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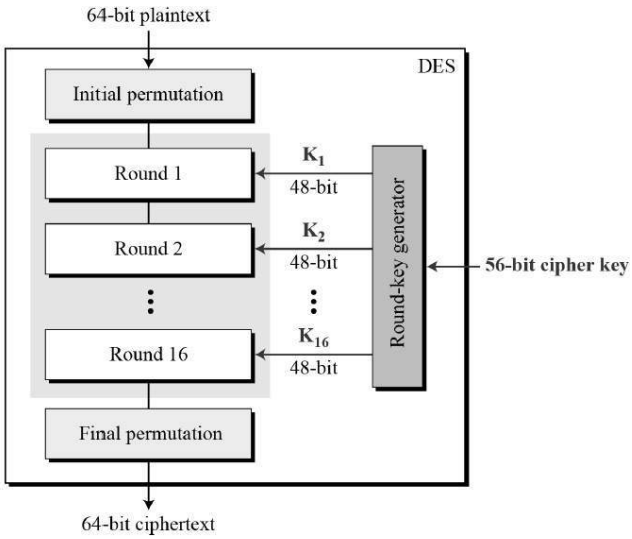
AIM: To implement a program to show encryption and decryption using DES.

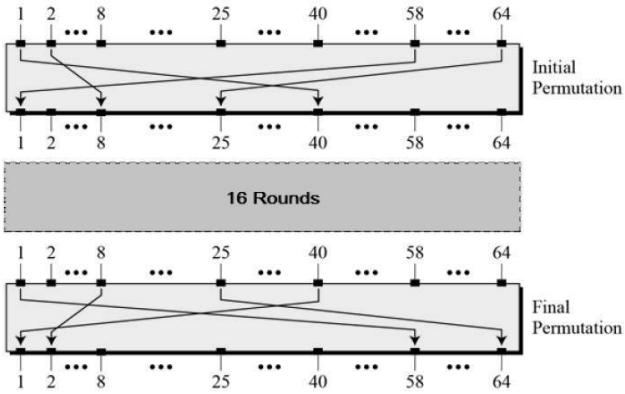
Introduction and Theory

The Data Encryption Standard (DES) is a symmetric-key block cipher published by the National Institute of Standards and Technology (NIST). DES is an implementation of a Feistel Cipher. It uses 16 round Feistel structure. The block size is 64-bit. Though, key length is 64-bit, DES has an effective key length of 56 bits, since 8 of the 64 bits of the key are not used by the encryption algorithm (function as check bits only).



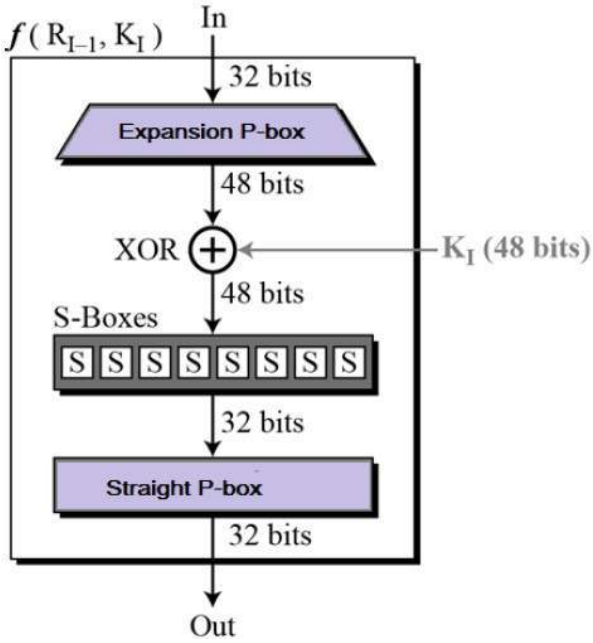
Initial and Final Permutation

The initial and final permutations are straight Permutation boxes (P-boxes) that are inverses of each other. They have no cryptography significance in DES.



Round Function

The heart of this cipher is the DES function, f. The DES function applies a 48-bit key to the rightmost 32 bits to produce a 32-bit output.



Expansion Permutation Box

- Since right input is 32-bit and round key is a 48-bit, we first need to expand right input to 48 bits.

XOR (Whitener)

- After the expansion permutation, DES does XOR operation on the expanded right section and the round key. The round key is used only in this operation.

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Substitution Boxes.

- The S-boxes carry out the real mixing (confusion). DES uses 8 S-boxes, each with a 6-bit input and a 4-bit output.
- There is a total of eight S-box tables. The output of all eight s-boxes is then combined in to 32-bit section.

Straight Permutation

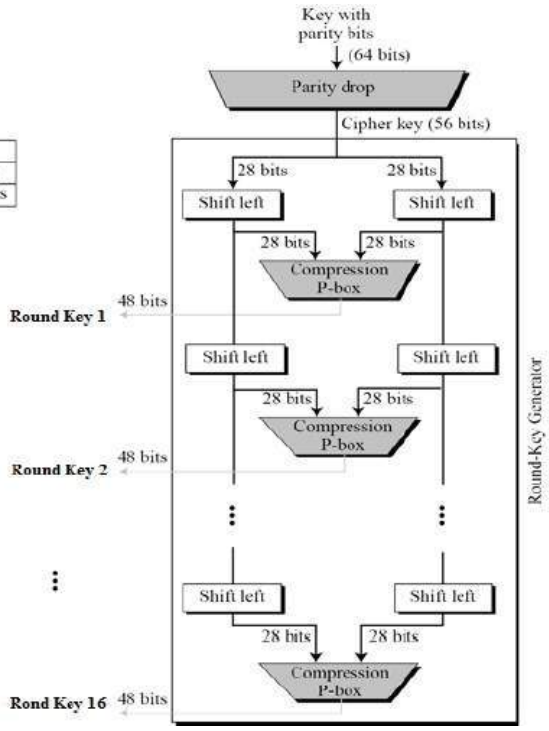
- The 32-bit output of S-boxes is then subjected to the straight permutation rule.

Key Generation

The round-key generator creates sixteen 48-bit keys out of a 56-bit cipher key.

Shifting

Rounds	Shift
1, 2, 9, 16	one bit
Others	two bits



DES Analysis

The DES satisfies both the desired properties of block cipher. These two properties make cipher very strong.

Avalanche effect

A small change in plaintext results in the very great change in the ciphertext.

Completeness

Each bit of ciphertext depends on many bits of plaintext.

During the last few years, cryptanalysis have found some weaknesses in DES when key selected are weak keys. These keys shall be avoided.

DES has proved to be a very well-designed block cipher. There have been no significant cryptanalytic attacks on DES other than exhaustive key search.

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Code

```
#include <stdio.h>
#include <fstream>
#include <string.h>
#include <iostream>
#include <stdlib.h>
using namespace std;

int key[64] =
    {
        0, 1, 1, 0, 1, 0, 0, 1,
        1, 1, 1, 1, 1, 0, 1, 0,
        1, 1, 0, 0, 0, 1, 1, 0,
        1, 0, 0, 1, 0, 1, 1, 0,
        1, 0, 0, 1, 0, 1, 1, 0,
        1, 0, 0, 1, 1, 1, 1, 1,
        1, 0, 1, 0, 1, 1, 0, 0,
        0, 1, 1, 0, 1, 0, 0, 1};

class Des
{
  public:
    int round_key[16][48], total[64], left[32], right[32], ck[28];
    int dk[28], E_box[48], z[48], xor1[48], sub[32];
    int p[32], xor2[32], temp[64], pc1[56], ip[64];
    int inv[8][8];

    char final[1000];
    void Init_perm();
    void PermChoice1();
    void PermChoice2();
    void E_Function();
    void inverse();
    void xor_two();
    void xor_oneE(int);
    void xor_oneD(int);
    void substitution();
    void permutation();
    void keygen();
    char *Encrypt(char *);
    char *Decrypt(char *);
};

void Des::Init_perm()
{
    /*
    Does the initial permutation
    No real significance
    */
    int k = 58, i;
    for (i = 0; i < 32; i++)
    {
        ip[i] = total[k - 1];
        if (k - 8 > 0)
            k = k - 8;
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```
        else
            k = k + 58;
    }
    k = 57;
    for (i = 32; i < 64; i++)
    {
        ip[i] = total[k - 1];
        if (k - 8 > 0)
            k = k - 8;
        else
            k = k + 58;
    }
}

void Des::PermChoice1() //Permutation Choice-1
{
    int k = 57, i;
    for (i = 0; i < 28; i++)
    {
        pc1[i] = key[k - 1];
        if (k - 8 > 0)
            k = k - 8;
        else
            k = k + 57;
    }
    k = 63;
    for (i = 28; i < 52; i++)
    {
        pc1[i] = key[k - 1];
        if (k - 8 > 0)
            k = k - 8;
        else
            k = k + 55;
    }
    k = 28;
    for (i = 52; i < 56; i++)
    {
        pc1[i] = key[k - 1];
        k = k - 8;
    }
}

void Des::E_Function()
{
    /* Explansion function from 32 to 48 bits */
    int exp[8][6], i, j, k;
    for (i = 0; i < 8; i++)
    {
        for (j = 0; j < 6; j++)
        {
            if ((j != 0) || (j != 5))
            {
                k = 4 * i + j;
                exp[i][j] = right[k - 1];
            }
            if (j == 0)
            {
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```
                k = 4 * i;
                exp[i][j] = right[k - 1];
            }
            if (j == 5)
            {
                k = 4 * i + j;
                exp[i][j] = right[k - 1];
            }
        }
    }
    exp[0][0] = right[31];
    exp[7][5] = right[0];

    k = 0;
    for (i = 0; i < 8; i++)
        for (j = 0; j < 6; j++)
            E_box[k++] = exp[i][j];
}

void Des::PermChoice2()
{
    int per[56], i, k;
    for (i = 0; i < 28; i++)
        per[i] = ck[i];

    for (k = 0, i = 28; i < 56; i++)
        per[i] = dk[k++];

    z[0] = per[13];  z[1] = per[16];  z[2] = per[10];  z[3] = per[23];
    z[4] = per[0];   z[5] = per[4];   z[6] = per[2];   z[7] = per[27];
    z[8] = per[14];  z[9] = per[5];   z[10] = per[20]; z[11] = per[9];
    z[12] = per[22]; z[13] = per[18]; z[14] = per[11]; z[15] = per[3];
    z[16] = per[25]; z[17] = per[7];  z[18] = per[15]; z[19] = per[6];
    z[20] = per[26]; z[21] = per[19]; z[22] = per[12]; z[23] = per[1];
    z[24] = per[40]; z[25] = per[51]; z[26] = per[30]; z[27] = per[36];
    z[28] = per[46]; z[29] = per[54]; z[30] = per[29]; z[31] = per[39];
    z[32] = per[50]; z[33] = per[46]; z[34] = per[32]; z[35] = per[47];
    z[36] = per[43]; z[37] = per[48]; z[38] = per[38]; z[39] = per[55];
    z[40] = per[33]; z[41] = per[52]; z[42] = per[45]; z[43] = per[41];
    z[44] = per[49]; z[45] = per[35]; z[46] = per[28]; z[47] = per[31];
}

void Des::xor_oneE(int round) //for Encrypt
{
    int i;
    for (i = 0; i < 48; i++)
        xor1[i] = E_box[i] ^ round_key[round - 1][i];
}

void Des::xor_oneD(int round) //for Decrypt
{
    int i;
    for (i = 0; i < 48; i++)
        xor1[i] = E_box[i] ^ round_key[16 - round][i];
}

void Des::substitution()
```

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```
{
    int s1[4][16] =
        {
            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};

    int s2[4][16] =
        {
            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};

    int s3[4][16] =
        {
            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};

    int s4[4][16] =
        {
            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};

    int s5[4][16] =
        {
            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};

    int s6[4][16] =
        {
            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};

    int s7[4][16] =
        {
            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};

    int s8[4][16] =
        {
            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};
    int a[8][6], k = 0, i, j, p, q, count = 0, g = 0, v;
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```

    for (i = 0; i < 8; i++)
    {
        for (j = 0; j < 6; j++)
        {
            a[i][j] = xor1[k++];
        }
    }

    for (i = 0; i < 8; i++)
    {
        p = 1;
        q = 0;
        k = (a[i][0] * 2) + (a[i][5] * 1);
        j = 4;
        while (j > 0)
        {
            q = q + (a[i][j] * p);
            p = p * 2;
            j--;
        }
        count = i + 1;
        switch (count)
        {
        case 1:
            v = s1[k][q];
            break;
        case 2:
            v = s2[k][q];
            break;
        case 3:
            v = s3[k][q];
            break;
        case 4:
            v = s4[k][q];
            break;
        case 5:
            v = s5[k][q];
            break;
        case 6:
            v = s6[k][q];
            break;
        case 7:
            v = s7[k][q];
            break;
        case 8:
            v = s8[k][q];
            break;
        }

        int d, i = 3, a[4];
        while (v > 0)
        {
            d = v % 2;
            a[i--] = d;
            v = v / 2;
        }
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```
        while (i >= 0)
        {
            a[i--] = 0;
        }

        for (i = 0; i < 4; i++)
            sub[g++] = a[i];
    }
}


void Des::permutation()
{
    p[0] = sub[15]; p[1] = sub[6];  p[2] = sub[19];   p[3] = sub[20];
    p[4] = sub[28]; p[5] = sub[11]; p[6] = sub[27];   p[7] = sub[16];
    p[8] = sub[0];  p[9] = sub[14]; p[10] = sub[22];  p[11] = sub[25];
    p[12] = sub[4]; p[13] = sub[17];p[14] = sub[30];  p[15] = sub[9];
    p[16] = sub[1]; p[17] = sub[7]; p[18] = sub[23];  p[19] = sub[13];
    p[20] = sub[31];p[21] = sub[26];p[22] = sub[2];   p[23] = sub[8];
    p[24] = sub[18];p[25] = sub[12];p[26] = sub[29];  p[27] = sub[5];
    p[28] = sub[21];p[29] = sub[10];p[30] = sub[3];   p[31] = sub[24];
}


void Des::xor_two()
{
    int i;
    for (i = 0; i < 32; i++)
    {
        xor2[i] = left[i] ^ p[i];
    }
}


void Des::inverse()
{
    int p = 40, q = 8, k1, k2, i, j;
    for (i = 0; i < 8; i++)
    {
        k1 = p;
        k2 = q;
        for (j = 0; j < 8; j++)
        {
            if (j % 2 == 0)
            {
                inv[i][j] = temp[k1 - 1];
                k1 = k1 + 8;
            }
            else if (j % 2 != 0)
            {
                inv[i][j] = temp[k2 - 1];
                k2 = k2 + 8;
            }
        }
        p = p - 1;
        q = q - 1;
    }
```

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```
}


char *Des::Encrypt(char *Text1)
{
    int i, a1, j, nB, m, iB, k, K, B[8], n, t, d, round;
    char *Text = new char[1000];
    strcpy(Text, Text1);
    i = strlen(Text);
    int mc = 0;
    a1 = i % 8;
    if (a1 != 0)
        for (j = 0; j < 8 - a1; j++, i++)
            Text[i] = ' ';
    Text[i] = '\0';
    keygen();
    for (iB = 0, nB = 0, m = 0; m < (strlen(Text) / 8); m++)
    {
        for (iB = 0, i = 0; i < 8; i++, nB++)
        {
            n = (int)Text[nB];
            for (K = 7; n >= 1; K--)
            {
                B[K] = n % 2;
                n /= 2;
            }
            for (; K >= 0; K--)
                B[K] = 0;
            for (K = 0; K < 8; K++, iB++)
                total[iB] = B[K];
        }
        Init_perm();
        for (i = 0; i < 64; i++)
            total[i] = ip[i];

        for (i = 0; i < 32; i++)
            left[i] = total[i];

        for (; i < 64; i++)
            right[i - 32] = total[i];
        for (round = 1; round <= 16; round++)
        {
            E_Function();
            xor_oneE(round);
            substitution();
            permutation();
            xor_two();
            for (i = 0; i < 32; i++)
                left[i] = right[i];
            for (i = 0; i < 32; i++)
                right[i] = xor2[i];
        }
        for (i = 0; i < 32; i++)
            temp[i] = right[i];
        for (; i < 64; i++)
            temp[i] = left[i - 32];
        inverse();
```

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```
        k = 128;
        d = 0;
        for (i = 0; i < 8; i++)
        {
            for (j = 0; j < 8; j++)
            {
                d = d + inv[i][j] * k;
                k = k / 2;
            }
            final[mc++] = (char)d;
            k = 128;
            d = 0;
        }
    } //for loop ends here
    final[mc] = '\0';
    return (final);
}


char *Des::Decrypt(char *Text1)
{
    int i, a1, j, nB, m, iB, k, K, B[8], n, t, d, round;
    char *Text = new char[1000];
    unsigned char ch;
    strcpy(Text, Text1);
    i = strlen(Text);
    keygen();
    int mc = 0;
    for (iB = 0, nB = 0, m = 0; m < (strlen(Text) / 8); m++)
    {
        for (iB = 0, i = 0; i < 8; i++, nB++)
        {
            ch = Text[nB];
            n = (int)ch;
            for (K = 7; n >= 1; K--)
            {
                B[K] = n % 2;
                n /= 2;
            }
            for (; K >= 0; K--)
                B[K] = 0;
            for (K = 0; K < 8; K++, iB++)
                total[iB] = B[K];
        }
        Init_perm();
        for (i = 0; i < 64; i++)
            total[i] = ip[i];
        for (i = 0; i < 32; i++)
            left[i] = total[i];
        for (; i < 64; i++)
            right[i - 32] = total[i];
        for (round = 1; round <= 16; round++)
        {
            E_Function();
            xor_oneD(round);
            substitution();
            permutation();
```

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```
            xor_two();
            for (i = 0; i < 32; i++)
                left[i] = right[i];
            for (i = 0; i < 32; i++)
                right[i] = xor2[i];
        }
        for (i = 0; i < 32; i++)
            temp[i] = right[i];
        for (; i < 64; i++)
            temp[i] = left[i - 32];
        inverse();
        k = 128;
        d = 0;
        for (i = 0; i < 8; i++)
        {
            for (j = 0; j < 8; j++)
            {
                d = d + inv[i][j] * k;
                k = k / 2;
            }
            final[mc++] = (char)d;
            k = 128;
            d = 0;
        }
    } //for loop ends here
    final[mc] = '\0';
    char *final1 = new char[1000];
    for (i = 0, j = strlen(Text); i < strlen(Text); i++, j++)
        final1[i] = final[j];
    final1[i] = '\0';
    return (final);
}


void Des::keygen()
{
    PermChoice1();

    int i, j, k = 0;
    for (i = 0; i < 28; i++)
    {
        ck[i] = pc1[i];
    }
    for (i = 28; i < 56; i++)
    {
        dk[k] = pc1[i];
        k++;
    }
    int noshift = 0, round;
    for (round = 1; round <= 16; round++)
    {
        if (round == 1 || round == 2 || round == 9 || round == 16)
            noshift = 1;
        else
            noshift = 2;
        while (noshift > 0)
        {
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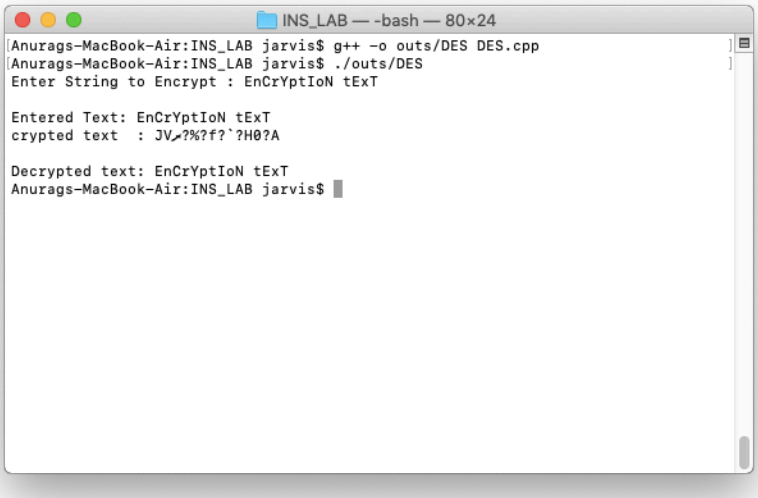
```
            int t;
            t = ck[0];
            for (i = 0; i < 28; i++)
                ck[i] = ck[i + 1];
            ck[27] = t;
            t = dk[0];
            for (i = 0; i < 28; i++)
                dk[i] = dk[i + 1];
            dk[27] = t;
            noshift--;
        }
        PermChoice2();
        for (i = 0; i < 48; i++)
            round_key[round - 1][i] = z[i];
    }
}


int main()
{
    Des d1, d2;
    char *str = new char[1000];
    char *str1 = new char[1000];
    cout << "Enter String to Encrypt : ";
    cin.getline(str, 1000);
    str1 = d1.Encrypt(str);
    cout << "\nEntered Text: " << str << endl;
    cout << "\Encrypted text  : " << str1 << endl;
    cout << "\nDecrypted text: " << d2.Decrypt(str1) << endl;
}
```

Results and Outputs:



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Findings and Learnings:

1. We have implemented DES for Encryption and Decryption