CPS633 Section 07 Fall2021

Lab 06 Report

Secret-Key Encryption Lab

Name: Tusaif Azmat (group leader)
Student#: 500660278.
And
Name: Ankit Sodhi
Student#: 500958004

Group 04.

CPS 633 - Lab 6 Report

Secret-Key Encryption Lab

Lab Tasks:

Task 1: Frequency Analysis

Step 1: Use the text of the Gettysburg Address as the original article file gettysburg.txt. The usage of tr is available in GNU documentations. -d means 'delete' and -cd means 'delete the complement of', so first we just keep the letters, spaces, and newlines as the plaintext.

```
$tr [:upper:] [:lower:] < gettysburg.txt > lowercase.txt
$tr -cd '[a-z][\n][:space:]' < lowercase.txt > plaintext.txt
```

Step 2: Use Python console to generate a permutation of a-z:

```
>>> import random
>>> s = "abcdefghijklmnopqrstuvwxyz"
>>> ''.join(random.sample(s,len(s)))
'azfgmunhrqwetlxicdksjbpvyo'
```

Step 3: Encryption

```
$tr "abcdefghijklmnopqrstuvwxyz" "azfgmunhrqwetlxicdksjbpvyo" < plaintext.txt > ciphertext.txt
```

Break

Use http://www.richkni.co.uk/php/crypta/freq.php to analyze the frequency of ciphertext.txt, its full report shows as analysis.md.
By single letter frequency and the letters in ciphertext sorted by frequency are:

```
msaxhdlrgkefpnubjiztywcqvo
```

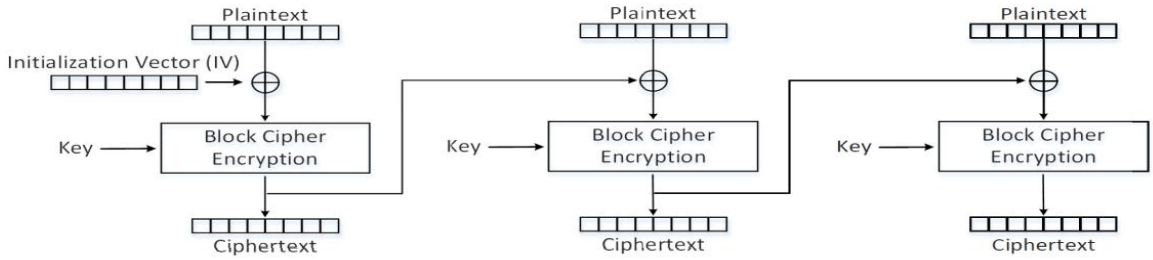
Compared with letter frequency rank as `eothasinrdluymwfgcbpkvjqxz` in modern English (see Wikipedia)

```
$ tr 'msaxhdlrgkefpnubjiztywcqvo' 'eothasinrdluymwfgcbpkvjqxz' < ciphertext.txt > out1.txt
```

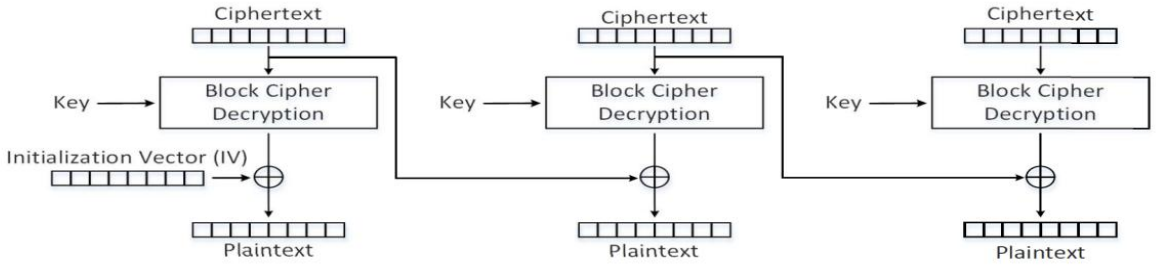
3 Task 2: Encryption using Different Ciphers and Modes

Cipher Block Chaining (CBC)

Each block of plaintext is XORed with the previous cipher block.



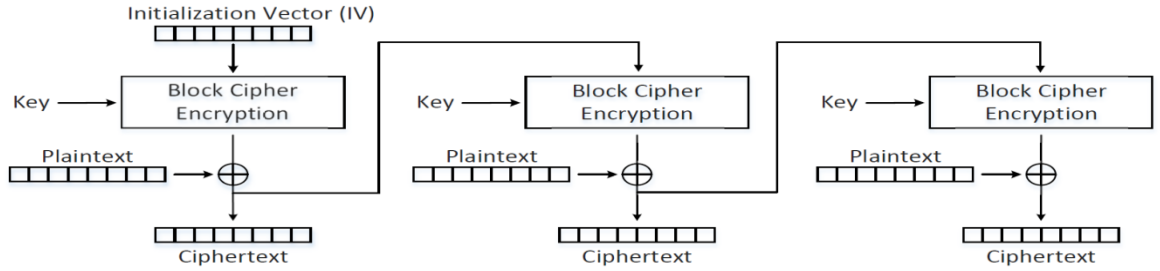
(a) Cipher Block Chaining (CBC) mode encryption



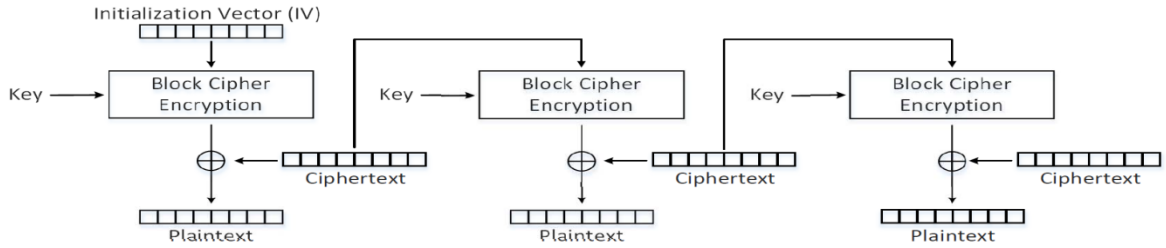

```
#encrypt
$openssl enc  -aes-128-cbc  -e -in plaintext.txt -out cbc_cipher.bin \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
#decrypt
$openssl enc  -aes-128-cbc  -d -in cbc_cipher.bin -out cbc_plain.txt \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
#valid
$diff plaintext.txt cbc_plain.txt
```

Cipher Feedback (CFB)

The ciphertext from the previous block is fed into the block cipher for encryption, and the output of the encryption is XORed with the plaintext to generate the actual ciphertext.



(a) Cipher Feedback (CFB) mode encryption

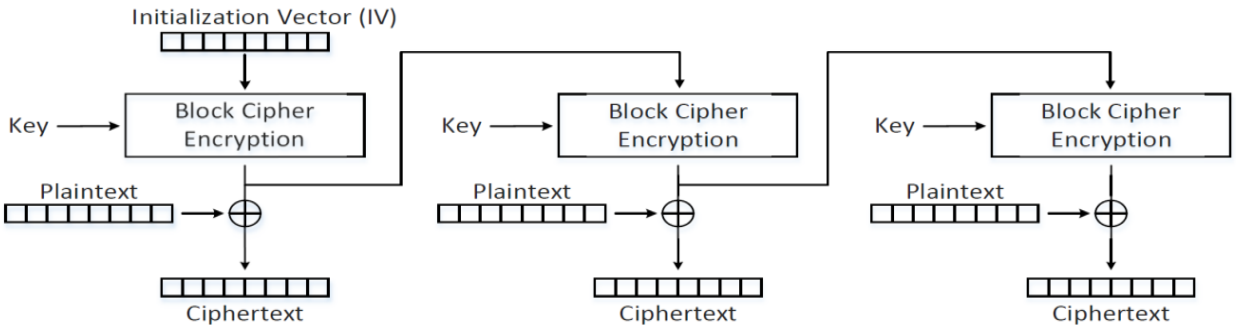


(b) Cipher Feedback (CFB) mode decryption

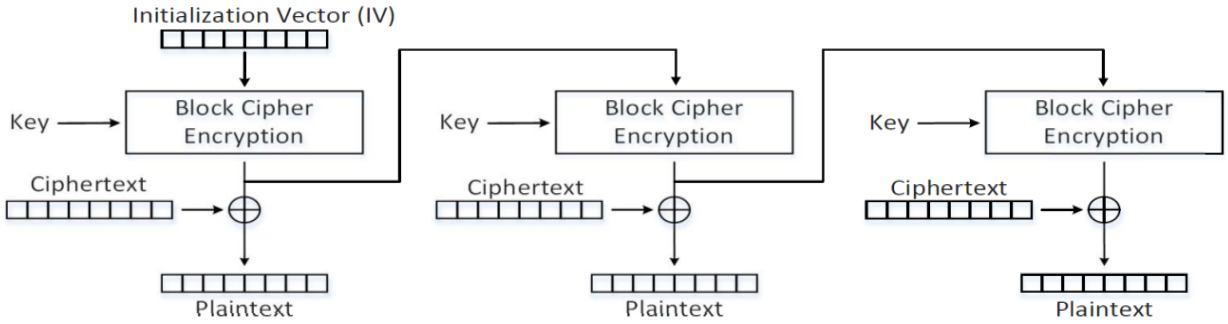
```
#encrypt
$openssl enc  -aes-128-cfb  -e -in plaintext.txt -out cfb_cipher.bin \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
#decrypt
$openssl enc  -aes-128-cfb  -d -in cfb_cipher.bin -out cfb_plain.txt \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
#valid
$diff plaintext.txt cfb_plain.txt
```

Output Feedback (OFB)

Similar to CFB, except that the data **before** *(while in CFB, it should be "after")* the XOR operation is fed into the next block.



(a) Output Feedback (OFB) mode encryption

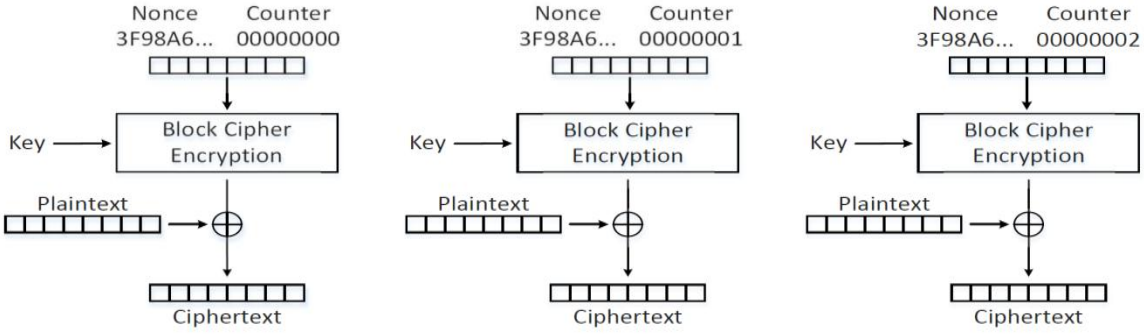


(b) Output Feedback (OFB) mode decryption

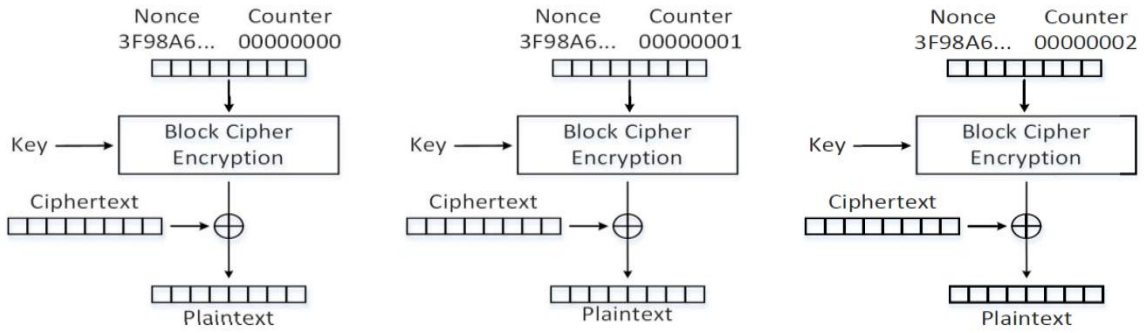
```
#encrypt
$openssl enc  -aes-128-ofb  -e -in plaintext.txt -out ofb_cipher.bin \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
#decrypt
$openssl enc  -aes-128-ofb  -d -in ofb_cipher.bin -out ofb_plain.txt \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
#valid
$diff plaintext.txt ofb_plain.txt
```

Counter (CTR)

Each block of key stream is generated by encrypting the counter value for the block. Nonce servers as IV, increased by some value (no need to be fixed to 1) as a counter.



(a) Counter (CTR) mode encryption

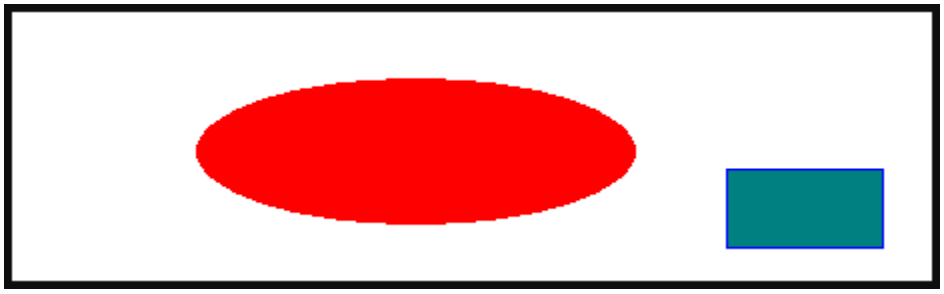


(b) Counter (CTR) mode decryption

```
#encrypt
$openssl enc  -aes-128-ctr  -e -in plaintext.txt -out ctr_cipher.bin \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
#decrypt
$openssl enc  -aes-128-ctr  -d -in ctr_cipher.bin -out ctr_plain.txt \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
#valid
$diff plaintext.txt ctr_plain.txt
```

4 Task 3: Encryption Mode – ECB vs. CBC

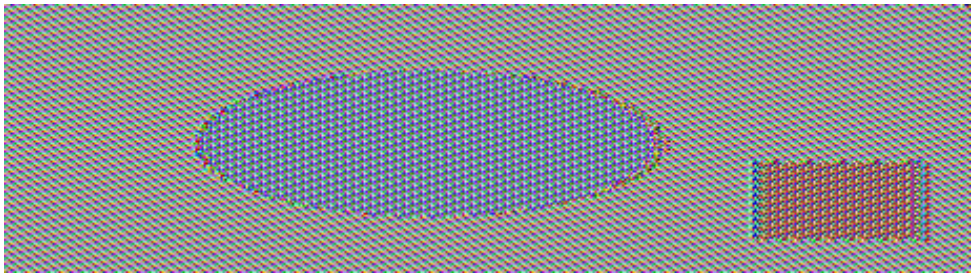
Encrypt the picture pic_original.bmp as



```
openssl enc  -aes-128-ecb  -e -in pic_original.bmp -out cipher_pic.bmp \
-K 00112233445566778889aabbccddeeff
```

Reset the header of the encrypted picture to make it open able by picture viewer:

```
head -c 54 pic_original.bmp > header
tail -c +55 cipher_pic.bmp > body
cat header body > full_cipher_pic.bmp
```



It seems similar to the original picture in some way. Because we break the file into blocks of size 128 bits, and the use AES algorithm to encrypt each block. If two blocks are the same in the original picture, they will remain identical in the encrypted one.

5 Task 4: Padding

```
echo -n "123456" > test.txt
ls -ld test.txt
openssl enc  -aes-128-ecb  -e -in test.txt -out output.bin \
-K 00112233445566778889aabbccddeeff
ls -ld output.bin
```

It shows that test.txt has 6 bytes while output.bin has 16. Padding occurs during ECB encryption.

Similar, try other modes by replacing -aes-128-ecb and adding the argument -iv

```
# cbc
openssl enc  -aes-128-cbc  -e -in test.txt -out output.bin \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
ls -ld output.bin # 16
# cfb
openssl enc  -aes-128-cfb  -e -in test.txt -out output.bin \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
ls -ld output.bin #6
# ofb
openssl enc  -aes-128-ofb  -e -in test.txt -out output.bin \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
ls -ld output.bin #6
```

CFB and OFB don't need padding. Because they take outputs of the previous block, which must be of the same size equal to cipher block size, as the inputs of its last cipher block encryption.

```
echo -n "12345" > f1.txt # 5 bytes
echo -n "123456789A" > f2.txt # 10 bytes
echo -n "0123456789ABCDEF" > f3.txt # 16 bytes
```

Encrypt 3 files with CBC mode:

```
openssl enc  -aes-128-cbc  -e -in f.txt -out output.bin \ # replace f.txt with actual plaintext
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
ls -ld output.bin
```

It shows that the output of **f3.txt** contains 32 bytes but the other 2 has 16 bytes.
The original **f1.txt**:

```
$xxd -g 1 f1.txt
00000000: 31 32 33 34 35                                  12345
```

Decrypt **output.bin** with **-nopad**:

```
openssl enc  -aes-128-cbc  -d -in output.bin -out plain_f1.txt \
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708 -nopad
```

Then the output file has 16 bytes, and:

```
$xxd -g 1 plain_f1.txt
00000000: 31 32 33 34 35 0b 0b 0b 0b 0b 0b 0b 0b 0b 0b 0b  12345...........
```

The paddings during encryption are treated as ciphertext.

6 Task 5: Error Propagation – Corrupted Cipher Text

Create a big file containing more than 1000 bytes

```
$python -c "print '1234567890'*100" > big_file.txt
$-ld big_file.txt
#1001
```

Encrypt it and then decrypt:

```
openssl enc  -aes-128-ecb  -e -in big_file.txt -out output.bin \
-K 00112233445566778889aabbccddeeff
```

Or

```
openssl enc  -aes-128-cbc  -e -in big_file.txt -out output.bin \ #replace cbc as cfb,ofb
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
```

Corrupt the 55-th(0x37) byte of output.bin as 0x00 using bless

And then decrypt it:

```
openssl enc  -aes-128-ecb  -d -in output.bin -out decrypted.txt \
-K 00112233445566778889aabbccddeeff
```

Or

```
openssl enc  -aes-128-cbc  -d -in output.bin -out decrypted.txt \ #replace cbc as cfb,ofb
-K 00112233445566778889aabbccddeeff \
-iv 0102030405060708
```

Check their differences by diff.py:

```
#!/usr/bin/python3
with open('big_file.txt', 'rb') as f:
    f1 = f.read()
with open('decrypted.txt', 'rb') as f:
    f2 = f.read()
res = 0
for i in range(min(len(f1), len(f2))):
    if f1[i] != f2[i]:
        res += 1
print("diff bytes: "+str(res+abs(len(f1)-len(f2))))
```

diff between the original files and decrypted files:

Mode	Different bytes
ECB	16
CBC	17
CFB	17
OFB	1

7 Task 6: Initial Vector (IV) and Common Mistakes

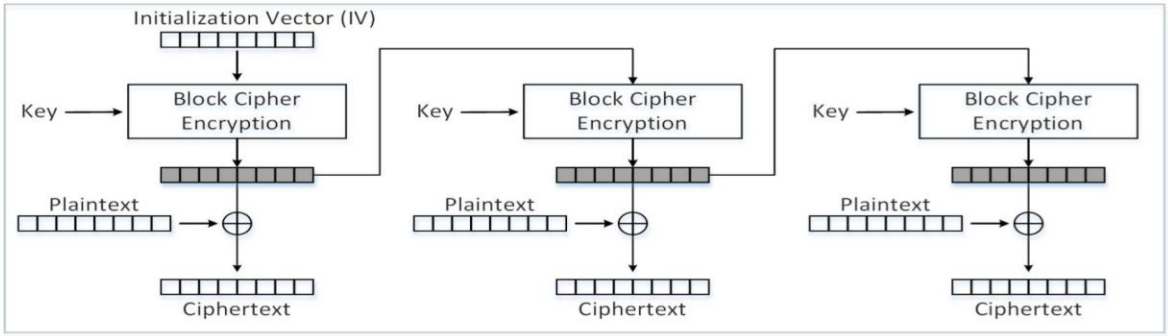
Task 6.1

When plaintexts are the same, using the same IV leads to the same ciphertext.

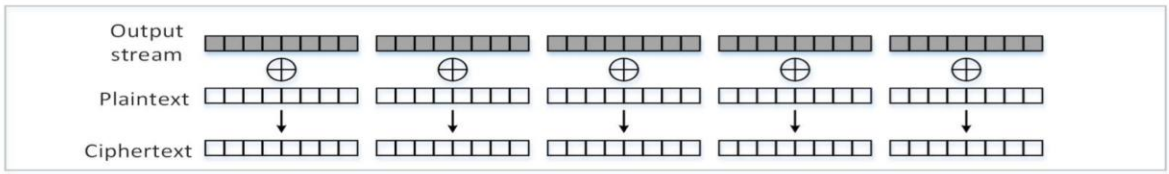
Task 6.2

For OFB mode, If the **key** and **IV** keep unchanged, *known-plaintext attack* is feasible.

Output stream can be obtained by XORing plaintext and ciphertext block by block. Similarly, to get plaintext, I can XOR plaintext and ciphertext. When sharing the same key and IV for OFB mode, the output streams are **identical** among encryptions.



(a) Output Feedback (OFB) mode encryption



(b) XOR the plaintext with the output stream

Assuming that we know a plaintext p1 and its OFB ciphertext c1,
and another OFB ciphertext c2 with the same key and IV.
But we do not know the plaintext p2 of c2, to figure about it:

First, get the output stream from the encryption of the first plaintext p1:

output_stream = p1 XOR c1

Then get p2 by:

p2 = output_stream XOR c2

Reduce it to:

p2 = p1 XOR c1 XOR c2

Use known-plaintext-attack.py:

```
#!/usr/bin/python3
from sys import argv

_, first, second, third = argv
p1 = bytearray(first,encoding='utf-8')
c1 = bytearray.fromhex(second)
c2 = bytearray.fromhex(third)
p2 = bytearray(x ^ y ^ z for x, y, z in zip(p1, c1, c2))
print(p2.decode('utf-8'))
```

On the instance of

```
Plaintext (P1): This is a known message!
Ciphertext (C1): a469b1c502c1cab966965e50425438e1bb1b5f9037a4c159
Plaintext (P2): (unknown to you)
Ciphertext (C2): bf73bcd3509299d566c35b5d450337e1bb175f903fafc159
```

```
known-plaintext-attack.py "This is a known message!" \
a469b1c502c1cab966965e50425438e1bb1b5f9037a4c159 \
bf73bcd3509299d566c35b5d450337e1bb175f903fafc159 \
```

Get P2 as "Order: Launch a missile!"

For CFB mode, as its demonstration, it is the same situation for the initial block (i.e. can get plaintext by simple XOR). However, if the key remains secret, the following parts of ciphertext will not be revealed.

Task 6.3

I guess p1 is "Yes".

So construct

P2 = "Yes" XOR IV XOR IV_NEXT

Where IV is the IV used to generate C1 and IV_NEXT is the predictable IV used to encrypt the next plaintext input.

In this case:

```
Encryption method: 128-bit AES with CBC mode.
Key (in hex): 00112233445566778899aabbccddeeff (known only to Bob)
Ciphertext (C1): bef65565572ccee2a9f9553154ed9498 (known to both)
IV used on P1 (known to both)
(in ascii): 1234567890123456
(in hex) : 31323334353637383930313233343536
Next IV (known to both)
(in ascii): 1234567890123457
(in hex) : 31323334353637383930313233343537
```

In practice, because the length of the payload is too short, which is required to padding according to PKCS#7, We have to do some subtle adoption based on known-plaintext-attack.py to create cipher_cons.py:

```
#!/usr/bin/python3
from sys import argv

_, first, second, third = argv
p1 = bytearray(first, encoding='utf-8')
padding = 16 - len(p1) % 16  # padding to match the block size as 128 bit
p1.extend([padding]*padding)
IV = bytearray.fromhex(second)
IV_NEXT = bytearray.fromhex(third)
p2 = bytearray(x ^ y ^ z for x, y, z in zip(p1, IV, IV_NEXT))
print(p2.decode('utf-8'), end='')

cipher_cons.py "Yes" 31323334353637383930313233343536 31323334353637383930313233343537 > p2
```

To get c2, query with p2:

```
openssl enc  -aes-128-cbc  -e -in p2 -out c2 \
-K 00112233445566778899aabbccddeeff \
-iv 31323334353637383930313233343537
```

Note that when the plaintext is a multiple of 16 bytes, it should be padded with another 16 bytes according to PKCS#7 for encryption. To compare with actual c1, we just need the first block of c2:

```
$xxd -p c2
bef65565572ccee2a9f9553154ed94983402de3f0dd16ce789e5475779aca405
```

Its first 16 bytes are the same as c1, therefore, the hypothesis holds:

p1 = "Yes"

Verify:

```
$echo -n "bef65565572ccee2a9f9553154ed9498" | xxd -r -p > c1
$openssl enc  -aes-128-cbc  -d -in c1 -out p1 \
-K 00112233445566778899aabbccddeeff \
-iv 31323334353637383930313233343536
$cat p2
Yes
```

8 Task 7: Programming using the Crypto Library

```
Plaintext (total 21 characters): This is a top secret.
Ciphertext (in hex format): 764aa26b55a4da654df6b19e4bce00f4
ed05e09346fb0e762583cb7da2ac93a2
IV (in hex format): aabbccddeeff00998877665544332211
```

To find out the key from words.txt, create the crack_key.py as:

```
#!/usr/bin/python3
from sys import argv
from Crypto.Cipher import AES
from Crypto.Util.Padding import pad

_, first, second, third = argv

assert len(first) == 21
data = bytearray(first, encoding='utf-8')
ciphertext = bytearray.fromhex(second)
iv = bytearray.fromhex(third)

with open('./words.txt') as f:
    keys = f.readlines()

for k in keys:
    k = k.rstrip('\n')
    if len(k) <= 16:
        key = k + '#'*(16-len(k))
        cipher = AES.new(key=bytearray(key,encoding='utf-8'), mode=AES.MODE_CBC, iv=iv)
        guess = cipher.encrypt(pad(data, 16))
        if guess == ciphertext:
            print("find the key:",key)
            exit(0)

print("cannot find the key!")
```

Then use it:

```
crack_key.py "This is a top secret." \
764aa26b55a4da654df6b19e4bce00f4ed05e09346fb0e762583cb7da2ac93a2 \
aabbccddeeff00998877665544332211
```

Finally, find the key:

```
find the key: Syracuse########
```