Report on Encryption and Decryption in Python (DES Manual)

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Subject: Implementation of Manual DES in Python
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Example.No: Task3

Introduction

The Data Encryption Standard (DES) is a symmetric-key block cipher that encrypts and decrypts data in 64-bit blocks using a 56-bit key. This report explains the complete DES encryption process, including key generation, initial permutation, 16 Feistel rounds, and the production of the final ciphertext. Furthermore, it describes how the DES decryption method is used to convert ciphertext back into plaintext by using the same key and reversing the encryption process. The code follows the official DES standard, utilizing predefined permutation tables (IP, FP, E, P, PC-1, PC-2) and S-boxes, along with custom-written functions for implementing DES manually.

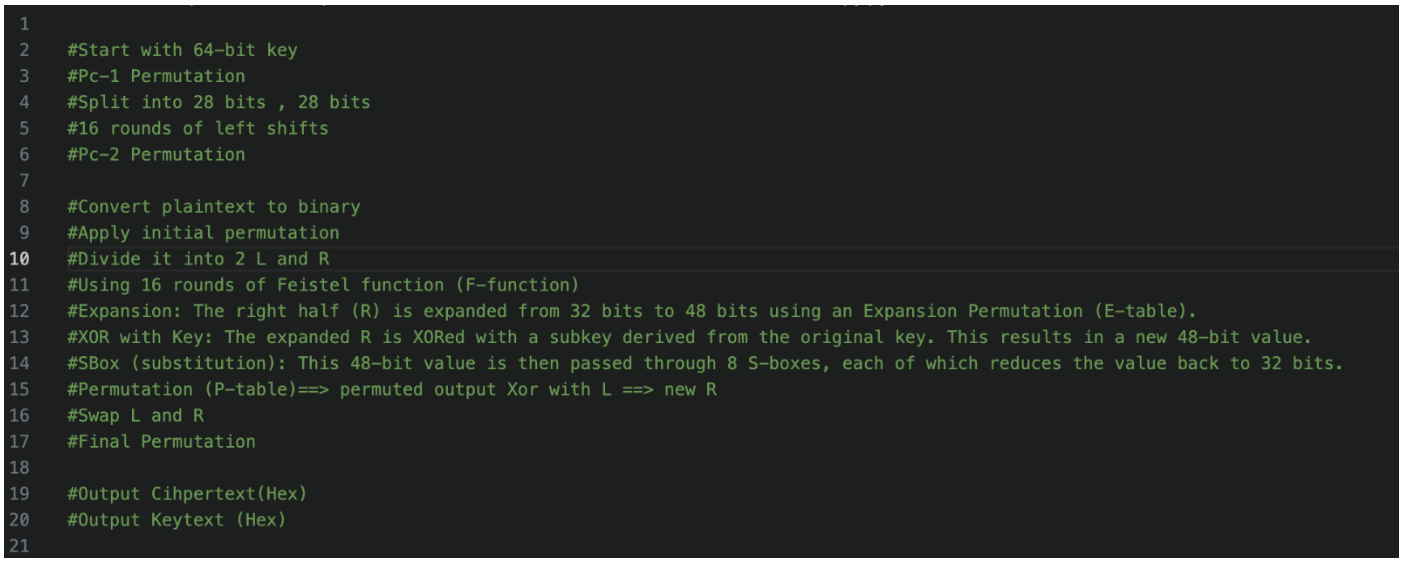
Overview

The Data Encryption Standard (DES) operates through 3 main phases:

1. Key scheduling: Generates a 48-bit key from the original 64-bit key

2. Data Encryption: Processes the plaintext through initial permutation, 16 Feistel rounds, Final permutation, and Outputs ciphertext and key in hexadecimal format

3. Data Decryption: Processes the ciphertext by reversing encryption using the same key and outputs decrypted text in the original format



```

#Start with 64-bit key
#Pc-1 Permutation
#Split into 28 bits , 28 bits
#16 rounds of left shifts
#Pc-2 Permutation

#Convert plaintext to binary
#Apply initial permutation
#Divide it into 2 L and R
#Using 16 rounds of Feistel function (F-function)
#Expansion: The right half (R) is expanded from 32 bits to 48 bits using an Expansion Permutation (E-table).
#XOR with Key: The expanded R is XORed with a subkey derived from the original key. This results in a new 48-bit value.
#SBox (substitution): This 48-bit value is then passed through 8 S-boxes, each of which reduces the value back to 32 bits.
#Permutation (P-table)==> permuted output Xor with L ==> new R
#Swap L and R
#Final Permutation

#Output Cihpertext(Hex)
#Output Keytext (Hex)

```

Figure 1- Code Overview

Step-by-Step DES Encryption Process

1. Key Generation

The encryption process in DES starts with key generation. Although a 64-bit key is initially provided, only 56 bits are used for encryption, as every eighth bit is reserved for parity checking and thus discarded. The remaining 56-bit key is permuted using the Permuted Choice 1 (PC-1) table, which rearranges the bits according to a predefined pattern. The permuted key is then split into two 28-bit halves. Throughout 16 encryption rounds, these halves undergo a series of left circular shifts. After each shift, the halves are combined and processed through the Permuted Choice 2 (PC-2) table to produce a distinct 48-bit subkey for each round.

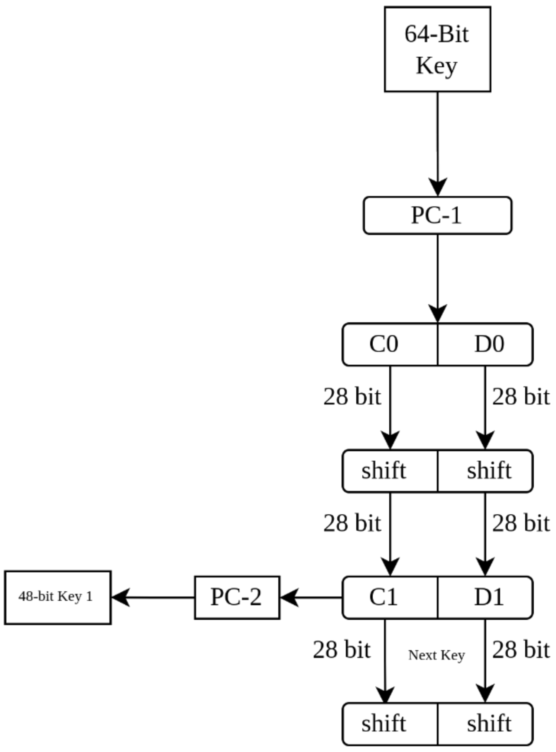
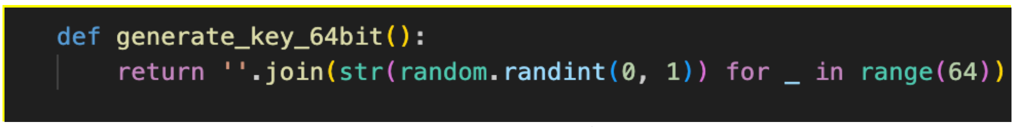


Figure 2 - Key Generation Process

1.1. Starting with a 64-bit key

First, the random library is utilized to generate a random key that serves as the input for the DES encryption process.

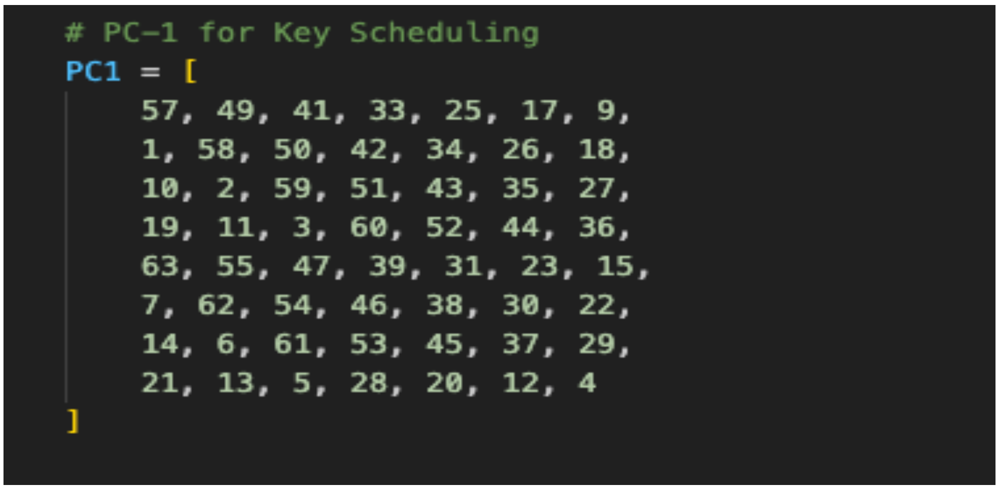


```
def generate_key_64bit():
    return ''.join(str(random.randint(0, 1)) for _ in range(64))
```

Figure 3 - Using Random Library for generating a key

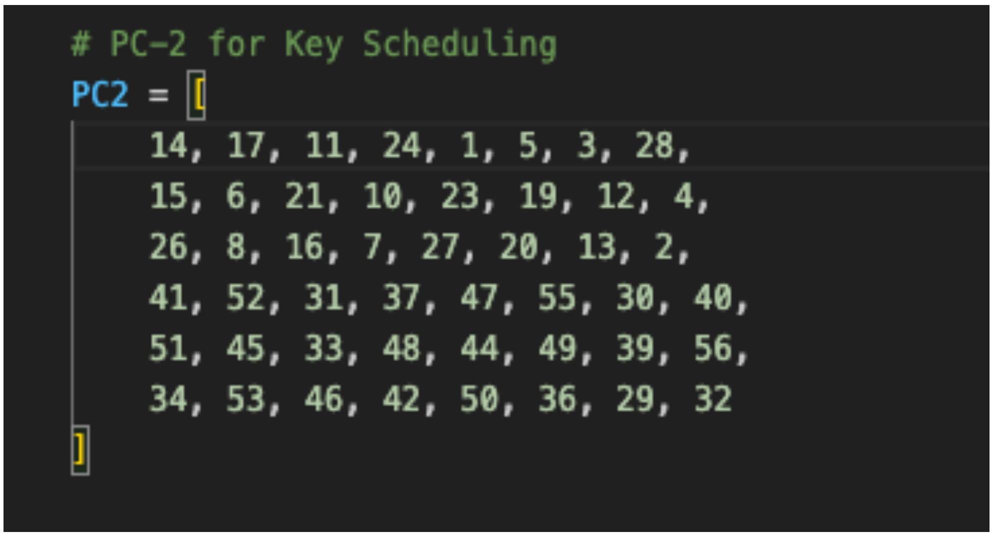
1.2 Generating Subkeys

Sixteen subkeys are generated, each 48 bits in length, to be used in the 16 rounds of DES encryption. These subkeys are derived from the original 56-bit key through a series of bit shifts and permutations using the **PC-1** and **PC-2** tables. First, a shift table is defined to specify how many left shifts should be applied in each round (Figure 6). A left shift function is then used to perform circular left shifts on the two 28-bit halves of the key. After each shift, the halves are combined and processed using the Permuted Choice 2 (PC-2) table to produce a 48-bit subkey.A detailed explanation of how subkeys are generated using these steps is provided below.



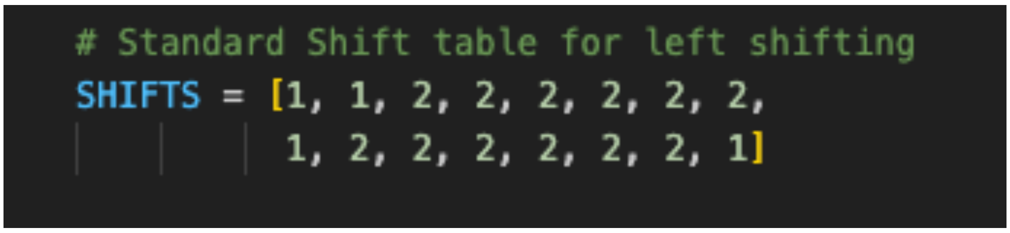
```
# PC-1 for Key Scheduling
PC1 = [
    57, 49, 41, 33, 25, 17, 9,
    1, 58, 50, 42, 34, 26, 18,
    10, 2, 59, 51, 43, 35, 27,
    19, 11, 3, 60, 52, 44, 36,
    63, 55, 47, 39, 31, 23, 15,
    7, 62, 54, 46, 38, 30, 22,
    14, 6, 61, 53, 45, 37, 29,
    21, 13, 5, 28, 20, 12, 4
]
```

Figure 4- Adding the PC-1 Table



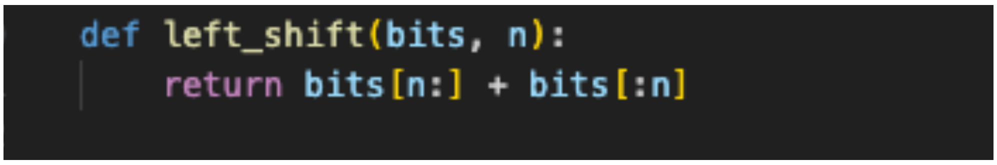
```python
# PC-2 for Key Scheduling
PC2 = [
    14, 17, 11, 24, 1, 5, 3, 28,
    15, 6, 21, 10, 23, 19, 12, 4,
    26, 8, 16, 7, 27, 20, 13, 2,
    41, 52, 31, 37, 47, 55, 30, 40,
    51, 45, 33, 48, 44, 49, 39, 56,
    34, 53, 46, 42, 50, 36, 29, 32
]
```

Figure 5- Adding the PC-2 Table



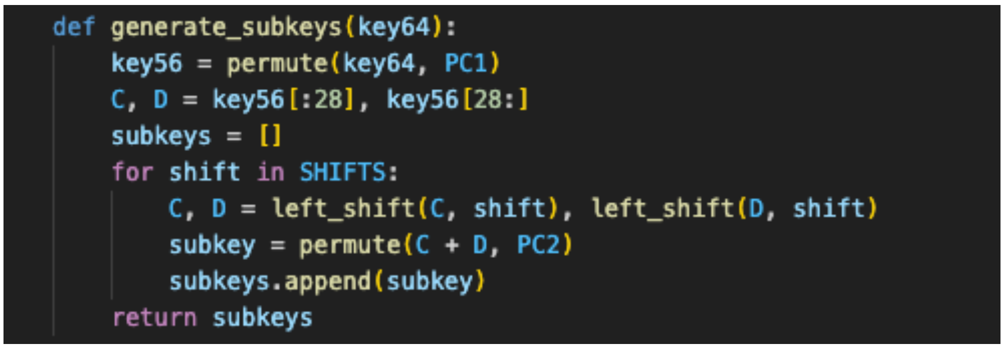
```python
# Standard Shift table for left shifting
SHIFTS = [1, 1, 2, 2, 2, 2, 2, 2,
          1, 2, 2, 2, 2, 2, 2, 1]
```

Figure 6- Adding the Shift Table



```python
def left_shift(bits, n):
    return bits[n:] + bits[:n]
```

Figure 7- Left shift function for splitting bits



```python
def generate_subkeys(key64):
    key56 = permute(key64, PC1)
    C, D = key56[:28], key56[28:]
    subkeys = []
    for shift in SHIFTS:
        C, D = left_shift(C, shift), left_shift(D, shift)
        subkey = permute(C + D, PC2)
        subkeys.append(subkey)
    return subkeys
```

Figure 8- Generating Subkeys

- **PC-1 Permutation (64-bit to 56-bit)**
  The original 64-bit key is processed through the **Permuted Choice 1 (PC-1)** table, which discards 8 bits (parity bits) and reduces the key to 56 bits.

- **Split into C and D**
  The 56-bit key is divided into two 28-bit halves:
  - **C**: The left 28 bits
  - **D**: The right 28 bits
- **Left Shift Function**
  A left shift function is applied to both halves (C and D). This function shifts the bits in a circular manner to prepare them for further processing.
- **16 Rounds of Left Shifts**
  Over the course of 16 rounds, the two halves undergo left shifts. The shift amounts are based on a predefined **shift table**:
  - **Rounds 1, 2, 9, 15**: Each shift is by **1 bit**
  - **Other rounds**: Each shift is by **2 bits**
- **PC-2 Permutation (64-bit to 48-bit Subkey)**
  After the left shifts, the two halves are combined and processed through the **Permuted Choice 2 (PC-2)** table. This step reduces the combined 56-bit key into a 48-bit subkey for each round.
- **Adding Generated Subkeys to the List**
  The 48-bit subkeys generated in each round are added to a list, and these subkeys will be used in the 16 rounds of DES encryption.

2. DES Encryption

Now that the subkeys are generated, we proceed with the DES encryption process. This involves block processing, Feistel rounds, and ciphertext conversion.

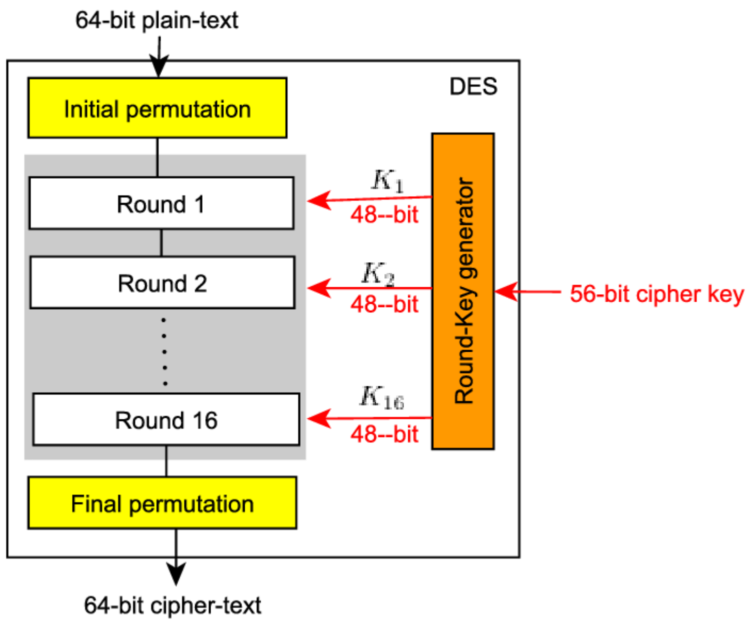
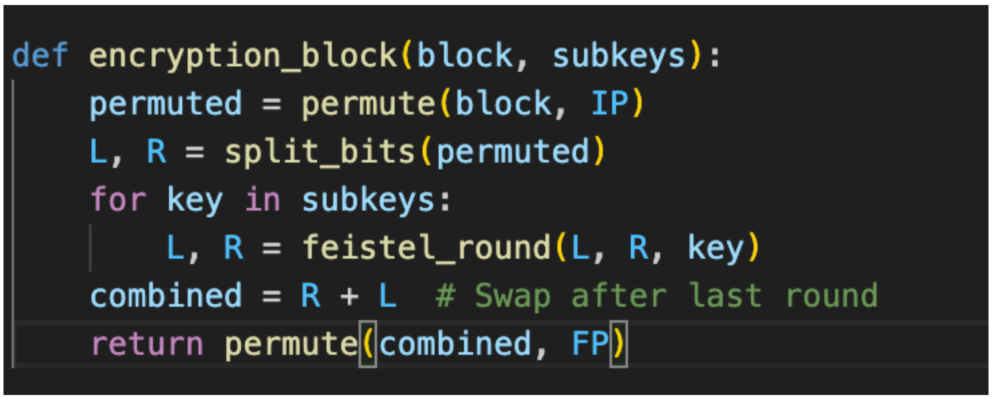


Figure 9- DES Encryption Process

2.1 Block Encryption

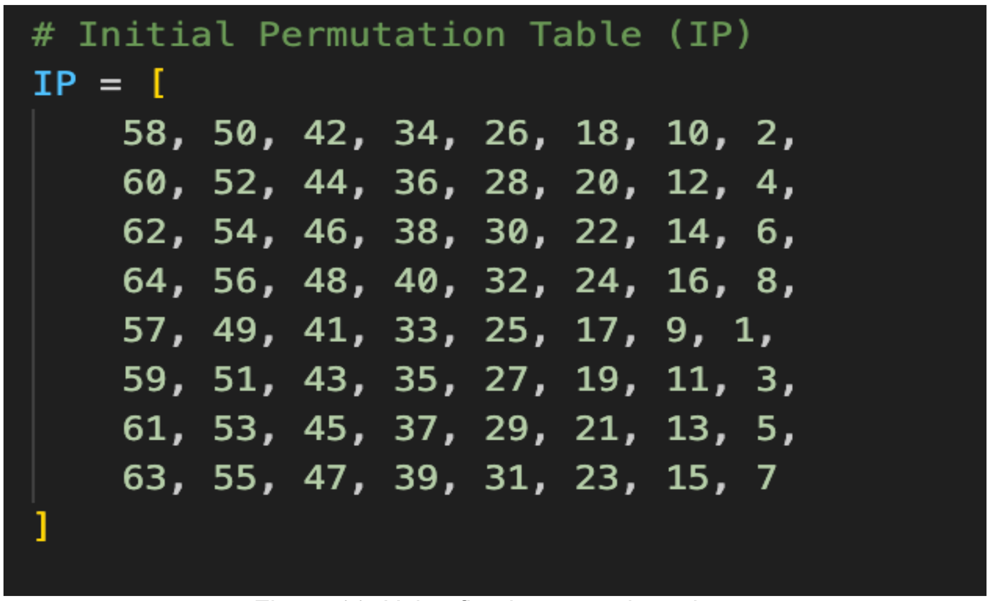
The core of the DES operates on 64-bit blocks of plaintext. The encryption process consists of multiple stages, starting with an initial permutation and proceeding through 16 Feistel rounds, ultimately producing a 64-bit ciphertext. The core of DES will work on 64-bit blocks. The following steps are added to the code, as can be seen in the following pictures:



```python
def encryption_block(block, subkeys):
    permuted = permute(block, IP)
    L, R = split_bits(permuted)
    for key in subkeys:
        L, R = feistel_round(L, R, key)
    combined = R + L  # Swap after last round
    return permute(combined, FP)
```

Figure 10- Block Encryption

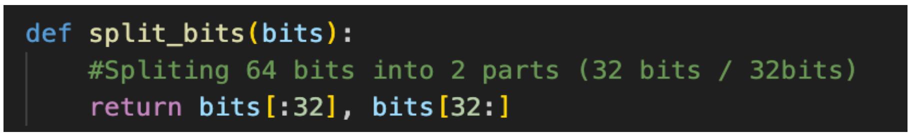
2.1.1 Initial Permutation (IP)



```python
# Initial Permutation Table (IP)
IP = [
    58, 50, 42, 34, 26, 18, 10, 2,
    60, 52, 44, 36, 28, 20, 12, 4,
    62, 54, 46, 38, 30, 22, 14, 6,
    64, 56, 48, 40, 32, 24, 16, 8,
    57, 49, 41, 33, 25, 17, 9, 1,
    59, 51, 43, 35, 27, 19, 11, 3,
    61, 53, 45, 37, 29, 21, 13, 5,
    63, 55, 47, 39, 31, 23, 15, 7
]
```

Figure 11- Using fixed permutation table

2.1.2 Splitting into L and R 32-bit halves

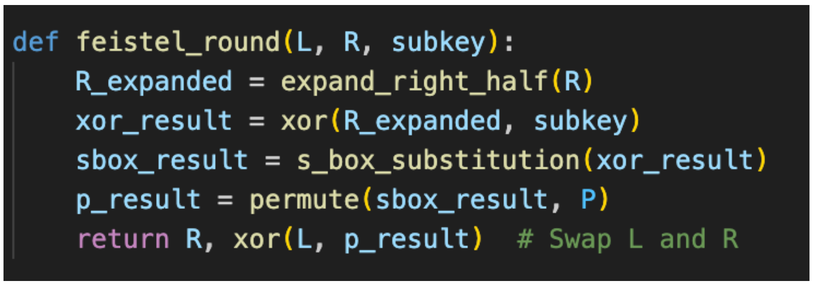


```python
def split_bits(bits):
    #Spliting 64 bits into 2 parts (32 bits / 32bits)
    return bits[:32], bits[32:]
```

Figure 12- L and R 32-bit halves

2.1.3 Feistel Round Function: which will be run 16 times

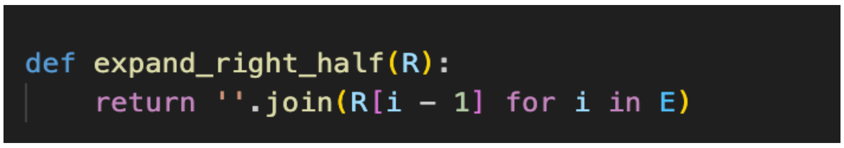
The Feistel function is applied for 16 rounds, each consisting of the following steps:



```
def feistel_round(L, R, subkey):
    R_expanded = expand_right_half(R)
    xor_result = xor(R_expanded, subkey)
    sbox_result = s_box_substitution(xor_result)
    p_result = permute(sbox_result, P)
    return R, xor(L, p_result)  # Swap L and R
```

Figure 13- Feistel Round Function

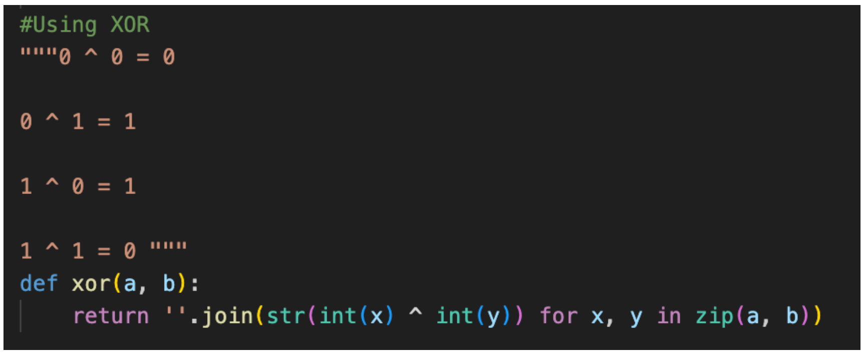
a) The 32-bit right half is expanded to 48 bits using the E table.



```
def expand_right_half(R):
    return ''.join(R[i - 1] for i in E)
```

Figure 13a- Expansion

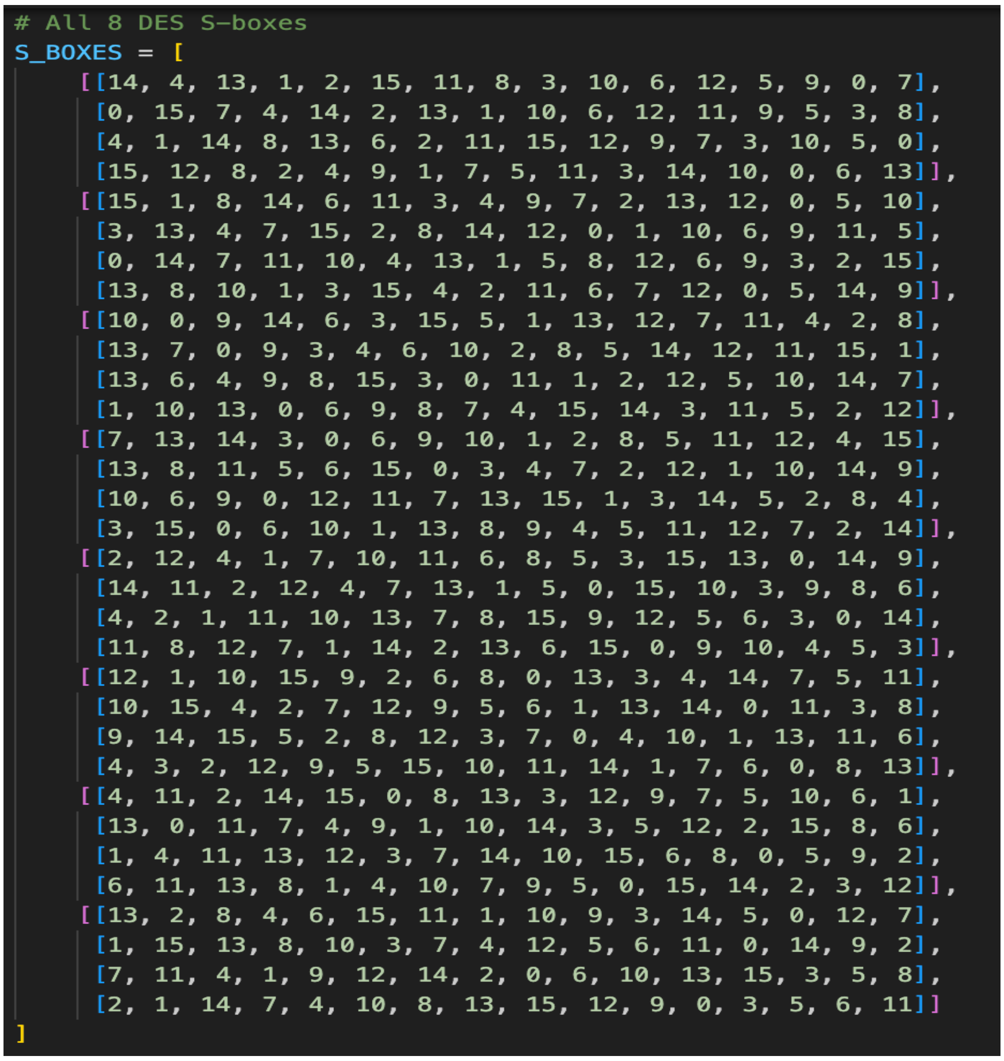
b) Align R size (48-bit) with the 48-bit subkey for XOR operation.



```
#Using XOR
"""0 ^ 0 = 0

0 ^ 1 = 1

1 ^ 0 = 1

1 ^ 1 = 0 """
def xor(a, b):
    return ''.join(str(int(x) ^ int(y)) for x, y in zip(a, b))
```

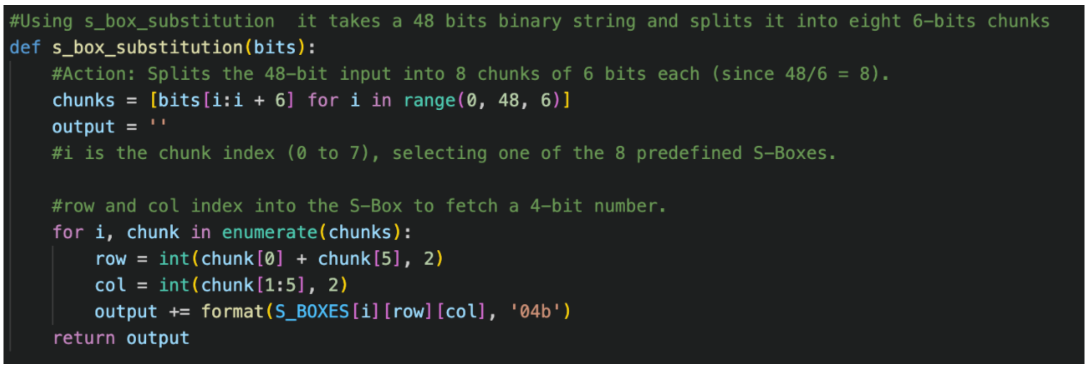
Figure 13b- Using XOR

c) S-BOX substitution



```python
# All 8 DES S-boxes
S_BOXES = [
    [[14, 4, 13, 1, 2, 15, 11, 8, 3, 10, 6, 12, 5, 9, 0, 7],
     [0, 15, 7, 4, 14, 2, 13, 1, 10, 6, 12, 11, 9, 5, 3, 8],
     [4, 1, 14, 8, 13, 6, 2, 11, 15, 12, 9, 7, 3, 10, 5, 0],
     [15, 12, 8, 2, 4, 9, 1, 7, 5, 11, 3, 14, 10, 0, 6, 13]],
    [[15, 1, 8, 14, 6, 11, 3, 4, 9, 7, 2, 13, 12, 0, 5, 10],
     [3, 13, 4, 7, 15, 2, 8, 14, 12, 0, 1, 10, 6, 9, 11, 5],
     [0, 14, 7, 11, 10, 4, 13, 1, 5, 8, 12, 6, 9, 3, 2, 15],
     [13, 8, 10, 1, 3, 15, 4, 2, 11, 6, 7, 12, 0, 5, 14, 9]],
    [[10, 0, 9, 14, 6, 3, 15, 5, 1, 13, 12, 7, 11, 4, 2, 8],
     [13, 7, 0, 9, 3, 4, 6, 10, 2, 8, 5, 14, 12, 11, 15, 1],
     [13, 6, 4, 9, 8, 15, 3, 0, 11, 1, 2, 12, 5, 10, 14, 7],
     [1, 10, 13, 0, 6, 9, 8, 7, 4, 15, 14, 3, 11, 5, 2, 12]],
    [[7, 13, 14, 3, 0, 6, 9, 10, 1, 2, 8, 5, 11, 12, 4, 15],
     [13, 8, 11, 5, 6, 15, 0, 3, 4, 7, 2, 12, 1, 10, 14, 9],
     [10, 6, 9, 0, 12, 11, 7, 13, 15, 1, 3, 14, 5, 2, 8, 4],
     [3, 15, 0, 6, 10, 1, 13, 8, 9, 4, 5, 11, 12, 7, 2, 14]],
    [[2, 12, 4, 1, 7, 10, 11, 6, 8, 5, 3, 15, 13, 0, 14, 9],
     [14, 11, 2, 12, 4, 7, 13, 1, 5, 0, 15, 10, 3, 9, 8, 6],
     [4, 2, 1, 11, 10, 13, 7, 8, 15, 9, 12, 5, 6, 3, 0, 14],
     [11, 8, 12, 7, 1, 14, 2, 13, 6, 15, 0, 9, 10, 4, 5, 3]],
    [[12, 1, 10, 15, 9, 2, 6, 8, 0, 13, 3, 4, 14, 7, 5, 11],
     [10, 15, 4, 2, 7, 12, 9, 5, 6, 1, 13, 14, 0, 11, 3, 8],
     [9, 14, 15, 5, 2, 8, 12, 3, 7, 0, 4, 10, 1, 13, 11, 6],
     [4, 3, 2, 12, 9, 5, 15, 10, 11, 14, 1, 7, 6, 0, 8, 13]],
    [[4, 11, 2, 14, 15, 0, 8, 13, 3, 12, 9, 7, 5, 10, 6, 1],
     [13, 0, 11, 7, 4, 9, 1, 10, 14, 3, 5, 12, 2, 15, 8, 6],
     [1, 4, 11, 13, 12, 3, 7, 14, 10, 15, 6, 8, 0, 5, 9, 2],
     [6, 11, 13, 8, 1, 4, 10, 7, 9, 5, 0, 15, 14, 2, 3, 12]],
    [[13, 2, 8, 4, 6, 15, 11, 1, 10, 9, 3, 14, 5, 0, 12, 7],
     [1, 15, 13, 8, 10, 3, 7, 4, 12, 5, 6, 11, 0, 14, 9, 2],
     [7, 11, 4, 1, 9, 12, 14, 2, 0, 6, 10, 13, 15, 3, 5, 8],
     [2, 1, 14, 7, 4, 10, 8, 13, 15, 12, 9, 0, 3, 5, 6, 11]]
]
```

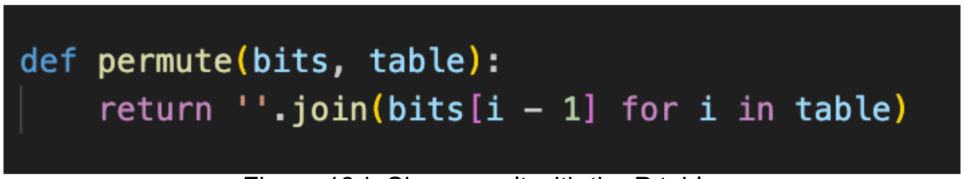
Figure 13c- Defining S-BOX substitution Table



```python
#Using s_box_substitution  it takes a 48 bits binary string and splits it into eight 6-bits chunks
def s_box_substitution(bits):
    #Action: Splits the 48-bit input into 8 chunks of 6 bits each (since 48/6 = 8).
    chunks = [bits[i:i + 6] for i in range(0, 48, 6)]
    output = ''
    #i is the chunk index (0 to 7), selecting one of the 8 predefined S-Boxes.

    #row and col index into the S-Box to fetch a 4-bit number.
    for i, chunk in enumerate(chunks):
        row = int(chunk[0] + chunk[5], 2)
        col = int(chunk[1:5], 2)
        output += format(S_BOXES[i][row][col], '04b')
    return output
```

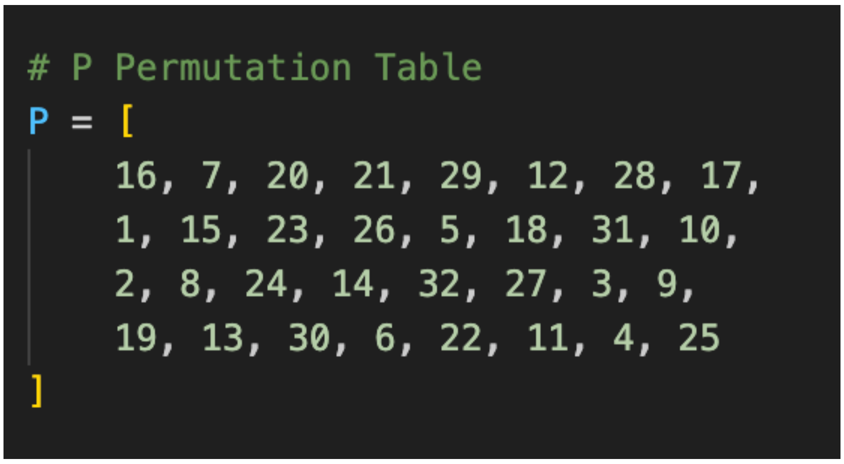
Figure 13c- S-BOX substitution Function

d) Permuting the Sbox_result with the P table



```python
def permute(bits, table):
    return ''.join(bits[i - 1] for i in table)
```

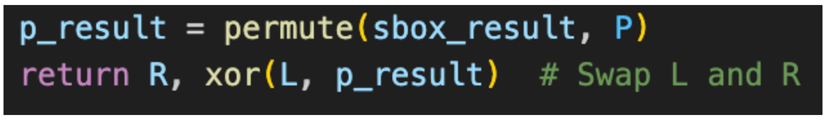
Figure 13d- Sbox_result with the P table



```python
# P Permutation Table
P = [
    16, 7, 20, 21, 29, 12, 28, 17,
    1, 15, 23, 26, 5, 18, 31, 10,
    2, 8, 24, 14, 32, 27, 3, 9,
    19, 13, 30, 6, 22, 11, 4, 25
]
```

Figure 13d- Sbox_result with the P table

e) The left half (L) is XORed with p_result

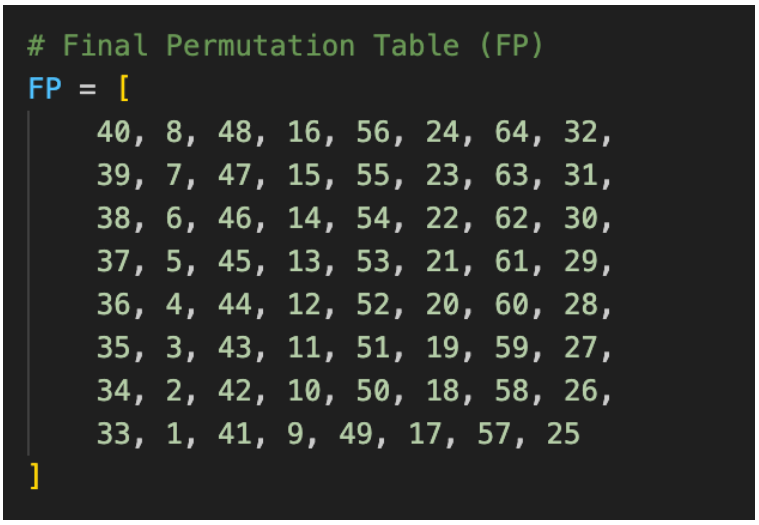


```python
p_result = permute(sbox_result, P)
return R, xor(L, p_result)  # Swap L and R
```

Figure 13e- XORed with p_result

f) The halves are swapped: (L, R)

2.1.4 Swap After the last round and Final Swap with the FP table

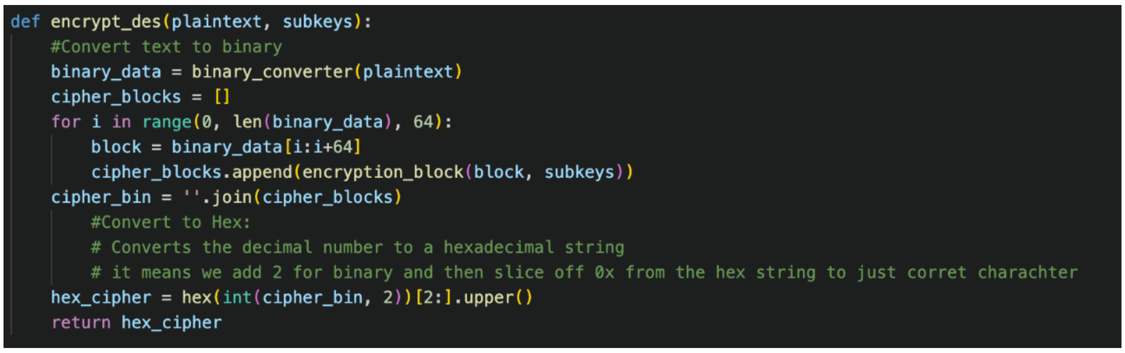


```python
# Final Permutation Table (FP)
FP = [
    40, 8, 48, 16, 56, 24, 64, 32,
    39, 7, 47, 15, 55, 23, 63, 31,
    38, 6, 46, 14, 54, 22, 62, 30,
    37, 5, 45, 13, 53, 21, 61, 29,
    36, 4, 44, 12, 52, 20, 60, 28,
    35, 3, 43, 11, 51, 19, 59, 27,
    34, 2, 42, 10, 50, 18, 58, 26,
    33, 1, 41, 9, 49, 17, 57, 25
]
```

Figure 14- Final Permutation Table (FP)

2.2 Full DES Encryption Process

The block encryption is applied to the entire plaintext after conversion to binary. The following steps are used to perform this process:

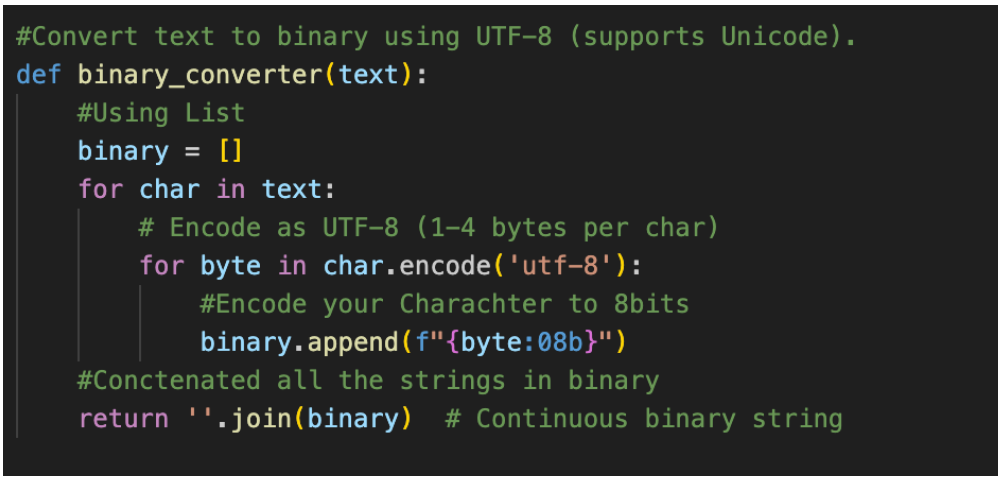


```python
def encrypt_des(plaintext, subkeys):
    #Convert text to binary
    binary_data = binary_converter(plaintext)
    cipher_blocks = []
    for i in range(0, len(binary_data), 64):
        block = binary_data[i:i+64]
        cipher_blocks.append(encryption_block(block, subkeys))
    cipher_bin = ''.join(cipher_blocks)
        #Convert to Hex:
        # Converts the decimal number to a hexadecimal string
        # it means we add 2 for binary and then slice off 0x from the hex string to just corret charachter
    hex_cipher = hex(int(cipher_bin, 2))[2:].upper()
    return hex_cipher
```

Figure 15- DES Encryption

2.2.1 Binary Conversion

The plain text is encoded into UTF-8 and converted to a binary string.



```python
#Convert text to binary using UTF-8 (supports Unicode).
def binary_converter(text):
    #Using List
    binary = []
    for char in text:
        # Encode as UTF-8 (1-4 bytes per char)
        for byte in char.encode('utf-8'):
            #Encode your Charachter to 8bits
            binary.append(f"{byte:08b}")
    #Conctenated all the strings in binary
    return ''.join(binary)  # Continuous binary string
```

Figure 16- Binary Conversion

2.2.2 Block Process

The binary data is split into 64-bit blocks, and the encryption_block() function will be run here.

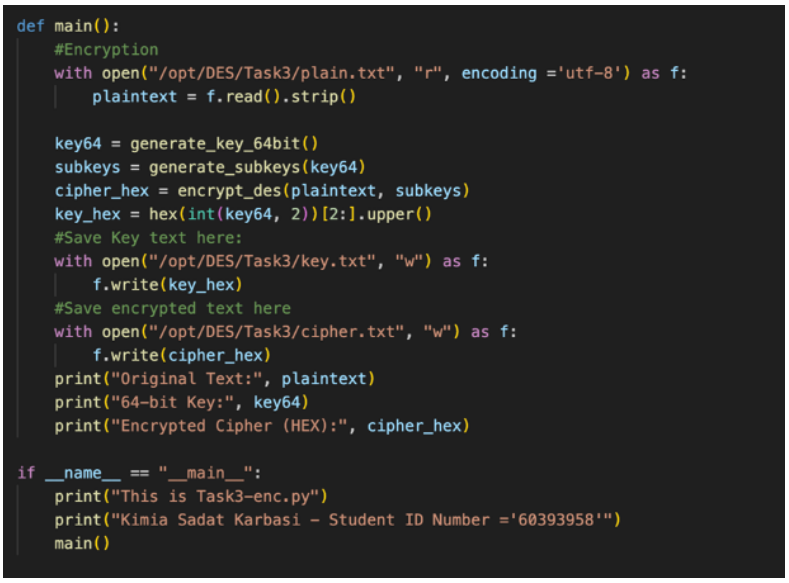
2.2.3 Hexadecimal Output

The ciphertext binary string is converted to hexadecimal

2.3 Output

This phase handles the final steps of the DES encryption process, saving the generated key and ciphertext to files and displaying the results for verification.

The detailed steps are explained below:



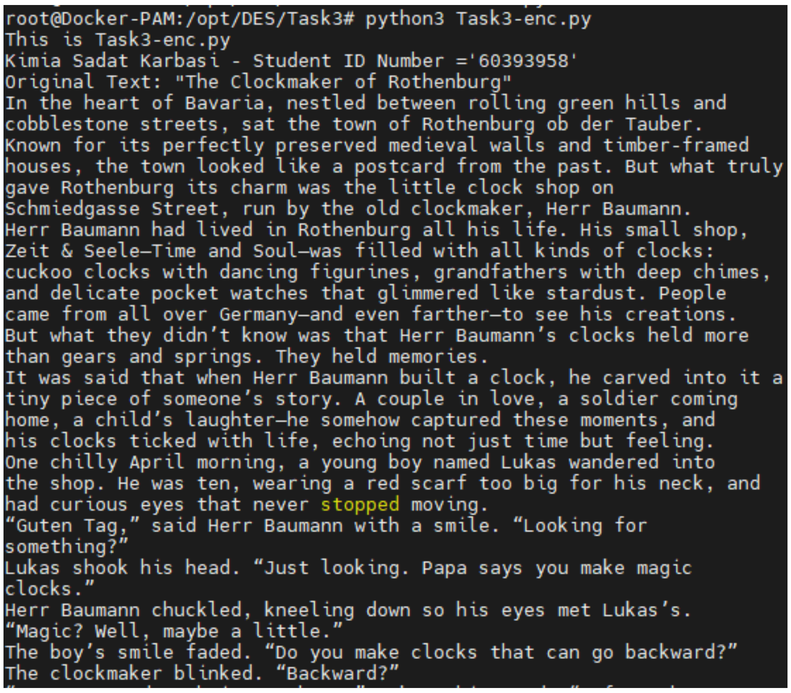
```
def main():
    #Encryption
    with open("/opt/DES/Task3/plain.txt", "r", encoding ='utf-8') as f:
        plaintext = f.read().strip()

    key64 = generate_key_64bit()
    subkeys = generate_subkeys(key64)
    cipher_hex = encrypt_des(plaintext, subkeys)
    key_hex = hex(int(key64, 2))[2:].upper()
    #Save Key text here:
    with open("/opt/DES/Task3/key.txt", "w") as f:
        f.write(key_hex)
    #Save encrypted text here
    with open("/opt/DES/Task3/cipher.txt", "w") as f:
        f.write(cipher_hex)
    print("Original Text:", plaintext)
    print("64-bit Key:", key64)
    print("Encrypted Cipher (HEX):", cipher_hex)

if __name__ == "__main__":
    print("This is Task3-enc.py")
    print("Kimia Sadat Karbasi - Student ID Number ='60393958'")
    main()
```

Figure 17- Encryption Final Steps

- Reading the Plaintext ()
- Key Generation: A 64-bit key is randomly generated
- Subkey Generation: The 64-bit key is expanded into 16 subkeys
- Encryption: The plaintext is encrypted using encrypt_des()
- Saving Outputs: The 64-bit key and encrypted result are saved into the defined path
- Console Output: Display the original text, 64-bit key, and ciphertext

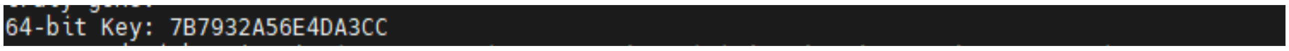
2.4 Execution and Results

Here are all the encryption code screenshots which were executed on a Linux machine. Each Picture has caption that indicates the corresponding step in DES encryption process.



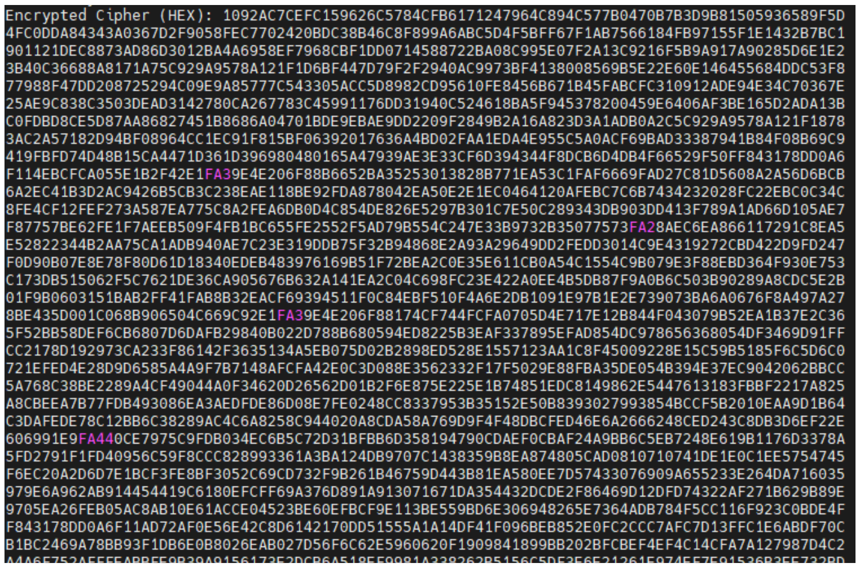
```
root@Docker-PAM:/opt/DES/Task3# python3 Task3-enc.py
This is Task3-enc.py
Kimia Sadat Karbasi - Student ID Number ='60393958'
Original Text: "The Clockmaker of Rothenburg"
In the heart of Bavaria, nestled between rolling green hills and
cobblestone streets, sat the town of Rothenburg ob der Tauber.
Known for its perfectly preserved medieval walls and timber-framed
houses, the town looked like a postcard from the past. But what truly
gave Rothenburg its charm was the little clock shop on
Schmiedgasse Street, run by the old clockmaker, Herr Baumann.
Herr Baumann had lived in Rothenburg all his life. His small shop,
Zeit & Seele—Time and Soul—was filled with all kinds of clocks:
cuckoo clocks with dancing figurines, grandfathers with deep chimes,
and delicate pocket watches that glimmered like stardust. People
came from all over Germany—and even farther—to see his creations.
But what they didn’t know was that Herr Baumann’s clocks held more
than gears and springs. They held memories.
It was said that when Herr Baumann built a clock, he carved into it a
tiny piece of someone’s story. A couple in love, a soldier coming
home, a child’s laughter—he somehow captured these moments, and
his clocks ticked with life, echoing not just time but feeling.
One chilly April morning, a young boy named Lukas wandered into
the shop. He was ten, wearing a red scarf too big for his neck, and
had curious eyes that never stopped moving.
“Guten Tag,” said Herr Baumann with a smile. “Looking for
something?”
Lukas shook his head. “Just looking. Papa says you make magic
clocks.”
Herr Baumann chuckled, kneeling down so his eyes met Lukas’s.
“Magic? Well, maybe a little.”
The boy’s smile faded. “Do you make clocks that can go backward?”
The clockmaker blinked. “Backward?”
```

Figure 18 - Plaintext



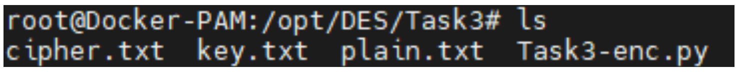
```
64-bit Key: 7B7932A56E4DA3CC
```

Figure 19 - bit Key (Hex Format)



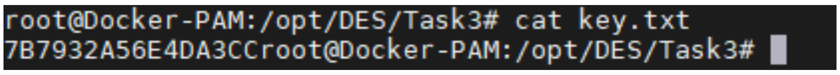
```
Encrypted Cipher (HEX): 1092AC7CEFC159626C5784CFB6171247964C894C577B0470B7B3D9B81505936589F5D
4FC0DDA84343A0367D2F9058FEC7702420BDC38B46C8F899A6ABC5D4F5BFF67F1AB7566184FB97155F1E1432B7BC1
901121DEC8873AD86D3012BA4A6958EF7968CBF1DD0714588722BA08C995E07F2A13C9216F5B9A917A90285D6E1E2
3B40C36688A8171A75C929A9578A121F1D6BF447D79F2F2940AC9973BF4138008569B5E22E60E146455684DDC53F8
77988F47DD208725294C09E9A85777C543305ACC5D8982CD95610FE8456B671B45FABCFC310912ADE94E34C70367E
25AE9C838C3503DEAD3142780CA267783C45991176DD31940C524618BA5F945378200459E6406AF3BE165D2ADA13B
C0FDBD8CE5D87AA86827451B8686A04701BDE9EBAE9DD2209F2849B2A16A823D3A1ADB0A2C5C929A9578A121F1878
3AC2A57182D94BF08964CC1EC91F815BF06392017636A4BD02FAA1EDA4E955C5A0ACF69BAD33387941B84F08B69C9
419FBFD74D48B15CA4471D361D396980480165A47939AE3E33CF6D394344F8DCB6D4DB4F66529F50FF843178DD0A6
F114EBCFCA055E1B2F42E1FA39E4E206F88B6652BA35253013828B771EA53C1FAF6669FAD27C81D5608A2A56D6BCB
6A2EC41B3D2AC9426B5CB3C238EAE118BE92FDA878042EA50E2E1EC0464120AFEBC7C6B7434232028FC22EBC0C34C
8FE4CF12FEF273A587EA775C8A2FEA6DB0D4C854DE826E5297B301C7E50C289343DB903DD413F789A1AD66D105AE7
F87757BE62FE1F7AEEB509F4FB1BC655FE2552F5AD79B554C247E33B9732B35077573FA28AEC6EA866117291C8EA5
E52822344B2AA75CA1ADB940AE7C23E319DDB75F32B94868E2A93A29649DD2FEDD3014C9E4319272CBD422D9FD247
F0D90B07E8E78F80D61D18340EDEB483976169B51F72BEA2C0E35E611CB0A54C1554C9B079E3F88EBD364F930E753
C173DB515062F5C7621DE36CA905676B632A141EA2C04C698FC23E422A0EE4B5DB87F9A0B6C503B90289A8CDC5E2B
01F9B0603151BAB2FF41FAB8B32EACF69394511F0C84EBF510F4A6E2DB1091E97B1E2E739073BA6A0676F8A497A27
8BE435D001C068B906504C669C92E1FA39E4E206F88174CF744FCFA0705D4E717E12B844F043079B52EA1B37E2C36
5F52BB58DEF6CB6807D6DAFB29840B022D788B680594ED8225B3EAF337895EFAD854DC97865636805 4DF3469D91FF
CC2178D192973CA233F86142F3635134A5EB075D02B2898ED528E1557123AA1C8F45009228E15C59B5185F6C5D6C0
721EFED4E28D9D6585A4A9F7B7148AFCFA42E0C3D088E3562332F17F5029E88FBA35DE054B394E37EC9042062BBCC
5A768C38BE2289A4CF49044A0F34620D26562D01B2F6E875E225E1B74851EDC8149862E5447613183FBBF2217A825
A8CBEEA7B77FDB493086EA3AEDFDE86D08E7FE0248CC8337953B35152E50B8393027993854BCCF5B2010EAA9D1B64
C3DAFEDE78C12BB6C38289AC4C6A8258C944020A8CDA58A769D9F4F48DBCFED46E6A2666248CED243C8DB3D6EF22E
606991E9FA440CE7975C9FDB034EC6B5C72D31BFBB6D358194790CDAEF0CBAF24A9BB6C5EB7248E619B1176D3378A
5FD2791F1FD40956C59F8CCC828993361A3BA124DB9707C1438359B8EA874805CAD0810710741DE1E0C1EE5754745
F6EC20A2D6D7E1BCF3FE8BF3052C69CD732F9B261B46759D443B81EA580EE7D57433076909A655233E264DA716035
979E6A962AB914454419C6180EFCFF69A376D891A913071671DA354432DCDE2F86469D12DFD74322AF271B629B89E
9705EA26FEB05AC8AB10E61ACCE04523BE60EFBCF9E113BE559BD6E306948265E7364ADB784F5CC116F923C0BDE4F
F843178DD0A6F11AD72AF0E56E42C8D6142170DD51555A1A14DF41F096BEB852E0FC2CCC7AFC7D13FFC1E6ABDF70C
B1BC2469A78BB93F1DB6E0B8026EAB027D56F6C62E5960620F1909841899BB202BFCBEF4EF4C14CFA7A127987D4C2
```

Figure 20 - Encryption Output (Ciphertext)



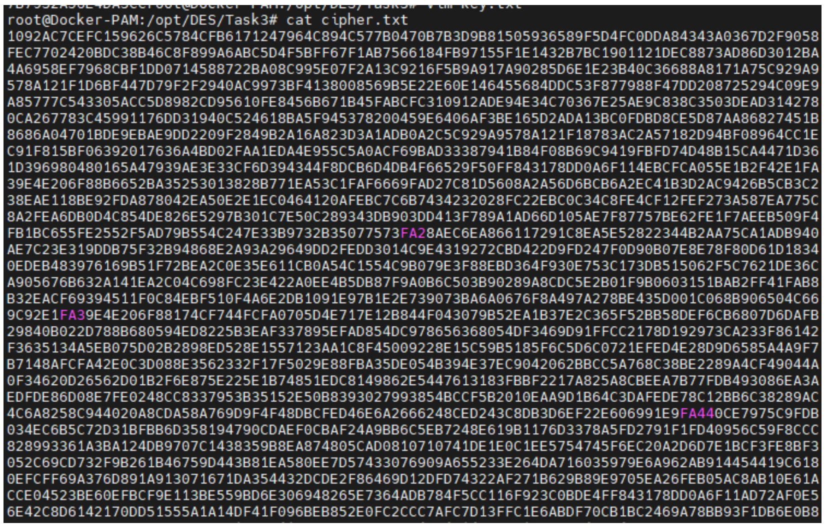
```
root@Docker-PAM:/opt/DES/Task3# ls
cipher.txt  key.txt  plain.txt  Task3-enc.py
```

Figure 21 - File Output (key.txt)



```
root@Docker-PAM:/opt/DES/Task3# cat key.txt
7B7932A56E4DA3CCroot@Docker-PAM:/opt/DES/Task3# 
```

Figure 21 - File Output (key.txt)



```
root@Docker-PAM:/opt/DES/Task3# cat cipher.txt
1092AC7CEFC159626C5784CFB6171247964C894C577B0470B7B3D9B81505936589F5D4FC0DDA84343A0367D2F9058
FEC7702420BDC38B46C8F899A6ABC5D4F5BFF67F1AB7566184FB97155F1E1432B7BC1901121DEC8873AD86D3012BA
4A6958EF7968CBF1DD0714588722BA08C995E07F2A13C9216F5B9A917A90285D6E1E23B40C36688A8171A75C929A9
578A121F1D6BF447D79F2F2940AC9973BF4138008569B5E22E60E146455684DDC53F877988F47DD208725294C09E9
A85777C543305ACC5D8982CD95610FE8456B671B45FABCFC310912ADE94E34C70367E25AE9C838C3503DEAD314278
0CA267783C45991176DD31940C524618BA5F945378200459E6406AF3BE165D2ADA13BC0FDBD8CE5D87AA86827451B
8686A04701BDE9EBAE9DD2209F2849B2A16A823D3A1ADB0A2C5C929A9578A121F18783AC2A57182D94BF08964CC1E
C91F815BF06392017636A4BD02FAA1EDA4E955C5A0ACF69BAD33387941B84F08B69C9419FBFD74D48B15CA4471D36
1D396980480165A47939AE3E33CF6D394344F8DCB6D4DB4F66529F50FF843178DD0A6F114EBCFCA055E1B2F42E1FA
39E4E206F88B6652BA35253013828B771EA53C1FAF6669FAD27C81D5608A2A56D6BCB6A2EC41B3D2AC9426B5CB3C2
38EAE118BE92FDA878042EA50E2E1EC0464120AFEBC7C6B7434232028FC22EBC0C34C8FE4CF12FEF273A587EA775C
8A2FEA6DB0D4C854DE826E5297B301C7E50C289343DB903DD413F789A1AD66D105AE7F87757BE62FE1F7AEEB509F4
FB1BC655FE2552F5AD79B554C247E33B9732B35077573FA28AEC6EA866117291C8EA5E52822344B2AA75CA1ADB940
AE7C23E319DDB75F32B94868E2A93A29649DD2FEDD3014C9E4319272CBD422D9FD247F0D90B07E8E78F80D61D1834
0EDEB483976169B51F72BEA2C0E35E611CB0A54C1554C9B079E3F88EBD364F930E753C173DB515062F5C7621DE36C
A905676B632A141EA2C04C698FC23E422A0EE4B5DB87F9A0B6C503B90289A8CDC5E2B01F9B0603151BAB2FF41FAB8
B32EACF69394511F0C84EBF510F4A6E2DB1091E97B1E2E739073BA6A0676F8A497A278BE435D001C068B906504C66
9C92E1FA39E4E206F88174CF744FCFA0705D4E717E12B844F043079B52EA1B37E2C365F52BB58DEF6CB6807D6DAFB
29840B022D788B680594ED8225B3EAF337895EFAD854DC978656368054DF3469D91FFCC2178D192973CA233F86142
F3635134A5EB075D02B2898ED528E1557123AA1C8F45009228E15C59B5185F6C5D6C0721EFED4E28D9D6585A4A9F7
B7148AFCFA42E0C3D088E3562332F17F5029E88FBA35DE054B394E37EC9042062BBCC5A768C38BE2289A4CF49044A
0F34620D26562D01B2F6E875E225E1B74851EDC8149862E5447613183FBBF2217A825A8CBEEA7B77FDB493086EA3A
EDFDE86D08E7FE0248CC8337953B35152E50B8393027993854BCCF5B2010EAA9D1B64C3DAFEDE78C12BB6C38289AC
4C6A8258C944020A8CDA58A769D9F4F48DBCFED46E6A2666248CED243C8DB3D6EF22E606991E9FA440CE7975C9FDB
034EC6B5C72D31BFBB6D358194790CDAEF0CBAF24A9BB6C5EB7248E619B1176D3378A5FD2791F1FD40956C59F8CCC
828993361A3BA124DB9707C1438359B8EA874805CAD0810710741DE1E0C1EE5754745F6EC20A2D6D7E1BCF3FE8BF3
052C69CD732F9B261B46759D443B81EA580EE7D57433076909A655233E264DA716035979E6A962AB914454419C618
0EFCFF69A376D891A913071671DA354432DCDE2F86469D12DFD74322AF271B629B89E9705EA26FEB05AC8AB10E61A
CCE04523BE60EFBCF9E113BE559BD6E306948265E7364ADB784F5CC116F923C0BDE4FF843178DD0A6F11AD72AF0E5
6E42C8D6142170DD51555A1A14DF41F096BEB852E0FC2CCC7AFC7D13FFC1E6ABDF70CB1BC2469A78BB93F1DB6E0B8
```

Figure 22 - File Output (cipher.txt)

3. DES Decryption Process

After generating key.txt and cipher.txt, we proceed with the DES decryption process. This involves block processing, Feistel rounds, and applying inverse operations to recover the original plaintext.

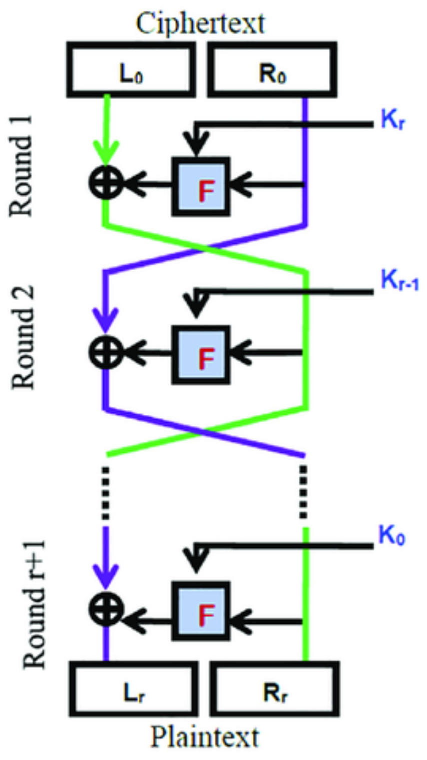
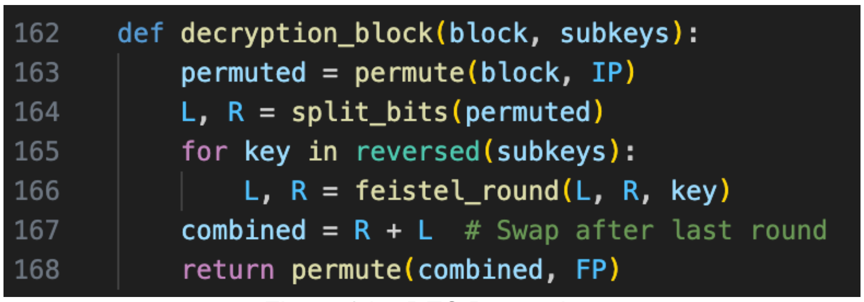


Figure 23 – DES Decryption

3.1 Block Decryption

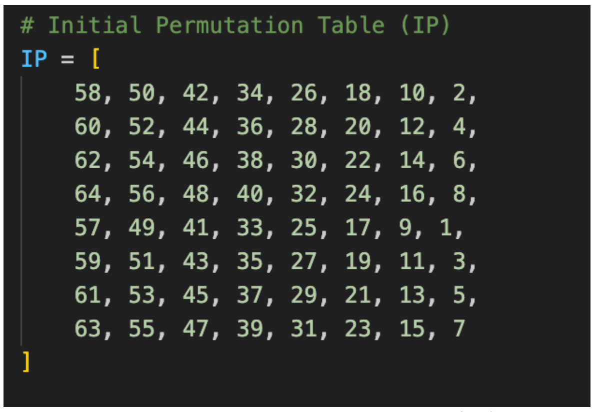
The DES decryption process operates on 64-bit blocks of ciphertext with the same key we generated, reversing the encryption steps through:



```python
def decryption_block(block, subkeys):
    permuted = permute(block, IP)
    L, R = split_bits(permuted)
    for key in reversed(subkeys):
        L, R = feistel_round(L, R, key)
    combined = R + L  # Swap after last round
    return permute(combined, FP)
```

Figure 24 – DES Decryption

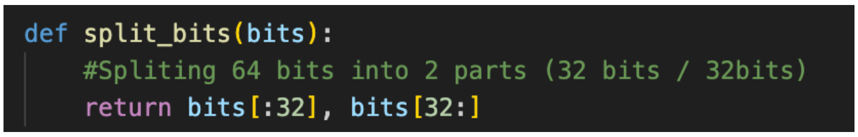
3.1.1 Initial Permutation (IP): Using fixed permutation table



```python
# Initial Permutation Table (IP)
IP = [
    58, 50, 42, 34, 26, 18, 10, 2,
    60, 52, 44, 36, 28, 20, 12, 4,
    62, 54, 46, 38, 30, 22, 14, 6,
    64, 56, 48, 40, 32, 24, 16, 8,
    57, 49, 41, 33, 25, 17, 9, 1,
    59, 51, 43, 35, 27, 19, 11, 3,
    61, 53, 45, 37, 29, 21, 13, 5,
    63, 55, 47, 39, 31, 23, 15, 7
]
```

Figure 25 – Initial Permutation (IP)

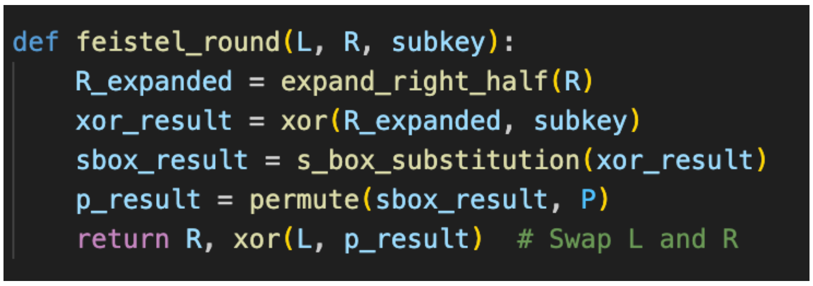
3.1.2 Splitting into L and R 32-bit halves



```python
def split_bits(bits):
    #Spliting 64 bits into 2 parts (32 bits / 32bits)
    return bits[:32], bits[32:]
```

Figure 26 – Splitting into L and R 32-bit

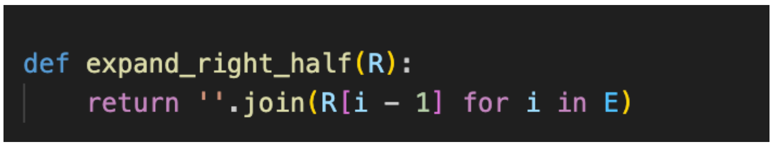
3.1.3 Feistel Round Function: which will be run 16 times in reverse order (k16 --> k1)



```python
def feistel_round(L, R, subkey):
    R_expanded = expand_right_half(R)
    xor_result = xor(R_expanded, subkey)
    sbox_result = s_box_substitution(xor_result)
    p_result = permute(sbox_result, P)
    return R, xor(L, p_result)  # Swap L and R
```

Figure 27 – Feistel Round Function

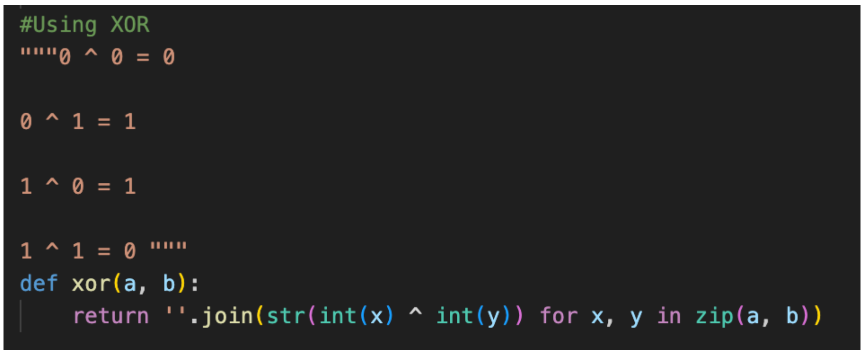
a) The 32-bit right half is expanded to 48 bits using the E table.



```python
def expand_right_half(R):
    return ''.join(R[i - 1] for i in E)
```

Figure 27a – Feistel Round Function

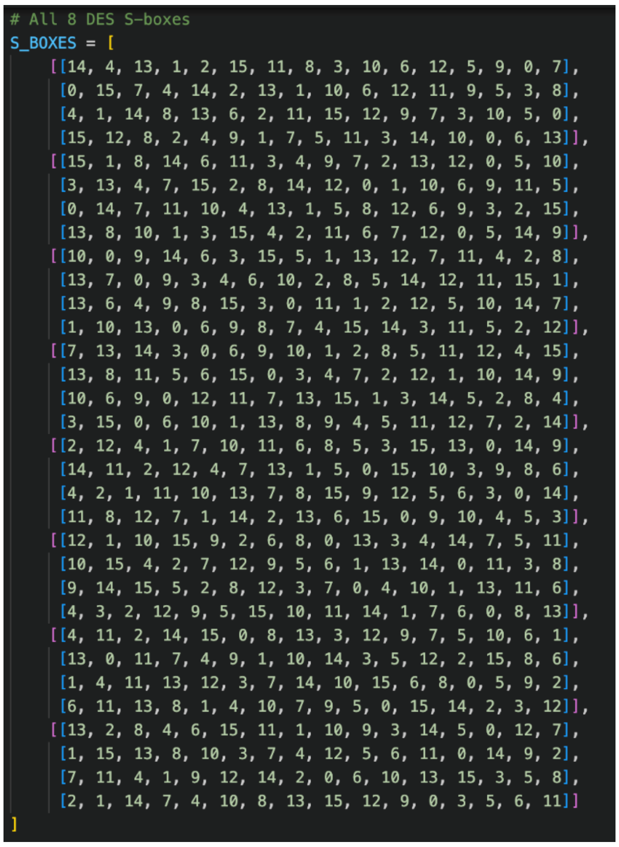
b) Align R size (48-bit) with the 48-bit subkey for XOR operation.



```python
#Using XOR
""""0 ^ 0 = 0

0 ^ 1 = 1

1 ^ 0 = 1

1 ^ 1 = 0 """
def xor(a, b):
    return ''.join(str(int(x) ^ int(y)) for x, y in zip(a, b))
```

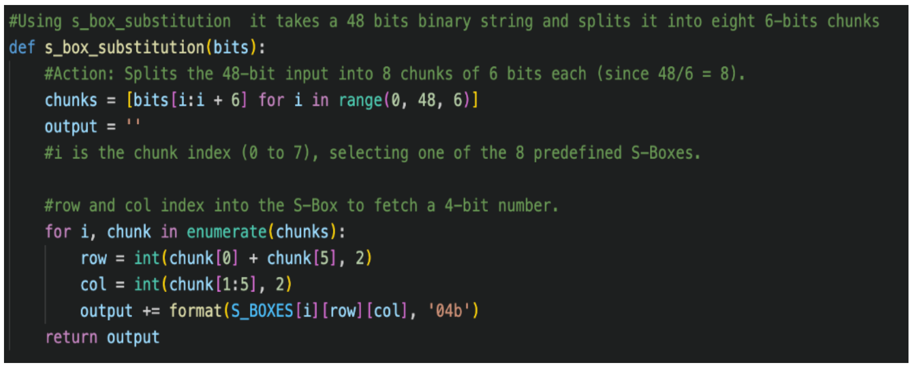
Figure 27b – XOR operation

c) S-BOX substitution



```python
# All 8 DES S-boxes
S_BOXES = [
    [[14, 4, 13, 1, 2, 15, 11, 8, 3, 10, 6, 12, 5, 9, 0, 7],
     [0, 15, 7, 4, 14, 2, 13, 1, 10, 6, 12, 11, 9, 5, 3, 8],
     [4, 1, 14, 8, 13, 6, 2, 11, 15, 12, 9, 7, 3, 10, 5, 0],
     [15, 12, 8, 2, 4, 9, 1, 7, 5, 11, 3, 14, 10, 0, 6, 13]],
    [[15, 1, 8, 14, 6, 11, 3, 4, 9, 7, 2, 13, 12, 0, 5, 10],
     [3, 13, 4, 7, 15, 2, 8, 14, 12, 0, 1, 10, 6, 9, 11, 5],
     [0, 14, 7, 11, 10, 4, 13, 1, 5, 8, 12, 6, 9, 3, 2, 15],
     [13, 8, 10, 1, 3, 15, 4, 2, 11, 6, 7, 12, 0, 5, 14, 9]],
    [[10, 0, 9, 14, 6, 3, 15, 5, 1, 13, 12, 7, 11, 4, 2, 8],
     [13, 7, 0, 9, 3, 4, 6, 10, 2, 8, 5, 14, 12, 11, 15, 1],
     [13, 6, 4, 9, 8, 15, 3, 0, 11, 1, 2, 12, 5, 10, 14, 7],
     [1, 10, 13, 0, 6, 9, 8, 7, 4, 15, 14, 3, 11, 5, 2, 12]],
    [[7, 13, 14, 3, 0, 6, 9, 10, 1, 2, 8, 5, 11, 12, 4, 15],
     [13, 8, 11, 5, 6, 15, 0, 3, 4, 7, 2, 12, 1, 10, 14, 9],
     [10, 6, 9, 0, 12, 11, 7, 13, 15, 1, 3, 14, 5, 2, 8, 4],
     [3, 15, 0, 6, 10, 1, 13, 8, 9, 4, 5, 11, 12, 7, 2, 14]],
    [[2, 12, 4, 1, 7, 10, 11, 6, 8, 5, 3, 15, 13, 0, 14, 9],
     [14, 11, 2, 12, 4, 7, 13, 1, 5, 0, 15, 10, 3, 9, 8, 6],
     [4, 2, 1, 11, 10, 13, 7, 8, 15, 9, 12, 5, 6, 3, 0, 14],
     [11, 8, 12, 7, 1, 14, 2, 13, 6, 15, 0, 9, 10, 4, 5, 3]],
    [[12, 1, 10, 15, 9, 2, 6, 8, 0, 13, 3, 4, 14, 7, 5, 11],
     [10, 15, 4, 2, 7, 12, 9, 5, 6, 1, 13, 14, 0, 11, 3, 8],
     [9, 14, 15, 5, 2, 8, 12, 3, 7, 0, 4, 10, 1, 13, 11, 6],
     [4, 3, 2, 12, 9, 5, 15, 10, 11, 14, 1, 7, 6, 0, 8, 13]],
    [[4, 11, 2, 14, 15, 0, 8, 13, 3, 12, 9, 7, 5, 10, 6, 1],
     [13, 0, 11, 7, 4, 9, 1, 10, 14, 3, 5, 12, 2, 15, 8, 6],
     [1, 4, 11, 13, 12, 3, 7, 14, 10, 15, 6, 8, 0, 5, 9, 2],
     [6, 11, 13, 8, 1, 4, 10, 7, 9, 5, 0, 15, 14, 2, 3, 12]],
    [[13, 2, 8, 4, 6, 15, 11, 1, 10, 9, 3, 14, 5, 0, 12, 7],
     [1, 15, 13, 8, 10, 3, 7, 4, 12, 5, 6, 11, 0, 14, 9, 2],
     [7, 11, 4, 1, 9, 12, 14, 2, 0, 6, 10, 13, 15, 3, 5, 8],
     [2, 1, 14, 7, 4, 10, 8, 13, 15, 12, 9, 0, 3, 5, 6, 11]]
]
```

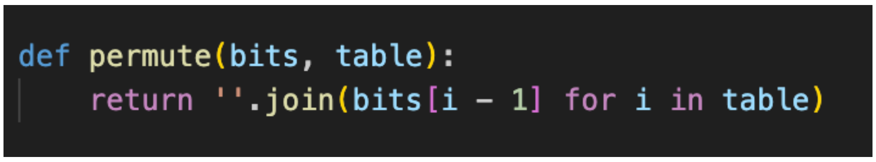
Figure 27c – S-BOX substitution



```python
#Using s_box_substitution  it takes a 48 bits binary string and splits it into eight 6-bits chunks
def s_box_substitution(bits):
    #Action: Splits the 48-bit input into 8 chunks of 6 bits each (since 48/6 = 8).
    chunks = [bits[i:i + 6] for i in range(0, 48, 6)]
    output = ''
    #i is the chunk index (0 to 7), selecting one of the 8 predefined S-Boxes.

    #row and col index into the S-Box to fetch a 4-bit number.
    for i, chunk in enumerate(chunks):
        row = int(chunk[0] + chunk[5], 2)
        col = int(chunk[1:5], 2)
        output += format(S_BOXES[i][row][col], '04b')
    return output
```

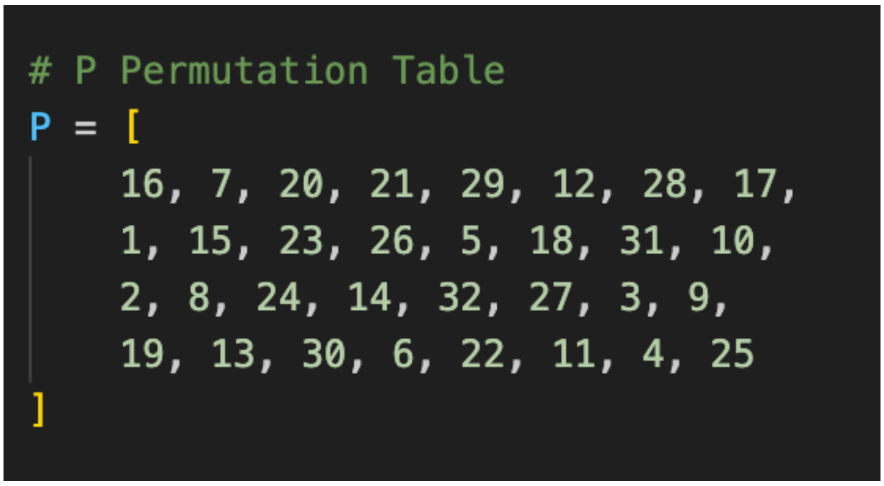
Figure 27c – S-BOX substitution

d) Permuting the Sbox_result with the P table



```python
def permute(bits, table):
    return ''.join(bits[i - 1] for i in table)
```

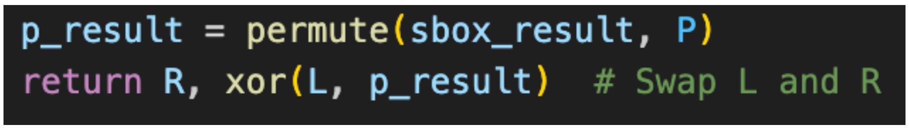
Figure 27d – Sbox_result with the P table



```python
# P Permutation Table
P = [
    16, 7, 20, 21, 29, 12, 28, 17,
    1, 15, 23, 26, 5, 18, 31, 10,
    2, 8, 24, 14, 32, 27, 3, 9,
    19, 13, 30, 6, 22, 11, 4, 25
]
```

Figure 27d – P Permutation Table

e) The left half (L) is XORed with p_result

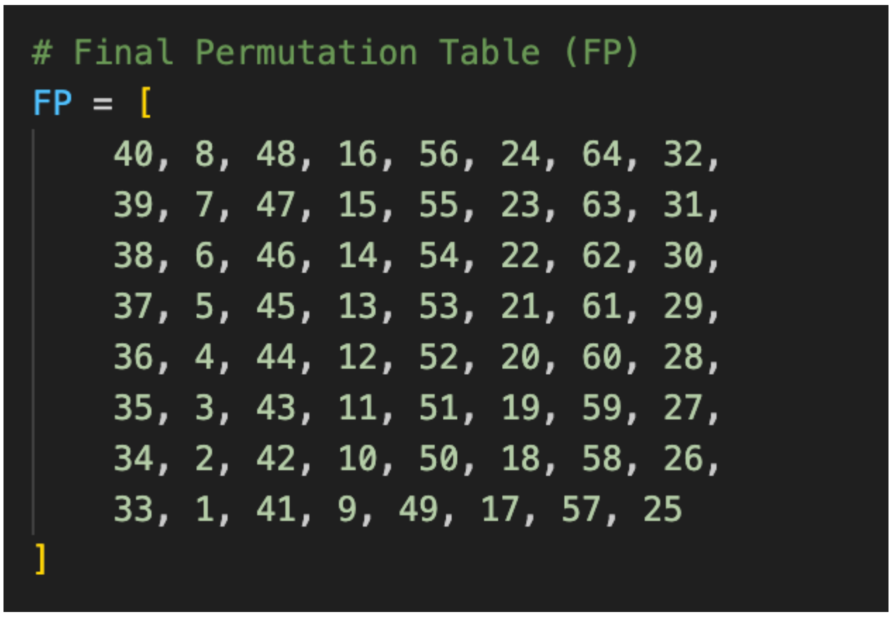


```python
p_result = permute(sbox_result, P)
return R, xor(L, p_result)  # Swap L and R
```

Figure 27e – XORed with p_result

f) The halves are swapped: (L, R)

3.1.4 Swap After the last round and Final Swap with the FP table

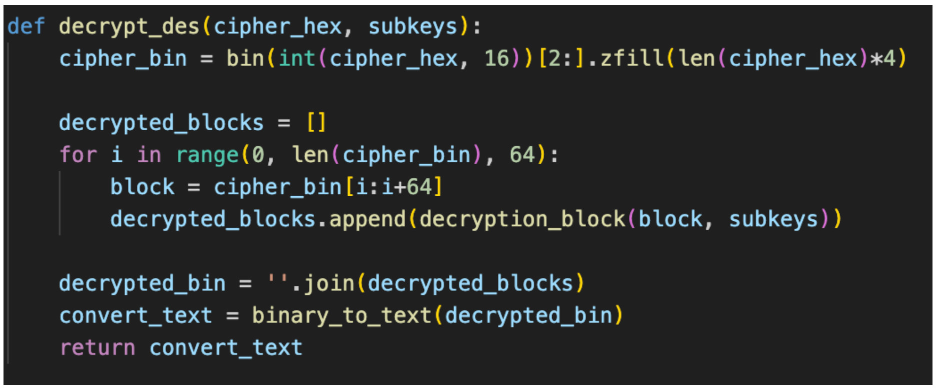


```python
# Final Permutation Table (FP)
FP = [
    40, 8, 48, 16, 56, 24, 64, 32,
    39, 7, 47, 15, 55, 23, 63, 31,
    38, 6, 46, 14, 54, 22, 62, 30,
    37, 5, 45, 13, 53, 21, 61, 29,
    36, 4, 44, 12, 52, 20, 60, 28,
    35, 3, 43, 11, 51, 19, 59, 27,
    34, 2, 42, 10, 50, 18, 58, 26,
    33, 1, 41, 9, 49, 17, 57, 25
]
```

Figure 28 – Final Permutation FP table

3.2 Full DES Encryption Process

The DES decryption process is applied to the entire ciphertext after it has been converted into binary format. It mirrors the encryption steps in reverse order, using the same subkeys applied in reverse to recover the original plaintext. Decryption steps are explained below:



```python
def decrypt_des(cipher_hex, subkeys):
    cipher_bin = bin(int(cipher_hex, 16))[2:].zfill(len(cipher_hex)*4)

    decrypted_blocks = []
    for i in range(0, len(cipher_bin), 64):
        block = cipher_bin[i:i+64]
        decrypted_blocks.append(decryption_block(block, subkeys))

    decrypted_bin = ''.join(decrypted_blocks)
    convert_text = binary_to_text(decrypted_bin)
    return convert_text
```

Figure 29 – Full DES Encryption Process

3.2.1 Hexadecimal to Binary Conversion

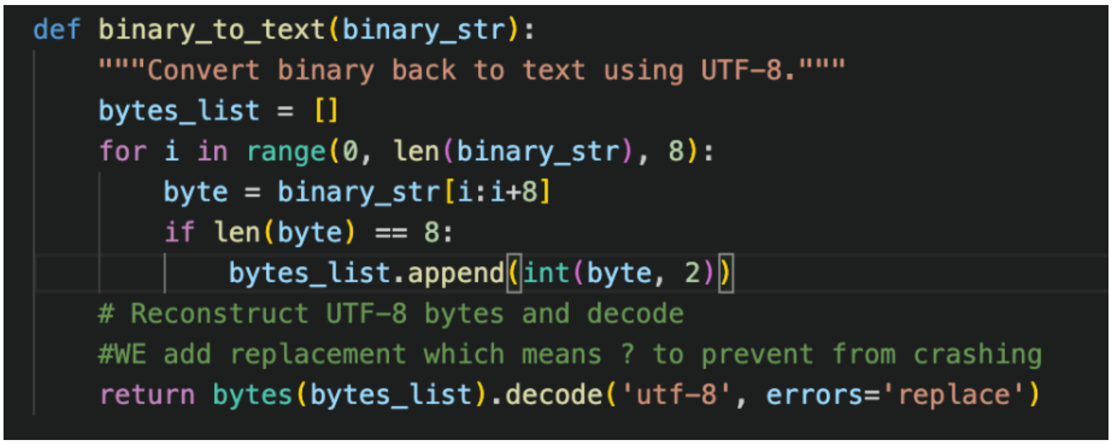
Convert human-readable hex to binary for bitwise operations.

3.2.2 Block Processing

The binary data is split into 64-bit blocks, and the decryption_block() function will be run here.

3.2.3 Binary to Text Conversion

The ciphertext binary string is converted to the original text using UTF-8 decoding.

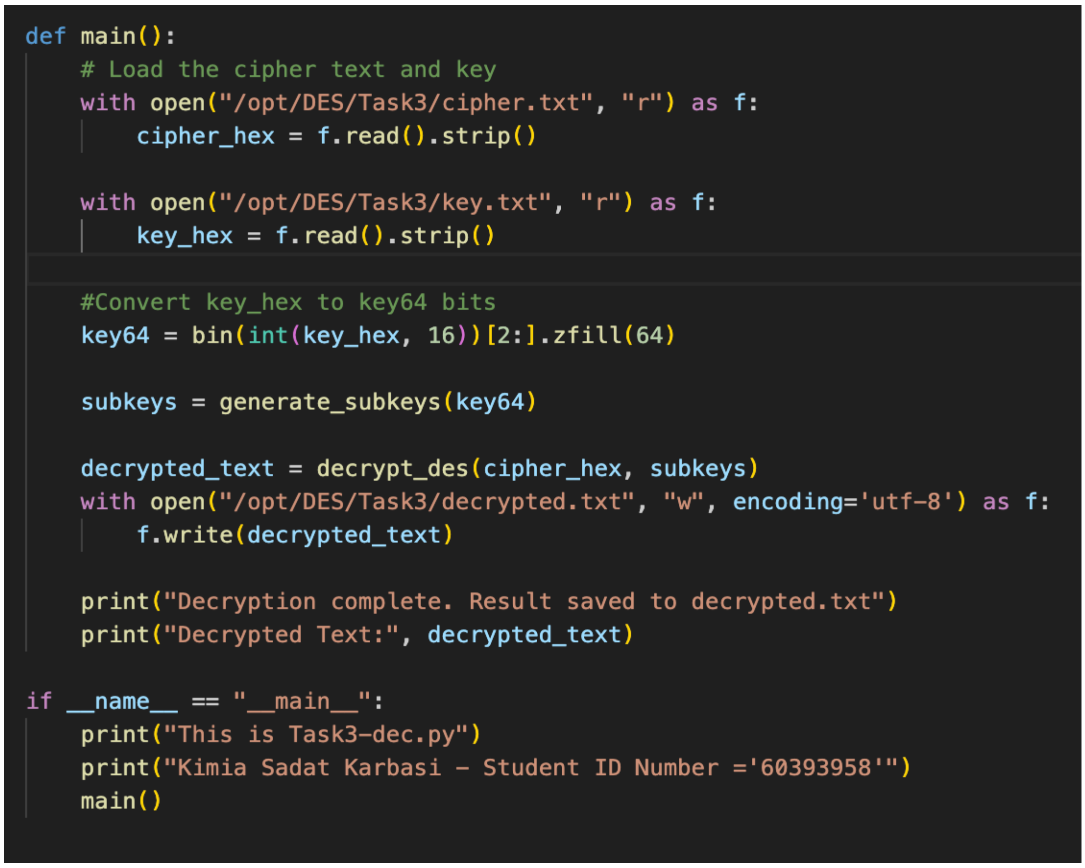


```python
def binary_to_text(binary_str):
    """Convert binary back to text using UTF-8."""
    bytes_list = []
    for i in range(0, len(binary_str), 8):
        byte = binary_str[i:i+8]
        if len(byte) == 8:
            bytes_list.append(int(byte, 2))
    # Reconstruct UTF-8 bytes and decode
    #WE add replacement which means ? to prevent from crashing
    return bytes(bytes_list).decode('utf-8', errors='replace')
```

Figure 30 – Convert Binary to Text

3.3 Output

The main() function orchestrates the complete decryption workflow, handling data I/O, key processing, and result verification. This section documents the critical output operations.



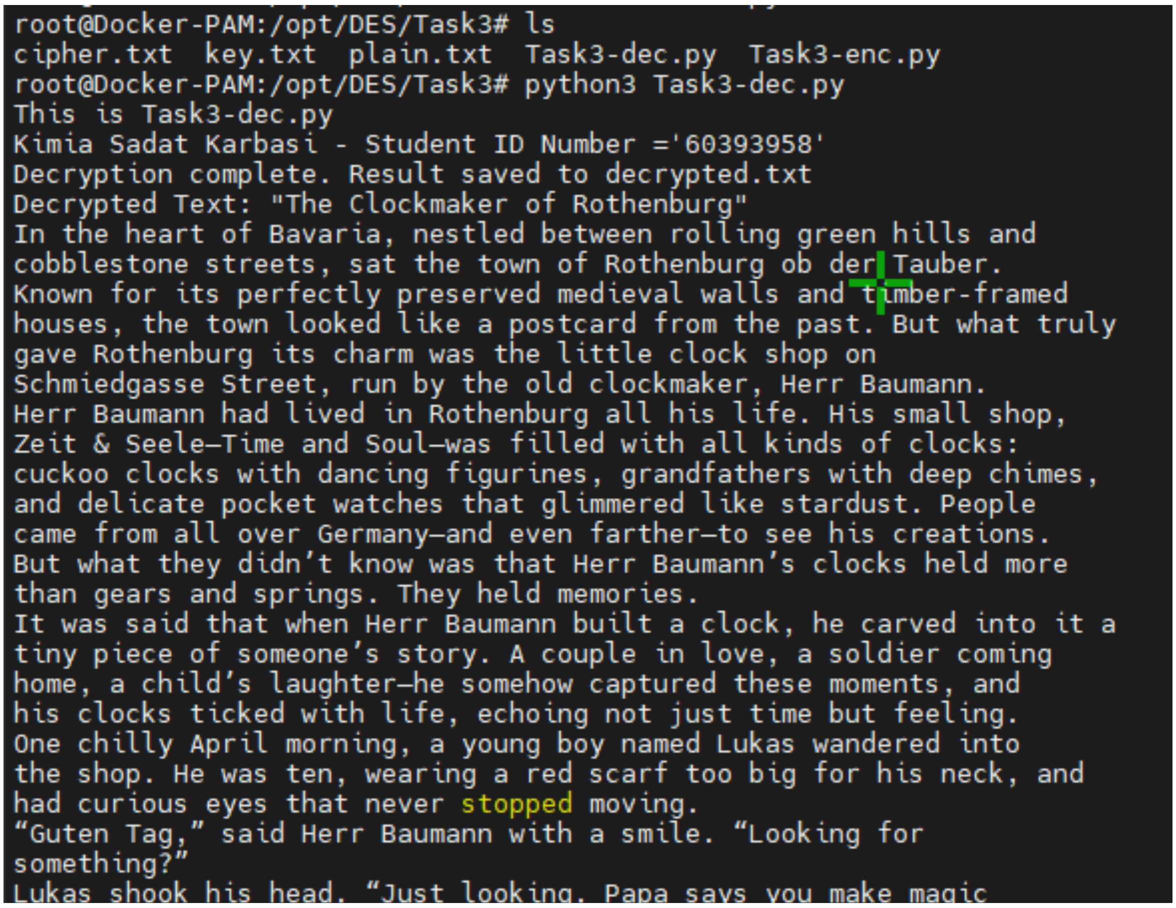
```python
def main():
    # Load the cipher text and key
    with open("/opt/DES/Task3/cipher.txt", "r") as f:
        cipher_hex = f.read().strip()

    with open("/opt/DES/Task3/key.txt", "r") as f:
        key_hex = f.read().strip()

    #Convert key_hex to key64 bits
    key64 = bin(int(key_hex, 16))[2:].zfill(64)

    subkeys = generate_subkeys(key64)

    decrypted_text = decrypt_des(cipher_hex, subkeys)
    with open("/opt/DES/Task3/decrypted.txt", "w", encoding='utf-8') as f:
        f.write(decrypted_text)

    print("Decryption complete. Result saved to decrypted.txt")
    print("Decrypted Text:", decrypted_text)

if __name__ == "__main__":
    print("This is Task3-dec.py")
    print("Kimia Sadat Karbasi - Student ID Number ='60393958'")
    main()
```

Figure 31 – Complete Decryption Workflow with main() function

a) File handling implementation (Reading cipher and key from a specific path)
b) Key processing (converting hex to binary and generating subkeys)
c) Result output (saving decrypted text in the correct path)
d) Console output

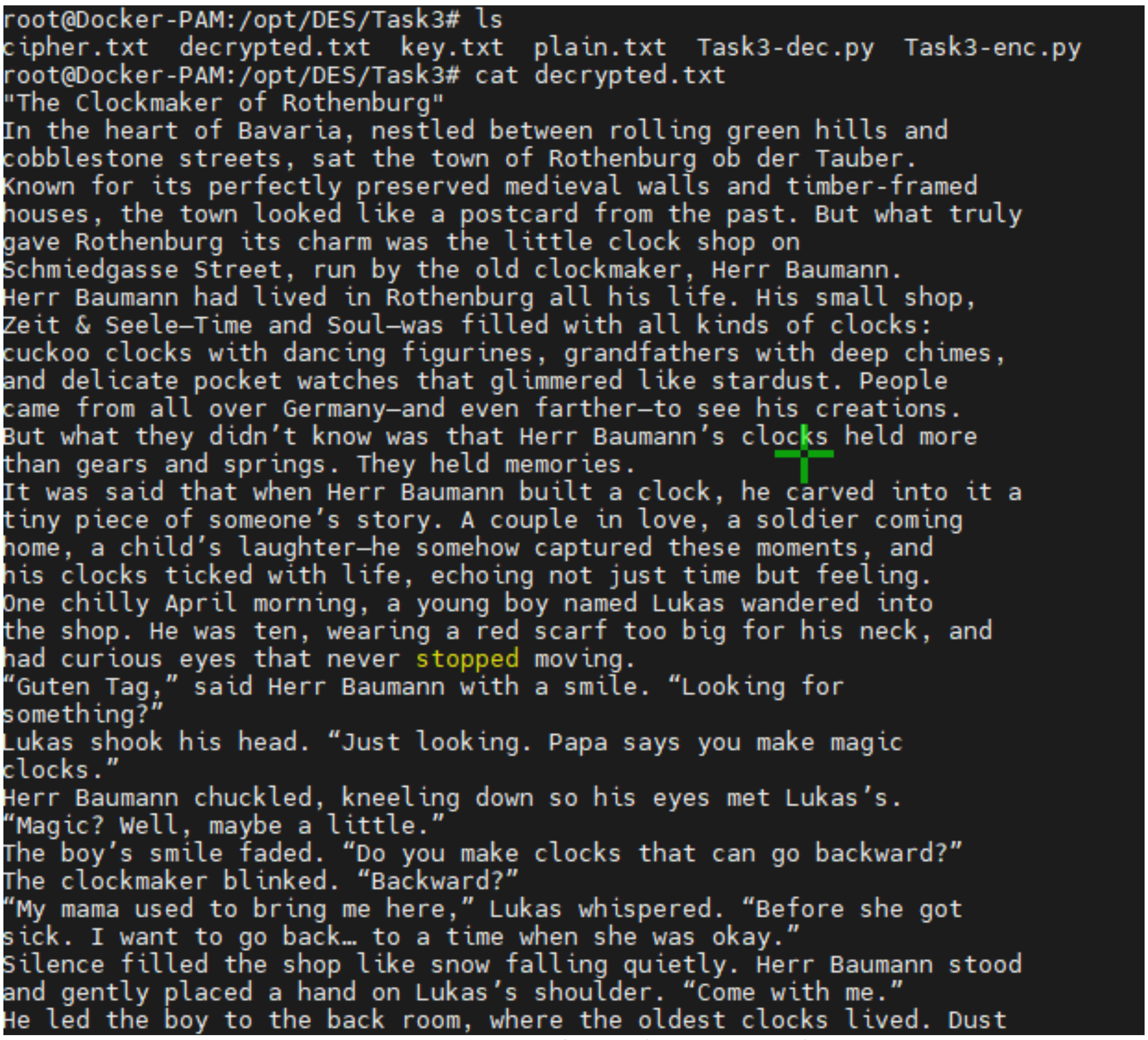
3.4 Execution and Results

Here are all the decryption code screenshots executed on a Linux machine. Each Picture has caption that indicates the corresponding step in DES decryption process.



```
root@Docker-PAM:/opt/DES/Task3# ls
cipher.txt  key.txt  plain.txt  Task3-dec.py  Task3-enc.py
root@Docker-PAM:/opt/DES/Task3# python3 Task3-dec.py
This is Task3-dec.py
Kimia Sadat Karbasi - Student ID Number ='60393958'
Decryption complete. Result saved to decrypted.txt
Decrypted Text: "The Clockmaker of Rothenburg"
In the heart of Bavaria, nestled between rolling green hills and
cobblestone streets, sat the town of Rothenburg ob der Tauber.
Known for its perfectly preserved medieval walls and timber-framed
houses, the town looked like a postcard from the past. But what truly
gave Rothenburg its charm was the little clock shop on
Schmiedgasse Street, run by the old clockmaker, Herr Baumann.
Herr Baumann had lived in Rothenburg all his life. His small shop,
Zeit & Seele—Time and Soul—was filled with all kinds of clocks:
cuckoo clocks with dancing figurines, grandfathers with deep chimes,
and delicate pocket watches that glimmered like stardust. People
came from all over Germany—and even farther—to see his creations.
But what they didn't know was that Herr Baumann's clocks held more
than gears and springs. They held memories.
It was said that when Herr Baumann built a clock, he carved into it a
tiny piece of someone's story. A couple in love, a soldier coming
home, a child's laughter—he somehow captured these moments, and
his clocks ticked with life, echoing not just time but feeling.
One chilly April morning, a young boy named Lukas wandered into
the shop. He was ten, wearing a red scarf too big for his neck, and
had curious eyes that never stopped moving.
“Guten Tag,” said Herr Baumann with a smile. “Looking for
something?”
Lukas shook his head. “Just looking. Papa says you make magic
```

Figure 32 – Decryption Output (Decrypted Text)



```
root@Docker-PAM:/opt/DES/Task3# ls
cipher.txt  decrypted.txt  key.txt  plain.txt  Task3-dec.py  Task3-enc.py
root@Docker-PAM:/opt/DES/Task3# cat decrypted.txt
"The Clockmaker of Rothenburg"
In the heart of Bavaria, nestled between rolling green hills and
cobblestone streets, sat the town of Rothenburg ob der Tauber.
Known for its perfectly preserved medieval walls and timber-framed
houses, the town looked like a postcard from the past. But what truly
gave Rothenburg its charm was the little clock shop on
Schmiedgasse Street, run by the old clockmaker, Herr Baumann.
Herr Baumann had lived in Rothenburg all his life. His small shop,
Zeit & Seele—Time and Soul—was filled with all kinds of clocks:
cuckoo clocks with dancing figurines, grandfathers with deep chimes,
and delicate pocket watches that glimmered like stardust. People
came from all over Germany—and even farther—to see his creations.
But what they didn’t know was that Herr Baumann’s clocks held more
than gears and springs. They held memories.
It was said that when Herr Baumann built a clock, he carved into it a
tiny piece of someone’s story. A couple in love, a soldier coming
home, a child’s laughter—he somehow captured these moments, and
his clocks ticked with life, echoing not just time but feeling.
One chilly April morning, a young boy named Lukas wandered into
the shop. He was ten, wearing a red scarf too big for his neck, and
had curious eyes that never stopped moving.
“Guten Tag,” said Herr Baumann with a smile. “Looking for
something?”
Lukas shook his head. “Just looking. Papa says you make magic
clocks.”
Herr Baumann chuckled, kneeling down so his eyes met Lukas’s.
“Magic? Well, maybe a little.”
The boy’s smile faded. “Do you make clocks that can go backward?”
The clockmaker blinked. “Backward?”
“My mama used to bring me here,” Lukas whispered. “Before she got
sick. I want to go back… to a time when she was okay.”
Silence filled the shop like snow falling quietly. Herr Baumann stood
and gently placed a hand on Lukas’s shoulder. “Come with me.”
He led the boy to the back room, where the oldest clocks lived. Dust
```

Figure 33 – File Output (Decrypted.txt)

4. Conclusion

This report provides a comprehensive implementation of the Data Encryption Standard (DES) algorithm, addressing key generation, Feistel encryption/decryption, and secure output handling. The project successfully demonstrated the following:

- **Precise Key Scheduling**: Accurate generation and application of round keys.
- **Hands-on Encryption/Decryption Implementation**: Practical execution of both the encryption and decryption processes.
- **Secure Data Handling**: Effective management of data throughout the encryption and decryption stages.