Modern client-side defenses

Deian Stefan

Modern web “site”

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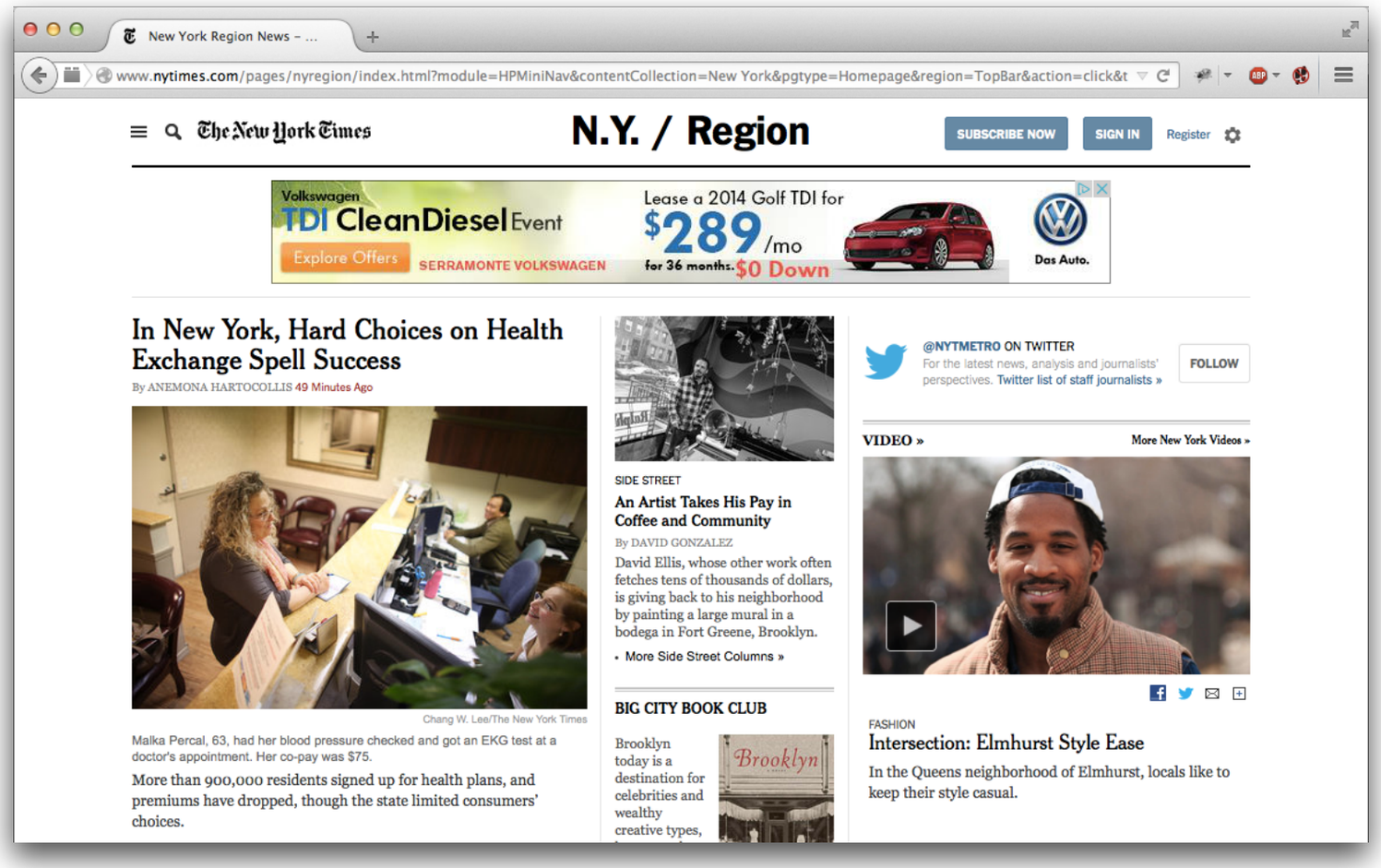

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Page code

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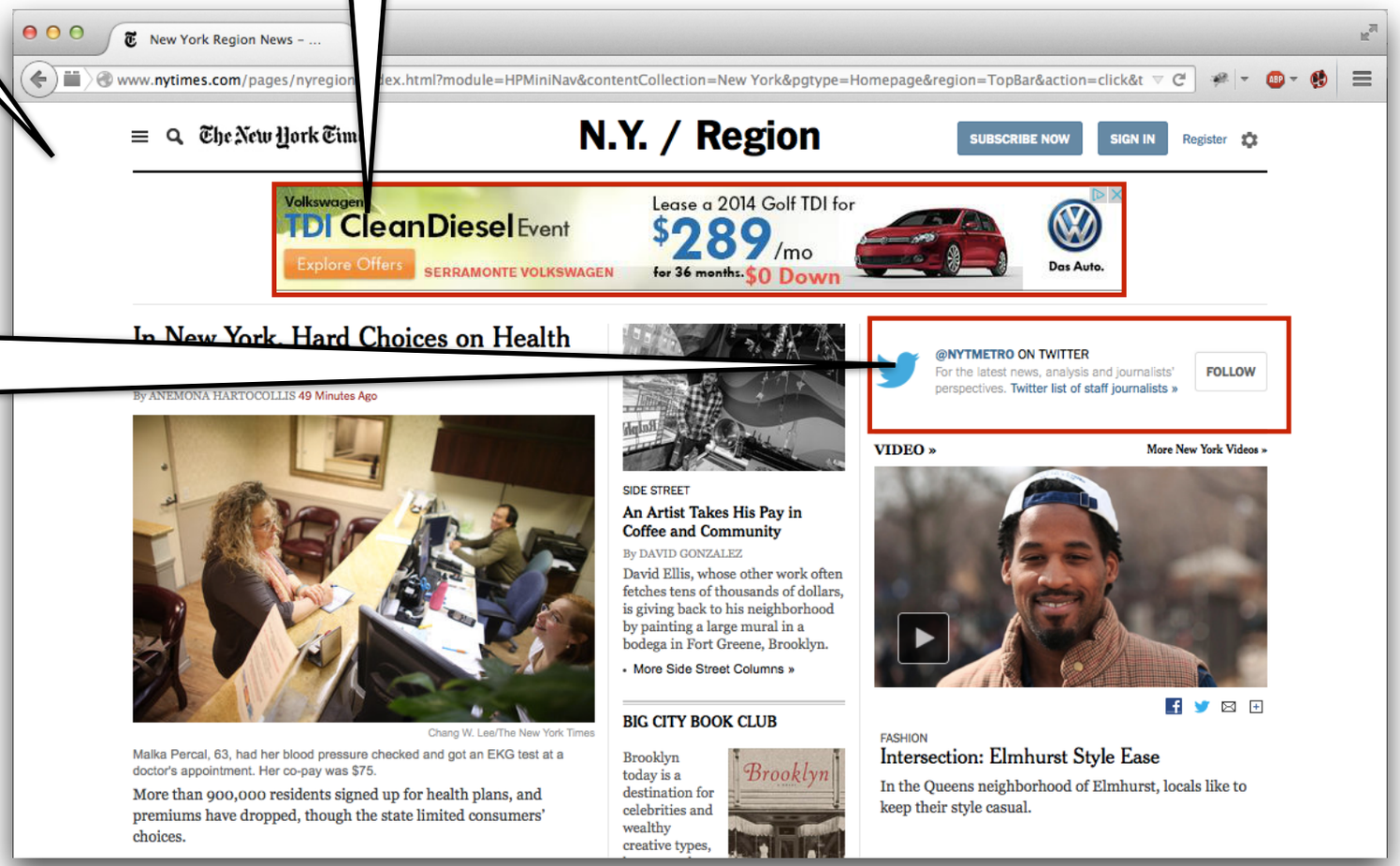

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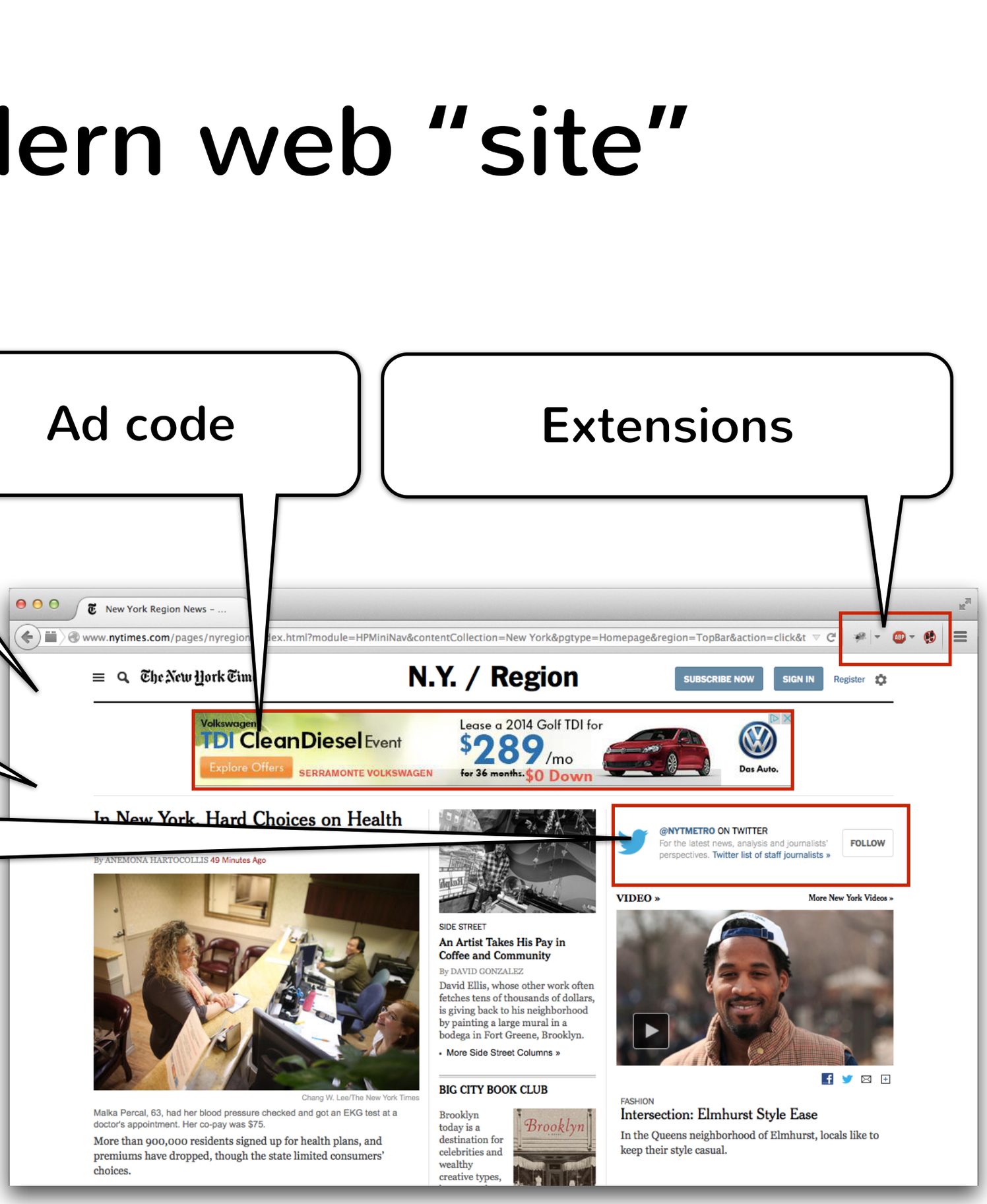

Sites handle sensitive data

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

Others want this information

- **Financial data**
  - Black-hat hackers, ...
- **Health data**
  - Insurance companies, ...
- **Personal data**
  - Ad companies, big governments, ...

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The acting parties on a site

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

Basic questions

- 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?
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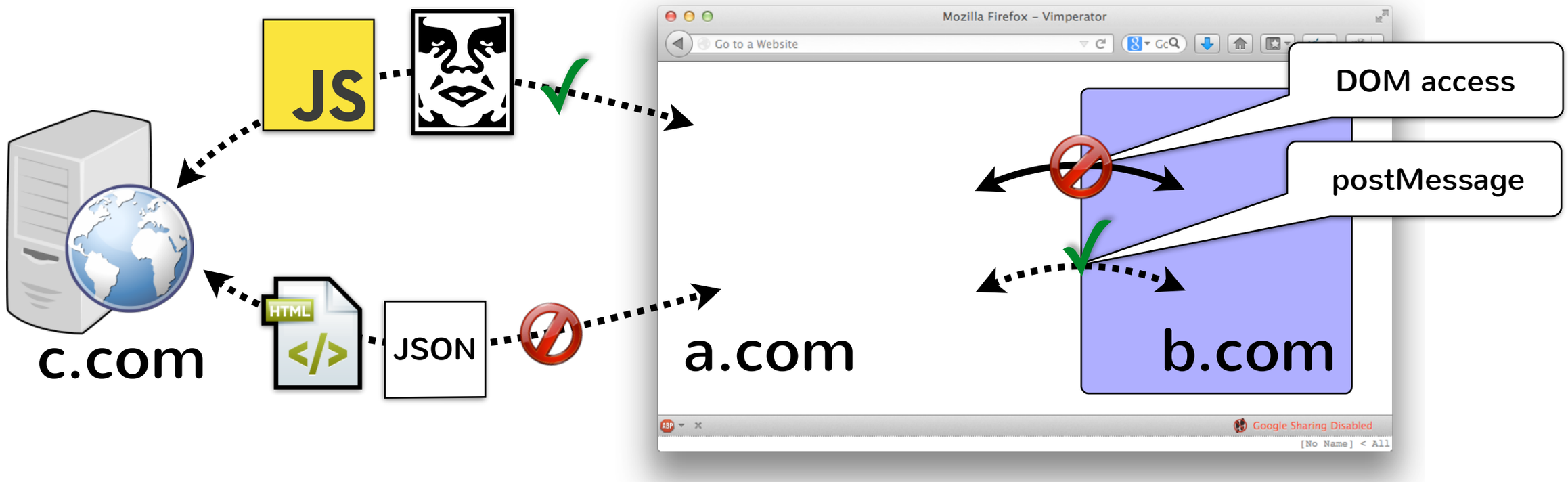
Recall: Same origin policy

Idea: isolate content from different origins

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



Is the same origin policy good enough?

The SOP is not strict enough

- **Third-party libs run with privilege of the page**
- **Code within page can arbitrarily leak data**
  - How?
- **iframes isolation is limited**
  - Can't isolate user-provided content from page (why?)
  - Can't isolate third-party ad placed in iframe (why?)

The SOP is not strict enough

- Third-party libs run with privilege of the page
- Code within page can arbitrarily leak data
  - How?
- iframes isolation is limited
  - Can't isolate us
  - Can't isolate th

The SOP is not flexible enough

- **Can't read cross-origin responses**
  - What if we want to fetch data from provider.com?
  - JSONP
    - To fetch data, insert new script tag:
      `<script src="https://provider.com/getData?cb=f"></script>`
    - To share data, reply back with script wrapping data
      `f({ ...data... })`
  - Why is this a terrible idea?
    - Provider data can easily be leaked (CSRF)
    - Page is not protected from provider (XSS)

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Outline: modern mechanisms

- iframe sandbox
- Content security policy (CSP)
- Web workers
  - Not originally intended for security; but they help
- Subresource integrity (SRI)
- Cross-origin resource sharing (CORS)

iframe sandbox

Idea: restrict actions iframe can perform

Approach: set sandbox attribute, by default:

- disallows JavaScript and triggers (autofocus, autoplay videos etc.)
- disallows form submission
- disallows popups
- disallows navigating embedding page
- runs page in unique origin: no storage/cookies

Whitelisting privileges

Can enable dangerous features by whitelisting:

- **allow-scripts:** allows JS + triggers (autofocus, autoplay, etc.)
- **allow-forms:** allow form submission
- **allow-pointer-lock:** allow fine-grained mouse moves
- **allow-popups:** allow iframe to create popups
- **allow-top-navigation:** allow breaking out of frame
- **allow-same-origin:** retain original origin

What can you do with iframe sandbox?

- Run content in iframe with least privilege
  - Only grant content privileges it needs
- **Privilege separate page into multiple iframes**
  - Split different parts of page into sandboxed iframes

E.g., least privilege: twitter button

```
<a class="twitter-share-button" href="https://twitter.com/share">Tweet</a>
<script>
window.twttr=(function(d,s,id){var js,fjs=d.getElementsByTagName(s)
[0],t=window.twttr||{};if(d.getElementById(id))return
t;js=d.createElement(s);js.id=id;js.src="https://platform.twitter.com/
widgets.js";fjs.parentNode.insertBefore(js,fjs);t._e=[];t.ready=function(f)
{t._e.push(f);};return t;}(document,"script","twitter-wjs"));
</script>
```

- What's the problem with this embedding approach?

- **Using iframes**

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

- What's the problem with this approach?

E.g., least privilege: twitter button

- With sandbox: remove all permissions and then enable JS, popups, form submission, etc.

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

  - Why is are these required (e.g., same origin)?

E.g., privilege separation: feed

- **Typically include user content inline:**

```
<div class="post">
  <div class="author">{{post.author}}</div>
  <div class="body">{{post.body}}</div>
</div>
```

  - Problem with this?

- **With iframe sandbox:**

```
<iframe sandbox srcdoc="...
<div class="post">
  <div class="author">{{post.author}}</div>
  <div class="body">{{post.body}}</div>
</div>..."></iframe>
```

  - May need allow-scripts - why? allow-same-origin ok?

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Limitations/questions on sandbox

- **Research: How can you determine what privileges you need to run a page with?**
  - Being overly restricting: breaks functionality
  - Bing overly permissive: can cause more damage
- **Research: Automatically compartmentalization?**
- **Is the loose definition of "least privilege" good enough?**
  - It mostly restricts features, not what you can do with the features; what can go wrong?

Motivation for CSP

- **Consider running library in sandboxed iframes**
  - E.g., password strength checker

  - **Desired guarantee:** checker cannot leak password
- **Problem: sandbox does not restrict exfiltration**
  - Can use XHR to write password to b.ru

Motivation for CSP

- **Can we limit the origins that the page (iframe or otherwise) can talk talk to?**
  - Can only leak to a trusted set of origins
  - Gives us a more fine-grained notion of least privilege
- **Can we extend this idea to prevent or limit damages due to XSS?**

Content security policy

- Goal: prevent or limit damage due to XSS
- Idea: restrict resource loading to a white list
  - By restricting to whom page can talk to: restrict where data is leaked!
- **Approach: send page with CSP header that contains fine-grained directives**
  - E.g., allow loads from CDN, no frames, no plugins

```
Content-Security-Policy: default-src https://cdn.example.net;
                         child-src 'none'; object-src 'none'
```

Example directives

- connect-src: limits the origins you can XHR to
- font-src: where to fetch web fonts form
- form-action: where forms can be submitted
- child-src: where to load frames/workers from
- frame-ancestors: sources that can embed this page
- default-src: default whitelist

Special keywords

- ‘none’ - match nothing
- ‘self’ - match this origin
- ‘unsafe-inline’ - allow unsafe JS & CSS
- ‘unsafe-eval’ - allow unsafe eval (and the like)
- http: - match anything with http scheme
- https: - match anything with https scheme
- * - match anything

How can CSP prevent XSS?

- If you whitelist all places you can load scripts from:
  - Only execute code from trusted origins
  - Remaining vector for attack: inline scripts
- **CSP by default disallows inline scripts**
  - If scripts are enabled at least it disallows eval

Adoption challenge

- **Problem: inline scripts are widely-used**
  - Page authors use the ‘unsafe-inline' directive
  - Is this a problem?
- **Solution: script nonce and script hash**
  - Allow scripts that have a particular hash
  - Allow scripts that have a white-listed nonce

Other adoption challenges

- **Goal: set most restricting CSP that is permissive enough to not break existing app**
- **How can you figure this out for a large app?**
- **CSP has report-only header and report-uri directive**
  - Report violations to server; don't enforce

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Limitations/questions on CSP

- Can still exfiltrate data (postMessage, navigation)
- Research: setting flexible CSP policy automatically
  - Dynamic loading content vs. CSP (Reddit imgurl)
- **Research: set CSP automatically with inline scripts in presence of user-supplied content?**
  - Stored XSS problem: user code vs. your inline code
- **Research [COWL]: is whitelisting enough?**

Web workers

- **Run code in separate context (in new thread)**
  - No DOM: no postMessage to iframes/navigation to leak
  - Only pure JavaScript + XHR + postMessage/ onmessage with parent
- **CSP header on worker can be more restricting than page**
  - A more secure sandbox for running untrusted code

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- **Subresource integrity (SRI)**
- Cross-origin resource sharing (CORS)

Motivation for SRI

- CSP can be used to limit the damage of code, but can't really defend against malicious code
- How do you know that the library you're loading is the correct one?

  - Won't using HTTPS address this problem?

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> **Massive denial-of-service attack on GitHub tied to Chinese government**
> Reports: Millions of innocent Internet users conscripted into Chinese DDoS army.

  - Won't using HTTPS address this problem?

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

Subresource integrity

- Idea: page author specifies hash of (sub)resource they are loading; browser checks **integrity**
  - E.g., integrity for scripts

```
<link rel="stylesheet" href="https://site53.cdn.net/style.css"
      integrity="sha256-SDfwewFAE...wefjijfE">
```

  - E.g., integrity for link elements

```
<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

Multiple hash algorithms

- **Authors may specify multiple hashes**
  - E.g., `<script src="hello_world.js" integrity="sha256-... sha512-...">`
- **Browser uses strongest algorithm**
- **Why support multiple algorithms?**
  - Don't break page on old browser

Multiple hash algorithms

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Limitations/questions on SRI

- Only supports stylesheets and scripts
- **Can extend to other elements? UI integrity?**
- **Can extend to downloads?**
- **Research: what if you used signatures?**
  - Talk to Henry Corrigan-Gibbs and Amit Levy

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Recall: SOP is also inflexible

- **Problem: Can't fetch cross-origin data**
  - Leads to building insecure sites/services: JSONP
- **Solution: Cross-origin resource sharing (CORS)**
  - Data provider explicitly whitelists origins that can inspect responses
  - Browser allows page to inspect response if its origin is listed in the header

E.g., CORS usage: amazon

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

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: *
- **CORS XHR may send cookies + custom headers**
  - Need “preflight” request to authorize this

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Limitations/questions on CORS

- **Can't share data with sandboxed iframe without making it completely public**
- **Research [COWL]: is whitelisting enough?**
  - Why doesn't chase.com share bank statements with mint.com?
- **Research: CORS + crypto for better sharing?**

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How do we protect extensions from pages?

- Firefox and Chrome:
  - Isolated worlds: extension script's heap is different from the heap of the page. Why?
  - E.g., getElementById = function() {...evil stuff...}

How do we protect extensions from pages?

- **Chrome forces developers to follow:**
  - Privilege separation by breaking extension into
    - Core extension script: has access to privileged APIs
    - Content script: can manipulate page but must ask core script to use privileged APIs on its behalf
  - Principle of least privileged via permission system
    - User must approve APIs granted to core extension scripts, so developers should be kept in line

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Limitations/questions on extension systems

- **Page can't protect itself from extension**
  - Extensions do directly inject code and have removed CSP headers [RAID]
- **Research [HotOS]: is trust model realistic? Is Chrome's system working? Can we do better?**
  - Extensions are third-party code; there have been malicious extensions in the wild
  - Extensions are not least privileged: over 71% of top 1000 need to read/write everything for every origin

Continuing w/ research questions

- Can we build an extension systems with more realistic attacker model?
- Where do existing mechanisms for the Web fall short?

Motivation for COWL (working spec draft)

- Same Origin Policy
- Content Security Policy
- Sandboxing

Motivation for COWL (working spec draft)

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All-or-nothing discretionary access control:

access data ➠ ability to leak it

Where DAC falls short...

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Third-party APIs

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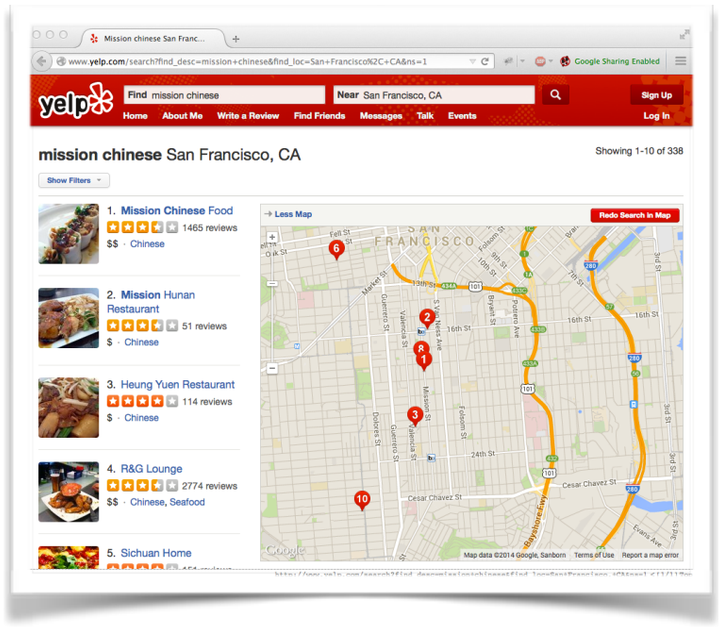
Mashups



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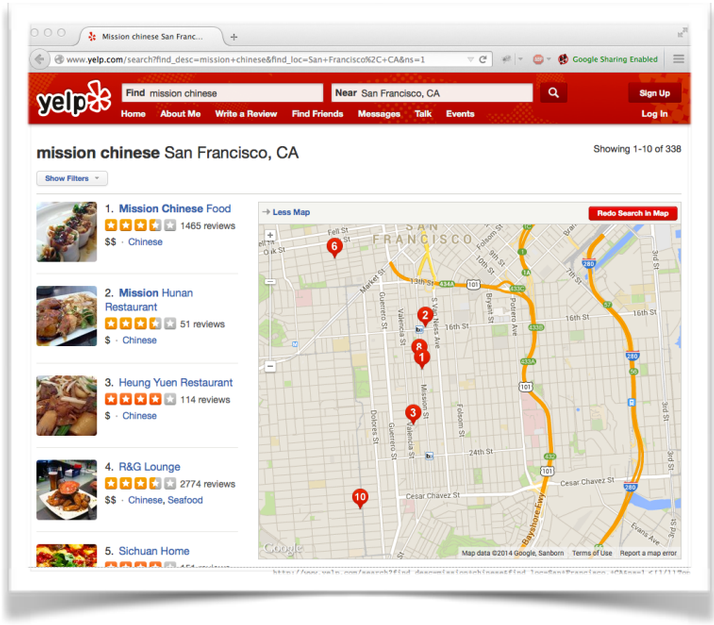

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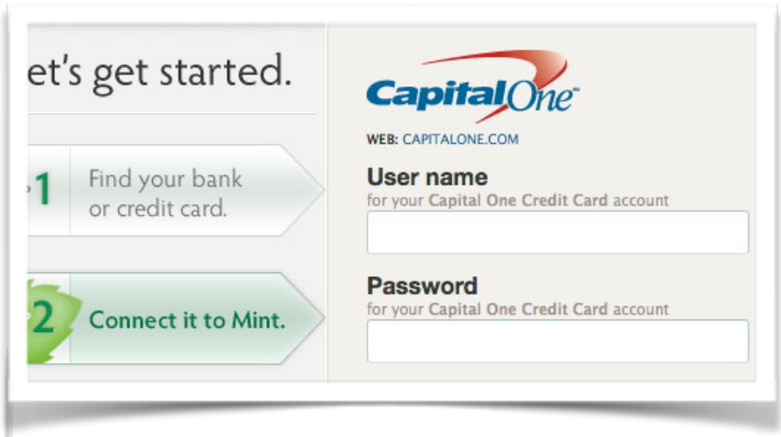

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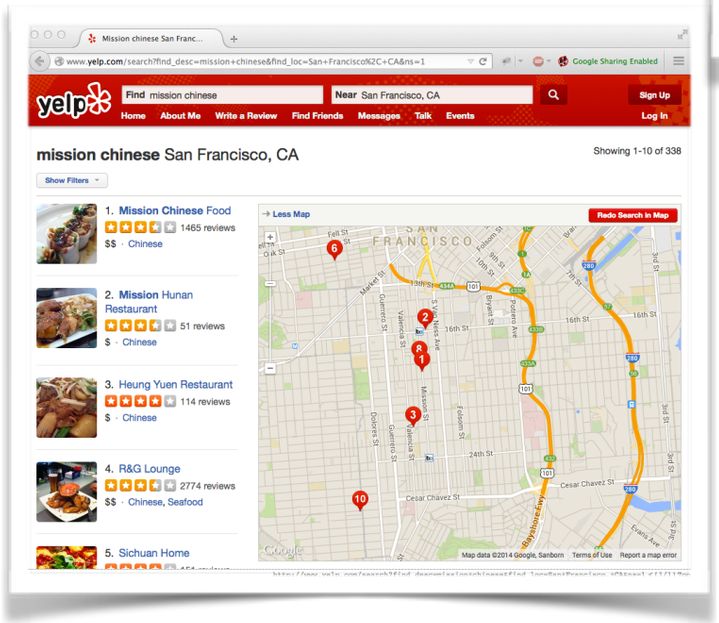

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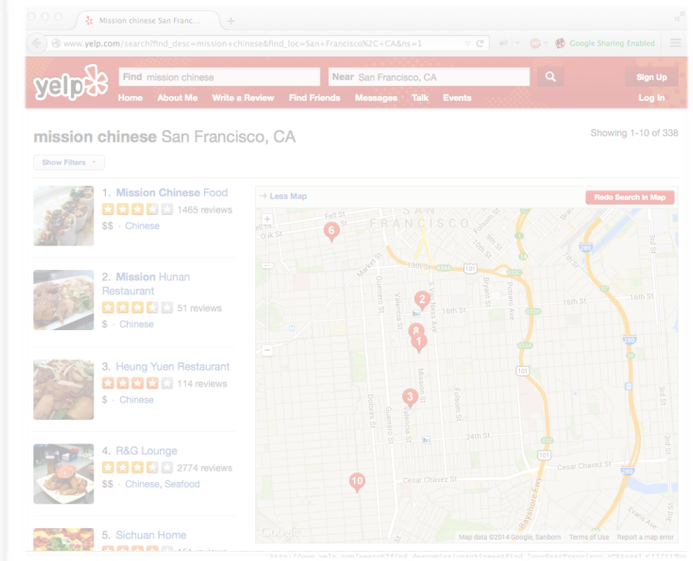

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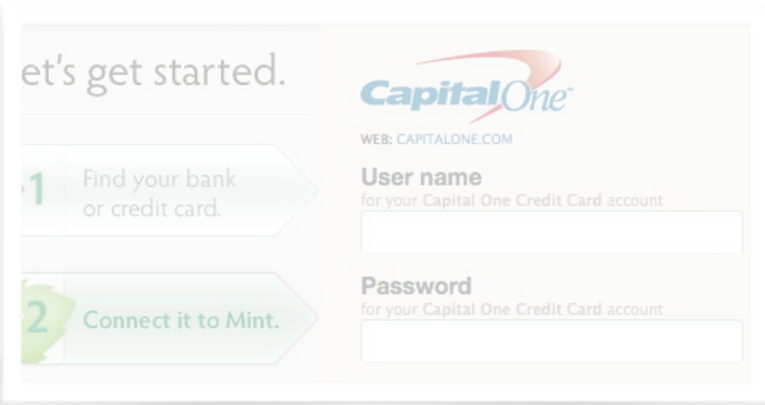

Recall: password-strength checker

Guarantee: checker cannot leak password

- At worst: checker lies about strength of password

Confining the checker using existing mechanisms

- Host the checker code on a.com
- Use CSP & Sandboxing
  - Need JavaScript: sandbox allow-scripts
  - Limit communication to postMessage with parent: default-src ‘none’ ‘unsafe-inline’

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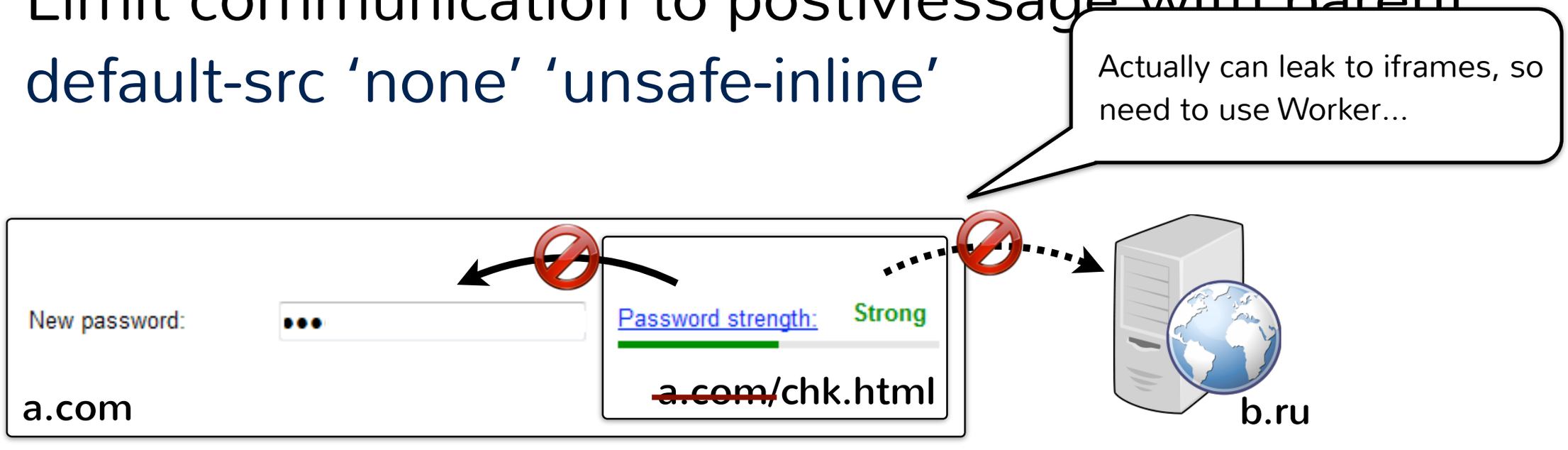


Why is this unsatisfactory?

- **Functionality of library is limited**
  - E.g., library cannot fetch resources from network
  - A more flexible CSP policy would weaken security
- **Security policy is not first-class**
  - Library cannot use code it itself doesn't trust
- **Security policy is not symmetric**
  - Library cannot consider parent untrusted

A new approach: COWL

Idea (a): Provide means for associating security label with data

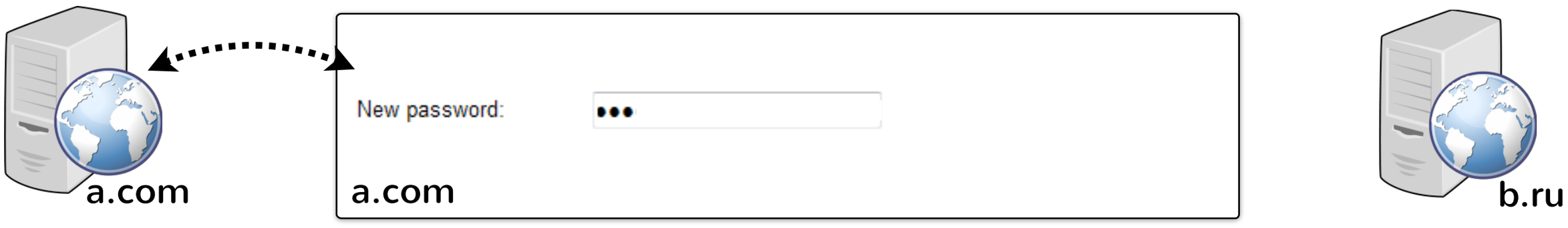
- E.g., password is sensitive to a.com

Idea (b): **Ensure code is confined to obey labels by associating labels with browsing contexts**

- E.g., password can only be sent to entities that are as sensitive as a.com
  (via XHR, postMessage, storage, ...)

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 to send labeled password**
  - Source specifies sensitivity of data at time of send



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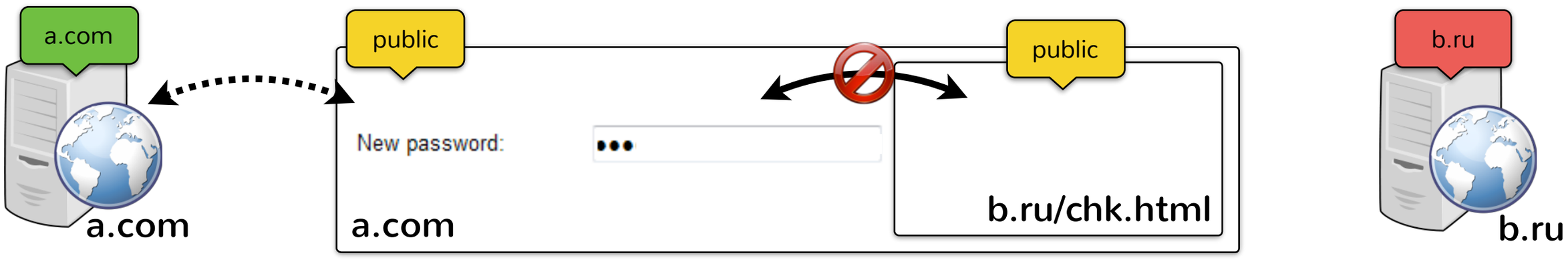

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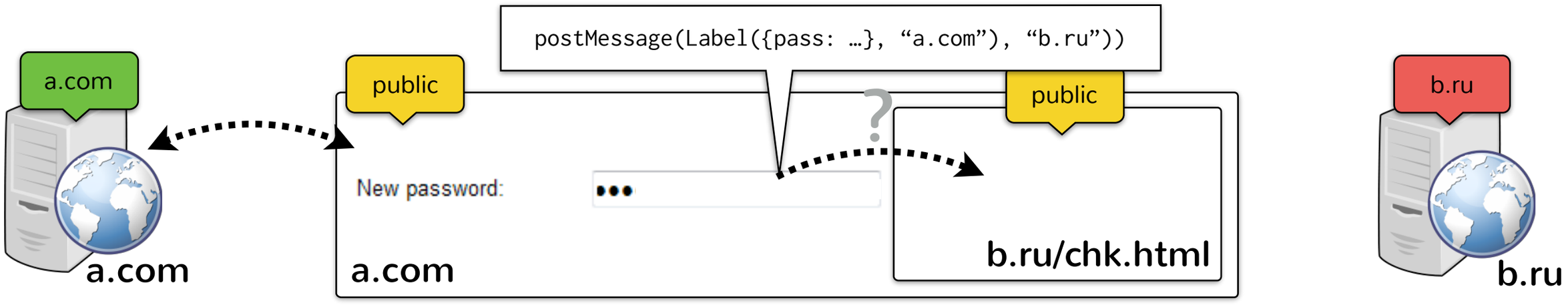

Confining the checker with COWL

- **Express sensitivity of data**
  - Checker can only receive password if its context label is as sensitive as the password
- **Use postMessage to send labeled password**
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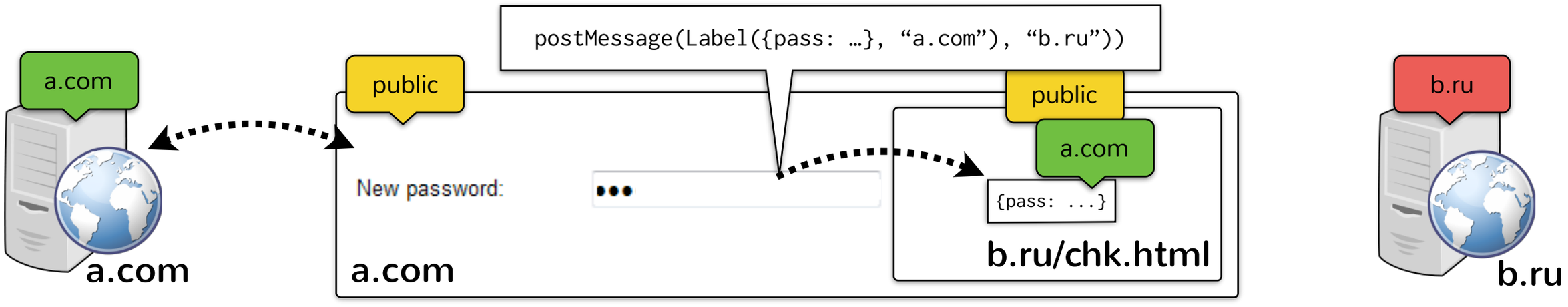

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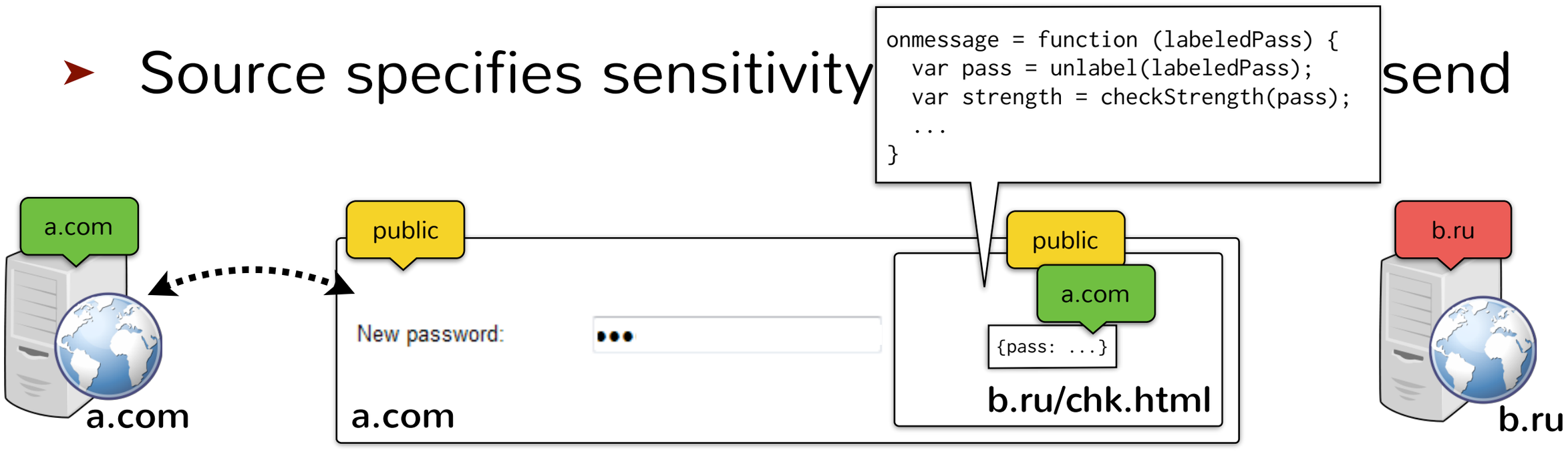

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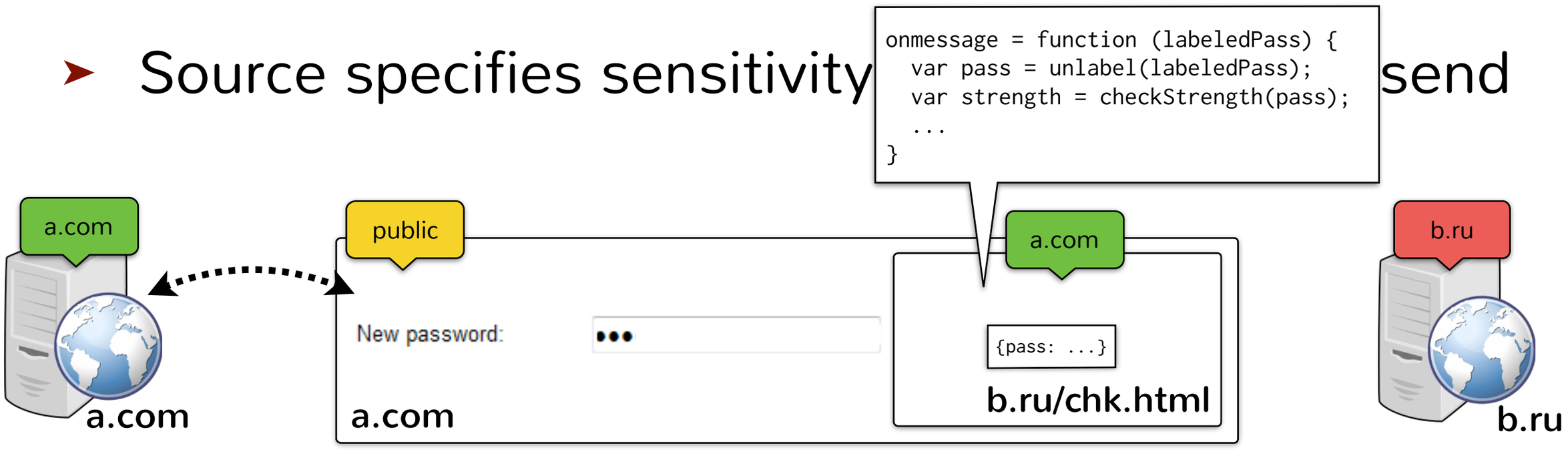

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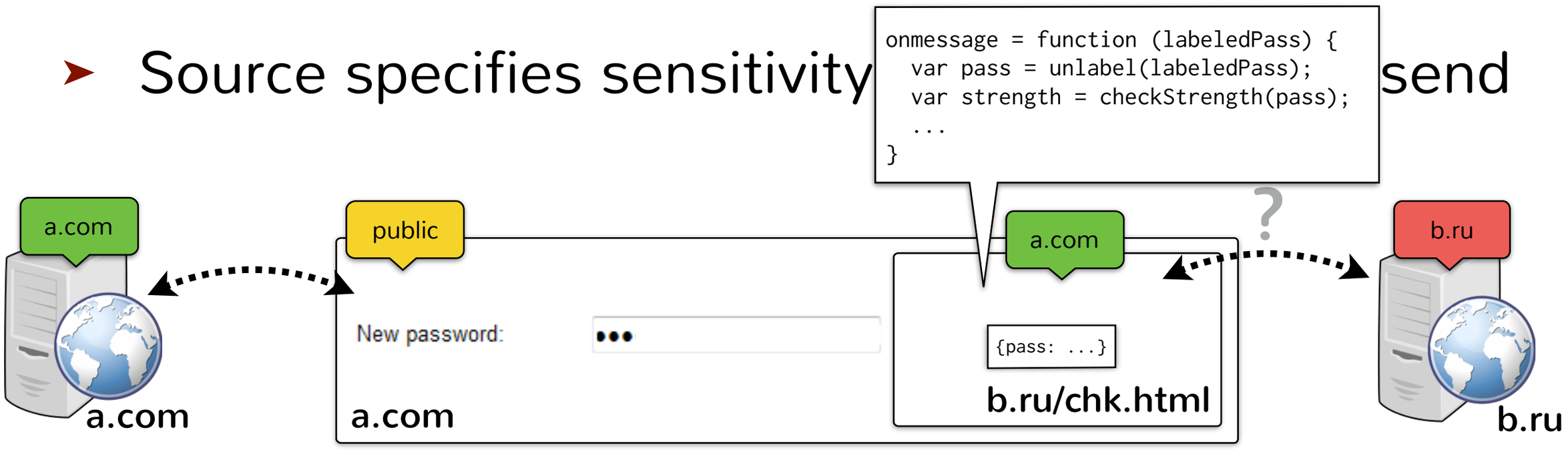

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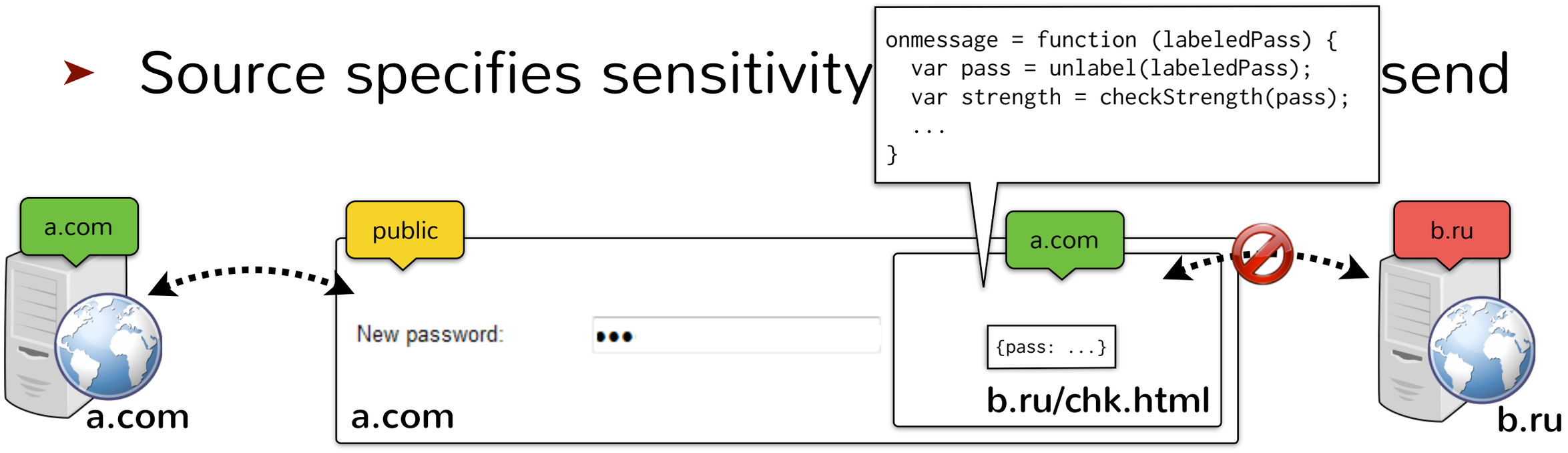

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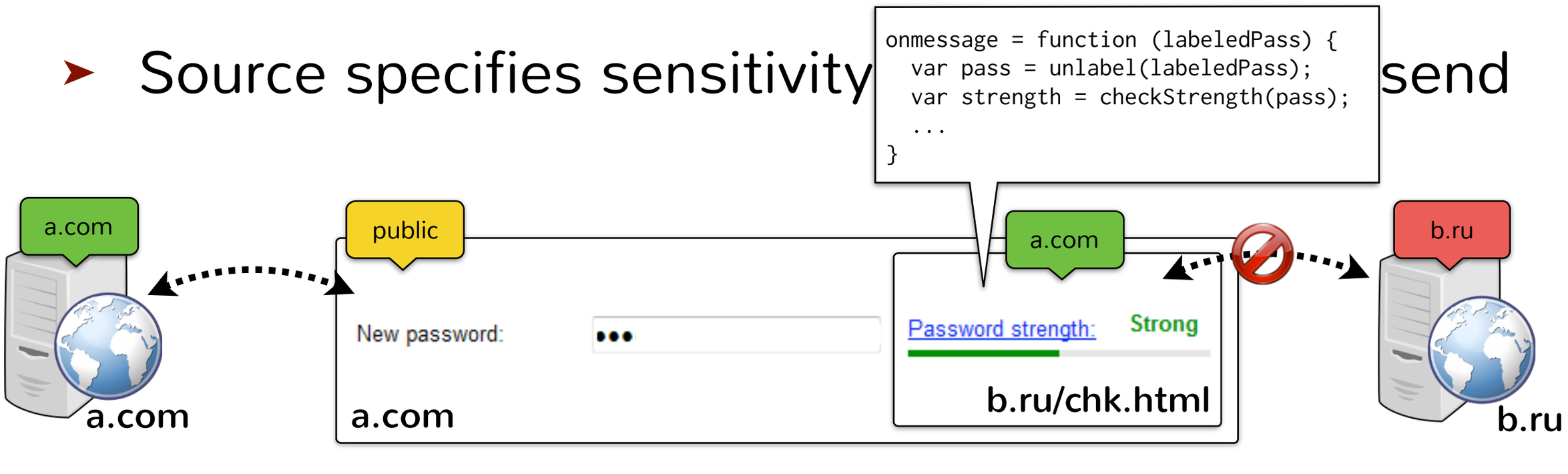

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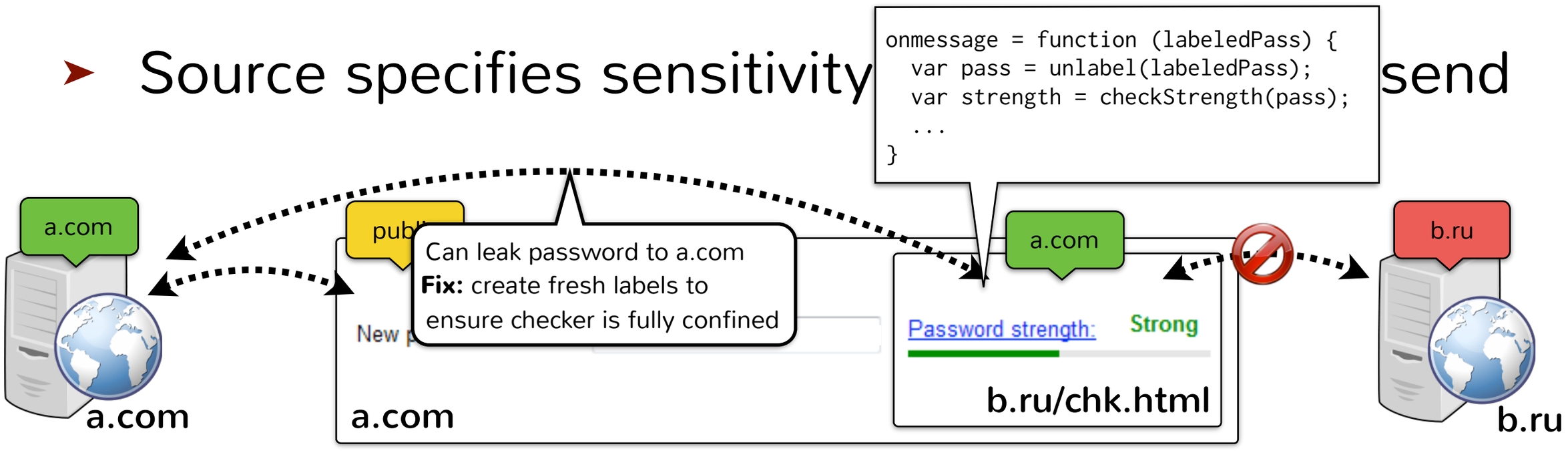

Summary

- **SOP has reached its limit for modern web apps**
- **New mechanisms: sandboxing, CSP, CORS, SRI**
  - Address limitations of SOP by reducing amount of trust authors need to place in code (by reducing the amount of damage code can cause)
  - Each has their own shortcomings
    - COWL address limitation of whitelists
    - Signatures can address limitations of SRI
    - Lot of work to do
- **Web apps do not run stand-alone: extensions**
  - Extension systems protect privileged code from untrusted app code, though design needs revising

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