Cryptography & Network Security

PRN - 2019BTECS00026

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Batch - B1

Assignment - 6

Title: Data encryption standard

Aim: To Demonstrate Data encryption standard

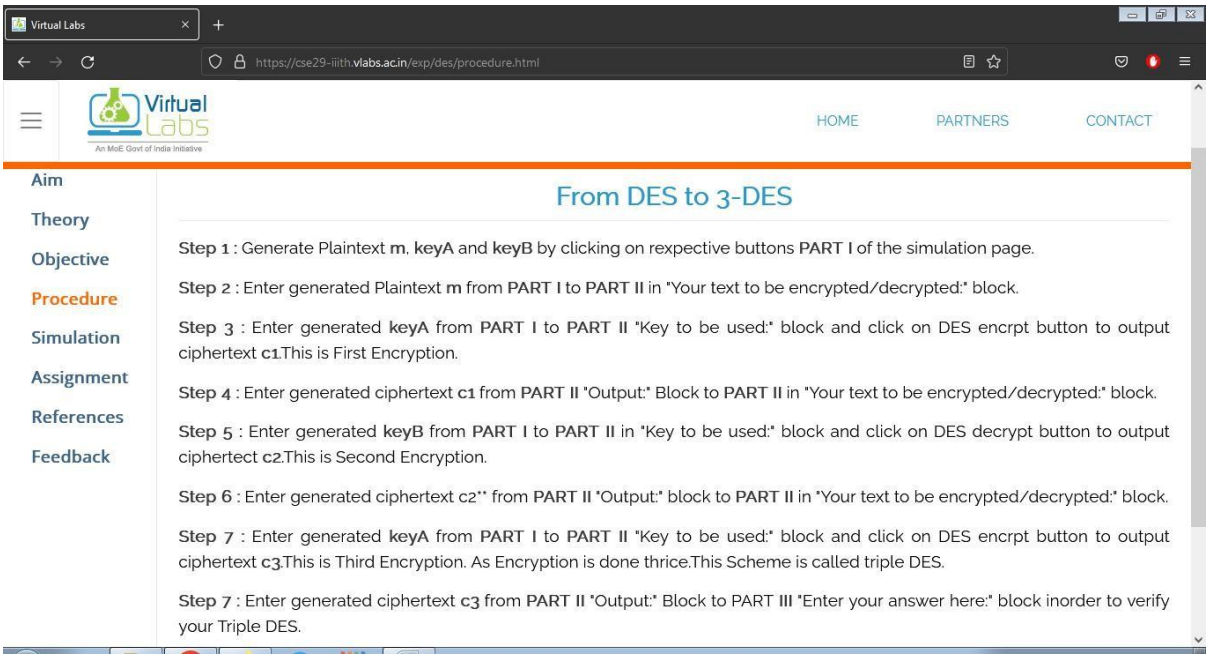
Theory:

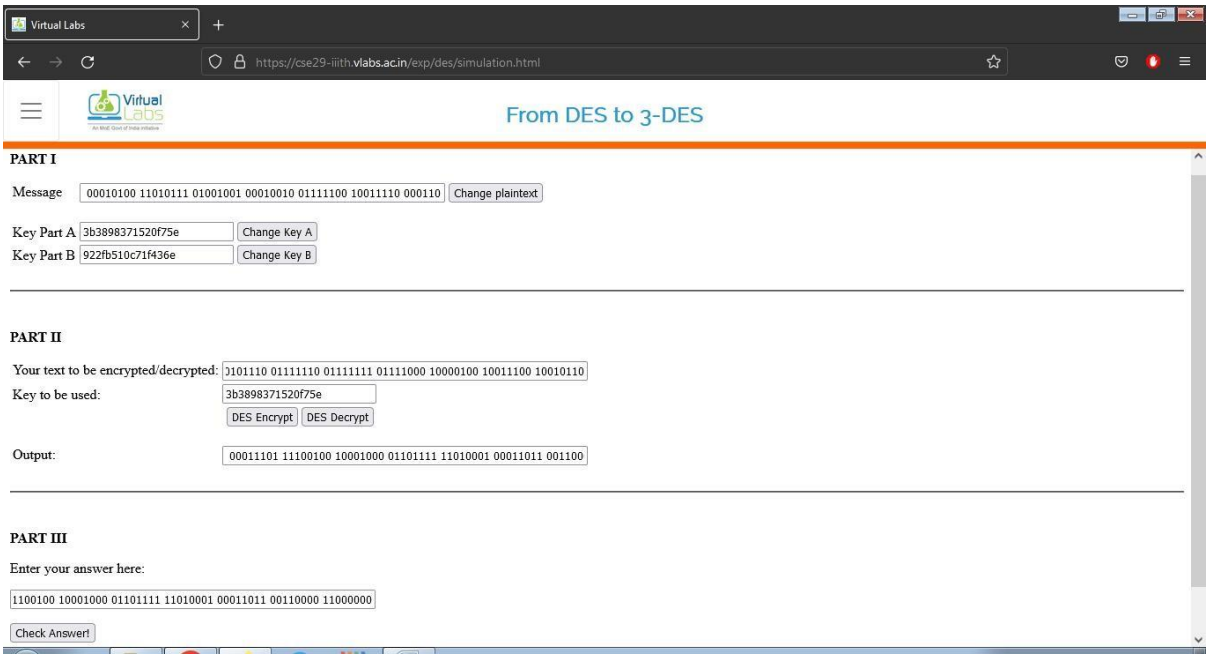
The Data Encryption Standard (DES) is a symmetric-key block cipher published by the National Institute of Standards and Technology (NIST). DES is an implementation of a Feistel Cipher. It uses 16 round Feistel structure. The block size is 64-bit. Though, key length is 64-bit, DES has an effective key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

Procedure:

1) In the first step, the 64-bit plain text block is handed over to an initial Permutation (IP) function.
2) The initial permutation is performed on plain text.
3) Next, the initial permutation (IP) produces two halves of the permuted block; saying Left Plain Text (LPT) and Right Plain Text (RPT).
4) Now each LPT and RPT go through 16 rounds of the encryption process.
5) In the end, LPT and RPT are rejoined and a Final Permutation (FP) is performed on the combined block
6) The result of this process produces 64-bit ciphertext.

Virtual Lab:





Code:

```cpp
#include <bits/stdc++.h>
using namespace std;

string hex2bin(string s)
{
    unordered_map<char, string> mp;
    mp['0'] = "0000";
    mp['1'] = "0001";
    mp['2'] = "0010";
    mp['3'] = "0011";
    mp['4'] = "0100";
    mp['5'] = "0101";
    mp['6'] = "0110";
    mp['7'] = "0111";
```

```
    mp['8'] = "1000";
    mp['9'] = "1001";
    mp['A'] = "1010";
    mp['B'] = "1011";
    mp['C'] = "1100";
    mp['D'] = "1101";
    mp['E'] = "1110";
    mp['F'] = "1111";
    string bin = "";
    for (int i = 0; i < s.size(); i++)
    {
        bin += mp[s[i]];
    }
    return bin;
}
string bin2hex(string s)
{
    unordered_map<string, string> mp;
    mp["0000"] = "0";
    mp["0001"] = "1";
    mp["0010"] = "2";
    mp["0011"] = "3";
    mp["0100"] = "4";
    mp["0101"] = "5";
    mp["0110"] = "6";
    mp["0111"] = "7";
    mp["1000"] = "8";
    mp["1001"] = "9";
    mp["1010"] = "A";
    mp["1011"] = "B";
    mp["1100"] = "C";
    mp["1101"] = "D";
    mp["1110"] = "E";
    mp["1111"] = "F";
    string hex = "";
    for (int i = 0; i < s.length(); i += 4)
    {
        string ch = "";
        ch += s[i];
        ch += s[i + 1];
        ch += s[i + 2];
        ch += s[i + 3];
        hex += mp[ch];
    }
    return hex;
}
string permute(string k, int *arr, int n)
{
    string per = "";
    for (int i = 0; i < n; i++)
    {
        per += k[arr[i] - 1];
    }
    return per;
}
string shift_left(string k, int shifts)
{
    string s = "";
    for (int i = 0; i < shifts; i++)
    {
        for (int j = 1; j < 28; j++)
        {
            s += k[j];
        }
        s += k[0];
        k = s;
```

```
        s = "";
    }
    return k;
}
string xor_(string a, string b)
{
    string ans = "";
    for (int i = 0; i < a.size(); i++)
    {
        if (a[i] == b[i])
        {
            ans += "0";
        }
        else
        {
            ans += "1";
        }
    }
    return ans;
}
string encrypt(string pt, vector<string> rkb,
               vector<string> rk)
{
    pt = hex2bin(pt);
    int initial_perm[64] = {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};
    pt = permute(pt, initial_perm, 64);
    cout << "After initial permutation: " << bin2hex(pt)
         << endl;
    string left = pt.substr(0, 32);
    string right = pt.substr(32, 32);
    cout << "After splitting: L0=" << bin2hex(left)
         << " R0=" << bin2hex(right) << endl;
    int exp_d[48] = {32, 1, 2, 3, 4, 5, 4, 5, 6, 7, 8, 9,
                     8, 9, 10, 11, 12, 13, 12, 13, 14, 15, 16, 17,
                     16, 17, 18, 19, 20, 21, 20, 21, 22, 23, 24, 25,
                     24, 25, 26, 27, 28, 29, 28, 29, 30, 31, 32, 1};
    int s[8][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},
        {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}};
    int per[32] = {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};
    cout << endl;
    for (int i = 0; i < 16; i++)
    {
        string right_expanded = permute(right, exp_d, 48);
        string x = xor_(rkb[i], right_expanded);
        string op = "";
        for (int i = 0; i < 8; i++)
        {
            int row = 2 * int(x[i * 6] - '0') + int(x[i * 6 + 5] - '0');
            int col = 8 * int(x[i * 6 + 1] - '0') + 4 * int(x[i * 6 + 2] - '0') + 2 * int(x[i * 6 + 3] -
'0') + int(x[i * 6 + 4] - '0');
            int val = s[i][row][col];
            op += char(val / 8 + '0');
            val = val % 8;
            op += char(val / 4 + '0');
            val = val % 4;
            op += char(val / 2 + '0');
            val = val % 2;
            op += char(val + '0');
        }
        op = permute(op, per, 32);
        x = xor_(op, left);
        left = x;
        if (i != 15)
        {
            swap(left, right);
        }
        cout << "Round " << i + 1 << " " << bin2hex(left)
             << " " << bin2hex(right) << " " << rk[i]
             << endl;
    }
    string combine = left + right;
    int final_perm[64] = {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};
    string cipher = bin2hex(permute(combine, final_perm, 64));
    return cipher;
}
int main()
{
    string pt, key;
    // pt = "123456ABCD132536";
    // key = "AABB09182736CCDD";
```

```
    cout << "Enter plain text(in hexadecimal): ";
    cin >> pt;
    cout << "Enter key(in hexadecimal): ";
    cin >> key;
    key = hex2bin(key);
    int keyp[56] = {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};
    key = permute(key, keyp, 56);
    int shift_table[16] = {1, 1, 2, 2, 2, 2, 2, 2,
                           1, 2, 2, 2, 2, 2, 2, 1};
    int key_comp[48] = {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};
    string left = key.substr(0, 28);
    string right = key.substr(28, 28);
    vector<string> rkb;
    vector<string> rk;
    for (int i = 0; i < 16; i++)
    {
        left = shift_left(left, shift_table[i]);
        right = shift_left(right, shift_table[i]);
        string combine = left + right;
        string RoundKey = permute(combine, key_comp, 48);
        rkb.push_back(RoundKey);
        rk.push_back(bin2hex(RoundKey));
    }
    cout << "\nEncryption:\n\n";
    string cipher = encrypt(pt, rkb, rk);
    cout << "\nCipher Text: " << cipher << endl;
    cout << "\nDecryption\n\n";
    reverse(rkb.begin(), rkb.end());
    reverse(rk.begin(), rk.end());
    string text = encrypt(cipher, rkb, rk);
    cout << "\nPlain Text: " << text << endl;
}
```

Output:

```
D:\BTECH\CNS_LAB\6 - Data Encryption Standard>cd "d:\BTECH\CNS_LAB\6 - D
LAB\6 - Data Encryption Standard\"DES
Enter plain text: ENCRYPTS
Enter key: DECRYPTS

Encryption:

After initial permutation: FFF843950000128E
After splitting: L0=FFF84395 R0=0000128E

Round 1 0000128E 8DA3192D B092CA582111
Round 2 8DA3192D 17123045 B01AD2A48035
Round 3 17123045 6FF0DB0F 347A50030EC2
Round 4 6FF0DB0F 902E63EC 0675541C8111
Round 5 902E63EC 5088C787 4E4555034444
Round 6 5088C787 55A73965 4FC12948A180
Round 7 55A73965 6EA8C586 8B81ABA0440D
Round 8 6EA8C586 463EA0A5 B90A8B4A1282
Round 9 463EA0A5 9566886E 391A8A08A132
Round 10 9566886E B51A77E3 3038CC254C04
Round 11 B51A77E3 8099499F 106C544800D2
Round 12 8099499F 57CC9559 446D3485C00D
Round 13 57CC9559 B09FCCE4 C6A5250216C0
Round 14 B09FCCE4 1D7B07E1 CB8623988125
Round 15 1D7B07E1 B400F9EF E992AA024E80
Round 16 D357ED6F B400F9EF A192AA0038C2

Cipher Text(Hex): 5F53970FD88F5FCE
Cipher Text(Plain Text): _Sù¤╪Å_╬

Decryption

After initial permutation: D357ED6FB400F9EF
After splitting: L0=D357ED6F R0=B400F9EF
```

```
Decryption

After initial permutation: D357ED6FB400F9EF
After splitting: L0=D357ED6F R0=B400F9EF

Round 1 B400F9EF 1D7B07E1 A192AA0038C2
Round 2 1D7B07E1 B09FCCE4 E992AA024E80
Round 3 B09FCCE4 57CC9559 CB8623988125
Round 4 57CC9559 8099499F C6A5250216C0
Round 5 8099499F B51A77E3 446D3485C00D
Round 6 B51A77E3 9566886E 106C544800D2
Round 7 9566886E 463EA0A5 3038CC254C04
Round 8 463EA0A5 6EA8C586 391A8A08A132
Round 9 6EA8C586 55A73965 B90A8B4A1282
Round 10 55A73965 5088C787 8B81ABA0440D
Round 11 5088C787 902E63EC 4FC12948A180
Round 12 902E63EC 6FF0DB0F 4E4555034444
Round 13 6FF0DB0F 17123045 0675541C8111
Round 14 17123045 8DA3192D 347A50030EC2
Round 15 8DA3192D 0000128E B01AD2A48035
Round 16 FFF84395 0000128E B092CA582111

Plain Text: ENCRYPTS

D:\BTECH\CNS_LAB\6 - Data Encryption Standard>
```

Conclusion:

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

1) Avalanche effect − A small change in plaintext results in a great change in the ciphertext.
2) Completeness − Each bit of ciphertext depends on many bits of plaintext.