CS459/698 Privacy, Cryptography, Network and Data Security

Malicious Software

Fall 2025, Tuesday/Thursday 8:30-9:50am

Malware

What is malware?

- Various forms of software written with **malicious intent**
- Common characteristic of all types of malware: needs to be **executed** in order to cause harm
- How might malware get executed?

How might malware get executed?

*…malware needs to be **executed** to cause harm*

- User action
  - Downloading and running malicious software
  - Viewing a web page containing malicious code
  - Opening an executable email attachment
  - Inserting a CD/DVD or USB flash drive
- Exploiting an existing flaw in a system
  - Buffer overflows in network daemons
  - Buffer overflows in email clients or web browsers

Some types of malware

- Viruses
  - Malicious code that adds itself to benign programs/files
  - Code for spreading + code for actual attack
  - Usually activated by users
- Worms
  - Malicious code spreading with no or little user involvement
- Trojans
  - Malicious code hidden in seemingly innocent program that you download
- Botnets
  - Coordinated network of compromised hosts

Viruses

What is a virus?

- A virus is a particular kind of malware that infects other files
  - Traditionally, a virus could infect only executable programs
  - Nowadays, many data document formats can contain executable code
    - Microsoft Word and Excel have macros, PDF files have JavaScript integrations
- Many different types of files can be infected with viruses
- Typically, when the file is executed (or sometimes just opened), the virus activates, and tries to infect other files with copies of itself
- In this way, the virus can spread between files, or between computers

Infection

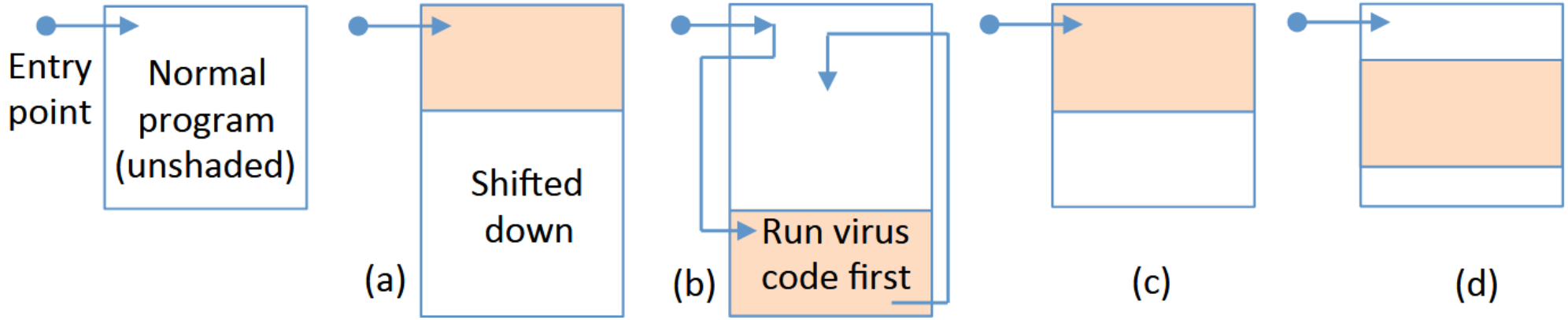
- What does it mean to “infect” a file?
- The virus modifies a (non-malicious) program or document (the host) in such a way that executing or opening it will **transfer control to the virus**
  - The virus can do its “dirty work” and then transfer control back to the host
- For executable programs:
  - The virus will modify other programs and **attach its code to the target**
- For documents with macros:
  - Goal: **add itself as a macro** which automatically runs when file is opened

Strategies for infecting executables

a) Shift and prepend: *original file is executed after virus, file length increased*

b) Append code to end of file: *execution JUMPs to virus code and then back to normal entry point. Evades start of file scans.*

c) Overwrite host file, from top (c) or from interior point (d): *original file destroyed; complicates removal. (d) benefits from avoiding start of file scans*



Computer Security and the Internet: Tools and Jewels from Malware to Bitcoin. Van Oorschot, 2021, p188 (link)

Infection

- In addition to infecting other files, a virus will try to **infect the computer itself**
  - This way, every time the computer is booted, the virus is automatically activated
- Possible examples:
  - Put itself in the boot sector of the hard disk
  - Add itself to the list of programs the OS runs at boot time
  - Infect one or more of the programs the OS runs at boot time
  - It might try many of these strategies
    - But it’s still trying to evade detection!

Spreading

- How do viruses spread between computers?
- Usually, when the user sends infected files (hopefully not knowing they're infected!) or compromised website links to his friends
- A virus usually requires some **user action** to spread to another machine
  - If it can spread on its own (via email, for example), it's more likely to be a worm than a virus

Payload

- In addition to trying to spread, what else might a virus try to do?
- Most viruses have some sort of payload (malicious action)
- At some point, the payload of an infected machine will activate, and do something (usually bad)
  - Disable any active virus-scanning software
  - Erase your hard drive, or make your data inaccessible
  - Subtly corrupt some of your spreadsheets
  - Install a keystroke logger to capture your online banking password
  - Start attacking a particular target website

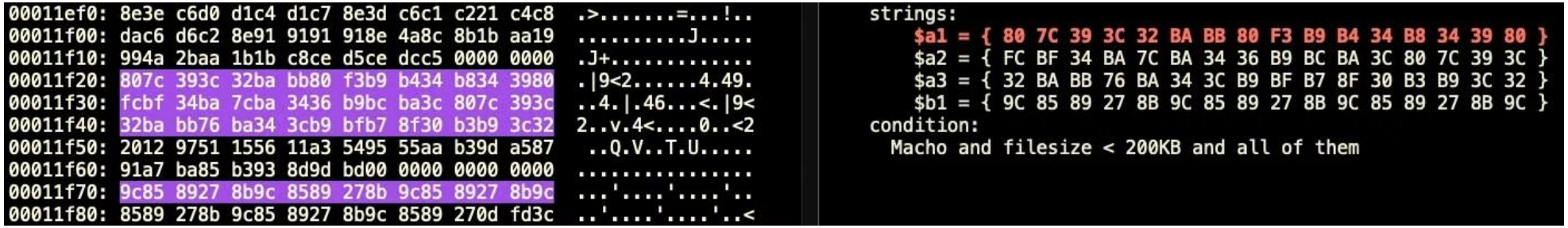
Spotting viruses

When should we look for viruses?

- As files are added to our computer
  - Via portable media
  - Via a network
- From time to time, scan the entire state of the computer
  - To catch anything we might have missed on its way in
  - But of course, any damage the virus might have done may not be reversible
- How do we look for viruses?
  - Signature-based protection and behaviour-based protection

Signature-based protection

- Keep a list of all known viruses
- For each virus in the list, store some characteristic features (the signature)
- Most signature-based systems use features of the virus code itself
  - In both the infection code and the payload code
  - Ex) Byte sequences, hashes, code/string matching



Sample of OceanLotus malware and a detection signature for it

Image source: [What is a Malware File Signature?]

Polymorphism

- To evade signature-based virus scanners, some viruses are polymorphic
- This means that instead of making perfect copies of itself every time it infects a new file or host, it makes a **modified** copy instead
- Often done by having most of the virus code encrypted
  - The virus starts with a decryption routine which decrypts the rest of the virus, which is then executed
  - When the virus spreads, it encrypts the new copy with a newly chosen random key

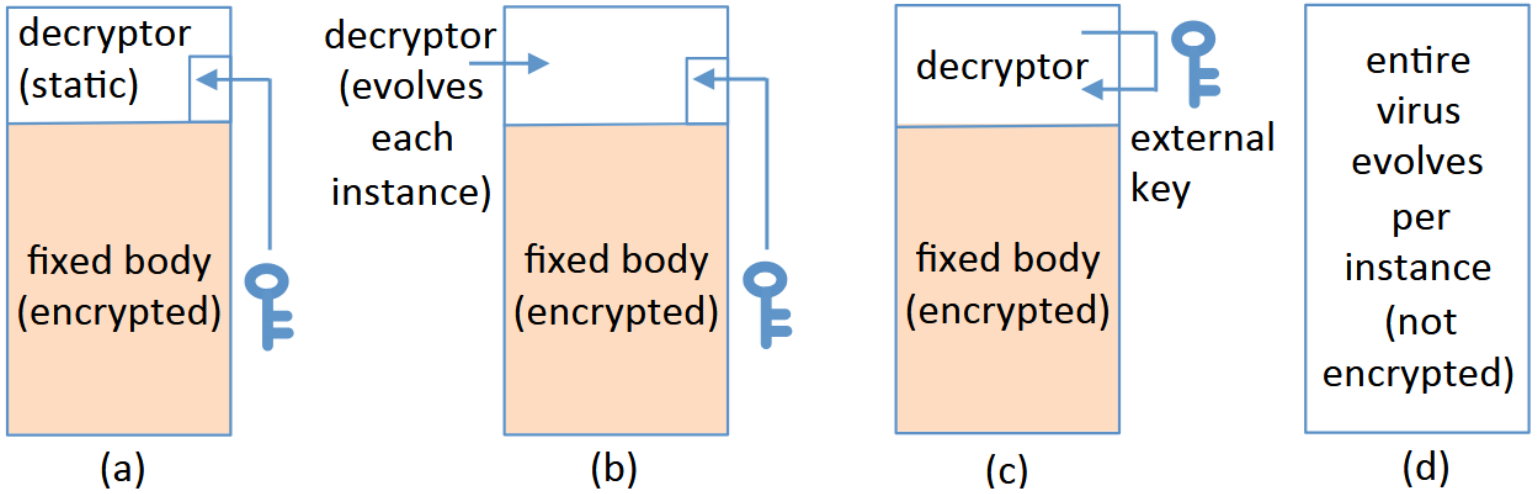
How do viruses evade signature detection?

a) Virus with encrypted body: *decryptor is static across infections*

b) Polymorphic viruses: *per-instance keys, changes decryptor across infections*

c) Virus with external decryption key: *stores key in another file or machine*

d) Metamorphic virus: *fully rewrites its code with each infection*



Computer Security and the Internet: Tools and Jewels from Malware to Bitcoin. Van Oorschot, 2021, p191 (link)

Downsides of signature-based protection

1. Polymorphic viruses rarely match known signatures
2. You can only scan for viurses that are in the list!
    - But there are brand-new viruses identified **every day**
    - This is another major limitation!

Q: How would you can for new or polymorphic viruses?

Behaviour-based protection

- Behaviour-based systems look for suspicious patterns of behaviour, rather than for specific code fragments
  - Where on the system it tries to hide itself
  - Unpacking behaviour
  - Accessing specific resources (files, registry keys, API calls)
  - How it propagates from one place to another
- Some systems run suspicious code in a *sandbox* first
  - *Sandbox = secure, isolated environment for executing malware*
- Q: Downsides?

Worms

What is a worm?

- A worm is a self-contained piece of code that can replicate with little or no user involvement
- Worms often use security flaws in widely deployed software as a path to infection
- Typically:
  - A worm exploits a security flaw in some software on your computer, infecting it
  - The worm immediately starts searching for other computers to infect
    - On your local network, or on the Internet generally
  - There may or may not be a payload that activates at a certain time, or by another trigger

The Morris worm, 1988

- The first Internet worm, launched by a graduate student at Cornell
- Once infected, a machine would try to infect others in three ways:
  - Exploit a buffer overflow in the “finger” daemon
  - Use a back door left in the “sendmail” mail daemon
  - Try a “dictionary attack” against local users’ passwords. If successful, log in as them, and spread to other machines they can access without requiring a password
- All three of these attacks were well known!
- First example of buffer overflow exploit in the wild
- Thousands of systems were offline for several days

The Code Red worm, 2001

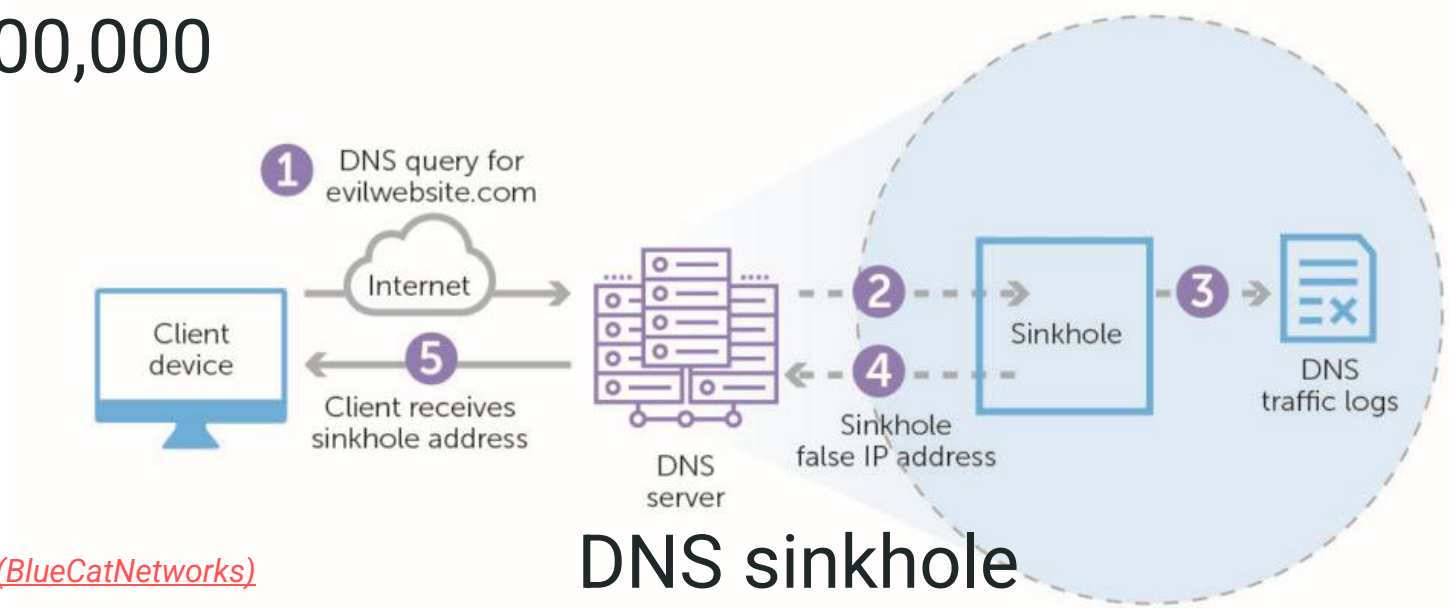
- Exploited a buffer overflow in Microsoft's IIS web server (for which a patch had been available for a month)
- An infected machine would:
  - Deface its home page
  - Launch attacks on other web servers (IIS or not)
  - Launch a denial-of-service attack on a handful of web sites, including www.whitehouse.gov
  - Installed a back door to deter disinfection
- Infected 250,000 systems in nine hours

The Slammer worm, 2003

- Performed **denial-of-service attack**
- First example of a “Warhol worm”
  - A worm which can infect nearly all vulnerable machines in just 15 mins
- Exploited a buffer overflow in Microsoft’s SQL Server (also had a patch available)
- A vulnerable machine could be infected with a **single UDP packet**!
  - This enabled the worm to spread extremely quickly
  - Exponential growth, doubling every **8.5 seconds**
  - 90% of vulnerable hosts infected in 10 minutes

Conficker Worm

- First detected in November 2008
- Propagated a command-and-control style botnet
- Security experts had to generate and sinkhole C&C domains
- Number of infected hosts in 2009: 9–15 million, 2011: 1.7 million, 2015: 400,000



DNS sinkhole

Image Source: DNS Sinkhole (BlueCatNetworks)

Stuxnet

- Discovered in 2010
- Allegedly created by the US and Israeli intelligence agencies
- Allegedly (pretty sure now) targeted Iranian uranium enrichment program
- Targets Siemens SCADA systems installed on Windows. One application is the operation of centrifuges
- It tries to be very specific and uses many criteria to select which systems to attack after infection

Stuxnet

- **Very sophisticated**: Used 4(!) different zero-day attacks to spread. Has to be installed manually (USB drive) for air-gapped systems.
- **Very targeted**: Detects if variable-frequency drives are installed, operating between 807–1210 Hz, and then subtly changes the frequencies so that distortion and vibrations occur resulting in broken centrifuges.
- **Very stealthy**: Intercepts commands to SCADA system and hides its presence

Stuxnet

- "Iranian President Mahmoud Ahmadinejad observes computer monitors at the Natanz uranium enrichment plant in central Iran, where Stuxnet was believed to have infected PCs and damaged centrifuges."

  https://www.wired.com/2014/11/countdown-to-zero-day-stuxnet/

Worms and the “salami attack”

- A salami attack is made up of smaller, seemingly inconsequential, attacks
- Classic example: send the fractions of cents of round-off error from many accounts to a single account owned by the attacker
- More commonly:
  - Credit card thieves make very small charges to very many cards
  - Clerks slightly overcharge customers for merchandise
  - Gas pumps misreport the amount of gas dispensed

Trojans

Have you ever seen this?

http://www.sampsonuk.net/B3TA/TrojanHorse.jpg

What are Trojan Horses?

- Trojan horses are programs which claim to do something innocuous (and usually do), but which also hide malicious behaviour

"You're surfing the Web and you see a button on the Web site saying, "Click here to see the dancing pigs." And you click on the Web site and then this window comes up saying, "Warning: this is an untrusted Java applet. It might damage your system. Do you want to continue? Yes/No."
Well, the ***average computer user is going to pick dancing pigs over security any day****. And we can't expect them not to."* — Bruce Schneier

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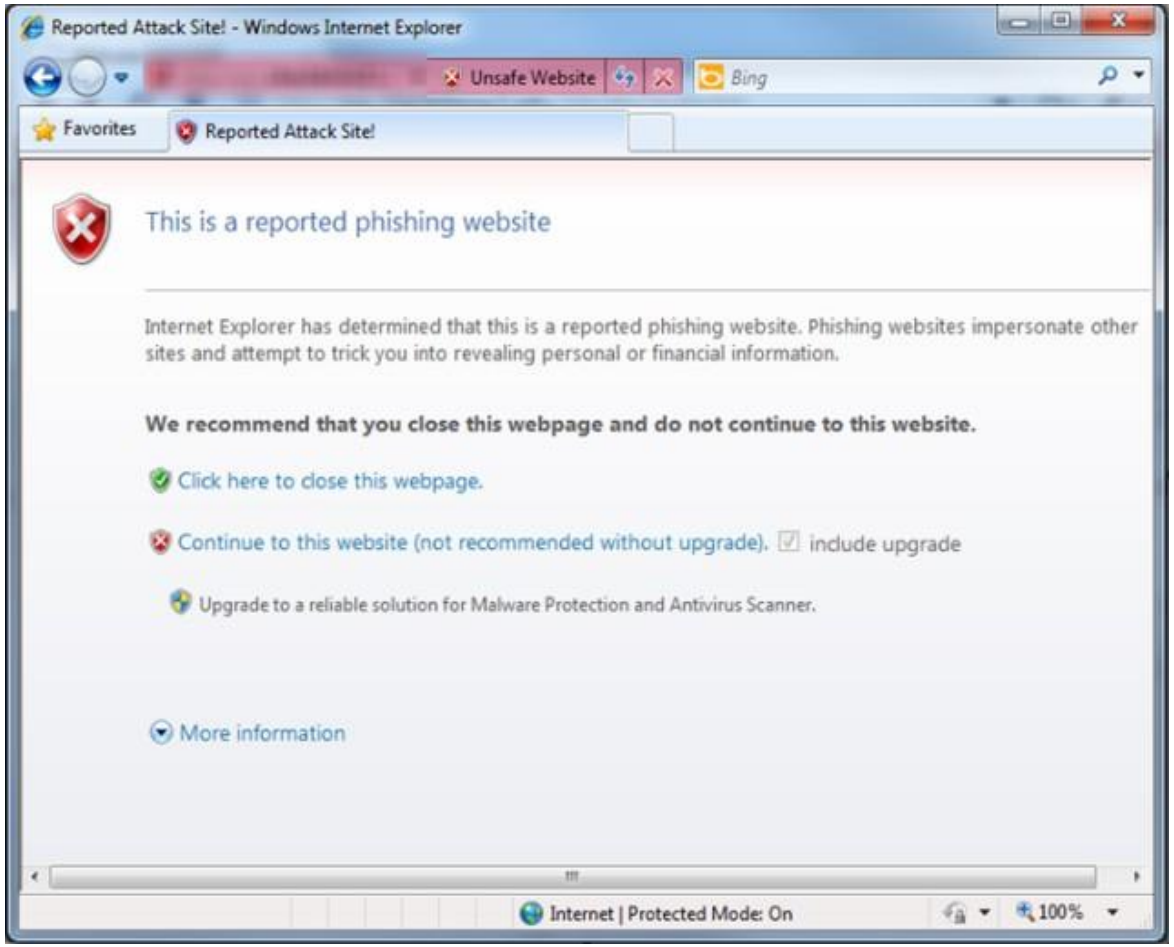
Image Source: Dancing Happy Pig

How do Trojan Horses work?

- Gain control by getting the user to run code of the attacker's choice, usually by also providing some code the user **wants** to run
  - "PUP" (potentially unwanted programs) are an example
  - For scareware, the user might even pay the attacker to run the code
- The payload can be anything; sometimes the payload of a Trojan horse is itself a virus, for example
- Trojan horses usually do not themselves spread between computers; they rely on multiple users executing the "trojaned" software

Scareware



http://static.arstechnica.com/malware_warning_2010.png

Ransomware

https://en.wikipedia.org/wiki/WannaCry_ransomware_attack#/media/File:Wana_Decrypt0r_screenshot.png

How does ransomware work?

- Demands ransom to return some hostage resource to the victim

- CryptoLocker in 2013:
  - Spread with spoofed e-mail attachments from a botnet
  - **Encrypted** victim's hard drive
  - Demanded ransom for **private key**
  - Botnet taken down in 2014; estimated ransom collected between $3 million to $30 million

- Could also be scareware

WannaCry

- Launched in May 2017, ransomware
- Infected ~230,000 computers
- Exploits a Windows SMB vulnerability originally discovered by the NSA
- NSA kept it secret (and exploited it)
- The “Shadow Brokers” leaked it (and others) in April 2017
- Microsoft had released a patch after being alerted by NSA but many systems remained unpatched
- Emergency patch for Windows XP and 8 in May 2017

See extra slide for more information on WannaCry’s Cryptographic Mechanism

WannaCry


NBC NEWS
POLITICS
U.S. NEWS
WORLD
BUSINESS
SHOPPING
SPORTS
HEALTH
NBC NEWS TIPLINE
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WORLD
Why 'WannaCry' Malware Caused Chaos for National Health Service in U.K.
The cyberattack has quickly become another political football in the years-long battle over the funding, remit, and existential future of the NHS.

Botnets

Motivations for building botnets

- Earlier worms (Nimda, Slammer) were written by hackers for fame with the goal to spread worm as fast as possible
  - Caused disruption and helped detection
- Today's botnets are controlled by crackers looking **for profit**, which rent them
  - Criminal organizations
- Can spread more slowly and in targeted ways
  - **Intelligence** and **espionage**?

New Generation Botnets

- Today's botnets are very sophisticated
- Virus/worm/trojan for propagation, exploit multiple vulnerabilities
- Stealthiness to hide from owner of computer
- Code morphing to make detection difficult
- Bot usable for different attacks (spam, DDoS, ...)

Botnet's infrastructure

- Distributed, dynamic & redundant control infrastructure
- "Fast Flux"
  - A single host name maps to hundreds of addresses
  - Machines are constantly swapped in/out of DNS to make tracking difficult
- "Domain Flux" (w/ Domain Generation Algorithm)
  - Infected machine generates a large set (50,000 in the case of Conficker) of domain names that changes every day, contacts a random subset of these names for updates
  - To control the botnet, authorities would have to take control of 50,000 different domain names each day – see optional reading!

Sample botnet: Storm

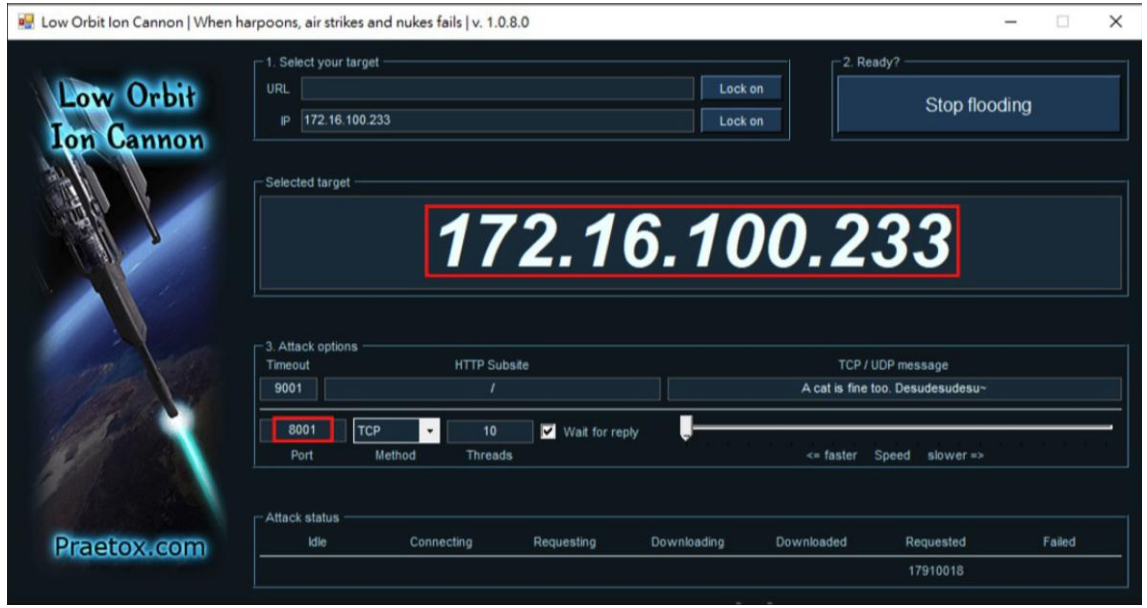
- In September 2007, Storm Worm botnet included hundreds of thousands or even millions of machines
- Bots were used to send out junk emails advertising web links that when clicked attempted to download and install worm, or to host these websites
- Botnet was also rented out for pharmacy and investment spam
- As a self-defence mechanism, it ran DDoS attacks against Internet addresses that scanned for it
- Problem: its P2P protocol created >10 times usual P2P traffic (=> detectable)

Sample botnet: Mirai

- In Fall 2016, the Mirai botnet attacked several high-profile targets, including a popular security blog and a large DNS provider
- Attack traffic of so far unseen **1 Tbps** or more
  - (previous DDoS attacks were 60 Gbps)
- Botnet consisted of **600,000 IoT devices** (routers, cameras) infected due to **unchanged default passwords**
- Distribution based on self-propagating worm
- Each bot flooded targets with UDP, TCP, and HTTP traffic
- Botnet developed by a Minecraft server DDoS protection company

The new script kiddie on the block

- All the discussed attacks, exploit code and complete attack scripts are available on the Internet
- Script kiddies can download scripts and raise an attack with minimum effort
- There are even tools that allow easy building of individual attacks:
  - E.g., Metasploit Framework, based on existing exploits
  - E.g., LOIC, stress testing and denial-of-service



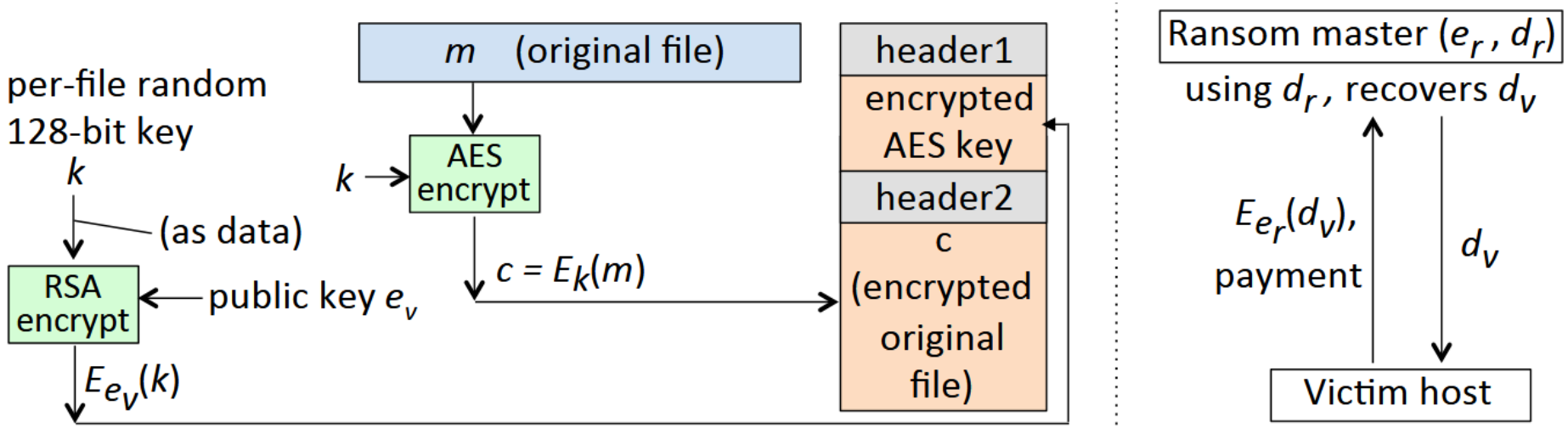
Extra slides (interesting info)

Cryptographic mechanism for WannaCry

- Asymmetric cryptography is slow to encrypt … might take too long
  - Will also create a file that's larger than original (ciphertext much larger than plaintext)
- Usually, for encrypting files they used block ciphers like AES
  - They can also encrypt the first few bytes for the file
  - Usually, the rest of the file would be unreadable
  - Efficient!
- WannaCry uses per-file random key
  - Keys are encrypted using public key of the attacker
  - Put encrypted key in the file itself

Cryptographic mechanism for WannaCry

1) Ransomware master possesses public/private key pair (e_r, d_r)
2) Generates per-victim key pair (e_v, d_v), but encrypts victim private key using master public key $E_{e_r}(d_v)$
3) Generates random AES key k for every file, and encrypts file
4) Every k gets encrypted $E_{e_v}(k)$ and placed at the start of each file



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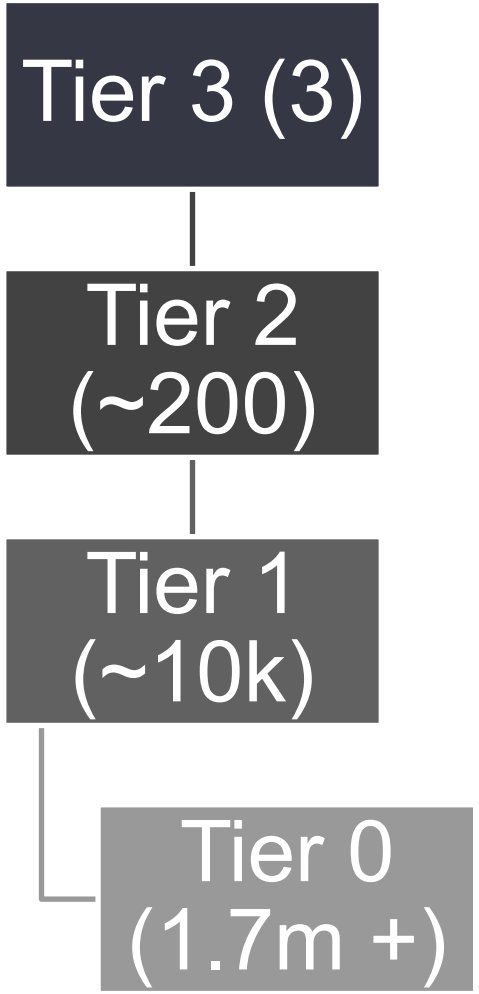
The EMOTET takedown (2018-2021)

EMOTET

- Botnet designed for **malware distribution** (a “loader”)
  - “Malware as a service”
  - Operators would sell (per computer) for malware to be deployed
    - For example, “pay me 1 BTC for your ransomware to be dropped on 500 machines”
- Initial infection via Excel/Word macros or email attachments
- More than 1.7 million computers infected

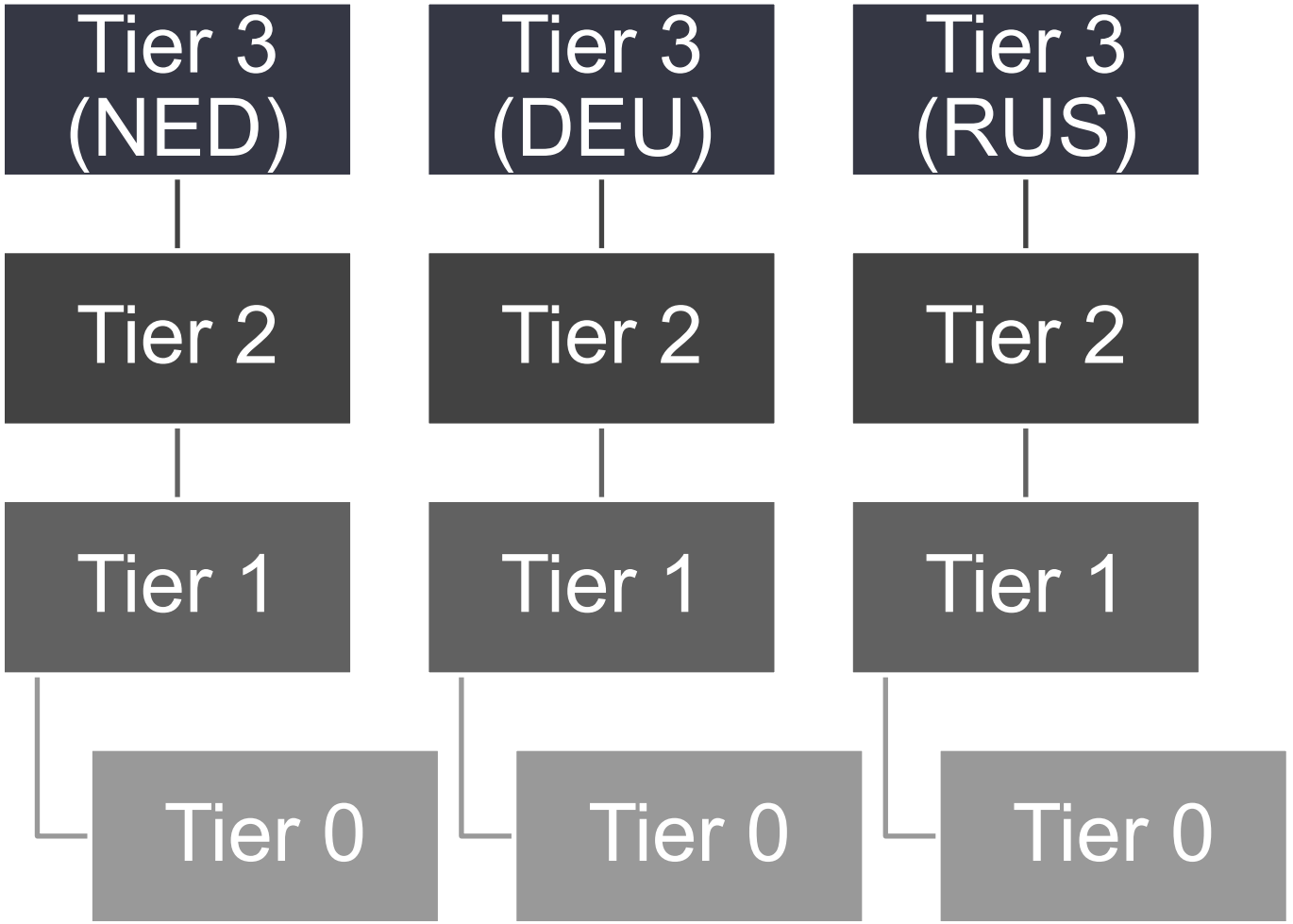
EMOTET victims

- Hierarchical model
- Most victims (1.7 million +) were in Tier 0
- Some victims “promoted” to Tier 1
- Tiers 2 and 3 were controller-owned
- Tier 3 was the control server



EMOTET had three separate operating channels

- Each channel isolated and distinct
- Three control servers located in three countries
- Each channel with 100k+ victims



Investigation (2018 -)

- Canada (RCMP) and 17(!) different countries collaborated
- 2020 - RCMP reverse engineers the malware, develops technique to **decrypt and hack the EMOTET control servers** (T2 & T3)
- RCMP, Germany, and Netherlands develop **mimic control servers**
  - Were able to use the communication keys already stored on the servers
- Global takedown planned on Jan 26, 2021
  - Would turn on police-controlled nodes
  - Raid known conspirators
  - In Canada, 5 telecoms collaborated

Day of action

- All police servers turned on
  - 1,500 unique bots checked in every minute
- NED and DEU channels neutralized
  - Pushed “127.0.0.1” in the list of victim IP addresses for T1-T3
  - Without victim IPs, can’t communicate or spread
- Ukraine forces raided a conspirator
  - Found servers, stacks of cash, gold and silver bars
  - Guy panicked and gave passwords
  - Germany used password to hack the RUS T3 server and wipe its memory

Aftermath

- Criminals tried to regain control, prevented by hardened OS
- 2021-2023 new variants appeared, did not gain as much traction
- 2023 – Microsoft released new update disabling Macros for external documents (finally!!)
- This stopped any future infection
- Criminals have been identified and profiled -> they are in Russia (no jurisdiction)