CS 4530: Fundamentals of Software Engineering

Module 15: Software Engineering & Security

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Learning Objectives for this Module

- By the end of this module, you should be able to:
  - Define key terms relating to software/system security
  - Describe some of the tradeoffs between security and other requirements in software engineering
  - Explain 5 common vulnerabilities in web applications and similar software systems, and describe some common mitigations for each of them.
  - Explain why software alone isn’t enough to assure security

Outline of this lecture

1. Definition of key vocabulary
2. Some common vulnerabilities, and possible mitigations
3. Getting security right is about people as well as software.

Security: Basic Vocabulary (1)

- Security is a set of non-functional requirements (sometimes called “CIA”):
- Confidentiality: is information disclosed to unauthorized individuals?
- Integrity: is code or data tampered with?
- Availability: is the system accessible and usable?

Security: Basic Vocabulary (2)

- Asset: something of value that is the subject of a security requirement
- Threat: potential event that could compromise a security requirement
- Security architecture: a set of mechanisms and policies that we build into our system to mitigate risks from threats

Security: Basic Vocabulary (3)

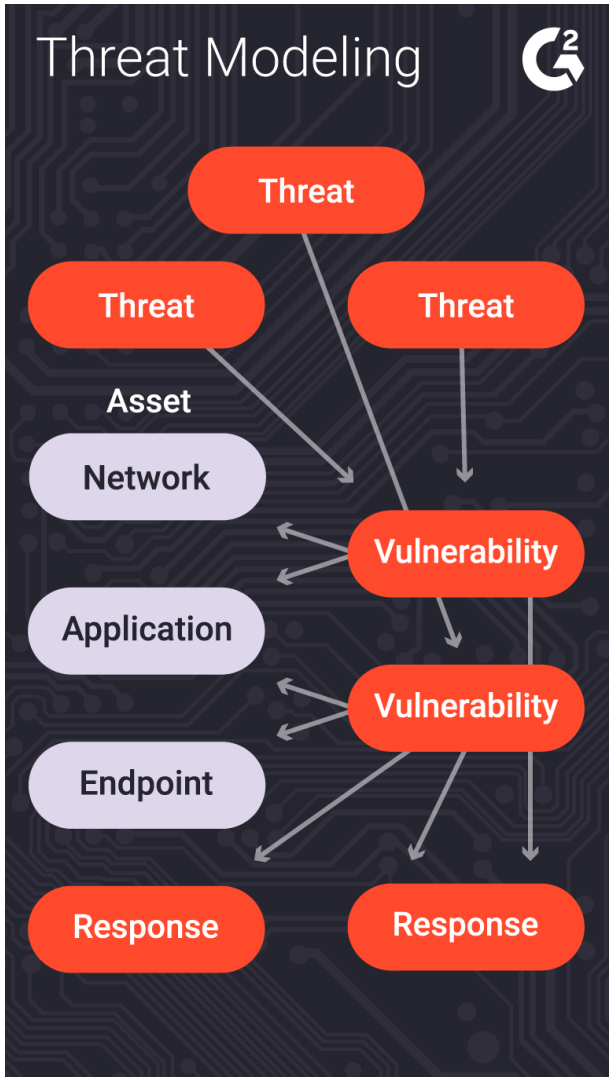
- Vulnerability: a characteristic or flaw in system design or implementation, or in the security procedures, that, if exploited, could result in a security compromise
- Exploit: a technique or method for exploiting a vulnerability
- Attack: realization of a threat
- Mitigation: a technique for making an attack less likely, more expensive, or less valuable to an attacker.

Security is about managing risk

- Increasing security might:
  - Increase development & maintenance cost
  - Increase infrastructure requirements
  - Degrade performance
- But, if we are attacked, increasing security might also:
  - Decrease financial and intangible losses
- How likely do we think we are to be attacked in some particular way?

Threat modeling can help us analyze the issues

- What is being defended?
- What malicious actors exist and what attacks might they employ?
- What value can an attacker extract from a vulnerability?
- Who do we trust? What parts of the system do we trust?
- What can we do in case of attack?



A Baseline Threat Model

- Trust:
  - Developers writing our code (at least for the code they touch)
  - Server running our code
  - Popular dependencies that we use and update
- Don’t trust:
  - Code running in browser
  - Inputs from users
  - Other employees (employees should have access only to the resources they need)

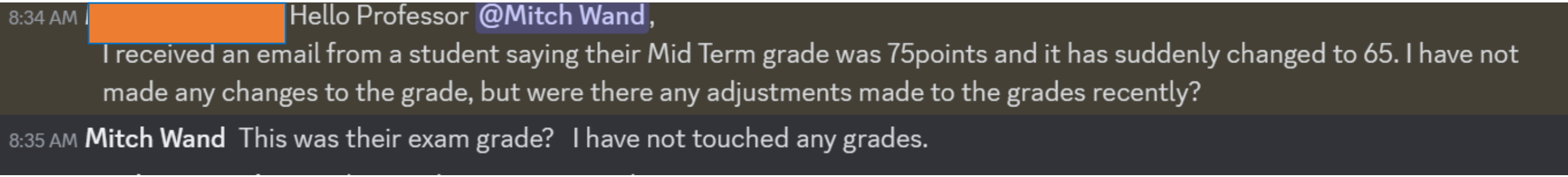
Man vs. Musk: A Whistleblower Creates Headaches for Tesla

An employee who was fired after expressing safety concerns leaked personnel records and sensitive data about driver-assistance software.

A Baseline Security Policy

- Encrypt all data in transit, sensitive data at rest
- Use multi-factor authentication
- Use encapsulated zones/layers of security
  - Different people have access to different resources
  - Principle of Least Privilege
- Log everything! (employee data accesses/modifications) (maybe)
- Do regular, automatic, off-site backups
- Bring in security experts early for riskier situations

How much should you log?



Backups can mitigate the risks of a ransomware attack

Off-site backups mitigate the risks of natural disasters

In the remainder of this module, we will discuss 5 major classes of vulnerabilities

- Vulnerability 1: Code that runs in an untrusted environment
- Vulnerability 2: Untrusted Inputs
- Vulnerability 3: Bad authentication (of both sender and receiver!)
- Vulnerability 4: Malicious software from the software supply chain
- Vulnerability 5: Failure to apply security policy.

https://owasp.org/www-project-top-ten/

Vulnerability 1 Example: authentication code in a web application

Curses! Foiled Again!

Front End

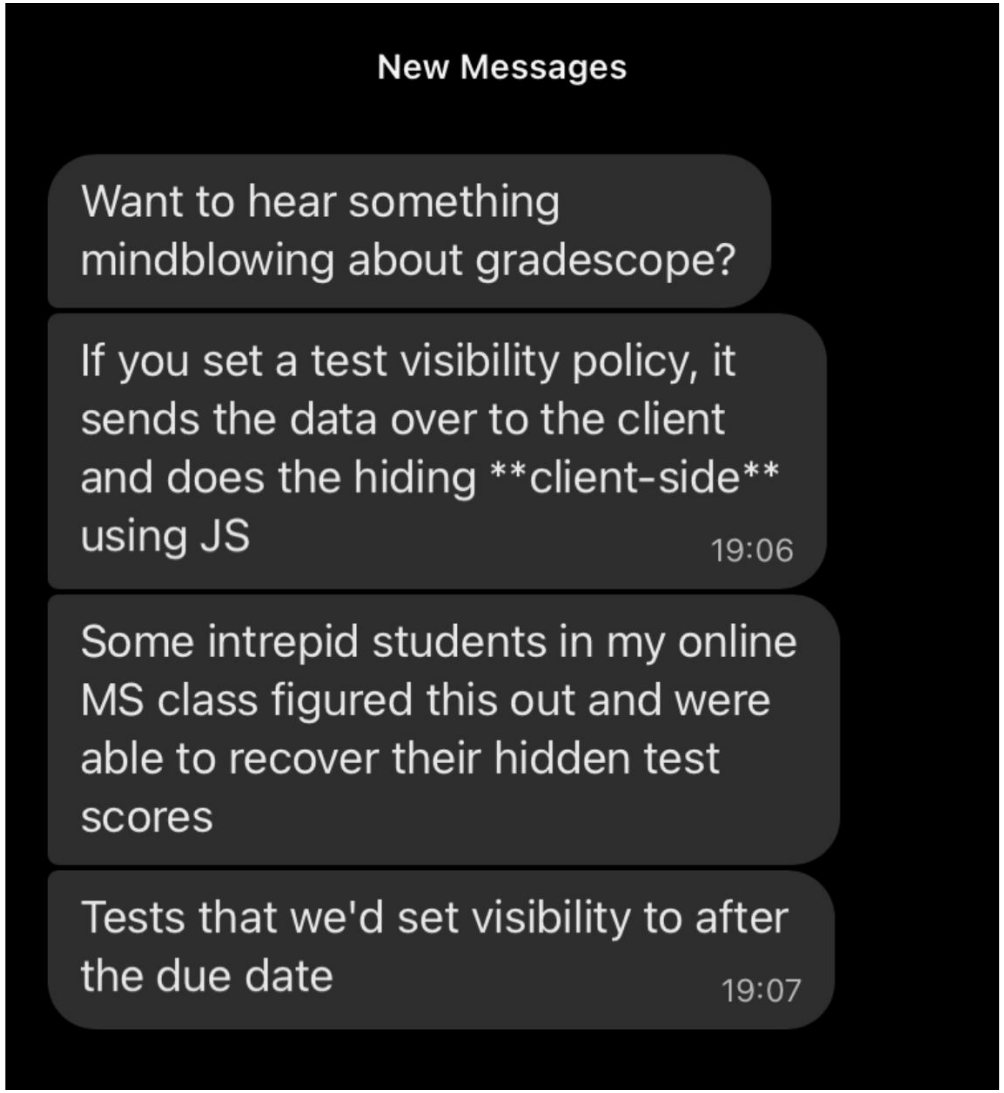
```
function checkPassword(inputPassword:
string){
  if(inputPassword === 'letmein'){
    return true;
  }
  return false;
}
```

Trust boundary

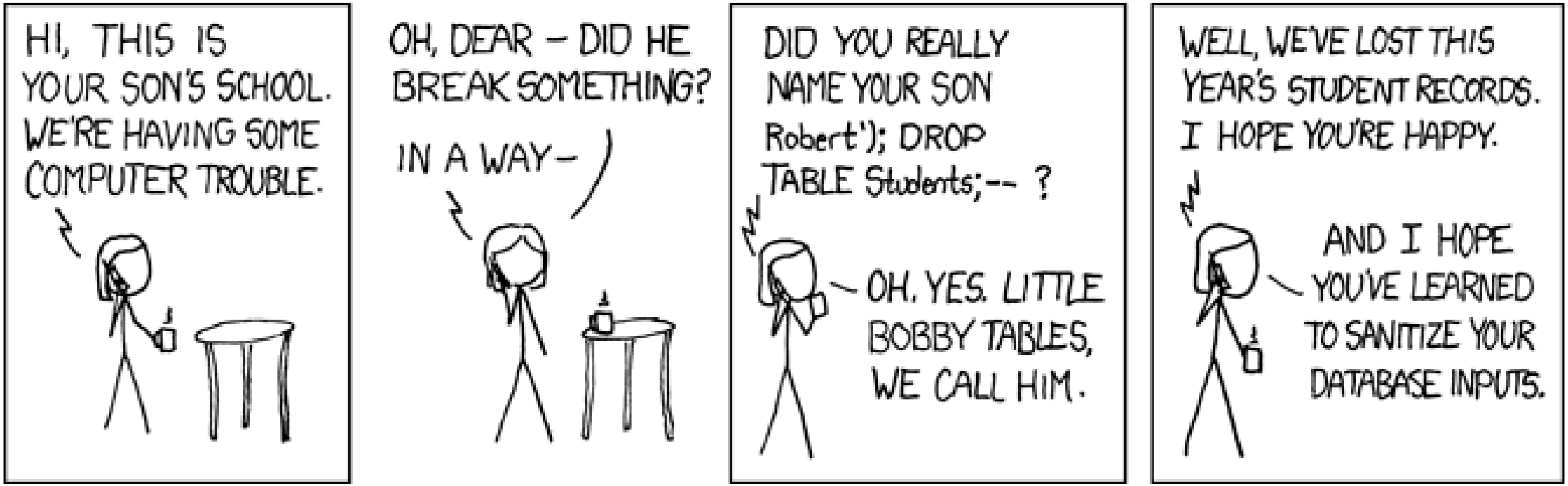
Fix: Move code to back end (duh!)

Back End

Who would do such a silly thing?



Vulnerability 2: Data controlled by a user flowing into our trusted codebase



https://xkcd.com/327/

Example: code injection

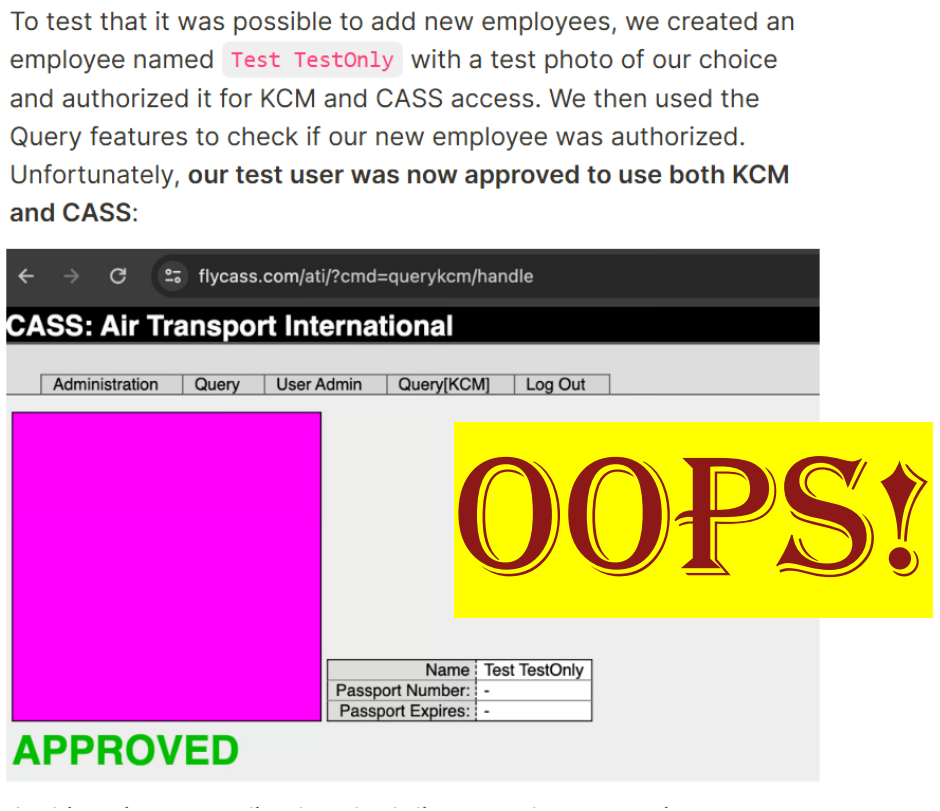
```
String query = "SELECT * FROM accounts WHERE
       name='" + request.getParameter("name") + "'";
```

Parameter name	Constructed Query	Effect
Alice	SELECT * FROM accounts WHERE name='Alice';	Select a single account
Alice O'Neal	SELECT * FROM accounts WHERE name='Alice O'Neal';	SQL Error
5' OR '1'='1	SELECT * FROM accounts WHERE name='5' OR '1'='1';	**Select all accounts**

- OWASP A03:2021-Injection

Bypassing airport security via SQL injection (2024!)

- "Known Crewmembers" can get to the cockpit without inspection.
- Large airlines: Each airline runs its own authorization system, but small airlines rely on a vendor
- The authors found one such vendor that had an SQL injection error
- Using the username of ' or '1'='1 and password of ') OR MD5('1')=MD5('1, we were able to login to FlyCASS as an administrator of Air Transport International!



https://ian.sh/tsa

A code injection attack (in Apache struts) cost Equifax $1.4 Billion

NEWS

Equifax Says Cybersecurity Breach Has Cost $1.4 Billion

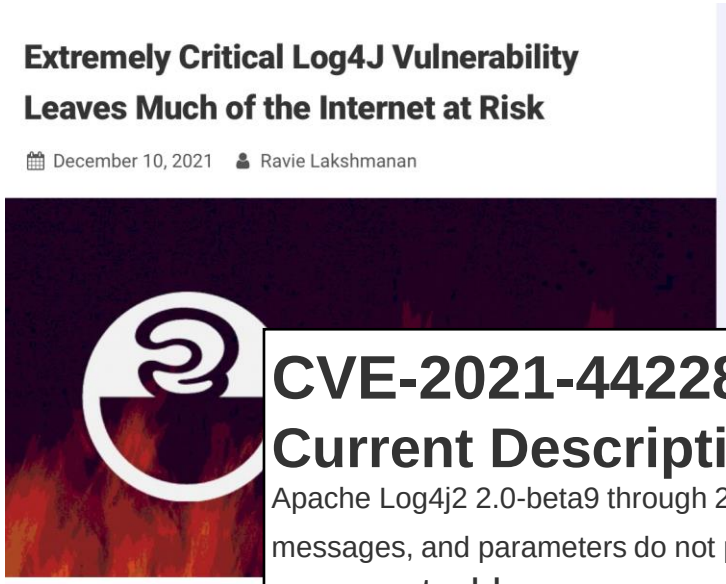
EMMA HURT • MAY 10, 2019

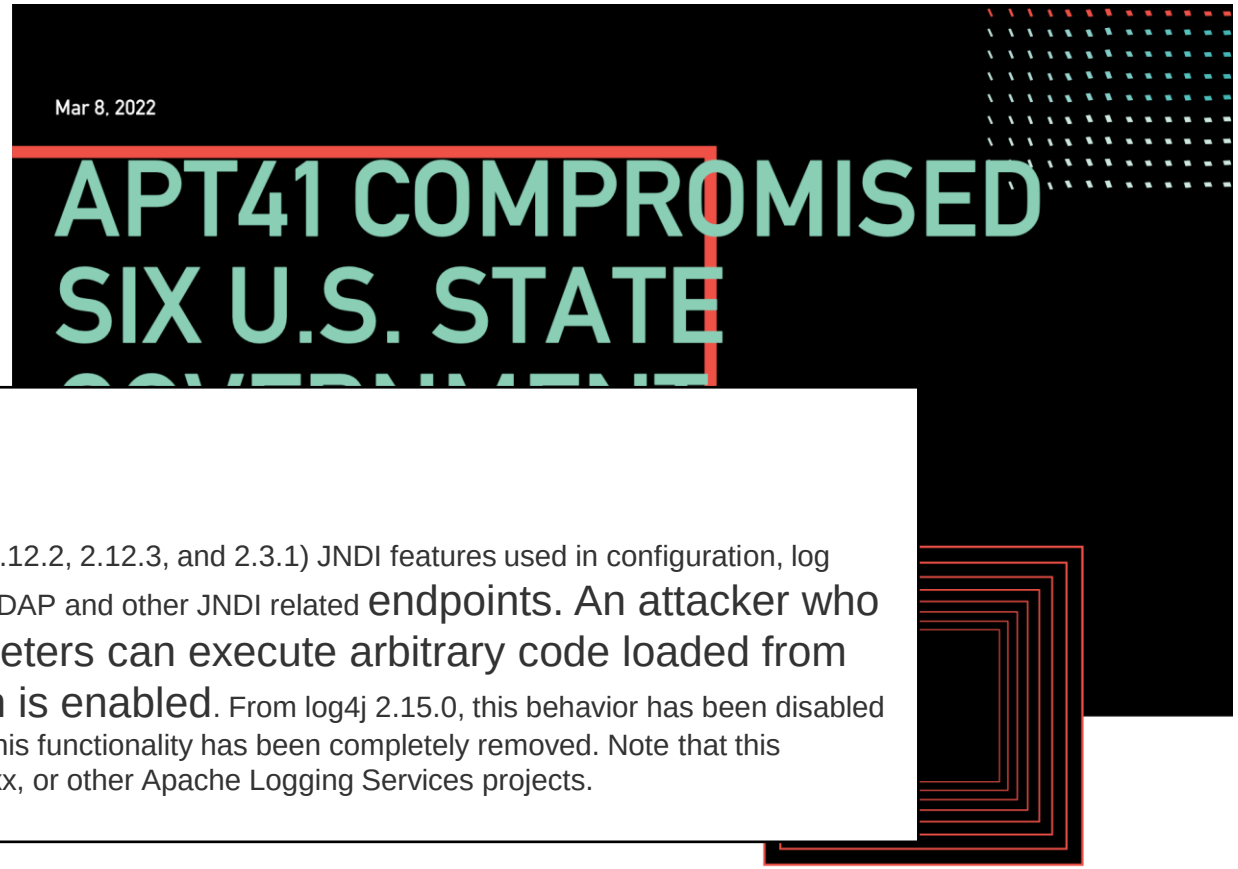
CVE-2017-5638 Detail

Current Description

The Jakarta Multipart parser in Apache Struts 2 2.3.x before 2.3.32 and 2.5.x before 2.5.10.1 has incorrect exception handling and error-message generation during file-upload attempts, which allows remote attackers to execute arbitrary commands via a crafted Content-Type, Content-Disposition, or Content-Length HTTP header, as exploited in the wild in March 2017 with a Content-Type header containing a #cmd= string.

The Log4J code injection vulnerability compromised many networks in 2021





CVE-2021-44228 Detail

Current Description

Apache Log4j2 2.0-beta9 through 2.15.0 (excluding security releases 2.12.2, 2.12.3, and 2.3.1) JNDI features used in configuration, log messages, and parameters do not protect against attacker controlled LDAP and other JNDI related endpoints. An attacker who can control log messages or log message parameters can execute arbitrary code loaded from LDAP servers when message lookup substitution is enabled. From log4j 2.15.0, this behavior has been disabled by default. From version 2.16.0 (along with 2.12.2, 2.12.3, and 2.3.1), this functionality has been completely removed. Note that this vulnerability is specific to log4j-core and does not affect log4net, log4cxx, or other Apache Logging Services projects.
https://nvd.nist.gov/vuln/detail/CVE-2021-44228

https://thehackernews.com/2021/12/extremely-critical-log4j-vulnerability.html

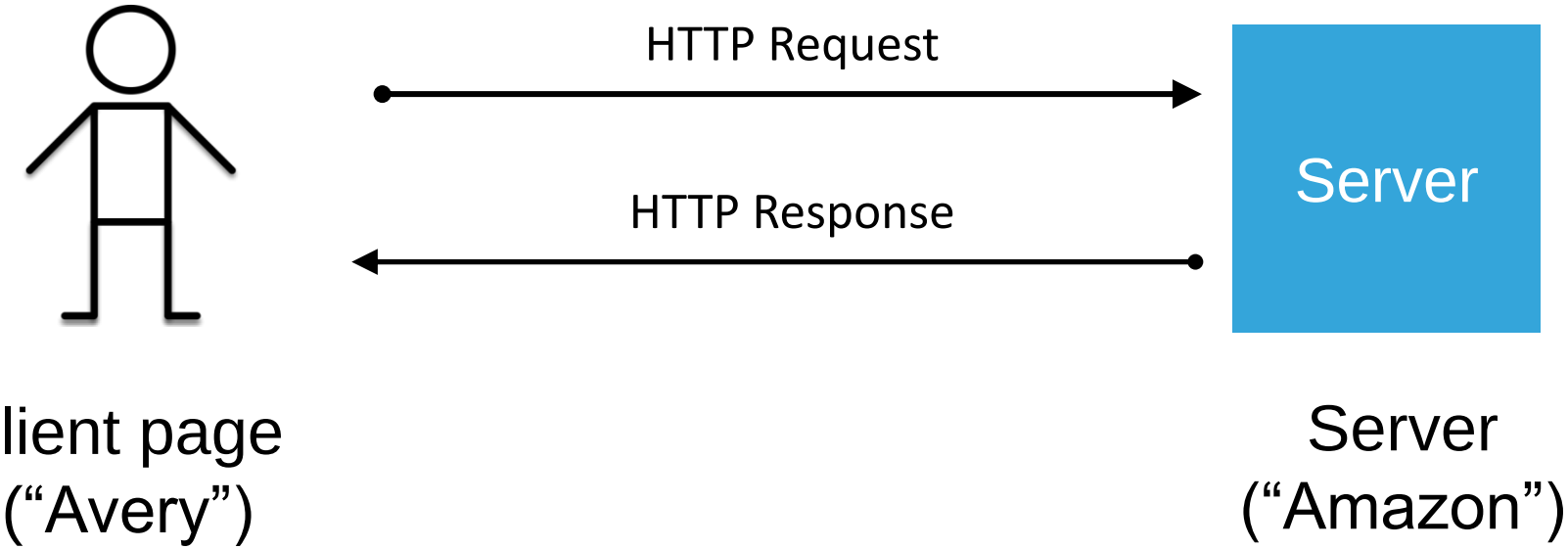
The APT41 group compromised at least six U.S. state government networks between May and February in a "deliberate campaign" that reflects new attack vectors and retooling by the prolific Chinese state-sponsored group.

https://duo.com/decipher/apt41-compromised-six-state-government-networks

SE-level mitigations for code injection attacks

- Use tools like TSOA to automatically generate safe code.
- Manually sanitize inputs to prevent them from being executable
- Avoid unsafe query languages (e.g. SQL, LDAP, language-specific languages like OGNL in java). Use “safe” subsets instead.
- Avoid use of languages (like C or C++) that allow code to construct arbitrary pointers or write beyond a valid array index
- eval() in JS – executes a string as JS code

Vulnerability 3: Bad Authentication



- How does Amazon know that this request is coming from Avery?
- How does Alice know that this request is coming from Amazon?

How does Amazon, Inc. know that this request is coming from Avery?

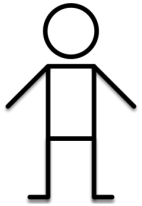
- Password
  - Establishes that the request is coming from someone who knows Avery's password
- 2-factor authentication is a way of linking Avery's password to the real Avery.
  - Something the real Avery has (physical key, bank card, device token)
  - Something the real Avery knows (name of first pet, etc.)
  - Something the real Avery is (biometrics, address history, etc.)

How does Avery know that this request is coming from Amazon, Inc.?

- Hmm, good question!
- The answer depends on public-key cryptography
  - also called "asymmetric cryptography"
- PKI can be used to answer these questions, and many, many more.

Public-Key Cryptography is based on using two keys: a private key and a public key

- Here's Avery.



- Avery has a private key:
  - Avery keeps it private;
  - nobody else knows it

Avery

- Avery also has a public key
  - Avery puts it where anybody who needs it can find it

Blair also has two keys

- Here's Blair.
- Blair has a private key:
  - Blair keeps it private;
  - nobody else knows it

Blair

- Blair also has a public key
  - Blair puts it where anybody who needs it can find it
  - How do I know that this public key really belongs to Blair and not somebody else?
    - we'll talk about that later….

"Key" properties

- A message encrypted with a with a public key can only be decrypted with the matching private key.
- A message encrypted with a private key can be decrypted by the matching public key.
- The owner of a private key keeps it secret and doesn't tell it to anyone,
- Decrypting with the wrong key will return gibberish or raise an error.

In a nutshell…

Encrypted with:	Who can encrypt?	Who can decrypt?
Private Key	Only the owner of the private key	Anyone
Public Key	Anyone	Only the owner of the corresponding private key

Achieving confidentiality

- Avery sends Blair a message, encrypted with Blair's public key.
- Only Blair owns the corresponding private key!

Only Blair has the key to decrypt the message!

Confidentiality achieved!

Assuring integrity

- Avery sends a message encrypted with Avery's own private key
- Anybody can use Avery's public key to read the message.
- Nobody else could have sent it
- And nobody else could have changed the message

But only Avery could have sent a message with that key!

Integrity achieved!

Can you get both confidentiality and integrity for a single message?

- example: can Avery send Blair a private message so that
  - only Blair can read it
  - Blair knows that it comes from Avery
  - Blair knows that the message is exactly as Avery sent it?

Answer: Yes, but it requires two key pairs instead of one.

PKI is hard to get right ☹

- "Cryptographic Failures" is #1 on the 2021 OWASP list of Top 10 Web Application Security Risks

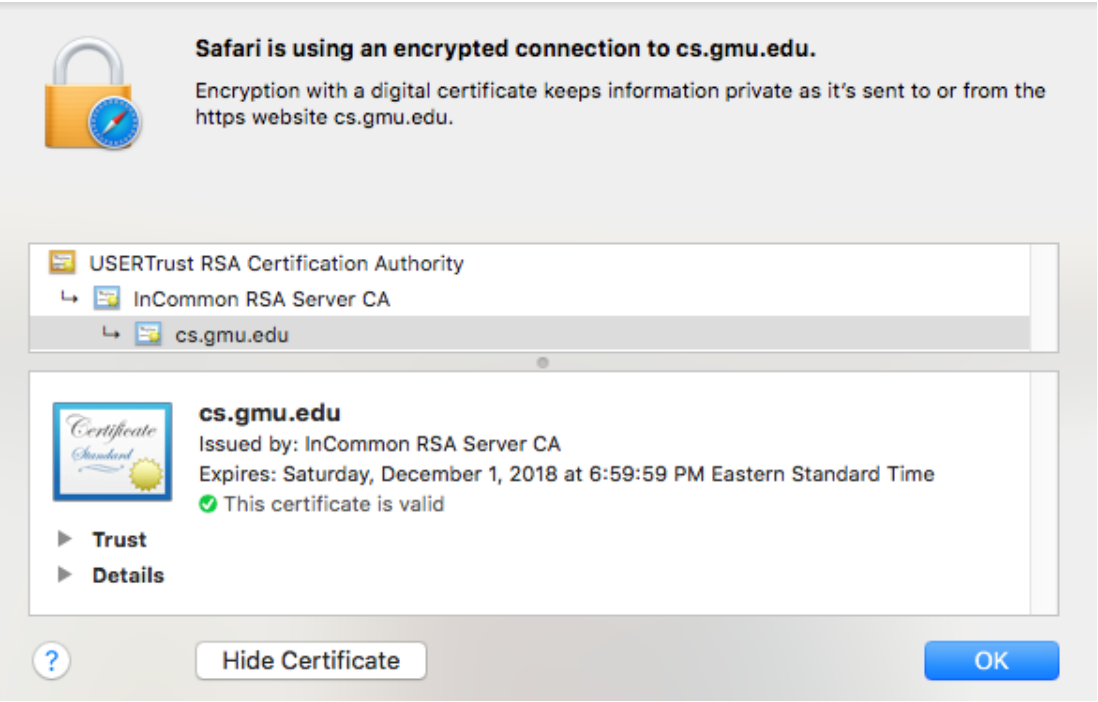
Back to the original question: How does Avery know that this request is coming from Amazon, Inc.?

- Avery can rely on a third party, called a "certificate authority" (CA).
- The CA can *endorse* that a public key is held by a certain real-world entity.
- The third party issues a *certificate* containing the Amazon's public key, encrypted with the CA's own private key.
- When our browser visits amazon.com, amazon.com sends its certificate to our browser.
- Avery decrypts the certificate, using the CA's public key. Avery now has the real public key of "Amazon Inc".

To acquire a certificate, Amazon, Inc. must have shared their public key and some real-world proof that they are amazon.com to the CA.

Why should we trust the CA?

- For this to work, we had to already know the CA's public key
- There are a small set of “root” CA’s (think: root DNS servers)
- Every computer/browser is shipped with these root CA public keys



You can do this for your website for free

- letsencrypt.com

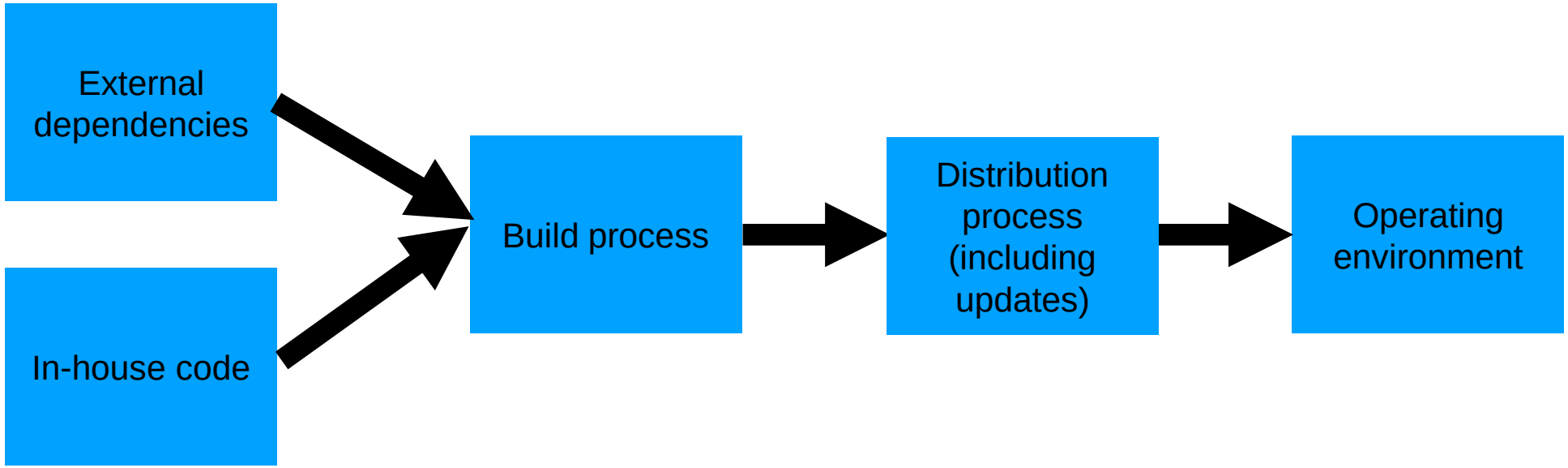
SE-level mitigations for access-control threats

- Implement multi-factor authentication
- Make sure passwords are not weak, have not been compromised.
- Apply per-record access control
  - Principle of least privilege
- Harden pathways for account creation, password reset.
- Use an SSO to handle login
  - They might do it better than you can.

Vulnerability 4: Supply-Chain Attacks

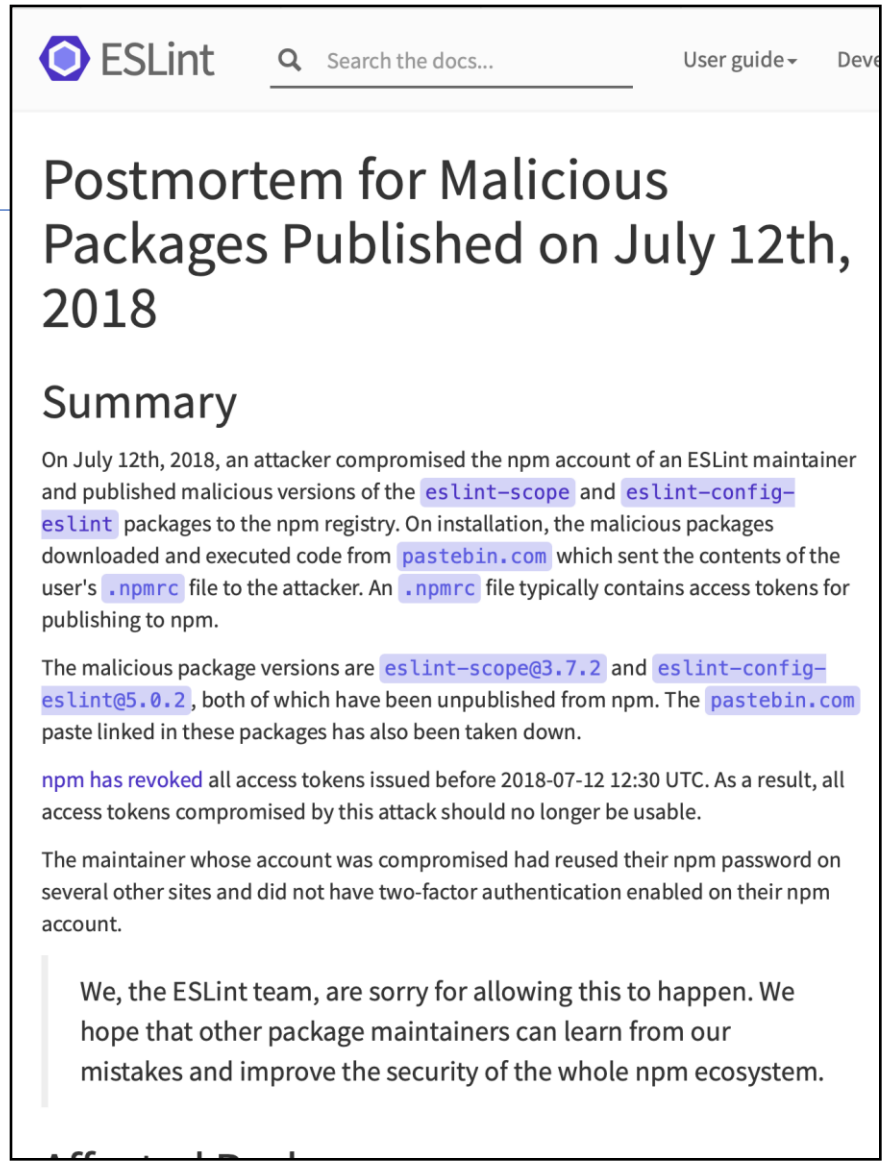
- Do we trust our own code?
- Third-party code provides an attack vector

The software supply chain has many points of weakness



Example: the eslint-scope attack (2018)

- On 7/12/2018, a malicious version of eslint-scope was published to npm.
- eslint-scope is a core element of eslint, so many many users were affected.
- Let’s analyze this…



ESLint Search the docs... User guide Deve

Postmortem for Malicious Packages Published on July 12th, 2018

Summary

On July 12th, 2018, an attacker compromised the npm account of an ESLint maintainer and published malicious versions of the `eslint-scope` and `eslint-config-eslint` packages to the npm registry. On installation, the malicious packages downloaded and executed code from `pastebin.com` which sent the contents of the user's `.npmrc` file to the attacker. An `.npmrc` file typically contains access tokens for publishing to npm.

The malicious package versions are `eslint-scope@3.7.2` and `eslint-config-eslint@5.0.2`, both of which have been unpublished from npm. The `pastebin.com` paste linked in these packages has also been taken down.

npm has revoked all access tokens issued before 2018-07-12 12:30 UTC. As a result, all access tokens compromised by this attack should no longer be usable.

The maintainer whose account was compromised had reused their npm password on several other sites and did not have two-factor authentication enabled on their npm account.

> We, the ESLint team, are sorry for allowing this to happen. We hope that other package maintainers can learn from our mistakes and improve the security of the whole npm ecosystem.

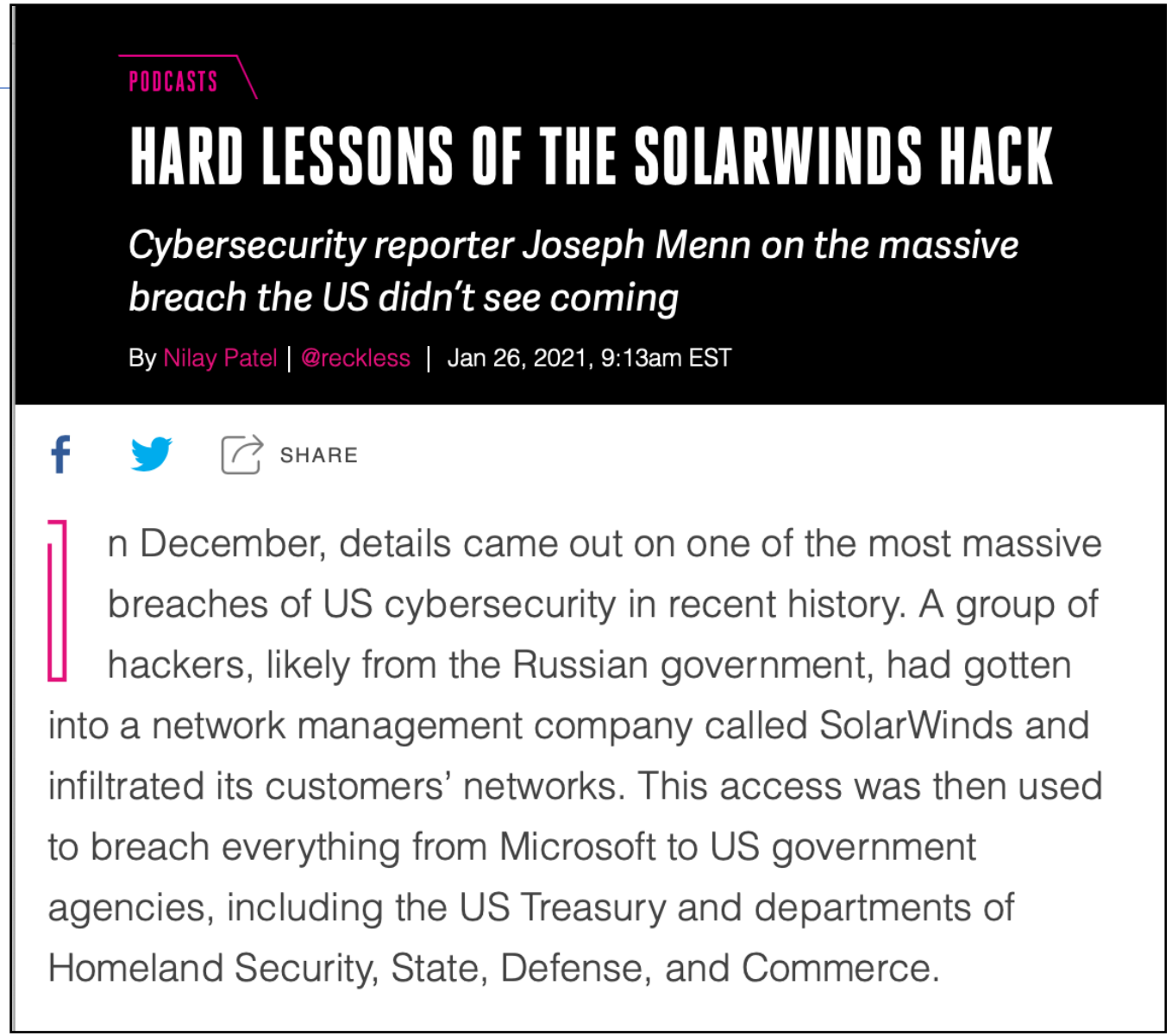
https://eslint.org/blog/2018/07/postmortem-for-malicious-package-publishes/

This incident leveraged several small security failures

- An eslint-scope developer used their same password on another site.
- The other site did not use 2FA
- Password was leaked from the other site.
- Attacker created malicious version of eslint-scope
- Many users did not use package-lock.json, so their packages automatically installed the new (evil) version.
- The malicious version sent copies of the user's .npmrc to the attacker. This file typically contains user tokens.
- Estimated 4500 tokens were leaked and needed to be revoked.

Example: the SolarWinds attack (2020)

- Many networks compromised
- Not discovered for months



PODCASTS

HARD LESSONS OF THE SOLARWINDS HACK

Cybersecurity reporter Joseph Menn on the massive breach the US didn't see coming

By Nilay Patel | @reckless | Jan 26, 2021, 9:13am EST

SHARE

In December, details came out on one of the most massive breaches of US cybersecurity in recent history. A group of hackers, likely from the Russian government, had gotten into a network management company called SolarWinds and infiltrated its customers' networks. This access was then used to breach everything from Microsoft to US government agencies, including the US Treasury and departments of Homeland Security, State, Defense, and Commerce.

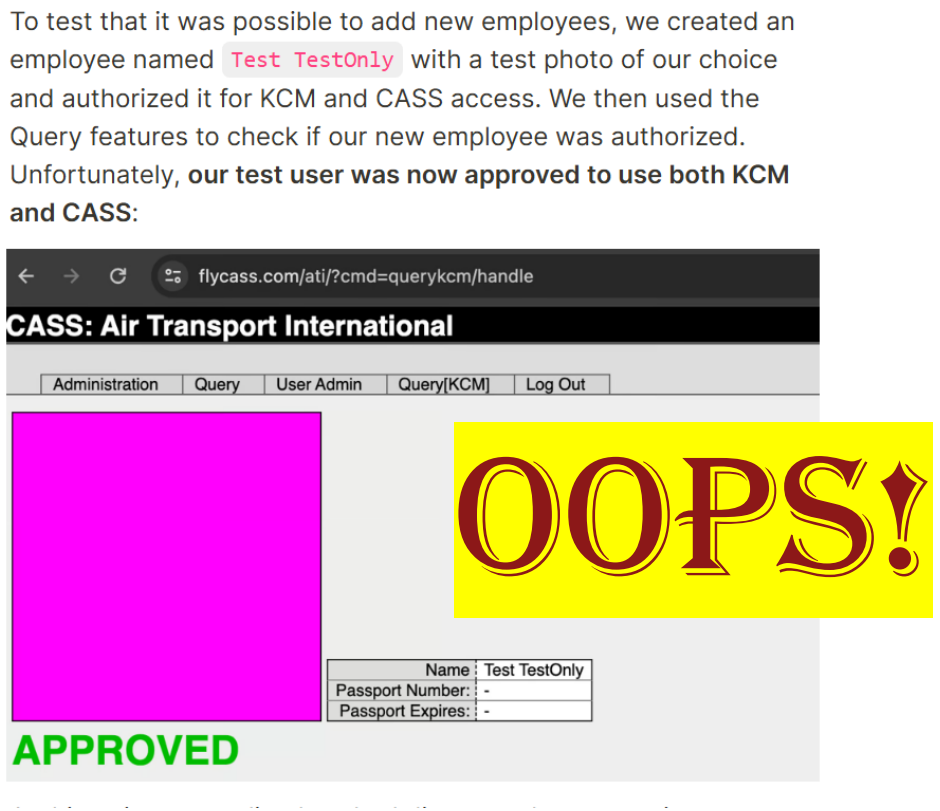
A 2021 NCSU/Microsoft found that many of the top 1% of npm packages had vulnerabilities

- Package inactive or deprecated, yet still in use
- No active maintainers
- At least one maintainer with an inactive (purchasable) email domain
- Too many maintainers or contributors to make effective maintenance or code control
- Maintainers are maintaining too many packages
- Many statistics/combinations: see the paper for details.

"What are Weak Links in the npm Supply Chain?" By: Nusrat Zahan, Thomas Zimmermann, Patrice Godefroid, Brendan Murphy, Chandra Maddila, Laurie Williams https://arxiv.org/abs/2112.10165

Your suppliers' risks are your risks

- "Known Crewmembers" can get to the cockpit without inspection.
- Large airlines: Each airline runs its own authorization system, but small airlines rely on a vendor
- The authors found one such vendor that had an SQL injection error
- Using the username of ' or '1'='1 and password of ') OR MD5('1')=MD5('1, we were able to login to FlyCASS as an administrator of Air Transport International!



https://ian.sh/tsa

Supply-chain risks include more than just software.

intertek
Total Quality. Assured.

Industries

Home / Industries & Services / Auditing / Business Assurance / Supply Chain Security

Supply Chain Security

In today's global marketplace, it is more important than ever to have a transparent view into your supply chain, no matter how remote suppliers may be from where you actually conduct your business. As a result, suppliers and manufacturers need solutions in place to demonstrate compliance in a number of areas dictated by today's business climate.

In order to demonstrate enforcement of and compliance to international supply chain security

Supply Chain Assessments - Using a series of risk-based assessment tools and audit solutions to evaluate and benchmark suppliers, supply chain assessments help global companies manage and track the performance in their supply chains. The assessments measure business risk, capacity and capabilities, workplace conditions, product quality and safety, security and environmental sustainability.

SE-level Threat Mitigations

- External dependencies
  - Audit all dependencies and their updates before applying them
- In-house code
  - Require developers to sign code before committing, require 2FA for signing keys, rotate signing keys regularly
- Build process
  - Audit build software, use trusted compilers and build chains
- Distribution process
  - Sign all packages, protect signing keys
- Operating environment
  - Isolate applications in containers or VMs

Vulnerability #5: Failure to Apply Security Policies

Remember the outline of our lecture:

1. Definition of key vocabulary
2. Some common vulnerabilities, and possible mitigations
3. Getting security right is about people as well as software.

Other mitigations for access-control threats

- Implement multi-factor authentication
- Make sure passwords are not weak, have not been compromised.
- Apply per-record access control
  - Principle of least privilege
- Harden account creation, password reset pathways
- Use an expert vendor, like Auth0, to handle login
  - They can do it better than you can.

But how do you get your developers to do all this?

David Blank-Edelman (former head of Systems at Khoury)

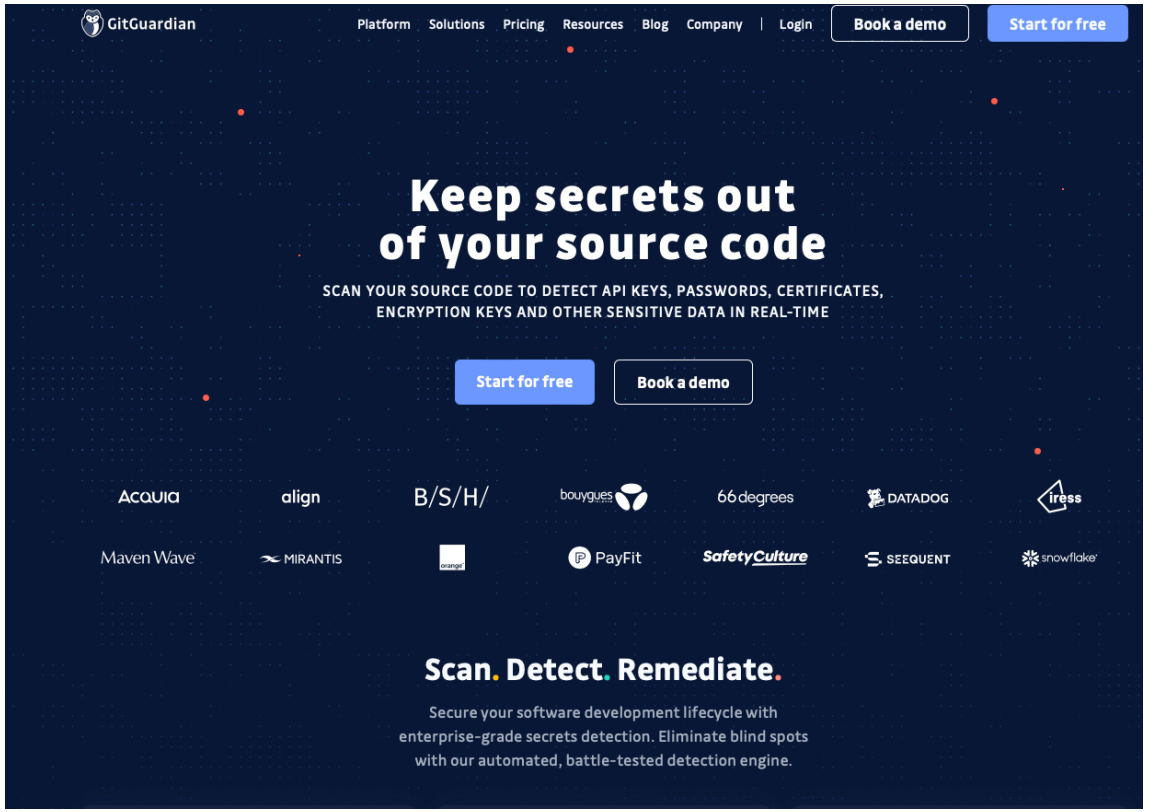
"The solution is in front of the screen, not behind it"

A security architecture must include a security culture

- Security architecture is a set of mechanisms and policies that we build into our system to mitigate risks from threats
- Vulnerability: a characteristic or flaw in system design or implementation, or in the security procedures, that, if exploited, could result in a security compromise
- Threat: potential event that could compromise a security requirement
- Attack: realization of a threat

Example mechanism: secret detection

- Recall: SSL only talks about public/private keys.
- Applications may have many other *secret* values (e.g. access tokens for other services)
- Tools like *GitGuardian* automatically detect secrets in repositories



Mechanisms aren't enough: Do developers keep secret keys secret?

- Industrial study of secret detection tool in a large software services company with over 1,000 developers, operating for over 10 years
- What do developers do when they get warnings of secrets in repository?
  - 49% remove the secrets; 51% bypass the warning
- Why do developers bypass warnings?
  - 44% report false positives, 6% are already exposed secrets, remaining are "development-related" reasons, e.g. "not a production credential" or "no significant security value"

Is it a management problem or a tool problem?

"Why secret detection tools are not enough: It's not just about false positives - An industrial case study"
Md Rayhanur Rahman, Nasif Imtiaz, Margaret-Anne Storey & Laurie Williams https://link.springer.com/article/10.1007/s10664-021-10109-y

Elements of a security culture

- Make security a regular part of the process.
  - Include security tools as part of the build/release process
  - Tools may have false positives and false negatives
  - Educate developers about when how to recognize positives that look false, but aren’t
  - Include security review as regular part of code review

Learning Objectives for this Module

- You should now be able to:
  - Define key terms relating to software/system security
  - Describe some of the tradeoffs between security and other requirements in software engineering
  - Explain 5 common vulnerabilities in web applications and similar software systems, and describe some common mitigations for each of them.
  - Explain why software alone isn’t enough to assure security