The State of the SameSite: Studying the Usage, Effectiveness, and Adequacy of SameSite Cookies

Soheil Khodayari and Giancarlo Pellegrino

CISPA Helmholtz Center for Information Security

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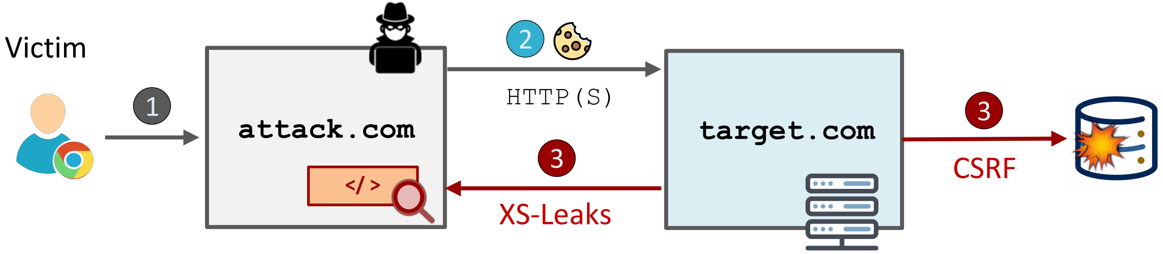

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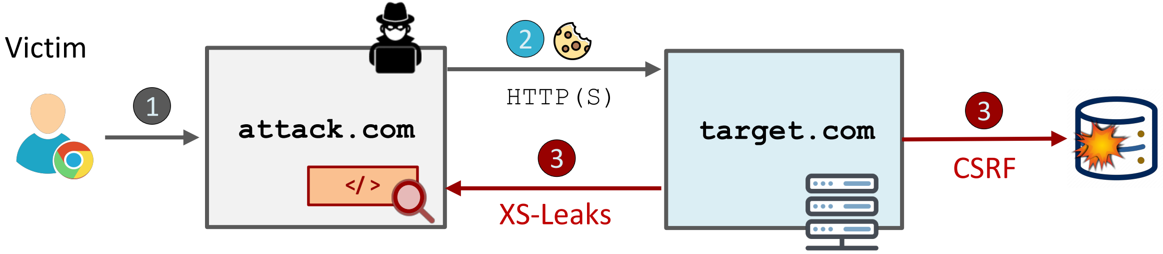

- **Solution:** limit the cookies' scope to a same-site context

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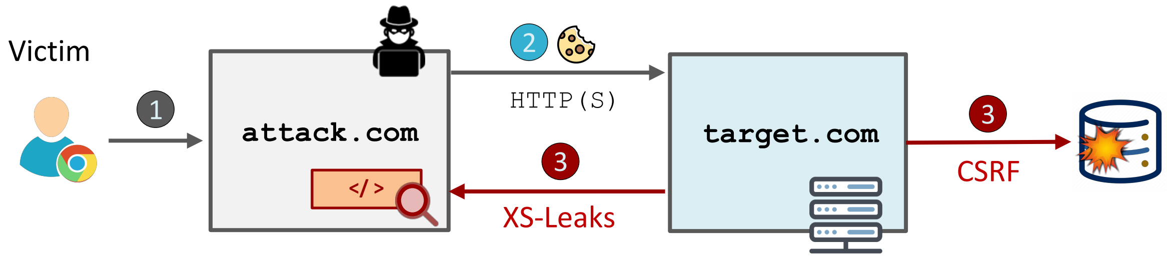

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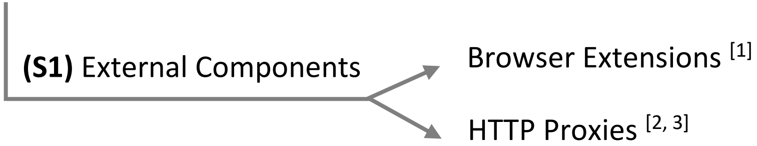

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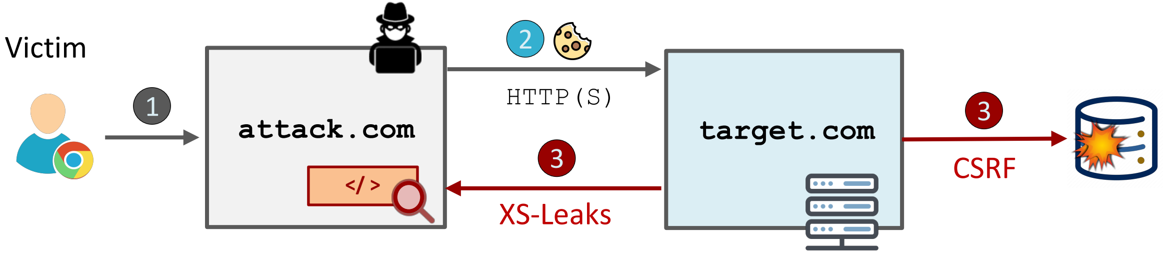

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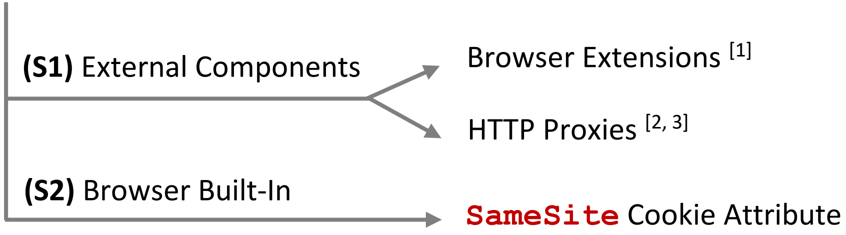

(S1) External Components → Browser Extensions [1], HTTP Proxies [2, 3]

(S2) Browser Built-In → **SameSite** Cookie Attribute

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SameSite Cookies

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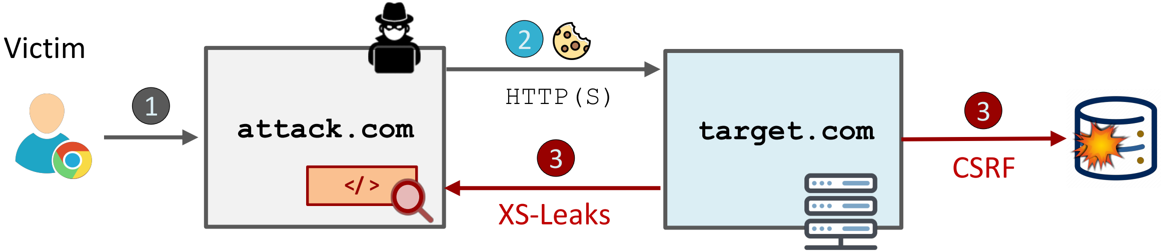

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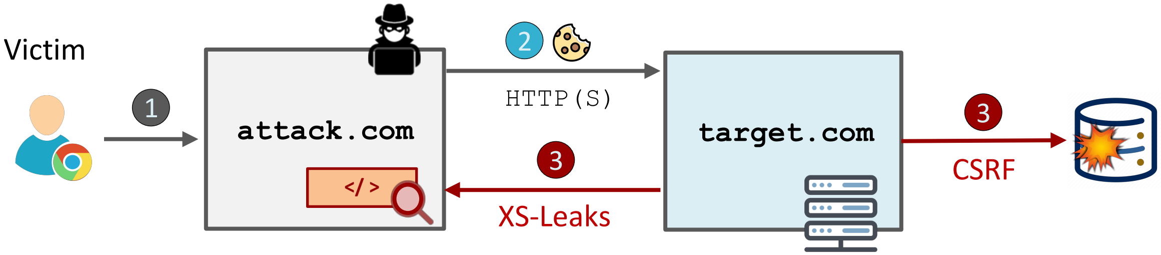

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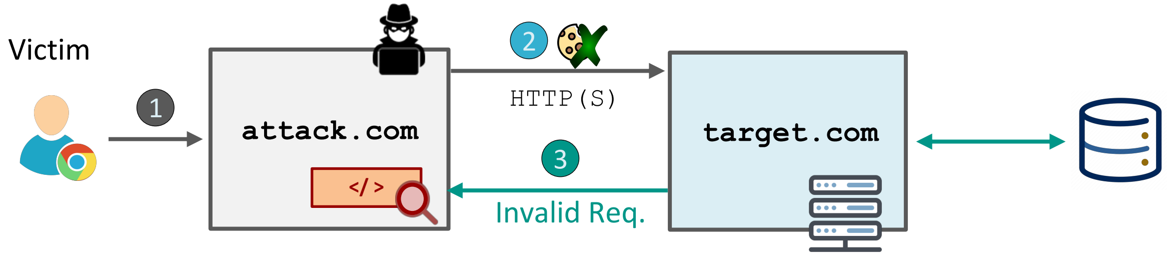
Strict 🍪 in **No** XS requests in step 2



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Lax	🍪 in **some** XS requests in step ② (e.g., navigations)
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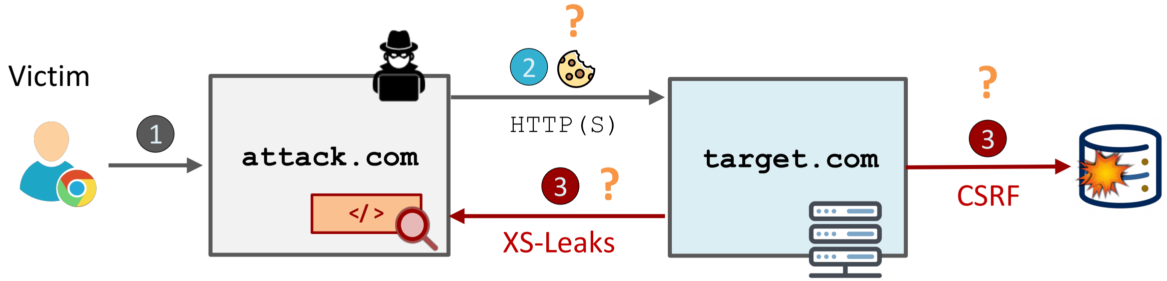

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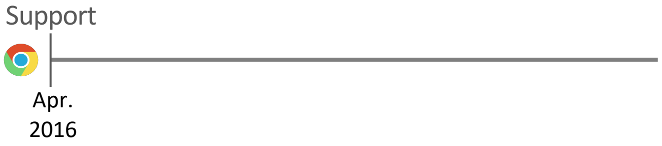

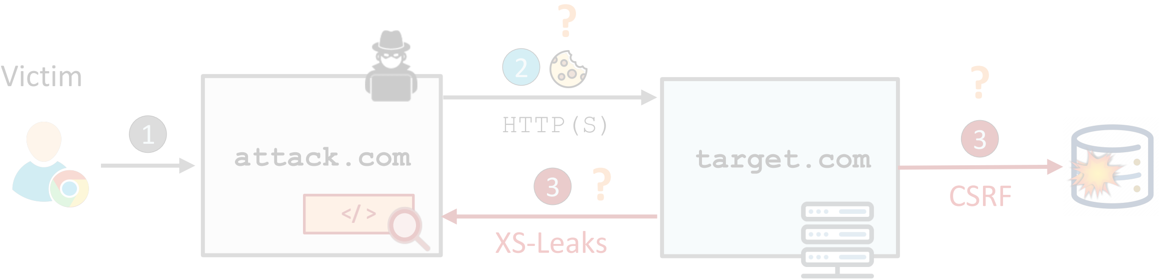

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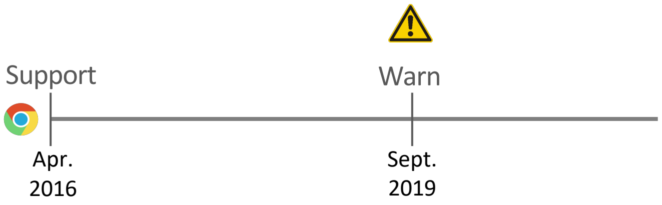

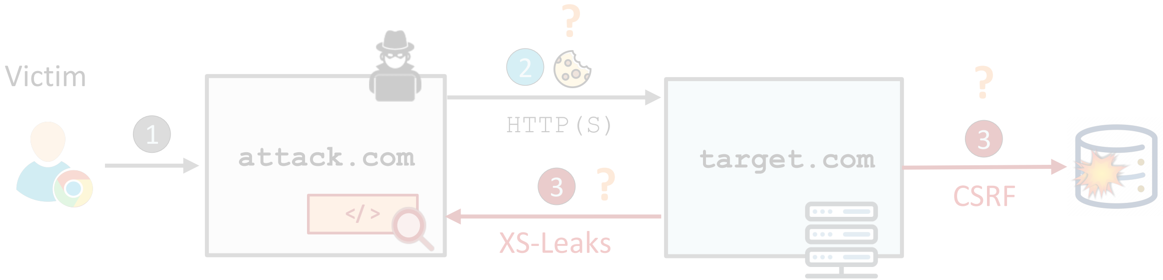

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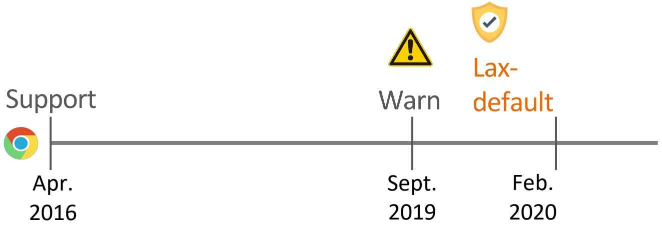

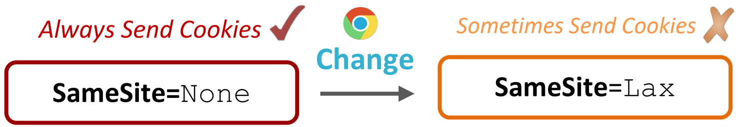

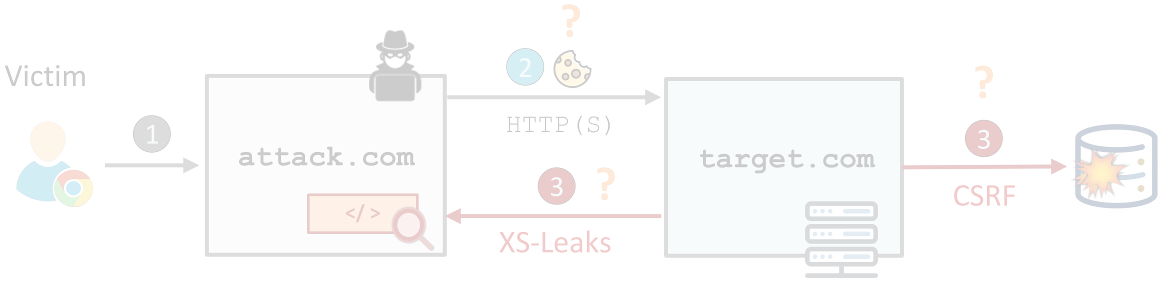

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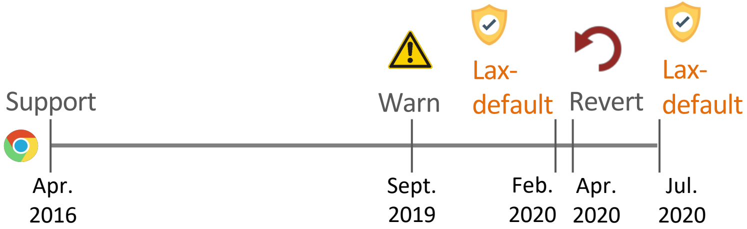


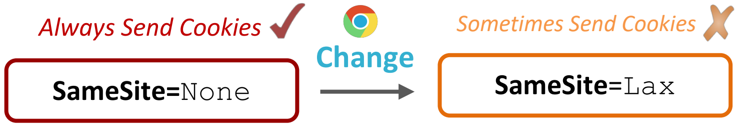
Support — Apr. 2016

Warn — Sept. 2019

Lax-default — Feb. 2020

Revert — Apr. 2020

Lax-default — Jul. 2020



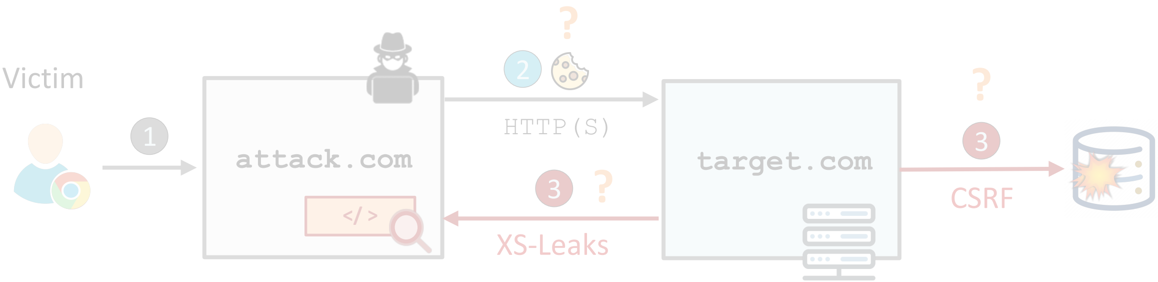
Always Send Cookies ✓

SameSite=`None`

Change

Sometimes Send Cookies ✗

SameSite=`Lax`



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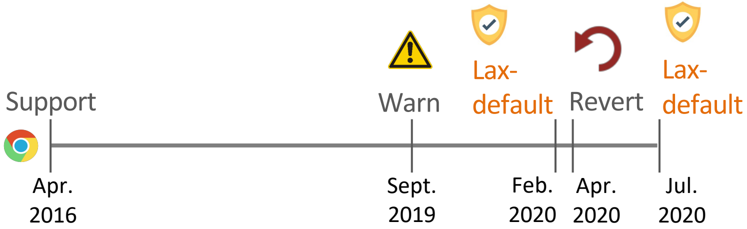

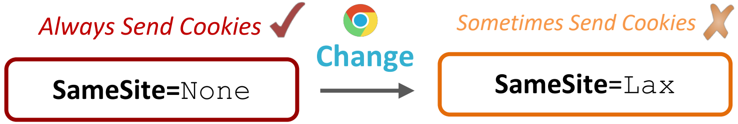

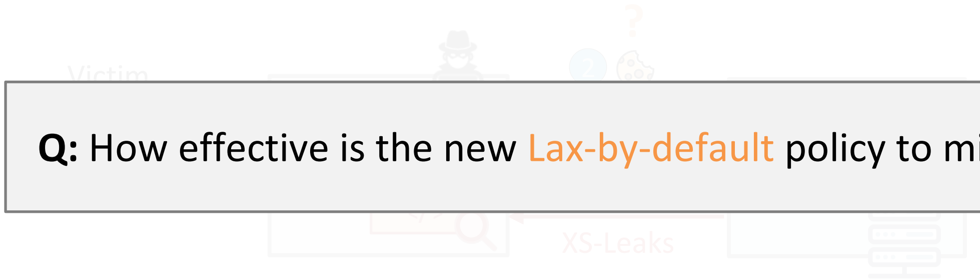

Q: How effective is the new Lax-by-default policy to mitigate XS attacks?

Problem Statement

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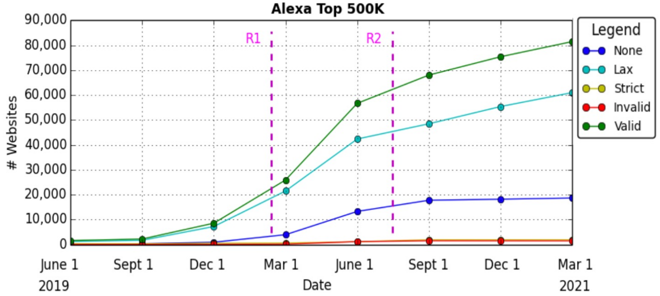
RQ1: Adoption of SameSite Policies

Longitudinal Analysis



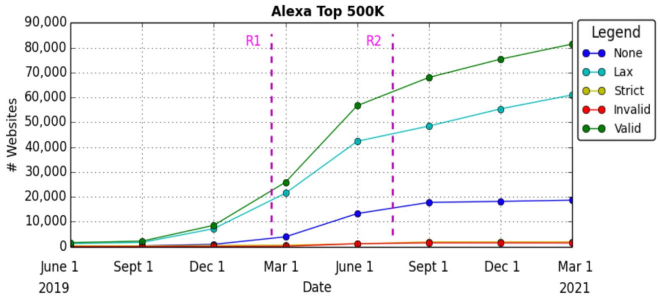
RQ1: Adoption of SameSite Policies

Longitudinal Analysis

Valid Policies

18.9%

% of Alexa 500K Sites



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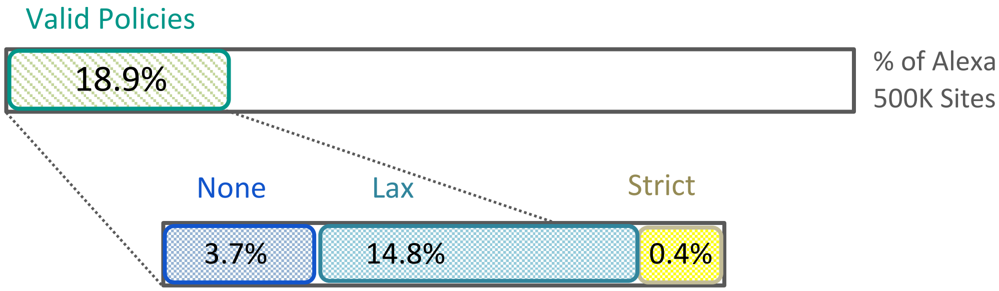

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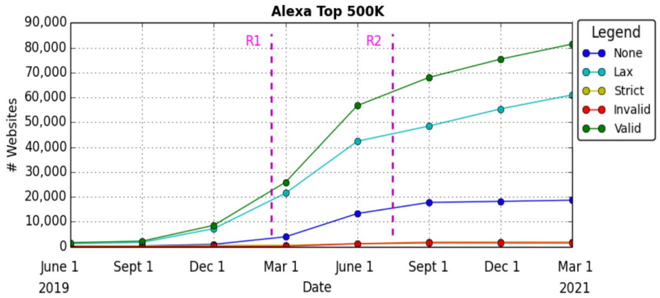

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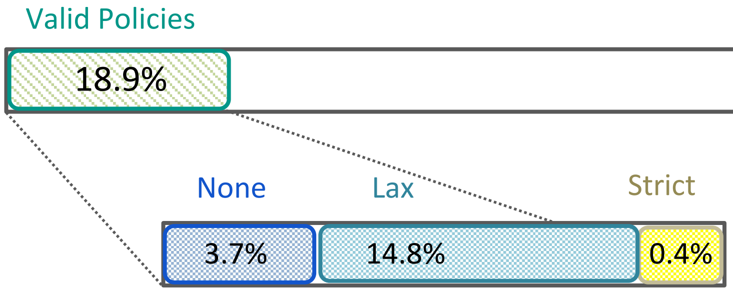

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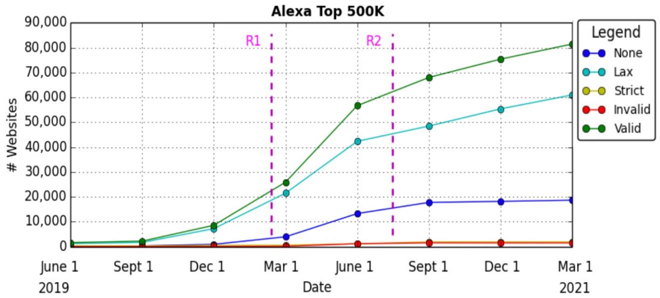

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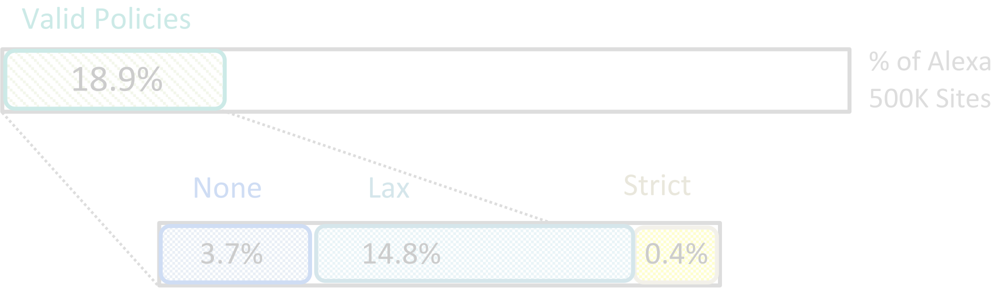

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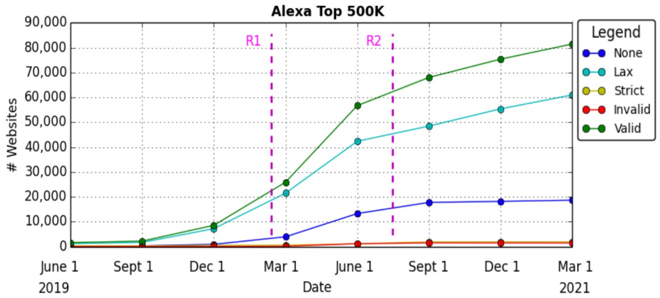

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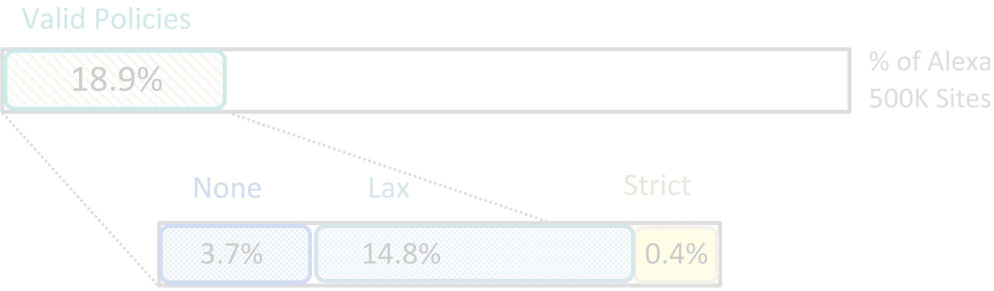

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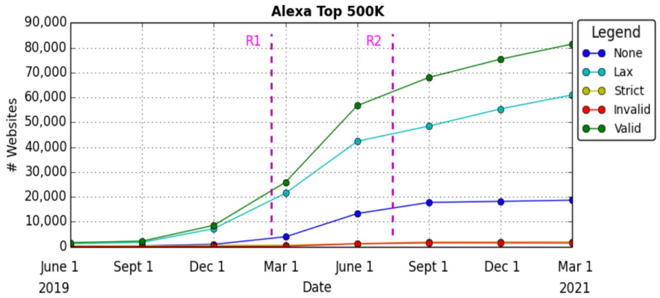

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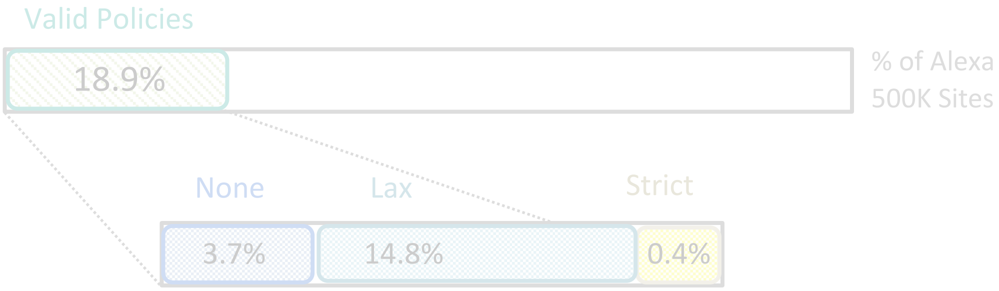

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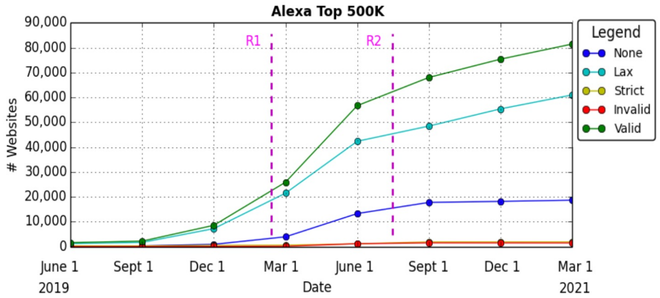

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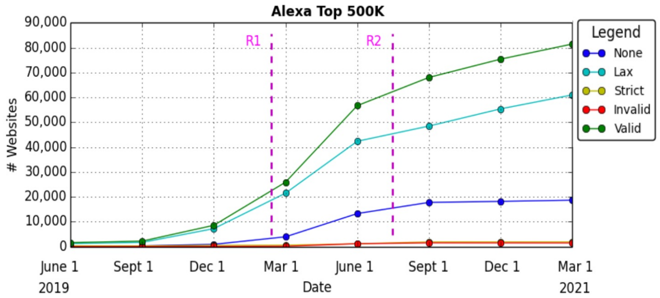

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Longitudinal Analysis

Valid Policies | Invalid

18.9% | 0.3%

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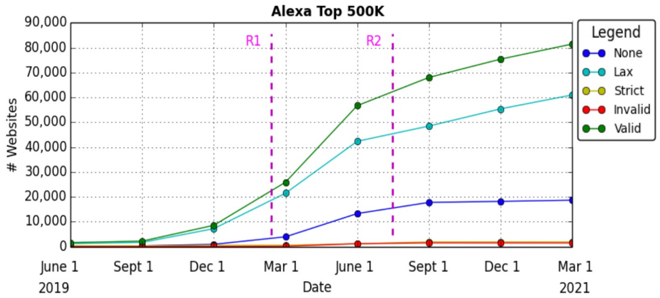

- Example:
  - `SameSite=1`

Should be treated as None [RFC 6265bis]

1,430 sites (0.3%) set an invalid policy due to developers' mistakes

RQ1: Adoption of SameSite Policies

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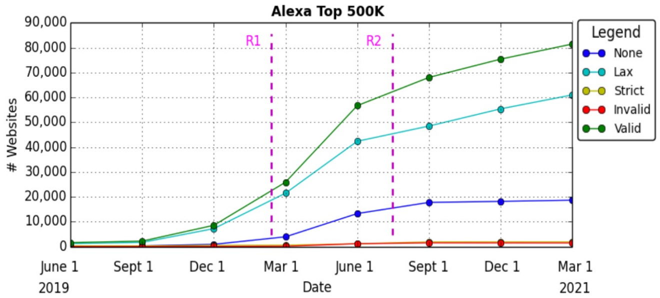
Longitudinal Analysis

Valid Policies	Invalid	Missing Policy	
18.9%	0.3%	80.8%	% of Alexa 500K Sites



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The remaining 80.8%:

- No explicit policy found, rely on the default browser behaviour

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- Websites use XS requests for various functionalities
  - Social media share buttons, advertising, etc

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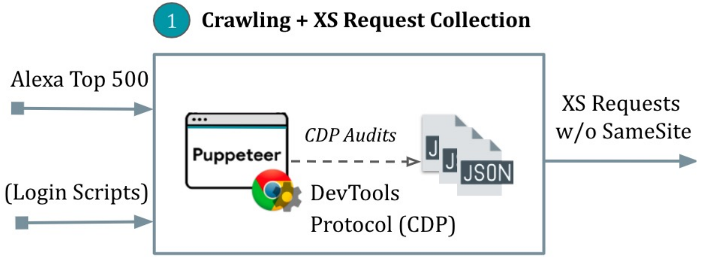

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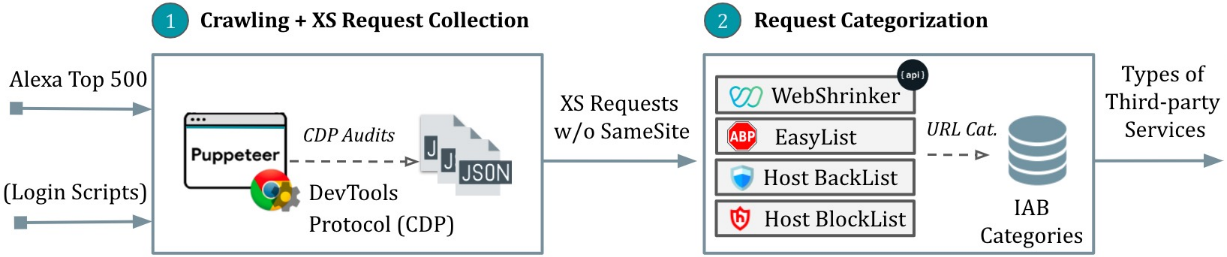

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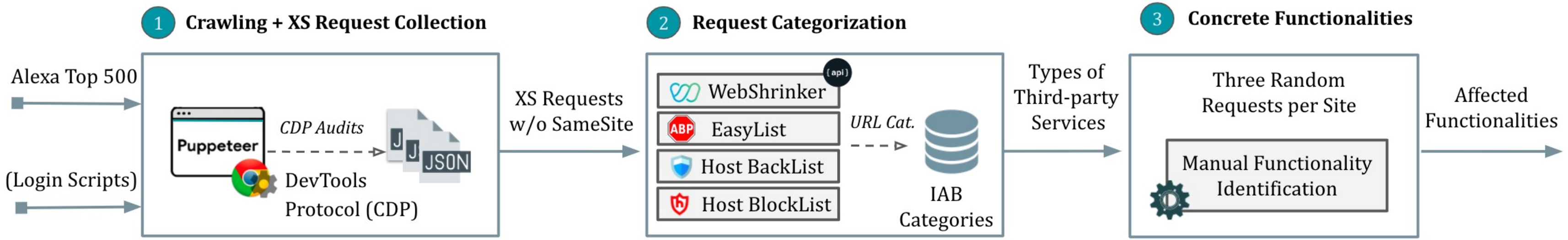

1 **Crawling + XS Request Collection**

Alexa Top 500

(Login Scripts)

Puppeteer

CDP Audits

DevTools Protocol (CDP)

JSON

XS Requests w/o SameSite

2 **Request Categorization**

WebShrinker

EasyList

Host BackList

Host BlockList

URL Cat.

IAB Categories

Types of Third-party Services

3 **Concrete Functionalities**

Three Random Requests per Site

Manual Functionality Identification

Affected Functionalities

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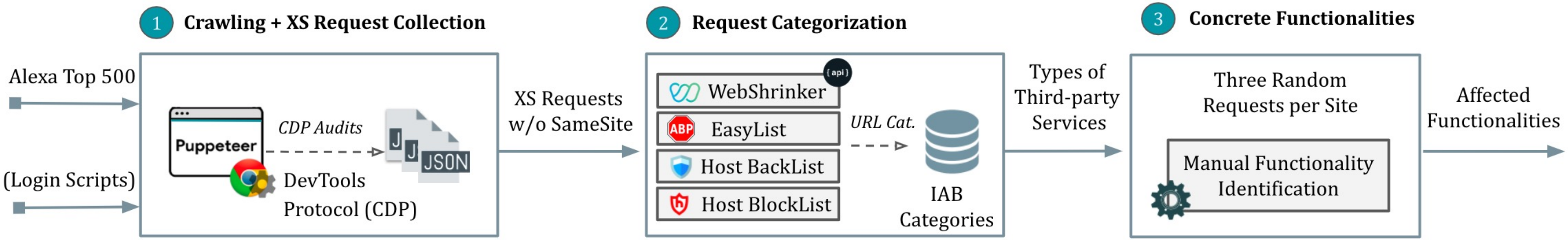

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- Identify potentially affected functionality before Lax-by-default rollout (R2), confirm breakage afterwards

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Data Collection

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- 22,992 XS requests without `SameSite`

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Breakage

- Examined three random requests per site

		After R2	
Functionality	**# Requests**	**# Broken**	**# Patched**
Advertising / Tracking	374	93	281
Single-Sign On	81	1	80
Social Media Like / Share	76	11	65
Live Chat Frames	62	8	54
PDF Embed APIs	13	4	9
(Re-)CAPTCHA	12	2	10
Content Servers / CDNs	9	0	9
Survey/Rating Services	6	1	5
Total	**633**	**120**	**513**

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Functionalities implemented by 19% of the affected requests are broken, affecting 17.5% of sites

The majority of broken requests (i.e., 77.5%) are for online ads & user tracking

RQ3: Lax Adequacy and Threats to Effectiveness

Benefit
Lax

***Q:** How adequate are SameSite cookies to prevent XS attacks?*

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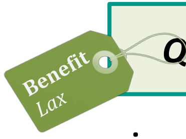

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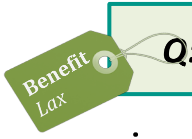

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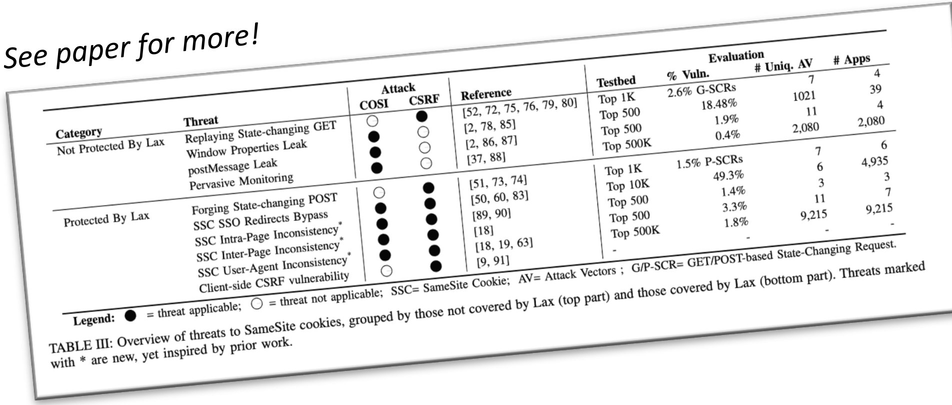


Category	Threat	Attack		Reference	Evaluation			
		COSI	CSRF		Testbed	% Vuln.	# Uniq. AV	# Apps
Not Protected By Lax	Replaying State-changing GET	○	●	[52, 72, 75, 76, 79, 80]	Top 1K	2.6% G-SCRs	7	4
	Window Properties Leak	●	○	[2, 78, 85]	Top 500	18.48%	1021	39
	postMessage Leak	●	○	[2, 86, 87]	Top 500	1.9%	11	4
	Pervasive Monitoring	●	○	[37, 88]	Top 500K	0.4%	2,080	2,080
Protected By Lax	Forging State-changing POST	○	●	[51, 73, 74]	Top 1K	1.5% P-SCRs	7	6
	SSC SSO Redirects Bypass	●	●	[50, 60, 83]	Top 10K	49.3%	6	4,935
	SSC Intra-Page Inconsistency*	●	●	[89, 90]	Top 500	1.4%	3	3
	SSC Inter-Page Inconsistency*	●	●	[18]	Top 500	3.3%	11	7
	SSC User-Agent Inconsistency*	●	●	[18, 19, 63]	Top 500K	1.8%	9,215	9,215
	Client-side CSRF vulnerability	○	●	[9, 91]	-	-	-	-

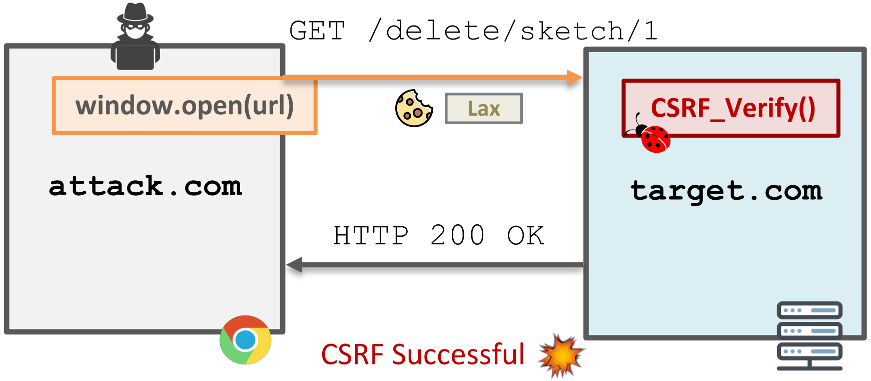
Legend: ● = threat applicable; ○ = threat not applicable; SSC= SameSite Cookie; AV= Attack Vectors ; G/P-SCR= GET/POST-based State-Changing Request.

TABLE III: Overview of threats to SameSite cookies, grouped by those not covered by Lax (top part) and those covered by Lax (bottom part). Threats marked with * are new, yet inspired by prior work.

Threat: CSRF by Replaying State-changing GET

Threat

- Top-level GET requests not covered by Lax
- Developers may misuse GET requests for state-changing operations



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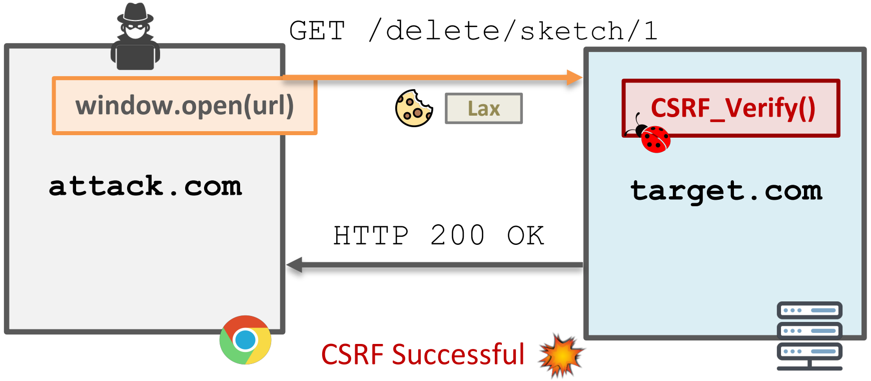
- Alexa top 1K, 42.5K URLs
- Located HTML forms with a CSRF token
- Quantified GET-based state-changes (lower-bound)
- Manually checked if CSRF verification is correct



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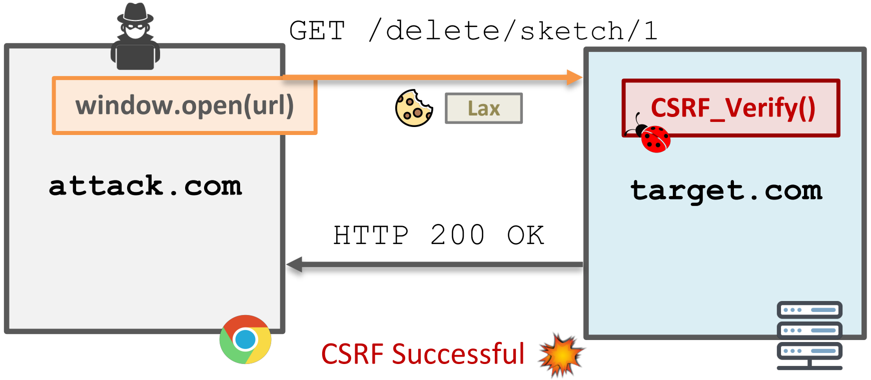


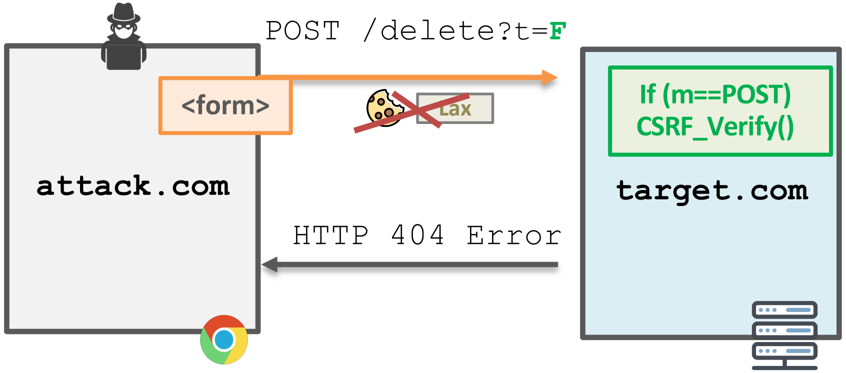
Results

- 6.9K state-changing requests, 10.3% are GET-based (in 88 webapps)
- 2.6% of the GET-based requests are forgeable due to faulty CSRF token verification ⚠
  - E.g., delete user sketches in Pixiv, or change user settings in Mailchimp

Threat: CSRF by Forging State-changing POST

Threat

- Forge POST requests with GET to bypass Lax protection



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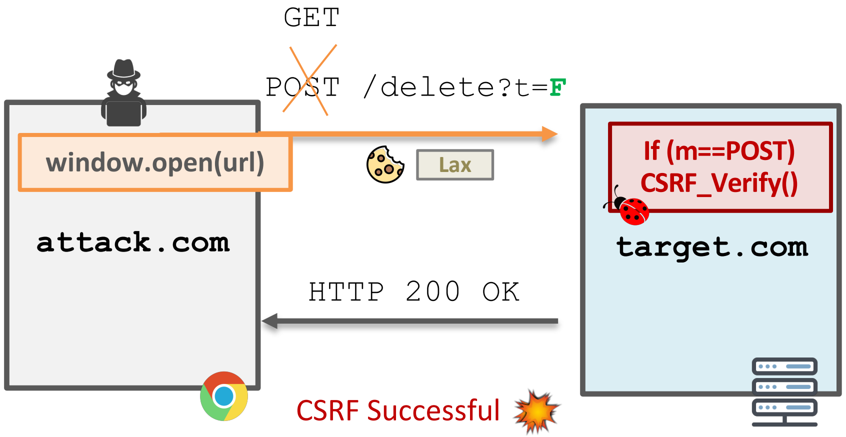

Threat: CSRF by Forging State-changing POST

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- Forge POST requests with GET to bypass Lax protection

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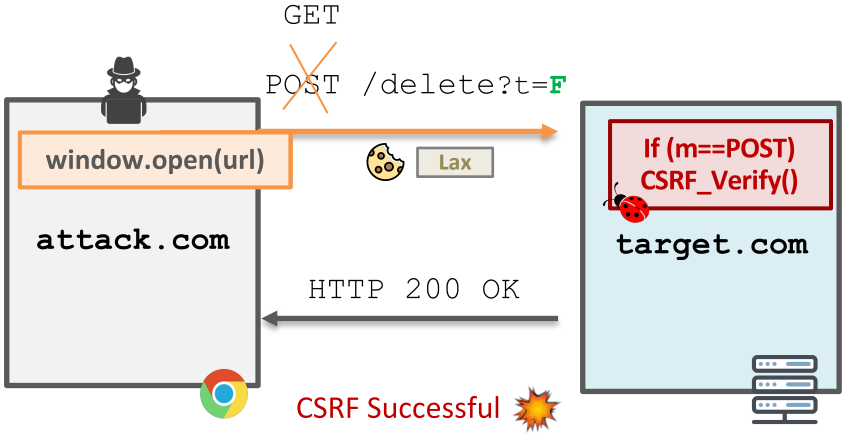
- 6.2K state-changing POST in webapps of Alexa top 1K
- Selected one random request per webapp
- Checked CSRF by replaying the request with GET



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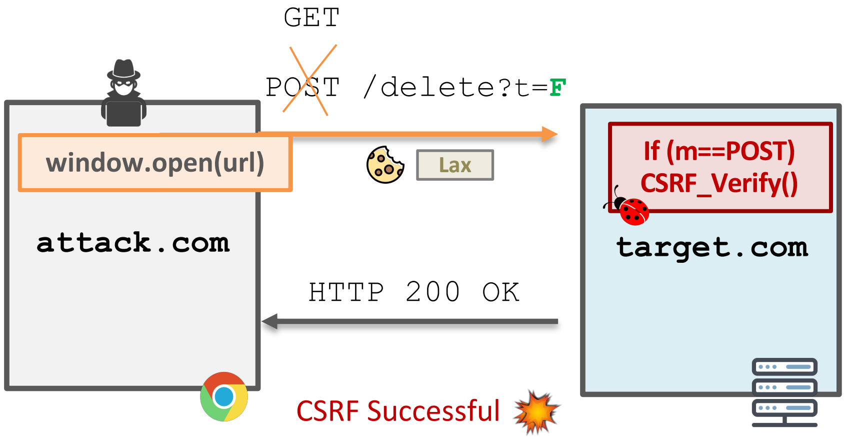

Results

- 1.5% of state-changing POST requests are forgeable with GET ⚠
- Affected popular sites:
  - Add or remove movies from user watchlist in IMDB
  - Remove notification alerts in Meetup

New Threats: Policy Downgrades

Intra-page Inconsistency

- Webapps may set redundant cookies to support incompatible clients
- **Bypass:** cookies with no `SameSite` and `Strict`, or `Lax` and `None`

Vuln: 1.4% of top 500 sites, e.g., GitHub, CNN, and Yahoo

```
// for incompatible clients
Set-cookie: 3pc-legacy=value;
// for newer clients
Set-cookie: 3pc=value; SameSite=Strict;
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- Different policies for the same cookie across two webpages

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GET /account.php \r\n

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GET /index.php \r\n

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User-Agent Inconsistency

- Different SameSite policy based on the User-Agent (e.g., mobile vs desktop)

Vuln: 1.8% of the top 500K sites, 138 webapps among the top 1K sites

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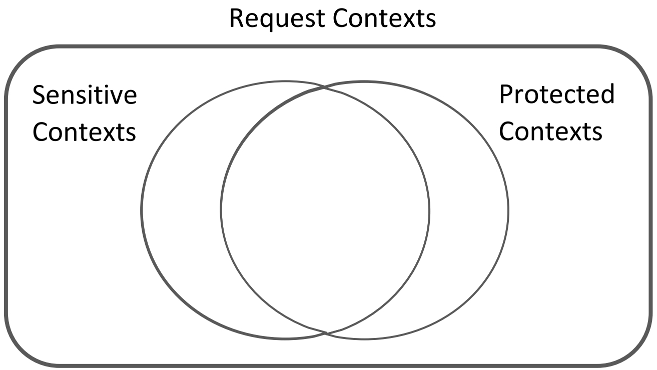

Request Contexts

Sensitive Contexts

Protected Contexts

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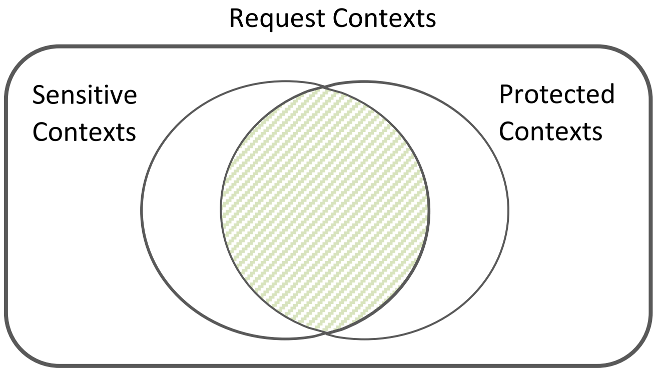
✓ Lax-by-default cookies significantly reduce the attack surface for XS attacks



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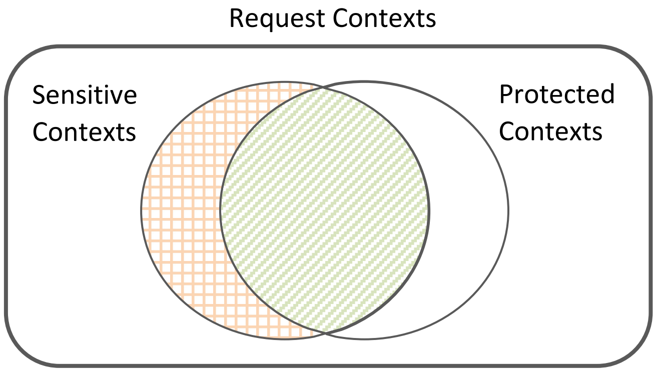

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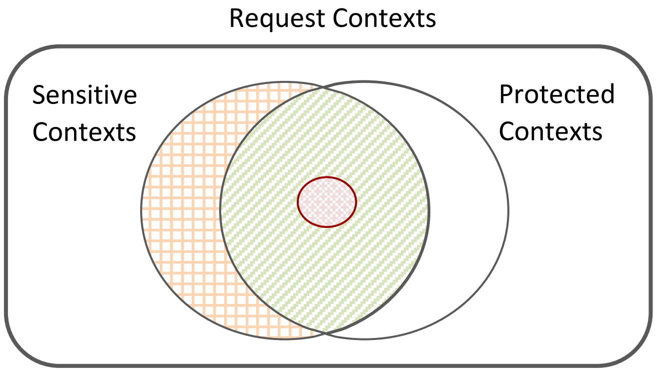
The Bad ☠ Implementation mistakes can lead to SameSite policy bypass



RQ4: Browser Inconsistencies and Web Frameworks

- Web browsers exhibit seven divergent behaviours wrt. SameSite cookie policy
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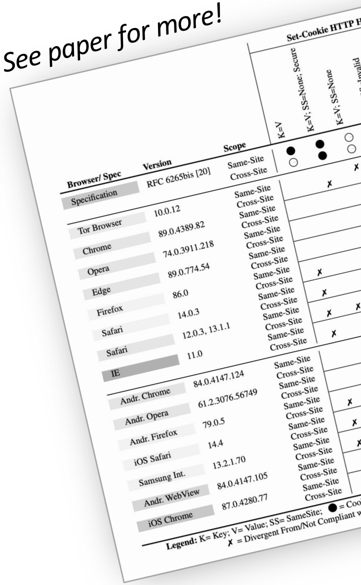

See paper for more!

			Set-Cookie HTTP H			
Browser/ Spec	**Version**	**Scope**	K=V	K=V; SS=None; Secure	K=V; SS=None	S=Invalid
Specification	RFC 6265bis [20]	Same-Site	●	●	○	
		Cross-Site	○	●	○	
Tor Browser	10.0.12	Same-Site			✗	
		Cross-Site		✗		
Chrome	89.0.4389.82	Same-Site				
		Cross-Site				
Opera	74.0.3911.218	Same-Site				
		Cross-Site				
Edge	89.0.774.54	Same-Site				
		Cross-Site				
Firefox	86.0	Same-Site				
		Cross-Site	✗			
Safari	14.0.3	Same-Site				
		Cross-Site	✗			
Safari	12.0.3, 13.1.1	Same-Site				
		Cross-Site	✗	✗		
IE	11.0	Same-Site				
		Cross-Site	✗			
Andr. Chrome	84.0.4147.124	Same-Site				
		Cross-Site				
Andr. Opera	61.2.3076.56749	Same-Site				
		Cross-Site				
Andr. Firefox	79.0.5	Same-Site				
		Cross-Site	✗			
iOS Safari	14.4	Same-Site				
		Cross-Site	✗			
Samsung Int.	13.2.1.70	Same-Site				
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		Cross-Site				
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Legend: K= Key; V= Value; SS= SameSite; ● = Coo
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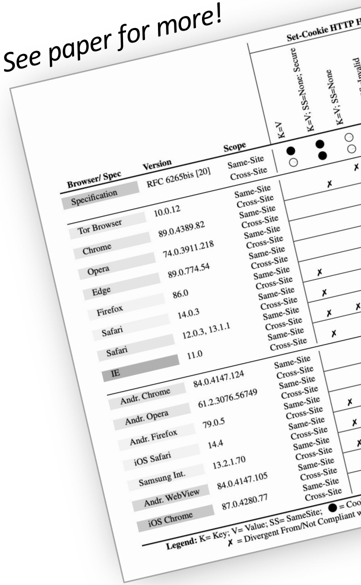

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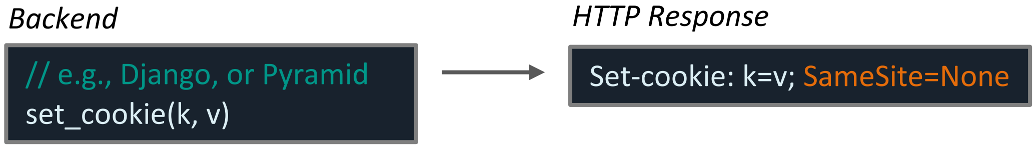
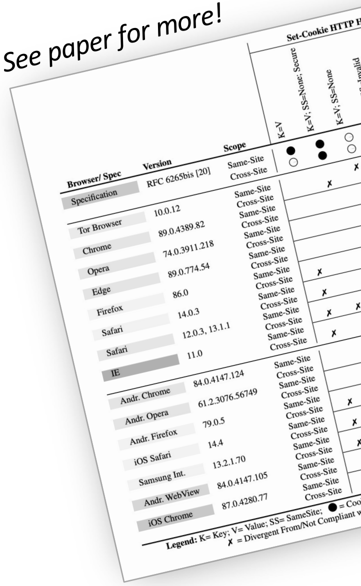


Backend

```
// e.g., Django, or Pyramid
set_cookie(k, v)
```

HTTP Response

```
Set-cookie: k=v; SameSite=None
```



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HELMHOLTZ CENTER FOR
INFORMATION SECURITY

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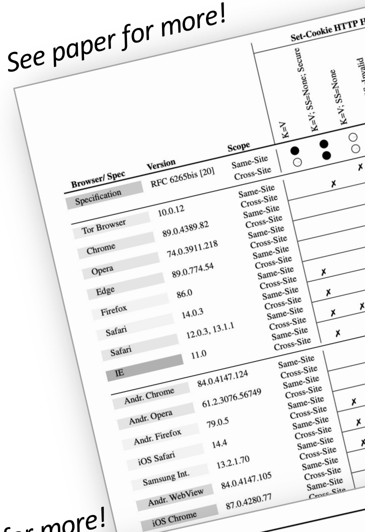

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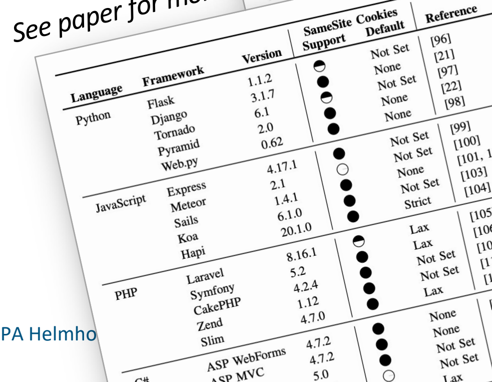

Language	Framework	Version	SameSite Cookies Support	SameSite Cookies Default	Reference
Python	Flask	1.1.2	◓	Not Set	[96]
	Django	3.1.7	●	None	[21]
	Tornado	6.1	◓	Not Set	[97]
	Pyramid	2.0	●	None	[22]
	Web.py	0.62	●	None	[98]
JavaScript	Express	4.17.1	●	Not Set	[99]
	Meteor	2.1	○	Not Set	[100]
	Sails	1.4.1	●	None	[101, 1
	Koa	6.1.0	●	Not Set	[103]
	Hapi	20.1.0	●	Strict	[104]
PHP	Laravel	8.16.1	◓	Lax	[105
	Symfony	5.2	●	Lax	[106
	CakePHP	4.2.4	●	Not Set	[10
	Zend	1.12	●	Not Set	[1
	Slim	4.7.0	●	Lax	[1
C#	ASP WebForms	4.7.2	●	None	
	ASP MVC	4.7.2	●	None	
		5.0	●	Not Set	
			○	Not Set	
				Lax	

Conclusion

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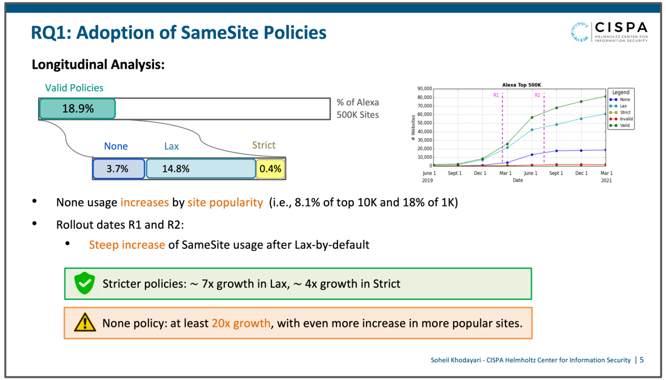

RQ1: Adoption of SameSite Policies

Longitudinal Analysis:

Valid Policies

18.9%

% of Alexa 500K Sites

None Lax Strict

3.7% 14.8% 0.4%

- None usage increases by site popularity (i.e., 8.1% of top 10K and 18% of 1K)
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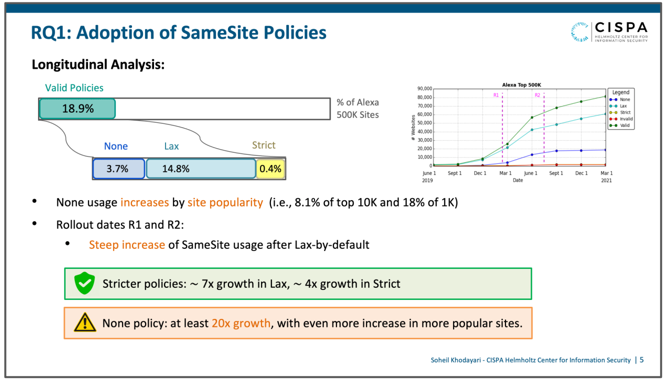

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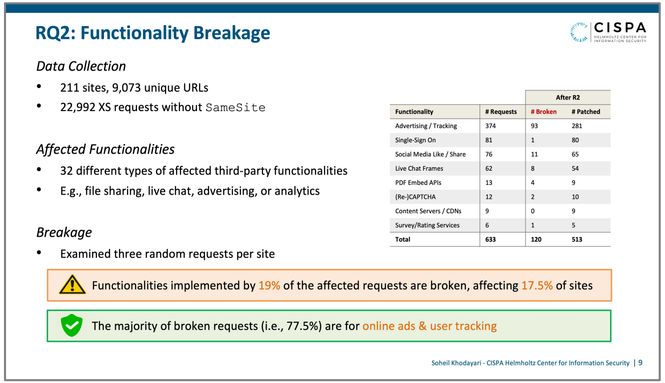

RQ2: Functionality Breakage

Data Collection

- 211 sites, 9,073 unique URLs
- 22,992 XS requests without `SameSite`

Affected Functionalities

- 32 different types of affected third-party functionalities
- E.g., file sharing, live chat, advertising, or analytics

Breakage

- Examined three random requests per site

		After R2	
Functionality	**# Requests**	**# Broken**	**# Patched**
Advertising / Tracking	374	93	281
Single-Sign On	81	1	80
Social Media Like / Share	76	11	65
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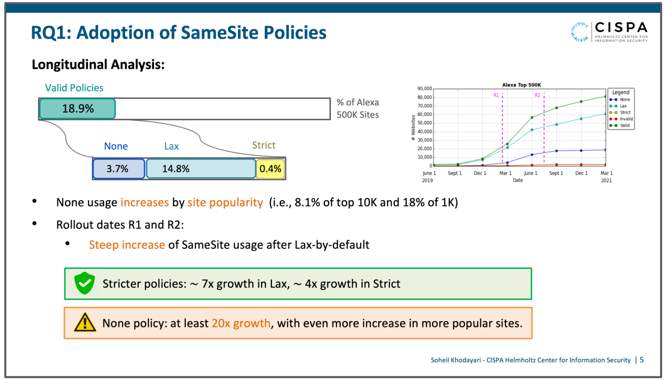

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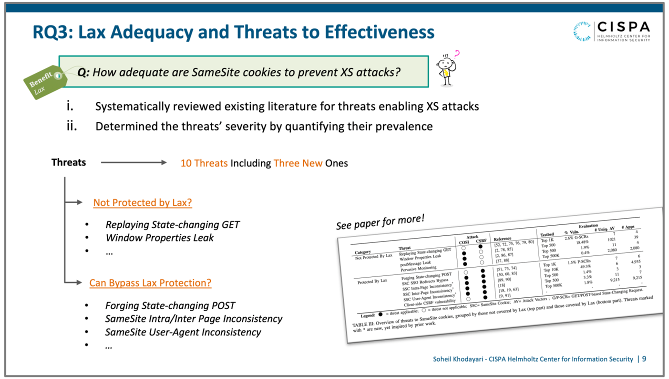

RQ3: Lax Adequacy and Threats to Effectiveness

Benefit Lax

Q: *How adequate are SameSite cookies to prevent XS attacks?*

i. Systematically reviewed existing literature for threats enabling XS attacks

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Threats → 10 Threats Including Three New Ones

Not Protected by Lax?

- *Replaying State-changing GET*
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- …

Can Bypass Lax Protection?

- *Forging State-changing POST*
- *SameSite Intra/Inter Page Inconsistency*
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See paper for more!

Category	Threat	Attack COSI	Attack CSRF	Reference	Evaluation Testbed	Evaluation % Vuln.	Evaluation # Uniq. AV	Evaluation # Apps
Not Protected By Lax	Replaying State-changing GET	○	●	[52, 72, 75, 76, 79, 80]	Top 1K	2.6% G-SCRs	7	4
	Window Properties Leak	●	○	[2, 78, 85]	Top 500	18.48%	1021	39
	postMessage Leak	●	○	[2, 86, 87]	Top 500	1.9%	11	4
	Pervasive Monitoring	●	○	[37, 88]	Top 500K	0.4%	2,080	2,080
Protected By Lax	Forging State-changing POST	○	●	[51, 73, 74]	Top 1K	1.5% P-SCRs	7	6
	SSC SSO Redirects Bypass	●	●	[50, 60, 83]	Top 10K	49.3%	6	4,935
	SSC Intra-Page Inconsistency*	●	●	[89, 90]	Top 500	1.4%	3	3
	SSC Inter-Page Inconsistency*	●	●	[18]	Top 500	3.3%	11	7
	SSC User-Agent Inconsistency*	●	●	[18, 19, 63]	Top 500K	1.8%	9,215	9,215
	Client-side CSRF vulnerability	○	●	[9, 91]	-	-	-	-

Legend: ● = threat applicable; ○ = threat not applicable; SSC= SameSite Cookie; AV= Attack Vectors ; G/P-SCR= GET/POST-based State-Changing Request.

TABLE III: Overview of threats to SameSite cookies, grouped by those not covered by Lax (top part) and those covered by Lax (bottom part). Threats marked with * are new, yet inspired by prior work.

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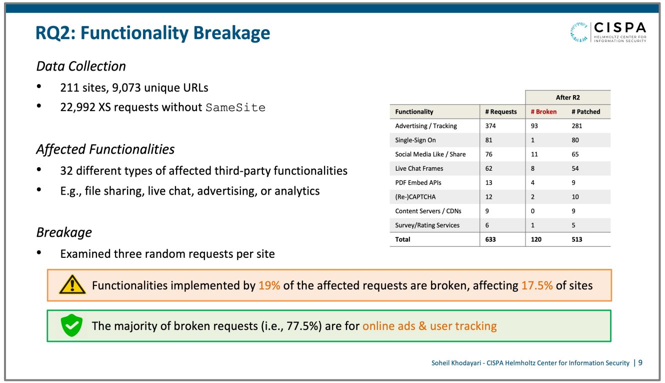

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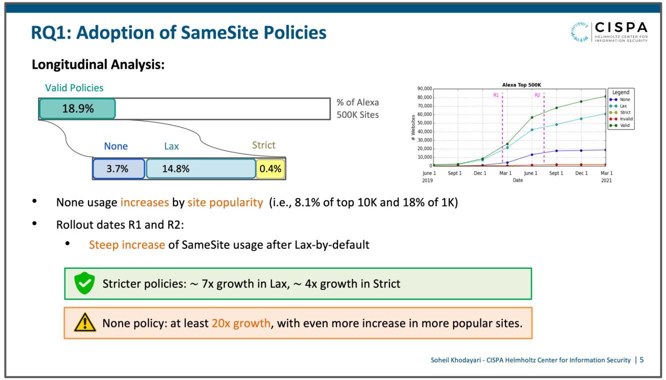

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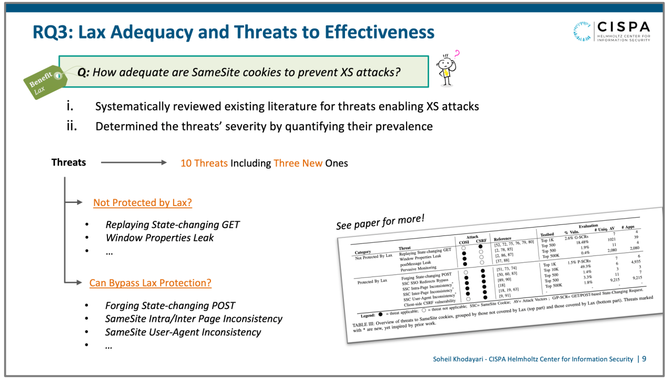

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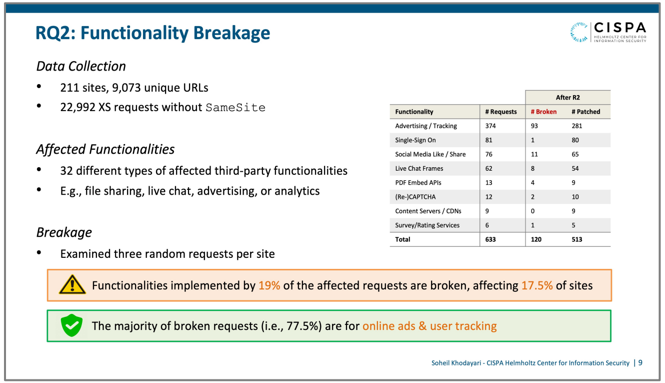

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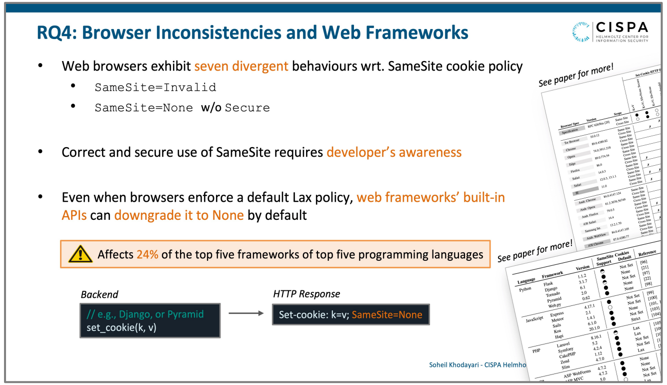

RQ4: Browser Inconsistencies and Web Frameworks

- Web browsers exhibit seven divergent behaviours wrt. SameSite cookie policy
  - `SameSite=Invalid`
  - `SameSite=None` w/o `Secure`
- Correct and secure use of SameSite requires developer's awareness
- Even when browsers enforce a default Lax policy, web frameworks' built-in APIs can downgrade it to None by default

Affects 24% of the top five frameworks of top five programming languages

See paper for more!

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Backend

```
// e.g., Django, or Pyramid
set_cookie(k, v)
```

→ *HTTP Response*

```
Set-cookie: k=v; SameSite=None
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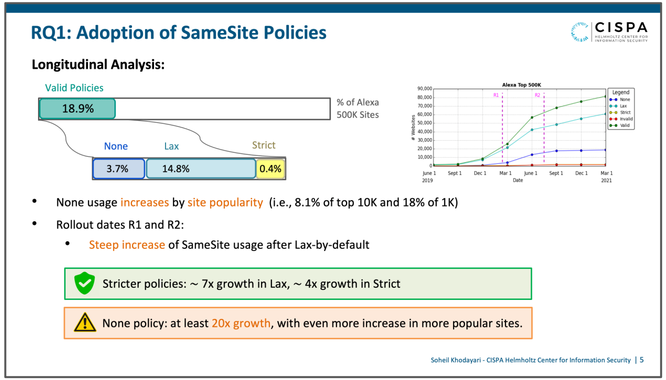
Conclusion

Thank You!



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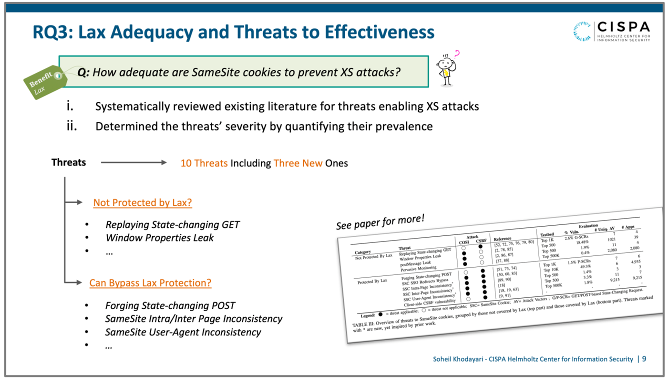

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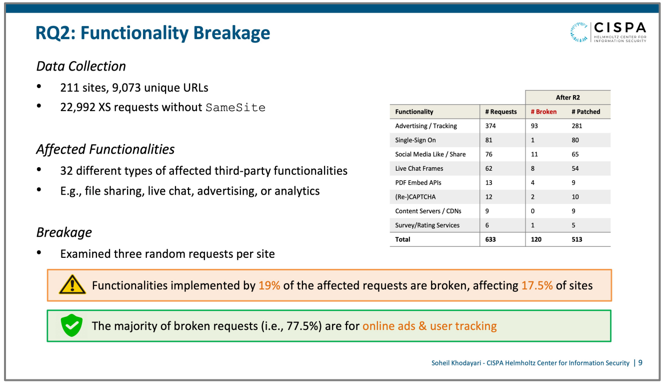

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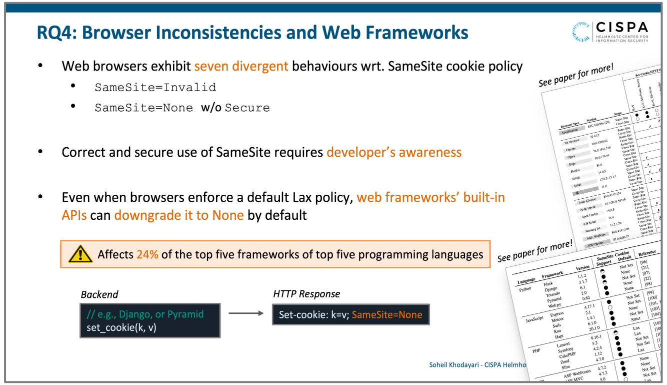

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