self-replicating malware

Changelog

Corrections made in this version not in first posting:

1 Feb 2017: slide 12: `cmpq` corrected to `test`

28 Feb 2017: slide 7: REX prefix's first nibble is `0100`

RE assignment

assembly reading practice

due Friday

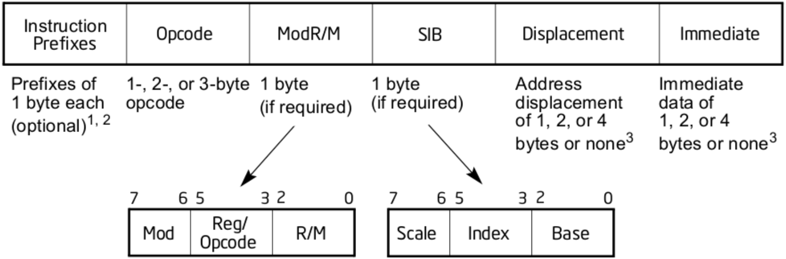
last time

executable formats
- using Linux as example, but concepts same elsewhere

started x86 encoding

why?
- manipulating machine code
  - malware does it
  - a little bit on assignments
- want you to have option besides “use objdump blindly” on assignments

overall encoding



1. The REX prefix is optional, but if used must be immediately before the opcode; see Section 2.2.1, "REX Prefixes" for additional information.
2. For VEX encoding information, see Section 2.3, "Intel® Advanced Vector Extensions (Intel® AVX)".
3. Some rare instructions can take an 8B immediate or 8B displacement.

Figure 2-1. Intel 64 and IA-32 Architectures Instruction Format

x86 encoding example (1)

`pushq %rax` encoded as `50`

- 5-bit opcode `01010` plus 3-bit register number `000`

`pushq %r13` encoded as `41 55`

- `41`: REX prefix `0100` (constant), w:`0`, r:`0`, s:`0`, b:`1`
- w = `0` because push is never 32-bit in 64-bit mode
- `55`: 5-bit opcode `01010`; 3-bit reg # `101`
- 4-bit reg # `1101` = 13

x86 encoding example (2)

`addq 0x12345678(%rax,%rbx,2), %ecx`

`03`: opcode — add r/m32 to r/m32

`8c`: ModRM: mod = `10`; reg = `001`, r/m: `100`

reg = `001` = `%ecx` (table)

SIB byte + 32-bit displacement (table)

`58`: SIB: scale = `01`, index = `011`, base = `000`

index `011` = `%rbx`; base `000` = `%rax`;

`78 56 32 12`: 32-bit constant `0x12345678`

x86 encoding example (3)

`addq 0x12345678(%r10,%r11,2), %rax`

`4b`: REX prefix `0010`+w:`1`, r:`0`, s:`1`, b:`1`

`03`: opcode — add r/m64 to r64 (with REX.w)

`84`: ModRM: mod = `10`; reg = `000`, r/m: `100`
- reg = `0000` = %rax
- SIB byte + 32-bit displacement (table)

`5a`: SIB: scale = `01`, index = `011`, base = `010`
- with REX: index = `1011` (11), base = `1010` (10)

`78 56 32 12`: 32-bit constant `0x12345678`

x86 encoding example (3)

`addq 0x12345678(%r10,%r11,2), %rax`

`4b`: REX prefix `0010`+w:`1`, r:`0`, s:`1`, b:`1`

`03`: opcode — add r/m64 to r64 (with REX.w)

`84`: ModRM: mod = `10`; reg = `000`, r/m: `100`
reg = `0000` = %rax
SIB byte + 32-bit displacement (table)

`5a`: SIB: scale = `01`, index = `011`, base = `010`
with REX: index = `1011` (11), base = `1010` (10)

`78 56 32 12`: 32-bit constant `0x12345678`

x86 encoding example (4)

`movq %fs:0x10,%r13`

64: FS segment override

48: REX: w: 1 (64-bit), r: 1, s: 0, b: 0

8b: opcode for MOV memory to register

2c: ModRM: mod = `00`, reg = `101`, r/m: `100`
with REX: reg = `1101` [%r12]; r/m = 100 (SIB follows)

25: SIB: scale = `00`; index = `0100`; base = `0101`
no register/no register in table

`10 00 00 00`: 4-byte constant `0x10`

x86: relative and absolute

addresses in `mov`/`lea` are absolute

- address appears directly in machine code
- `mov foo, %eax`:
  - `8b 04 25` (address of foo)
- except `mov foo(%rip), ...`, etc.

addresses in `jmp` are relative

- `jmp skip_nop; nop; skip_nop: ...`:
  - `eb 01` (jmp skip_nop)
  - `90` (nop)
  - `(skip_nop:)`
- value in machine code **added** to PC

addresses in `call` are relative

x86-64 impossibilities

illegal: `movq 0x12345678ab(%rax), %rax`

- maximum 32-bit displacement
- `movq 0x12345678ab, %rax` okay
  - extra mov opcode for `%rax` only

illegal: `movq $0x12345678ab, %rbx`

- maximum 32-bit (signed) constant
- `movq $0x12345678ab, %rax` okay

illegal: `pushl %eax`

- no 32-bit push/pop in 64-bit mode
- but 16-bit allowed (operand size prefix byte 66)

illegal: `movq (%rax, %rsp), %rax`

- cannot use `%rsp` as index register
- `movq (%rsp, %rax), %rax` okay

instruction prefixes

REX (64-bit and/or extra register bits)

VEX (SSE/AVX instructions; other new instrs.)

operand/address-size change (64/32 to 16 or vice-versa)

LOCK — synchronization between processors

REPNE/REPNZ/REP/REPE/REPZ — turns instruction into loop

segment overrides

string instructions (1)

```
memcpy: // copy %rdx bytes from (%rsi) to (%rdi)
        test %rdx, %rdx
        je done
        movsb
        subq $1, %rdx
        jmp memcpy
done:   ret
```

`movsb` (move data from string to string, byte)

mov one byte from `(%rsi)` to `(%rdi)`

increment %rsi and %rdi (*)

cannot specify other registers

string instructions (2)

```
memcpy: // copy %rdx bytes from (%rsi) to (%rdi)
    rep movsb
    ret
```

`rep` prefix byte

repeat instruction until `%rdx` is 0

decrement `%rdx` each time

cannot specify other registers

cannot use `rep` with all instructions

string instructions (3)

`lodsb`, `stosb` — load/store into string

`movsw`, `movsd` — word/dword versions

string comparison instructions

`rep movsb` is still recommended on modern Intel

- special-cased in processor?

exploring assembly

compiling little C programs looking at the assembly is nice:

`gcc -S -O`

- extra stuff like `.cfi` directives (for try/catch)

or disassemble:

`gcc -O -c file.c` (or make an executable)

`objdump -dr file.o` (or on an executable)

- d: disassemble
- r: show (non-dynamic) relocations

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assembly without optimizations

compilers do really silly things without optimizations:

```
int sum(int x, int y) { return x + y; }
```

```
sum:
    pushq   %rbp
    movq    %rsp, %rbp
    movl    %edi, −4(%rbp)
    movl    %esi, −8(%rbp)
    movl    −4(%rbp), %edx
    movl    −8(%rbp), %eax
    addl    %edx, %eax
    popq    %rbp
    ret
```

instead of `gcc -O` version:

```
sum:
    leal (%rdi,%rsi), %eax
    ret
```

assembly reading advice

don't know what an instruction does: look it up!

machine code: start with assembler/objdump

- might need to edit addresses, etc.

remember calling conventions

function/variable names (if present) help

try to name values in registers, on stack

- based on context
- "input size" not "rax"

self-replicating malware

attacker's problem:
getting malware to run where they want

some options:

connect to machine and install it there

send to someone

convince someone else to send it to someone

self-replicating malware

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some options:

connect to machine and install it there

send to someone

convince someone else to send it to someone

all automatable!

recall: kinds of malware

viruses — infects other programs

worms — own malicious programs

trojans — useful (looking) program that also is malicious

rootkit — silent control of system

viruses: hiding in files

get someone run your malware?

program they already want to run

to spread your malware?

program they already want to copy

trojan approach: create/modify new program

simpler: modify already used/shared program

virus prevalence

viruses on commerically sold software media

from 1990 memo by Chris McDonald:

```
4.  MS-DOS INFECTIONS

SOFTWARE                REPORTING LOCATION     DATE     VIRAL INFECTION

a.  Unlock Masterkey    Kennedy Space Center   Oct 89   Vienna
b.  SARGON III          Iceland                Sep 89   Cascade (1704)
c.  ASYST RTDEMO02.EXE  Fort Belvoir           Aug 89   Jerusalem-B
d.  Desktop Fractal     Various                Jan 90   Jerusalem (1813)
        Design System
e.  Bureau of the       Government Printing    Jan 90   Jerusalem-B
    Census, Elec. County   Office/US Census Bureau
    & City Data Bk., 1988
f.  Northern Computers  Iceland                Mar 90   Disk Killer
    (PC Manufacturer shipped infected systems.)
5.  MACINTOSH INFECTIONS

    SOFTWARE            REPORTING LOCATION     DATE     VIRAL INFECTION

a.  NoteWriter          Colgate College        Sep 89   Scores and nVIR
.......
```

https://groups.google.com/forum/#!original/comp.virus/XJCfYR9T6nI/azflHz5goooJ

early virus motivations

lots of (but not all) early virus software was “for fun”

not trying to monetize malware

(like is common today)

hard: Internet connections uncommon

Case Study: Vienna Virus

Vienna: virus from the 1980s

This version: published in Ralf Burger, "Computer Viruses: a high-tech disease" (1988)

targetted COM-format executables on DOS

Diversion: .COM files

.COM is a very simple executable format

no header, no segments, no sections

file contents loaded at fixed address `0x0100`

execution starts at `0x0100`

everything is read/write/execute (no virtual memory)

Vienna: infection

uninfected

```
0x0100:
    mov $0x4f28, %cx
    /* b9 28 4f */
0x0103:
    mov $0x9e4e, %si
    /* be 4e 9e */
    mov %si, %di
    push %ds
    /* more normal
       program
       code */
....
0x0700: /* end */
```

infected

```
0x0100: jmp 0x0700
0x0103: mov $0x9e4e, %si
...
0x0700:
    push %cx
    ... // %si ← 0x903
    mov $0x100, %di
    mov $3, %cx
    rep movsb
    ...
    mov $0x0100, %di
    push %di
    xor %di, %di
    ret
...
0x0903:
    .bytes 0xb9 0x28 0x4f
...
```

Vienna: “fixup”

```
0x0700:
    push %cx // initial value of %cx matters??
    mov $0x8fd, %si // %si ← beginning of data
    mov %si, %dx // save %si
        // movsb uses %si, so
        // can't use another register
    add $0xa, %si // offset of saved code in data
    mov $0x100, %di // target address
    mov $3, %cx // bytes changed
    /* copy %cx bytes from (%si) to (%di) */
    rep movsb
    ...
...
// saved copy of original application code
0x903: .byte 0xb9 .byte 0x28 .byte 0x4f
```

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    mov $0x100, %di // target address
    mov $3, %cx // bytes changed
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    rep movsb
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    add $0xa, %si // offset of saved code in data
    mov $0x100, %di // target address
    mov $3, %cx // bytes changed
    /* copy %cx bytes from (%si) to (%di) */
    rep movsb
    ...
...
// saved copy of original application code
0x903: .byte 0xb9 .byte 0x28 .byte 0x4f
```

Vienna: return

```
0x08e7:
    pop %cx // restore initial value of %cx, %sp
    xor %ax, %ax // %ax ← 0
    xor %bx, %bx
    xor %dx, %dx
    xor %si, %si
    // push 0x0100
    mov $0x0100, %di
    push %di
    xor %di, %di // %di ← 0
    // pop 0x0100 from stack
    // jmp to 0x0100
    ret
```

question: why not just jmp 0x0100 ?

Vienna: infection outline

Vienna appends code to infected application

where does it read the code come from?

how is code adjusted for new location in the binary?

- what linker would do

how does it keep files from getting infinitely long?

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quines

exercise: write a C program that outputs its source code

(pseudo-code only okay)

possible in any (Turing-complete) programming language

called a “quine”

clever quine solution

```
#include <stdio.h>
char*x="int main(){
      printf(p,10,34,x,34,10,34,p,34,10,x,10);
      }";
char*p="#include <stdio.h>%c
    char*x=%c%s%c;%cchar*p=%c%s%c;
    %c%s%c";
int main(){
    printf(p,10,34,x,34,10,34,p,34,10,x,10);
}
```

some line wrapping for readability — shouldn't be in actual quine

clever quine solution

```
#include <stdio.h>
char*x="int main(){
        printf(p,10,34,x,34,10,34,p,34,10,x,10);
        }";
char*p="#
    char*
    %c%s%
int main(){
    printf(p,10,34,x,34,10,34,p,34,10,x,10);
}
```

`printf` to fill template:
`10` = newline; `34` = double-quote;
`x`, `p` = template/constant strings

some line wrapping for readability — shouldn't be in actual quine

clever quine solution

```
#include <stdio.h>
char*x="int main(){
        printf(p,10,34,x,34,10,34,p,34,10,x,10);
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    %c%s%c";
int main(){
    printf(p,10,34,x,34,10,34,p,34,10,x,10);
}
```

template filled by printf

some line wrapping for readability — shouldn't be in actual quine

dumb quine solution

```
#include <stdio.h>
int main(void) {
    char buffer[1024];
    FILE *f = fopen("quine.c", "r");
    size_t bytes = fread(buffer, 1,
                         sizeof(buffer), f);
    fwrite(buffer, 1, bytes, stdout);
    return 0;
}
```

a lot more straightforward!

but “cheating”

Vienna copying

```
mov $0x8f9, %si // %si = beginning of virus data
...
mov $0x288, %cx // length of virus
mov $0x40, %ah  // system call # for write
mov %si, %dx
sub $0x1f9, %dx // %dx = beginning of virus code
int 0x21 // make write system call
```

Vienna copying

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what linker would do

how does it keep files from getting infinitely long?

Vienna relocation

very little use of absolute addresses:

- jmps use relative addresses (value to add to PC)

virus uses `%si` as a “base register”

- points to beginning of virus data
- set very early in virus execution

set via `mov $0x8fd, %si` near beginning of virus

Vienna relocation

```
// set virus data address:
0x700: mov $0x8f9, %si
       // machine code: be f9 08
       // be: opcode
       // f9 08: immediate
...
// %ax contains file length (of file to infect)
mov %ax, %cx
...
add $0x2f9, %cx
mov %si, %di
sub $0x1f7, %di // %di ← 0x701
mov %cx, (%di)  // update mov instruction
...
```

Vienna relocation

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// set virus data address:
0x700: mov $0x8f9, %si
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mov %cx, (%di)  // update mov instruction
...
```

Vienna relocation

edit actual code for `mov`

why doesn't this disrupt virus execution?

Vienna relocation

edit actual code for `mov`

why doesn't this disrupt virus execution?

- already ran that instruction

Vienna relocation

```
0x700: mov $0x8f9, %si
...
// %ax contains file length
//      (of file to infect)
mov %ax, %cx
sub $3, %ax
// update template jmp instruction
mov %ax, 0xe(%si) // 0xe + %si = 0x907
...
mov $40, %ah
mov $3, %cx
mov %si, %dx
add $0xD, %dx // dx ← 0x906
int 0x21 // system call: write 3 bytes from 0x906
...
0x906: e9 fd 05 // jmp PC+FD 05
```

Vienna relocation

```
0x700: mov $0x8f9, %si
...
// %ax contains file length
//     (of file to infect)
mov %ax, %cx
sub $3, %ax
// update template jmp instruction
mov %ax, 0xe(%si) // 0xe + %si = 0x907
...
mov $40, %ah
mov $3, %cx
mov %si, %dx
add $0xD, %dx // dx ← 0x906
int 0x21 // system call: write 3 bytes from 0x906
...
0x906: e9 fd 05 // jmp PC+FD 05
```

Vienna relocation

```
0x700: mov $0x8f9, %si
...
// %ax contains file length
//     (of file to infect)
mov %ax, %cx
sub $3, %ax
// update template jmp instruction
mov %ax, 0xe(%si) // 0xe + %si = 0x907
...
mov $40, %ah
mov $3, %cx
mov %si, %dx
add $0xD, %dx // dx ← 0x906
int 0x21 // system call: write 3 bytes from 0x906
...
0x906: e9 fd 05 // jmp PC+FD 05
```

alternative relocation

could avoid having pointer to update:

```
0000000000000000 <next-0x3>:
   0:   e8 00 00                      call   3 <next>
    target addresses encoded relatively
    pushes return address (next) onto stack
0000000000000003 <next>:
   3:   59                            pop    %cx
    cx containts address of the pop instruction
```

why didn't Vienna do this?

Vienna: infection outline

Vienna appends code to infected application

where does it read the code come from?

how is code adjusted for new location in the binary?

  what linker would do

how does it keep files from getting infinitely long?

Vienna: avoiding reinfection

scans through active directories for executables

"marks" infected executables in file metadata

- could have checked for virus code — but slow

DOS last-written times

16-bit number for date; 16-bit number for time

Y-1980	Mon	Day
15 … 9	8 … 5	4 … 0

H	Min	Sec/2
15 … 11	10 … 5	4 … 0

DOS last-written times

16-bit number for date; 16-bit number for time

Y-1980	Mon	Day
15 9	8 5	4 0

H	Min	Sec/2
15 11	10 5	4 0

Sec/2: 5 bits: range from 0–31

corresponds to 0 to **62** seconds

Vienna trick: set infected file times to **62** seconds

need to update times anyways — hide tracks

virus choices

where to put code

how to get code ran

virus choices

where to put code

how to get code ran

where to put code

considerations:

- spreading — files that will be copied/reused
- spreading — files that will be ran
- stealth — user shouldn't know until too late

where to put code: options

one *or more* of:

replacing executable code

after executable code (Vienna)

in unused executable code

inside OS code

in memory

where to put code: options

one *or more* of:

replacing executable code

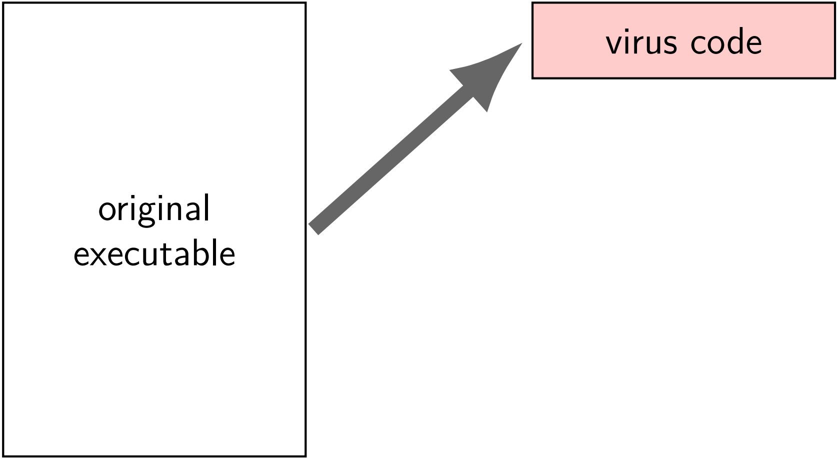
after executable code (Vienna)

in unused executable code

inside OS code

in memory

replace executable



replace executable?

seems silly — not stealthy!

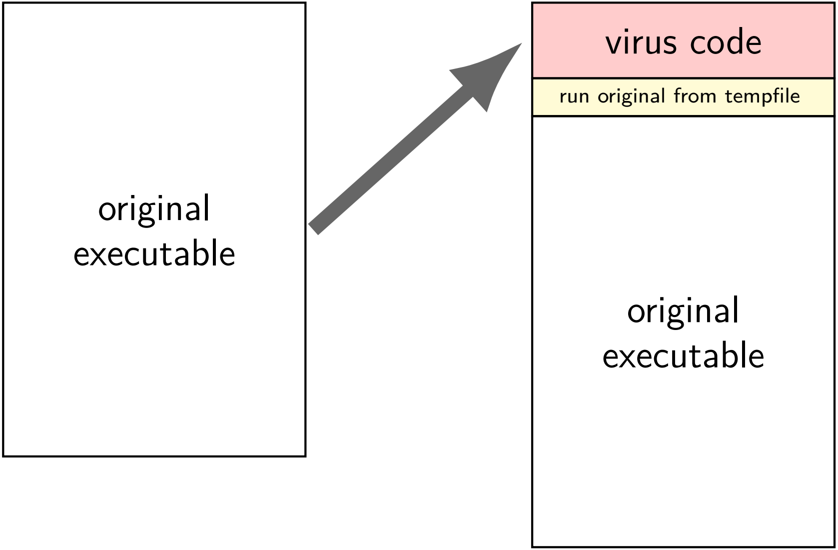
has appeared in the wild — ILOVEYOU

2000 ILOVEYOU Worm

- written in Visual Basic (!)
- spread via email
- replaced lots of files with copies of itself

huge impact

replace executable — subtle



where to put code: options

one *or more* of:

replacing executable code

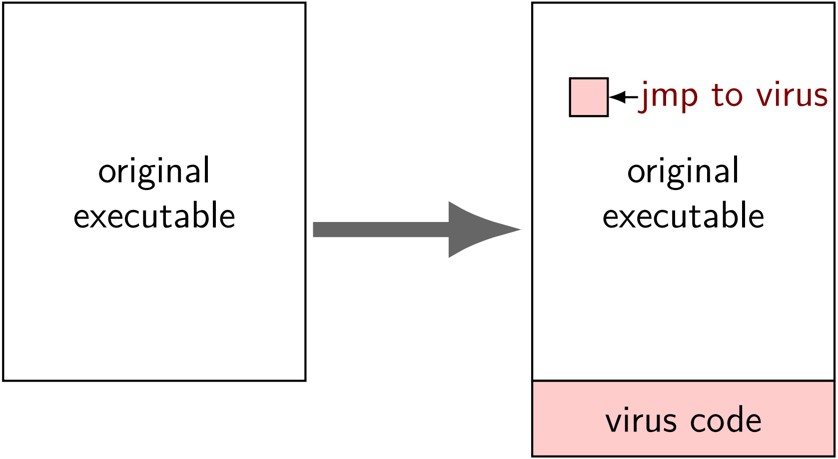
after executable code (Vienna)

in unused executable code

inside OS code

in memory

appending


original
executable
jmp to virus
original
executable
virus code

note about appending

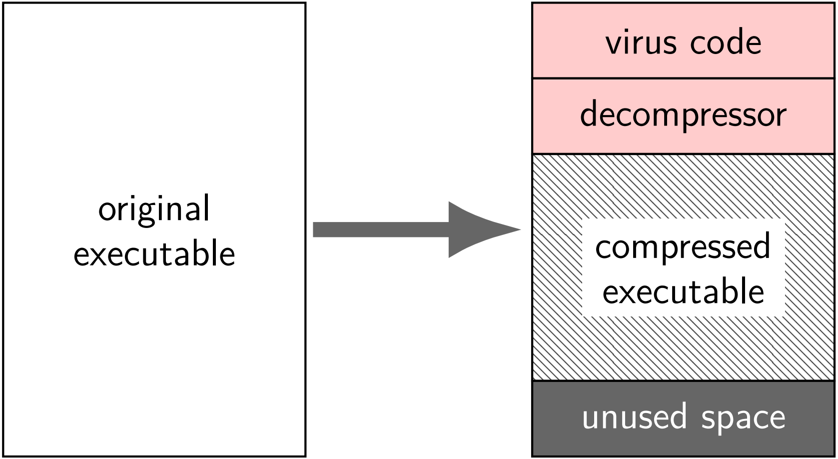
COM files are very simple — no metadata

modern executable formats have length information to update

- add segment to program header
- update last segment of program header (size + make it executable)

compressing viruses

file too big? how about compression



where to put code: options

one *or more* of:

replacing executable code

after executable code (Vienna)

in unused executable code

inside OS code

in memory

unused code???

why would a program have unused code????

unused code case study: /bin/ls

unreachable no-ops!

```
...
  403788:        e9 59 0c 00 00              jmpq   4043e6 <__spr
  40378d:        0f 1f 00                    nopl   (%rax)
  403790:        ba 05 00 00 00              mov    $0x5,%edx
...
  403ab9:        eb 4d                       jmp    403b08 <__spr
  403abb:        0f 1f 44 00 00              nopl   0x0(%rax,%rax
  403ac0:        4d 8b 7f 08                 mov    0x8(%r15),%r1
...
  404a01:        c3                          retq
  404a02:        0f 1f 40 00                 nopl   0x0(%rax)
  404a06:        66 2e 0f 1f 84 00 00        nopw   %cs:0x0(%rax,
  404a0d:        00 00 00
  404a10:        be 00 e6 61 00              mov    $0x61e600,%es
...
```

why empty space?

Intel Optimization Reference Manual:
"**Assembly/Compiler Coding Rule 12. (M impact, H generality)** All branch targets should be 16-byte aligned."

- better for instruction cache (and TLB and related caches)
- better for instruction decode logic
- function calls count as branches for this purpose

other empty space

unused dynamic linking structure

unused debugging/symbol table information?

unused header space

- recall — header loaded into memory!

other empty space

unused dynamic linking structure

unused debugging/symbol table information?

unused header space

- recall — header loaded into memory!

dynamic linking cavity

`.dynamic` section — data structure used by dynamic linker:

format: list of 8-byte type, 8-byte value

terminated by type == 0 entry

```
Contents of section .dynamic:
 600e28 01000000 00000000 01000000 00000000  ................
    ... several non-empty entries ...
 600f88 f0ffff6f 00000000 56034000 00000000  ...o....V.@.....
    VERSYM (required library version info at) 0x400356
 600f98 00000000 00000000 00000000 00000000  ................
    NULL --- end of linker info
 600fa8 00000000 00000000 00000000 00000000  ................
    unused! (and below)
 600fb8 00000000 00000000 00000000 00000000  ................
 600fc8 00000000 00000000 00000000 00000000  ................
 600fd8 00000000 00000000 00000000 00000000  ................
 600fe8 00000000 00000000 00000000 00000000  ................
```

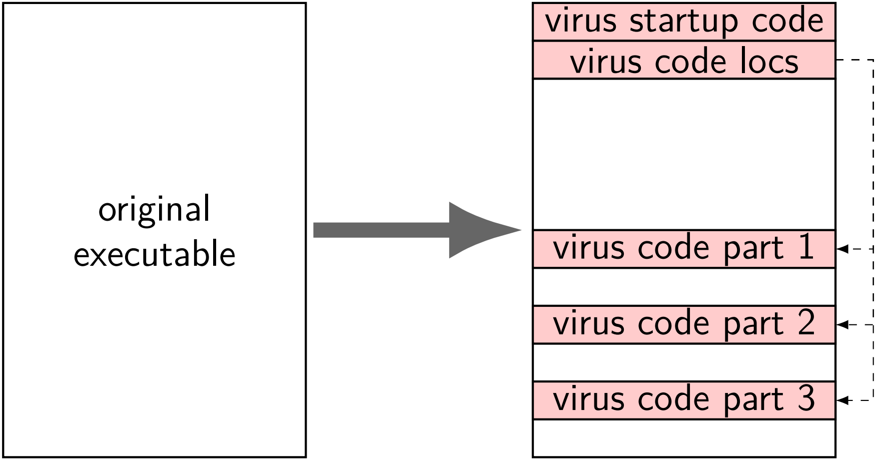
is there enough empty space?

cavities look awfully small

really small viruses?

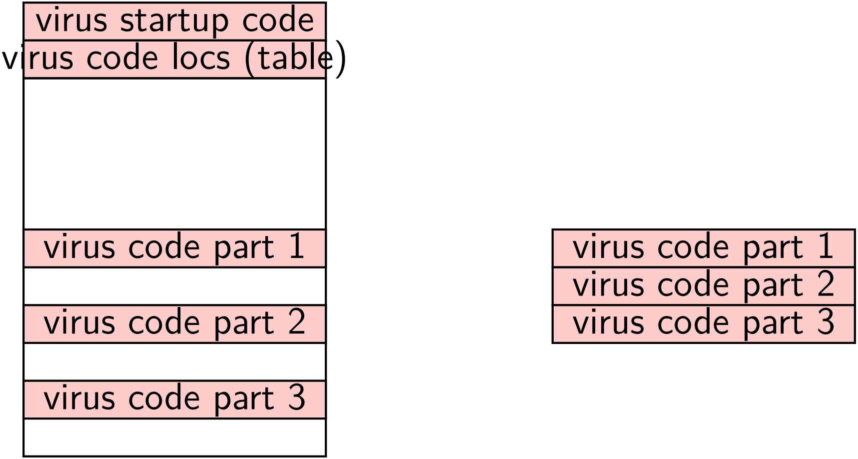
solution: chain cavities tgoether

case study: CIH (1)



case study: CIH (2)

in memory:



CIH cavities

gaps between sections

- common Windows linker aligned sections
- (align = start on address multiple of N, e.g. 4096)
- (normal Linux linker doesn't do this...)

reassembling code avoids worrying about splitting instructions

where to put code: options

one *or more* of:

replacing executable code

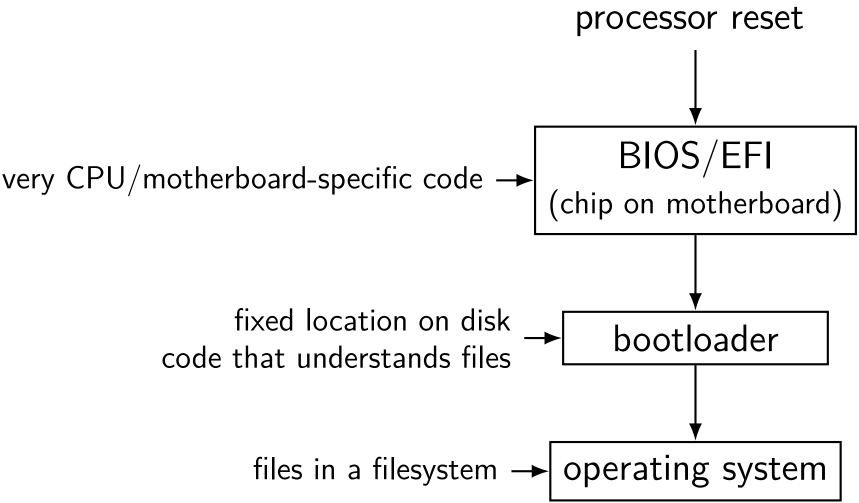
after executable code (Vienna)

in unused executable code

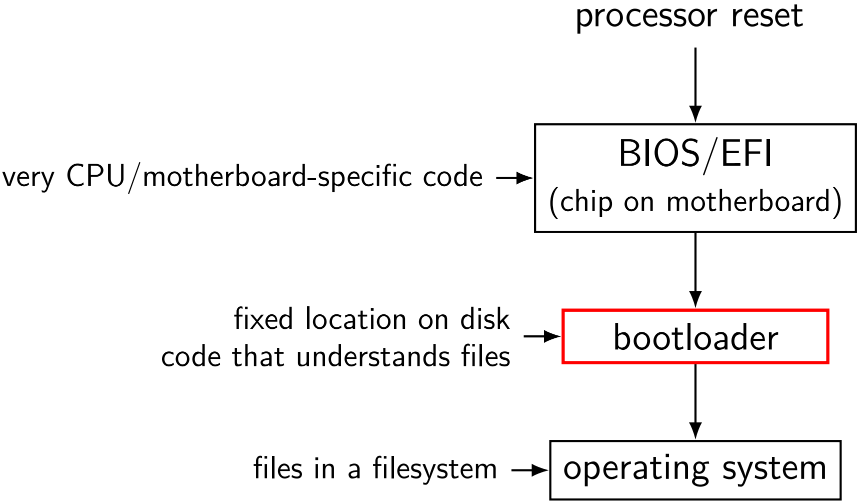
inside OS code

in memory

boot process



boot process



bootloaders in the DOS era

used to be common to boot from floppies

default to booting from floppy if present

even if hard drive to boot from

applications distributed as bootable floppies

so bootloaders on all devices were a target for viruses

historic bootloader layout

bootloader in first sector (512 bytes) of device

(along with partition information)

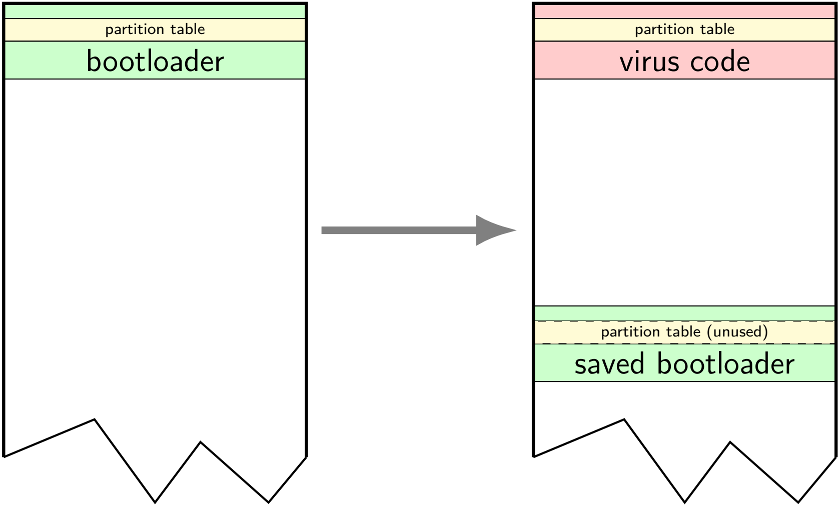
code in BIOS to copy bootloader into RAM, start running

bootloader responsible for disk I/O etc.

- some library-like functionality in BIOS for I/O

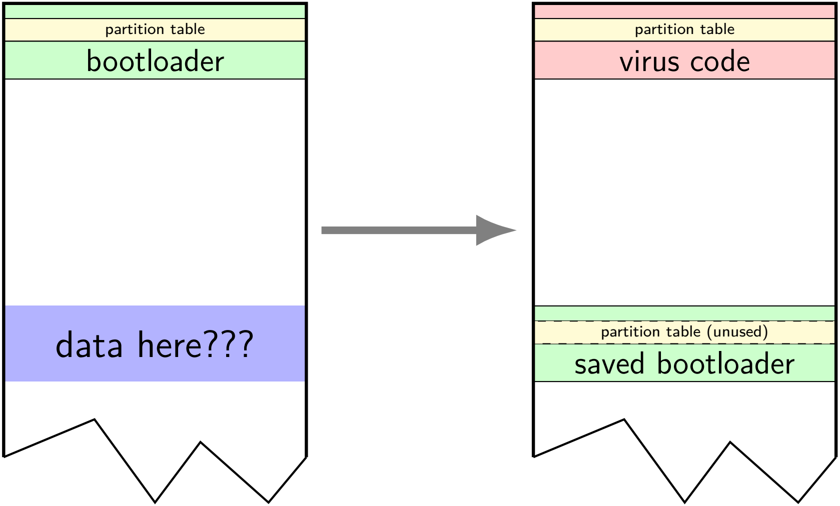
bootloader viruses

example: Stoned



bootloader viruses

example: Stoned



data here???

might be data there — risk

some unused space after partition table/boot loader common

(allegedly)

also be filesystem metadata not used on smaller floppies/disks

but could be wrong — oops

modern bootloaders — UEFI

BIOS-based boot is going away (slowly)

new thing: UEFI (Universal Extensible Firmware Interface)

like BIOS:

- library functionality for bootloaders
- loads initial code from disk/DVD/etc.

unlike BIOS:

- much more understanding of file systems
- much more modern set of library calls

modern bootloaders — secure boot

"Secure Boot" is a common feature of modern bootloaders

idea: UEFI/BIOS code checks bootloader code, fails if not okay

- requires user intervention to use not-okay code

Secure Boot and keys

Secure Boot relies on cryptographic signatures

- idea: accept only "legitimate" bootloaders
- legitimate: known authority vouched for them

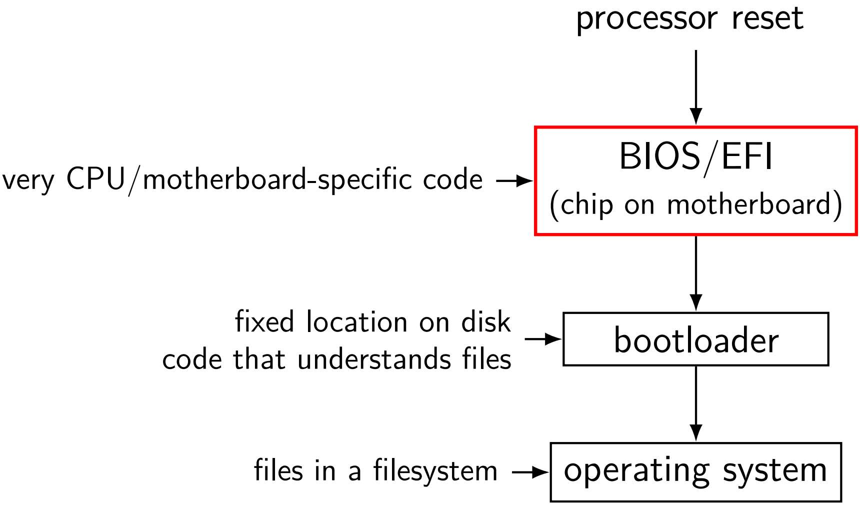
user control of their own systems?

- in theory: can add own keys

what about changing OS instead of bootloader?

- need smart bootloader

boot process



BIOS/UEFI implants

infrequent

BIOS/UEFI code is very non-portable

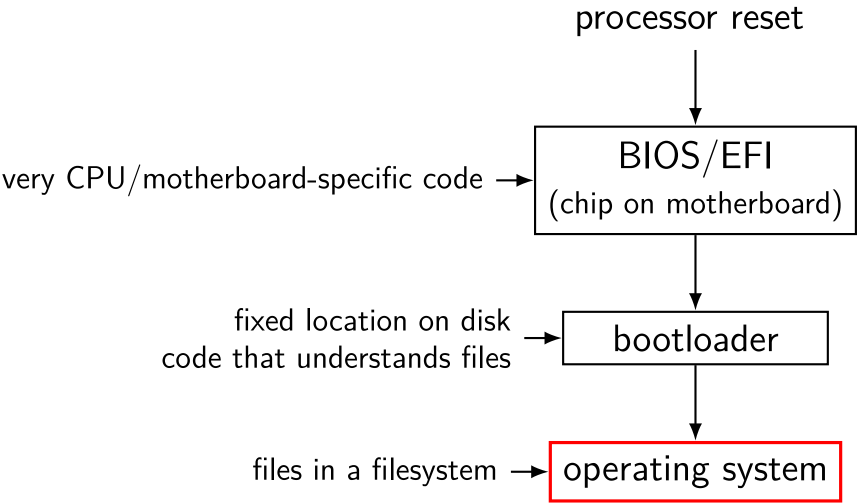
BIOS/UEFI update often requires physical access

BIOS/UEFI code sometimes requires cryptographic signatures

…but very hard to remove — can reinstall other malware

reports that Hacking Team (Milan-based malware company) had UEFI-infecting "rootkit"

boot process



system files

simpliest strategy: stuff that runs when you start your computer

add a new startup program, run in the background

- easy to blend in

alternatively, infect one of many system programs automatically run

memory residence

malware wants to keep doing stuff

one option — background process (easy on modern OSs)

also stealthy options:

- insert self into OS code
- insert self into other running programs

more commonly, OS code used for hiding malware

- topic for later

virus choices

where to put code

how to get code ran

invoking virus code: options

boot loader

change starting location

alternative approaches: “entry point obscuring”

edit code that’s going to run anyways

replace a function pointer (or similar)

…

invoking virus code: options

boot loader

change starting location

alternative approaches: “entry point obscuring”

edit code that’s going to run anyways

replace a function pointer (or similar)

…

starting locations

```
/bin/ls:     file format elf64-x86-64
/bin/ls
architecture: i386:x86-64, flags 0x00000112:
EXEC_P, HAS_SYMS, D_PAGED
start address 0x00000000004049a0
```

modern executable formats have 'starting address' field

just change it, insert jump to old address after virus code

invoking virus code: options

boot loader

change starting location

alternative approaches: “entry point obscuring”

edit code that’s going to run anyways

replace a function pointer (or similar)

…

run anyways?

add code at start of program (Vienna)

return with padding after it:

```
404a01:     c3              retq
404a02:     0f 1f 40 00     nopl   0x0(%rax)
            replace with
404a01:     e9 XX XX XX XX  jmpq    YYYYYYY
```

any random place in program?

just not in the middle of instruction

challenge: valid locations

x86: probably don't want a full instruction parser

x86: might be non-instruction stuff mixed in with code:

```
do_some_floating_point_stuff:
            movss float_one(%rip), %xmm0
            ...
            retq
float_one: .float 1
```

- floating point value one (`00 00 80 3f`) is not valid machine code
- disassembler might lose track of instruction boundaries

finding function calls

one idea: replace calls

normal x86 call FOO: E8 *(32-bit value: PC - address of foo)*

could look for E8 in code — lots of false positives

- probably even if one excludes out-of-range addresses

really finding function calls

e.g. some popular compilers started x86-32 functions with

```
foo:
    push %ebp          // push old frame pointer
    // 0x55
    mov %ebp, %esp  // set frame pointer to stack
    // 0x89 0xec
```

use to identify when `e8` refers to real function

- (full version: also have some other function start patterns)

remember stubs?

```
0000000000400400 <puts@plt>:
  400400:        ff 25 12 0c 20 00            jmpq   *0x200c12(%rip)
                    /* 0x200c12+RIP = _GLOBAL_OFFSET_TABLE_+0x18 */
  400406:        68 00 00 00 00               pushq  $0x0
  40040b:        e9 e0 ff ff ff               jmpq   4003f0 <_init+0x28>
     replace with:
  400400:        e8 XX XX XX XX          jmpq virus_code
  400405:       90                      nop
  400406:        68 00 00 00 00               pushq  $0x0
  40040b:        e9 e0 ff ff ff               jmpq   4003f0 <_init+0x28>
```

in known location (particular section of executable)

invoking virus code: options

boot loader

change starting location

alternative approaches: “entry point obscuring”

edit code that's going to run anyways

replace a function pointer (or similar)

…

stubs again

```
0000000000400400 <puts@plt>:
  400400:        ff 25 12 0c 20 00               jmpq   *0x200c12(%rip)
                    /* 0x200c12+RIP = _GLOBAL_OFFSET_TABLE_+0x18 */
  400406:        68 00 00 00 00                  pushq  $0x0
  40040b:        e9 e0 ff ff ff                  jmpq   4003f0 <_init+0x28>
```

don't edit stub — edit initial value of `_GLOBAL_OFFSET_TABLE`

- stored in data section of executable

originally: pointer `0x400406`; new — virus code

relocations?

```
hello.exe:     file format elf64-x86-64

DYNAMIC RELOCATION RECORDS
OFFSET           TYPE              VALUE
0000000000600ff8 R_X86_64_GLOB_DAT  __gmon_start__
0000000000601018 R_X86_64_JUMP_SLOT  puts@GLIBC_2.2.5
    replace with:
0000000000601018 R_X86_64_JUMP_SLOT  _start + offset_of_virus
0000000000601020 R_X86_64_JUMP_SLOT  __libc_start_main@GLIBC_2.2.5
```

tricky — usually no symbols from executable in dynamic symbol table

- (symbols from debugger/disassembler are a different table)
- Linux — need to link with `-rdynamic`

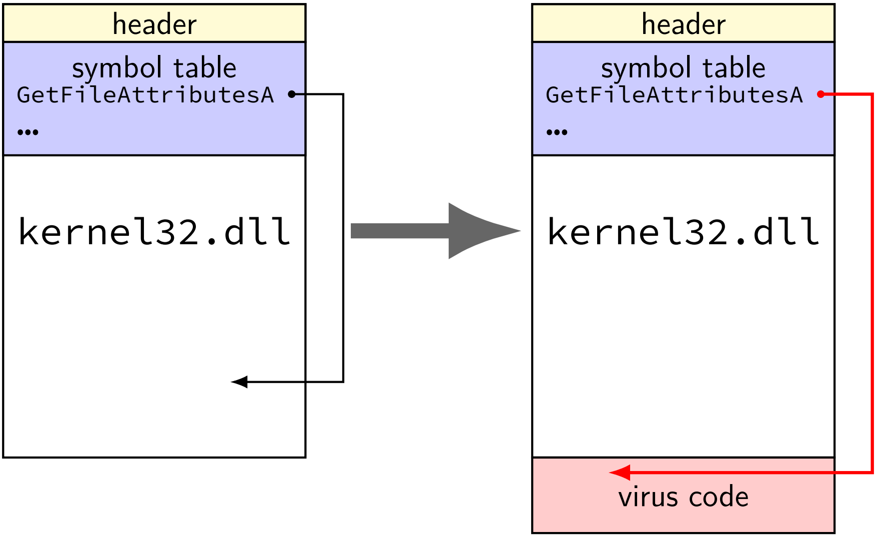
relocations?

```
hello.exe:     file format elf64-x86-64

DYNAMIC RELOCATION RECORDS
OFFSET           TYPE              VALUE
0000000000600ff8 R_X86_64_GLOB_DAT  __gmon_start__
0000000000601018 R_X86_64_JUMP_SLOT  puts@GLIBC_2.2.5
    replace with:
0000000000601018 R_X86_64_JUMP_SLOT  _start + offset_of_virus
0000000000601020 R_X86_64_JUMP_SLOT  __libc_start_main@GLIBC_2.2.5
```

but...same idea works on shared library itself

infecting shared libraries



summary

how to hide:

- separate executable
- append
- existing “unused” space
- compression

how to run:

- change entry point
- or “entry point obscuring”:
- change some code (requires care!)
- change library

32-bit ModRM table

r8(/r) r16(/r) r32(/r) mm(/r) xmm(/r) (In decimal) /digit (Opcode) (In binary) REG =		
Effective Address	**Mod**	**R/M**
[EAX]	00	000
[ECX]		001
[EDX]		010
[EBX]		011
[--][--][1]		100
disp32[2]		101
[ESI]		110
[EDI]		111
[EAX]+disp8[3]	01	000
[ECX]+disp8		001
[EDX]+disp8		010
[EBX]+disp8		011
[--][--]+disp8		100
[EBP]+disp8		101
[ESI]+disp8		110
[EDI]+disp8		111
[EAX]+disp32	10	000
[ECX]+disp32		001
[EDX]+disp32		010
[EBX]+disp32		011
[--][--]+disp32		100
[EBP]+disp32		101
[ESI]+disp32		110
[EDI]+disp32		111
EAX/AX/AL/MM0/XMM0	11	000
ECX/CX/CL/MM/XMM1		001
EDX/DX/DL/MM2/XMM2		010
EBX/BX/BL/MM3/XMM3		011
ESP/SP/AH/MM4/XMM4		100
EBP/BP/CH/MM5/XMM5		101
ESI/SI/DH/MM6/XMM6		110
EDI/DI/BH/MM7/XMM7		111

SIB table

Table 2-3. 32-Bit Addressing Forms with the SIB Byte

r32 (In decimal) Base = (In binary) Base =			EAX 0 000	ECX 1 001	EDX 2 010	EBX 3 011	ESP 4 100	[*] 5 101	ESI 6 110	EDI 7 111
Scaled Index	**SS**	**Index**	**Value of SIB Byte (in Hexadecimal)**							
[EAX]	00	000	00	01	02	03	04	05	06	07
[ECX]		001	08	09	0A	0B	0C	0D	0E	0F
[EDX]		010	10	11	12	13	14	15	16	17
[EBX]		011	18	19	1A	1B	1C	1D	1E	1F
none		100	20	21	22	23	24	25	26	27
[EBP]		101	28	29	2A	2B	2C	2D	2E	2F
[ESI]		110	30	31	32	33	34	35	36	37
[EDI]		111	38	39	3A	3B	3C	3D	3E	3F
[EAX*2]	01	000	40	41	42	43	44	45	46	47
[ECX*2]		001	48	49	4A	4B	4C	4D	4E	4F
[EDX*2]		010	50	51	52	53	54	55	56	57
[EBX*2]		011	58	59	5A	5B	5C	5D	5E	5F
none		100	60	61	62	63	64	65	66	67
[EBP*2]		101	68	69	6A	6B	6C	6D	6E	6F
[ESI*2]		110	70	71	72	73	74	75	76	77
[EDI*2]		111	78	79	7A	7B	7C	7D	7E	7F
[EAX*4]	10	000	80	81	82	83	84	85	86	87
[ECX*4]		001	88	89	8A	8B	8C	8D	8E	8F
[EDX*4]		010	90	91	92	93	94	95	96	97
[EBX*4]		011	98	99	9A	9B	9C	9D	9E	9F
none		100	A0	A1	A2	A3	A4	A5	A6	A7
[EBP*4]		101	A8	A9	AA	AB	AC	AD	AE	AF
[ESI*4]		110	B0	B1	B2	B3	B4	B5	B6	B7
[EDI*4]		111	B8	B9	BA	BB	BC	BD	BE	BF
[EAX*8]	11	000	C0	C1	C2	C3	C4	C5	C6	C7
[ECX*8]		001	C8	C9	CA	CB	CC	CD	CE	CF
[EDX*8]		010	D0	D1	D2	D3	D4	D5	D6	D7
[EBX*8]		011	D8	D9	DA	DB	DC	DD	DE	DF
none		100	E0	E1	E2	E3	E4	E5	E6	E7
[EBP*8]		101	E8	E9	EA	EB	EC	ED	EE	EF
[ESI*8]		110	F0	F1	F2	F3	F4	F5	F6	F7
[EDI*8]		111	F8	F9	FA	FB	FC	FD	FE	FF

NOTES:

1. The [*] nomenclature means a disp32 with no base if the MOD is 00B. Otherwise, [*] means disp8 or disp32 + [EBP]. This provides the