CS155

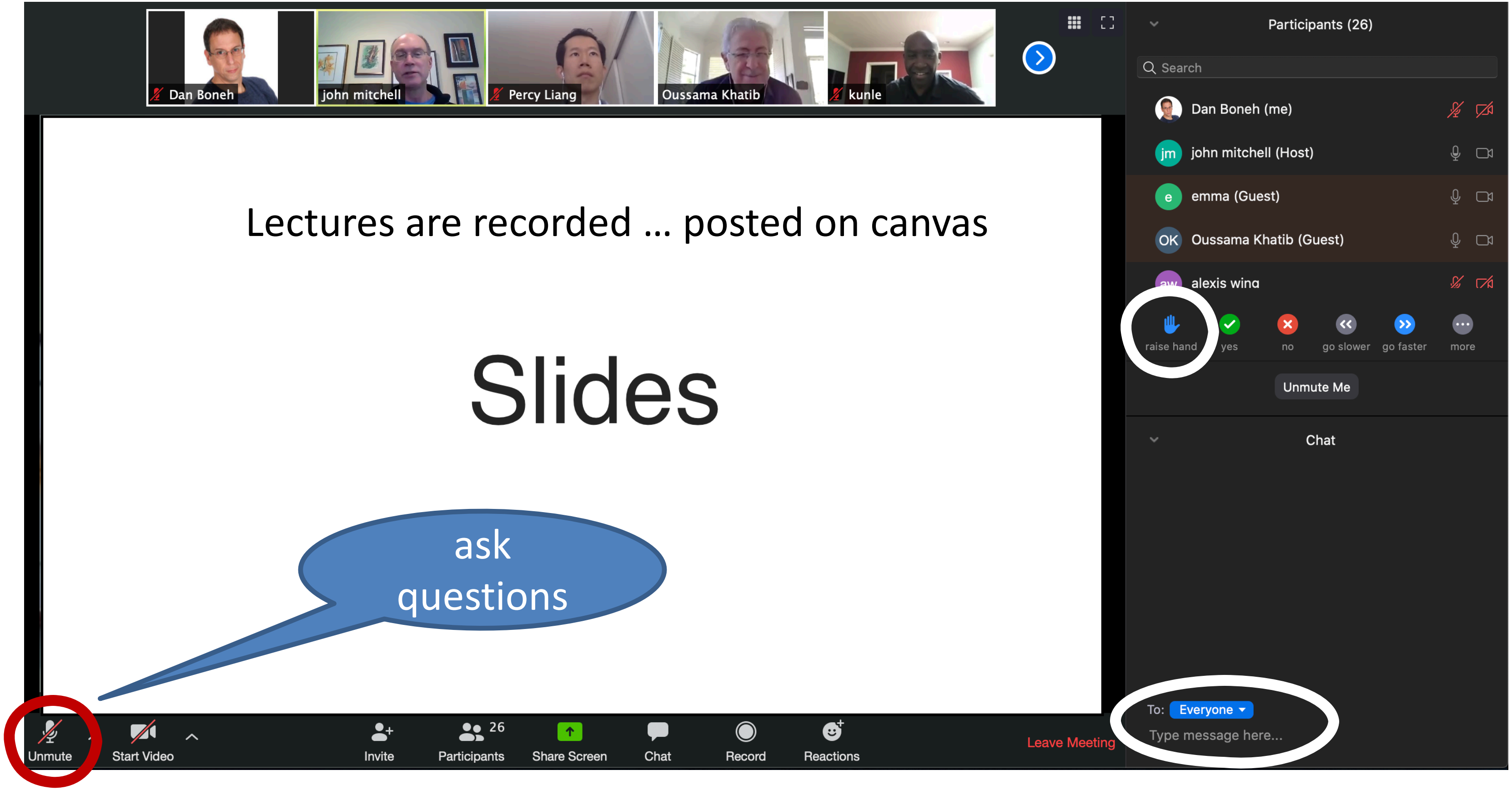
Computer Security

Course overview

Admin

- Course web site: https://cs155.Stanford.edu
- Profs: Dan Boneh and Zakir Durumeric
- Three programming projects (pairs) and two written homeworks
- **Project #1 is posted. Please attend section this Friday!**
- Use Piazza and Gradescope
- Automatic 72 hour extension
- No final exam this year

Live lectures on Zoom



Lectures are recorded … posted on canvas

Slides

ask questions

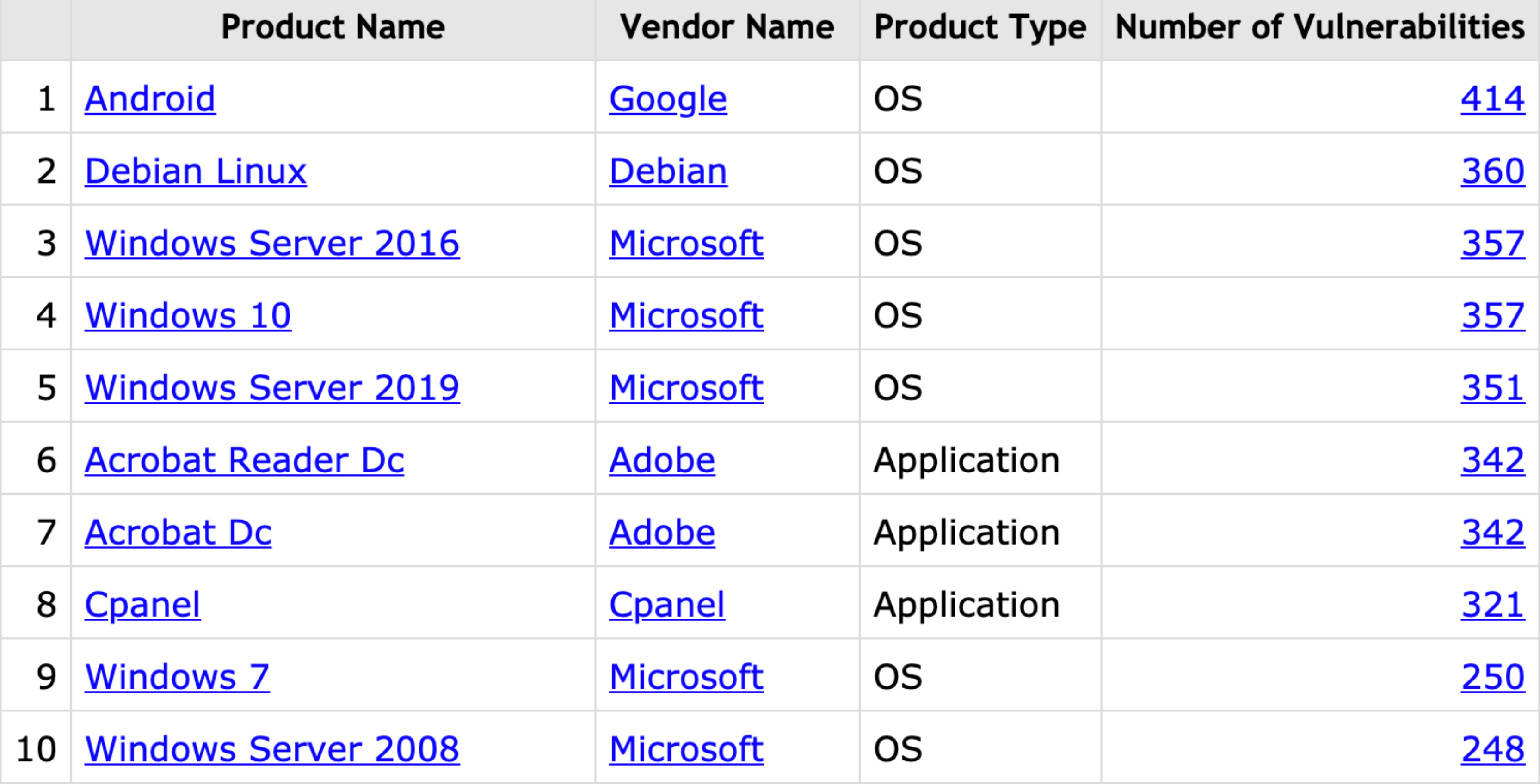
The computer security problem

- **Lots of buggy software**
- **Social engineering is very effective**
- **Money can be made from finding and exploiting vulns**.

1. Marketplace for exploits
2. Marketplace for owned machines (PPI)
3. Many methods to profit from owned machines

current state of computer security

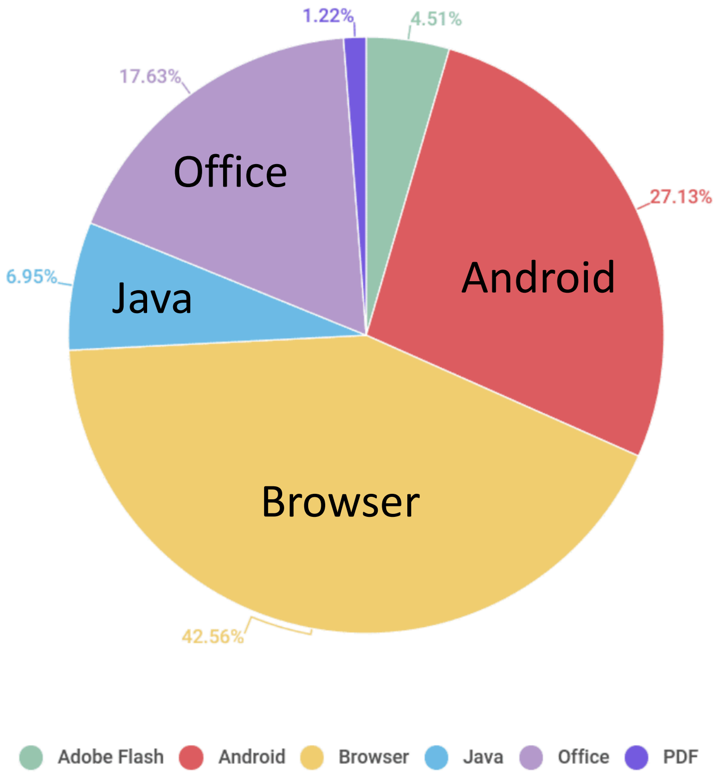
Top 10 products by total number of “distinct” vulnerabilities in 2019



	Product Name	Vendor Name	Product Type	Number of Vulnerabilities
1	Android	Google	OS	414
2	Debian Linux	Debian	OS	360
3	Windows Server 2016	Microsoft	OS	357
4	Windows 10	Microsoft	OS	357
5	Windows Server 2019	Microsoft	OS	351
6	Acrobat Reader Dc	Adobe	Application	342
7	Acrobat Dc	Adobe	Application	342
8	Cpanel	Cpanel	Application	321
9	Windows 7	Microsoft	OS	250
10	Windows Server 2008	Microsoft	OS	248

source: https://www.cvedetails.com/top-50-products.php?year=2019

Vulnerable applications being exploited



Source: Kaspersky Security Bulletin 2017

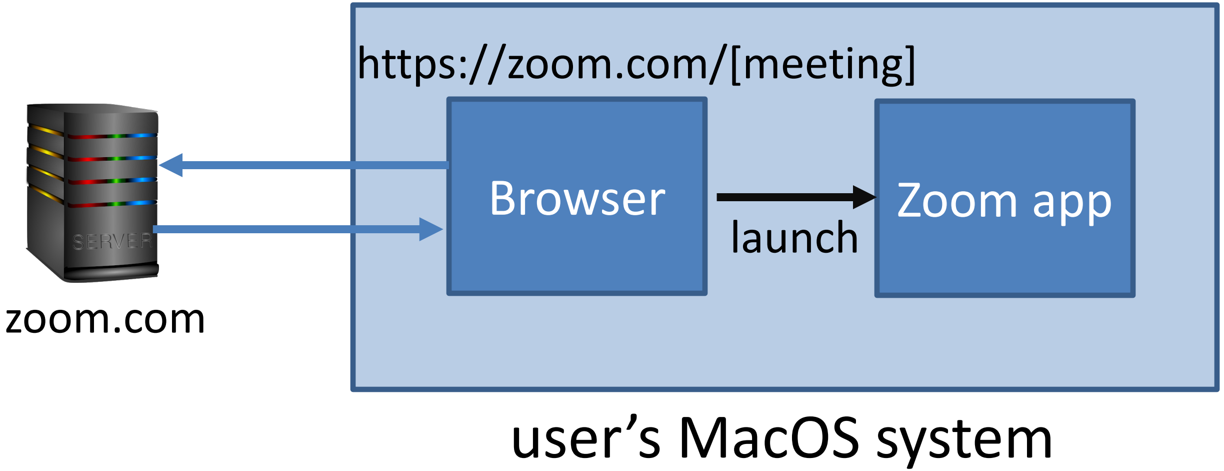
Dan Boneh

Why so many security bugs? Case study: Zoom client

Users have an expectation of privacy. But:

(1) Problems with crypto (Marczak and Scott-Railton, April 2020)

(2) How **not** to save a user click (J. Leitschuh, July 2019)



Why so many security bugs? Case study: Zoom client

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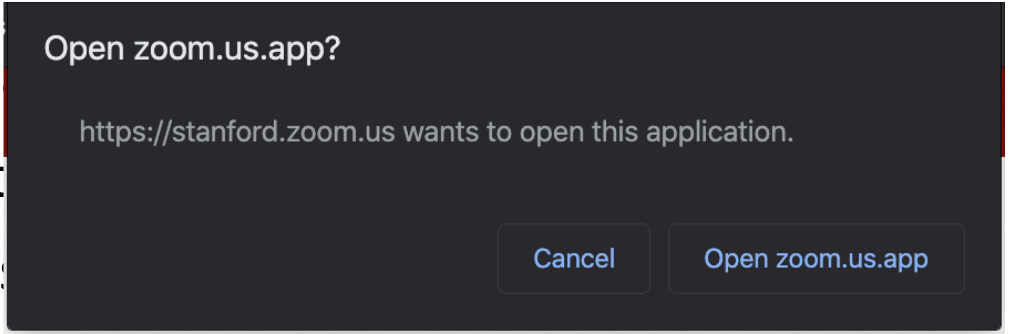
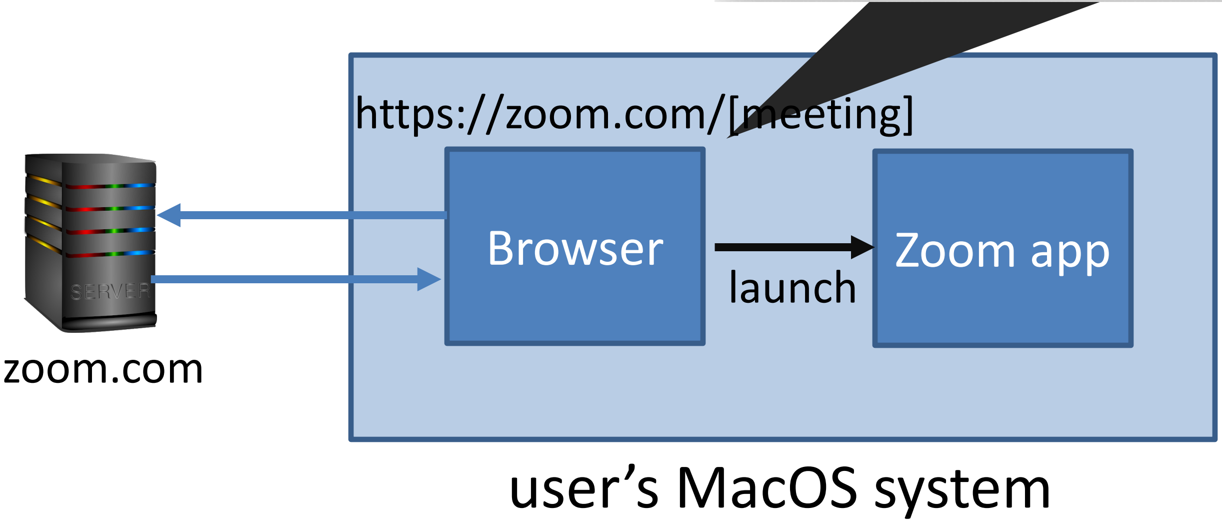


Open zoom.us.app?

https://stanford.zoom.us wants to open this application.



https://zoom.com/[meeting]

Browser

launch

Zoom app

zoom.com

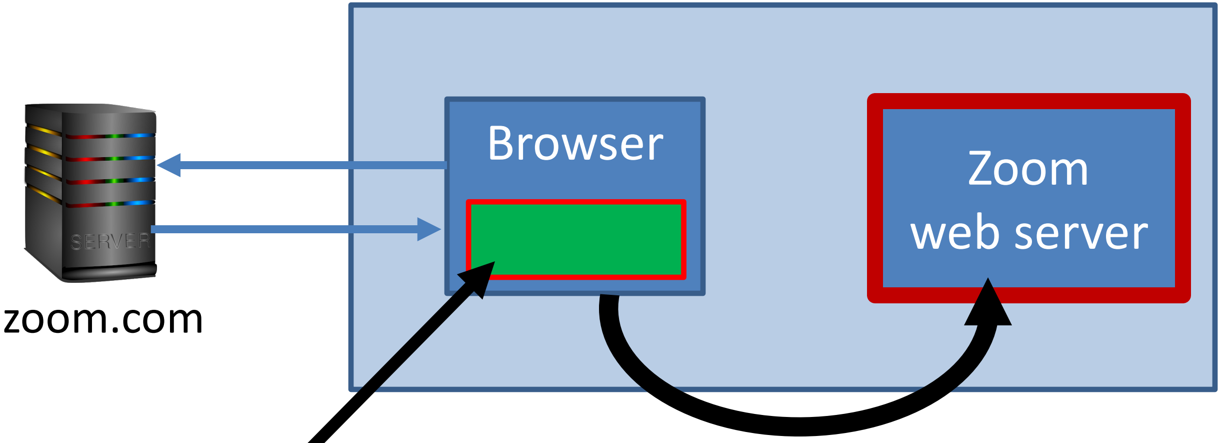
user's MacOS system

Can we bypass the security dialog?

Why so many security bugs? Case study: Zoom client

Local Zoom web server listens on port **localhost:19421**

- **To launch app**: web page from zoom.com tells browser to send an HTTP request to the local web server
- Web requests do not require a dialog …



Can this be attacked?

http://localhost:19421/launch?action=join&confno=[confrence number]

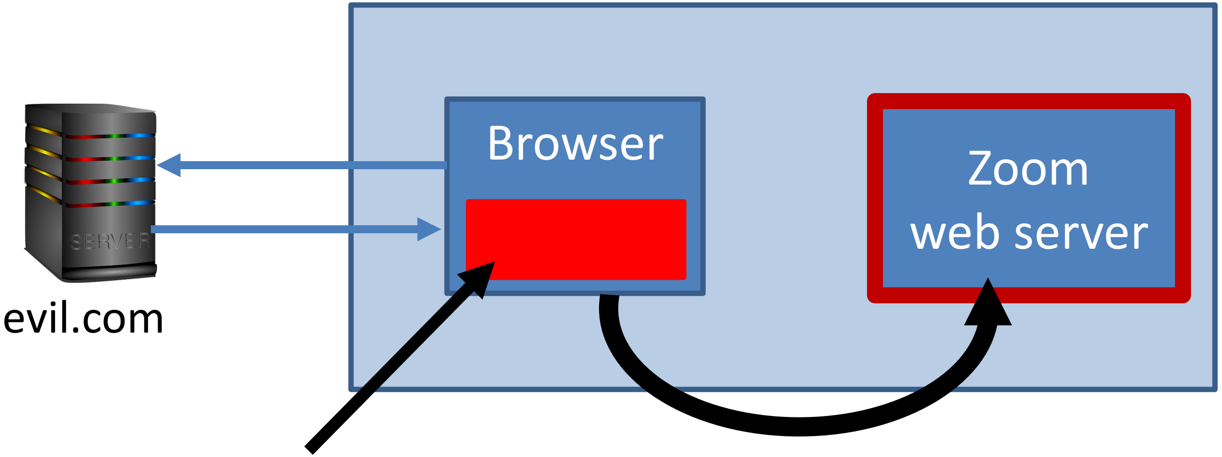
The problem [J. Leitschuh, July 2019]

Any web site can send a request to the local web server

- Joins users to conference w/o user’s knowledge!

What happened next? Responsible disclosure, 90 days (CVE-2019-13450).

- Fixed by Zoom. Web server removed by Apple’s MRT tool.



http://localhost:19421/launch?action=join&confno=[confrence number]

Why so many security bugs? Case study: Zoom client

Users have an expectation of privacy. But:

(1) Problems with crypto (Marczak and Scott-Railton, April 2020)

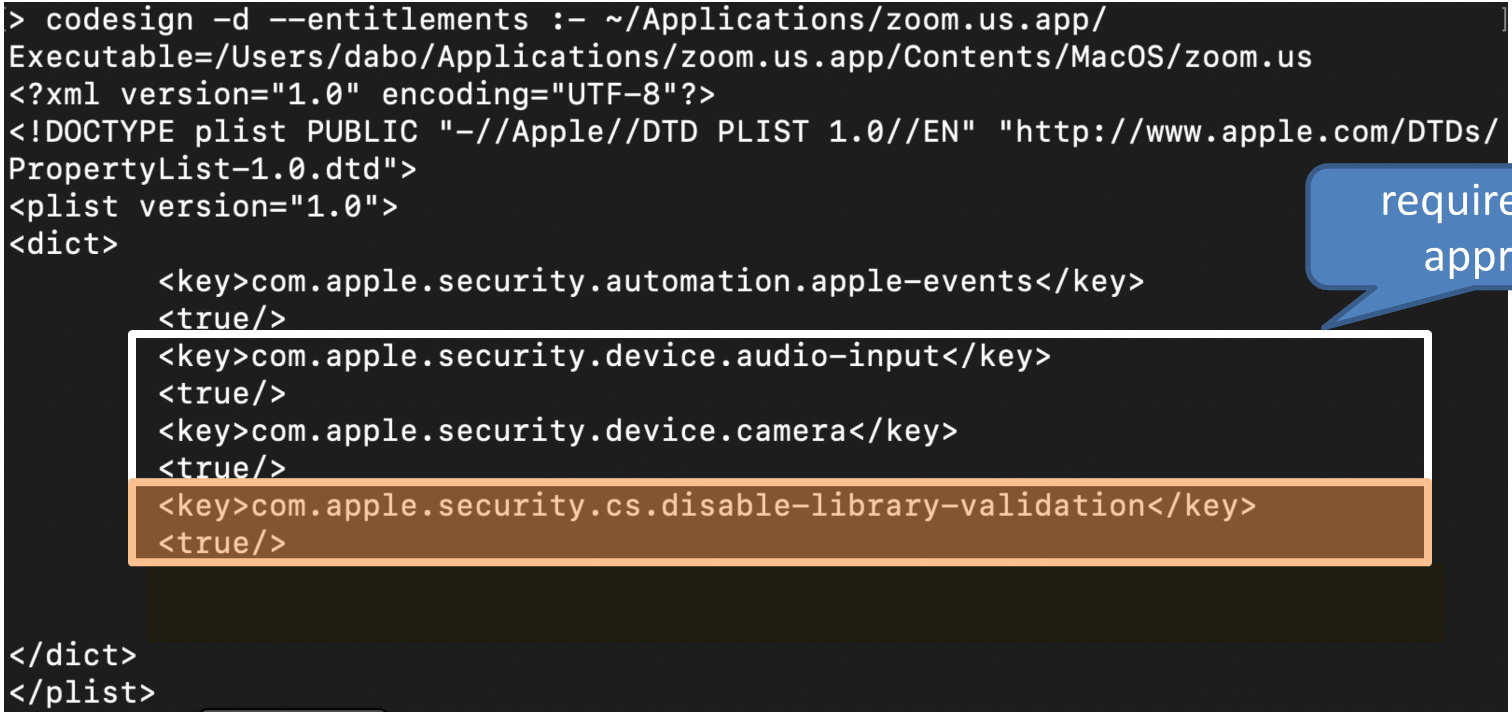
(2) How not to save a user click (J. Leitschuh, July 2019)

(3) Disable MacOS hardened runtime (P. Wardle, April 2020)

Defends against code injection, library hijacking,
and process memory space tampering.

Once user gives Zoom access to camera and mic,
MacOS ensures that entire application code does not change

What happens if protection is disabled?



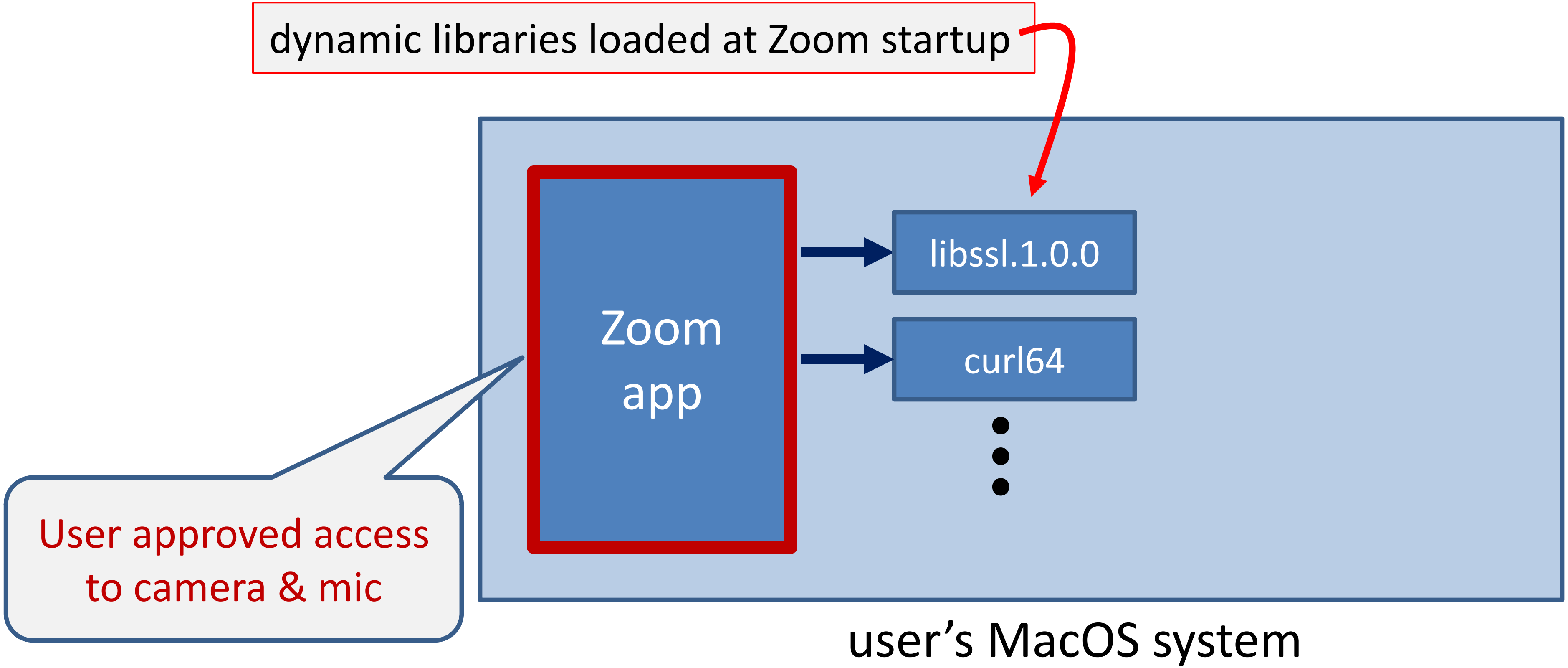
```
> codesign -d --entitlements :- ~/Applications/zoom.us.app/
Executable=/Users/dabo/Applications/zoom.us.app/Contents/MacOS/zoom.us
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN" "http://www.apple.com/DTDs/
PropertyList-1.0.dtd">
<plist version="1.0">
<dict>
        <key>com.apple.security.automation.apple-events</key>
        <true/>
        <key>com.apple.security.device.audio-input</key>
        <true/>
        <key>com.apple.security.device.camera</key>
        <true/>
        <key>com.apple.security.cs.disable-library-validation</key>
        <true/>


</dict>
</plist>
```

requires user approval

Can this be abused?

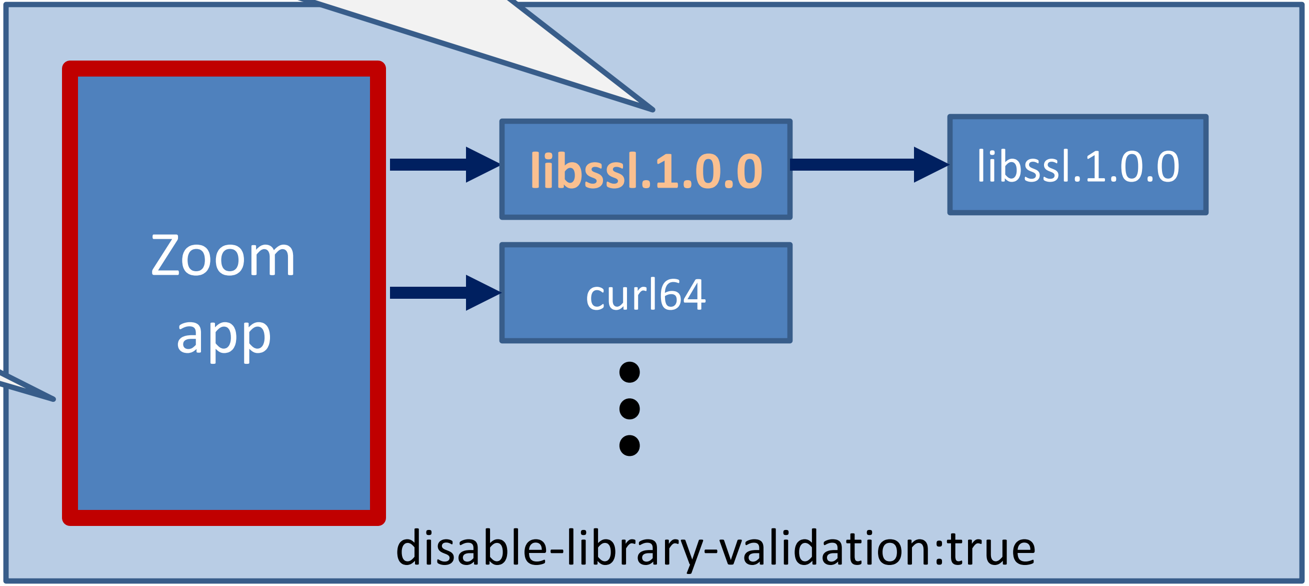
The impact [Wardle, 4/2020]


dynamic libraries loaded at Zoom startup
Zoom app
libssl.1.0.0
curl64
User approved access to camera & mic
user’s MacOS system

The impact [Wardle, 4/2020]

Attacker installs malware library that proxies libssl.
⇒ has access to camera & mic

hardened runtime
does not notify user
of change to libssl!



user’s MacOS system

Goals for this course

- Understand exploit techniques
  - Learn to defend and prevent common exploits

- Understand the available security tools

- Learn to architect secure systems

This course

Part 1: **basics** (architecting for security)

- Securing apps, OS, and legacy code:
  sandboxing, access control, and security testing

Part 2: **Web security** (defending against a web attacker)

- Building robust web sites, understand the browser security model

Part 3: **network security** (defending against a network attacker)

- Monitoring and architecting secure networks.

Part 4: **securing mobile applications**

Don’t try this at home !

Introduction

What motivates attackers?

… economics

Why compromise systems?
1. IP address and bandwidth stealing

Attacker’s goal: look like a random Internet user

Use the IP address of infected machine or phone for:

- **Spam** (e.g. the storm botnet)

  Spamalytics: 1:12M pharma spams leads to purchase
  1:260K greeting card spams leads to infection

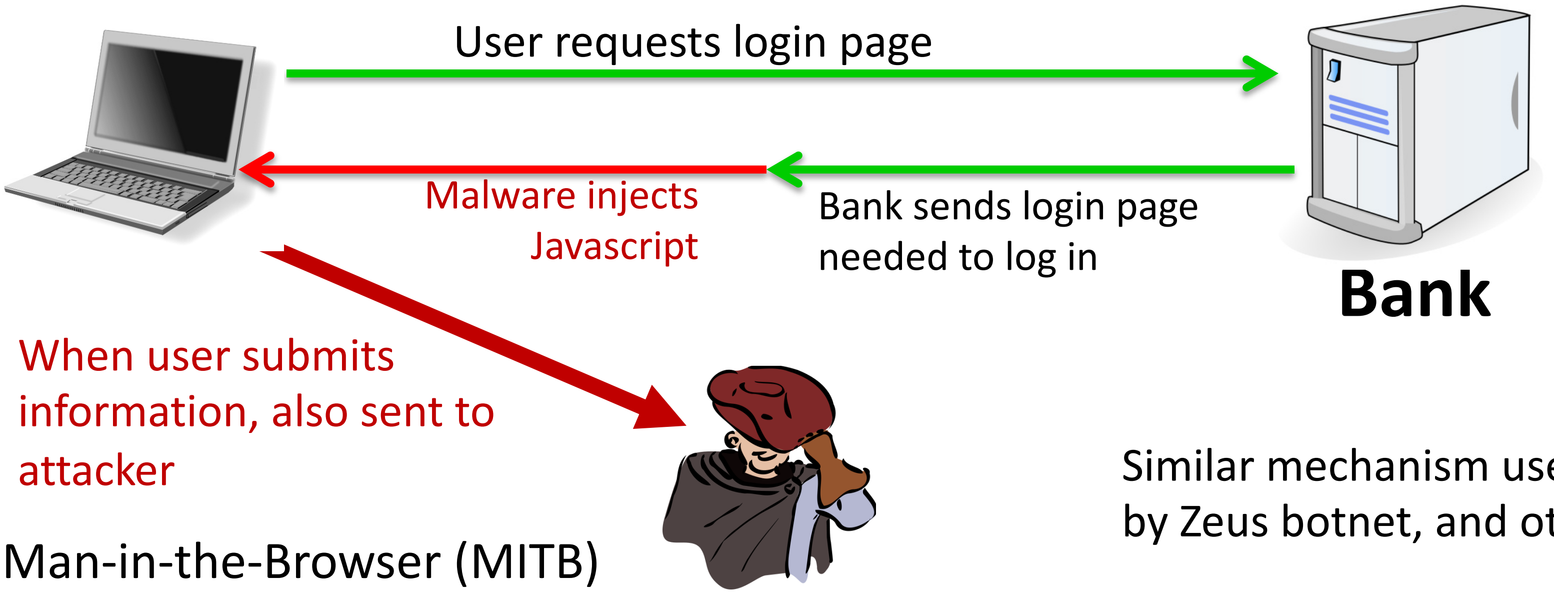
- **Denial of Service:** Services: 1 hour (20$), 24 hours (100$)
- **Click fraud** (e.g. Clickbot.a)

Why compromise systems?

2. Steal user credentials

keylog for banking passwords, corporate passwords, gaming pwds

Example: SilentBanker (and many like it)



User requests login page

Bank sends login page needed to log in

Malware injects Javascript

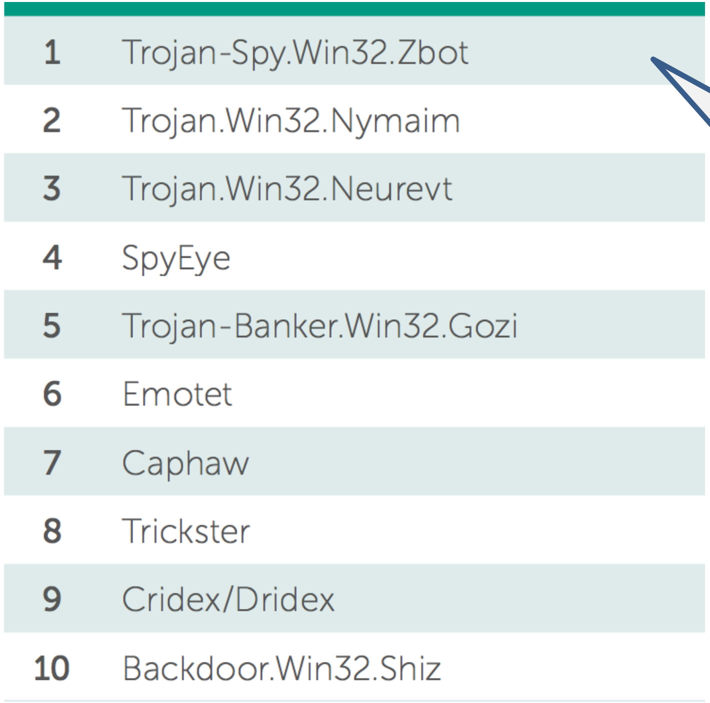
Bank

When user submits information, also sent to attacker

Man-in-the-Browser (MITB)

Similar mechanism used by Zeus botnet, and others

Lots of financial malware



1	Trojan-Spy.Win32.Zbot
2	Trojan.Win32.Nymaim
3	Trojan.Win32.Neurevt
4	SpyEye
5	Trojan-Banker.Win32.Gozi
6	Emotet
7	Caphaw
8	Trickster
9	Cridex/Dridex
10	Backdoor.Win32.Shiz

- records banking passwords via keylogger
- spread via spam email and hacked web sites
- maintains access to PC for future installs

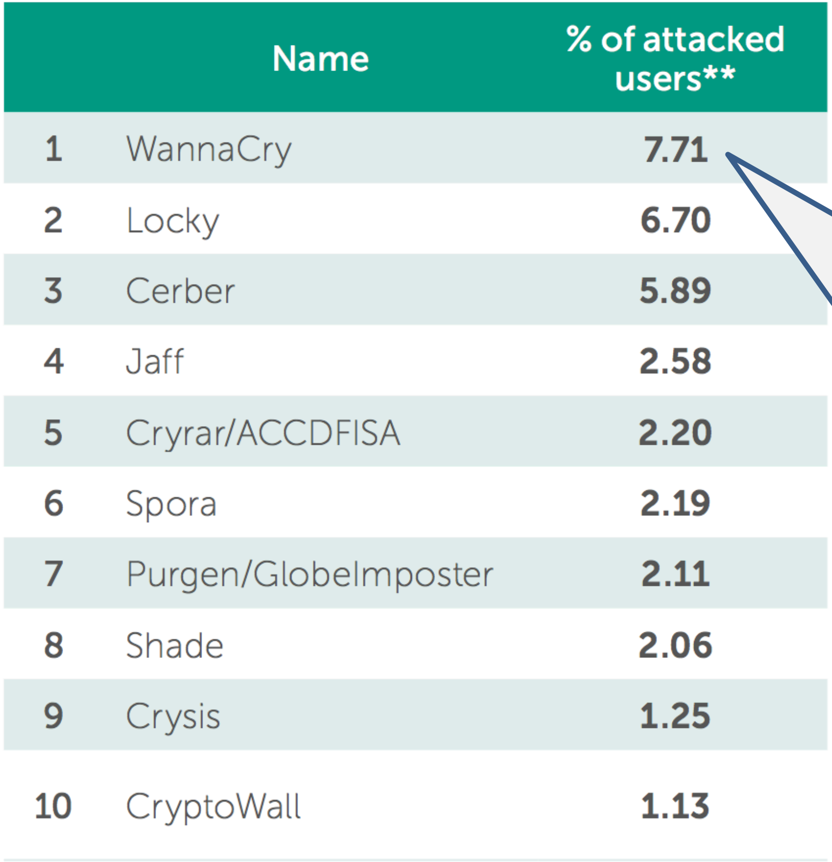
Source: Kaspersky Security Bulletin 2017

Similar attacks on mobile devices

Example: FinSpy.

- Works on **iOS and Android** (and Windows)
- once installed: collects contacts, call history, geolocation,
  texts, messages in encrypted chat apps, …
- <u>How installed</u>?
  - Android pre-2017: links in SMS / links in E-mail
  - iOS and Android post 2017: physical access

Why own machines: 3. **Ransomware**

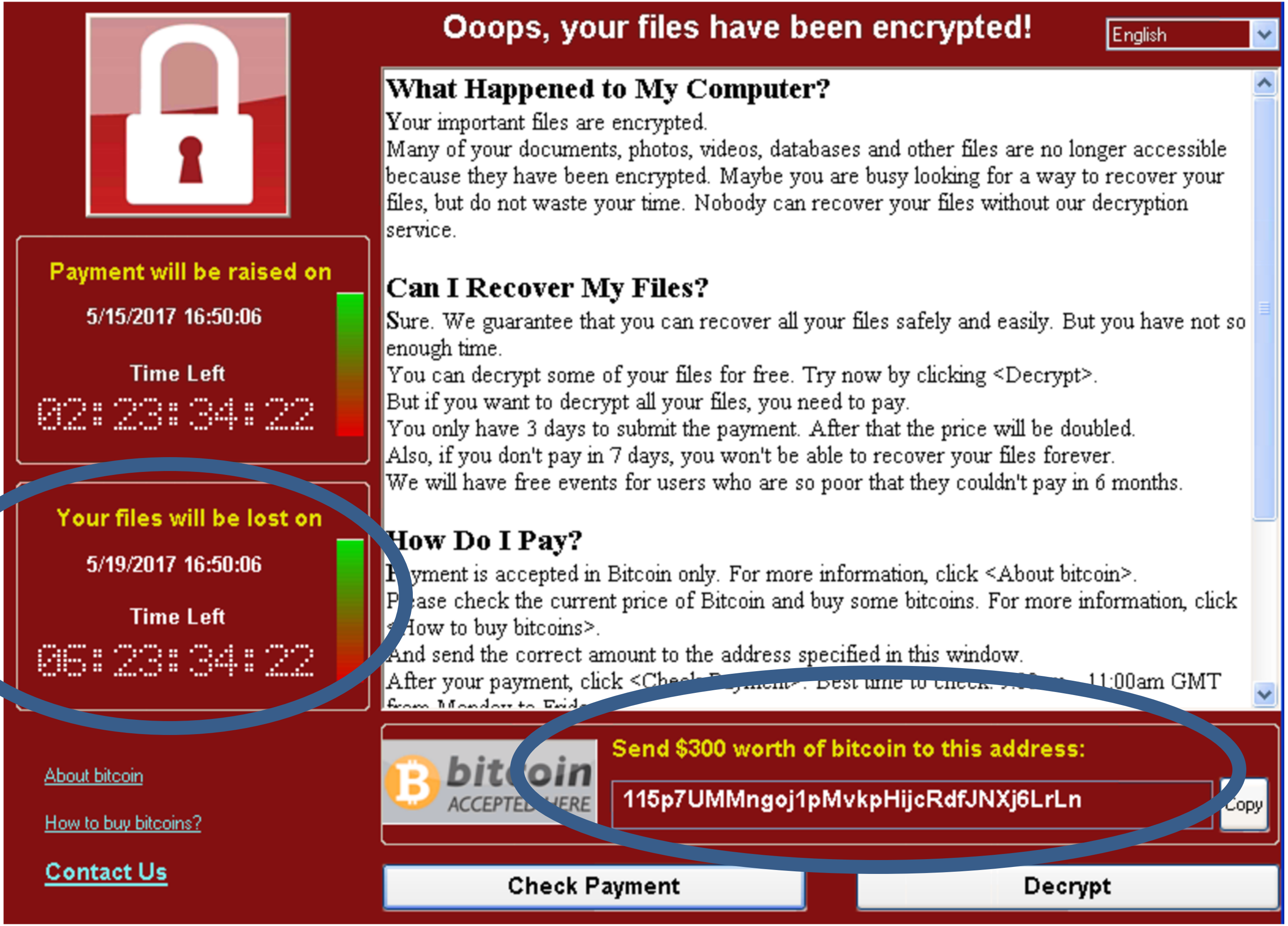


	Name	% of attacked users**
1	WannaCry	7.71
2	Locky	6.70
3	Cerber	5.89
4	Jaff	2.58
5	Cryrar/ACCDFISA	2.20
6	Spora	2.19
7	Purgen/GlobeImposter	2.11
8	Shade	2.06
9	Crysis	1.25
10	CryptoWall	1.13

a worldwide problem

- Worm spreads via a vuln. in SMB (port 445)
- Apr. 14, 2017: Eternalblue vuln. released by ShadowBrokers
- May 12, 2017: Worm detected (3 weeks to weaponize)

WannaCry ransomware



Ooops, your files have been encrypted!

Payment will be raised on

5/15/2017 16:50:06

Time Left

02:23:34:22

Your files will be lost on

5/19/2017 16:50:06

Time Left

06:23:34:22

What Happened to My Computer?

Your important files are encrypted.

Many of your documents, photos, videos, databases and other files are no longer accessible because they have been encrypted. Maybe you are busy looking for a way to recover your files, but do not waste your time. Nobody can recover your files without our decryption service.

Can I Recover My Files?

Sure. We guarantee that you can recover all your files safely and easily. But you have not so enough time.

You can decrypt some of your files for free. Try now by clicking <Decrypt>.

But if you want to decrypt all your files, you need to pay.

You only have 3 days to submit the payment. After that the price will be doubled.

Also, if you don't pay in 7 days, you won't be able to recover your files forever.

We will have free events for users who are so poor that they couldn't pay in 6 months.

How Do I Pay?

Payment is accepted in Bitcoin only. For more information, click <About bitcoin>.

Please check the current price of Bitcoin and buy some bitcoins. For more information, click <How to buy bitcoins>.

And send the correct amount to the address specified in this window.

After your payment, click <Check Payment>. Best time to check: 9:00am - 11:00am GMT from Monday to Frid

Send $300 worth of bitcoin to this address:

115p7UMMngoj1pMvkpHijcRdfJNXj6LrLn

Server-side attacks

- **Data theft**: credit card numbers, intellectual property
  - Example: Equifax (July 2017), ≈ 143M "customer" data impacted
    - Exploited known vulnerability in Apache Struts (RCE)
  - Many many similar attacks since 2000
- **Political motivation**:
  - DNC, Tunisia Facebook (Feb. 2011), GitHub (Mar. 2015)
- **Infect visiting users**

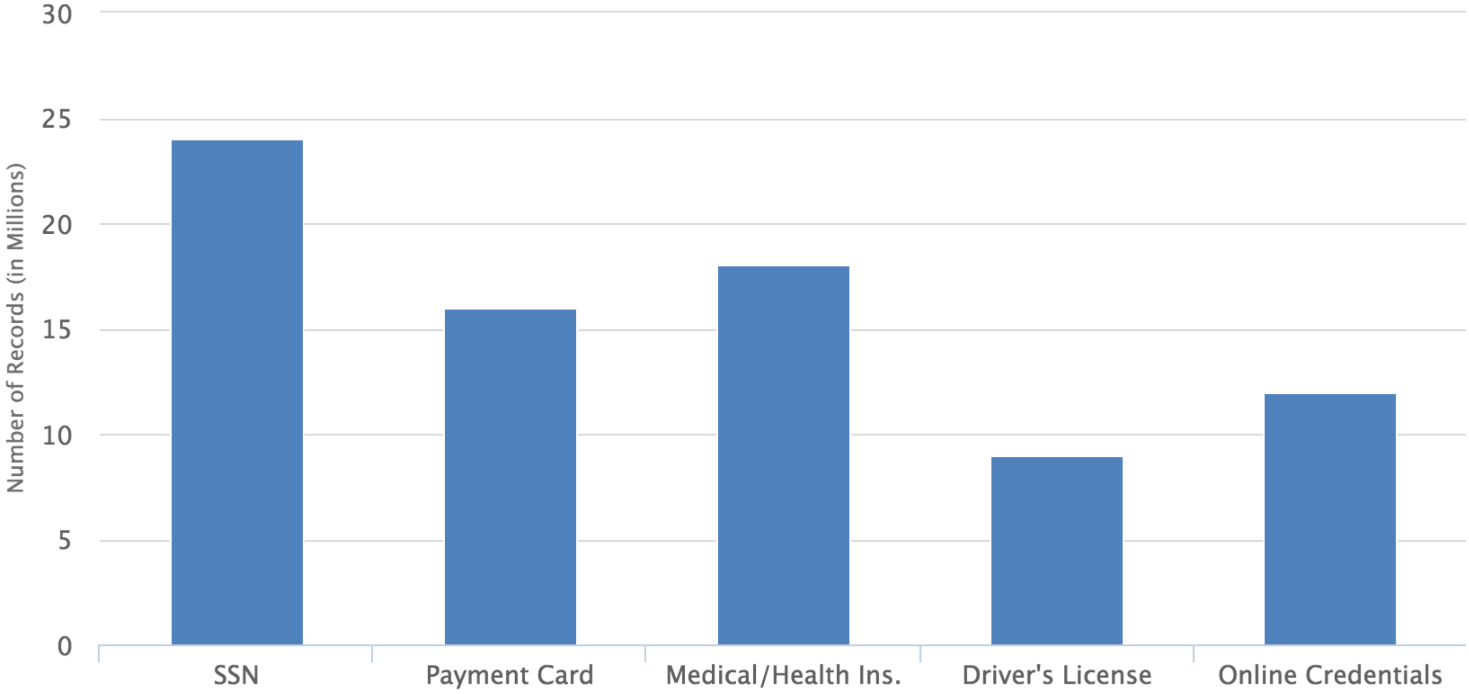
Infecting visiting users. Example: Mpack

- PHP-based tools installed on compromised web sites
  - Embedded as an iframe on infected page
  - Infects browsers that visit site

- Features
  - management console provides stats on infection rates
  - Sold for several 100$
  - Customer care can be purchased, one-year support contract

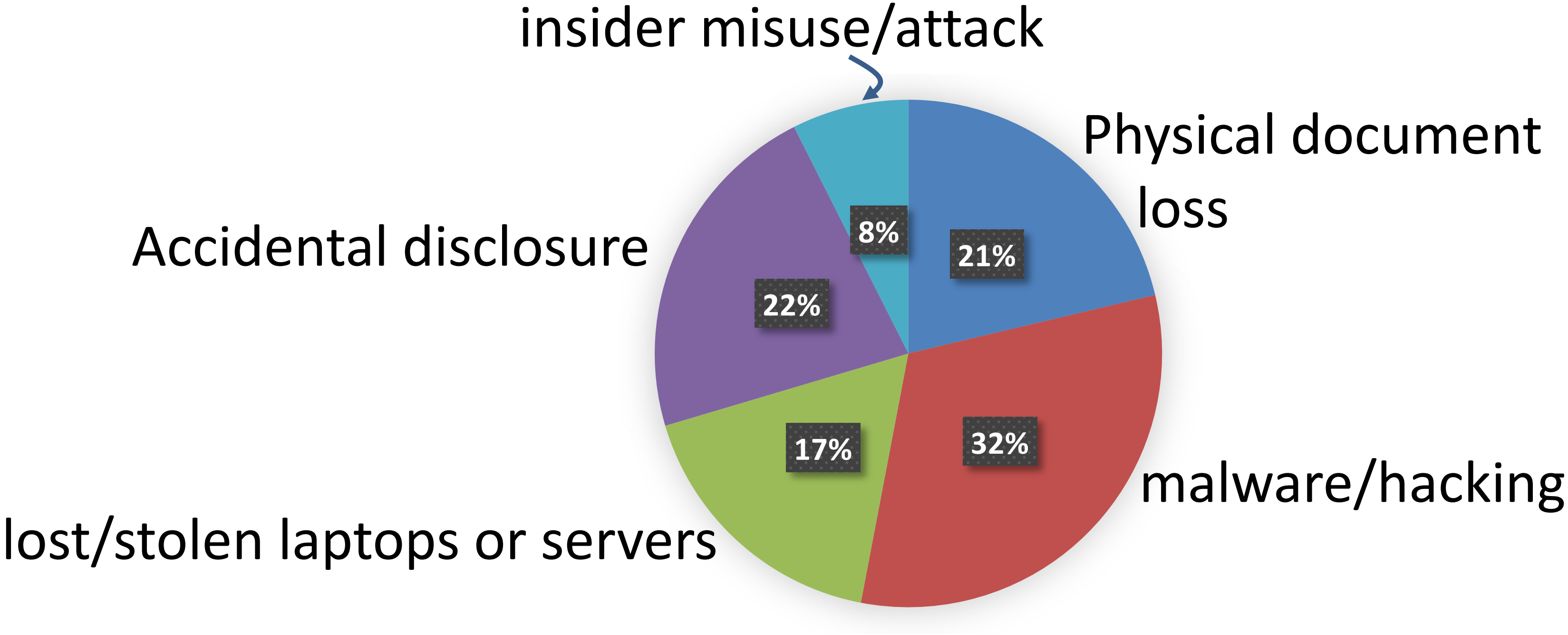
- Impact: 500,000 infected sites (compromised via SQL injection)
  - Several defenses: e.g. Google safe browsing

Data theft: what is stolen (2012-2015)



Source: California breach notification report, 2015

How companies lose customer data



How do we have this data?

Source: PrivacyRights.org, 2020

Introduction

The Marketplace for Vulnerabilities

Marketplace for Vulnerabilities

Option 1: bug bounty programs (many)

- Google Vulnerability Reward Program: up to $31,337
- Microsoft Bounty Program: up to $100K
- Apple Bug Bounty program: up to $200K
- Stanford bug bounty program: up to $1K
- Pwn2Own competition: $15K

Option 2:

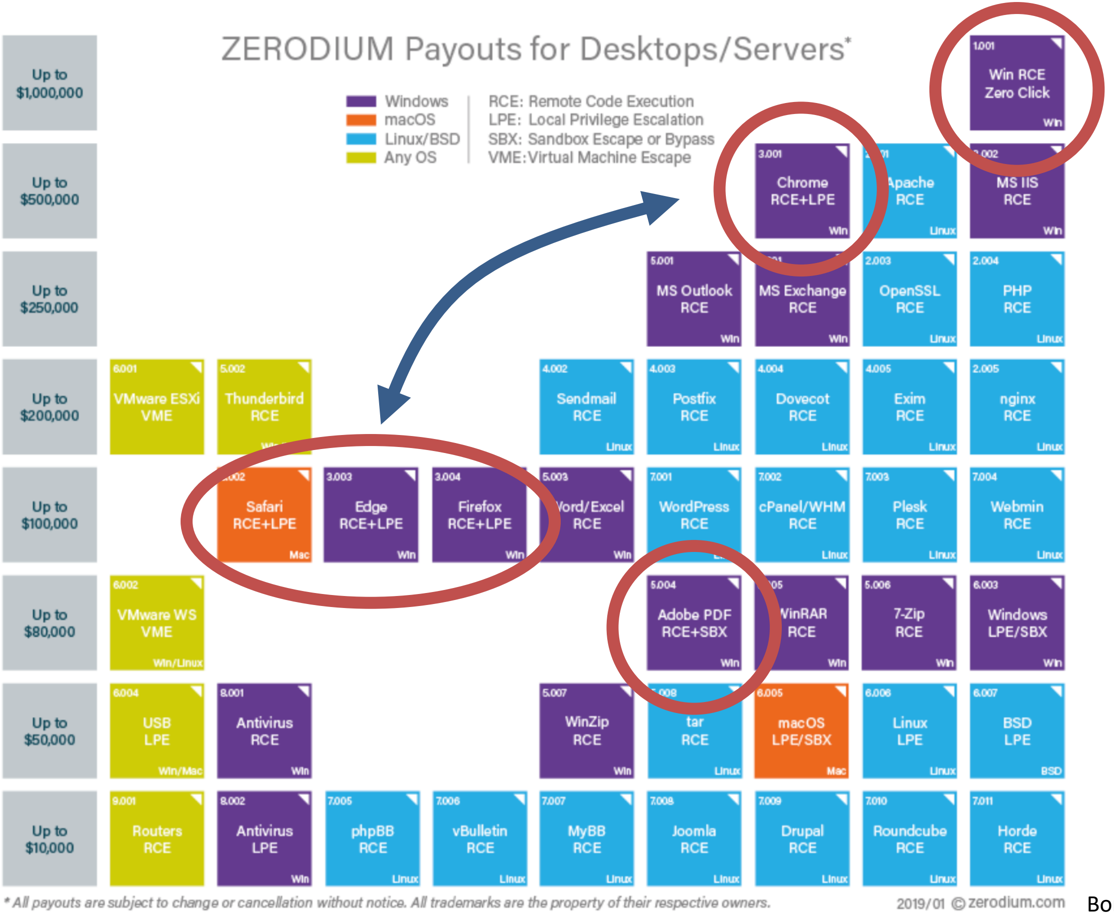
- Zerodium: up to $2M for iOS, $2.5M for Android (2019)
- … many others

Marketplace for Vulnerabilities

RCE: remote code execution

LPE: local privilege escalation

SBX: sandbox escape



ZERODIUM Payouts for Desktops/Servers*

▇ Windows	RCE: Remote Code Execution
▇ macOS	LPE: Local Privilege Escalation
▇ Linux/BSD	SBX: Sandbox Escape or Bypass
▇ Any OS	VME: Virtual Machine Escape

Up to $1,000,000									1.001 Win RCE Zero Click Win
Up to $500,000							3.001 Chrome RCE+LPE Win	2.001 Apache RCE Linux	2.002 MS IIS RCE Win
Up to $250,000						5.001 MS Outlook RCE Win	4.001 MS Exchange RCE Win	2.003 OpenSSL RCE Linux	2.004 PHP RCE Linux
Up to $200,000	6.001 VMware ESXi VME	5.002 Thunderbird RCE Win			4.002 Sendmail RCE Linux	4.003 Postfix RCE Linux	4.004 Dovecot RCE Linux	4.005 Exim RCE Linux	2.005 nginx RCE Linux
Up to $100,000		3.002 Safari RCE+LPE Mac	3.003 Edge RCE+LPE Win	3.004 Firefox RCE+LPE Win	5.003 Word/Excel RCE Win	7.001 WordPress RCE Linux	7.002 cPanel/WHM RCE Linux	7.003 Plesk RCE Linux	7.004 Webmin RCE Linux
Up to $80,000	6.002 VMware WS VME Win/Linux					5.004 Adobe PDF RCE+SBX Win	5.005 WinRAR RCE Win	5.006 7-Zip RCE Win	6.003 Windows LPE/SBX Win
Up to $50,000	6.004 USB LPE Win/Mac	8.001 Antivirus RCE Win			5.007 WinZip RCE Win	5.008 tar RCE Linux	6.005 macOS LPE/SBX Mac	6.006 Linux LPE Linux	6.007 BSD LPE BSD
Up to $10,000	9.001 Routers RCE	8.002 Antivirus LPE Win	7.005 phpBB RCE Linux	7.006 vBulletin RCE Linux	7.007 MyBB RCE Linux	7.008 Joomla RCE Linux	7.009 Drupal RCE Linux	7.010 Roundcube RCE Linux	7.011 Horde RCE Linux

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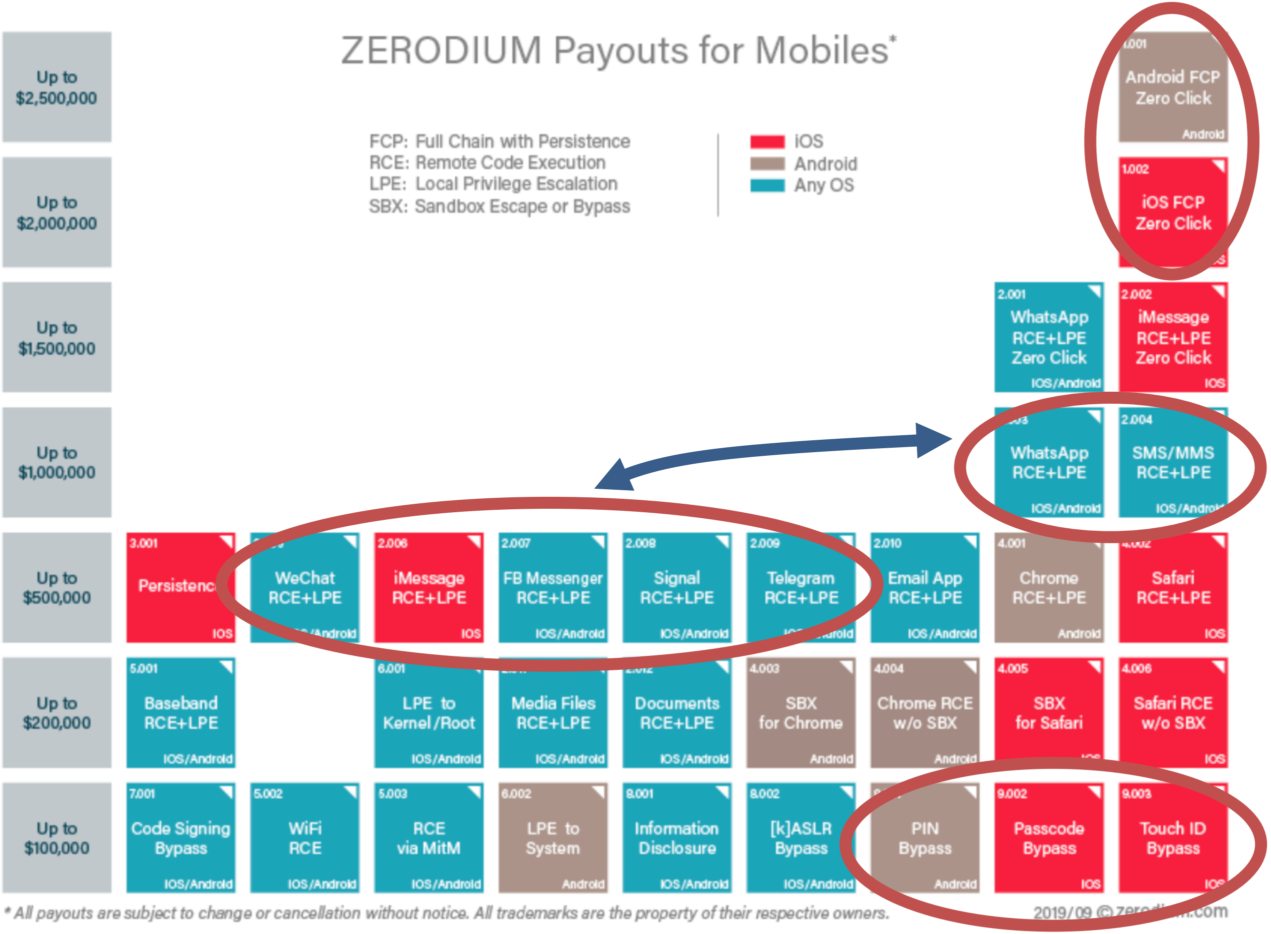
Source: Zerodium payouts

Marketplace for Vulnerabilities

RCE: remote code execution

LPE: local privilege escalation

SBX: sandbox escape



ZERODIUM Payouts for Mobiles*

FCP: Full Chain with Persistence
RCE: Remote Code Execution
LPE: Local Privilege Escalation
SBX: Sandbox Escape or Bypass

🟥	iOS
🟫	Android
🟦	Any OS

Up to $2,500,000									1.001 Android FCP Zero Click Android
Up to $2,000,000									1.002 iOS FCP Zero Click iOS
Up to $1,500,000								2.001 WhatsApp RCE+LPE Zero Click iOS/Android	2.002 iMessage RCE+LPE Zero Click iOS
Up to $1,000,000								[illegible]03 WhatsApp RCE+LPE iOS/Android	2.004 SMS/MMS RCE+LPE iOS/Android
Up to $500,000	3.001 Persistence iOS	WeChat RCE+LPE iOS/Android	2.006 iMessage RCE+LPE iOS	2.007 FB Messenger RCE+LPE iOS/Android	2.008 Signal RCE+LPE iOS/Android	2.009 Telegram RCE+LPE iOS/Android	2.010 Email App RCE+LPE iOS/Android	4.001 Chrome RCE+LPE Android	4.002 Safari RCE+LPE iOS
Up to $200,000	5.001 Baseband RCE+LPE iOS/Android		6.001 LPE to Kernel/Root iOS/Android	Media Files RCE+LPE iOS/Android	2.012 Documents RCE+LPE iOS/Android	4.003 SBX for Chrome Android	4.004 Chrome RCE w/o SBX Android	4.005 SBX for Safari iOS	4.006 Safari RCE w/o SBX iOS
Up to $100,000	7.001 Code Signing Bypass iOS/Android	5.002 WiFi RCE iOS/Android	5.003 RCE via MitM iOS/Android	6.002 LPE to System Android	8.001 Information Disclosure iOS/Android	8.002 [k]ASLR Bypass iOS/Android	PIN Bypass Android	9.002 Passcode Bypass iOS	9.003 Touch ID Bypass iOS

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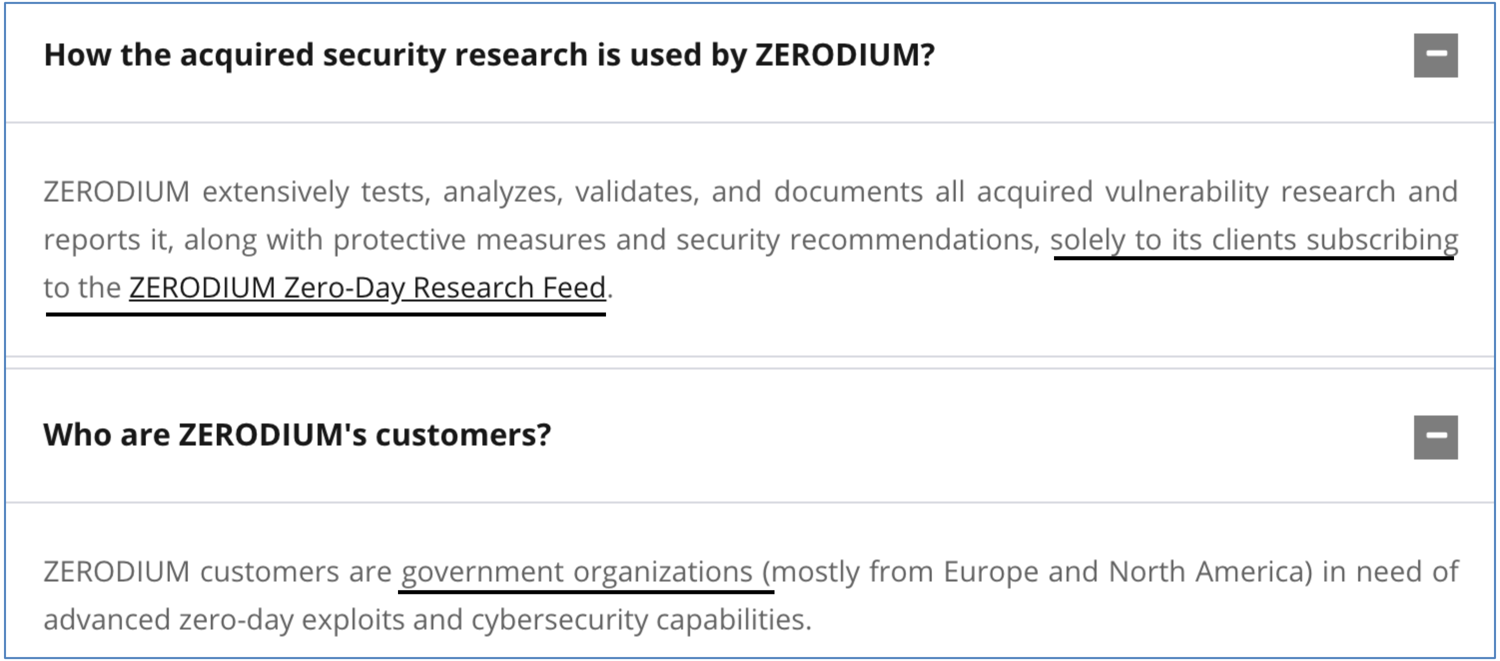
Source: Zerodium payouts

Why buy 0days?



How the acquired security research is used by ZERODIUM?

ZERODIUM extensively tests, analyzes, validates, and documents all acquired vulnerability research and reports it, along with protective measures and security recommendations, solely to its clients subscribing to the ZERODIUM Zero-Day Research Feed.

Who are ZERODIUM's customers?

ZERODIUM customers are government organizations (mostly from Europe and North America) in need of advanced zero-day exploits and cybersecurity capabilities.

https://zerodium.com/faq.html

Ken Thompson’s clever Trojan

Turing award lecture

(CACM Aug. 1984)

What code can we trust?

What code can we trust?

Can we trust the “login” program in a Linux distribution? (e.g. Ubuntu)

- No! the login program may have a backdoor

  ⇾ records my password as I type it

- **Solution: recompile login program from source code**

Can we trust the login source code?

- No! but we can inspect the code, then recompile

Can we trust the compiler?

No!   Example malicious compiler code:

```
compile(s) {
      if (match(s, “login-program”)) {
            compile(“login-backdoor”);
            return
      }
      /*  regular compilation */
}
```

What to do?

Solution: inspect compiler source code,
then recompile the compiler

Problem: C compiler is itself written in C, compiles itself

What if compiler binary has a backdoor?

Thompson’s clever backdoor

Attack step 1: change compiler source code:

```
compile(s) {
    if (match(s, “login-program”)) {
            compile(“login-backdoor”);
            return
    }
    if (match(s, “compiler-program”)) {
            compile(“compiler-backdoor”);
            return
    }
    /*  regular compilation */
}
```

(*)

Thompson’s clever backdoor

Attack step 2:

- Compile modified compiler ⇒ compiler binary
- Restore compiler source to original state

Now: inspecting compiler source reveals nothing unusual

… but compiling compiler gives a corrupt compiler binary

Complication: compiler-backdoor needs to include all of (*)

What can we trust?

I order a laptop by mail. When it arrives, what can I trust on it?

- Applications and/or operating system may be backdoored

  ⇒ solution: reinstall OS and applications

- How to reinstall? Can’t trust OS to reinstall the OS.

  ⇒ Boot *Tails* from a USB drive (Debian)

- Need to trust pre-boot BIOS,UEFI code. Can we trust it?

  ⇒ No! (e.g. ShadowHammer operation in 2018)

- Can we trust the motherboard? Software updates?

So, what can we trust?

Sadly, nothing … anything can be compromised

- but then we can't make progress

Trusted Computing Base (TCB)

- Assume some minimal part of the system is not compromised
- Then build a secure environment on top of that

will see how during the course.

Next time: control hijacking vulnerabilities

THE END