CS 4530: Fundamentals of Software Engineering

Module 15: Software Engineering & Security

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Learning Objectives for this Lesson

By the end of this lesson, 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

Security: Basic Vocabulary 1 (“CIA”)

Security as a set of non-functional requirements

- 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

- 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
- Vulnerability: a characteristic or flaw in system design or implementation, or in the security procedures, that, if exploited, could result in a security compromise
- Attack: realization of a threat

Security isn't (always) free

In software, as in the real world…

- You just moved to a new house, someone just moved out of it. What do you do to protect your belongings/property?
- Do you change the locks?
- Do you buy security cameras?
- Do you hire a security guard?
- Do you even bother locking the door?

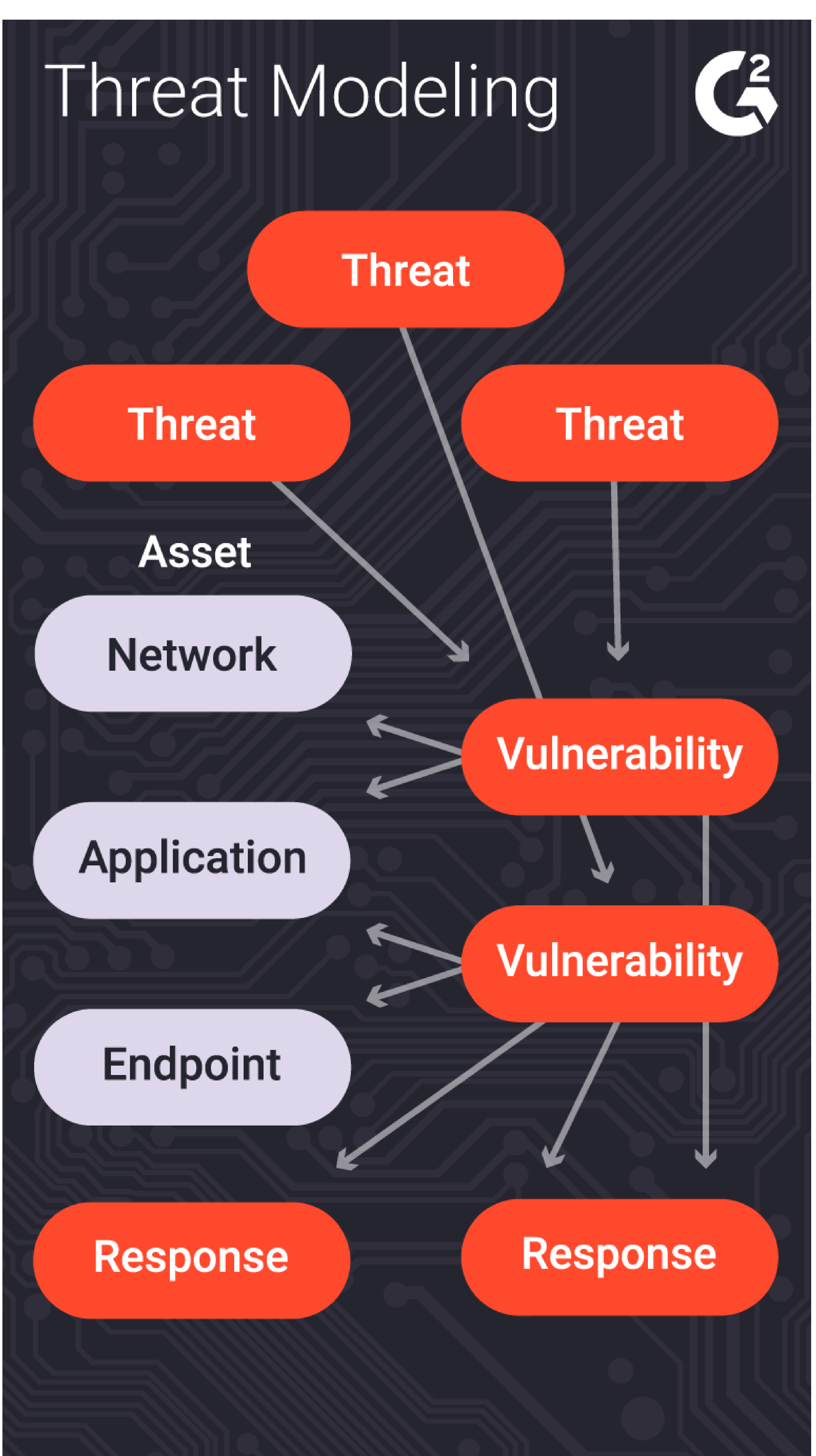
Security is about managing risk

Cost of attack vs cost of defense?

- 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
- So: How likely do we think we are to be attacked in way **X**?

Threat Models help analyze these tradeoffs

- What is being defended?
  - What resources are important to defend?
  - What malicious actors exist and what attacks might they employ?
  - What value can an attacker extract from a vulnerability?
- Who do we trust?
  - What entities or parts of system can be considered secure and trusted
- Plan responses to possible attacks
  - Prioritize?



A Baseline Security Architecture (1)

Best practices applicable in most situations

- 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 (different employees should have access to different resources)

A Baseline Security Architecture (2)

Best practices applicable in most situations

- Practice good security practices:
  - Encryption (all data in transit, sensitive data at rest)
  - Code signing, multi-factor authentication
  - Encapsulated zones/layers of security (different people have access to different resources)
  - Log everything! (employee data accesses/modifications) (maybe)
- Bring in security experts early for riskier situations

OWASP Top Security Risks

All 10: https://owasp.org/www-project-top-ten/

- Broken authentication + access control
- Cryptographic failures
- Code injection (various forms - SQL/command line/XSS/XML/deserialization)
- Weakly protected sensitive data
- Using components with known vulnerabilities

Threats discussed in this lesson:

- Threat 1: Code that runs in an untrusted environment
- Threat 2: Inputs that are controlled by an untrusted user
- Threat 3: Bad authentication (of both sender and receiver!)
- Threat 4: Untrusted Inputs
- Threat 5: Software supply chain delivers malicious software
- Recurring theme: No silver bullet

Threat 1: Code that runs in an untrusted environment

Authentication code in a web application

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

Should this go in our frontend code?

Threat 1: Code that runs in an untrusted environment

Authentication code in a web application

Frontend

Users might be malicious

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

Trust boundary

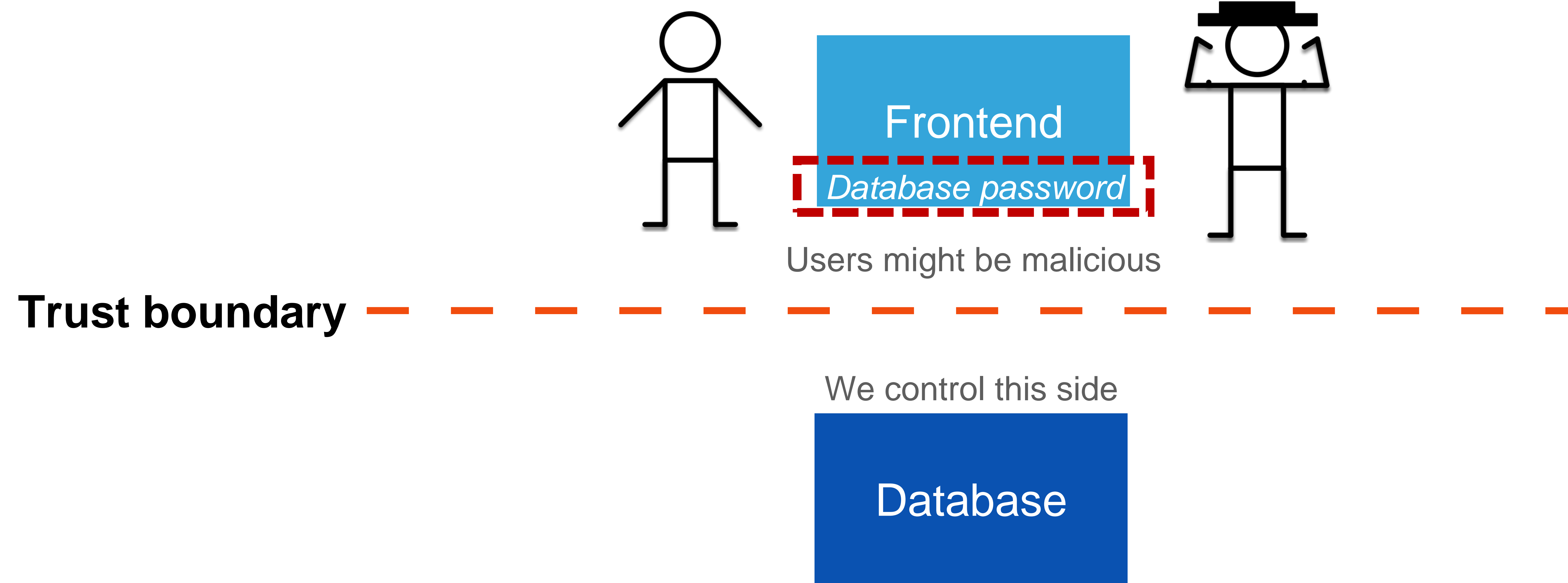
We control this side

Backend

Fix: Move code to back end (duh!)

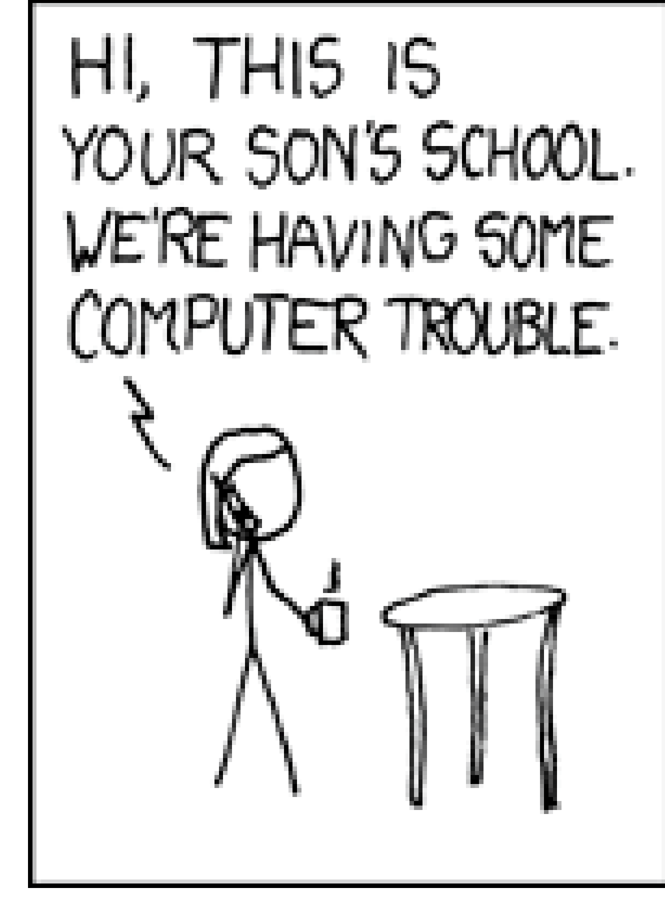
Threat Category 1: Code that runs in an untrusted environment

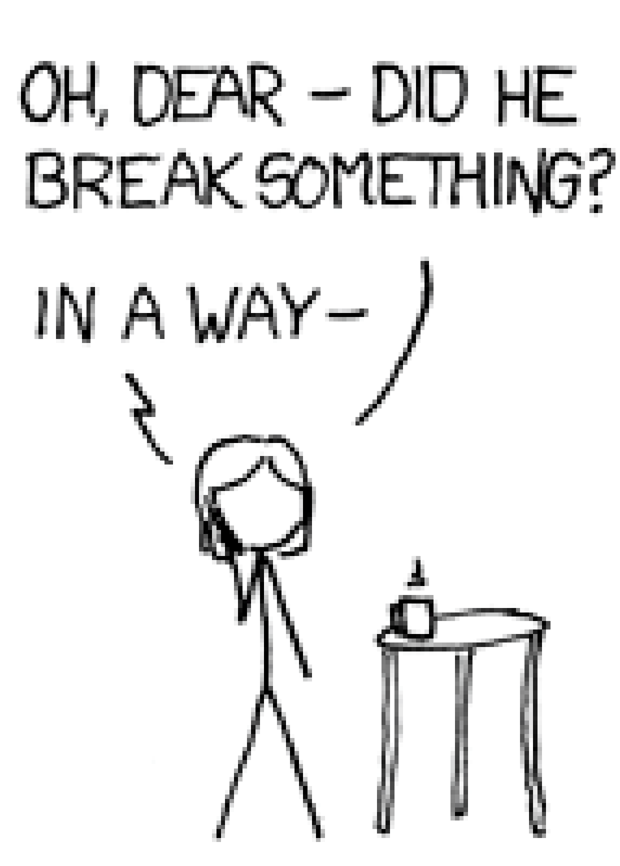
Access controls to database

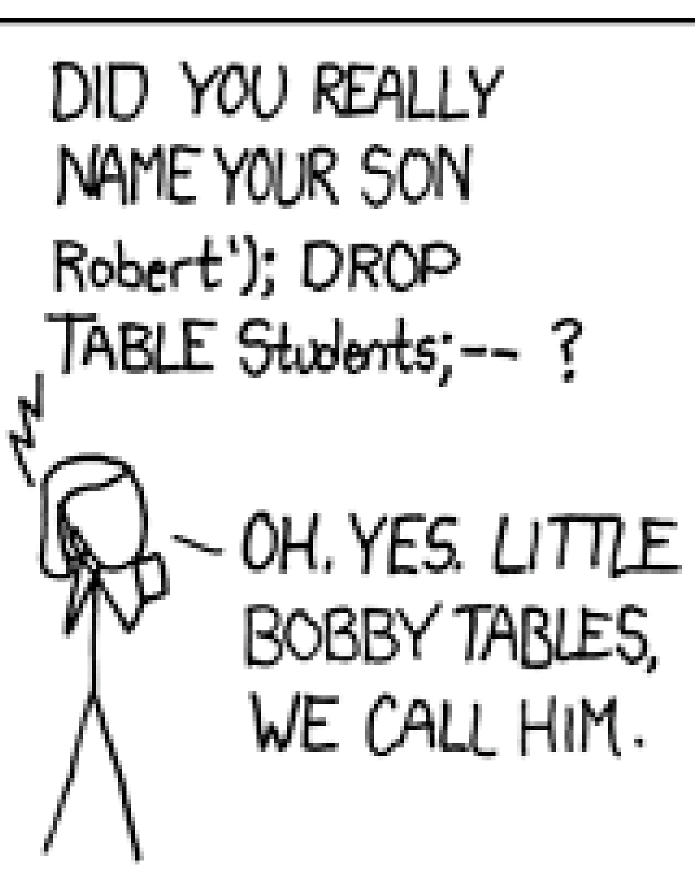


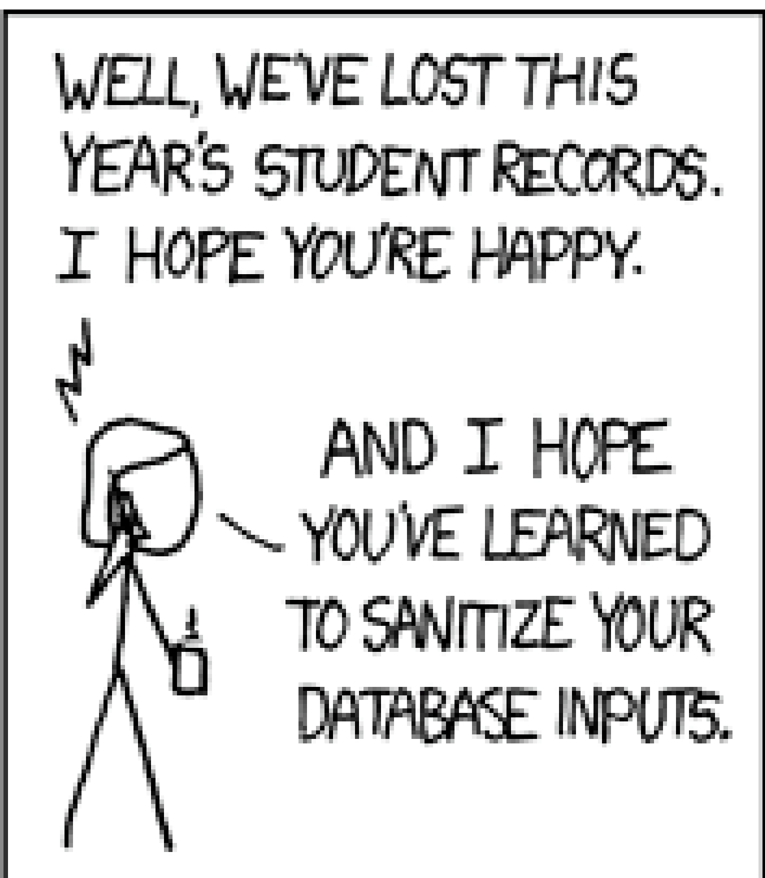
Fix: Don't distribute sensitive credentials

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





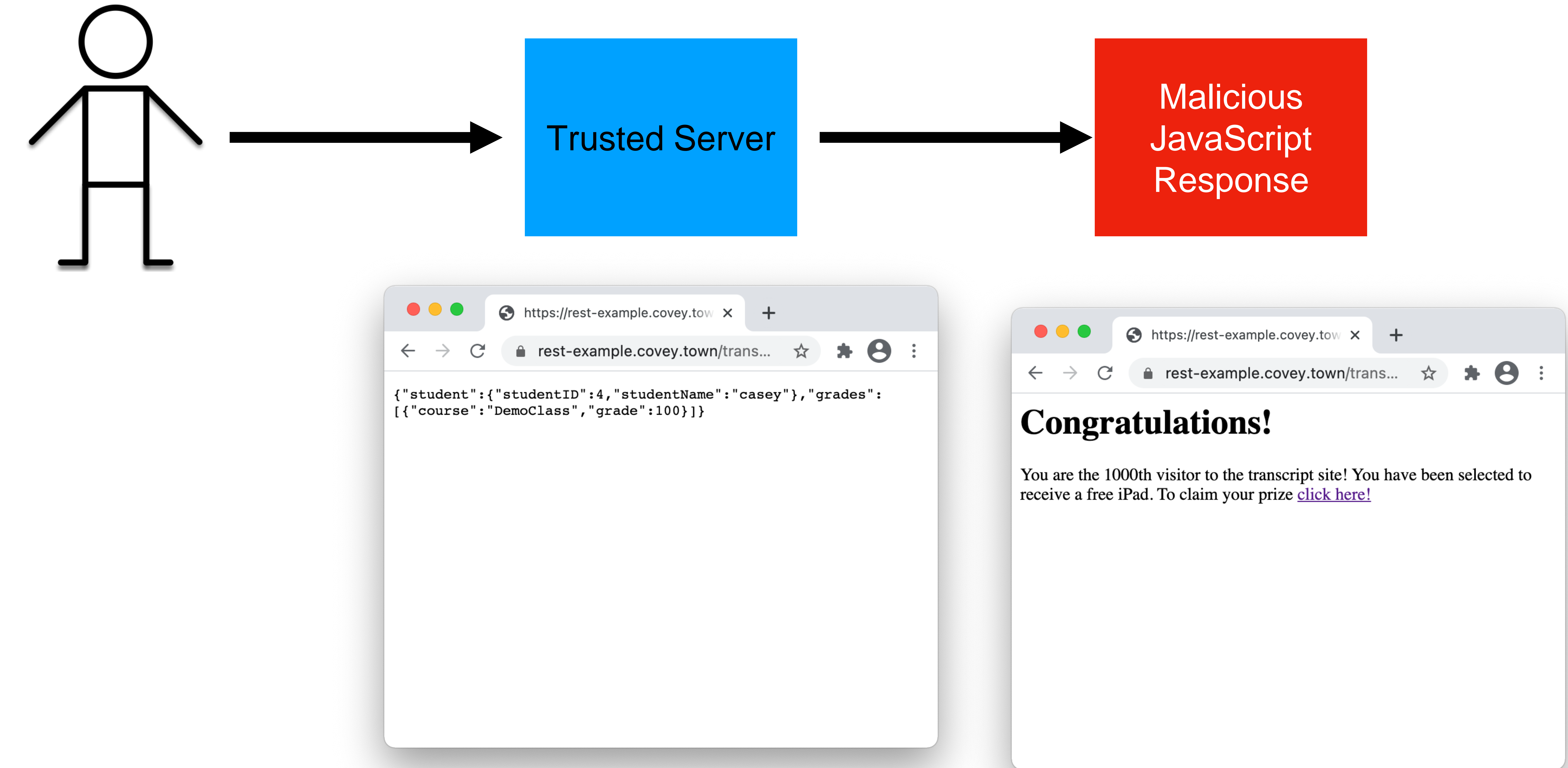




https://xkcd.com/327/

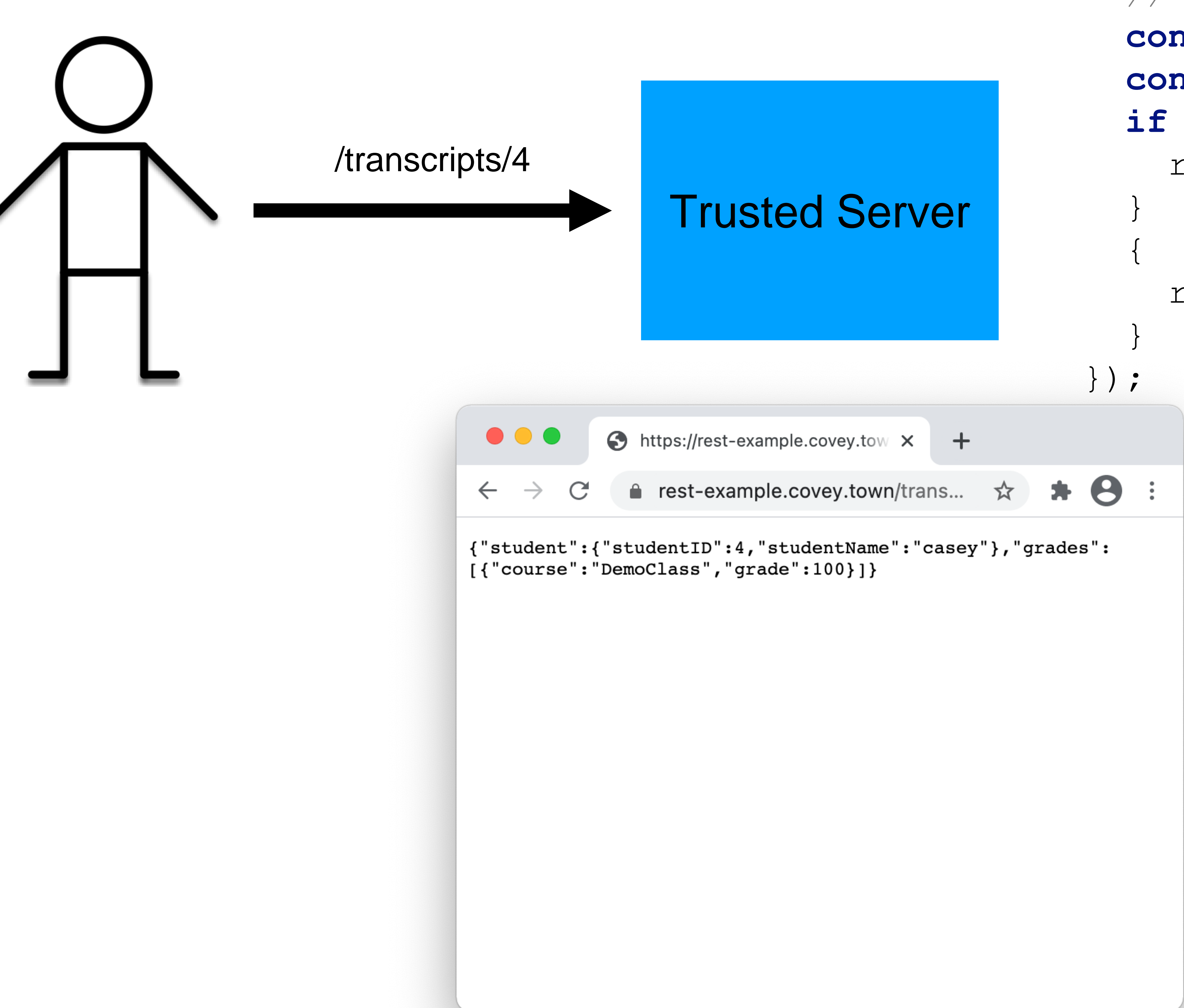
Threat 2: Data controlled by a user flowing into our trusted codebase

Cross-site scripting (XSS) vulnerability



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

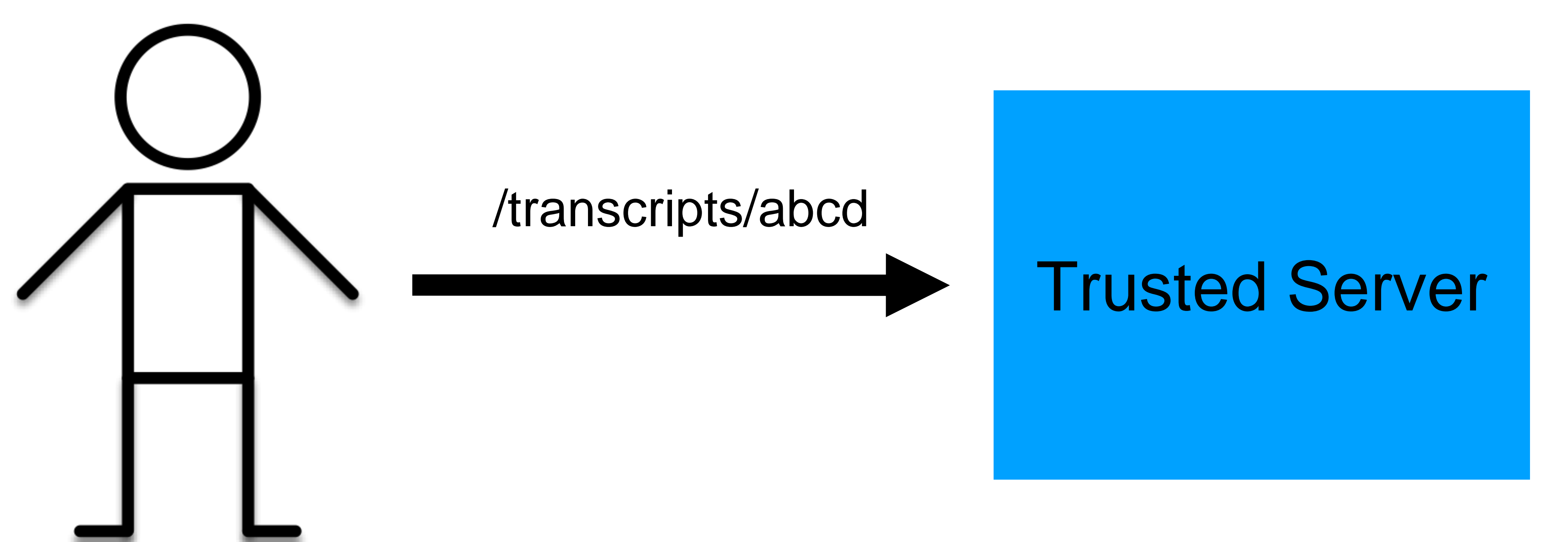
Cross-site scripting (XSS) vulnerability




```
app.get('/transcripts/:id', (req, res) => {
  // req.params to get components of the path
  const {id} = req.params;
  const theTranscript = db.getTranscript(parseInt(id));
  if (theTranscript === undefined) {
    res.status(404).send(`No student with id = ${id}`);
  }
  {
    res.status(200).send(theTranscript);
  }
});
```

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

Cross-site scripting (XSS) vulnerability

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});
```

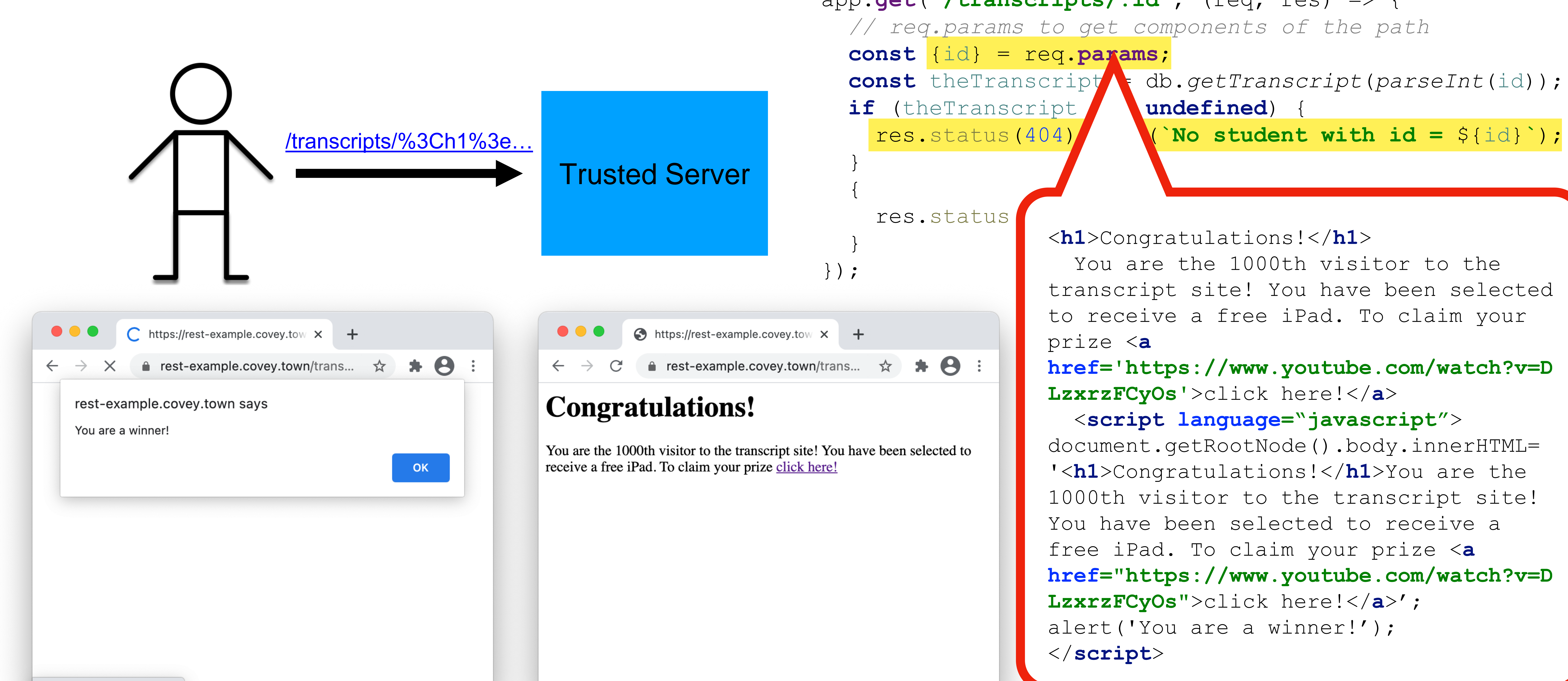
https://rest-example.covey.tow

rest-example.covey.town/trans...

No student with id = abcd

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

Cross-site scripting (XSS) vulnerability



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

Java code injection vulnerability in Apache Struts (@Equifax)

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.

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

Java code injection vulnerability in Log4J

Extremely Critical Log4J Vulnerability Leaves Much of the Internet at Risk

December 10, 2021 Ravie Lakshmanan

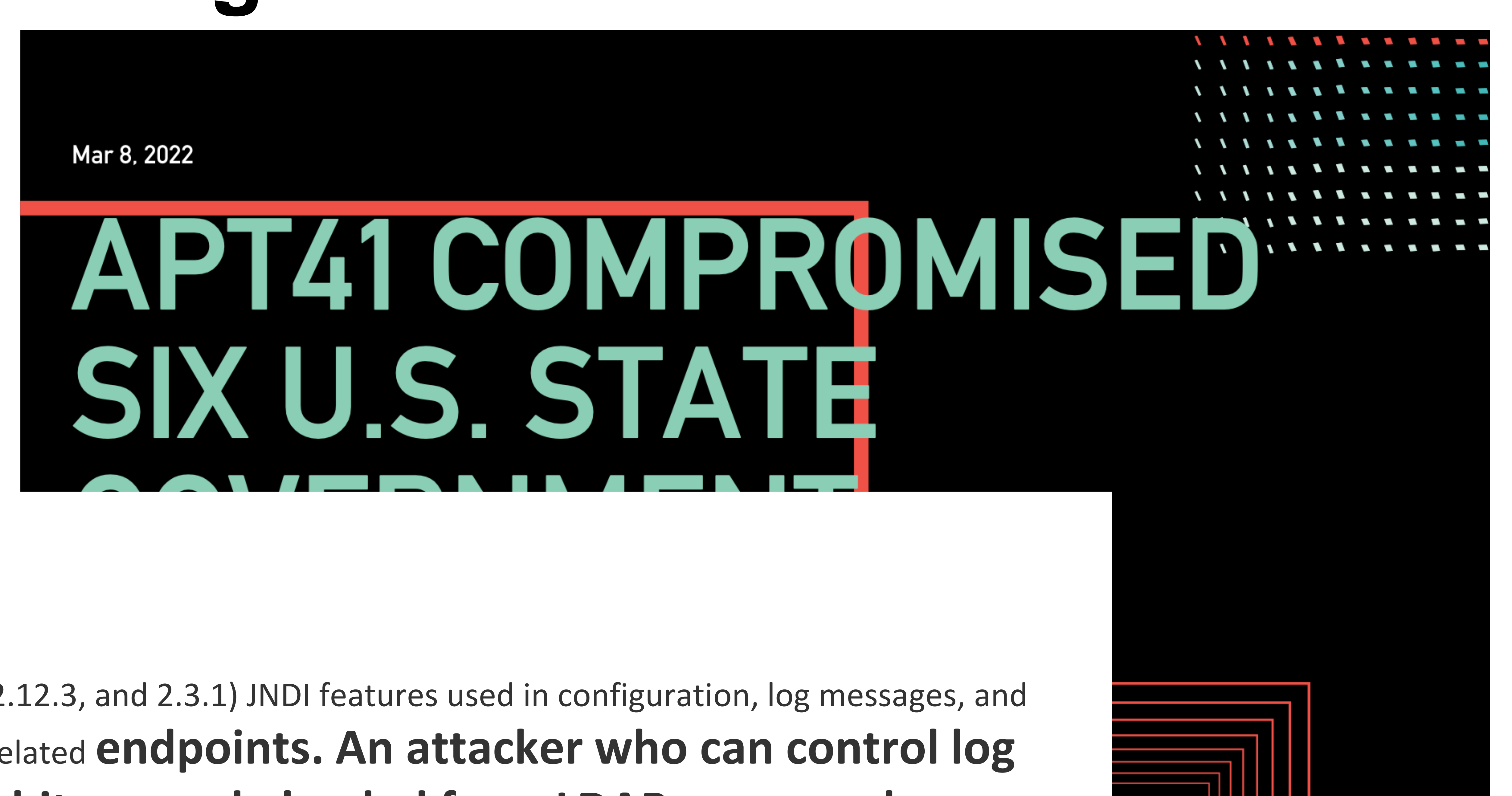
The Apache Software Fou
actively exploited zero-da
Apache Log4j Java-basec
execute malicious code a
systems.

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

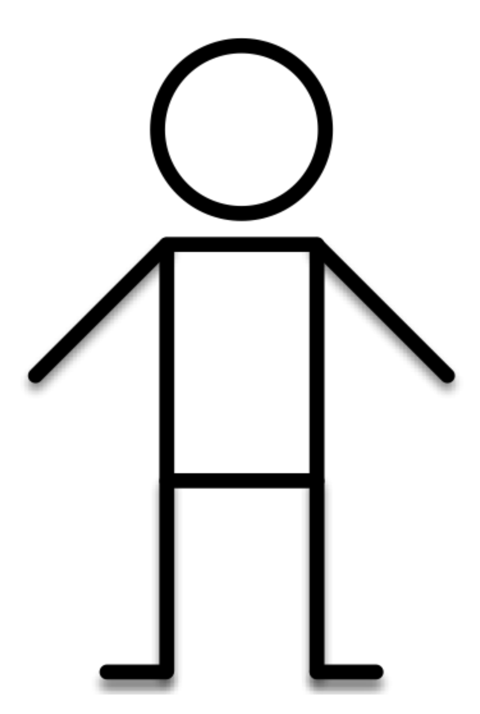


The APT41 group compromised at least six U.S. state government networks between May and February in a "deliberate campaign" that reflects new attack vectors and retooling by the prolific Chinese state-sponsored group.

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

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

Threat 3: Bad authentication



HTTP Request

HTTP Response

client page
(the "user")

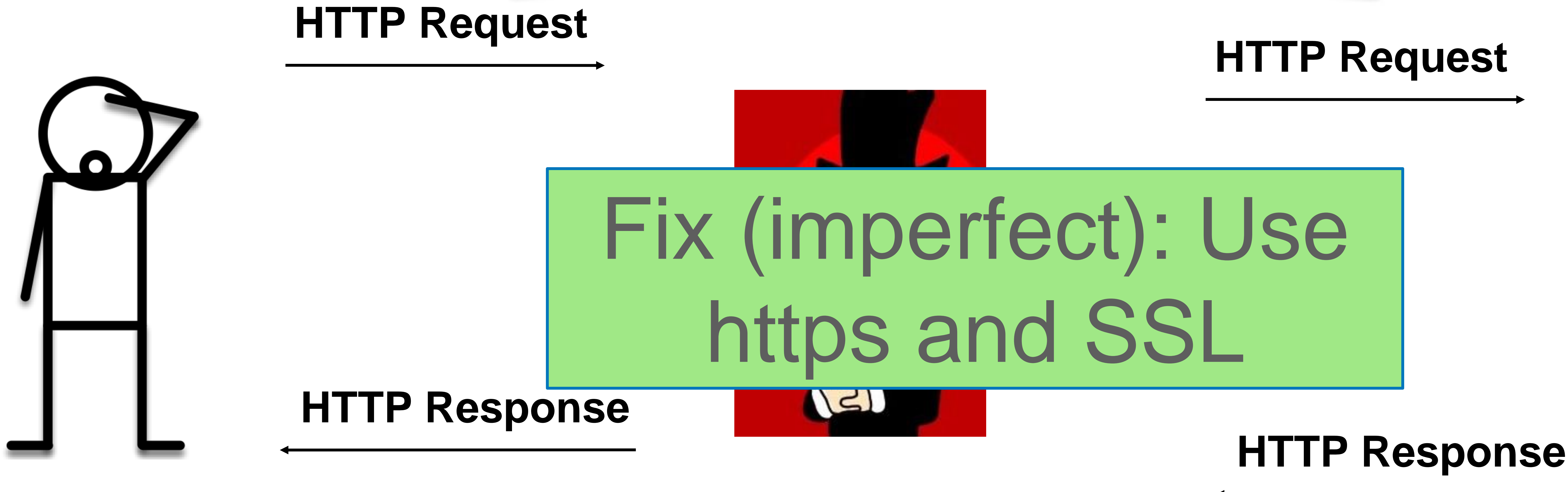
server

Do I trust that this response *really* came from the server?

Do I trust that this request *really* came from the user?

Threat 3: Bad au

Might be “man in the middle” that intercepts requests and impersonates user or server.



client page
(the “user”)

malicious actor
“black hat”

server

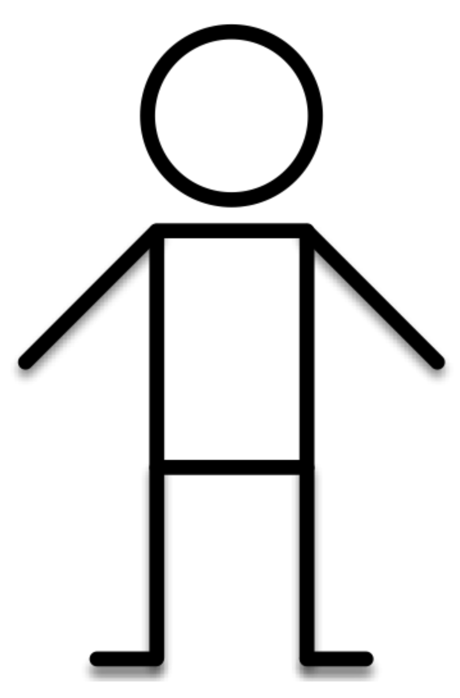
Do I trust that this response *really* came from the server?

Do I trust that this request *really* came from the user?

Threat 3: Bad authentication

Preventing the man-in-the-middle with SSL

HTTP Request



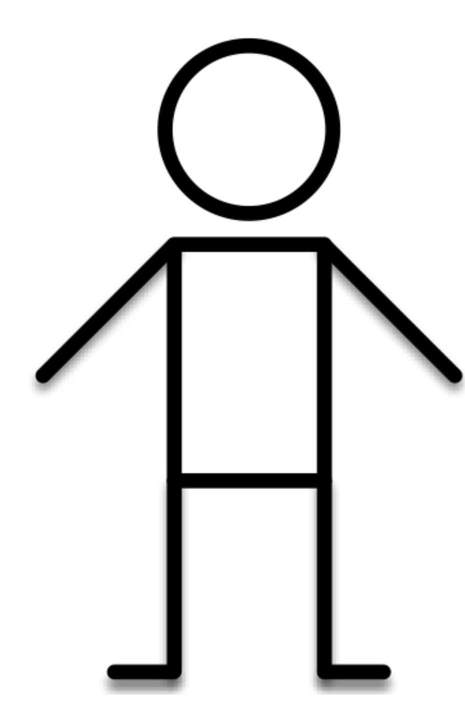
HTTP Response

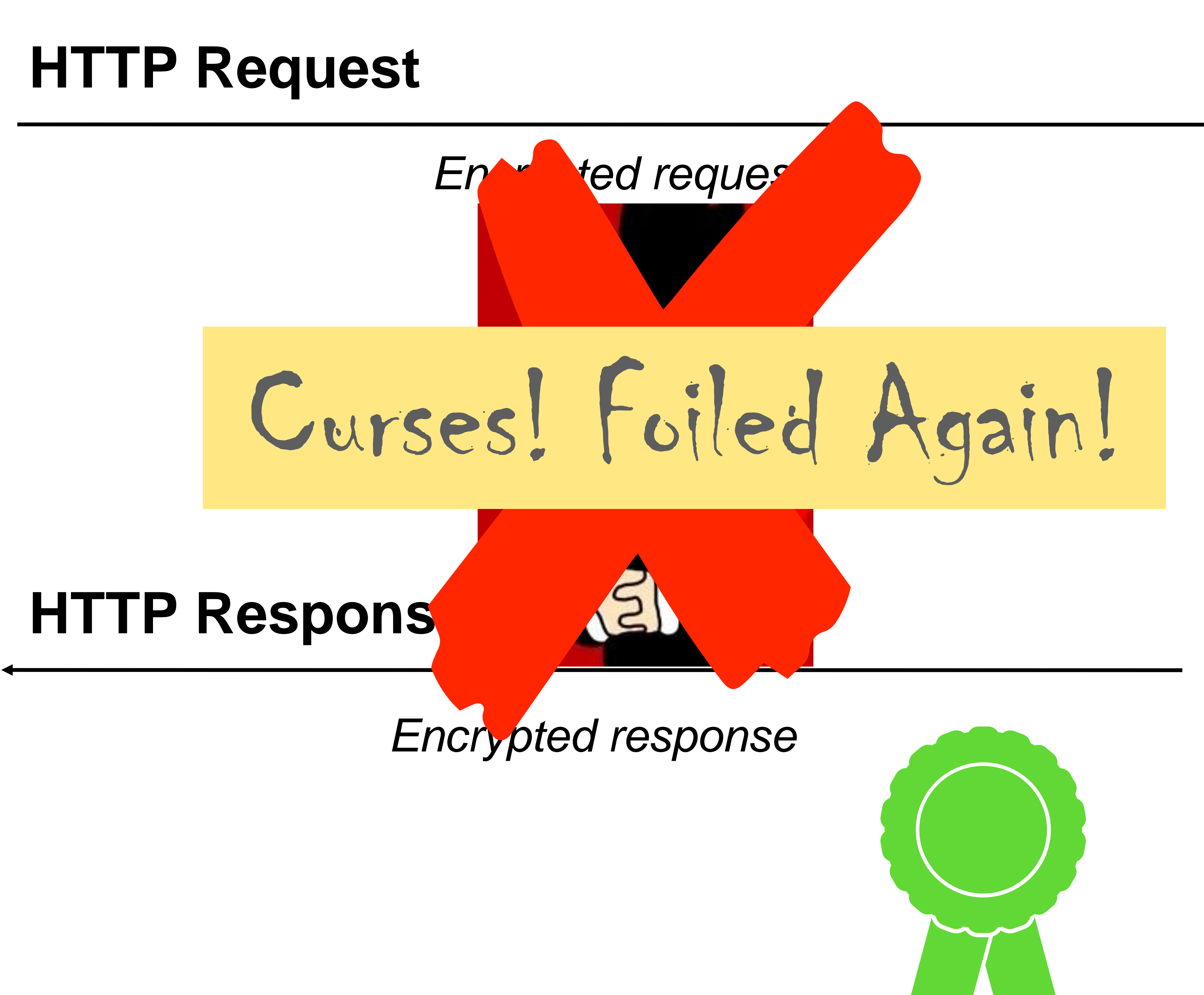
client page
(the "user")

amazon.com certificate
(AZ's public key + CA's sig)

server

Preventing the man-in-the-middle with SSL





Your connection is not private

Attackers might be trying to steal your information from **192.168.18.4** (for example, passwords, messages, or credit cards). Learn more

NET::ERR_CERT_AUTHORITY_INVALID

amazon.com certificate
(AZ's public key + CA's sig)

SSL: A perfect solution?

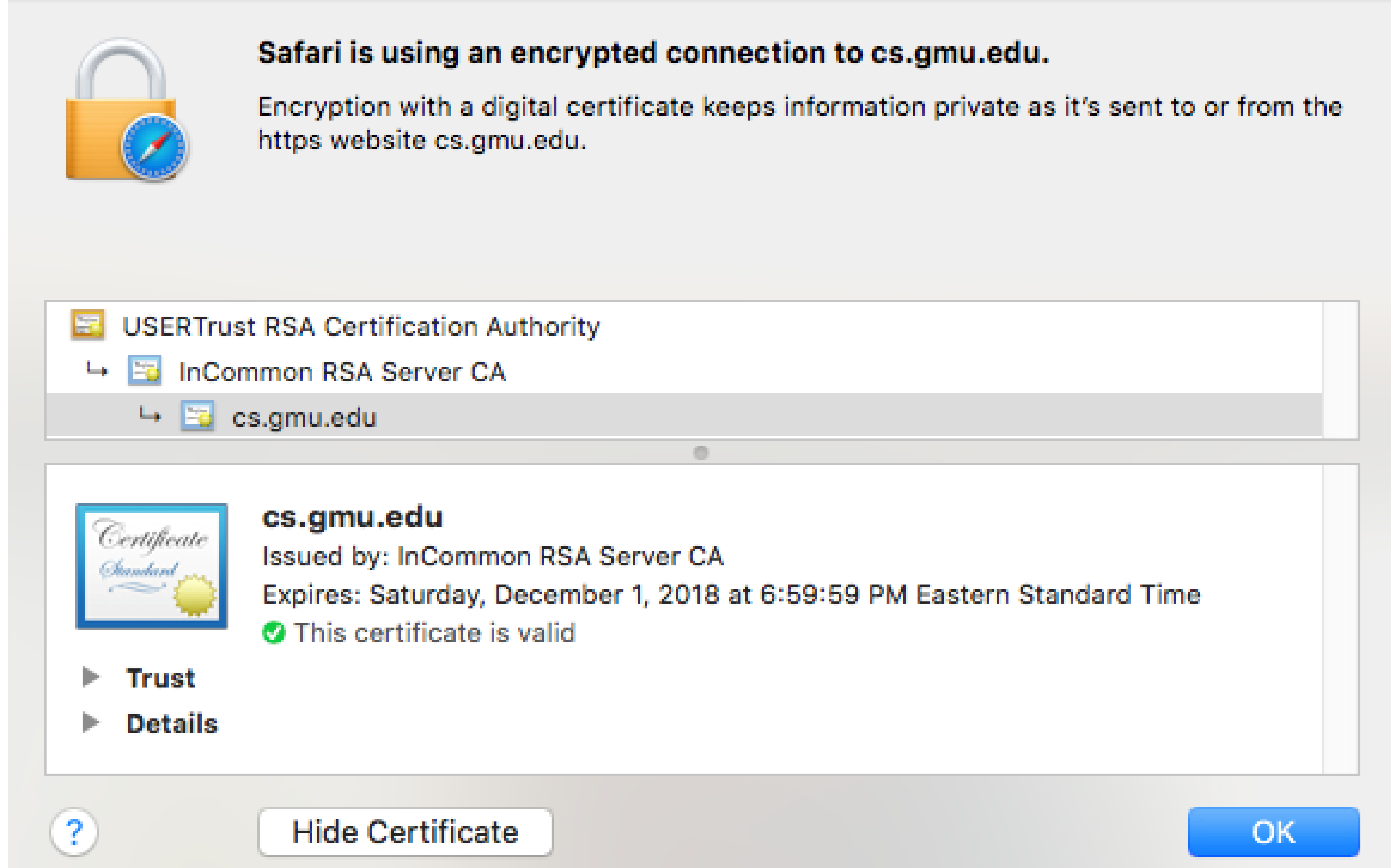
Certificate authorities

- A certificate authority (or CA) binds some public key to a real-world entity that we might be familiar with
- The CA is the clearinghouse that verifies that amazon.com is truly amazon.com
- CA creates a certificate that binds amazon.com's public key to the CA’s public key (signing it using the CA’s private key)

Certificate Authorities issue SSL Certificates

Certificate Authorities are Implicitly Trusted

- Note: 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



Should Certificate Authorities be Implicitly Trusted?

Signatures only endorse trust if you trust the signer!

- What happens if a CA is compromised, and issues invalid certificates?
- Not good times.

Security

Comodo-gate hacker brags about forged certificate exploit

Tiger-blooded Persian cracker boasts of mighty exploits

Security

Fuming Google tears Symantec a new one over rogue SSL certs

We've got just the thing for you, Symantec ...

By Iain Thomson in San Francisco 29 Oct 2015 at 21:32 36 SHARE ▼

Google has read the riot act to Symantec, scolding the security biz for its

You can do this for your website for free

letsencrypt.com

Threat 4: Untrusted Inputs

Restrict inputs to only “valid” or “safe” characters

- Special characters like <, >, ‘, “ and ` are often involved in exploits involving untrusted inputs

Fix: Always use input validation

Create password

Please create your password. Click here to read our password security policy.

Your password needs to have:

- ✓ At least 8 characters with no space
- ✓ At least 1 upper case letter
- ✓ At least 1 number
- ✓ At least 1 of the following special characters from ! # $ ^ * (other special characters are not supported)

Password
••••••••••

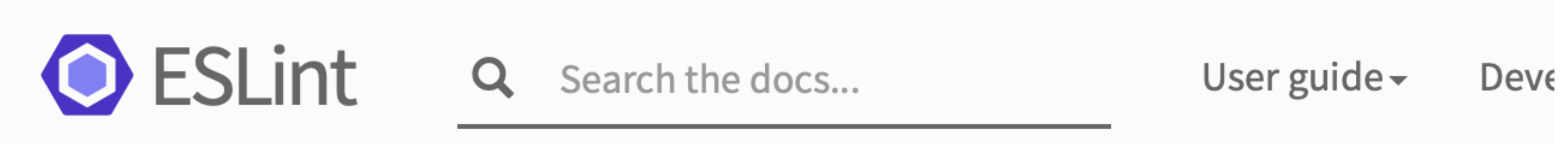
⚠ Your password must contain a minimum of 8 characters included with at least 1 upper case letter, 1 number, and 1 special character from !, #, $, ^, and * (other special characters are not supported).

Other ways to sanitize your inputs:

- Sanitize inputs – prevent them from being executable
- Avoid use of languages or features that can allow for remote code execution, such as:
  - eval() in JS – executes a string as JS code
  - Query languages (e.g. SQL, LDAP, language-specific languages like OGNL in java)
  - Languages that allow code to construct arbitrary pointers or write beyond a valid array index

Threat 5: Software Supply Chain

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



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

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

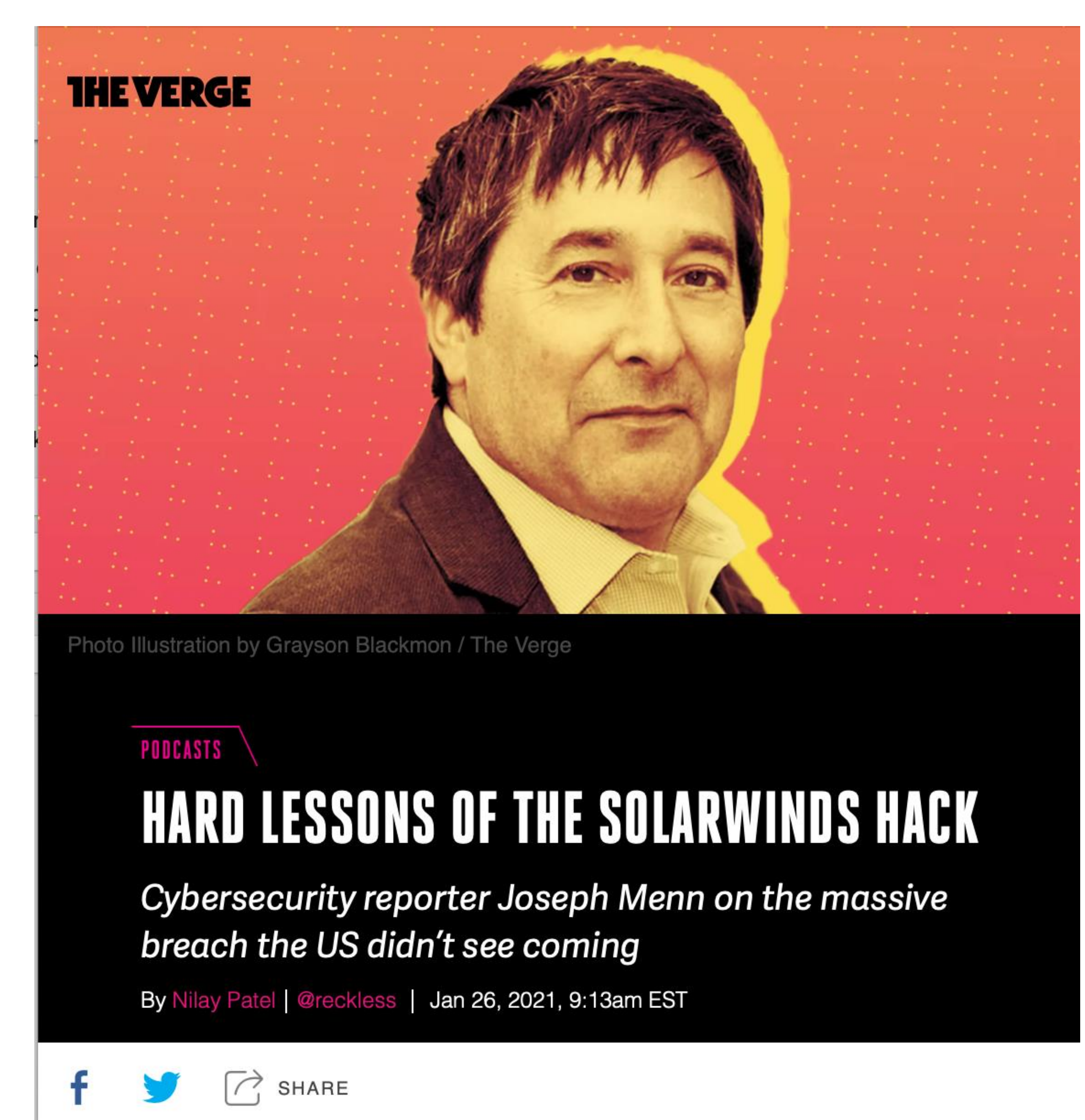

THE VERGE

Photo Illustration by Grayson Blackmon / The Verge

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

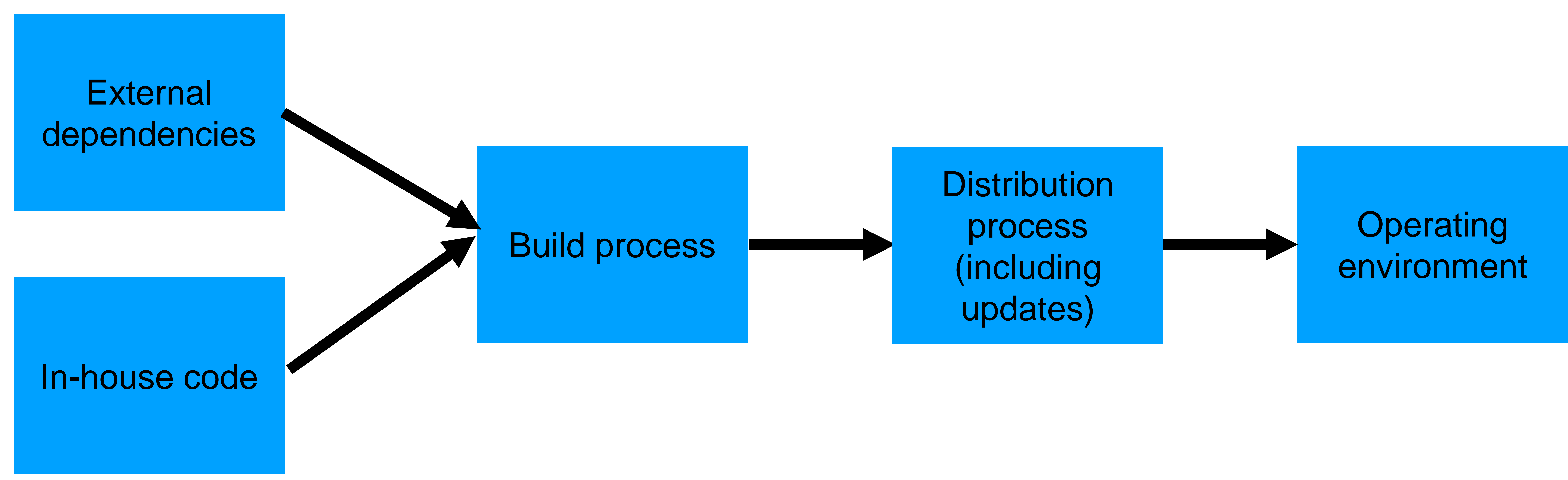
SHARE

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 cu...

to breach ever...

https://www.theverge.com/2021/1/26/22248631/solarwinds-hack-cybersecurity-us-menn-decoder-podcast

Threat 5: The software supply chain has many points of weakness



Common vulnerabilities in top 1% of npm packages

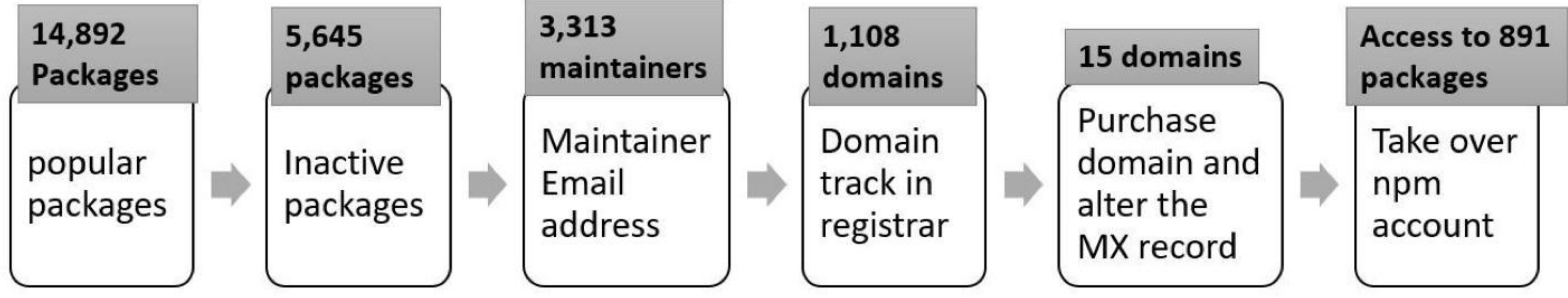
2021 NCSU/Microsoft Study

- 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

A possible attack…

2021 NCSU/Microsoft Study



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Threat Mitigation: Software Supply Chain

Process-based solutions for process-based problems

- 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

Building a security architecture

- 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 co … equirement
- Attack: realization of a threat

It's a management problem!!

Which threats to protect against, at what cost?

Consider various costs:

- Performance:
  - Encryption is not free;
  - C may be faster than Typescript, but is vulnerable to buffer overflows, etc.
- Expertise:
  - It is easy to try to implement these measures, it is hard to get them right
- Financial:
  - Implementing these measures takes time and resources

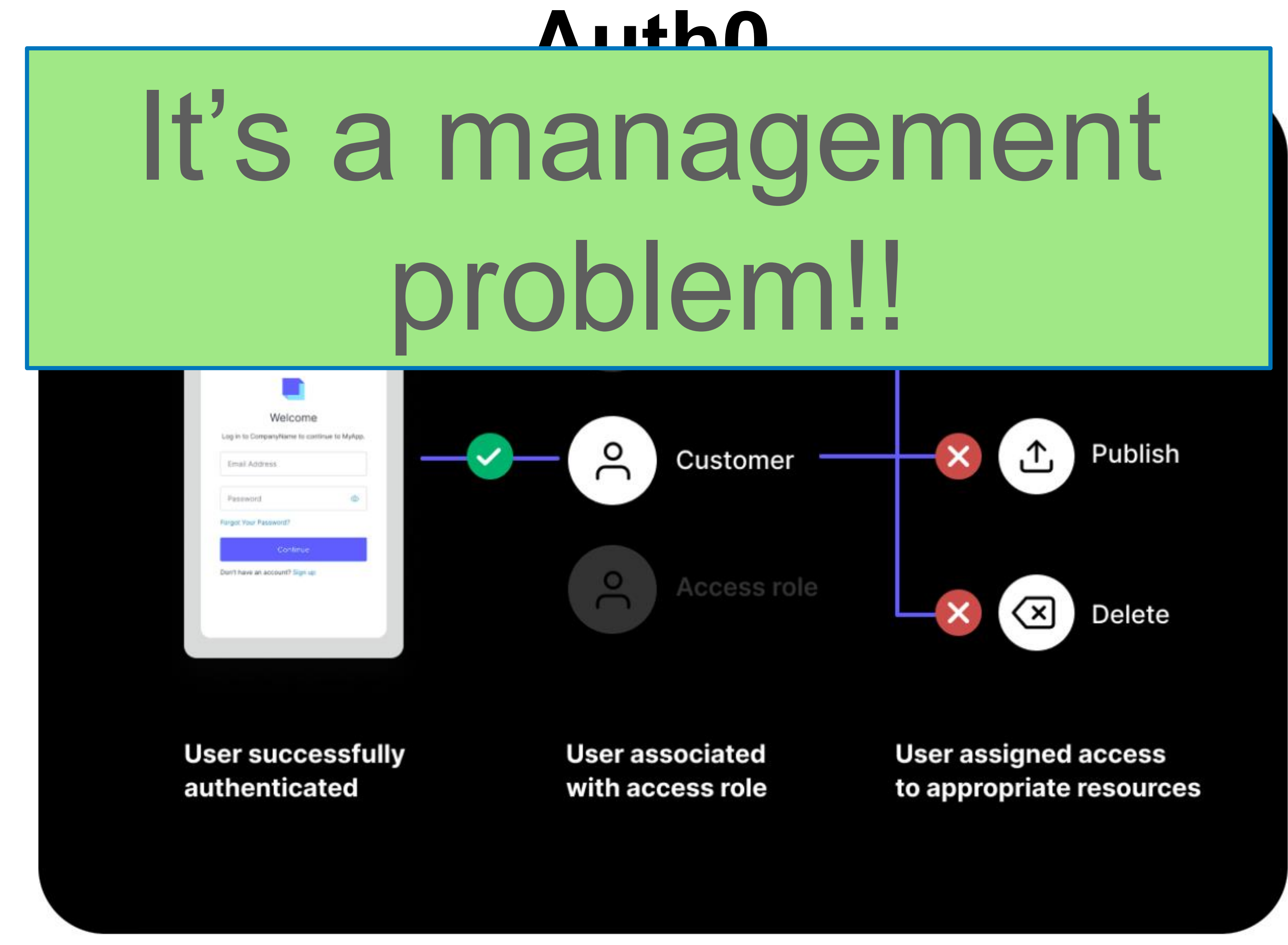
Broken Authentication + Access Control

OWASP #1

- Use SSL.
- Implement multi-factor authentication
- Implement weak-password checks
- Apply per-record access control
- Harden account creation, password reset pathways
- The software engineering approach: rely on a trusted component

But how to get your developers to do this? Always.

It's a management problem!!



https://auth0.com

Cryptographic Failures

OWASP #2

- Enforce encryption on all communication
- Validate SSL certificates; rotate certificate regularly
- Protect user-data at rest (passwords, cred card numbers, etc)
- Protect application "secrets" (e.g. signing keys)

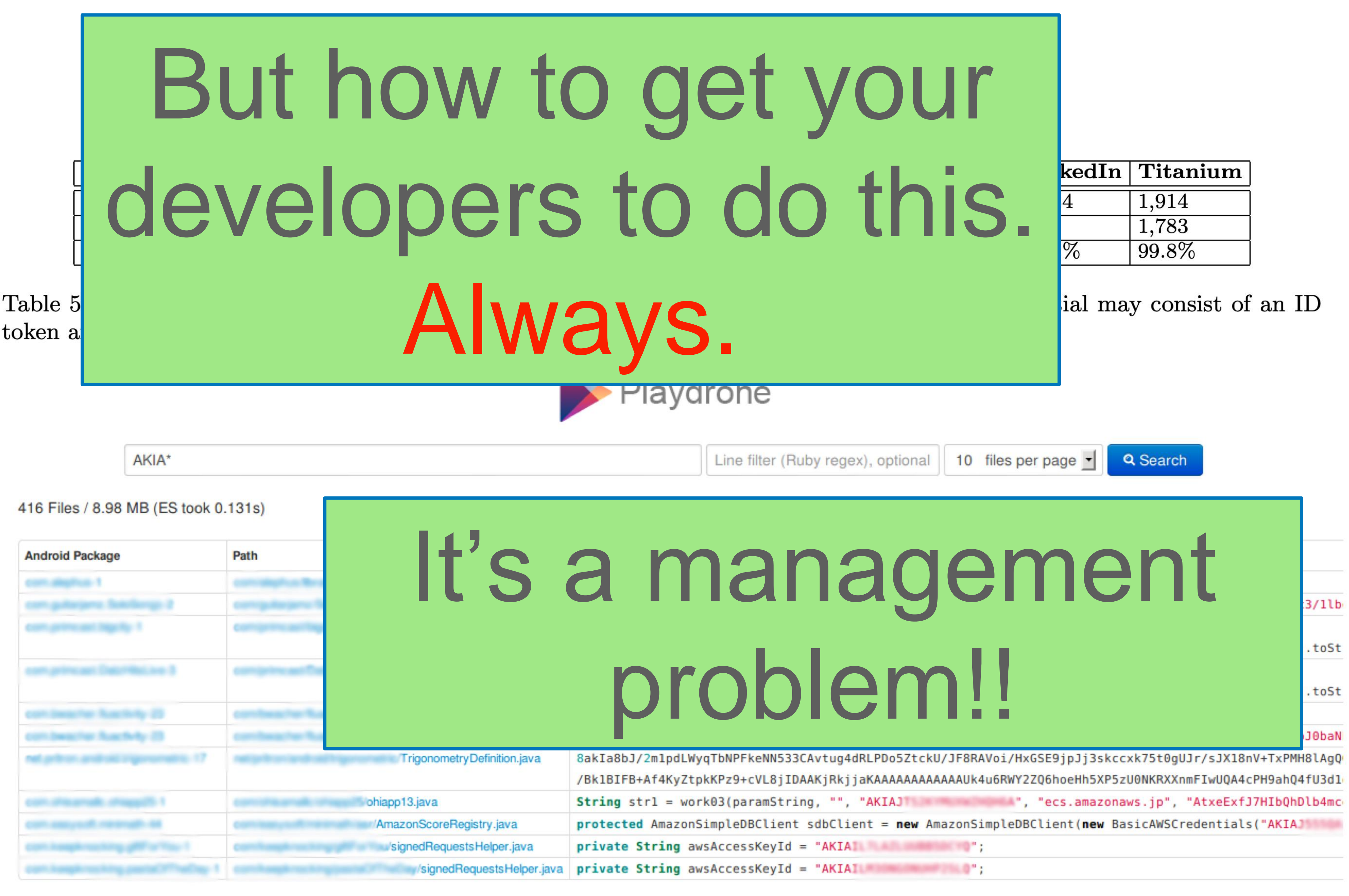


Figure 9: PLAYDRONE's web interface to search decompiled sources showing Amazon Web Service tokens found in 130 ms.
"A Measurement Study of Google Play," Viennot et al, SIGMETRICS '14

Do developers pay attention? Do they have good reason not to?

- 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 se
  - 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

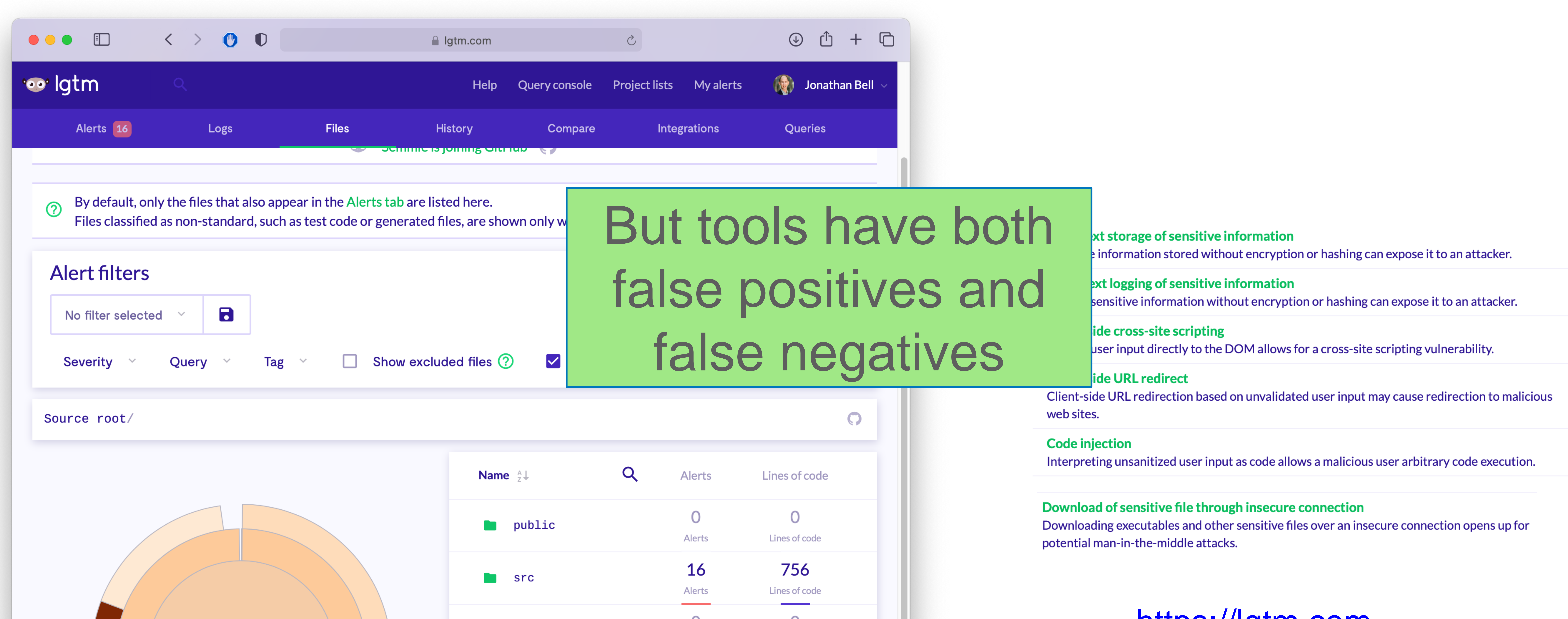
Code Injection

OWASP #3

- **Sanitize** user-controlled inputs (remove HTML)
- Use tools like LGTM to detect vulnerable data flows (insert into commit workflow?)
- Use middleware that side-steps the problem (e.g. return data as JSON, client puts that data into React component) (how to get engineers to actually do this?)

Detecting Weaknesses in Apps with Static Analysis

LGTM + CodeQL



https://lgtm.com

Weakly Protected Sensitive Data

OWASP #4

- Classify your data by sensitivity
- Encrypt sensitive data - in transit and at rest
- Make a plan for data controls, stick to it
- Software engineering fix: can we avoid storing sensitive data?
  - Payment processors: Stripe, Square, etc

Learning Objectives for this Lesson

By the end of this lesson, you should be able to…

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- 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.
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