Exploring Symmetric Key Encryption Modes

Getting Started

Download Virtual Box
https://www.virtualbox.org/wiki/Downloads
Download the given Ubuntu Machine

Extract the file

Open VirtualBox > Menu > Machine > Add > Select the "CSF_Labs_VM.vbox" file > Open

Boot your Linux system or VM using Virtual Box.
User: lab
Password: lab

In this lab, you will explore the concept of encryption modes and their properties. To perform this exploration, you will be using an open source encryption product known as OpenSSL. You will explore the properties of these modes, seeing a visual representation of the state of the ciphertext, and exploring error propagation during decryption in these various modes.

Note: You can use the commands "`man openssl`" and "`man enc`" to get additional help on how to use the `openssl` command line tool. Appendix A contains a quick reference sheet of commonly used Unix commands and appendix B explains hexadecimal.

Task 1: Encrypt and then decrypt any file

In this task you are only getting used to the syntax of the `openssl` command.

Do the following:

1. Create a text file with some small amount of content by either using an editor (e.g., `nano`) or the combination of the `echo` command and redirection ('>').

   ```
   echo test encryption > plain.txt
   nano plain.txt
   ls
   ```

2. To encrypt the text file as "cipher.txt" type:

   ```
   openssl
   CIPHER -e -in plain.txt -out cipher.txt -K KEY -iv IV
   ```

replacing:

- *CIPHER* with a specific cipher and CBC mode of operation, *e.g.* **aes-128-cbc**. (To see all the options use "man enc").
- *plain.txt* is the name of the plain text file you just created
- *cipher.txt* is the name of the output file which will be the ciphertext
- *KEY* with a hexadecimal representation of a symmetric key (your choice)
- *IV* with a hexadecimal representation of an initialization vector (your choice)

Be sure to use the -K option, and not the -k option. The latter may not produce an error, but may cause issues later in the lab.

3. Observe the ciphertext you've created using `cat`, `more`, `less or nano`.
4. You should have observed that the encrypted file is gibberish that will not always display well. To see the actual hex values of the ciphertext, enter the following:
   `hexdump -C FILENAME`
5. List the contents of the directory using "`ls -l`" to see the sizes for your original file and the encrypted file.
   Record the size of the plaintext file in the report.

   Record the size of the corresponding ciphertext file in the report.

   When you consider the file sizes that you recorded above, explain why the size of the ciphertext file is different.

6. You can decrypt the ciphertext you've created using the following command. **Be sure to**

output to a new plaintext file, and not overwrite the original plaintext.

```
openssl

CIPHER -d -in cipher.txt -out plainmod.txt -K KEY -iv IV
```

7. Compare the decrypted plaintext with the original plaintext using the `diff` command, as shown below (replacing ORIGINAL and UNENCRYPTED with the file names you used):

```
diff -a plain.txt plainmod.txt
```

[Note: if the two files are different then you did something wrong. If `diff` returns nothing, then there were no differences, which is what you would expect.]

Task 2: Encryption Modes

In this task, you will explore the differences in security attained by several modes of encryption. You will use a web browser on your host Linux system to view files that you create and modify. You will use a given logo.bmp file (https://drive.google.com/file/d/12uqzPZa_fVj67UKJw0lR3HjjdNKRHKsr/view?usp=sharing). You can open it using Firefox.

1. ECB Mode

   a. Observe the logo.

   b. Encrypt `logo.bmp` using AES in **ECB** mode (with the option **aes-128-ecb**) to create a ciphertext (Name your ciphertext as "`logo_mod.bmp`". [Because ECB mode does not require an IV, you do not need to provide one.]

   c. List the contents of the directory using "`ls -l`" to see the sizes for the plaintext logo file and the encrypted file.

      Record the size of the plaintext logo file in the report.
      Record the size of the encrypted logo file in the report.

   Note: When you open the modified logo in the web browser, it fails to display the file because it does not recognize it as a valid image.

   d. You can visualize the ciphertext by tricking an browser into thinking that the encrypted file is still a valid image file. To do this, you need to do a little "preprocessing" to make the file viewable.
   BMP images have a 54-byte header that informs the image viewer about the image, such as the image size, and its dimensions. You need to replace the encrypted BMP header in the ciphertext you created with a valid BMP header from `logo.bmp`.

To replace the 54-byte header with one command, do the following

```
dd if=logo.bmp of=logo_mod.bmp bs=1 count=54 conv=notrunc
```

e. After modifying the header, go back to the web browser and refresh the web page to view the encrypted image.

Describe the visualization of the encrypted logo in your report.

Referring to your observations, what is it about the inner-workings of ECB mode that caused it to do such a poor job of encrypting the logo

2. CBC Mode
   a. Encrypt logo.bmp again, but this time use **CBC** mode to create a ciphertext (with the **aes-128-cbc** option). [This time you need to provide an IV.]
   b. List the contents of the directory using "`ls -l`" to see the size of the ciphertext file you just created.

Record the size of the CBC-encrypted logo file in the report.

   c. Using the `dd` command described above, modify the header of the new ciphertext to have the same 54 bytes as the original BMP file.
   d. View the encrypted ciphertext using the web browser refresh.

Describe the visualization of the encrypted logo in your report.

3. CFB Mode
    a. Encrypt the `logo.bmp` file again, but this time use the **CFB** mode (with the **aes-128-cfb** option). [You need to provide an IV.]
    b. List the contents of the directory using "`ls -l`" to see the size of the ciphertext file you just created.

       Record the size of the CFB-encrypted logo file in the report.

    c. Using the `dd` command described above, modify the header of the new ciphertext to have the same 54 bytes as the original BMP file.
    d. View the encrypted ciphertext using the web browser refresh.

       Describe the visualization of the encrypted logo in your report.

4. OFB Mode
    a. Encrypt the logo.bmp file again, but this time use the **OFB** mode (with the **aes-128-ofb** option). [You need to provide an IV.]
    b. List the contents of the directory using "`ls -l`" to see the size of the ciphertext file you just created.

       Record the size of the OFB-encrypted logo file in the report.

    c. Using the `dd` command described above, modify the header of the new ciphertext to have the same 54 bytes as the original BMP file.
    d. View the encrypted ciphertext using the web browser refresh.

       Describe the visualization of the encrypted logo in your report.

       Referring to your observations in CBC, CFB, and OFB modes, explain why these modes were able to do a better job of encrypting the logo

Task 3: Error Propagation During Decryption (Optional)

This task will help you understand the ability of various cipher modes of operation to recover from corruption.
You will encrypt a text file in two different modes, change a single bit in the middle of the encrypted file, decrypt the corrupted file, and then view the effects of the corrupted bit on the plaintext file.

1. Introduction
    a. Download the given `declare.txt` file (https://drive.google.com/file/d/1RJzbYtg9qQqdHy09yWEy91WLit2lbIDn/view?usp=sharing).
    b. List the contents of the download directory using "`ls -l`" so you can see the size of the `declare.txt` file (in bytes).
    Record the size of `declare.txt`.

    Calculate the number of AES blocks it will take to encrypt `declare.txt`. Write your answer in the report.

    If each character in a text file is represented in ASCII format, where each character is represented in one byte, how many characters does it take to fill up an AES block? Write your answer in the report.

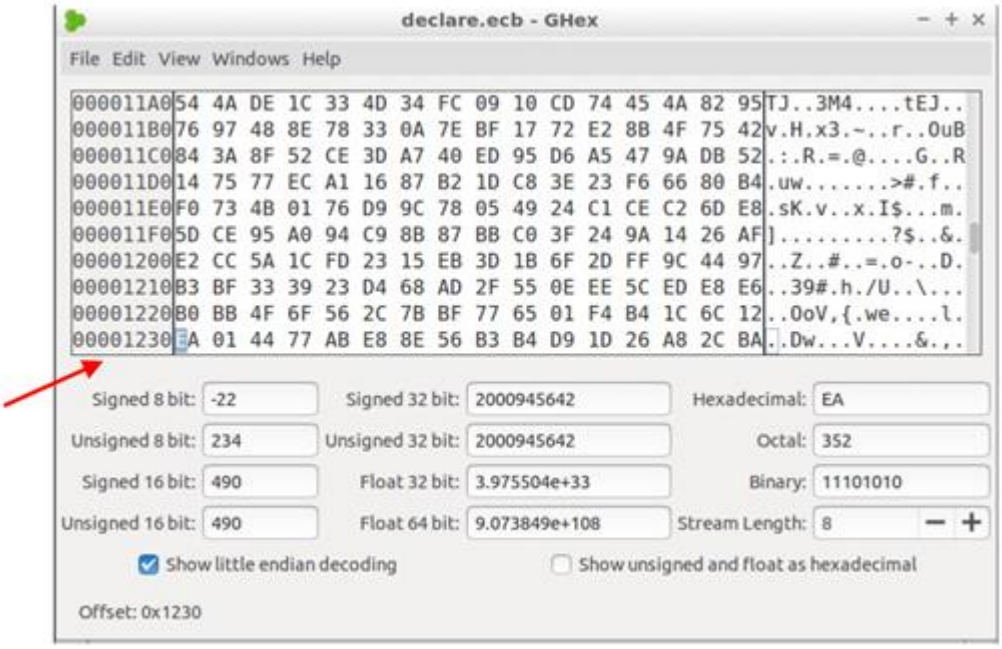
2. ECB Mode
    a. Encrypt `declare.txt` using AES-128 in **ECB** mode (with the **aes-128-ecb** option).
    b. If not installed, install ghex package on Linux running the following command on terminal:

    sudo apt-get update

    sudo apt-get install ghex

    c. Open the encrypted file using ghex, as shown below, replacing ENCRYPTEDFILE with the name you chose:
    `ghex ENCRYPTEDFILE`

    d. Select **Edit > Goto Byte** and enter `0x1230`, to take you to near the middle of the encrypted file. You should end up with "`0x1230`" as the "Offset:" in the lower left of the GHex window, and the cursor highlighted on the first of two hex characters reflecting the value stored at address as in the following figure.



Note: The addresses displayed on the left side may differ on your display, but the highlighted byte should correspond to address 1230.

e. Change the right-most digit of this pair (in the Binary field) such that only one bit is modified. (**Refer to the table in Appendix C** to determine whether to change the hex digit up or down one to ensure that only one bit is modified in the ciphertext.)
f. **Save the change** when you are done and then exit the hex editor.
g. Decrypt the ciphertext **without** overwriting the original file.
h. Use the `diff` command (with the "`-a`" option, as shown earlier) to show where the original file is different from the decrypted file.

Describe the corruption of the decrypted file.

Explain why ECB mode corrupted the plaintext in the manner you observe

Appendix – Some Unix Commands

`cd` Change the current directory.

```
cd destination
```

With no "destination" your current directory will be changed to your home directory. If you "destination" is "..", then your current directory will be changed to the parent of your current directory.

`cp` Copy a file.

```
cp source destination
```

This will copy the file with the "source" name to a copy with the "destination" name. The "destination" can also include the path to another directory.

`clear` Erase all the output on the current terminal and place the shell prompt at the top of the terminal.

`less` Display a page of a text file at a time in the terminal. (Also see `more`).

```
less file
```

To see another page press the space bar. To see one more line press the Enter key. To quit at any time press 'q' to quit.

`ls` List the contents and/or attributes of a directory or file

```
ls  location
ls  file
```

With no "location" or "file" it will display the contents of the current working directory.

`man` Manual

```
man command
```

Displays the manual page for the given "command". To see another page press the space bar. To see one more line press the Enter key. To quit before reaching the end of the file enter 'q'.

`more` Display a page of a text file at a time in the terminal. (Also see `less`).

```
more file
```

To see another page press the space bar. To see one more line press the Enter key. To quit at any time press 'q' to quit.

`mv` Move and/or Rename a file/directory

```
mv source destination
```

The "source" file will be moved and/or renamed to the given "destination."

`pwd` Display the present working directory

```
pwd
```

Appendix B – Hex Explained

Hex is short for hexadecimal. Numbers can be represented in many ways. We typically count in base-10, or decimal. Binary is counting in base-2. Hexadecimal is counting in base-16.

A standard way to describe these notations is to explain that each 'position' counts powers in these bases. Let $\mathbf{X_b}$ be a number whose value (**X**) should be interpreted as being written in base-**b**. The decimal number 13 might be written as 13_{10}, for clarity.

Counting by powers:

1534_{10} = 4 x 100+ 3 x 101 + 5x 102+ 1 x 103 = 4 + 30 + 500 + 1000
1011_2 = 1x 20 + 1x 21+ 0x 22+ 1x 23 = 1 + 2 + 8 = 11_{10}

The symbols we use to count by powers are all values less than base:

- Base 2 uses two symbols (0,1) to count.
- Base 10 uses ten symbols (0,1,2,3,4,5,6,7,8,9) to count.
- Base 16 uses symbols sixteen symbols: 0,1,2,3,4,5,6,7,8,9,a,b,c,d,e,f.

1534_{16} = 4x 160+ 3x 161+ 5x 162+ 1x 163 = 5428_{10}
1011_{16} = 1x 160+ 1x 161+ 0x 162+ 1x 163 = 4113_{10}
$beef_{16}$ = 15 x 160 + 14 x 161 + 14x 162 + 11 x 163 = 48879_{10}

Sometimes we write hex digits using a leading '0x' to signal that the number is in hex, since its not always clear: 0x1534, 0x1011, 0xbeef, etc.

A single hex digit can represent any four-digit binary value, or 4 bits:

0000_2 = 0x0, 0001_2 = 0x1, ..., 1110_2 = 0xe, 1111_2 = 0xf

As an aside, just as 8 bits is a byte, we sometimes call 4 bits a nibble. Since a byte is eight bits, this means a byte is two nibbles, or two hex digits:

0x1f is the byte 00011111_2

This makes hex a convenient notation for writing bytes of random data, like keys.

Appendix C – Hex to Binary Translation

The following table provides the translation of hex to binary.

Hex digit	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
A	1010
B	1011
C	1100
D	1101
E	1110
F	1111