How the Web Tangled Itself: Uncovering the History of Client-Side Web (In)Security

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Motivation...

- Web's client side becomes more powerful every day
  - grew from static HTML rendering to fully-fledged applications
  - many "enabling" APIs such as postMessages
- Development also carries security issues
  - specific to the Web, e.g., XSS
  - general issues: e.g., trusting data from untrusted sources
- Web grew without a security blueprint into the "Tangled Web"

... and Research Questions

- **Goal: evaluate how web and security evolved**
- What were most prevalent technologies over time?
- Which security issues surfaced over time?
- What measures were introduced to countermand these issues? How were they adopted?
- What are the implications of the past for the future of Web security?

How to go back in time?

- Client-side code stored in The Internet Archive
  - Stores client-side code of crawled sites since 1996
  - Archives HTTP Headers (prefixed with `X-Archive-Orig-`)

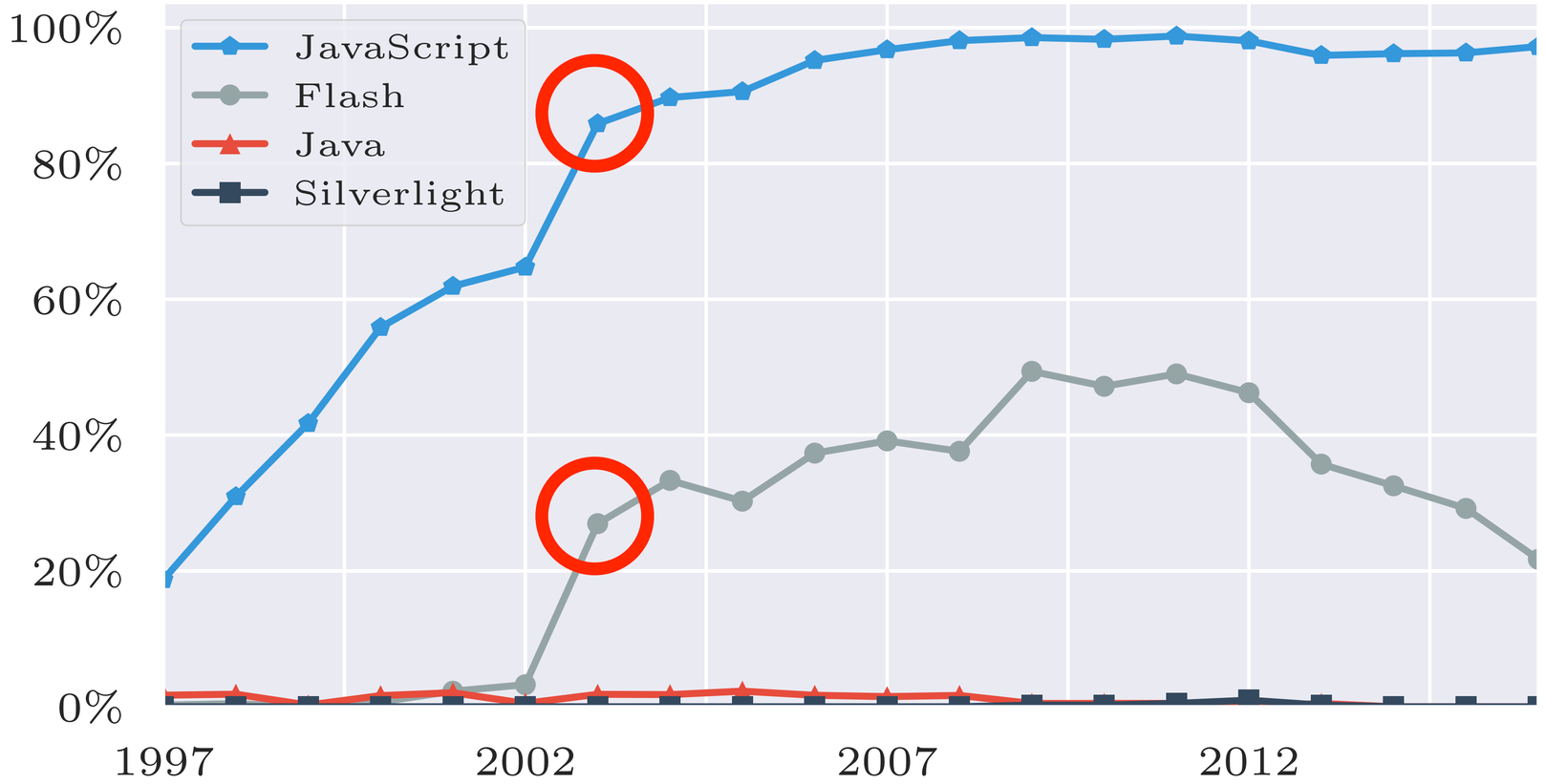
- Analyze most important sites of the time
  - 500 most frequented domains for each year
    - *Internet Jones and the Raiders of the Lost Trackers (Lerner et al., USENIX 2016)*
    - blocked access to resources outside +/- three months from original timestamp
  - Main page + first level of same-domain links
    - 659,710 unique URLs, 1,376,429 frames, 5,440,958 scripts, 21,169,634 HTTP headers

Evolution of Client-Side Technology

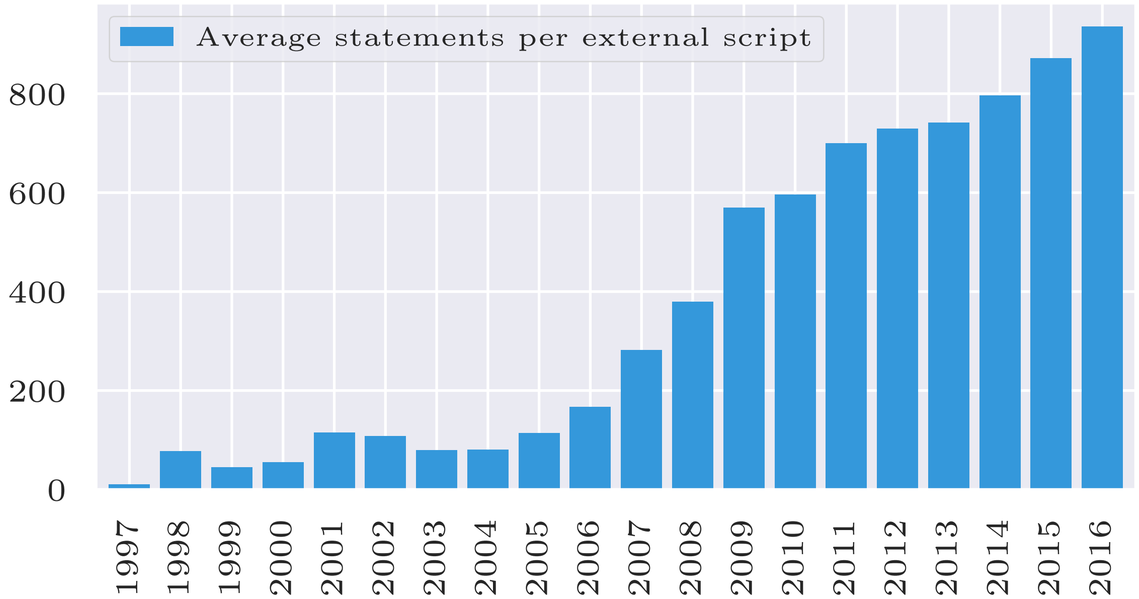
Discovered Security Issues

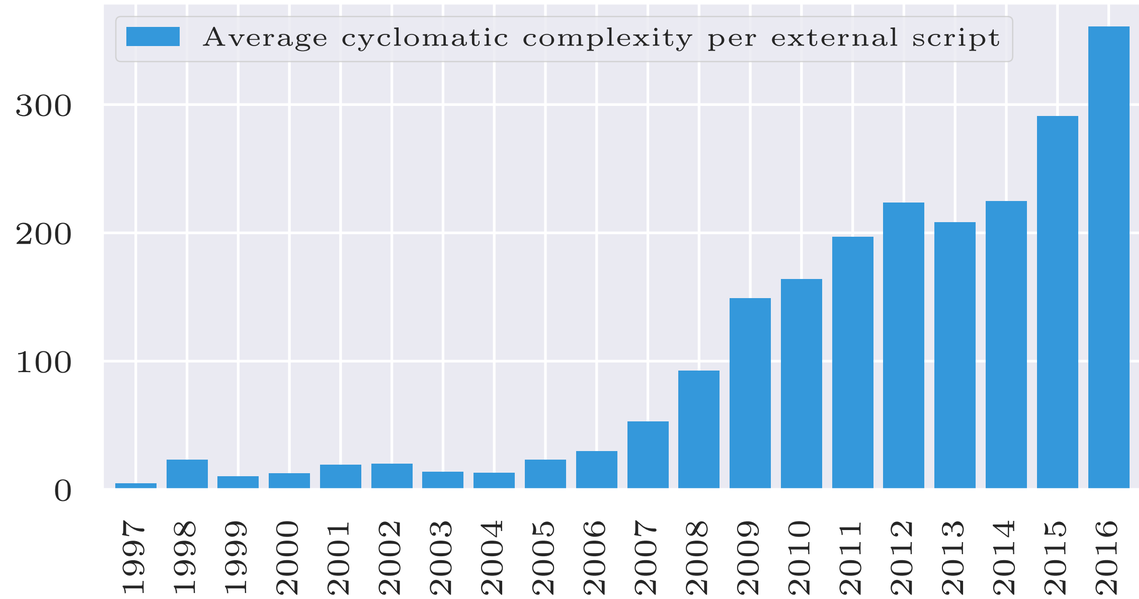
Indicators of Security Awareness/Measures

Technologies used by the top 500 sites

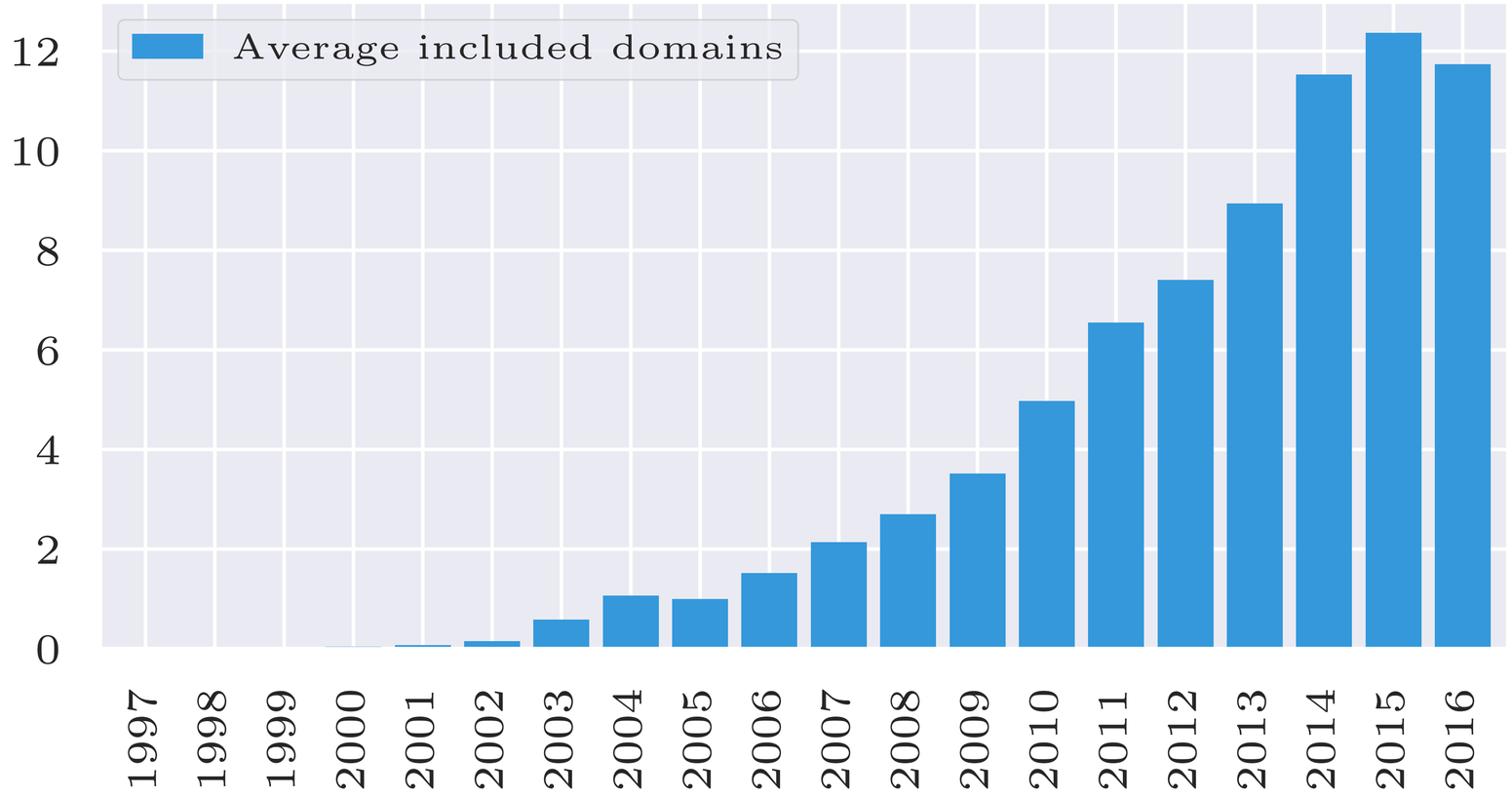


JavaScript complexity on the rise





Multiple parties contribute JavaScript code



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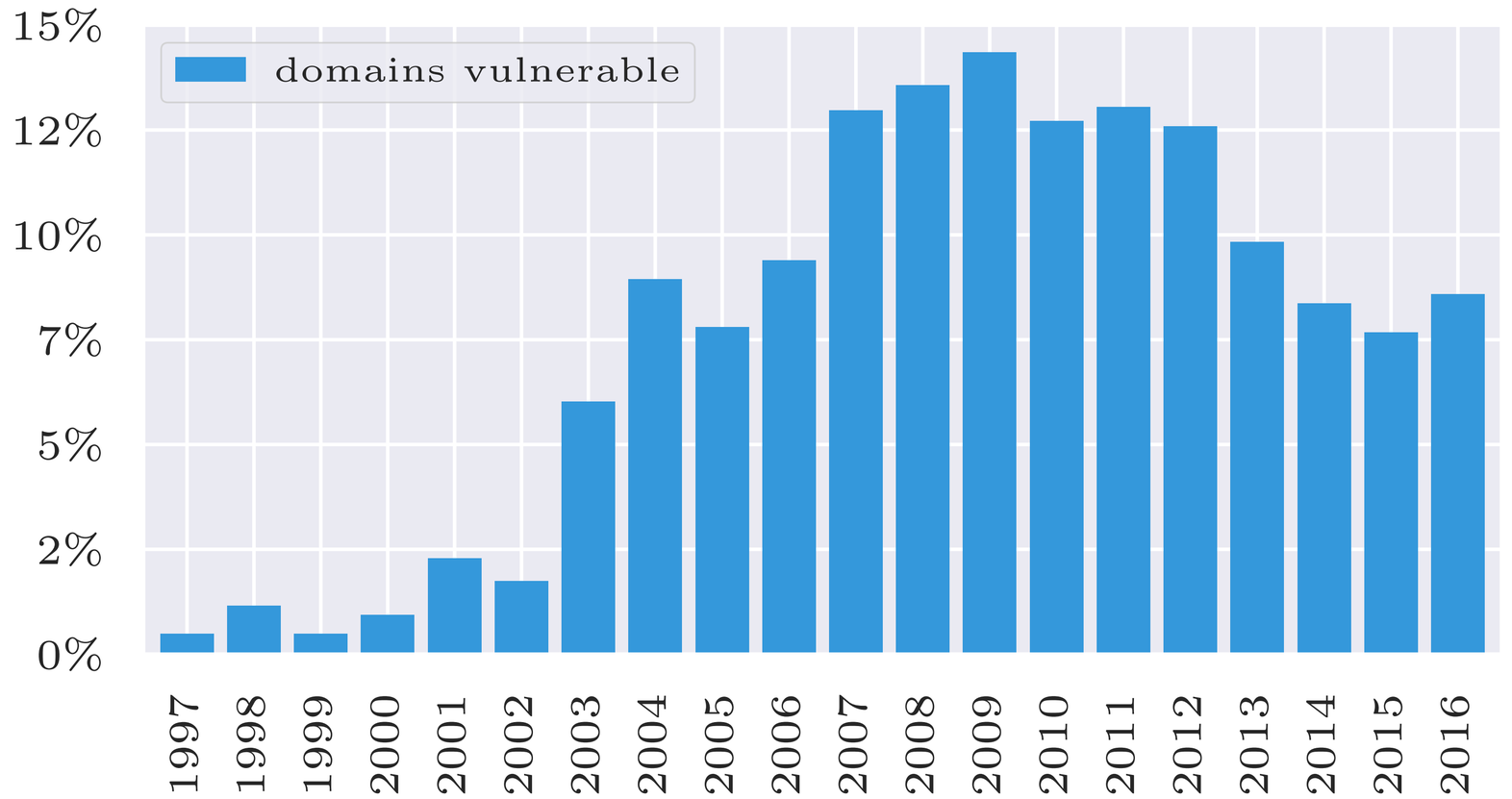
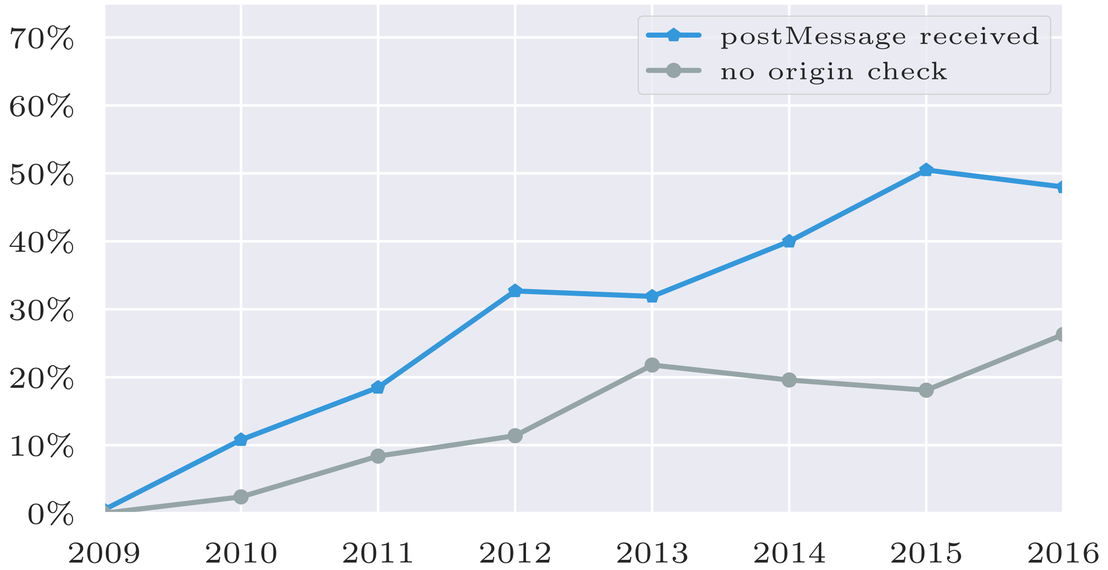
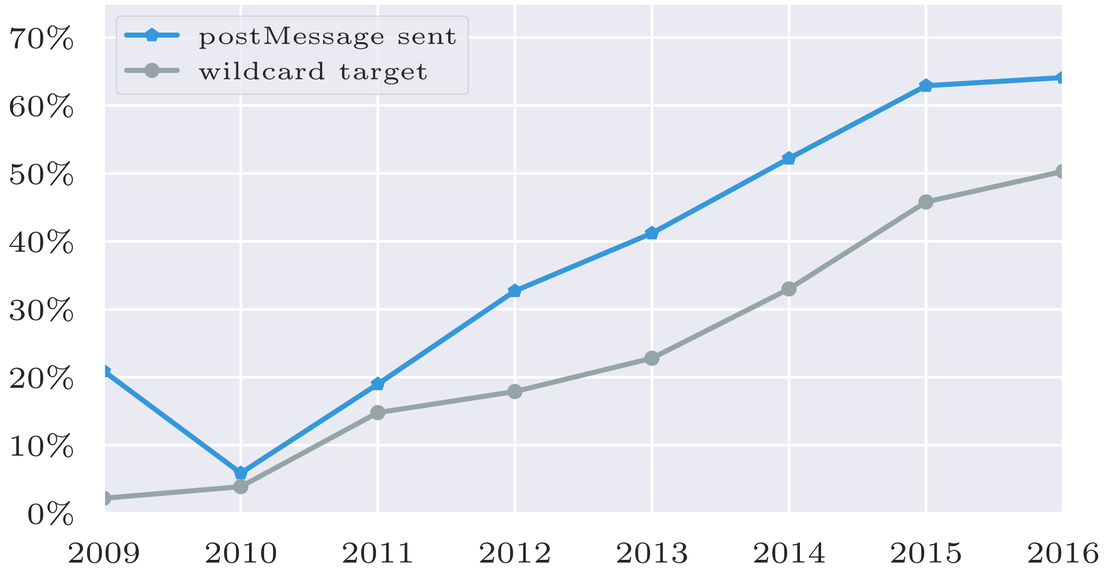
Client-Side Cross-Site Scripting still going strong



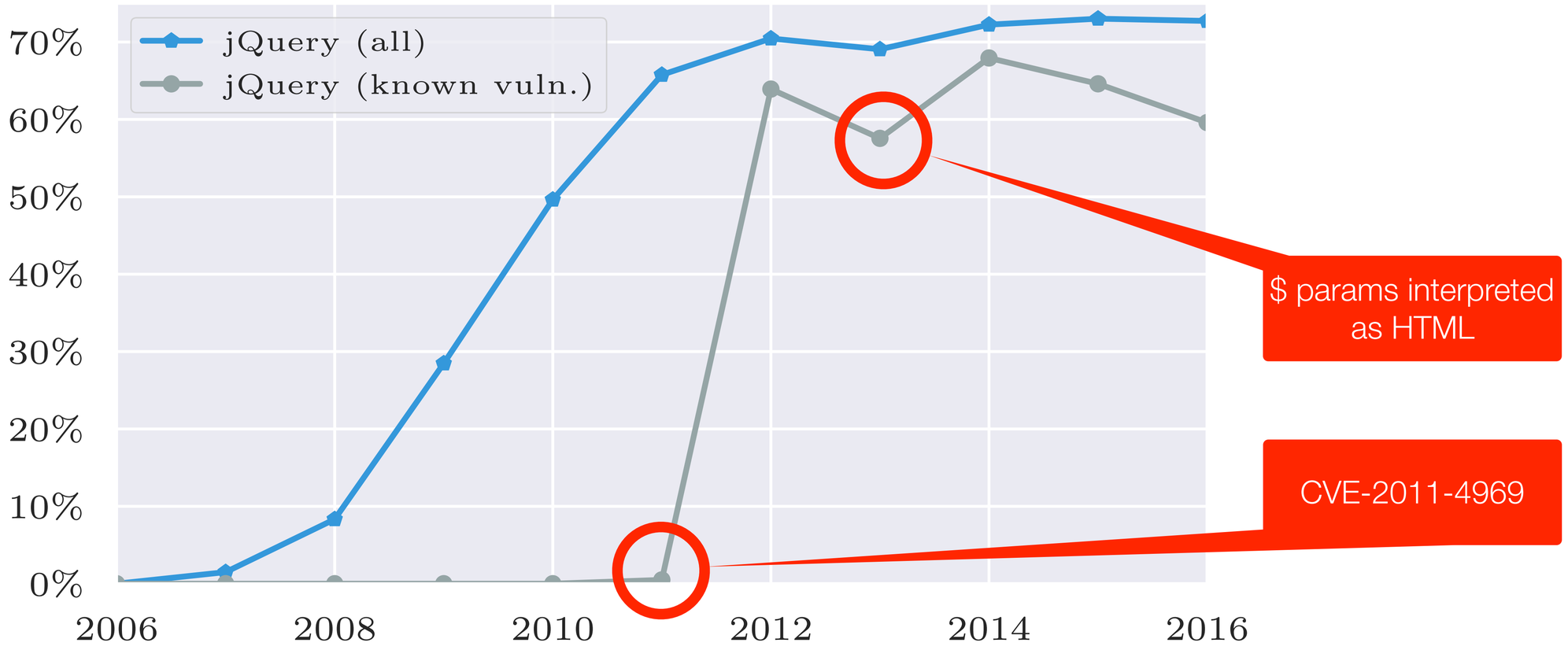
Insecure postMessage handling

- postMessages allow origin and destination verification
  - Protects integrity and confidentiality

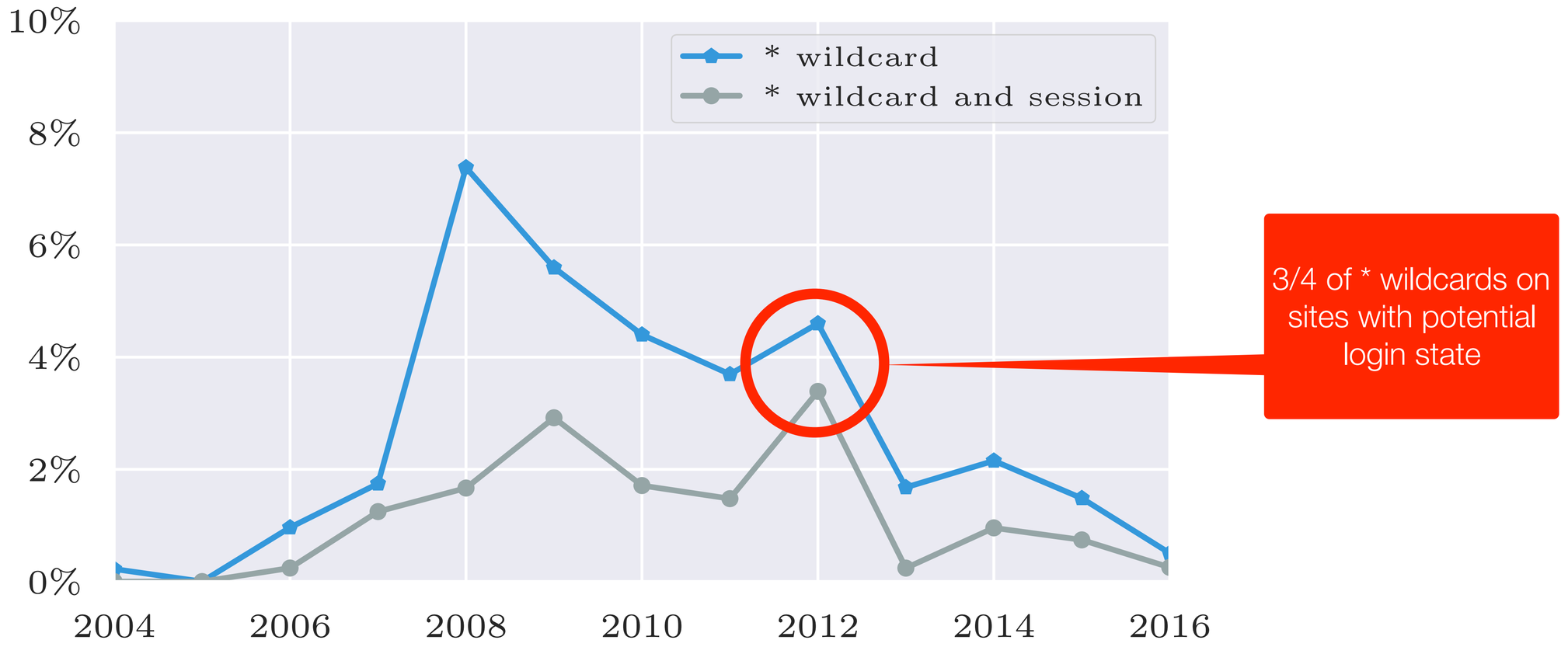




Known vulnerable jQuery versions



Flash Cross-Domain Policies



Evolution of Client-Side Technology

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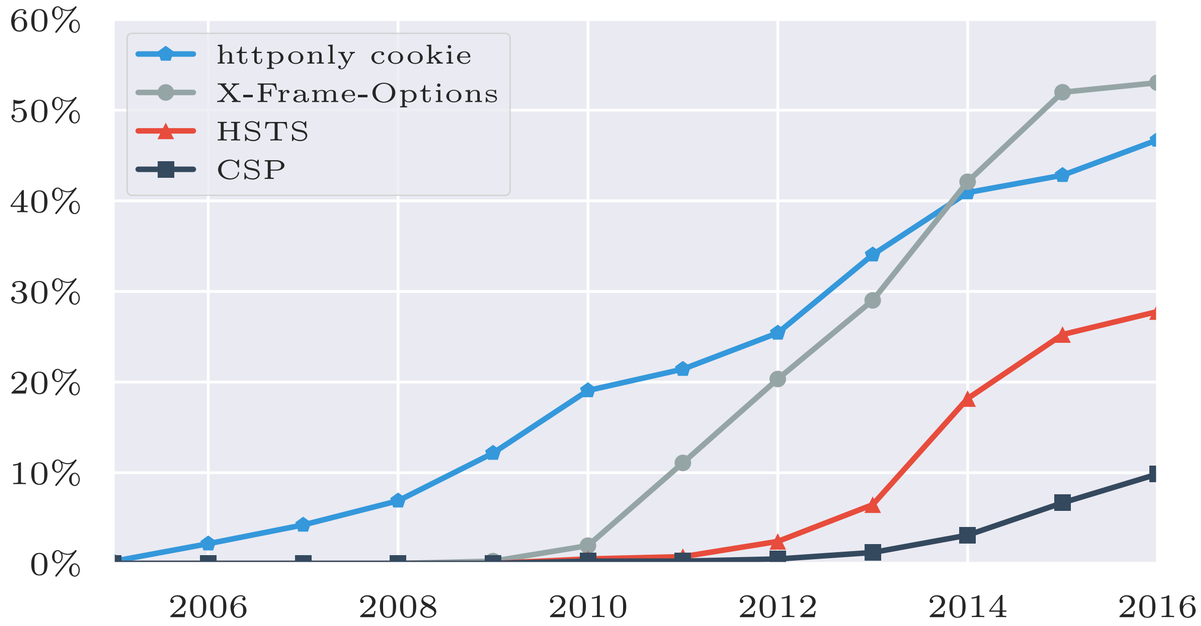
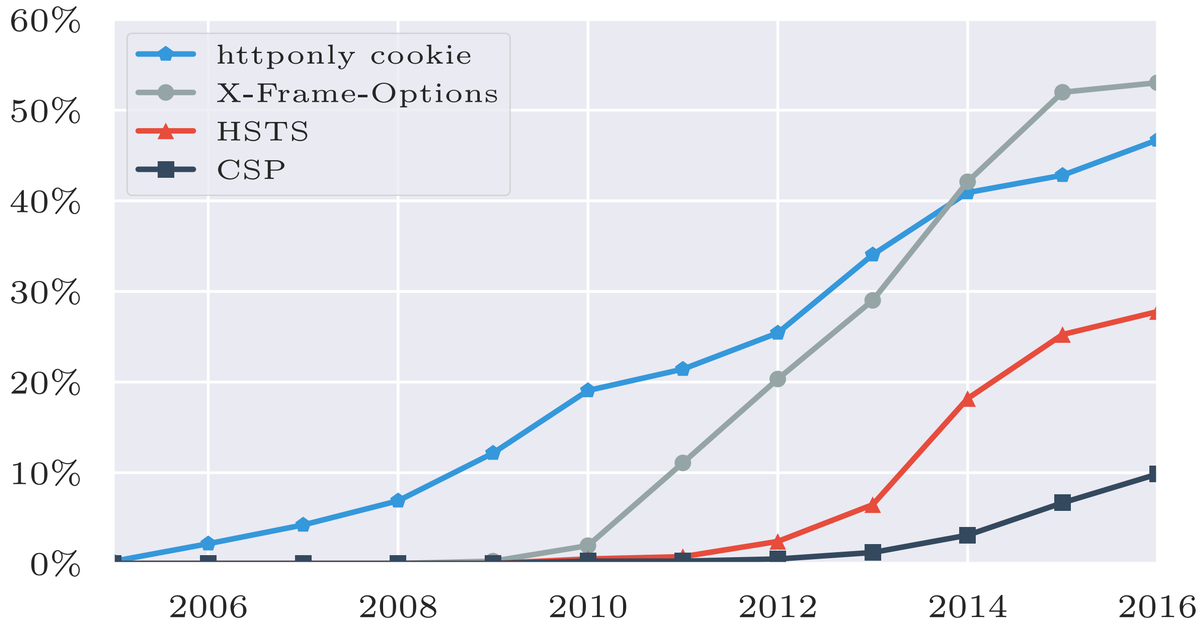
HTTP only cookies

- Introduced in 2001 for IE
  - meant as XSS mitigation
  - cookies not accessible from JavaScript
- First used in 2006, steady increase since 2009
  - almost 50% adoption in 2016
  - lower bound as crawler does not log in



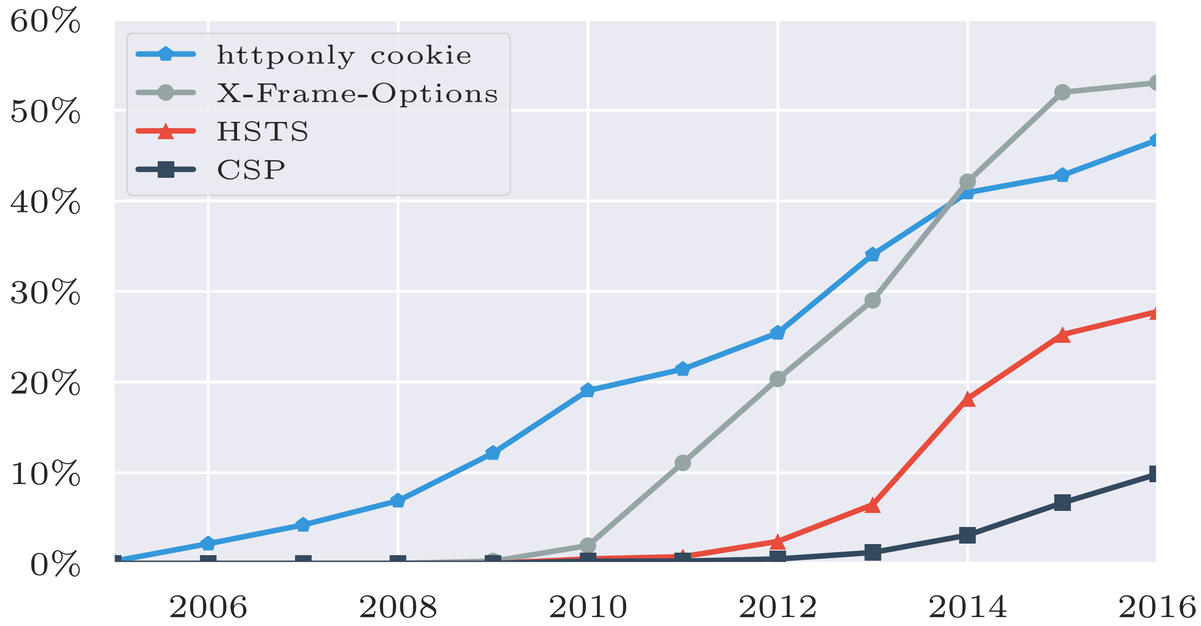
Clickjacking Protection through X-Frame-Options

- Introduced in 2009 for IE/Firefox
  - ability to disallow (third-party) framing
- First used in 2010, steady increase since then
  - over 50% adoption by now
- Deprecated by CSP since 2015
  - still slight increase in 2016



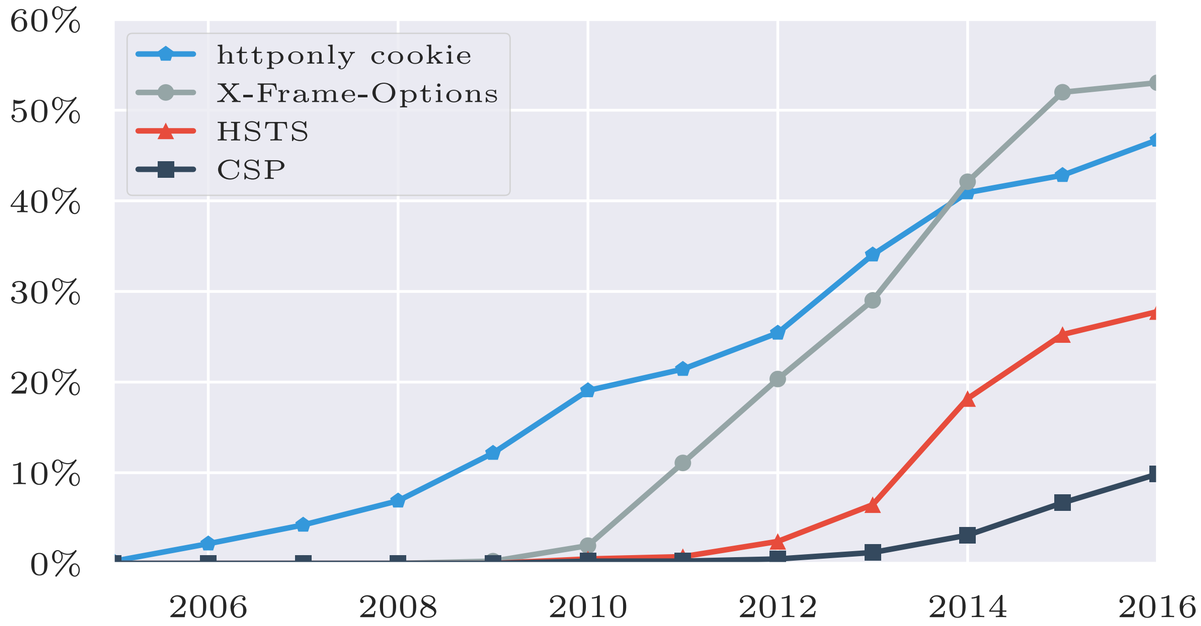
HTTP Strict Transport Security

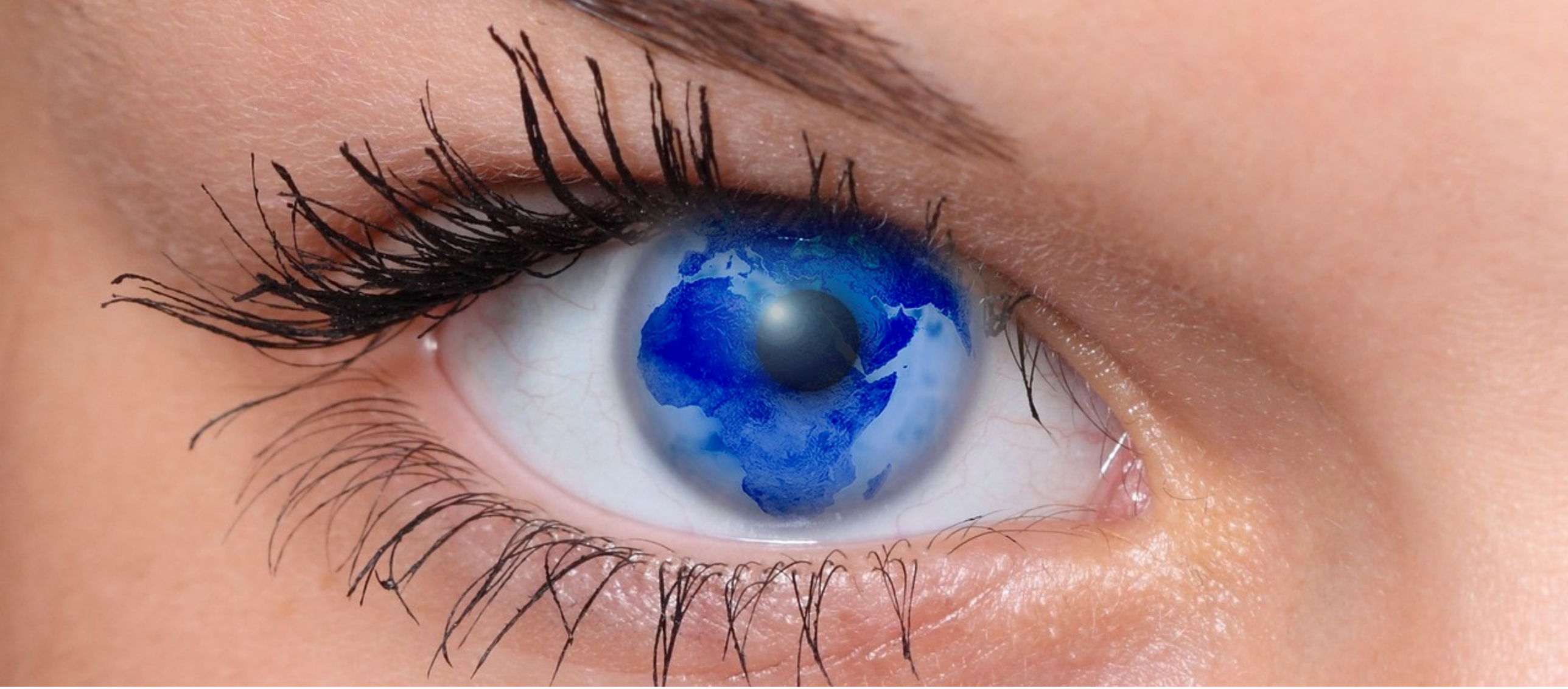
- Introduced in 2010 for Chrome/Firefox
  - auto-upgrades HTTP to HTTPS
- First used in 2012, steady increase
  - almost 30% adoption in 2016



Content Security Policy

- Introduced in 2010 for Firefox
  - explicit whitelisting of resources, e.g., scripts, images, ..
- First used in 2013, very slow increase
  - less than 10% after three years





Insights of our Analysis

Client-Side Technology

- Web's complexity is still on the rise
  - steady increase in code size and cyclomatic complexity
- Increased involvement of third-parties
  - 12 distinct origins in 2016
  - including several vulnerable versions of libraries
- Towards a multi-origin Web
  - e.g., increase in postMessages for cross-domain communication
  - applications no longer bound to a single origin

Client-Side Security

CISPA Center for IT-Security, Privacy and Accountability

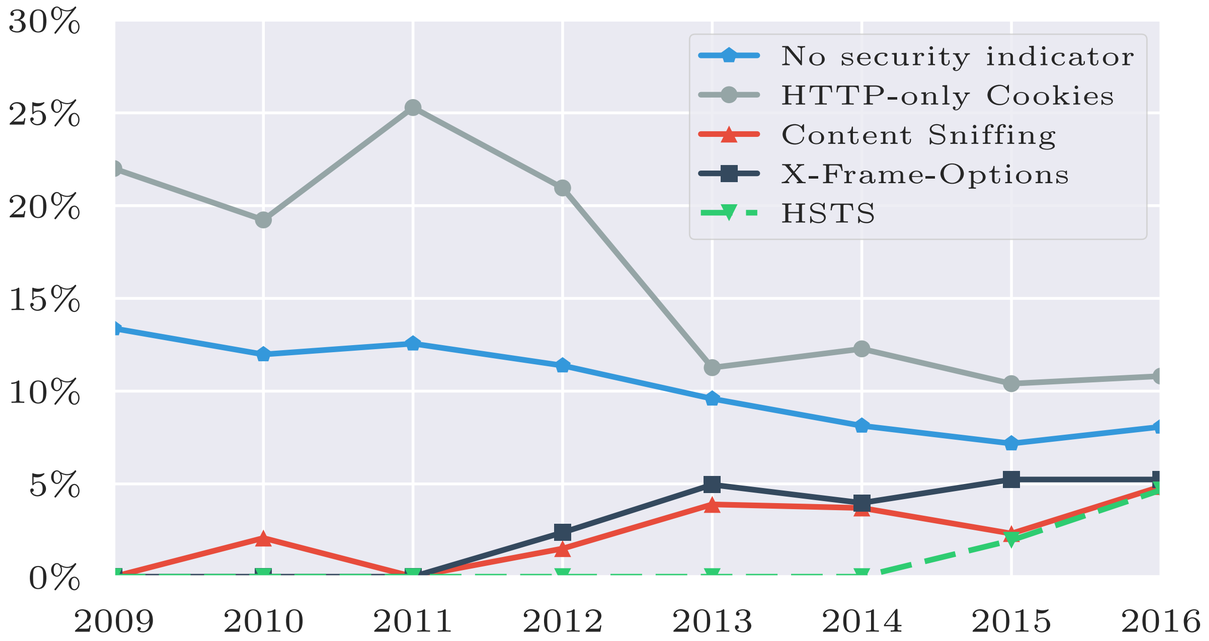
- Client-Side XSS remains constant issue
  - up to 15% vulnerable in 2009, still around 8% in 2016
- Utility trumps Security
  - Even safe defaults are circumvented, e.g, `crossdomain.xml`
- Complexity of Deploying Security Measures
  - Easy to deploy measures are rolled out rapidly, e.g., X-Frame-Options
  - In contrast, CSP is very slow to market

Confirming Intuitions

- Applications become more and more complex 
- Simple security mechanisms are quickly adopted 
- More involved mechanisms (e.g., CSP) lack behind in adoption 
- Administrators aware of general security concepts have less vulnerabilities. 

Correlating Client-Side XSS and Awareness Indicators

- HTTPonly Cookies
  - Fraction of sites with HTTPonly and XSS higher than no measure and XSS
- X-Frame-Options (2010) & HSTS (2013)
  - Early adopters rarely have an XSS, fraction increases, almost at baseline in 2016
- CSP
  - CSP sites don't even have any Client-Side Cross-Site Scripting
  - Might be early adopter phenomenon



Threats to Validity

- Limited view into applications (missing login)
  - not all cookies stored
  - protected resources might have other headers (e.g., X-Frame-Options)
- Blocked "Bubble escapes"
  - blocked access to newer resources
  - JavaScript was collected dynamically
- However, historical results align with previous papers
  - cross-domain policies, JS inclusions, Client-Side XSS, outdated libraries

Lessons learnt from our 20-year study

- Ease of Use for Security Measures
  - simple security measures are quickly adopted
- Make Security Mandatory
  - e.g., postMessage origin must be accessed before data can be accessed
  - soft integration of stricter policies: warn first, block later
- Improve tools for and awareness of developers
  - tools help to rewrite secure code
  - updatability on libraries

```
function loadAdvertisementInsecure() {
  document.write("<script src='http://ad.com/?referrer="
   + location.href + "'></script>");
}
```

```
function loadAdvertisementSecure() {
 var script = document.createElement("script");
 script.src = 'http://ad.com/?referrer=' + location.href;
 document.body.appendChild(script);
}
```

Conclusion

- We studied evolution of the Client side over 20 years
  - technologies used
  - discovered vulnerabilities
  - deployed mitigation techniques
- Several intuitions could be confirmed
  - However, HTTPonly cookie sites more likely to have an XSS
- Client-Side Web Security remains hard problem
  - Protection barely keeps up with increased attack surface/flaws
  - Lessons learnt from the last 20 years should be incorporated in upcoming APIs/technologies

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Thanks! Questions?