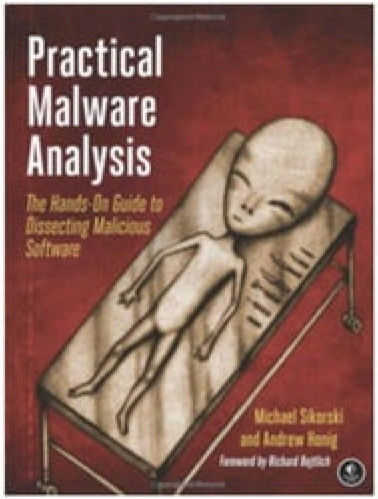
Practical Malware Analysis

Ch 8: Debugging


Practical
Malware
Analysis
The Hands-On Guide to Dissecting Malicious Software
Michael Sikorski
and Andrew Honig
Foreword by Richard Bejtlich

Rev. 3-14-16

Disassemblers v. Debuggers

- A disassembler like IDA Pro shows the state of the program just before execution begins
- Debuggers show
  - Every memory location
  - Register
  - Argument to every function
- At any point during processing
  - And let you change them

Two Debuggers

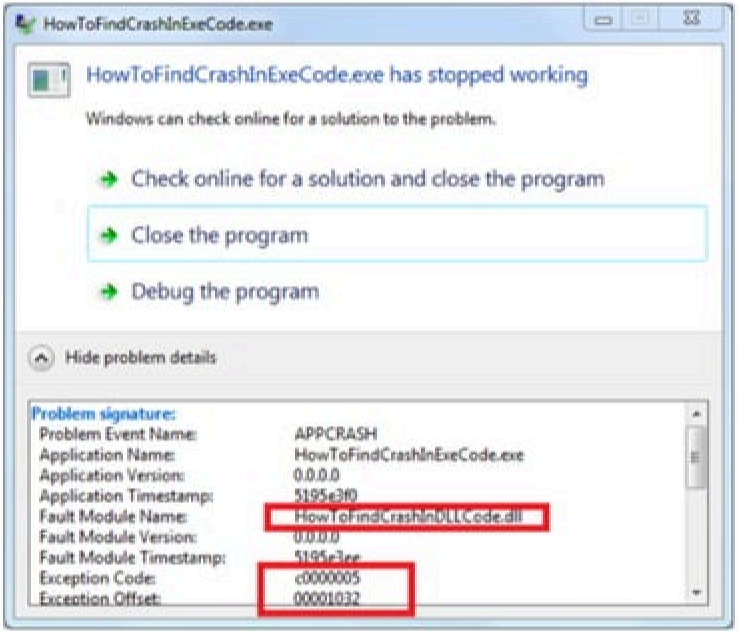
- Ollydbg
  - Most popular for malware analysis
  - User-mode debugging only
  - IDA Pro has a built-in debugger, but it's not as easy to use or powerful as Ollydbg
- Windbg
  - Supports kernel-mode debugging

Source-Level v. Assembly-Level Debuggers

- Source-level debugger
  - Usually built into development platform
  - Can set breakpoints (which stop at lines of code)
  - Can step through program one line at a time
- Assembly-level debuggers (low-level)
  - Operate on assembly code rather than source code
  - Malware analysts are usually forced to use them, because they don't have source code

Windows Crashes

- When an app crashes, Windows may offer to open it in a debugger
- Usually it uses Windbg
- Links Ch 8c, 8d



HowToFindCrashInExeCode.exe

HowToFindCrashInExeCode.exe has stopped working

Windows can check online for a solution to the problem.

```
Problem signature:
  Problem Event Name:          APPCRASH
  Application Name:            HowToFindCrashInExeCode.exe
  Application Version:         0.0.0.0
  Application Timestamp:       5195e3f0
  Fault Module Name:           HowToFindCrashInDLLCode.dll
  Fault Module Version:        0.0.0.0
  Fault Module Timestamp:      5195e3ee
  Exception Code:              c0000005
  Exception Offset:            00001032
```

Kernel v. User-Mode Debugging

User Mode Debugging

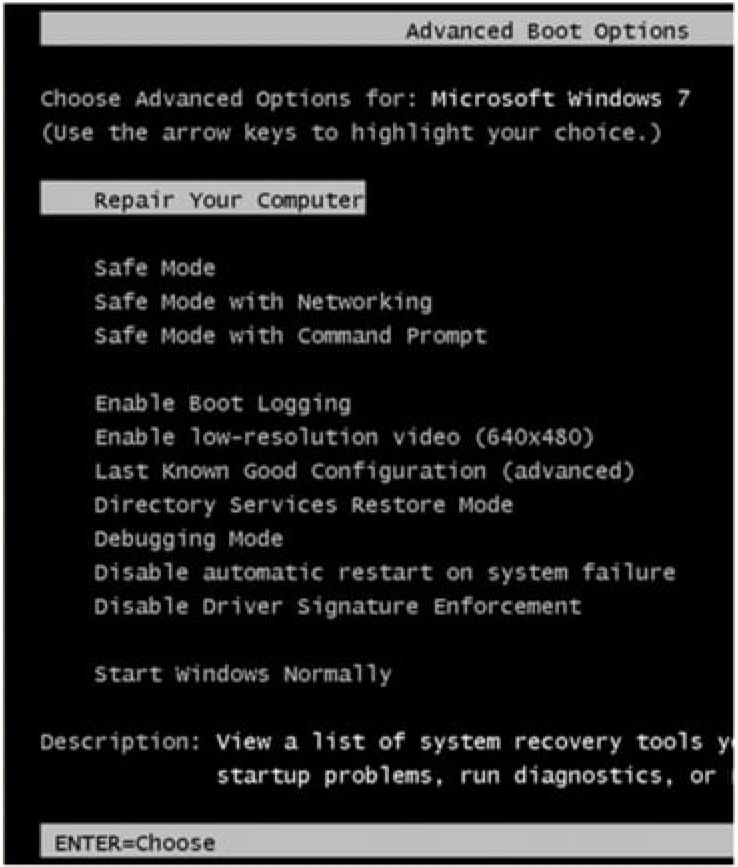
- Debugger runs on the same system as the code being analyzed
- Debugging a single executable
- Separated from other executables by the OS

Kernel Mode Debugging

- Requires two computers, because there is only one kernel per computer
- If the kernel is at a breakpoint, the system stops
- One computer runs the code being debugged
- Other computer runs the debugger
- OS must be configured to allow kernel debugging
- Two machines must be connected

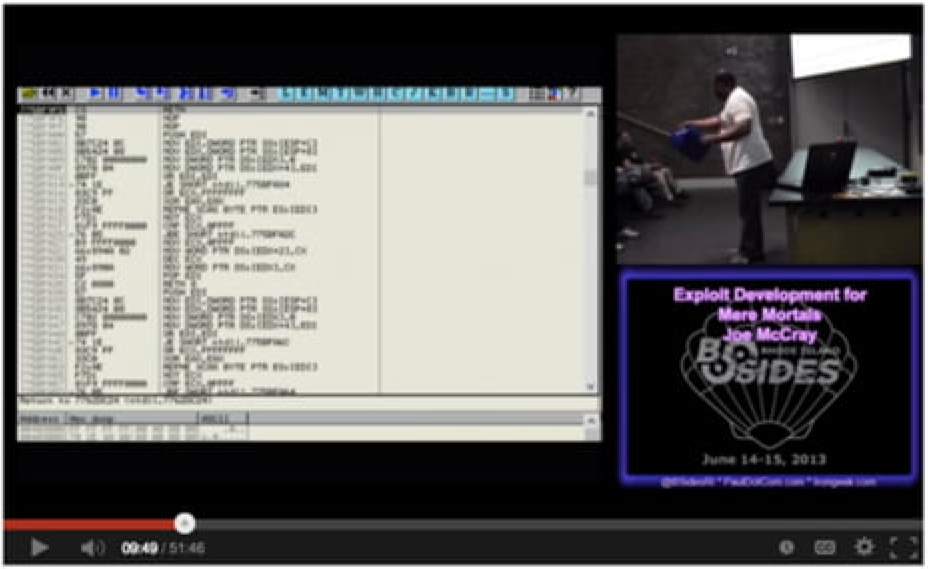
Windows 7 Advanced Boot Options

- Press F8 during startup
- "Debugging Mode"



```
                                             Advanced Boot Options

Choose Advanced Options for: Microsoft Windows 7
(Use the arrow keys to highlight your choice.)

    Repair Your Computer

    Safe Mode
    Safe Mode with Networking
    Safe Mode with Command Prompt

    Enable Boot Logging
    Enable low-resolution video (640x480)
    Last Known Good Configuration (advanced)
    Directory Services Restore Mode
    Debugging Mode
    Disable automatic restart on system failure
    Disable Driver Signature Enforcement

    Start Windows Normally

Description: View a list of system recovery tools y
             startup problems, run diagnostics, or

 ENTER=Choose
```

Good Intro to OllyDbg



BsidesRI 2013 1 4 Exploit Development for Mere Mortals Joe Mc…

- Link Ch 8a

Using a Debugger

Two Ways

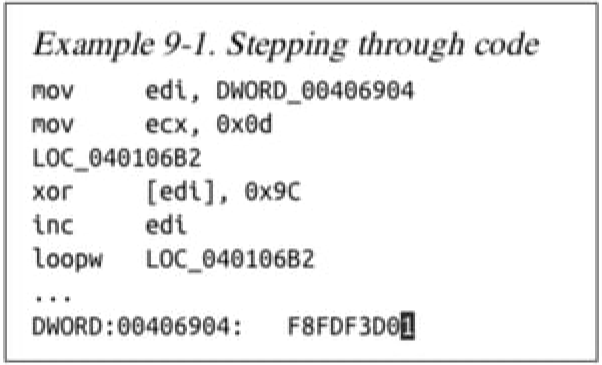
- Start the program with the debugger
  - It stops running immediately prior to the execution of its entry point
- Attach a debugger to a program that is already running
  - All its threads are paused
  - Useful to debug a process that is affected by malware

Single-Stepping

- Simple, but slow
- Don't get bogged down in details

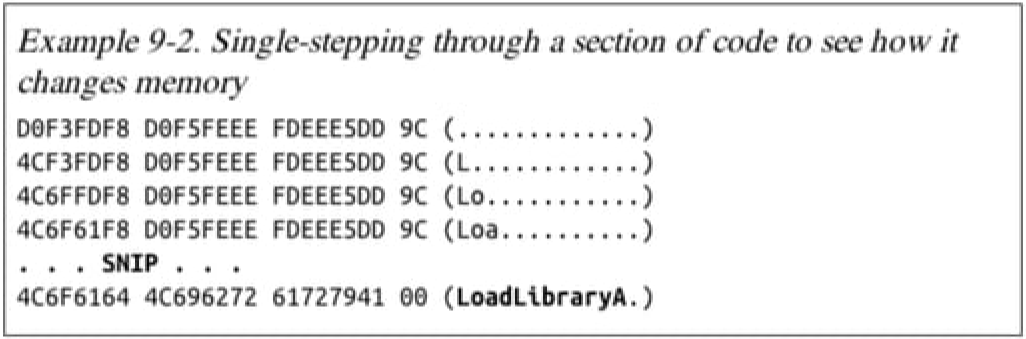
Example

- This code decodes the string with XOR



Example 9-1. Stepping through code

```
mov     edi, DWORD_00406904
mov     ecx, 0x0d
LOC_040106B2
xor     [edi], 0x9C
inc     edi
loopw   LOC_040106B2
...
DWORD:00406904:   F8FDF3D01
```



Example 9-2. Single-stepping through a section of code to see how it changes memory

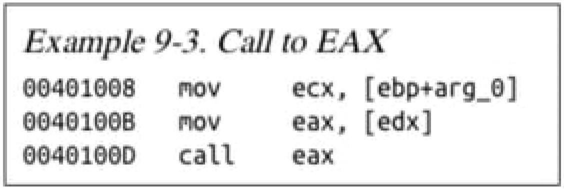
```
D0F3FDF8 D0F5FEEE FDEEE5DD 9C (.............)
4CF3FDF8 D0F5FEEE FDEEE5DD 9C (L............)
4C6FFDF8 D0F5FEEE FDEEE5DD 9C (Lo...........)
4C6F61F8 D0F5FEEE FDEEE5DD 9C (Loa..........)
. . . SNIP . . .
4C6F6164 4C696272 61727941 00 (LoadLibraryA.)
```

Stepping-over v. Stepping-Into

- Single step executes one instruction
- **Step-over** call instructions
  - Completes the call and returns without pausing
  - Decreases the amount of code you need to analyze
  - Might miss important functionality, especially if the function never returns
- **Step-into** a call
  - Moves into the function and stops at its first command

Pausing Execution with Breakpoints

- A program that is paused at a **breakpoint** is called **broken**
- Example
  - You can't tell where this call is going
  - Set a breakpoint at the call and see what's in eax



Example 9-3. Call to EAX

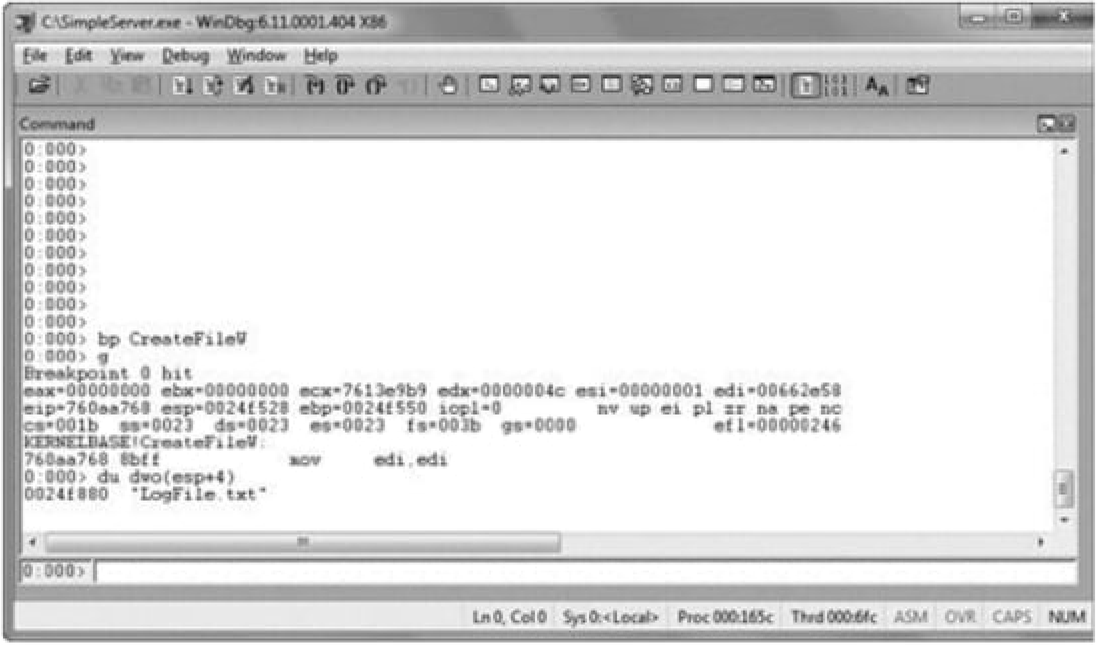
```
00401008   mov     ecx, [ebp+arg_0]
0040100B   mov     eax, [edx]
0040100D   call    eax
```

- This code calculates a filename and then creates the file
- Set a breakpoint at CreateFileW and look at the stack to see the filename

Example 9-4. Using a debugger to determine a filename

```
0040100B  xor     eax, esp
0040100D  mov     [esp+0D0h+var_4], eax
00401014  mov     eax, edx
00401016  mov     [esp+0D0h+NumberOfBytesWritten], 0
0040101D  add     eax, 0FFFFFFFEh
00401020  mov     cx, [eax+2]
00401024  add     eax, 2
00401027  test    cx, cx
0040102A  jnz     short loc_401020
0040102C  mov     ecx, dword ptr ds:a_txt ; ".txt"
00401032  push    0                ; hTemplateFile
00401034  push    0                ; dwFlagsAndAttributes
00401036  push    2                ; dwCreationDisposition
00401038  mov     [eax], ecx
0040103A  mov     ecx, dword ptr ds:a_txt+4
00401040  push    0                ; lpSecurityAttributes
00401042  push    0                ; dwShareMode
00401044  mov     [eax+4], ecx
00401047  mov     cx, word ptr ds:a_txt+8
0040104E  push    0                ; dwDesiredAccess
00401050  push    edx              ; lpFileName
00401051  mov     [eax+8], cx
00401055 1call    CreateFileW ; CreateFileW(x,x,x,x,x,x,x)
```

WinDbg


C:\SimpleServer.exe - WinDbg:6.11.0001.404 X86
File Edit View Debug Window Help
Command
Ln 0, Col 0 Sys 0:<Local> Proc 000:165c Thrd 000:6fc ASM OVR CAPS NUM

```
0:000>
0:000>
0:000>
0:000>
0:000>
0:000>
0:000>
0:000>
0:000>
0:000>
0:000>
0:000> bp CreateFileW
0:000> g
Breakpoint 0 hit
eax=00000000 ebx=00000000 ecx=7613e9b9 edx=0000004c esi=00000001 edi=00662e58
eip=760aa768 esp=0024f528 ebp=0024f550 iopl=0         nv up ei pl zr na pe nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00000246
KERNELBASE!CreateFileW:
760aa768 8bff            mov     edi,edi
0:000> du dwo(esp+4)
0024f880  "LogFile.txt"
```

```
0:000>
```

Figure 9-1. Using a breakpoint to see the parameters to a function call. We set a breakpoint on `CreateFileW` and then examine the first parameter of the stack.

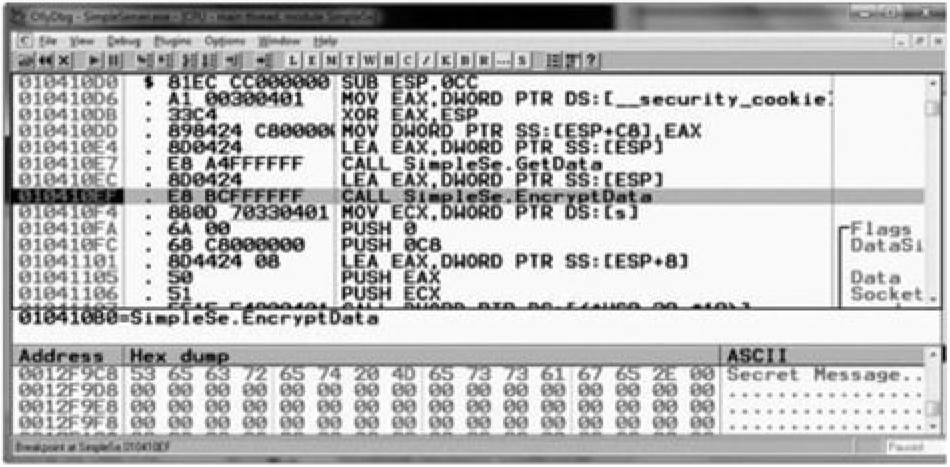
Encrypted Data

- Suppose malware sends encrypted network data
- Set a breakpoint before the data is encrypted and view it

Example 9-5. Using a breakpoint to view data before the program encrypts it

```
004010D0  sub     esp, 0CCh
004010D6  mov     eax, dword_403000
004010DB  xor     eax, esp
004010DD  mov     [esp+0CCh+var_4], eax
004010E4  lea     eax, [esp+0CCh+buf]
004010E7  call    GetData
004010EC  lea     eax, [esp+0CCh+buf]
004010EF 1call    EncryptData
004010F4  mov     ecx, s
004010FA  push    0                ; flags
004010FC  push    0C8h             ; len
00401101  lea     eax, [esp+0D4h+buf]
00401105  push    eax              ; buf
00401106  push    ecx              ; s
00401107  call    ds:Send
```

OllyDbg



File View Debug Plugins Options Window Help
L E M T W H C / K B R ... S

```
010410D0   $  81EC CC000000   SUB ESP,0CC
010410D6   .  A1 00300401     MOV EAX,DWORD PTR DS:[__security_cookie]
010410DB   .  33C4            XOR EAX,ESP
010410DD   .  898424 C800000  MOV DWORD PTR SS:[ESP+C8],EAX
010410E4   .  8D0424          LEA EAX,DWORD PTR SS:[ESP]
010410E7   .  E8 A4FFFFFF     CALL SimpleSe.GetData
010410EC   .  8D0424          LEA EAX,DWORD PTR SS:[ESP]
010410EF   .  E8 BCFFFFFF     CALL SimpleSe.EncryptData
010410F4   .  8B0D 70330401   MOV ECX,DWORD PTR DS:[s]
010410FA   .  6A 00           PUSH 0                                   ┌Flags
010410FC   .  68 C8000000     PUSH 0C8                                 │DataSi
01041101   .  8D4424 08       LEA EAX,DWORD PTR SS:[ESP+8]             │
01041105   .  50              PUSH EAX                                 │Data
01041106   .  51              PUSH ECX                                 │Socket
01041080=SimpleSe.EncryptData

Address   Hex dump                                          ASCII
0012F9C8  53 65 63 72 65 74 20 4D 65 73 73 61 67 65 2E 00   Secret Message..
0012F9D8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0012F9E8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0012F9F8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
```

Figure 9-2. Viewing program data prior to the encryption function call

Types of Breakpoints

- Software execution
- Hardware execution
- Conditional

Software Execution Breakpoints

- The default option for most debuggers
- Debugger overwrites the first byte of the instruction with 0xCC
  - The instruction for INT 3
  - An interrupt designed for use with debuggers
  - When the breakpoint is executed, the OS generates an exception and transfers control to the debugger

Memory Contents at a Breakpoint

- There's a breakpoint at the push instruction
- Debugger says it's 0x55, but it's really 0xCC

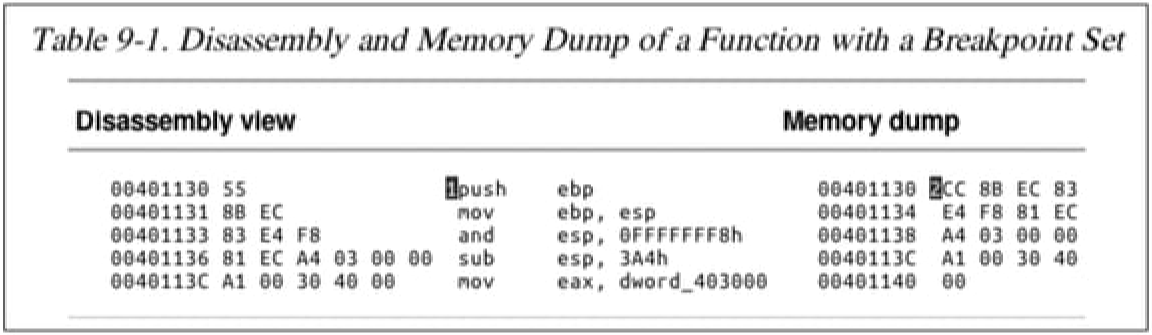


Table 9-1. Disassembly and Memory Dump of a Function with a Breakpoint Set

```
Disassembly view                                              Memory dump

00401130 55                  ❶push     ebp                    00401130 ❷CC 8B EC 83
00401131 8B EC                 mov      ebp, esp               00401134  E4 F8 81 EC
00401133 83 E4 F8              and      esp, 0FFFFFFF8h        00401138  A4 03 00 00
00401136 81 EC A4 03 00 00     sub      esp, 3A4h              0040113C  A1 00 30 40
0040113C A1 00 30 40 00        mov      eax, dword_403000      00401140  00
```

When Software Execution Breakpoints Fail

- If the 0xCC byte is changed during code execution, the breakpoint won't occur
- If other code reads the memory containing the breakpoint, it will read 0xCC instead of the original byte
- Code that verifies integrity will notice the discrepancy

Hardware Execution Breakpoints

- Uses four hardware Debug Registers
  - DR0 through DR3 - addresses of breakpoints
  - DR7 stores control information
- The address to stop at is in a register
- Can break on access or execution
  - Can set to break on read, write, or both
- No change in code bytes

Hardware Execution Breakpoints

- Running code can change the DR registers, to interfere with debuggers
- General Detect flag in DR7
  - Causes a breakpoint prior to any mov instruction that would change the contents of a Debug Register
  - Does not detect other instructions, however

Conditional Breakpoints

- Breaks only if a condition is true
  - Ex: Set a breakpoint on the GetProcAddress function
  - Only if parameter being passed in is RegSetValue
- Implemented as software breakpoints
  - The debugger always receives the break
  - If the condition is not met, it resumes execution without alerting the user

Conditional Breakpoints

- Conditional breakpoints take much longer than ordinary instructions
- A conditional breakpoint on a frequently-accessed instruction can slow a program down
- Sometimes so much that it never finishes

Exceptions

Exceptions

- Used by debuggers to gain control of a running program
- Breakpoints generate exceptions
- Exceptions are also caused by
  - Invalid memory access
  - Division by zero
  - Other conditions

First- and Second-Chance Exceptions

- When a exception occurs while a debugger is attached
  - The program stops executing
  - The debugger is given **first chance** at control
  - Debugger can either handle the exception, or pass it on to the program
  - If it's passed on, the program's exception handler takes it

Second Chance

- If the application doesn't handle the exception
- The debugger is given a **second chance** to handle it
  - This means the program would have crashed if the debugger were not attached
- In malware analysis, first-chance exceptions can usually be ignored
- Second-chance exceptions cannot be ignored
  - They usually mean that the malware doesn't like the environment in which it is running

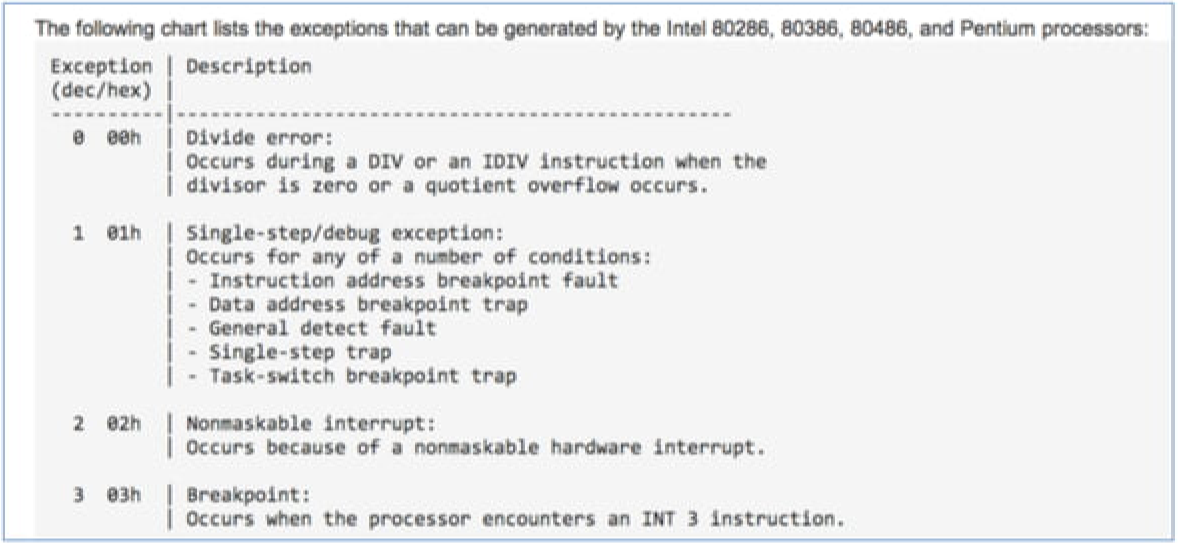
Common Exceptions

- INT 3 (Software breakpoint)
- Single-stepping in a debugger is implemented as an exception
  - If the **trap flag** in the flags register is set,
  - The processor executes one instruction and then generates an exception
- Memory-access violation exception
  - Code tries to access a location that it cannot access, either because the address is invalid or because of access-control protections

Common Exceptions

- Violating Privilege Rules
  - Attempt to execute privileged instruction with outside privileged mode
  - In other words, attempt to execute a kernel mode instruction in user mode
  - Or, attempt to execute Ring 0 instruction from Ring 3

List of Exceptions



The following chart lists the exceptions that can be generated by the Intel 80286, 80386, 80486, and Pentium processors:

```
Exception | Description
(dec/hex) |
----------|-------------------------------------------------
  0  00h  | Divide error:
          | Occurs during a DIV or an IDIV instruction when the
          | divisor is zero or a quotient overflow occurs.

  1  01h  | Single-step/debug exception:
          | Occurs for any of a number of conditions:
          | - Instruction address breakpoint fault
          | - Data address breakpoint trap
          | - General detect fault
          | - Single-step trap
          | - Task-switch breakpoint trap

  2  02h  | Nonmaskable interrupt:
          | Occurs because of a nonmaskable hardware interrupt.

  3  03h  | Breakpoint:
          | Occurs when the processor encounters an INT 3 instruction.
```

- Link Ch 8b

Modifying Execution with a Debugger

Skipping a Function

- You can change control flags, the instruction pointer, or the code itself
- You could avoid a function call by setting a breakpoint where at the call, and then changing the instruction pointer to the instruction after it
  - This may cause the program to crash or malfunction, or course

Testing a Function

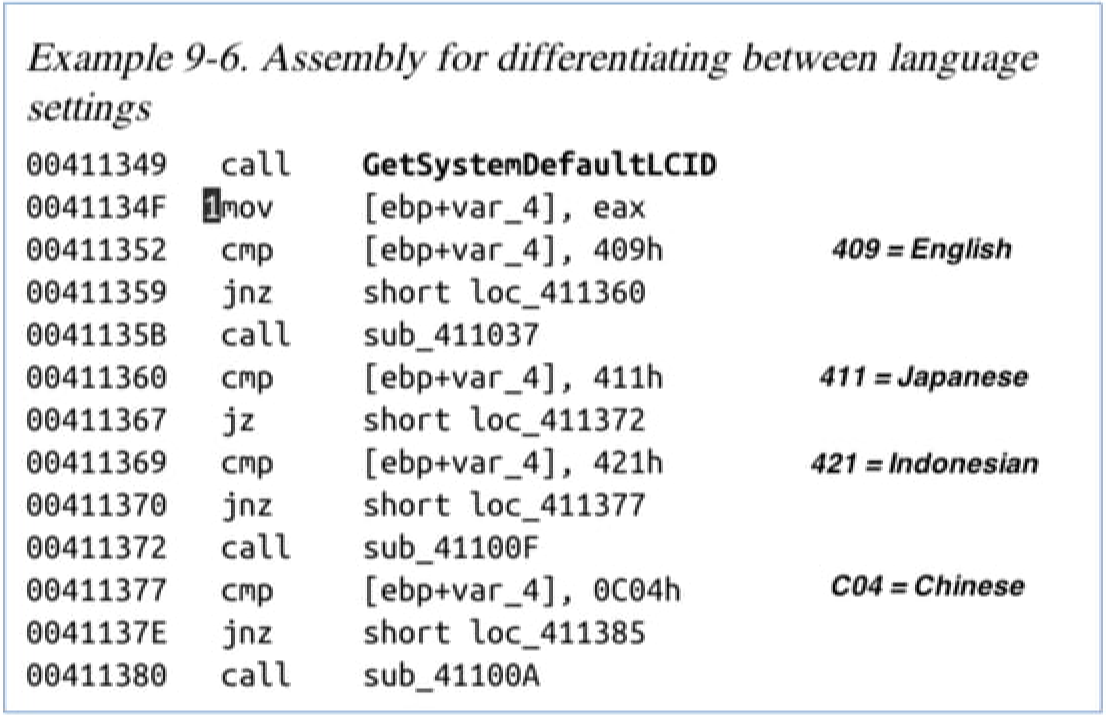
- You could run a function directly, without waiting for the main code to use it
  - You will have to set the parameters
  - This destroys a program's stack
  - The program won't run properly when the function completes

Modifying Program Execution in Practice

Real Virus

- Operation depends on language setting of a computer
  - Simplified Chinese
    - Uninstalls itself & does no harm
  - English
    - Display pop-up "Your luck's no good"
  - Japanese or Indonesian
    - Overwrite the hard drive with random data

Break at 1; Change Return Value



Example 9-6. Assembly for differentiating between language settings

```
00411349   call    GetSystemDefaultLCID
0041134F  1mov     [ebp+var_4], eax
00411352   cmp     [ebp+var_4], 409h          409 = English
00411359   jnz     short loc_411360
0041135B   call    sub_411037
00411360   cmp     [ebp+var_4], 411h          411 = Japanese
00411367   jz      short loc_411372
00411369   cmp     [ebp+var_4], 421h          421 = Indonesian
00411370   jnz     short loc_411377
00411372   call    sub_41100F
00411377   cmp     [ebp+var_4], 0C04h         C04 = Chinese
0041137E   jnz     short loc_411385
00411380   call    sub_41100A
```