Software Reverse Engineering

COMP 272 | Spring 2022 | University of the Pacific | Jeff Shafer

Anti-RE 2

Malware

Stuxnet – To Kill a Centrifuge

Imagine there was an industrial facility located deep out in the desert…

Stuxnet – To Kill a Centrifuge

… and it was full of gas centrifuges for uranium enrichment

Stuxnet – To Kill a Centrifuge

… and protected by a military who didn’t like *you* very much

Stuxnet – To Kill a Centrifuge

… and you wanted the facility to suffer an *unfortunate accident*

Stuxnet – To Kill a Centrifuge

… without using methods (e.g. airstrikes) that would allow *blame* for the “accident” to be placed on you

Idea: Computer Virus

Stuxnet – To Kill a Centrifuge

- **How to we get our malware to an isolated, network air-gapped facility in the middle of the Iranian desert?**
- People come and go from the facility regularly (e.g. contractors, employees)
- Use spies or other malware to infect **USB keys** that contractors regularly carry into the facility and connect to computers inside

Stuxnet – To Kill a Centrifuge

- **What if the contractors don't have access to all the computers?**
- Malware contains a *worm* that will allow it to spread inside the air-gapped network
- **How can we help ensure malware will spread to all computers inside?**
- Cash in *four zero-day vulnerabilities* that three-letter-agencies were hoarding for a special project
  - Spread from USB: PNK/PIF vulnerability (viewing the icon in Windows Explorer executes the malicious code!)
  - Spread over network: Remote code execution on PC with printer sharing enabled
  - Two privilege escalation vulnerabilities

Stuxnet – To Kill a Centrifuge

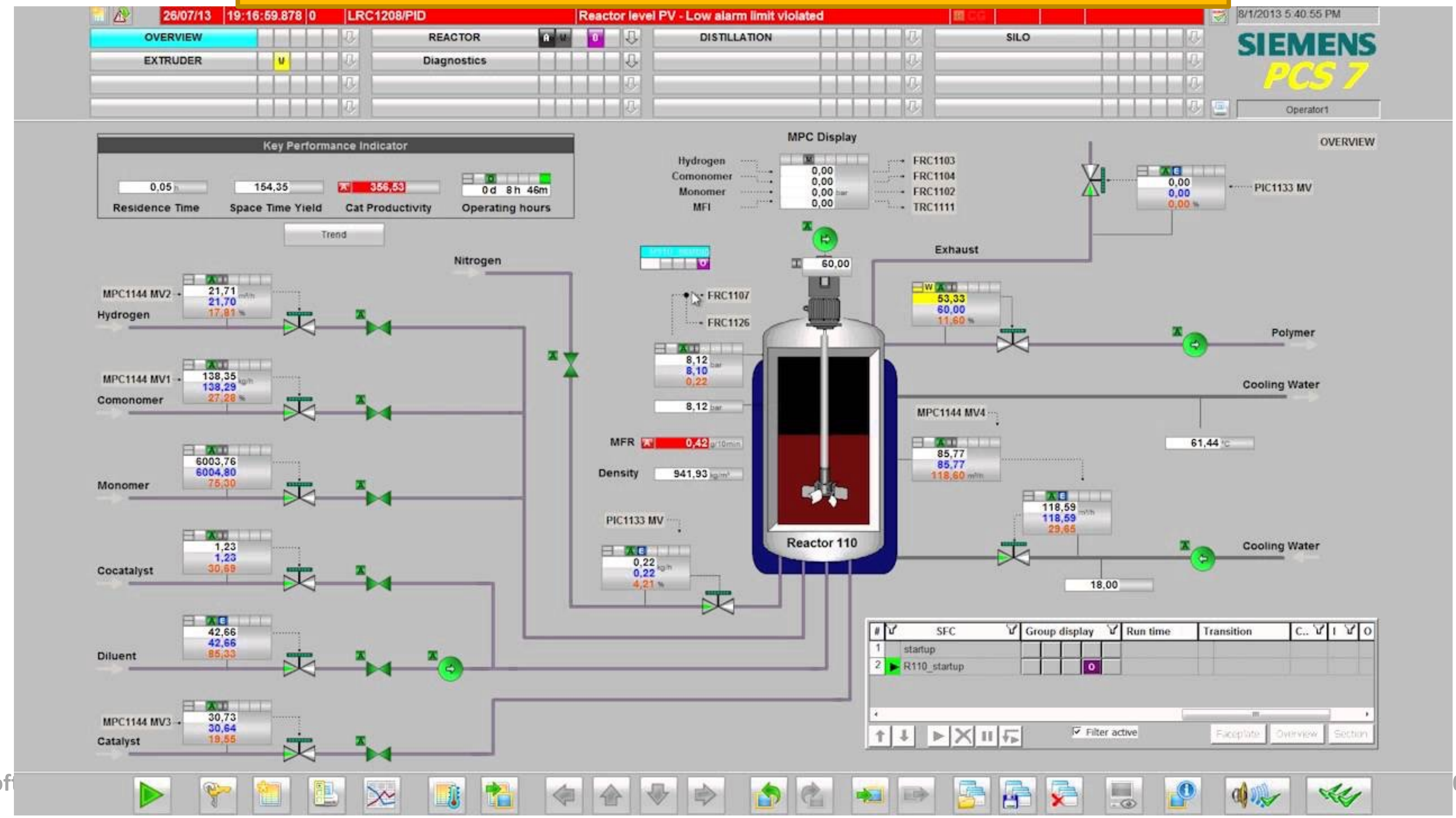
- **How do we ensure that our malware isn't detected?**
- Malware is signed by keys stolen (via spies!) from Jmicron and Realtek in Taiwan
  - Driver signing allows kernel-mode rootkit to be installed
- Safeguards
  - Malware will erase itself after specific date
  - Malware will only spread to a few other targets (worm is not aggressive)
  - Malware will become inert if PC isn't *intended target*

Stuxnet – To Kill a Centrifuge

- **Besides spreading, what do we want the malware to do?**
- Sabotage uranium enrichment centrifuges
- But make it look like innocent technical malfunctions, poor design, shoddy construction, poor quality materials due to embargo, anything *other than* evil hackers!
- These are high performance devices that require *exacting computer controls* to function properly

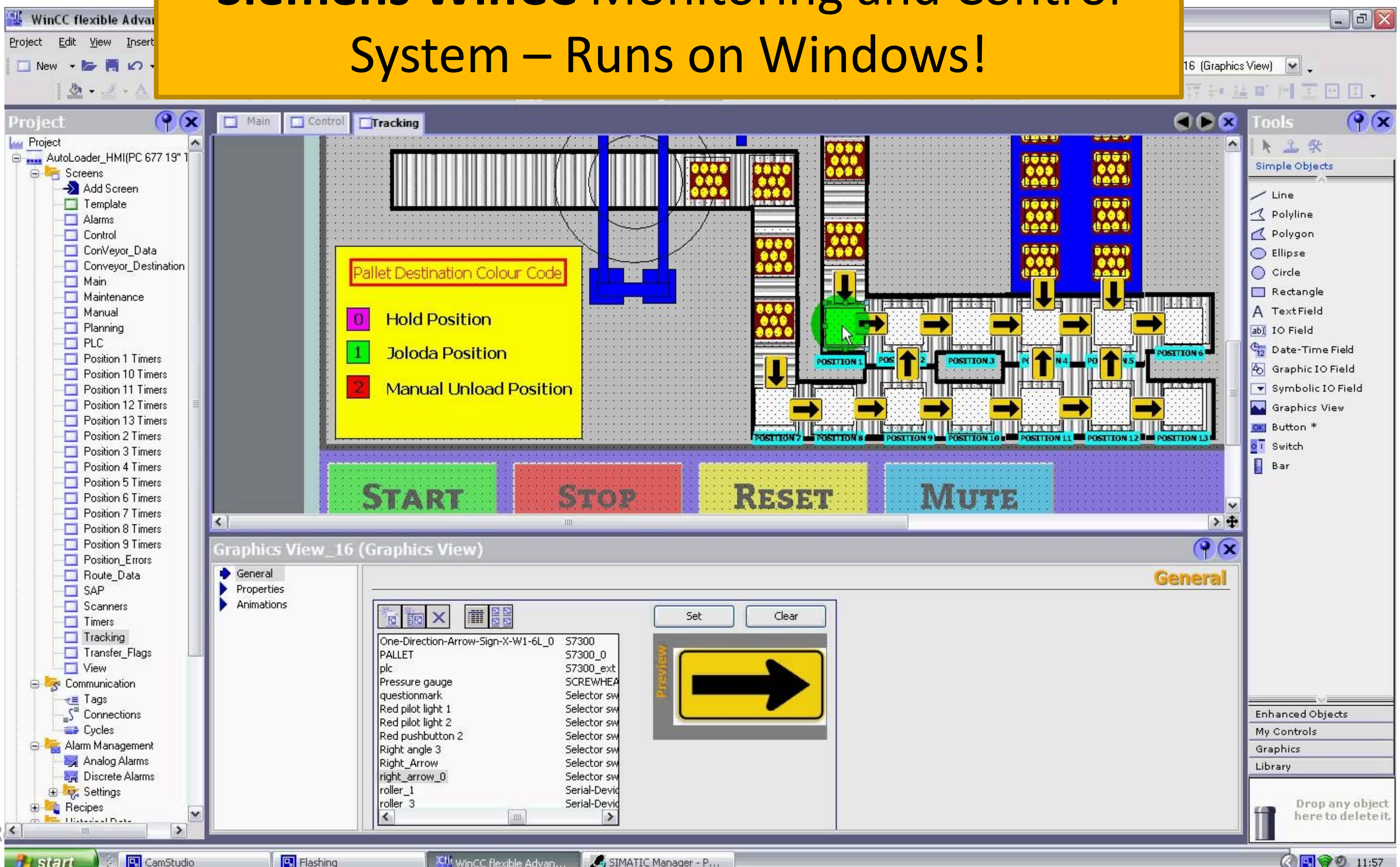
Stuxnet – To Kill a Centrifuge

Siemens PCS 7 Distributed Control System



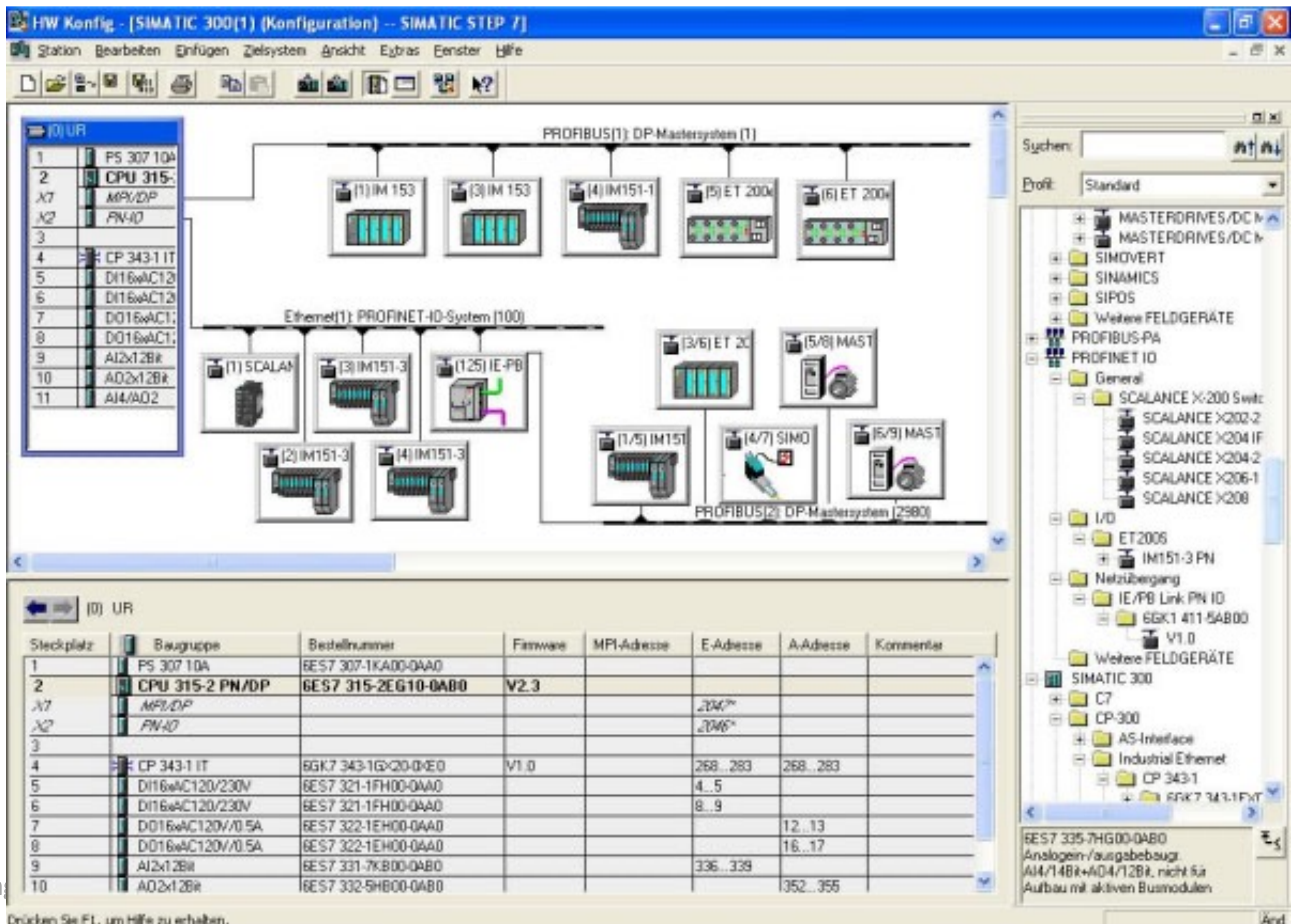
Stuxnet – To Kill a Centrifuge

Siemens WinCC Monitoring and Control System – Runs on Windows!



Stuxnet – To Kill a Centrifuge

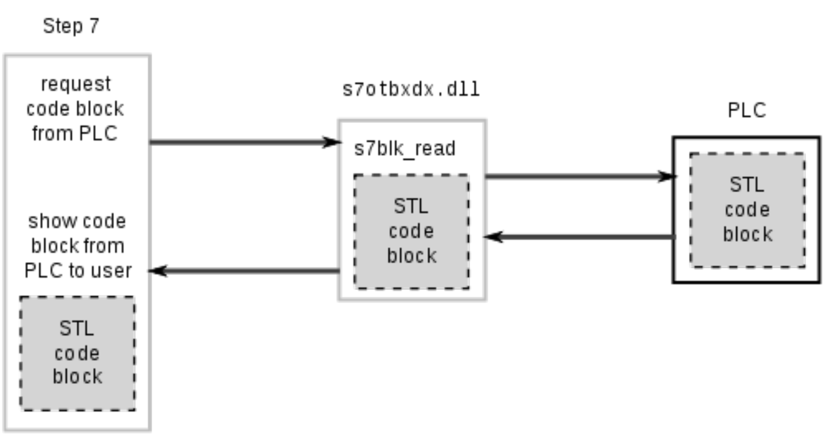
Siemens Step7 Controller Programmer – Runs on Windows!



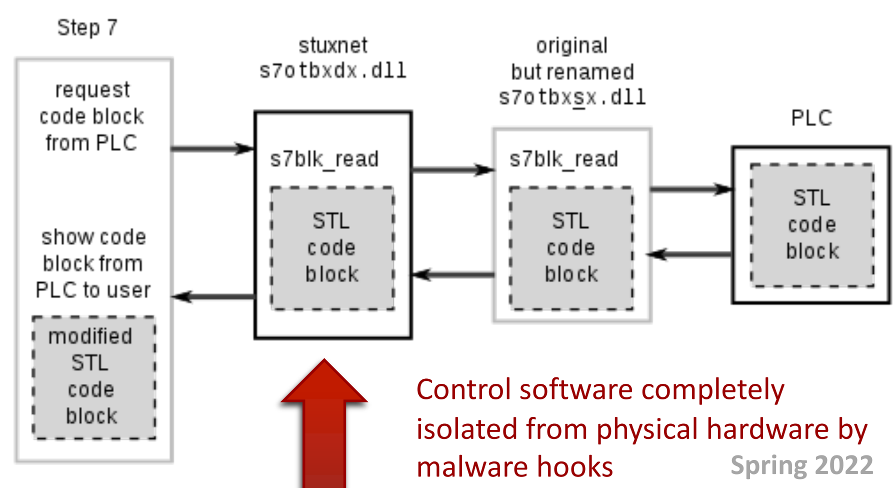
Stuxnet – To Kill a Centrifuge

- **Besides spreading, what do we want the malware to do?**
- Let's **speed up and slow down** the centrifuge in dangerous ways, and **lie to the monitoring system**

Normal Operation:



Malicious Operation ("Hooked"):



Control software completely isolated from physical hardware by malware hooks


THIS IS FINE.

Stuxnet – To Kill a Centrifuge

- Required very detailed (inside) knowledge of centrifuge design and construction
  - Centrifuges were 1960’s-70’s Pakistani designs
- Required very detailed (inside) knowledge of control system monitoring centrifuges
- Malware was tailored for a very specific set of control systems and devices
  - Only attack Siemens S7-300 PLCs controlling variable-frequency drives from two vendors (Vacon and Fararo Paya), spinning between 807Hz and 1210Hz
  - *Most locations in the world? Malware does nothing at all*

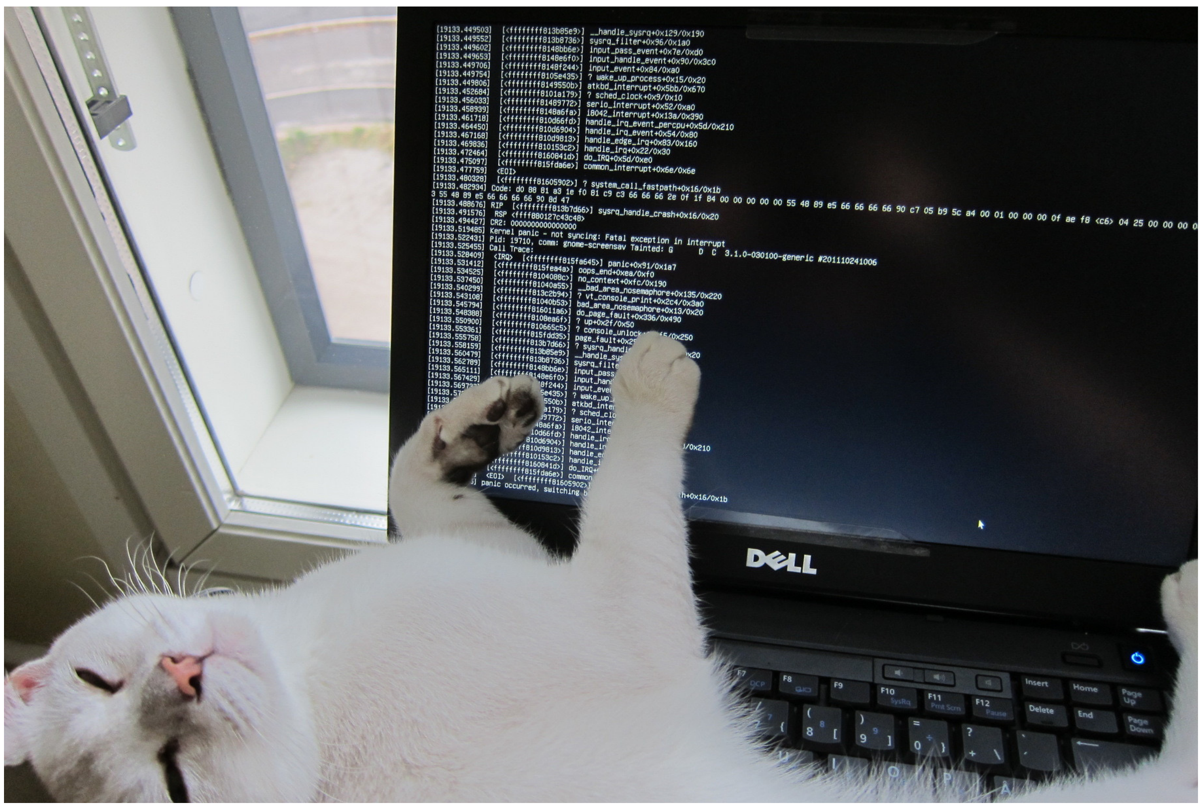
Stuxnet – To Kill a Centrifuge

- "To Kill a Centrifuge"
  - **https://www.langner.com/wp-content/uploads/2017/03/to-kill-a-centrifuge.pdf**
- Attack #1 – Induce minor malfunctions (overpressure) intended to degrade plant operations, *delay* nuclear production and **remain undetected**
- Attack #2 – Induce major malfunctions even at the risk of being detected
  - *"History's first field experiment in cyber-physical weapon technology"*

Anti-RE

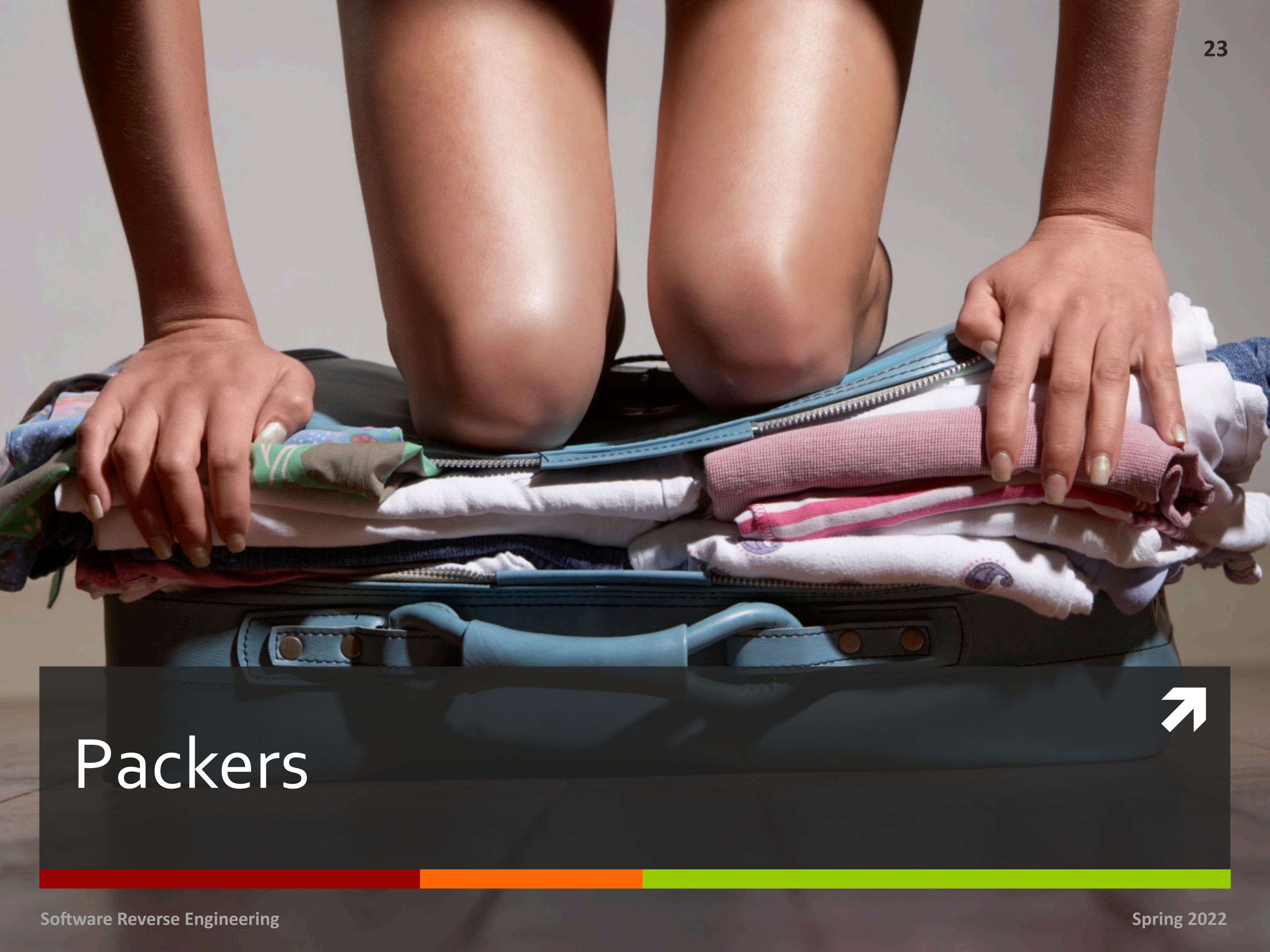
Life as a Malware Analyst

- **The malware authors are <u>actively trying to subvert you</u>**



- *At a minimum, they want to obfuscate their malware to avoid automated detection*
- *And they really don't like you analyzing their code either…*

Constant game of cat and mouse



Packers

Recap – Packers

- Method to hide malicious program from detection
  - Might *compress* original malware
  - Might *encrypt* original malware ("crypter")
  - Might *byte-fiddle* (XOR, …) original malware

Recap – Packers

- *Here's an executable – Is it packed?*
- Signs
  - Few readable strings
  - Few imports in IAT
  - High entropy in program section (i.e. program sections are "too random")
    - Normal code entropy: 5-6 bits per byte
    - Packed code entropy: >7 bits per byte
  - You get lucky / malware author is inexperienced
    - Program sections or embedded strings contain name of packer

Recap – Packers

- You only see the decompression routine
  - Real malware is a compressed/encrypted blob
- Goal: See the extracted blob without wasting time understanding intricate details of the unpacker
- Challenge: Each unpacker is different!
  - Different techniques to conceal code
  - Different techniques to resist debuggers

Methods to *Deal With* Packed Malware

- Method 1 – Direct Memory Dump
- Method 2 – Selective Debugging w/Memory Dump
- Method 3 – Don't Dump, Just Debug

Method 1 – Direct Memory Dump

- **Idea**: Dump the malware executable from memory after unpacking
  - No skill required! ☺
- **Demo #1**
  - Disable ASLR via CFF Explorer (“DLL can move”)
  - Detonate malware
  - Attach to active malware with standalone Scylla
  - Fix IAT, Get Imports, and then Dump
    - Result will have both unpacking code + unpacked malware
- **Problem:** Can’t run the resulting dump. Original Entry Point (OEP) still points to original unpacker code
  - *Would have to wildly guess what correct location is*

Method 2 – Selective Debugging

- **Idea:** Run the malware in the debugger until it unpacks and jumps to unpacked code, then dump contents from memory
  - *As practiced in Lab 8*
- Advantage: You can observe the Original Entry Point (OEP) and fix the dumped executable
  - Better chance of obtaining a *runnable* executable
  - The better the dumped executable, the more useful it will be in IDA

Method 2 – Selective Debugging

- **Demo #2**
  - Disable ASLR via CFF Explorer (“DLL can move”)
  - Load malware into debugger (x64dbg)
  - Locate end of unpacker and set breakpoint there
    - *Finding this location requires skill/detective work*
  - Run to breakpoint, allowing malware to unpack
  - Carefully single-step to jump into unpacked code
    - This is the new OEP – You discovered it!
  - Dump unpacked process (via OllyDumpEx plugin)
  - Fix IAT and OEP (via Scylla plugin, IAT Autosearch, Get Imports)

Finding the End of the Unpacker (1)

- **Thought process for *(potentially)* helpful shortcut**
- **Assumptions**
  - The original binary has no idea it will be packed
  - The packing utility has no idea about the specific binary that will be packed
  - Thus, the unpacker logic, when it uses the stack, has to eventually clean up the stack by the end of the unpacking stub before it jumps to run the now-unpacked binary
- **Shortcut**
  - Set a hardware breakpoint on the first element of the stack
  - Sooner or letter (probably sooner), you will arrive at the end of the unpacker right before a jump or call to the unpacked binary

Finding the End of the Unpacker (2)

- **A different thought process for *(potentially)* helpful shortcut**

- **Assumptions**
  - The unpacked binary must go *somewhere* – You need to find that location
  - Perhaps a PE section has a `real-size` of 0 bytes but a `virtual-size` of <u>many</u> bytes?
  - Perhaps the packed binary calls a single memory allocation function (`VirtualAlloc`)?
  - Perhaps there's a huge block of 0's in the file?

- **Shortcut**
  - Set a <u>hardware</u> write breakpoint at the first and last address of your suspected region
  - Run until you hit those breakpoints
  - Look around in the debugger (via "View as Disassembly")
    - Does it look like *code* got placed in that region? Is the region full now?
  - Cross your fingers and hope that the unpacker is "nearly finished" now
  - Do some aggressive single-stepping or loop skipping (via run until selection) until you see a jump whose target address is inside your suspected region
    - This is the new OEP – You discovered it!

Method 3 – Don't Dump, Just Debug

- **Idea:** Malware unpacker may be too obfuscated to easily find jump to unpacked code, or there may be inscrutable problems fixing IAT
  - Do you **really need** to dump the unpacked file to answer your analysis questions about the malware?
  - Don't bother trying to find the end of the unpacking routine or the unpacked OEP
- Use the debugger to examine the original packed malware after it completes its unpacking work and the malware is running
  - Use behavioral analysis to generate *questions*
  - Use the debugger to *selectively* answer those questions

Method 3 – Don't Dump, Just Debug

- **Demo #3**
  - Disable ASLR via CFF Explorer ("DLL can move")
  - Load into x64dbg
  - Goal – We want to set a breakpoint on an API that the malware uses (`SetBPX FunctionName`)
    - Option 1: Guess likely API names based on behavioral analysis – Perhaps you observe file I/O or network I/O?
    - Option 2: Inspect program memory map for likely regions of unpacked <u>executable</u> code (ignoring DLLs, less likely)
  - Run to that breakpoint!
    - Malware should be unpacked by this point
  - In this *region* you can inspect strings, intermodular calls, etc…
    - Set <u>hardware</u> breakpoints and reset execution to run to them

Code Injection

Code Injection

- Malware doesn't always have to operate from its own `malware.exe` process
  - Malicious code can be injected into other user-space processes and the original `malware.exe` exits
- Advantage: Makes infection harder to spot, as there are only "normal processes" running on the system
- Code injection may be done by the *unpacker*

Code Injection – API Calls

1. Get list of processes on system
   `CreateToolhelp32Snapshot`, `EnumProcesses`
2. Obtain handle to target process
   `OpenProcess`
3. Allocate space in memory of target process
   `VirtualAllocEx`
4. Write injected code into target process
   `WriteProcessMemory`
5. Run the code
   `CreateRemoteThread`

Many variations exist using normal Win32 API calls

Code Injection – API Calls

- Malware might call undocumented native API (NtXXX or ZwXXX) directly, bypassing the official Windows API functions

1. `CreateToolhelp32Snapshot`
   `-> NtQuerySystemInformation`

2. `OpenProcess`
   `-> NtOpenProcess`

3. `VirtualAllocEx`
   `-> NtAllocateVirtualMemory`

4. `WriteProcessMemory`
   `-> NtWriteProcessMemory`

5. `CreateRemoteThread`
   `-> NtCreateThreadEx`

Anti-RE

Debugger Detection

- **Demo #4** – Methods to defeat debugger detection
  - Manual register tampering
  - Manual code patching
  - Cloaking device (ScyllaHide plugin)