x86 & PE

$berlinsides_

28th December 2011

Ange Albertini

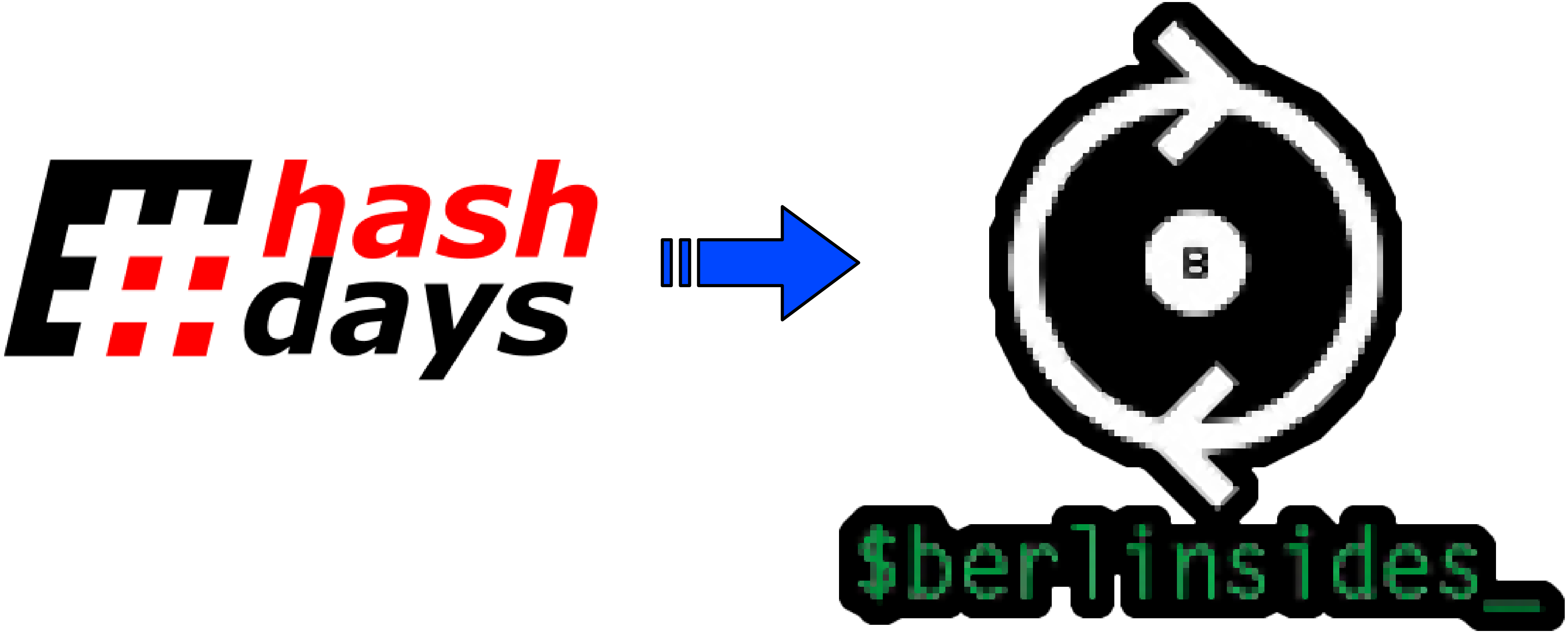
HIDDEN SLIDE

before you decide to read further...

Contents of this slide deck:

1. Introduction
    1. introduce Corkami, my reverse engineering site
    2. explain (in easy terms)
        1. why correct disassembly is important for analysis
        2. why undocumented opcodes are a dead end
2. Main part
    1. a few examples of undocumented opcodes and CPU weirdness
    2. theory-only sucks, so I created CoST for practicing and testing.
    3. CoST also tests PE, but it's not enough by itself
    4. So I documented PE separately, and give some examples.

Improved, but similar

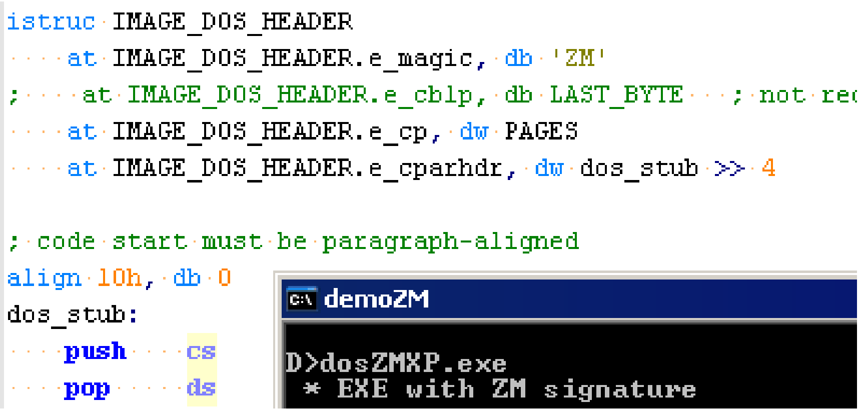


Author

- Corkami
  - reverse engineering
  - technical, really free
  - MANY handmade and focused PoCs
    - nightly builds
    - summary wiki pages
  - but... only a hobby!

“there's a PoC for that”

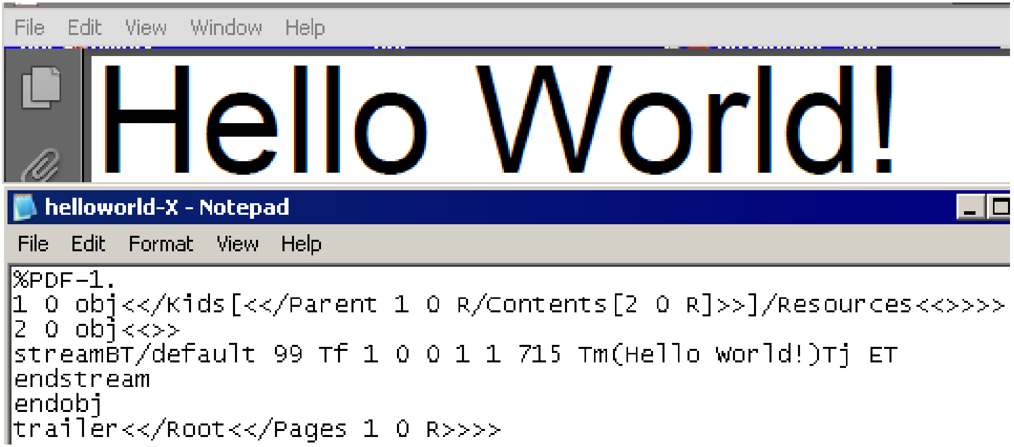
and if there's none yet, there will be soon ;)



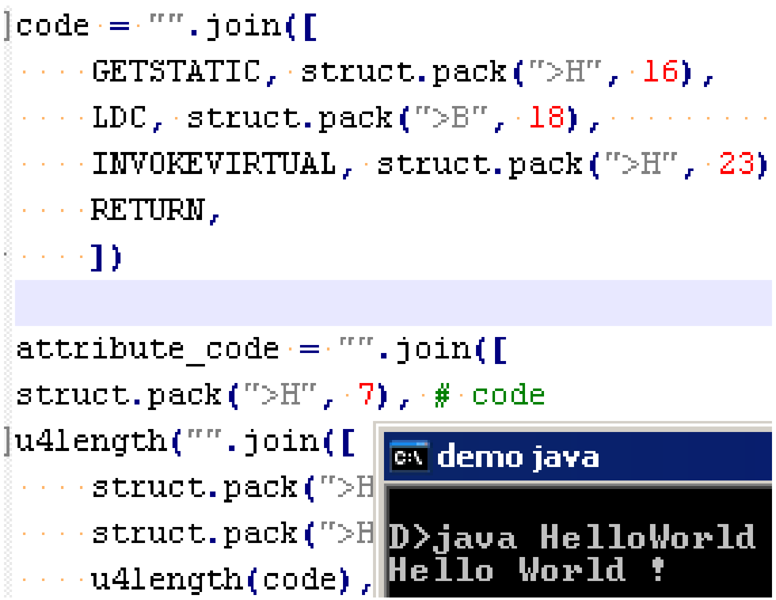
```
istruc IMAGE_DOS_HEADER
    at IMAGE_DOS_HEADER.e_magic, db 'ZM'
;    at IMAGE_DOS_HEADER.e_cblp, db LAST_BYTE   ; not re
    at IMAGE_DOS_HEADER.e_cp, dw PAGES
    at IMAGE_DOS_HEADER.e_cparhdr, dw dos_stub >> 4

; code start must be paragraph-aligned
align 10h, db 0
dos_stub:
    push    cs
    pop     ds
```

```
D>dosZMXP.exe
 * EXE with ZM signature
```



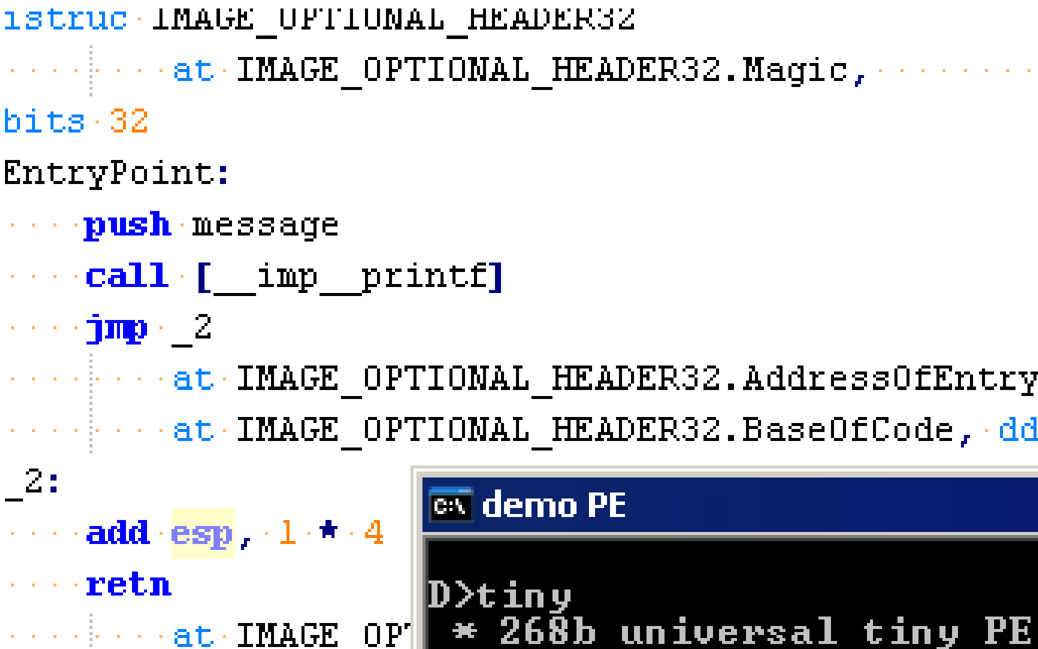
```
%PDF-1.
1 0 obj<</Kids[<</Parent 1 0 R/Contents[2 0 R]>>]/Resources<<>>>>
2 0 obj<<>>
streamBT/default 99 Tf 1 0 0 1 1 715 Tm(Hello World!)Tj ET
endstream
endobj
trailer<</Root<</Pages 1 0 R>>>>
```



```
code = "".join([
    GETSTATIC, struct.pack(">H", 16),
    LDC, struct.pack(">B", 18),
    INVOKEVIRTUAL, struct.pack(">H", 23)
    RETURN,
    ])

attribute_code = "".join([
struct.pack(">H", 7), # code
u4length("".join([
    struct.pack(">H
    struct.pack(">H
    u4length(code),
```

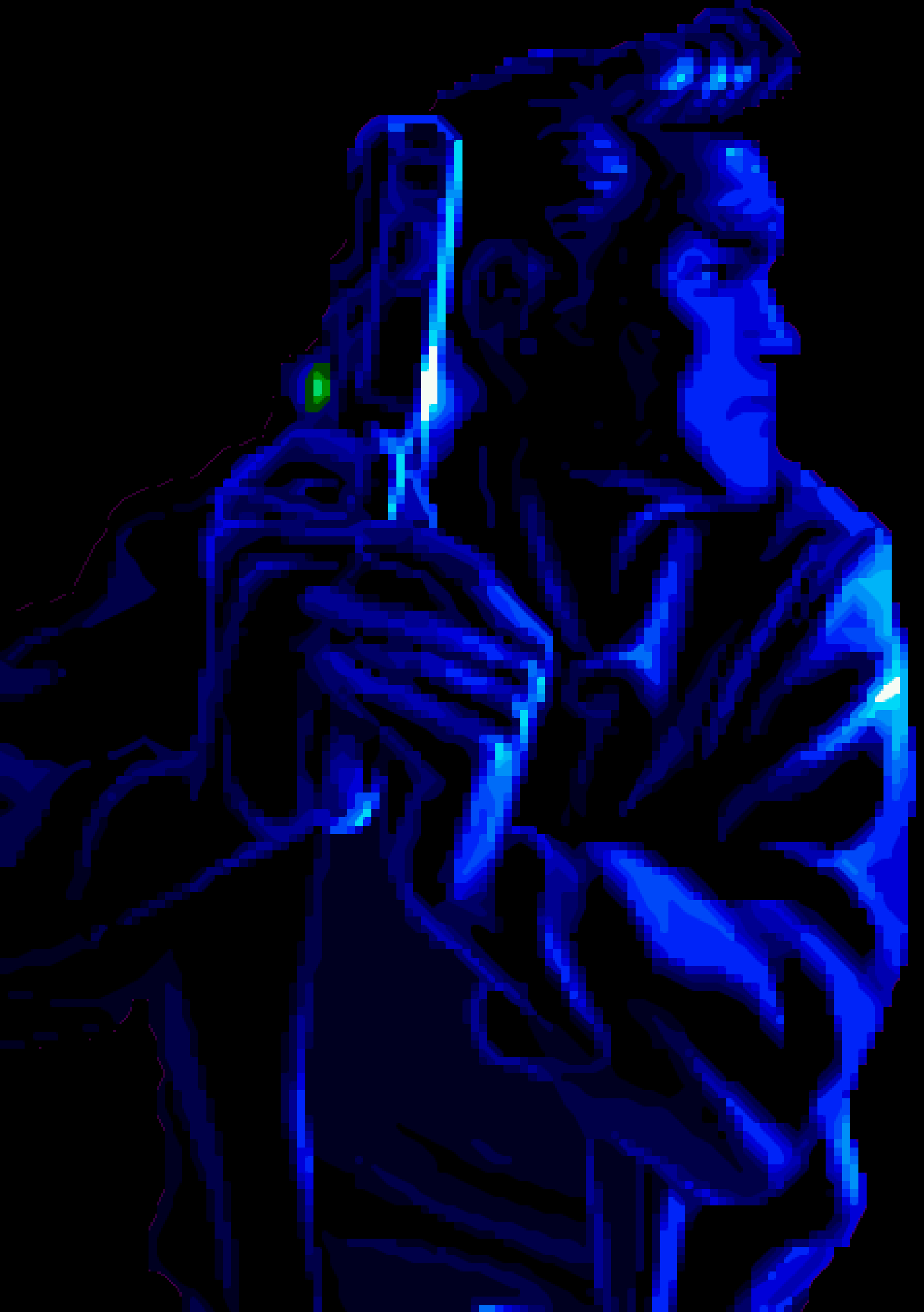
```
D>java HelloWorld
Hello World !
```

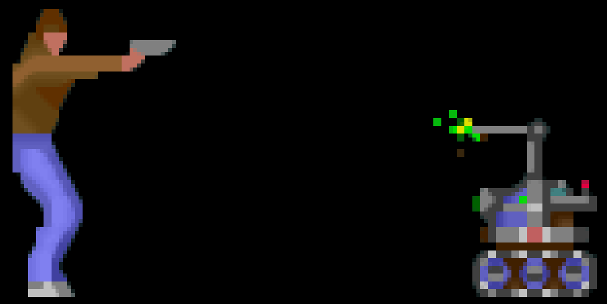


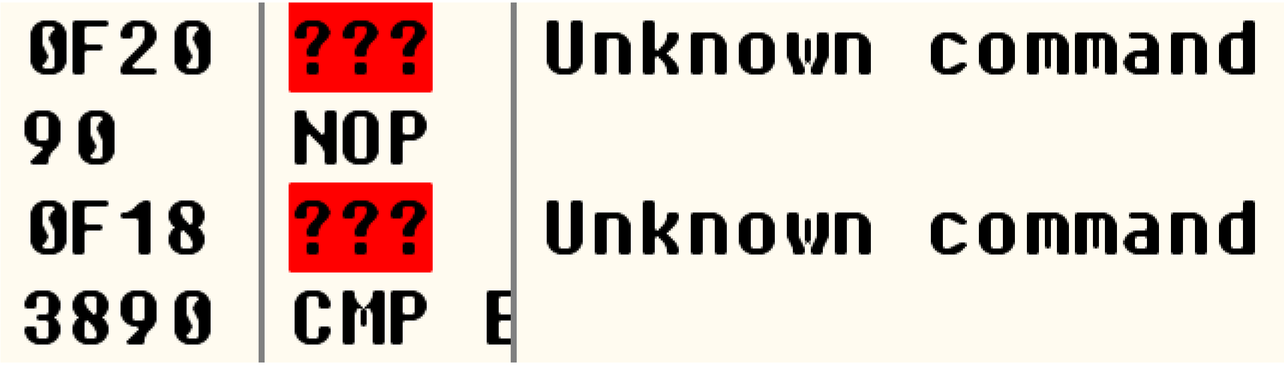
```
istruc IMAGE_OPTIONAL_HEADER32
        at IMAGE_OPTIONAL_HEADER32.Magic,
bits 32
EntryPoint:
    push message
    call [__imp__printf]
    jmp _2
        at IMAGE_OPTIONAL_HEADER32.AddressOfEntry
        at IMAGE_OPTIONAL_HEADER32.BaseOfCode, dd
_2:
    add esp, 1 * 4
    retn
        at IMAGE_OP
```

```
D>tiny
 * 268b universal tiny PE
```

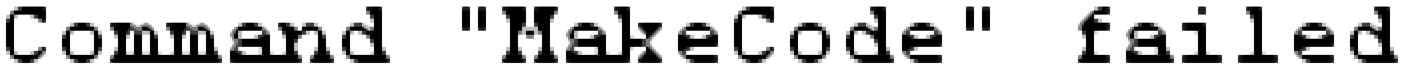
the story behind this presentation



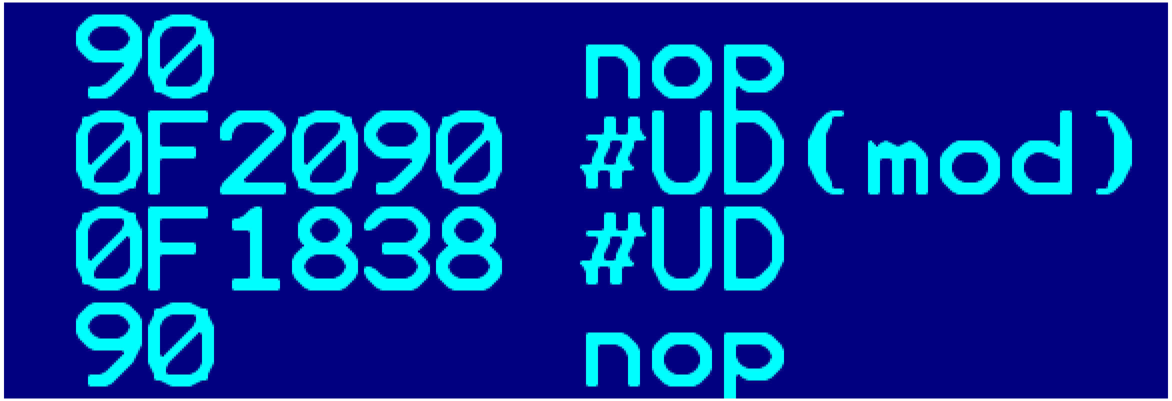




```
0F20  ???     Unknown command
90    NOP
0F18  ???     Unknown command
3890  CMP E
```

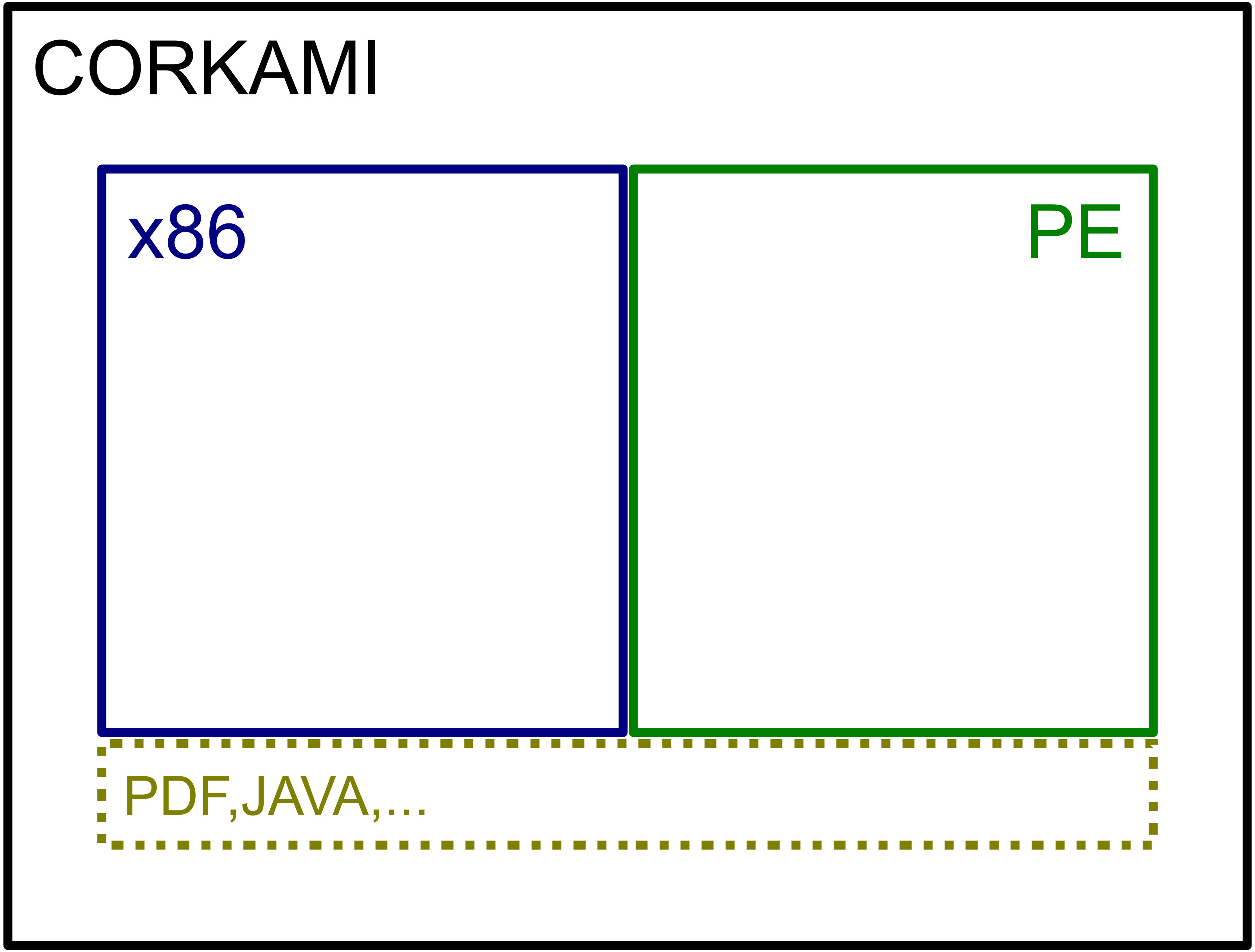


```
Command "MakeCode" failed
```



```
90      nop
0F2090  #UD(mod)
0F1838  #UD
90      nop
```

BACK TO THE BASICS

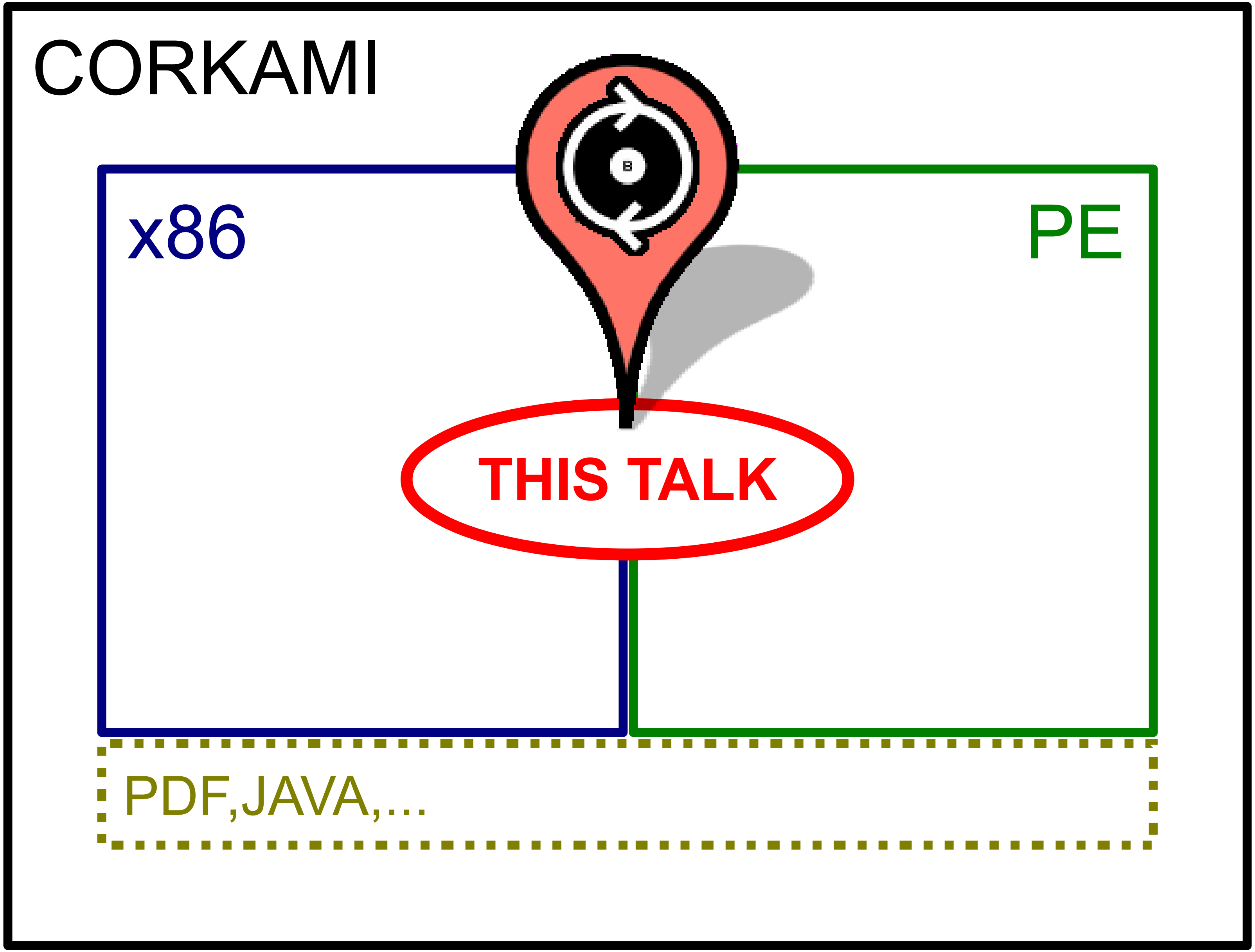


CORKAMI

x86

PE

PDF,JAVA,...



CORKAMI

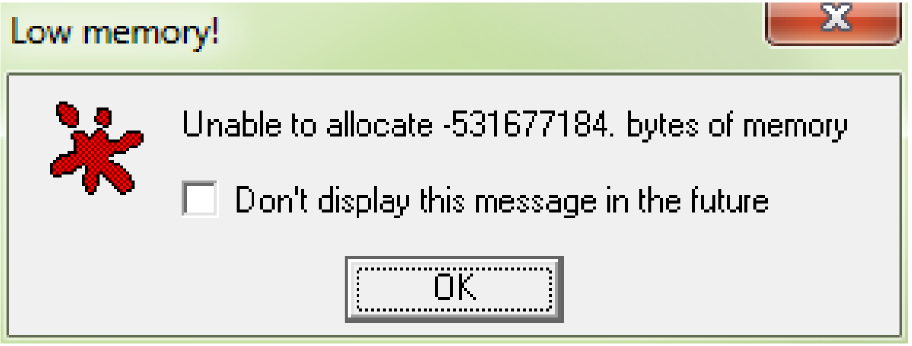
x86

PE

THIS TALK

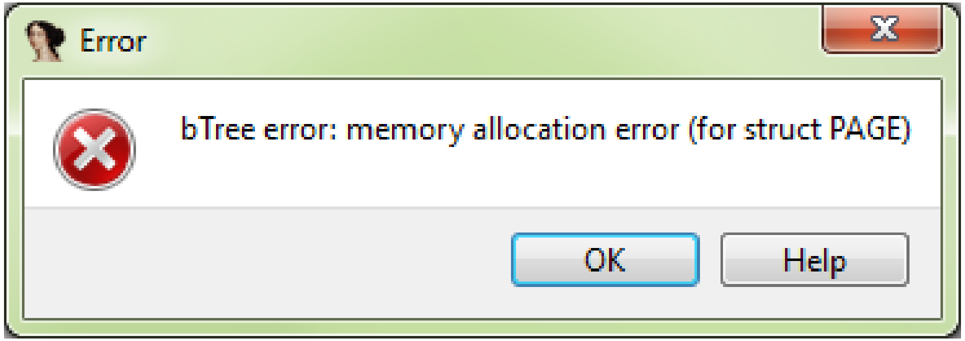
PDF,JAVA,...

“Achievement unlocked”

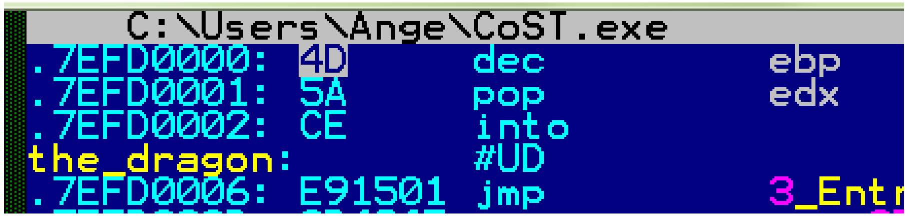


Unable to allocate -531677184. bytes of memory

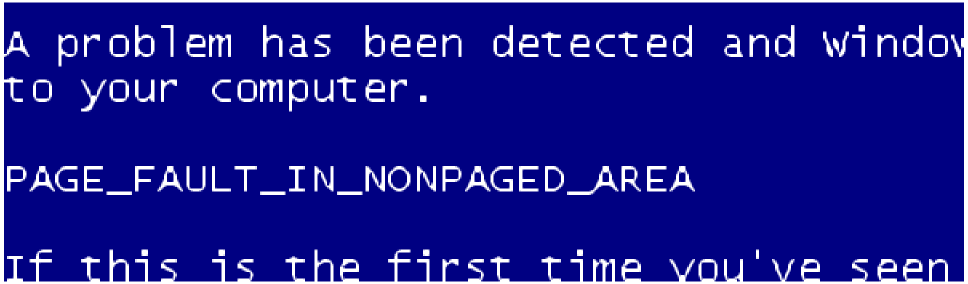
☐ Don't display this message in the future



bTree error: memory allocation error (for struct PAGE)



```
    C:\Users\Ange\CoST.exe
.7EFD0000: 4D       dec          ebp
.7EFD0001: 5A       pop          edx
.7EFD0002: CE       into
the_dragon:         #UD
.7EFD0006: E91501  jmp           3_Entr
```



```
A problem has been detected and window
to your computer.

PAGE_FAULT_IN_NONPAGED_AREA

If this is the first time you've seen
```

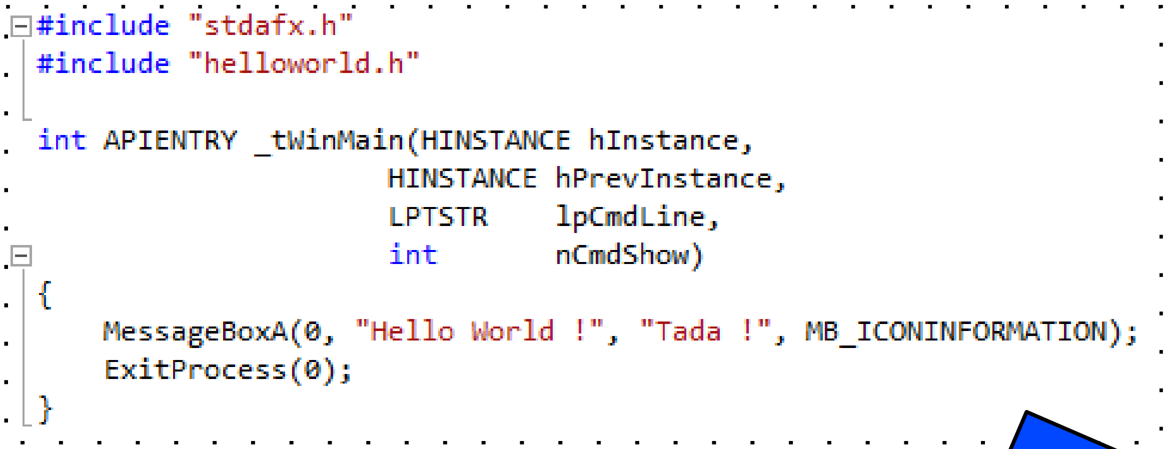
(Authors notified, and most bugs already fixed)

Agenda

I. why does it matter?
    I. assembly
    II. undocumented assembly
II. x86 oddities
        (technical stuff starts now)
III. CoST
IV. a bit more of PE

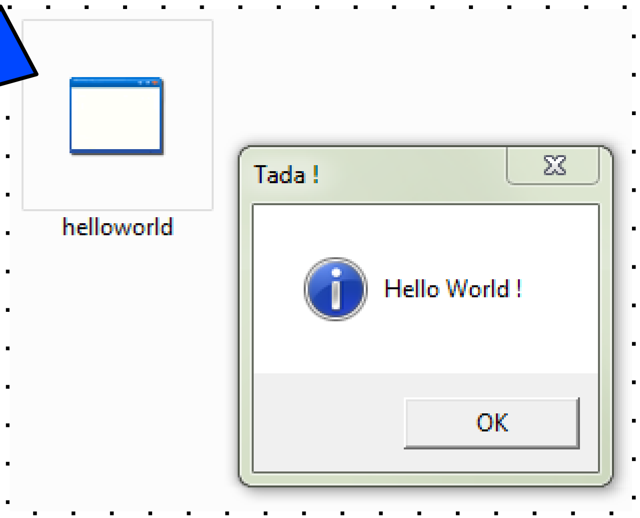
assembly, in 8 slides

from C to binary



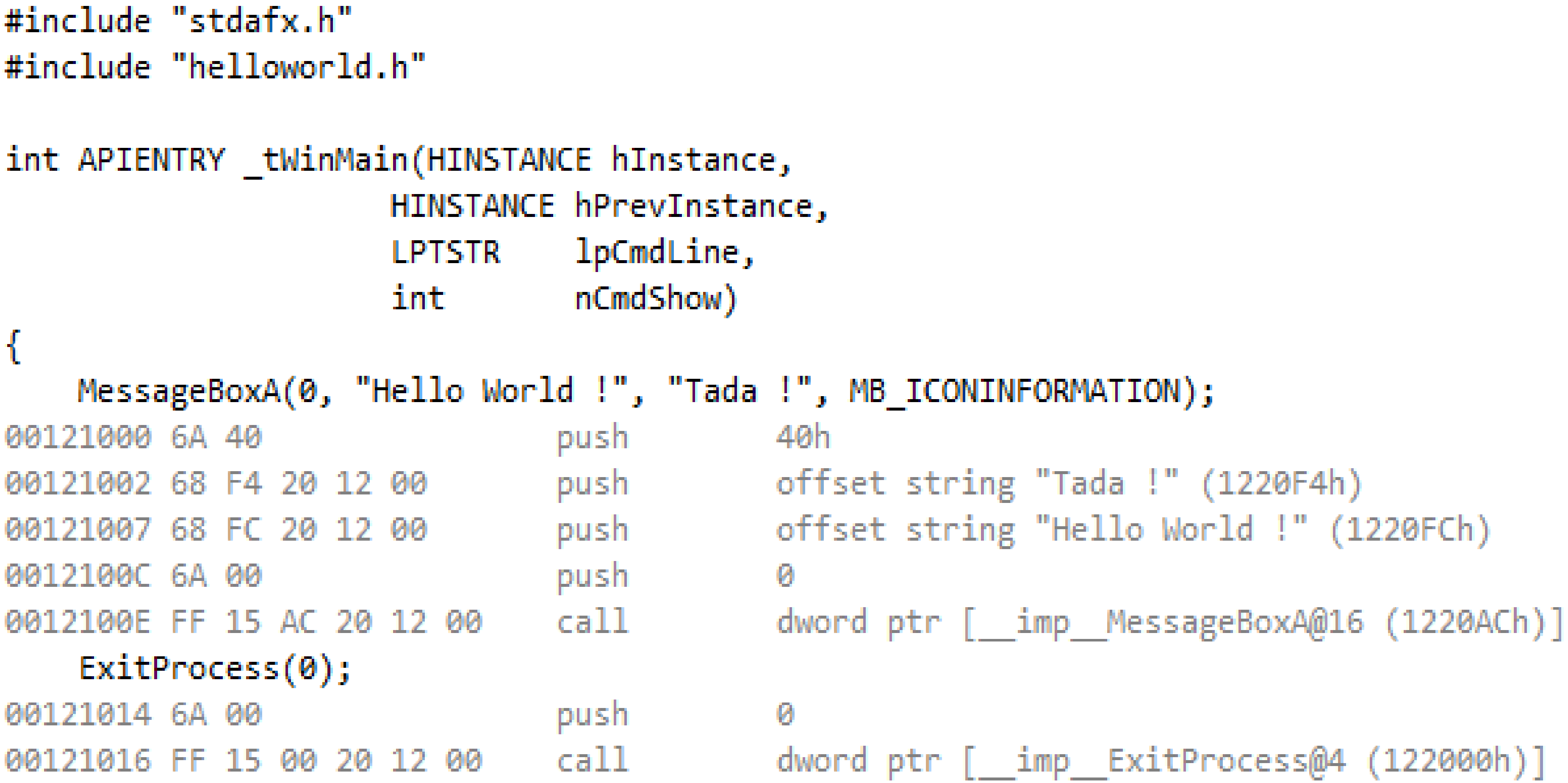
```
#include "stdafx.h"
#include "helloworld.h"

int APIENTRY _tWinMain(HINSTANCE hInstance,
                     HINSTANCE hPrevInstance,
                     LPTSTR    lpCmdLine,
                     int       nCmdShow)
{
    MessageBoxA(0, "Hello World !", "Tada !", MB_ICONINFORMATION);
    ExitProcess(0);
}
```



Hello World !

inside the binary



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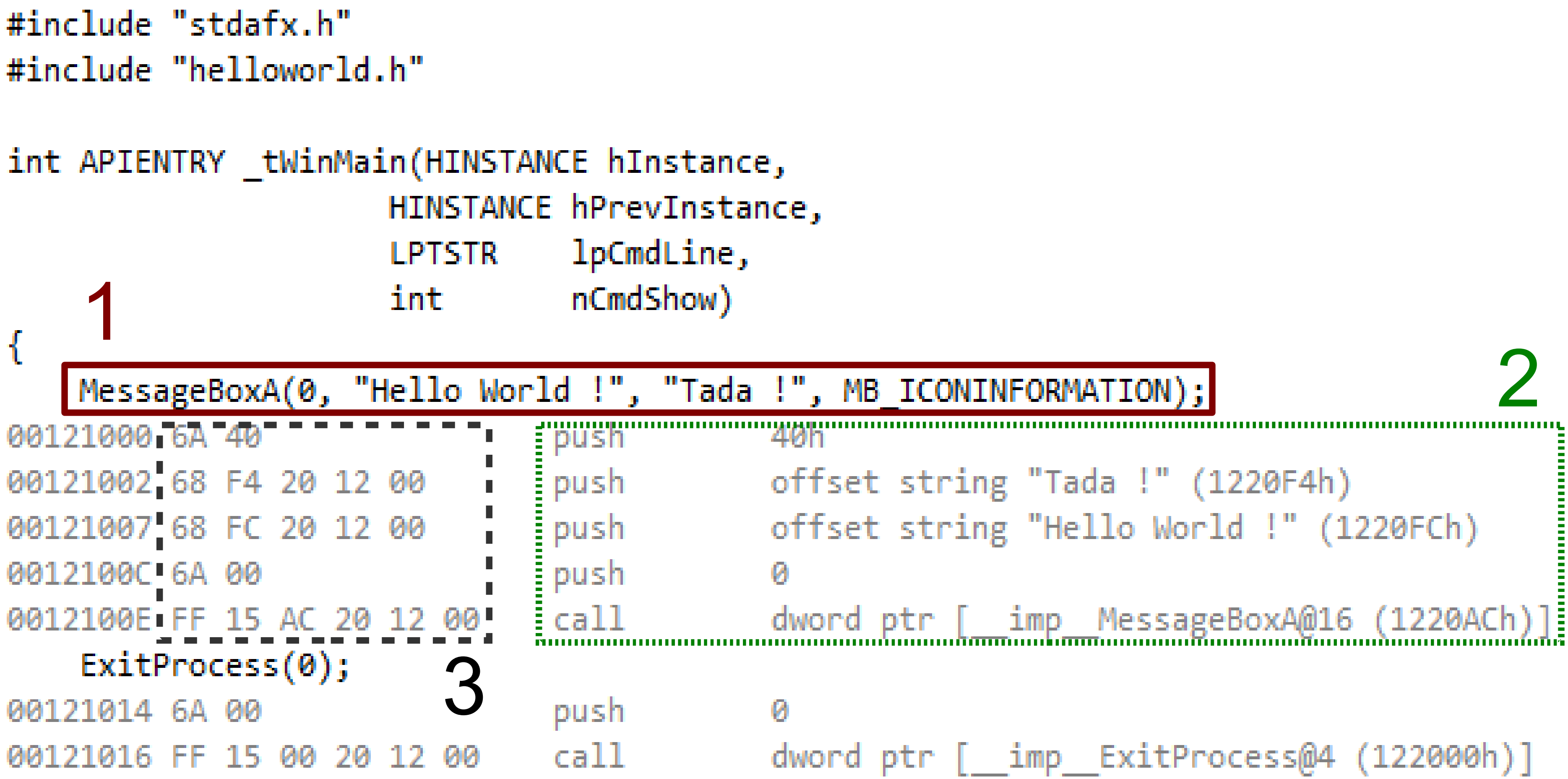
#include "helloworld.h"

int APIENTRY _tWinMain(HINSTANCE hInstance,
                     HINSTANCE hPrevInstance,
                     LPTSTR    lpCmdLine,
                     int       nCmdShow)
{
    MessageBoxA(0, "Hello World !", "Tada !", MB_ICONINFORMATION);
00121000 6A 40                push        40h
00121002 68 F4 20 12 00       push        offset string "Tada !" (1220F4h)
00121007 68 FC 20 12 00       push        offset string "Hello World !" (1220FCh)
0012100C 6A 00                push        0
0012100E FF 15 AC 20 12 00    call        dword ptr [__imp__MessageBoxA@16 (1220ACh)]
    ExitProcess(0);
00121014 6A 00                push        0
00121016 FF 15 00 20 12 00    call        dword ptr [__imp__ExitProcess@4 (122000h)]
```

order



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0012100C 6A 00                push        0
0012100E FF 15 AC 20 12 00    call        dword ptr [__imp__MessageBoxA@16 (1220ACh)]
    ExitProcess(0);
00121014 6A 00                push        0
00121016 FF 15 00 20 12 00    call        dword ptr [__imp__ExitProcess@4 (122000h)]
```
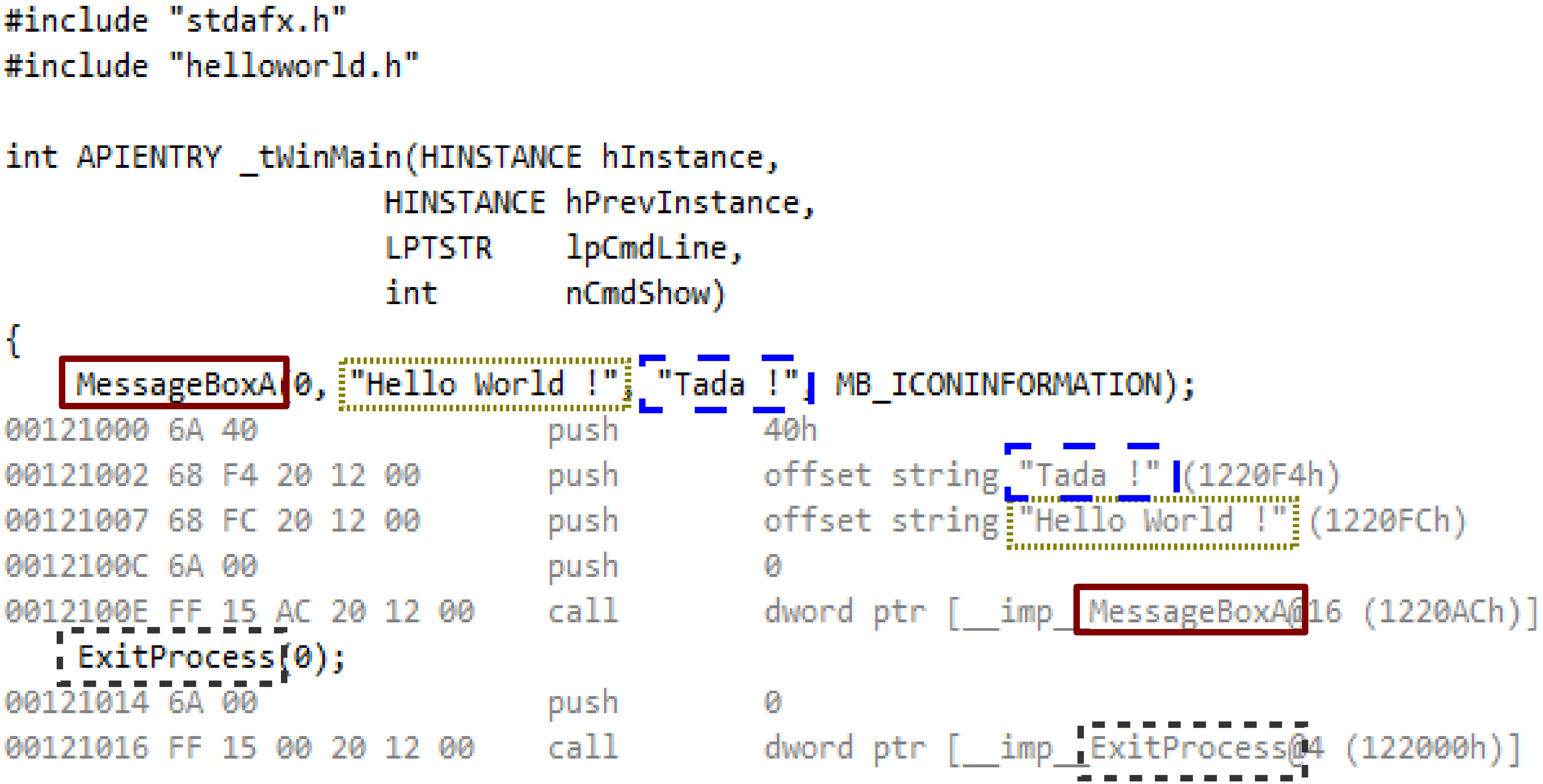

our code, 'translated'



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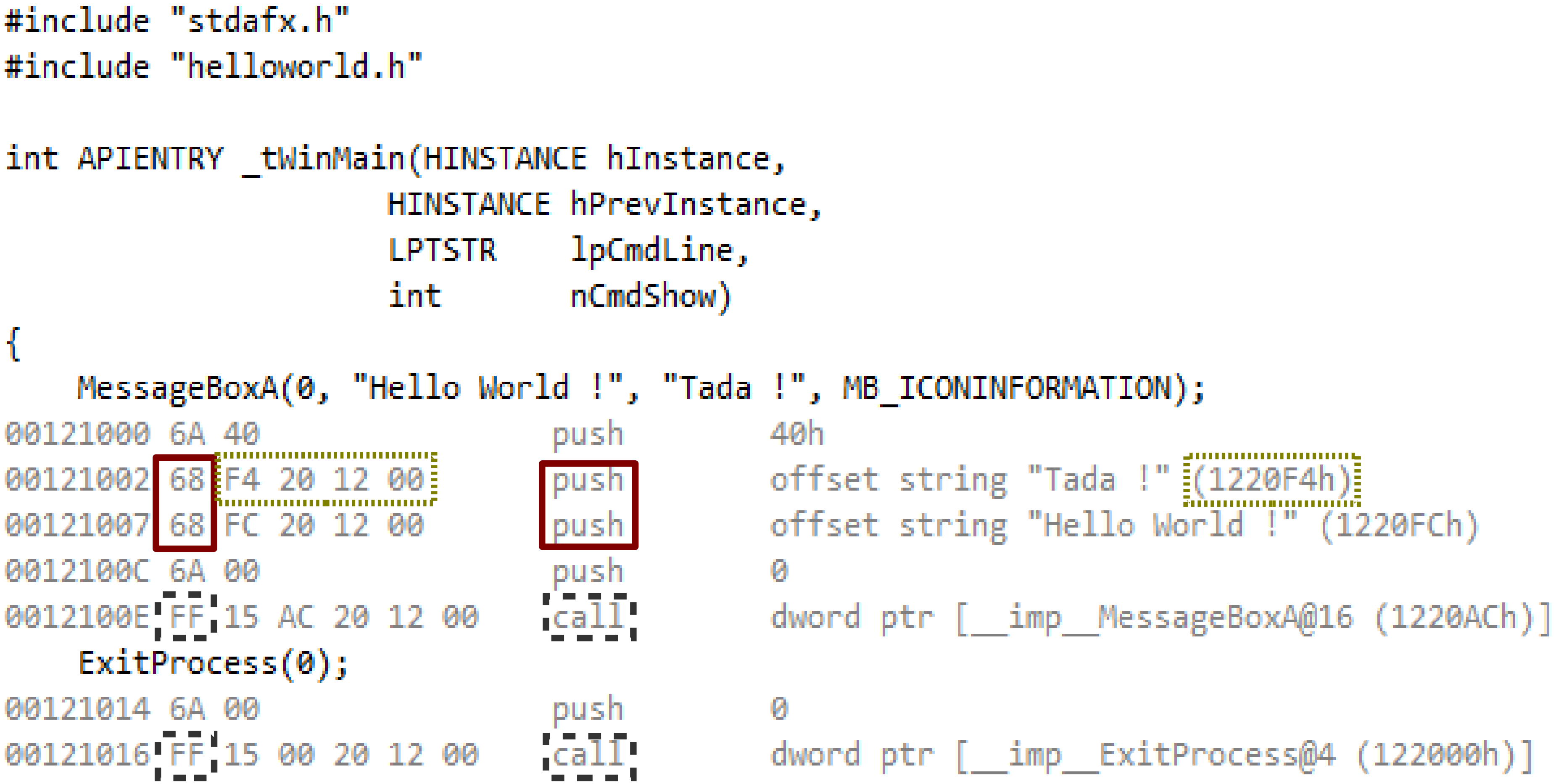
0012100C 6A 00                push        0
0012100E FF 15 AC 20 12 00    call        dword ptr [__imp__MessageBoxA@16 (1220ACh)]
   ExitProcess(0);
00121014 6A 00                push        0
00121016 FF 15 00 20 12 00    call        dword ptr [__imp__ExitProcess@4 (122000h)]
```

opcodes ⇔ assembly



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#include "stdafx.h"
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0012100C 6A 00                push        0
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    ExitProcess(0);
00121014 6A 00                push        0
00121016 FF 15 00 20 12 00    call        dword ptr [__imp__ExitProcess@4 (122000h)]
```
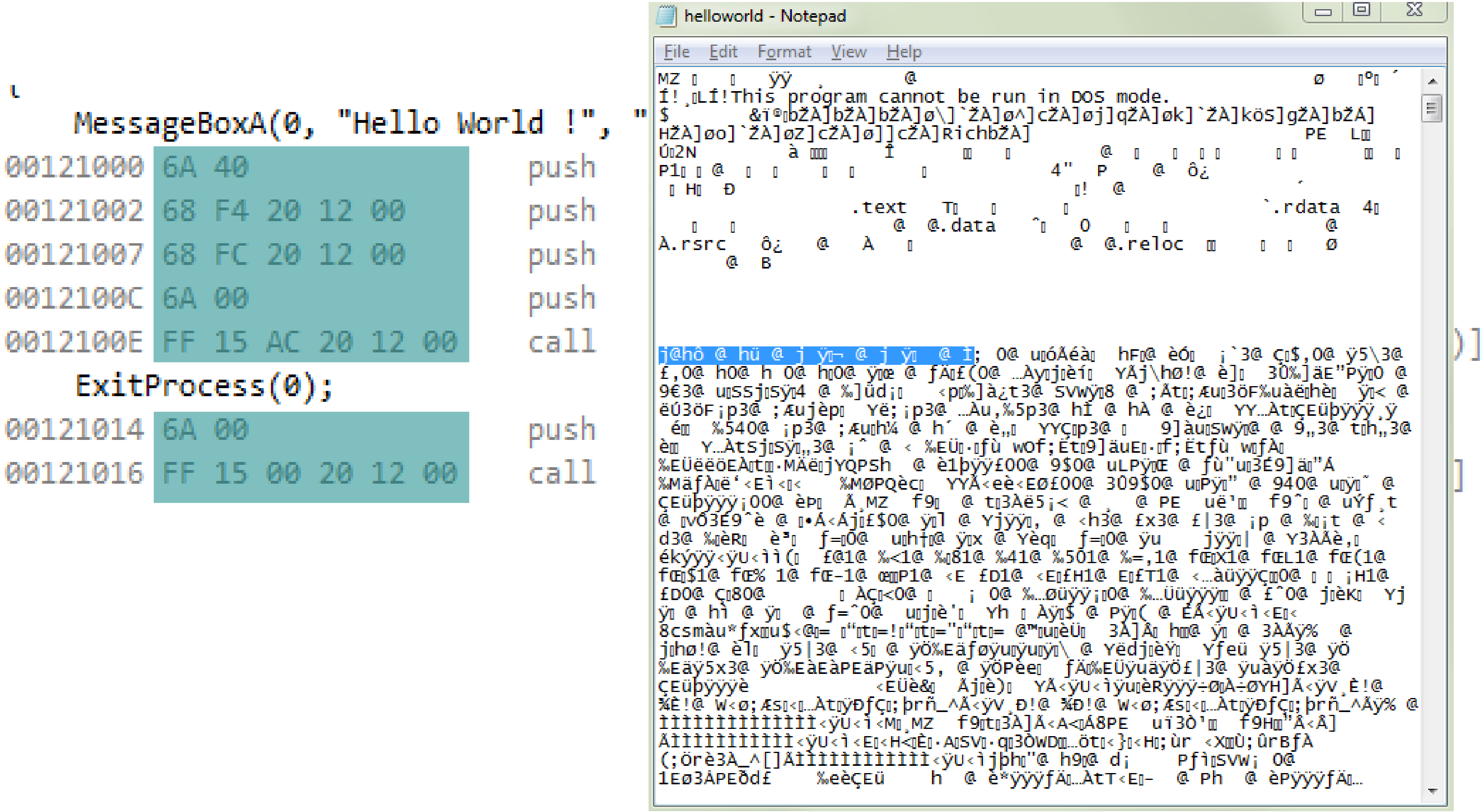
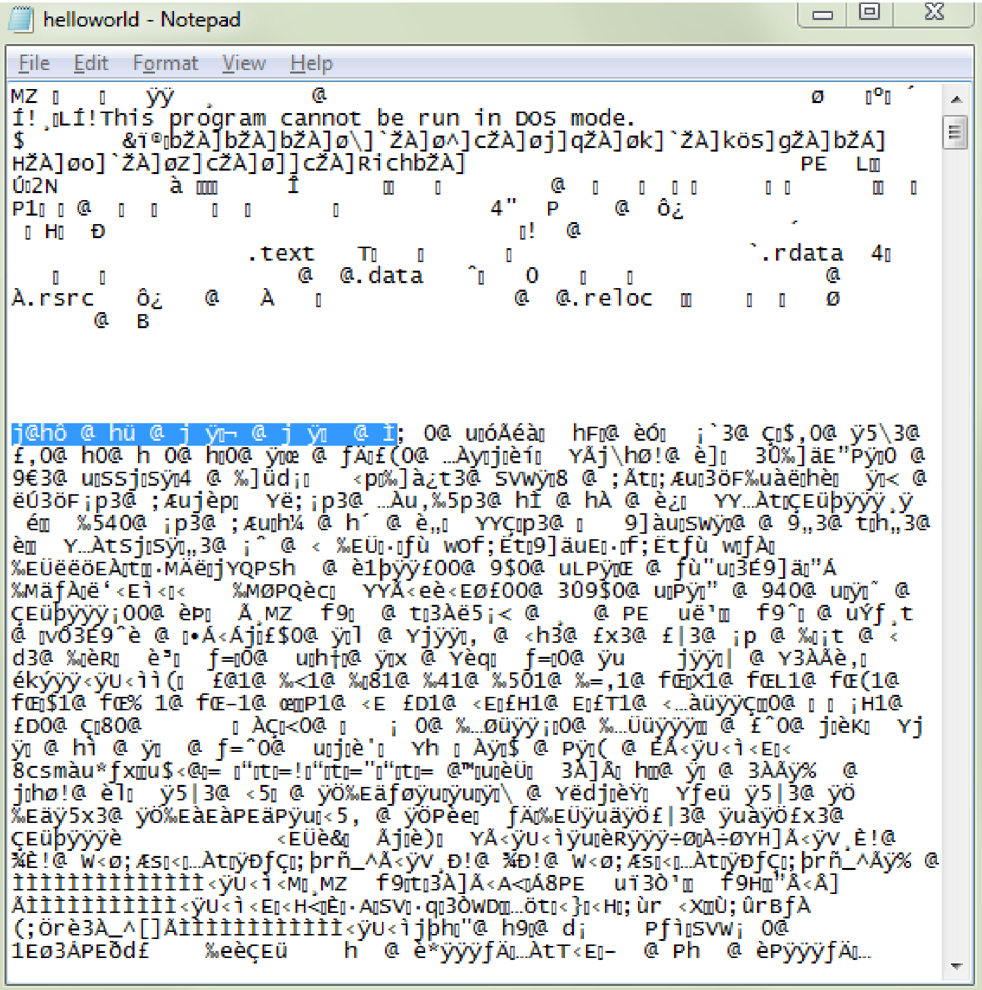

what's (only) in the binary



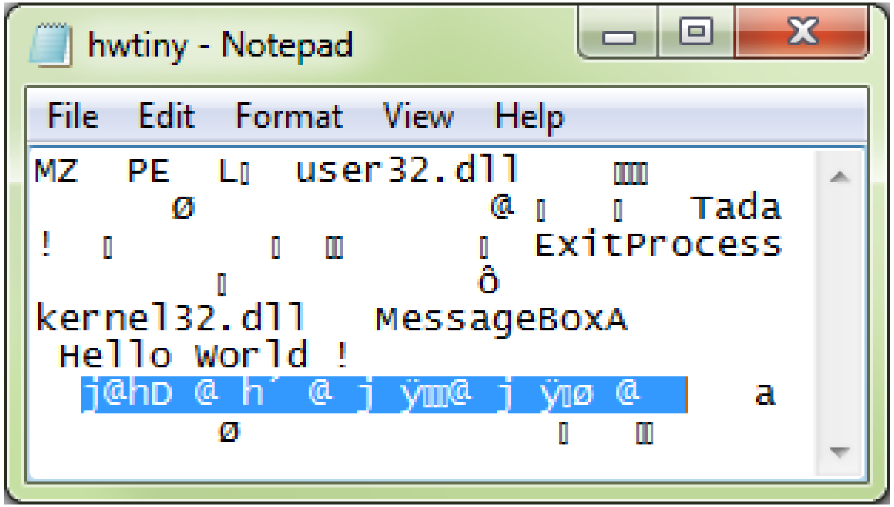
```
    MessageBoxA(0, "Hello World !", "
00121000 6A 40                push
00121002 68 F4 20 12 00       push
00121007 68 FC 20 12 00       push
0012100C 6A 00                push
0012100E FF 15 AC 20 12 00    call
    ExitProcess(0);
00121014 6A 00                push
00121016 FF 15 00 20 12 00    call
```

```
MZ          ÿÿ            @
!This program cannot be run in DOS mode.
$
Rich                                        PE   L
                .text                                  `.rdata
                @.data
À.rsrc            @.reloc
```

execution ⇔ CPU + opcodes



```
MZ ▯   ▯    ÿÿ  ¸          @                                  ø    ▯º▯ ´
Í!¸▯LÍ!This program cannot be run in DOS mode.
$        &ï®▯bŽÀ]bŽÀ]bŽÀ]ø\]`ŽÀ]ø^]cŽÀ]øj]qŽÀ]øk]`ŽÀ]kös]gŽÀ]bŽÀ]
HŽÀ]øo]`ŽÀ]øz]cŽÀ]ø]]cŽÀ]RichbŽÀ]                              PE  L▯
Ú▯2N          à ▯▯▯     Î      ▯   ▯         @  ▯   ▯  ▯ ▯     ▯ ▯      ▯  ▯
P1▯ ▯ @  ▯  ▯    ▯  ▯      ▯            4"   P    @  ô¿
 ▯ H▯  Ð                                 ▯!  @                    ´
                 .text   T▯    ▯       ▯                   `.rdata  4▯
   ▯   ▯                @  @.data   ˆ▯   O   ▯   ▯                   @
À.rsrc   ô¿   @   À   ▯                @  @.reloc  ▯▯    ▯  ▯   Ø
      @  B

j@hö @ hü @ j ÿ▯¬ @ j ÿ▯  @ ▯; 0@ u▯óÅéà▯  hF▯@ èó▯   ¡`3@ Ç▯$,0@ ÿ5\3@
```



```
MZ   PE   L▯  user32.dll      ▯▯▯
        Ø                   @ ▯    ▯    Tada
!  ▯        ▯  ▯▯       ▯  ExitProcess
             ▯              Ô
kernel32.dll   MessageBoxA
 Hello World !
  j@hD @ h´ @ j ÿ▯▯@ j ÿ▯ø @       a
        Ø                    ▯    ▯▯
```

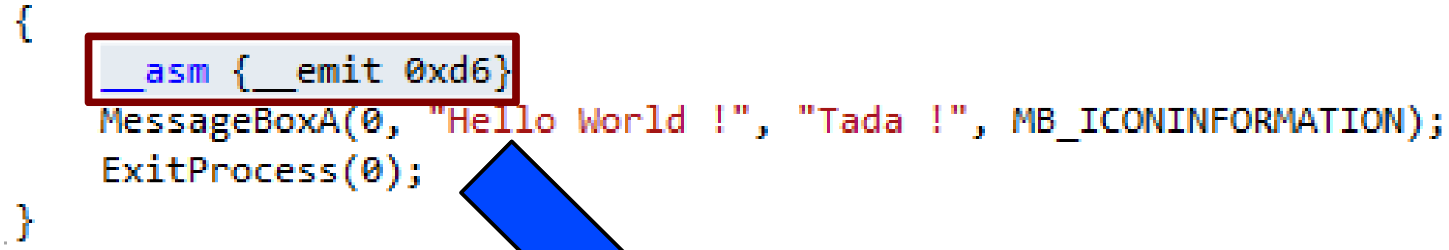
opcodes

- generated by compilers, tools,...
  - or written by hand
- executed directly by the CPU
- the only code information, in a standard binary
  - what 'we' read
    - **after** disassembly

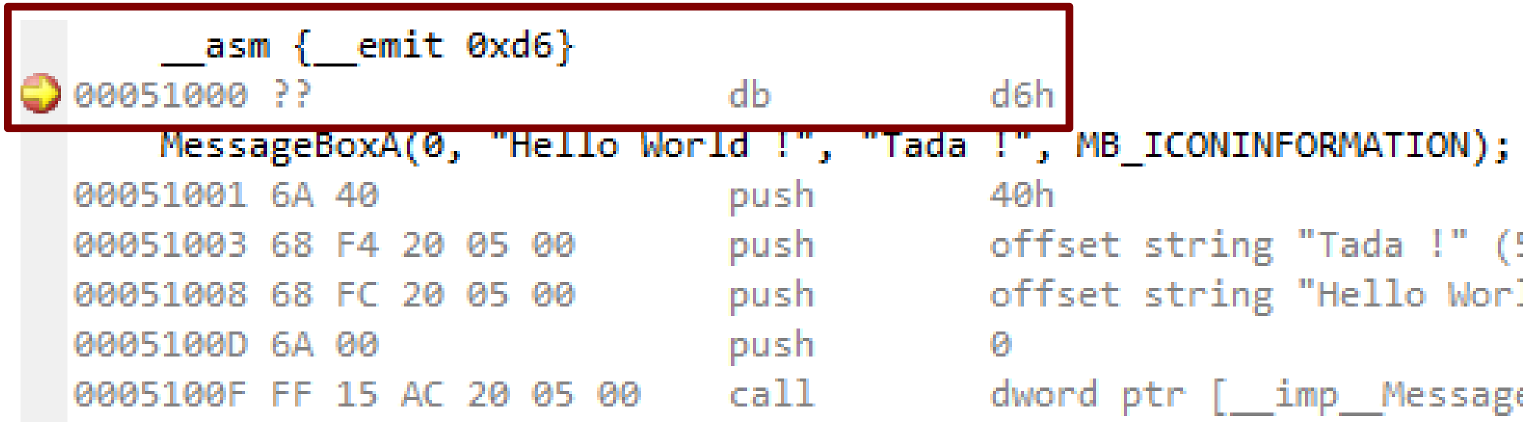
- disassembly is only for humans
  - no text code in the final binary

let's mess a bit now...

let's insert 'something'

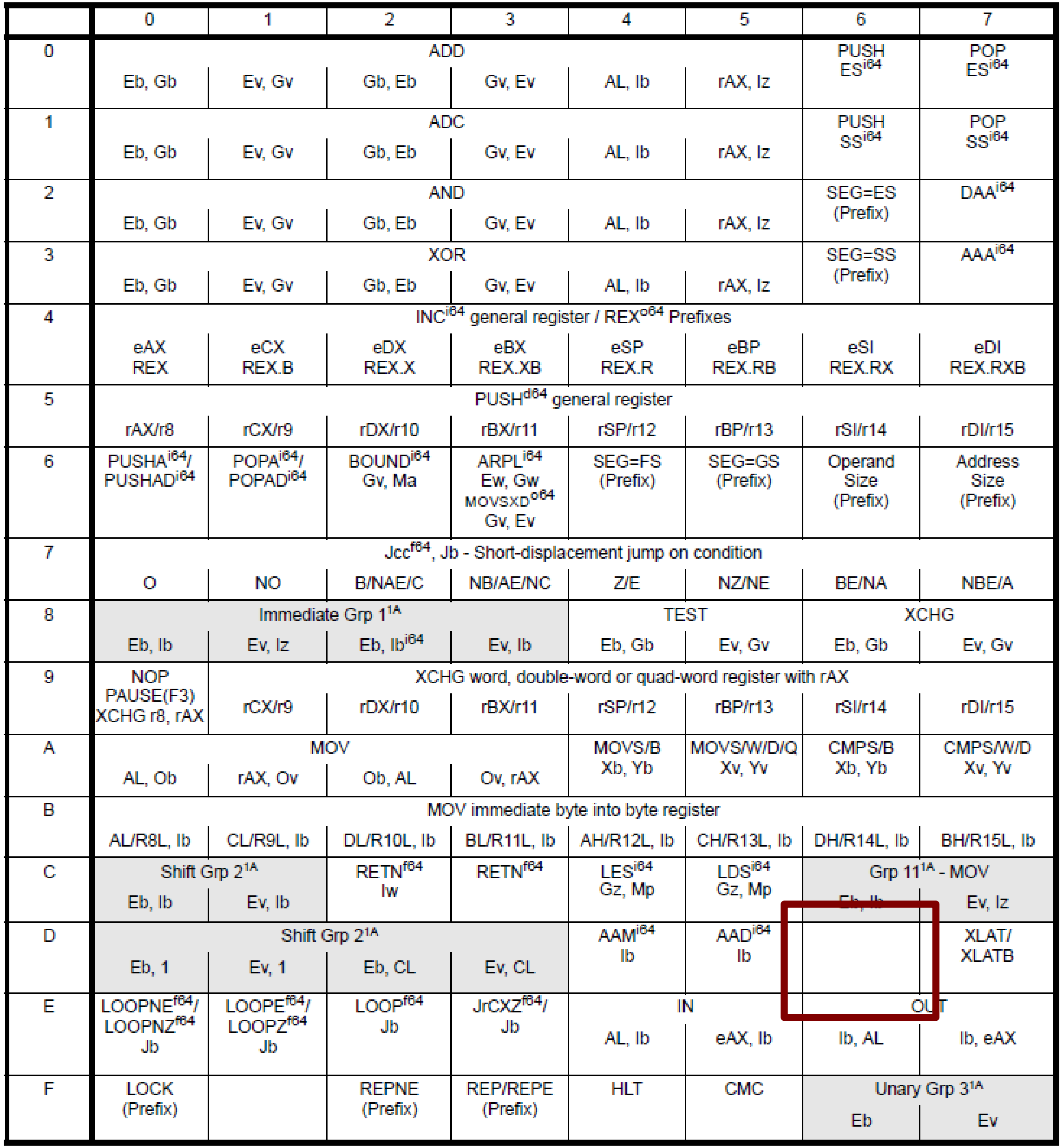


```
{
    __asm {__emit 0xd6}
    MessageBoxA(0, "Hello World !", "Tada !", MB_ICONINFORMATION);
    ExitProcess(0);
}
```



```
        __asm {__emit 0xd6}
00051000 ??                         db          d6h
        MessageBoxA(0, "Hello World !", "Tada !", MB_ICONINFORMATION);
00051001 6A 40                      push        40h
00051003 68 F4 20 05 00             push        offset string "Tada !" (
00051008 68 FC 20 05 00             push        offset string "Hello Worl
0005100D 6A 00                      push        0
0005100F FF 15 AC 20 05 00          call        dword ptr [__imp__Message
```

Table A-2. One-byte Opcode Map: (00H — F7H) *



	0	1	2	3	4	5	6	7
0	ADD Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	PUSH ES^{i64}	POP ES^{i64}
1	ADC Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	PUSH SS^{i64}	POP SS^{i64}
2	AND Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	SEG=ES (Prefix)	DAA^{i64}
3	XOR Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	SEG=SS (Prefix)	AAA^{i64}
4	INC^{i64} general register / REX^{o64} Prefixes eAX REX	eCX REX.B	eDX REX.X	eBX REX.XB	eSP REX.R	eBP REX.RB	eSI REX.RX	eDI REX.RXB
5	PUSH^{d64} general register rAX/r8	rCX/r9	rDX/r10	rBX/r11	rSP/r12	rBP/r13	rSI/r14	rDI/r15
6	PUSHA^{i64}/ PUSHAD^{i64}	POPA^{i64}/ POPAD^{i64}	BOUND^{i64} Gv, Ma	ARPL^{i64} Ew, Gw MOVSXD^{o64} Gv, Ev	SEG=FS (Prefix)	SEG=GS (Prefix)	Operand Size (Prefix)	Address Size (Prefix)
7	Jcc^{f64}, Jb - Short-displacement jump on condition O	NO	B/NAE/C	NB/AE/NC	Z/E	NZ/NE	BE/NA	NBE/A
8	Immediate Grp 1^{1A} Eb, Ib	Ev, Iz	Eb, Ib^{i64}	Ev, Ib	TEST Eb, Gb	Ev, Gv	XCHG Eb, Gb	Ev, Gv
9	NOP PAUSE(F3) XCHG r8, rAX	XCHG word, double-word or quad-word register with rAX rCX/r9	rDX/r10	rBX/r11	rSP/r12	rBP/r13	rSI/r14	rDI/r15
A	MOV AL, Ob	rAX, Ov	Ob, AL	Ov, rAX	MOVS/B Xb, Yb	MOVS/W/D/Q Xv, Yv	CMPS/B Xb, Yb	CMPS/W/D Xv, Yv
B	MOV immediate byte into byte register AL/R8L, Ib	CL/R9L, Ib	DL/R10L, Ib	BL/R11L, Ib	AH/R12L, Ib	CH/R13L, Ib	DH/R14L, Ib	BH/R15L, Ib
C	Shift Grp 2^{1A} Eb, Ib	Ev, Ib	RETN^{f64} Iw	RETN^{f64}	LES^{i64} Gz, Mp	LDS^{i64} Gz, Mp	Grp 11^{1A} - MOV Eb, Ib	Ev, Iz
D	Shift Grp 2^{1A} Eb, 1	Ev, 1	Eb, CL	Ev, CL	AAM^{i64} Ib	AAD^{i64} Ib		XLAT/ XLATB
E	LOOPNE^{f64}/ LOOPNZ^{f64} Jb	LOOPE^{f64}/ LOOPZ^{f64} Jb	LOOP^{f64} Jb	JrCXZ^{f64}/ Jb	IN AL, Ib	eAX, Ib	OUT Ib, AL	Ib, eAX
F	LOCK (Prefix)		REPNE (Prefix)	REP/REPE (Prefix)	HLT	CMC	Unary Grp 3^{1A} Eb	Ev

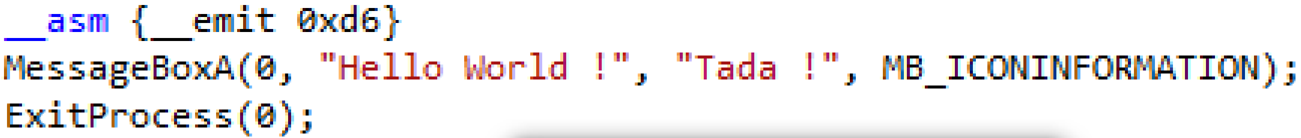
what did we do?

- Inserting an unrecognized byte
  - directly in the binary
    - to be executed by the CPU
  - not even documented, nor identified!

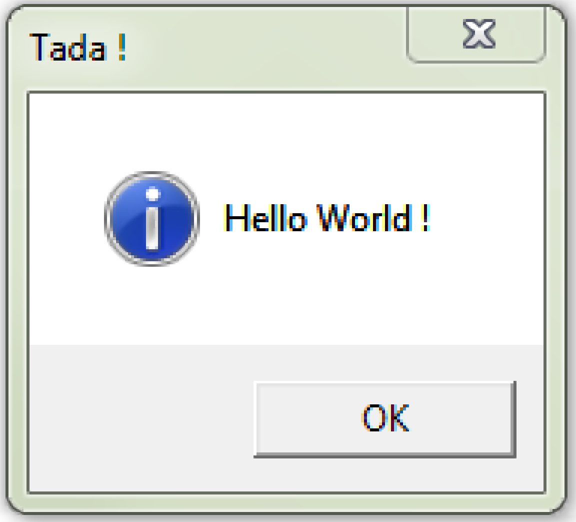
“kids, don't try this at home!”

the CPU doesn't care

- **it** knows
  - and does its own stuff



```
__asm {__emit 0xd6}
MessageBoxA(0, "Hello World !", "Tada !", MB_ICONINFORMATION);
ExitProcess(0);
```

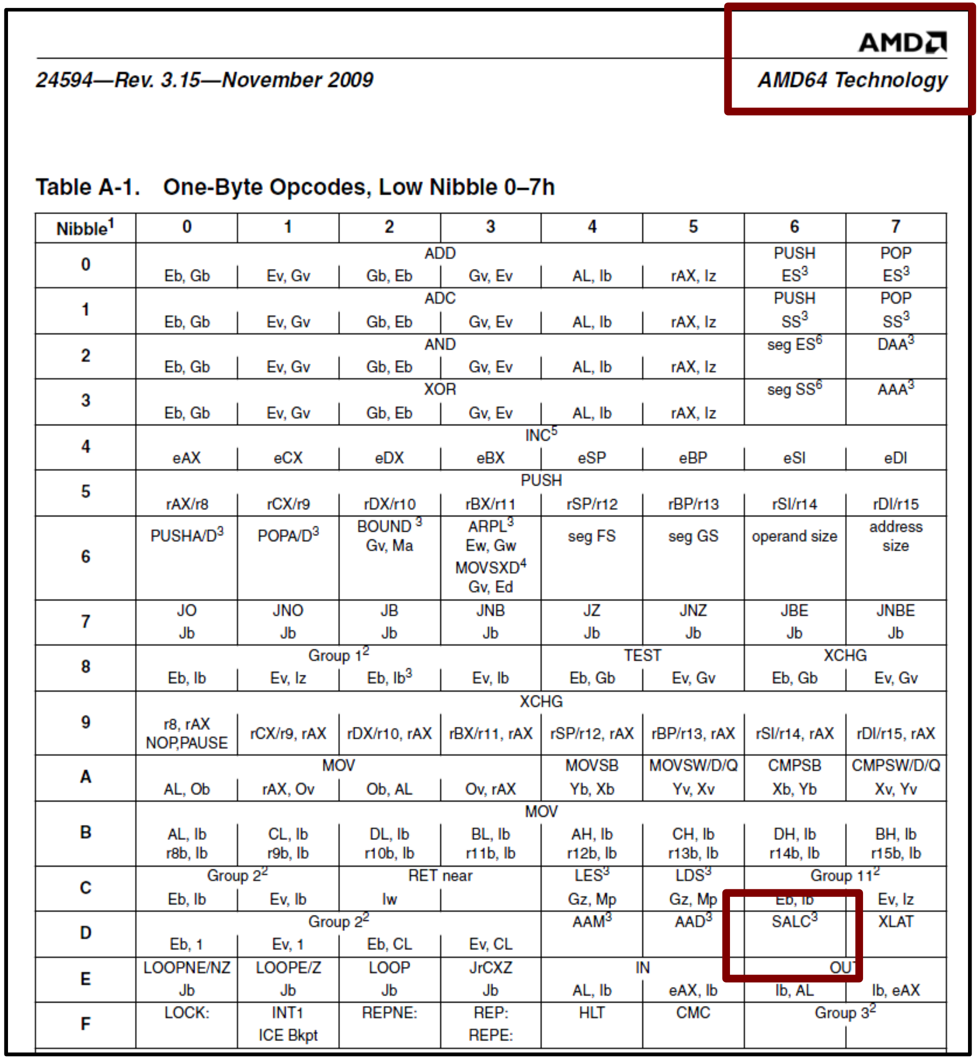


Tada !

Hello World !

what happened ?

- D6 = S[ET]ALC
  - Set AL on Carry
    - AL = CF ? -1 : 0
- trivial
- but not documented
  - unreliable, or shameful ?



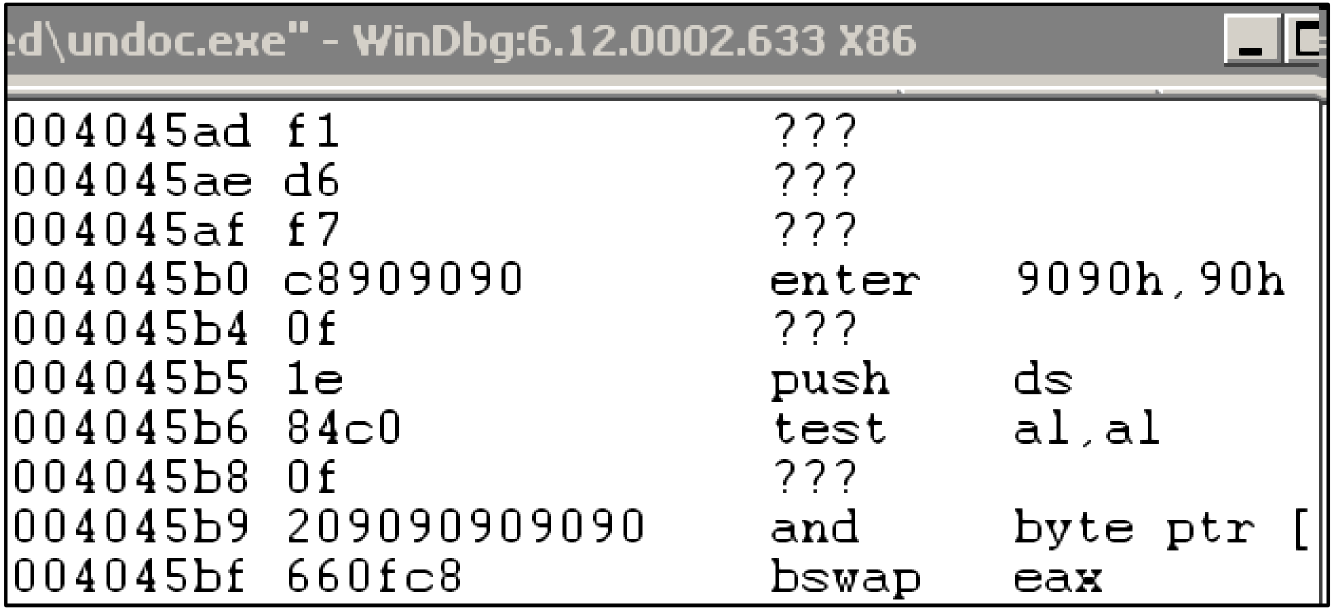
24594—Rev. 3.15—November 2009

AMD64 Technology

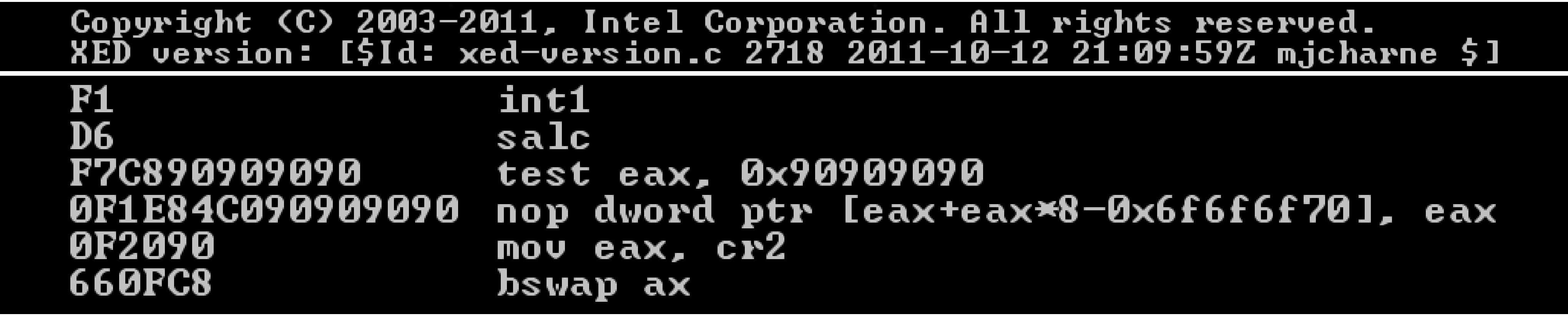
Table A-1. One-Byte Opcodes, Low Nibble 0–7h

Nibble[1]	0	1	2	3	4	5	6	7
0	ADD Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	PUSH ES[3]	POP ES[3]
1	ADC Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	PUSH SS[3]	POP SS[3]
2	AND Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	seg ES[6]	DAA[3]
3	XOR Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	seg SS[6]	AAA[3]
4	INC[5] eAX	eCX	eDX	eBX	eSP	eBP	eSI	eDI
5	PUSH rAX/r8	rCX/r9	rDX/r10	rBX/r11	rSP/r12	rBP/r13	rSI/r14	rDI/r15
6	PUSHA/D[3]	POPA/D[3]	BOUND [3] Gv, Ma	ARPL[3] Ew, Gw MOVSXD[4] Gv, Ed	seg FS	seg GS	operand size	address size
7	JO Jb	JNO Jb	JB Jb	JNB Jb	JZ Jb	JNZ Jb	JBE Jb	JNBE Jb
8	Group 1[2] Eb, Ib	Ev, Iz	Eb, Ib[3]	Ev, Ib	TEST Eb, Gb	Ev, Gv	XCHG Eb, Gb	Ev, Gv
9	XCHG r8, rAX NOP,PAUSE	rCX/r9, rAX	rDX/r10, rAX	rBX/r11, rAX	rSP/r12, rAX	rBP/r13, rAX	rSI/r14, rAX	rDI/r15, rAX
A	MOV AL, Ob	rAX, Ov	Ob, AL	Ov, rAX	MOVSB Yb, Xb	MOVSW/D/Q Yv, Xv	CMPSB Xb, Yb	CMPSW/D/Q Xv, Yv
B	MOV AL, Ib r8b, Ib	CL, Ib r9b, Ib	DL, Ib r10b, Ib	BL, Ib r11b, Ib	AH, Ib r12b, Ib	CH, Ib r13b, Ib	DH, Ib r14b, Ib	BH, Ib r15b, Ib
C	Group 2[2] Eb, Ib	Ev, Ib	RET near Iw		LES[3] Gz, Mp	LDS[3] Gz, Mp	Group 11[2] Eb, Ib	Ev, Iz
D	Group 2[2] Eb, 1	Ev, 1	Eb, CL	Ev, CL	AAM[3]	AAD[3]	SALC[3]	XLAT
E	LOOPNE/NZ Jb	LOOPE/Z Jb	LOOP Jb	JrCXZ Jb	IN AL, Ib	eAX, Ib	OUT Ib, AL	Ib, eAX
F	LOCK:	INT1 ICE Bkpt	REPNE:	REP: REPE:	HLT	CMC	Group 3[2]	

“do what I do...”



```
004045ad f1                 ???
004045ae d6                 ???
004045af f7                 ???
004045b0 c8909090           enter   9090h,90h
004045b4 0f                 ???
004045b5 1e                 push    ds
004045b6 84c0               test    al,al
004045b8 0f                 ???
004045b9 209090909090       and     byte ptr [
004045bf 660fc8             bswap   eax
```



```
Copyright (C) 2003-2011, Intel Corporation. All rights reserved.
XED version: [$Id: xed-version.c 2718 2011-10-12 21:09:59Z mjcharne $]
```

```
F1                 int1
D6                 salc
F7C890909090       test eax, 0x90909090
0F1E84C090909090   nop dword ptr [eax+eax*8-0x6f6f6f70], eax
0F2090             mov eax, cr2
660FC8             bswap ax
```

the problem (1/2)

- the CPU does its stuff
  - whatever we (don't) know
- if we/our tools don't know what's next, we're blind.

the problem (2/2)

no exhaustive or clean test set

- deep into malwares or packers
- scattered

→ Corkami

let's start exploring x86...

Questions

Generalities

- opcodes
- registers
    - relation
    - initial values

Specificities

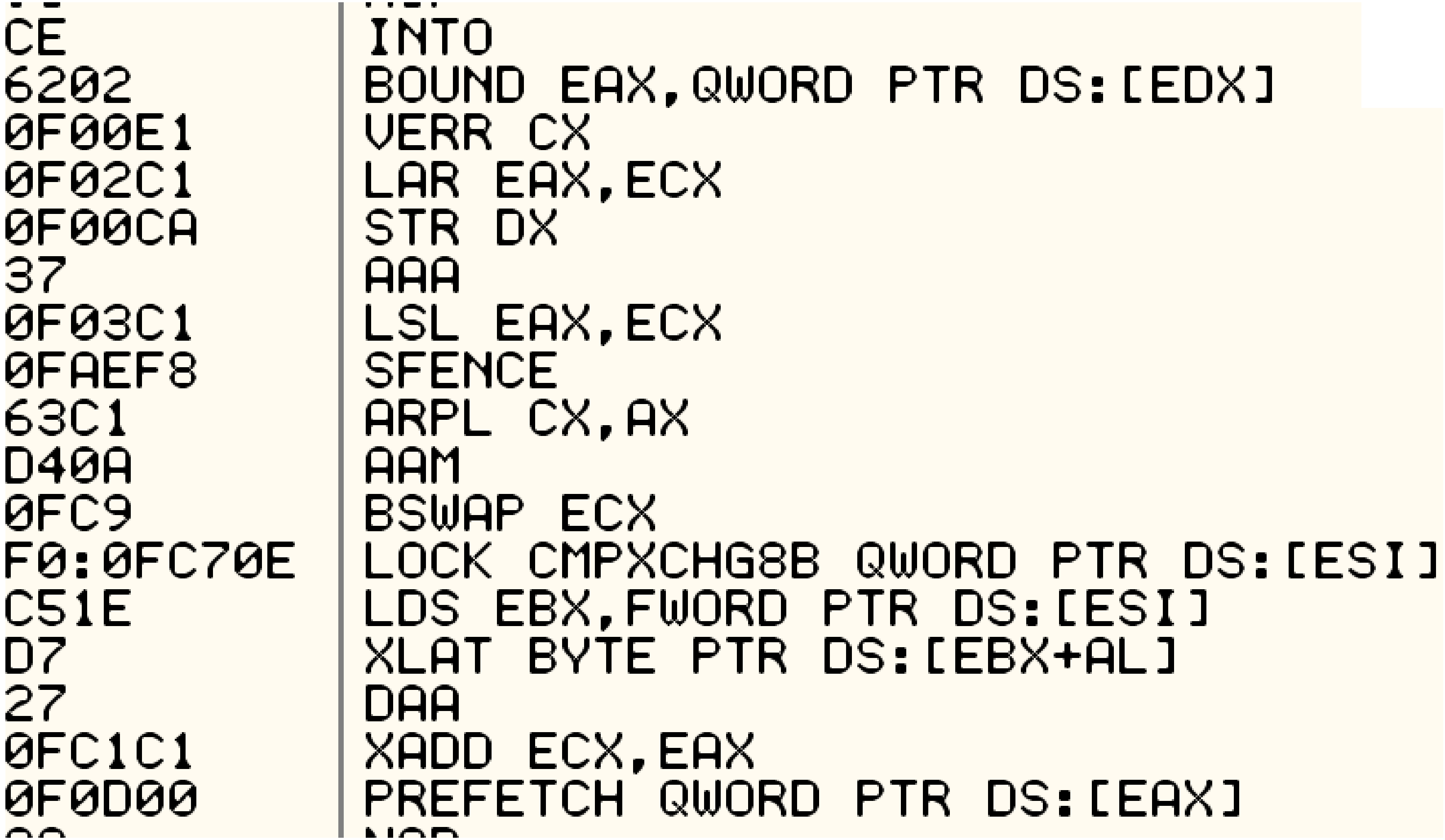
a multi-generation CPU: modern...

English	Assembly
let's go!	*push*
you win	*mov*
sandwich	*call*
hello	*retn*
f*ck	*jmp*

...shakespeare...

thou	*aaa*
porpentine	*xlat*
enmity	*verr*
hither	*smsw*
unkennel	*lsl*

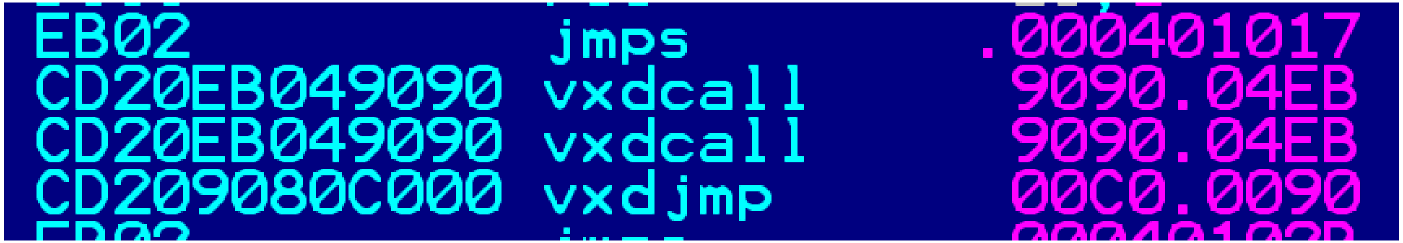
(old, but fully supported)



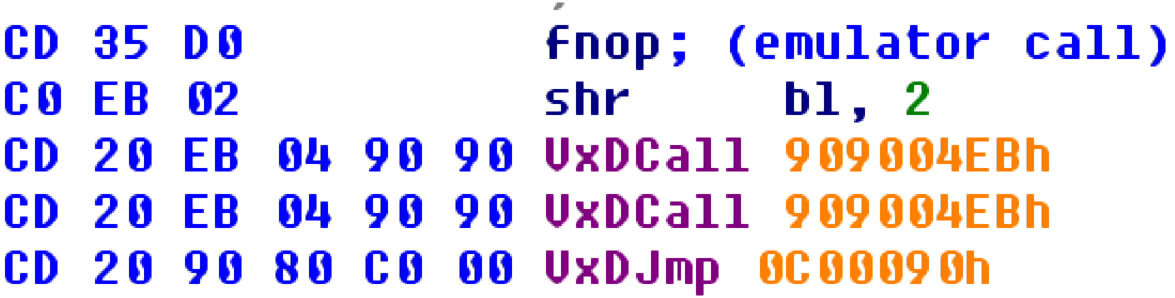
```
CE            INTO
6202          BOUND EAX,QWORD PTR DS:[EDX]
0F00E1        VERR CX
0F02C1        LAR EAX,ECX
0F00CA        STR DX
37            AAA
0F03C1        LSL EAX,ECX
0FAEF8        SFENCE
63C1          ARPL CX,AX
D40A          AAM
0FC9          BSWAP ECX
F0:0FC70E     LOCK CMPXCHG8B QWORD PTR DS:[ESI]
C51E          LDS EBX,FWORD PTR DS:[ESI]
D7            XLAT BYTE PTR DS:[EBX+AL]
27            DAA
0FC1C1        XADD ECX,EAX
0F0D00        PREFETCH QWORD PTR DS:[EAX]
```

'over-disassembling'

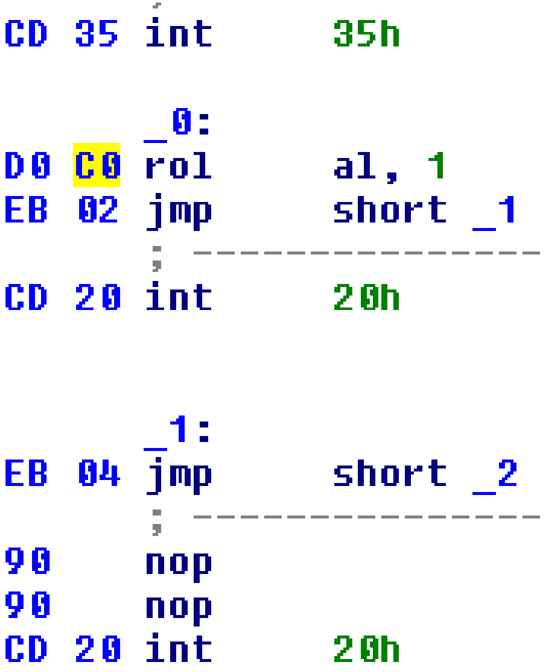
- CD XX: int XX
- deprecated behaviors:
  - int 20h = VXD, int 35-39 = FPU



```
EB02           jmps       .000401017
CD20EB049090   vxdcall     9090.04EB
CD20EB049090   vxdcall     9090.04EB
CD209080C000   vxdjmp      00C0.0090
```



```
CD 35 D0             fnop; (emulator call)
C0 EB 02             shr     bl, 2
CD 20 EB 04 90 90    VxDCall 909004EBh
CD 20 EB 04 90 90    VxDCall 909004EBh
CD 20 90 80 C0 00    VxDJmp  0C00090h
```

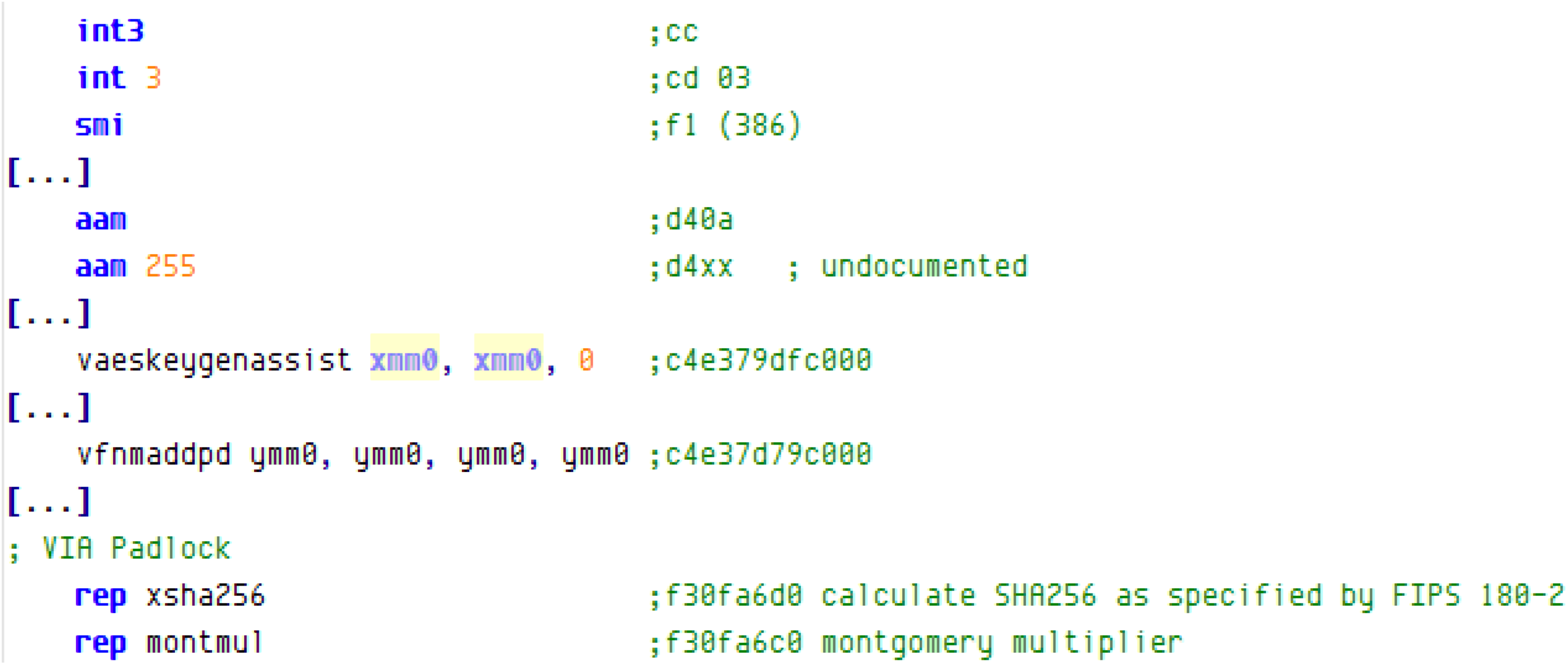


```
CD 35 int     35h

      _0:
D0 C0 rol     al, 1
EB 02 jmp     short _1
      ; ---------------
CD 20 int     20h


      _1:
EB 04 jmp     short _2
      ; ---------------
90    nop
90    nop
CD 20 int     20h
```

...next generation

tweet	*crc32*
poke	*aesenc*
google	*pcmpistrm*
pwn	*vfmsubadd132ps* Fused Multiply-Alternating Subtract/Add of Packed Single-Precision Floating-Point Values
apps	*movbe* only in netbooks!

all opcodes PoC



```
    int3                             ;cc
    int 3                            ;cd 03
    smi                              ;f1 (386)
[...]
    aam                              ;d40a
    aam 255                          ;d4xx    ; undocumented
[...]
    vaeskeygenassist xmm0, xmm0, 0   ;c4e379dfc000
[...]
    vfnmaddpd ymm0, ymm0, ymm0, ymm0 ;c4e37d79c000
[...]
; VIA Padlock
    rep xsha256                      ;f30fa6d0 calculate SHA256 as specified by FIPS 180-2
    rep montmul                      ;f30fa6c0 montgomery multiplier
```

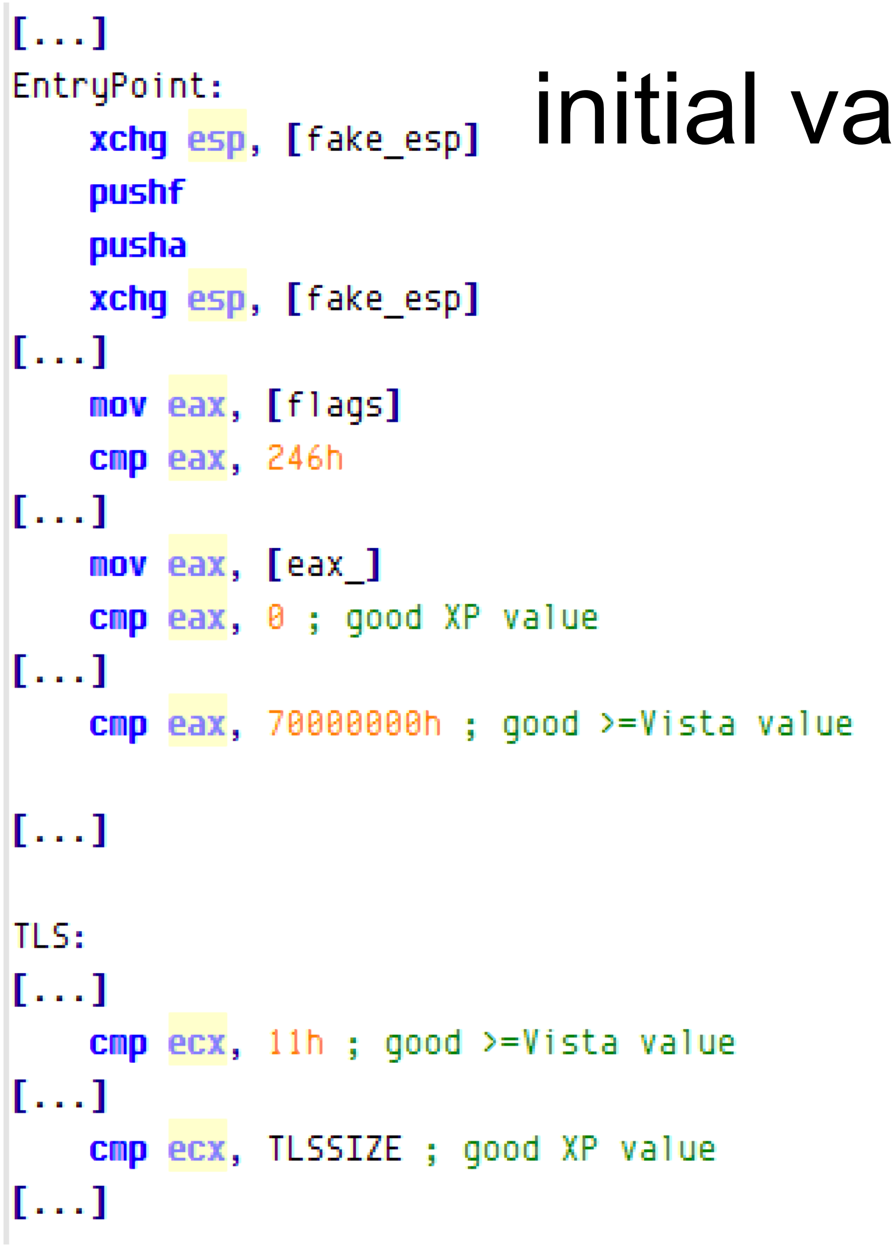
registers

- Complex relations
  - FPU changes FST, STx, Mmx (ST0 overlaps MM7)
    - also changes CR0 (under XP)

- Initial values
  - AX = <OS generation>
    - OS = (EAX == 0) ? XP : newer
  - GS = <number of bits>

    bits = (GS == 0) ? 32 : 64

initial values PoC



```
[...]
EntryPoint:
    xchg esp, [fake_esp]
    pushf
    pusha
    xchg esp, [fake_esp]
[...]
    mov eax, [flags]
    cmp eax, 246h
[...]
    mov eax, [eax_]
    cmp eax, 0 ; good XP value
[...]
    cmp eax, 70000000h ; good >=Vista value

[...]

TLS:
[...]
    cmp ecx, 11h ; good >=Vista value
[...]
    cmp ecx, TLSSIZE ; good XP value
[...]
```

	XP	**W7**
Flags	🟦	🟦
TLS		
eax	🟥	🟦
ecx	⬛	🟦
edx	🟥	🟩
ebx	🟦	🟥
EntryPoint		
eax	🟦	🟩
ecx	🟩	🟦
edx	🟩	🟥

fully ctrl-ed

controlled

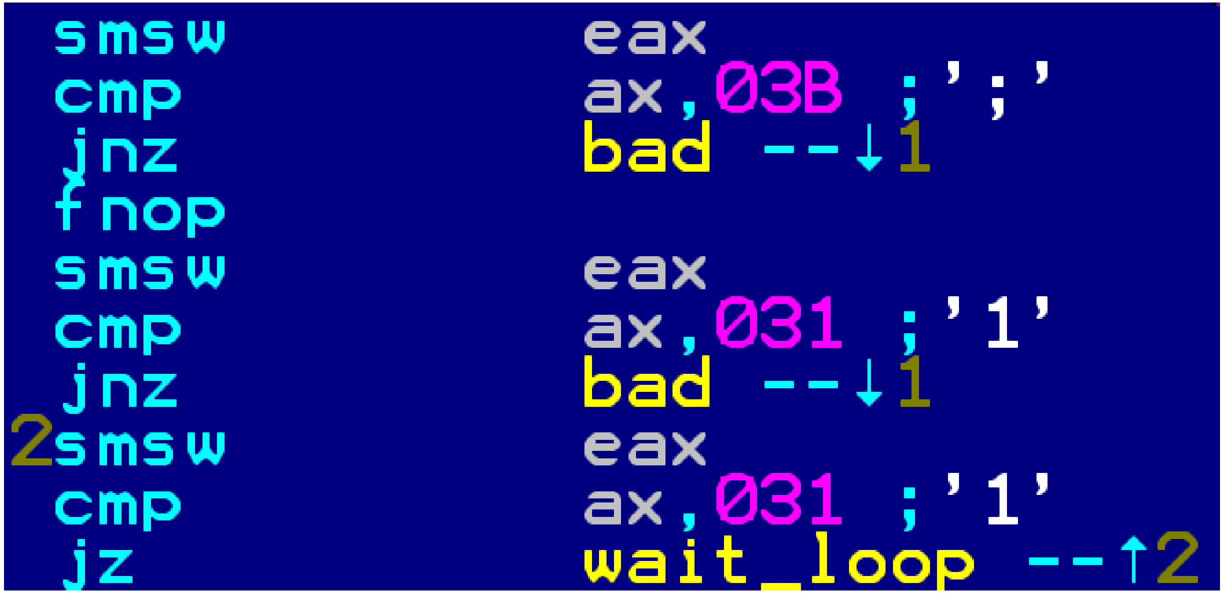
fixed

range

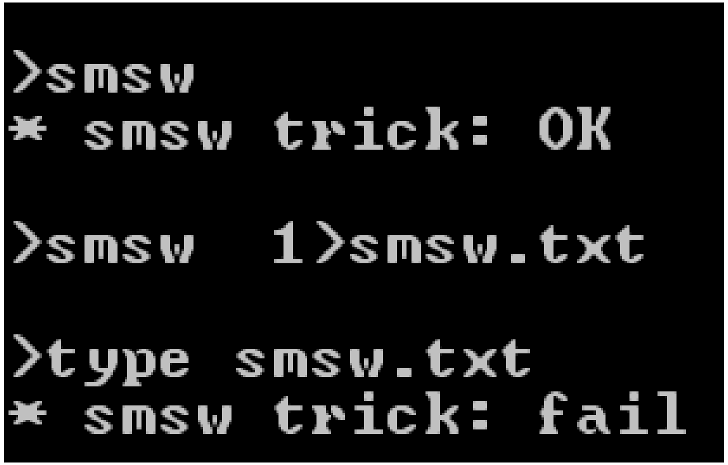
smsw

- CR0 access, from user-mode
  - 286 opcode
- higher word of reg32 'undefined'
- under XP
  - influenced by FPU
  - eventually reverts

DEMO



```
  smsw      eax
  cmp       ax,03B ;';'
  jnz       bad --↓1
 f nop
  smsw      eax
  cmp       ax,031 ;'1'
  jnz       bad --↓1
2smsw      eax
  cmp       ax,031 ;'1'
  jz        wait_loop --↑2
```

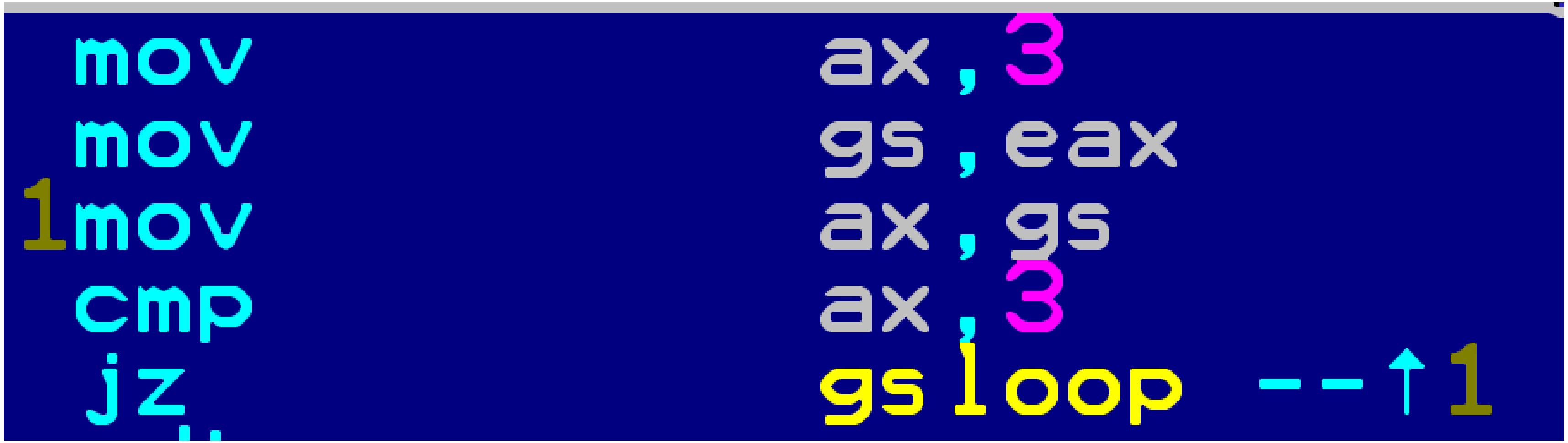


```
>smsw
* smsw trick: OK

>smsw  1>smsw.txt

>type smsw.txt
* smsw trick: fail
```

GS

- unused on Windows 32b
    - on 64b: FS, GS = TEB32, TEB64
- reset on thread switch
    - eventually reset
        - debugger stepping
        - wait
        - timings

DEMO



```
 mov           ax,3
 mov           gs,eax
1mov           ax,gs
 cmp           ax,3
 jz            gsloop --↑1
```

nop

- *nop* is *xchg *ax, *ax*
  - but *xchg *ax, *ax* can **do** something, in 64b !

    87 c0: xchg eax, eax

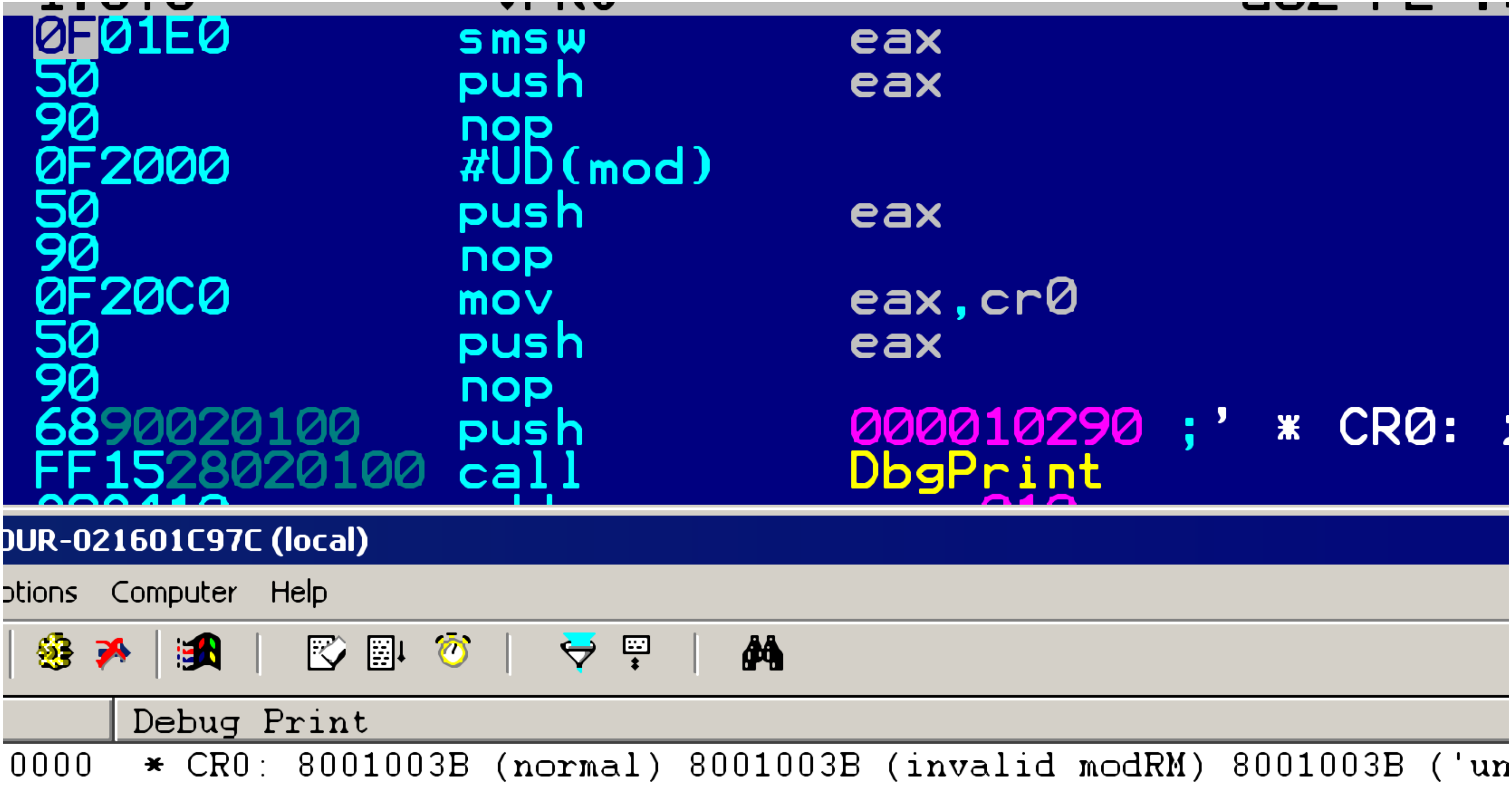
```
.. .. .. .. 01 23 45 67 => 00 00 00 00 01 23 45 67
```

- *hint nop* `0F1E84C090909090 nop dword ptr [eax+eax*8-0x6f6f6f70], eax`
  - partially undocumented, actually 0f 18-1f
  - can trigger exception

mov

- documented, but sometimes tricky
  - *mov [cr0], eax*   *mov cr0, eax*
    - mod/RM is ignored
  - *movsxd eax, ecx*   *mov eax, ecx*
    - no REX prefix
  - *mov eax, cs*   *movzx eax,cs*
    - 'undefined' upper word

non standard CR0 access



```
0F01E0          smsw    eax
50              push    eax
90              nop
0F2000          #UD(mod)
50              push    eax
90              nop
0F20C0          mov     eax,cr0
50              push    eax
90              nop
6890020100      push    00010290 ;' * CR0:
FF1528020100    call    DbgPrint
```

```
0000   * CR0: 8001003B (normal) 8001003B (invalid modRM) 8001003B ('un
```

bswap

rax

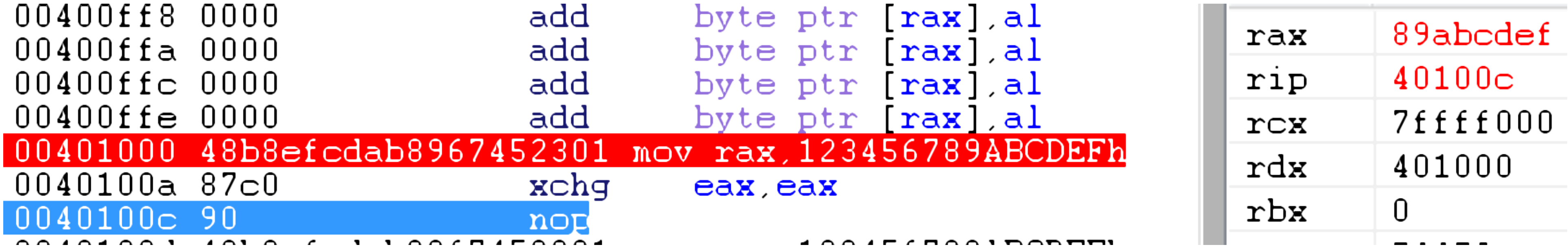
`12 34 56 78 90 ab cd ef => ef cd ab 90 78 56 34 12`

eax

`.. .. .. .. 01 23 45 67 => 00 00 00 00 67 45 23 01`

ax

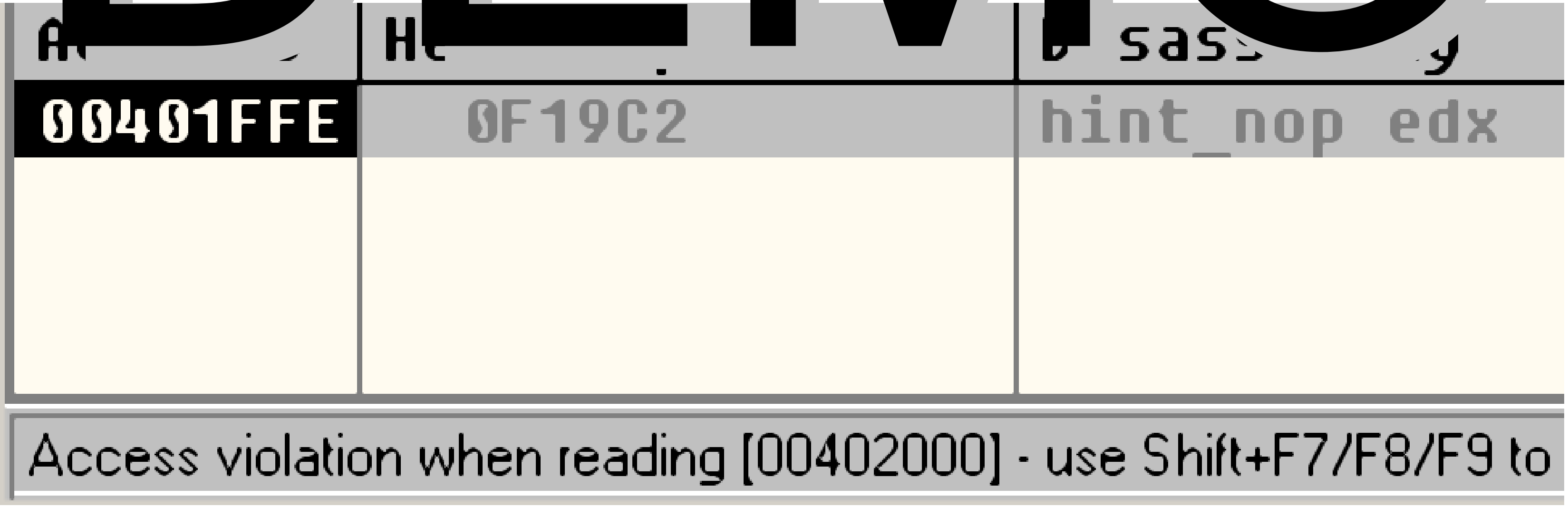
`.. .. .. .. .. .. 01 23 => .. .. .. .. .. .. 00 00`



```
00400ff8 0000                 add     byte ptr [rax],al
00400ffa 0000                 add     byte ptr [rax],al
00400ffc 0000                 add     byte ptr [rax],al
00400ffe 0000                 add     byte ptr [rax],al
00401000 48b8efcdab8967452301 mov rax,123456789ABCDEFh
0040100a 87c0                 xchg    eax,eax
0040100c 90                   nop
```

```
rax   89abcdef
rip   40100c
rcx   7ffff000
rdx   401000
rbx   0
```

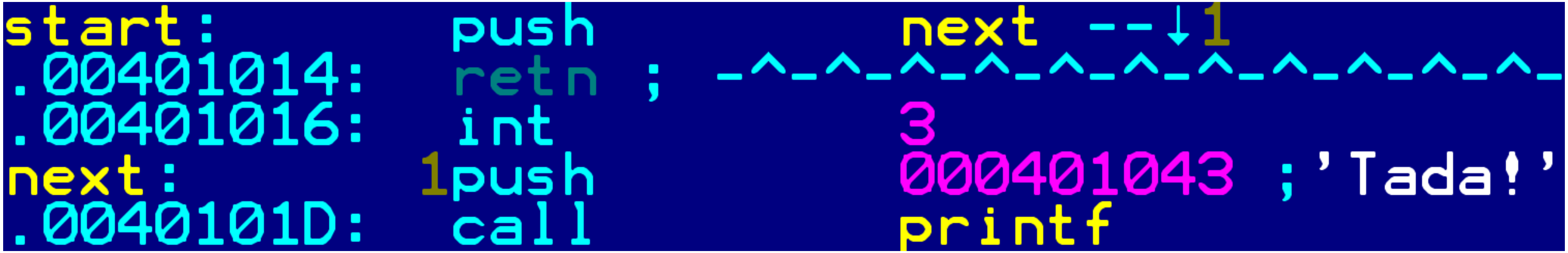
DEMO



```
00401FFE    0F19C2    hint_nop edx
```

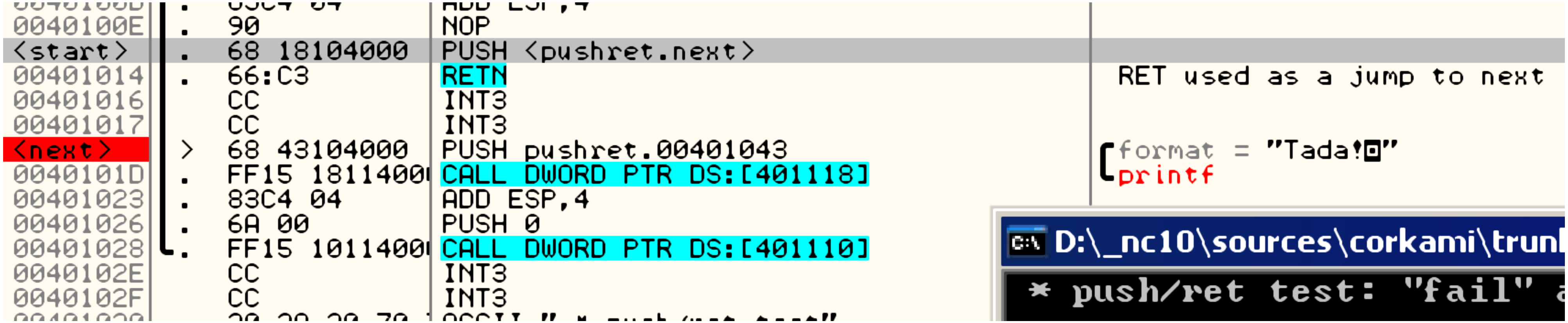
Access violation when reading [00402000] - use Shift+F7/F8/F9 to

push+ret



```
start:      push        next --↓1
.00401014:  retn ; _^_^_^_^_^_^_^_^_^_^_^_
.00401016:  int         3
next:      1push        000401043 ;'Tada!'
.0040101D:  call        printf
```

DEMO



```
0040100E   .  90            NOP
<start>    .  68 18104000   PUSH <pushret.next>
00401014   .  66:C3         RETN                                  RET used as a jump to next
00401016      CC            INT3
00401017      CC            INT3
<next>     >  68 43104000   PUSH pushret.00401043                 [format = "Tada!◘"
0040101D   .  FF15 1811400  CALL DWORD PTR DS:[401118]            [printf
00401023   .  83C4 04       ADD ESP,4
00401026   .  6A 00         PUSH 0
00401028   .  FF15 1011400  CALL DWORD PTR DS:[401110]
0040102E      CC            INT3
0040102F      CC            INT3
```

```
D:\_nc10\sources\corkami\trun
* push/ret test: "fail" a
```

...and so on...

- much more @ http://x86.corkami.com
  - also graphs, cheat sheet...
- too much theory for now...

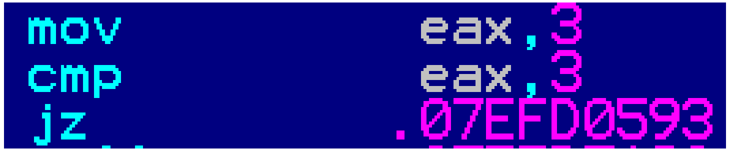
Corkami Standard Test

CoST

- http://cost.corkami.com
- testing opcodes
- in a hardened PE
    - available in easy mode

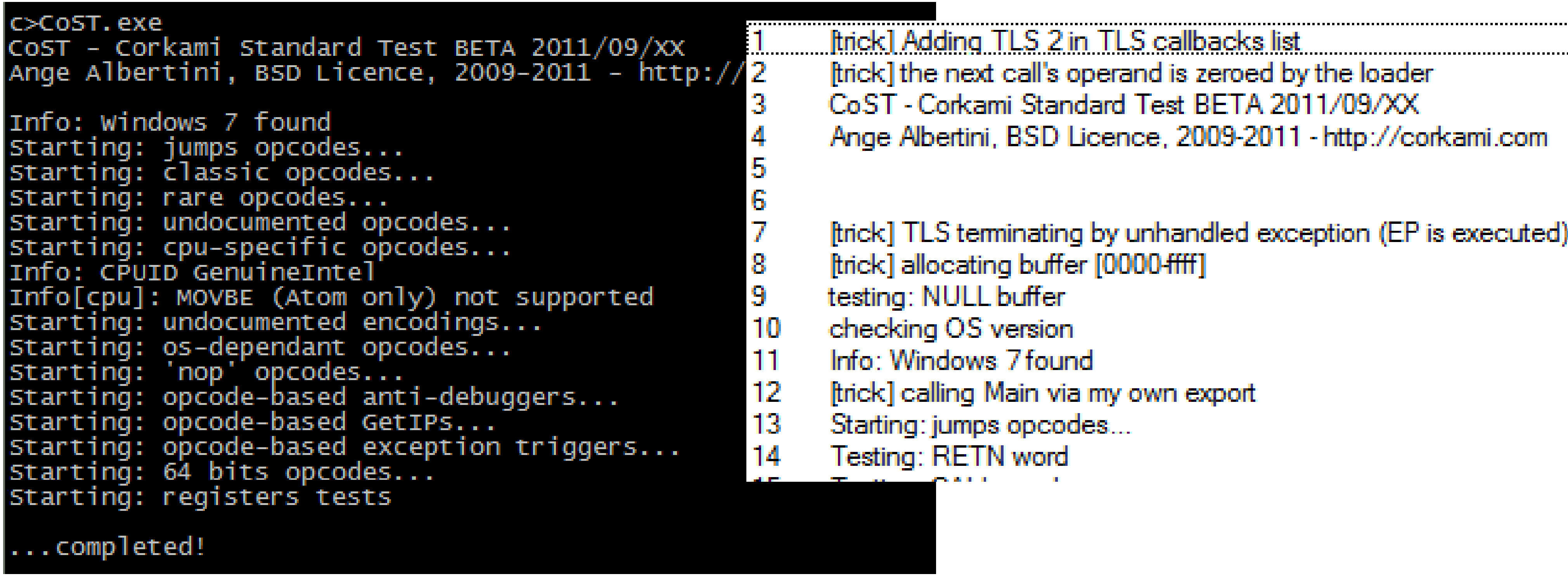
more than 150 tests

- classic, rare
- jumps (JMP to IP, IRET, …)
- undocumented (IceBP, SetALc...)
- cpu-specific (MOVBE, POPCNT,...)
- os-dependant, anti-VM/debugs
- exceptions triggers, interrupts, OS bugs,...
- ...



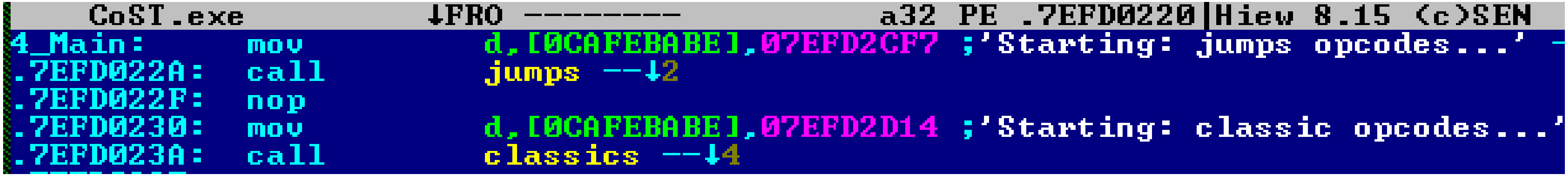
```
mov                 eax,3
cmp                 eax,3
jz                 .07EFD0593
```

CoST's internals



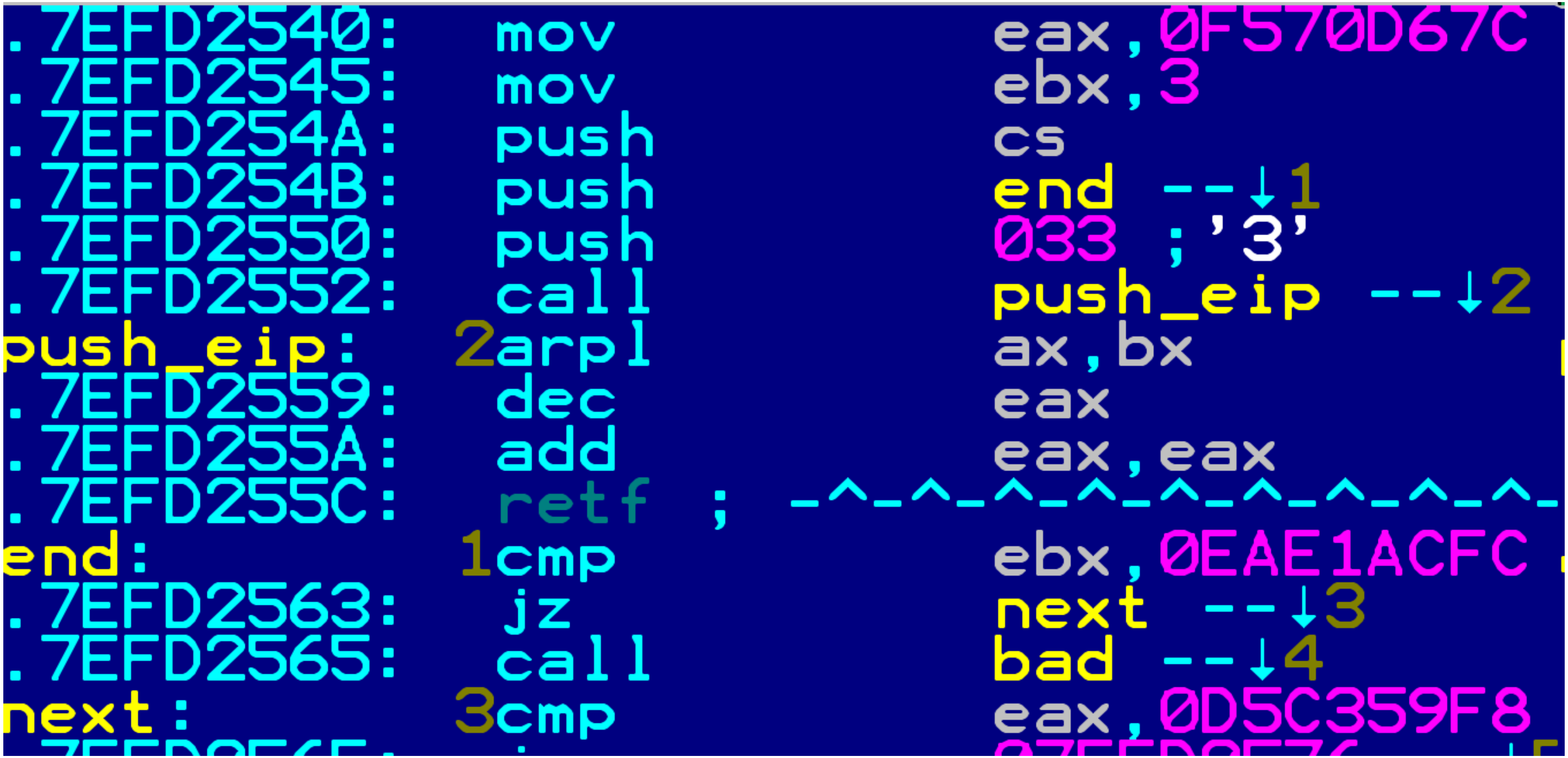
```
c>CoST.exe
CoST - Corkami Standard Test BETA 2011/09/XX
Ange Albertini, BSD Licence, 2009-2011 - http://

Info: Windows 7 found
Starting: jumps opcodes...
Starting: classic opcodes...
Starting: rare opcodes...
Starting: undocumented opcodes...
Starting: cpu-specific opcodes...
Info: CPUID GenuineIntel
Info[cpu]: MOVBE (Atom only) not supported
Starting: undocumented encodings...
Starting: os-dependant opcodes...
Starting: 'nop' opcodes...
Starting: opcode-based anti-debuggers...
Starting: opcode-based GetIPs...
Starting: opcode-based exception triggers...
Starting: 64 bits opcodes...
Starting: registers tests

...completed!
```

```
1     [trick] Adding TLS 2 in TLS callbacks list
2     [trick] the next call's operand is zeroed by the loader
3     CoST - Corkami Standard Test BETA 2011/09/XX
4     Ange Albertini, BSD Licence, 2009-2011 - http://corkami.com
5
6
7     [trick] TLS terminating by unhandled exception (EP is executed)
8     [trick] allocating buffer [0000-ffff]
9     testing: NULL buffer
10    checking OS version
11    Info: Windows 7 found
12    [trick] calling Main via my own export
13    Starting: jumps opcodes...
14    Testing: RETN word
```

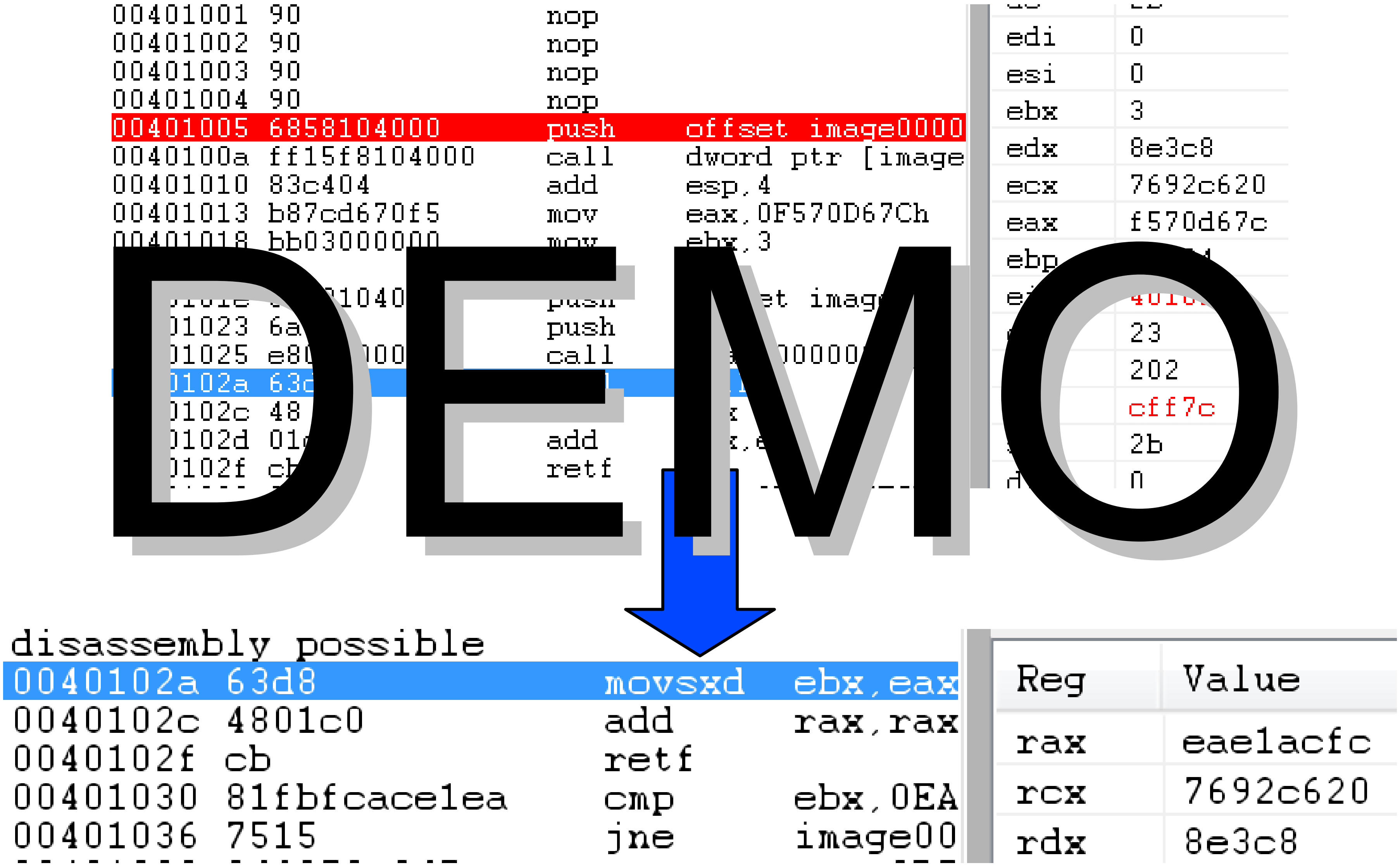


```
   CoST.exe                ↓FRO --------          a32 PE .7EFD0220|Hiew 8.15 (c)SEN
4_Main:       mov          d,[0CAFEBABE],07EFD2CF7 ;'Starting: jumps opcodes...'
.7EFD022A:    call         jumps --↓2
.7EFD022F:    nop
.7EFD0230:    mov          d,[0CAFEBABE],07EFD2D14 ;'Starting: classic opcodes...'
.7EFD023A:    call         classics --↓4
```

32+64 = ...



```
.7EFD2540:   mov              eax,0F570D67C
.7EFD2545:   mov              ebx,3
.7EFD254A:   push             cs
.7EFD254B:   push             end --↓1
.7EFD2550:   push             033 ;'3'
.7EFD2552:   call             push_eip --↓2
push_eip:   2arpl             ax,bx
.7EFD2559:   dec              eax
.7EFD255A:   add              eax,eax
.7EFD255C:   retf ; _^_^_^_^_^_^_^_^_^_
end:        1cmp              ebx,0EAE1ACFC
.7EFD2563:   jz               next --↓3
.7EFD2565:   call             bad --↓4
next:       3cmp              eax,0D5C359F8
```



DEMO

```
00401001 90           nop
00401002 90           nop
00401003 90           nop
00401004 90           nop
00401005 6858104000   push    offset image0000
0040100a ff15f8104000 call    dword ptr [image
00401010 83c404       add     esp,4
00401013 b87cd670f5   mov     eax,0F570D67Ch
00401018 bb03000000   mov     ebx,3
```

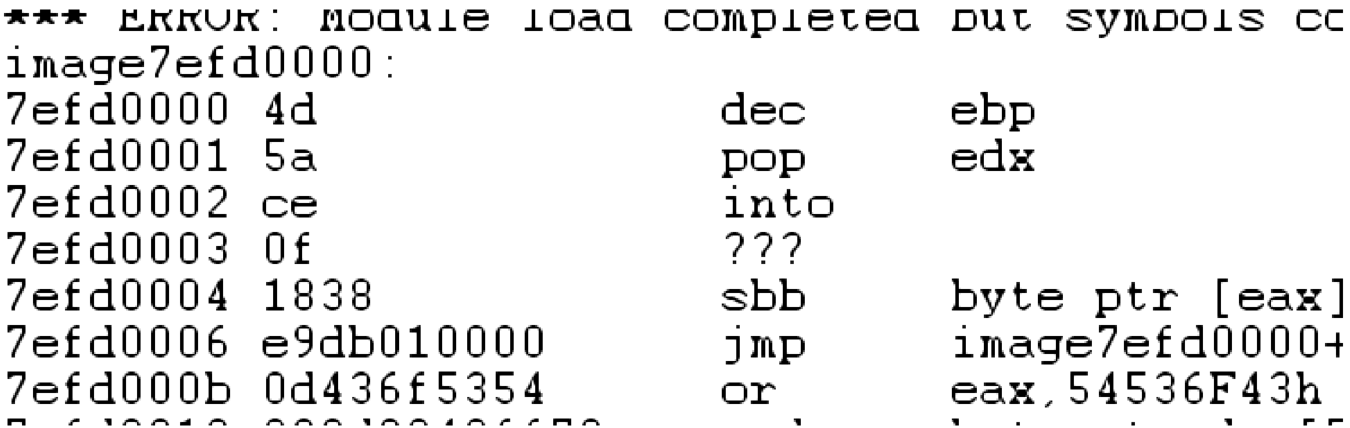
```
edi   0
esi   0
ebx   3
edx   8e3c8
ecx   7692c620
eax   f570d67c
```

```
disassembly possible
0040102a 63d8          movsxd  ebx,eax
0040102c 4801c0        add     rax,rax
0040102f cb            retf
00401030 81fbfcace1ea  cmp     ebx,0EA
00401036 7515          jne     image00
```

Reg	Value
rax	eae1acfc
rcx	7692c620
rdx	8e3c8

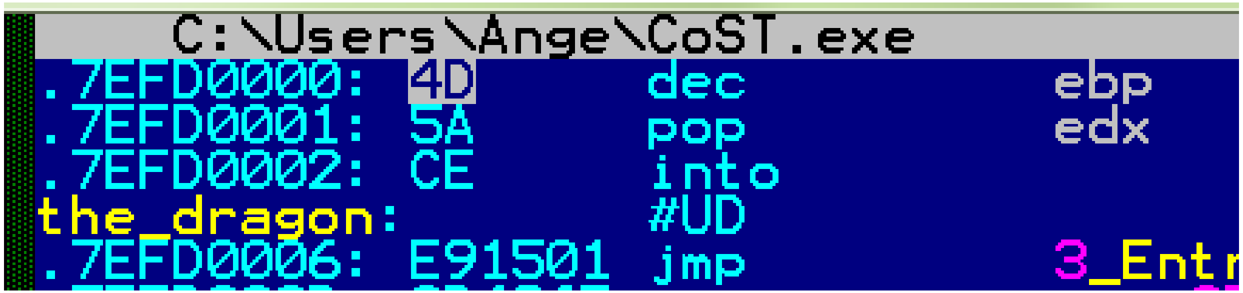
CoST vs WinDbg & Hiew

WinDbg 6.12.0002.633



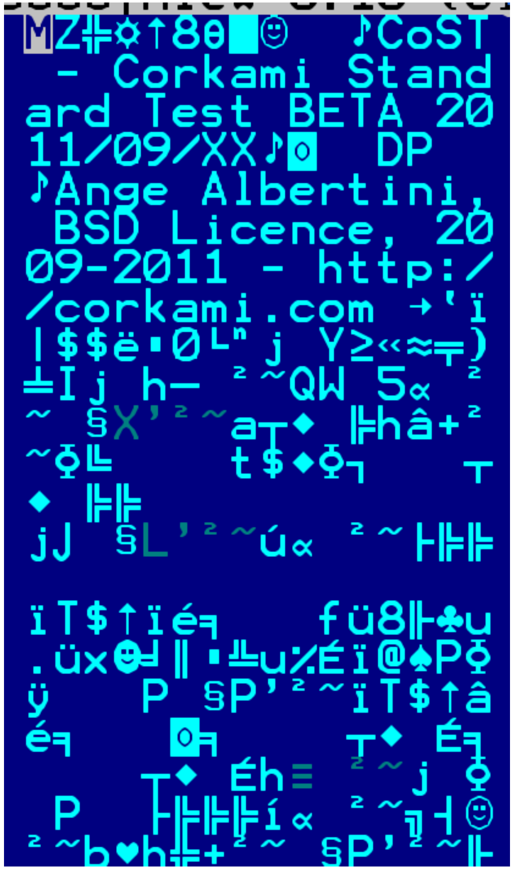
```
*** ERROR: Module load completed but symbols cc
image7efd0000:
7efd0000 4d                    dec     ebp
7efd0001 5a                    pop     edx
7efd0002 ce                    into
7efd0003 0f                    ???
7efd0004 1838                  sbb     byte ptr [eax]
7efd0006 e9db010000            jmp     image7efd0000+
7efd000b 0d436f5354            or      eax,54536F43h
```

Hiew 8.15



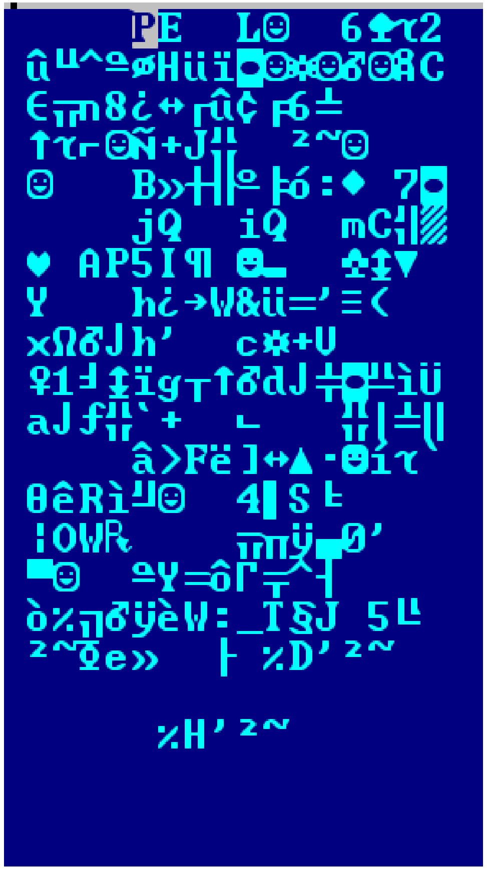
```
    C:\Users\Ange\CoST.exe
.7EFD0000: 4D      dec          ebp
.7EFD0001: 5A      pop          edx
.7EFD0002: CE      into
the_dragon:        #UD
.7EFD0006: E91501  jmp          3_Entr
```

a hardened PE



```
MZ╫☼↑8θ█☺   ♪CoST
 - Corkami Stand
ard Test BETA 20
11/09/XX♪◘  DP
♪Ange Albertini,
 BSD Licence, 20
09-2011 - http:/
/corkami.com →'ï
```

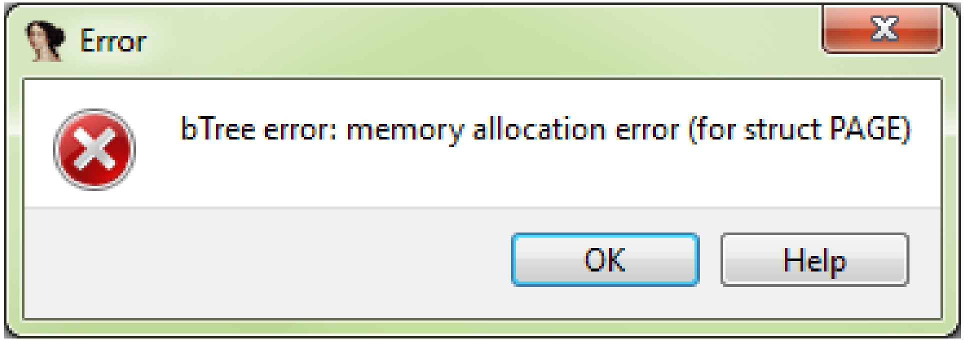
Top



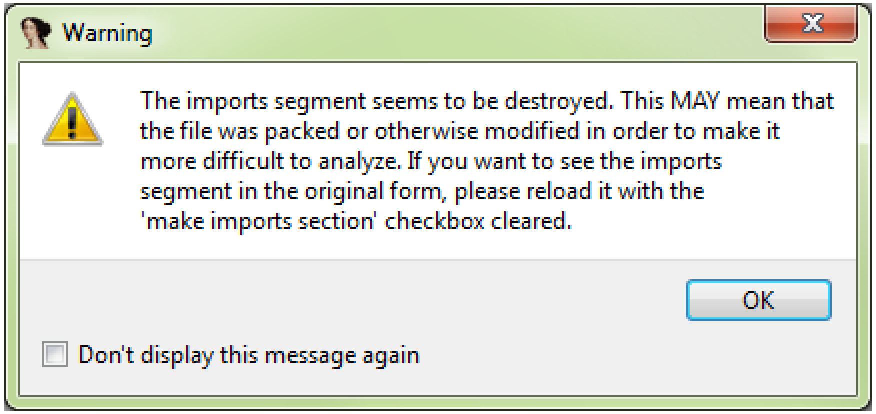
```
     PE   L☺   6
```

PE 'footer'

CoST vs IDA

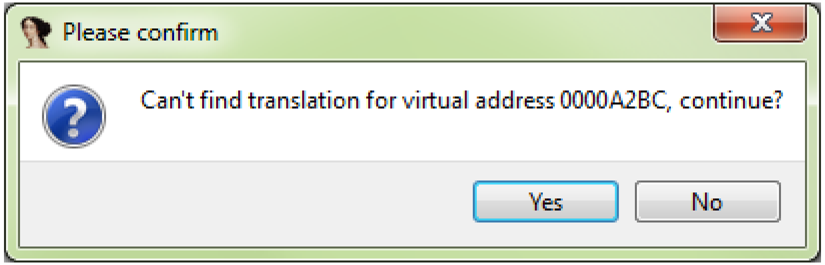


bTree error: memory allocation error (for struct PAGE)

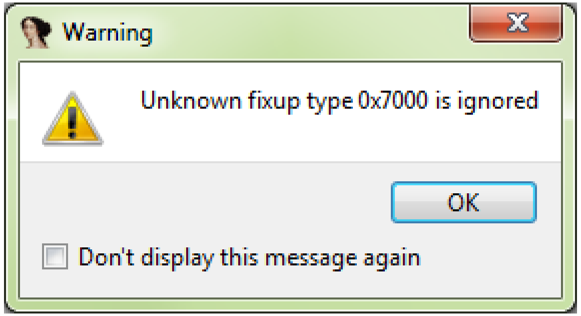


The imports segment seems to be destroyed. This MAY mean that the file was packed or otherwise modified in order to make it more difficult to analyze. If you want to see the imports segment in the original form, please reload it with the 'make imports section' checkbox cleared.

☐ Don't display this message again

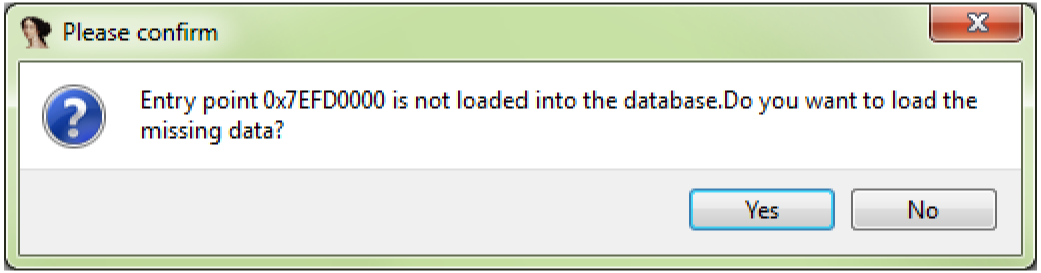


Can't find translation for virtual address 0000A2BC, continue?



Unknown fixup type 0x7000 is ignored

☐ Don't display this message again



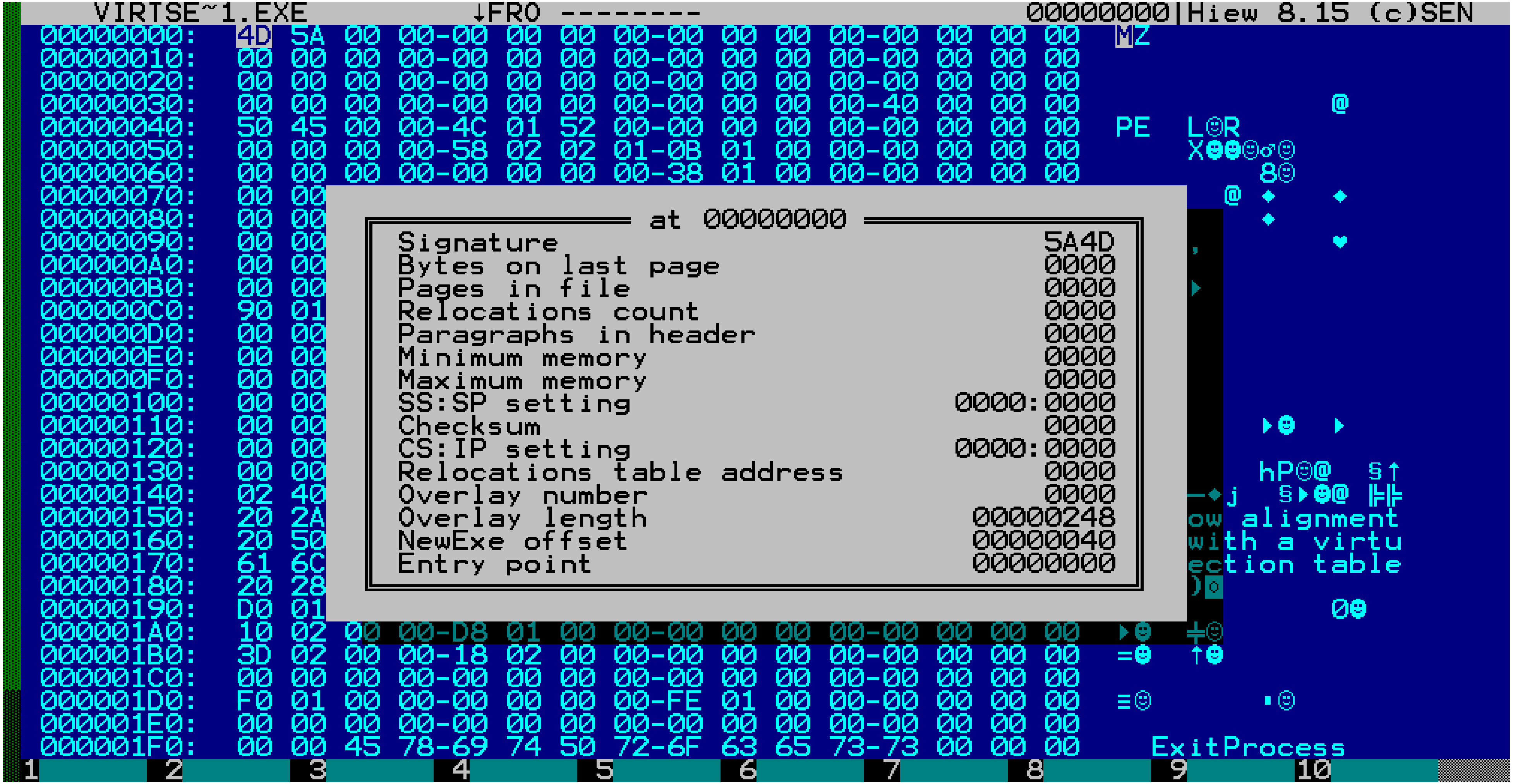
Entry point 0x7EFD0000 is not loaded into the database.Do you want to load the missing data?

a bit more of PE...

PE on Corkami

- still in progress
- more than 120 PoCs
    - covering many aspects
    - good enough to break <you name it>
- 'summary' page http://pe.corkami.com
- printable graphs

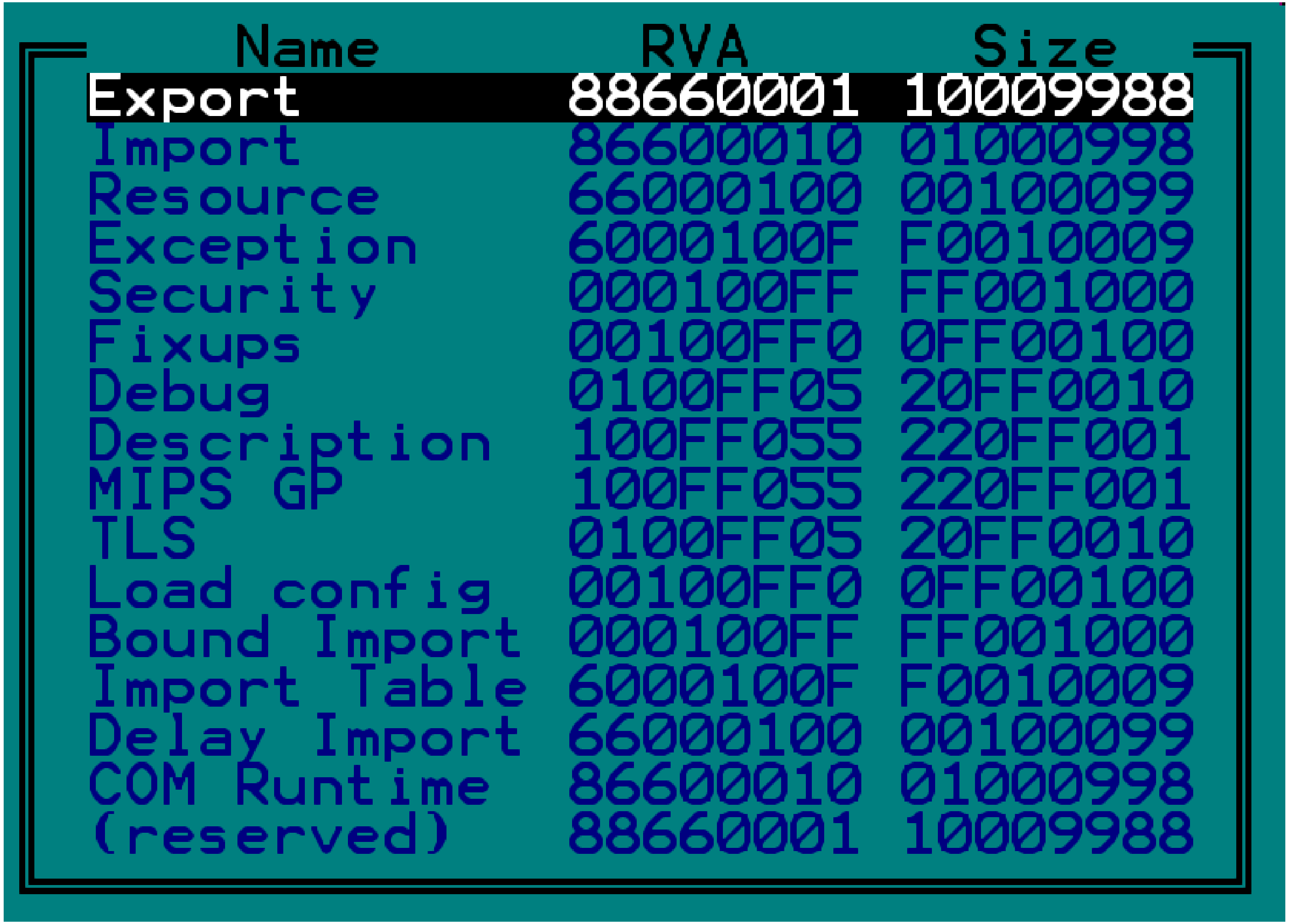
virtual section table vs Hiew



```
    VIRTSE~1.EXE          ↓FRO ---------          00000000|Hiew 8.15 (c)SEN
00000000:  4D 5A 00 00-00 00 00 00-00 00 00 00-00 00 00 00   MZ
00000010:  00 00 00 00-00 00 00 00-00 00 00 00-00 00 00 00
00000020:  00 00 00 00-00 00 00 00-00 00 00 00-00 00 00 00
00000030:  00 00 00 00-00 00 00 00-00 00 00 00-40 00 00 00               @
00000040:  50 45 00 00-4C 01 52 00-00 00 00 00-00 00 00 00   PE  L☺R
00000050:  00 00 00 00-58 02 02 01-0B 01 00 00-00 00 00 00       X☻☻☺♂☺
00000060:  00 00 00 00-00 00 00 00-38 01 00 00-00 00 00 00           8☺
00000070:  00 00
00000080:  00 00
00000090:  00 00
000000A0:  00 00
000000B0:  00 00
000000C0:  90 01
000000D0:  00 00
000000E0:  00 00
000000F0:  00 00
00000100:  00 00
00000110:  00 00
00000120:  00 00
00000130:  00 00                                                   hP☺@   §↑
00000140:  02 40                                                 ─◆j   §►☻@ ╠╠
00000150:  20 2A                                                 ow alignment
00000160:  20 50                                                 with a virtu
00000170:  61 6C                                                 ection table
00000180:  20 28                                                 )○
00000190:  D0 01                                                         0☻
000001A0:  10 02 00 00-D8 01 00 00-00 00 00 00-00 00 00 00   ►☻    ╪☺
000001B0:  3D 02 00 00-18 02 00 00-00 00 00 00-00 00 00 00   =☻    ↑☻
000001C0:  00 00 00 00-00 00 00 00-00 00 00 00-00 00 00 00
000001D0:  F0 01 00 00-00 00 00 00-FE 01 00 00-00 00 00 00   ≡☺      ■☺
000001E0:  00 00 00 00-00 00 00 00-00 00 00 00-00 00 00 00
000001F0:  00 00 45 78-69 74 50 72-6F 63 65 73-73 00 00 00     ExitProcess
1       2       3       4       5       6       7       8       9       10
```

```
═══════════ at 00000000 ═══════════
 Signature                              5A4D
 Bytes on last page                     0000
 Pages in file                          0000
 Relocations count                      0000
 Paragraphs in header                   0000
 Minimum memory                         0000
 Maximum memory                         0000
 SS:SP setting                     0000:0000
 Checksum                               0000
 CS:IP setting                     0000:0000
 Relocations table address              0000
 Overlay number                         0000
 Overlay length                     00000248
 NewExe offset                      00000040
 Entry point                        00000000
```

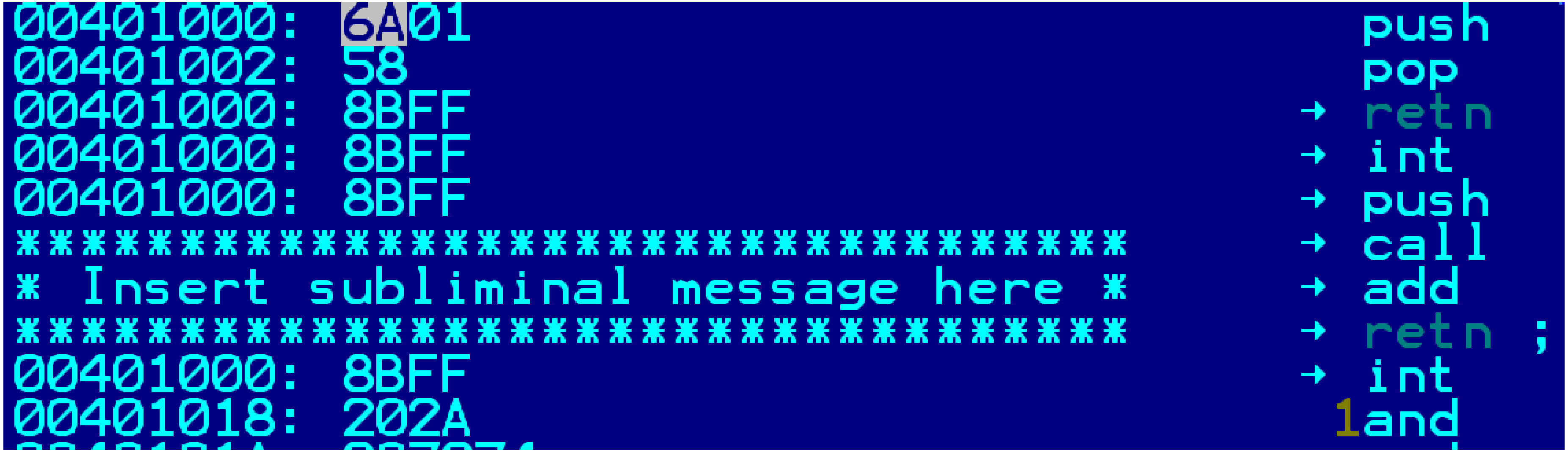
Folded header



```
       Name            RVA      Size
Export              88660001 10009988
Import              86600010 01000998
Resource            66000100 00100099
Exception           6000100F F0010009
Security            000100FF FF001000
Fixups              00100FF0 0FF00100
Debug               0100FF05 20FF0010
Description         100FF055 220FF001
MIPS GP             100FF055 220FF001
TLS                 0100FF05 20FF0010
Load config         00100FF0 0FF00100
Bound Import        000100FF FF001000
Import Table        6000100F F0010009
Delay Import        66000100 00100099
COM Runtime         86600010 01000998
(reserved)          88660001 10009988
```

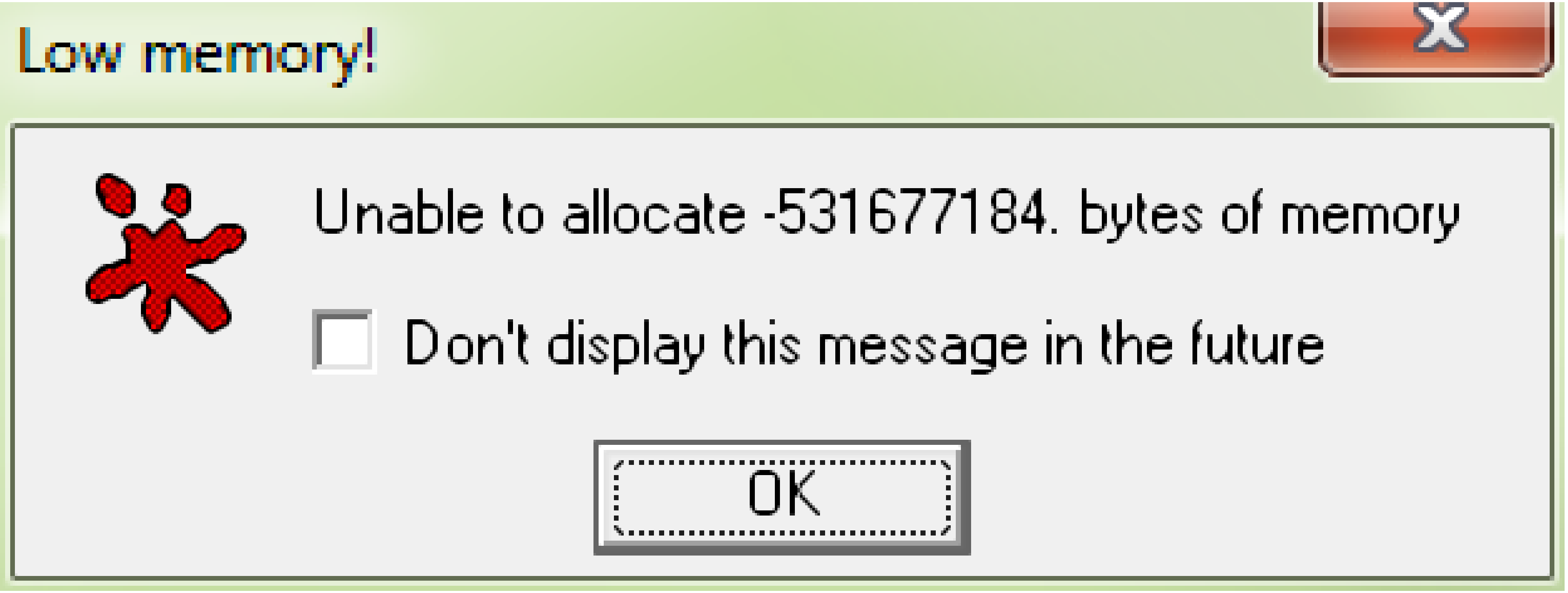
Weird export names

- exports = <anything non null>, 0



```
00401000: 6A01                                 push
00401002: 58                                   pop
00401000: 8BFF                               → retn
00401000: 8BFF                               → int
00401000: 8BFF                               → push
**********************************           → call
* Insert subliminal message here *           → add
**********************************           → retn ;
00401000: 8BFF                               → int
00401018: 202A                                1and
```

65535 sections vs OllyDbg

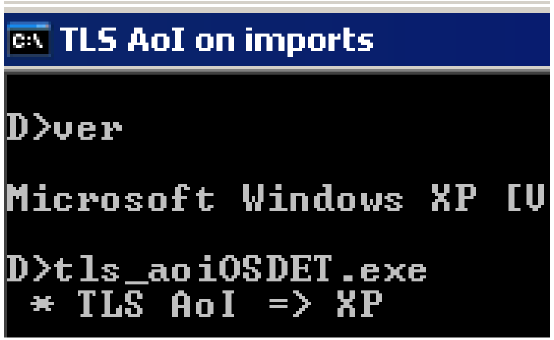


Unable to allocate -531677184. bytes of memory

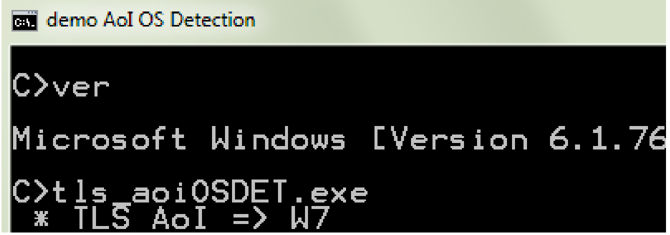
☐ Don't display this message in the future

a last one...

- TLS AddressOfIndex is overwritten on loading
- Imports are parsed until Name is 0
- under XP, overwritten after imports
    - imports are fully parsed
- under W7, before
    - truncated



```
D>ver

Microsoft Windows XP [V

D>tls_aoiOSDET.exe
 * TLS AoI => XP
```



```
C>ver

Microsoft Windows [Version 6.1.76

C>tls_aoiOSDET.exe
 * TLS AoI => W7
```

same PE, loaded differently

Conclusion (1/2)

- x86 and PE are far from perfectly documented

official docs ⇒ FAIL

Conclusion (2/2)

1. visit Corkami
2. download the PoCs
   - read the doc / source
3. fix the bugs ;)
   - or answer my bug reports ?#$!

Acknowledgments

- Peter Ferrie
- Ivanlef0u

Adam Błaszczyk, BeatriX, Bruce Dang, Candid Wüest, Cathal Mullaney, Czerno, Daniel Reynaud, Elias Bachaalany, Ero Carrera, Eugeny Suslikov, Georg Wicherski, Gil Dabah, Guillaume Delugré, Gunther, Igor Skochinsky, Ilfak Guilfanov, Ivanlef0u, Jean-Baptiste Bédrune, Jim Leonard, Jon Larimer, Joshua J. Drake, Markus Hinderhofer, Mateusz Jurczyk, Matthieu Bonetti, Moritz Kroll, Oleh Yuschuk, Renaud Tabary, Rewolf, Sebastian Biallas, StalkR, Yoann Guillot,...

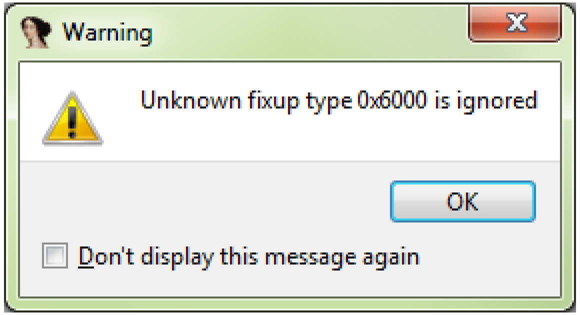
Questions?

Thank YOU!

@ange4771

Bonus

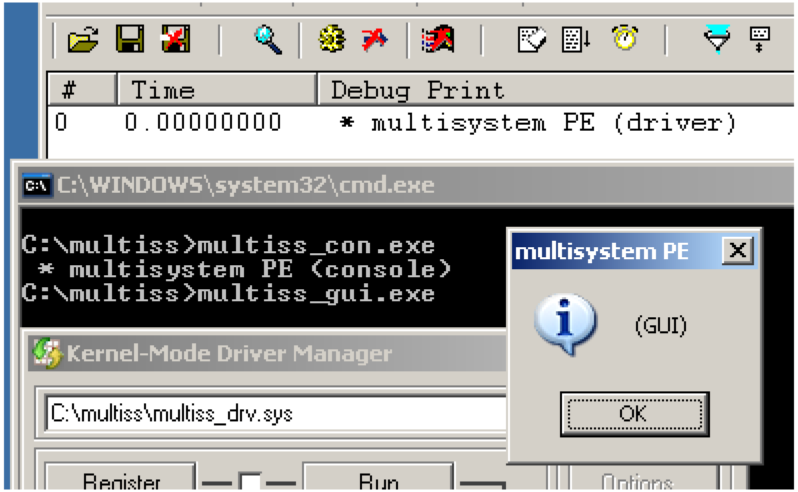
- Mips relocs (on relocs)
- ImageBase reloc
- multi-subsystem PE
- regs on TLS & DllMain



Warning

Unknown fixup type 0x6000 is ignored

☐ Don't display this message again



#	Time	Debug Print
0	0.00000000	* multisystem PE (driver)

C:\WINDOWS\system32\cmd.exe

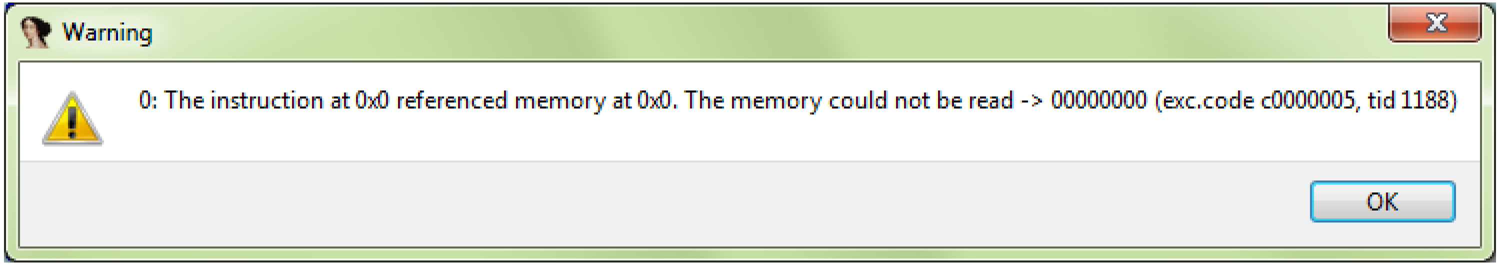
```
C:\multiss>multiss_con.exe
 * multisystem PE (console)
C:\multiss>multiss_gui.exe
```

Kernel-Mode Driver Manager

C:\multiss\multiss_drv.sys

multisystem PE

(GUI)



Warning

0: The instruction at 0x0 referenced memory at 0x0. The memory could not be read -> 00000000 (exc.code c0000005, tid 1188)

x86 & PE

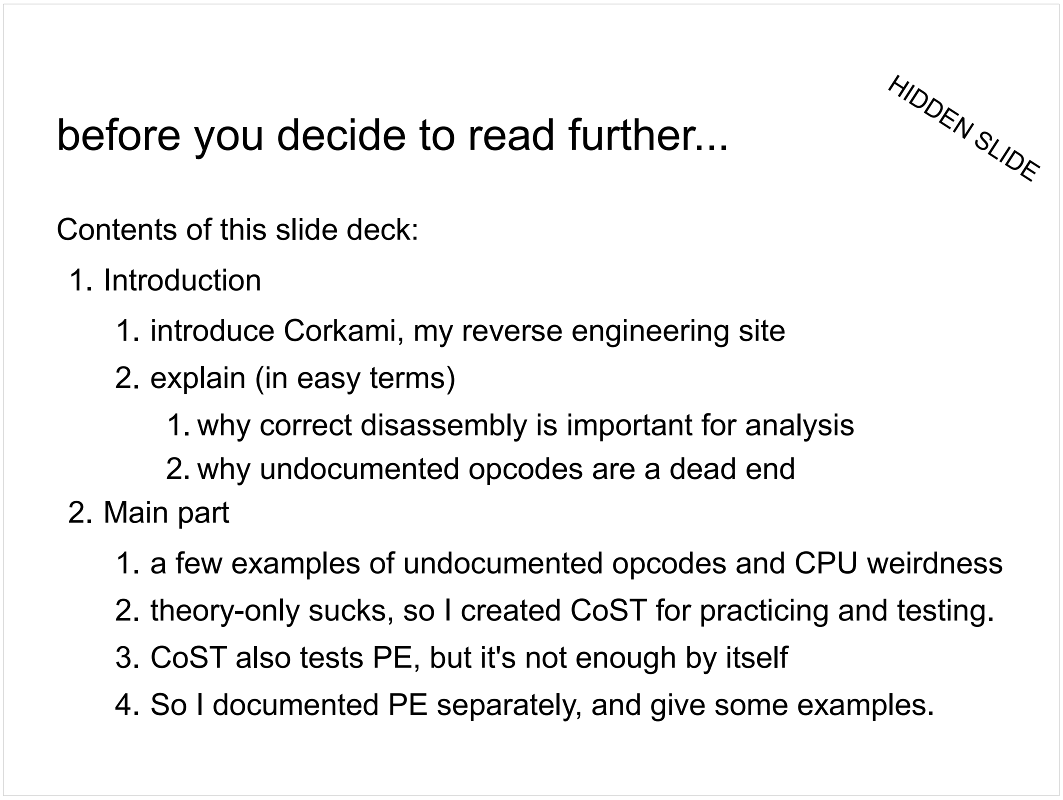
$berlinsides_

28th December 2011

Ange Albertini

Welcome!

I'm Ange Albertini, and I will talk about x86 and PE



HIDDEN SLIDE

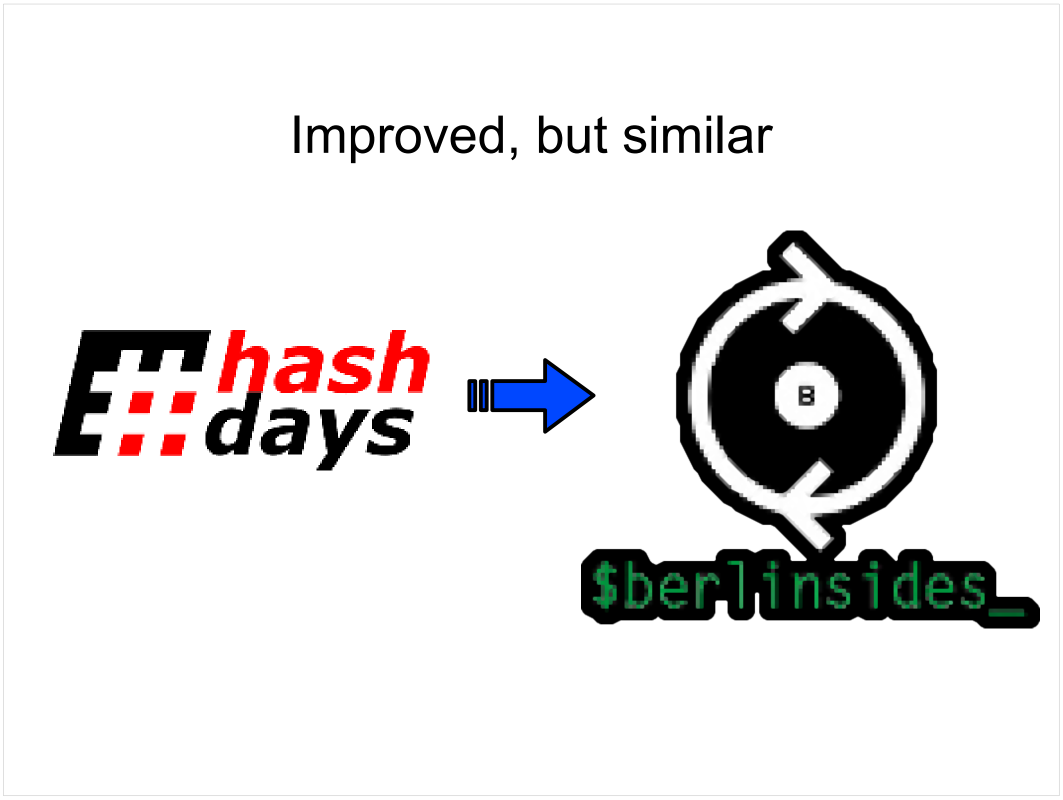
before you decide to read further...

Contents of this slide deck:

1. Introduction
    1. introduce Corkami, my reverse engineering site
    2. explain (in easy terms)
        1. why correct disassembly is important for analysis
        2. why undocumented opcodes are a dead end
2. Main part
    1. a few examples of undocumented opcodes and CPU weirdness
    2. theory-only sucks, so I created CoST for practicing and testing.
    3. CoST also tests PE, but it's not enough by itself
    4. So I documented PE separately, and give some examples.

this extra slide to let you decide if you really want to read further ;)

1. I studied ASM and PE, from scratch
2. I failed all tools I tried: IDA, OllyDbg, Hiew, pefile, WinDbg, HT, CFF Explorer...
3. here are a few of my findings

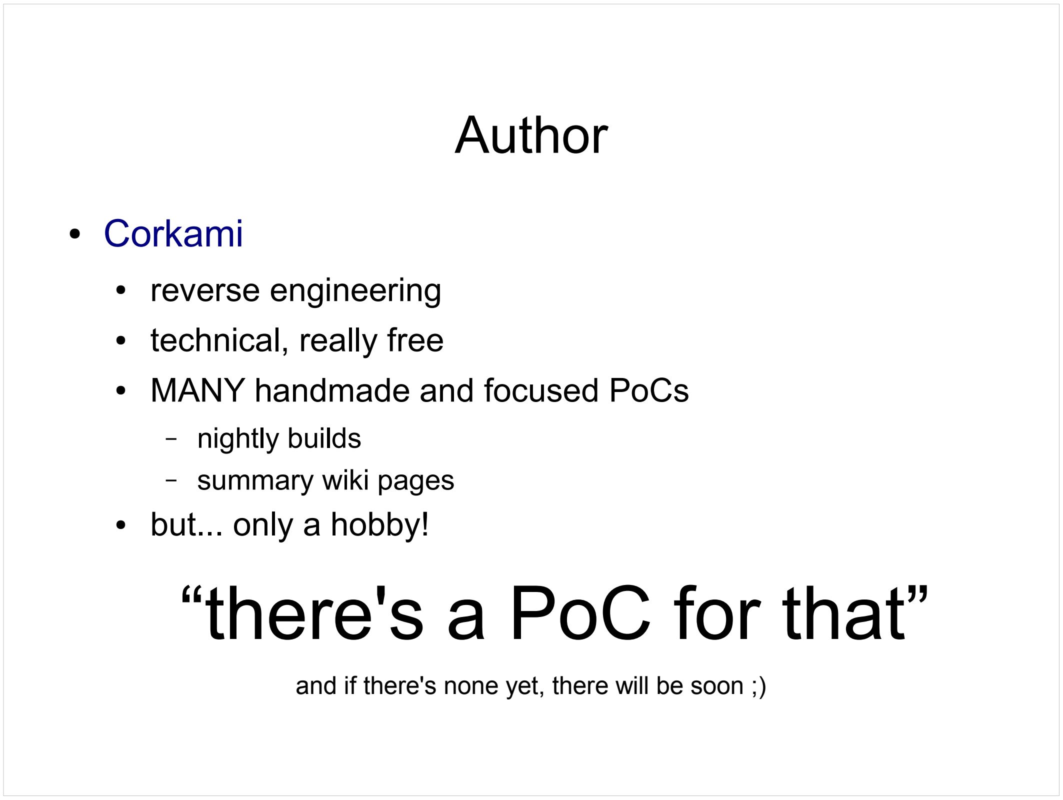


Improved, but similar

hash
days
$berlinsides_

This is an improved version of my presentation at Hashdays.

I reworked it, but most of the content is still the same.



Author

- Corkami
  - reverse engineering
  - technical, really free
  - MANY handmade and focused PoCs
    - nightly builds
    - summary wiki pages
  - but... only a hobby!

“there's a PoC for that”

and if there's none yet, there will be soon ;)

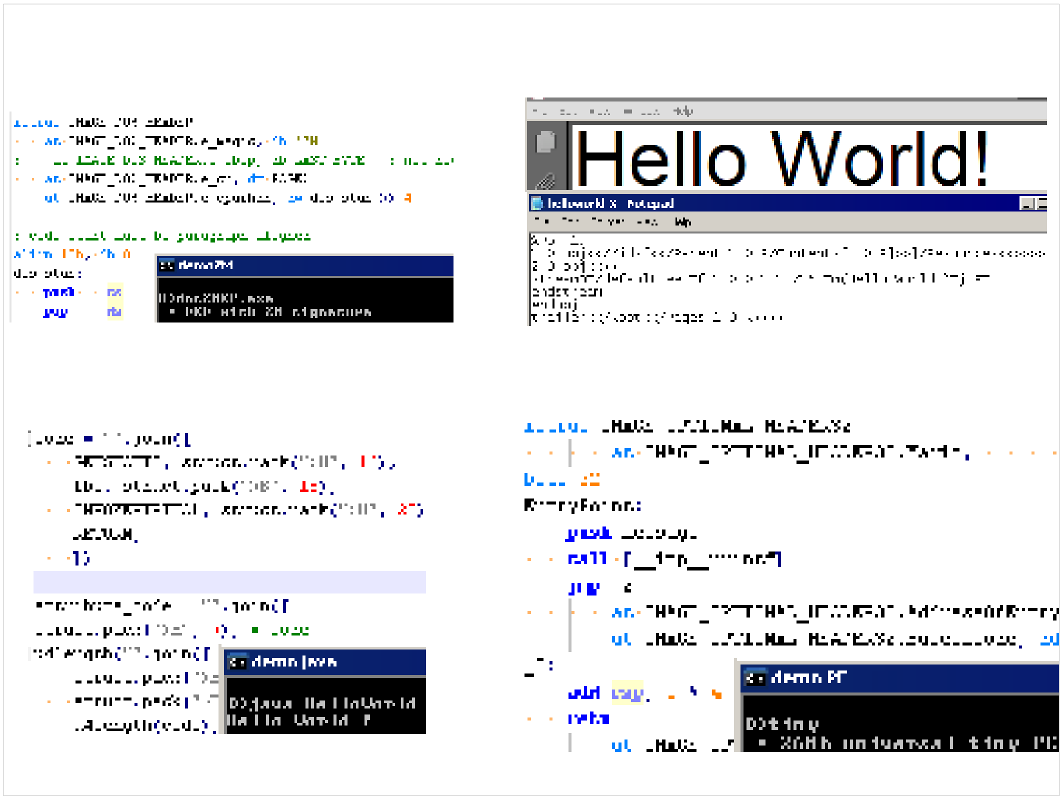
I created Corkami, a website about reverse engineering.

it's technical, and free: open-source, relying on free tools, free for commercial use, no ads, no log-in.

I focus on creating a LOT of small focused PoCs. they're handmade so really no extra stuff. each of them is probably meaningless, but altogether, they're a useful toolbox to test and learn.
then I write a summary page. but I put more work in PoCs than in the pages.

the important is: for each feature I study, there's a PoC available

but it's only a hobby, so it's quite messy, and not as good as I'd like it to be.

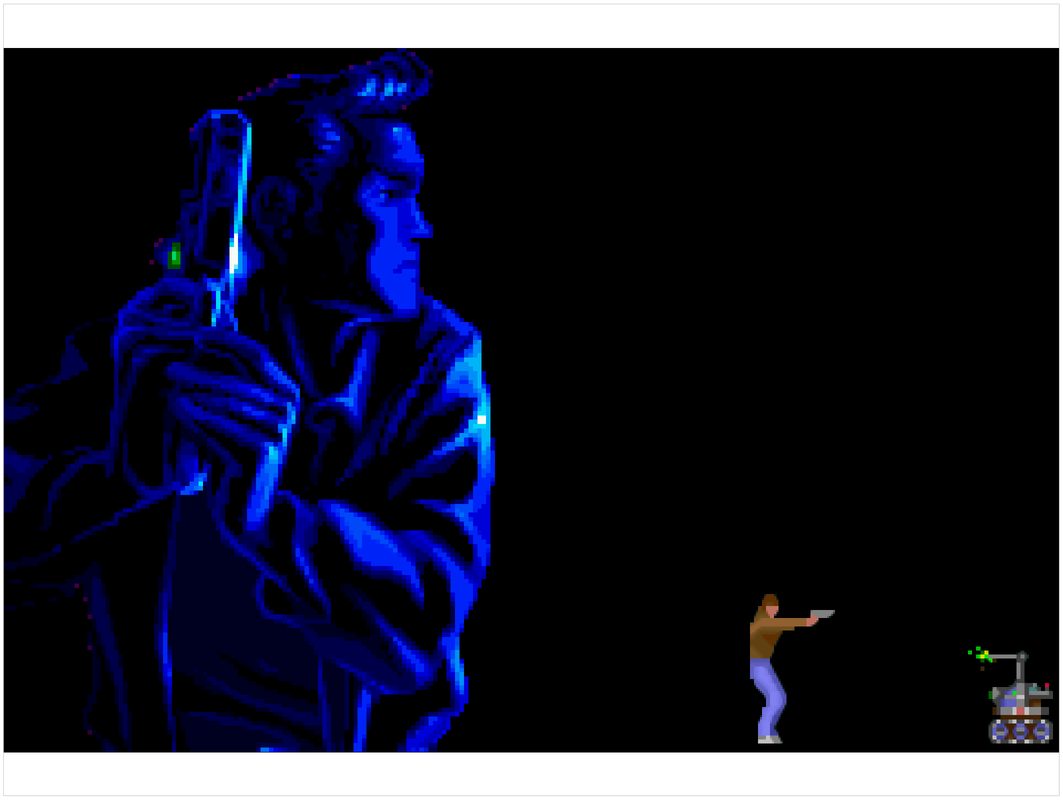


so, whether it's
- a non PE exe with an inverted ZM signature, in 16bits asm.
- a complete 'correct' PDF with text (that's the full PDF btw), typed in notepad
- a working java class, with opcodes generated manually
- a tiny PE, with imports and code in the middle of the header

you can see that all of them only have the necessary elements.

the story behind this presentation

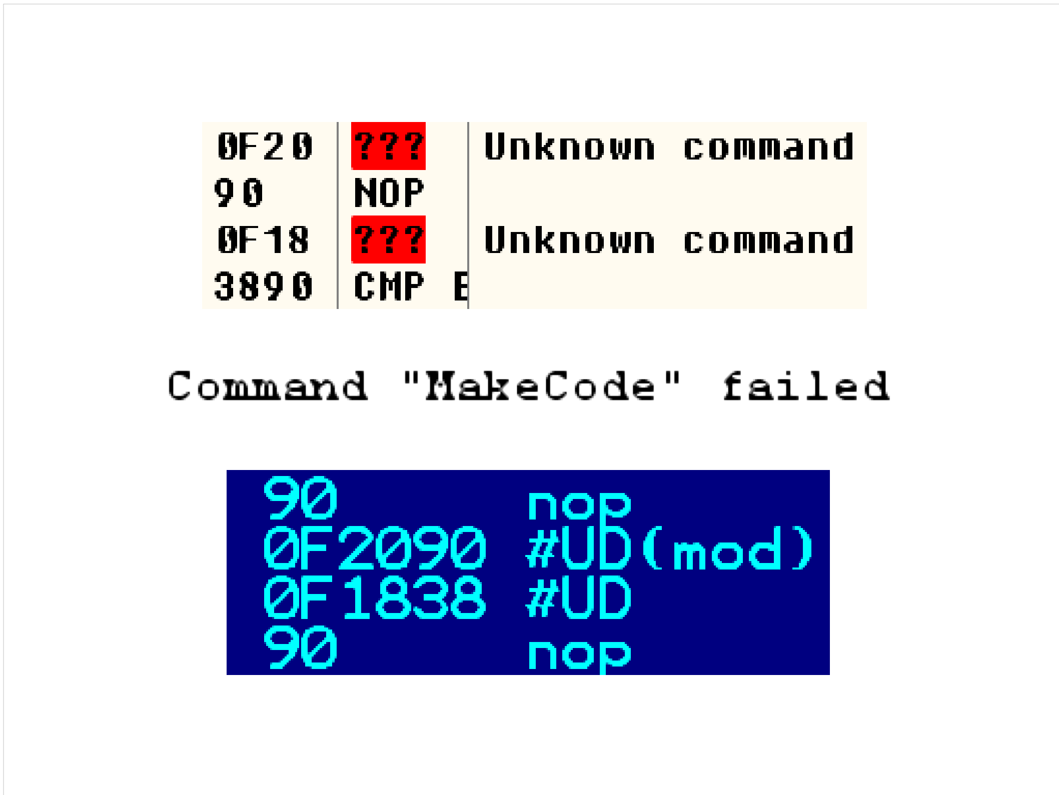
and here is the story behind this presentation



first, a small flashback

years ago, I was young and innocent, believing that CPU would be perfect, because they're made of transistor, not software.

and I thought I knew assembly.



```
0F20 | ??? | Unknown command
90   | NOP |
0F18 | ??? | Unknown command
3890 | CMP E
```

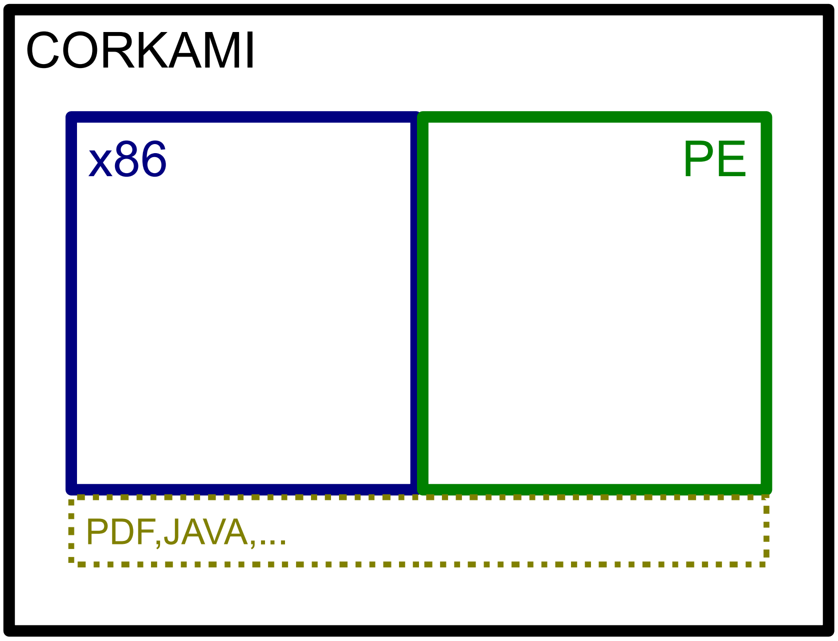
```
Command "MakeCode" failed
```

```
90      nop
0F2090  #UD(mod)
0F1838  #UD
90      nop
```

then I encountered my first undocumented opcodes.
and shortly after, my first sectionless PE.

I was shocked, but I thought I was still young...

So I decided to go back to the basics, studying x86 and PE from scratch.



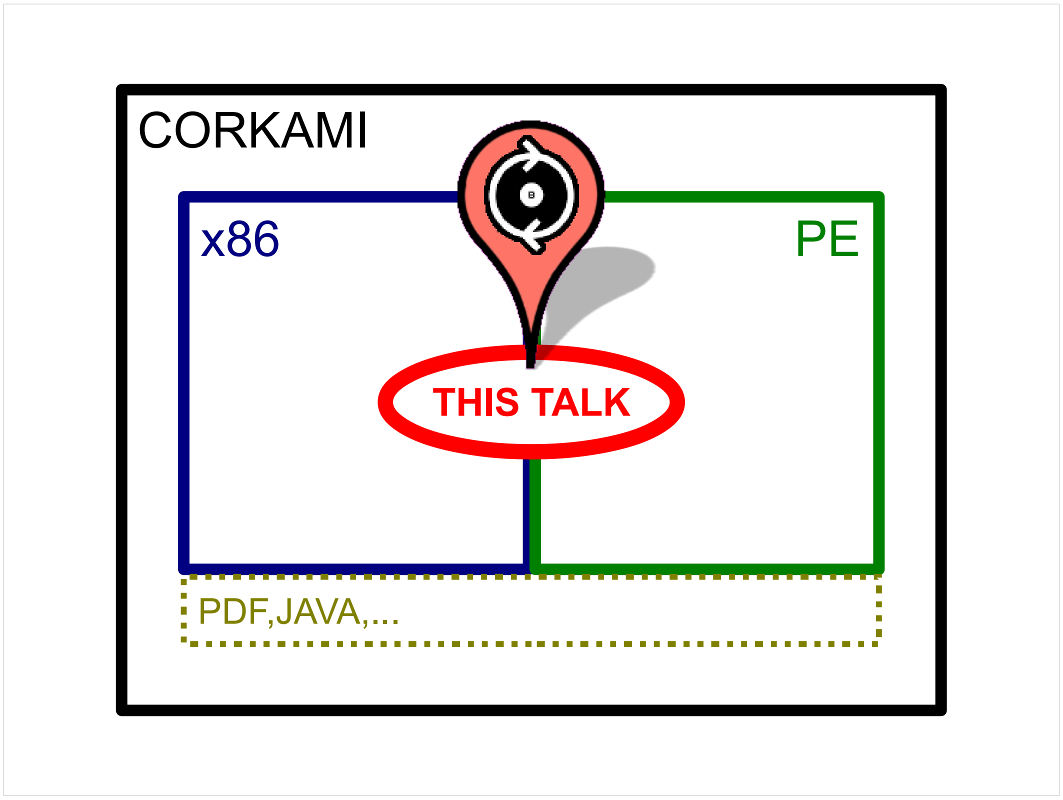
CORKAMI

x86

PE

PDF,JAVA,...

and writing my findings on the way, on Corkami.



CORKAMI

x86

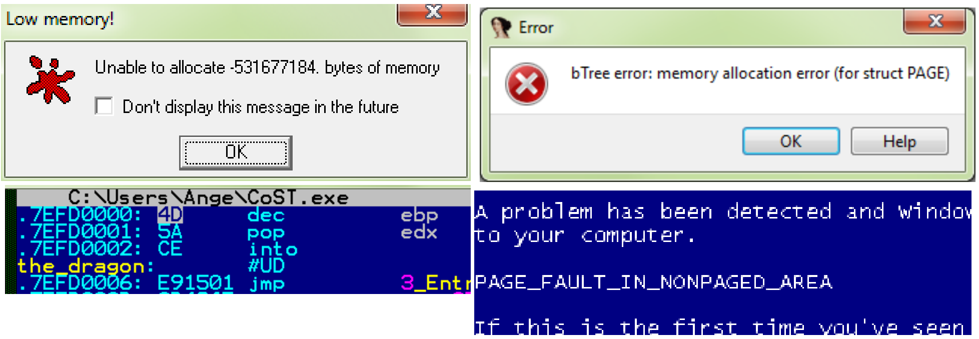
PE

THIS TALK

PDF,JAVA,...

This talk is only a subset of what's available on the site, even on these topics.

“Achievement unlocked”



Low memory!

Unable to allocate -531677184. bytes of memory

☐ Don't display this message in the future

Error

bTree error: memory allocation error (for struct PAGE)

```
   C:\Users\Ange\CoST.exe
.7EFD0000: 4D      dec      ebp
.7EFD0001: 5A      pop      edx
.7EFD0002: CE      into
the_dragon:        #UD
.7EFD0006: E91501  jmp      3_Entr
```

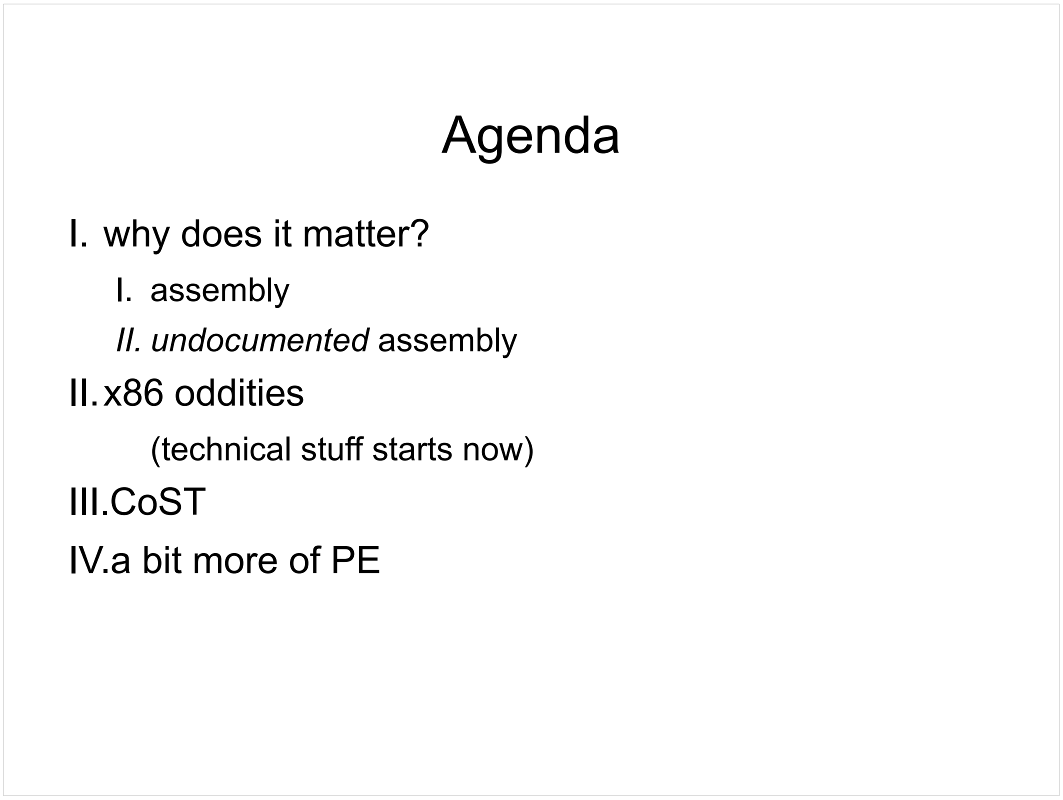
```
A problem has been detected and Window
to your computer.

PAGE_FAULT_IN_NONPAGED_AREA

If this is the first time you've seen
```

(Authors notified, and most bugs already fixed)

but, if I was just a guy learning ASM and PE, I probably wouldn't be presenting here.

So, here is why I'm here :)

Most of these bugs were already reported and fixed.



Agenda

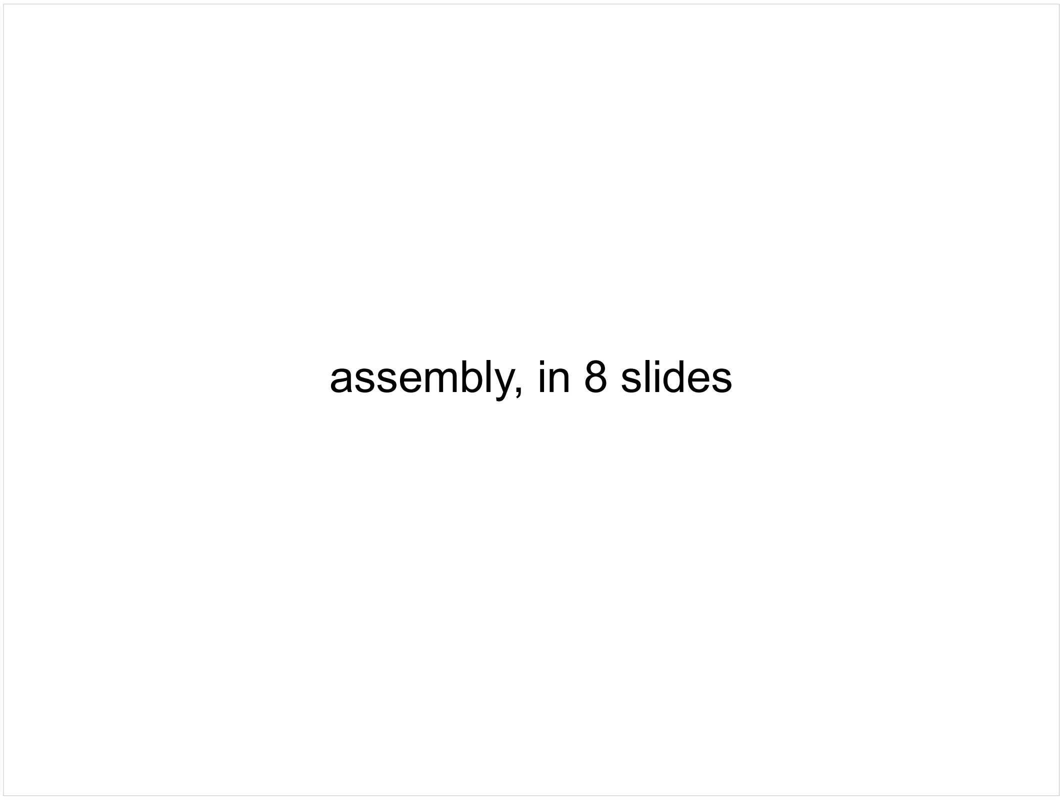
I. why does it matter?
    I. assembly
    II. undocumented assembly
II. x86 oddities
        (technical stuff starts now)
III. CoST
IV. a bit more of PE

so, first, I'll start slowly, trying to introduce assembly to beginners, and make them understand the problem of undocumented opcodes.

then, it will get more technical:
I'll cover a few assembly tricks, including some found in malware.

then I'll introduce my opcode tester, CoST.

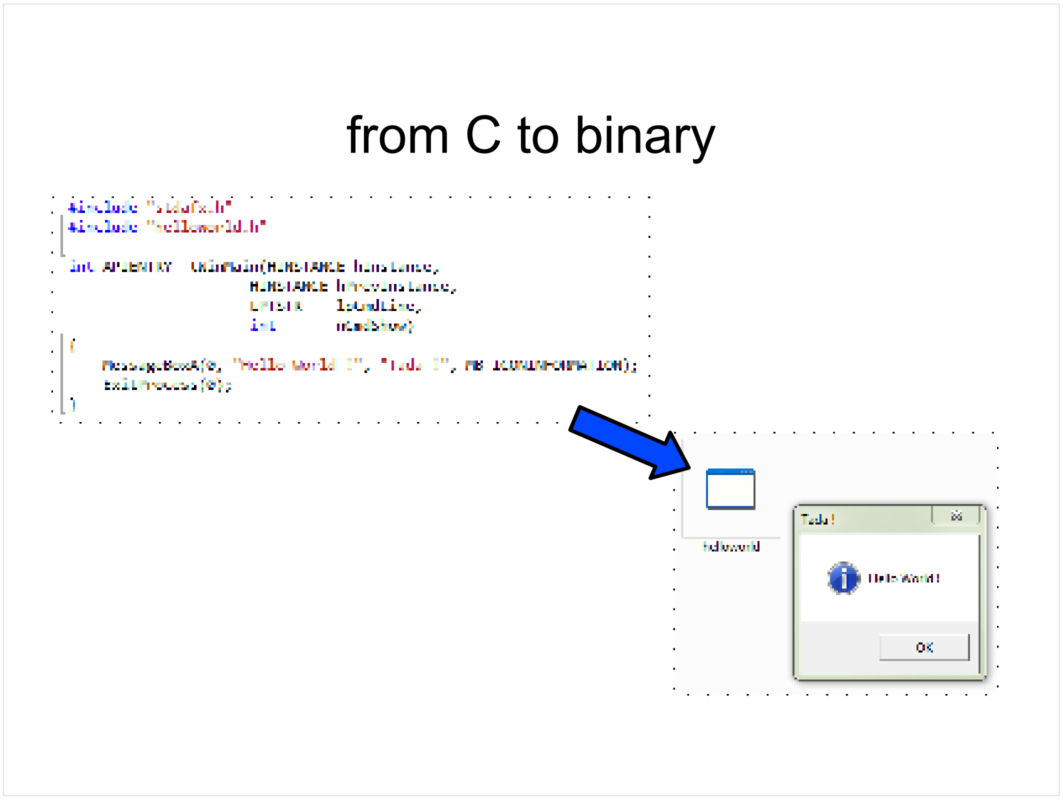
and I'll also present my last project which deals with the PE format.



assembly, in 8 slides

So, let's start and try to make everybody understand the problem of undocumented opcodes.

so first, introduce opcodes themselves



from C to binary

```
#include "stdafx.h"
#include "helloworld.h"

int APIENTRY  WinMain(HINSTANCE hInstance,
                      HINSTANCE hPrevInstance,
                      LPTSTR    lpCmdLine,
                      int       nCmdShow)
{
    MessageBoxA(0, "Hello World !", "Tada !", MB_ICONINFORMATION);
    ExitProcess(0);
}
```

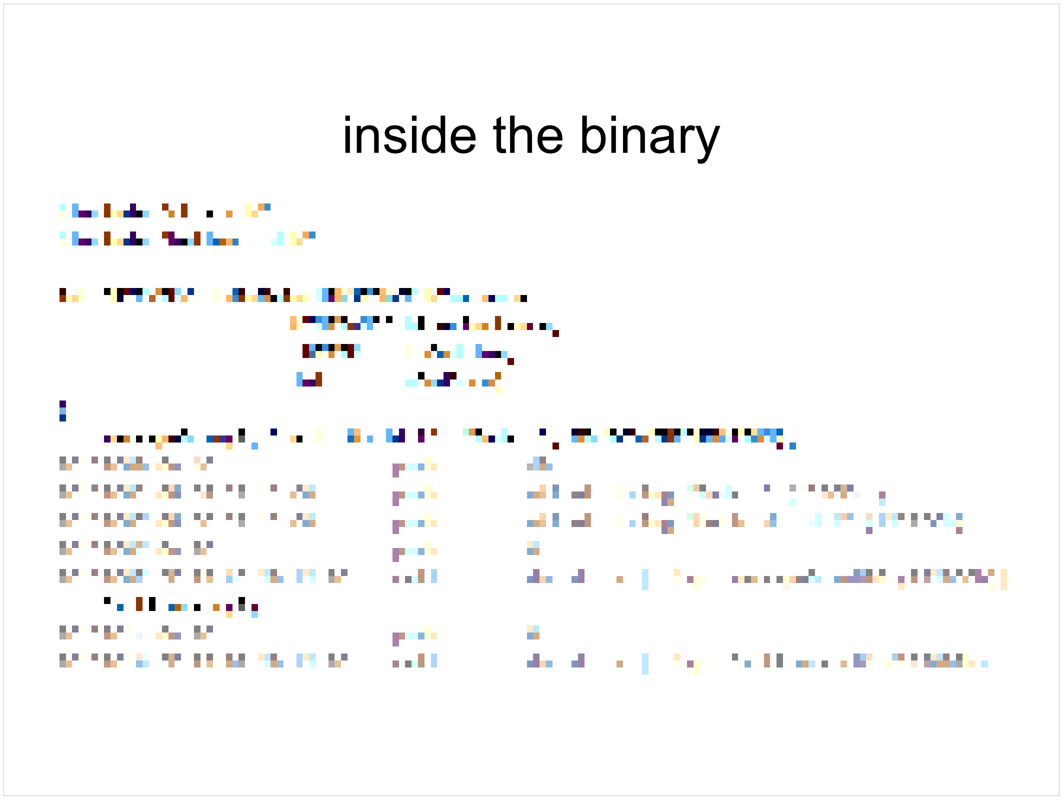
Hello World !

so, we create a simple program in a language, such as C.

Here, in Visual Studio, Microsoft standard development environment.

this program shows a simple message box on screen, then terminates.

an executable is generated, and indeed does what we expected.



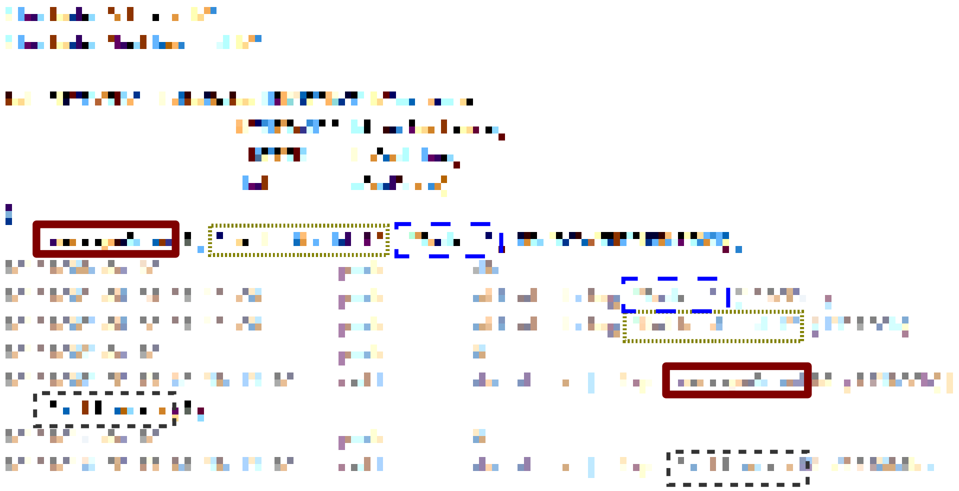
inside the binary

what the Visual Studio compiler did from our C code is actually generate sequences of assembly code instruction that will generate the wanted actions.

order

so, the C code is turned into assembly. which is itself encoded in the binary as opcodes.

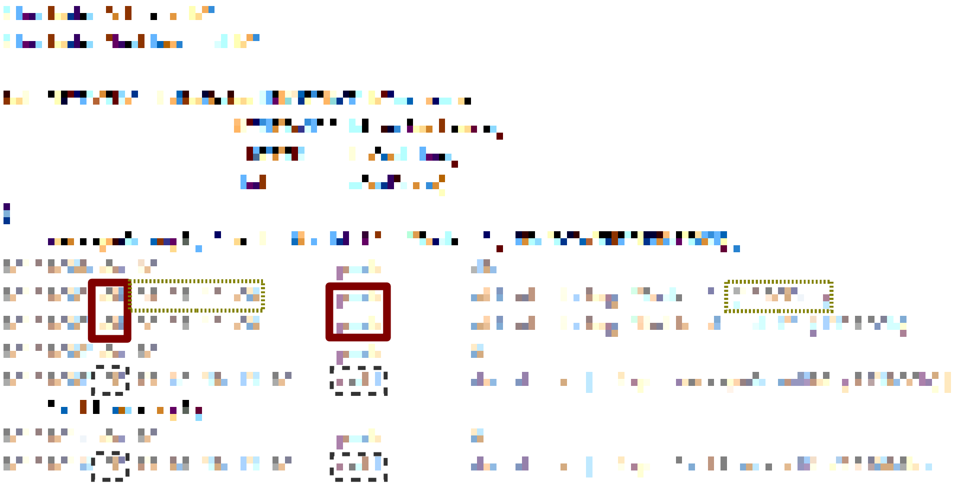
our code, 'translated'



Here, you can see calls to MessageBox, then ExitProcess (the names are self-explaining), with the parameters above.

these assembly operations are stored in opcodes directly in the binary, as visible on the left.

opcodes ⇔ assembly



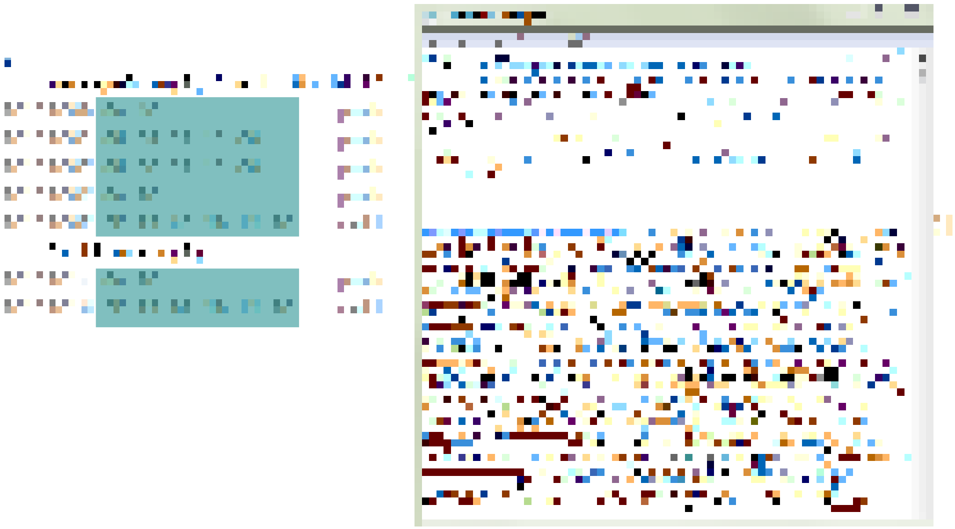
now you know that this is what is in the file itself.
this is how it's read by 'us' (reverse engineers, malware analysts, exploit developers...).

the CPU itself only reads the hex.

as you can see, there is a relation:
68 - in hex - is used to push offsets
calls starts with FF 15...
and you can see the used addresses here (read them backward).

so, you see the first byte determine the actual opcode.
and depending on each opcode, the length is variable.

what's (only) in the binary

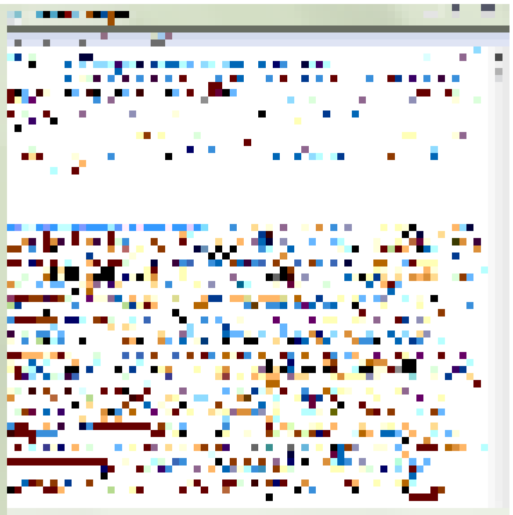


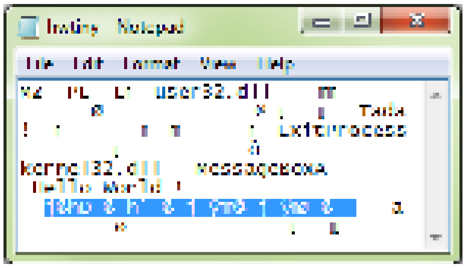
This is what is actually in the file on the hard disk (the 'hex').

If you'd accidentally open the file in, say notepad - it doesn't really make sense, but at least you have that on your machine - you could find it here (remember, it's hex).

Note that it's actually a very tiny part of the whole file (<30bytes out of 56000).

execution ⇔ CPU + opcodes

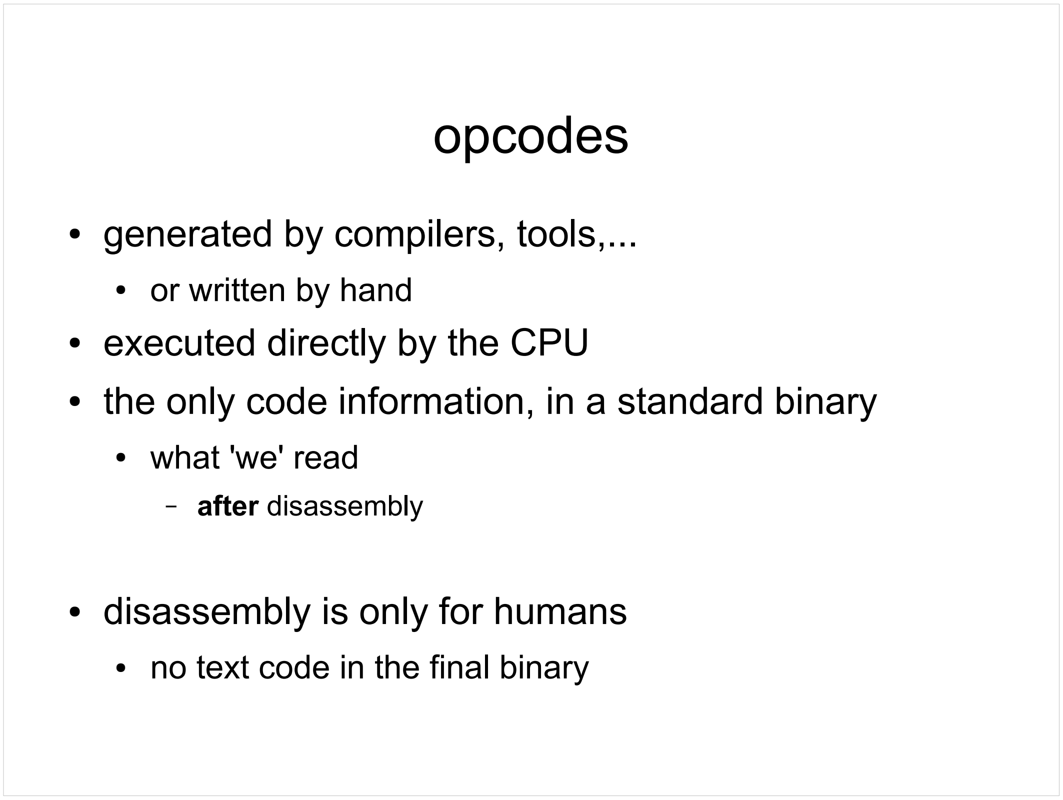




```
MZ   PE   L   user32.dll
ExitProcess
kernel32.dll   MessageBoxA
 Hello World!
```

What's important is that in the end, anything running on your machine is about the CPU executing opcode, no matter what.

the compiled file is full of 'unneeded' stuff. while you can make a much smaller file with exactly the same functionality (that's the whole file), and even though they're very different, the same opcodes are present again.



opcodes

- generated by compilers, tools,...
  - or written by hand
- executed directly by the CPU
- the only code information, in a standard binary
  - what 'we' read
    - **after** disassembly

- disassembly is only for humans
  - no text code in the final binary

so, the compiler translates our C to a series of assembly operations, which is itself encoded in opcodes.

the resulting executable only contains the opcodes, which are directly understood and executed by the CPU. If no error happens, what is here directly affects the behavior of the program, there is no 'man in the middle' from the OS.

so our C code will just eventually lead the CPU to read and execute

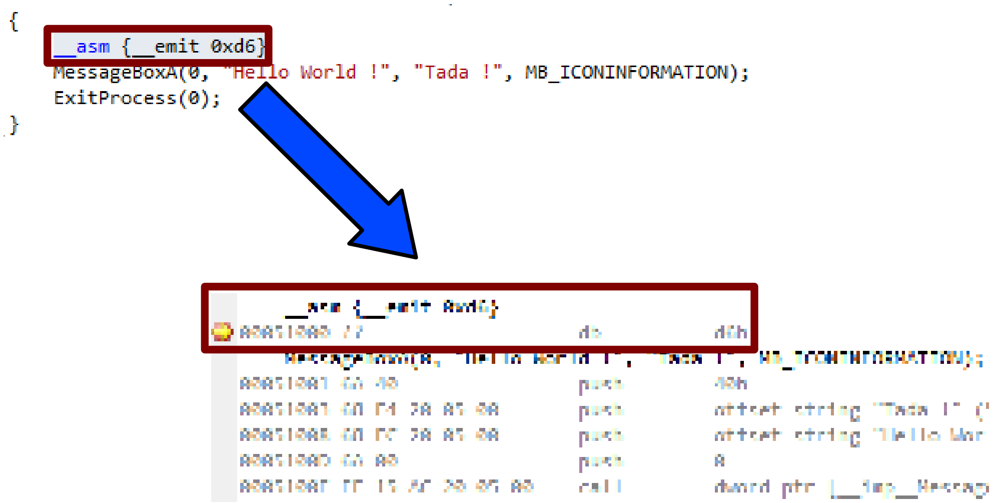
6A 40 68 F4 20 40 00 68 FC 20...

if, by any chance, there is some opcodes that we are not aware of, or doesn't do what we expect, the CPU doesn't care, it just knows what to do.

let's mess a bit now...

so now, let's interfere with the compiling process

let's insert 'something'

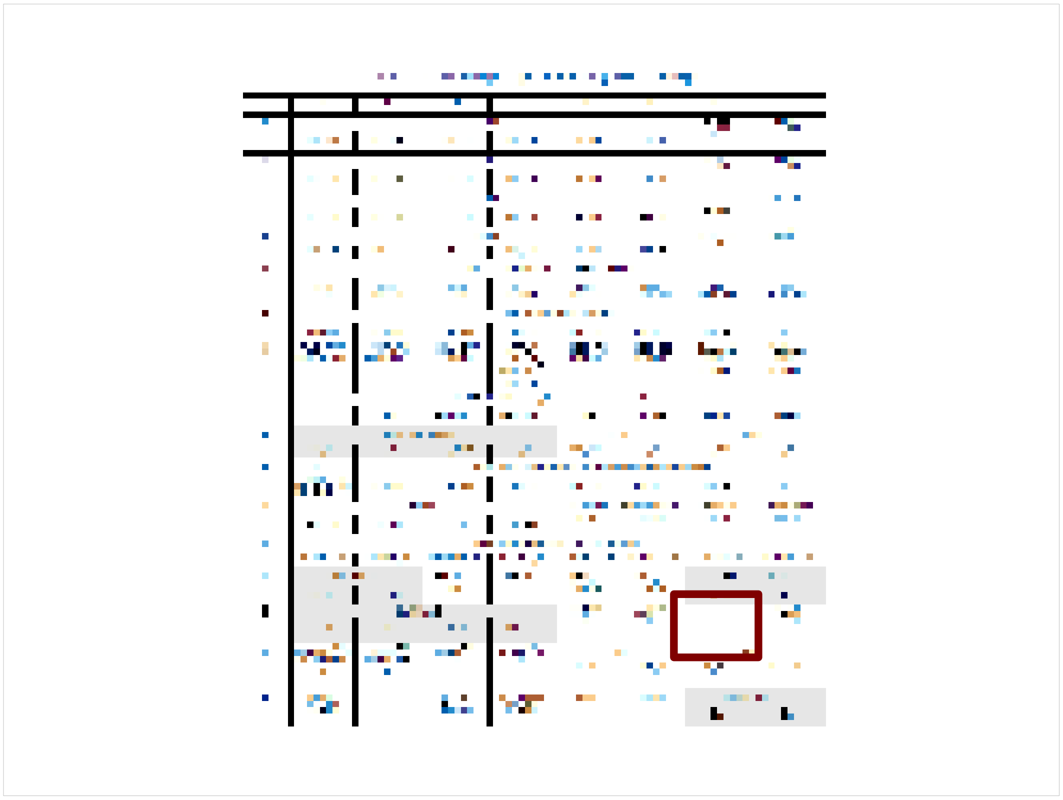


```
{
    __asm {__emit 0xd6}
    MessageBoxA(0, "Hello World !", "Tada !", MB_ICONINFORMATION);
    ExitProcess(0);
}
```

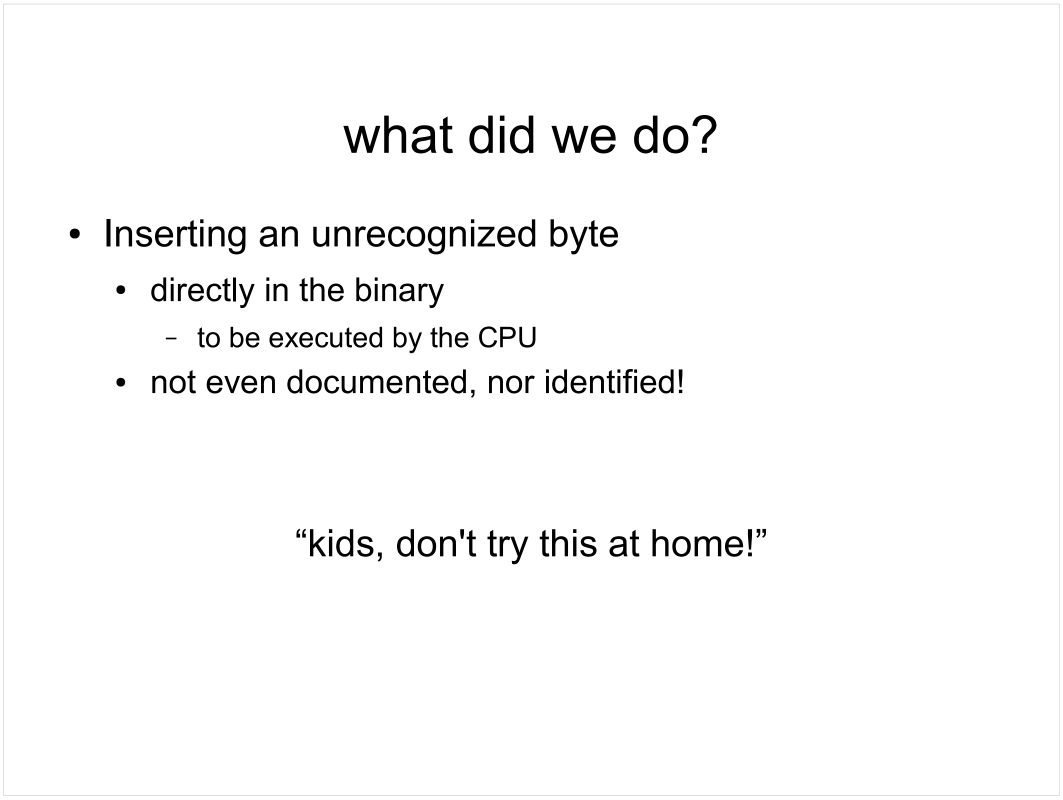
```
        __asm {__emit 0xd6}
00851000 ??                    db          d6h
        MessageBoxA(0, "Hello World !", "Tada !", MB_ICONINFORMATION);
00851001 6A 40                 push        40h
00851003 68 F4 20 85 00        push        offset string "Tada !" ('
00851008 68 FC 20 85 00        push        offset string "Hello Wor
0085100D 6A 00                 push        0
0085100F FF 15 AC 20 85 00     call        dword ptr [__imp__Messag
```

let's add a command that will force a specific byte in the opcodes.

this result is not known to visual studio, which only shows ??



indeed, if we check Intel official documentation, there is nothing to see here...



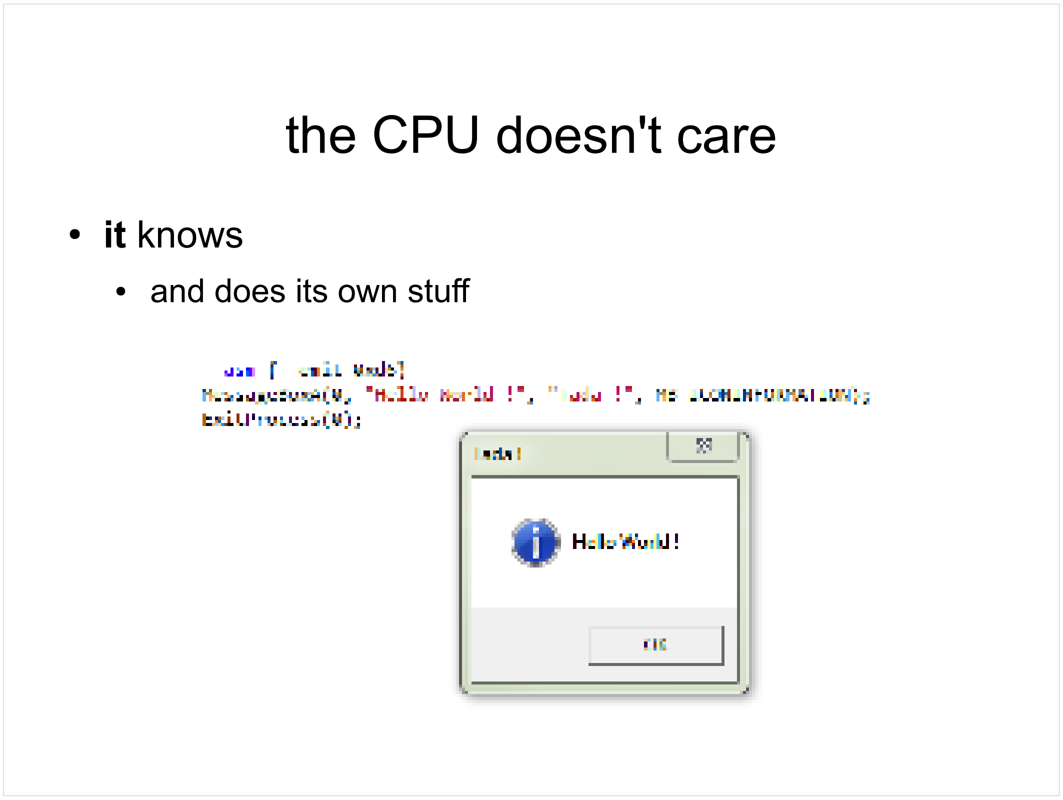
what did we do?

- Inserting an unrecognized byte
  - directly in the binary
    - to be executed by the CPU
  - not even documented, nor identified!

“kids, don't try this at home!”

so, we forced something that is not recognized by the most expensive Microsoft compiler to execute, which is not even in Intel's books.

We should only expect a crash, right ?



the CPU doesn't care

- **it** knows
  - and does its own stuff

```
  __asm {__emit 0xd6}
MessageBoxA(0, "Hello World !", "Tada !", MB_ICONINFORMATION);
ExitProcess(0);
```

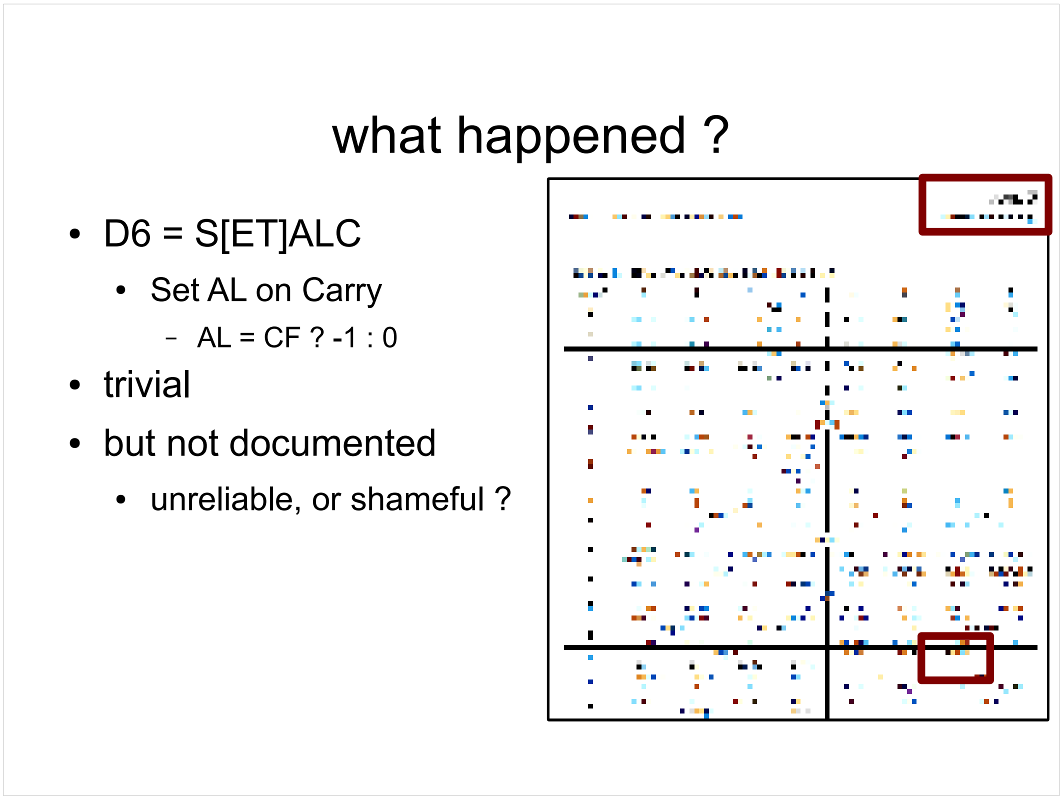
Tada !

Hello World !

but the CPU doesn't care about what YOU (or VS) know, and it just executes that mysterious D6 just fine (apparently)

it doesn't look like a big problem, but if like Microsoft, you base your judgment on Intel's documentation, you just don't know what happens next. No automated analysis, proactive detection, etc... and you need to understand that undocumented opcode.

You can't even skip it:
you don't know if it will jump, do nothing, trigger an exception...
and because of variable instruction length, you can't even tell what would be the next instruction, so you can't guess easily backward from the next instruction.



what happened ?

- D6 = S[ET]ALC
  - Set AL on Carry
    - AL = CF ? -1 : 0
- trivial
- but not documented
  - unreliable, or shameful ?

so what did we do in reality ?

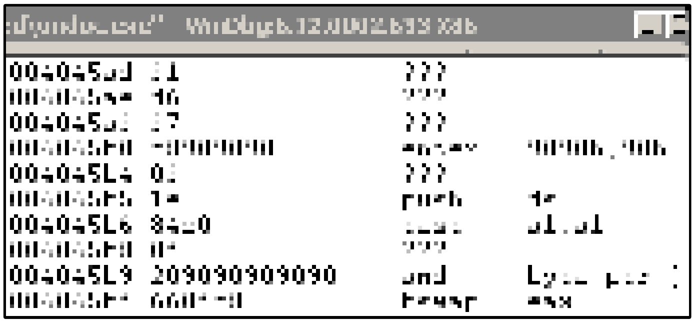
D6 will be decoded as SETALC, which is quite simple.

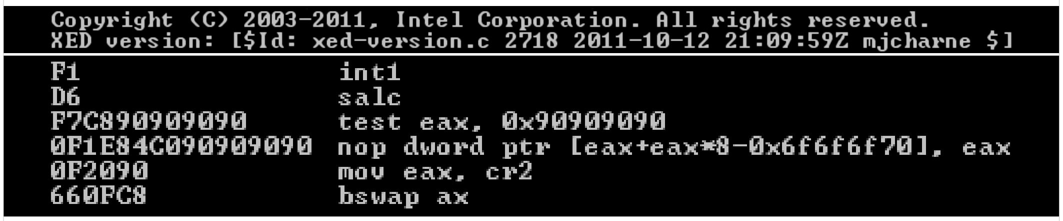
It doesn't interfere with the execution of this example (it could have, of course).

surprisingly, it's not documented by Intel, but it's documented by AMD.

anyone knows why ?
I'd be curious to know.

“do what I do...”

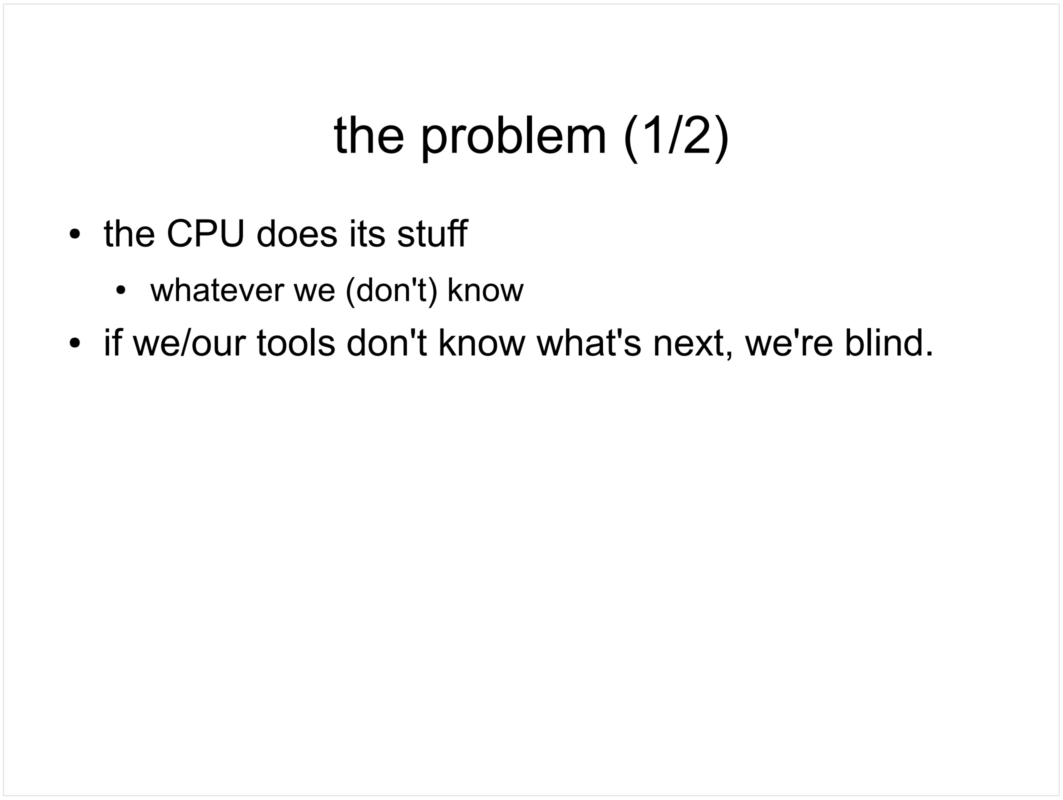




```
Copyright (C) 2003-2011, Intel Corporation. All rights reserved.
XED version: [$Id: xed-version.c 2718 2011-10-12 21:09:59Z mjcharne $]
F1                  int1
D6                  salc
F7C890909090        test eax, 0x90909090
0F1E84C090909090    nop dword ptr [eax+eax*8-0x6f6f6f70], eax
0F2090              mov eax, cr2
660FC8              bswap ax
```

the funny thing is, even though Intel docs are full of holes, Intel free tools are fully aware of what to expect...

Sadly, Microsoft WinDbg decided to follow the official docs, which makes it a very bad tool against malware, which commonly use undocumented tricks.

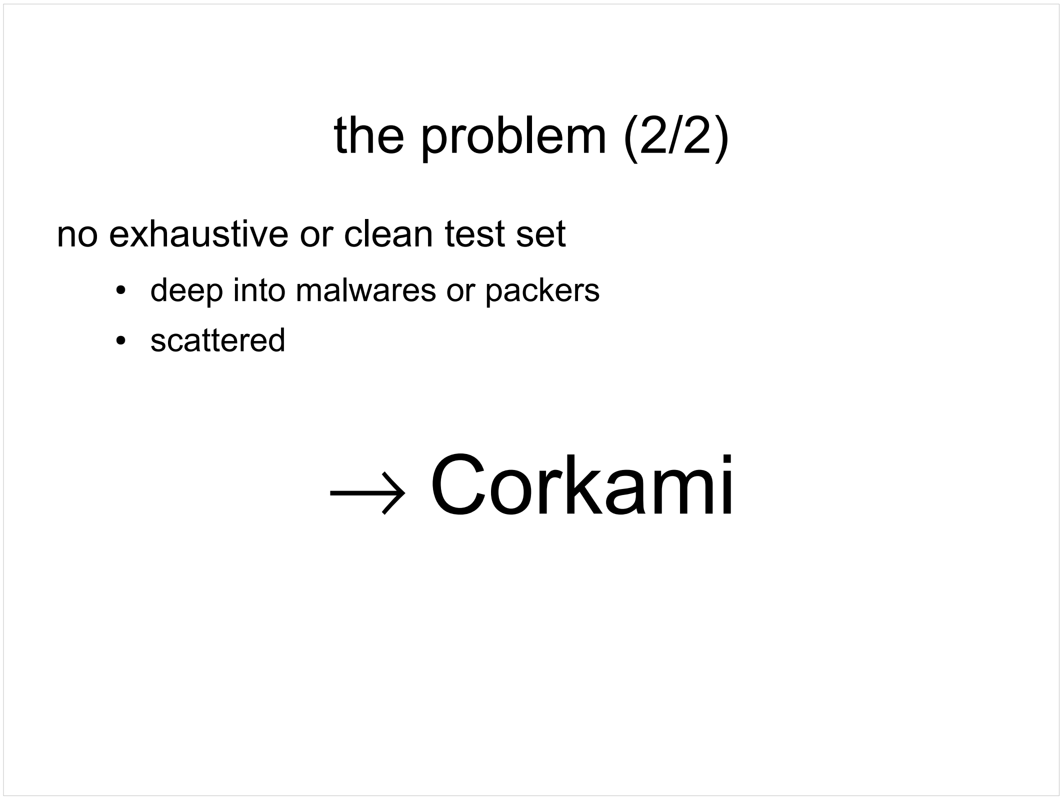


the problem (1/2)

- the CPU does its stuff
    - whatever we (don't) know
- if we/our tools don't know what's next, we're blind.

So, you now know that the CPU knows things that the Intel documentations omits.

if we or our tools are not able to tell what the CPU will do, we're just blind.



the problem (2/2)

no exhaustive or clean test set

- deep into malwares or packers
- scattered

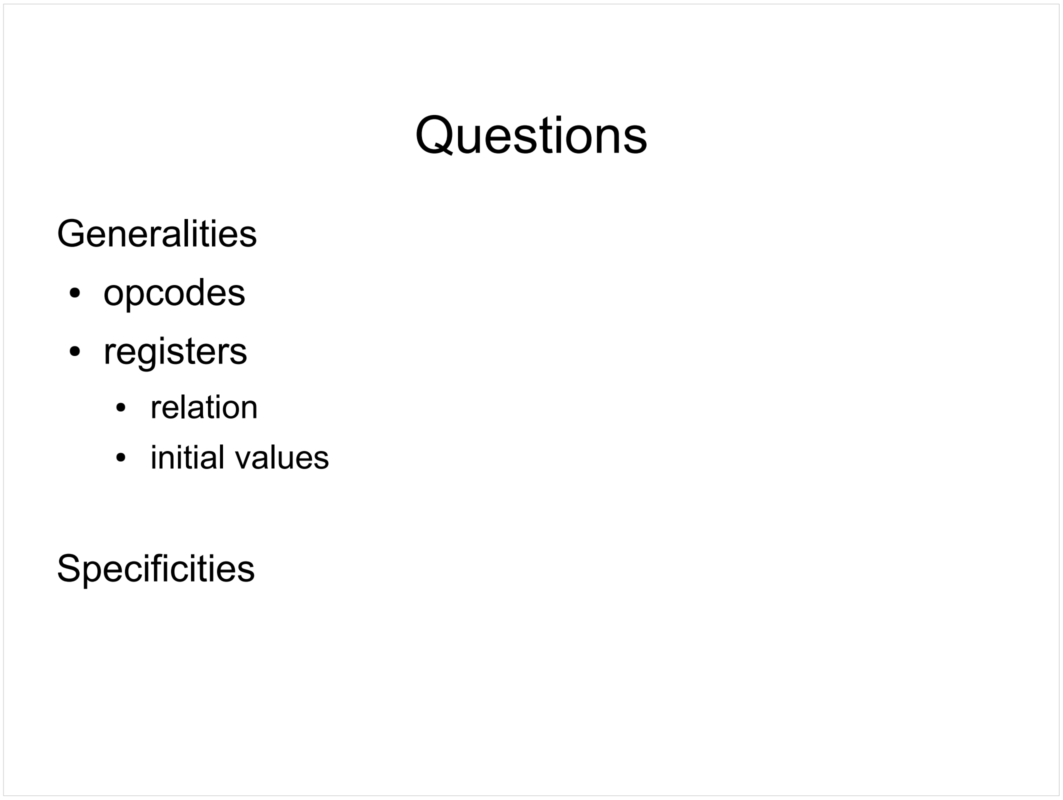
→ Corkami

the extra problem is that each of this oddities are usually scattered in various files, deep under obfuscations or in malicious behavior. no 'ready to use' toolbox.

that's the hole I wanted to fill.

let's start exploring x86...

Now, let's start the real stuff



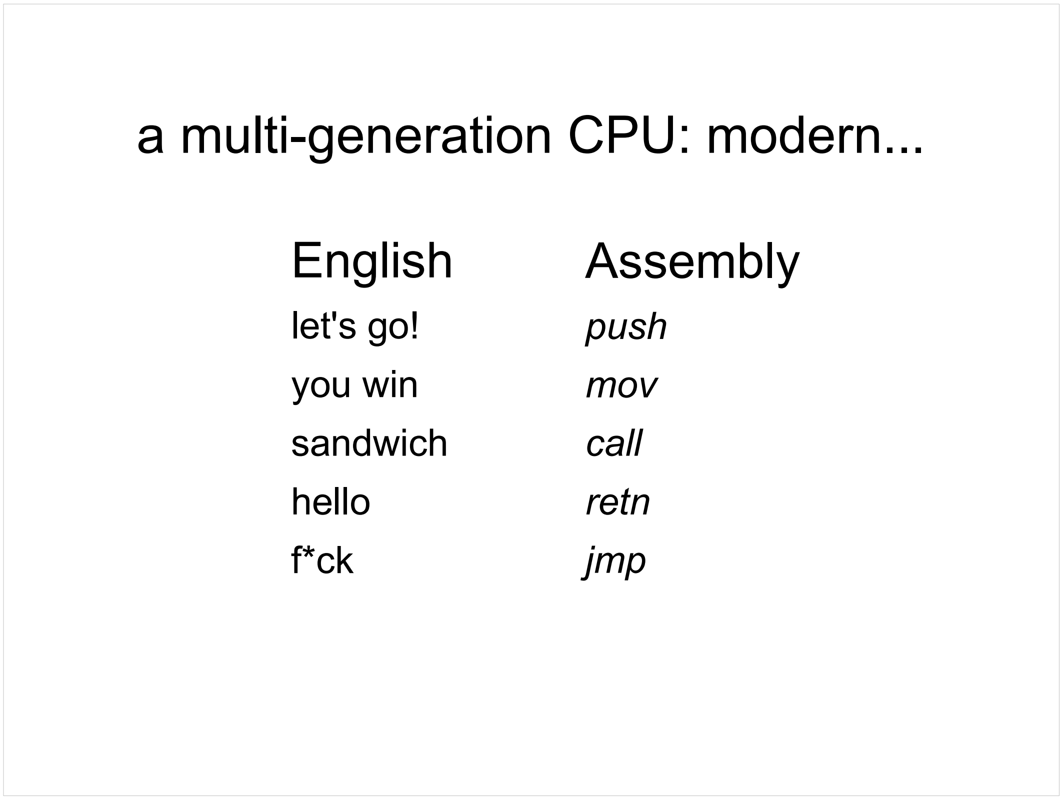
Questions

Generalities

- opcodes
- registers
  - relation
  - initial values

Specificities

before focusing on particular opcodes,
my first questions was:
what are actually all the supported opcodes ?
then, actually how many registers are there ?
before anything happen, do they have any particular value ?



a multi-generation CPU: modern...

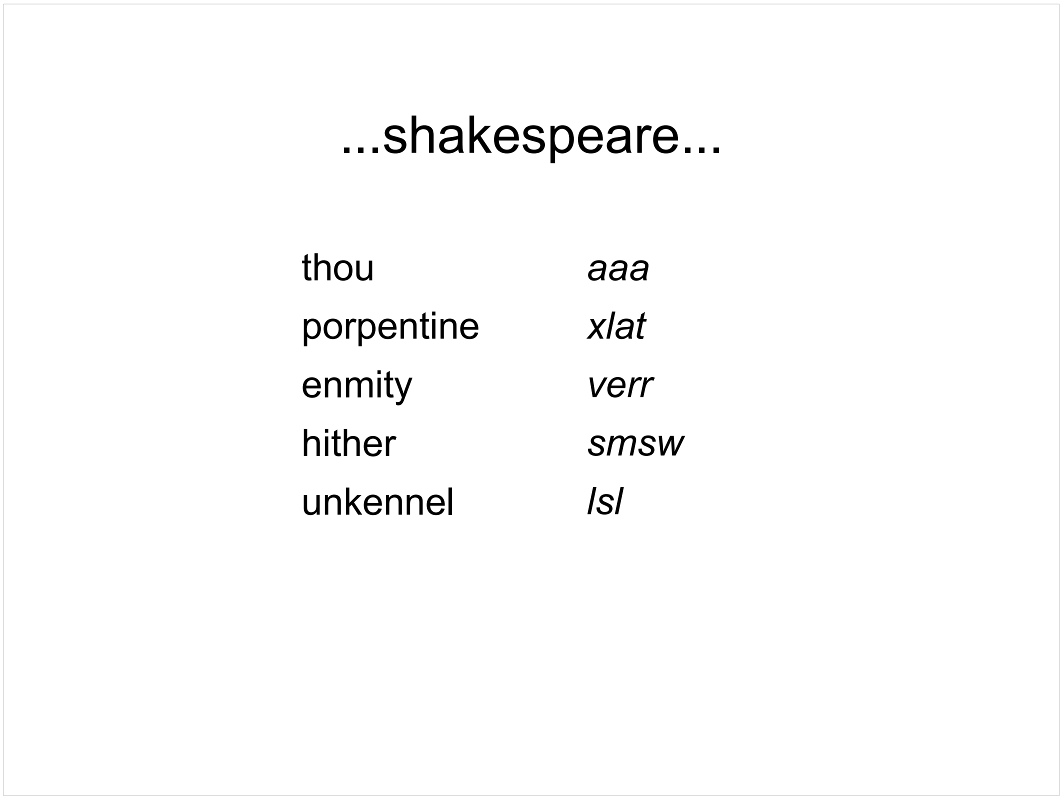
English	Assembly
let's go!	*push*
you win	*mov*
sandwich	*call*
hello	*retn*
f*ck	*jmp*

that's the problem.
like English language, assembly uses mainly always the same 'standard' opcodes.

which means, what everybody is used to hear or read:

Here, 'standard language'. What all generations understand.

most people would understand...



...shakespeare...

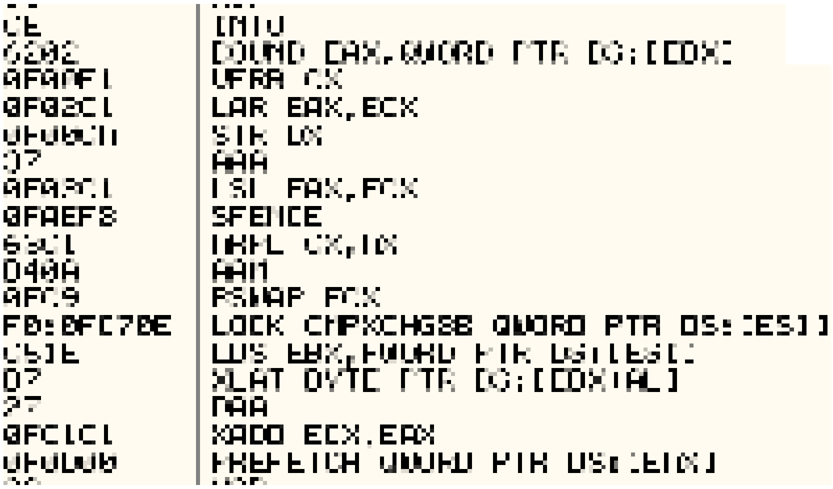
thou	*aaa*
porpentine	*xlat*
enmity	*verr*
hither	*smsw*
unkennel	*lsl*

but Intel CPU are from the 70's and still backward compatible...

here is an example of Shakespeare English and old x86 mnemonics

unknown to most people.
yet still fully working on a modern CPU.

(old, but fully supported)



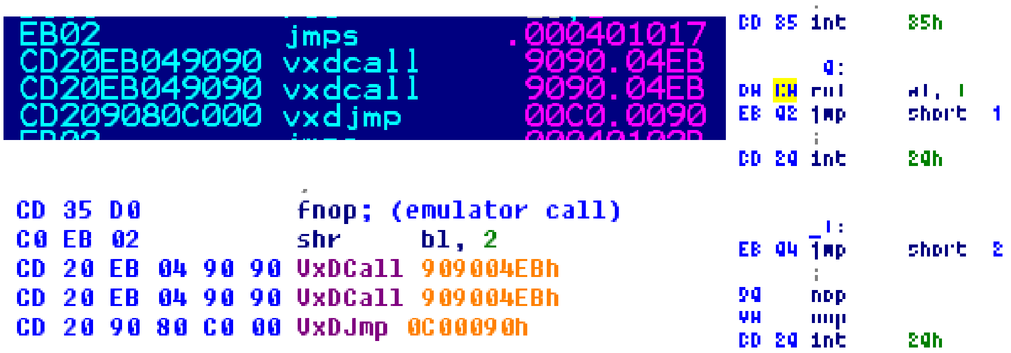
```
CE          | INTO
6202        | BOUND EAX,QWORD PTR DS:[EDX]
0F00E1      | VERR CX
0F02C1      | LAR EAX,ECX
0F00C8      | STR AX
37          | AAA
[illegible]
0FAEF8      | SFENCE
63C1        | ARPL CX,AX
D40A        | AAM
0FC9        | BSWAP ECX
F0:0FC70E   | LOCK CMPXCHG8B QWORD PTR DS:[ESI]
C51E        | LDS EBX,FWORD PTR DS:[ESI]
D7          | XLAT BYTE PTR DS:[EBX+AL]
27          | DAA
0FC1C1      | XADD ECX,EAX
0F0D06      | PREFETCH QWORD PTR DS:[ESI]
```

so here is a small executable where I only use uncommon opcodes. some are not really doing anything, some are actually doing something meaningful.

I expect that most of us are not even used to see these opcodes, yet they're fully supported by all CPUs.

'over-disassembling'

- CD XX: int XX
- deprecated behaviors:
  - int 20h = VXD, int 35-39 = FPU



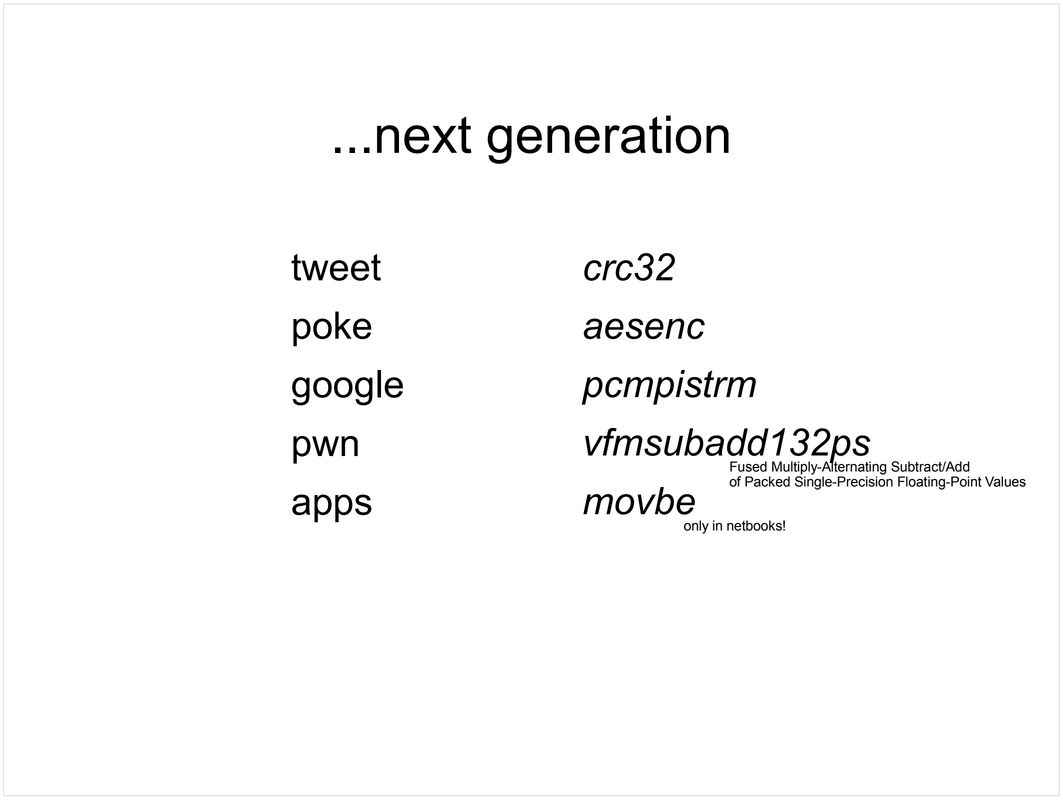
```
EB02           jmps       .000401017
CD20EB049090 vxdcall     9090.04EB
CD20EB049090 vxdcall     9090.04EB
CD209080C000 vxdjmp      00C0.0090
```

```
CD 35 D0          fnop; (emulator call)
C0 EB 02          shr      bl, 2
CD 20 EB 04 90 90 VxDCall 909004EBh
CD 20 EB 04 90 90 VxDCall 909004EBh
CD 20 90 80 C0 00 VxDJmp  0C00090h
```

```
CD 35 int      35h

         0:
D0 C0 rol      al, 1
EB 02 jmp      short  1

CD 20 int      20h


         1:
EB 04 jmp      short  2

90    nop
90    nop
CD 20 int      20h
```

Another funny fact is that some specific opcodes (interrupt) used to be for various functionality, which made IDA and Hiew over-interpret them.

in IDA, you can disable the option which is by default.



...next generation

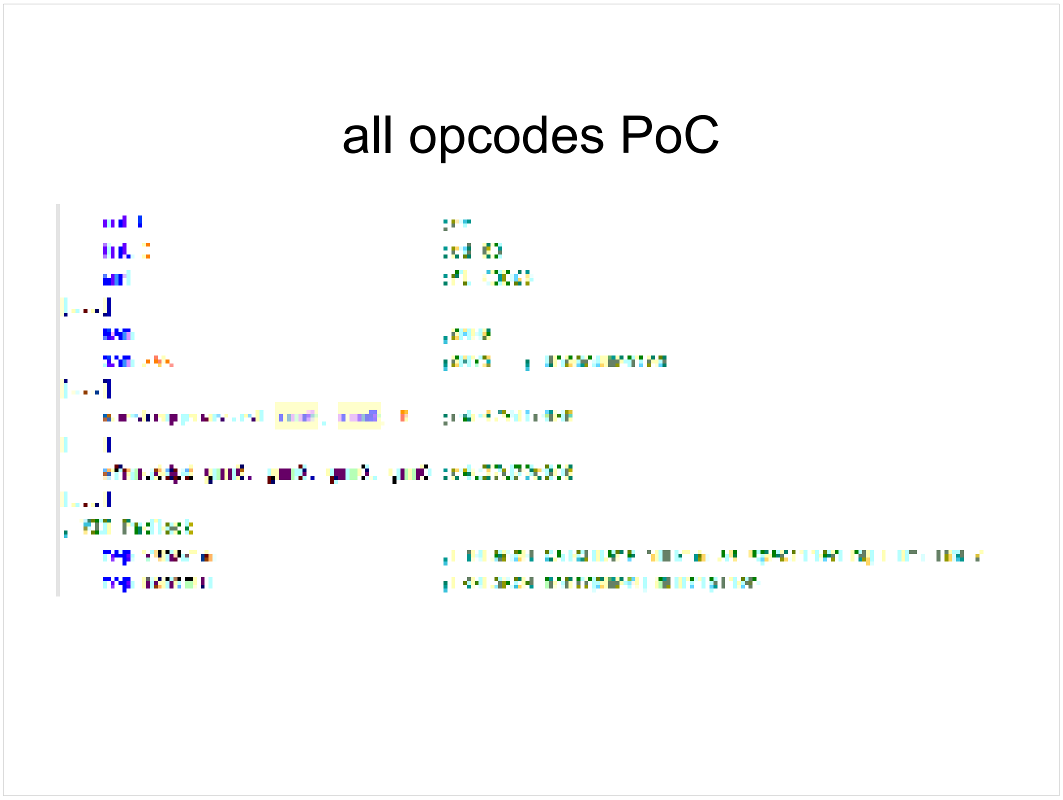
tweet	*crc32*
poke	*aesenc*
google	*pcmpistrm*
pwn	*vfmsubadd132ps* Fused Multiply-Alternating Subtract/Add of Packed Single-Precision Floating-Point Values
apps	*movbe* only in netbooks!

new generation : English and opcodes.

probably unknown to most people

single opcodes for CRC, AES, string masking...

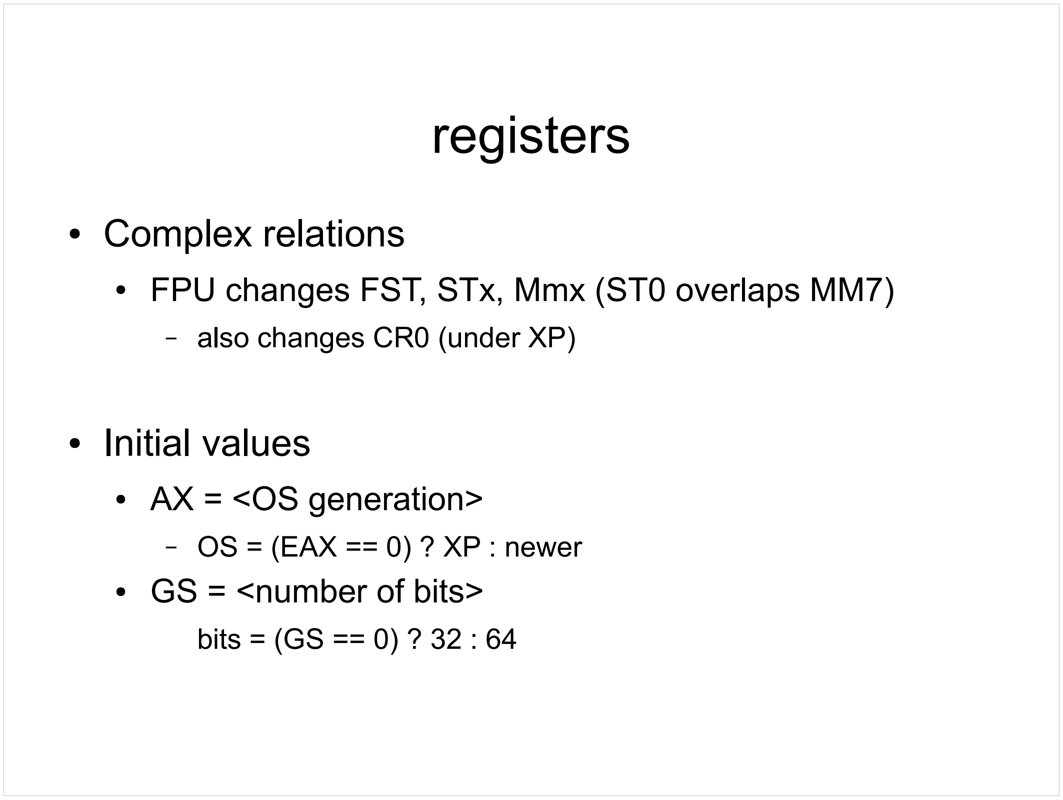
MOVBE = rejected offspring
netbook only. absent from i7
=> so much for backward compatibility



all opcodes PoC

I made a 'non working' PoC with all opcodes encoded, and various tricky situation.

very useful to quickly test the abilities of a disassembler.



registers

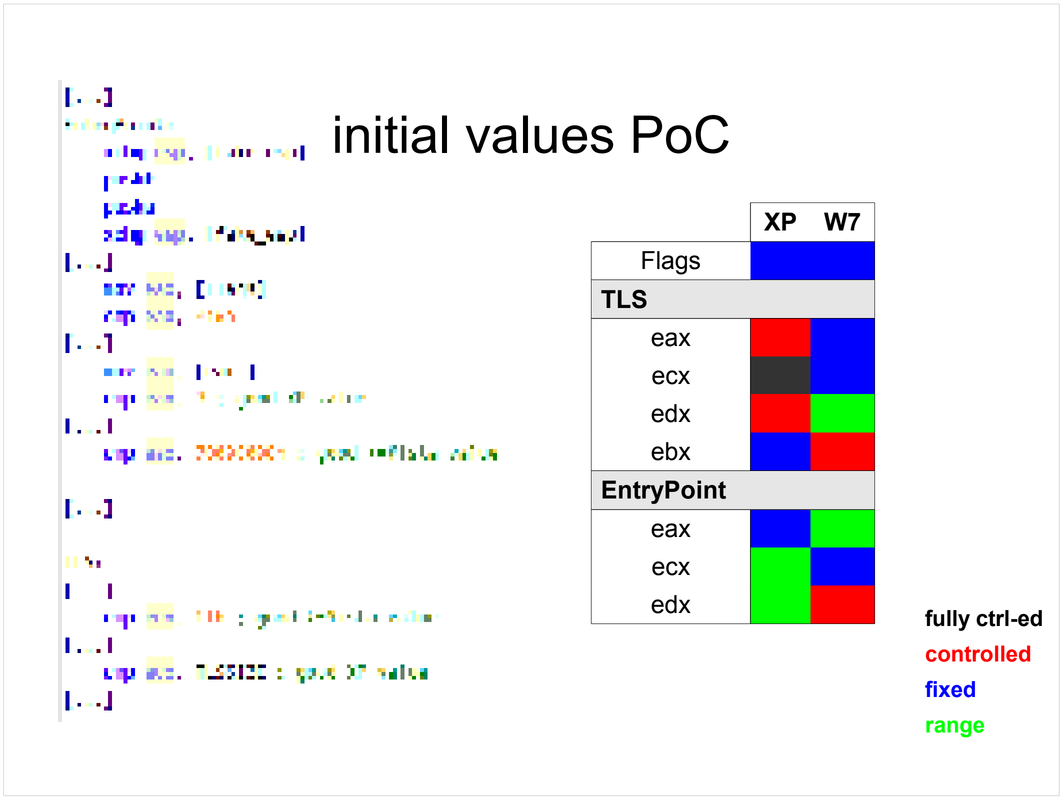
- Complex relations
  - FPU changes FST, STx, Mmx (ST0 overlaps MM7)
    - also changes CR0 (under XP)
- Initial values
  - AX = <OS generation>
    - OS = (EAX == 0) ? XP : newer
  - GS = <number of bits>
    bits = (GS == 0) ? 32 : 64

the basics of assembly are the registers...

registers are overlapping.
unlike many documentations, ST0 <> MM7

before any operation, registers have the value assigned to themselves by the OS.
I collected these values
under windows, specific values it's not CPU specific, but the initial values of the register on process start-up, under windows, gives a few hint that are used by malwares.

eax can immediately tell if you're on an older OS or not.
While GS can tell you if the machine is 64b or not, even in a 32b process.



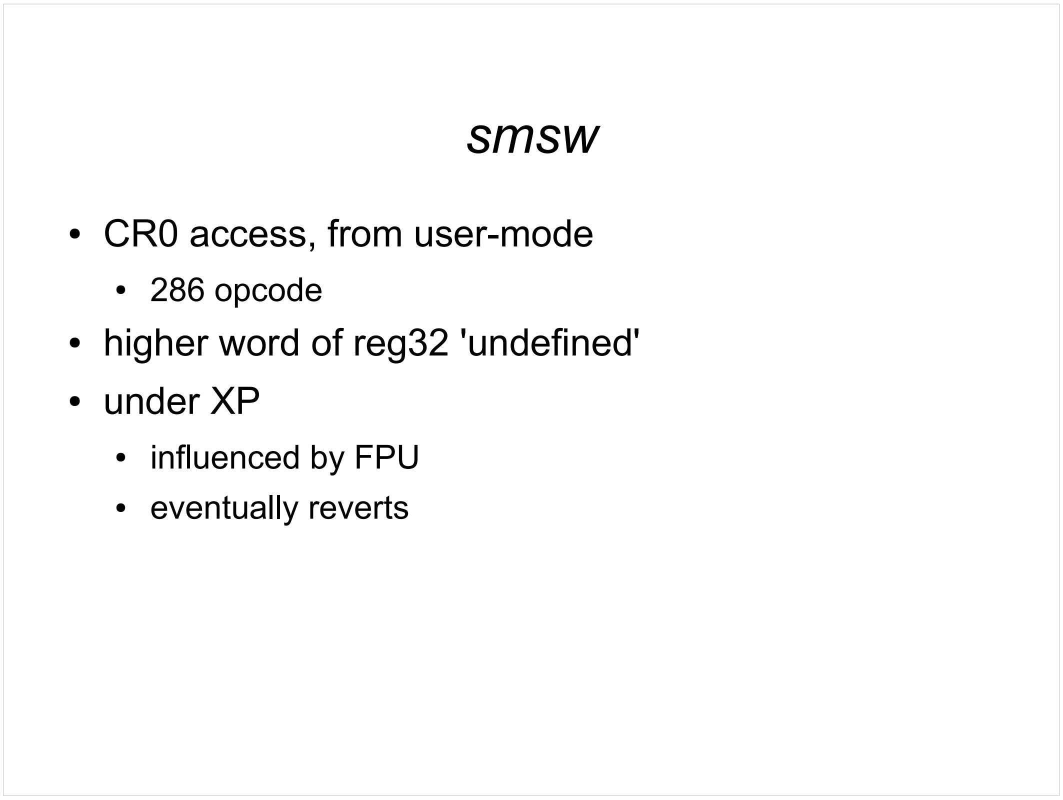
initial values PoC

	XP	W7
Flags	🟦	🟦
TLS		
eax	🟥	🟦
ecx	⬛	🟦
edx	🟥	🟩
ebx	🟦	🟥
EntryPoint		
eax	🟦	🟩
ecx	🟩	🟦
edx	🟩	🟥

fully ctrl-ed
controlled
fixed
range

I created a PoC that just gets all registers from EP and TLS, and checks the validity of result.

easy check see if a malware/tool is interfering with the loading process.



smsw

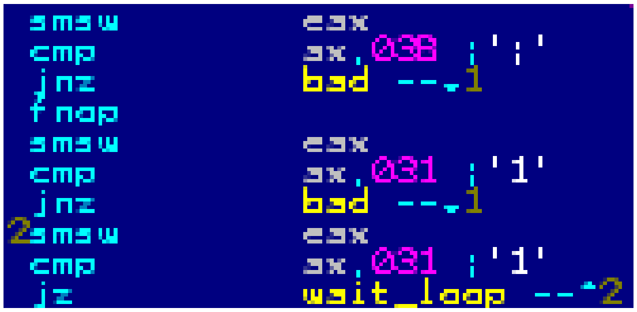
- CR0 access, from user-mode
  - 286 opcode
- higher word of reg32 'undefined'
- under XP
  - influenced by FPU
  - eventually reverts

smsw is an old 286-era mnemonic (before protected mode was 'complete'): it allows usermode access to cr0.
the higher word of a reg32 target is 'undefined', yet always modified (and same as cr0)

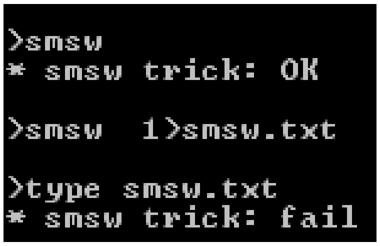
under XP, right after an FPU operation, the returned value is modified [bits 1 and 3, called MP (Monitor Coprocessor) and TS (Task switched)], but eventually reverted after some time.

too tricky ? redirection fails. any idea why ?

DEMO



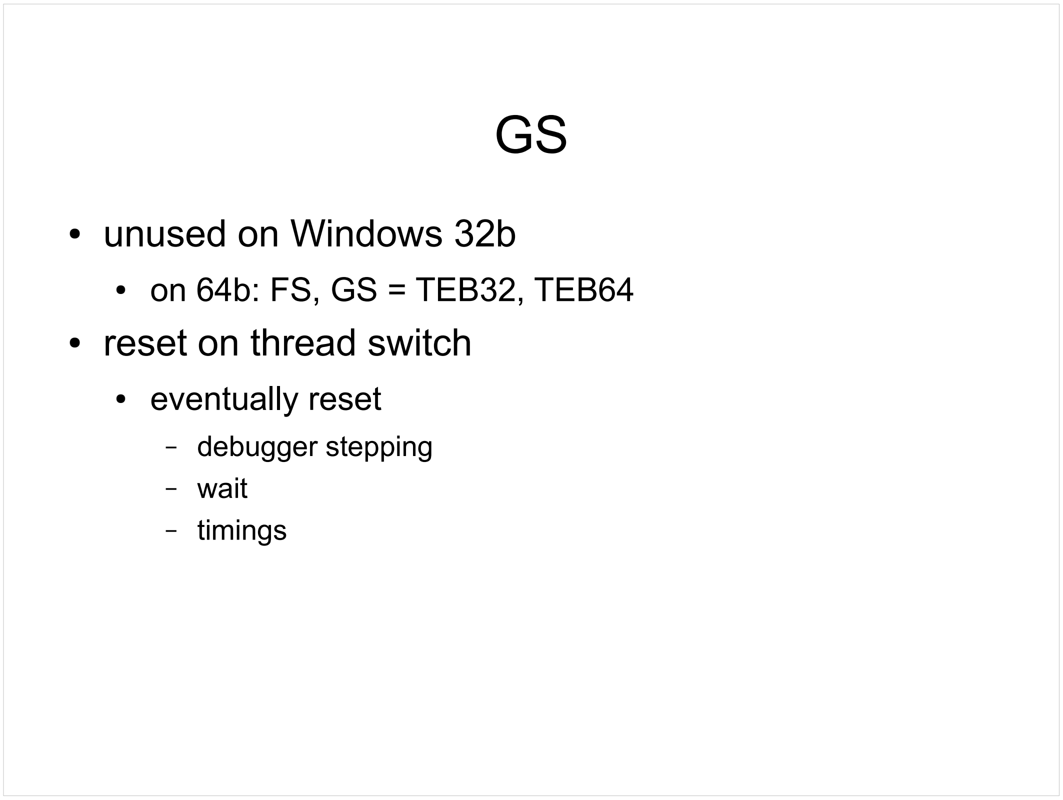
```
 smsw                  eax
 cmp                   ax,03B ;';'
 jnz                   bad --↓1
 fnop
 smsw                  eax
 cmp                   ax,031 ;'1'
 jnz                   bad --↓1
2smsw                  eax
 cmp                   ax,031 ;'1'
 jz                    wait_loop --↑2
```



```
>smsw
* smsw trick: OK

>smsw  1>smsw.txt

>type smsw.txt
* smsw trick: fail
```

demo of smsw:

- undocumented behavior
- fpu relation (xp)
- redirection weirdness



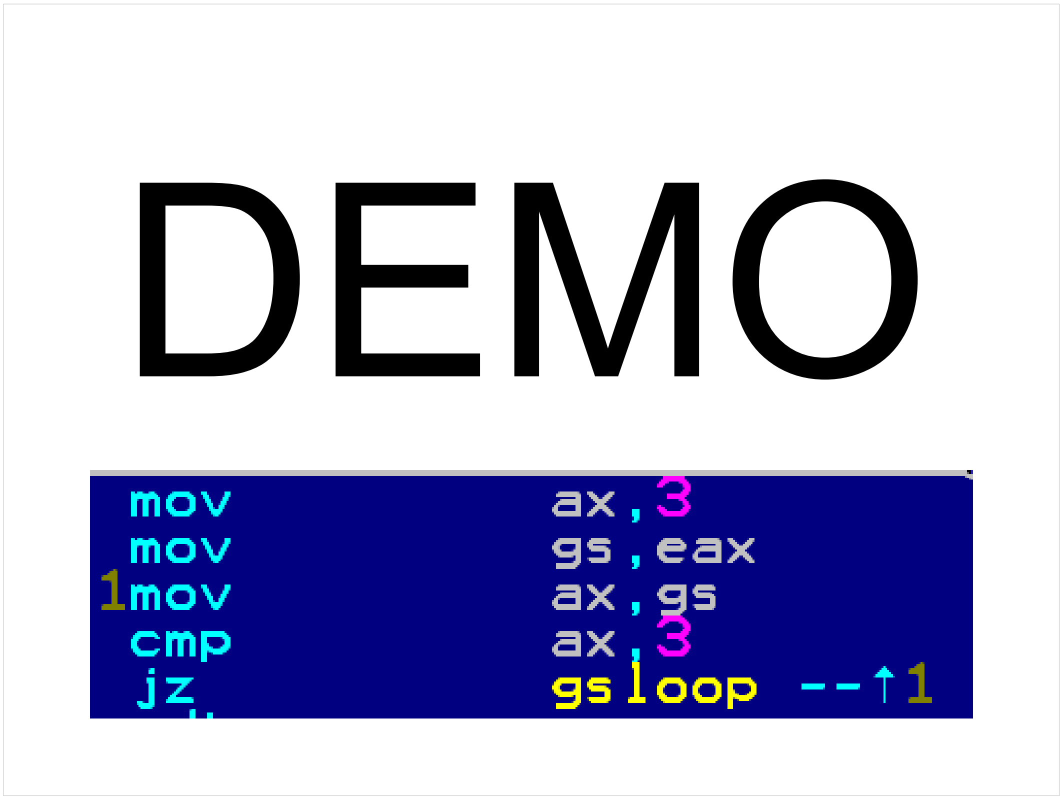
GS

- unused on Windows 32b
  - on 64b: FS, GS = TEB32, TEB64
- reset on thread switch
  - eventually reset
    - debugger stepping
    - wait
    - timings

the GS trick is similar.
•on 32b of windows, GS is reset on thread switch.
•on 64b windows, it's already used by the OS (value non null at start)

ie wait long enough, it's null, whatever the value before.

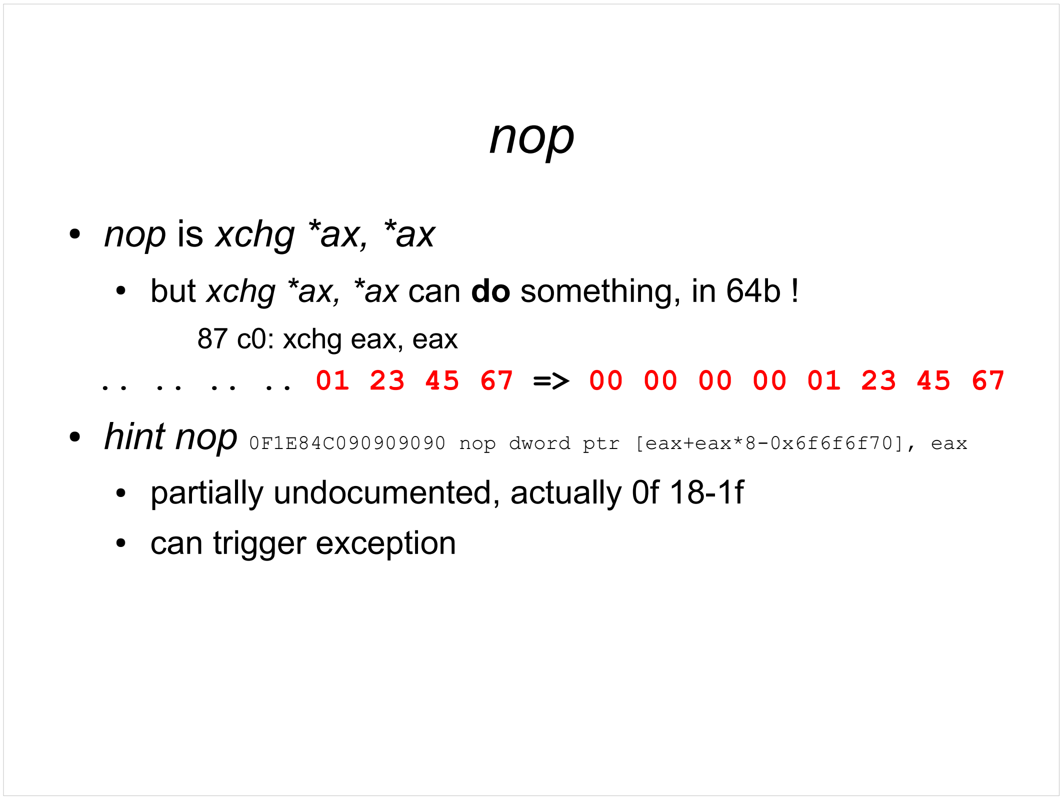
if you just step manually, instantly lost.
after some time, but not a too short time, it's reset



DEMO

```
 mov          ax,3
 mov          gs,eax
1mov          ax,gs
 cmp          ax,3
 jz           gsloop --↑1
```

demo of all GS features



nop

- *nop* is *xchg *ax, *ax*
  - but *xchg *ax, *ax* can **do** something, in 64b !

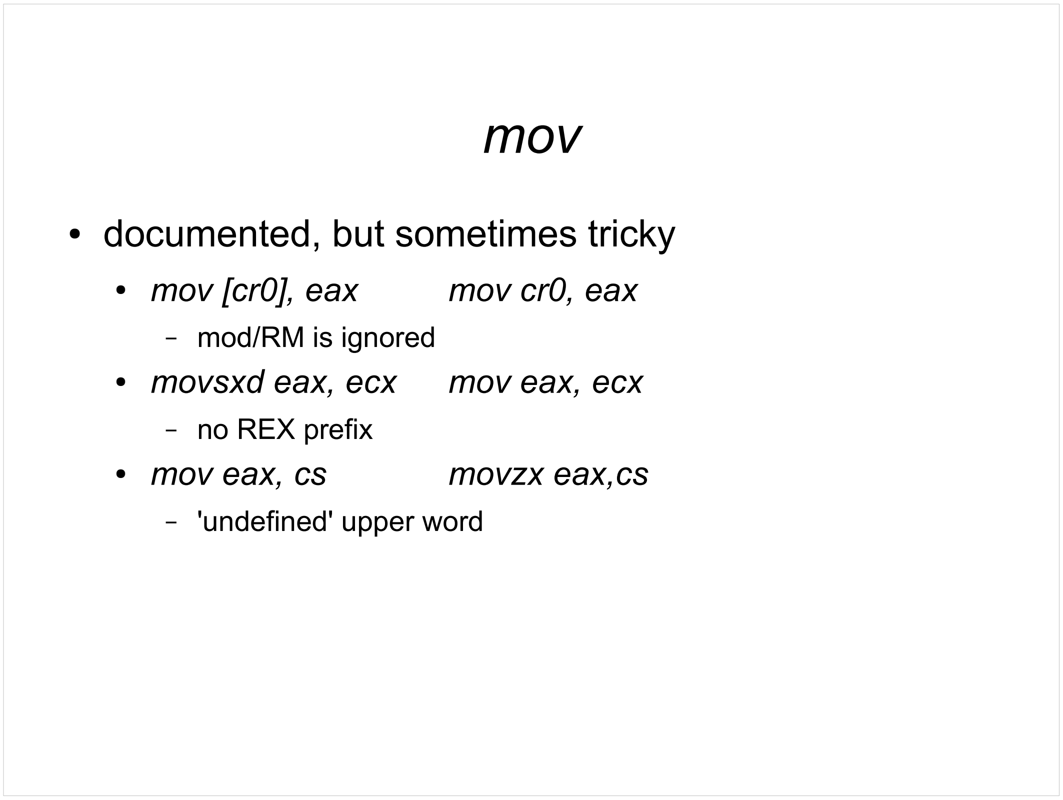
    87 c0: xchg eax, eax

```
.. .. .. .. 01 23 45 67 => 00 00 00 00 01 23 45 67
```

- *hint nop* `0F1E84C090909090 nop dword ptr [eax+eax*8-0x6f6f6f70], eax`
  - partially undocumented, actually 0f 18-1f
  - can trigger exception

xchg eax, eax is 90, which originally did nothing.
(xchg eax, ecx is 91)
thus 90 became nop
but 87 c0 is an xchg eax, eax that is not a nop and does something in 64b, as it resets the upper dword.

hint nop gives hint of what to access next. it does nothing, but it's multi-byte.
first, it's not completely documented by intel
and, being a multi-byte opcode, if it overlaps an invalid page, it can trigger an exception!



mov

- documented, but sometimes tricky
  - *mov [cr0], eax*   *mov cr0, eax*
    - mod/RM is ignored
  - *movsxd eax, ecx*   *mov eax, ecx*
    - no REX prefix
  - *mov eax, cs*   *movzx eax,cs*
    - 'undefined' upper word

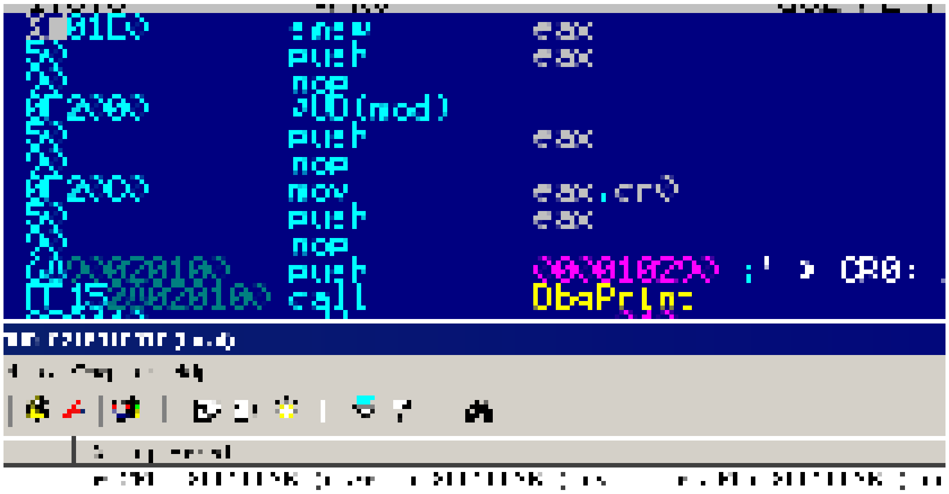
Mov is documented, but has a few quirks.

* to/from control and debug registers, memory operands are not allowed. but not rejected !

* in 64b, with no REX prefix, movsxd can actually work to and from a 32b register, which is against the logic of 'sign extending'

* on the contrary, mov from a selector actually affects a complete 32b register. the upper word is theoretically undefined, but actually 0 (used by malware to see if upper part is actually reset or if wrongly emulated as 'mov ax, cs'.)

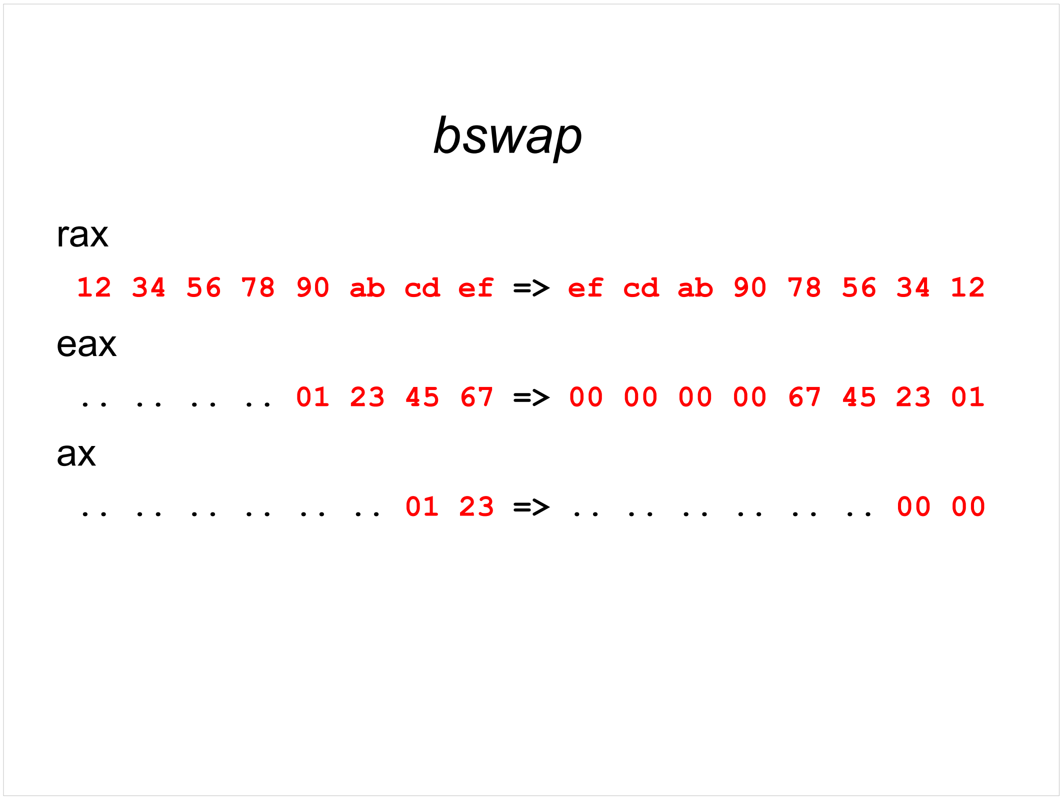
non standard CR0 access



```
smsw    eax
push    eax
nop
        (mod)
push    eax
nop
mov     eax,cr0
push    eax
nop
push            CR0:
call    DbgPrint
```

smsw (undocumented) gives full cr0 access.
then cr0 access with 'ignored' Mod/RM
then standard cr0 access...

same results, in all 3 cases.



bswap

rax

```
 12 34 56 78 90 ab cd ef => ef cd ab 90 78 56 34 12
```

eax

```
 .. .. .. .. 01 23 45 67 => 00 00 00 00 67 45 23 01
```

ax

```
 .. .. .. .. .. .. 01 23 => .. .. .. .. .. .. 00 00
```

Bswap... is like an administration... rules prevent it to work correctly most of the time...

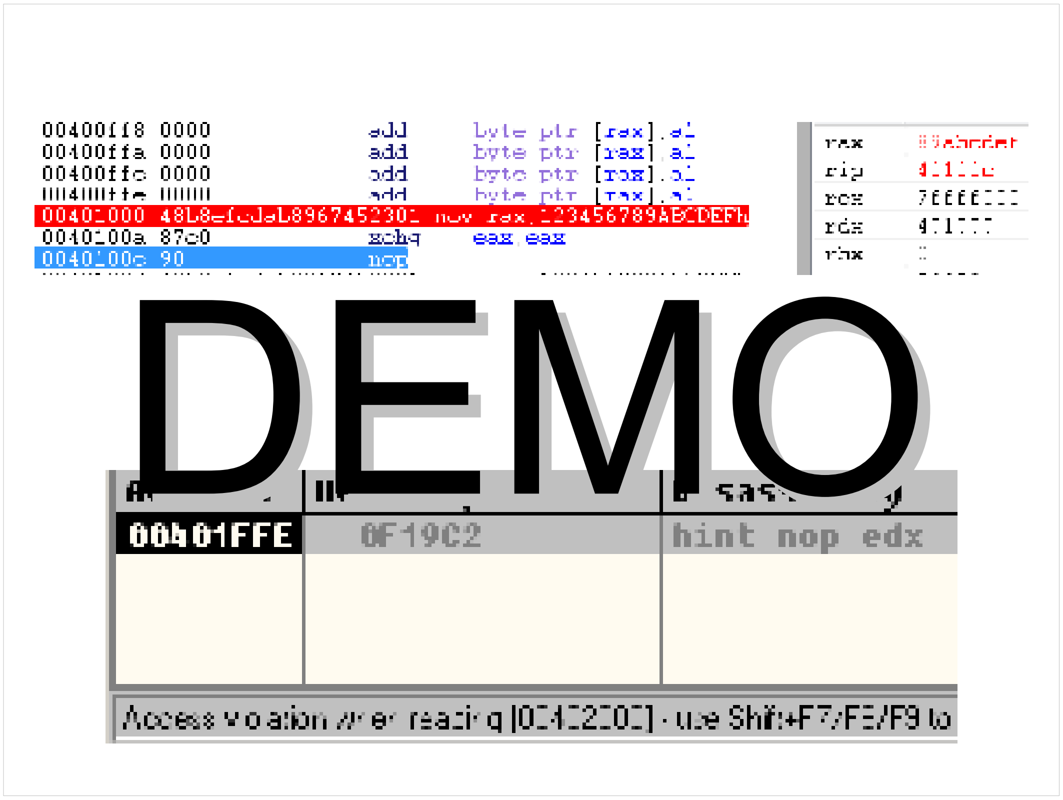
it's supposed to swap the endianness of a register.

but most of the time, it does something unexpected.

with a 64b register, it swaps the quadword around. good.

with a 32b, it resets the highest dword. 'as usual', of course...

and on 16b, it's 'undefined' but it just clears the 16b register itself (the rest stays unchanged, of course)...



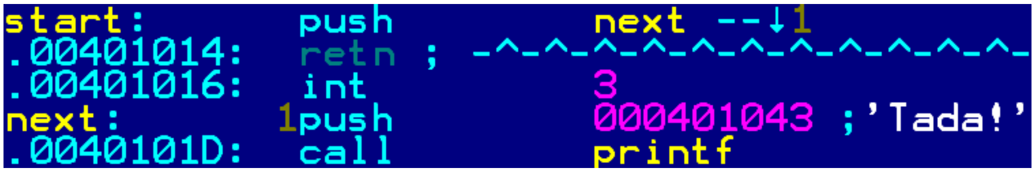
```
00400ff8 0000                 add     byte ptr [rax],al
00400ffa 0000                 add     byte ptr [rax],al
00400ffc 0000                 add     byte ptr [rax],al
00400ffe 0000                 add     byte ptr [rax],al
00401000 48b8efcdab8967452301 mov rax,123456789ABCDEFh
0040100a 87c0                 xchg    eax,eax
0040100c 90                   nop
```

```
00401FFE   0F19C2   hint nop edx
```

Access violation when reading [00402000] - use Shift+F7/F8/F9 to

demo of nop / mov / bswap, in both 32b and 64b

push+ret



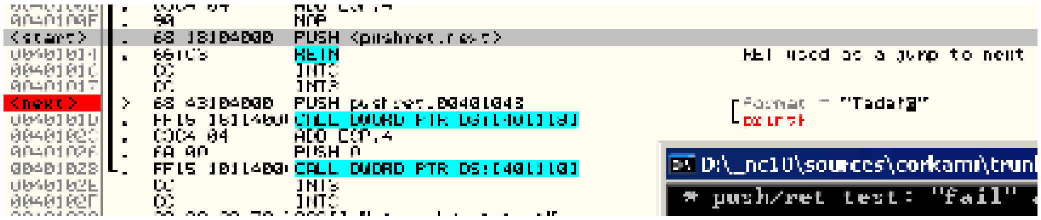
```
start:       push        next --↓1
.00401014:   retn ; -^-^-^-^-^-^-^-^-^-^-^-
.00401016:   int         3
next:       1push        000401043 ;'Tada!'
.0040101D:   call        printf
```

anyone knows what will happen here ?

push, ret.
put an address on the stack, pop it and jump to it.

no possible trick, right...

DEMO



```
0040100F  .  90            NOP
<start>   .  68 18104000   PUSH <pushret.next>
00401014  .  66:C3         RETN                             RET used as a jump to next
00401016     CC            INT3
00401017     CC            INT3
<next>    >  68 43104000   PUSH pushret.00401043            [format = "Tada!"
00401018  .  FF15 18104000 CALL DWORD PTR DS:[401018]       [printf
00401022  .  83C4 04       ADD ESP,4
00401025  .  6A 00         PUSH 0
00401028  .  FF15 10104000 CALL DWORD PTR DS:[401010]
0040102E     CC            INT3
0040102F     CC            INT3
```

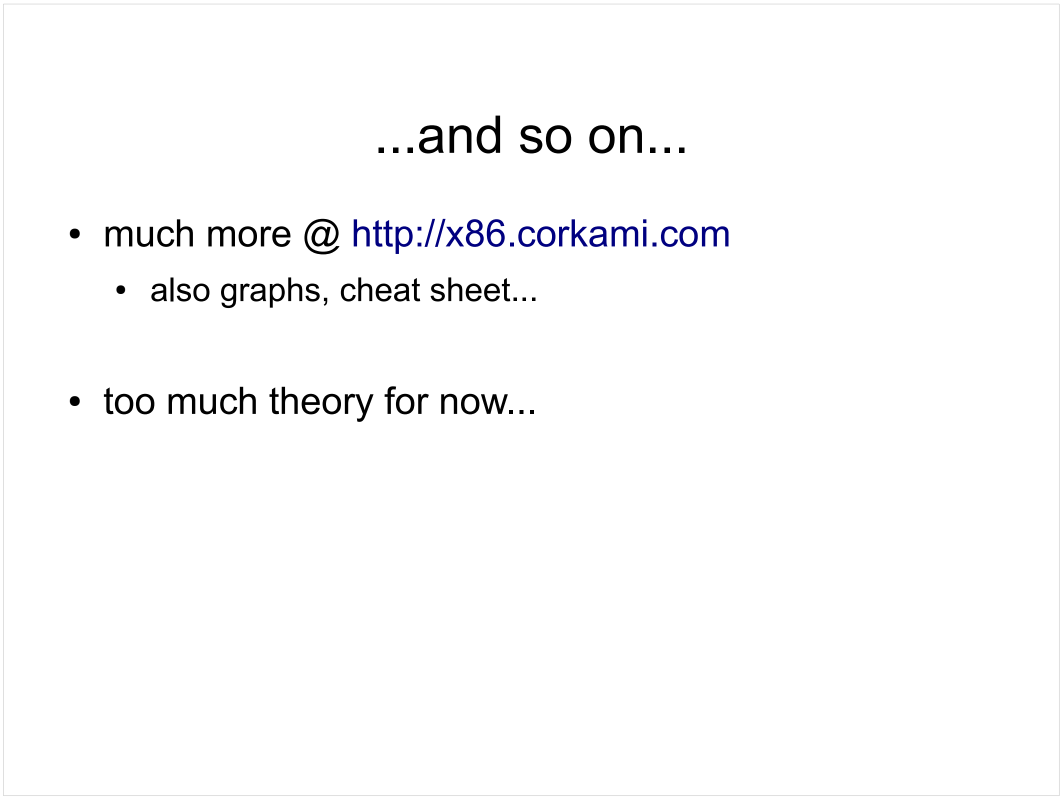
```
D:\_nc10\sources\corkami\trunk
* push/ret test: "fail"
```

so, what happened ?
olly even auto-comments the ret!

the 66: before the RETN makes return to IP, not EIP.

so here we returned to 1008, not 401008.

the other problem is that while different, there is no official name for this ret to word, 'small ret', 'ret16'....

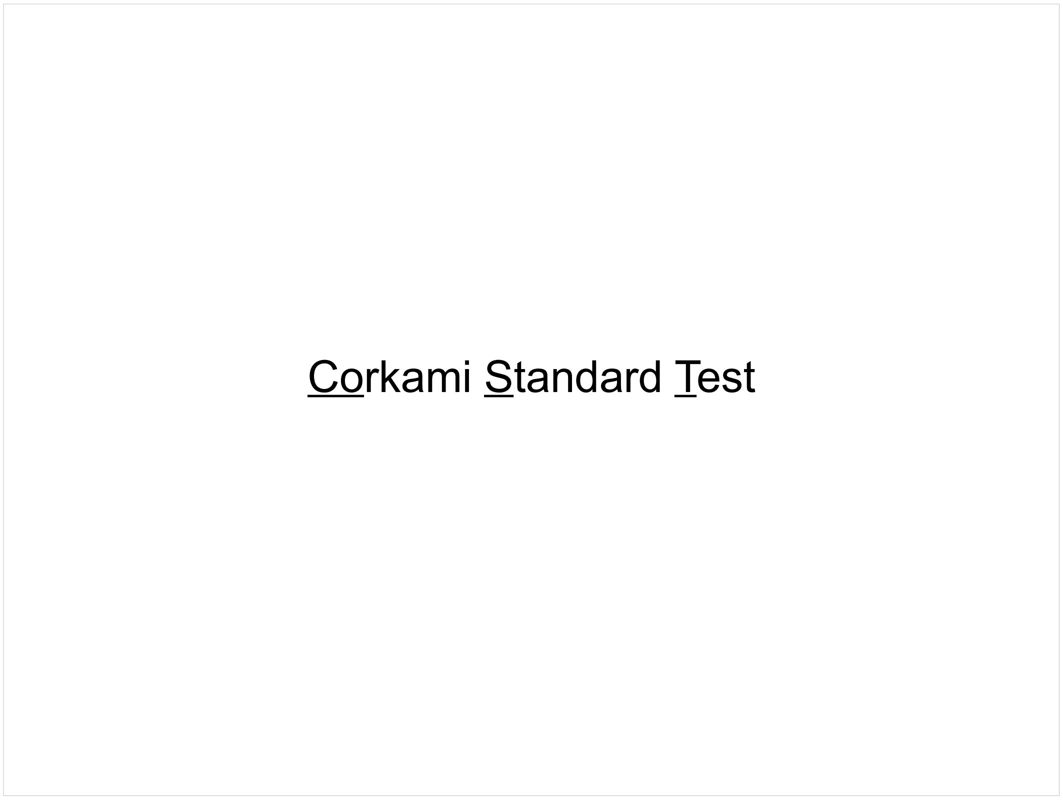


...and so on...

- much more @ http://x86.corkami.com
  - also graphs, cheat sheet...
- too much theory for now...

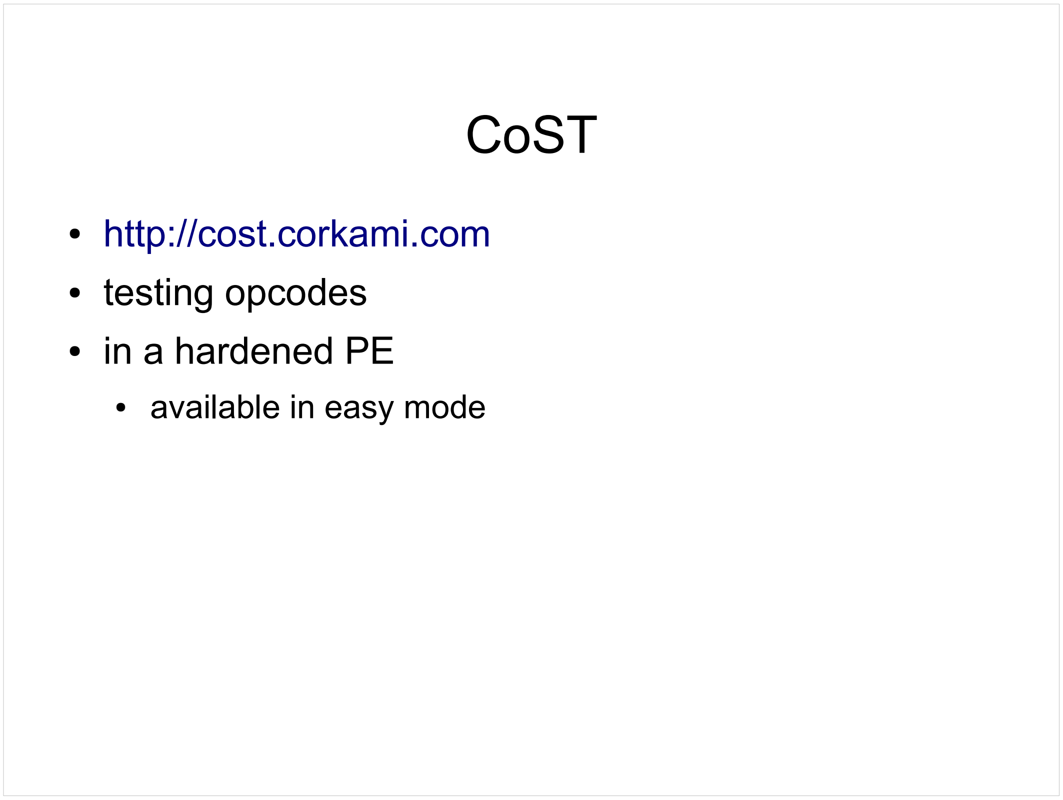
I won't enumerate them all.
they're already on Corkami, with some other x86 stuff that might be useful to print.

too much theory with no practice never gives good results...



Corkami Standard Test

so I created CoST.



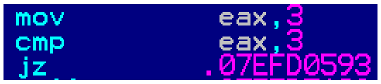
CoST

- http://cost.corkami.com
- testing opcodes
- in a hardened PE
  - available in easy mode

an opcode tester, in a tricky PE.
available in easy mode compile (less tricky), as CoST is quite difficult to debug :)

just run, and it roughly displays what happened.

more than 150 tests



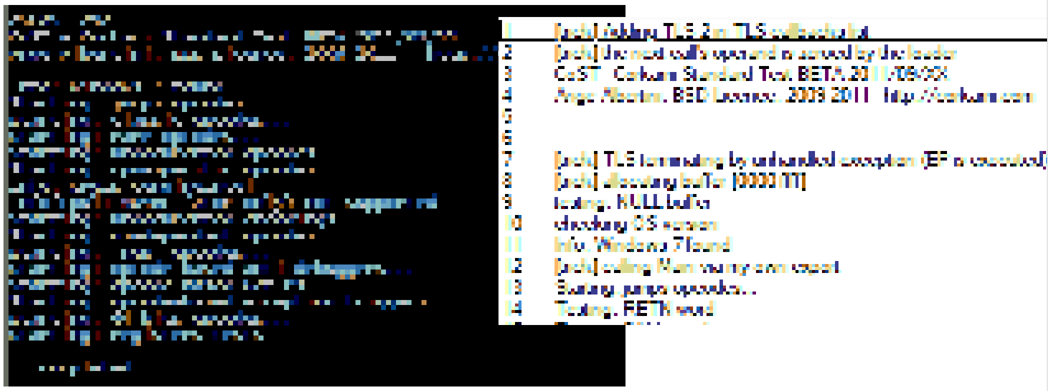
```
mov         eax,3
cmp         eax,3
jz         .07EFD0593
```

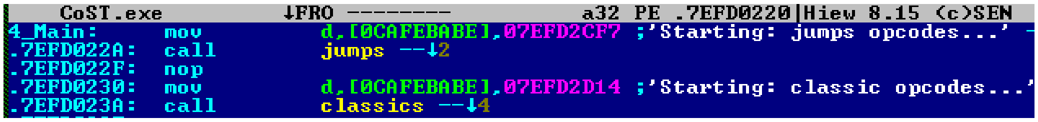
- classic, rare
- jumps (JMP to IP, IRET, …)
- undocumented (IceBP, SetALc...)
- cpu-specific (MOVBE, POPCNT,...)
- os-dependant, anti-VM/debugs
- exceptions triggers, interrupts, OS bugs,...
- ...

so, it contains a lot of various tests... (150 is the lower margin, depend how you count)

some trivial... some less trivial.

CoST's internals





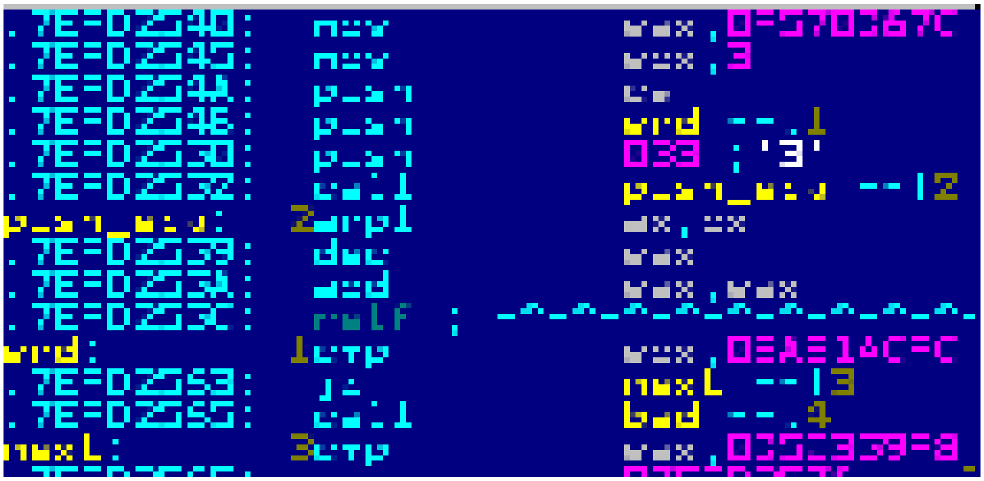
```
   CoST.exe            ↓FRO ---------          a32 PE .7EFD0220|Hiew 8.15 (c)SEN
4_Main:    mov         d,[0CAFEBABE],07EFD2CF7 ;'Starting: jumps opcodes...' -
.7EFD022A: call        jumps --↓2
.7EFD022F: nop
.7EFD0230: mov         d,[0CAFEBABE],07EFD2D14 ;'Starting: classic opcodes...'
.7EFD023A: call        classics --↓4
```

Cost just gives some output when ran from the command line.

but actually it gives much more output on debug output.

even if the binary is hand-made, it's self documented, via one-line calls to VEH printing, and internal exports for different internal chapters.

32+64 = ...

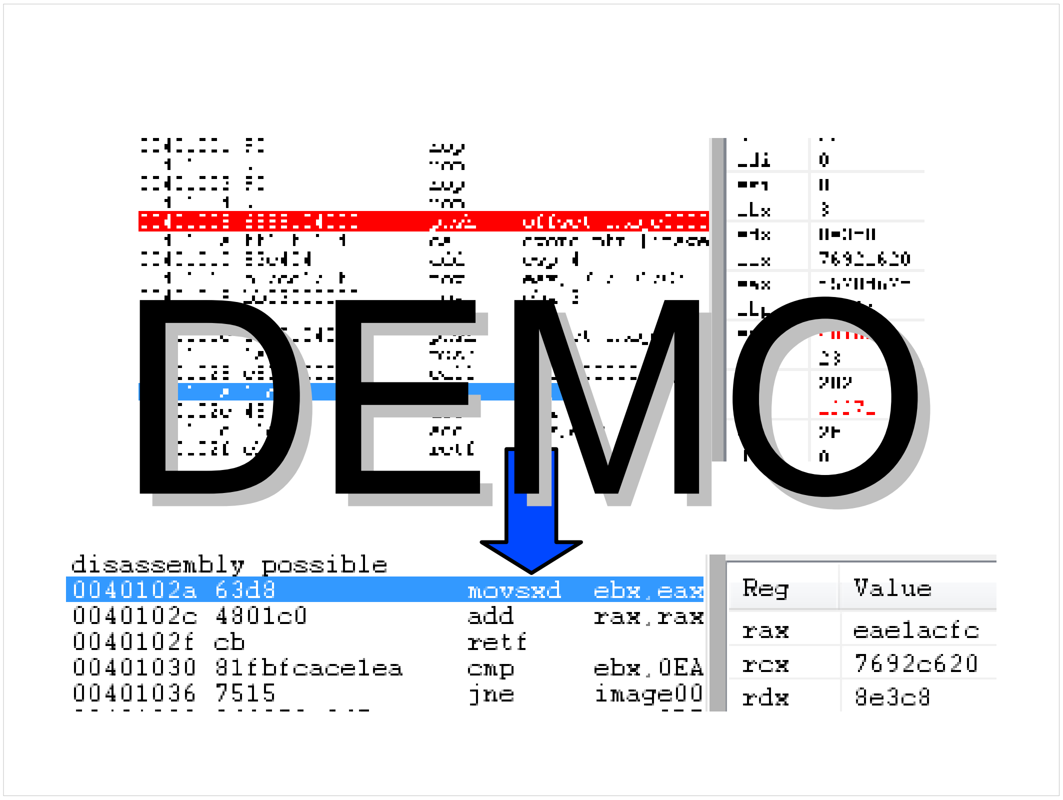


here is my favorite part of CoST:

anyone sees what this is doing ?

executing code at push_eip...
then the same code with selector 33 (64b code)

so the same opcodes are executed twice, first in 32b mode, then in 64b.



```
disassembly possible
0040102a 63d8            movsxd  ebx,eax
0040102c 4801c0          add     rax,rax
0040102f cb              retf
00401030 81fbfcace1ea    cmp     ebx,0EA
00401036 7515            jne     image00
```

Reg	Value
rax	eae1acfc
rcx	7692c620
rdx	8e3c8

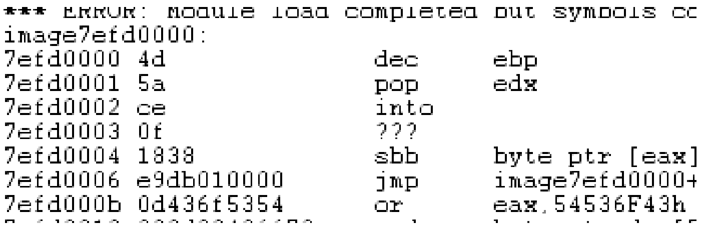
and these opcodes gives exclusive mnemonics to each side...

works fine under a 64b OS.

same EIP, same opcodes, twice, and different code.

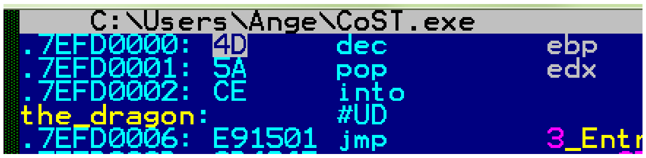
CoST vs WinDbg & Hiew

WinDbg 6.12.0002.633



```
*** ERROR: Module load completed but symbols cc
image7efd0000:
7efd0000 4d                dec     ebp
7efd0001 5a                pop     edx
7efd0002 ce                into
7efd0003 0f                ???
7efd0004 1838              sbb     byte ptr [eax]
7efd0006 e9db010000        jmp     image7efd0000+
7efd000b 0d436f5354        or      eax,54536F43h
```

Hiew 8.15



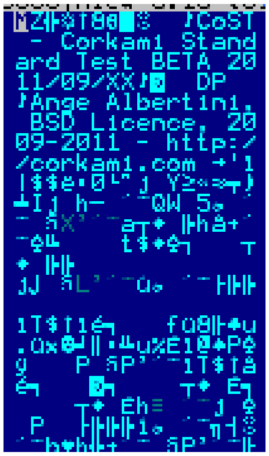
```
    C:\Users\Ange\CoST.exe
.7EFD0000: 4D      dec         ebp
.7EFD0001: 5A      pop         edx
.7EFD0002: CE      into
the_dragon:        #UD
.7EFD0006: E91501  jmp         3_Entr
```

as you'd expect, WinDbg, following Intel docs too closely, will give you '??'

Hiew does that too a little.

but honestly, I found bugs in all disassemblers I looked at, no exception AFAIR. Even a crash in XED.

a hardened PE



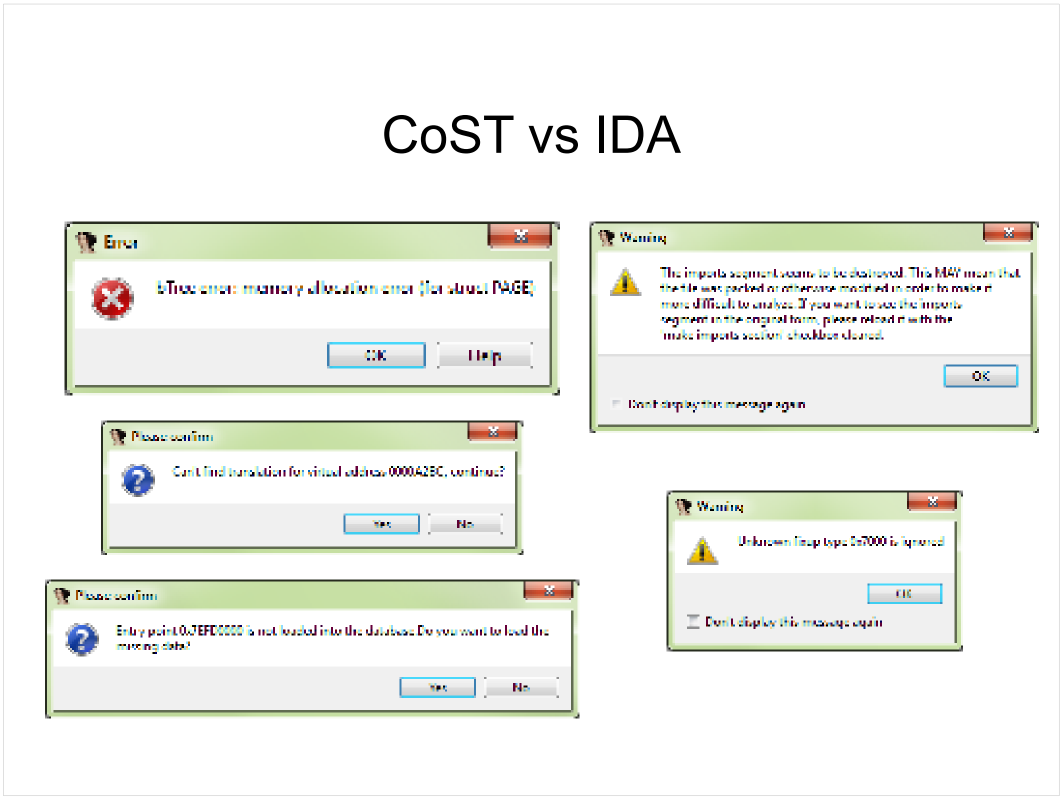
Top

PE 'footer'

CoST was originally only an opcode tester.

then I added a few PE tricks...

have a look yourself, the top of the file, and the PE header (right at the bottom)



CoST vs IDA

Error

bTree error: memory allocation error (for struct PAGE)

Warning

The imports segment seems to be destroyed. This MAY mean that the file was packed or otherwise modified in order to make it more difficult to analyse. If you want to see the imports segment in the original form, please reload it with the 'make imports section' checkbox cleared.

☐ Don't display this message again

Please confirm

Can't find translation for virtual address 0000A2BC, continue?

Warning

Unknown fixup type 0x7000 is ignored

☐ Don't display this message again

Please confirm

Entry point 0x7EFD0000 is not loaded into the database. Do you want to load the missing data?

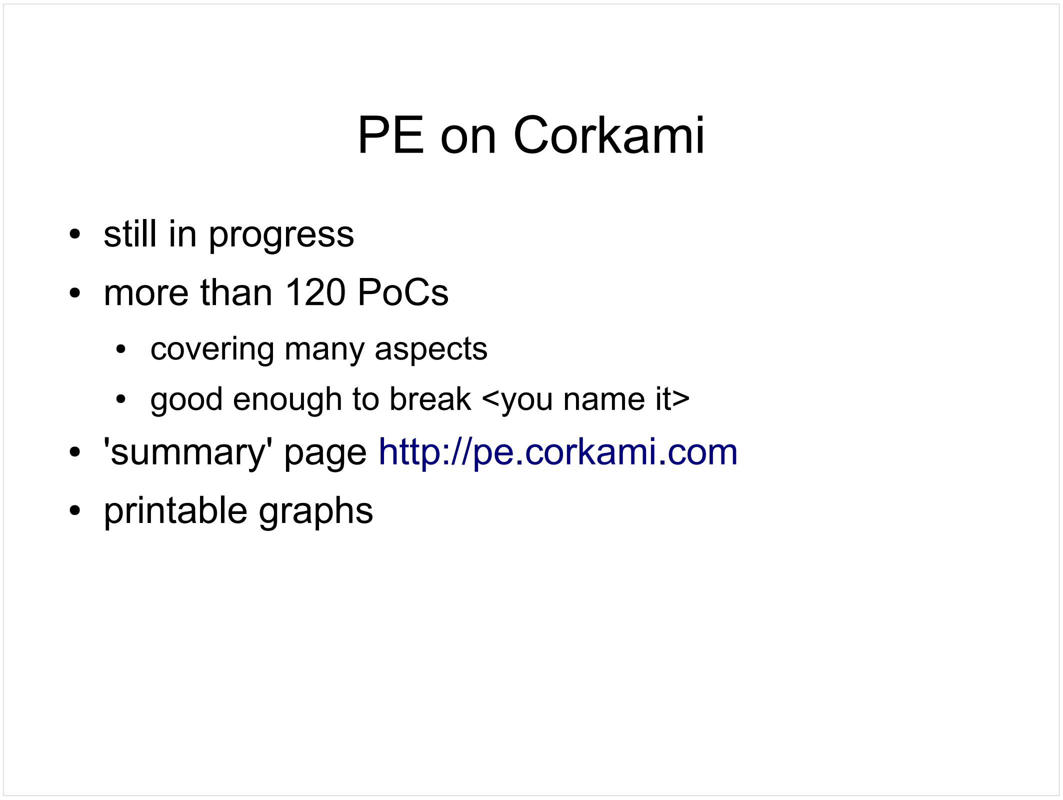
As you can see, IDA didn't really like it at first (fixed, now)

So, if CoST helps you to find a few bugs in your program, I'm not really surprised.

a bit more of PE...

but one single file, even full of tricks, is not enough to express all the possibilities of the PE file.

so I created more.



PE on Corkami

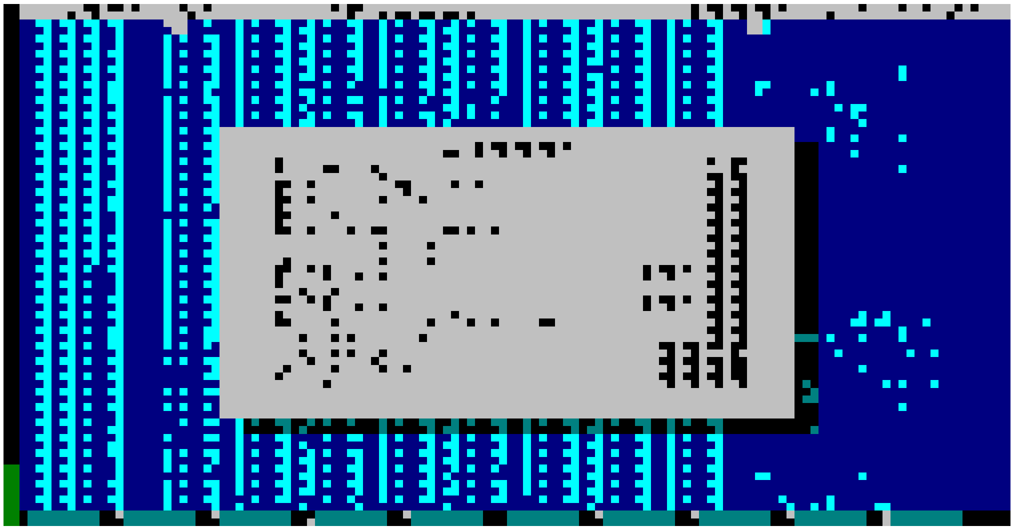
- still in progress
- more than 120 PoCs
  - covering many aspects
  - good enough to break <you name it>
- 'summary' page http://pe.corkami.com
- printable graphs

I already made some useful graphs for PE files.

and I started a wiki page, with more than 120 PoCs, focusing, as usual, on precise aspects of the PE.

PE with no section, with 64k sections, with huge ImageBase, relocation encryption...

virtual section table vs Hiew



in low alignments, the section table is checked but not used at all.

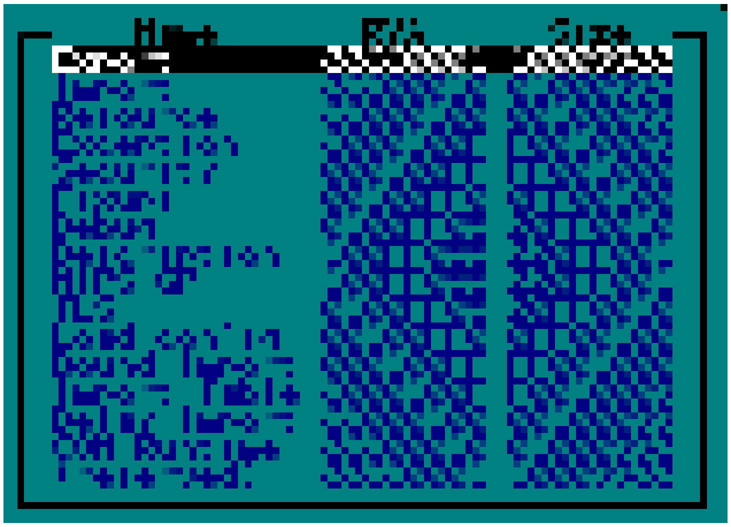
so, if it's full of zeroes, it will still work – under XP.

thus, with SizeOfOptionalHeader, you can set it in virtual space...

Hiew doesn't like that.

check the picture, it doesn't even identify it as a PE.

Folded header



what do you think ?

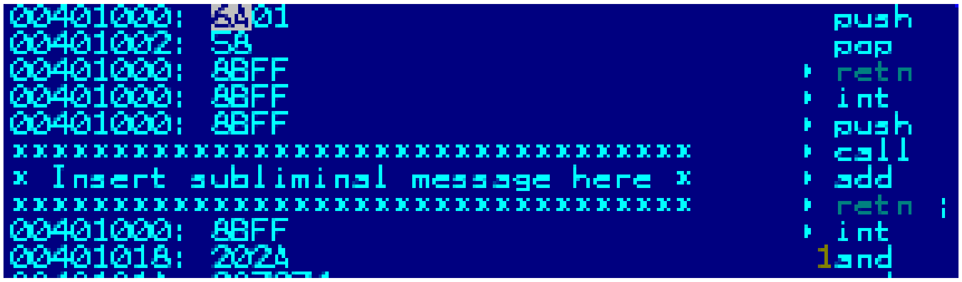
when you can do ASCII art with the PE info, something dodgy is going on :)

this is ReversingLabs' dual PE header.
the PE header is partially overwritten (at exports directories) on loading.

the upper part is read from disk, the lower part, read in memory, is overwritten by the section that is folded over the bottom of the header.

Weird export names

- exports = <anything non null>, 0



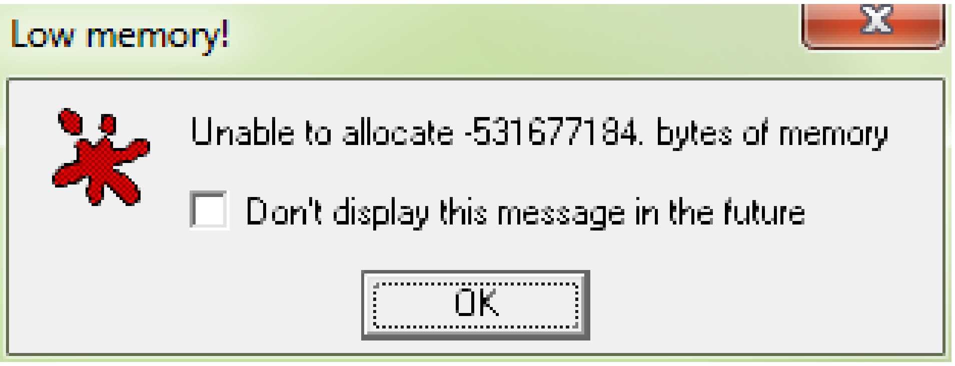
```
00401000: 6A01                                 push
00401002: 58                                   pop
00401000: ABFF                               ▸ retn
00401000: ABFF                               ▸ int
00401000: ABFF                               ▸ push
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx          ▸ call
x Insert subliminal message here x           ▸ add
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx          ▸ retn ;
00401000: ABFF                               ▸ int
00401018: 2024                                1and
```

export names can be anything until 0, or even null.

Hiew displays them inline, so, well, here is the PoC of weird export names

one of the other names in this PoC is LOOOONG enough to trigger a buffer overflow >:)

65535 sections vs OllyDbg



Unable to allocate -531677184. bytes of memory

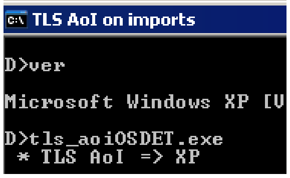
☐ Don't display this message in the future

this is a 64k section PE against the latest Olly.

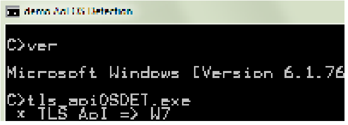
amazingly, it doesn't crash despite this funny message...

a last one...

- TLS AddressOfIndex is overwritten on loading
- Imports are parsed until Name is 0
- under XP, overwritten after imports
    - imports are fully parsed
- under W7, before
    - truncated



```
D>ver

Microsoft Windows XP [V

D>tls_aoiOSDET.exe
 * TLS AoI => XP
```



```
C>ver

Microsoft Windows [Version 6.1.76

C>tls_aoiOSDET.exe
 x TLS AoI => W7
```

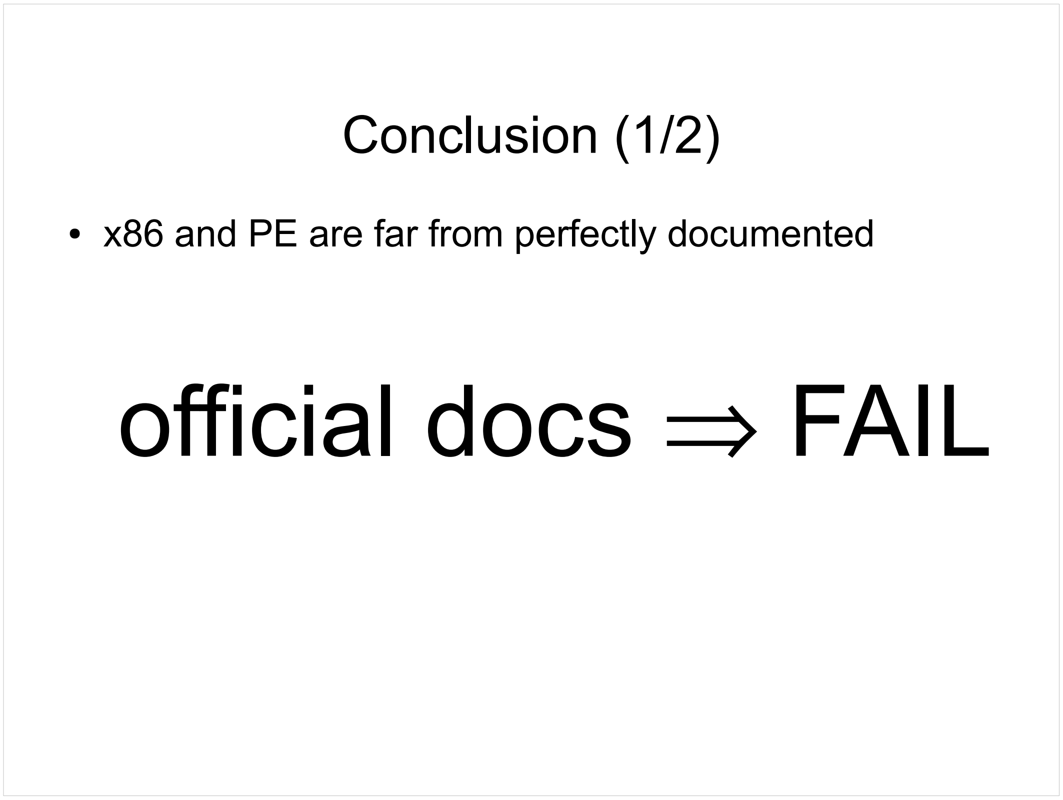
same PE, loaded differently

this one is not very visual, yet quite unique.

TLS AoI points to an Import descriptor Name member...

depending on AoI or imports happening first, this is a terminator or not...

so the same PE gets loaded with more or less imports depending on the OS.



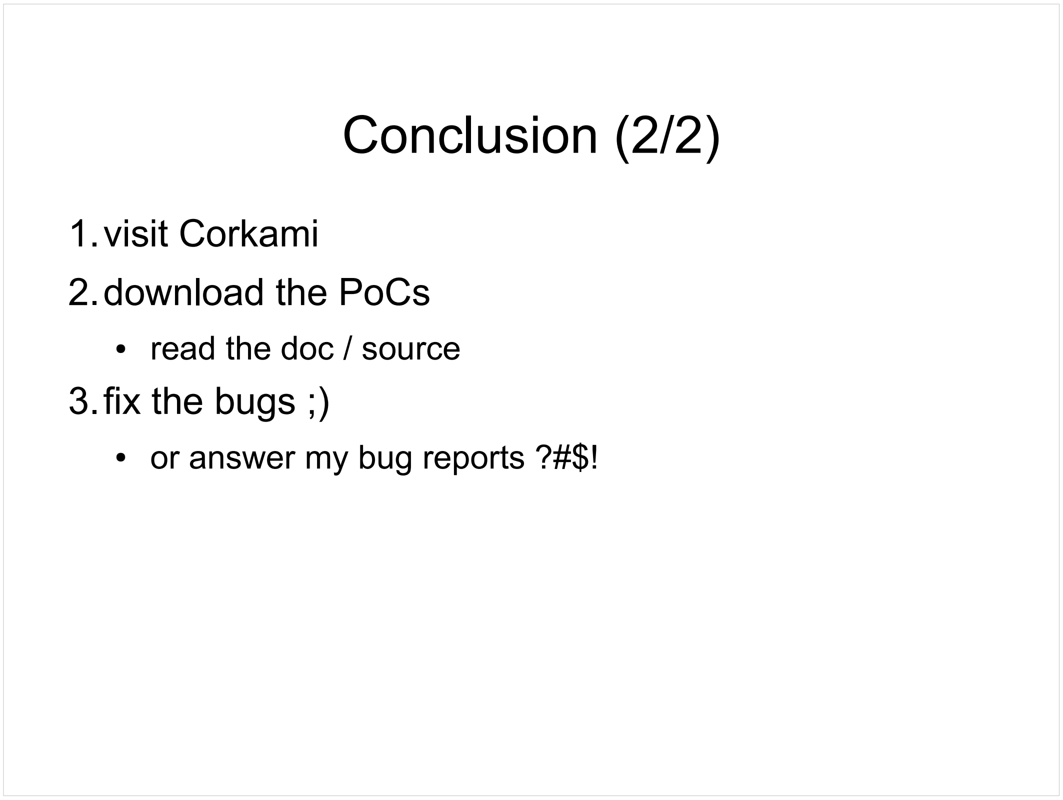
Conclusion (1/2)

- x86 and PE are far from perfectly documented

official docs ⇒ FAIL

unlike what I used to believe, cpus and windows binaries are far from perfectly logical nor documented

If you only follow the official doc, you're bound to fail. especially with the malware landscape out there.



Conclusion (2/2)

1. visit Corkami
2. download the PoCs
    - read the doc / source
3. fix the bugs ;)
    - or answer my bug reports ?#$!

so give Corkami PoCs a try – and send me a postcard if you found some bugs

I seriously hope that MS will put WinDbg back to a more reactive release cycle, and will update it...

Acknowledgments

- Peter Ferrie
- Ivanlef0u

Adam Błaszczyk, BeatriX, Bruce Dang, Candid Wüest, Cathal Mullaney, Czerno, Daniel Reynaud, Elias Bachaalany, Ero Carrera, Eugeny Suslikov, Georg Wicherski, Gil Dabah, Guillaume Delugré, Gunther, Igor Skochinsky, Ilfak Guilfanov, Ivanlef0u, Jean-Baptiste Bédrune, Jim Leonard, Jon Larimer, Joshua J. Drake, Markus Hinderhofer, Mateusz Jurczyk, Matthieu Bonetti, Moritz Kroll, Oleh Yuschuk, Renaud Tabary, Rewolf, Sebastian Biallas, StalkR, Yoann Guillot,...

Questions?

Eternal thanks to Peter Ferrie, my permanent reviewer.
Ivanlef0u is also very helpful.

a lot of people helped me in the process to make this presentation and the content on corkami, in one way or another.

Any questions?

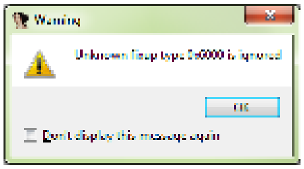
Thank YOU!

@ange4771

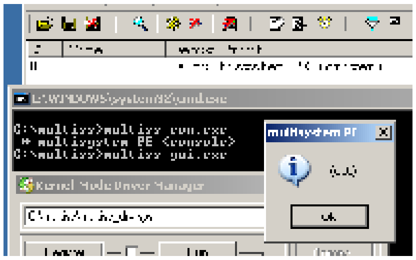
Thanks for your attention. I hope you liked it.

Bonus

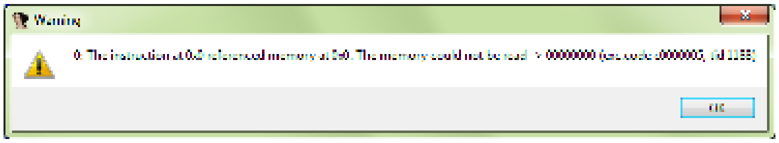
- Mips relocs (on relocs)
- ImageBase reloc
- multi-subsystem PE
- regs on TLS & DllMain


Warning

Unknown fixup type 0x6000 is ignored


C:\WINDOWS\system32\cmd.exe

```
C:\multiss>multiss_con.exe
 * multisystem PE (console)
C:\multiss>multiss_gui.exe
```


Warning

0: The instruction at 0x0 referenced memory at 0x0. The memory could not be read -> 00000000 (exc.code c0000005, tid 1188)

mips relocs are still working, even with x86 CPU and PE. and relocs apply on relocs data themselves... so does my PoC

adding an extra relocation on the imagebase doesn't influence the loading (the PE is already mapped), but it interferes with the EP calculation.

Drivers are just low alignment PEs with different import. so I made a PE with low alig and no imports, that detects how it's ran, and resolves its own imports accordingly

on TLS and DLLMain return, only ESI and EIP have to be correct, so my PoC corrupts everything else... IDA didn't like a weird ESP...