CNS Lab Assignment 5: SAES

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Code

```c

#include <sys/types.h>
#include <unistd.h>
#include <fcntl.h>
#include <errno.h>
#include <stdio.h>
#include <stdlib.h>
#include <stdint.h>

#define DEBUG_MODE 0
#if DEBUG_MODE
#define DEBUGPRINT(token) {printf(#token ": %x\n", token);}
#else
#define DEBUGPRINT(token) {;}
#endif


typedef uint8_t u8;

typedef uint16_t u16;

typedef uint32_t u32;

static u16 subkeys[3];

/* S-box */
static u16 S[] = {9, 4, 10, 11, 13, 1, 8, 5, 6, 2, 0, 3, 12, 14, 15, 7};

/* Inverse S-box */
static u16 invS[] =  {10, 5, 9, 11, 1, 7, 8, 15, 6, 0, 2, 3, 12, 4, 13, 14};

/* row indicates the multiplyer specified by AES
 * col is the dataword */
static u8 galois_field_multiply[16][16] = {
        {}, // 0
        {0, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f}, // 1
        {0, 0x02, 0x04, 0x06, 0x08, 0x0a, 0x0c, 0x0e, 0x03, 0x01, 0x07, 0x05, 0x0b, 0x09, 0x0f, 0x0d}, // 2
        {}, // 3
        {0, 0x04, 0x08, 0x0c, 0x03, 0x07, 0x0b, 0x0f, 0x06, 0x02, 0x0e, 0x0a, 0x05, 0x01, 0x0d, 0x09}, // 4
        {}, // 5
        {}, // 6
        {}, // 7
        {}, // 8
        {0, 0x09, 0x01, 0x08, 0x02, 0x0b, 0x03, 0x0a, 0x04, 0x0d, 0x05, 0x0c, 0x06, 0x0f, 0x07, 0x0e}, // 9
        // .. all zeros, not used
};

u8 higher_nibble(u8 in) {
        return (in & 0xf0) >> 4;
}

u8 lower_nibble(u8 in) {
        return in & 0x0f;
}

/* swap the two nibbles in 8 bit word */
u8 RotNib(u8 in) {
        u8 lower, higher;
        lower = lower_nibble(in);
        higher = higher_nibble(in);
        return (lower << 4) | higher;
}

/* substitute each nibble in byte */
u8 SubNib(u8 in) {
        u8 lower, higher;
        lower = lower_nibble(in);
        higher = higher_nibble(in);
        return (S[higher] << 4) | S[lower];
}

/* substitute each nibble in word */
u16 NibbleSubstitution(u16 in) {
        u8 n0, n1, n2, n3;
        u16 result;

        n0 = (in & 0xf000) >> 12;
        n1 = (in & 0x0f00) >> 8;
        n2 = (in & 0x00f0) >> 4;
        n3 = (in & 0x000f);

        result = S[n0] << 12
                |S[n1] << 8
                |S[n2] << 4
                |S[n3];

        return result;
}

/* inverse substitution of each nibble in word */
u16 InverseNibbleSubstitution(u16 in) {
        u8 n0, n1, n2, n3;
        u16 result;

        n0 = (in & 0xf000) >> 12;
        n1 = (in & 0x0f00) >> 8;
        n2 = (in & 0x00f0) >> 4;
        n3 = (in & 0x000f);

        result = invS[n0] << 12
                |invS[n1] << 8
                |invS[n2] << 4
                |invS[n3];

        return result;
}

/* swap the 2nd and 4th nibble of 16 bit word (MSB is a bit of first nibble) */
u16 ShiftRow(u16 in) {

        u16 clean_word;
        u8 n0, n1, n2, n3; /* 2nd and 4th nibbles */

        clean_word = in & 0xf0f0;

        n0 = (in & 0xf000) >> 12;
        n1 = (in & 0x0f00) >> 8;
        n2 = (in & 0x00f0) >> 4;
        n3 = (in & 0x000f);

        u16 result;

        result = n0 << 12
                |(n3 << 8)
                |n2 << 4
                |n1;

        return result;
}


/* generate the three subkeys needed for SAES
 * subkeys should be an array of 3 or more elements */
void generate_subkeys(u16 key) {
        u8 w0, w1, w2, w3, w4, w5;

        w0 = (key & 0xff00) >> 8;
        w1 = key & 0x00ff;

        /* 0x80 is equivalent to 10000000 */
        w2 = w0 ^ 0x80 ^ SubNib(RotNib(w1));
        w3 = w2 ^ w1;

        /* 0x30 is equivalent to 00110000 */
        w4 = w2 ^ 0x30 ^ SubNib(RotNib(w3));
        w5 = w4 ^ w3;

        subkeys[0] = (w0 << 8) | w1;
        subkeys[1] = (w2 << 8) | w3;
        subkeys[2] = (w4 << 8) | w5;
}

/* convert word to matrix */
void make_matrix(u8 mat[][2], u16 in) {

        u8 n0, n1, n2, n3;

        n0 = (in & 0xf000) >> 12;
        n1 = (in & 0x0f00) >> 8;
        n2 = (in & 0x00f0) >> 4;
        n3 = (in & 0x000f);

        mat[0][0] = n0;
        mat[1][0] = n1;
        mat[0][1] = n2;
        mat[1][1] = n3;
}

/* convert matrix to word */
u16 make_num(u8 mat[][2]) {
        u16 res;
        res = mat[0][0] << 12
                | mat[1][0] << 8
                | mat[0][1] << 4
                | mat[1][1];

        return res;
}

/* galois field multiplication */
u8 gfm(u8 en, u8 in) {
        return galois_field_multiply[en][in];
}

/* performs galois field matrix multiplication
 * res = me X md
 * NOTE: me will only contain 1, 2, 4, 9 */
void galois_matrix_multiply(u8 res[][2], const u8 me[][2], const u8 md[][2]) {

        res[0][0] = gfm(me[0][0], md[0][0]) ^ gfm(me[0][1], md[1][0]);

        DEBUGPRINT(res[0][0]);

        res[0][1] = gfm(me[0][0], md[0][1]) ^ gfm(me[0][1], md[1][1]);

        DEBUGPRINT(res[0][1]);

        res[1][0] = gfm(me[1][0], md[0][0]) ^ gfm(me[1][1], md[1][0]);

        DEBUGPRINT(res[1][0]);

        res[1][1] = gfm(me[1][0], md[0][1]) ^ gfm(me[1][1], md[1][1]);

        DEBUGPRINT(res[1][1]);
}

/* encryption operation */
u16 saes_encrypt(u16 msg, u16 key) {

        /* MixColumns Transformation */
        const static u8 Me[2][2] = {
                {1, 4},
                {4, 1},
        };

        u8 msgmat[2][2], resmat[2][2];

        u16 r0_sa, r1_ns, r1_sr, r1_mx, r1_sa, r2_ns, r2_sr, r2_sa;

        r0_sa = msg ^ subkeys[0];

        /* round 1 starts */

        DEBUGPRINT(r0_sa);

        r1_ns = NibbleSubstitution(r0_sa);

        DEBUGPRINT(r1_ns);

        r1_sr = ShiftRow(r1_ns);

        DEBUGPRINT(r1_sr);

        make_matrix(msgmat, r1_sr);

        galois_matrix_multiply(resmat, Me, msgmat);

        r1_mx = make_num(resmat);

        DEBUGPRINT(r1_mx);

        r1_sa = r1_mx ^ subkeys[1];

        DEBUGPRINT(r1_sa);

        /* round 2 starts */

        r2_ns = NibbleSubstitution(r1_sa);

        DEBUGPRINT(r2_ns);

        r2_sr = ShiftRow(r2_ns);

        DEBUGPRINT(r2_sr);

        r2_sa = r2_sr ^ subkeys[2];

        DEBUGPRINT(r2_sa);

        return r2_sa;
}

u16 saes_decrypt(u16 cipher, u16 key) {
        const static u8 Md[2][2] = {
                {9, 2},
                {2, 9},
        };

        u8 msgmat[2][2], resmat[2][2];

        u16 r2_as, r2_sr, r2_ns, r1_as, r1_imx, r1_sr, r1_ns, r0_as;

        /* inverse of round 2 operations */

        r2_as = cipher ^ subkeys[2];

        DEBUGPRINT(r2_as);

        r2_sr = ShiftRow(r2_as);

        DEBUGPRINT(r2_sr);

        r2_ns = InverseNibbleSubstitution(r2_sr);

        DEBUGPRINT(r2_ns);

        /* inverse of round 1 operation */

        r1_as = r2_ns ^ subkeys[1];

        DEBUGPRINT(r1_as);

        make_matrix(msgmat, r1_as);

        galois_matrix_multiply(resmat, Md, msgmat);

        r1_imx = make_num(resmat);

        DEBUGPRINT(r1_imx);

        r1_sr = ShiftRow(r1_imx);

        DEBUGPRINT(r1_sr);

        r1_ns = InverseNibbleSubstitution(r1_sr);

        DEBUGPRINT(r1_ns);

        /* add subkey */

        r0_as = r1_ns ^ subkeys[0];

        DEBUGPRINT(r0_as);

        return r0_as;
}


/* based on:
 * Simplified AES Example
 * Steve Gordon */

int main(int argc, char *argv[]) {
        if (argc != 5) {
                fprintf(stderr, "usage: sdes <mode> <key> <input_file> <output_file>\n");
                return EINVAL;
        }

        u16 in, op, key;
        int num;

        /* key has to be 64 bit */
        key = atoi(argv[2]) % (1 << 16);

        generate_subkeys(key);

        int fi, fo;

        char mode = argv[1][0];


        if ((fi = open(argv[3], O_RDONLY)) == -1) {
                perror(argv[3]);
                return errno;
        }

        if ((fo = open(argv[4], O_WRONLY | O_CREAT | O_TRUNC, S_IRUSR | S_IWUSR)) == -1) {
                perror(argv[4]);
                return errno;
        }

        while((num = read(fi, &in, 2))) {
                if (mode == 'e') {
                        op = saes_encrypt(in, key);
                }
                else if (mode == 'd') {
                        op = saes_decrypt(in, key);
                }
                else {
                        break;
                }
                if (write(fo, &op, num) != num) {
                        perror("write");
                        return errno;
                }
        }

        close(fi);
        close(fo);

        return 0;
}
```

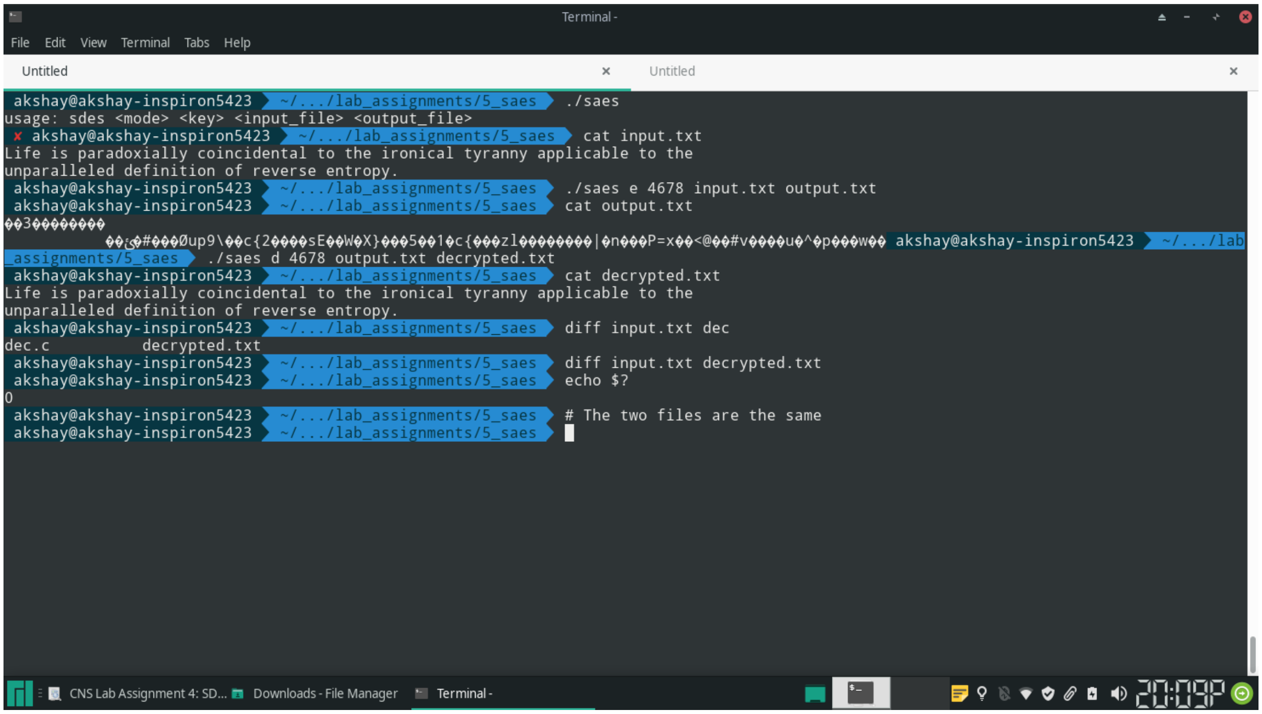
Output

Statistics

The file used for encryption is a pdf file having size **6.6MB**

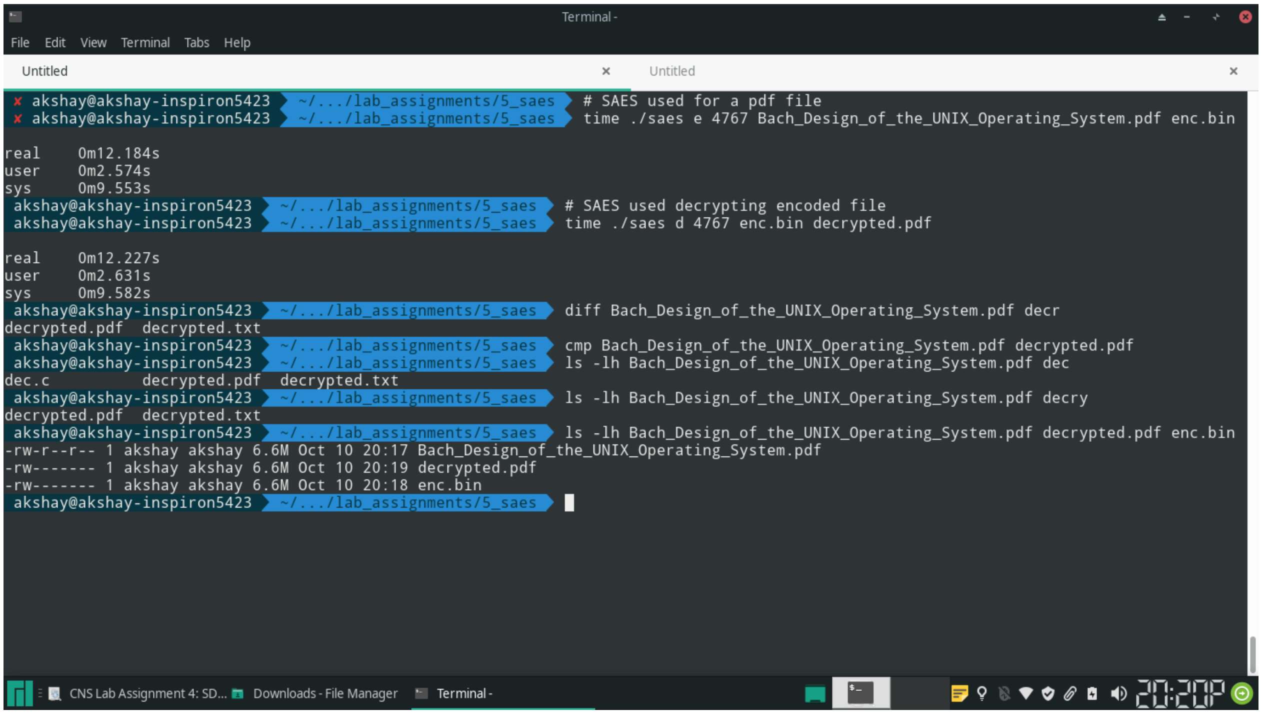
The average time needed for encryption (4 repetitions) is **2.6s**.

The average time needed for decryption (4 repetitions) is **2.56s**.



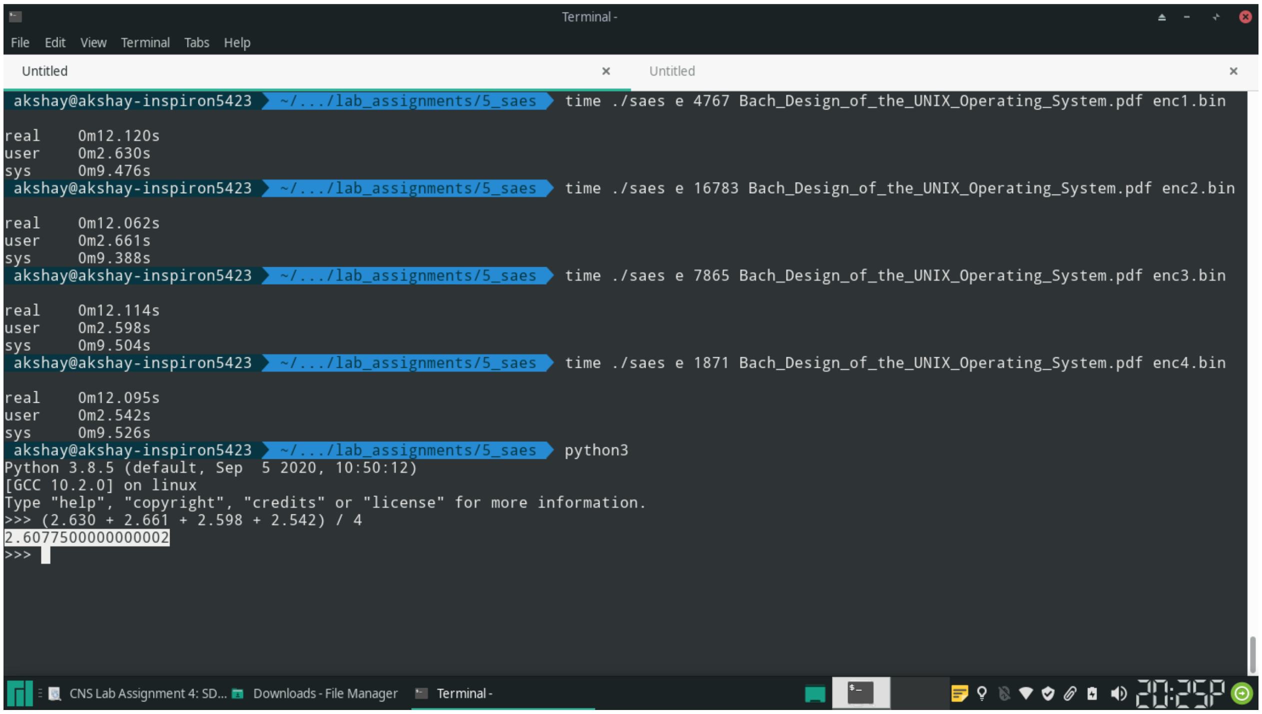
```
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  ./saes
usage: sdes <mode> <key> <input_file> <output_file>
 ✘ akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  cat input.txt
Life is paradoxially coincidental to the ironical tyranny applicable to the
unparalleled definition of reverse entropy.
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  ./saes e 4678 input.txt output.txt
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  cat output.txt
��3��������
           ���#���Øup9\��c{2����sE��W�X}���5��1�c{���zl��������|�n���P=x��<@��#v����u�^�p���w�� akshay@akshay-inspiron5423  ~/.../lab
_assignments/5_saes  ./saes d 4678 output.txt decrypted.txt
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  cat decrypted.txt
Life is paradoxially coincidental to the ironical tyranny applicable to the
unparalleled definition of reverse entropy.
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff input.txt dec
dec.c          decrypted.txt
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff input.txt decrypted.txt
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  echo $?
0
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  # The two files are the same
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  █
```

Figure 1: Example text file encryption and decryption



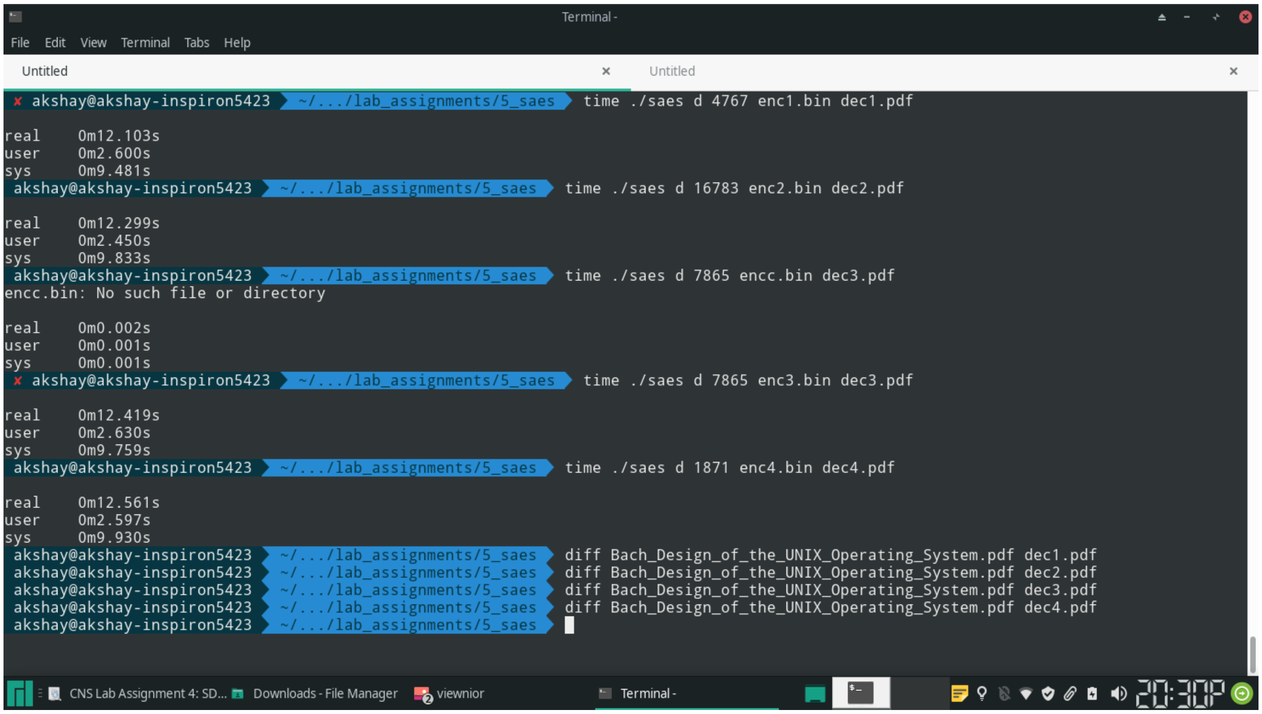
```
 ✘ akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  # SAES used for a pdf file
 ✘ akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes e 4767 Bach_Design_of_the_UNIX_Operating_System.pdf enc.bin

real    0m12.184s
user    0m2.574s
sys     0m9.553s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  # SAES used decrypting encoded file
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 4767 enc.bin decrypted.pdf

real    0m12.227s
user    0m2.631s
sys     0m9.582s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff Bach_Design_of_the_UNIX_Operating_System.pdf decr
decrypted.pdf  decrypted.txt
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  cmp Bach_Design_of_the_UNIX_Operating_System.pdf decrypted.pdf
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  ls -lh Bach_Design_of_the_UNIX_Operating_System.pdf dec
dec.c          decrypted.pdf  decrypted.txt
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  ls -lh Bach_Design_of_the_UNIX_Operating_System.pdf decry
decrypted.pdf  decrypted.txt
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  ls -lh Bach_Design_of_the_UNIX_Operating_System.pdf decrypted.pdf enc.bin
-rw-r--r-- 1 akshay akshay 6.6M Oct 10 20:17 Bach_Design_of_the_UNIX_Operating_System.pdf
-rw------- 1 akshay akshay 6.6M Oct 10 20:19 decrypted.pdf
-rw------- 1 akshay akshay 6.6M Oct 10 20:18 enc.bin
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  █
```

Figure 2: Encryption and decryption of pdf file, and time needed using "time" command


Terminal -
File Edit View Terminal Tabs Help
Untitled
Untitled
CNS Lab Assignment 4: SD...
Downloads - File Manager
Terminal -

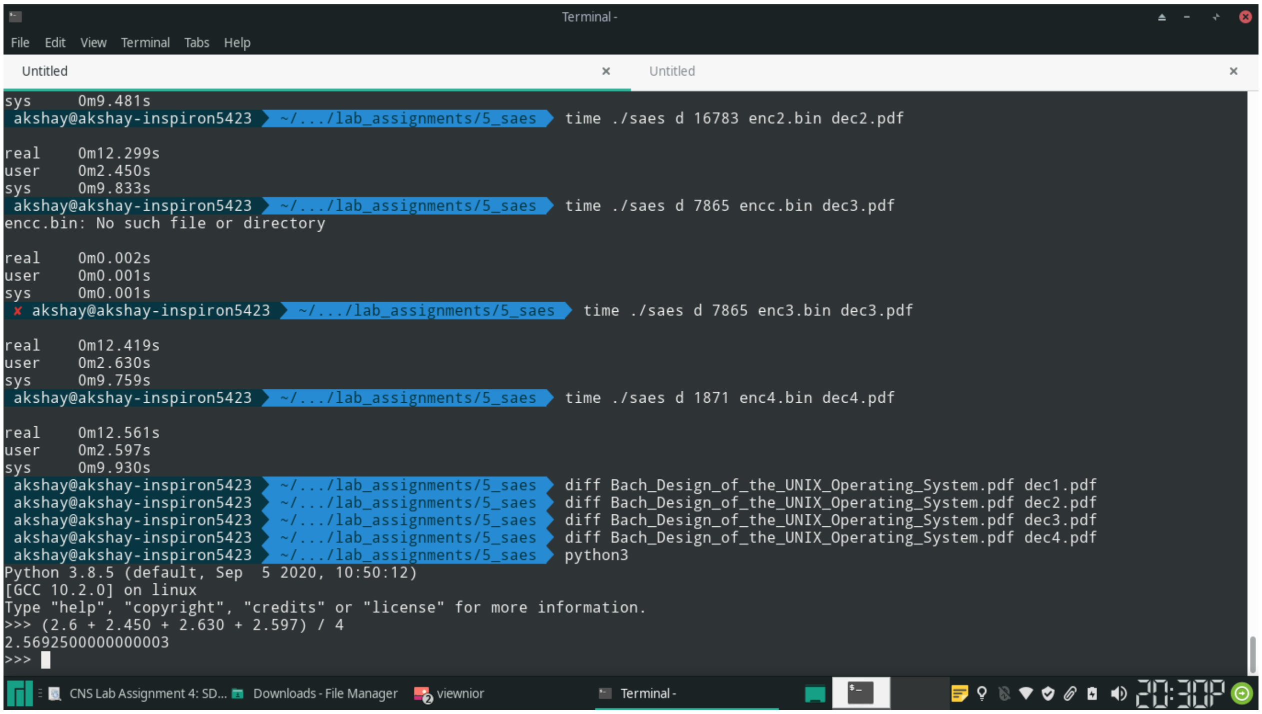
```
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes e 4767 Bach_Design_of_the_UNIX_Operating_System.pdf enc1.bin

real    0m12.120s
user    0m2.630s
sys     0m9.476s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes e 16783 Bach_Design_of_the_UNIX_Operating_System.pdf enc2.bin

real    0m12.062s
user    0m2.661s
sys     0m9.388s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes e 7865 Bach_Design_of_the_UNIX_Operating_System.pdf enc3.bin

real    0m12.114s
user    0m2.598s
sys     0m9.504s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes e 1871 Bach_Design_of_the_UNIX_Operating_System.pdf enc4.bin

real    0m12.095s
user    0m2.542s
sys     0m9.526s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  python3
Python 3.8.5 (default, Sep  5 2020, 10:50:12)
[GCC 10.2.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> (2.630 + 2.661 + 2.598 + 2.542) / 4
2.6077500000000002
>>> 
```

Figure 3: Encryption times



```
 x akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 4767 enc1.bin dec1.pdf

real    0m12.103s
user    0m2.600s
sys     0m9.481s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 16783 enc2.bin dec2.pdf

real    0m12.299s
user    0m2.450s
sys     0m9.833s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 7865 encc.bin dec3.pdf
encc.bin: No such file or directory

real    0m0.002s
user    0m0.001s
sys     0m0.001s
 x akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 7865 enc3.bin dec3.pdf

real    0m12.419s
user    0m2.630s
sys     0m9.759s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 1871 enc4.bin dec4.pdf

real    0m12.561s
user    0m2.597s
sys     0m9.930s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff Bach_Design_of_the_UNIX_Operating_System.pdf dec1.pdf
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff Bach_Design_of_the_UNIX_Operating_System.pdf dec2.pdf
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff Bach_Design_of_the_UNIX_Operating_System.pdf dec3.pdf
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff Bach_Design_of_the_UNIX_Operating_System.pdf dec4.pdf
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  
```

Figure 4: Decryption times



```
sys     0m9.481s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 16783 enc2.bin dec2.pdf

real    0m12.299s
user    0m2.450s
sys     0m9.833s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 7865 encc.bin dec3.pdf
encc.bin: No such file or directory

real    0m0.002s
user    0m0.001s
sys     0m0.001s
 ✘ akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 7865 enc3.bin dec3.pdf

real    0m12.419s
user    0m2.630s
sys     0m9.759s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  time ./saes d 1871 enc4.bin dec4.pdf

real    0m12.561s
user    0m2.597s
sys     0m9.930s
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff Bach_Design_of_the_UNIX_Operating_System.pdf dec1.pdf
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff Bach_Design_of_the_UNIX_Operating_System.pdf dec2.pdf
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff Bach_Design_of_the_UNIX_Operating_System.pdf dec3.pdf
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  diff Bach_Design_of_the_UNIX_Operating_System.pdf dec4.pdf
 akshay@akshay-inspiron5423  ~/.../lab_assignments/5_saes  python3
Python 3.8.5 (default, Sep  5 2020, 10:50:12)
[GCC 10.2.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> (2.6 + 2.450 + 2.630 + 2.597) / 4
2.5692500000000003
>>> 
```

Figure 5: Average time for decryption