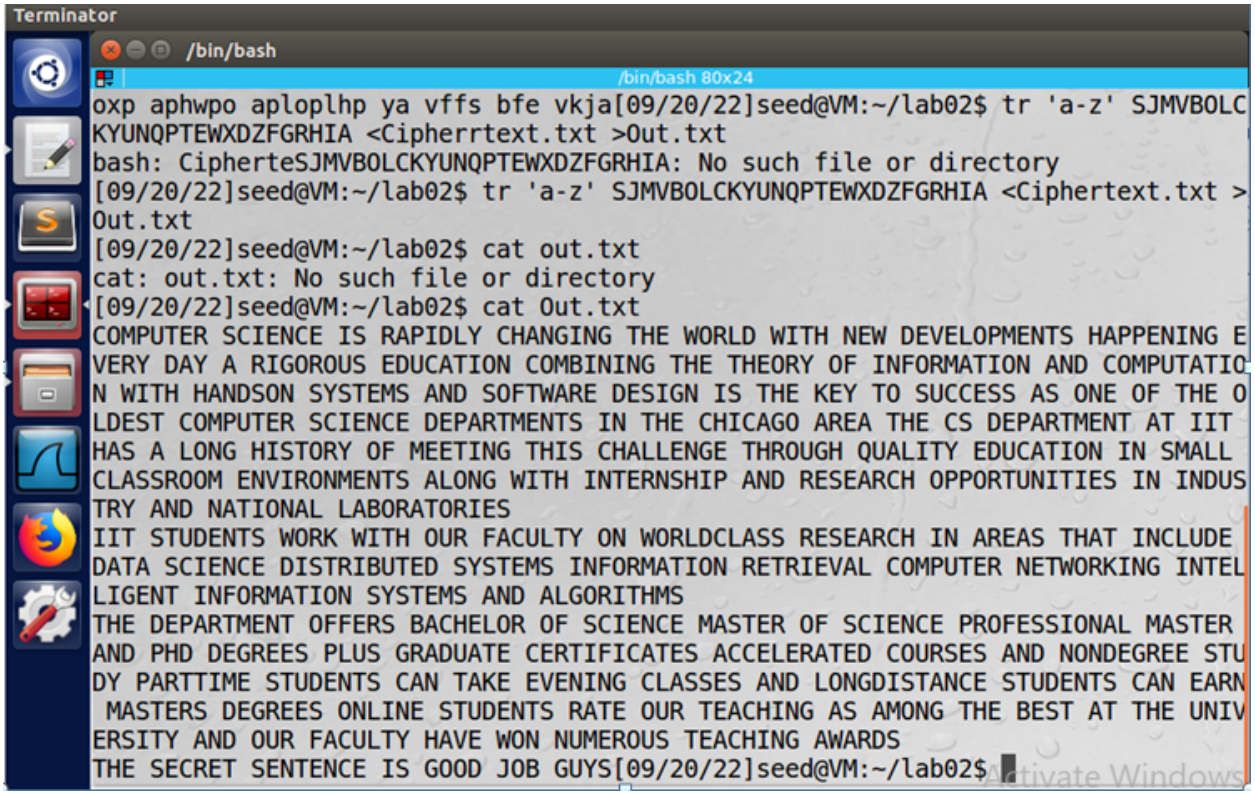
2.1)

Task 1.Frequency Analysis and Decoding the ciphertext

I have taken the encrypted text present in the cipher text and then have performed the frequency analysis on the same and below are the count of each letter

Code	Count
P	116
O	93
L	85
A	81
Z	79
Y	68
F	64
W	61
H	45
S	41
X	35
K	31
G	30
C	26
V	26
N	18
J	16
U	15
Q	12
D	7
E	6
I	4
M	1
B	1

The key is : ‘SJMVBOLCKYUNQPTEWXDZFGRHIA’ and the text is decoded as shown below



2.2).

Task 2). Encryption using different ciphers and modes

I have considered the plain text ‘Introduction to Information Security course is an amazing course’ and stored it in a file ‘plain.txt’ and then made use of different encryption methods to encrypt the plain.txt file.

Firstly, I went through the different modes of operation in block cipher:

There are totally 5 different modes of operation in block cipher:

1).ECB(Electronic Codebook Mode)

2).CBC(Cipher Block Chaining Mode)

3). CFB(Cipher Feedback Mode)

4). OFB(Output Feedback Mode)

5). CTR(Counter Mode)

I am making use of CFB,OFB and CTR modes.

CFB- The CFB mode uses block cipher but in a way acts as Stream cipher. I mean data is encrypted in smaller 8 bits rather than a predefined size of 64 bits. In this mode, 64 bits of initialization vector is used which is kept in 64 bits of shift register. The cipher text of the one block is given as input to the shift register of the next block.

OFB- The OFB mode is similar in structure to CFB but here the cipher text is not fed to the next block instead the output of the encryption of 1st is fed to the next block. The biggest advantage of using this mode is that even if there is a small error in individual bits then it will not corrupt the whole encrypted message.
CTR- The CTR mode is similar to OFB mode with slight changes. Instead of Nonce(as in OFB), it makes use of Counters as input to the algorithm and there is no chaining process as in CFB and OFB.
AES Cipher:

```
[09/17/22]seed@VM:~/lab2$ openssl enc -aes-128-cfb -e -in plain.txt -out cipher.bin \-K 00010203040506070809aabbccddeeff \-iv 0a0b0c0d0e0f01020304050607080
9
[09/17/22]seed@VM:~/lab2$ xxd cipher.bin
00000000: 8cd5 fd87 43e8 327c 2a70 2a42 31bb e9ca  ....C.2|*p*B1...
00000010: a6a6 9dcc 69aa 2734 fedb d8e5 f2e9 efac  ....i.'4........
00000020: 63b4 0452 b0df 4a5b 21a6 dba3 5a51 95d3  c..R..J[!...ZQ..
00000030: a22a 9d38 6170 c938 d9f0                 .*.8ap.8..
[09/17/22]seed@VM:~/lab2$ openssl enc -aes-128-ofb -e -in plain.txt -out cipher1.bin \-K 00010203040506070809aabbccddeeff \-iv 0a0b0c0d0e0f0102030405060708
09
[09/17/22]seed@VM:~/lab2$ xxd cipher1.bin
00000000: 8cd5 fd87 43e8 327c 2a70 2a42 31bb e9ca  ....C.2|*p*B1...
00000010: 89f0 467a 2480 e578 dec9 3c4f c418 e93d  ..Fz$..x..<O...=
00000020: f5a4 537e 2cca 6556 9393 4c05 6d44 552d  ..S~,.eV..L.mDU-
00000030: e423 8ca4 36ff 1a57 a0cd                 .#..6..W..
[09/17/22]seed@VM:~/lab2$ openssl enc -aes-128-ctr -e -in plain.txt -out cipher1.bin \-K 00010203040506070809aabbccddeeff \-iv 0a0b0c0d0e0f0102030405060708
09
[09/17/22]seed@VM:~/lab2$ xxd cipher1.bin
00000000: 8cd5 fd87 43e8 327c 2a70 2a42 31bb e9ca  ....C.2|*p*B1...
00000010: c1f1 774d bc12 b4bc 00b1 1895 18b2 21cf  ..wM..........!.
00000020: 20c3 2068 5c8a 67ff 87a9 2467 34f5 3885   . h\.g...$g4.8.
00000030: b51e 7a88 46cf 5961 f0c5                 ..z.F.Ya..
```

Blowfish Cipher:

```
cipher1.bin  cipher.bin  ciphertxt.txt  Key  plain.txt
[09/17/22]seed@VM:~/lab2$ openssl enc -bf-cfb -e -in plain.txt -out cipher2.bin \-K 00010203040506070809aabbccddeeff \-iv 0a0b0c0d0e0f010203040506070809
[09/17/22]seed@VM:~/lab2$ xxd cipher2.bin
00000000: ea17 8b1f cf59 0bdb 79c4 8240 7df0 943f  .....Y..y..@}..?
00000010: a8cd 68c5 e611 5e2d 86f5 ac64 0bd6 7380  ..h...^-...d..s.
00000020: 9e0a 8f9d b8a7 b426 7afb 1b98 d970 a537  .......&z....p.7
00000030: dce2 f8fc cc97 a82e e216                 ..........
[09/17/22]seed@VM:~/lab2$ openssl enc -bf-ofb -e -in plain.txt -out cipher3.bin \-K 00010203040506070809aabbccddeeff \-iv 0a0b0c0d0e0f010203040506070809
[09/17/22]seed@VM:~/lab2$ xxd cipher3.bin
00000000: ea17 8b1f cf59 0bdb 6c8b f1e6 3717 38d9  .....Y..l...7.8.
00000010: e3e2 09bc c7e3 00fc 90f9 b8b5 f17e 6db7  ............~m.
```

Note: Blowfish cipher does not support Counter mode.

ARC2 Cipher:

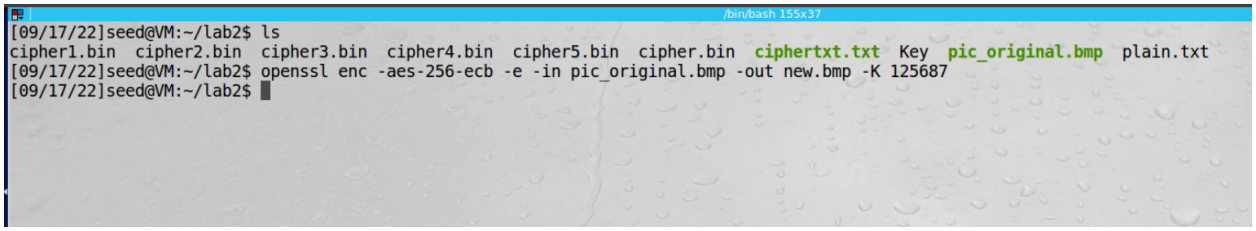
```
[09/17/22]seed@VM:~/lab2$ openssl enc -rc2-cfb -e -in plain.txt -out cipher4.bin \-K 00010203040506070809aabbccddeeff \-iv 0a0b0c0d0e0f010203040506070809
[09/17/22]seed@VM:~/lab2$ xxd cipher4.bin
00000000: 4073 f1cb a7c6 99ba 7726 3d1a 3d84 1f71  @s......w&=.=..q
00000010: c84a 492f eb28 73ba c044 331b 5bd1 917b  .JI/.(s..D3.[..{
00000020: 41e0 56f7 fc8f 2232 f260 744b e2dc 8988  A.V..."2.`tK....
00000030: 3309 ca92 2d81 5bab 94b0                 3...-.[...
[09/17/22]seed@VM:~/lab2$ openssl enc -rc2-ofb -e -in plain.txt -out cipher5.bin \-K 00010203040506070809aabbccddeeff \-iv 0a0b0c0d0e0f010203040506070809
[09/17/22]seed@VM:~/lab2$ xxd cipher5.bin
00000000: 4073 f1cb a7c6 99ba adbb e095 ec92 adf6  @s..............
00000010: 6158 06c6 2ed3 57f2 e243 290b 9e37 8aa8  aX....W..C)..7..
00000020: 858f 3164 26d8 d91c 58e0 7b5c 86ce 8637  ..1d&...X.{\...7
00000030: 5b4f e0d9 d50e 2aa8 30e7                 [O....*.0.
[09/17/22]seed@VM:~/lab2$ openssl enc -rc2-ecb -e -in plain.txt -out cipher5.bin \-K 00010203040506070809aabbccddeeff \-iv 0a0b0c0d0e0f010203040506070809
warning: iv not use by this cipher
[09/17/22]seed@VM:~/lab2$ xxd cipher5.bin
00000000: 58af 5973 9b79 83e9 369f c0de eadb 4cdc  X.Ys.y..6.....L.
00000010: 5fa2 c424 9750 0a75 168e 6560 33fb 21d7  _..$.P.u..e`3.!.
00000020: ad65 956a 2e83 d99a 6abb 4f92 706e 44d7  .e.j....j.O.pnD.
00000030: 337a d422 6e5a a4c8 89e8 5b2b 61cf be39  3z."nZ....[+a..9
[09/17/22]seed@VM:~/lab2$
```

I have made use of xxd command to observe the encrypted contents in hexadecimal format.
2.3).

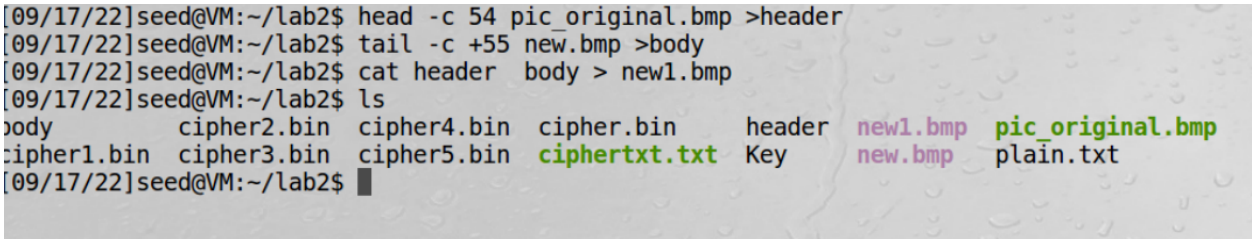
Task 3 : Encryption Mode- ECB vs CBC

I downloaded the pic_original.bmp file and placed it in the shared folder and then took the file from the shared folder and placed it in the lab2 folder in VM.

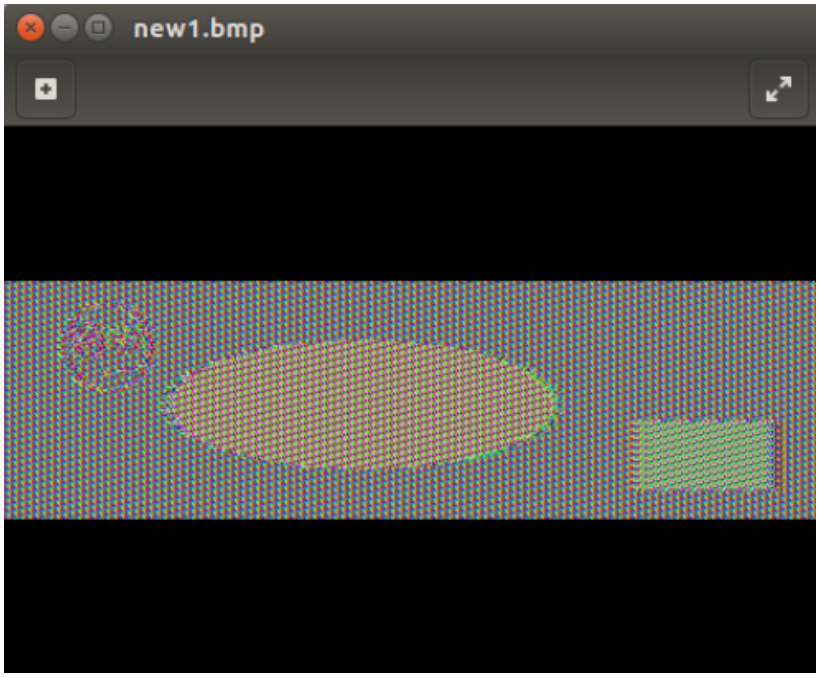
First I am encrypting the image pic_original.bmp using **AES-256 cipher in ECB mode** and the output file is new.bmp



As mentioned in the question, I copied the header from pic_original.bmp and tail from new.bmp and put both into the new bmp file i.e. new1.bmp.



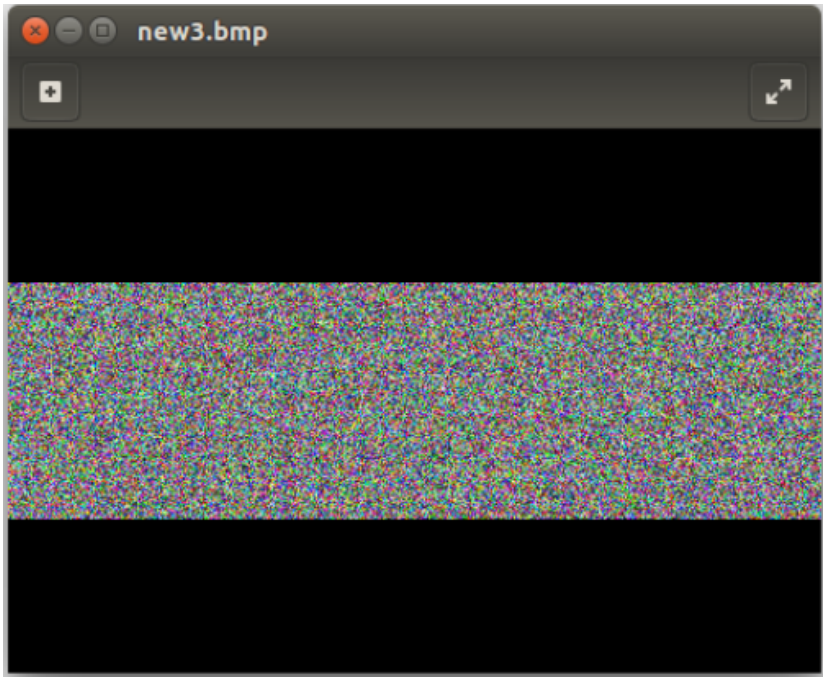
And the Image after encryption looks like as shown below:



The same process is repeated with the AES cipher in CBC mode.

```
[09/17/22]seed@VM:~/lab2$ openssl enc -aes-256-cbc -e -in pic_original.bmp -out new2.bmp -K 125687 -iv 0a0b0c0d0e0f010203040506070809
[09/17/22]seed@VM:~/lab2$ head -c 54 pic_original.bmp >header
[09/17/22]seed@VM:~/lab2$ tail -c +55 new2.bmp >body
[09/17/22]seed@VM:~/lab2$ cat header  body > new3.bmp
[09/17/22]seed@VM:~/lab2$
```

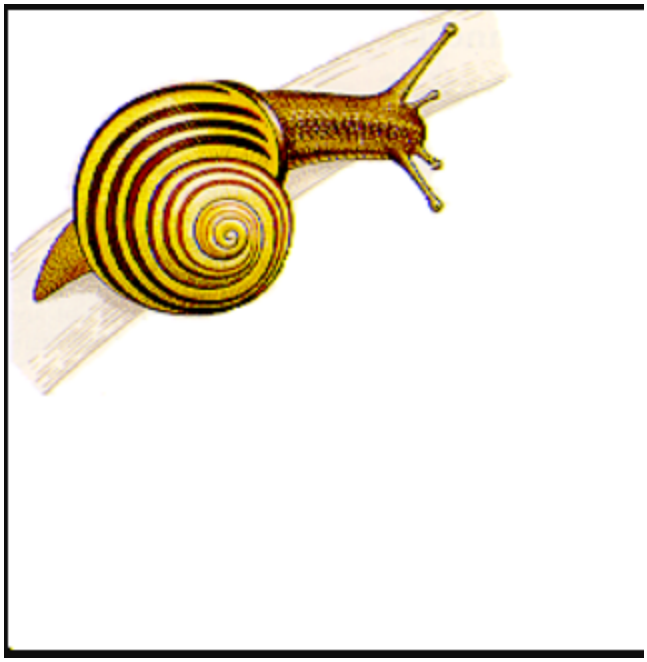
And the encrypted image is shown as below:



From both the encrypted pictures we can see that the image encrypted in ECB mode is very basic as we can roughly see the content i.e. the content of the image is not fully encrypted whereas the image encrypted in CBC mode is very good as it does not give any hint about the original image's content. I think in CBC mode, each cipher block is dependent on all the plaintext processed until that point and this adds an extra level of security to the encrypted data making it more complex.

2.3.1).

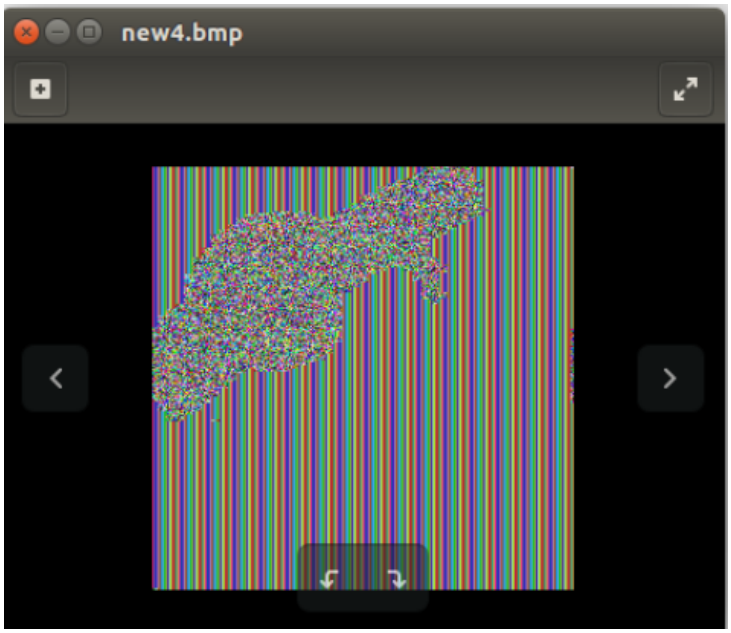
I choose the picture snail.bmp as shown below to experiment:



(I have pasted the screenshot of the image as .bmp is image is not supported in google docs)
Encrypting using in ecb mode:

```
/bin/bash 155x37
[09/17/22]seed@VM:~/lab2$ openssl enc -aes-256-ecb -e -in snail.bmp -out new_snail.bmp -K 125687
[09/17/22]seed@VM:~/lab2$ head -c 54 snail.bmp >header
[09/17/22]seed@VM:~/lab2$ tail -c +55 new_snail.bmp >body
[09/17/22]seed@VM:~/lab2$ cat header  body > new4.bmp
[09/17/22]seed@VM:~/lab2$
```

And the resulting encrypted image is



Encryption in cbc mode :

```
[09/17/22]seed@VM:~/lab2$ openssl enc -aes-256-cbc -e -in snail.bmp -out new_snail_1.bmp -K 125687 -iv 0a0b0c0d0e0f010203040506070809
[09/17/22]seed@VM:~/lab2$ head -c 54 snail.bmp >header
[09/17/22]seed@VM:~/lab2$ tail -c +55 new_snail_1.bmp >body
[09/17/22]seed@VM:~/lab2$ cat header  body > new6.bmp
[09/17/22]seed@VM:~/lab2$
```

2.4).

Task 4 Padding:

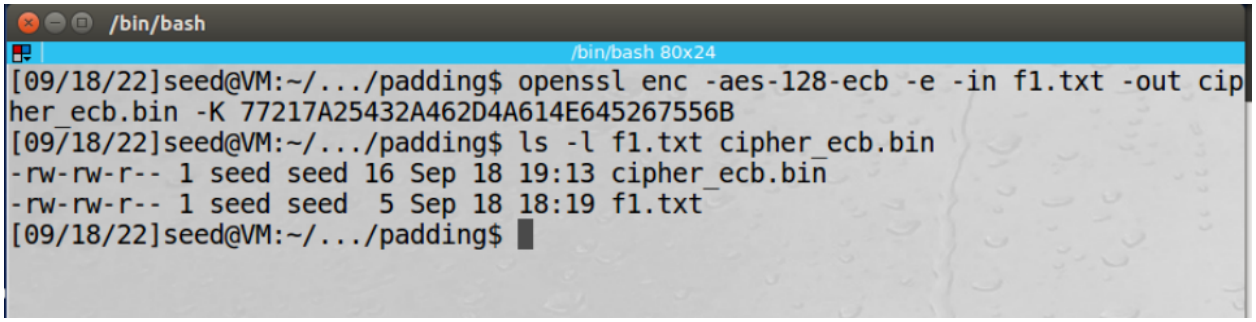
In this task as per the question I first created three files of size 5bytes(f1.txt), 10 bytes(f2.txt) and 16 bytes(f3.txt) as shown below:

```
[09/18/22]seed@VM:~/.../padding$ ls
[09/18/22]seed@VM:~/.../padding$ echo -n "12345" > f1.txt
[09/18/22]seed@VM:~/.../padding$ echo -n "1234512345" > f2.txt
[09/18/22]seed@VM:~/.../padding$ echo -n "12345123451234567" > f3.txt
[09/18/22]seed@VM:~/.../padding$ ls
f1.txt  f2.txt  f3.txt
[09/18/22]seed@VM:~/.../padding$
```

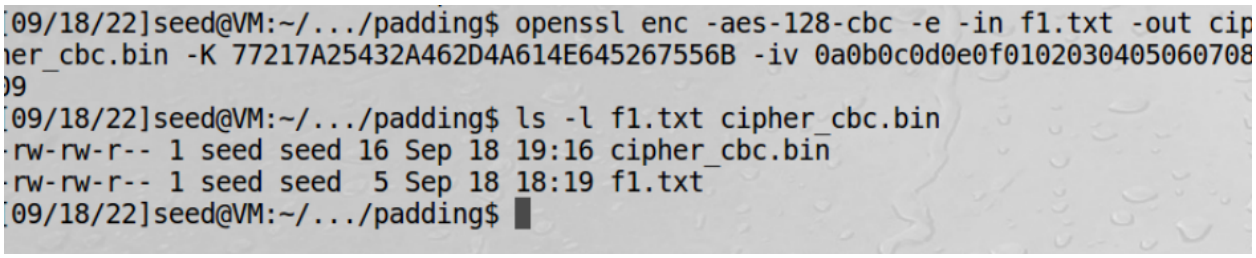
1). Now I am making use of the f1.txt(5 bytes) file to encrypt using aes-128 cipher in different modes ECB,CBC,CFB and OFB.

And the Key I am using to encrypt is : 77217A25432A462D4A614E645267556B and IV

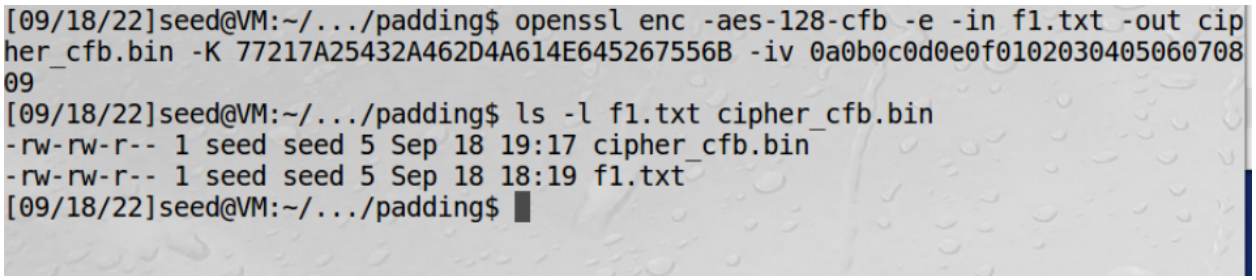
In ECB mode, there was padding :



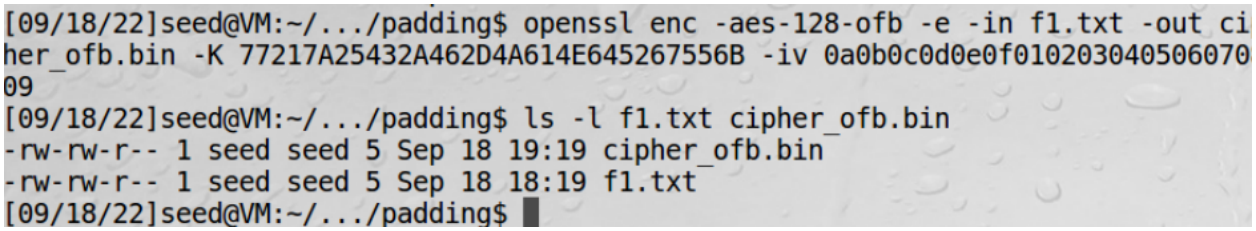
In CBC mode, there was padding:



In CFB mode, there was **no padding**:



In OFB mode, there was **no padding**:



The ECB and CBC mode needs to have a plain text size in the multiple of 128 bits i.e. 16 bytes and in our case we only have 5 bytes of plain text. ECB and CBC dont have mechanisms to encrypt if the size of the plain text is less than 16 bytes so padding is done and that's the reason we are finding the size of encrypted file as 16 bytes.

Whereas in OFB and CFB mode they have the mechanisms which makes us feel block ciphers as stream ciphers and these modes where CFB has identical encryption and decryption functions and as a result doesn't require padding to the plain text.

2). Encrypting and Decrypting 5 bytes(f1.txt) file

Encrypting the f1.txt :

```
[09/18/22]seed@VM:~/.../padding$ openssl enc -aes-128-cbc -e -in f1.txt -out cip
her_cbc_f1.bin -K 77217A25432A462D4A614E645267556B -iv 0a0b0c0d0e0f0102030405060
70809
[09/18/22]seed@VM:~/.../padding$ ls
cipher_cbc.bin     cipher_cfb.bin  cipher_ofb.bin  f2.txt
cipher_cbc_f1.bin  cipher_ecb.bin  f1.txt          f3.txt
```

Decrypting the file without removing padding and we can see that 11 bytes have been padded zero since we had only 5 bytes of plain text as shown below:

```
[09/18/22]seed@VM:~/.../padding$ openssl enc -aes-128-cbc -d -nopad -in cipher_c
bc_f1.bin -out f1_nopad.txt  -K 77217A25432A462D4A614E645267556B -iv 0a0b0c0d0e0
f0102030405060708 09
[09/18/22]seed@VM:~/.../padding$ hexdump -C f1_nopad.txt
00000000  31 32 33 34 35 0b 0b 0b  0b 0b 0b 0b 0b 0b 0b 0b  |12345...........|
00000010
[09/18/22]seed@VM:~/.../padding$
```

Encrypting and Decrypting 10 bytes file:
Here 6 bytes have been padded as zero because we have plain text of 10 bytes only.

```
/bin/bash
/bin/bash 80x24
[09/18/22]seed@VM:~/.../padding$ openssl enc -aes-128-cbc -e -in f2.txt -out cip
her_cbc_f2.bin -K 77217A25432A462D4A614E645267556B -iv 0a0b0c0d0e0f0102030405060
70809
[09/18/22]seed@VM:~/.../padding$ openssl enc -aes-128-cbc -d -nopad -in cipher_c
bc_f2.bin -out f2_nopad.txt  -K 77217A25432A462D4A614E645267556B -iv 0a0b0c0d0e0
f0102030405060708 09
[09/18/22]seed@VM:~/.../padding$ hexdump -C f2_nopad.txt
00000000  31 32 33 34 35 31 32 33  34 35 06 06 06 06 06 06  |1234512345......|
00000010
[09/18/22]seed@VM:~/.../padding$
```

Encrypting and Decrypting 16 bytes file:
Here there is no padding as we have a plaintext of 16 bytes which is the size of one block.

```
/bin/bash
/bin/bash 80x24
[09/18/22]seed@VM:~/.../padding$ openssl enc -aes-128-cbc -e -in f3.txt -out cip
her_cbc_f3.bin -K 77217A25432A462D4A614E645267556B -iv 0a0b0c0d0e0f0102030405060
70809
[09/18/22]seed@VM:~/.../padding$ openssl enc -aes-128-cbc -d -nopad -in cipher_c
bc_f3.bin -out f3_nopad.txt  -K 77217A25432A462D4A614E645267556B -iv 0a0b0c0d0e0
f0102030405060708 09
[09/18/22]seed@VM:~/.../padding$ hexdump -C f3_nopad.txt
00000000  31 32 33 34 35 31 32 33  34 35 31 32 33 34 35 36  |1234512345123456|
00000010  10 10 10 10 10 10 10 10  10 10 10 10 10 10 10 10  |................|
00000020
[09/18/22]seed@VM:~/.../padding$ xxd f3_nopad.txt
00000000: 3132 3334 3531 3233 3435 3132 3334 3536  1234512345123456
00000010: 1010 1010 1010 1010 1010 1010 1010 1010  ................
[09/18/22]seed@VM:~/.../padding$
```

2.5)
Task 5: Error Propagation- Corrupted Cipher Text

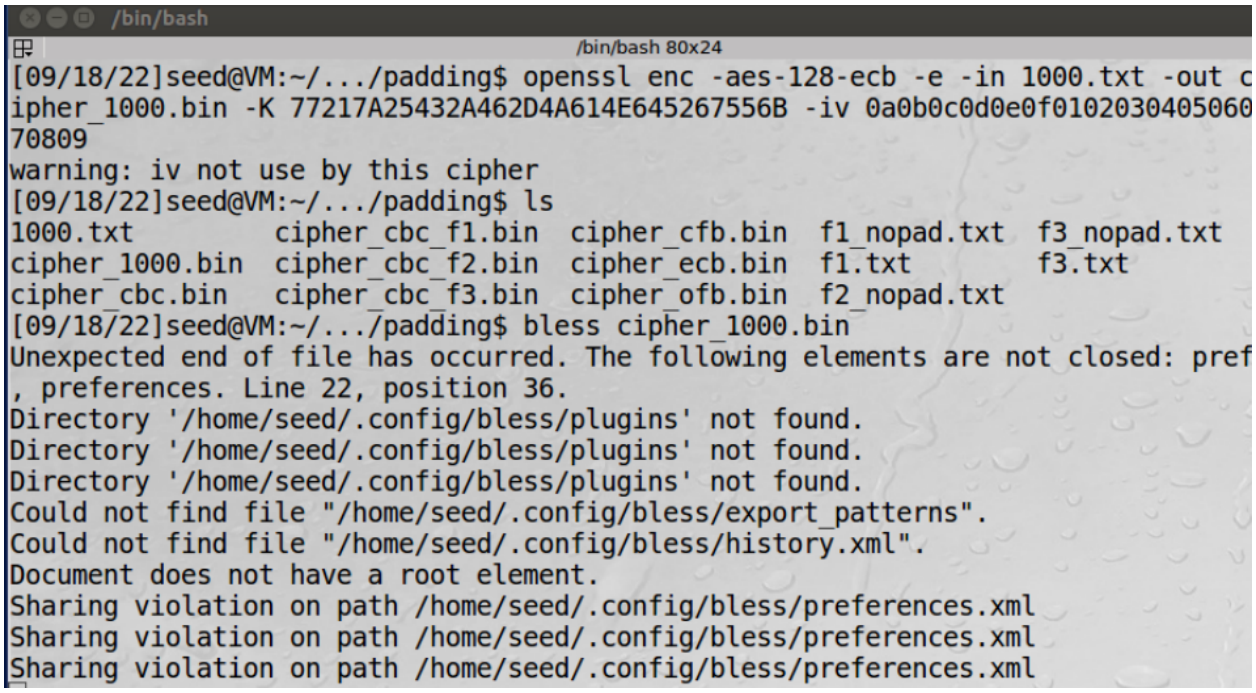
ECB mode- Each block is encrypted and decrypted separately. So, I feel only a specific block i.e. the block which 55th bit blocks will get affected.

CBC mode- The ciphertext block is used for two things
1). As an input to the block cipher to calculate the output which is then XORed with the IV key to get the plain text.
2). As the input to the XOR to calculate the next plaintext block with the next decrypted block. So even in this scenario the bits which are changed or corrupted will affect the bit or probably only that block max.

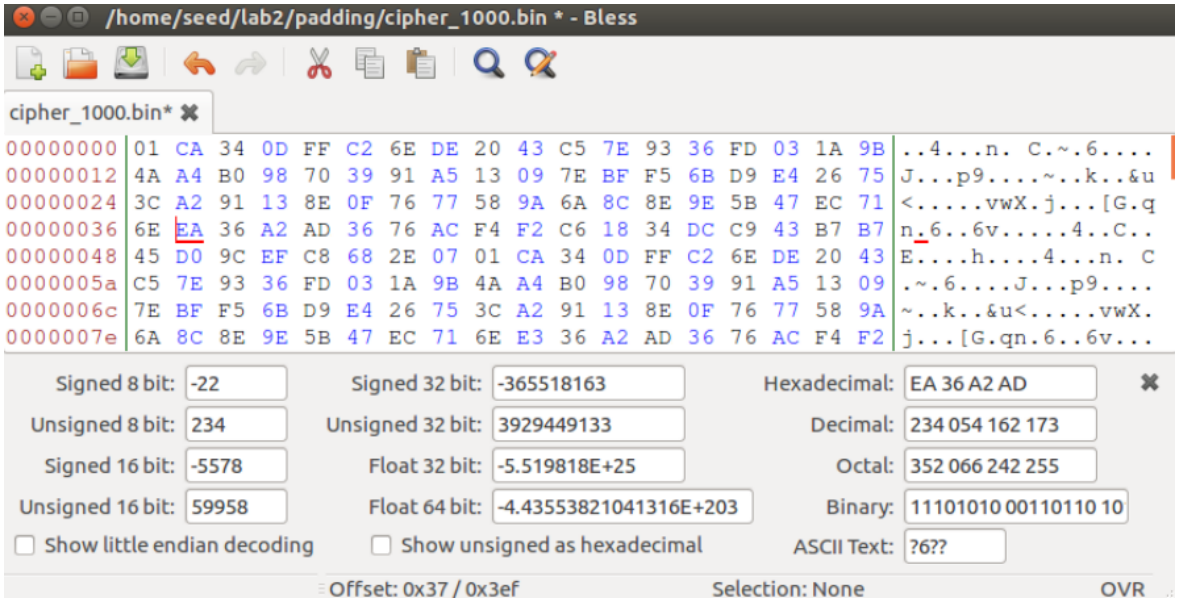
CFB mode- I feel the result of CFB decryption will be similar to CBC.

OFB mode- Here the feedback is only in the key generation system. If the single digit is corrupted from a 1000 byte encrypted file then in plain text only that byte will be corrupted.

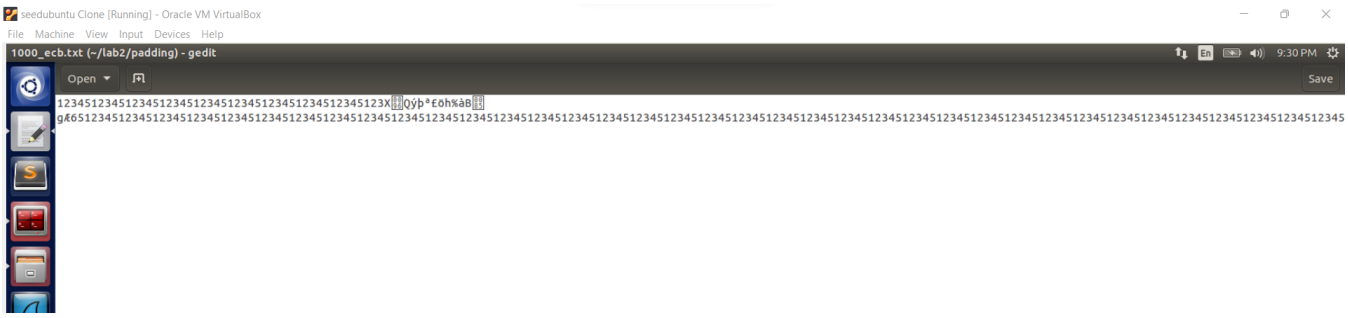
ECB mode:
Created 1000.txt (1000 bytes) file and then encrypted it as shown below:



Changing the 55th bit:



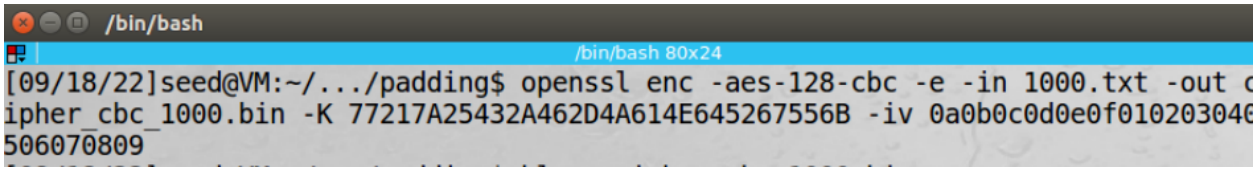
The plaintext file after decrypting the corrupted file:



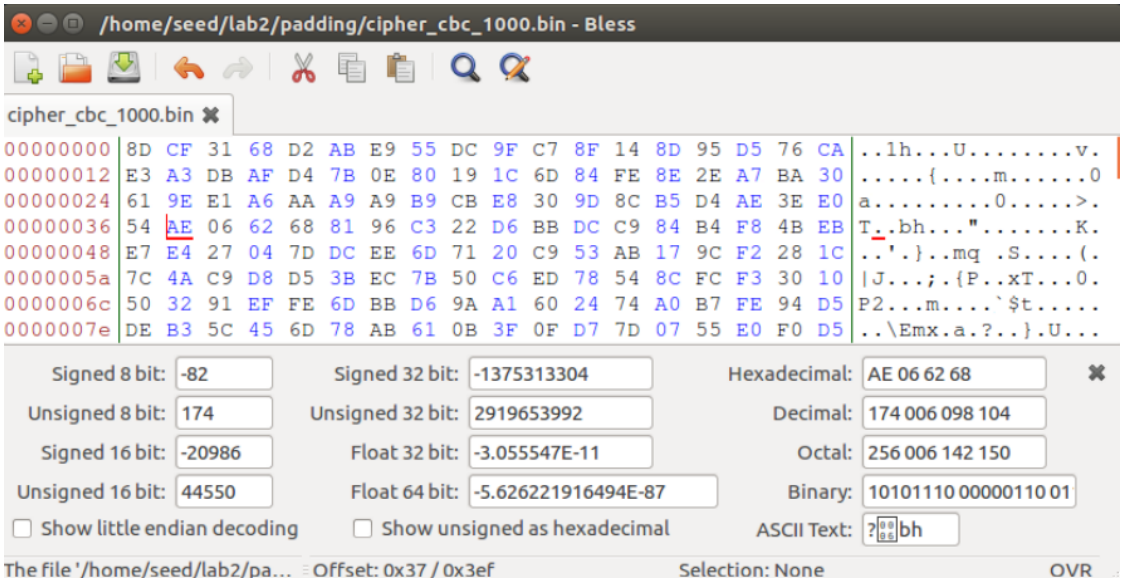
Here my 1000 bytes file had contents 123451234512345….12345 format so 1 bit change in the ciphertext has changed a part of info in decrypted plain text file.

CBC mode:

Created 1000.txt (1000 bytes) file and then encrypted it as shown below:



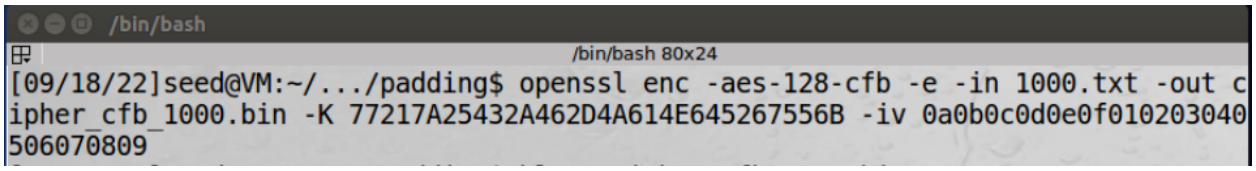
Changing the 55th bit:



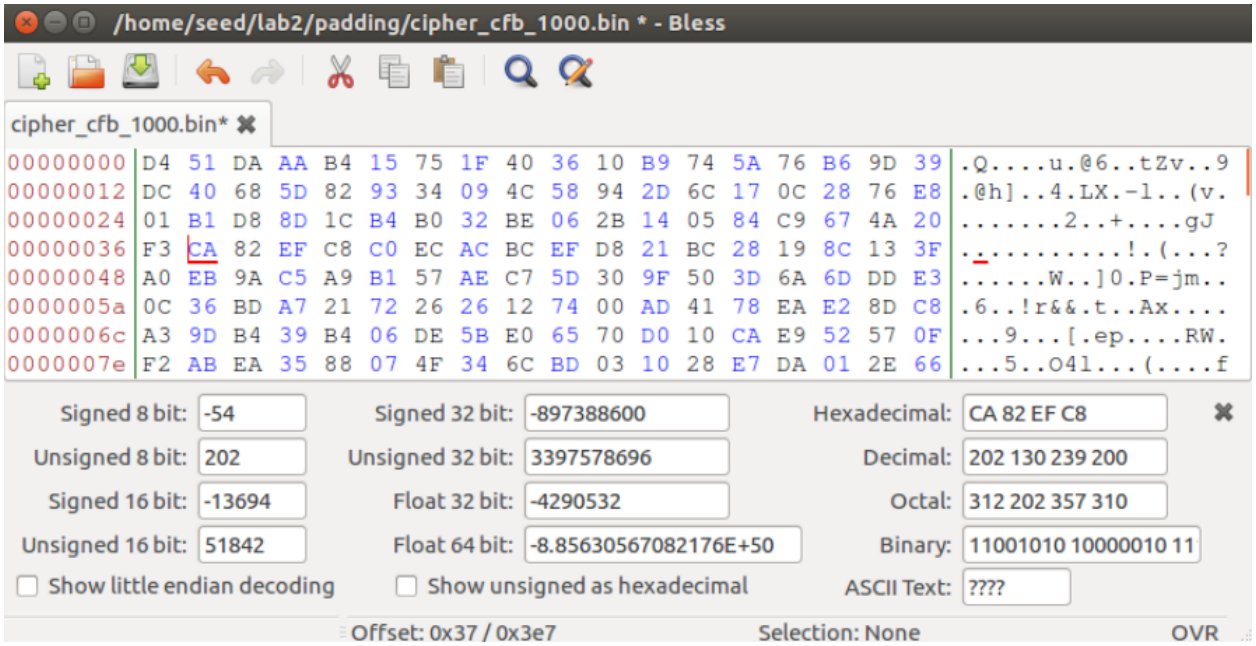
Plain text after decrypting corrupted file:

The whole block of bits is not decrypted in the plain text as in ECB.

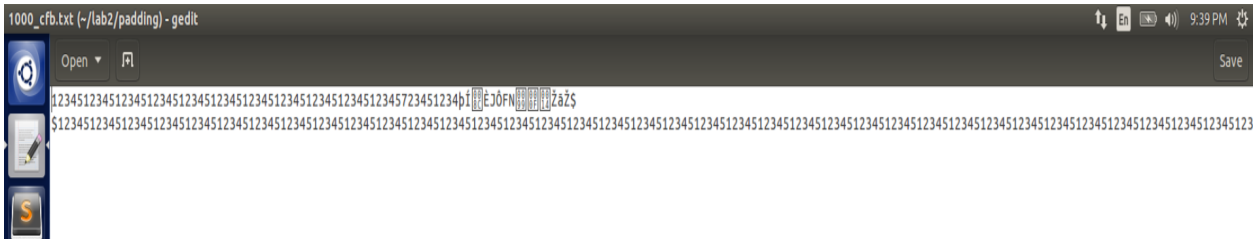
CFB:
Created 1000.txt (1000 bytes) file and then encrypted it as shown below:



Changing the 55th bit:

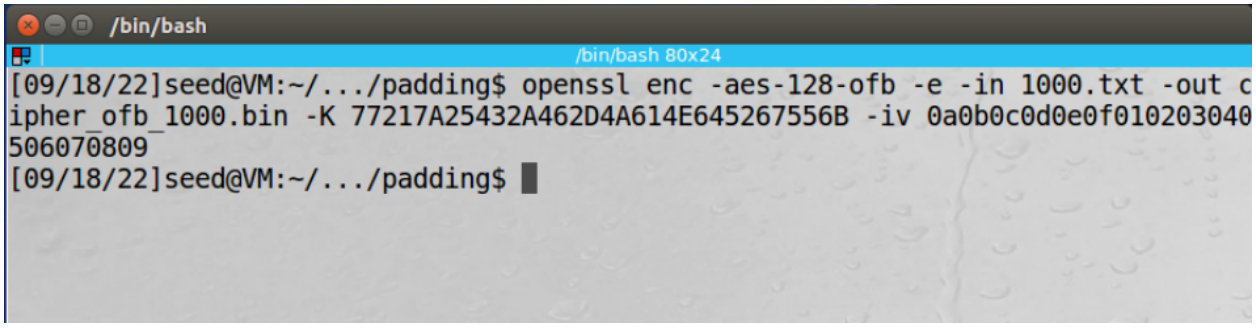


The plaintext file after decrypting the corrupted file:

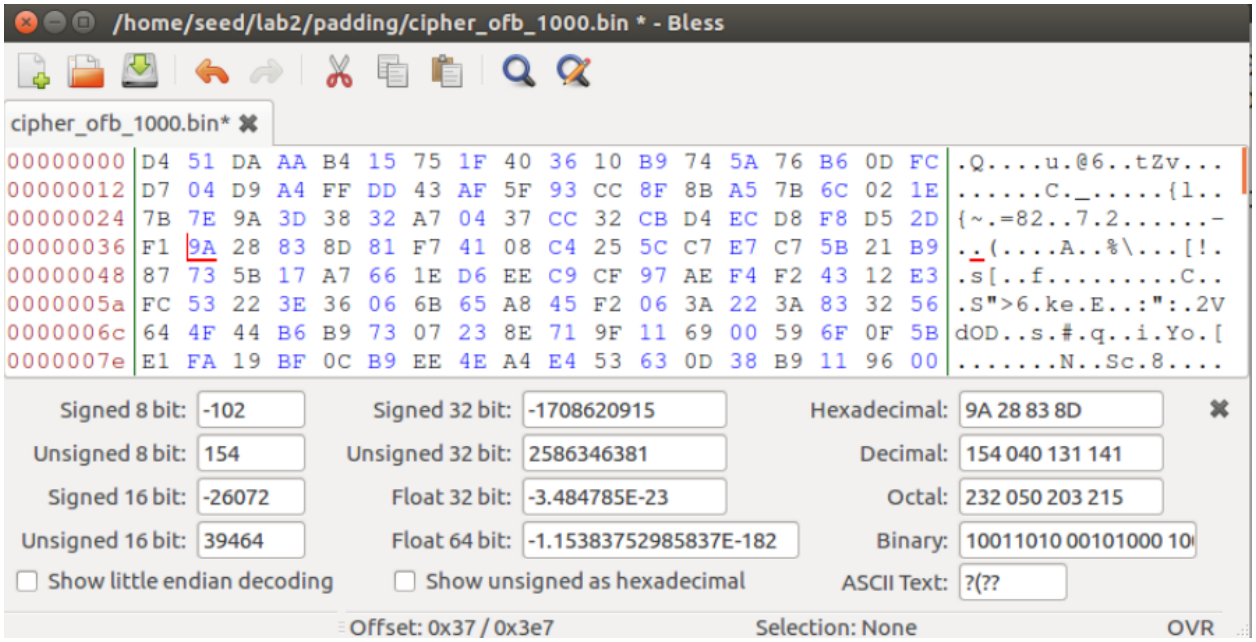


OFB mode:

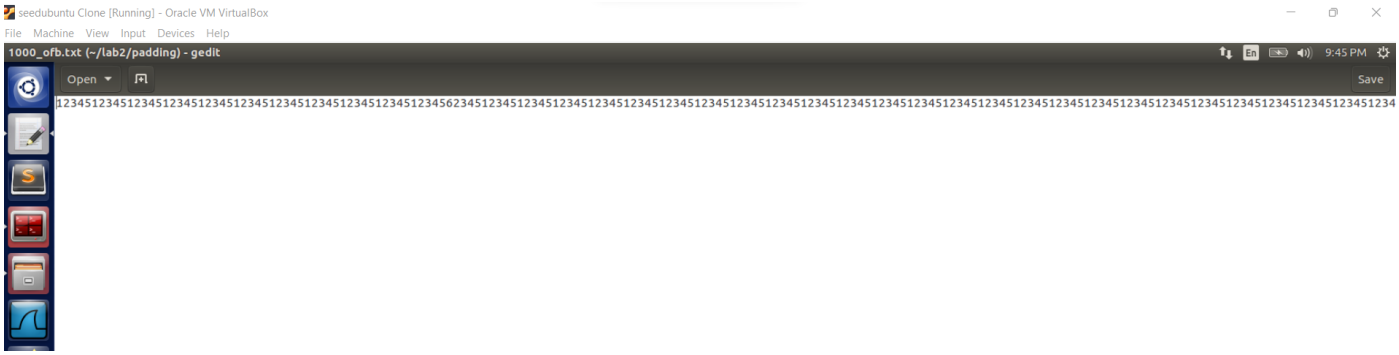
Created 1000.txt (1000 bytes) file and then encrypted it as shown below:



Changing the 55th bit:

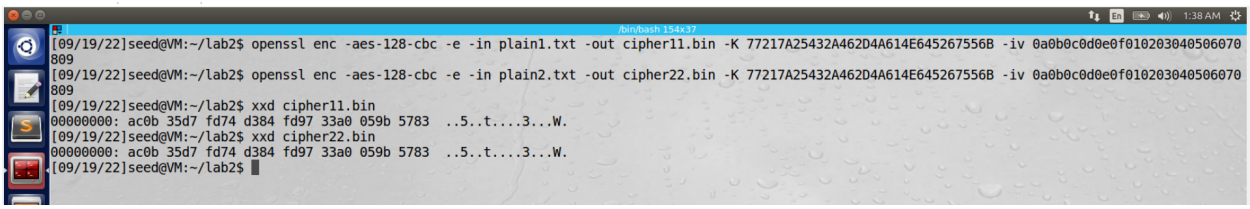


Only the 55th bit is affected in the decrypted file:

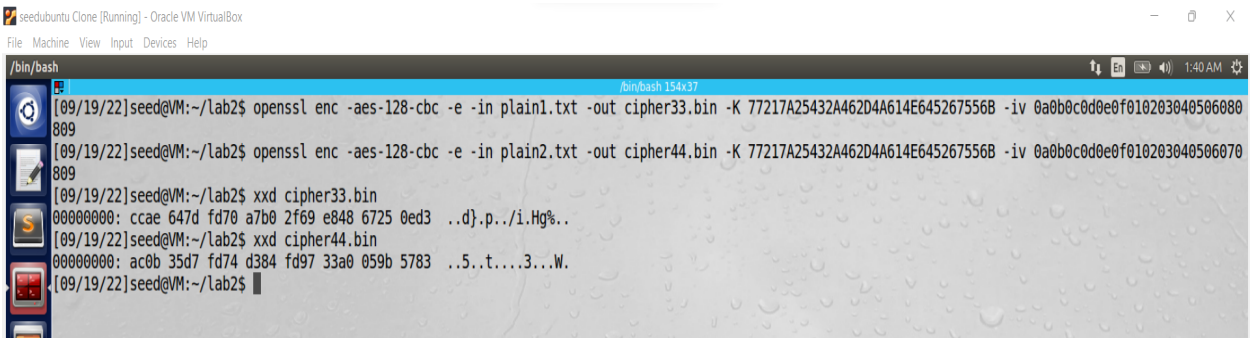


2.6.1). **Task 6: Initial Vector(IV)**

6.1) I first created two plaintexts plain1.txt and plain2.txt each of them contain 5 bytes(12345) I encrypted them using same key(77217A25432A462D4A614E645267556B) and initial vector(0a0b0c0d0e0f010203040506070809) as shown below with the contents of the ciphertext:



Then I encrypted same plain text files using different Initial Vectors:



The encrypted files were not the same and were completely different from each other.

2.6.2) **Common Mistakes: Use the same IV**
In the Boolean algebra we know that if A XOR B = C then A XOR C= B.
Let's use the above rule to find the plaintext P2.

Given Plaintext P1 : This is a known message!

Plaintext P1 converted to Hex: 546869732069732061206b6e6f776e206d6573736167652100
Then plaintext is padded with 2 zeros as it is 2bytes smaller than cipher text.
Ciphertext C1 : a469b1c502c1cab966965e50425438e1bb1b5f9037a4c15913

Now if we XOR P1 and C1 we get the output of the block cipher(Which takes key and IV as input) and let's call this output as Ks

Ks : f001d8b622a8b99907b6353e2d2356c1d67e2ce356c3a47813

The catch here is this is given as input to the next block and since its mentioned IVs are the same then the output of the second block cipher will also lead to the same Ks. So if we XOR Ks and Ciphertext we will be able to retrieve Plain text P2.

P2= Ks XOR C2= 4f726465723a204c61756e63682061206d697373696c652100

Hex to text of P2= Order: Launch a missile!

Thus, I was able to recover full P2.

In the same question if CFB is there then also we can recover full Plaintext.

2.6.3) **Task 6.3. Common Mistake: Use a Predictable IV**

The encryption method used is 128-bit AES with CBC mode.

Key (in hex): 00112233445566778899 aabbccddeeff (known only to Bob)

Ciphertext (C1): bef65565572ccee2a9f9553154ed9498 (known to both) I V used on P1 (known to both)(in ascii): 1234567890123456 (in hex) : 31323334353637383930313233343536

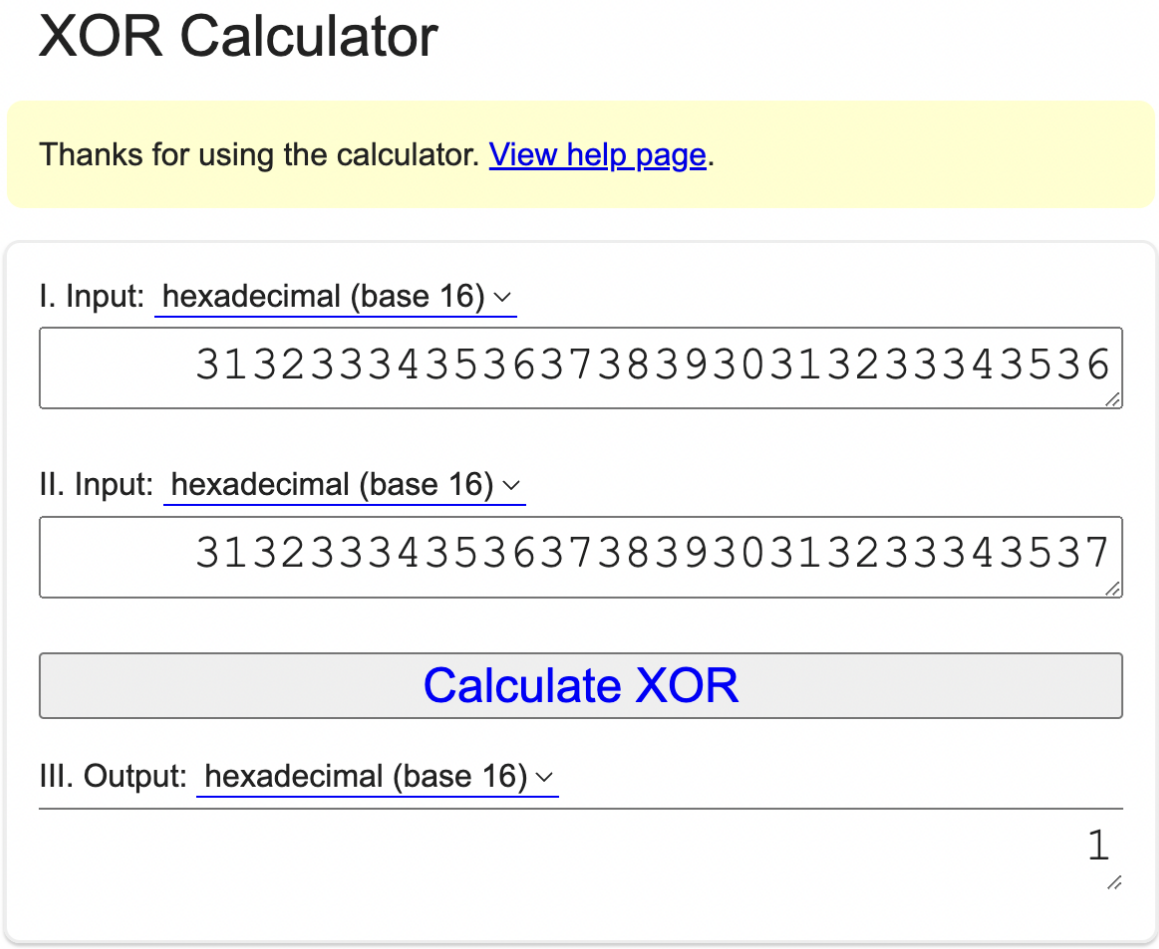
Next IV (known to both)(in ascii): 1234567890123457 (in hex) : 31323334353637383930313233343537

P2(hex)= 31323334353637383930313233343536 XOR 31323334353637383930313233343537 XOR 596572

P2(hex):596572

Since it is known that plane text is either yes or no, we can find the hex similar to the p2 to conclude it to be the required value in this case P2 is “yes”

In this case 1 = yes and 0 = no,



2.8 Task 7: Programming using the Crypto Library - Extra Credit 5%

Code:

```
#include <openssl/conf.h>

#include <openssl/evp.h>

#include <openssl/err.h>

#include <string.h>
```

```
void handleErrors(void);
void pad(char *s, int length);
int strcicmp(char const *a, char *b);


int main (void)
{
    unsigned char match[]= "MATCH";
    unsigned char nomatch[]= "NOMATCH";
    int i,outlen,tmplen;
    unsigned char outbuf[1024 + EVP_MAX_BLOCK_LENGTH];
    FILE *key;
    EVP_CIPHER_CTX ctx;
    EVP_CIPHER_CTX_init(&ctx);


    /*
     * Set up the key and iv. Do I need to say to not hard code these in a
     * real application? :-)
     */




    /* A 128 bit IV */
```

```
    unsigned char iv[16] ="0102030405060708090000a0b0c0d0e0f";


    /* Message to be encrypted */

    char inText[]="This is a secret tool";


    key= fopen("words.txt","r");


    /*

     * Buffer for ciphertext. Ensure the buffer is long enough for the

     * ciphertext which may be longer than the plaintext, depending on the

     * algorithm and mode.

     */

    char ciphertext[]=
"ece6753e938f8f903cabbbe12d395bf5f7eae38ad918a2d3e1c3a832476d5c7a";


    while (fgets(words,16, key))

    {

      i= strlen(words);

     words[i-1]='\0';

     i= strlen(words);

     if(i<16)

     {

    pad(words,(16));

     }
```

```
    EVP_EncryptInit_ex(&ctx, EVP_aes_128_cbc(), NULL, words, iv);

    if(!EVP_EncryptUpdate(&ctX, outbuf, Boutlen, InText, strlen(intext)))

       {EVP_CIPHER_CTX_cleanup(&ctX);

         return 0:

    }

if(!EVP_EncryptFinal_ex(&ctX, outbuf + outlen, stmplen))

{

EVP_CIPHER_CTX_cleanup(&ctx);

return 0;

}

outlen += tmplen;
```

```
int j;

char *buf_str= (char*) malloc (2*outlen +1);

char *buf_ptr= buf_str;

for(i=0; i<outlen;i++){

    buf_ptr += sprintf(buf_ptr, "%02X",outbuf[i]);

}

*(buf_ptr +1)='\0';



if(strcicmp(ciphertext,buf_str)==0){

    printf("%s\n", words)

}



}

fclose(key);

     return 1;

}




void handleErrors(void)

{

    ERR_print_errors_fp(stderr);

    abort();

}
```

```
void pad(char *s, int length)
{


 int l;
 l=(strlen(s));


 while(l<length){
    s[l] = ' ';
    l++;
 }
 s[l]= '\0';
}


int strcicmp(char const *a, char const *b){
    for(;;a++;b++){
        int d= tolower(*a)- tolower(*b);
        if (d!=0 || !*a){
             return d;
        }
    }
}
```