SYSTEM AND NETWORK SECURITY

FALL 2024 – RSA Public-Key Encryption and Signature Lab

Due: 9th September, 2024

Task 1: Deriving the Private Key

- We create a C file "`task1.c`" which will derive the private key using the values of `p`, `q` and `e` which are provided to us.

```
p = F7E75FDC469067FFDC4E847C51F452DF
q = E85CED54AF57E53E092113E62F436F4F
e = 0D88C3
```

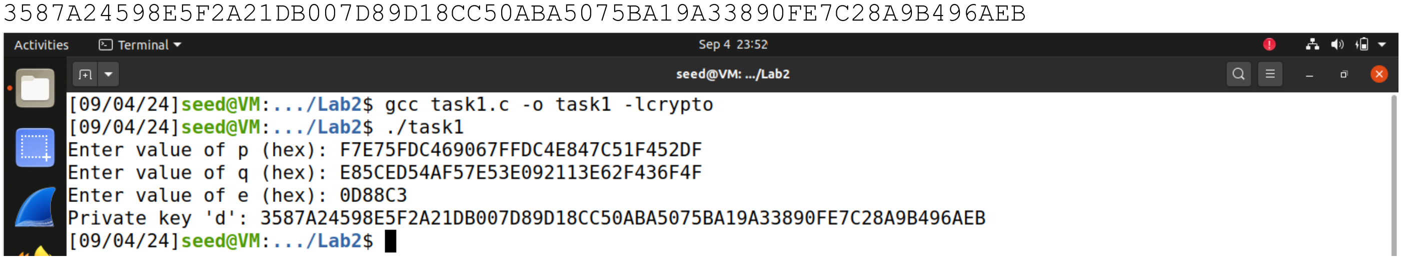
  - BIGNUM are created such as `p`, `q`, `n`, `euler_func`, `e`, `d` and all that is necessary. We then assign `p`, `q` and `e` as given by converting them from `HEX` to `Binary` using `BN_hex2bn()`.
- Steps we follow for RSA:
  - Assign Values: Initialize the big numbers (`p`, `q`, and `e`) with specific hexadecimal values.
  - Calculate `p * q`: Compute the modulus `n` as the product of p and q.
  - Calculate `p - 1` and `q - 1`: Subtract 1 from both `p` and `q` to prepare for the next step.
  - Compute `φ(n)` i.e, `euler_func(n) = (p - 1 * (q - 1)`: Calculate `φ(n)`, which is crucial for determining the private key.
  - Check if `e` and `φ(n)` are Relatively Prime: Ensure that `e` and `φ(n)` have no common divisors other than 1.
  - Calculate the Private Key (`d`): Derive `d` as the modular inverse of `e modulo φ(n)`.
  - Cleanup: Free the memory used for the big numbers.

```c
#include <stdio.h>
#include <openssl/bn.h>

#define NBITS 256

int main()
{
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *p = BN_new();
    BIGNUM *q = BN_new();
    BIGNUM *n = BN_new();
    BIGNUM *euler_func = BN_new();
    BIGNUM *e = BN_new();
    BIGNUM *d = BN_new();
    BIGNUM *res = BN_new();
    BIGNUM *p_1 = BN_new();
    BIGNUM *q_1 = BN_new();

    char p_str[NBITS], q_str[NBITS], e_str[NBITS];

    printf("Enter value of p (hex): ");
    scanf("%s", p_str);
    printf("Enter value of q (hex): ");
    scanf("%s", q_str);
    printf("Enter value of e (hex): ");
```

```
    scanf("%s", e_str);

    BN_hex2bn(&p, p_str);
    BN_hex2bn(&q, q_str);
    BN_hex2bn(&e, e_str);

    // n = p * q
    BN_mul(n, p, q, ctx);

    // Euler's totient function: φ(n) or fai(n) = (p - 1) x (q - 1)
    BN_sub(p_1, p, BN_value_one());
    BN_sub(q_1, q, BN_value_one());
    BN_mul(euler_func, p_1, q_1, ctx);

    // Ensure e and φ(n) or fai(n) are relatively prime
    BN_gcd(res, euler_func, e, ctx);
    if (!BN_is_one(res))
    {
        char *euler_func_str = BN_bn2hex(euler_func);
        char *e_str_converted = BN_bn2hex(e);
        printf("Error: %s and %s are not relatively prime\n", e_str_converted,
euler_func_str);
        OPENSSL_free(euler_func_str);
        OPENSSL_free(e_str_converted);
        return 1;
    }

    // Calculate the private key d (modular inverse of e mod φ(n))
    BN_mod_inverse(d, e, euler_func, ctx);

    // Print the private key
    char *private_key_str = BN_bn2hex(d);
    printf("Private key 'd': %s\n", private_key_str);
    OPENSSL_free(private_key_str);

    // Clear and free allocated memory
    BN_clear_free(p);
    BN_clear_free(q);
    BN_clear_free(n);
    BN_clear_free(res);
    BN_clear_free(euler_func);
    BN_clear_free(e);
    BN_clear_free(d);
    BN_clear_free(p_1);
    BN_clear_free(q_1);

    return 0;
}
```

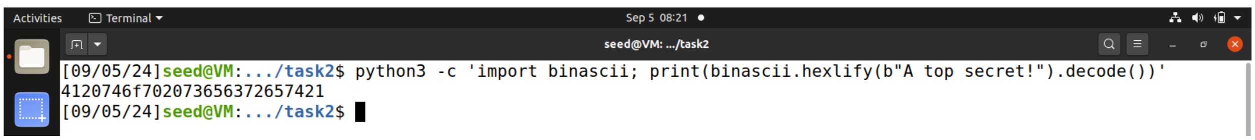
The private key ‘d’ is

`3587A24598E5F2A21DB007D89D18CC50ABA5075BA19A33890FE7C28A9B496AEB`



Task 2: Encrypting a Message

- I attempted to run the following commands from the lab instructions:
    - `python3 -c 'print("A top secret!".encode("utf-8").hex())'`
    - `python -c 'print("A top secret!".encode("hex"))'`
- However, it appears that these commands are no longer supported in Python 3. To resolve this and successfully convert the string `"A top secret!"` into its hexadecimal format, I used the following command:
    - `python3 -c 'import binascii; print(binascii.hexlify(b"A top secret!").decode())'`
- This command provides the `binascii` module to perform the hexadecimal conversion, which works properly in Python 3.
- Message in HEX: `4120746f702073656372657421`



- We also have the below parameters foe encryption.

`n = DCBFFE3E51F62E09CE7032E2677A78946A849DC4CDDE3A4D0CB81629242FB1A5`
`e = 010001 (this hex value equals to decimal 65537)`
`M = A top secret!`
`d = 74D806F9F3A62BAE331FFE3F0A68AFE35B3D2E4794148AACBC26AA381CD7D30D`

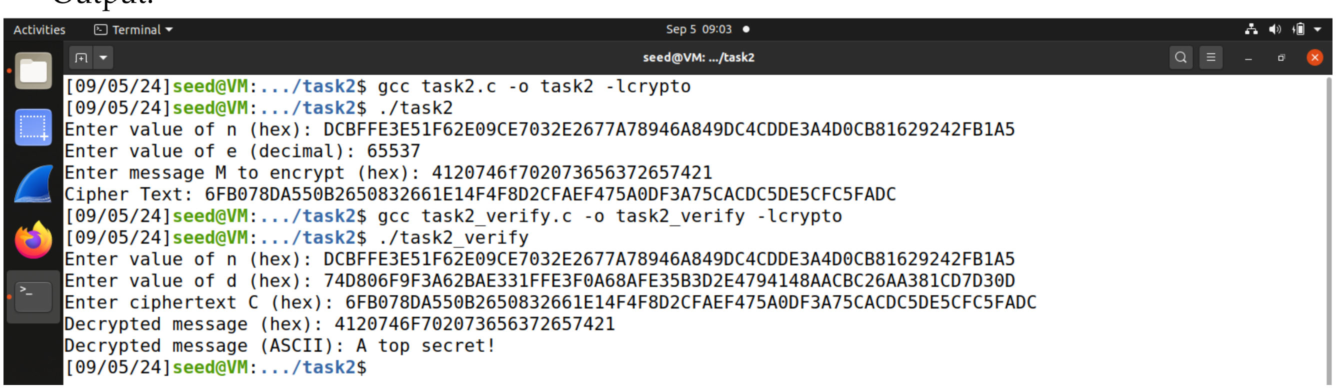
- I've created 2 C scripts. `task2.c` for encryption and `task2_verify.c` for decryption and verification.
- The first script: task2.c
    - We first create BIGNUM structures for `n`, `e`, `M`, and `C`. Next we take all the inuts that are `n`, `e`, and `M` (M is taken as input in decimal format but then while encryption we convert it to HEX format)
    - We perform the RSA Encryption using the formula $C = M^e \bmod n$ where M is the message, (`e, n`) is the public key pair.
    - The last step is to print this encrypted text in `HEX` format using the printBN function.
    - Before terminating the code, we free all the allocated memory for `BIGNUM` variables.
- The verification script: `task2_verify.c`
    - Similar to task2.c, we first create BIGNUM structures for `n`, `d`, `C`, and `M`.
    - Next, we take inputs for `n`, `d`, and `C` (C is in HEX). These are converted into `BIGNUM` format using the `BN_hex2bn()` function.
    - We perform the RSA Decryption using the formula $M = C^d \bmod n$, where C is the cipher text, and (d, n) is the private key pair.
    - The decrypted message is printed in both hexadecimal and `ASCII` format using the `printBN` and `printBNAsASCII` functions. Before terminating the code, we free all the allocated memory for the `BIGNUM` variables
- Below are both the codes separated by a bolded line (**----**). First is **`task2.c`** and the second is **`task2_verify.c`**

```c
#include <stdio.h>
#include <openssl/bn.h>

#define NBITS 256

void printBN(char *msg, BIGNUM *a)
{
    char *number_str_a = BN_bn2hex(a);
    printf("%s %s\n", msg, number_str_a);
    OPENSSL_free(number_str_a);
}

int main()
{
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *n = BN_new();
    BIGNUM *e = BN_new();
    BIGNUM *M = BN_new();
    BIGNUM *C = BN_new(); // For ciphertext

    char n_str[NBITS], e_str[NBITS], M_str[NBITS];

    // Take inputs
    printf("Enter value of n (hex): ");
    scanf("%s", n_str);
    printf("Enter value of e (decimal): ");
    scanf("%s", e_str);
    printf("Enter message M to encrypt (hex): ");
    scanf("%s", M_str);

    // Convert all inputs to BIGNUM
    BN_hex2bn(&n, n_str);
    BN_dec2bn(&e, e_str);
    BN_hex2bn(&M, M_str);

    // RSA Encryption: C = M^e mod n
    BN_mod_exp(C, M, e, n, ctx);
    printBN("Cipher Text:", C);

    // Clear all data and free allocated memory
    BN_clear_free(n);
    BN_clear_free(e);
    BN_clear_free(M);
    BN_clear_free(C);
    BN_CTX_free(ctx);

    return 0;
}
```

```c
#include <stdio.h>
#include <openssl/bn.h>
#include <string.h>

#define NBITS 256

void printBN(char *msg, BIGNUM *a)
{
    char *number_str_a = BN_bn2hex(a);
    printf("%s %s\n", msg, number_str_a);
    OPENSSL_free(number_str_a);
}

void printBNAsASCII(char *msg, BIGNUM *a)
{
    char *number_str_a = BN_bn2hex(a);
```

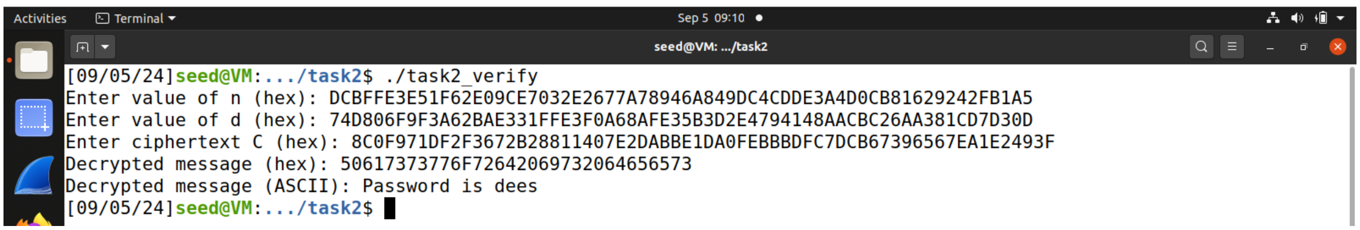
```
    printf("%s ", msg);
    for (size_t i = 0; i < strlen(number_str_a); i += 2)
    {
        char hex_byte[3] = {number_str_a[i], number_str_a[i+1], '\0'};
        printf("%c", (char)strtol(hex_byte, NULL, 16));
    }
    printf("\n");
    OPENSSL_free(number_str_a);
}

int main()
{
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *n = BN_new();
    BIGNUM *d = BN_new();
    BIGNUM *C = BN_new();
    BIGNUM *M = BN_new(); // For decrypted message (plaintext)

    char n_str[NBITS], d_str[NBITS], C_str[NBITS];

    // Take inputs
    printf("Enter value of n (hex): ");
    scanf("%s", n_str);
    printf("Enter value of d (hex): ");
    scanf("%s", d_str);
    printf("Enter ciphertext C (hex): ");
    scanf("%s", C_str);

    // Convert all inputs to BIGNUM
    BN_hex2bn(&n, n_str);
    BN_hex2bn(&d, d_str);
    BN_hex2bn(&C, C_str);

    // RSA Decryption M = C^d mod n
    BN_mod_exp(M, C, d, n, ctx);

    // Print the decrypted text in hex and ASCII
    printBN("Decrypted message (hex):", M);
    printBNAsASCII("Decrypted message (ASCII):", M);

    // Clear all data and free allocated memory
    BN_clear_free(n);
    BN_clear_free(d);
    BN_clear_free(C);
    BN_clear_free(M);
    BN_CTX_free(ctx);

    return 0;
}
```

- Output:



Task 3: Decrypting a Message

- I have already performed a similar decryption operation in Task 2 using the same public/private key pair. The process of decrypting the cipher text C and converting it back to an ASCII string is identical to what I completed in Task 2.
- In Task 2, I decrypted the cipher text using the private key d with the formula $M = C^d \bmod n$, and printed the plaintext message in both hexadecimal and ASCII format within the script without using the python command.
- I can apply the same decryption process to the new cipher text C that is given for this task (`8C0F971DF2F3672B28811407E2DABBE1DA0FEBBBDFC7DCB67396567EA1E2493F`) using the same approach for verification.
- Here's the output using the same private key pair of (d,n):



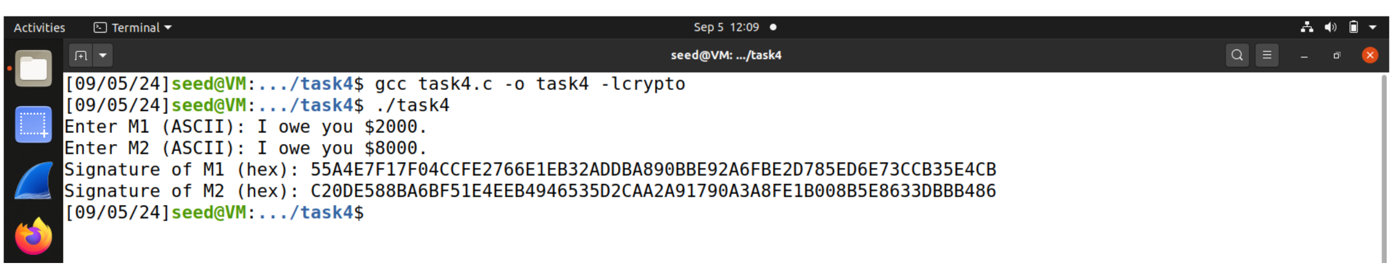
Task 4: Signing a Message

- I've created a C file `task4.c` that will perform RSA signature operation on 2 messages.
- We begin by the same thing here as well. `BIGNUM` structures for `n`, `d`, M1, M2, C1 and C2.
- We assign the values of n and the private key d using the `BN_hex2bn()` function, converting the HEX strings into BIGNUM format.
- Next, we give the code our inputs of two messages in the ASCII format. These are converted to HEX using the `asci_to_bn()` function and then stored in `M1` and `M2` as BIGNUMs.
- The RSA signature is computed for both messages using the formula $C = M^d \bmod n$.
- Once we have the signatures of both the messages, we clear all the allocated memory.
- Below is the task4.c code:

```
#include <stdio.h>
#include <openssl/bn.h>
#include <string.h>

#define NBITS 256

void printBN(char *msg, BIGNUM *a)
{
    char *number_str_a = BN_bn2hex(a);
    printf("%s %s\n", msg, number_str_a);
    OPENSSL_free(number_str_a);
}

void ascii_to_bn(BIGNUM *bn, const char *ascii)
{
    char hex_str[NBITS * 2 + 1];
    int i;

    for (i = 0; i < strlen(ascii); i++)
    {
        sprintf(hex_str + i * 2, "%02x", ascii[i]);
    }
```

```
    hex_str[i * 2] = '\0';
    BN_hex2bn(&bn, hex_str);
}

int main()
{
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *n = BN_new();
    BIGNUM *d = BN_new();
    BIGNUM *M1 = BN_new();
    BIGNUM *M2 = BN_new();
    BIGNUM *C1 = BN_new();
    BIGNUM *C2 = BN_new();

    // RSA parameters (n and d) are set
    BN_hex2bn(&n,
"DCBFFE3E51F62E09CE7032E2677A78946A849DC4CDDE3A4D0CB81629242FB1A5");
    BN_hex2bn(&d,
"74D806F9F3A62BAE331FFE3F0A68AFE35B3D2E4794148AACBC26AA381CD7D30D");

    // Input for the messages
    char ascii_M1[NBITS], ascii_M2[NBITS];
    printf("Enter M1 (ASCII): ");
    fgets(ascii_M1, NBITS, stdin);
    ascii_M1[strcspn(ascii_M1, "\n")] = 0;

    printf("Enter M2 (ASCII): ");
    fgets(ascii_M2, NBITS, stdin);
    ascii_M2[strcspn(ascii_M2, "\n")] = 0;
    ascii_to_bn(M1, ascii_M1);
    ascii_to_bn(M2, ascii_M2);
    // RSA signature: C = M^d mod n
    BN_mod_exp(C1, M1, d, n, ctx);
    BN_mod_exp(C2, M2, d, n, ctx);

    // Print the signatures of both the messages in hex format
    printBN("Signature of M1 (hex):", C1);
    printBN("Signature of M2 (hex):", C2);

    // Clear all data and free allocated memory
    BN_clear_free(n);
    BN_clear_free(d);
    BN_clear_free(M1);
    BN_clear_free(M2);
    BN_clear_free(C1);
    BN_clear_free(C2);
    BN_CTX_free(ctx);

    return 0;
}
```

- Output:



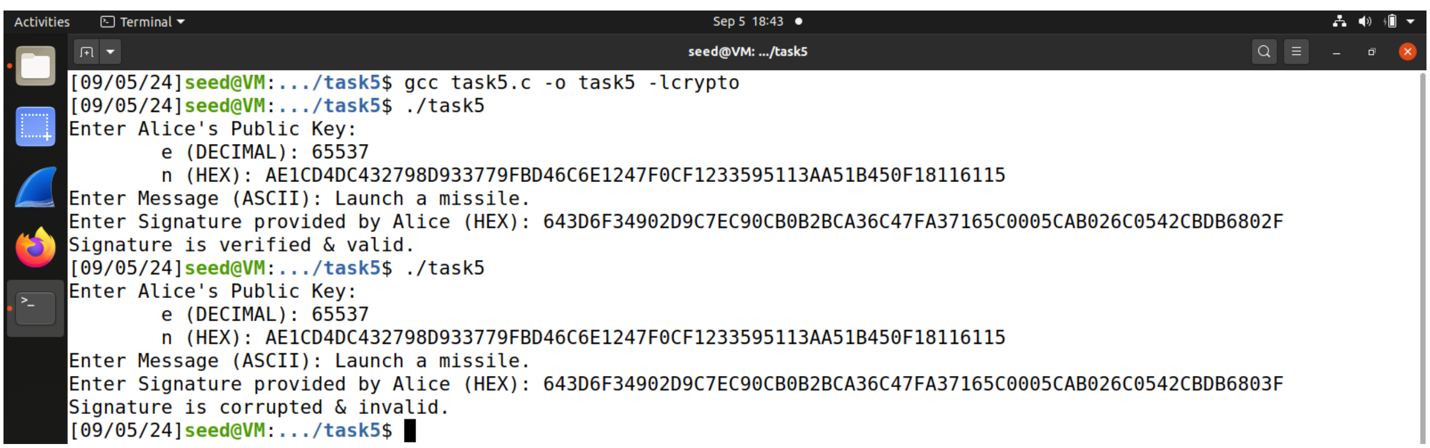
Task 5: Verifying a Signature

- I've created `task5.c` file that will verify the RSA signature provided by Alice.
- The initial steps are same as before; initialize `BIGNUM` structures for all the parameters. Here, we have `n, e, M, S`, and `C`. Inputs are given by the user based on the format mentioned.
- Next, to verify the signature, we perform the operation $C = S^e \bmod n$ to decrypt the signature using Alice's public key i.e., (e, n).
- We then compare the output with the original message (in HEX format as the output obtained after decryption will be in HEX).
- If they match, the signature is declared valid; else it is invalid. Once the verification is complete, all the allocated memory is cleared as usual.
- Below is the `task5.c` code:

```
#include <stdio.h>
#include <openssl/bn.h>
#include <string.h>

#define NBITS 256

void printBN(char *msg, BIGNUM *a)
{
    char *number_str_a = BN_bn2hex(a);
    printf("%s %s\n", msg, number_str_a);
    OPENSSL_free(number_str_a);
}

void ascii_to_bn(BIGNUM *bn, const char *ascii)
{
    char hex_str[NBITS * 2 + 1];
    int i;

    for (i = 0; i < strlen(ascii); i++)
    {
        sprintf(hex_str + i * 2, "%02x", ascii[i]);
    }
    hex_str[i * 2] = '\0';
    BN_hex2bn(&bn, hex_str);
}

int main()
{
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *n = BN_new();
    BIGNUM *e = BN_new();
    BIGNUM *M = BN_new();
    BIGNUM *S = BN_new();
    BIGNUM *C = BN_new();

    // Input for Alice's Public Key and Signature
    char n_str[NBITS], e_str[NBITS], ascii_msg[NBITS], S_str[NBITS];

    printf("Enter Alice's Public Key: \n");
    printf("\te (DECIMAL): ");
    scanf("%s", e_str);
    printf("\tn (HEX): ");
    scanf("%s", n_str);

    printf("Enter Message (ASCII): ");
    getchar();
    fgets(ascii_msg, NBITS, stdin);
    ascii_msg[strcspn(ascii_msg, "\n")] = 0;
```

```
    printf("Enter Signature provided by Alice (HEX): ");
    scanf("%s", S_str);

    // Convert inputs to BIGNUM format
    BN_hex2bn(&n, n_str);
    BN_dec2bn(&e, e_str);
    ascii_to_bn(M, ascii_msg);
    BN_hex2bn(&S, S_str);

    // Signature verification: C = S^e mod n
    BN_mod_exp(C, S, e, n, ctx);

    // Compare the calculated ciphertext C with the original message M
    if (BN_cmp(C, M) == 0)
    {
        printf("Signature is verified & valid.\n");
    }
    else
    {
        printf("Signature is corrupted & invalid.\n");
    }

    // Clear all data and free allocated memory
    BN_clear_free(n);
    BN_clear_free(e);
    BN_clear_free(M);
    BN_clear_free(S);
    BN_clear_free(C);
    BN_CTX_free(ctx);

    return 0;
}
```

- Output:



- Changing the last byte of the signature causes the verification to fail because the decrypted signature no longer matches the original message, making it clear that the signature is invalid.

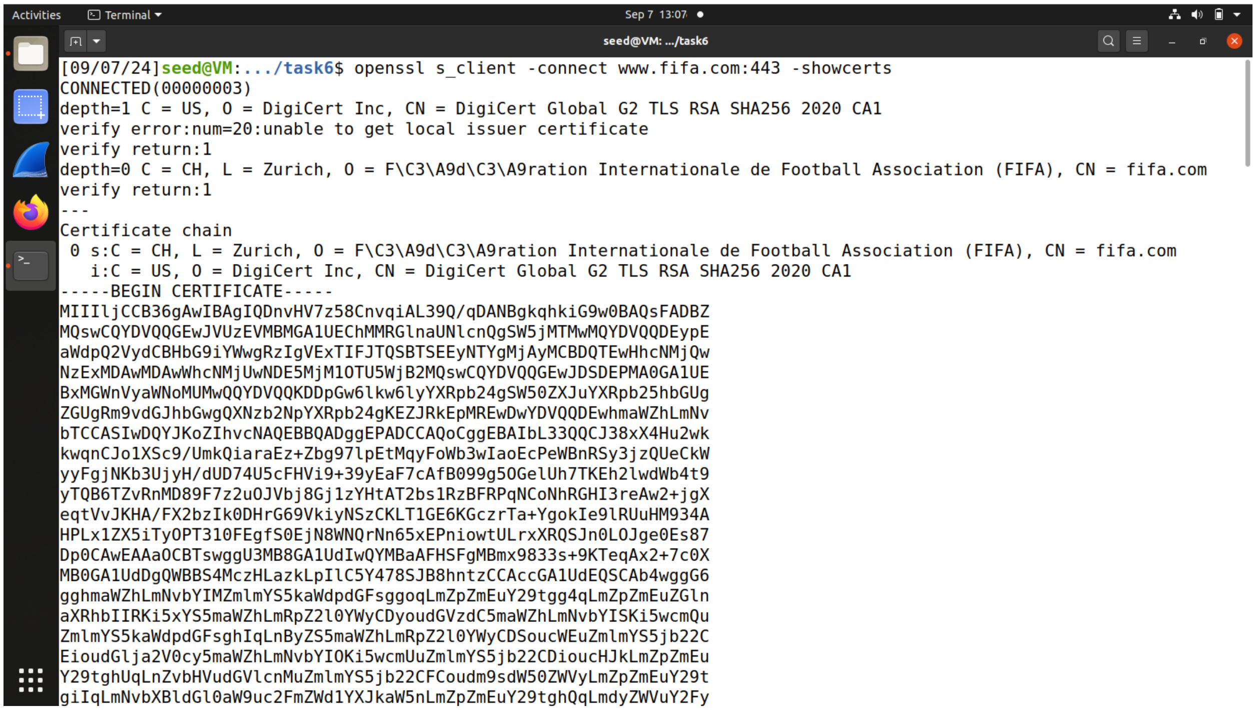
Task 6: Manually Verifying an X.509 Certificate

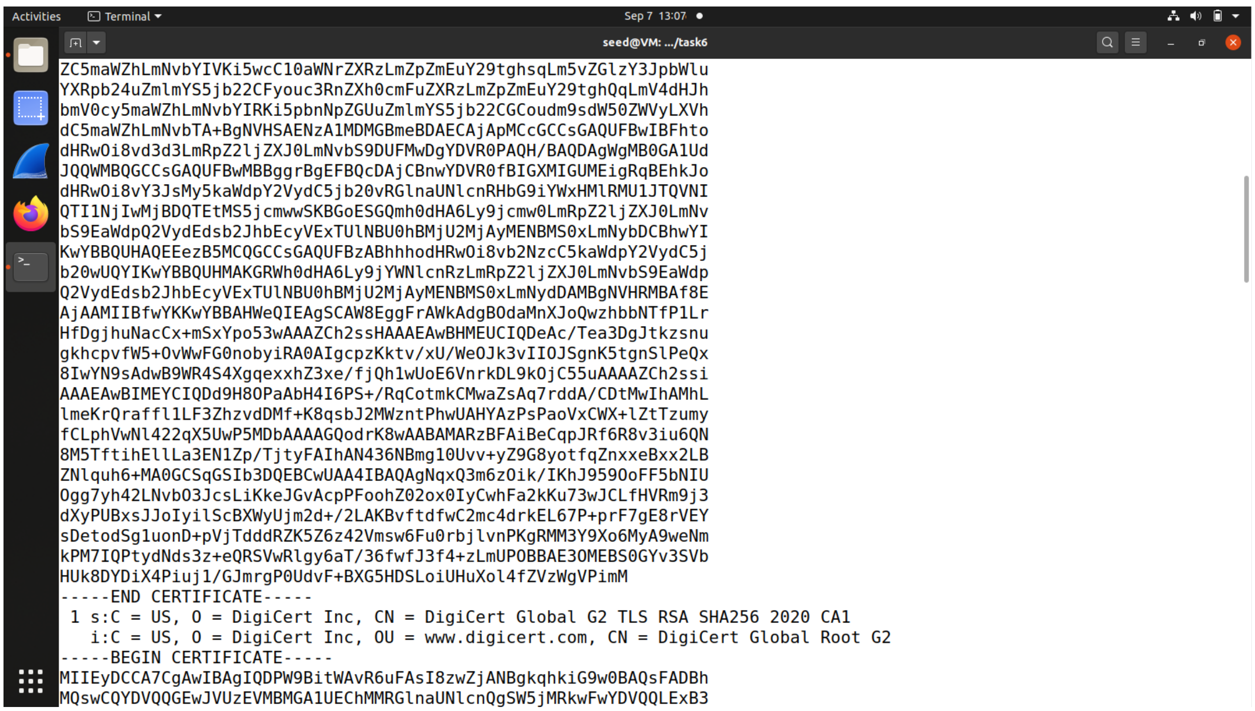
- In this task, I'll be using the FIFA WORLD CUP 2026 website (www.fifa.com)

STEP 1: Download a certificate from a real web server

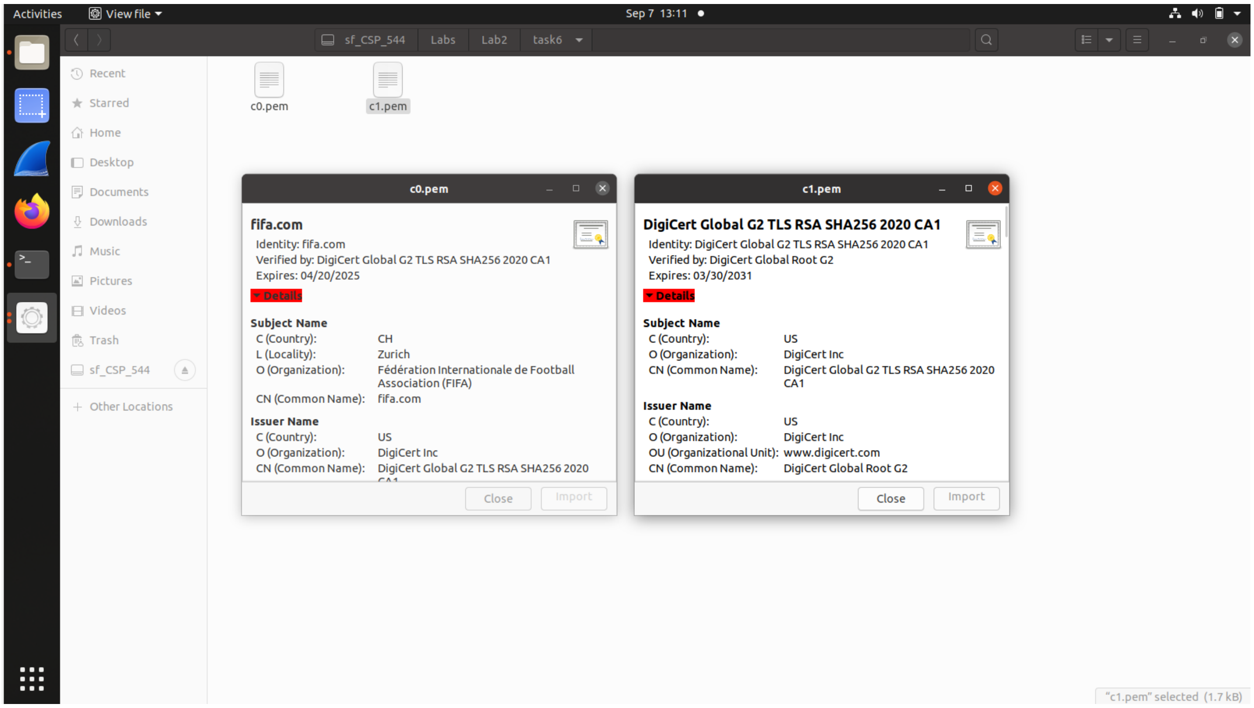
- Run the below command to download the certificate from this website.

```
openssl s_client -connect www.fifa.com:443 -showcerts
```





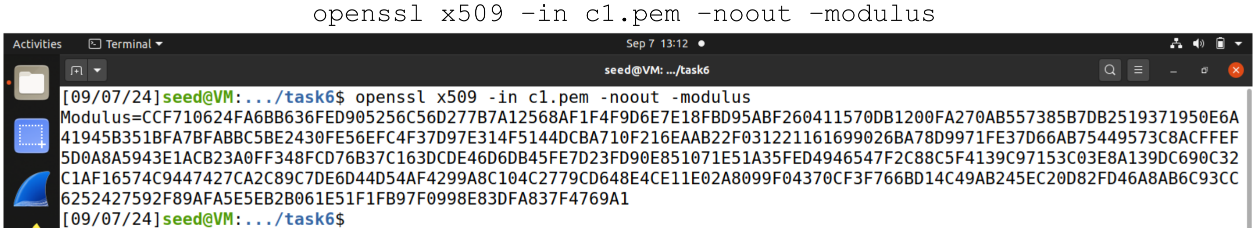
- Save the two certificates in `c0.pem` and `c1.pem`



STEP 2: Extract the public key (e, n) from the issuer's certificate

- As mentioned in the document, for finding the modulus (n), we run the below command

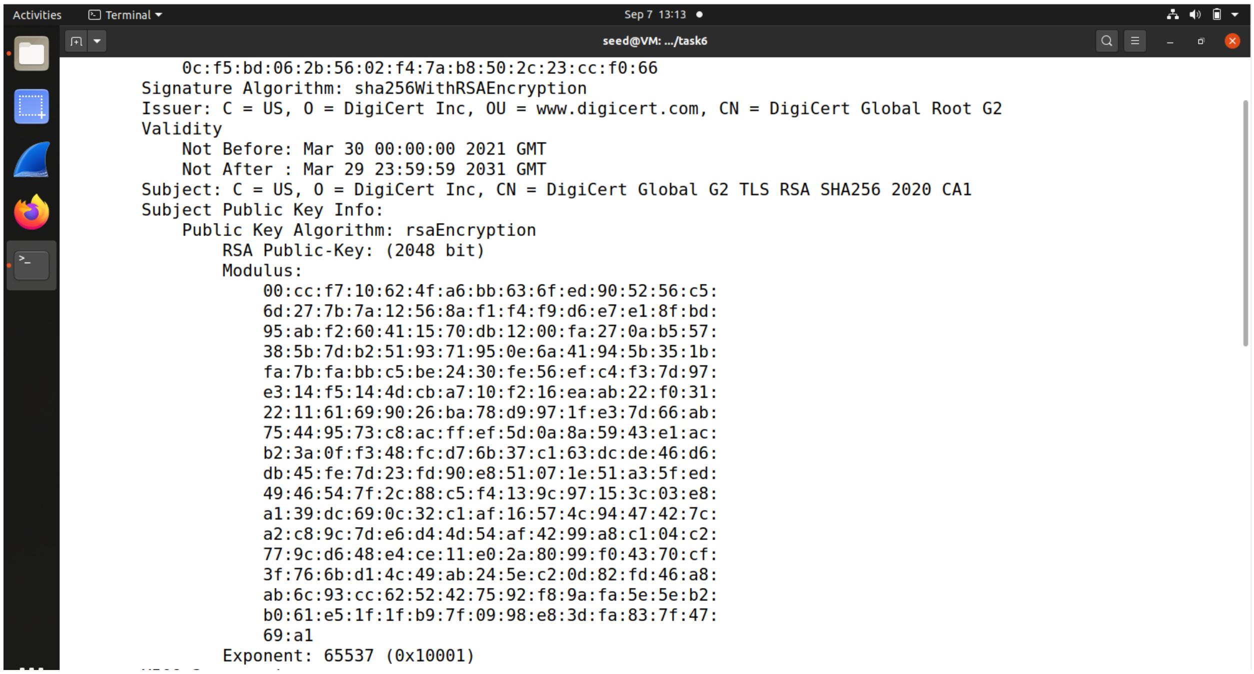
```
openssl x509 -in c1.pem -noout -modulus
```



Modulus =
CCF710624FA6BB636FED905256C56D277B7A12568AF1F4F9D6E7E18FBD95ABF260411570DB120
0FA270AB557385B7DB2519371950E6A41945B351BFA7BFABBC5BE2430FE56EFC4F37D97E314F5
144DCBA710F216EAAB22F031221161699026BA78D9971FE37D66AB75449573C8ACFFEF5D0A8A5
943E1ACB23A0FF348FCD76B37C163DCDE46D6DB45FE7D23FD90E851071E51A35FED4946547F2C
88C5F4139C97153C03E8A139DC690C32C1AF16574C9447427CA2C89C7DE6D44D54AF4299A8C10
4C2779CD648E4CE11E02A8099F04370CF3F766BD14C49AB245EC20D82FD46A8AB6C93CC625242
7592F89AFA5E5EB2B061E51F1FB97F0998E83DFA837F4769A1

- And for finding the exponent (e), we run this command

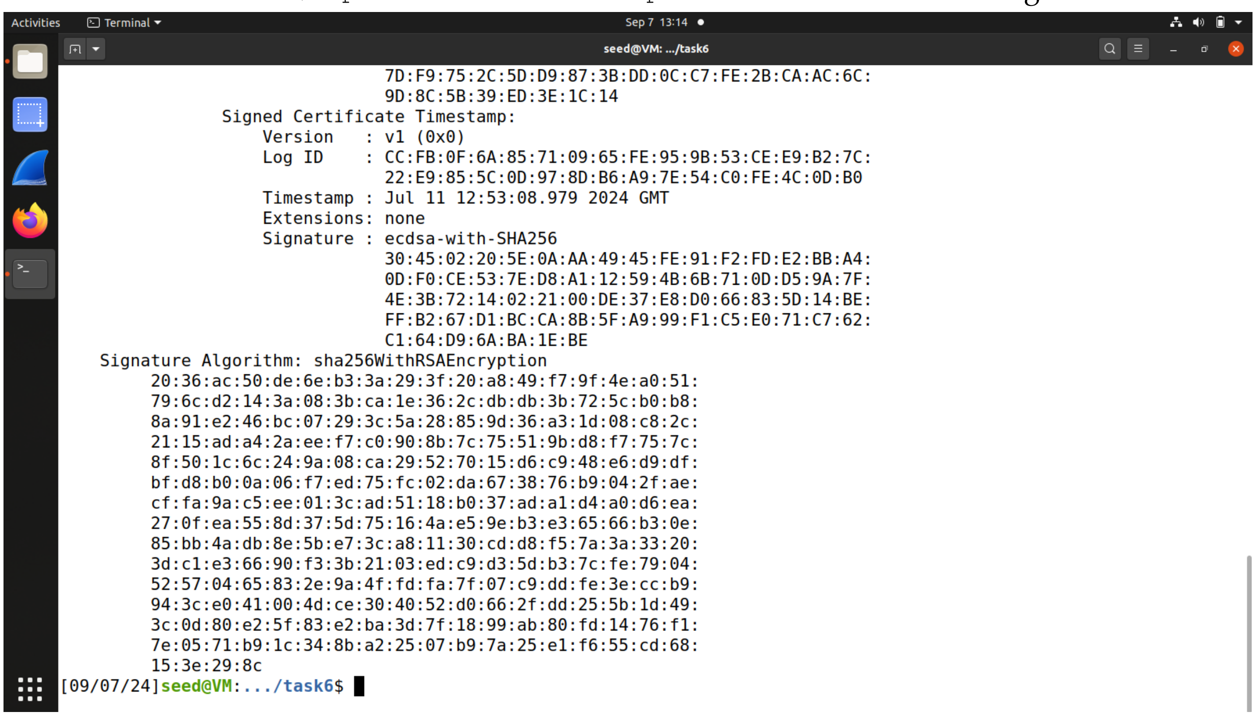
```
openssl x509 -in c1.pem -text -noout
```



```
        0c:f5:bd:06:2b:56:02:f4:7a:b8:50:2c:23:cc:f0:66
    Signature Algorithm: sha256WithRSAEncryption
    Issuer: C = US, O = DigiCert Inc, OU = www.digicert.com, CN = DigiCert Global Root G2
    Validity
        Not Before: Mar 30 00:00:00 2021 GMT
        Not After : Mar 29 23:59:59 2031 GMT
    Subject: C = US, O = DigiCert Inc, CN = DigiCert Global G2 TLS RSA SHA256 2020 CA1
    Subject Public Key Info:
        Public Key Algorithm: rsaEncryption
            RSA Public-Key: (2048 bit)
            Modulus:
                00:cc:f7:10:62:4f:a6:bb:63:6f:ed:90:52:56:c5:
                6d:27:7b:7a:12:56:8a:f1:f4:f9:d6:e7:e1:8f:bd:
                95:ab:f2:60:41:15:70:db:12:00:fa:27:0a:b5:57:
                38:5b:7d:b2:51:93:71:95:0e:6a:41:94:5b:35:1b:
                fa:7b:fa:bb:c5:be:24:30:fe:56:ef:c4:f3:7d:97:
                e3:14:f5:14:4d:cb:a7:10:f2:16:ea:ab:22:f0:31:
                22:11:61:69:90:26:ba:78:d9:97:1f:e3:7d:66:ab:
                75:44:95:73:c8:ac:ff:ef:5d:0a:8a:59:43:e1:ac:
                b2:3a:0f:f3:48:fc:d7:6b:37:c1:63:dc:de:46:d6:
                db:45:fe:7d:23:fd:90:e8:51:07:1e:51:a3:5f:ed:
                49:46:54:7f:2c:88:c5:f4:13:9c:97:15:3c:03:e8:
                a1:39:dc:69:0c:32:c1:af:16:57:4c:94:47:42:7c:
                a2:c8:9c:7d:e6:d4:4d:54:af:42:99:a8:c1:04:c2:
                77:9c:d6:48:e4:ce:11:e0:2a:80:99:f0:43:70:cf:
                3f:76:6b:d1:4c:49:ab:24:5e:c2:0d:82:fd:46:a8:
                ab:6c:93:cc:62:52:42:75:92:f8:9a:fa:5e:5e:b2:
                b0:61:e5:1f:1f:b9:7f:09:98:e8:3d:fa:83:7f:47:
                69:a1
            Exponent: 65537 (0x10001)
```

STEP 3: Extract the signature from the server's certificate

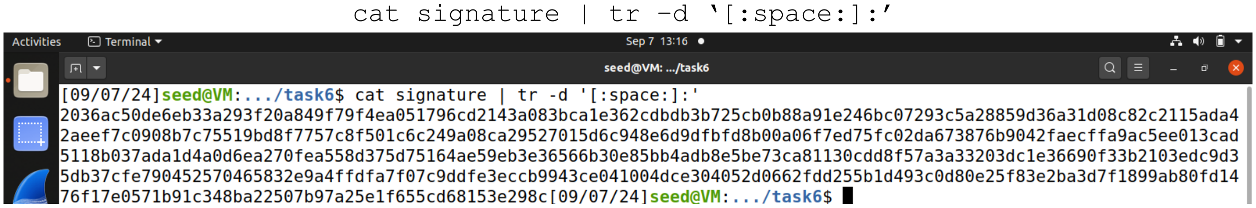
- We run the command `$ openssl x509 -in c0.pem -text -noout` for the signature.



```
                        7D:F9:75:2C:5D:D9:87:3B:DD:0C:C7:FE:2B:CA:AC:6C:
                        9D:8C:5B:39:ED:3E:1C:14
            Signed Certificate Timestamp:
                Version   : v1 (0x0)
                Log ID    : CC:FB:0F:6A:85:71:09:65:FE:95:9B:53:CE:E9:B2:7C:
                            22:E9:85:5C:0D:97:8D:B6:A9:7E:54:C0:FE:4C:0D:B0
                Timestamp : Jul 11 12:53:08.979 2024 GMT
                Extensions: none
                Signature : ecdsa-with-SHA256
                            30:45:02:20:5E:0A:AA:49:45:FE:91:F2:FD:E2:BB:A4:
                            0D:F0:CE:53:7E:D8:A1:12:59:4B:6B:71:0D:D5:9A:7F:
                            4E:3B:72:14:02:21:00:DE:37:E8:D0:66:83:5D:14:BE:
                            FF:B2:67:D1:BC:CA:8B:5F:A9:99:F1:C5:E0:71:C7:62:
                            C1:64:D9:6A:BA:1E:BE
    Signature Algorithm: sha256WithRSAEncryption
         20:36:ac:50:de:6e:b3:3a:29:3f:20:a8:49:f7:9f:4e:a0:51:
         79:6c:d2:14:3a:08:3b:ca:1e:36:2c:db:db:3b:72:5c:b0:b8:
         8a:91:e2:46:bc:07:29:3c:5a:28:85:9d:36:a3:1d:08:c8:2c:
         21:15:ad:a4:2a:ee:f7:c0:90:8b:7c:75:51:9b:d8:f7:75:7c:
         8f:50:1c:6c:24:9a:08:ca:29:52:70:15:d6:c9:48:e6:d9:df:
         bf:d8:b0:0a:06:f7:ed:75:fc:02:da:67:38:76:b9:04:2f:ae:
         cf:fa:9a:c5:ee:01:3c:ad:51:18:b0:37:ad:a1:d4:a0:d6:ea:
         27:0f:ea:55:8d:37:5d:75:16:4a:e5:9e:b3:e3:65:66:b3:0e:
         85:bb:4a:db:8e:5b:e7:3c:a8:11:30:cd:d8:f5:7a:3a:33:20:
         3d:c1:e3:66:90:f3:3b:21:03:ed:c9:d3:5d:b3:7c:fe:79:04:
         52:57:04:65:83:2e:9a:4f:fd:fa:7f:07:c9:dd:fe:3e:cc:b9:
         94:3c:e0:41:00:4d:ce:30:40:52:d0:66:2f:dd:25:5b:1d:49:
         3c:0d:80:e2:5f:83:e2:ba:3d:7f:18:99:ab:80:fd:14:76:f1:
         7e:05:71:b9:1c:34:8b:a2:25:07:b9:7a:25:e1:f6:55:cd:68:
         15:3e:29:8c
[09/07/24]seed@VM:.../task6$
```

- We take this signature and save it in a file and name it signature. Now we remove all the spaces and colons from the signature in order to get a hexadecimal format of the signature. We can do this by running the following command.

`cat signature | tr -d '[:space:]:'`

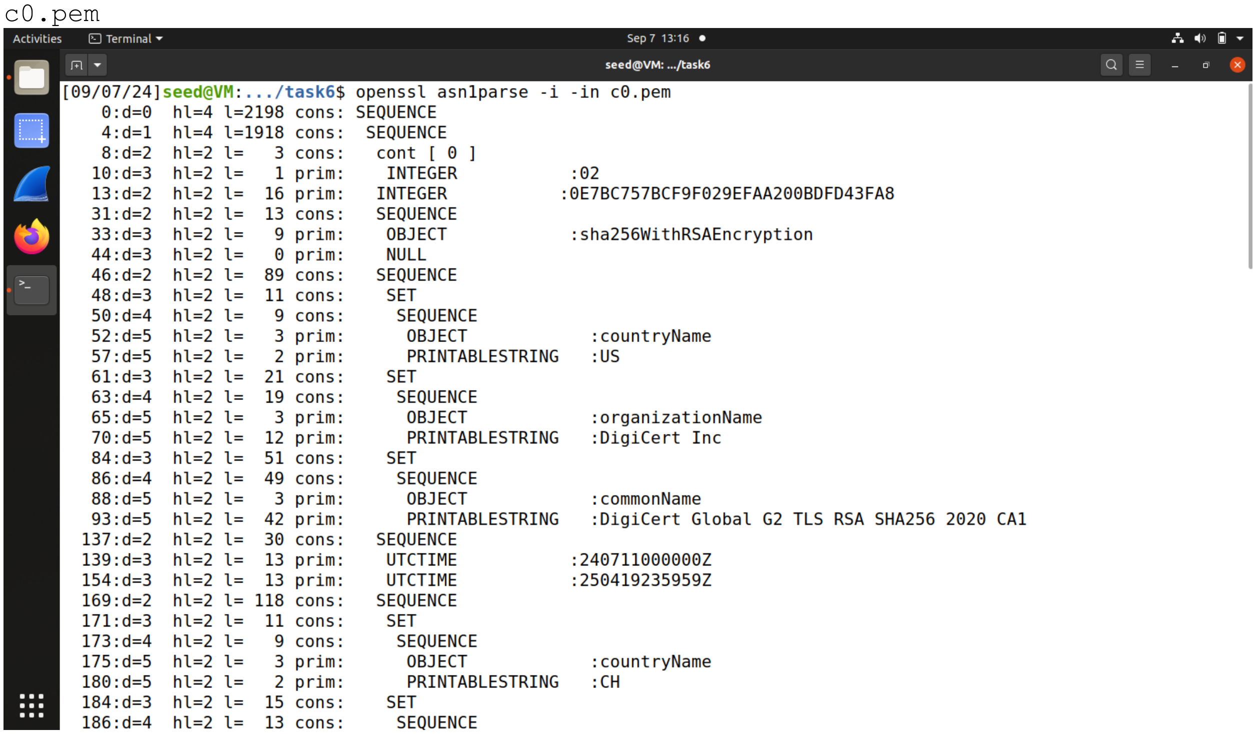


```
[09/07/24]seed@VM:.../task6$ cat signature | tr -d '[:space:]:'
2036ac50de6eb33a293f20a849f79f4ea051796cd2143a083bca1e362cdbdb3b725cb0b88a91e246bc07293c5a28859d36a31d08c82c2115ada4
2aeef7c0908b7c75519bd8f7757c8f501c6c249a08ca29527015d6c948e6d9dfbfd8b00a06f7ed75fc02da673876b9042faecffa9ac5ee013cad
5118b037ada1d4a0d6ea270fea558d375d75164ae59eb3e36566b30e85bb4adb8e5be73ca81130cdd8f57a3a33203dc1e36690f33b2103edc9d3
5db37cfe790452570465832e9a4ffdfa7f07c9ddfe3eccb9943ce041004dce304052d0662fdd255b1d493c0d80e25f83e2ba3d7f1899ab80fd14
76f17e0571b91c348ba22507b97a25e1f655cd68153e298c[09/07/24]seed@VM:.../task6$
```

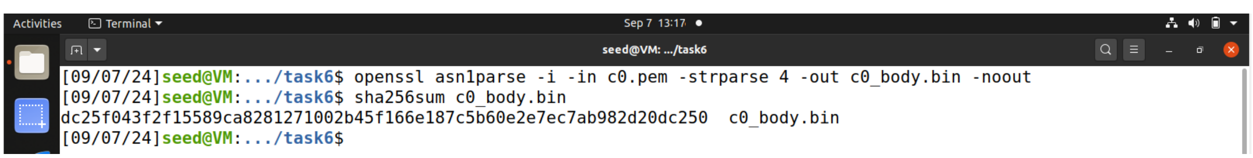
Certificate Signature (hex) =
2036ac50de6eb33a293f20a849f79f4ea051796cd2143a083bca1e362cdbdb3b725cb0b88a91e
246bc07293c5a28859d36a31d08c82c2115ada42aeef7c0908b7c75519bd8f7757c8f501c6c24
9a08ca29527015d6c948e6d9dfbfd8b00a06f7ed75fc02da673876b9042faecffa9ac5ee013ca
d5118b037ada1d4a0d6ea270fea558d375d75164ae59eb3e36566b30e85bb4adb8e5be73ca811
30cdd8f57a3a33203dc1e36690f33b2103edc9d35db37cfe790452570465832e9a4ffdfa7f07c
9ddfe3eccb9943ce041004dce304052d0662fdd255b1d493c0d80e25f83e2ba3d7f1899ab80fd
1476f17e0571b91c348ba22507b97a25e1f655cd68153e298c

STEP 4: Extract the body of the server's certificate.

- Openssl has a command called asn1parse used to extract data from ASN.1 formatted data, and is able to parse our X.509 certificate. We run the command `$ openssl asn1parse -i -in c0.pem`



- Next we run `$ openssl asn1parse -i -in c0.pem -strparse 4 -out c0_body.bin -noout.`
- We have out body of the certificate stored in c0_body.bin file. We now find the hash of this file using the command `$ sha256sum c0_body.bin`



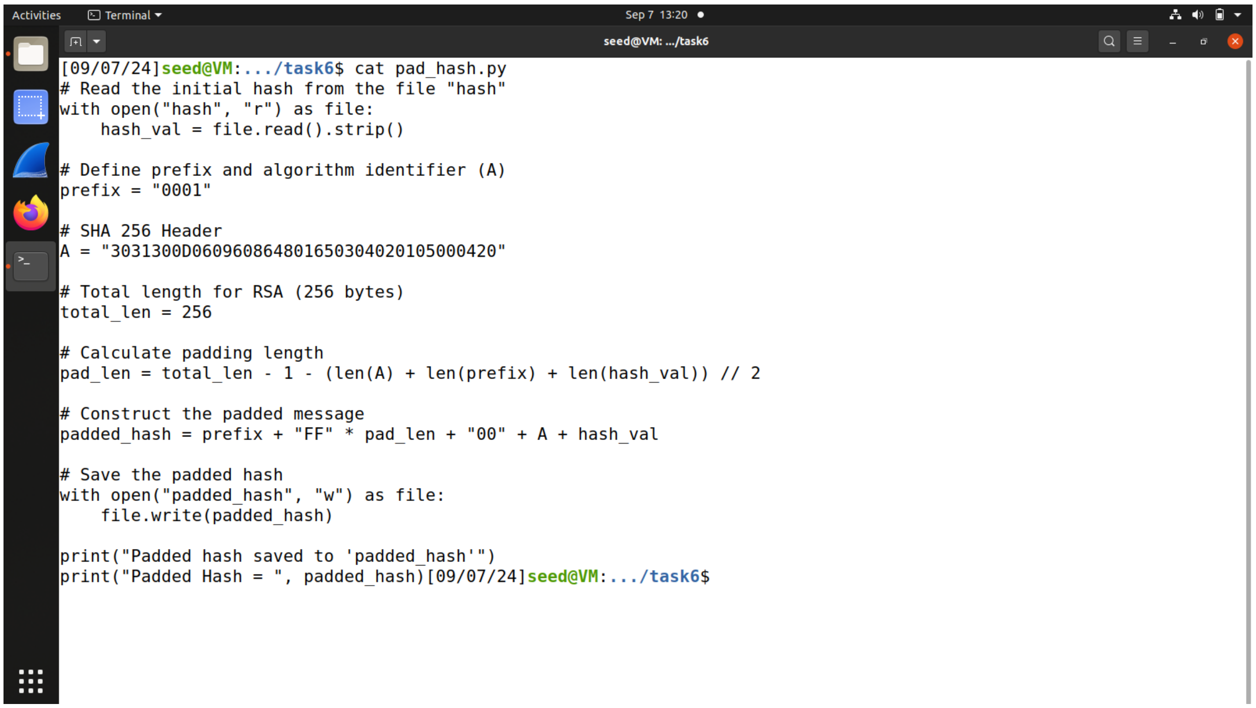
- The hash value is
dc25f043f2f15589ca8281271002b45f166e187c5b60e2e7ec7ab982d20dc250

- Note here that the sizes of modulus (`n`) and the signature are equal to 256 bytes (unlike `task5` where the size was just 32 bytes) and the size of the hash value is way smaller (32 bytes). So, for that reason we will need to pad the hash value to 256 bytes.
- The hash value (32 bytes) is wrapped into two successive layers:
    - In practice, if the hash value is H, then the first wrapping results in the sequence of bytes `A || H` where "||" is concatenation, and "A" is a header which is specific to

the hash function (typically 15 to 20 bytes). For SHA256, the value of A is "`3031300D060960864801650304020105000420`" (20 bytes).

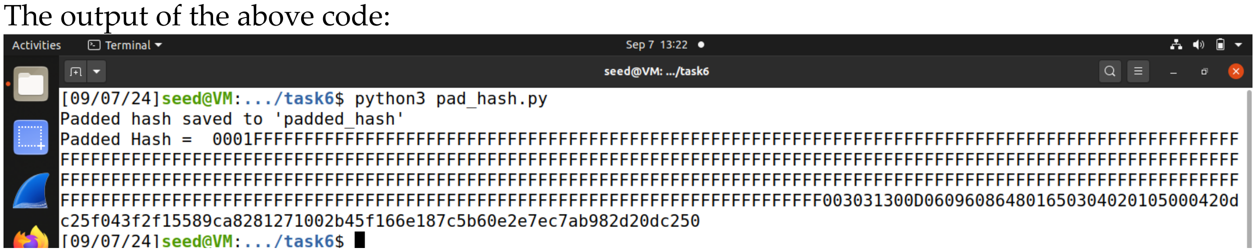
- The "A || H" is now expanded with some extra bytes:
  `0x00 0x01 0xFF 0xFF ... 0xFF 0x00 || A || H`

- The number of bytes of value `0xFF` is adjusted to that the total size equals the size of the RSA modulus (i.e. 256 bytes for a 2048-bit RSA key).
- Below is the python code (`pad_hash.py`) which performs padding to the hash.




```
# Read the initial hash from the file "hash"
with open("hash", "r") as file:
    hash_val = file.read().strip()

# Define prefix and algorithm identifier (A)
prefix = "0001"
A = "30 31 30 0D 06 09 60 86 48 01 65 03 04 02 01 05 00 04 20".replace(' ', '')

# Total length for RSA (256 bytes)
total_len = 256

# Calculate padding length
pad_len = total_len - 1 - (len(A) + len(prefix) + len(hash_val)) // 2

# Construct the padded message
padded_message = prefix + "FF" * pad_len + "00" + A + hash_val

# Save the padded message to a file named "padded_hash"
with open("padded_hash", "w") as file:
    file.write(padded_message)

print("Padded hash saved to 'padded_hash'")
```

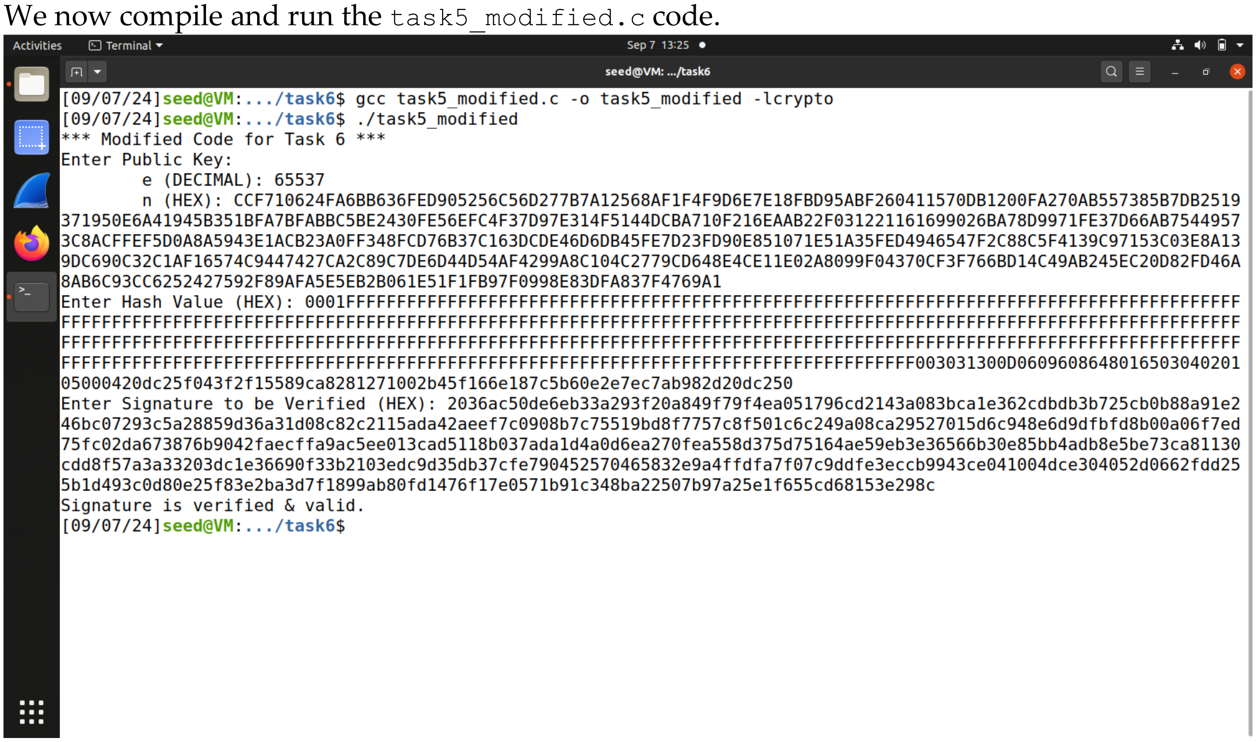
- The output of the above code:



- I now go back to `task5` folder and copy the C file, `task5.c`, where I can verify whether the signature is valid or not. Once I copy, I'll need to a change in the code as the code I've written takes the message in ASCII format. I'll need to change that to HEX format and then we compile and run the file `task5_modified.c` within the `task6` folder.

- We have
    - Modulus (n) (hex) = `CCF710624FA6BB636FED905256C56D277B7A12568AF1F4F9D6E7E18FBD95ABF260411570DB1200FA270AB557385B7DB2519371950E6A41945B351BFA7BFABBC5BE2430FE56EFC4F37D97E314F5144DCBA710F216EAAB22F031221161699026BA78D9971FE37D66AB75449573C8ACFFEF5D0A8A5943E1ACB23A0FF348FCD76B37C163DCDE46D6DB45FE7D23FD90E851071E51A35FED4946547F2C88C5F4139C97153C03E8A139DC690C32C1AF16574C9447427CA2C89C7DE6D44D54AF4299A8C104C2779CD648E4CE11E02A8099F04370CF3F766BD14C49AB245EC20D82FD46A8AB6C93CC6252427592F89AFA5E5EB2B061E51F1FB97F0998E83DFA837F4769A1`
    - Exponent (e) (hex) = `65537 (0x10001)`
    - Message (hash value) (hex) = `0001FF003031300D060960864801650304020105000420dc25f043f2f15589ca8281271002b45f166e187c5b60e2e7ec7ab982d20dc250`
    - Certificate Signature (hex) = `2036ac50de6eb33a293f20a849f79f4ea051796cd2143a083bca1e362cdbdb3b725cb0b88a91e246bc07293c5a28859d36a31d08c82c2115ada42aeef7c0908b7c75519bd8f7757c8f501c6c249a08ca29527015d6c948e6d9dfbfd8b00a06f7ed75fc02da673876b9042faecffa9ac5ee013cad5118b037ada1d4a0d6ea270fea558d375d75164ae59eb3e36566b30e85bb4adb8e5be73ca81130cdd8f57a3a33203dc1e36690f33b2103edc9d35db37cfe790452570465832e9a4ffdfa7f07c9ddfe3eccb9943ce041004dce304052d0662fdd255b1d493c0d80e25f83e2ba3d7f1899ab80fd1476f17e0571b91c348ba22507b97a25e1f655cd68153e298c`

- We now compile and run the `task5_modified.c` code.




```
[09/07/24]seed@VM:.../task6$ gcc task5_modified.c -o task5_modified -lcrypto
[09/07/24]seed@VM:.../task6$ ./task5_modified
*** Modified Code for Task 6 ***
Enter Public Key:
        e (DECIMAL): 65537
        n (HEX):
CCF710624FA6BB636FED905256C56D277B7A12568AF1F4F9D6E7E18FBD95ABF260411570DB1200FA270AB557385B7DB2519371950E6A41945B3
51BFA7BFABBC5BE2430FE56EFC4F37D97E314F5144DCBA710F216EAAB22F031221161699026BA78D9971FE37D66AB75449573C8ACFFEF5D0A8A
5943E1ACB23A0FF348FCD76B37C163DCDE46D6DB45FE7D23FD90E851071E51A35FED4946547F2C88C5F4139C97153C03E8A139DC690C32C1AF1
6574C9447427CA2C89C7DE6D44D54AF4299A8C104C2779CD648E4CE11E02A8099F04370CF3F766BD14C49AB245EC20D82FD46A8AB6C93CC6252
427592F89AFA5E5EB2B061E51F1FB97F0998E83DFA837F4769A1
```

```
Enter Hash Value (HEX):
0001FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF003031300D060960864801650304020105000420dc25f043f2f1
5589ca8281271002b45f166e187c5b60e2e7ec7ab982d20dc250
Enter Signature to be Verified (HEX):
2036ac50de6eb33a293f20a849f79f4ea051796cd2143a083bca1e362cdbdb3b725cb0b88a91e246bc07293c5a28859d36a31d08c82c2115ada
42aeef7c0908b7c75519bd8f7757c8f501c6c249a08ca29527015d6c948e6d9dfbfd8b00a06f7ed75fc02da673876b9042faecffa9ac5ee013c
ad5118b037ada1d4a0d6ea270fea558d375d75164ae59eb3e36566b30e85bb4adb8e5be73ca81130cdd8f57a3a33203dc1e36690f33b2103edc
9d35db37cfe790452570465832e9a4ffdfa7f07c9ddfe3eccb9943ce041004dce304052d0662fdd255b1d493c0d80e25f83e2ba3d7f1899ab80
fd1476f17e0571b91c348ba22507b97a25e1f655cd68153e298c
Signature is verified & valid.
```

- The signature is verified and is valid.