Cookie Crumbles:

Breaking and Fixing Web Session Integrity

Marco Squarcina (TU Wien)

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Joint work with

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Lorenzo **Veronese**[2]

Matteo **Maffei**[2]

[1] IST, Universidade de Lisboa, [2] TU Wien

Have Weak Integrity

8.6. Weak Integrity

Cookies do not provide integrity guarantees for sibling domains (and their subdomains). For example, consider foo.site.example and bar.site.example. The foo.site.example server can set a cookie with a Domain attribute of "site.example" (possibly overwriting an existing "site.example" cookie set by bar.site.example), and the user agent will include that cookie in HTTP requests to bar.site.example. In the worst case, bar.site.example will be unable to distinguish this cookie from a cookie it set itself. The foo.site.example server might be able to leverage this ability to mount an attack against bar.site.example. [...]

An active network attacker can also inject cookies into the Cookie header field sent to https://site.example/ by impersonating a response from http://site.example/ and injecting a Set-Cookie header field. The HTTPS server at site.example will be unable to distinguish these cookies from cookies that it set itself in an HTTPS response. An active network attacker might be able to leverage this ability to mount an attack against site.example even if site.example uses HTTPS exclusively. [...]

Finally, an attacker might be able to force the user agent to delete cookies by storing a large number of cookies. Once the user agent reaches its storage limit, the user agent will be forced to evict some cookies. Servers SHOULD NOT rely upon user agents retaining cookies.

RFC 6265bis

Typical attacks: Session Fixation, Login CSRF, **CSRF**, application specific vulns, ...

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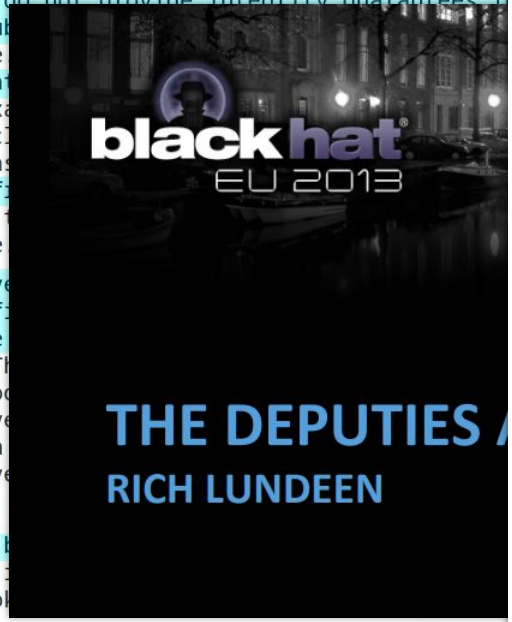

Cookies Lack Integrity: Real-World Implications

Xiaofeng Zheng[1,2,3], Jian Jiang[7], Jinjin Liang[1,2,3], Haixin Duan[1,3,4], Shuo Chen[5], Tao Wan[6], and Nicholas Weaver[4,7]

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[3]Tsinghua National Laboratory for Information Science and Technology
[4]International Computer Science Institute
[5]Microsoft Research Redmond
[6]Huawei Canada
[7]UC Berkeley

usenix THE ADVANCED COMPUTING SYSTEMS ASSOCIATION

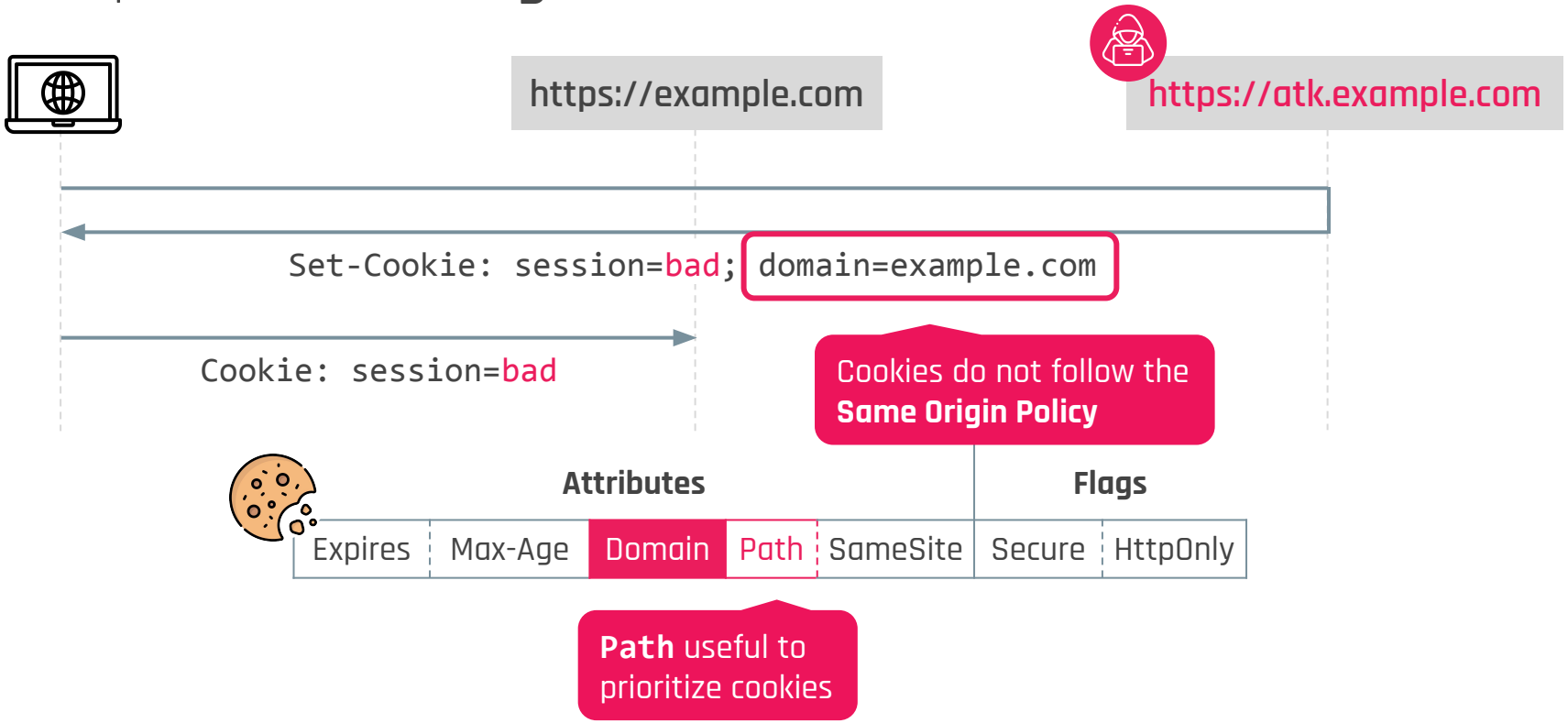
Abstract

A cookie can contain a "secure" flag, indicating that it should be only sent over an HTTPS connection. Yet there is no corresponding flag to indicate how a cookie was set: attackers who act as a man-in-the-midddle even temporarily on an HTTP session can inject cookies which will be attached to subsequent HTTPS connections. Similar attacks can also be launched by a web attacker from a related domain. Although an acknowledged threat, it has not yet been studied thoroughly. This paper aims to fill this gap with an in-depth empirical assessment of cookie injection attacks. We find that cookie-related vulnerabilities are present in important sites (such as Google and Bank of America), and can be made worse by the implementation weaknesses we discovered in major web browsers (such as Chrome, Firefox, and Safari). Our successful attacks have included privacy violation, online victimization, and even financial loss and account man-in-the-middle (MITM). However, there is no similar measure to protect its integrity from the same adversary: an HTTP response is allowed to set a secure cookie for its domain. An adversary controlling a related domain is also capable to disrupt a cookie's integrity by making use of the shared cookie scope. Even worse, there is an asymmetry between cookie's read and write operations involving pathing, enabling more subtle form of cookie integrity violation.

The lack of cookie integrity is a known problem, noted in the current specification [2]. However, the real-world implications are under-appreciated. Although the problem has been discussed by several previous researchers [4, 5, 30, 32, 24, 23], none provided in-depth and real-world empirical assessment. Attacks enabled by merely injecting malicious cookies could be elusive, and the consequence could be serious. For example, a cautious user might only visit news websites at open wireless

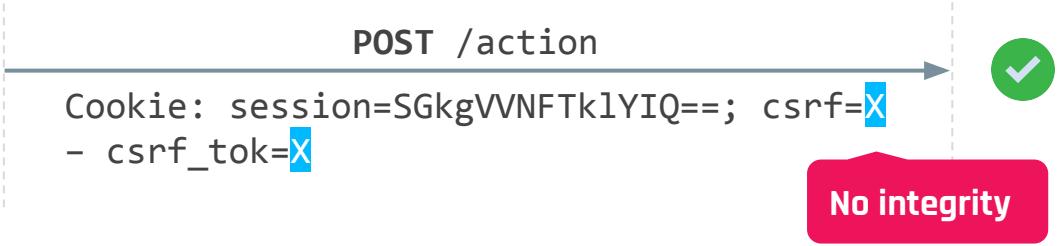
Typical attacks: Session Fixation, Login CSRF, **CSRF**, application specific vulns, ...

Recap: **Cookie Tossing** (**Same-Site** & **Network Attackers**)



Cross-Origin Request Forgery (CORF) Protections

- **SameSite** attribute does not apply in same-site context → **Token-based defenses**!
- **Double-Submit Pattern** (**DSP**) is broken!



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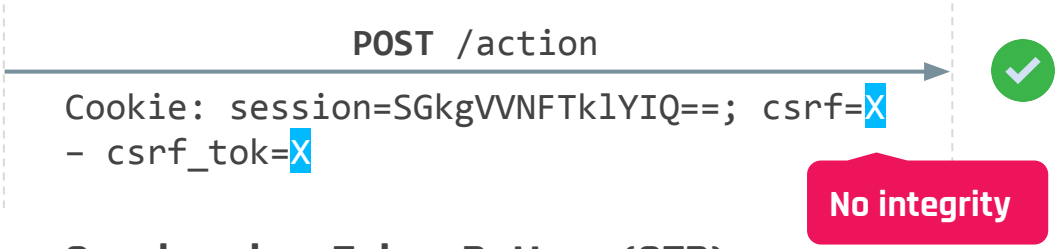
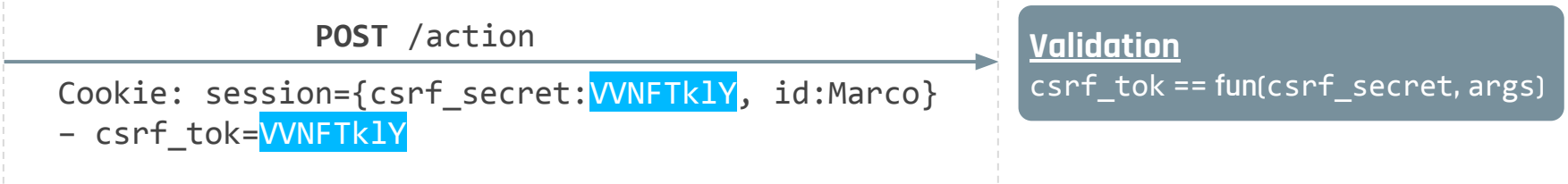


- **Synchronizer Token Pattern** (**STP**)



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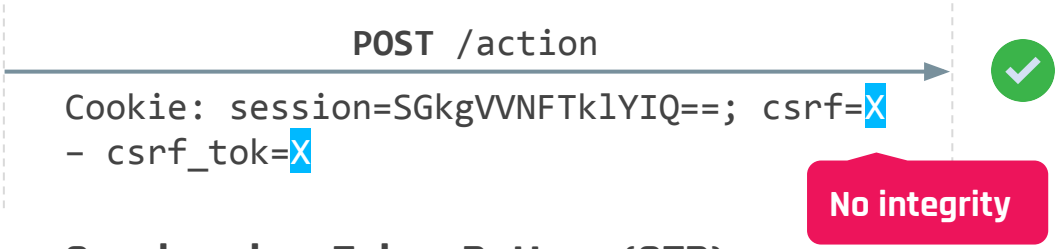

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CORF Token Fixation (Flask-login + Flask-WTF)

https://bank.com

https://atk.bank.com

1 Attacker obtains CSRF token **t0** and **sess0**

`sess0 = {csrf:s, id:None}`

GET /login

2 Pre-Login Session Fixation with `session=sess0`

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GET /login

2 Pre-Login Session Fixation with `session=sess0`

3 **User authenticates** with `sess0`, obtains `sess1`

`sess1 = {csrf:s, id:bob}`

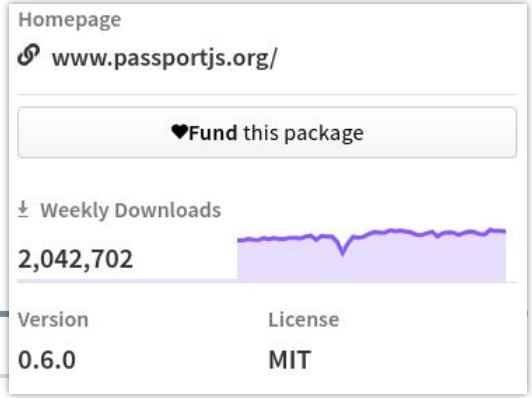
4

POST /action

```
Cookie: session={csrf:s, id:bob}
- csrf_token=t0
```

CSRF token **t0** is valid!

Web Frameworks Analysis



Framework (9/13 vulnerable)	Broken STP	Default DSP	Session Fixation			
Express (passport + csurf)	●		●	CVE-2022-25896		
Koa (koa-passport + csrf)	●					
Fastify (fastify/passport + csrf-protection)	●	●	●	CVE-2023-29020	CVE-2023-27495	CVE-2023-29019
Sails* (csurf)	●		●			
Flask (flask-login+flask-wtf)	●					
Tornado		●				
Symfony (security-bundle)	●			CVE-2022-24895		
CodeIgniter4 (shield)	●	●		CVE-2022-35943		
Yii2		●				

*affects the bootstrap template app

Are  Getting Better?

Methodology

2 **Browser testing suite** for tossing & eviction: check **discrepancies**

Manual **review** of the cookie standard

1

Simple **differential fuzzing** to test server implementations

3

Strict Secure &  Prefixes (__Host-)

HTTP Working Group — M. West
Internet-Draft — Google, Inc
Updates: 6265 (if approved) — September 5, 2016
Intended status: Standards Track
Expires: March 9, 2017

Deprecate modification of 'secure' cookies from non-secure origins
draft-ietf-httpbis-cookie-alone-01

block setting cookie without the **Secure** flag if the cookie jar contains Secure cookie with the same name

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```
> document.cookie = '__Host-sess=bar; Path=/; Secure; Domain=example.com'
<· '__Host-sess=bar; Path=/; Secure; Domain=example.com'
> document.cookie
<· ''
```

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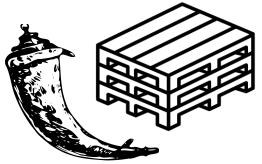
High-integrity cookies, cannot be set from a sibling domain!

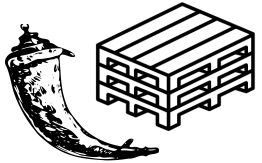
Browser vs Server



Werkzeug <2.2.3

Set-Cookie:	Cookie:	Key	Value	Server <key, value>
foo=	foo=	foo		<foo, >
=foo				
=foo=				
==foo				
foo				

Browser vs Server



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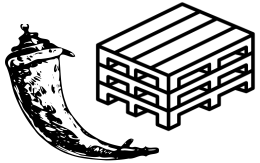
Set-Cookie:	Cookie:	Key	Value	Server <key, value>
foo=	foo=	foo		<foo, >
=foo	foo		foo	
=foo=	foo=		foo=	
==foo	=foo		=foo	
foo	foo		foo	

Browser vs Server

CVE-2023-23934



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Set-Cookie:	Cookie:	Key	Value	Server <key, value>
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=foo	foo		foo	<foo, >
=foo=	foo=		foo=	<foo, >
==foo	=foo		=foo	<foo, >
foo	foo		foo	<foo, >

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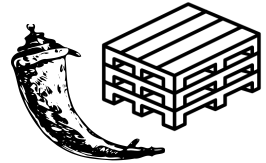


Werkzeug <2.2.3

[RFC6265bis] Accept nameless cookies. (#1018)

Browse files

```
This patch alters the cookie parsing algorithm to treat
`Set-Cookie: token` as creating a cookie with an empty name and a value
of "token". It also rejects cookies with neither names nor values (e.g.
`Set-Cookie:` and `Set-Cookie: =`.

Closes #159.
```

main (#1018)

draft-ietf-httpbis-unprompted-auth-02 ··· b68e4ff

committed on Jan 10, 2020

1 parent c43cdae commit 0178223

Set	Server <key, value>
foo	<foo, >
=fo	<foo, >
=fo	<foo, >
==f	<foo, >
foo	<foo, >

Real World Implications

CVE-2022-2860*

CVE-2022-40958*

- **Bypass __Host- cookies**

Value of a nameless cookie
__Host-sess=bad

← Set-Cookie: =__Host-sess=bad; domain=bank.com

→ Cookie: __Host-sess=bad

Fixed in rfc6265bis and browsers

* Reported almost simultaneously with **Axel Chong**, our issues were merged to jointly discuss mitigations and additional security implications. See also https://github.com/httpwg/http-extensions/issues/2229

Real World Implications

CVE-2022-2860*

CVE-2022-40958*

- **Bypass __Host- cookies**

Value of a nameless cookie
__Host-sess=bad

```
← Set-Cookie: =__Host-sess=bad; domain=bank.com
→ Cookie: __Host-sess=bad
```

Fixed in rfc6265bis and browsers

- **Bypass Strict Secure cookies**

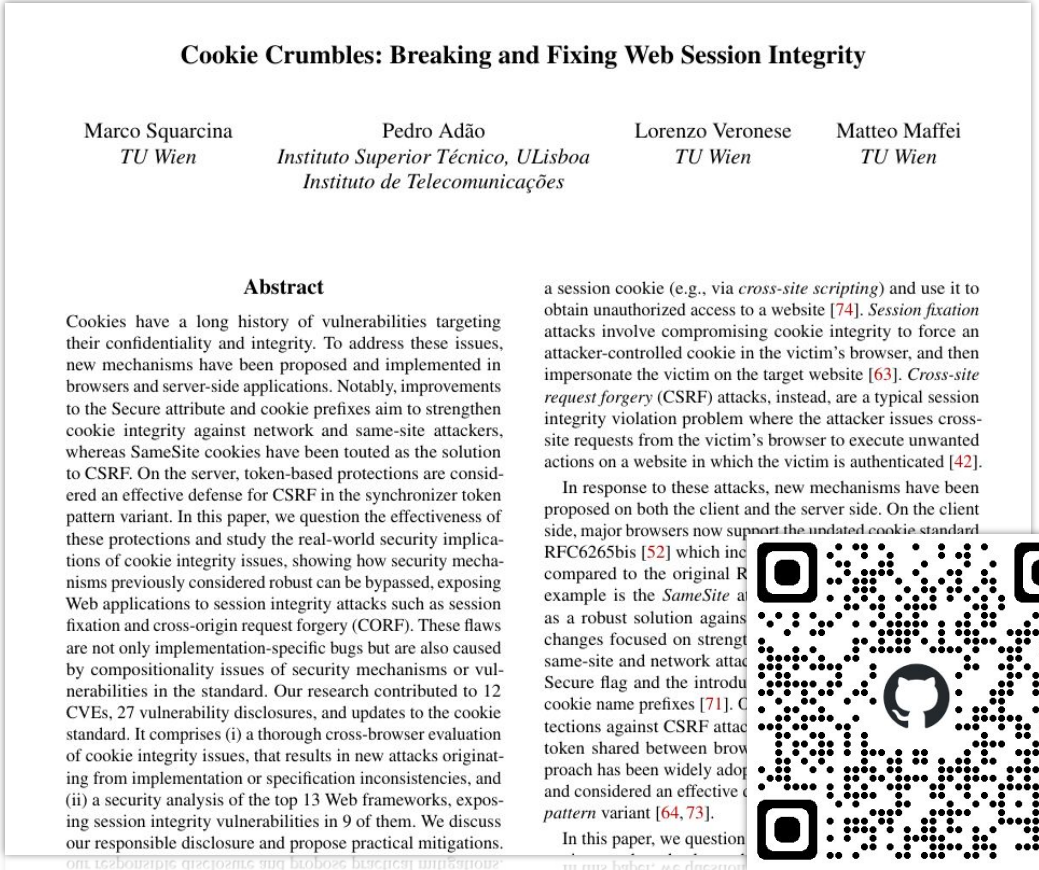
```
← Set-Cookie: sess=good; Secure          https://bank.com
← Set-Cookie: =sess=bad; Path=/app/      http://bank.com
→ Cookie: sess=bad; sess=good            https://bank.com/app/
```

* Reported almost simultaneously with **Axel Chong**, our issues were merged to jointly discuss mitigations and additional security implications. See also https://github.com/httpwg/http-extensions/issues/2229

- Details on all **framework vulnerabilities**
- Cookie **measurement** for prefixes and nameless cookies
- More **browser issues, client-server discrepancies**, **server parsing issues**
- **Formal modeling** of (patched) Web frameworks using ProVerif

Artifact

https://github.com/SecPriv/cookiecrumbles



Cookie Crumbles: Breaking and Fixing Web Session Integrity

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Pedro Adão, *Instituto Superior Técnico, ULisboa*, *Instituto de Telecomunicações*
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Abstract

Cookies have a long history of vulnerabilities targeting their confidentiality and integrity. To address these issues, new mechanisms have been proposed and implemented in browsers and server-side applications. Notably, improvements to the Secure attribute and cookie prefixes aim to strengthen cookie integrity against network and same-site attackers, whereas SameSite cookies have been touted as the solution to CSRF. On the server, token-based protections are considered an effective defense for CSRF in the synchronizer token pattern variant. In this paper, we question the effectiveness of these protections and study the real-world security implications of cookie integrity issues, showing how security mechanisms previously considered robust can be bypassed, exposing Web applications to session integrity attacks such as session fixation and cross-origin request forgery (CORF). These flaws are not only implementation-specific bugs but are also caused by compositionality issues of security mechanisms or vulnerabilities in the standard. Our research contributed to 12 CVEs, 27 vulnerability disclosures, and updates to the cookie standard. It comprises (i) a thorough cross-browser evaluation of cookie integrity issues, that results in new attacks originating from implementation or specification inconsistencies, and (ii) a security analysis of the top 13 Web frameworks, exposing session integrity vulnerabilities in 9 of them. We discuss our responsible disclosure and propose practical mitigations.

a session cookie (e.g., via *cross-site scripting*) and use it to obtain unauthorized access to a website [74]. *Session fixation* attacks involve compromising cookie integrity to force an attacker-controlled cookie in the victim's browser, and then impersonate the victim on the target website [63]. *Cross-site request forgery* (CSRF) attacks, instead, are a typical session integrity violation problem where the attacker issues cross-site requests from the victim's browser to execute unwanted actions on a website in which the victim is authenticated [42].

In response to these attacks, new mechanisms have been proposed on both the client and the server side. On the client side, major browsers now support the updated cookie standard RFC6265bis [52] which inc
compared to the original R
example is the *SameSite* a
as a robust solution agains
changes focused on strengt
same-site and network attac
Secure flag and the introdu
cookie name prefixes [71]. C
tections against CSRF attac
token shared between brow
proach has been widely adop
and considered an effective
pattern variant [64, 73].

In this paper, we question

… and that's the way the cookie crumbles!

Icons by **flaticon**

Thank You! Questions?

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