

# Advanced x86: BIOS and System Management Mode Internals

## *Reset Vector*

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# Reset Vector Execution Environment



# Real-Address Mode (Real Mode)

- The original x86 operating mode
- Referred to as “Real Mode” for short
- Introduced way back in 8086/8088 processors
- Was the only operating mode until Protected Mode (with its "virtual addresses") was introduced in the Intel 286
- Exists today solely for compatibility so that code written for 8086 will still run on a modern processor
  - Someday processors will boot into protected mode instead
- In the BIOS' I have looked at, the general theme seems to be to get out of Real Mode as fast as possible
- Therefore we won't stay here long either

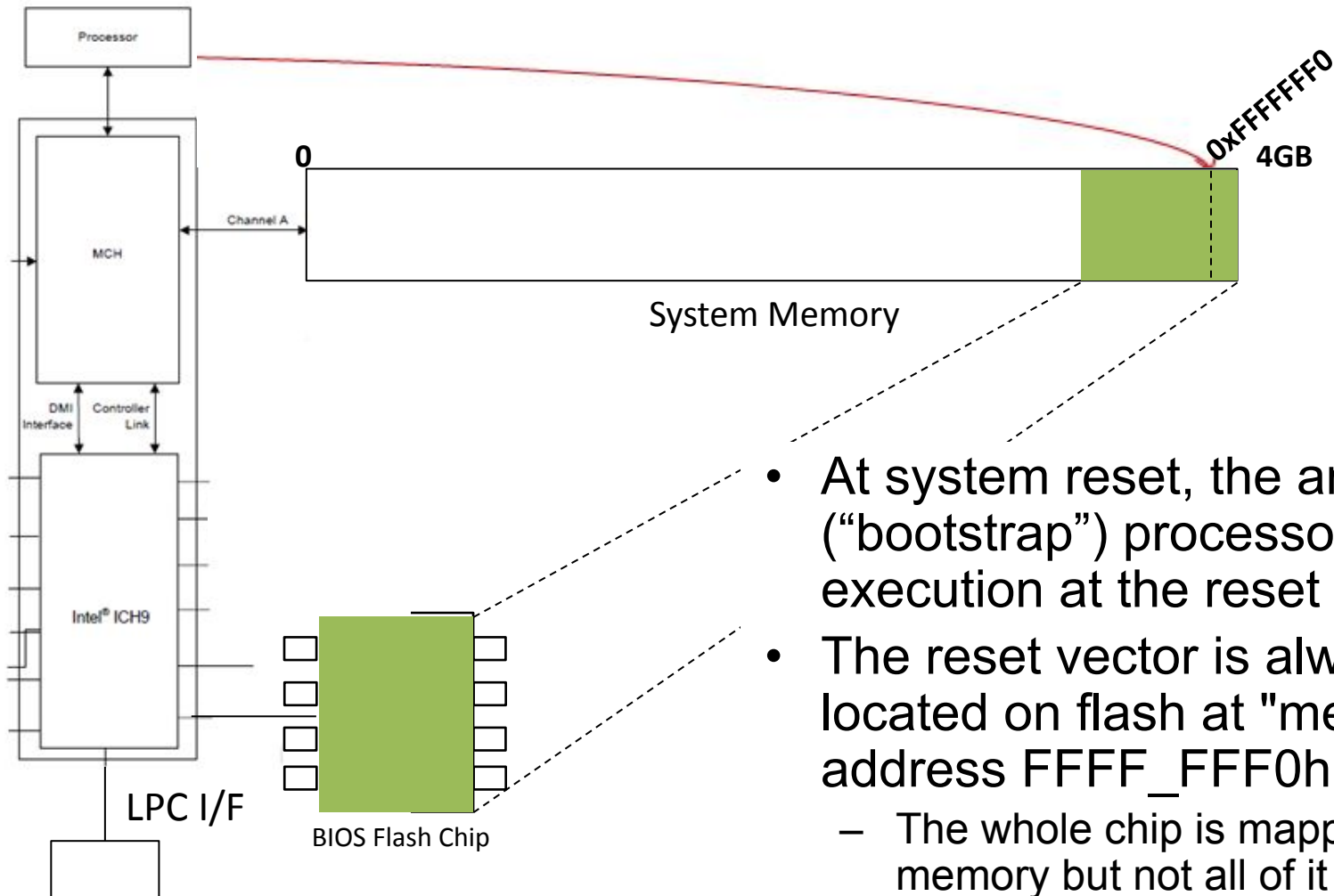
| Name   | Value     |
|--------|-----------|
| EAX    | 00000000  |
| EBX    | 00000000  |
| ECX    | 00000000  |
| EDX    | 00010676* |
| EBP    | 00000000  |
| ESI    | 00000000  |
| EDI    | 00000000  |
| ESP    | 00000000  |
| CS     | F000      |
| DS     | 0000      |
| SS     | 0000      |
| ES     | 0000      |
| FS     | 0000      |
| GS     | 0000      |
| EIP    | 0000FFF0  |
| EFLAGS | 00000002  |

# Processor State After Reset

- EAX, EBX, ECX, EBP, ESI, EDI, ESP are all reset to 0
- EDX contains the CPU stepping identification information
  - Same info returned in EAX when CPUID is called with EAX initialized to '1'
  - \*This will vary of course, the value in the table to the left corresponds to the Core2Duo inside the E6400
- The base registers are 0 with the exception of CS which is initialized with F000
- EIP (or IP since it's 16-bit mode) is initialized with (0000)FFF0
  - CS:IP = F:FFF0h
- EFLAGS is 00000002h
  - Only hard-coded bit 1 is asserted
  - If I were sitting at a breakpoint at the entry vector, then bit 16 (resume flag) would be asserted indicating that debug exceptions (#DB) are disabled.

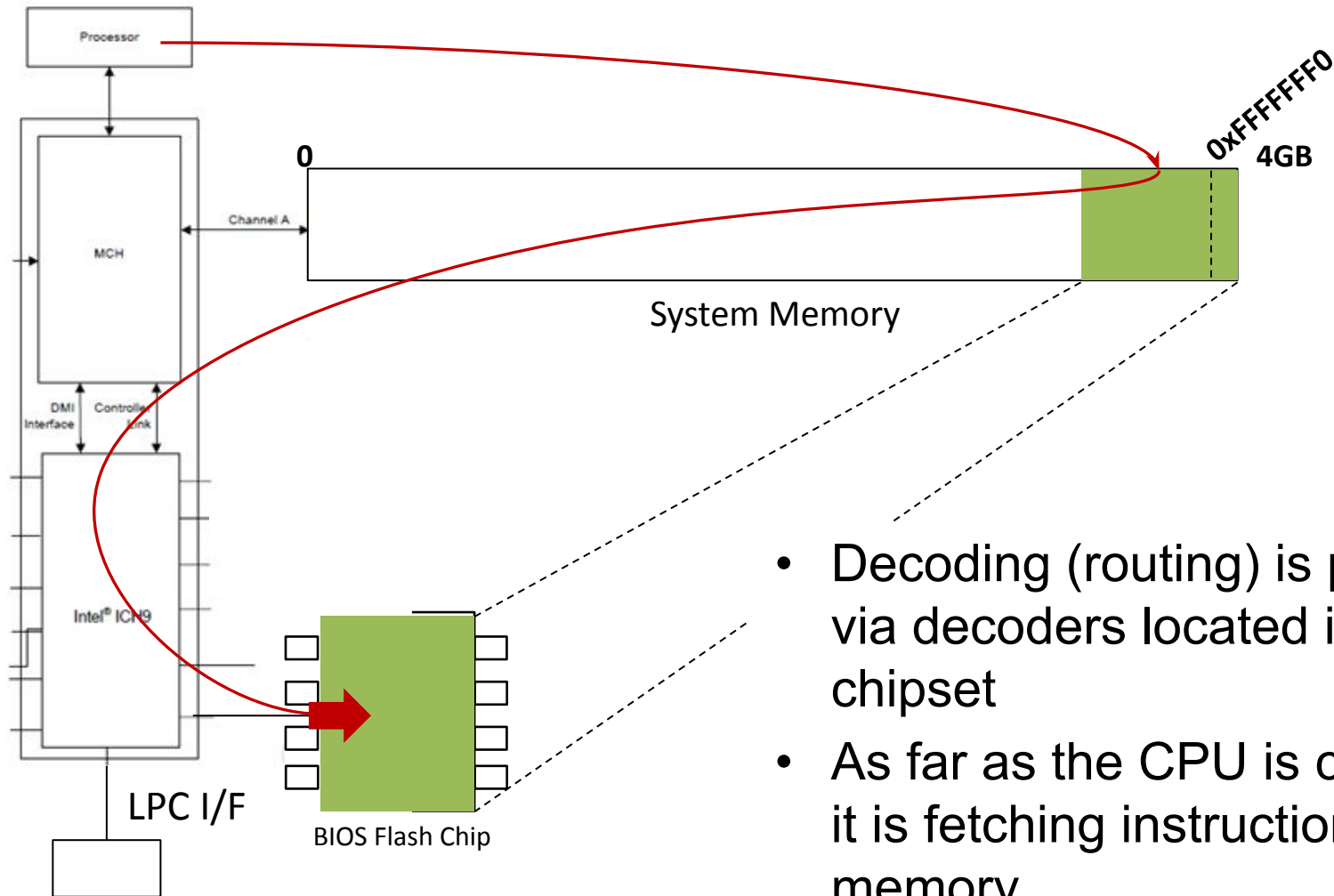


# Reset Vector



- At system reset, the an initial (“bootstrap”) processor begins execution at the reset vector
- The reset vector is always located on flash at "memory" address FFFF\_FFF0h
  - The whole chip is mapped to memory but not all of it is readable due to protections on the flash device itself

# Reset Vector Decoding



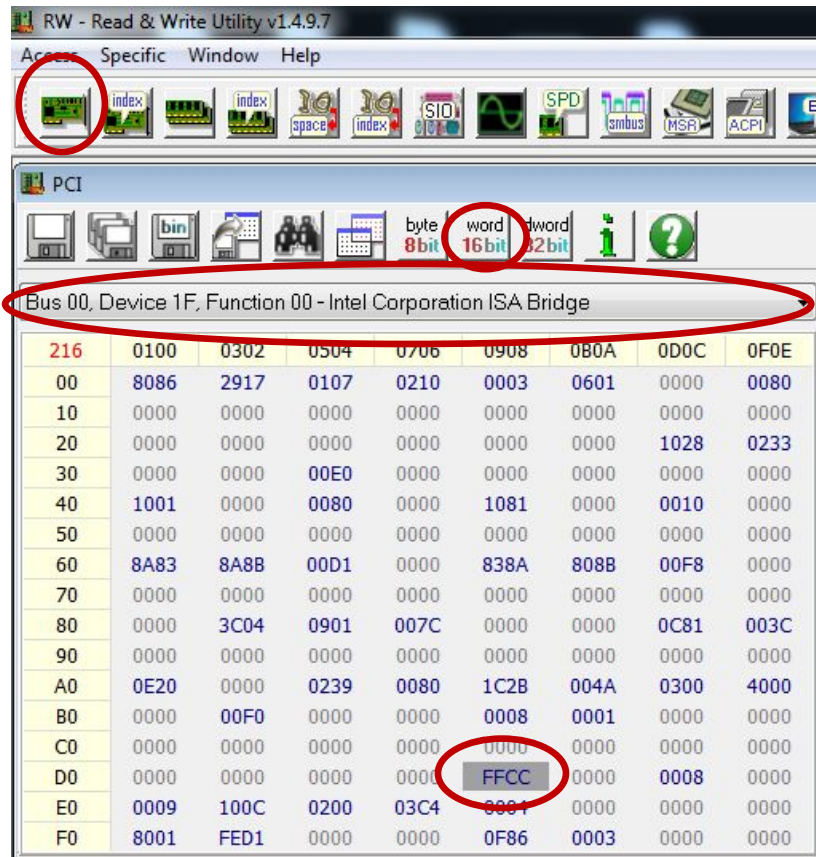
- Decoding (routing) is performed via decoders located in the chipset
- As far as the CPU is concerned it is fetching instructions from memory
- But in fact it's from the SPI flash



# Aside: Forensics People

- If the top of memory always contains a memory-mapped copy of part of the SPI flash chip, that means it should theoretically show up in memory forensic dumps (e.g. those given out by memory forensic challenges)
- I've never had time to test this, but you should see if you can go grab some memory forensics dumps and determine whether there is a complete copy of the BIOS in the memory dump, or only a partial copy (and if partial, where it ends)
  - Probably should start by testing on a system you have known BIOS dump for
  - As I mentioned before, virtual machines have virtual BIOSes, so you could also determine if the dump was taken off a virtual machine by comparing against some virtual BIOSes
- Let me know what you find! :)
  - A volatility plugin to carve BIOS out of memdumps would be cool 😊
    - IIRC someone might have done this now, but I can't find the link again...

# Mini-Lab: BIOS Flash Decoding



- Let's look at some of the decoding (routing) of the BIOS to memory
- Open RW Everything and click on the PCI tab to open up the PCI window
- Click the drop-down tab and select Bus 00, Device 1F, Function 00
- This is the LPC device
- Click on the Word 16 bit button to arrange the PCI configuration registers into 16-bit words
- Notice word offset D8-D9h

# Mini-Lab: BIOS Flash Decoding

## FWH\_DEC\_EN1—Firmware Hub Decode Enable Register (LPC I/F—D31:F0)

Offset Address: D8h-D9h                      Attribute:                      R/W, RO  
Default Value: FFCFh                          Size:                              16 bits

| Bit | Description  |
|-----|--|
| 15  | <b>FWH_F8_EN</b> — RO. This bit enables decoding two 512-KB Firmware Hub memory ranges, and one 128-KB memory range.<br>0 = Disable<br>1 = Enable the following ranges for the Firmware Hub<br>FFF80000h – FFFFFFFFh<br>FFB80000h – FFBFFFFFFh |
| 14  | <b>FWH_F0_EN</b> — R/W. This bit enables decoding two 512-KB Firmware Hub memory ranges.<br>0 = Disable.<br>1 = Enable the following ranges for the Firmware Hub:<br>FFF00000h – FFF7FFFFh<br>FFB00000h – FFB7FFFFh                            |
|     | <b>FWH_E8_EN</b> — R/W. This bit enables decoding two 512-KB Firmware Hub memory ranges.   |

- Offset D8-D9h is FWH\_DEC\_EN1
- As stated, this controls the decoding of ranges to the FWH
- If your system uses SPI and not a Firmware Hub (and it does since FWH is very rare), it still decodes to the SPI BIOS
- We want bit 14 which decodes FFF0\_0000h – FFF7\_FFFFh

**Note: “FWH” is substituted with “BIOS” in the above in the newer datasheets**

# Mini-Lab: BIOS Flash Decoding

- Click Memory button and type address FFF00000

RW - Read & Write Utility v1.4.9.7

Access Specific Window Help

PCI

Bus 00, Device 1F, Function 00 - Intel Corporation ISA Bridge

| 216 | 0100 | 0302 | 0504 | 0706 | 0908 | 0B0A | 0D0C | 0F0E |
|-----|------|------|------|------|------|------|------|------|
| 00  | 8086 | 2917 | 0107 | 0210 | 0003 | 0601 | 0000 | 0080 |
| 10  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 20  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 1028 | 0233 |
| 30  | 0000 | 0000 | 00E0 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 40  | 1001 | 0000 | 0080 | 0000 | 1081 | 0000 | 0010 | 0000 |
| 50  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 60  | 8A83 | 8A8B | 00D1 | 0000 | 838A | 808B | 00F8 | 0000 |
| 70  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 80  | 0000 | 3C04 | 0901 | 007C | 0000 | 0000 | 0C81 | 003C |
| 90  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| A0  | 0E20 | 0000 | 0239 | 0080 | 1C2B | 004A | 0300 | 4000 |
| B0  | 0000 | 00F0 | 0000 | 0000 | 0008 | 0001 | 0000 | 0000 |
| C0  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| D0  | 0000 | 0000 | 0000 | 0000 | FFCC | 0000 | 0008 | 0000 |
| E0  | 0009 | 100C | 0200 | 03C4 | 0004 | 0000 | 0000 | 0000 |
| F0  | 8001 | FED1 | 0000 | 0000 | 0F86 | 0003 | 0000 | 0000 |

Memory

Address = FFF00000

| 18 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 00 | D2 | 46 | D1 | 39 | 01 | 12 | D4 | 3C | A1 | 06 | 30 | 74 | 63 | 68 | 21 | D2 |
| 10 | 89 | 40 | 36 | 11 | E8 | 59 | F0 | 93 | 05 | 40 | 8C | F0 | E9 | DA | FE | 17 |
| 20 | 1B | 00 | 34 | 62 | D1 | A3 | 47 | D1 | BD | 00 | 65 | 55 | DF | 13 | 29 | D1 |
| 30 | 8E | 80 | 6E | 66 | 69 | 67 | 75 | 72 | 61 | 74 | 69 | 02 | ED | 40 | 73 | 70 |
| 40 | 61 | 63 | 65 | 92 | B2 | 20 | 89 | 0E | 46 | 92 | 08 | 03 | B0 | 71 | 99 | 10 |
| 50 | B8 | 0A | 06 | B0 | C0 | A7 | E8 | EE | 07 | 0F | 82 | 63 | FF | 3C | 1A | 75 |
| 60 | 09 | 66 | 72 | 3A | D1 | 9A | F1 | 3D | C0 | 2F | BA | 04 | 00 | F6 | C1 | 04 |
| 70 | 74 | 02 | D1 | E2 | 03 | FA | 07 | 29 | E1 | 0E | F0 | 03 | 7B | FF | F6 | C1 |
| 80 | 01 | 75 | ED | E8 | BD | 07 | 3C | 11 | 74 | 04 | 3C | 12 | 75 | 07 | 03 | 30 |
| 90 | D1 | 41 | E1 | 93 | 70 | E1 | F0 | 66 | 8B | D9 | E9 | 46 | FE | E4 | A7 | E0 |
| A0 | EA | 00 | 08 | F2 | 97 | 71 | FB | 45 | 34 | F2 | E0 | F8 | 93 | 22 | 47 | 00 |
| B0 | 01 | 92 | 62 | 03 | 07 | E0 | 02 | D2 | 77 | E0 | 07 | 42 | 3C | F2 | 93 | D1 |
| C0 | 5D | 30 | D2 | 8B | 5F | 04 | 17 | 85 | 10 | 72 | 22 | 23 | 38 | 30 | 10 | 83 |
| D0 | C7 | 04 | 13 | 73 | 00 | 03 | 02 | 07 | 05 | 16 | 00 | 0B | 23 | 4F | 00 | 06 |
| E0 | 14 | 5B | 32 | 3A | 00 | C2 | 34 | 14 | D1 | F7 | 00 | 52 | D2 | 6B | 90 | 60 |
| F0 | 12 | 9C | FA | 81 | FA | F8 | 0C | 75 | 3B | 82 | 72 | 50 | A8 | 12 | 66 | EF |

- Therefore, with FWH\_DEC\_EN bit 14 asserted, we're decoding to a portion of BIOS binary



# Mini-Lab: BIOS Flash Decoding

- This memory range is still read-only
- This example is to help provide a picture of the initial boot environment

PCI configuration tool showing the configuration for Bus 00, Device 1F, Function 00 - Intel Corporation ISA Bridge. The tool displays a grid of configuration registers. A red arrow points from the 'BFCC' value in the D0 register to the text box below.

| 216 | 0100 | 0302 | 0504 | 0706 | 0908 | 0B0A | 0D0C | 0F0E |
|-----|------|------|------|------|------|------|------|------|
| 00  | 8086 | 2917 | 0107 | 0210 | 0003 | 0601 | 0000 | 0080 |
| 10  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 20  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 1028 | 0233 |
| 30  | 0000 | 0000 | 00E0 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 40  | 1001 | 0000 | 0080 | 0000 | 1081 | 0000 | 0010 | 0000 |
| 50  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 60  | 8A83 | 8A8B | 00D1 | 0000 | 838A | 808B | 00F8 | 0000 |
| 70  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 80  | 0000 | 3C04 | 0901 | 007C | 0000 | 0000 | 0C81 | 003C |
| 90  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| A0  | 0E20 | 0000 | 0239 | 0080 | 1C2B | 004A | 0300 | 4000 |
| B0  | 0000 | 00F0 | 0000 | 0000 | 0008 | 0001 | 0000 | 0000 |
| C0  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| D0  | 0000 | 0000 | 0000 | 0000 | BFCC | 0000 | 0008 | 0000 |
| E0  | 0009 | 100C | 0200 | 03C4 | 0004 | 0000 | 0000 | 0000 |
| F0  | 8001 | FED1 | 0000 | 0000 | 0F86 | 0003 | 0000 | 0000 |

Memory tool showing a memory dump at Address = FFF00000. The dump displays a grid of memory addresses and their corresponding values, which are all FF. A red circle highlights the memory range from address 00 to F0.

| 18 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 00 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| 10 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| 20 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| 30 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| 40 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| 50 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| 60 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| 70 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| 80 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| 90 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| A0 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| B0 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| C0 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| D0 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| E0 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |
| F0 | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF | FF |

- De-assert bit 14 (set to 0xBFCC)
- Decoded to memory now

# Mini-Lab: BIOS Flash Decoding

RW - Read & Write Utility v1.4.9.7

Access Specific Window Help

PCI

Bus 00, Device 1F, Function 00 - Intel Corporation ISA Bridge

| 216 | 0100 | 0302 | 0504 | 0706 | 0908 | 0B0A | 0D0C | 0F0E |
|-----|------|------|------|------|------|------|------|------|
| 00  | 8086 | 2917 | 0107 | 0210 | 0003 | 0601 | 0000 | 0080 |
| 10  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 20  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 1028 | 0233 |
| 30  | 0000 | 0000 | 00E0 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 40  | 1001 | 0000 | 0080 | 0000 | 1081 | 0000 | 0010 | 0000 |
| 50  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 60  | 8A83 | 8A8B | 00D1 | 0000 | 838A | 808B | 00F8 | 0000 |
| 70  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 80  | 0000 | 3C04 | 0901 | 007C | 0000 | 0000 | 0C81 | 003C |
| 90  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| A0  | 0E20 | 0000 | 0239 | 0080 | 1C2B | 004A | 0300 | 4000 |
| B0  | 0000 | 00F0 | 0000 | 0000 | 0008 | 0001 | 0000 | 0000 |
| C0  | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| D0  | 0000 | 0000 | 0000 | 0000 | FFCC | 0000 | 0008 | 0000 |
| E0  | 0009 | 100C | 0200 | 03C4 | 0001 | 0000 | 0000 | 0000 |
| F0  | 8001 | FED1 | 0000 | 0000 | 0F86 | 0003 | 0000 | 0000 |

- Reset it back to 0xFFCC
- Couple of notes:
- Your original values may differ since BIOS flips them on and off as the developers decided necessary
- Bit 15 is Read Only and always asserted

# Mini-data-collection Lab: Reset Vector in BIOS Binary

```
File Edit Search View Analysis Extras Window ?
16 ANSI hex
e6400_bios_A29.bin
Offset(h) 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
003FFF70 FF FF 00 00 FD 9F 01 FF 78 00 00 FF FF FF 00 00 ỳỳ..ỳỲ.ỳx..ỳỲỳ..
003FFF80 EA 87 FF 00 00 08 00 B8 10 00 8E D8 8E C0 8E E0 ề+ỳ.....žøžÀžà
003FFF90 90 EA F0 FF 30 00 00 00 00 00 00 00 00 00 00 00  .ềỳ0.....
003FFFA0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  .....
003FFFB0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  .....
003FFFC0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  .....
003FFFD0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  .....
003FFFE0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  .....
003FFFF0 E9 3D FE 00 00 00 00 00 00 00 00 00 00 00 00 00 00  é=p.....
Offset: 0 Overwrite
```

- If we dump the BIOS and look at it in a hex editor, at the end of the file we will see a jump instruction (near, relative jump)
- The chipset aligns the flash so that the limit of the BIOS region (always either the only/last region on the flash) aligns with address FFFF\_FFF0h
- The CPU executes these instructions in 16-bit Real Mode

# Real Mode Memory

- 16-bit operating mode
- Segmented memory model
- When operating in real-address mode, the default addressing and operand size is 16 bits
- An address-size override can be used in real-address mode to enable access to 32-bit addressing (like the extended general-purpose registers EAX, EDX, etc.)
- However, the maximum allowable 32-bit linear address is still 000F\_FFFFH ( $2^{20} - 1$ )
- So how can it address FFFF\_FFF0h?
  - We'll answer that in a bit



# Real Mode Addressing: Segment Registers

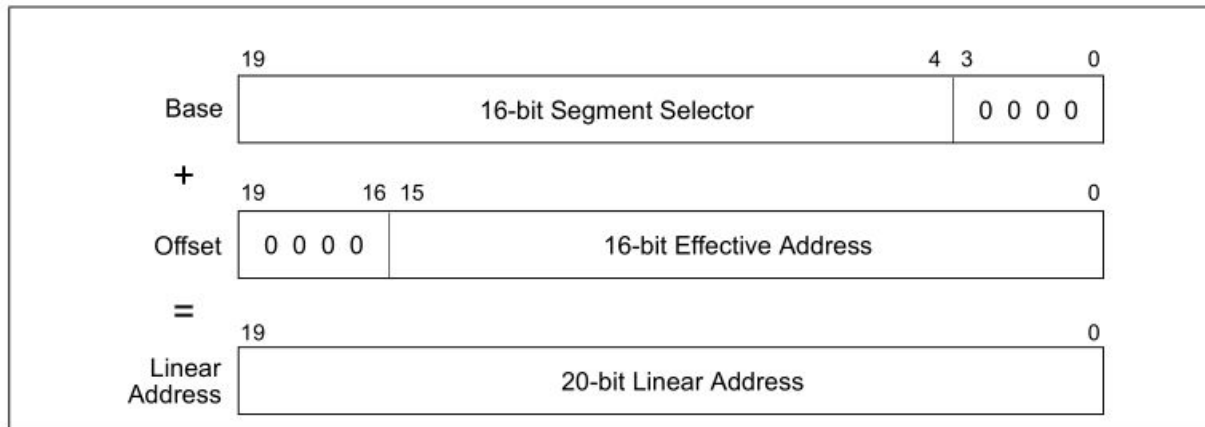


Figure 20-1. Real-Address Mode Address Translation

- CS, DS, SS, ES, FS, GS
- Only six segments can be active at any one time
- 16-bit segment selector contains a pointer to a memory segment of 64 Kbytes (max)
- 16-bit Effective address can access up to 64KB of memory address space
- Segment Selector combines with effective address to provide a 20-bit linear address
- So an application running in real mode can access an address space of up to 384 KB at a time (including stack segment) without switching segments

# Real Mode Addressing

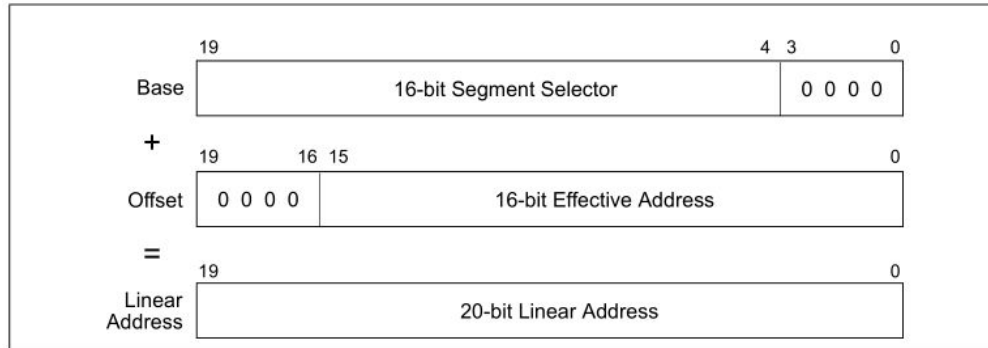


Figure 20-1. Real-Address Mode Address Translation

$$\begin{array}{r} 1234:5678 = 12340H \\ + 5678H \\ \hline 179B8H \end{array}$$

- As shown in Figure 20-1 in the Intel SW Developers guide
- The Segment Selector (CS, DS, SS, etc.) is left-shifted 4 bits
- The 16-bit Segment Selector is then added to a 16-bit effective address (or offset if you will) within the segment
- Remember, upon entry into the BIOS, all linear addresses are translated as physical (per CR0)

# Real Mode Addressing Problem: Overlap

|           |   |        |
|-----------|---|--------|
| 1234:5678 | = | 12340H |
|           | + | 5678H  |
|           |   | -----  |
|           |   | 179B8H |
|           |   |        |
| 1663:1338 | = | 16630H |
|           | + | 1338H  |
|           |   | -----  |
|           |   | 179B8H |

- Addresses in different segments can overlap
- Given such a limited environment it's no wonder we want to choose a different operating mode as soon as possible

# F:FFFO != FFFF:FFFO

- Every segment register has a “visible” part and a “hidden” part.
- Intel sometimes refers to the “hidden part” as the “descriptor cache”
- It’s called “cache” because it stores the descriptor info so that the processor doesn’t have to resolve it each time a memory address is accessed

| Visible Part     | Hidden Part                             |    |
|------------------|---|----|
| Segment Selector | Base Address, Limit, Access Information | CS |
|                  |   | SS |
|                  |   | DS |
|                  |   | ES |
|                  |   | FS |
|                  |   | GS |

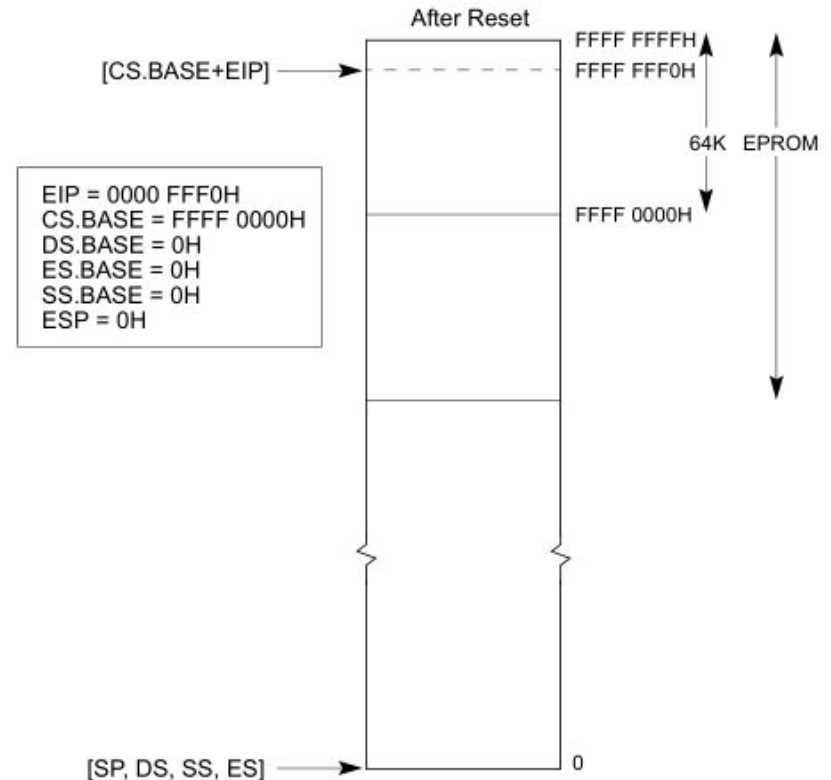
**Figure 3-7. Segment Registers**

# Descriptor Cache

- “When a segment selector is loaded into the visible part of a segment register, the processor also loads the hidden part of the segment register with the base address, segment limit, and [access information] from the segment descriptor pointed to by the segment selector.”
- Real Mode doesn't have protected mode style access-control so the [access information] part is ignored
- This means that the hidden part isn't modified until after a value is loaded into the segment selector
- So the moment CS is modified, the CS.BASE of FFFF\_0000H is replaced with the new value of CS (left shifted 4 bits)

# CS.BASE + EIP

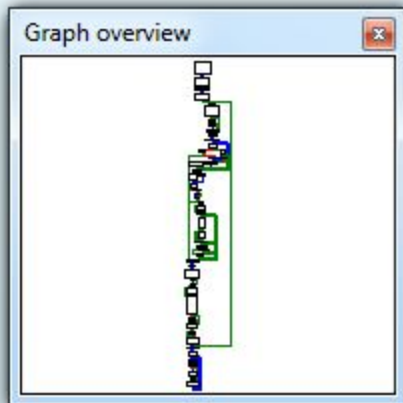
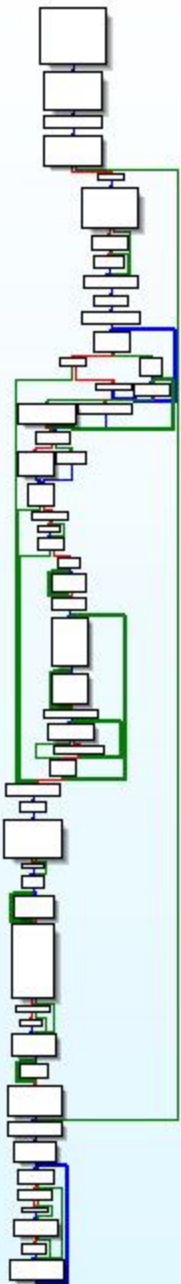
- *CS.BASE* is pre-set to *FFFF\_0000H* upon CPU reset/power-up
- EIP set to *0000\_FFF0H*
- So even though CS is set to *F000H*, *CS.BASE+EIP* makes *FFFF\_FFF0H*
- So when you see references to CS:IP upon power-up being equal to *F:FFF0h*, respectively, now you know how what it really means and how it equates to an entry vector at *FFFF\_FFF0h*



# Reset Vector

- So upon startup, while the processor stays in Real Mode, it can access only the memory range FFFF\_0000h to FFFF\_FFFFh.
- If BIOS were to modify CS while still in Real Mode, the processor would only be able to address 0\_0000h to F\_FFFFh.
  - PAM0 helps out by mapping this range to high memory (another decoder)
- So therefore if your BIOS is large enough that it is mapped below FFFF\_0000H and you want to access that part of it, you best get yourself into Protected Mode ASAP.
  - And this is typically what they do

# Analyzing *any* x86 BIOS Binary



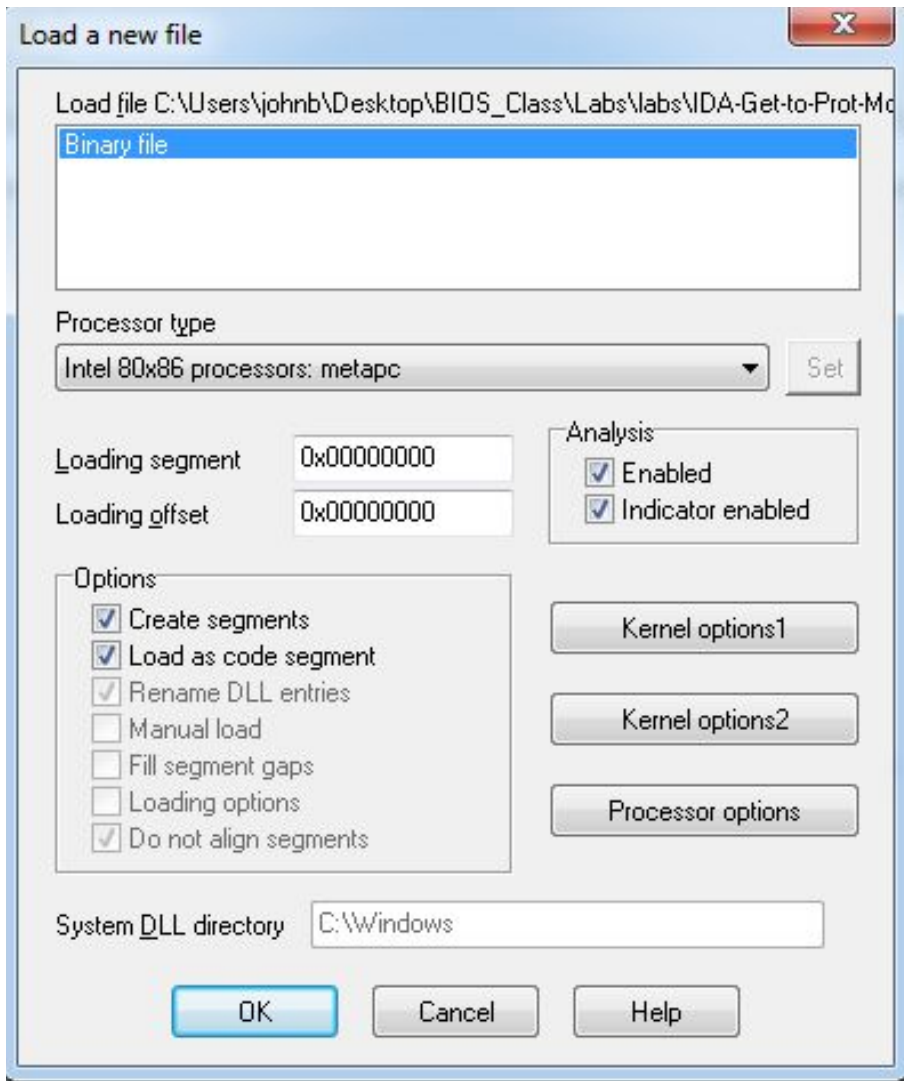
- With UEFI we can usually skip straight to analyzing code we care about.
- But what if you want to analyze a legacy BIOS, or some other non-UEFI x86 BIOS like CoreBoot?
- In that case you may need to do as the computer does, and really read starting from the first instruction
- The subsequent slides provide the generic process to do that



# A dream deferred

- We're going to hold off on the rest of the entry vector analysis for now, and go back to it later if we have time.
  - We never have time ;)
- I left the slides in here for if you want to try to go through an equivalent process
  - Note: I know the slides are a little hard to follow and occasionally make jumps in intuition. I've been wanting to clean these up from John's version, but haven't had time

# 1: Disassemble the BIOS Binary



- Acquire a dump of the BIOS flash from a tool like Flashrom or Copernicus and open it in IDA
- Intel 80x86 metapc setting is fine regardless of IDA version
- Choose to disassemble in **32-bit** mode
- Not a typo, most BIOS' jump into 32-bit protected mode as soon as possible
  - If your BIOS is much older, just edit the segment to 16-bit
- I have the full version of IDA Pro but am using Free version 5.0 to show you that this works with that version
- Other debuggers like OllyDbg should also work

# FIXME

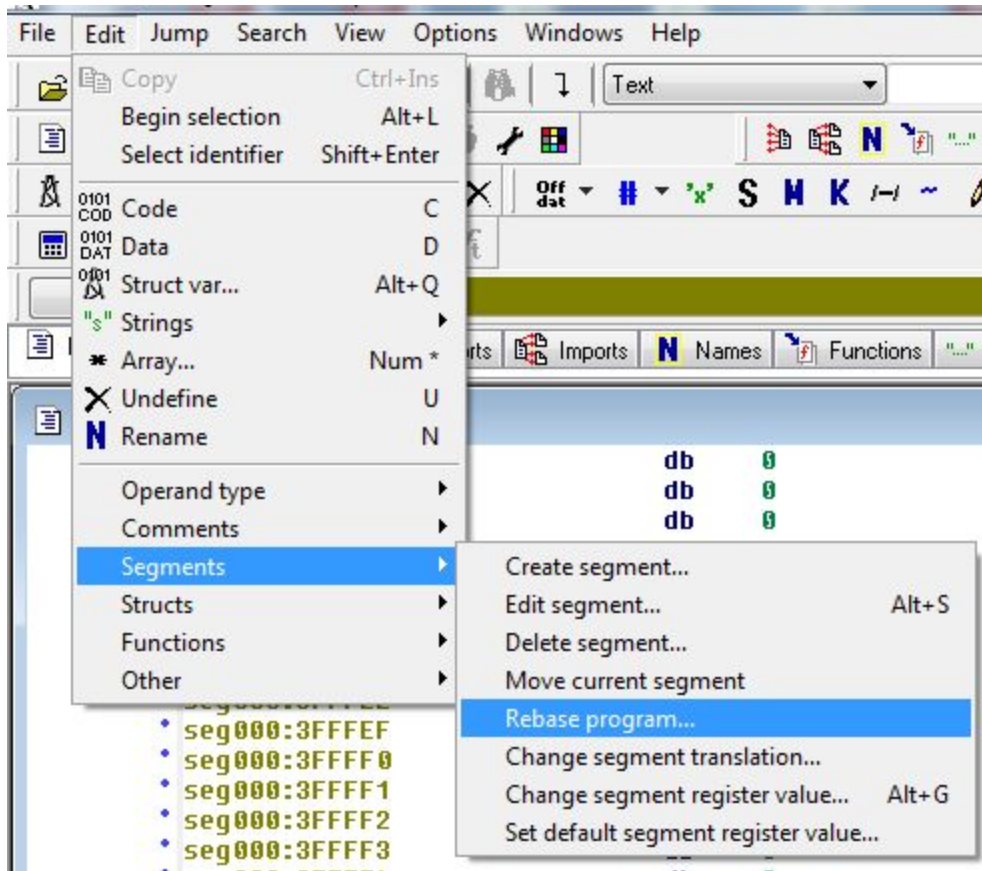
- Update procedure for new IDA demo 6.6

## 2: Rebase the Program

```
IDA View-A
• seg000:0019FFD0 db 0
• seg000:0019FFDE db 0
• seg000:0019FFDF db 0
• seg000:0019FFE0 db 0
• seg000:0019FFE1 db 0
• seg000:0019FFE2 db 0
• seg000:0019FFE3 db 0
• seg000:0019FFE4 db 0
• seg000:0019FFE5 db 0
• seg000:0019FFE6 db 0
• seg000:0019FFE7 db 0
• seg000:0019FFE8 db 0
• seg000:0019FFE9 db 0
• seg000:0019FFEA db 0
• seg000:0019FFEB db 0
• seg000:0019FFEC db 0
• seg000:0019FFED db 0
• seg000:0019FFEE db 0
• seg000:0019FFEF db 0
• seg000:0019FFF0 db 0E9h ; T
• seg000:0019FFF1 db 3Dh ; =
• seg000:0019FFF2 db 0FEh ; !
• seg000:0019FFF3 db 0
• seg000:0019FFF4 db 0
• seg000:0019FFF5 db 0
• seg000:0019FFF6 db 0
• seg000:0019FFF7 db 0
```

- First thing we're going to do is rebase the program
- We know the entire image of this BIOS is mapped to memory so that its upper address boundary is at FFFF\_FFFFh with the entry vector at FFFF\_FFF0h
- Let's touch these up to reflect this

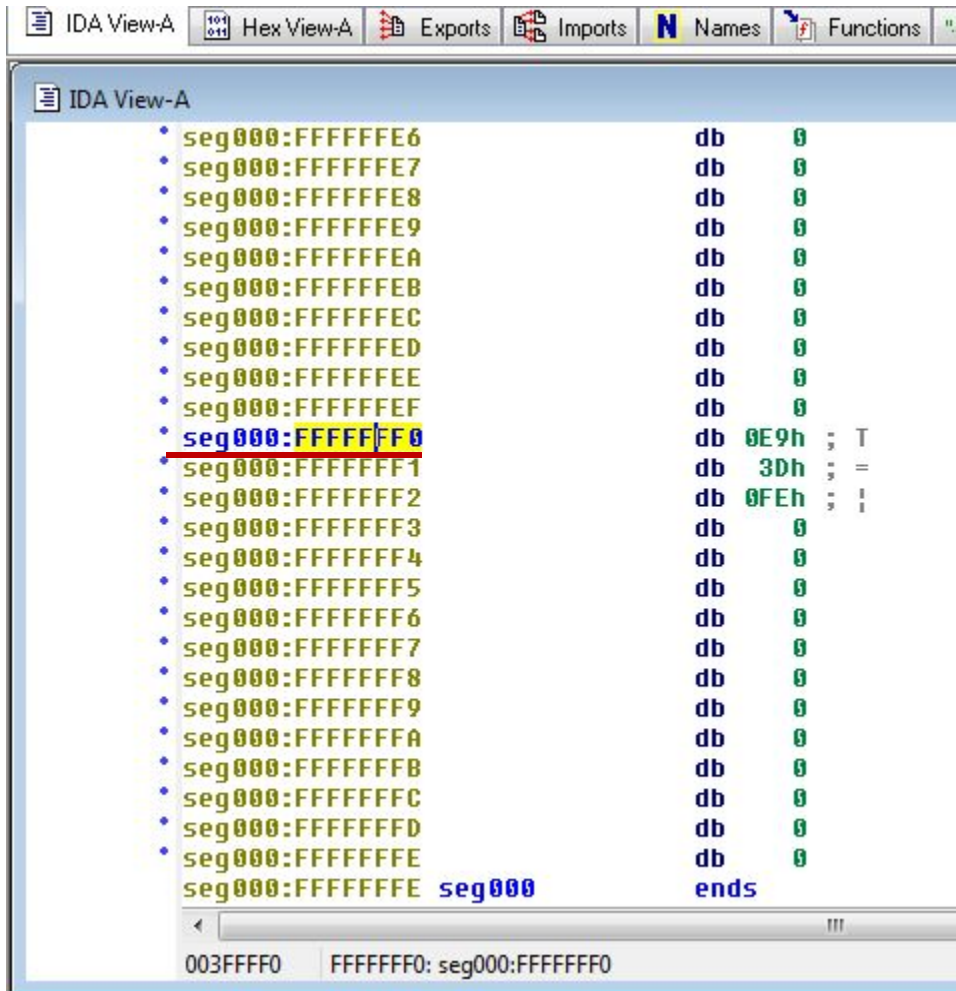
# 2.1: Rebase the Program



- In this lab our file contains only the BIOS portion of the flash.
- The value to enter is:
- 4 GB – (Size of BIOS Binary)
- For this lab it is 0xFFE60000 – (for BIOS Length 1A0000h)
- Example: If you had a 2 MB BIOS binary you would rebase the program to FFE0\_0000h
- The idea is for the entry vector at FFFF\_FFF0h in memory to be displayed in IDA at linear address FFFF\_FFF0h

**!** If you encounter a size-related error, open the binary file with a hex editor (like HxD) and delete the last byte. Then re-open the binary in IDA and rebase it. Still treat it like it were its original size.

## 2.2: Rebase the Program



```
IDA View-A
Hex View-A
Exports
Imports
Names
Functions

IDA View-A
seg000:FFFFFFE6 db 0
seg000:FFFFFFE7 db 0
seg000:FFFFFFE8 db 0
seg000:FFFFFFE9 db 0
seg000:FFFFFFEA db 0
seg000:FFFFFFEB db 0
seg000:FFFFFFEC db 0
seg000:FFFFFFED db 0
seg000:FFFFFFEE db 0
seg000:FFFFFFEF db 0
seg000:FFFFFFF0 db 0E9h ; T
seg000:FFFFFFF1 db 3Dh ; =
seg000:FFFFFFF2 db 0FEh ; i
seg000:FFFFFFF3 db 0
seg000:FFFFFFF4 db 0
seg000:FFFFFFF5 db 0
seg000:FFFFFFF6 db 0
seg000:FFFFFFF7 db 0
seg000:FFFFFFF8 db 0
seg000:FFFFFFF9 db 0
seg000:FFFFFFFA db 0
seg000:FFFFFFFB db 0
seg000:FFFFFFFC db 0
seg000:FFFFFFFD db 0
seg000:FFFFFFFE db 0
seg000:FFFFFFFE seg000 ends

003FFFF0 | FFFFFFF0: seg000:FFFFFFF0
```

- You know you have done it right when you see executable instructions at FFFF\_FFF0h, such as:
- E9 3D FE
- E9 is a relative JMP instruction (JMP FE3Dh)
- Note: The JMP instruction may be preceded by a WBINVD instruction or a couple NOP instructions
  - In this case, these instructions will be at FFFF\_FFF0h instead of the JMP
- There always will be a JMP here following those

# 3. Determine IDA Segments: Manually Analyze the Reset Vector JMP

```
IDA View-A
Hex View-A
Exports
Imports
Names
Functions

IDA View-A
seg000:FFFFFFE6 db 0
seg000:FFFFFFE7 db 0
seg000:FFFFFFE8 db 0
seg000:FFFFFFE9 db 0
seg000:FFFFFFEA db 0
seg000:FFFFFFEB db 0
seg000:FFFFFFEC db 0
seg000:FFFFFFED db 0
seg000:FFFFFFEE db 0
seg000:FFFFFFEF db 0
seg000:FFFFFFF0 db 0E9h ; T
seg000:FFFFFFF1 db 3Dh ; =
seg000:FFFFFFF2 db 0FEh ; !
seg000:FFFFFFF3 db 0
seg000:FFFFFFF4 db 0
seg000:FFFFFFF5 db 0
seg000:FFFFFFF6 db 0
seg000:FFFFFFF7 db 0
seg000:FFFFFFF8 db 0
seg000:FFFFFFF9 db 0
seg000:FFFFFFFA db 0
seg000:FFFFFFFB db 0
seg000:FFFFFFFC db 0
seg000:FFFFFFFD db 0
seg000:FFFFFFFE db 0
seg000:FFFFFFFE seg000 ends

003FFFF0 | FFFFFFF0: seg000:FFFFFFF0
```

- So now we want to create some IDA segments to help us (and IDA) interpret the disassembly
- One goal is to keep the 16-bit segment that contains the entry vector as small as possible
  - From experience, BIOS takes a FAR JMP away from here after entering protected mode
- JMP FE3Dh is relative to the address following the JMP:
- FFFF\_FFF3h, in this case



# 3.1: JMP rel16

| JMP—Jump     |                  |       |             |                 |   |
|--------------|------------------|-------|-------------|-----------------|---|
| Opcode       | Instruction      | Op/En | 64-Bit Mode | Compat/Leg Mode | Description   |
| EB <i>cb</i> | JMP <i>rel8</i>  | D     | Valid       | Valid           | Jump short, RIP = RIP + 8-bit displacement sign extended to 64-bits                           |
| E9 <i>cw</i> | JMP <i>rel16</i> | D     | N.S.        | Valid           | Jump near, relative, displacement relative to next instruction. Not supported in 64-bit mode. |
| E9 <i>cd</i> | JMP <i>rel32</i> | D     | Valid       | Valid           | Jump near, relative, RIP = RIP + 32-bit displacement sign extended to 64-bits                 |

- The address following our JMP instruction is FFFF\_FFF3h
  - We'll treat it like a 64KB segment (FFF3h) for easier readability
  - Technically it is a 64KB segment so we don't have to worry about this assumption throwing off our calculation
- Take the 2's compliment of the operand in the JMP FE3Dh instruction:
  1. (FE3Dh – 1) = FE3Ch
  2. ~FE3Ch = 01C3h
- Subtract this displacement from the address following the JMP instruction to find the destination:
- FFF3h – 01C3h = **FE30h**



## 3.2: Determine Segment Boundary

```
seg000:FFFFFFFD db 0FFh
seg000:FFFFFFFE db 0FFh
seg000:FFFFFFFF db 0FFh
seg000:FFFFFE00 db 44h ; D
seg000:FFFFFE01 db 65h ; e
seg000:FFFFFE02 db 6Ch ; l
seg000:FFFFFE03 db 6Ch ; l
seg000:FFFFFE04 db 20h
seg000:FFFFFE05 db 53h ; S
seg000:FFFFFE06 db 79h ; y
seg000:FFFFFE07 db 73h ; s
seg000:FFFFFE08 db 74h ; t
seg000:FFFFFE09 db 65h ; e
seg000:FFFFFE0A db 6Dh ; m
seg000:FFFFFE0B db 20h
seg000:FFFFFE0C db 4Ch ; L
seg000:FFFFFE0D db 61h ; a
seg000:FFFFFE0E db 74h ; t
seg000:FFFFFE0F db 69h ; i
seg000:FFFFFE10 db 74h ; t
seg000:FFFFFE11 db 75h ; u
seg000:FFFFFE12 db 64h ; d
seg000:FFFFFE13 db 65h ; e
seg000:FFFFFE14 db 20h
```

- So we know the destination of the JMP at the entry vector is FFFF\_FE30h
- We can now make an assumption that the address FFFF\_FE00h can serve as a segment boundary for us
- Our goal is to keep the segment containing the entry JMP as small as possible
- The assumption is that code will be aligned and will take a far JMP to a lower address space
- This assumption is based on experience, but could vary
- Remember these are segments to help IDA translate our disassembly, not necessarily mimic the system



# 5: Identify Memory Model

```
boot:FFEC      db      0
boot:FFED      db      0
boot:FFEE      db      0
boot:FFEF      db      0
boot:FFF0 ; -----
boot:FFF0      jmp     loc_FFFFE30
boot:FFF0 ; -----
boot:FFF3      db      0
```

```
boot:FE30 ; -----
boot:FE30
boot:FE30 loc_FFFFE30:      db      66h      ; CODE XREF:
boot:FE30      lgdt   fword ptr cs:byte_FFFFFFF8
boot:FE37      db      66h
boot:FE37      lidt   fword ptr cs:byte_FFFFFFFE
boot:FE3E      mov     eax, cr0
boot:FE41      or      al, 1
boot:FE43      mov     cr0, eax
boot:FE46      jmp     short $+2
boot:FE48      mov     ax, 10h
boot:FE4B      mov     ds, ax
boot:FE4D      assume ds:nothing
boot:FE4D      mov     es, ax
boot:FE4F      mov     fs, ax
boot:FE51      jmp     large far ptr 8:0FFFFFF0900h
boot:FE51 ; -----
```

- Once this segment is created, IDA “automagically” recognizes the destination of the entry vector jump
- What we see here is the BIOS preparing to enter protected mode
- Likely it will be using a flat memory model
- Note the ‘8’ in the far jump operand
- That references the entry at offset 8 in the GDT
- Now let’s look at that LGDT instruction

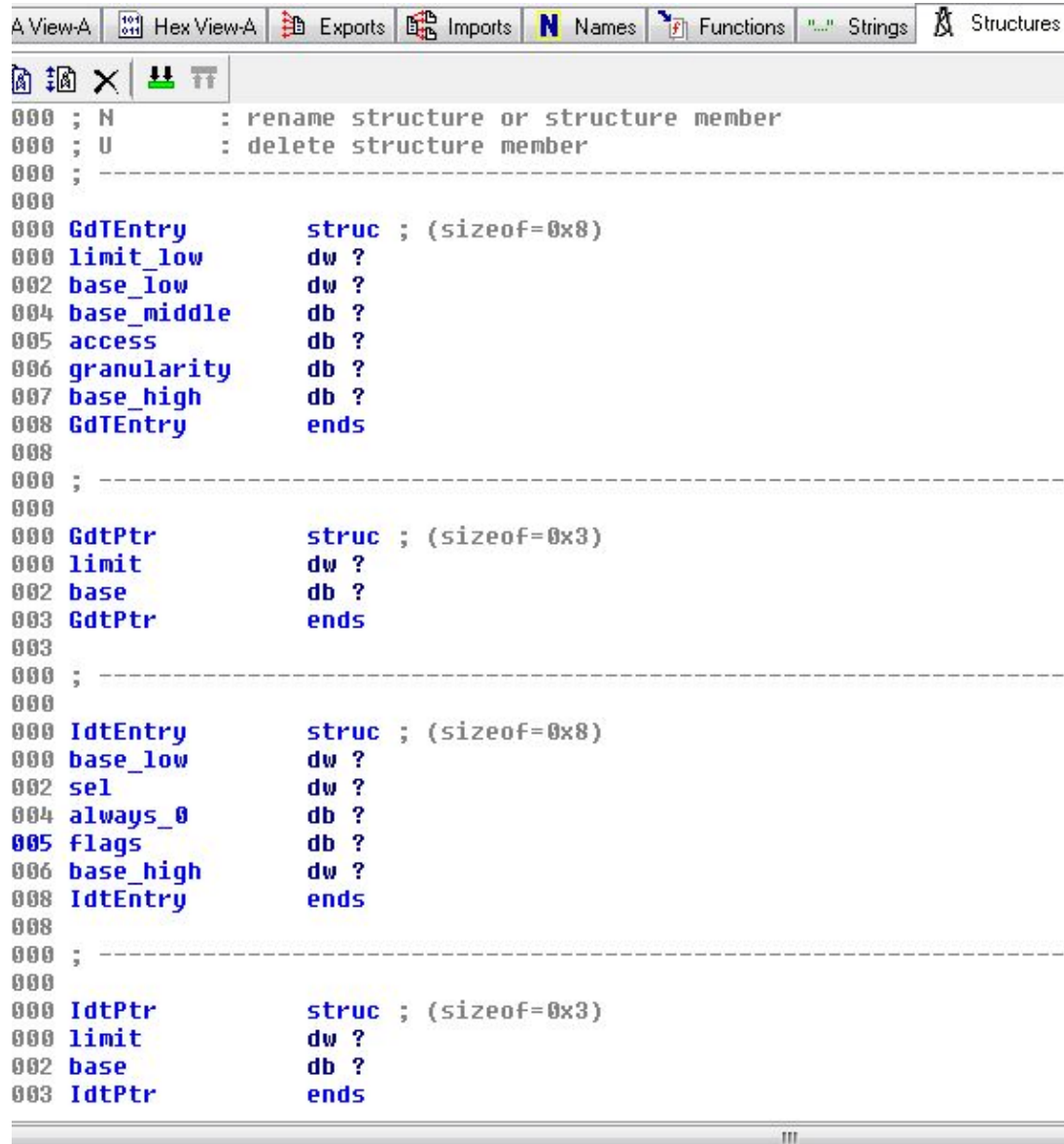
## 5.1: LGDT Instruction

### LGDT/LIDT—Load Global/Interrupt Descriptor Table Register

| Opcode   | Instruction            | Op/<br>En | 64-Bit<br>Mode | Compat/<br>Leg Mode | Description              |
|----------|------------------------|-----------|----------------|---------------------|--------------------------|
| 0F 01 /2 | LGDT <i>m16&amp;32</i> | M         | N.E.           | Valid               | Load <i>m</i> into GDTR. |
| 0F 01 /3 | LIDT <i>m16&amp;32</i> | M         | N.E.           | Valid               | Load <i>m</i> into IDTR. |
| 0F 01 /2 | LGDT <i>m16&amp;64</i> | M         | Valid          | N.E.                | Load <i>m</i> into GDTR. |
| 0F 01 /3 | LIDT <i>m16&amp;64</i> | M         | Valid          | N.E.                | Load <i>m</i> into IDTR. |

- LGDT loads the values in the source operand into the global descriptor table register (GDTR)
- The operand specifies a 6-byte structure containing the size of the table (2-bytes) and a 4-byte pointer to the location of the table data
- The table data contains segment bases, limits, access rights
- More than likely it will be a single base of 0000\_0000h and a limit of FFFF\_FFFFh
- If this is true, then they are using a Flat Memory Model
  - And you shall rejoice!
  - Really there is no point in not using the flat memory model, you can generally just assume they are

# 5.2: Import GDT/IDT Structures




```
A View-A 100 Hex View-A Exports Imports Names Functions Strings Structures
000 ; N      : rename structure or structure member
000 ; U      : delete structure member
000 ; -----
000
000 GdtEntry      struc ; (sizeof=0x8)
000 limit_low     dw ?
002 base_low     dw ?
004 base_middle  db ?
005 access       db ?
006 granularity  db ?
007 base_high    db ?
008 GdtEntry     ends
008
000 ; -----
000
000 GdtPtr        struc ; (sizeof=0x3)
000 limit         dw ?
002 base         db ?
003 GdtPtr       ends
003
000 ; -----
000
000 IdtEntry      struc ; (sizeof=0x8)
000 base_low     dw ?
002 sel         dw ?
004 always_0    db ?
005 flags       db ?
006 base_high    dw ?
008 IdtEntry     ends
008
000 ; -----
000
000 IdtPtr        struc ; (sizeof=0x3)
000 limit         dw ?
002 base         db ?
003 IdtPtr       ends
```

- You can import these structures into IDA by parsing the file “descriptors.h”
- Screenshot included so you can enter them manually if necessary
- IDT structures are also provided
- Importing structures like this is very useful for analyzing BIOS
- Legacy BIOS is filled with proprietary structure definitions
- Contrasted with UEFI structures which are defined in a publically-released standard



## 5.3: Define GdtPtr

```
boot:FF78 unk_FFFFFFF78 db 78h ; x
boot:FF79 db 0
boot:FF7A db 0
boot:FF7B db 0FFh
boot:FF7C db 0FFh
boot:FF7D db 0FFh
boot:FF7E unk_FFFFFFF7E db 0
boot:FF7F db 0
boot:FF80 db 0EAh ; 0
boot:FF81 db 87h ; 0
```



```
seg001:FF77 db 0FFh
seg001:FF78 stru_FFFFFFF78 Gdt_Ptr <78h, 0FFFFFFF00h>
seg001:FF7E unk_FFFFFFF7E db 0
seg001:FF7F db 0
```

- Go to the address referenced by the operand to the LGDT instruction
- IDA will have already tried to interpret this and failed, undefine that
- Now define it as structure of type GdtPtr
- As per the structure definition, the first member is the size of the GDT table and the second is a pointer to the location of the GDT entries
- That pointer won't translate properly for us, but we can tell where the entries are defined just by looking at the value

## 5.4: Define GDT Entries

```
seg001:FF77      db  0FFh
seg001:FF78      stru_FFFFFFF78  Gdt_Ptr <78h, 0FFFFF00h>
seg001:FF7E      unk_FFFFFFF7E  db  0
seg001:FF7F      db  0
```

Hex View-A

v-A

```
• seg001:FEFB      db  24h ; $
• seg001:FEFC      db  0
• seg001:FEFD      db  0
• seg001:FEFE      db  0
• seg001:FEFF      db  0
• seg001:FF00      GdtEntry <0>
• seg001:FF08      GdtEntry <0FFFFh, 0, 0, 9Fh, 0CFh, 0>
• seg001:FF10      db  0FFh
• seg001:FF11      db  0FFh
• seg001:FF12      db  0
• seg001:FF13      db  0
• seg001:FF14      db  0
• seg001:FF15      0101 DAT Byte 0FFh
• seg001:FF16      0101 DAT Word 0FFFFh
• seg001:FF17      0101 DAT Double word 0FFFFh
• seg001:FF18      0101 DAT Structure
• seg001:FF19      0101 DAT IdtPtr (sizeof 6)
• seg001:FF1A      0101 DAT GdtEntry (sizeof 8)
• seg001:FF1B      0101 DAT Gdt_Ptr (sizeof 6)
• seg001:FF1C      db  0C8h ; +
• seg001:FF1D      db  93h ; ô
```

- We know it's location is in our 16-bit segment
- Manually go there by jumping to seg:FF00
- This is where the GDT entries are defined
- Look at the structure definition in peewee.h to interpret
- The table size is 0x78 bytes, but we only want the second entry into the table at offset 8:
- BASE = 0000\_0000h
- LIMIT = FFFF\_FFFFh
- This is the flat memory model
- These descriptors will be used by the subsequent code so you can fill out the rest as needed

\*There may be a superior way to set up our segments so that it all "just works" but I have not found it yet. Also, disregard the different segment names.

## 5.5: Full GDT

```
struct GdtEntry {
    uint16 limit_low;           // The lower 16 bits of the limit.
    uint16 base_low;           // The lower 16 bits of the base.
    uint8  base_middle;        // The next 8 bits of the base.
    uint8  access;             // Access flags
    uint8  granularity;
    uint8  base_high;          // The last 8 bits of the base.
} Gdt_Entry;
```

```
GdtEntry <0>
GdtEntry <0FFFFh, 0, 0, 9Fh, 0CFh, 0>
GdtEntry <0FFFFh, 0, 0, 93h, 0CFh, 0>
GdtEntry <1000h, 0, 0C8h, 93h, 0, 0FEh>
GdtEntry <0FFFFh, 0, 0, 93h, 0CFh, 0>
GdtEntry <0FFFFh, 0, 0, 93h, 0, 0>
GdtEntry <0FFFFh, 0, 0Fh, 9Fh, 0, 0>
GdtEntry <0FFFFh, 0, 0, 93h, 0, 0>
GdtEntry <0FFFFh, 0, 0, 93h, 0, 0>
GdtEntry <0FFFFh, 0, 0, 93h, 0, 0>
GdtEntry <0FFFFh, 0, 0, 93h, 0, 0>
GdtEntry <0FFFFh, 0, 0, 92h, 0CFh, 0>
GdtEntry <0Fh, 0C000h, 0Eh, 9Fh, 80h, 0>
GdtEntry <0FFFFh, 0E000h, 0FCh, 9Fh, 0, 0FFh>
GdtEntry <0FFFFh, 0, 0FDh, 9Fh, 1, 0FFh>
```

- The GdtEntry structure definition in peewee.h can be used to interpret the GDT entries
- Each structure is 8 bytes in size
- The FAR JMP is referencing the second entry (offset 8)
- Base 0, Limit FFFF\_FFFFh



# 5.5: Full GDT

|    | Offset | Type     | Attributes                        | Values                |
|----|--------|----------|-----------------------------------|-----------------------|
| 0  | 0000   | Reserved |                                   | H=00000000 L=00000000 |
| 1  | 0008   | Code     | P=1 G=1 D=1 C=1 R=1 A=1 L=0 DPL=0 | B=00000000 L=FFFFFFFF |
| 2  | 0010   | Data     | P=1 G=1 B=1 E=0 W=1 A=1 DPL=0     | B=00000000 L=FFFFFFFF |
| 3  | 0018   | Data     | P=1 G=0 B=0 E=0 W=1 A=1 DPL=0     | B=FEC80000 L=00001000 |
| 4  | 0020   | Data     | P=1 G=1 B=1 E=0 W=1 A=1 DPL=0     | B=00000000 L=FFFFFFFF |
| 5  | 0028   | Data     | P=1 G=0 B=0 E=0 W=1 A=1 DPL=0     | B=00000000 L=0000FFFF |
| 6  | 0030   | Code     | P=1 G=0 D=0 C=1 R=1 A=1 L=0 DPL=0 | B=000F0000 L=0000FFFF |
| 7  | 0038   | Data     | P=1 G=0 B=0 E=0 W=1 A=1 DPL=0     | B=00000000 L=0000FFFF |
| 8  | 0040   | Data     | P=1 G=0 B=0 E=0 W=1 A=1 DPL=0     | B=00000000 L=0000FFFF |
| 9  | 0048   | Data     | P=1 G=0 B=0 E=0 W=1 A=1 DPL=0     | B=00000000 L=0000FFFF |
| 10 | 0050   | Data     | P=1 G=0 B=0 E=0 W=1 A=1 DPL=0     | B=00000000 L=0000FFFF |
| 11 | 0058   | Data     | P=1 G=1 B=1 E=0 W=1 A=0 DPL=0     | B=00000000 L=FFFFFFFF |
| 12 | 0060   | Code     | P=1 G=1 D=0 C=1 R=1 A=1 L=0 DPL=0 | B=000EC000 L=0000FFFF |
| 13 | 0068   | Code     | P=1 G=0 D=0 C=1 R=1 A=1 L=0 DPL=0 | B=FFFCE000 L=0000FFFF |
| 14 | 0070   | Code     | P=1 G=0 D=0 C=1 R=1 A=1 L=0 DPL=0 | B=FFFD0000 L=0001FFFF |

- Here is the entire GDT for reference. You don't need an expensive debugger to analyze BIOS (but it does save a lot of time)

# 6: Create the 32-bit BIOS segment

Copernicus\_Log.txt

```
Determining size of SPI flash chip
SPI Region 0 (Flash Descriptor) base = 00000000, limit = 00000fff
SPI Region 1 (BIOS) base = 00260000, limit = 003fffff
SPI Region 2 (Management Engine) base = 0000b000, limit = 0025ffff
SPI Region 3 (Gigabit Ethernet) base = 00001000, limit = 00002fff
SPI Region 4 (Platform Data) base = 00003000, limit = 0000afff
SPI Flash chip size = 0x00400000
```

- Now create the 32-bit segment
- Start address is `FFFF_FFFFh - <size of the BIOS region> + 1`
  - `FFFF_FFFFh - 1A_0000h` in this example
  - SPI regions will be explained more during BIOS flash portion of the course
- End Address is our segment boundary Address
  - `FFFF_FE00h` in this example
- Base Address matches that of the GDT table, entry 8 (`0000_0000h`)



# 7: Touch up the Far Jump

```
seg001:FE30 ; Segment type: Regular
seg001:FE30 seg001      segment byte public '16bit' use16
seg001:FE30                assume cs:seg001
seg001:FE30                ;org 0FE30h
seg001:FE30                assume es:nothing, ss:nothing, ds:nothing
seg001:FE30 loc_FFFFE30:                ; CODE XREF: se
seg001:FE30                db          66h
seg001:FE30                lgdt     fword ptr cs:byte_FFFFFFF78
seg001:FE37                db          66h
seg001:FE37                lidt     fword ptr cs:byte_FFFFFFF7E
seg001:FE3E                mov     eax, cr0
seg001:FE41                or      al, 1
seg001:FE43                mov     cr0, eax
seg001:FE46                jmp     short $+2
seg001:FE48                mov     ax, 10h
seg001:FE4B                mov     ds, ax
seg001:FE4D                assume ds:nothing
seg001:FE4D                mov     es, ax
seg001:FE4F                assume es:nothing
seg001:FE4F                mov     fs, ax
seg001:FE51                assume fs:nothing
seg001:FE51                jmp     large far ptr 8:0FFFF0100h
seg001:FE51 ;
```

- So we know that this is loading the descriptor entry at offset 8 in the GDT
- We can visually inspect the operand of this JMP to see that it's going to FFFF\_0100h
- We can manually fix this operand
- Right click the operand and select 'Manual'
- Change it to:
- bios:FFFF0100h
- Uncheck 'Check Operand'
- A little ugly

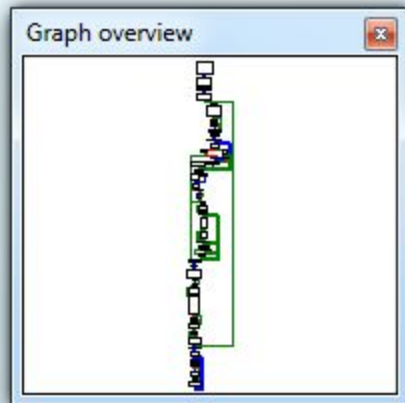
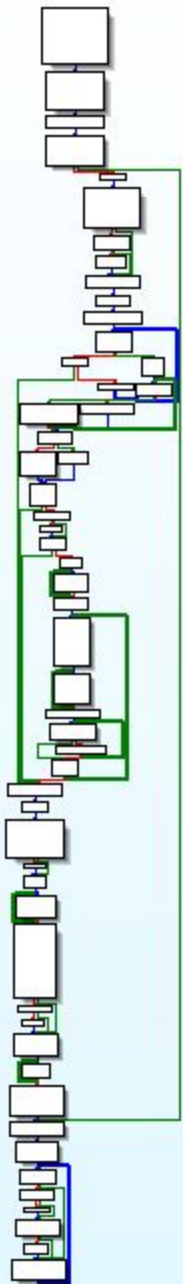
Enter alternate string for the 1 operand

Original operand: large far ptr 8:0FFFF0100h

Operand:

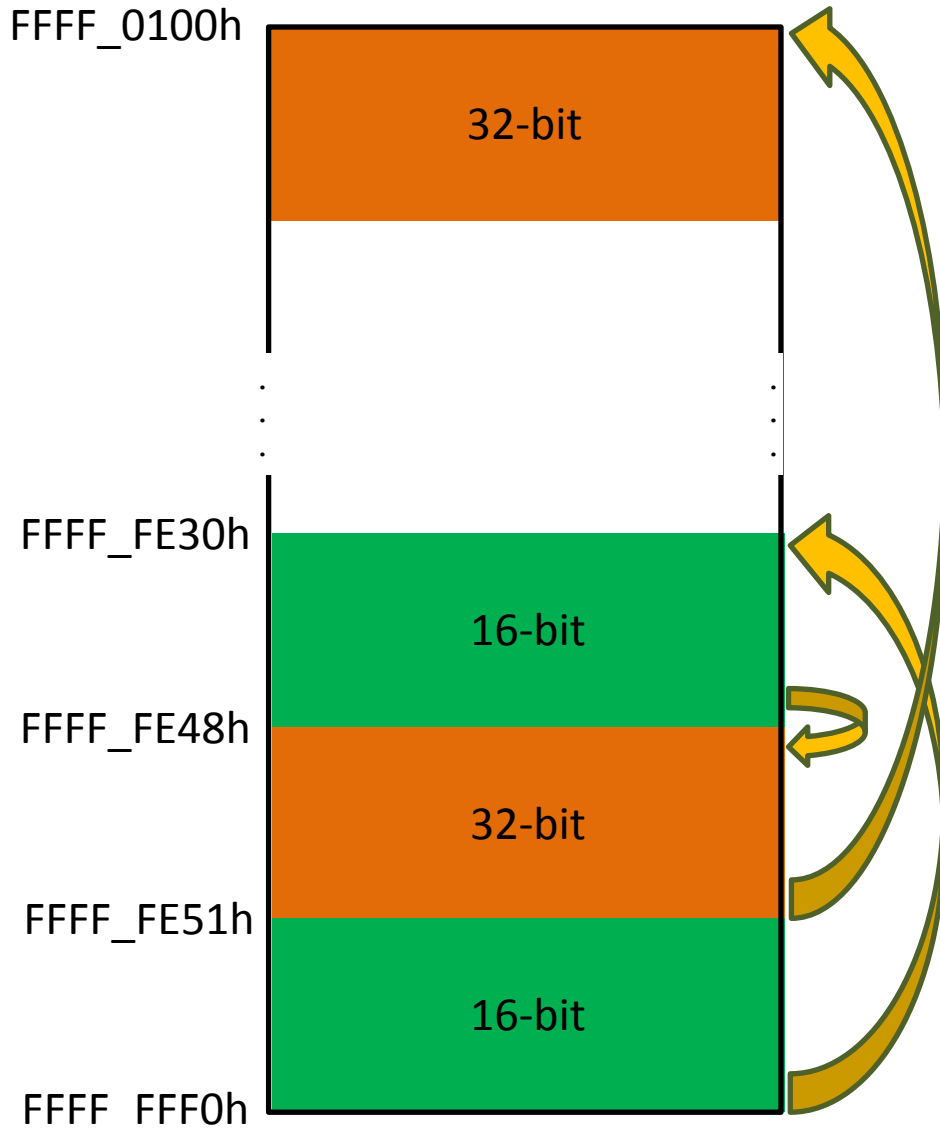
Check operand  
 Allow not matched operand

# Welcome to BIOS Analysis



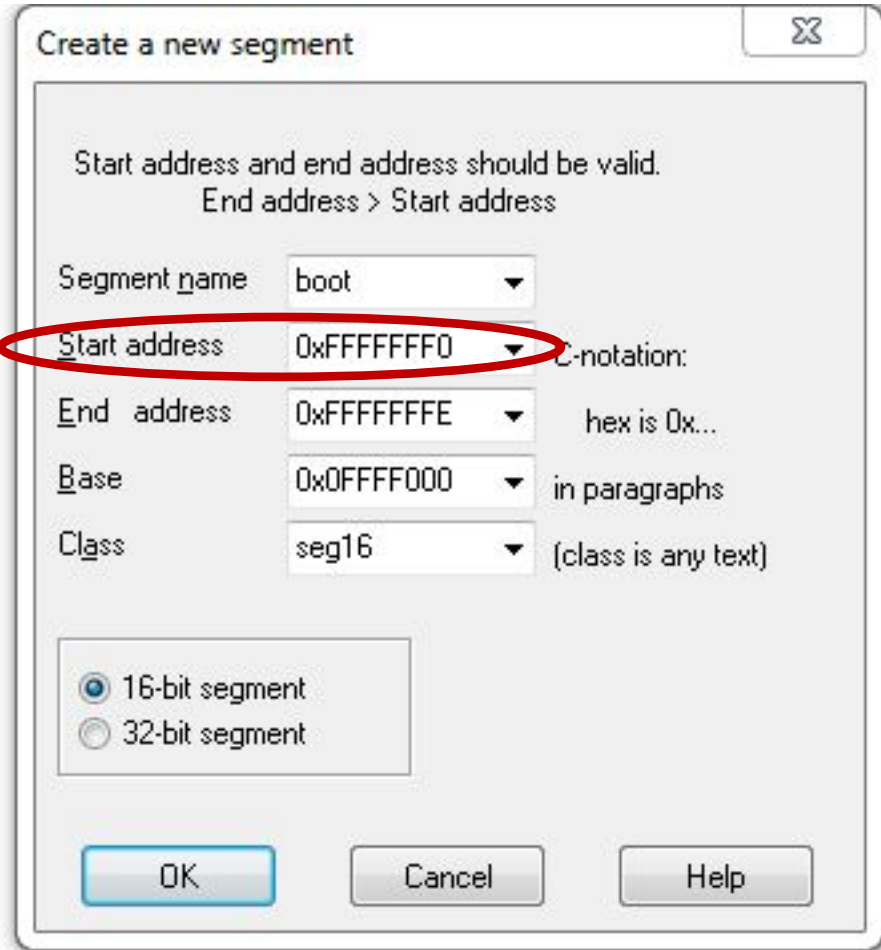
- Converting the binary at FFFF\_0100h to code provides you the entry point to the real BIOS initialization
- Up until this point everything we covered is pretty standard across many BIOSes
  - This applies to UEFI BIOS too
  - Even really old BIOS will basically follow the path we took, perhaps staying in real mode longer though
- From here on though, if legacy, it's completely proprietary to the OEM (data structures, etc.)
- By contrast, UEFI is standardized from head to toe

# Why so Ugly? IDA Segments



- IDA can't combine 16-bit and 32-bit instructions in the same segment
- We could have created another 32-bit segment to account for the processor entering 32-bit protected mode
- But then we'd have to create 4 segments
- Not really necessary since we can visually inspect it and determine what's going on
- Fudging it is okay since the important stuff happens after all this

# BIOS Reset Vector Analysis: Short Cut 1



- You can likely skip a few of the steps and make some assumptions to get to the initialization code faster:
- Open your BIOS binary file in IDA same as before
- Rebase the program, same as before
- Don't bother analyzing the entry vector JMP, just create a 16-bit segment the exact same as before, except:
  - Start Address: **0xFFFFFFFF0**
  - We can count on IDA being smart enough to interpret this properly even though it makes our segment a little odd



# BIOS Reset Vector Analysis: Short Cut 2

```
seg001:FE30 ; Segment type: Regular
seg001:FE30 seg001      segment byte public '16bit' use16
seg001:FE30          assume cs:seg001
seg001:FE30          ;org 0FE30h
seg001:FE30          assume es:nothing, ss:nothing, ds:nothing
seg001:FE30 loc_FFFFE30: ; CODE XREF: se
seg001:FE30          db          66h
seg001:FE30          lgdt     fword ptr cs:byte_FFFFFFF78
seg001:FE37          db          66h
seg001:FE37          lidt     fword ptr cs:byte_FFFFFFF7E
seg001:FE3E          mov     eax, cr0
seg001:FE41          or      al, 1
seg001:FE43          mov     cr0, eax
seg001:FE46          jmp     short $+2
seg001:FE48          mov     ax, 10h
seg001:FE4B          mov     ds, ax
seg001:FE4D          assume   ds:nothing
seg001:FE4D          mov     es, ax
seg001:FE4F          assume   es:nothing
seg001:FE4F          mov     fs, ax
seg001:FE51          assume   fs:nothing
seg001:FE51          jmp     large far ptr 8:0FFFF0100h
seg001:FE51          ;
```

Enter alternate string for the 1 operand

Original operand: large far ptr 8:0FFFF0100h

Operand:

Check operand

Allow not matched operand

- Follow the entry JMP
  - Notice that IDA automatically modified our segment so it begins at seg:FE30
- Manually touch up the FAR JMP same as before
- We could optionally create a 32-bit segment here just to ensure it has a base of 0h
  - Assume a flat memory model
- Now we can go to the real BIOS initialization code entry, just like before!
- This shortcut doesn't always work



# Lab: Scratch the surface

- Repeat the process we just did for the E6400 BIOS on each of your BIOS dumps
- We'll see if there are any where it leads to early confusion

