An exercise in binary analysis and reverse compilation

KEYGENNING EVAL4

Nathan Rittenhouse – nathan_@mit.edu

Target

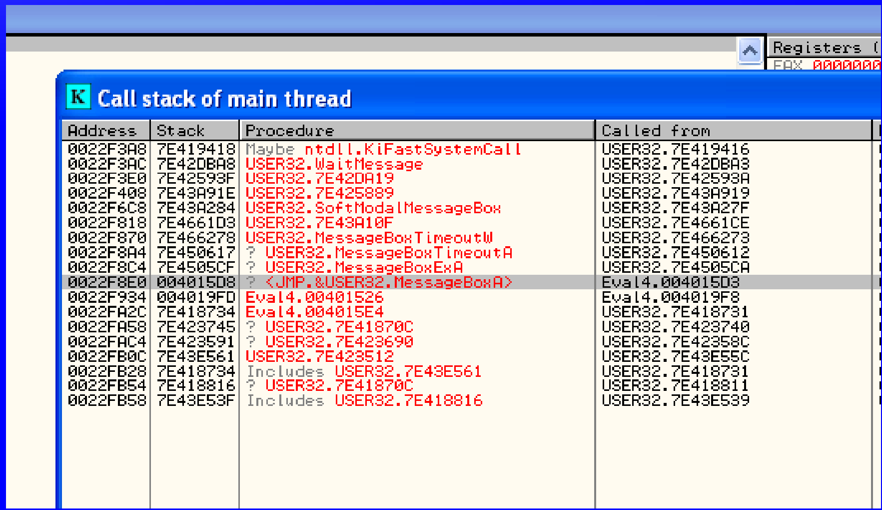
- http://crackmes.de/users/ezqui3l/eval_n4/browse
- Enter a user name and a serial number, the program says whether the input is valid or not

Our Purpose

- Understand eval4's anti-debugging mechanisms
- Decompile eval4's key verification algorithm
- Construct a program that when given a user name, will output a sequence of numbers that the program considers correct

Examining Input Flow

- Open target, attach
- Enter input, see results
- After dialog displays
  - Halt program
  - View call stack
- Observe
  - Program halted inside of MessageBoxA



Call stack of main thread

Address	Stack	Procedure	Called from
0022F3A8	7E419418	Maybe ntdll.KiFastSystemCall	USER32.7E419416
0022F3AC	7E42DBA8	USER32.WaitMessage	USER32.7E42DBA3
0022F3E0	7E42593F	USER32.7E42DA19	USER32.7E42593A
0022F408	7E43A91E	USER32.7E425889	USER32.7E43A919
0022F6C8	7E43A284	USER32.SoftModalMessageBox	USER32.7E43A27F
0022F818	7E4661D3	USER32.7E43A10F	USER32.7E4661CE
0022F870	7E466278	USER32.MessageBoxTimeoutW	USER32.7E466273
0022F8A4	7E450617	? USER32.MessageBoxTimeoutA	USER32.7E450612
0022F8C4	7E4505CF	? USER32.MessageBoxExA	USER32.7E4505CA
0022F8E0	004015D8	? <JMP.&USER32.MessageBoxA>	Eval4.004015D3
0022F934	004019FD	Eval4.00401526	Eval4.004019F8
0022FA2C	7E418734	Eval4.004015E4	USER32.7E418731
0022FA58	7E423745	? USER32.7E41870C	USER32.7E423740
0022FAC4	7E423591	? USER32.7E423690	USER32.7E42358C
0022FB0C	7E43E561	USER32.7E423512	USER32.7E43E55C
0022FB28	7E418734	Includes USER32.7E43E561	USER32.7E418731
0022FB54	7E418816	? USER32.7E41870C	USER32.7E418811
0022FB58	7E43E53F	Includes USER32.7E418816	USER32.7E43E539

Examining Input Flow

- Walk the call stack to find the DialogProc
- Examine the function
- Observe
  - Calls to GetDlgItemTextA, atoi, and sscanf
  - "%d" says the input should be decimal
  - A block of many mathematical operations
    - The hallmark of a key validation routine

Breaking The Algorithm

- Some global variables appear to be referenced
  - Always find out the global's purpose if it feels relevant
  - IDA can easily show all direct references
- Examine the first global after the sscanf's
  - Only one area of code modifies the value
  - It appears used inside of the long (~370 byte) arithmetic block

Anti-Debugging

- Inside the function referencing the global
  - FindWindowA with parameter "Ollydbg"
  - GetWindowThreadProcessId
- Follow the first non-symbolic call inside
  - Check references
  - This call is checksumming memory
- Clearly, the anti-debug mechanisms play a role in key validation

Anti-Debugging

- Close both olly and eval4
  - Open olly, then eval4
- Observe
  - Olly terminates
- To be sure the key validation mechanism is not affected by the debugger's presence, we must reverse the anti-debugging before reversing the algorithm

TLS Callback

- A common culprit for anti-debugging code is a TLS callback
  - These run when threads execute, which includes the time when a debugger is attached
- One is referenced by the first call in the anti-debug code calling block

Anti-Debugging

- Refer to the previous function called from getOllydbgProcessId
- IDA shows this being used in a **huge** block of anti-debugging functions

```
call    killProgramIfTlsIsModified ; appears to be a block of checksumming functions
call    scanAntiDebugFunctionsForBreakpoints
call    decodeDisplayBoxAndGetSerialNumMethods
call    scanStatusBoxAndGetSerialMethodsForBreakpoints
push    3
push    offset aRooGej1hH ; "Roo|Gej1H[H"
call    scanAndKillEncodedProcessName
push    1
push    offset aPmmzechFyf ; "PMMZECH/FYF"
call    scanAndKillEncodedProcessName
push    2
push    offset aUpf0gzg ; "UPF0GZG"
call    scanAndKillEncodedProcessName
call    killProgramIfScanAndKillEncodedProcessNameIsModified
call    scanGetOllydbgProcessIdForBPs
call    getOllydbgProcessId
```

Implications

- We cannot
  - Set breakpoints
  - Use a program to debug that has "Ollydbg" as its title
  - Modify any **useful** functions without difficulty
- We **can**
  - Use hardware breakpoints
  - Patch Olly to remove the window naming
  - Statically analyze with impunity

Introduction to Decompilation

- Take assembly, recover high level meaning
- This involves
  - Reconstructing type information
    - In C, this is usually just length, signedness
    - Structure / array composition
  - Reconstructing program logic
    - Loops, control flow, arithmetic operations, etc..

Type Recovery

```
movsx   edx, byte ptr [userNameCopy+ecx]
lea     eax, [ebx+2]
imul    eax, edx
movsx   edx, byte ptr [userNameCopy+ecx+5]
sub     eax, edx
mov     [ebp+ecx*4+var_6C], eax
inc     ecx
cmp     ecx, 5
jnz     short loc_401828
movsx   eax, [ebp+userNameCopy]
```

- Size
  - Look at register length
  - Look for `[byte|word|dword] ptr`
    - Then look for the sign extension
- Sign
  - `i` prefix – implies that the operation is signed
    - `idiv`/`div`
    - `imul`/`mul`
  - ‘Sign extended’ vs ‘zero extended’
    - `movsx`/`movzx`

Array Size

```
movsx   edx, byte ptr [userNameCopy+ecx]
lea     eax, [ebx+2]
imul    eax, edx
movsx   edx, byte ptr [userNameCopy+ecx+5]
sub     eax, edx
mov     [ebp+ecx*4+var_6C], eax
inc     ecx
cmp     ecx, 5
jnz     short loc_401828
movsx   eax, [ebp+userNameCopy]
```

- Structure composition and array size must be revealed through contextual analysis
  - Note \`var_6C\` as the base of a signed integer array
    - \`ecx*4\` - an integer is 4 bytes in length
      - Each increment to ecx moves pointer to next array element
      - Ecx is incremented until it reaches 5
    - This decomposes to
      - \`int var_6C[5]\`

Loop Reconstruction

- Easy way
  - IDA can identify them
  - Watch for `cmp` then `jXX` opcode sequences to learn what conditions the loop must meet to continue

```
.text:004012F1                 mov     edx, offset sub_401322
.text:004012F6                 xor     ecx, ecx
.text:004012F8                 cmp     edx, offset scanAntiDebugFunctionsForBreakpo
.text:004012FE                 mov     ebp, esp
.text:00401300                 jnb     short loc_401318
.text:00401302
.text:00401302 loc_401302:                             ; CODE XREF: killProgramIfSc
.text:00401302                 movzx   eax, byte ptr [edx]
.text:00401305                 inc     edx
.text:00401306                 add     ecx, eax
.text:00401308                 cmp     edx, offset scanAntiDebugFunctionsForBreakpo
.text:0040130E                 jb      short loc_401302
.text:00401310                 cmp     ecx, 0A63Eh
.text:00401316                 jz      short locret_40131F
.text:00401318
.text:00401318 loc_401318:                             ; CODE XREF: killProgramIfSc
```

Pattern #1 – Inline strlen

- [cl]ear [d]irection flag
  - Go forward, not backward in memory during the operation
- `repne scasb`
  - "While byte [edi] != al, decrement ecx by 1"
  - The not and dec turn ecx into the real string length

```
cld
or      ecx, 0FFFFFFFFh
xor     eax, eax
repne scasb
not     ecx
dec     ecx
```

Pattern #2 – adc Optimizations

```
mov     ecx, ds:checksumOnAntiDebugFunctionFailed

                              ; CODE XREF: DialogFunc+1F7↓j
movzx   eax, byte ptr [userName+edx] ; this is a reference to
cmp     ecx, 1
mov     [userNameCopy+edx], al ; copy of user name

                              ; adds 0xffffffff with the carry flag
adc     [ebp+unknown1], 0FFFFFFFFh
inc     edx
inc     [ebp+unknown1]
```

- [ad]d with [c]arry
- \`cmp\` is \`sub\` without actually changing register contents
  - This means \`sub ecx, 1\`
    - If ecx is zero, there will be a ‘carry’ because ecx will loop back to -1
    - **If** it loops, then unknown1 += 0 because the carry flag will be set
    - If not, unknown1 -= 1

Pattern #3 – sbb Optimizations

- [s]u[b]tract with [b]orrow
  - `adc` but with subtraction
- If eax == 0, carry flag is set
  - If not, carry flag is not set
- Translation
  - If carry flag set: `sub eax, (eax+1)`
    - Result: eax = -1
  - If carry flag not set: `sub eax, eax`
    - Result: eax = 0

```
mov     eax, ebx
and     eax, ecx
cmp     eax, 1
sbb     eax, eax
and     al, 20h
add     ecx, ecx
add     al, 41h
mov     [edx+ebp-0B8h], al
dec     edx
jns     short loc_402220
```

Decompiling the Monster

- Watch for writes to memory
  - In this case, to stack variables
- When the write is hit, observe operations on the value written before that point
  - Find the location where the variable was defined
    - Utilize IDA's highlighting functionality
  - Watch for all operations to the variable after that point
  - Record for each variable involved in the write

Intermediate Result

```
int var_6c[5];
char var_4C[UNKNOWN];
char userNameCopy[UNKNOWN];

// the serial numbers are just sscanf'd user supplied integers

var_A4 = (userNameCopy[0] * 2) - userNameCopy[5];
serialNumber2 -= var_6c[1];
var_AC = (userNameCopy[0] * 2) - userNameCopy[7];
serialNumber1 -= var_6c[0];
var_B4 = (userNameCopy[3] * 2) - userNameCopy[8];
var_BC = (userNameCopy[4] * 2) - userNameCopy[9];
var_C0 = serialNumber3 - var_6C[2];
serialNumber3 = var_C0;
var_C4 = serialNumber4 - var_6C[3];
serialNumber4 = var_C4;
var_C8 = serialNumber5 - var_6C[4];
serialNumber5 = var_C8;
var_CC = counter_getOllydbgProcessId;
var_E4 = counter_getOllydbgProcessId + counter_scanAndKillEncodedProcessName - 1;
var_E8 = var_E4 * 2 + 1;
var_4C = ((var_A4 * var_E4) + serialNumber1) / var_E8;
var_4B = ((serialNumber2 - var_6C[1]) + (userNameCopy[1] * 2 - userNameCopy[6]) * var_E4) / var_E8;
var_4A = ((var_AC * var_E4) + var_C0) / var_E8;
var_49 = ((var_B4 * var_E4) + var_C4) / var_E8;
var_48 = ((var_BC * var_E4) + var_C8) / var_E8;
var_47 = 0;
```

Readability

- The intermediate result may be ugly
  - Discern variables of interest
  - Adjust decompilation to understand those variables
    - From the disassembly, var_4C[x] is the important range

```
movzx   eax, [edx+ebp+var_4C]
cmp     byte ptr [edx+ebp+userName], al
setz    al
movzx   eax, al
add     [ebp+var_9C], eax
inc     edx
cmp     edx, 5
jnz     short loc_4019BB
cmp     [ebp+var_9C], 5 ; this seems to be the check that fails with the data
                        ; I've inputted
jnz     short loc_4019F1
cmp     [ebp+var_CC], 3 ; this one, however, seems correct
jnz     short loc_4019F1
push    3               ; we want to hit here
```

Still Ugly

```
var_4C[0] = ((((userNameCopy[0] * 2) - userNameCopy[5]) * (counter_gODBPid + counter_sAKEPN - 1)) + (serialNumber1 - var_6C[0])) / ((counter_gODBPid + counter_sAKEPN - 1) * 2 + 1);
var_4C[1] = ((((userNameCopy[1] * 2) - userNameCopy[6]) * (counter_gODBPid + counter_sAKEPN - 1)) + (serialNumber2 - var_6C[1])) / ((counter_gODBPid + counter_sAKEPN - 1) * 2 + 1);
var_4C[2] = ((((userNameCopy[2] * 2) - userNameCopy[7]) * (counter_gODBPid + counter_sAKEPN - 1)) + (serialNumber3 - var_6C[2])) / ((counter_gODBPid + counter_sAKEPN - 1) * 2 + 1);
var_4C[3] = ((((userNameCopy[3] * 2) - userNameCopy[8]) * (counter_gODBPid + counter_sAKEPN - 1)) + (serialNumber4 - var_6C[3])) / ((counter_gODBPid + counter_sAKEPN - 1) * 2 + 1);
var_4C[4] = ((((userNameCopy[4] * 2) - userNameCopy[9]) * (counter_gODBPid + counter_sAKEPN - 1)) + (serialNumber5 - var_6C[4])) / ((counter_gODBPid + counter_sAKEPN - 1) * 2 + 1);
var_4C[5] = 0;
```

Better

- Debugger check variables are replaced with numbers present during a 'normal' run

```
var_4C[0] = (((userNameCopy[0] * 2) - userNameCopy[5]) * 5 + (serialNumber1 - var_6C[0])) / 11;
var_4C[1] = (((userNameCopy[1] * 2) - userNameCopy[6]) * 5 + (serialNumber2 - var_6C[1])) / 11;
var_4C[2] = (((userNameCopy[2] * 2) - userNameCopy[7]) * 5 + (serialNumber3 - var_6C[2])) / 11;
var_4C[3] = (((userNameCopy[3] * 2) - userNameCopy[8]) * 5 + (serialNumber4 - var_6C[3])) / 11;
var_4C[4] = (((userNameCopy[4] * 2) - userNameCopy[9]) * 5 + (serialNumber5 - var_6C[4])) / 11;
var_4C[5] = 0;
```

Best

- This looks awfully like a loop

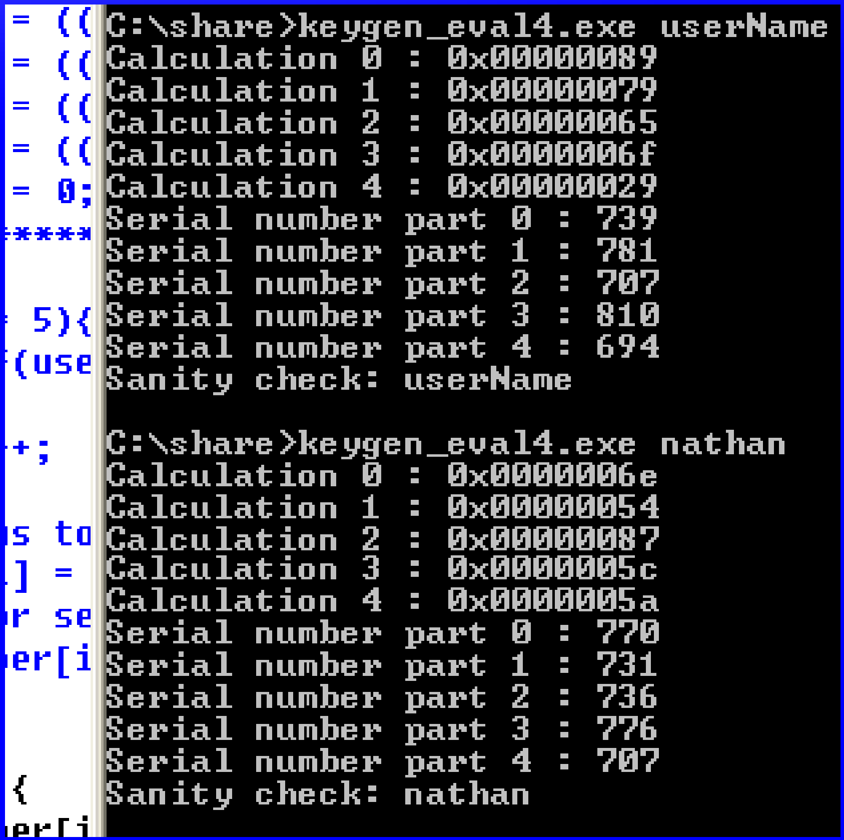
```
for(i=0; i<5; i++)
        userName[i] = (((userNameCopy[i] * 2) - userNameCopy[i+5]) * 5 + (serialNumber[i] - var_6C[i])) / 11;
```

Solve The Equation

- Solve for the serial number

```
for(i=0; i<5; i++){
        serialNumber[i] = userName[i] * 11 - ((userNameCopy[i] * 2) - userNameCopy[i+5]) * 5 + var_6C[i];
        printf("Serial number part %d : %d\n", i, serialNumber[i]);
}
```

Game Over



C:\share>keygen_eval4.exe userName
Calculation 0 : 0x00000089
Calculation 1 : 0x00000079
Calculation 2 : 0x00000065
Calculation 3 : 0x0000006f
Calculation 4 : 0x00000029
Serial number part 0 : 739
Serial number part 1 : 781
Serial number part 2 : 707
Serial number part 3 : 810
Serial number part 4 : 694
Sanity check: userName
C:\share>keygen_eval4.exe nathan
Calculation 0 : 0x0000006e
Calculation 1 : 0x00000054
Calculation 2 : 0x00000087
Calculation 3 : 0x0000005c
Calculation 4 : 0x0000005a
Serial number part 0 : 770
Serial number part 1 : 731
Serial number part 2 : 736
Serial number part 3 : 776
Serial number part 4 : 707
Sanity check: nathan

Go Further

- Check out Rolf Rolle's decompilation class
- Alex Sotirov's speech on quirks with Microsoft specific code
- Openrce.org