
**AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY**

Department of Computer Science and Engineering

Program: Bachelor of Science in Computer Science and Engineering

Course Code: CSE 4174
Course Title: Cyber Security Lab
Academic Semester: Spring 2023

Assignment Topic: Data Encryption Standard (DES)

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**Question:**

**a) Devise a program for implementation of CFB-64 mode of DES..**

*Code: Here is a sample Java code that takes a plaintext and a key as inputs and performs 64 bit encryption and decryption with the DES in CFB mode:*

```
/*
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 * 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 encryptCFB(String pt, String[] rkb, String[] rk, int[][][] sbox, int[]
initialPermutation, int[] expansionPermutation, int[] permutation, int[] finalPermutation,
String iv) {
```

```
    pt = hex2Binary(pt);

    // Initial Permutation
    iv = hex2Binary(iv);
    iv = permute(iv, initialPermutation, 64);
    System.out.println("After initial permutation: " + binary2Hex(iv));

    // Splitting
    String left, right;

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

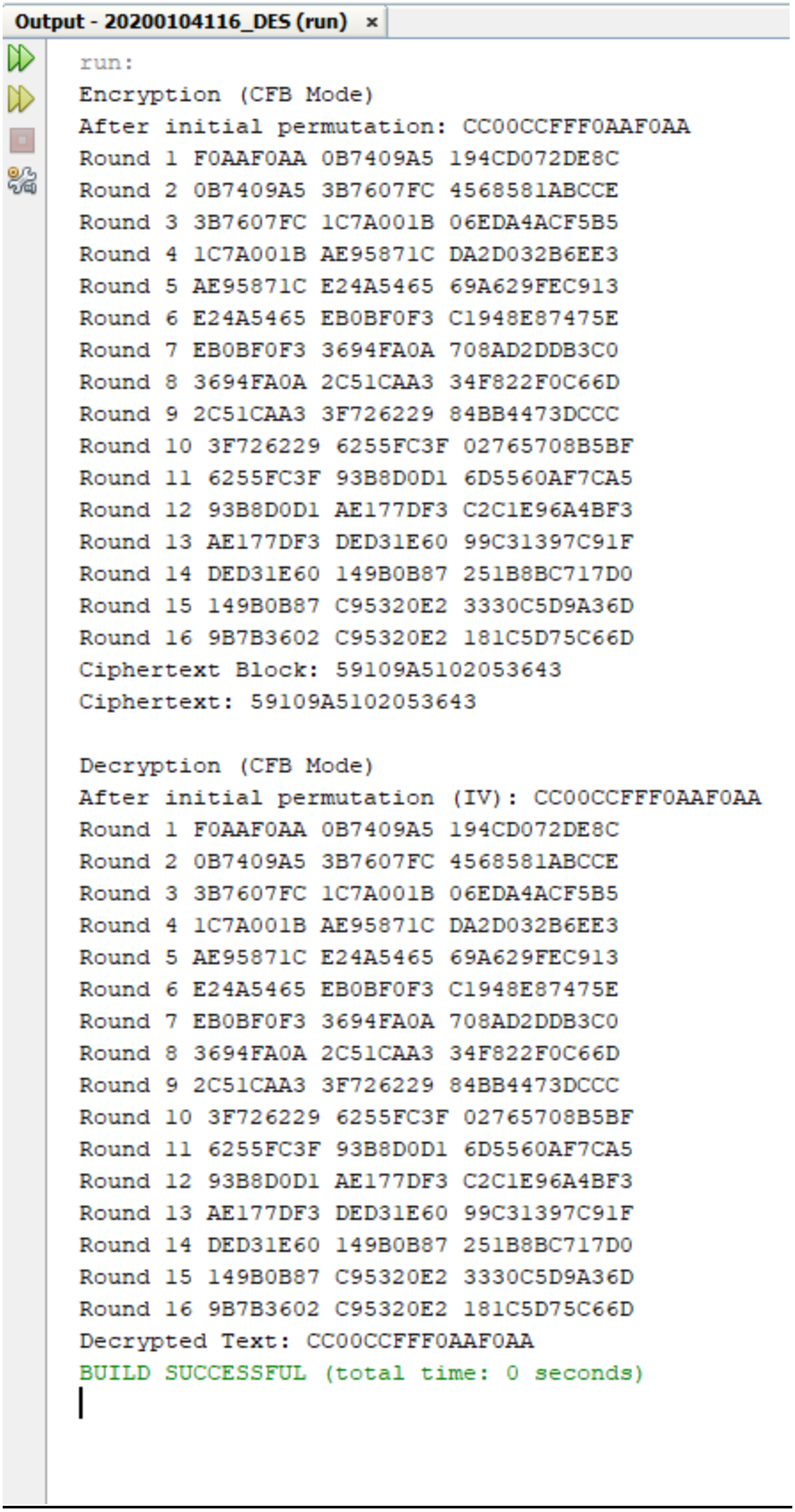
```
        System.out.println("Round " + (j + 1) + " " + binary2Hex(left) + " " +
binary2Hex(right) + " " + rk[j]);
      }

      // Combine and XOR with plaintext
      String combine = left + right;
      combine = xor(combine, pt.substring(i, i + 64));

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

      // Update IV for the next iteration
      iv = ciphertextBlock;

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

   return iv; // return the last IV block
}
public static String decryptCFB(String ct, String[] rkb, String[] rk, int[][][] sbox, int[]
initialPermutation, int[] expansionPermutation, int[] permutation, int[] finalPermutation,
String iv) {
   ct = hex2Binary(ct);

   // Initial Permutation for IV
   iv = hex2Binary(iv);
   iv = permute(iv, initialPermutation, 64);
   System.out.println("After initial permutation (IV): " + binary2Hex(iv));

   // Splitting IV into left and right parts
   String leftIV = iv.substring(0, 32);
   String rightIV = iv.substring(32, 64);

   // Splitting ciphertext
   String left, right;

   for (int i = 0; i < ct.length(); i += 64) {
      // Perform DES encryption on IV
      for (int j = 0; j < 16; j++) {
         // Expansion D-box: Expanding the 32 bits data into 48 bits
         String rightIVExpanded = permute(rightIV, expansionPermutation, 48);

         // XOR RoundKey[i] and right_expanded
         String xorX = xor(rightIVExpanded, 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 leftIV and sBoxStr
        String result = xor(leftIV, sBoxStr);
        leftIV = result;

        // Swapper
        if (j != 15) {
            leftIV = rightIV;
            rightIV = result;
        }

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

    // Combine and XOR with ciphertext
    String combine = leftIV + rightIV;
    combine = xor(combine, ct.substring(i, i + 64));

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

    // Update IV for the next iteration
    leftIV = ct.substring(i, i + 32);
    rightIV = ct.substring(i + 32, i + 64);

    //System.out.println("Plaintext Block: " + binary2Hex(plaintextBlock));
  }

  return iv; // return the last IV block
}


public static void main(String[] args) {
```

```
    String pt = "123456ABCD132536";
    String key = "AABB09182736CCDD";
    String iv = "0123456789ABCDEF"; // Initialization Vector

    // Key generation
    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
    };

    key = permute(key, keyp, 56);

    int[] shiftTable = {1, 1, 2, 2, 2, 2, 2, 2, 1, 2, 2, 2, 2, 2, 2, 1};
    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};

    String left = key.substring(0, 28);
    String right = key.substring(28, 56);

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

    for (int i = 0; i < 16; i++) {
        left = shiftLeft(left, shiftTable[i]);
        right = shiftLeft(right, shiftTable[i]);
        String combineStr = left + right;
        String roundKey = permute(combineStr, keyComp, 48);
        rkb[i] = roundKey;
        rk[i] = binary2Hex(roundKey);
    }

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

```
    // Decryption (CFB Mode)
    System.out.println("\nDecryption (CFB Mode)");
    String decryptedText = binary2Hex(decryptCFB(ciphertext, rkb, rk, sBox,
initialPermutation, expansionPermutation, permutation, finalPermutation, iv));
    System.out.println("Decrypted Text: " + decryptedText);
}
}

  // TODO code application logic here
```

**OUTPUT:**


Output - 20200104116_DES (run)
run:
Encryption (CFB Mode)
After initial permutation: CC00CCFFF0AAF0AA
Round 1 F0AAF0AA 0B7409A5 194CD072DE8C
Round 2 0B7409A5 3B7607FC 4568581ABCCE
Round 3 3B7607FC 1C7A001B 06EDA4ACF5B5
Round 4 1C7A001B AE95871C DA2D032B6EE3
Round 5 AE95871C E24A5465 69A629FEC913
Round 6 E24A5465 EB0BF0F3 C1948E87475E
Round 7 EB0BF0F3 3694FA0A 708AD2DDB3C0
Round 8 3694FA0A 2C51CAA3 34F822F0C66D
Round 9 2C51CAA3 3F726229 84BB4473DCCC
Round 10 3F726229 6255FC3F 02765708B5BF
Round 11 6255FC3F 93B8D0D1 6D5560AF7CA5
Round 12 93B8D0D1 AE177DF3 C2C1E96A4BF3
Round 13 AE177DF3 DED31E60 99C31397C91F
Round 14 DED31E60 149B0B87 251B8BC717D0
Round 15 149B0B87 C95320E2 3330C5D9A36D
Round 16 9B7B3602 C95320E2 181C5D75C66D
Ciphertext Block: 59109A5102053643
Ciphertext: 59109A5102053643
Decryption (CFB Mode)
After initial permutation (IV): CC00CCFFF0AAF0AA
Round 1 F0AAF0AA 0B7409A5 194CD072DE8C
Round 2 0B7409A5 3B7607FC 4568581ABCCE
Round 3 3B7607FC 1C7A001B 06EDA4ACF5B5
Round 4 1C7A001B AE95871C DA2D032B6EE3
Round 5 AE95871C E24A5465 69A629FEC913
Round 6 E24A5465 EB0BF0F3 C1948E87475E
Round 7 EB0BF0F3 3694FA0A 708AD2DDB3C0
Round 8 3694FA0A 2C51CAA3 34F822F0C66D
Round 9 2C51CAA3 3F726229 84BB4473DCCC
Round 10 3F726229 6255FC3F 02765708B5BF
Round 11 6255FC3F 93B8D0D1 6D5560AF7CA5
Round 12 93B8D0D1 AE177DF3 C2C1E96A4BF3
Round 13 AE177DF3 DED31E60 99C31397C91F
Round 14 DED31E60 149B0B87 251B8BC717D0
Round 15 149B0B87 C95320E2 3330C5D9A36D
Round 16 9B7B3602 C95320E2 181C5D75C66D
Decrypted Text: CC00CCFFF0AAF0AA
BUILD SUCCESSFUL (total time: 0 seconds)