Advanced Topics in Malware Analysis

Dynamic Malware Analysis Tools and Techniques

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Advantages and Disadvantages of Dynamic Malware Analysis

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Learning Objectives

- Integrate various types of dynamic malware analysis tools for analysis
- Identify data transmitted/ received by applications
- Employ basic techniques of malware sandboxing
- Use debuggers to analyze malware executable at runtime

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Welcome to Dynamic Analysis!

- Dynamic program analysis solves problems by inspecting software execution
- Inspecting executions vs. static binaries
  - Not all statements are executed, but one statement may be executed many times
  - Analysis is always local to a single path --- the executed path
  - All variables are instantiated
    - No aliasing! Yay!
    - Memory addresses are concrete
- This results in dynamic analysis having ….
  - A relatively lower learning curve
  - Better precision
  - More widely applicable analyses
  - Better scalability (i.e., no more path explosion!)

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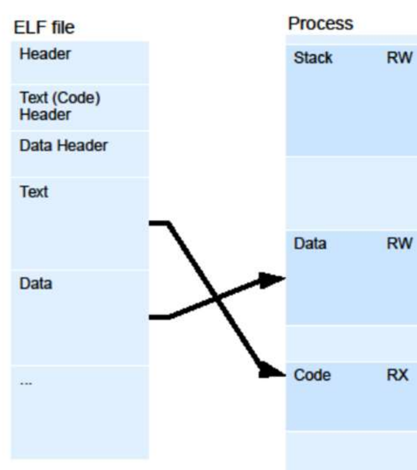
A Look Inside of an Executing Process

- Loader maps runtime sections of all shared objects into virtual address space
- The loader calls global initialization functions of all libraries
  - Why is the order important?
  - E.g., Libc initializes heap data structures and uses the sbrk and brk system calls to set up space for the memory allocator
- In Summary: Executing binaries look nothing like binary files!
  - But it is possible to go back from memory to a file! We will see it…



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Dynamic Analysis of Malware

- Execute and monitor malware sample
- Be careful…
- **Advantages**
  - Insight into behavior w/o deep understanding of code
  - Can overcome encryption/packing schemes
- **Disadvantages**
  - Can & will accidentally execute dangerous payloads!
  - You may have to overcome anti-analysis behaviors
  - Some tools may help you, but…
  - Malware detect tools, virtual machines, debuggers, anything…

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Basic Tools

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Basic Dynamic Analysis Tools

- Process/Filesystem/Registry analysis
  - Live analysis of modification of Windows registry
  - Filesystem activity monitoring
    - Basic: $ watch ls –l
    - Periodically execute a command & show the changing output
  - System call traces
    - dtruss, ptrace, etc.
  - Library call traces
    - ltrace
  - Process monitoring
    - Best Ever: procmon

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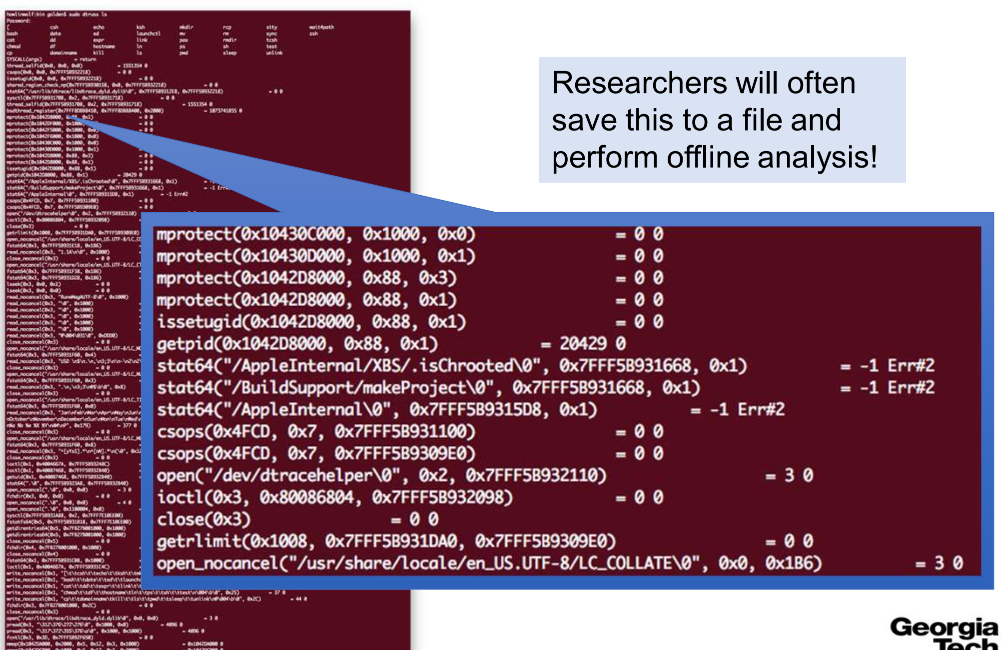
dtruss



Researchers will often save this to a file and perform offline analysis!

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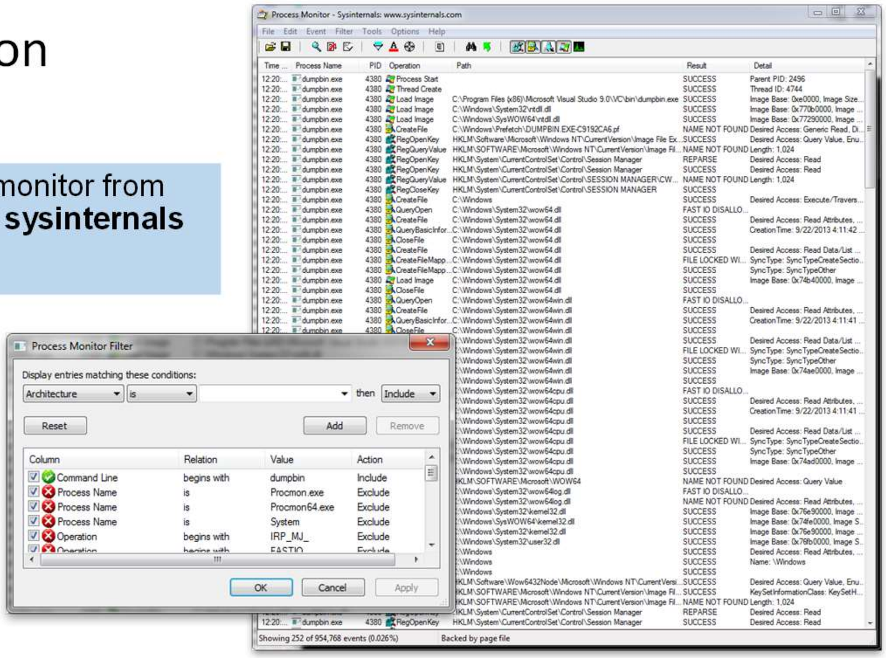
Procmon

Process monitor from Windows **sysinternals** tool suite



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More BASIC Dynamic Analysis Tools

- **Network Trace Capture/Analysis**
  - Discover data transmitted/received by application
    - e.g., WireShark
  - Discover remote peers
  - Allows reverse engineering of network protocols used by an application
    - A lot of research done on this!
    - **Highly Recommended Read:** Comparetti, P. M., Wondracek, G., Kruegel, C., & Kirda, E. (2009). Prospex: Protocol Specification Extraction. *2009 30th IEEE Symposium on Security and Privacy*.
- **Serial/Parallel Port Monitoring**
  - Reverse engineer serial/ parallel protocols
  - E.g., portmon
  - Not just old malware!
  - Newer cyber-physical (“close to the hardware”) malware

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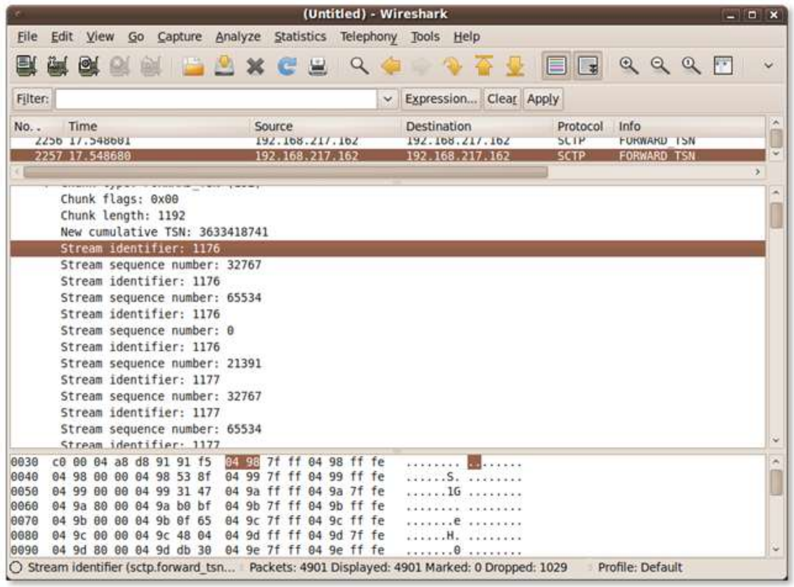
Wireshark



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Major Advantage of Dynamic Malware Analysis

- Analysis of **encrypted**/**packed**/**obfuscated** malware
- Obfuscation or encryption of parts of the malware body **makes static analysis much harder** or impossible!
  - This buys the malware author time to keep the infection & spread going!
- Reverse engineers will often have to supplement static analysis with **dynamic analysis** or **emulation techniques**
- There are some basic techniques
  - Debuggers
  - IDA support
  - Extracting decrypted/unpacked executable code from memory
  - We will see next…

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Debuggers

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The Dynamic Analysis Fan Favorite: Debuggers

- Not just for fixing your buggy C pointers anymore!
- Reverse engineers can analyze the malware executable at runtime
- Provides a disassembly of executable
  - Like static disassembly but local to the execution path!
- Also allows reverse engineers to monitor and **modify** execution
  - Modify = change the "call kill_your_machine" instruction to "nop"
- Monitor CPU registers, memory, flags, and control flow
- Trace access to specific memory regions
- Set breakpoints to avoid extremely fine-grained analysis

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Kernel vs. User-mode Debugging

- **User-mode debuggers** analyze only user-mode side of application
- Examples: OllyDbg, debuggers in IDA Pro, GDB & WinDbg (can be both!)
- Often sufficient for most malware

- God Mode Activate: **Kernel-mode debuggers**
  - Often used by kernel developers
- Examples: SoftICE (gone) , KD/NTKD, GDB & WinDbg (can be both!)
- Allow analysis of user-level code, kernel code, & low-level breakpoints

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More on Kernel-Mode Debuggers

- In the old days, required a second system connected via serial cable for inspecting kernel instructions & data

- Nowadays we can simply attach the debugger to a guest VM from the host

- Example from malware analysis:
  - Low level breakpoint on kernel code that provides window movement
  - This allows window movement action to be located regardless of which high-level API is used

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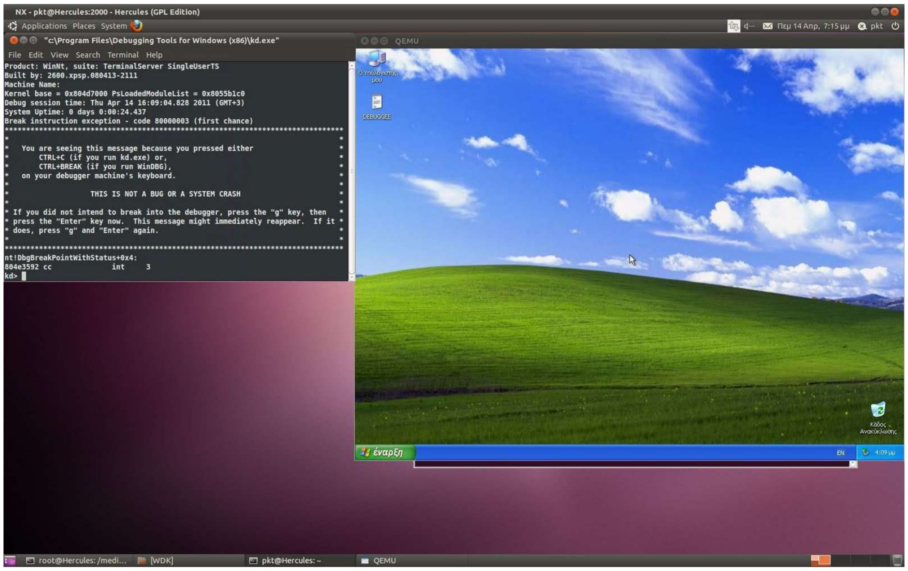
Debugging Windows Kernel in a VM



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SoftICE Screenshot (Rest in Peace)

- Tricking Skype to run while being debugged by SoftICE
- Ref: http://gcasiez.pagesperso-orange.fr/skypeandsoftice.html
- Skype has many anti-debugging tricks, maybe it is a malware?
- We will see anti-debugging tricks later…

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The Big Kahuna: GDB

- GDB is the default debugger on Linux machines and part of the GNU toolchain
- `disas` symbol to disassemble a symbol
- `break *0xf00` to set a break point (sets breakpoints anywhere)
- `bt` prints a backtrace of the stack (either frame pointers or debug information is needed)
- `info registers` displays current register contents
- `set` can update memory cells, variables, even change code
- Infinitely extensible via plug-ins!

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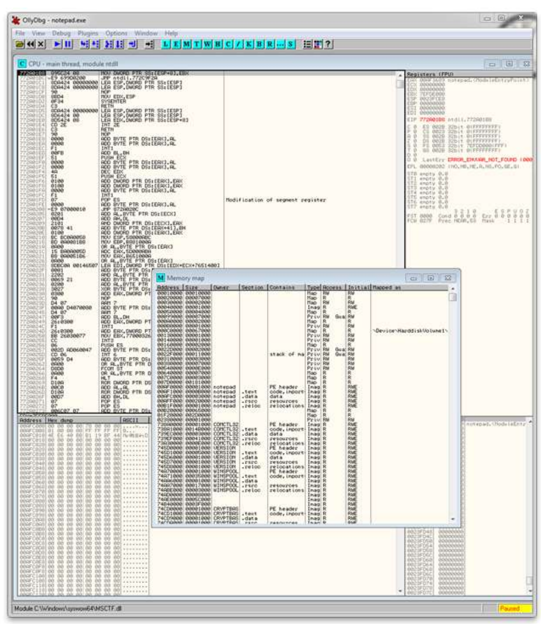
OLLYDBG

- The fan favorite of user-mode debuggers
- So many features… ☺
- Decent GUI ☺
- Becoming totally outdated ☹



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Ollydbg Basics

- User-mode debugger
- **Typical functionality**:
  - Single stepping, step into, step over, etc.
  - Examination of memory, registers
- Supports several kinds of breakpoints
  - **Software** (unlimited # via int 3, writes "0xCC" into code)
    - Easy for malware to defeat
  - **Hardware** (only four at a time, CPU watched for code addresses stored in registers)
    - Harder to defeat
  - **Memory** (one and only one at a time)
    - OllyDbg single steps and catches access to memory location!
    - Less likely to be defeated

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Ollydbg Basics (Cont.)

- For some packed/encrypted executables, you can isolate decryptor, execute it, and then analyze unpacked executable
- Careful not to execute the viral payload!

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Debugging Malware, Easy?

- No
- Reverse engineering modern malware is never easy
- Many layers of obscured code, anti-debugger, anti-emulation, anti-VM
  - Malware detects use of software/hardware breakpoints
  - Use of rdtsc
  - Side effects of debuggers
  - APIs for debugger detection
  - See http://www.securityfocus.com/infocus/1893 for lots more on Windows debugger detection
- Recommended read: Chapter 17 in Volume 3B of the Intel manuals for detailed information on debugging
- Often requires using multiple tools at the same time to get a high-level idea of what is going on BEFORE doing fine-grained analysis

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Real World Malware Investigation

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Real World Malware Investigation

Unlocking Ransomware Without Paying The Russians

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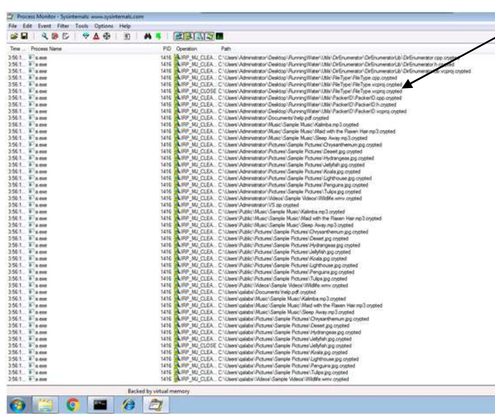
Ransomware Case Study

Step 1: Fire up a VM and fill it with "realistic" user files

Step 2: Detect RansomLock.AK with Procmon



- Victim files are given a ".crypted" extension
- File extensions and target files change among different families
- E.g., This family does encrypt source code (c, cpp, h files), but others do not
- No families encrypt executables --- They want the system to keep running!

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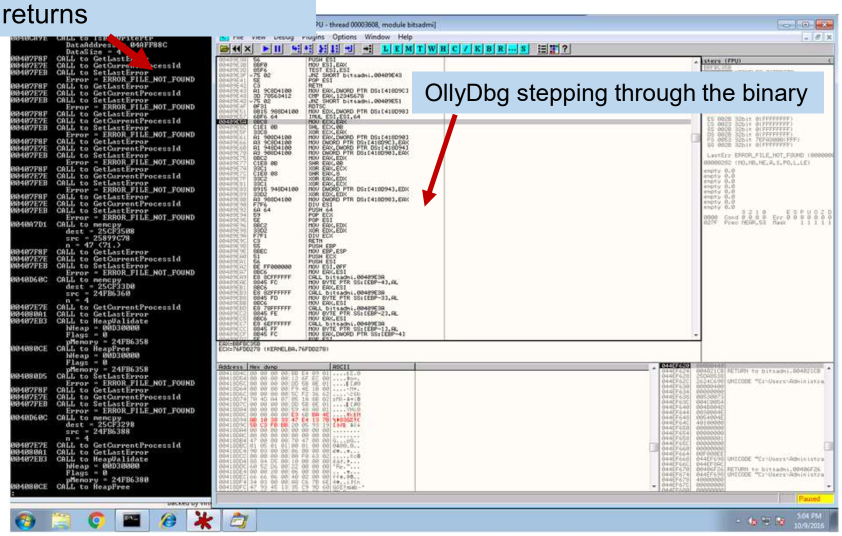
Finding The Decryption Loop in Cryptolocker.AH

Terminal logging library function calls & returns

OllyDbg stepping through the binary



- Uses "baked-in" inline statically-compiled RSA encryption/decryption loop
  - Finding it was not fun ;)

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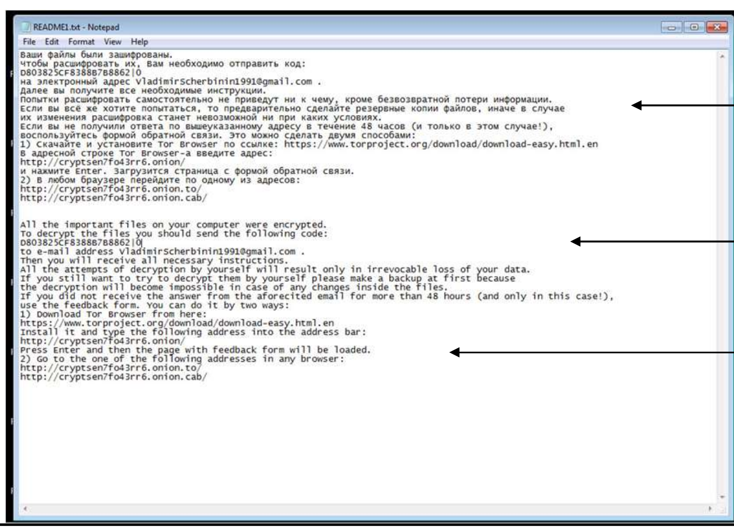
I had to Reverse engineer it…
The readme.txt was not helpful!



Russian?

Please email the following ID to vladimirscherbinin1991@gmail.com
(perhaps 25 years old?)

If you do not hear back in 48 hours then please use the Feedback Form!

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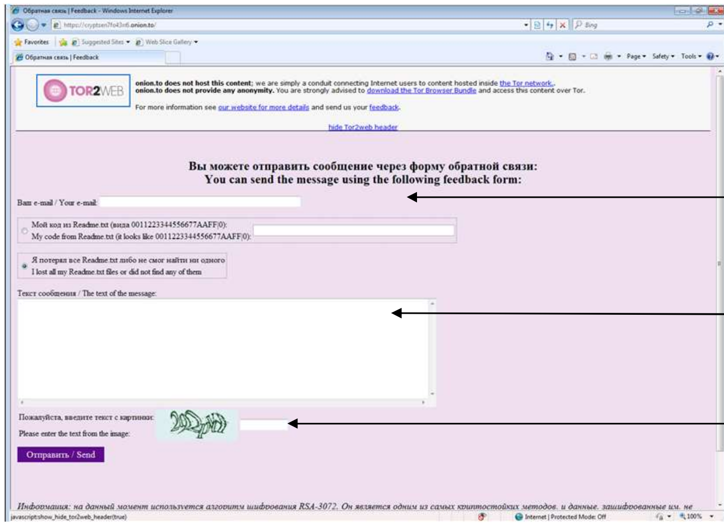
But The Feedback Form Was Nice!



Enter your email

Personal message

And the CAPTCHA
(Vladimir doesn't
want spam!)

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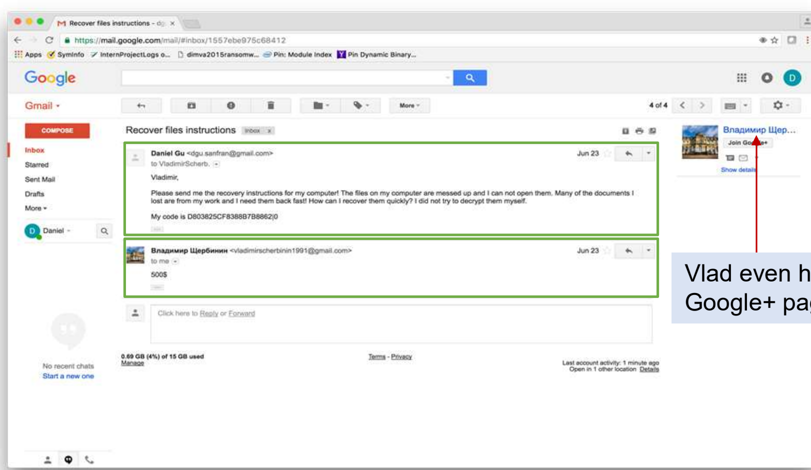
I had to Reverse engineer it…
I wasn't paying $500 to get Symantec's files back!



Vlad even had a Google+ page!

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Software/Hardware Breakpoints

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Software Breakpoints

- Software breakpoints use **int 3**
- **int 3** opcode is a one byte instruction specifically to support easy replacement of other instructions by debugger
- Debugger replaces the target instruction with **int 3** opcode (0xCC)
- Executing **int 3** directly calls a system call which looks up if the process is being debugged
- Debugger regains control through **int 3** handler

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Detection of Software Breakpoints

- Malware simply search their own code for the **0xCC opcode**
- Malware can also checksum/hash its own code to make sure **int 3** has not been inserted
- Malware can remove breakpoint, exit, etc.
- Obvious sign for reverse engineers: Debugging stops working/ exits/ crashes, whatever…

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Detection of Hardware Breakpoints

- Debug registers **DR0**, **DR1**, **DR2**, **DR3** contain linear addresses for breakpoints
- Debug register **DR7** is debug status register
- Indicates which breakpoints **DR0 - DR3** are set and has other status info
- When the CPU detects **RIP == DR(0-3)**, then it raises an interrupt
- Does the same stuff as **int 3** handler
- Again: Chapter 17 in Volume 3B of the Intel manuals for detailed information on debugging

- Malware can scan debug registers to determine if breakpoints are set
- If set: can exit, perform alternate behavior, etc.

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Use of rdtsc to Detect Debugging

- `rdtsc` (opcodes 0x0F 0x31) introduced for Pentium and beyond
- Read Time Stamp Counter
- Gets # of ticks since last CPU reset into rdx:rax
- However, this can reveal dynamic analysis to a malware!
- **Idea**: Debugged/monitored code runs slightly more slowly than un-debugged code
- Malware measures the passage of time using `rdtsc` and executes evasive action if its execution seems to be taking too long
- Try for yourself: set breakpoints on NOPs after `rdtsc` instructions

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Detecting Side Effects of Debuggers

- Example: Detect **SoftICE** debugging your kernel from inside a malware!
- **SoftICE** replaces a few interrupt handlers in the kernel's **interrupt descriptor table** (IDT)
  - Namely, **int 1** and **int 3** in order to handle debugging the kernel itself!

```
mov eax, dword ptr [pIDT+2] ; eax -> IDT
add eax, 8                  ; eax -> int 1 vector
mov ebx, [eax]              ; ebx == int 1 vector
add eax, 16                 ; eax -> int 3 vector
mov eax, [eax]              ; eax == int 3 vector
and eax, 0ffffh             ; strip the selector
and ebx, 0ffffh             ; part of it
sub eax, ebx                ; find displacement
cmp eax, 10h
jne HackedVector            ; if it isn't equal, then chances are
                            ; SoftICE had tampered with these vectors
```

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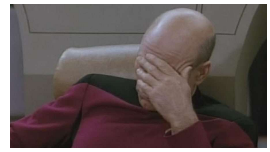
Windows Leaks for Debugger Detection



- Windows provides ways to if you're being debugged
- Offset 2 in PEB (**Process Environment Block**) structure is a flag for "**is debugger present**"
- Windows provides an API called "**IsDebuggerPresent()**" which simply checks this flag
- **PEB!NtGlobalFlags** determines how some heap management is performed and the flags get changed for debugged processes

- Many others, some are very obscure
- More info https://www.symantec.com/connect/articles/windows-anti-debug-reference

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Case Study: Armadilo

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Brief Packer Case Study: Armadillo

- Malware (or their packers) may also include very complex custom techniques to thwart debuggers
- Case Study: Armadillo
- Commercial packer from Silicon Realms
  - They call it an "**executable compressor**"
- Widely used to protect expensive commercial software from being reverse engineered
- Three amazing features:
  - Double process debugging
  - "Magic" jumps (conditional branches instead of JMPs)
  - Encryption

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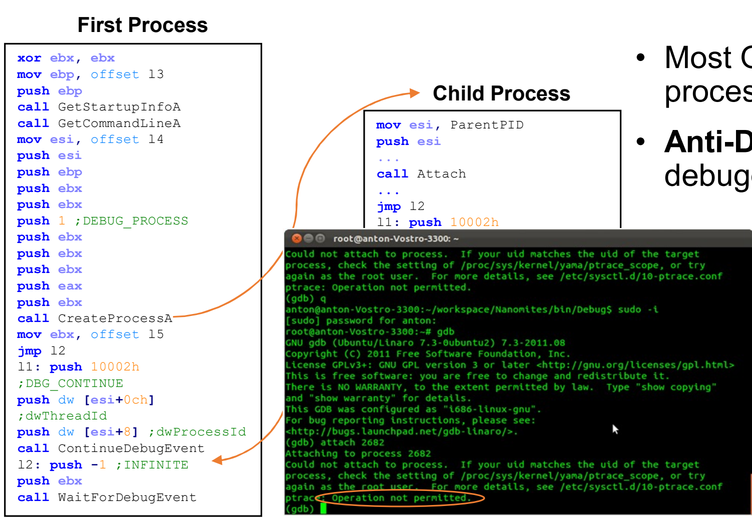
Double process debugging



- Most OSs only allow 1 debugger process to debug 1 debugee process
- **Anti-Debug Solution**: 2 processes debugging each other!

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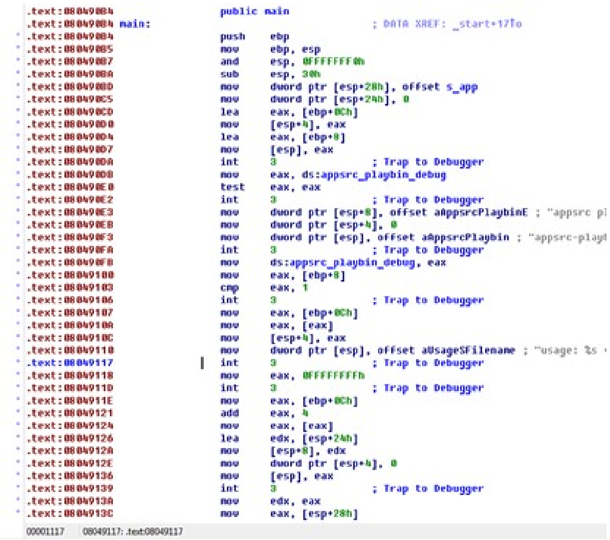
Armadillo's Magic

- "**Nanomites**": Twist on double process debugging
  - Jump instructions replaced with int 3 software breakpoint opcodes in child process
  - Parent handles software breakpoints and looks up actual jump targets in an encrypted table
  - Decrypts the jump target & patches child code before resuming the child's execution



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Defeating Nanomites

- Reverse engineers need to repeatedly & carefully terminate the child/parent debug relationship after monitoring behavior
  - Have to keep doing this until all needed nanomite patches have been detected!
- Manual unpacking very tedious
- Recommended read: https://www.apriorit.com/white-papers/293-nanomite-technology
- Constant war between crackers and Silicon Realms
- Evidence that all versions have been cracked, eventually
- Excellent additional read:
  - Ferrie, P. (2008). Anti-unpacker tricks- part one. *Virus Bulletin*.

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Defeating Anti-Debugger Techniques

- To combat anti-debugger stuff, reverse engineers will generally have to patch the malware binary to kill one or more of:
  - Double process debugging
  - Debugger detection leaks
  - Breakpoint tampering
  - Use of rdtsc or other timing APIs
  - Illegal instructions

But… when an interpreter is used by the malware, you will probably have to keep it intact unless you want to reverse engineer the interpreter too ☹

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Defeating Anti-Debugger Techniques (Cont.)

- Difficulty varies by packer
- Different versions of packer will likely require some different techniques
- Recommended Read:
  - Deng, Z., Zhang, X., & Xu, D. (2013). Spider. *Proceedings of the 29th Annual Computer Security Applications Conference on - ACSAC 13*

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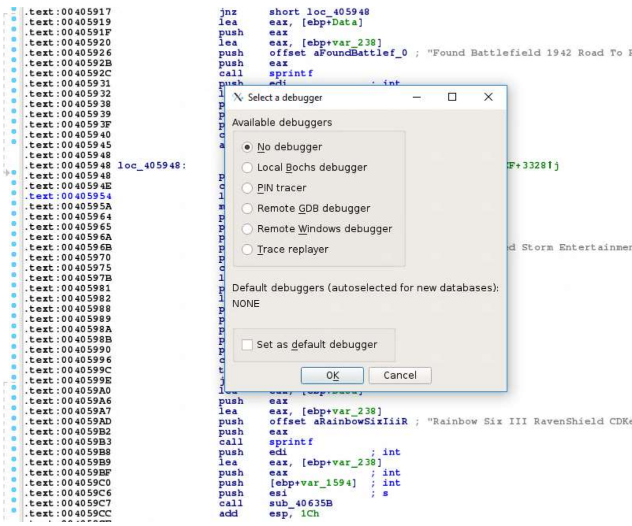
Debuggers in IDA

- IDA knows that you will be performing static and dynamic analysis
- So why not use the power of IDA to help with debugging…
- … and feed the knowledge gained from debugging back to IDA!
- So IDA integrates with many debuggers
- Plug-ins can add support for all others!



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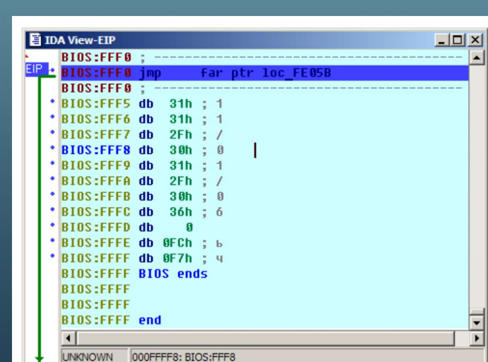
Debuggers in IDA (Cont.)

- IDA + Debuggers + Plugins = Extremely powerful
- https://www.hex-rays.com/products/ida/support/tutorials/remote-debugging.shtml
- IDA can connect to a remote debugger and supply all of that debugger's functionality within IDA
- Even remote debuggers on VMs (remember kernel debuggers?)
- Here is IDA debugging the BIOS of a Windows kernel during boot!



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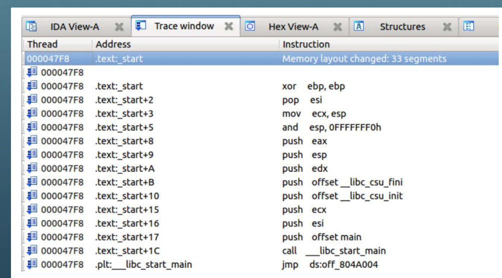
IDA Trace and Replay

- IDA can also record a trace of the instructions which execute during dynamic analysis
- Then replay those exact instructions over and over again!
- Allows for repeating analysis without having to re-execute the malware
  - E.g., Avoid miserable unpacking, Command and control server is gone, etc.
  - Research e.g., Differential analysis -> “What paths differ when I give this argument?”
- Much more on tracing in the next slide set…



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Instruction Emulation: x86emu

- Plug-in for IDA Pro written by Chris Eagle (author of The IDA Pro book!)
- Very IDA Pro SDK version specific, but has been updated!
- Available @ http://sourceforge.net/projects/ida-x86emu/
- Provides x86 emulation
- Safe, because it’s not really executing code that’s been loaded into IDA
- Memory/register/stack emulation
- Does not execute Win32 API functions
- Does allow you to specify their effects
- Often enough to let the decryptor in an encrypted/packed executable complete
- Automatically updates the IDA disassembly listing

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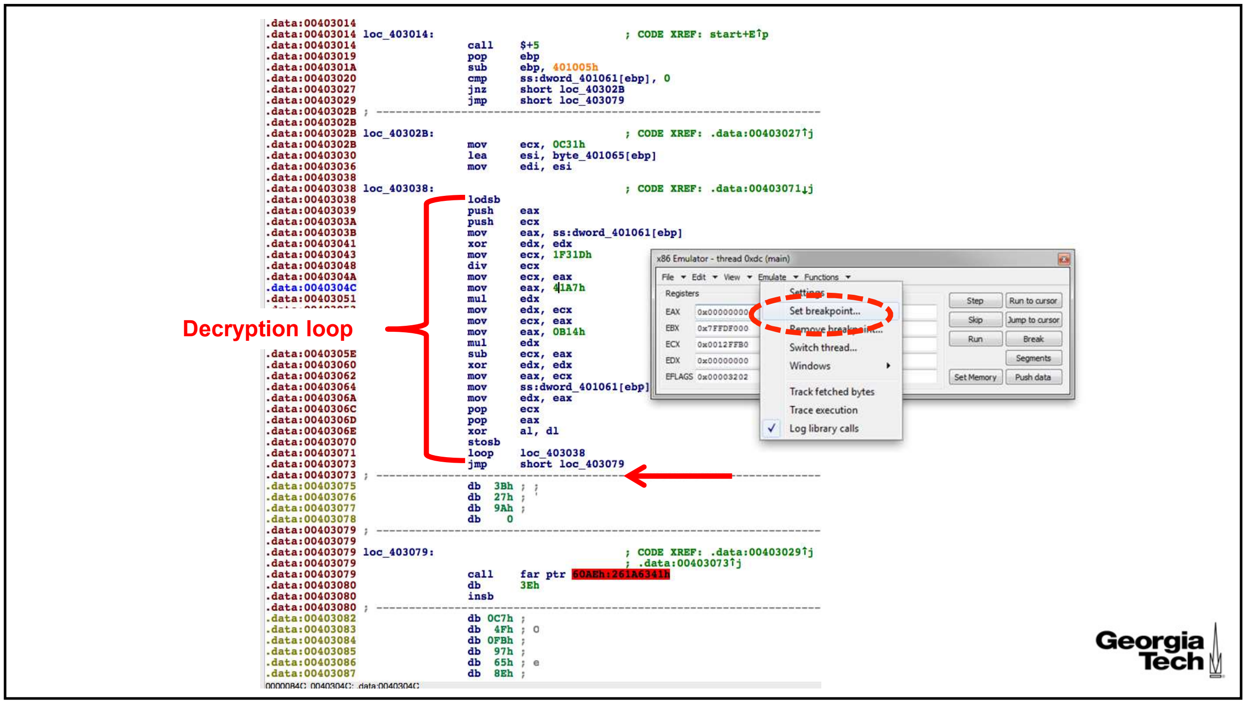

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Lesson Summary

- Integrate various types of dynamic malware analysis tools for analysis
- Identify data transmitted/received by applications
- Employed basic techniques of malware sandboxing
- Use debuggers to analyze malware executable at runtime

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