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Batch: B1

Assignment: 5

Title of assignment: Implementation of DES – Data Encryption Standard

Title:

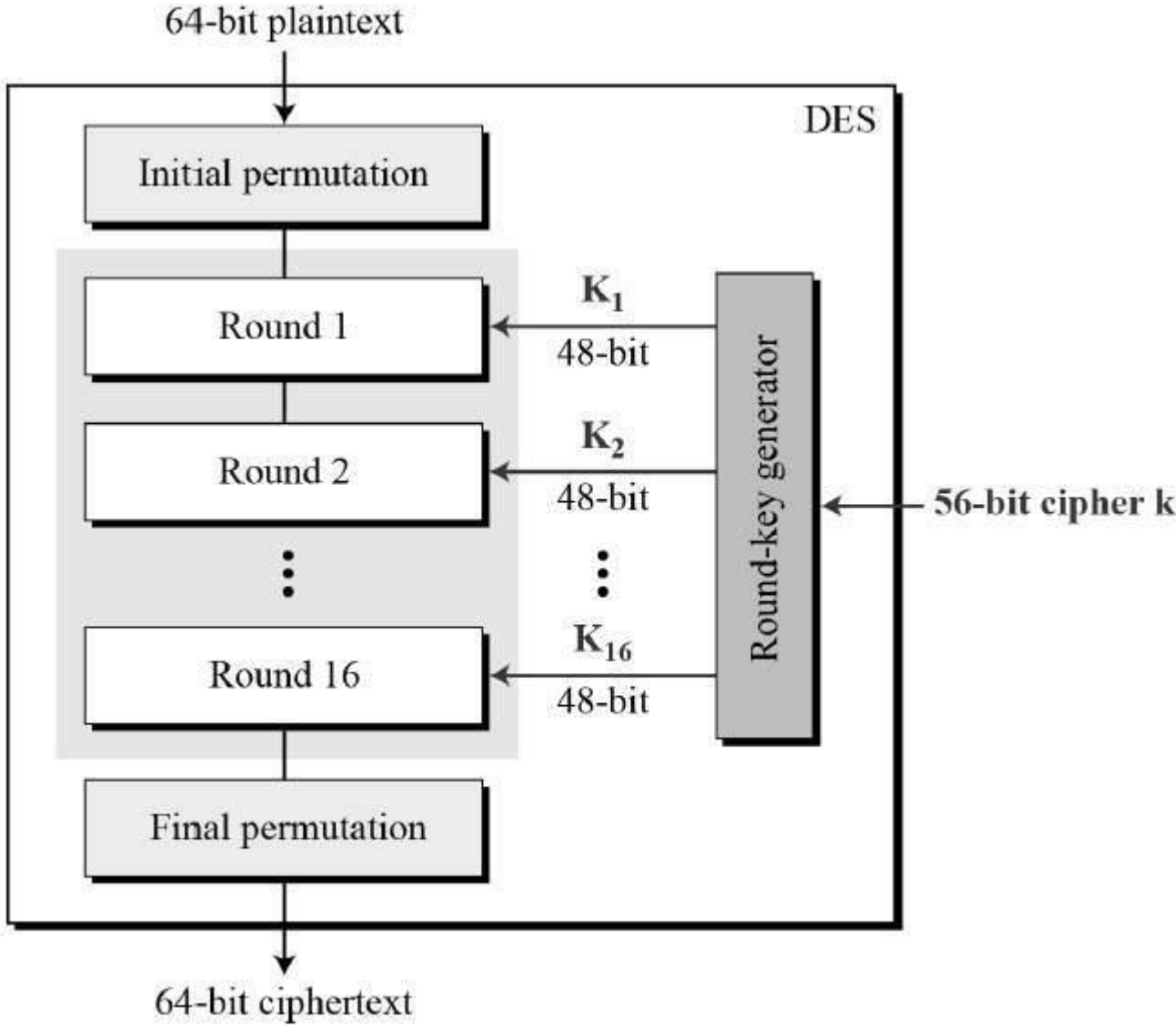
Implementation of Data Encryption Standard

Aim:

To develop and implement the Data Encryption Standard and to do encryption and decryption on the input plaintext

Theory:

- The Data Encryption Standard (DES) is a symmetric key block cipher published by National Institute of Standard and Technology (NIST)
- DES is an implementation of a Feistel Cipher. It uses 16 round Feistel structure.
- DES is a block cipher and encrypts data in blocks of size of 64 bits each
- 64 bits of plain text go as the input to DES, which produces 64 bits of ciphertext.
- 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



- Since DES is based on the Feistel Cipher, all that is required to specify DES is
  - Round function
  - Key schedule
  - Any additional processing − Initial and final permutation

Implementation of Data Encryption Standard

Code:

```
// DES
#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,
```

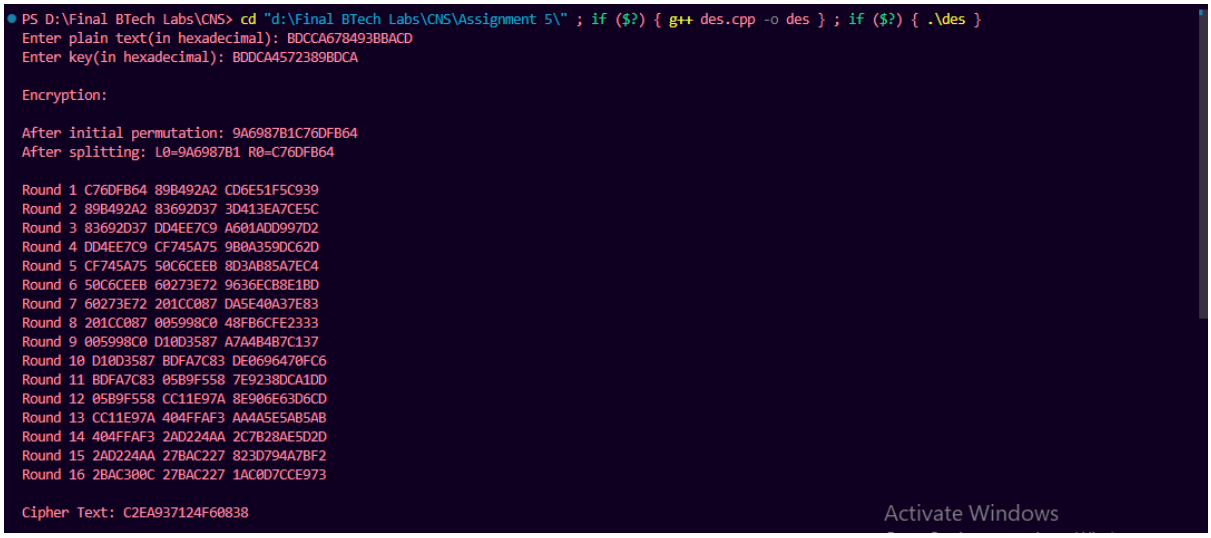
```
         2, 12, 1, 10, 14, 9, 10, 6, 9, 0, 12, 11, 7,
         13, 15, 1, 3, 14, 5, 2, 8, 4, 3, 15, 0, 6,
         10, 1, 13, 8, 9, 4, 5, 11, 12, 7, 2, 14},
        {2, 12, 4, 1, 7, 10, 11, 6, 8, 5, 3, 15, 13,
         0, 14, 9, 14, 11, 2, 12, 4, 7, 13, 1, 5, 0,
         15, 10, 3, 9, 8, 6, 4, 2, 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;
    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:



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.