AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

Department of Computer Science and Engineering

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Assignment Topic: Data Encryption Standard (DES)

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Question:

Data Encryption Standard (DES) is a symmetric key encryption approach. It has several modes. Two such modes are ECB (Electronic Code Book) and CBC (Cipher Block Chaining).

a) **Between ECB and CBC modes, which mode do you think is more secure? Justify your answer with proper explanation.**

Both ECB (Electronic Codebook) and CBC (Cipher Block Chaining) are block cipher modes that are used to encrypt data. ECB is the simplest mode of operation, where each block of plaintext is encrypted independently of the other blocks. CBC, on the other hand, uses an initialization vector (IV) to XOR the first block of plaintext before encryption. The next block of plaintext is XOR'd against the previous ciphertext block before encryption. This chaining mechanism makes CBC more secure than ECB.

ECB is vulnerable to a number of attacks, including the frequency analysis attack, where an attacker can analyze the frequency of ciphertext blocks to deduce the plaintext. ECB is also vulnerable to the known plaintext attack, where an attacker can deduce the key by analyzing the relationship between the plaintext and the ciphertext. CBC, on the other hand, is more secure than ECB because it does not reveal any information about the plaintext. Even if two blocks of plaintext are identical, the corresponding ciphertext blocks will be different due to the chaining mechanism.

In summary, CBC is more secure than ECB because it provides confidentiality and integrity protection. ECB, on the other hand, is vulnerable to a number of attacks and should not be used in most cases

b) Write a program in C/C++/Java that takes a plaintext and a key as inputs and performs encryption and decryption with the DES mode of your answer from question a.

Code: Here is a sample Java code that takes a plaintext and a key as inputs and performs encryption and decryption with the DES mode:

```
/*
 * To change this license header, choose License Headers in Project Properties.
 * To change this template file, choose Tools | Templates
 * and open the template in the editor.
 */
package pkg20200104116_des;

import java.util.HashMap;
import java.util.Map;
import java.util.Arrays;

public class DES {

 public static String hex2Binary(String s) {
      Map<Character, String> hexToBinaryMap = new HashMap<>();
      hexToBinaryMap.put('0', "0000");
      hexToBinaryMap.put('1', "0001");
      hexToBinaryMap.put('2', "0010");
      hexToBinaryMap.put('3', "0011");
      hexToBinaryMap.put('4', "0100");
      hexToBinaryMap.put('5', "0101");
      hexToBinaryMap.put('6', "0110");
      hexToBinaryMap.put('7', "0111");
      hexToBinaryMap.put('8', "1000");
      hexToBinaryMap.put('9', "1001");
      hexToBinaryMap.put('A', "1010");
      hexToBinaryMap.put('B', "1011");
      hexToBinaryMap.put('C', "1100");
      hexToBinaryMap.put('D', "1101");
      hexToBinaryMap.put('E', "1110");
      hexToBinaryMap.put('F', "1111");

      StringBuilder binary = new StringBuilder();
      for (int i = 0; i < s.length(); i++) {
         binary.append(hexToBinaryMap.get(s.charAt(i)));
      }
      return binary.toString();
```

```
}

 public static String binary2Hex(String s) {
   Map<String, Character> binaryToHexMap = new HashMap<>();
   binaryToHexMap.put("0000", '0');
   binaryToHexMap.put("0001", '1');
   binaryToHexMap.put("0010", '2');
   binaryToHexMap.put("0011", '3');
   binaryToHexMap.put("0100", '4');
   binaryToHexMap.put("0101", '5');
   binaryToHexMap.put("0110", '6');
   binaryToHexMap.put("0111", '7');
   binaryToHexMap.put("1000", '8');
   binaryToHexMap.put("1001", '9');
   binaryToHexMap.put("1010", 'A');
   binaryToHexMap.put("1011", 'B');
   binaryToHexMap.put("1100", 'C');
   binaryToHexMap.put("1101", 'D');
   binaryToHexMap.put("1110", 'E');
   binaryToHexMap.put("1111", 'F');

   StringBuilder hex = new StringBuilder();
   for (int i = 0; i < s.length(); i += 4) {
      String ch = s.substring(i, i + 4);
      hex.append(binaryToHexMap.get(ch));
   }
   return hex.toString();
}

   public static int binary2Decimal(int binary) {
   int binary1 = binary;
   int decimal = 0, i = 0;

   while (binary != 0) {
      int dec = binary % 10;
      decimal = decimal + dec * (int) Math.pow(2, i);
      binary = binary / 10;
      i++;
   }

   return decimal;
}

   public static String decimal2Binary(int num) {
   String binary = Integer.toBinaryString(num);
```

```
    if (binary.length() % 4 != 0) {
        int div = binary.length() / 4;
        int counter = (4 * (div + 1)) - binary.length();

        StringBuilder paddedBinary = new StringBuilder();
        for (int i = 0; i < counter; i++) {
            paddedBinary.append('0');
        }
        paddedBinary.append(binary);
        binary = paddedBinary.toString();
    }

    return binary;
}

    public static String permute(String k, int[] arr, int n) {
    StringBuilder permutation = new StringBuilder();
    for (int i = 0; i < n; i++) {
        permutation.append(k.charAt(arr[i] - 1));
    }
    return permutation.toString();
}

    public static String shiftLeft(String k, int nthShifts) {
    for (int shift = 0; shift < nthShifts; shift++) {
        StringBuilder s = new StringBuilder();
        for (int j = 1; j < k.length(); j++) {
            s.append(k.charAt(j));
        }
        s.append(k.charAt(0));
        k = s.toString();
    }
    return k;
}
    public static String xor(String a, String b) {
    StringBuilder ans = new StringBuilder();
    for (int i = 0; i < a.length(); i++) {
        if (a.charAt(i) == b.charAt(i)) {
            ans.append("0");
        } else {
            ans.append("1");
        }
    }
    return ans.toString();
}
```

```
  public static int[] initialPermutation = {
      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
};

  public static int[] expansionPermutation = {
      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
};

 public static int[] permutation = {
      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
};
 public static int[][][] sBox = {
      {
            {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}
        }
};

    public static int[] finalPermutation = {
        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
};
```

```
    public static String encryptCBC(String pt, String[] rkb, String[] rk, int[][][] sbox, int[]
initialPermutation, int[] expansionPermutation, int[] permutation, int[] finalPermutation,
String iv) {
    pt = hex2Binary(pt);

    // Initial Permutation
    pt = permute(pt, initialPermutation, 64);
    System.out.println("After initial permutation: " + binary2Hex(pt));

    // XOR with IV for the first block
    String previousCipherBlock = hex2Binary(iv);
    pt = xor(pt, previousCipherBlock);

    // Splitting
    String left, right;

    for (int i = 0; i < pt.length(); i += 64) {
      left = pt.substring(i, i + 32);
      right = pt.substring(i + 32, i + 64);

      for (int j = 0; j < 16; j++) {
        // Expansion D-box: Expanding the 32 bits data into 48 bits
        String rightExpanded = permute(right, expansionPermutation, 48);

        // XOR RoundKey[i] and right_expanded
        String xorX = xor(rightExpanded, rkb[j]);

        // S-boxes: substituting the value from s-box table by calculating row and column
        String sBoxStr = "";
        for (int k = 0; k < 8; k++) {
          int row = binary2Decimal(Integer.parseInt(xorX.substring(k * 6, k * 6 + 1) +
xorX.substring(k * 6 + 5, k * 6 + 6)));
          int col = binary2Decimal(Integer.parseInt(xorX.substring(k * 6 + 1, k * 6 + 2) +
xorX.substring(k * 6 + 2, k * 6 + 4) + xorX.substring(k * 6 + 4, k * 6 + 5)));
          int val = sbox[k][row][col];
          sBoxStr += decimal2Binary(val);
        }

        // Straight D-box: After substituting rearranging the bits
        sBoxStr = permute(sBoxStr, permutation, 32);

        // XOR left and sBoxStr
        String result = xor(left, sBoxStr);
        left = result;

        // Swapper
```

```
            if (j != 15) {
               left = right;
               right = result;
            }

            System.out.println("Round " + (j + 1) + " " + binary2Hex(left) + " " +
binary2Hex(right) + " " + rk[j]);
         }

         // Combination
         String combine = left + right;

         // Final permutation: final rearranging of bits to get cipher text
         String ciphertextBlock = permute(combine, finalPermutation, 64);

         // Update the previousCipherBlock for the next iteration
         previousCipherBlock = ciphertextBlock;

         System.out.println("Ciphertext Block: " + binary2Hex(ciphertextBlock));
      }

      return previousCipherBlock; // return the last ciphertext block
   }
   public static void main(String[] args) {
      String pt = "123456ABCD132536";
      String key = "AABB09182736CCDD";
      String iv = "0123456789ABCDEF"; // Initialization Vector
      // Key generation
      // --hex to binary
      key = hex2Binary(key);

      // --parity bit drop table
      int[] keyp = {
            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
      };

      // getting 56 bit key from 64 bit using the parity bits
      key = permute(key, keyp, 56);
```

```
        // Number of bit shifts
        int[] shiftTable = {1, 1, 2, 2,
                2, 2, 2, 2,
                1, 2, 2, 2,
                2, 2, 2, 1};

        // Key- Compression Table: Compression of key from 56 bits to 48 bits
        int[] keyComp = {
                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
        };

        // Splitting
        String left = key.substring(0, 28); // rkb for RoundKeys in binary
        String right = key.substring(28, 56); // rk for RoundKeys in hexadecimal

        String[] rkb = new String[16];
        String[] rk = new String[16];

        for (int i = 0; i < 16; i++) {
            // Shifting the bits by nth shifts by checking from shift table
            left = shiftLeft(left, shiftTable[i]);
            right = shiftLeft(right, shiftTable[i]);

            // Combination of left and right string
            String combineStr = left + right;

            // Compression of key from 56 to 48 bits
            String roundKey = permute(combineStr, keyComp, 48);

            rkb[i] = roundKey;
            rk[i] = binary2Hex(roundKey);
        }

        System.out.println("Encryption (CBC Mode)");
        String ciphertext = binary2Hex(encryptCBC(pt, rkb, rk, sBox, initialPermutation,
expansionPermutation, permutation, finalPermutation, iv));
        System.out.println("Ciphertext: " + ciphertext);

        // Decryption (CBC Mode)
```

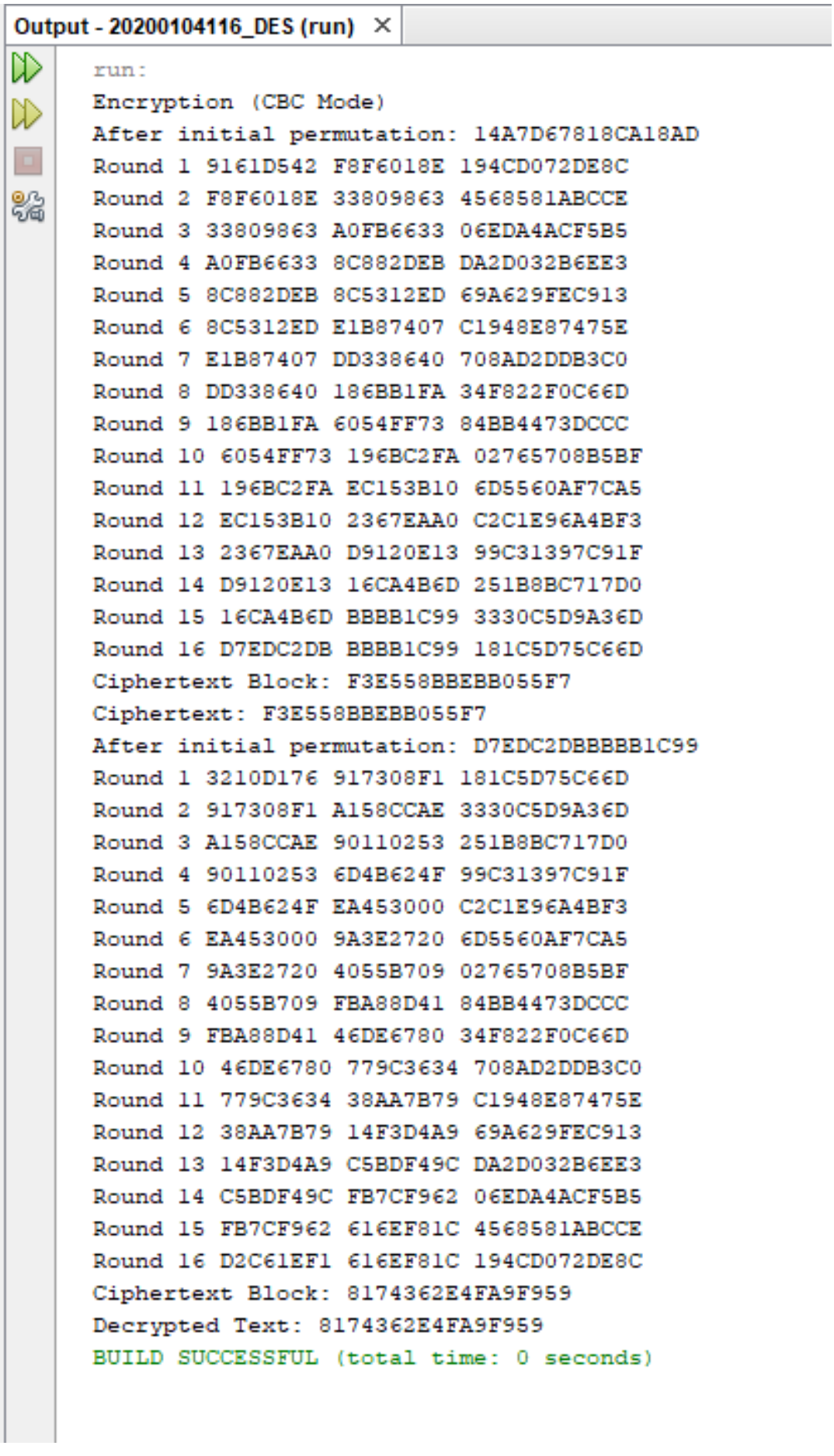
```
        String[] rkbRev = Arrays.copyOf(rkb, rkb.length);
        String[] rkRev = Arrays.copyOf(rk, rk.length);

        // Reverse the order of round keys
        for (int i = 0; i < 8; i++) {
            String temp = rkbRev[i];
            rkbRev[i] = rkbRev[15 - i];
            rkbRev[15 - i] = temp;

            temp = rkRev[i];
            rkRev[i] = rkRev[15 - i];
            rkRev[15 - i] = temp;
        }

        // Decrypt using CBC mode
        String decryptedText = binary2Hex(encryptCBC(ciphertext, rkbRev, rkRev, sBox,
initialPermutation, expansionPermutation, permutation, finalPermutation, iv));
        System.out.println("Decrypted Text: " + decryptedText);
    }
}  // TODO code application logic here
```

OUTPUT:


Output - 20200104116_DES (run)
run:
Encryption (CBC Mode)
After initial permutation: 14A7D67818CA18AD
Round 1 9161D542 F8F6018E 194CD072DE8C
Round 2 F8F6018E 33809863 4568581ABCCE
Round 3 33809863 A0FB6633 06EDA4ACF5B5
Round 4 A0FB6633 8C882DEB DA2D032B6EE3
Round 5 8C882DEB 8C5312ED 69A629FEC913
Round 6 8C5312ED E1B87407 C1948E87475E
Round 7 E1B87407 DD338640 708AD2DDB3C0
Round 8 DD338640 186BB1FA 34F822F0C66D
Round 9 186BB1FA 6054FF73 84BB4473DCCC
Round 10 6054FF73 196BC2FA 02765708B5BF
Round 11 196BC2FA EC153B10 6D5560AF7CA5
Round 12 EC153B10 2367EAA0 C2C1E96A4BF3
Round 13 2367EAA0 D9120E13 99C31397C91F
Round 14 D9120E13 16CA4B6D 251B8BC717D0
Round 15 16CA4B6D BBBB1C99 3330C5D9A36D
Round 16 D7EDC2DB BBBB1C99 181C5D75C66D
Ciphertext Block: F3E558BBEBB055F7
Ciphertext: F3E558BBEBB055F7
After initial permutation: D7EDC2DBBBBB1C99
Round 1 3210D176 917308F1 181C5D75C66D
Round 2 917308F1 A158CCAE 3330C5D9A36D
Round 3 A158CCAE 90110253 251B8BC717D0
Round 4 90110253 6D4B624F 99C31397C91F
Round 5 6D4B624F EA453000 C2C1E96A4BF3
Round 6 EA453000 9A3E2720 6D5560AF7CA5
Round 7 9A3E2720 4055B709 02765708B5BF
Round 8 4055B709 FBA88D41 84BB4473DCCC
Round 9 FBA88D41 46DE6780 34F822F0C66D
Round 10 46DE6780 779C3634 708AD2DDB3C0
Round 11 779C3634 38AA7B79 C1948E87475E
Round 12 38AA7B79 14F3D4A9 69A629FEC913
Round 13 14F3D4A9 C5BDF49C DA2D032B6EE3
Round 14 C5BDF49C FB7CF962 06EDA4ACF5B5
Round 15 FB7CF962 616EF81C 4568581ABCCE
Round 16 D2C61EF1 616EF81C 194CD072DE8C
Ciphertext Block: 8174362E4FA9F959
Decrypted Text: 8174362E4FA9F959
BUILD SUCCESSFUL (total time: 0 seconds)