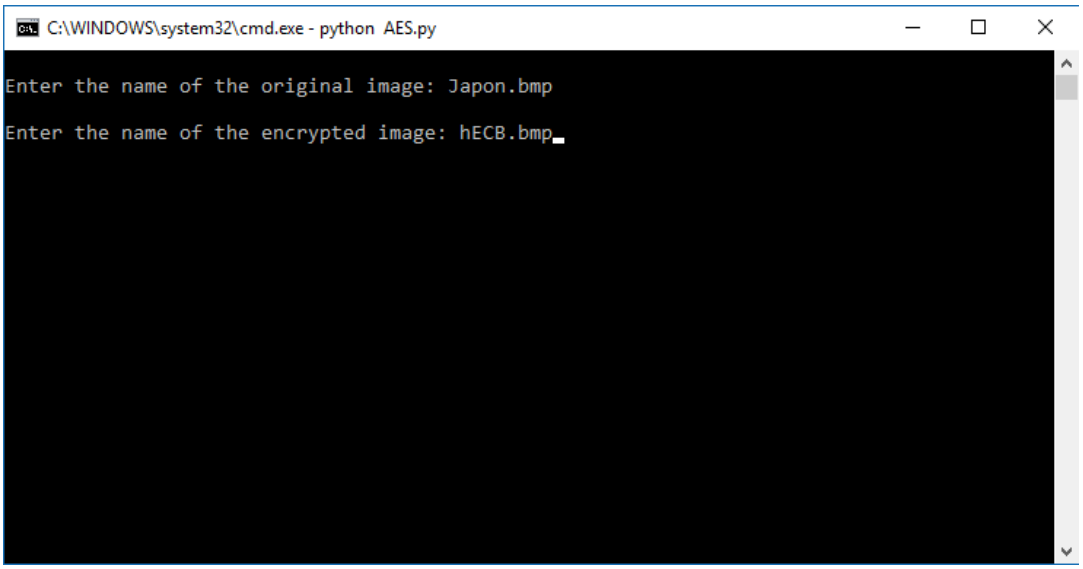


Figure 7. Introducing the name of the original and encrypted/decrypted image

On Figure 8, you can see how the program asks for the option you want (encrypt or decrypt).

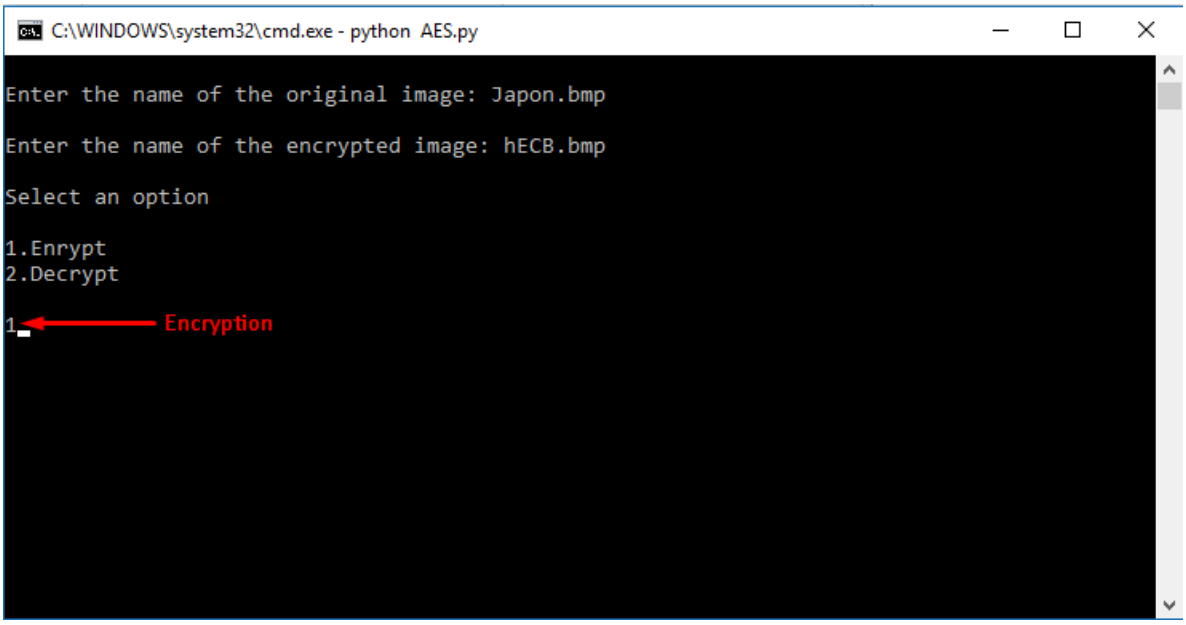


Figure 8. Introducing the option (encrypt/decrypt)

After we select the option (in this case, encryption), the program will ask us for the mode of operation that we want to use as shown in the following Figure 9:

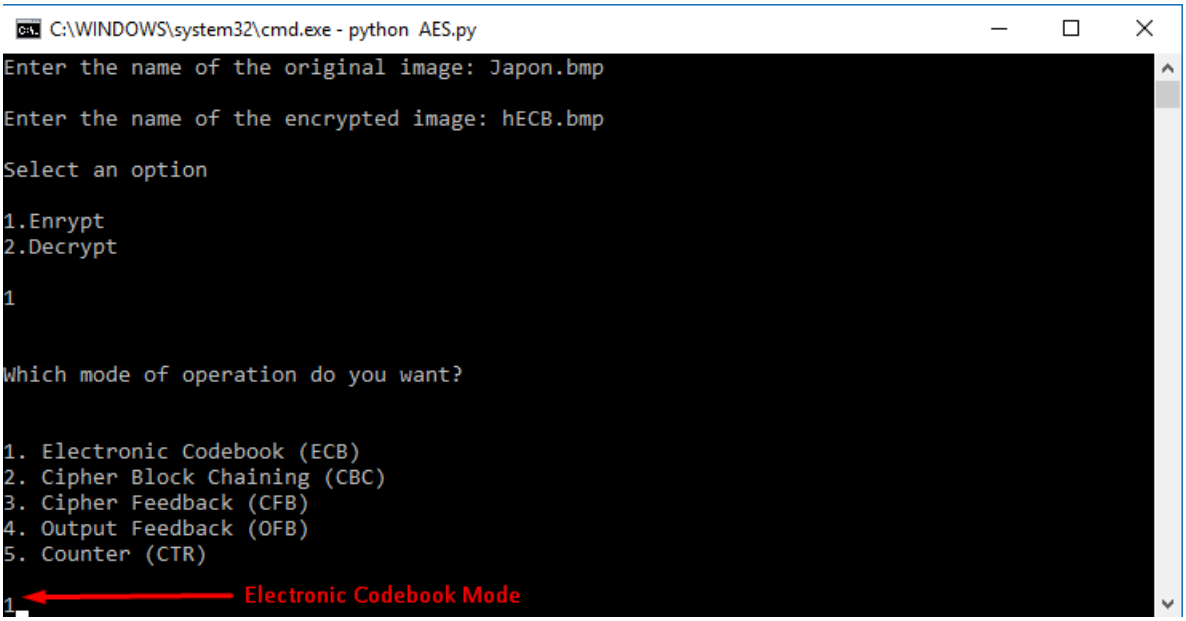


Figure 9. Selecting the mode of operation

After we finish with the mode of operation (ECB in this case) we need to introduce the key (and depending on the mode of operation, an initialization vector) as shown in the following in the Figure 10:

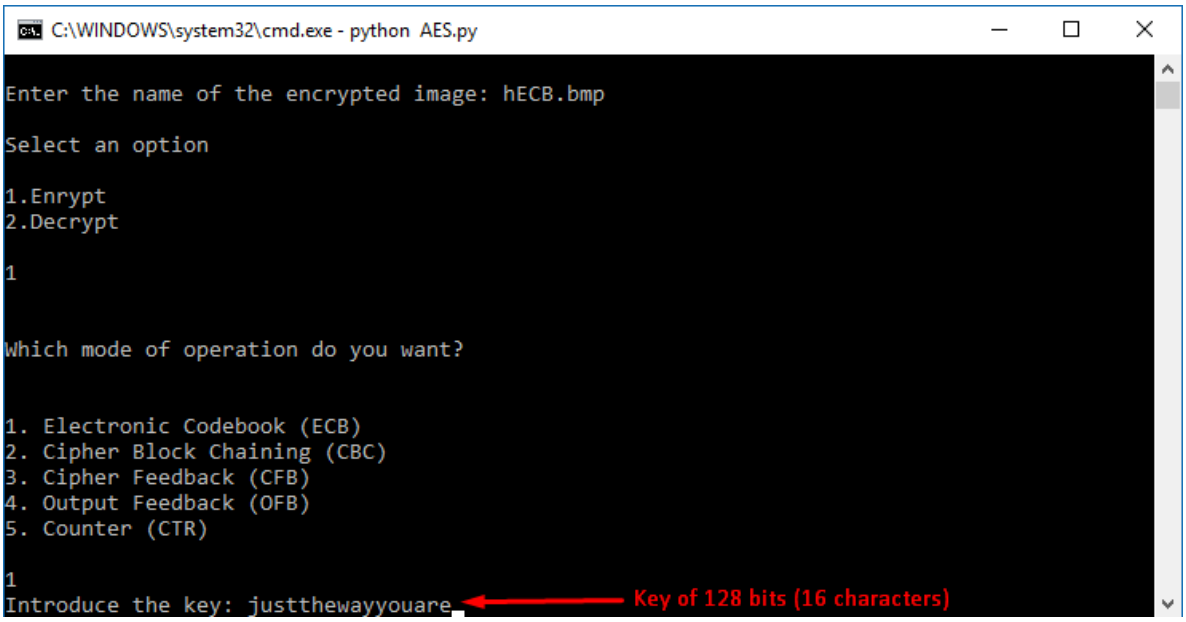


Figure 10. Introducing the key of 128 bits length

After the program finishes, it will appear a message to the user indicating everything was correct (Figure 11).

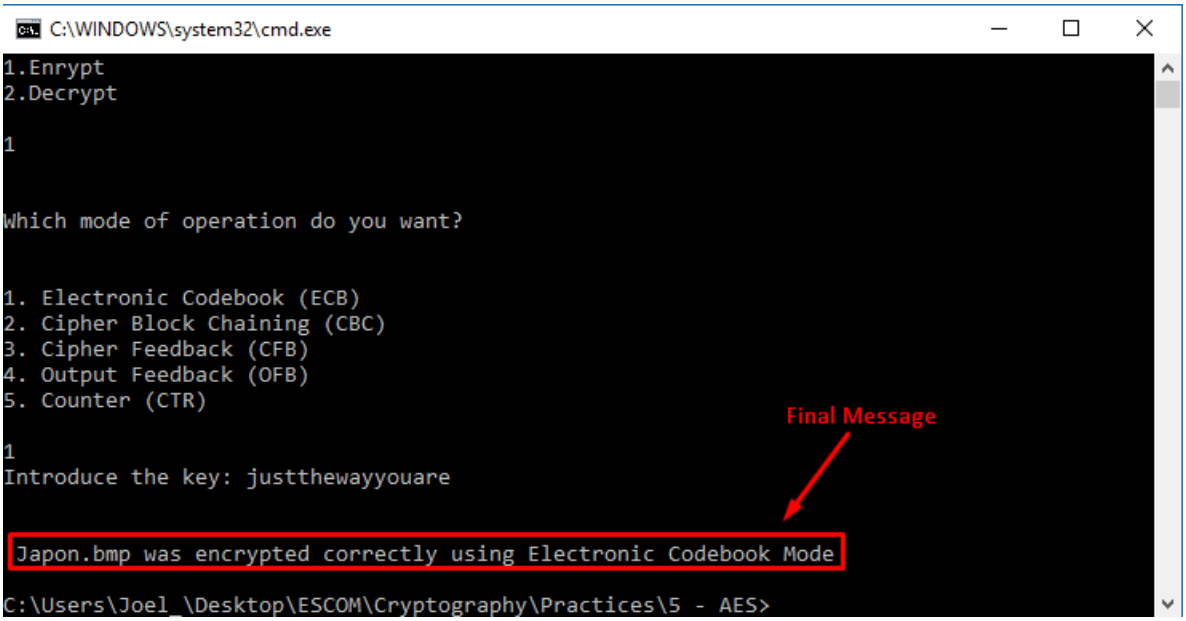


Figure 11. Final message to the user indicating everything was ok

In the next section, I will present the original images and the encryption with all the modes of operation (the same images presented on Table 2).

Results

We previously show how to initialize the program, in this section it will be just presented the original images and the result of its encryption with all the implemented modes of operation.

First of all, Figure 12 shows the original image (just 2 colors).

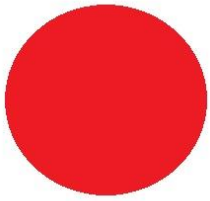


Figure 12. Original image (Japon.bmp)

On Figure 13, it is shown the encrypted image with ECB Mode of Operation.

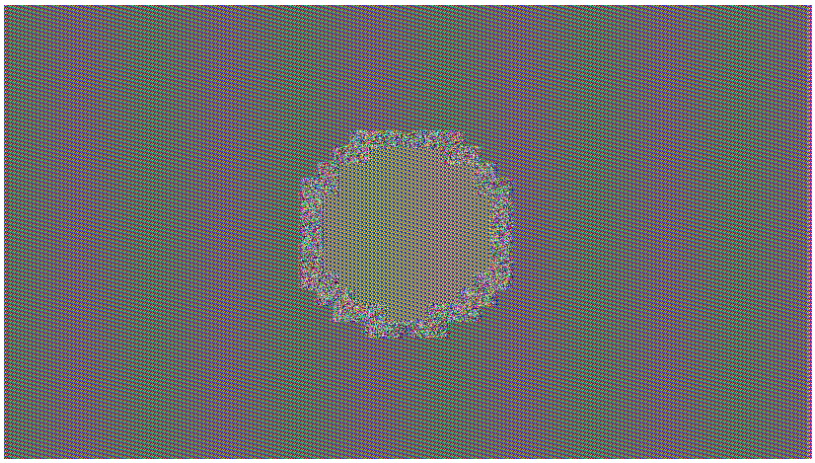


Figure 13. Encrypted image with ECB (hECB)

On Figure 14, it is shown the encrypted image with CBC Mode of Operation.

Figure 14. Encrypted image with CBC (hCBC)

On Figure 15, it is shown the encrypted image with CFB Mode of Operation.

Figure 15. Encrypted image with CFB (hCFB)

On Figure 16, it is shown the encrypted image with OFB Mode of Operation.

Figure 16. Encrypted image with OFB (hOFB)

On Figure 17, it is shown the encrypted image with CTR Mode of Operation.

Figure 17. Encrypted image with CTR (hCTR)

For all of these tests, the password was **justthewayyouare** and the initialization vector (in the mode of operation that corresponds) was 8765432112345678. For decryption, I will show how to introduce the name of the images (now, the original is the encrypted image, as we already explained on the procedure).

On Figure 18, you can see how to introduce the name of the images and selecting mode to obtain the decrypted image.

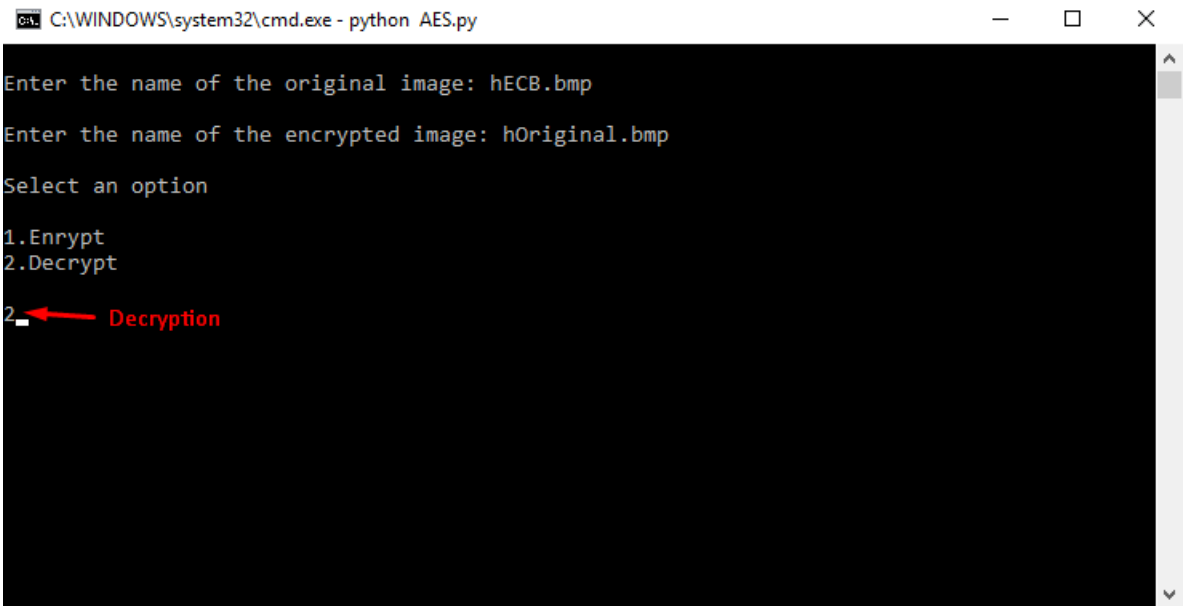


Figure 18. Introducing the name of images and selecting decryption option

Now, we need to introduce the same key that we used to encrypt (justthewayyouare), but, just for testing, I will introduce another key to observe what happen with the image.

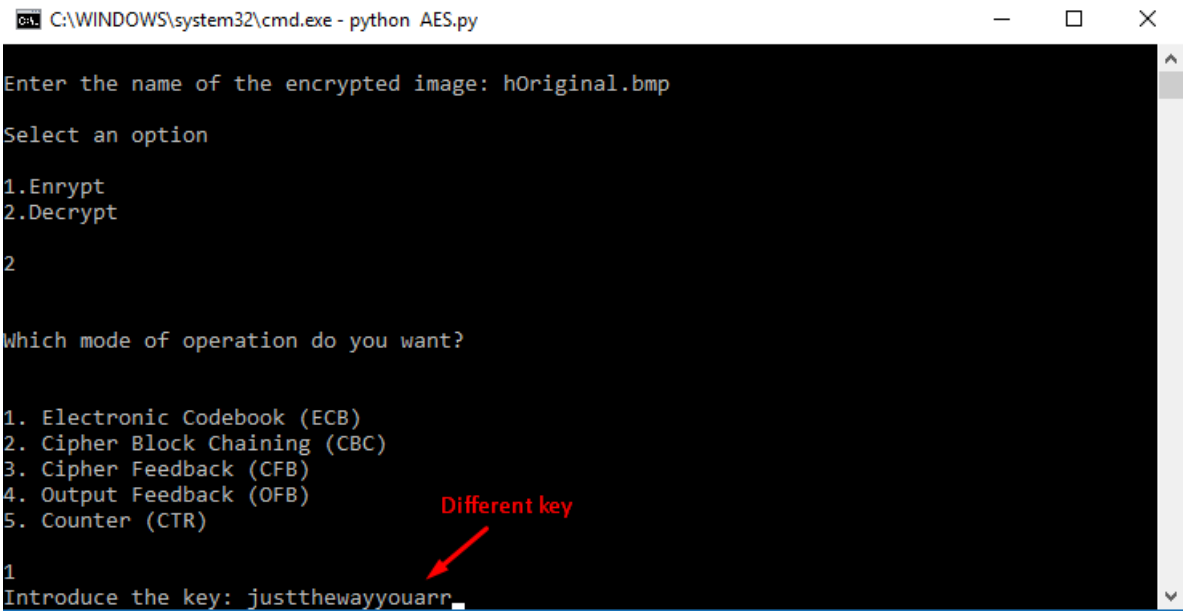


Figure 19. Introducing a different key

As you can see, the key is different, the original key is *justthewayyouare* and this is *justthewayyouarr*, with just 1 character different. On Figure 20, you can see the result of giving the program a different key.

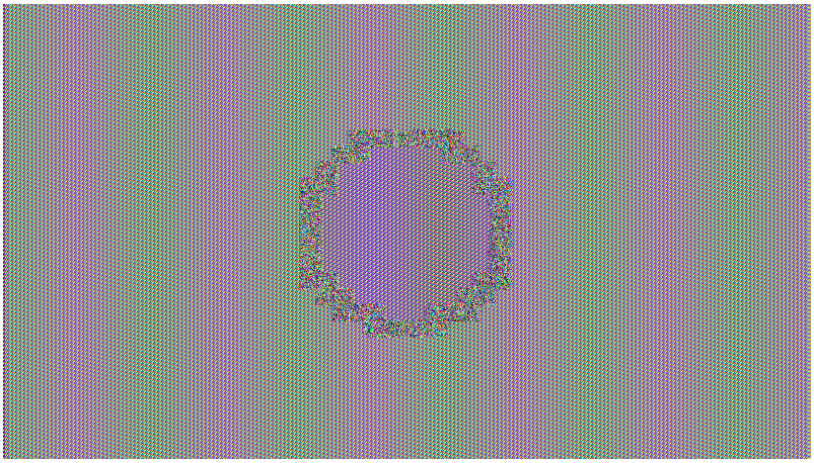


Figure 20. Decryption of Japon.bmp with different key

Now, on Figure 21 you can see the correct key used to encrypt the image.

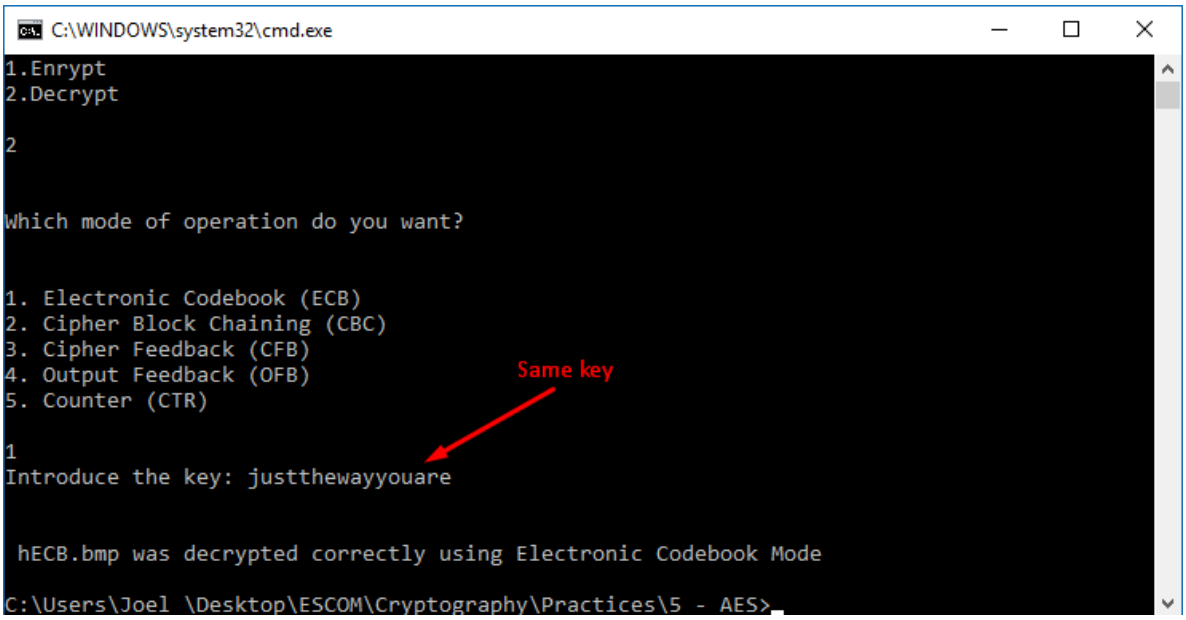


Figure 21. Introducing the same key

On Figure 22, you can see the result of giving it the same key.

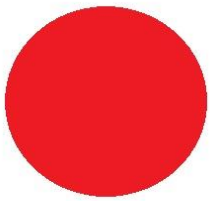


Figure 22. Decrypted image (hOriginal.bmp)

As you can see, we obtain again the original image by introducing the correct key. On Figures 23 - 24 you can see the process of giving the correct key but incorrect initialization vector for CBC, CFB and OFB.

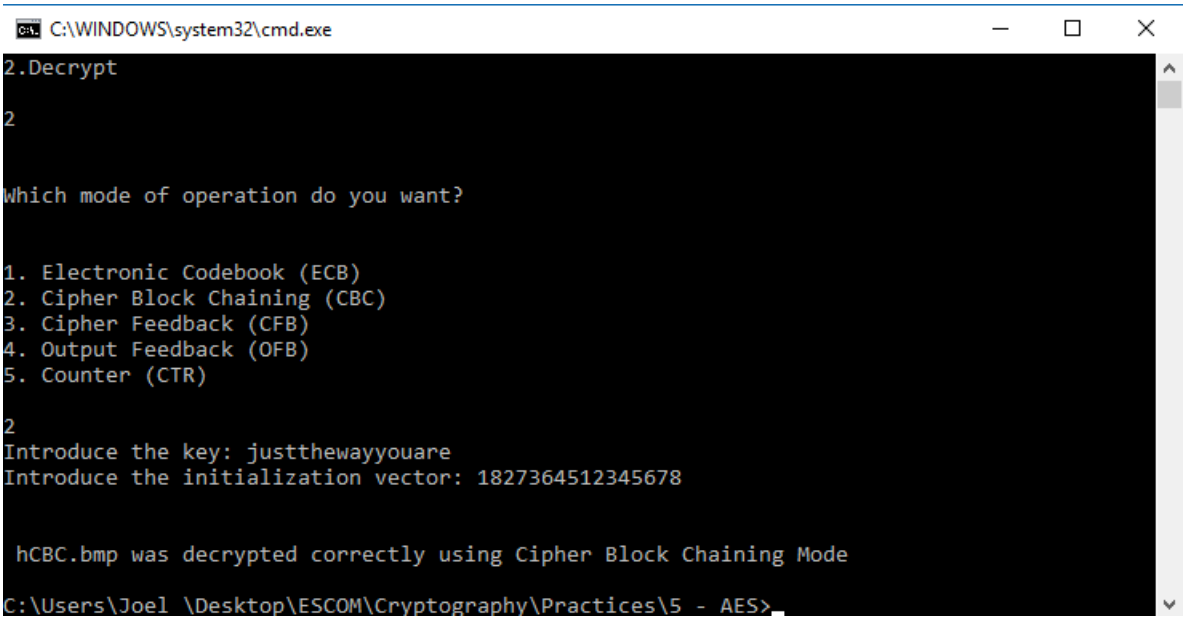


Figure 23. Introducing correct key but initialization vector

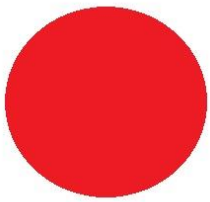


Figure 24. Decrypted image (hOriginal.bmp)

As you can see, the image looks alike the original one, because IV only affects 2 pixels of the image indistinguishable for us. But in Figure 25 (OFB mode), you can see the change with a correct key but different IV.

Figure 25. Introducing different IV in OFB Mode

On Figure 26, you can see the decrypted image with different IV.

Figure 26. Decrypted image (hOriginal.bmp)

As you can see the image is unrecognizable because this mode of operation changes all pixels if the IV is wrong.

Now, what we are going to do is to decrypt some images with another mode of operation to see what happen with the pixels.

On Figure 27 you can see the decryption of hECB with OFB Mode.

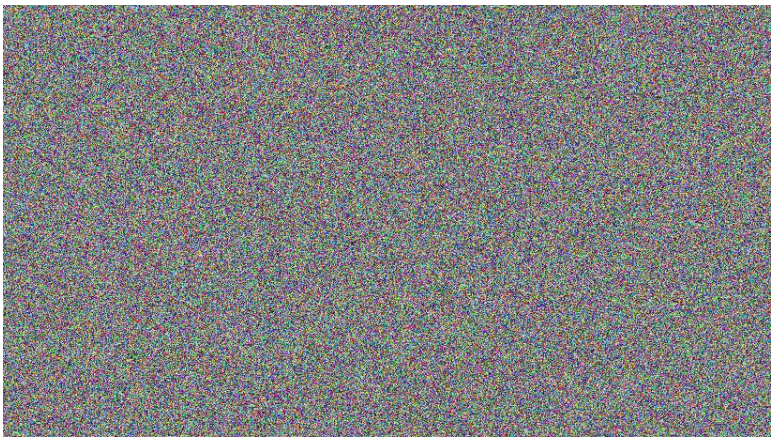


Figure 27. Decryption of hECB.bmp with OFB Mode

On Figure 28 you can see the decryption of hCFB with CBC Mode.

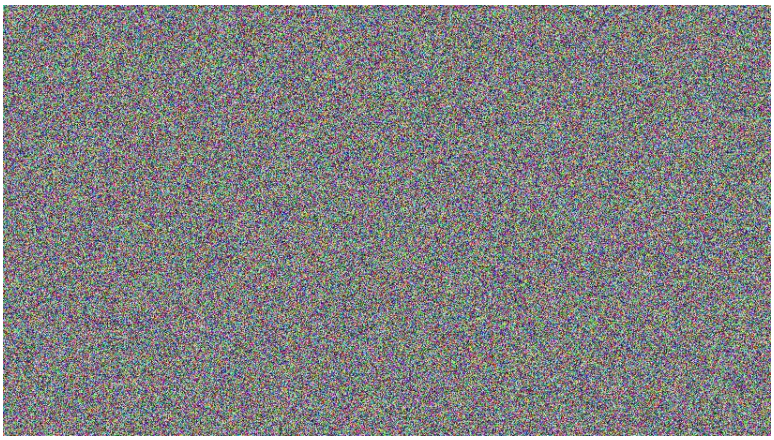


Figure 28. Decryption of hCFB.bmp with CBC Mode

On Figure 28 you can see the decryption of hCBC with ECB Mode.

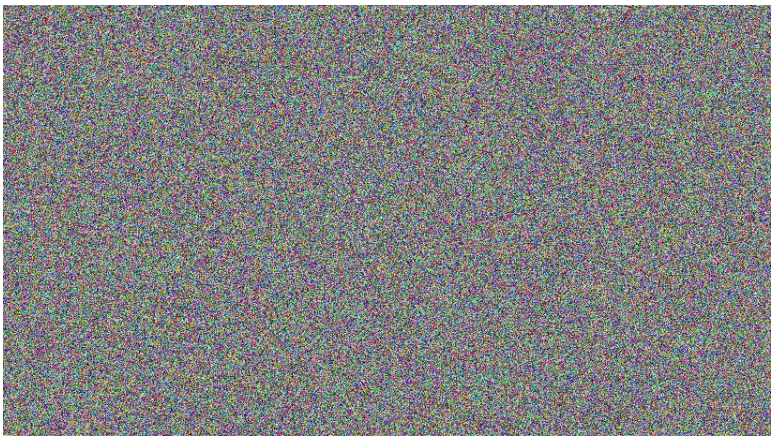


Figure 29. Decryption of hCBC.bmp with ECB Mode

Now, you can see on Figure 30 the encryption process of the encrypted image hOFB with OFB Mode.

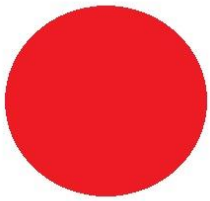


Figure 30. Encryption of hOFB with OFB Mode

We can observe that the image decrypted even we encrypt it again, this is because OFB Mode of operation works on that way [6].

After this, from Figures 31 to Figure __ you can observe just the images corresponding to the same tests we did for Japon.bmp to another image with a lot of variation of colors Paisaje.bmp

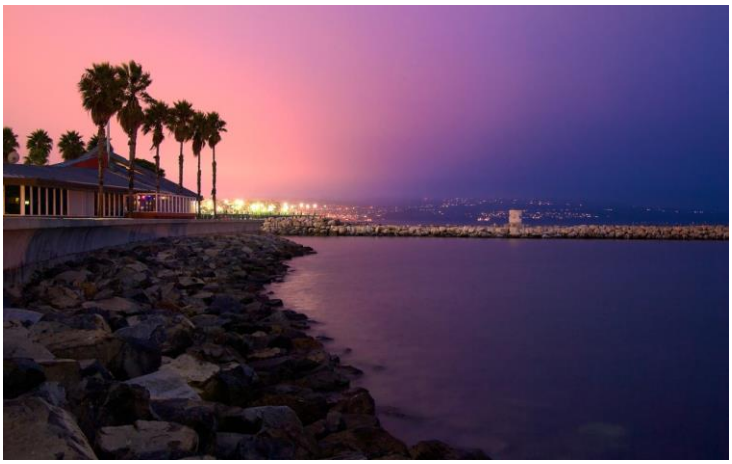


Figure 31. Original image (Paisaje.bmp)

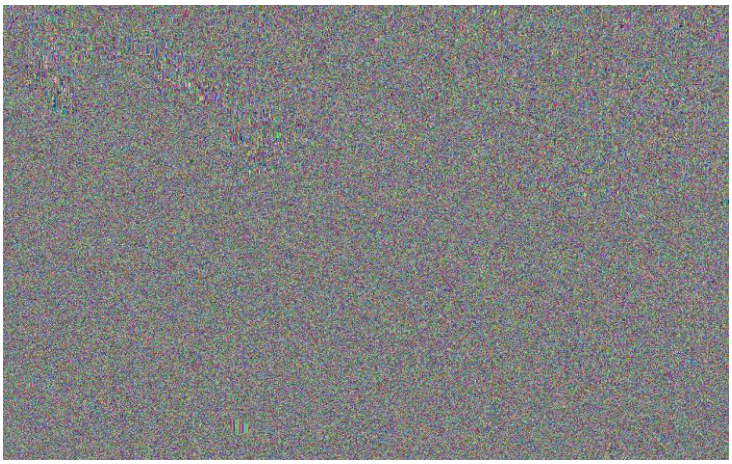


Figure 32. Encrypted Image with ECB Mode (hECB)

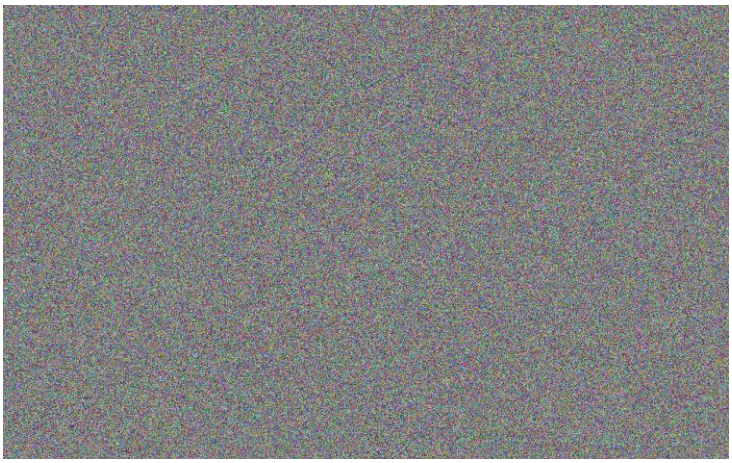


Figure 33. Encrypted Image with CBC Mode (hCBC)

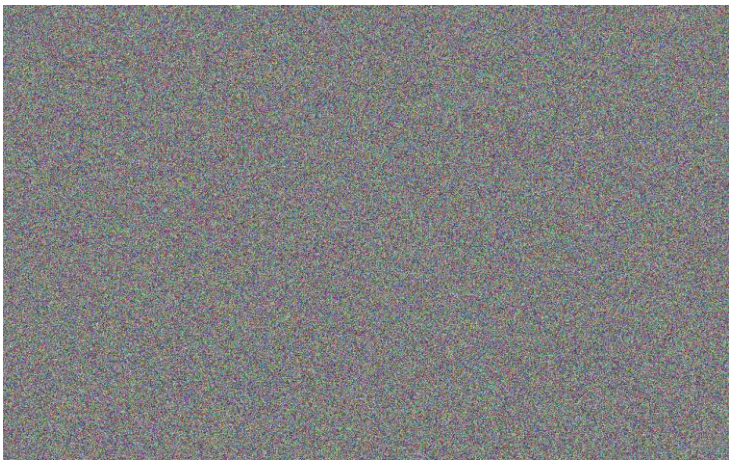


Figure 34. Encrypted Image with CFB Mode (hCFB)

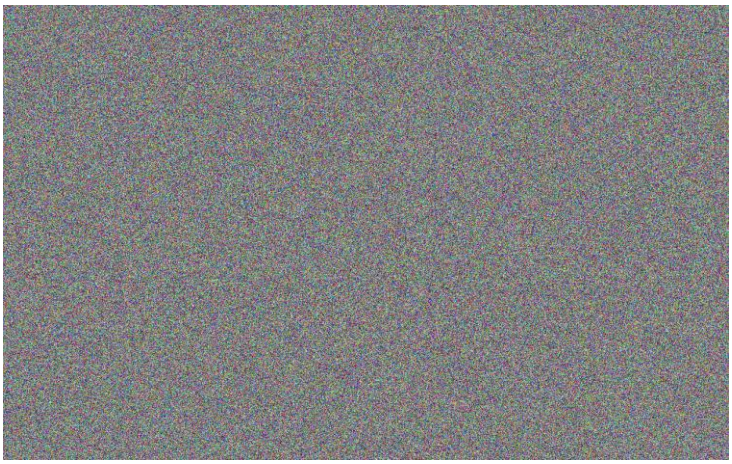


Figure 35. Encrypted Image with OFB Mode (hOFB)

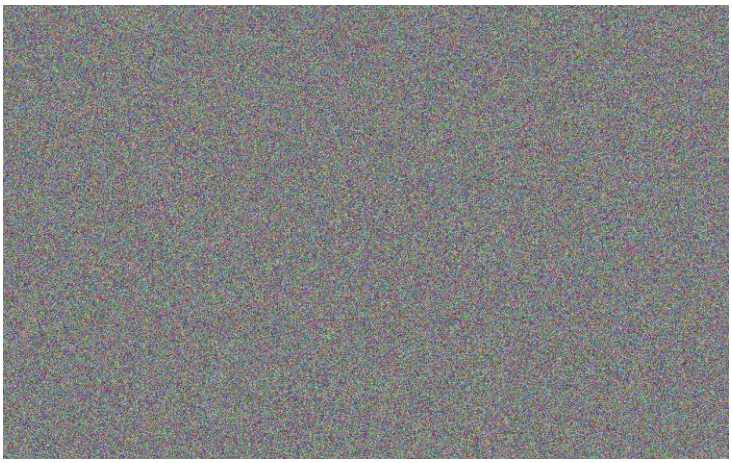


Figure 36. Encrypted Image with CTR Mode (hCTR)

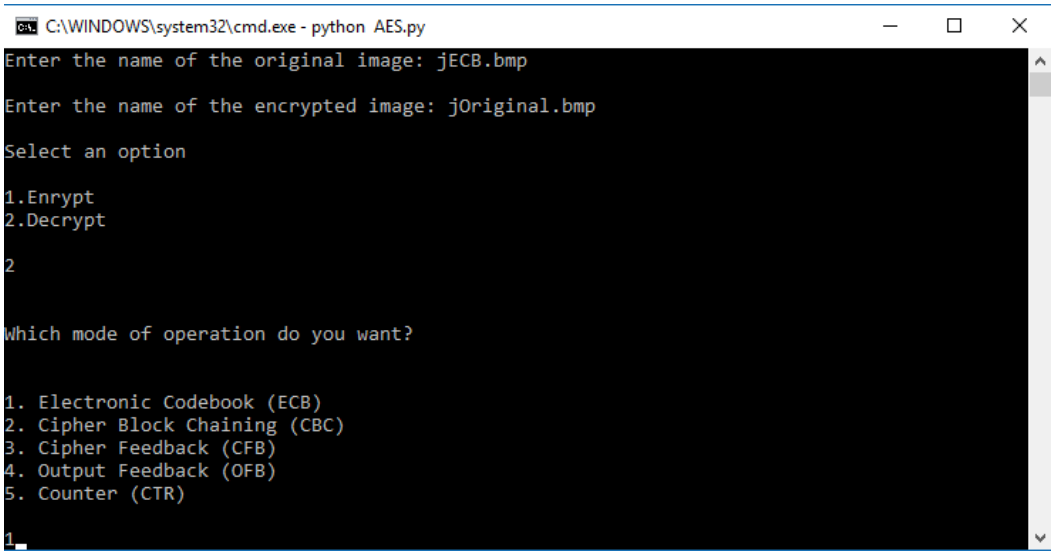


Figure 37. Decrypting images (hECB, hCBC, hCFB, hOFB, hCTR)

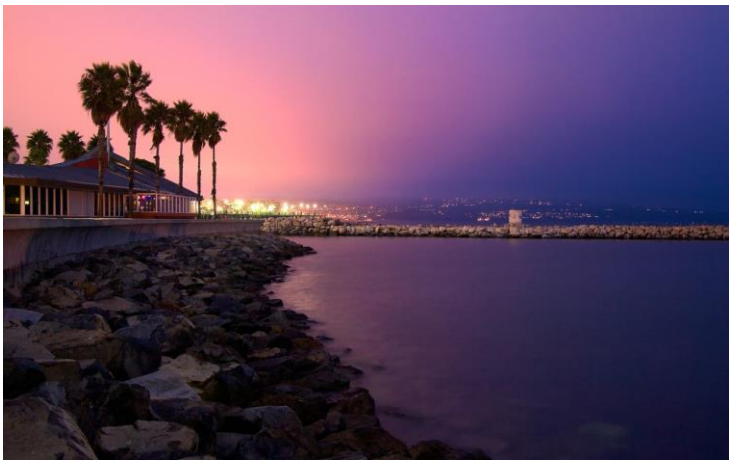


Figure 38. Decrypted Image (hOriginal.bmp)

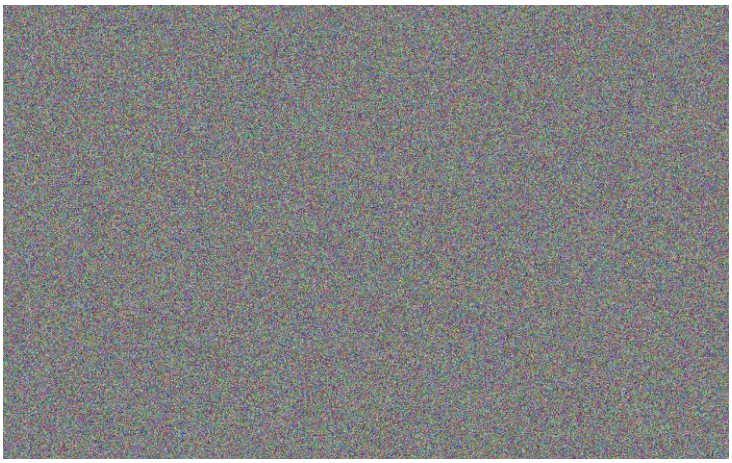


Figure 39. Decryption of hECB.bmp with OFB Mode

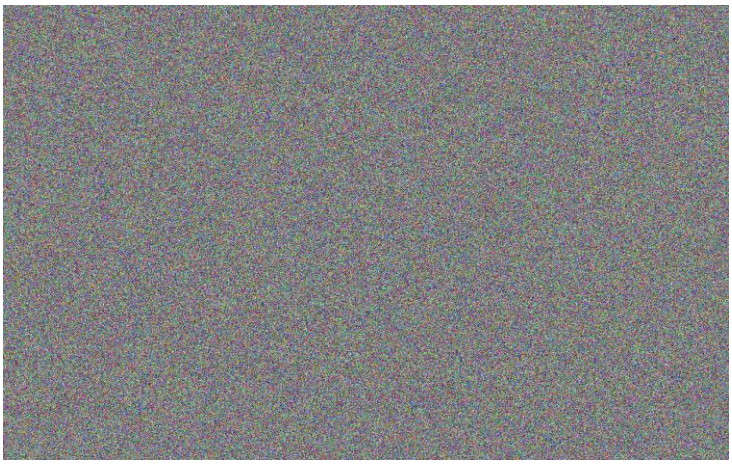


Figure 40. Decryption of hCFB.bmp with CBC Mode

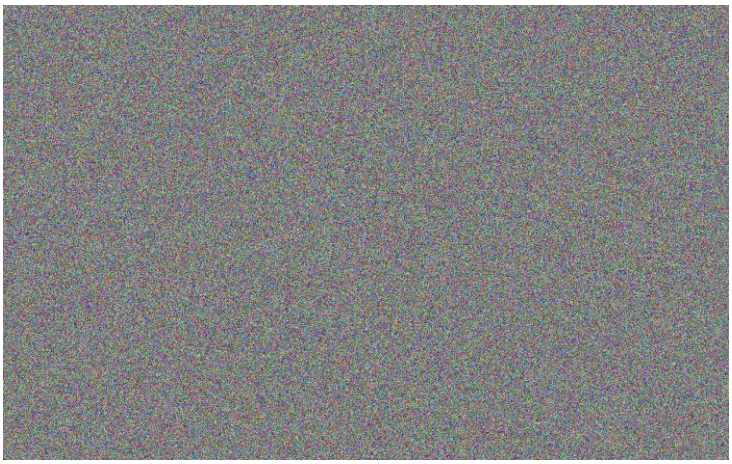


Figure 41. Decryption of hCBC.bmp with ECB Mode

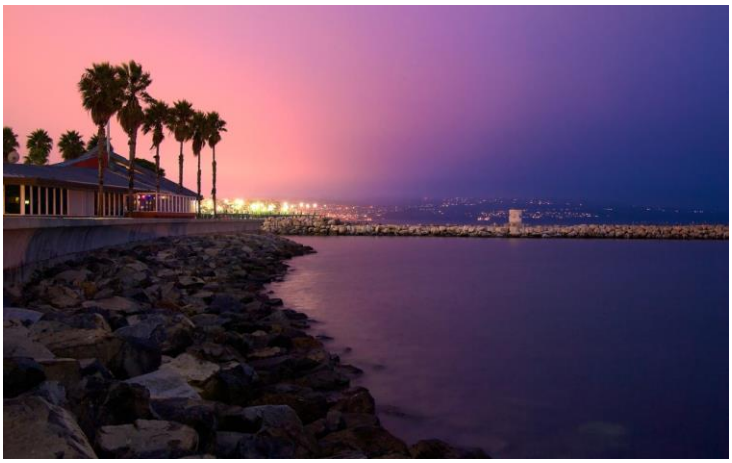


Figure 42. Encryption of hOFB.bmp with OFB Mode

In the next section we will discuss why another encryption with OFB Mode gives us the original image as such as if we had decrypted it.

Discussion:

It is funny that if we encrypt again with OFB mode if we had already encrypted an image, gives us the original image, this is simple to explain:

$$P_n = C_n \oplus E_k^n (C_0) \qquad \text{and} \qquad C_n = E_k^n (C_0) \oplus P_n$$

Substituting P_n on C_n…

$$C_n = E_k^n (C_0) \oplus C_n \oplus E_k^n (C_0)$$

$$\text{Finally: } C_n = C_n$$

Another interesting fact is that in modes CBC and CFB, if we introduce a wrong IV but a correct key, the image will be seen look alike the original one, because these two modes of operation in their decryption process [6], just affect 1 or 2 pixels of the entire image (composed by 131, 600 pixels).

Also, we now know that is impossible to decrypt an image with a different mode of operation we used to encrypt it, it doesn't matter if the image has just 1 color, or two, etc. It is because these modes of operation work in a very different way each other, there's no equivalence between any of them.

Conclusions:

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Here

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This practice was very simple with the support of a simple language as such as Python, because it has the modules and methods necessaries for the implementation of AES Cipher, also implemented with each mode of operation.

It is important to note that here, the most important thing is the key (obviously), because if we change just a little character (as shown in the results section) the resulted image will be completely different to the original one. We can say that this cipher has a security of 128 bits and it means that there are 2^{128} possible combinations for a key (length of it), that's why this cipher could withstand a brute force attack due to the huge possible combinations.

Also, I could appreciate that Output Feedback Mode is the worst (just after Electronic Codebook) because if we encrypt 2 times, the message (in this case, the image) will be revealed, that is a big problem. Maybe the best of these modes of operation is Cipher Block Chaining because it changes a lot and you can see that on the diagram that describes this mode.

References:

[1] Federal Information Processing Standards, "Advanced Encryption Standard (AES)", November 2001. [Online]. Available: https://csrc.nist.gov/csrc/media/publications/fips/197/final/documents/fips-197.pdf

[2] EpyDoc, "API Documentation - Package Crypto", May 2012. [Online]. Available: https://www.dlitz.net/software/pycrypto/api/2.6/

[3] EpyDoc, "API Documentation – Class AESCipher", May 2012. [Online]. Available: https://www.dlitz.net/software/pycrypto/api/2.6/Crypto.Cipher.AES.AESCipher-class.html

[4] Sublime HQ Pty Ltd, "Sublime Text – Download", November 2017. [Online]. Available: https://www.sublimetext.com/3

[5] Python Software Foundation, “python”, October 2017. [Online]. Available: https://www.python.org/downloads/

[6] Joel Mauricio Romero Gamarra, “HILL Cipher”, October 2017. [Online]. Available: https://github.com/JoelRomero97/Cryptography/blob/master/Practices/2%20-%20HILL%20Cipher/Report.pdf

Code

AES.py

```
import os
from Crypto.Cipher import AES
from Crypto.Util import Counter

def main ():
    os.system ("cls")

    #We define the functions (modes of operation) inside a dictionary
    modos_operacion = {1: ECB, 2: CBC, 3: CFB, 4: OFB, 5: CTR}

    #Menu to the user
    original = input ("\nEnter the name of the original image: ")
    cipher = input ("\nEnter the name of the encrypted image: ")
    option = int (input ("\nSelect an option\n\n1.Enrypt\n2.Decrypt\n\n"))
    print ("\n\nWhich mode of operation do you want?\n\n")
    print ("1. Electronic Codebook (ECB)")
    print ("2. Cipher Block Chaining (CBC)")
    print ("3. Cipher Feedback (CFB)")
    print ("4. Output Feedback (OFB)")
    print ("5. Counter (CTR)")
    mode = int (input ("\n"))

    #Calling the selected mode of operation
    modos_operacion [mode] (original, cipher, option)


#Electronic Codebook
def ECB (original, ciphered, option):

    #Asking for the key to the user (16 bytes)
    key = bytes (input ('Introduce the key: '), 'utf-8')

    #Creating a new AES cipher
    cipher = AES.new (key, AES.MODE_ECB)

    #Opening both files
    original_file = open (original, "rb")
    encrypted_file = open (ciphered, "wb")

    #We copy the entire head of the image
    data = original_file.read (54)
    encrypted_file.write (data)

    #Obtaining the size of the image
    original_file.seek (34)
    size = int.from_bytes (original_file.read (4), byteorder = 'little')

    #We move to the start of the real image to encrypt it
    original_file.seek (54)

    i = 0

    #Encrypt
```

```
    if option == 1:
        while (i < size):
            #Reading 16 bytes to encrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
            encrypted_pixels = cipher.encrypt (pixels)

            #Writing encrypted pixels
            encrypted_file.write (encrypted_pixels)

            #Updating the counter
            i = i + 16
        print ("\n\n", original, "was encrypted correctly using Electronic Codebook Mode")

    #Decrypt
    elif option == 2:
        while (i < size):
            #Reading 16 bytes to decrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
            encrypted_pixels = cipher.decrypt (pixels)

            #Writing decrypted pixels
            encrypted_file.write (encrypted_pixels)

            #Updating the counter
            i = i + 16
        print ("\n\n", original, "was decrypted correctly using Electronic Codebook Mode")

    original_file.close ()
    encrypted_file.close ()


#Cipher Block Chaining
def CBC (original, ciphered, option):

    #Asking for the key to the user (16 bytes)
    key = bytes (input ('Introduce the key: '), 'utf-8')

    #Asking for the initialization vector to the user (16 bytes)
    IV = bytes (input ('Introduce the initialization vector: '), 'utf-8')

    #Creating a new AES cipher
    cipher = AES.new (key, AES.MODE_CBC, IV)

    #Opening both files
    original_file = open (original, "rb")
    encrypted_file = open (ciphered, "wb")

    #We copy the entire head of the image
    data = original_file.read (54)
    encrypted_file.write (data)

    #Obtaining the size of the image
    original_file.seek (34)
    size = int.from_bytes (original_file.read (4), byteorder = 'little')

    #We move to the start of the real image to encrypt it
    original_file.seek (54)

    i = 0

    #Encrypt
    if option == 1:
        while (i < size):
            #Reading 16 bytes to encrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
```

```
            encrypted_pixels = cipher.encrypt (pixels)

            #Writing encrypted pixels
            encrypted_file.write (encrypted_pixels)

            #Updating the counter
            i = i + 16
        print ("\n\n", original, "was encrypted correctly using Cipher Block Chaining Mode")

    #Decrypt
    elif option == 2:
        while (i < size):
            #Reading 16 bytes to decrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
            encrypted_pixels = cipher.decrypt (pixels)

            #Writing decrypted pixels
            encrypted_file.write (encrypted_pixels)

            #Updating the counter
            i = i + 16
        print ("\n\n", original, "was decrypted correctly using Cipher Block Chaining Mode")

    original_file.close ()
    encrypted_file.close ()


#Cipher Feedback
def CFB (original, ciphered, option):

    #Asking for the key to the user (16 bytes)
    key = bytes (input ('Introduce the key: '), 'utf-8')

    #Asking for the initialization vector to the user (16 bytes)
    IV = bytes (input ('Introduce the initialization vector: '), 'utf-8')

    #Creating a new AES cipher
    cipher = AES.new (key, AES.MODE_CFB, IV)

    #Opening both files
    original_file = open (original, "rb")
    encrypted_file = open (ciphered, "wb")

    #We copy the entire head of the image
    data = original_file.read (54)
    encrypted_file.write (data)

    #Obtaining the size of the image
    original_file.seek (34)
    size = int.from_bytes (original_file.read (4), byteorder = 'little')

    #We move to the start of the real image to encrypt it
    original_file.seek (54)

    i = 0

    #Encrypt
    if option == 1:
        while (i < size):
            #Reading 16 bytes to encrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
            encrypted_pixels = cipher.encrypt (pixels)

            #Writing encrypted pixels
            encrypted_file.write (encrypted_pixels)

            #Updating the counter
```

```
            i = i + 16
        print ("\n\n", original, "was encrypted correctly using Cipher Feedback Mode")

    #Decrypt
    elif option == 2:
        while (i < size):
            #Reading 16 bytes to decrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
            encrypted_pixels = cipher.decrypt (pixels)

            #Writing decrypted pixels
            encrypted_file.write (encrypted_pixels)

            #Updating the counter
            i = i + 16
        print ("\n\n", original, "was decrypted correctly using Cipher Feedback Mode")

    original_file.close ()
    encrypted_file.close ()


#Output Feedback
def OFB(original,ciphered,option):

    #Asking for the key to the user (16 bytes)
    key = bytes (input ('Introduce the key: '), 'utf-8')

    #Asking for the initialization vector to the user (16 bytes)
    IV = bytes (input ('Introduce the initialization vector: '), 'utf-8')

    #Creating a new AES cipher
    cipher = AES.new (key, AES.MODE_OFB, IV)

    #Opening both files
    original_file = open (original, "rb")
    encrypted_file = open (ciphered, "wb")

    #We copy the entire head of the image
    data = original_file.read (54)
    encrypted_file.write (data)

    #Obtaining the size of the image
    original_file.seek (34)
    size = int.from_bytes (original_file.read (4), byteorder = 'little')

    #We move to the start of the real image to encrypt it
    original_file.seek (54)

    i = 0

    #Encrypt
    if option == 1:
        while (i < size):
            #Reading 16 bytes to encrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
            encrypted_pixels = cipher.encrypt (pixels)

            #Writing encrypted pixels
            encrypted_file.write (encrypted_pixels)

            #Updating the counter
            i = i + 16
        print ("\n\n", original, "was encrypted correctly using Output Feedback Mode")

    #Decrypt
    elif option == 2:
        while (i < size):
```

```
            #Reading 16 bytes to decrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
            encrypted_pixels = cipher.decrypt (pixels)

            #Writing decrypted pixels
            encrypted_file.write (encrypted_pixels)

            #Updating the counter
            i = i + 16
        print ("\n\n", original, "was decrypted correctly using Output Feedback Mode")

    original_file.close ()
    encrypted_file.close ()


#Counter
def CTR(original,ciphered,option):

    #Asking for the key to the user (16 bytes)
    key = bytes (input ('Introduce the key: '), 'utf-8')

    #Creating a new AES cipher
    ctr = Counter.new (128)
    cipher = AES.new (key, AES.MODE_CTR, counter = ctr)

    #Opening both files
    original_file = open (original, "rb")
    encrypted_file = open (ciphered, "wb")

    #We copy the entire head of the image
    data = original_file.read (54)
    encrypted_file.write (data)

    #Obtaining the size of the image
    original_file.seek (34)
    size = int.from_bytes (original_file.read (4), byteorder = 'little')

    #We move to the start of the real image to encrypt it
    original_file.seek (54)

    i = 0

    #Encrypt
    if option == 1:
        while (i < size):
            #Reading 16 bytes to encrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
            encrypted_pixels = cipher.encrypt (pixels)

            #Writing encrypted pixels
            encrypted_file.write (encrypted_pixels)

            #Updating the counter
            i = i + 16
        print ("\n\n", original, "was encrypted correctly using Counter Mode")

    #Decrypt
    elif option == 2:
        while (i < size):
            #Reading 16 bytes to decrypt it using AES cipher
            pixels = original_file.read (16)

            #Encrypting 16 bytes readed
            encrypted_pixels = cipher.decrypt (pixels)

            #Writing decrypted pixels
            encrypted_file.write (encrypted_pixels)
```

```
            #Updating the counter
            i = i + 16
        print ("\n\n", original, "was decrypted correctly using Counter Mode")

    original_file.close ()
    encrypted_file.close ()

#Main function
main ()
```