RSA Public-Key Encryption and Signature Lab Report

1. Introduction

RSA (RivestShamirAdleman) is one of the first public-key cryptosystems and is widely used for secure communication. The RSA algorithm first generates two large random prime numbers, and then use them to generate public and private key pairs, which can be used to do encryption, decryption, digital signature generation, and digital signature verification. The RSA algorithm is built upon number theories, and it can be quite easily implemented with the support of libraries. Essentially, students will be implementing the RSA algorithm using the C program language.

The lab covers the following security-related topics:

- Public-key cryptography
- The RSA algorithm and key generation
- Big number calculation
- Encryption and Decryption using RSA
- Digital signature
- X.509 certificate

Lab environment: This lab requires the openssl library. I am using Ubuntu 16.04, which is already installed on.

2. Background

The RSA algorithm involves computations on large numbers. These computations cannot be directly conducted using simple arithmetic operators in programs, because those operators can only operate on primitive SEED Labs data types. In this lab, we will use the Big Number library provided by openssl. To use this library, we will define each big number as a BIGNUM type, and then use the APIs provided by the library for various operations, such as addition, multiplication, exponentiation, modular operations, etc.

First, I create a new folder named cs458lab2.Then I write all of the lab codes in this floder.

```
$ mkdir cs458Lab2
```

3. Task

3.1 Task 1: Deriving the Private Key

Let p, q, and e be three prime numbers. Let n = p*q. We will use (e, n) as the public key. Please calculate the private key d.

First, I create a Task1.c and use the code showing in the lab insturctions.

```
$ vi task1.c
#include <stdio.h>
#include <openssl/bn.h>
#define NBITS 256

void printBN(char *msg, BIGNUM *a){
// Convert the BIGNUM to number string
char * number_str = BN_bn2hex(a);
// Print out the number string
printf("%s %s\n", msg, number_str);
// Free the dynamically allocated memory
OPENSSL_free(number_str);
}

int main(){
BN_CTX *ctx = BN_CTX_new();
BIGNUM *p = BN_new();
BIGNUM *q = BN_new();
BIGNUM *e = BN_new();
BIGNUM *d = BN_new();
BIGNUM *res1 = BN_new();
BIGNUM *res2 = BN_new();
BIGNUM *res3 = BN_new();
BIGNUM *one = BN_new();
// initalize p q e
// Assign the first large prime
BN_hex2bn(&p, "F7E75FDC469067FFDC4E847C51F452DF");

// Assign the second large prime
BN_hex2bn(&q, "E85CED54AF57E53E092113E62F436F4F");

// Assign the Modulus
BN_hex2bn(&e, "0D88C3");
BN_dec2bn(&one,"1");
//res1 = p-1
BN_sub(res1, p, one);
//res2 = q-1
BN_sub(res2, q, one);
//res3=res1*res2
BN_mul(res3, res1, res2, ctx);
//res=a*b mod n
BN_mod_inverse(d, e, res3, ctx);
//print BN
printBN("d= ",d);
return 0;
}
```

First print out a big number:

```
void printBN(char *msg, BIGNUM *a){
// Convert the BIGNUM to number string
char * number_str = BN_bn2dec(a);
// Print out the number string
printf("%s %s\n", msg, number_str);
// Free the dynamically allocated memory
OPENSSL_free(number_str);
}
```

Then in the main method, create a BN CTX structure to holds BIGNUM temporary variables used by library functions. We need to create such a structure and pass it to the functions that require it. Then we initialize BIGNUM variables: p,q,e,d,res1.res2.res3.one.

There are a number of ways to assign a value to a BIGNUM variable(p,q,e.one)

```
int main(){
BN_CTX *ctx = BN_CTX_new();
BIGNUM *p = BN_new();
BIGNUM *q = BN_new();
BIGNUM *e = BN_new();
BIGNUM *d = BN_new();
BIGNUM *res1 = BN_new();
BIGNUM *res2 = BN_new();
BIGNUM *res3 = BN_new();
BIGNUM *one = BN_new();
// initalize p q e
// Assign the first large prime
BN_hex2bn(&p, "F7E75FDC469067FFDC4E847C51F452DF");

// Assign the second large prime
BN_hex2bn(&q, "E85CED54AF57E53E092113E62F436F4F");

// Assign the Modulus
BN_hex2bn(&e, "0D88C3");
BN_dec2bn(&one,"1");
```

Compute functions: Compute res1 = p-1,res2= q-1, res3 = res1 ∗ res2, d*e mod res3 =1

```
//res1 = p-1
BN_sub(res1, p, one);
//res2 = q-1
BN_sub(res2, q, one);
//res3=res1*res2
BN_mul(res3, res1, res2, ctx);
//res=a*b mod n
BN_mod_inverse(d, e, res3, ctx);
//print BN
printBN("d= ",d);
return 0;
}
-- INSERT --                                45,1
```

Finally, we can get d by following commands:

```
[02/27/24]seed@VM:~$ gcc -o task1 task1.c -lccrypto
[02/27/24]seed@VM:~$ ./task1
d=3587A24598E5F2A21DB007D89D18CC50ABA5075BA19A33890FE7C28A9B496AEB
```

Therefore, we get the private key

d=3587A24598E5F2A21DB007D89D18CC50ABA5075BA19A33890FE7C28A9B496AEB

3.2 Task 2: Encrypting a Message

Let (e, n) be the public key, We need to convert this ASCII string to a hex string, and then convert the hex string to a BIGNUM using the hex-to-bn API BN hex2bn().
In this task, I create a task2.c using command

```
1. vi task2.c
```

Import libary

```
#include <stdio.h>
#include <openssl/bn.h>
#define NBITS 256
```

Print method to make the result

```
//print a big number
void printBN(char *msg, BIGNUM *a){
// Convert the BIGNUM to number string
char * number_str = BN_bn2dec(a);
// Print out the number string
printf("%s %s\n", msg, number_str);
// Free the dynamically allocated memory
OPENSSL_free(number_str);
}
```

According to the lab, we know

```
$ python -c 'print("A top secret!".encode("hex"))'
4120746f702073656372657421
```

Therefore, we can use the hexadecimal of M

```
int main(){
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *m = BN_new();
    BIGNUM *e = BN_new();
    BIGNUM *n = BN_new();
    BIGNUM *d = BN_new();
    BIGNUM *enc = BN_new();
    BIGNUM *dec = BN_new();
    //Initialize
    BN_hex2bn(&e,"010001");
    BN_hex2bn(&n,"DCBFFE3E51F62E09CE7032E2677A78946A849
DC4CDDE3A4D0CB81629242FB1A5");
    BN_hex2bn(&m,"4120746f702073656372657421");//A top
secret!
    BN_hex2bn(&d," 74D806F9F3A62BAE331FFE3F0A68AFE35B3D
2E4794148AACBC26AA381CD7D30D");
    //encry = m^e mod n
    BN_mod_exp(enc,m,e,n,ctx);
    printBN("encrypt message = ", enc);
```

```
    //decry = enc^d mod n
    BN_mod_exp(dec,enc,d,n,ctx);
    printBN("decrypt message = ",dec);
    return 0;
}
```

Then, we run the code in the terminal, the result as shown

```
[02/27/24]seed@VM:~$ vi task2.c
[02/27/24]seed@VM:~$ gcc -o task2 task2.c -lccrypto
[02/27/24]seed@VM:~$ ./task2
encrpyt message = 6FB078DA550B2650832661E14F4F8D2CFAEF
475A0DF3A75CACDC5DE5CFC5FADC
decrpyt message = 4120746f702073656372675421
```

We can see that the decrypted message and the original message are the same.

Task2 code:

```
#include <stdio.h>
#include <openssl/bn.h>
#define NBITS 256

//print a big number
void printBN(char *msg, BIGNUM *a){
// Convert the BIGNUM to number string
```

```c
char * number_str = BN_bn2hex(a);
// Print out the number string
printf("%s %s\n", msg, number_str);
// Free the dynamically allocated memory
OPENSSL_free(number_str);
}

int main(){
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *m = BN_new();
    BIGNUM *e = BN_new();
    BIGNUM *n = BN_new();
    BIGNUM *d = BN_new();
    BIGNUM *enc = BN_new();
    BIGNUM *dec = BN_new();
    //Initialize
    BN_hex2bn(&e,"010001");
    BN_hex2bn(&n,"DCBFFE3E51F62E09CE7032E2677A78946A849DC4CDDE3A4D0CB81629242FB1A5");
    BN_hex2bn(&m,"4120746f702073656372657421");//A top secret!
    BN_hex2bn(&d,"74D806F9F3A62BAE331FFE3F0A68AFE35B3D2E4794148AACBC26AA381CD7D30D");
    //encry = m^e mod n
    BN_mod_exp(enc,m,e,n,ctx);
    printBN("encrypt message = ", enc);

    //decry = enc^d mod n
    BN_mod_exp(dec,enc,d,n,ctx);
    printBN("decrypt message = ",dec);
    return 0;
}
```

3.3 Task3 Decrypting a Message

The public/private keys used in this task are the same as the ones used in Task 2. Please decrypt the following ciphertext C, and convert it back to a plain ASCII string

Code is similar to task2:

```c
#include <stdio.h>
#include <openssl/bn.h>
#define NBITS 256

//print a big number
void printBN(char *msg, BIGNUM *a){
// Convert the BIGNUM to number string
char * number_str = BN_bn2hex(a);
// Print out the number string
printf("%s %s\n", msg, number_str);
// Free the dynamically allocated memory
OPENSSL_free(number_str);
}

int main(){
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *n = BN_new();
    BIGNUM *d = BN_new();
    BIGNUM *c = BN_new();
    BIGNUM *dec = BN_new();
    //Initialize
    BN_hex2bn(&n,"DCBFFE3E51F62E09CE7032E2677A78946A849DC4CDDE3A4D0CB81629242FB1A5");
```

```c
    BN_hex2bn(&c,"8C0F971DF2F3672B28811407E2DABBE1DA0FEBBBDFC7DCB67396567EA1E2493F");
    BN_hex2bn(&d,"74D806F9F3A62BAE331FFE3F0A68AFE35B3D2E4794148AACBC26AA381CD7D30D");
    //encry = m^e mod n
    BN_mod_exp(dec,c,d,n,ctx);
    printBN("encrypt message = ", dec);

    return 0;
}
```

We decrypt the given cipher text, *c* using the formula: *c^d mod n.*
By decrypting, we get the hex value of the message.
We then use the python to decode the hex value:

```
[02/27/24]seed@VM:~/cs458Lab2$ gcc -o task3 task3.c -lcrypto
[02/27/24]seed@VM:~/cs458Lab2$ ./task3
encrypt message = 50617373776F72642069732064656573
[02/27/24]seed@VM:~/cs458Lab2$ python -c 'print("A top secret!".encode("hex"))'
4120746f702073656372657421
```

3.4 Task4 Signing a Message

First, we get the hex value of " I owe you $2000."

```
[02/27/24] seed@VM:~/cs458Lab2$ python -c
'print("I owe you $2000.".encode("hex"))'
49206f776520796f75202432303030302e
```

Value is 49206f776520796f752024323030302e

We run our code to produce the signature for the message

```
[02/27/24] seed@VM:~/cs458Lab2$ vi task4.c
[02/27/24] seed@VM:~/cs458Lab2$ gcc -o
task4 task4.c -lcrypto
[02/27/24] seed@VM:~/cs458Lab2$ ./task4
encrypt message =
BCC20FB7568E5D48E434C387C06A6025E90D29D848
AF9C3EBAC0135D99305822
```

Then, we get the hex value of "I owe you $3000."

```
[02/27/24] seed@VM:~/cs458Lab2$ python -c 'print("Launch
a missle.".encode("hex"))'
4c61756e63682061206d6973736c652e
```

Value is 49206f776520796f752024333030302e

We run our code to produce the signature for the message:

```
[02/27/24] seed@VM:~/cs458Lab2$ vi task4.c
[02/27/24] seed@VM:~/cs458Lab2$ gcc -o
task4 task4.c -lcrypto
[02/27/24] seed@VM:~/cs458Lab2$ ./task4
encrypt message =
BCC20FB7568E5D48E434C387C06A6025E90D29D848
AF9C3EBAC0135D99305822
```

We can observe that, though there is only one byte of difference in the message, their signatures differ completely.

Code is similar to task3

```c
#include <stdio.h>
#include <openssl/bn.h>
#define NBITS 256

//print a big number
void printBN(char *msg, BIGNUM *a){
// Convert the BIGNUM to number string
char * number_str = BN_bn2hex(a);
// Print out the number string
printf("%s %s\n", msg, number_str);
// Free the dynamically allocated memory
OPENSSL_free(number_str);
}

int main(){
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *n = BN_new();
    BIGNUM *d = BN_new();
    BIGNUM *c = BN_new();
    BIGNUM *dec = BN_new();
    //Initialize
    BN_hex2bn(&n,"DCBFFE3E51F62E09CE7032E2677A78946A849DC4CDDE3A4D0CB81629242FB1A5");
    BN_hex2bn(&c,"49206f776520796f752024323030302e");// HEX value of "I owe you $2000."
    //BN_hex2bn(&c,"49206f776520796f752024333030302e");// HEX value of "I owe you $3000."
    BN_hex2bn(&d,"74D806F9F3A62BAE331FFE3F0A68AFE35B3D2E4794148AACBC26AA381CD7D30D");
    //encry = m^e mod n
    BN_mod_exp(dec,c,d,n,ctx);
    printBN("encrypt message = ", dec);

    return 0;
}
```

3.5 Task5: Verifying a Signature

First, We get the hex value of the message M, “Launch a missile.” using python

```
[02/27/24] seed@VM:~/cs458Lab2$ python -c 'print("Launch
a missle.".encode("hex"))'
4c61756e63682061206d6973736c652e
```

We use the signature to compute the value of the message C.

We then use the BN_cmp API in order to compare the two messages and conclude whether the signature is Alice’s or not:

```
[02/27/24]seed@VM:~/cs458Lab2$ vi task5.c
[02/27/24]seed@VM:~/cs458Lab2$ gcc -o task5 task5.c -lcrypto
[02/27/24] seed@VM:~/cs458Lab2$ ./task5
Original Message : 4C61756E63682061206D697373696C652E
Value of computed :
Walid Signature!
4C61756E63682061206D697373696C652E
```

From the result, we know the same message value, therefore, it’s Alice’s signature.

Code:

```c
//  task5.c
//
//
//  Created by SHIQI LIU on 10/18/20.
//
#include <stdio.h>
#include <openssl/bn.h>
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()
{
    // init
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *n = BN_new();
    BIGNUM *e = BN_new();
    BIGNUM *M = BN_new();
    // BIGNUM *d = BN_new();
    BIGNUM *C = BN_new();
    BIGNUM *S = BN_new();

    // assign values
    BN_hex2bn(&n, "AE1CD4DC432798D933779FBD46C6E1247F0CF1233595113AA51B450F18116115");

    BN_dec2bn(&e, "65537");
    BN_hex2bn(&M, "4c61756e63682061206d697373696c652e"); //hex encode for " Launch a missile."
    BN_hex2bn(&S, "643D6F34902D9C7EC90CB0B2BCA36C47FA37165C0005CAB026C0542CBDB6802F");
```

```c
    // Get S^e mod: if S=M^d mod n, C=M
    BN_mod_exp(C, S, e, n, ctx);
printBN("Original Message : ", M );
printBN("Value of computed : ", C);
    // verify the signature
    if (BN_cmp(C, M) == 0)
    {
        printf("Valid Signature! \n");
    }
    else
    {
        printf("Verification fails! \n");
    }

    return 0;
}
```

Suppose that the signature in is corrupted, such that the last byte of the signature changes from 2F to 3F,

S = 643D6F34902D9C7EC90CB0B2BCA36C47FA37165C0005CAB026C0542CBDB6803F

We use the signature to compute the value of the message C.

We then use the BN_cmp API in order to compare the two messages and conclude whether the signature is Alice’s or not:

```
[02/27/24]seed@VM:~/cs458Lab2$ vi task5.c
[02/27/24] seed@VM:~/cs458Lab2$ gcc -o task5 task5.c -lcrypto
[02/27/24]seed@VM:~/cs458Lab2$ ./task5
Original Message : 4C61756E63682061206D697373696C652E
Value of computed : 91471927C80DF1E42C154FB4638CE8BC72 6D3D66C83A4EB6B7BE0203B41AC294
Verification fails!
```

Therefore, we get the value of computed message is entirely different form original message, though only 1 byte of the signature is changed. It causes the verification fails.

3.6 Task6 Manually Verifying an X.509 Certificate

- Step 1

  Download a certificate from a real web server. We use the www.google.com server in this document

```
[02/27/24]seed@VM:~/cs458Lab2$ openssl s_client -connect www.google.com:443 -
showcerts
CONNECTED(00000003)
depth=2 OU = GlobalSign Root CA - R2, O = GlobalSign, CN = GlobalSign
verify return:1
depth=1 C = US, O = Google Trust Services, CN = GTS CA 101
verify return:1
depth=0 C = US, ST = California, L = Mountain View, O = Google LLC, CN = www.google.com

verify return:1
---
Certificate chain
 0 s:/C=US/ST=California/L=Mountain View/O=Google LLC/CN=www.google.com
   i:/C=US/O=Google Trust Services/CN=GTS CA 101
-----BEGIN CERTIFICATE-----
```

```
MIIFkTCCBHmgAwIBAgIQB5q2sT+2NbIIAAAAAFst1zANBgkqhkiG9w0BAQsFADBC
MQswCQYDVQQGEwJVUzEeMBwGA1UEChMVR29vZ2xlIFRydXN0IFNlcnZpY2VzMRMw
EQYDVQQDEwpHVFMgQ0EgMU8xMB4XDTIwMDkyMjE1MTYxOVoXDTIwMTIxNTE1MTYx
OVowaDELMAkGA1UEBhMCVVMxEzARBgNVBAgTCkNhbGlmb3JuaWExFjAUBgNVBAcT
DU1vdW50YWluIFZpZXcxEzARBgNVBAoTCkdvb2dsZSBMTEMxFzAVBgNVBAMTDnd3
dy5nb29nbGUuY29tMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEAnG1D
Z2Tl8l5ruTFxLz5PmUKZjYFEihvXKsmiu2d0NTKv8RgWvMItgvP/1IfIz+O76jn3
meC71lP10LST+wI+vFPE9vEL/Zie5veUijpXE0bUApeud+Rnlsw4UJ1x50PCBdSN
r41sNVCAAU98ibSGlc5n2Qr1/YYhs2qnqKKG8i8zNMbjDYyzOWyjfmRVi8W7eU2Z
FpJVwc3D6WEACqQrLATPcFNK0Jb3f5j7eohea9eMCslB13e43iIbA2zHb8owE2Mu
F7GKhYiTr8OEFy4aq7meEeIFHDB/O5eO+6nSxV0p3dBsdxXu/BlEVRuwnigCtMAn
LVS5OEhwBuz1Wl+VWwIDAQABo4ICWzCCAlcwDgYDVR0PAQH/BAQDAgWgMBMGA1Ud
JQQMMAoGCCsGAQUFBwMBMAwGA1UdEwEB/wQCMAAwHQYDVR0OBBYEFDDRC4ywBM9P
OAk0QWnLJlg3HjmJMB8GA1UdIwQYMBaAFJjR+G4Q68+b7GCfGJAboOt9Cf0rMGgG
CCsGAQUFBwEBBFwwWjArBggrBgEFBQcwAYYfaHR0cDovL29jc3AucGtpLmdvb2cv
Z3RzMW8xY29yZTArBggrBgEFBQcwAoYfaHR0cDovL3BraS5nb29nL2dzcjIvR1RT
MU8xLmNydDAZBgNVHREEEjAQgg53d3cuZ29vZ2xlLmNvbTAhBgNVHSAEGjAYMAgG
BmeBDAECAjAMBgorBgEEAdZ5AgUDMDMGA1UdHwQsMCowKKAmoCSGImh0dHA6Ly9j
cmwucGtpLmdvb2cvR1RTMU8xY29yZS5jcmwwggEDBgorBgEEAdZ5AgQCBIH0BIHx
AO8AdQDwlaRZ8gDRgkAQLS+TiI6tS/4dR+OZ4dA0prCoqo6ycwAAAXS2mgE4AAAE
AwBGMEQCIBA000C/IxSaE2sVhS+dJtnXsh7fSYjeybHOnFOtoRFCAiBnTcymqGeb
lwBe5U3nJyG3tngeH9YCfBdkeShmHdf6DgB2ALIeBcyLos2KIE6HZvkruYolIGdr
2vpw57JJUy3vi5BeAAABdLaaADoAAAQDAEcwRQIgBFJa178fY3/4Pb95N5hh2JfR
3EJ9AUbb0vff31qx/NsCIQDJTBFLs1QdubTe6S+Xc7EuQC9rh3YVLSYc8+dSRZuV
3zANBgkqhkiG9w0BAQsFAAOCAQEAfznjbmvP1GKbyj7RIT5L/x6dkPBCWp6u6toi
1ak4chqHN7mkJkazcb+DGoSAkz7DWfvrVt6Kruh7Vq93Z90g9Nnp5ZiMvkHd5+JM
VqVq3SEK0x+Bd//cW7364zsqnCP97Dg1kvPZz/Rqkq04i9ajSGNxkiMjkkFG4klO
tBuMXOmjoIPwa81iXT1tpV8TqV3uQj0FJ+WZXrYP33HSFGgEXO4VJq6cAh1o5V4z
+3KOF1Si5pVAzIHjEbTB9RP2WK7XQ2VkmyfqcnEJYCEnLDAReQkkGQMmJVO14jHh
SRcKMTc/HXPKihjE7cPmhElEehHzWkJLsYwYZcIGOP+shpz1rw==
-----END CERTIFICATE-----
 1 s:/C=US/O=Google Trust Services/CN=GTS CA 1O1
   i:/OU=GlobalSign Root CA - R2/O=GlobalSign/CN=GlobalSign
-----BEGIN CERTIFICATE-----
MIIESjCCAzKgAwIBAgINAeO0mqGNiqmBJWlQuDANBgkqhkiG9w0BAQsFADBMMSAw
HgYDVQQLExdHbG9iYWxTaWduIFJvb3QgQ0EgLSBSMjETMBEGA1UEChMKR2xvYmFs
U2lnbjETMBEGA1UEAxMKR2xvYmFsU2lnbjAeFw0xNzA2MTUwMDAwNDJaFw0yMTEy
MTUwMDAwNDJaMEIxCzAJBgNVBAYTAlVTMR4wHAYDVQQKExVHb29nbGUgVHJ1c3Qg
U2VydmljZXMxEzARBgNVBAMTCkdUUyBDQSAxTzEwggEiMA0GCSqGSIb3DQEBAQUA
A4IBDwAwggEKAoIBAQDQGM9F1IvN05zkQO9+tN1pIRvJzzyOTHW5DzEZhD2ePCnv
UA0Qk28FgICfKqC9EksC4T2fWBYk/jCfC3R3VZMdS/dN4ZKCEPZRrAzDsiKUDzRr
mBBJ5wudgzndIMYcLe/RGGFl5yODIKgjEv/SJH/UL+dEaltN11BmsK+eQmMF++Ac
xGNhr59qM/9il71I2dN8FGfcddwuaej4bXhp0LcQBbjxMcI7JP0aM3T4I+DsaxmK
FsbjzaTNC9uzpFlgOIg7rR25xoynUxv8vNmkq7zdPGHXkxWY7oG9j+JkRyBABk7X
rJfoucBZEqFJJSPk7XA0LKW0Y3z5oz2D0c1tJKwHAgMBAAGjggEzMIIBLzAOBgNV
HQ8BAf8EBAMCAYYwHQYDVR0lBBYwFAYIKwYBBQUHAwEGCCsGAQUFBwMCMBIGA1Ud
EwEB/wQIMAYBAf8CAQAwHQYDVR0OBBYEFJjR+G4Q68+b7GCfGJAboOt9Cf0rMB8G
A1UdIwQYMBaAFJviB1dnHB7AagbeWbSaLd/cGYYuMDUGCCsGAQUFBwEBBCkwJzAl
BggrBgEFBQcwAYYZaHR0cDovL29jc3AucGtpLmdvb2cvZ3NyMjAyBgNVHR8EKzAp
MCegJaAjhiFodHRwOi8vY3JsLnBraS5nb29nL2dzcjIvZ3NyMi5jcmwwPwYDVR0g
BDgwNjA0BgZngQwBAgIwKjAoBggrBgEFBQcCARYcaHR0cHM6Ly9wa2kuZ29vZy9y
ZXBvc2l0b3J5LzANBgkqhkiG9w0BAQsFAAOCAQEAGoA+Nnn78y6pRjd9XlQWNa7H
TgiZ/r3RNGkmUmYHPQq6Scti9PEajvwRT2iWTHQr02fesqOqBY2ETUwgZQ+lltoN
FvhsO9tvBCOIazpswWC9aJ9xju4tWDQH8NVU6YZZ/XteDSGU9YzJqPjY8q3MDxrz
mqepBCf5o8mw/wJ4a2G6xzUr6Fb6T8McDO22PLRL6u3M4Tzs3A2M1j6bykJYi8wW
IRdAvKLWZu/axBVbzYmqmwkm5zLSDW5nIAJbELCQCZwMH56t2Dvqofxs6BBcCFIZ
USpxu6x6td0V7SvJCCosirSmIatj/9dSSVDQibet8q/7UK4v4ZUN80atnZz1yg==
-----END CERTIFICATE-----
---
Server certificate
subject=/C=US/ST=California/L=Mountain View/O=Google LLC/CN=www.google.com
```

```
issuer=/C=US/O=Google Trust Services/CN=GTS CA 1O1
---
No client certificate CA names sent
Peer signing digest: SHA256
Server Temp Key: ECDH, P-256, 256 bits
---
SSL handshake has read 3247 bytes and written 431 bytes
---
New, TLSv1/SSLv3, Cipher is ECDHE-RSA-AES128-GCM-SHA256
Server public key is 2048 bit
Secure Renegotiation IS supported
Compression: NONE
Expansion: NONE
No ALPN negotiated
SSL-Session:
    Protocol  : TLSv1.2
    Cipher    : ECDHE-RSA-AES128-GCM-SHA256
    Session-ID: BC337A8A0CE22588A9845CD955A25131346F558771B2B435CFB7373C3534E9E7
    Session-ID-ctx:
    Master-
Key: 42EA2EB90D0B1F59618908405370AAB39B2C8E27CD06BB4C99E71435294027B3DAB36CCA97E370AA4A
738095F45CDBC0
    Key-Arg   : None
    PSK identity: None
    PSK identity hint: None
    SRP username: None
    TLS session ticket lifetime hint: 100800 (seconds)
        TLS session ticket:
        0000 - 01 95 05 1c 6a 74 90 8c-f9 0e 6c 5a cc dc cd 1b   ....jt....lZ....
        0010 - e0 a3 61 6d 1a 72 be 3c-e5 8a b1 55 2e d7 5a ab   ..am.r.<...U..Z.
        0020 - a9 01 59 f0 e8 eb 0e a2-e5 34 a4 b6 be 05 ec 7c   ..Y......4.....|
        0030 - 08 9e e2 70 94 9c e1 8b-47 8e 10 24 c8 e6 e6 5c   ...p....G..$...\
        0040 - cc 83 71 a2 a2 1c c8 c3-db 1f df c9 15 23 3e e0   ..q..........#>.
        0050 - dc f9 73 33 46 83 27 d9-ab 92 40 0d 92 41 89 6f   ..s3F.'...@..A.o
        0060 - 49 bb 2f 30 8c 8e fc fd-bc 3a 44 c5 67 3d c2 15   I./0.....:D.g=..
        0070 - 29 2c 86 39 53 66 a0 68-70 48 36 99 50 e7 09 ba   ),.9Sf.hpH6.P...
        0080 - 39 ce 7f 5b d1 fb a1 7f-83 b9 6b be 36 b5 c1 a6   9..[......k.6...
        0090 - a7 32 f0 85 d7 04 77 1b-e4 c4 03 77 d3 0b 27 92   .2....w....w..'.
        00a0 - 1d 4d a5 06 35 67 69 5e-8b 51 cd 64 2e 91 8f 79   .M..5gi^.Q.d...y
        00b0 - fa c8 5b 17 8f 63 f4 c5-89 e0 83 2d 16 2f 9e f7   ..[..c.....-./..
        00c0 - 33 20 5d 03 00 c6 f4 0d-ec b5 a2 d0 6a 49 a4 49   3 ]........jI.I
        00d0 - e5 6a a9 fc f7 05 34 d5-7d 63 af 4d 79            .j....4.}c.My

        Start Time: 1603076169
        Timeout   : 300 (sec)
        Verify return code: 0 (ok)
    ---
    read:errno=0
```

```
        seed@VM:~/cs458Lab2$
[02/27/24] seed@VM:~/cs458Lab2$ openssl s_client -connec t www.google.com: 443 - showcerts
CONNECTED (00000003)
depth=2 OU = GlobalSign Root CA - R2, 0 = GlobalSign, C N = GlobalSign
verify return:1
depth=1 C = US, 0 = Google Trust Services, CN = GTS CA 101
verify return:1
depth=0 C=US, ST = California, L = Mountain View, 0 = Google LLC, CN = www.google.com
verify return:1
Certificate chain
0 s:/C=US/ST=California/L=Mountain View/O=Google LLC/C
N=www.google.com
i:/C=US/0=Google Trust Services/CN=GTS_CA_101 -BEGIN CERTIFICATE-----
MIIFKTCCBHmgAwIBAgIQB5q2sT+2NbIIAAAAAFstlzANBgkqhkiG9w0
BAQsFADBC

VqVq3SEK0x+Bd//cW7364zsqnCP97Dg1kvPZz/Rqkq04i9ajSGNxKi
jkkFG4kl0
tBuMXOmjoIPwa81iXT1tpV8TqV3uQjOFJ+WZXrYP33HSFGgEX04VJq
cAh1o5V4z
+3K0F1Si5pVAzIHjEbTB9RP2WK7XQ2VkmyfqcnEJYCEnLDAReQkkGQN
mJV014jHh
SRcKMTc/HXPKihjE7cPmhElEehHzWkJLsYwYZcIGOP+shpz1rw==
--END CERTIFICATE----
1 s:/C=US/0=Google Trust Services/CN=GTS CA 101 i:/OU=
GlobalSign Root CA - R2/0=GlobalSign/CN=Global
Sign
--BEGIN CERTIFICATE--
MIIESjCCAzKgAwIBAgINAe00mqGNiqmBJWlQuDANBgkqhkiG9w0BAQ:
FADBMMSAW
HgYDVQQLExdHbG9iYWxTaWduIFJvb3QgQ0EgLSBSMjETMBEGA1UEChM
KR2xvYmFs
U2lnbjETMBEGA1UEAXMKR2xvYmFsU2lnbjAeFw0xNzA2MTUwMDAwND.
aFw0yMTEy
MTUwMDAwNDJaMEIxCzAJBgNVBAYTALVTMR4wHAYDVQQKEXVHb29nbGl
gVHJ1c3Qg
U2VydmljZXMxEzARBgNVBAMTCkdUUyBDQSAxTzEwggEiMA0GCSqGSI
3DQEBAQUA
```

We save these two certificates in the files c0.pem and c1.pem respectively

- Step2 Extract the public key (e, n) from the issuer's certificate.

  We get the value of n using -modulus:

```
[02/27/24]seed@VM:~/cs458Lab2$ openssl x509 -in c1.pem -noout -modulus
Modulus=D018CF45D48BCDD39CE440EF7EB4DD69211BC9CF3C8E4C75B90F3119843D9E3C29EF
500D10936F0580809F2AA0BD124B02E13D9F581624FE309F0B747755931D4BF74DE1928210F6
51AC0CC3B222940F346B981049E70B9D8339DD20C61C2DEFD1186165E7238320A82312FFD224
7FD42FE7446A5B4DD75066B0AF9E426305FBE01CC46361AF9F6A33FF6297BD48D9D37C1467DC
75DC2E69E8F86D7869D0B71005B8F131C23B24FD1A3374F823E0EC6B198A16C6E3CDA4CD0BDB
B3A4596038883BAD1DB9C68CA7531BFCBCD9A4ABBCDD3C61D7931598EE81BD8FE26447204006
4ED7AC97E8B9C05912A1492523E4ED70342CA5B4637CF9A33D83D1CD6D24AC07
```

```
[02/27/24] seed@VM:~/cs458Lab2$ vi c0.pem [10/18/20]seed@VM:~/cs458Lab2$ vi cl.pem
[02/27/24] seed@VM:~/cs458Lab2$ openssl x509 -in cl.pem -noout -modulus
Modulus=D018CF45D48BCDD39CE440EF7EB4DD69211BC9CF3C8E4C7 5B90F3119843D9E3C29EF500D10936F0580809F2AA0BD124B02E13D
9F581624FE309F0B747755931D4BF74DE1928210F651AC0CC3B2229
40F346B981049E70B9D8339DD20C61C2DEFD1186165E7238320A823
12FFD2247FD42FE7446A5B4DD75066B0AF9E426305FBE01CC46361A
F9F6A33FF6297BD48D9D37C1467DC75DC2E69E8F86D7869D0B71005
B8F131C23B24FD1A3374F823E0EC6B198A16C6E3CDA4CD0BDBB3A45 96038883BAD1DB9C68CA7531BFCBCD9A4ABBCDD3C61D7931598EE81
BD8FE264472040064ED7AC97E8B9C05912A1492523E4ED70342CA5B
4637CF9A33D83D1CD6D24AC07
2/10/201
HOWM
```

Print all attributes of the certificate, and then find the exponent, which is public key e(line 35)

```
1.  [02/27/24]seed@VM:~/cs458Lab2$ openssl x509 -in c1.pem -text -noout
2.  Certificate:
3.      Data:
4.          Version: 3 (0x2)
5.          Serial Number:
6.              01:e3:b4:9a:a1:8d:8a:a9:81:25:69:50:b8
7.      Signature Algorithm: sha256WithRSAEncryption
8.          Issuer: OU=GlobalSign Root CA - R2, O=GlobalSign, CN=GlobalSign
9.          Validity
10.             Not Before: Jun 15 00:00:42 2017 GMT
11.             Not After : Dec 15 00:00:42 2021 GMT
12.         Subject: C=US, O=Google Trust Services, CN=GTS CA 1O1
13.         Subject Public Key Info:
14.             Public Key Algorithm: rsaEncryption
15.                 Public-Key: (2048 bit)
16.                 Modulus:
17.                     00:d0:18:cf:45:d4:8b:cd:d3:9c:e4:40:ef:7e:b4:
18.                     dd:69:21:1b:c9:cf:3c:8e:4c:75:b9:0f:31:19:84:
19.                     3d:9e:3c:29:ef:50:0d:10:93:6f:05:80:80:9f:2a:
20.                     a0:bd:12:4b:02:e1:3d:9f:58:16:24:fe:30:9f:0b:
21.                     74:77:55:93:1d:4b:f7:4d:e1:92:82:10:f6:51:ac:
22.                     0c:c3:b2:22:94:0f:34:6b:98:10:49:e7:0b:9d:83:
23.                     39:dd:20:c6:1c:2d:ef:d1:18:61:65:e7:23:83:20:
24.                     a8:23:12:ff:d2:24:7f:d4:2f:e7:44:6a:5b:4d:d7:
25.                     50:66:b0:af:9e:42:63:05:fb:e0:1c:c4:63:61:af:
26.                     9f:6a:33:ff:62:97:bd:48:d9:d3:7c:14:67:dc:75:
27.                     dc:2e:69:e8:f8:6d:78:69:d0:b7:10:05:b8:f1:31:
28.                     c2:3b:24:fd:1a:33:74:f8:23:e0:ec:6b:19:8a:16:
29.                     c6:e3:cd:a4:cd:0b:db:b3:a4:59:60:38:88:3b:ad:
30.                     1d:b9:c6:8c:a7:53:1b:fc:bc:d9:a4:ab:bc:dd:3c:
31.                     61:d7:93:15:98:ee:81:bd:8f:e2:64:47:20:40:06:
32.                     4e:d7:ac:97:e8:b9:c0:59:12:a1:49:25:23:e4:ed:
33.                     70:34:2c:a5:b4:63:7c:f9:a3:3d:83:d1:cd:6d:24:
34.                     ac:07
35.                 Exponent: 65537 (0x10001)
```

```
-text -noout
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            01:e3:b4:9a:a1:8d:8a:a9:81:25:69:50:b8
    Signature Algorithm: sha256WithRSAEncryption
        Issuer: OU=GlobalSign Root CA - R2, O=GlobalSig
n, CN=GlobalSign
        Validity
            Not Before: Jun 15 00:00:42 2017 GMT
            Not After : Dec 15 00:00:42 2021 GMT
        Subject: C=US, O=Google Trust Services, CN=GTS
CA 1O1
        Subject Public Key Info:
            Public Key Algorithm: rsaEncryption
                Public-Key: (2048 bit)
                Modulus:
                    00:d0:18:cf:45:d4:8b:cd:d3:9c:e4:40
:ef:7e:b4:
```

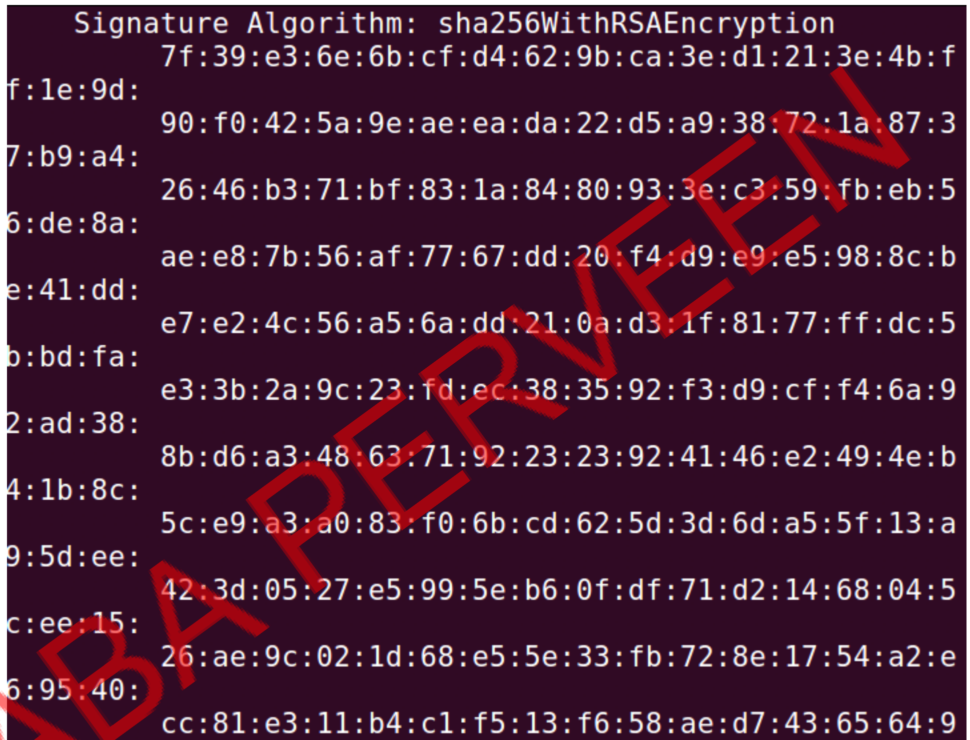
```
63:61:af:
                   9f:6a:33:ff:62:97:bd:48:d9:d3:7c:14
67:dc:75:
                   dc:2e:69:e8:f8:6d:78:69:d0:b7:10:05
b8:f1:31:
                   c2:3b:24:fd:1a:33:74:f8:23:e0:ec:6b
19:8a:16:
                   c6:e3:cd:a4:cd:0b:db:b3:a4:59:60:38
88:3b:ad:
                   1d:b9:c6:8c:a7:53:1b:fc:bc:d9:a4:ab
bc:dd:3c:
                   61:d7:93:15:98:ee:81:bd:8f:e2:64:47
20:40:06:
                   4e:d7:ac:97:e8:b9:c0:59:12:a1:49:25
23:e4:ed:
                   70:34:2c:a5:b4:63:7c:f9:a3:3d:83:d1
cd:6d:24:
                   ac:07
                Exponent: 65537 (0x10001)
```


- Step3 Extract the signature from the server's certificate:

  We run the command: openssl x509 -in c0.pem -text –noout to extract the signature from the server's certificate, c0.pem. We put this signature into a file.

```
[02/27/24]seed@VM:~/cs458Lab2$  openssl x509 -in c0.pem -text -noout
    Signature Algorithm: sha256WithRSAEncryption
         7f:39:e3:6e:6b:cf:d4:62:9b:ca:3e:d1:21:3e:4b:ff:1e:9d:
         90:f0:42:5a:9e:ae:ea:da:22:d5:a9:38:72:1a:87:37:b9:a4:
         26:46:b3:71:bf:83:1a:84:80:93:3e:c3:59:fb:eb:56:de:8a:
```

```
        ae:e8:7b:56:af:77:67:dd:20:f4:d9:e9:e5:98:8c:be:41:dd:
        e7:e2:4c:56:a5:6a:dd:21:0a:d3:1f:81:77:ff:dc:5b:bd:fa:
        e3:3b:2a:9c:23:fd:ec:38:35:92:f3:d9:cf:f4:6a:92:ad:38:
        8b:d6:a3:48:63:71:92:23:23:92:41:46:e2:49:4e:b4:1b:8c:
        5c:e9:a3:a0:83:f0:6b:cd:62:5d:3d:6d:a5:5f:13:a9:5d:ee:
        42:3d:05:27:e5:99:5e:b6:0f:df:71:d2:14:68:04:5c:ee:15:
        26:ae:9c:02:1d:68:e5:5e:33:fb:72:8e:17:54:a2:e6:95:40:
        cc:81:e3:11:b4:c1:f5:13:f6:58:ae:d7:43:65:64:9b:27:ea:
        72:71:09:60:21:27:2c:30:11:79:09:24:19:03:26:25:53:b5:
        e2:31:e1:49:17:0a:31:37:3f:1d:73:ca:8a:18:c4:ed:c3:e6:
        84:49:44:7a:11:f3:5a:42:4b:b1:8c:18:65:c2:06:38:ff:ac:
        86:9c:f5:af
[02/27/24]seed@VM:~/cs458Lab2$
```



We put this signature into a file, then remove all the colons and spaces from the signature:

```
[02/27/24]seed@VM:~/cs458Lab2$ vi signature
[02/27/24]seed@VM:~/cs458Lab2$ cat signature | tr -d '[:space:]:'
ee87b56af7767dd20f4d9e9e5988cbe41dde7e24c56a56add210ad31f8177ffdc5bbdfae33b2a9c23fdec383592f3d9cff46a92ad388bd6a348637192232392414 6e2494eb41b8c5ce9a3a083f06bcd625d3d6da55f13a95dee423d0527e5995eb60fdf71d21468045cee1526ae9c021d68e55e33fb728e1754a2e69540[02/27/24]seed@VM:~/cs458Lab2$
```

```
[02/27/24] seed@VM:~/cs458Lab2$ vi signature
[02/27/24] seed@VM:~/cs458Lab2$ cat signature | tr -d '[ :space: ]:
ee87b56af7767dd20f4d9e9e5988cbe41dde7e24c56a56add210ad3 1f8177ffdc5
bbdfae33b2a9c23fdec383592f3d9cff46a92ad388bd 6a3486371922323924146e
2494eb41b8c5ce9a3a083f06bcd625d3d 6da55f13a95dee423d0527e5995eb60fd
f71d21468045cee1526ae9c021d68e55e33fb728e1754a2e69540
[02/27/24] seed@VM:~/cs45
8Lab2$
```

- Step4 : Extract the body of the server's certificate

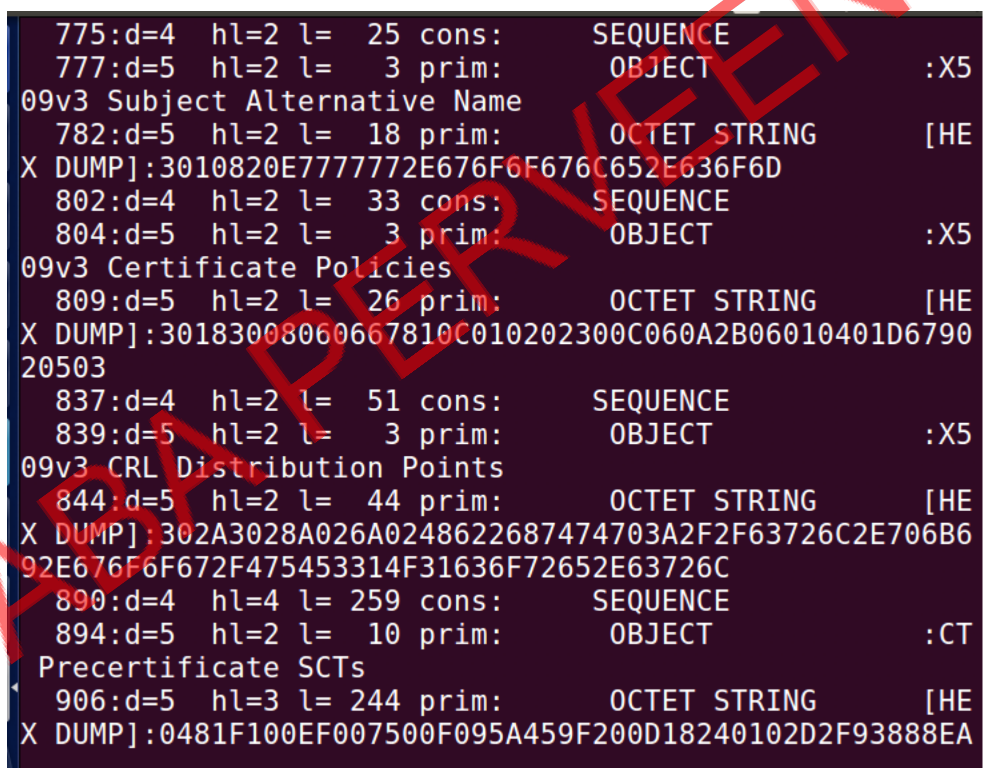
```
[02/27/24]seed@VM:~/cs458Lab2$ openssl asn1parse -i -in c0.pem
    0:d=0  hl=4 l=1425 cons: SEQUENCE
    4:d=1  hl=4 l=1145 cons:  SEQUENCE
    8:d=2  hl=2 l=   3 cons:   cont [ 0 ]
   10:d=3  hl=2 l=   1 prim:    INTEGER           :02
   13:d=2  hl=2 l=  16 prim:   INTEGER           :079AB6B13FB635B20800000000
5B2DD7
   31:d=2  hl=2 l=  13 cons:   SEQUENCE
   33:d=3  hl=2 l=   9 prim:    OBJECT            :sha256WithRSAEncryption
   44:d=3  hl=2 l=   0 prim:    NULL
   46:d=2  hl=2 l=  66 cons:   SEQUENCE
   48:d=3  hl=2 l=  11 cons:    SET
   50:d=4  hl=2 l=   9 cons:     SEQUENCE
   52:d=5  hl=2 l=   3 prim:      OBJECT            :countryName
   57:d=5  hl=2 l=   2 prim:      PRINTABLESTRING   :US
   61:d=3  hl=2 l=  30 cons:    SET
   63:d=4  hl=2 l=  28 cons:     SEQUENCE
   65:d=5  hl=2 l=   3 prim:      OBJECT            :organizationName
   70:d=5  hl=2 l=  21 prim:      PRINTABLESTRING   :Google Trust Services
   93:d=3  hl=2 l=  19 cons:    SET
   95:d=4  hl=2 l=  17 cons:     SEQUENCE
   97:d=5  hl=2 l=   3 prim:      OBJECT            :commonName
  102:d=5  hl=2 l=  10 prim:      PRINTABLESTRING   :GTS CA 1O1
  114:d=2  hl=2 l=  30 cons:   SEQUENCE
  116:d=3  hl=2 l=  13 prim:    UTCTIME           :200922151619Z
  131:d=3  hl=2 l=  13 prim:    UTCTIME           :201215151619Z
  146:d=2  hl=2 l= 104 cons:   SEQUENCE
  148:d=3  hl=2 l=  11 cons:    SET
  150:d=4  hl=2 l=   9 cons:     SEQUENCE
  152:d=5  hl=2 l=   3 prim:      OBJECT            :countryName
  157:d=5  hl=2 l=   2 prim:      PRINTABLESTRING   :US
  161:d=3  hl=2 l=  19 cons:    SET
  163:d=4  hl=2 l=  17 cons:     SEQUENCE
  165:d=5  hl=2 l=   3 prim:      OBJECT            :stateOrProvinceName
  170:d=5  hl=2 l=  10 prim:      PRINTABLESTRING   :California
  182:d=3  hl=2 l=  22 cons:    SET
  184:d=4  hl=2 l=  20 cons:     SEQUENCE
  186:d=5  hl=2 l=   3 prim:      OBJECT            :localityName
  191:d=5  hl=2 l=  13 prim:      PRINTABLESTRING   :Mountain View
  206:d=3  hl=2 l=  19 cons:    SET
  208:d=4  hl=2 l=  17 cons:     SEQUENCE
```

```
  210:d=5  hl=2 l=   3 prim:      OBJECT            :organizationName
  215:d=5  hl=2 l=  10 prim:      PRINTABLESTRING   :Google LLC
  227:d=3  hl=2 l=  23 cons:    SET
  229:d=4  hl=2 l=  21 cons:     SEQUENCE
  231:d=5  hl=2 l=   3 prim:      OBJECT            :commonName
  236:d=5  hl=2 l=  14 prim:      PRINTABLESTRING   :www.google.com
  252:d=2  hl=4 l= 290 cons:   SEQUENCE
  256:d=3  hl=2 l=  13 cons:    SEQUENCE
  258:d=4  hl=2 l=   9 prim:     OBJECT            :rsaEncryption
  269:d=4  hl=2 l=   0 prim:     NULL
  271:d=3  hl=4 l= 271 prim:    BIT STRING
  546:d=2  hl=4 l= 603 cons:   cont [ 3 ]
  550:d=3  hl=4 l= 599 cons:    SEQUENCE
  554:d=4  hl=2 l=  14 cons:     SEQUENCE
  556:d=5  hl=2 l=   3 prim:      OBJECT            :X509v3 Key Usage
  561:d=5  hl=2 l=   1 prim:      BOOLEAN           :255
  564:d=5  hl=2 l=   4 prim:      OCTET STRING      [HEX DUMP]:030205A0
  570:d=4  hl=2 l=  19 cons:     SEQUENCE
  572:d=5  hl=2 l=   3 prim:      OBJECT            :X509v3 Extended Key Usa
ge
  577:d=5  hl=2 l=  12 prim:      OCTET STRING      [HEX DUMP]:300A06082B060
10505070301
  591:d=4  hl=2 l=  12 cons:     SEQUENCE
  593:d=5  hl=2 l=   3 prim:      OBJECT            :X509v3 Basic Constraint
s
  598:d=5  hl=2 l=   1 prim:      BOOLEAN           :255
  601:d=5  hl=2 l=   2 prim:      OCTET STRING      [HEX DUMP]:3000
  605:d=4  hl=2 l=  29 cons:     SEQUENCE
  607:d=5  hl=2 l=   3 prim:      OBJECT            :X509v3 Subject Key Iden
tifier
  612:d=5  hl=2 l=  22 prim:      OCTET STRING      [HEX DUMP]:041430D10B8CB
004CF4F3809344169CB2658371E3989
  636:d=4  hl=2 l=  31 cons:     SEQUENCE
  638:d=5  hl=2 l=   3 prim:      OBJECT            :X509v3 Authority Key Id
entifier
  643:d=5  hl=2 l=  24 prim:      OCTET STRING      [HEX DUMP]:301680149 8D1F
86E10EBCF9BEC609F18901BA0EB7D09FD2B
  669:d=4  hl=2 l= 104 cons:     SEQUENCE
  671:d=5  hl=2 l=   8 prim:      OBJECT            :Authority Information A
ccess
  681:d=5  hl=2 l=  92 prim:      OCTET STRING      [HEX DUMP]:305A302B06082
B06010505073001861F687474703A2F2F6F6373702E706B692E676F6F672F677473316F31636
F7265302B06082B06010505073002861F687474703A2F2F706B692E676F6F672F677372322F4
75453314F312E637274
  775:d=4  hl=2 l=  25 cons:     SEQUENCE
  777:d=5  hl=2 l=   3 prim:      OBJECT            :X509v3 Subject Alternat
ive Name
  782:d=5  hl=2 l=  18 prim:      OCTET STRING      [HEX DUMP]:3010820E77777
72E676F6F676C652E636F6D
  802:d=4  hl=2 l=  33 cons:     SEQUENCE
  804:d=5  hl=2 l=   3 prim:      OBJECT            :X509v3 Certificate Poli
cies
  809:d=5  hl=2 l=  26 prim:      OCTET STRING      [HEX DUMP]:3018300806066
7810C010202300C060A2B06010401D679020503
  837:d=4  hl=2 l=  51 cons:     SEQUENCE
  839:d=5  hl=2 l=   3 prim:      OBJECT            :X509v3 CRL Distribution
 Points
```

```
 844:d=5  hl=2 l=  44 prim:      OCTET STRING      [HEX DUMP]:302A3028A026A
0248622687474703A2F2F63726C2E706B692E676F6F672F475453314F31636F72652E63726C

 890:d=4  hl=4 l= 259 cons:     SEQUENCE
 894:d=5  hl=2 l=  10 prim:      OBJECT            :CT Precertificate SCTs

 906:d=5  hl=3 l= 244 prim:      OCTET STRING      [HEX DUMP]:0481F100EF007
500F095A459F200D18240102D2F93888EAD4BFE1D47E399E1D034A6B0A8AA8EB27300000174B
69A0138000004030046304402201034D340BF23149A136B15852F9D26D9D7B21EDF4988DEC9B
1CE9C53ADA111420220674DCCA6A8679B97005EE54DE72721B7B6781E1FD6027C17647928661
DD7FA0E007600B21E05CC8BA2CD8A204E8766F92BB98A2520676BDAFA70E7B249532DEF8B905
E00000174B69A003A0000040300473045022004525AD7BF1F637FF83DBF79379861D897D1DC4
27D0146DBD2F7DFDF5AB1FCDB022100C94C114BB3541DB9B4DEE92F9773B12E402F6B8776152
D261CF3E752459B95DF
1153:d=1  hl=2 l=  13 cons:  SEQUENCE
1155:d=2  hl=2 l=   9 prim:   OBJECT            :sha256WithRSAEncryption
1166:d=2  hl=2 l=   0 prim:   NULL
1168:d=1  hl=4 l= 257 prim:  BIT STRING
```



```
  775:d=4  hl=2 l=  25 cons:      SEQUENCE
  777:d=5  hl=2 l=   3 prim:       OBJECT            :X5
09v3 Subject Alternative Name
  782:d=5  hl=2 l=  18 prim:       OCTET STRING      [HE
X DUMP]:3010820E7777772E676F6F676C652E636F6D
  802:d=4  hl=2 l=  33 cons:      SEQUENCE
  804:d=5  hl=2 l=   3 prim:       OBJECT            :X5
09v3 Certificate Policies
  809:d=5  hl=2 l=  26 prim:       OCTET STRING      [HE
X DUMP]:3018300806066781 0C010202300C060A2B06010401D6790
20503
  837:d=4  hl=2 l=  51 cons:      SEQUENCE
  839:d=5  hl=2 l=   3 prim:       OBJECT            :X5
09v3 CRL Distribution Points
  844:d=5  hl=2 l=  44 prim:       OCTET STRING      [HE
X DUMP]:302A3028A026A0248622687474703A2F2F63726C2E706B6
92E676F6F672F475453314F31636F72652E63726C
  890:d=4  hl=4 l= 259 cons:      SEQUENCE
  894:d=5  hl=2 l=  10 prim:       OBJECT            :CT
 Precertificate SCTs
  906:d=5  hl=3 l= 244 prim:       OCTET STRING      [HE
X DUMP]:0481F100EF007500F095A459F200D18240102D2F93888EA
```


In this we cannot determine the end of the body. So we use -strparse to get the field from the offset 4, which will give us the body of the certificate, excluding the signature block.

```
[02/27/24]seed@VM:~/cs458Lab2$ openssl asn1parse -i -in c0.pem -strparse 4 -out c0_body.bin -noout
[02/27/24]seed@VM:~/cs458Lab2$ sha256sum c0_body.bin
fe5623d9b8e79ffa12b3b6471ae96c3ebc8ee5b6144305320c8c7de06443269a  c0_body.bin
```

- Step5: Verify the signature.

  Code is similar to 3.5, We use the values obtained from the previous steps, get the signature and verify the signature obtained with the original signature

```
#include <stdio.h>
#include <openssl/bn.h>
#define NBITS 256

//print a big number
void printBN(char *msg, BIGNUM *a){
char * number_str = BN_bn2hex(a);
printf("%s %s\n", msg, number_str);
OPENSSL_free(number_str);
}

int main(){
    BN_CTX *ctx = BN_CTX_new();
    BIGNUM *S = BN_new();//signature from server step3
    BIGNUM *M = BN_new();//signature cerificate
    BIGNUM *n = BN_new();//modulus
    BIGNUM *e = BN_new();//exponent
    BIGNUM *M1 = BN_new();
    //Initialize
    BN_hex2bn(&e,"01001");
@
"task6.c" 44L, 1731C
```

```
[02/27/24] seed@VM:~/cs458Lab2$ vi task6.c
[02/27/24] seed@VM:~/cs458Lab2$ gcc -o task6 task6.c -lc rypto
[02/27/24] seed@VM:~/cs458Lab2$ ./task6
Valid Signature!
[02/27/24] seed@VM:~/cs458Lab2$
```

  We can notice that the original message and the hash value of the computed message is the same. Hence we can conclude that the www.google.com certificate is verified to be right.