Malware

CSE 536 Fall 2026

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Malware *vs.* viruses

- Malware
  - Some personal or political relationship between the binary object and individuals
  - Often exceeds authorization
  - Can be targeted at *one* individual or at *billions* of individuals
- Viruses (including worms, *etc.*)
  - Often malicious, *i.e.*, malware
  - *Self-propagating/self-replicating*

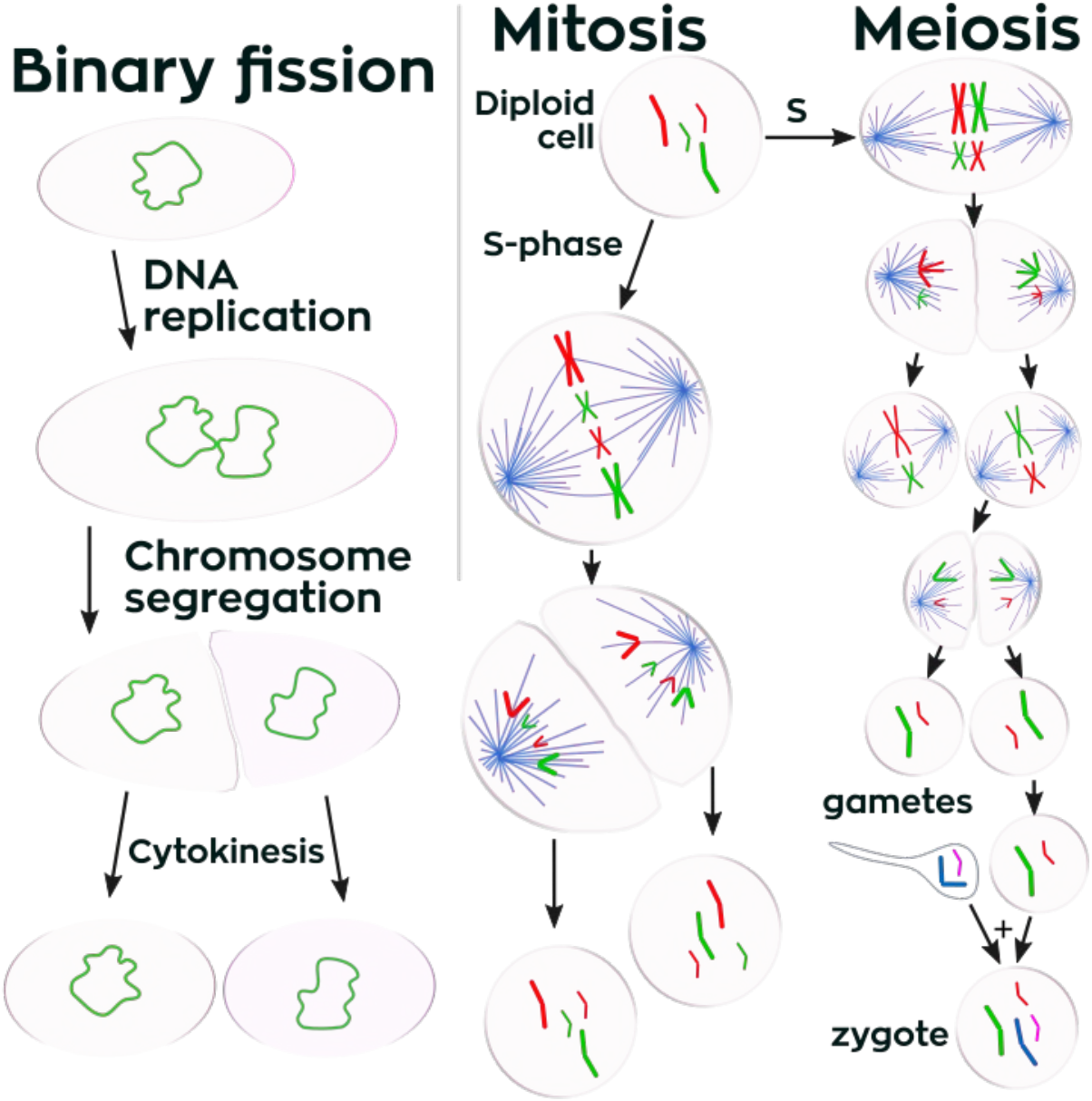
Dimensions

Targeted?
Persistent?
Self-propagating?
Stealthy?
Malicious?

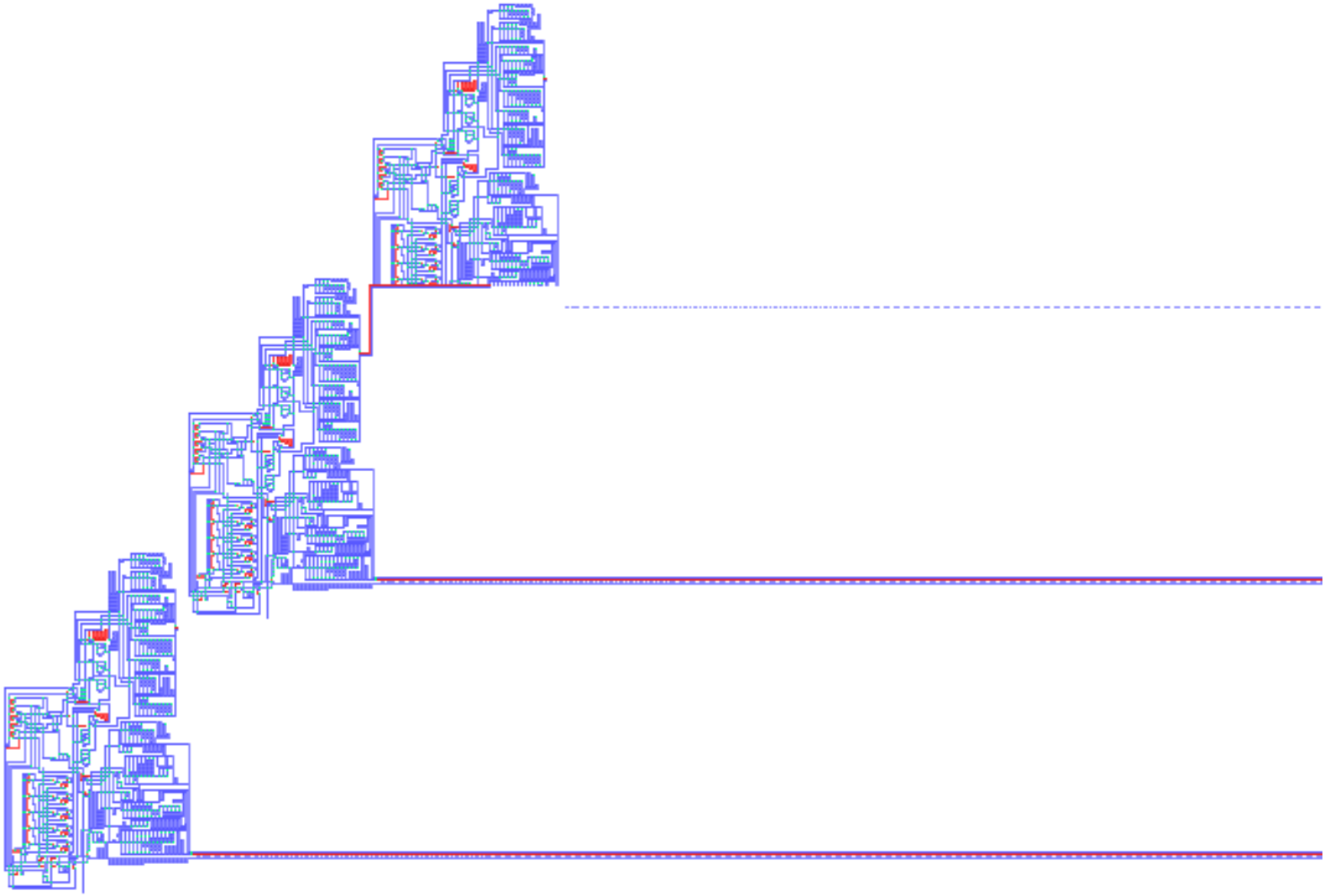
Self replication examples

- Fission (think bacteria)
- Mitosis (think animals and plants, *etc*. growing)
- Meiosis (think sperm and eggs)

https://en.wikipedia.org/wiki/Cell_division



https://en.wikipedia.org/wiki/Von_Neumann_universal_constructor
(1940s)

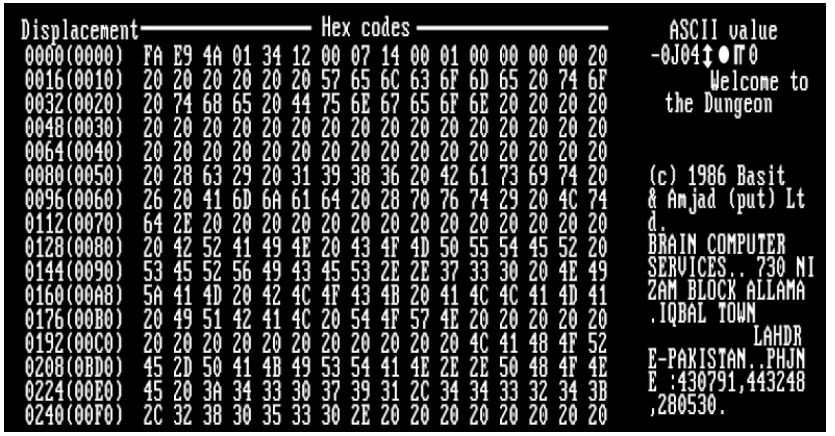


The dawn of computer viruses/worms

- “Worm” came from John Brunner's *The Shockwave Rider* in 1975, “virus” not coined until 1983
  - Creeper in 1971 for TENEX systems (Reaper)
  - ANIMAL in 1975
  - Elk Cloner in 1981 (Skrenta)
  - Morris Worm in 1988
  - Code Red in 2001
- “Virus” coined by Cohen in 1983 (“Information only has meaning in that it is subject to interpretation”)
  - https://web.eecs.umich.edu/~aprakash/eecs588/handouts/cohen-viruses.html
- A “worm” uses a computer network as its main mode of propagation
  - Also alarming to people in 2001: staying in memory and never going out to disk

Malware gets personal

- Brain PC virus in 1986
  - Goal was to protect their copyright
  - Infected machines worldwide
- Amiga viruses (late 1980's)
- MSOffice Macroviruses (1995 to 2003ish)



https://en.wikipedia.org/wiki/Brain_(computer_virus)#/media/File:Brain-virus.jpg



https://en.wikipedia.org/wiki/Amiga_500#/media/File:Amiga500_system.jpg

Macroviruses

- Natural evolution in the wild
  - “ON ERROR RESUME NEXT”
- https://bontchev.nlcv.bas.bg/papers/macidpro.html

Outline of examples

- “Reflections on Trusting Trust”
  - Example of a Trojan Horse
- Cohen
  - Self-replication and self-propagation
- Elk Cloner
  - Stealthy? Targeted?
- Code Red and other worms from the 2000s
  - Infect as many servers as possible, as fast as possible
- Botnets
  - Command and control
- Stuxnet
  - Stealthy and targeted
- Pegasus
  - A “flying Trojan”
- XZ backdoor

Reflections on Trusting Trust (1984)

- https://www.cs.cmu.edu/~rdriley/487/papers/Thompson_1984_ReflectionsonTrustingTrust.pdf
- A Trojan Horse is hidden malicious logic in a program or system

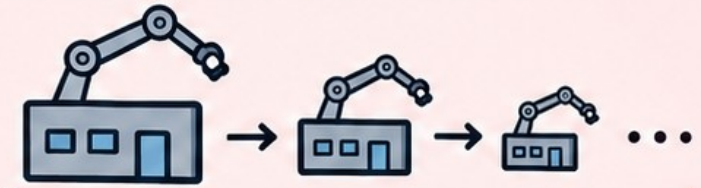
```
compile(s)
char *s;
{
        if(match(s, "pattern1")) {
                compile ("bug1");
                return;
        }
        if(match(s, "pattern 2")) {
                compile ("bug 2");
                return;
        }
        ...
}
```

FIGURE 3.3.

Von Neumann's universal constructor

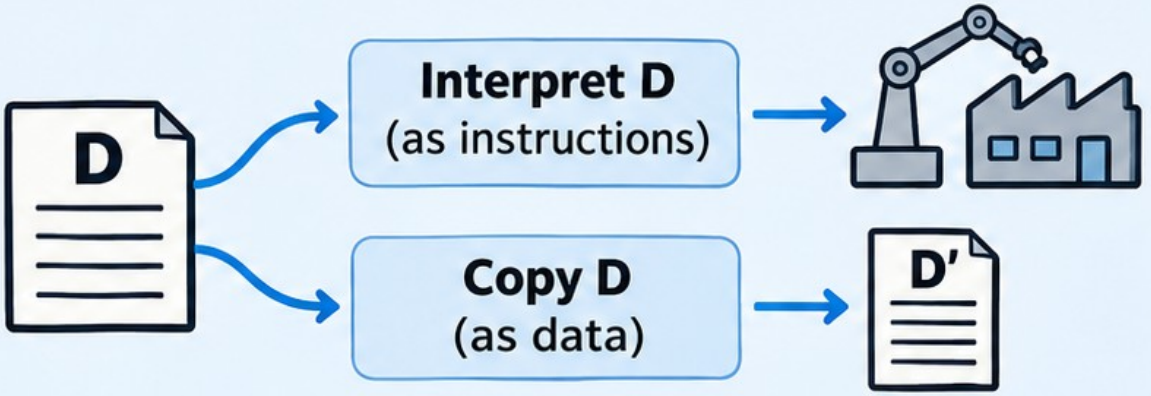
Problem: self-replication

A machine that can build an exact copy of itself.



Why it gets smaller:
if the builder is just a copy of itself inside the product, that copy is part of the product, so each generation includes another copy and is smaller.

Key insight: copy a description (a quine)



Make the builder read the same description *D* both as instructions and as data to copy, so the copy is the same size (no regression).

Thompson's quine (a concrete example)

`repr(x)` in Python

Returns a quoted representation of x (adds quotation marks).

```
repr("hi")  →  'hi'
```

```
s = "print('s =', repr(s)); print(s)"
```

`print('s =', repr(s))`	`print(s)`
`s = "print('s =', repr(s)); print(s)"`	`print('s =', repr(s)); print(s)`

Computer Viruses: Theory and Experiments (1984)

- https://www.cnsr.ictas.vt.edu/QEpaper/cohen.pdf
- “Information only has meaning in that it is subject to interpretation”

```
program contradictory-virus:=
{...
main-program:=
 {if ~D(contradictory-virus) then
    {infect-executable;
    if trigger-pulled then do-damage;
    }
 goto next;
 }
}
```

https://en.wikipedia.org/wiki/Apple_II



Elk Cloner (1981)

Boot #	Behavior
10th	Overwrote the reset vector so that pressing CONTROL-RESET enters the Monitor program instead of DOS.
15th	Modified the video mode so that the text on the screen was inverted.
20th	Wrote to the speaker, causing a brief click to be heard.
25th	Modified the video mode so that the text on the screen flashed.
30th	Rearranged the characters that represent the file type of a file when the CATALOG command was executed
35th	Modified the value that represented

...

(from https://arxiv.org/pdf/2007.15759.pdf)

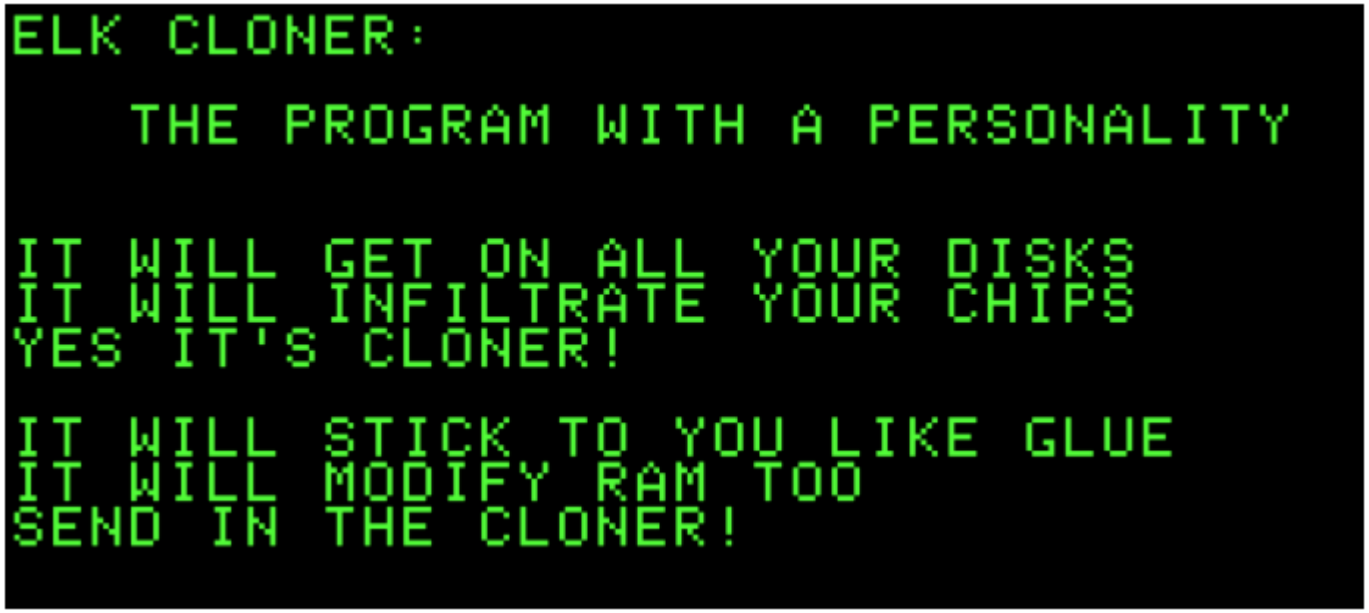
Elk Cloner (continued)

	the program instead.)
50th	Modified the reset vector so that pressing CONTROL-RESET caused the Elk Cloner poem to be displayed.
55th	Modified a constant in the diskette calibration code, causing the sound the disk calibration process made during the boot process to change. [4]
60th	Same as the 55th boot except that a different value was written to the constant in the disk calibration code.
65th	Overwrote the first instruction of the DOS command handler with a jump to the Monitor routine, so that the disk booted into the Monitor.
70th	Same as the 55th boot except that a different

...

(from https://arxiv.org/pdf/2007.15759.pdf)

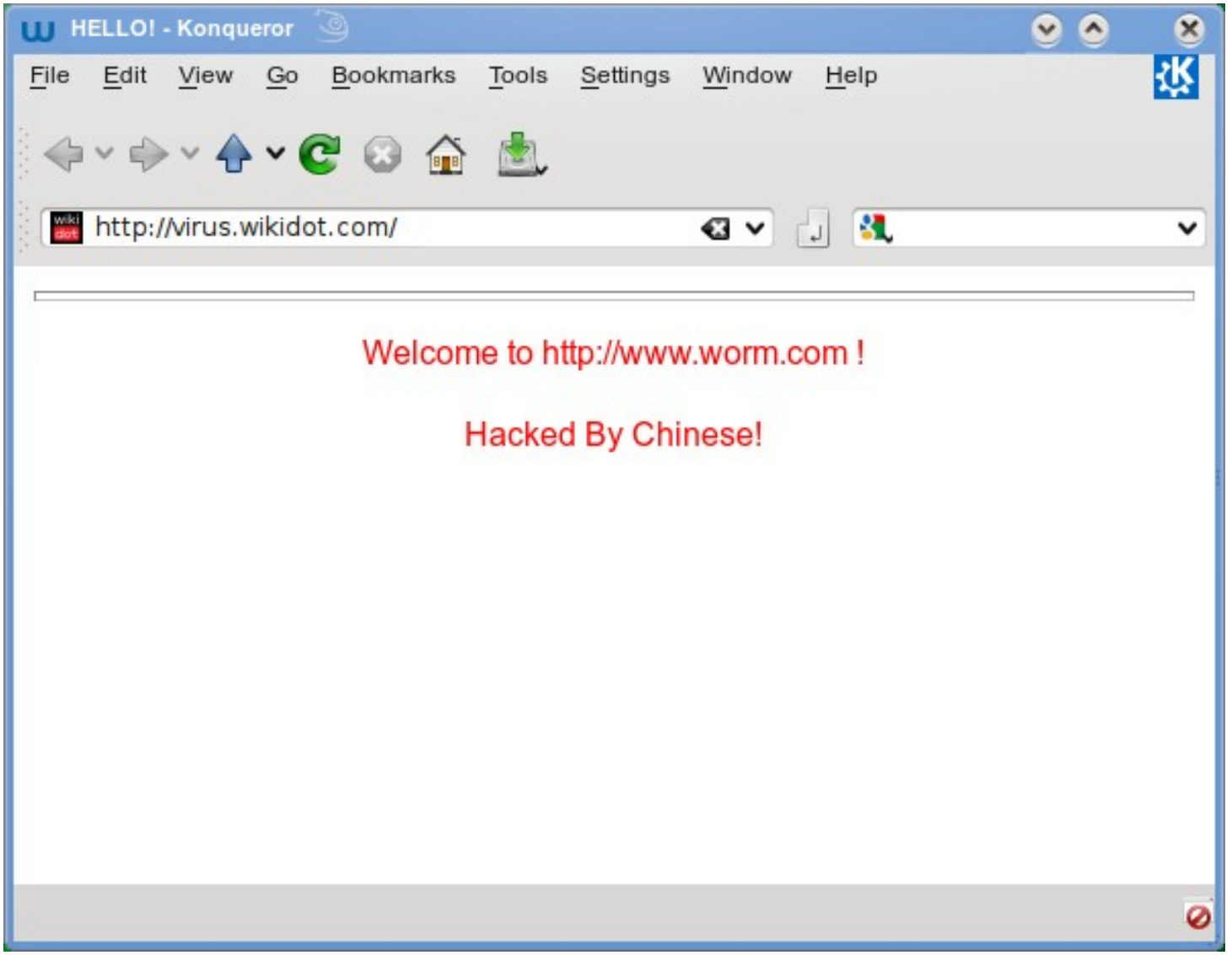
Elk Cloner poem



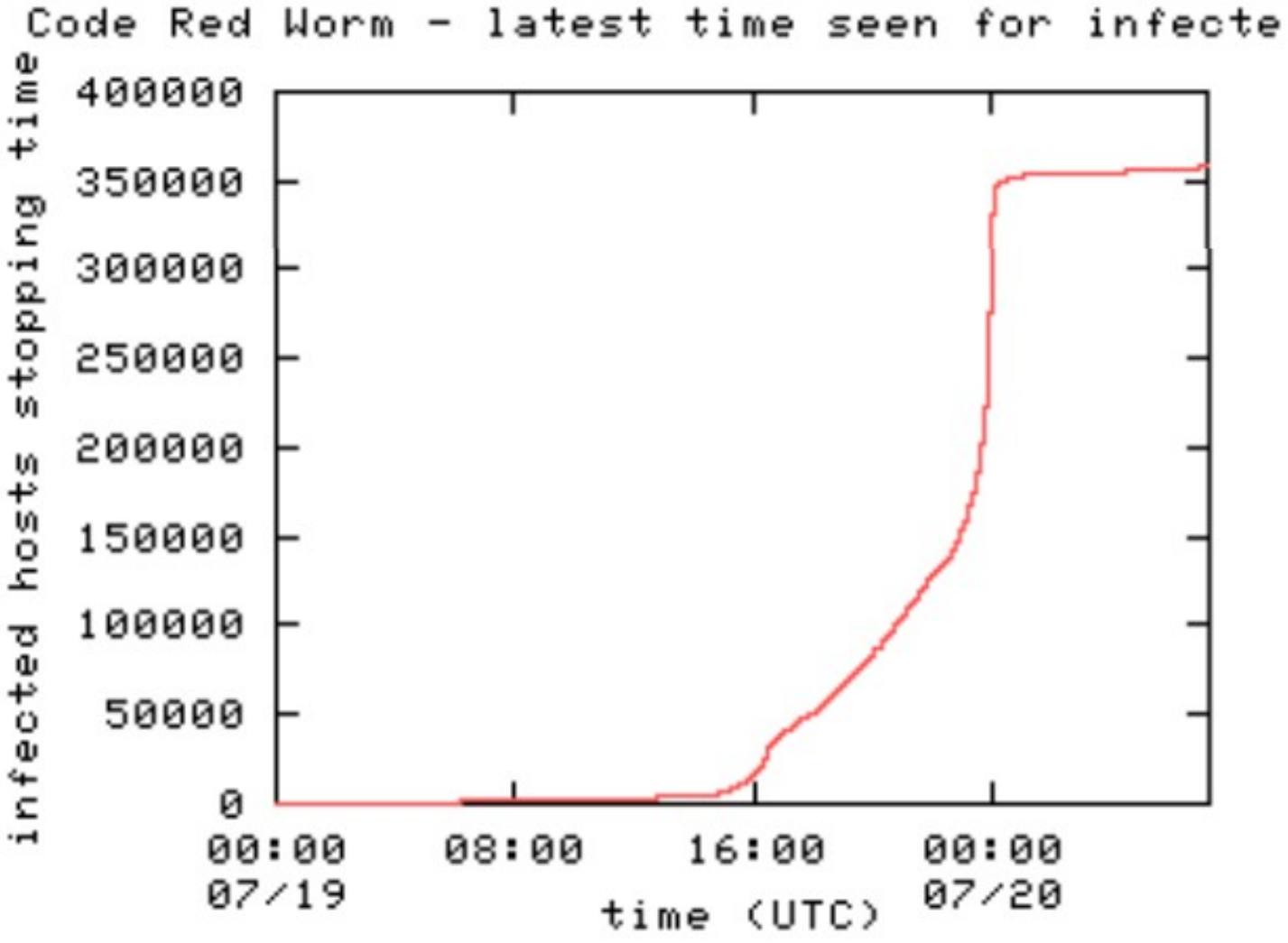
Code Red (2001)

```
GET /default.ida NNNN
```

https://www.cybereason.com/blog/what-is-code-red-worm

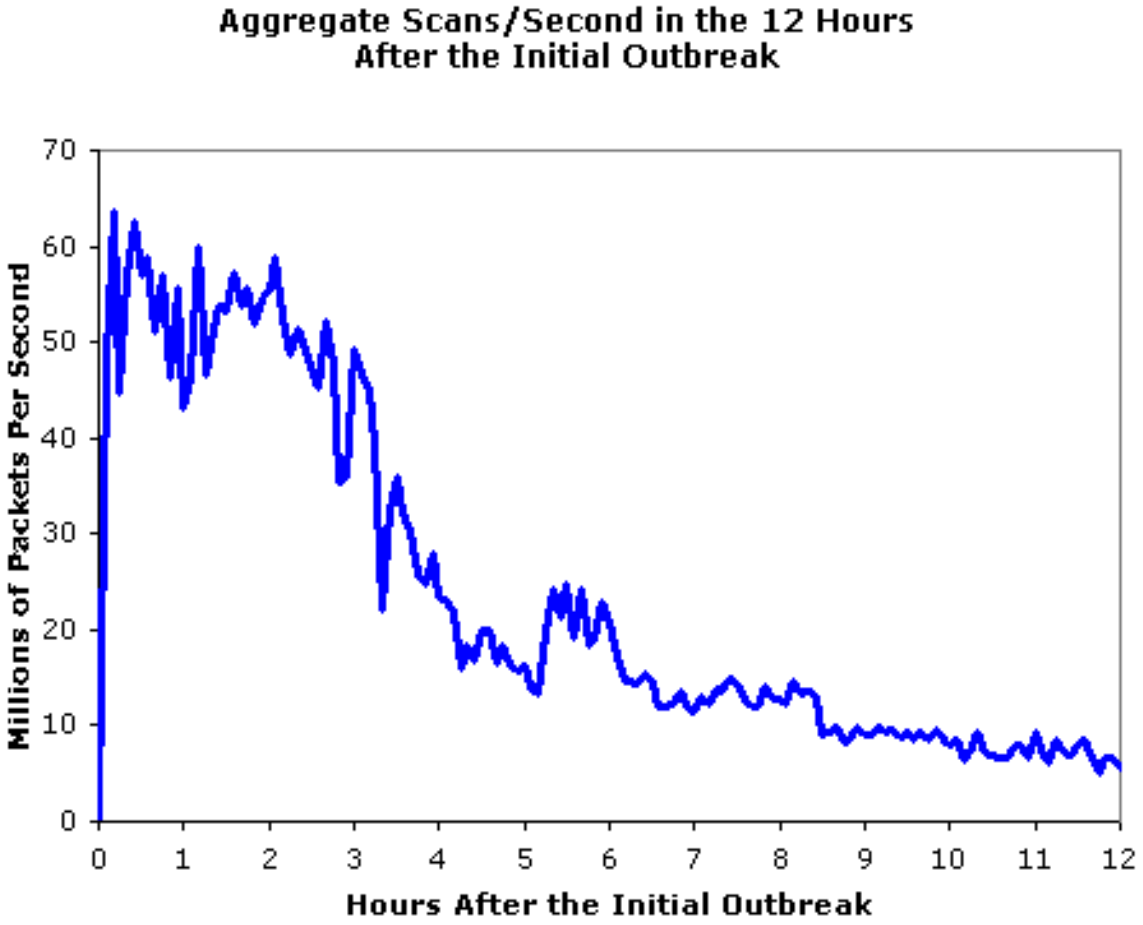


Code Red



From: https://www.cs.ucf.edu/~czou/research/codered.pdf

Slammer (2003)



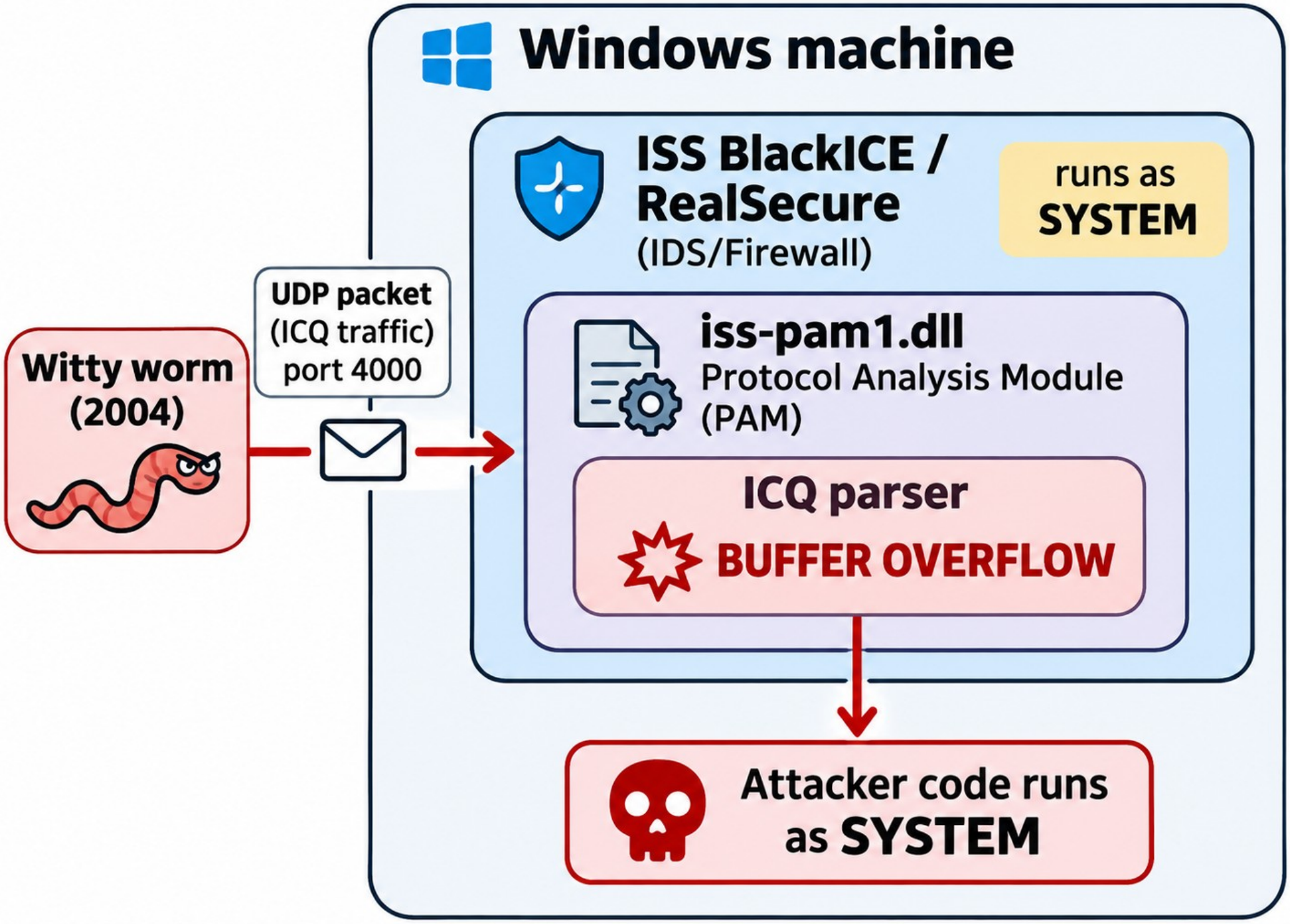
Over 75K machines in 10 minutes.
(From: https://www.caida.org/catalog/papers/2003_sapphire/)

Witty Worm (2004)

```
rand(){
    # Note that 32-bit integers obviate the need for
    # a modulus operation here.
    X = X * 214013 + 2531011;
    return X; }
srand(seed){ X = seed; }
main(){
 1.     srand(get_tick_count());
 2.     for (i=0; i < 20,000; ++i)
 3.         dest_ip ← rand()[0...15]||rand()[0...15];
 4.         dest_port ← rand()[0...15];
 5.         packetsize ← 768+rand()[0...8];
 6.         packetcontents ← top of stack;
 7.         sendto();
 8.     if(open(physicaldisk, rand()[13...15]))
 9.         overwrite_block(rand()[0...14]||0x4e20);
10.         goto 1;
11.     else goto 2; }
```

Figure 2: Pseudocode of the Witty worm

From: https://www.icir.org/vern/papers/witty-imc05.pdf


Windows machine
ISS BlackICE / RealSecure
(IDS/Firewall)
runs as SYSTEM
iss-pam1.dll
Protocol Analysis Module (PAM)
ICQ parser
BUFFER OVERFLOW
UDP packet
(ICQ traffic)
port 4000
Witty worm
(2004)
Attacker code runs as SYSTEM

Stuxnet (discovered 2010)



Stuxnet

- Attacked the Iranian nuclear program
- Multiple ways of spreading
- Attempt to limit spread, several attempts
- Not as buggy as typical malware
- Attacked very specific centrifuges with a very specific frequency

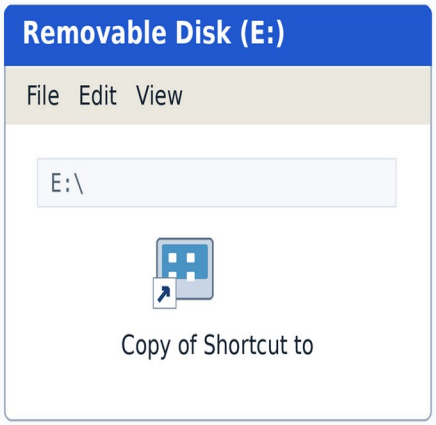
https://en.wikipedia.org/wiki/Stuxnet

Displaying a shortcut icon ran Stuxnet

What Explorer displays

Valid LNK header

Explorer reads the shortcut to find its icon source.



Viewing the folder is enough.
No double-click needed.

Files on the USB drive

Copy of Shortcut to.lnk

TEXT VIEW

4C 00 00 00 01 14 02 00	L.......
… icon source path …	
7E 57 54 52 34 31 34 31	~WTR4141
2E 54 4D 50	.TMP

references this file for its icon

~WTR4141.TMP — contains a DLL

4D 5A	MZ
50 45 00 00	PE..

Selected byte sequences; other fields omitted.

What Windows executes

The icon handler treats this as a Control Panel **module (CPL).**

`LoadLibraryW(...)`

loads the DLL into Explorer.

DLL initialization runs
`inside explorer.exe`

MZ / PE headers

Executable code

Loads the Stuxnet payload.

Loading an icon source also ran its executable code.

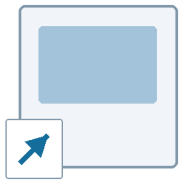
Two separate files: the shortcut points to the DLL.

Sources: Symantec, W32.Stuxnet Dossier v1.4, pp. 29–30; ESET, Jumping the Air Gap (2021), pp. 13–14.

Stuxnet: isolate icon rendering

2010 WINDOWS

explorer.exe



.lnk

LoadLibraryW()

~WTR4141.TMP

DllMain() runs

ISOLATED IPC DESIGN

explorer.exe

requests an icon



RenderIcon(bytes)

Pixels(w,h,RGBA)

icon service

reads resources as data

~WTR4141.TMP

no network / no file writes

IPC + isolation + least privilege

Original mechanism: Geoff Chappell, The CPL Icon Loading Vulnerability.

Pegasus spyware (released 2016)

- https://en.wikipedia.org/wiki/Pegasus_(spyware)
- NSO group
- “Flying Trojan”



https://en.wikipedia.org/wiki/Trojan_Horse#/media/File:RomanVirgilFolio101r.jpg



https://en.wikipedia.org/wiki/Pegasus#/media/File:Bellerophon_riding_Pegasus_and_killing_the_Chimera,_Roman_mosaic,_the_Rolin_Museum_in_Autun,_France,_2nd_to_3rd_century_AD.jpg

Pegasus

- Supposedly for law enforcement, antiterrorism efforts, *etc.*
- Often used against civil society
  - Full control of the infected system, including calls, microphone, camera, messages, passwords, files, *etc.*
  - Can be used to plant evidence
- Often delivered *via* sophisticated zero-click zero-day exploits

Pegasus examples

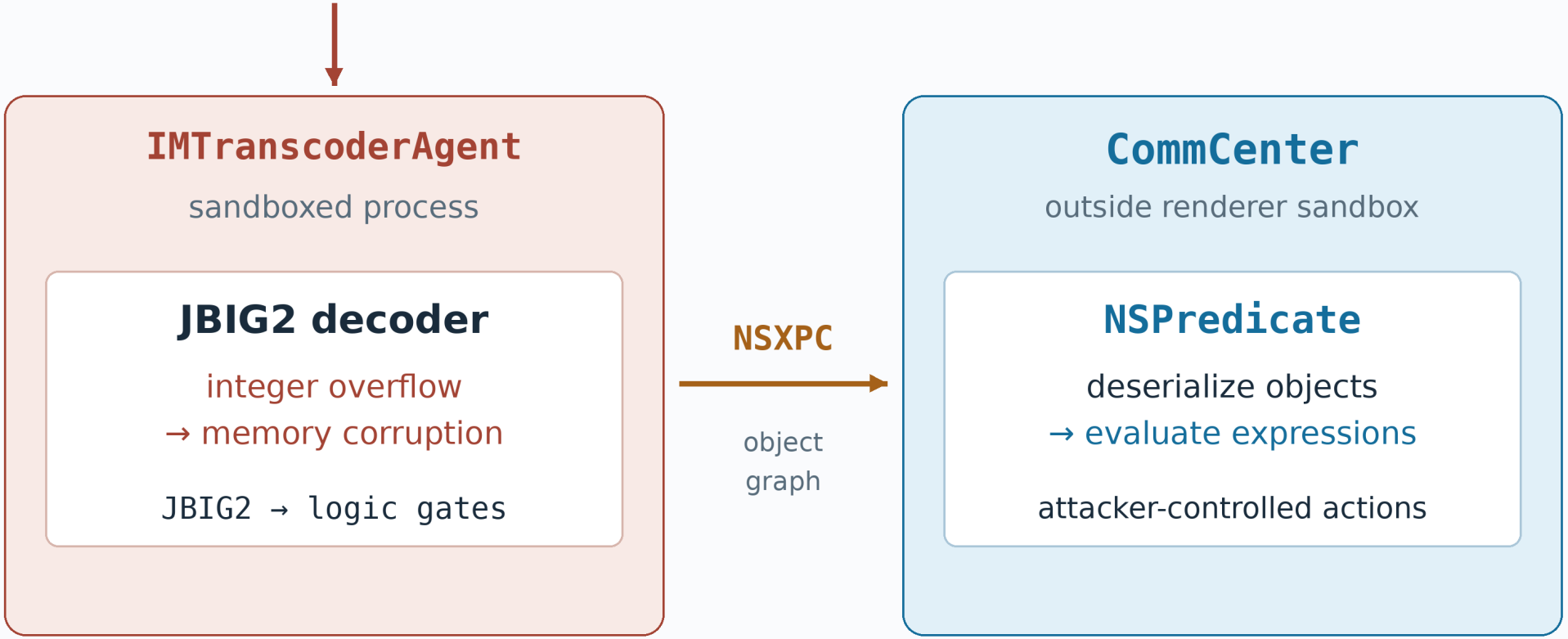
- Ahmed Mansoor in 2016 (first technical analysis of Pegasus by the Citizen Lab and Lookout Security)
  - https://citizenlab.ca/2016/08/million-dollar-dissident-iphone-zero-day-nso-group-uae/
- Many more examples from Mexico, Saudi Arabia, Bahrain, Jordan, and more…
  - https://citizenlab.ca/tag/pegasus/
- Bhima Koregaon 16
  - https://www.arsenalexperts.com/
  - https://netalert.me/bhima-koregaon.html

FORCEDENTRY

Pegasus / iMessage / 2021

“.gif” attachment — actually PDF + JBIG2

Processed automatically; no tap required.



com.apple.commcenter.xpc

NSXPC is Apple’s object-oriented RPC system.

Sources: Citizen Lab (2021); Google Project Zero, FORCEDENTRY analyses (2021, 2022).

https://arstechnica.com/security/2024/04/what-we-know-about-the-xz-utils-backdoor-that-almost-infected-the-world/

XZ Outbreak (CVE-2024-3094)

XZ Utils is a collection of open-source tools and libraries for the XZ compression format, that are used for high compression ratios with support for multiple compression algorithms, notably LZMA2.

On Friday 29th of March, Andres Freund (principal software engineer at Microsoft) emailed oss-security informing the community of the discovery of a backdoor in xz/liblzma version 5.6.0 and 5.6.1.

Github Activity Summary (user: JiaT75)

Repository:
https://github.com/tukaani-project/xz

2021
User Jia Tan (JiaT75) creates his Github Account

2022-02-06
JiaT75's first commit to the XZ repo

2023-06-28
Potential infrastructure testing: liblzma: "Add ifunc implementation to crc64_fast.c."

2023-07-08
PR opened in oss-fuzz to disable ifunc for fuzzing builds. Allegedly to mask the malicious changes.

2024-02-16
Malicious "build-to-host.m4" file added to .gitignore, later incorporated to the package release.

2024-03-09
Obfuscated/encrypted stages binary backdoor hidden in two test files:
- tests/files/bad-3-corrupt_lzma2.xz
- tests/files/good-large_compressed.lzma.

xz/libzma
v5.6.0 & v5.6.1

Packaged in the final releases

m4/build-to-host.m4

tests/files/bad-3-corrupt_lzma2.xz

Substitution to uncorrupt

Packaged in the final releases

m4/build-to-host.m4

The M4 macro is executed during the build process and runs the malicious code below.

```
...
63 gl_[$1]_config='sed \"r\n\" $gl_am_configmake |
eval $gl_path_map | $gl_[$1]_prefix -d 2>/dev/null'
...
95 gl_path_map='tr "\t \-_" " \t_\-"'
...
```

Read Bytes

tests/files/bad-3-corrupt_lzma2.xz

Substitution to uncorrupt malformed XZ file

- 0x09 (\t) are replaced with 0x20
- 0x20 (whitespace) are replaced with 0x09
- 0x2d (-) are replaced with 0x5f
- 0x5f (_) are replaced with 0x2d



Uncorrupted
bad-3-corrupt_lzma2.xz

Stage 1 - Bash File

v5.6.0
- Bytes in comment: 86 F9 5A F7 2E 68 6A BC
- Custom substitution (byte value mapping)

v5.6.1
- Bytes in comment: E5 55 89 B7 24 04 D8 17
- Check if script running on Linux
- Custom substitution (byte value mapping)

tests/files/good-large_compressed.lzma

1. Decompress the file with xz -dc
2. Remove junk data from the file using multiple head tool calls
3. Portion of the file is discarded (contains the binary backdoor)
4. Use custom substitution cipher to decipher the data
5. Deciphered data is decompressed using xz -F raw --lzma1 -dc



Bash script

Stage 2 - Bash File

Stage 2 - Bash File

v5.6.0 Backdoor extraction

An .o file extracted & integrated into compilation/linking

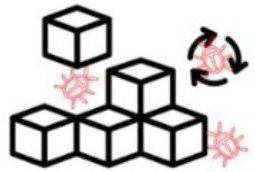
1. Extract & decipher tests/files/good-large_compressed.lzma
2. Manipulate output with: LC_ALL=C sed "s/\(.\)/\1\n/g"
3. Decrypt using AWK script (RC4-like)
4. Decompress with xz -dc --single-stream
5. Binary backdoor stored as liblzma_la-crc64-fast.o

liblzma_la-crc64-fast.o is then added to the compilation/linking process!

v5.6.1 Extension Mechanism

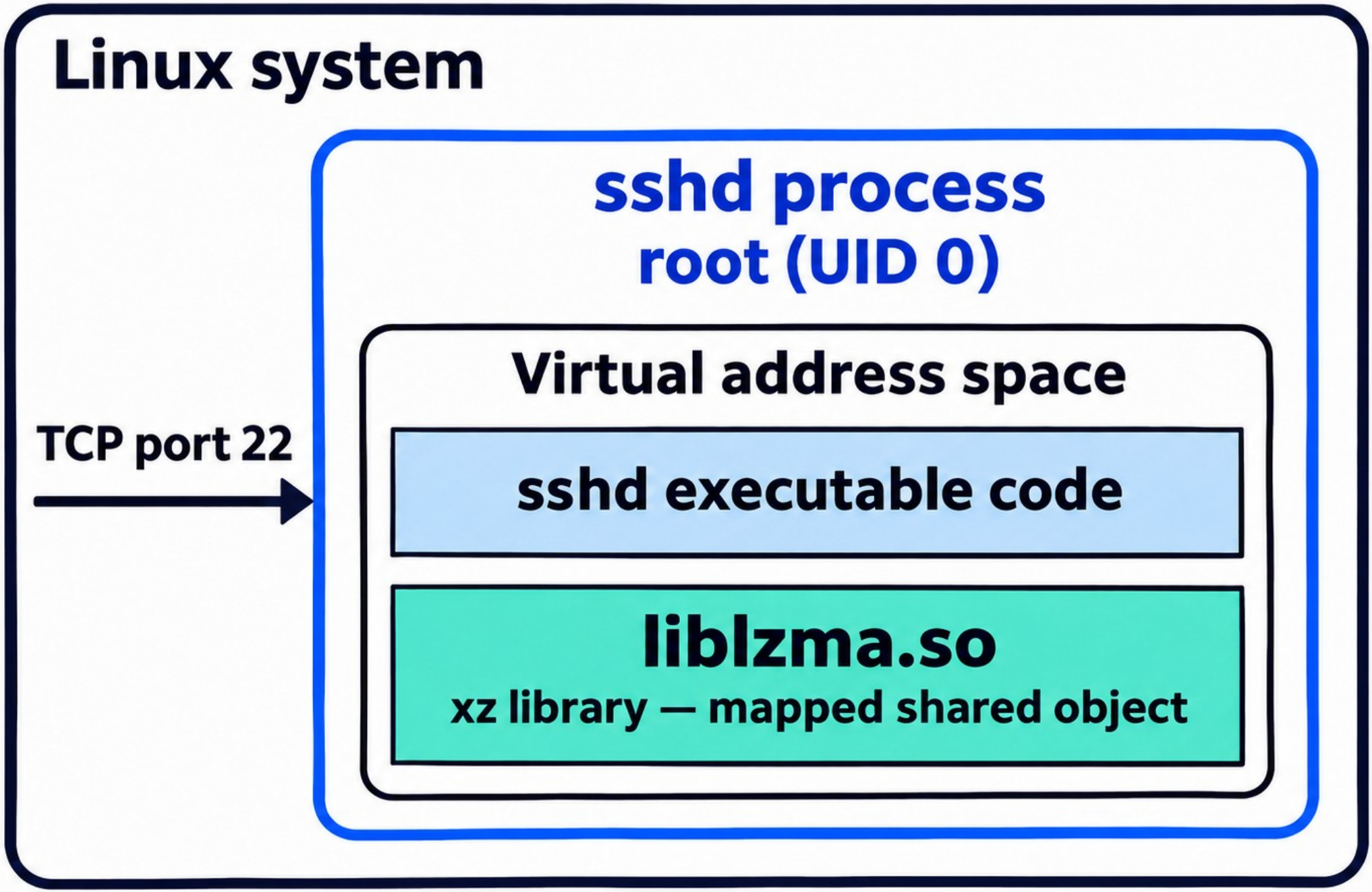
1. Search Files: use grep -broaF in tests/files/ for signatures:
   a. "~!:_W", "|_!{ -"
   b. "jV!.^%", "%.R.IZ"

   output: "file_name:offset:signature"
2. If Found:
   a. Save first offset + 7 as $start
   b. Save second file's offset as $end
3. Next Steps:
   a. Merge found segments
   b. Decipher with custom byte mapping
   c. Decompress & execute data



No files with the signatures were found, however it highlights the framework's potential modularity for future updates.

@FRØGGER_
THOMAS ROCCIA


Linux system
sshd process
root (UID 0)
Virtual address space
TCP port 22
sshd executable code
liblzma.so
xz library — mapped shared object

More resources

- *Cryptovirology* by Young and Yung
- *The Art of Computer Virus Research and Defense* by Szor
- *Practical Malware Analysis* by Honig and Sikorski
- http://www.forensicswiki.org/wiki/Tools