Veil: Private Browsing Semantics without Browser-side Assistance

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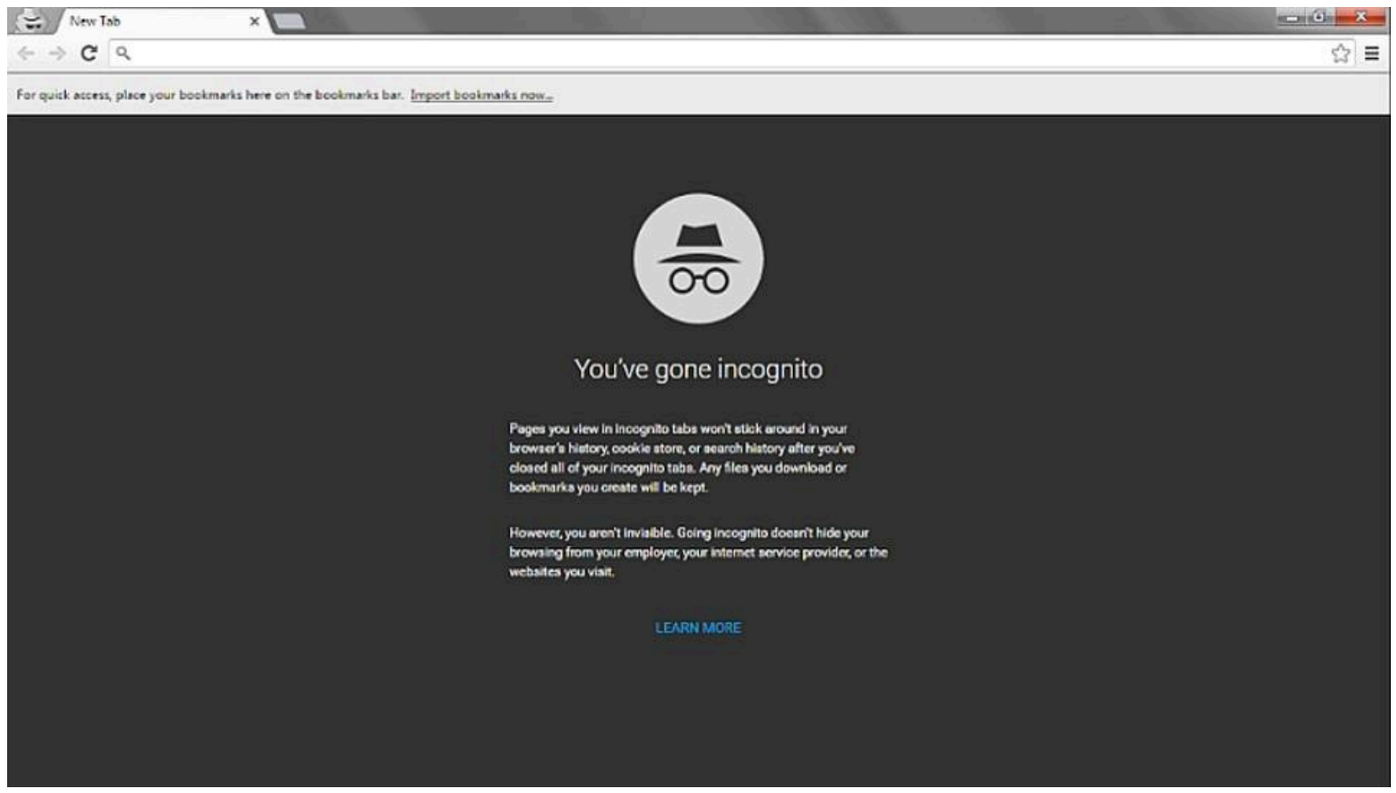
All popular browsers offer private browsing



In private browsing, web pages shouldn't leave identifiable, persistent client-side state

Private browser modes are leaky

- DNS cache and database pollution
- Leave RAM artifacts in page swap, hibernation files
- Forensic tools can easily recover this data and fingerprint activity

Problem: Private browsing is hard to implement with only client-side support

- Browsers complex and constantly adding new features
- They lack a priori knowledge of sensitive content
  - Example: prevent RAM from paging to disk, use `mlock()` to pin memory
- Even transmission of web content to a user can pollute in-memory and on-disk regions

What if developers can implement private browsing semantics?

Goal: Protect greppable content from post-session attacker

Insight: Web services control

1) the content they deliver

2) the servers that deliver this content

Our solution: Veil

Developer **Blinding servers** **Client browser**

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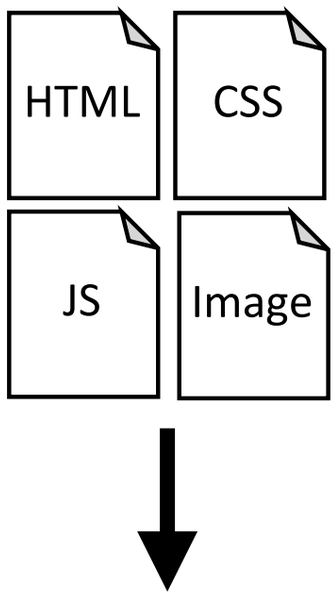
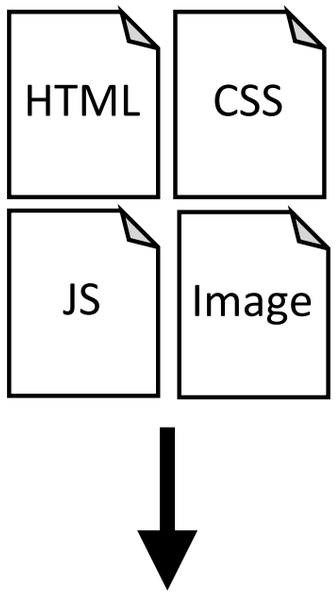


Veil Compiler

Rewrite webpages

Our solution: Veil

Developer



Veil Compiler

Rewrite webpages

Blinding servers

Store and mutate content

Client browser

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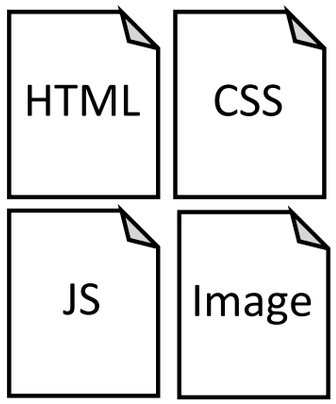

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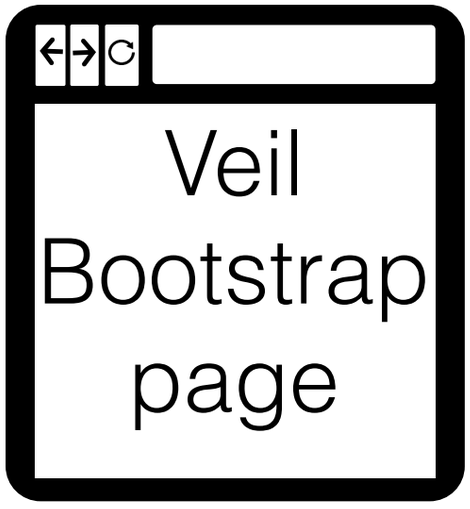


Hide page-specific URLs and display pages

Contributions

Veil: first web framework that allows developers to provide private browsing semantics

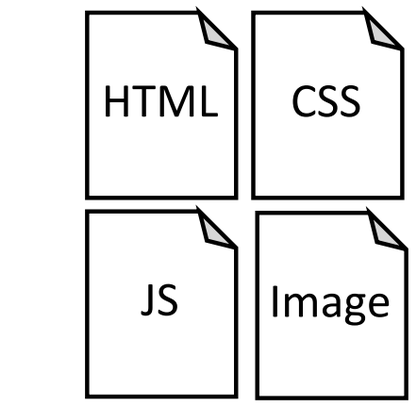
- Techniques, such as URL blinding, content mutation, and heap walking, to protect privacy
- Two browsing modes to provide different amounts of privacy
- Evaluation on real websites
- No client/browser changes required

Outline

- Veil Architecture
- Implementation
- Evaluation

Overview

Developer



Veil Compiler

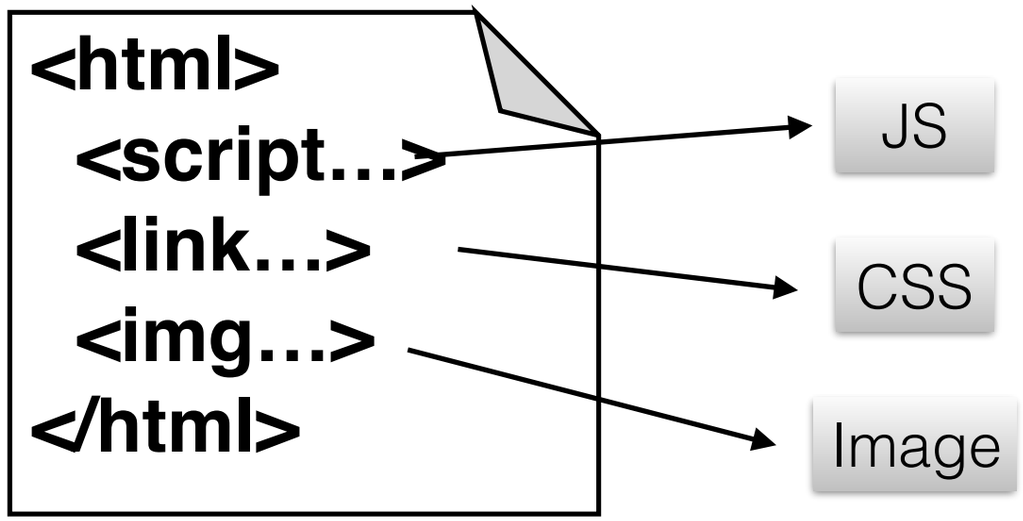
Rewritten HTML

Blinding servers

URL blinding,
Content mutation

Client browser

Veil Compiler



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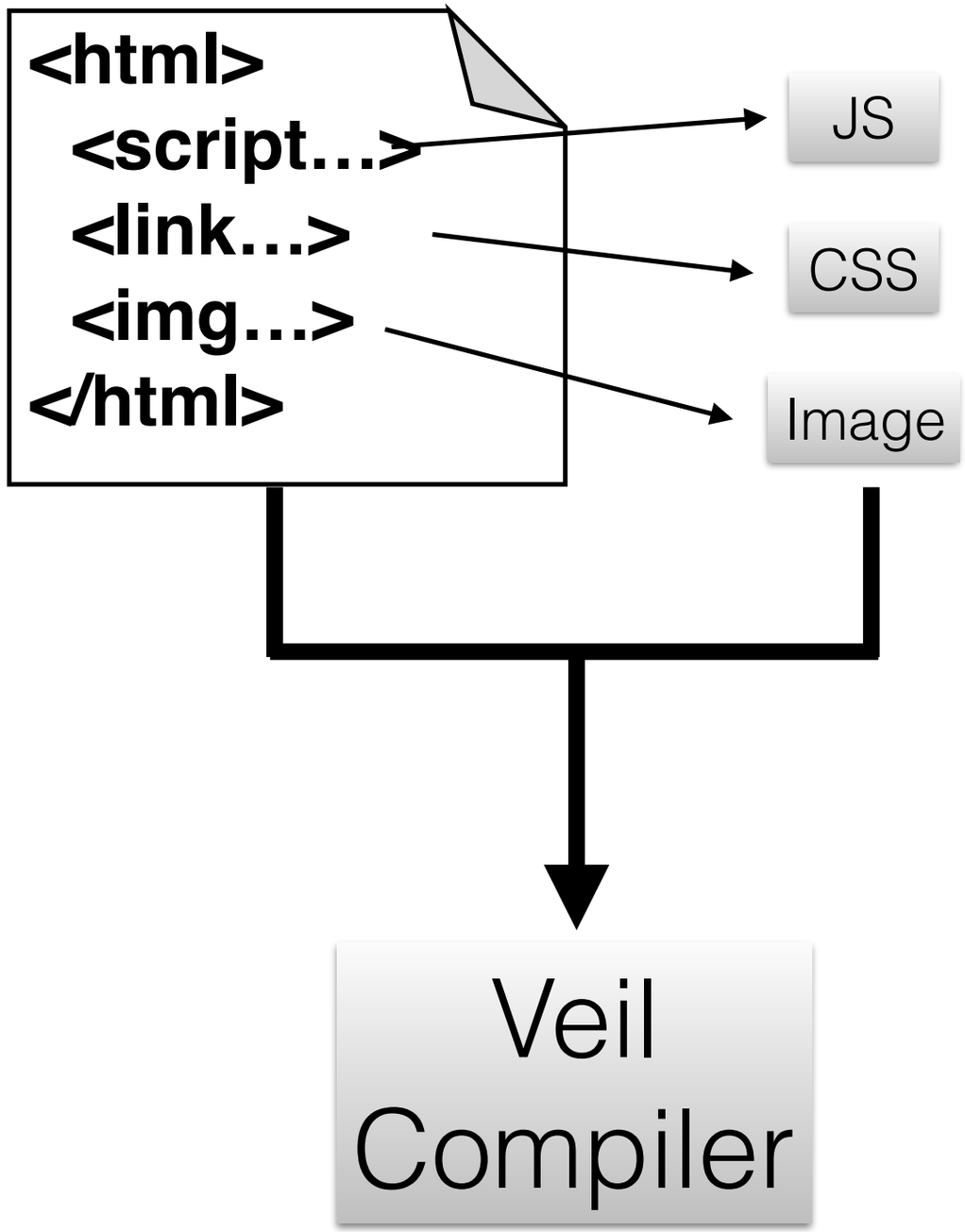

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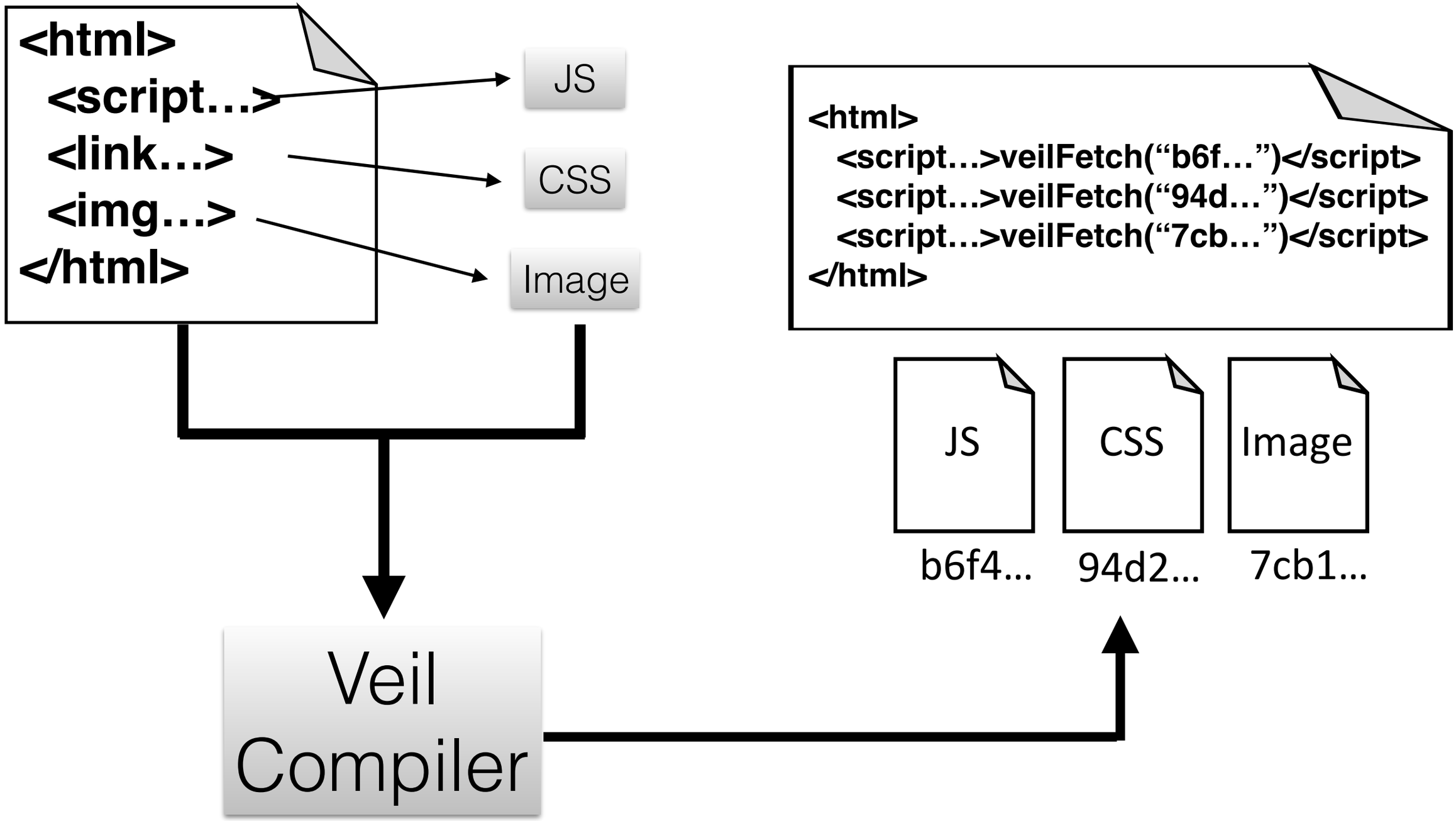

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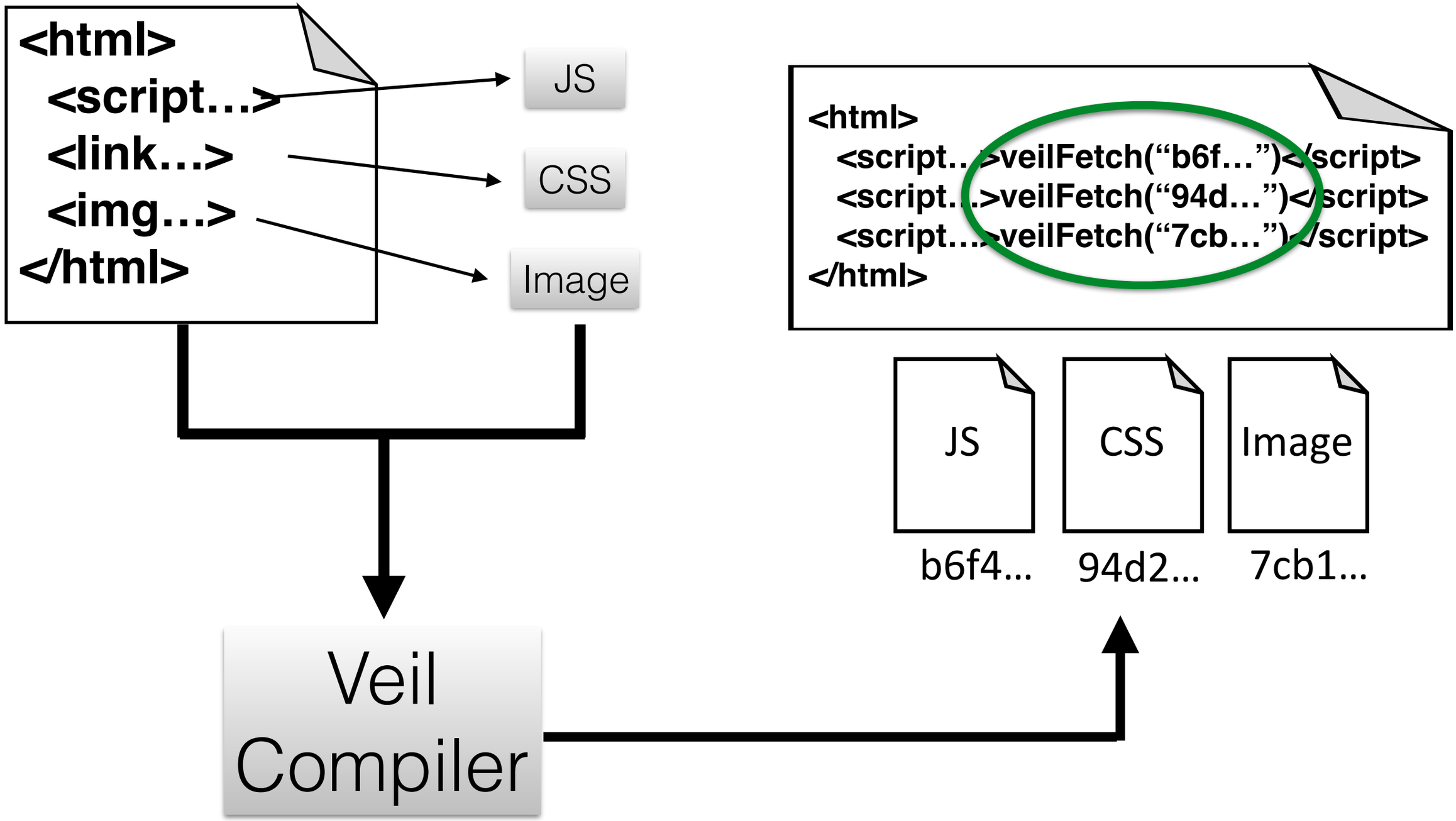
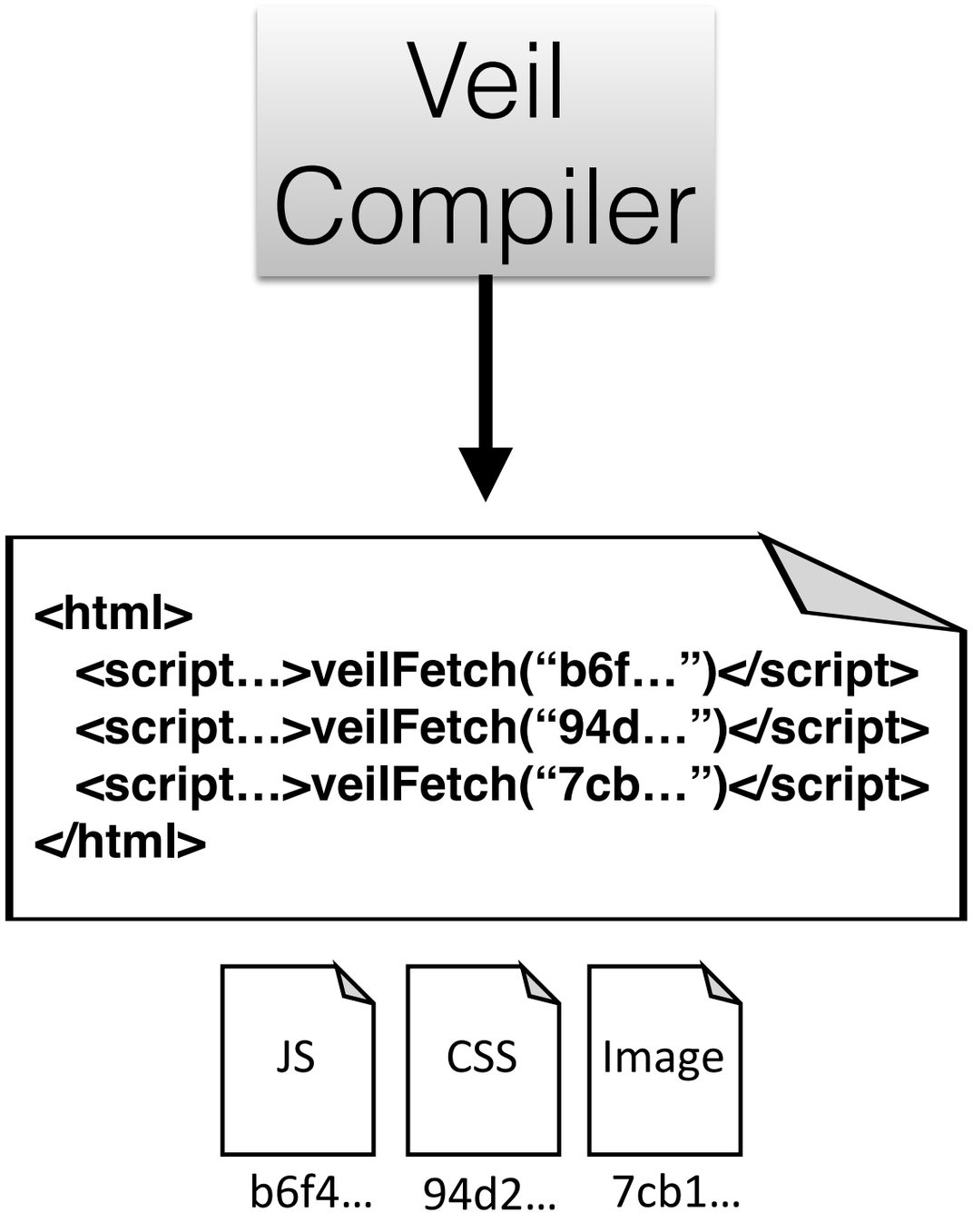


Blinding Servers



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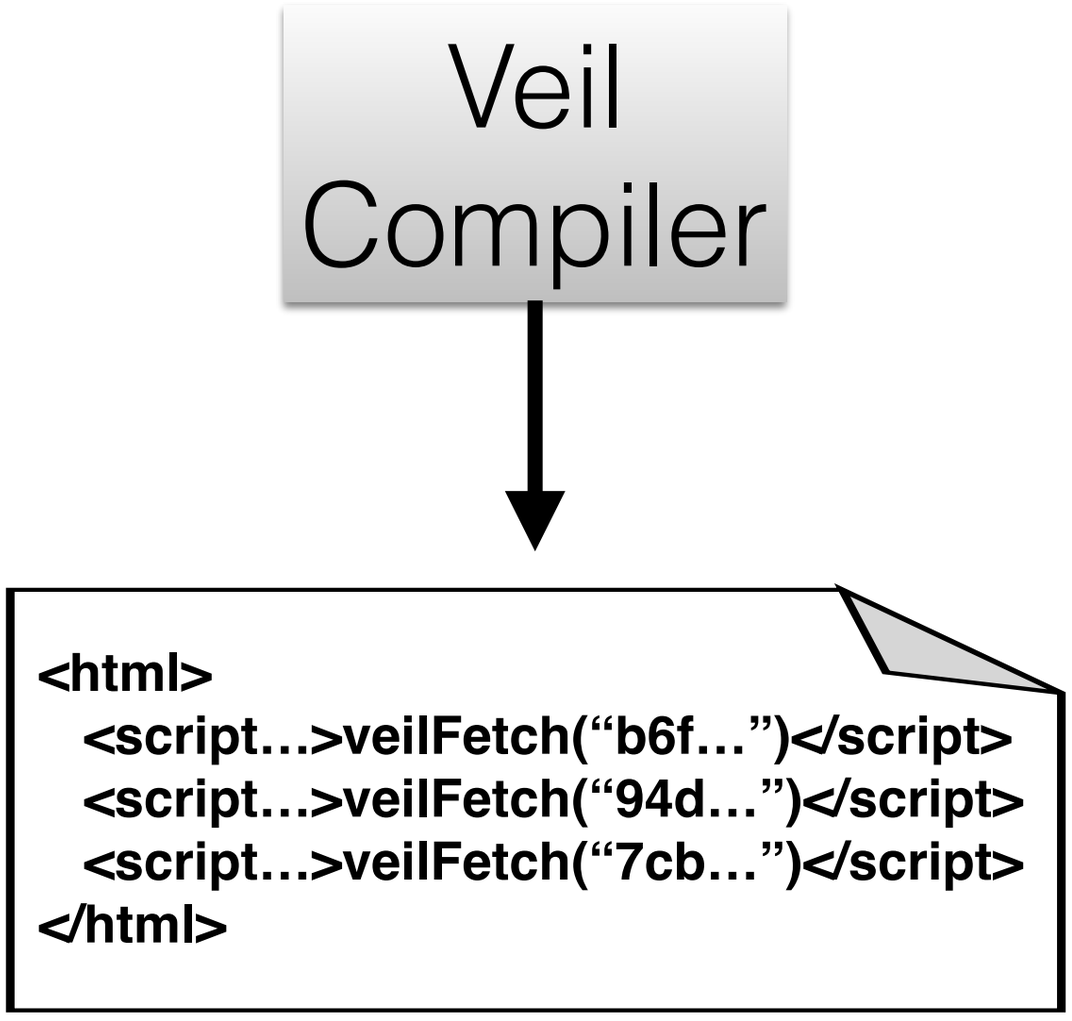
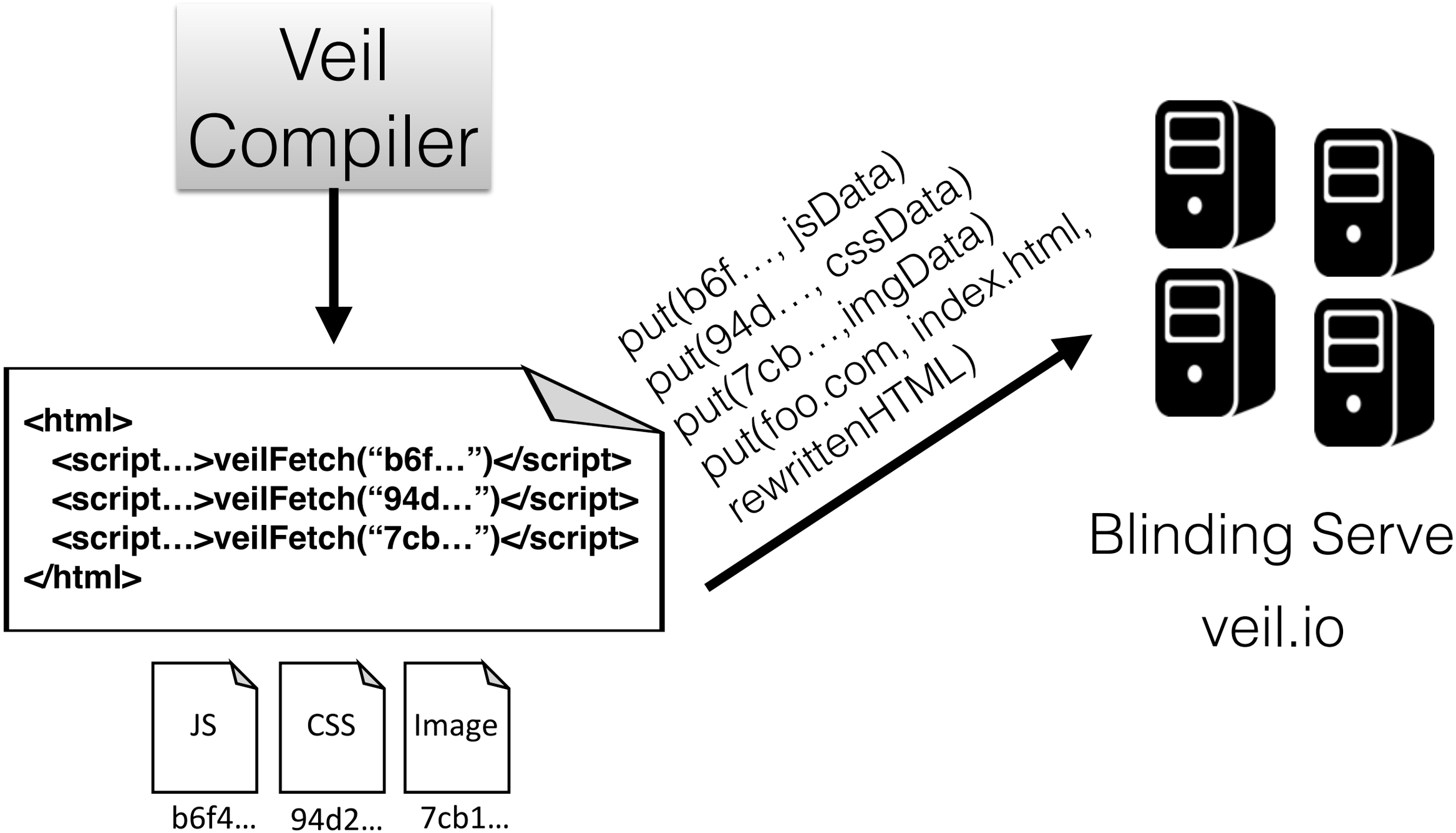


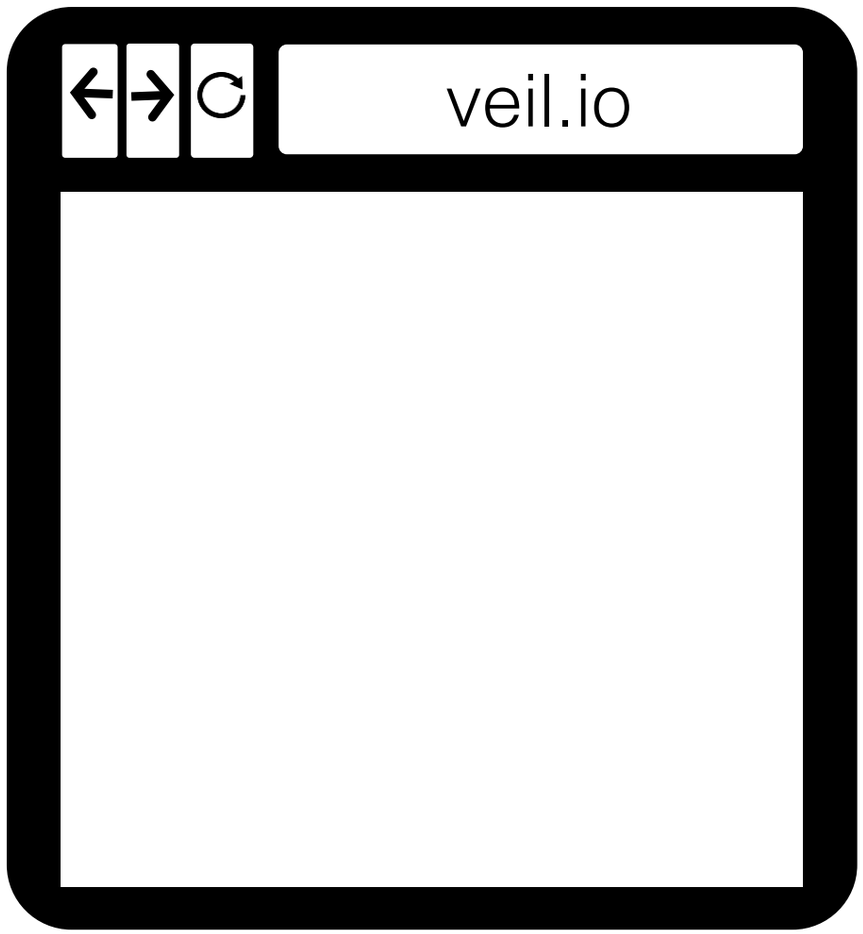
Blinding Servers

veil.io

Blinding Servers



Client Browser: Dynamic Reassembly



Browser

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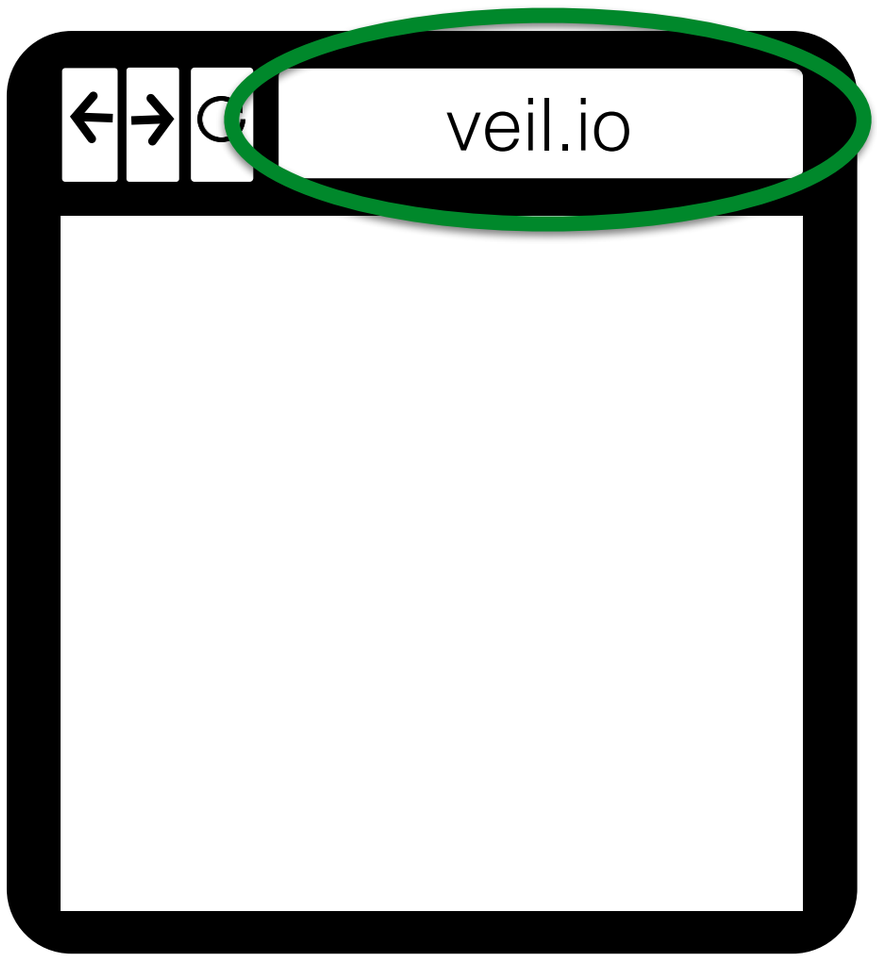

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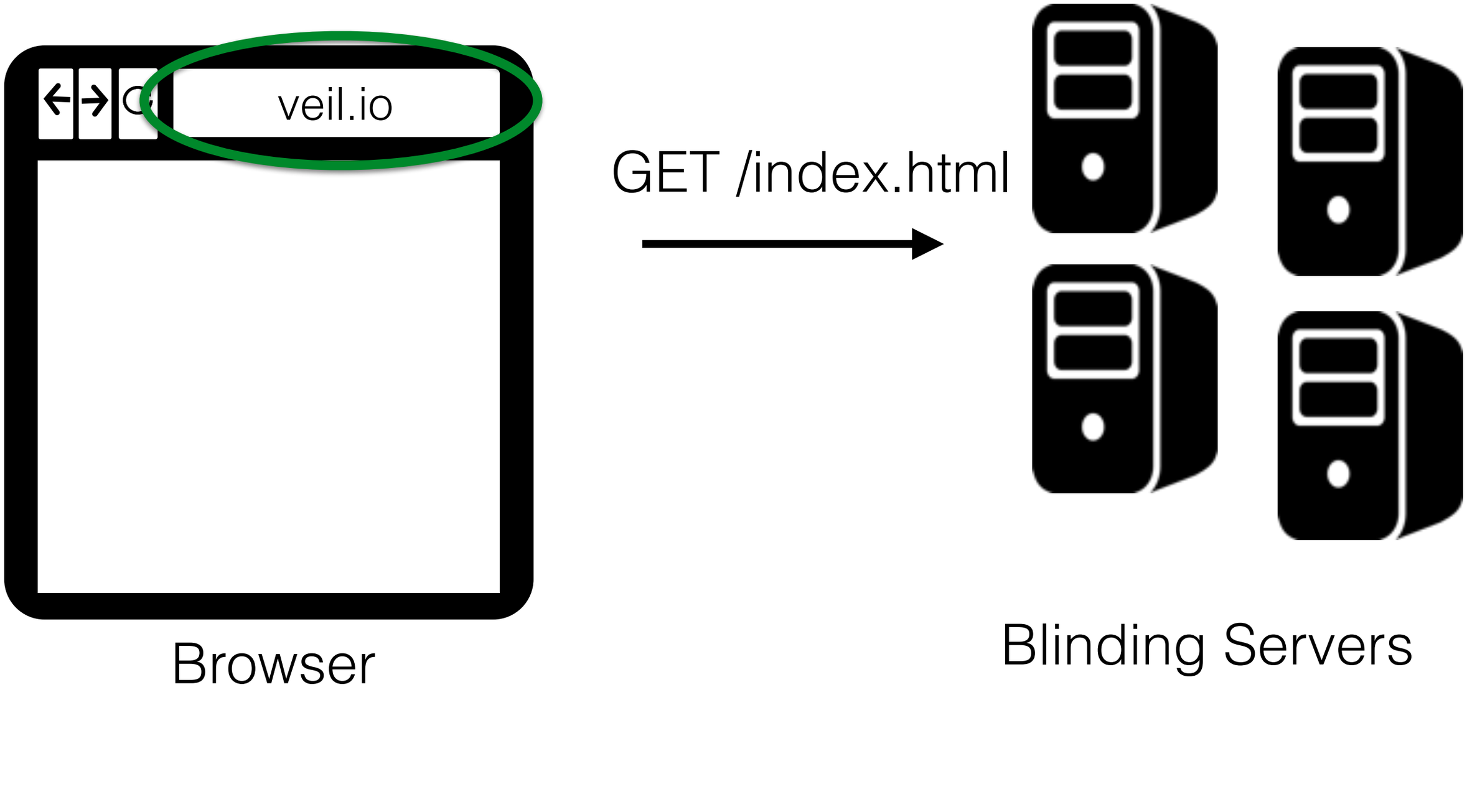

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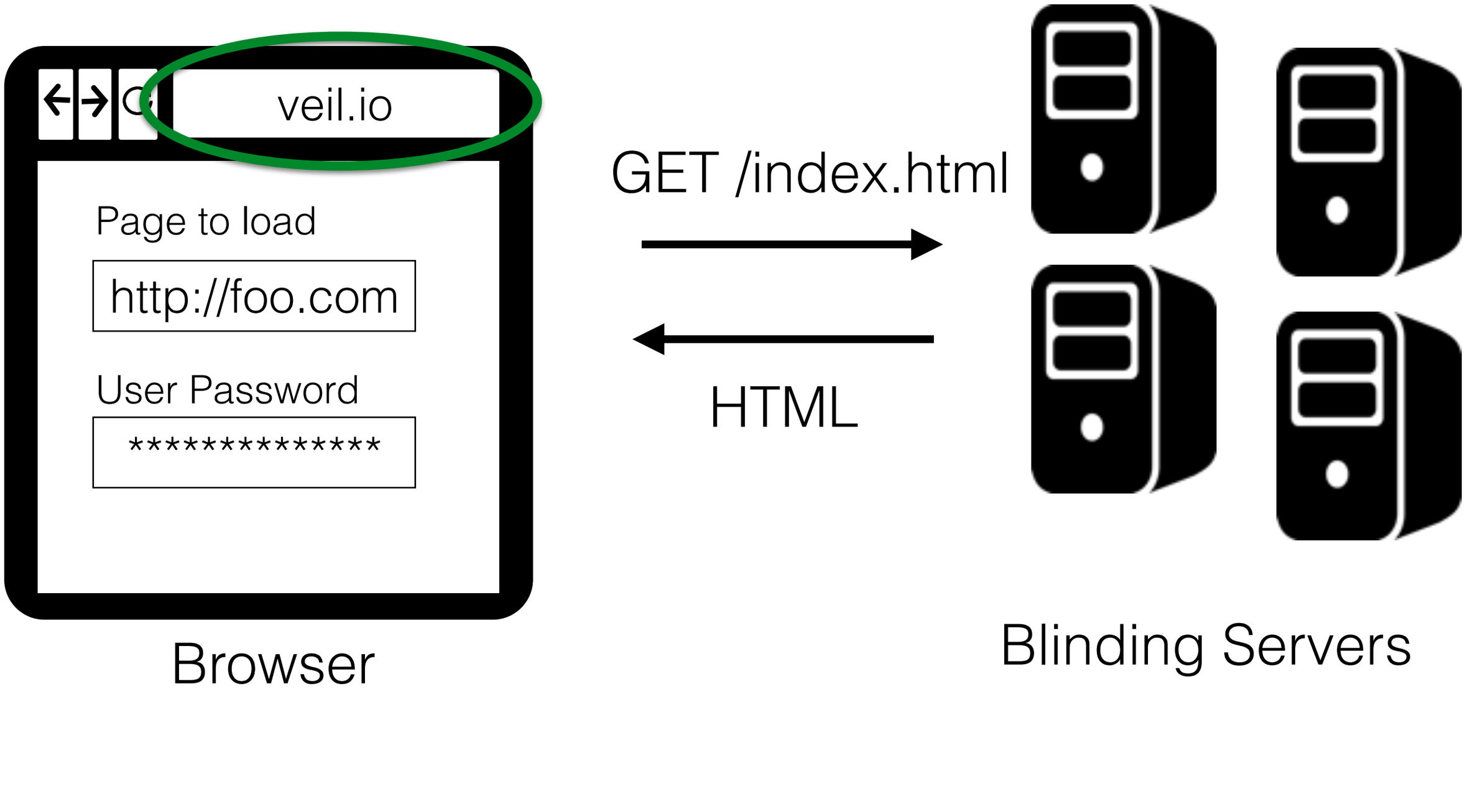

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Browser

GET <foo.com/index.html>$_{Kuser}$

Veil-Key: <K_{user}>$_{Kpub\_veil}$

Blinding Servers

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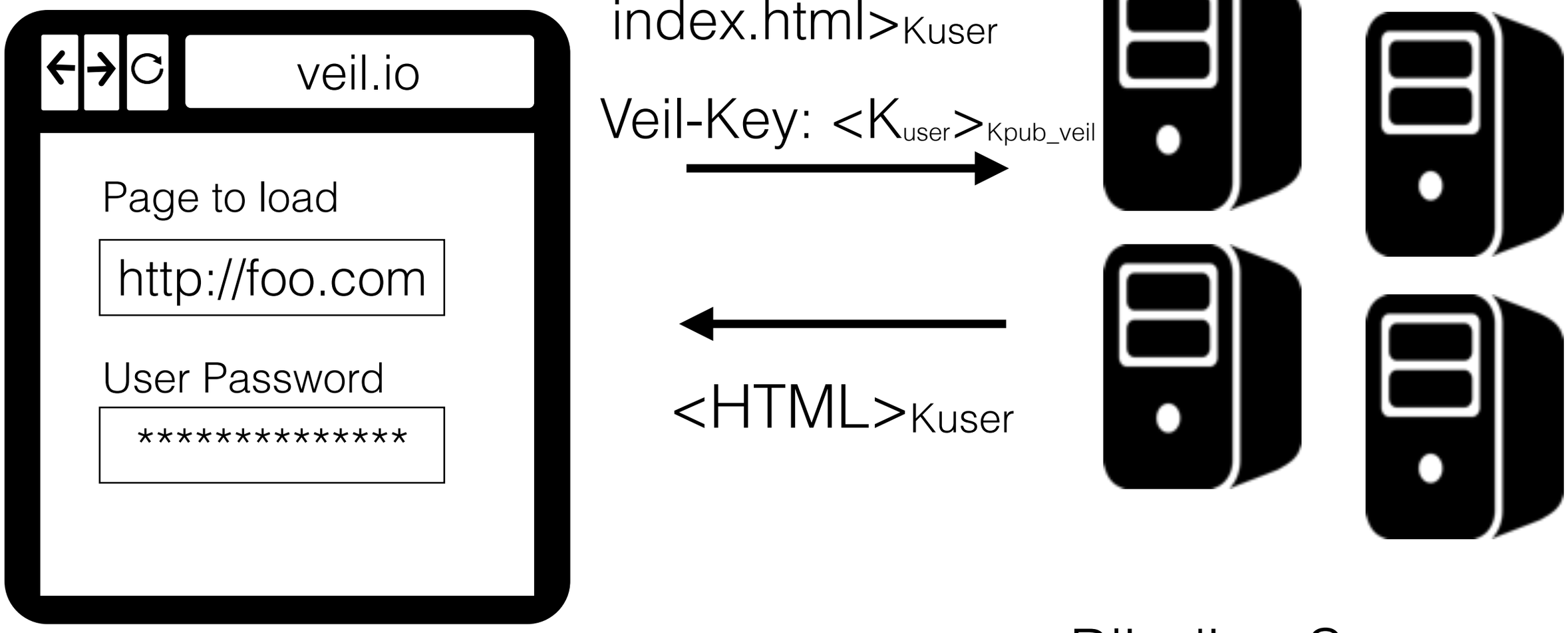

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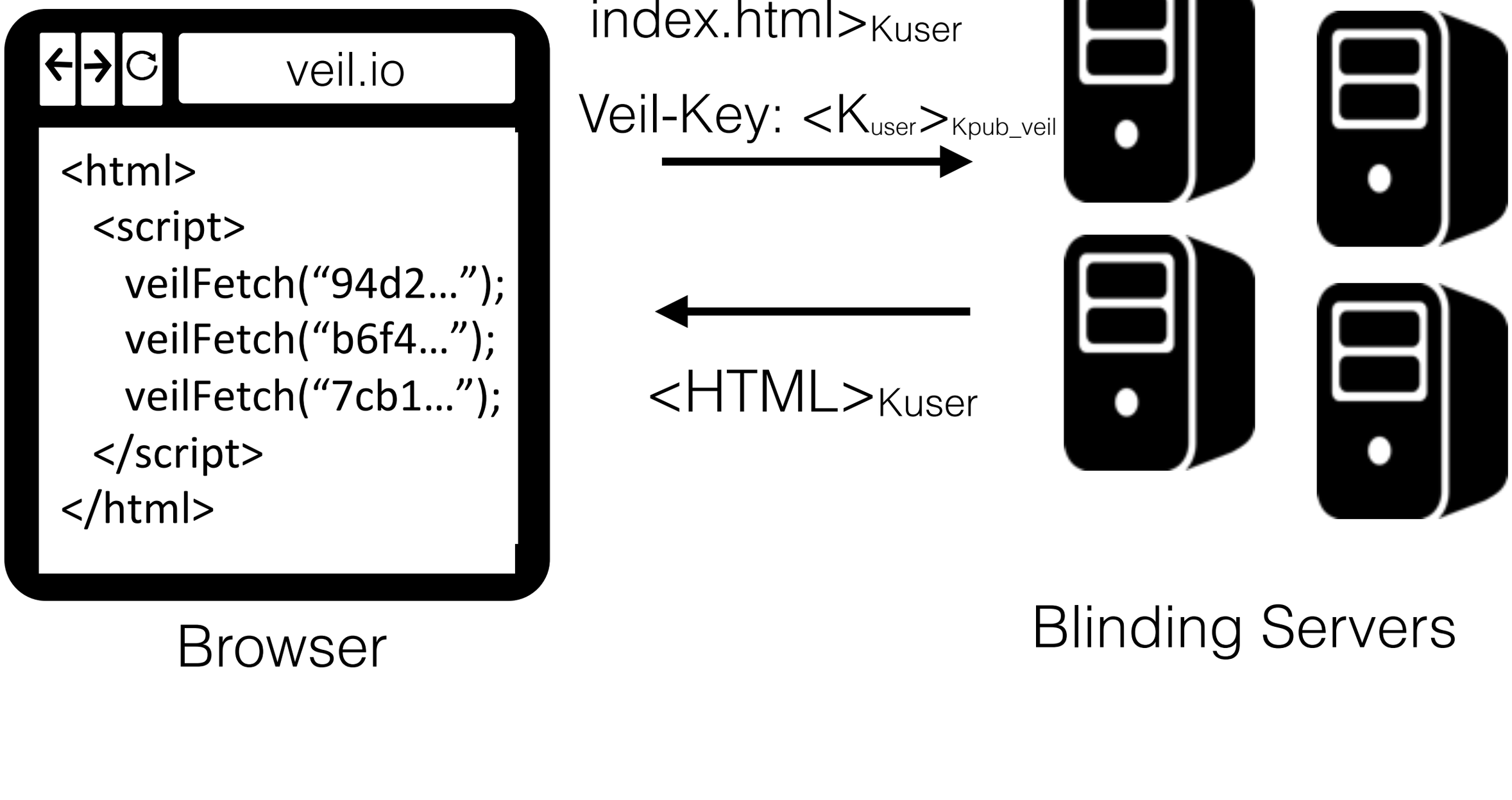

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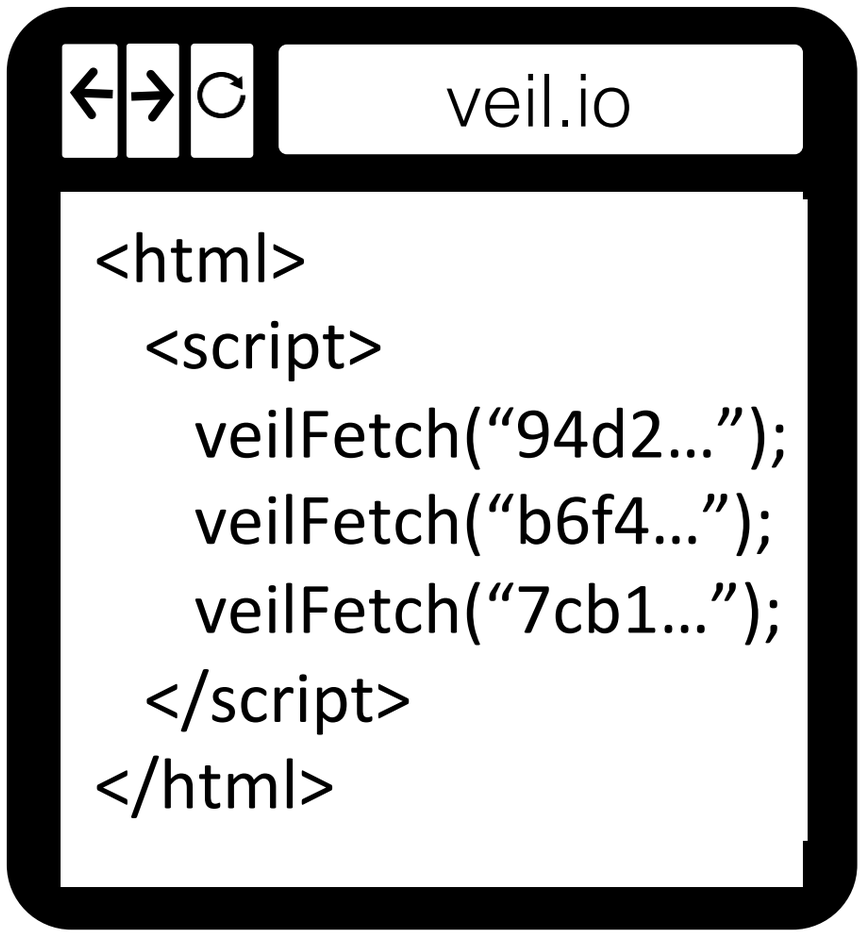

Browser

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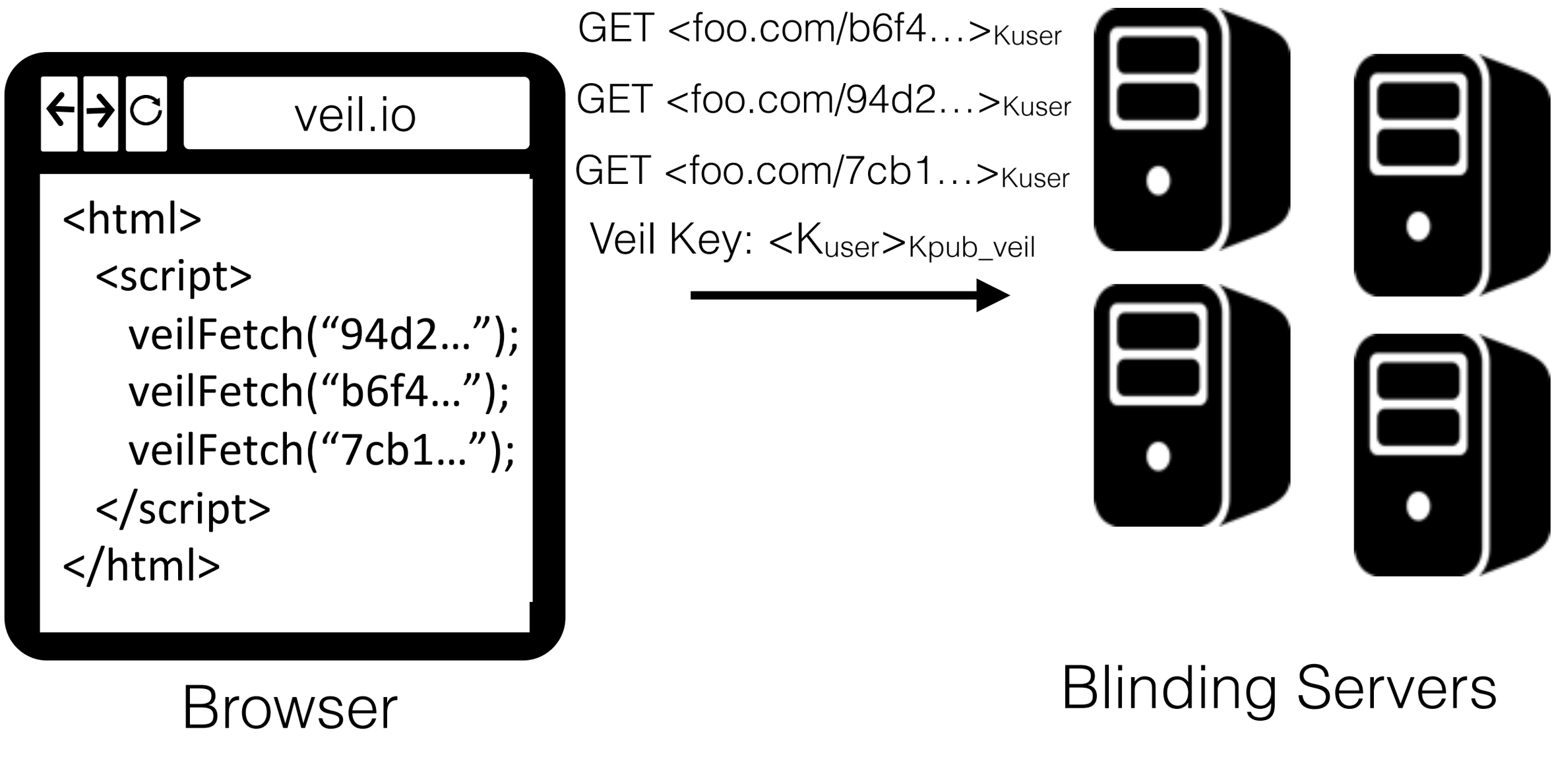

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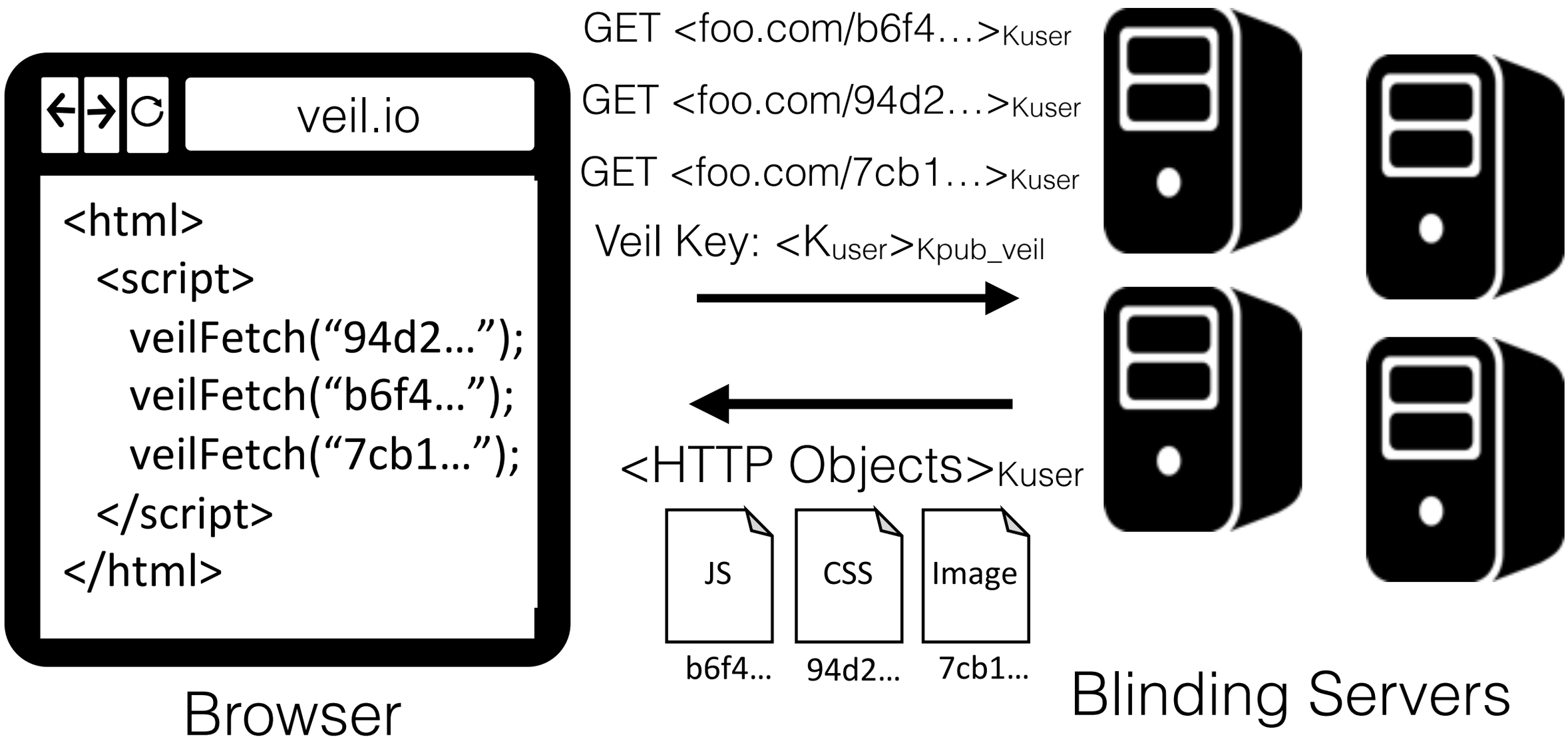

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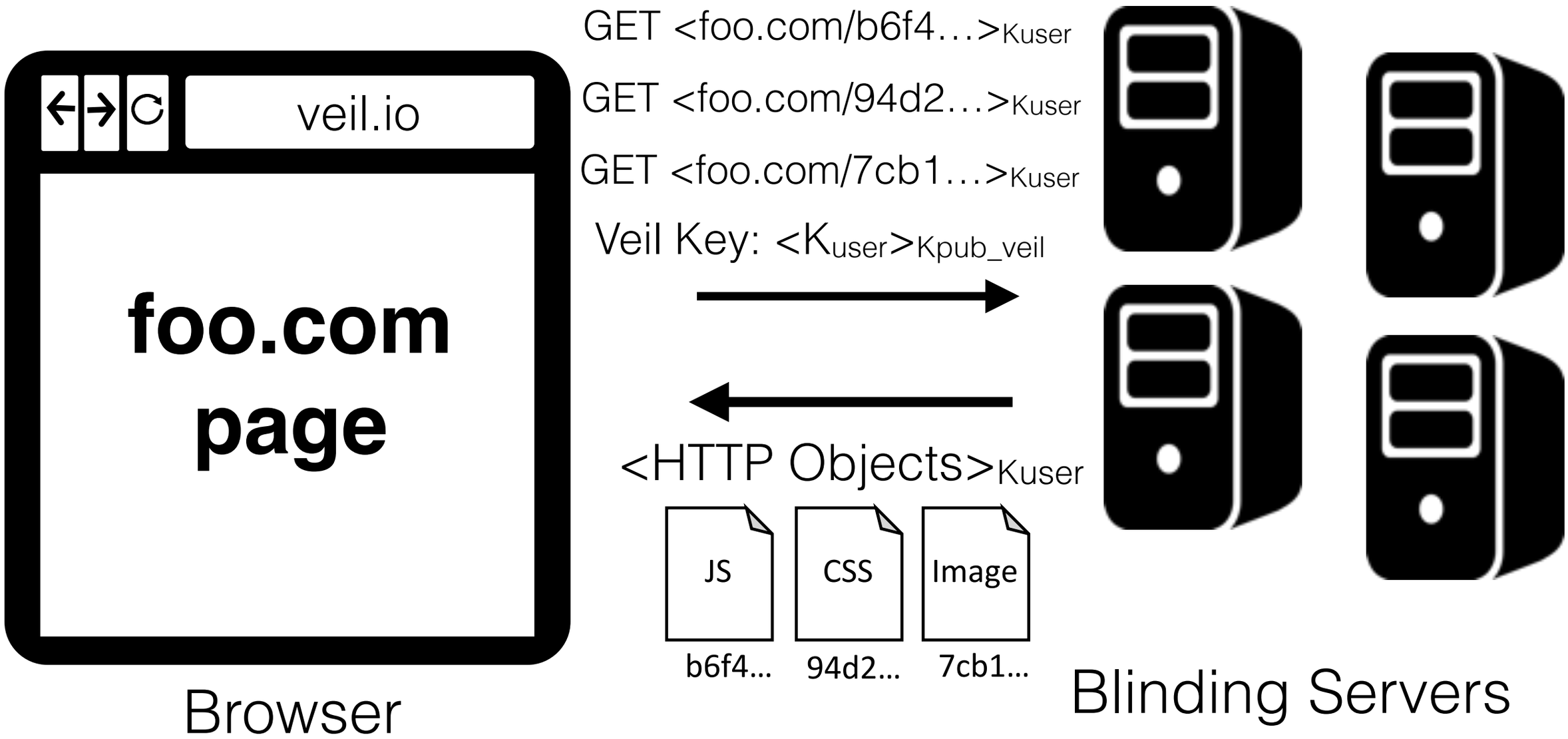

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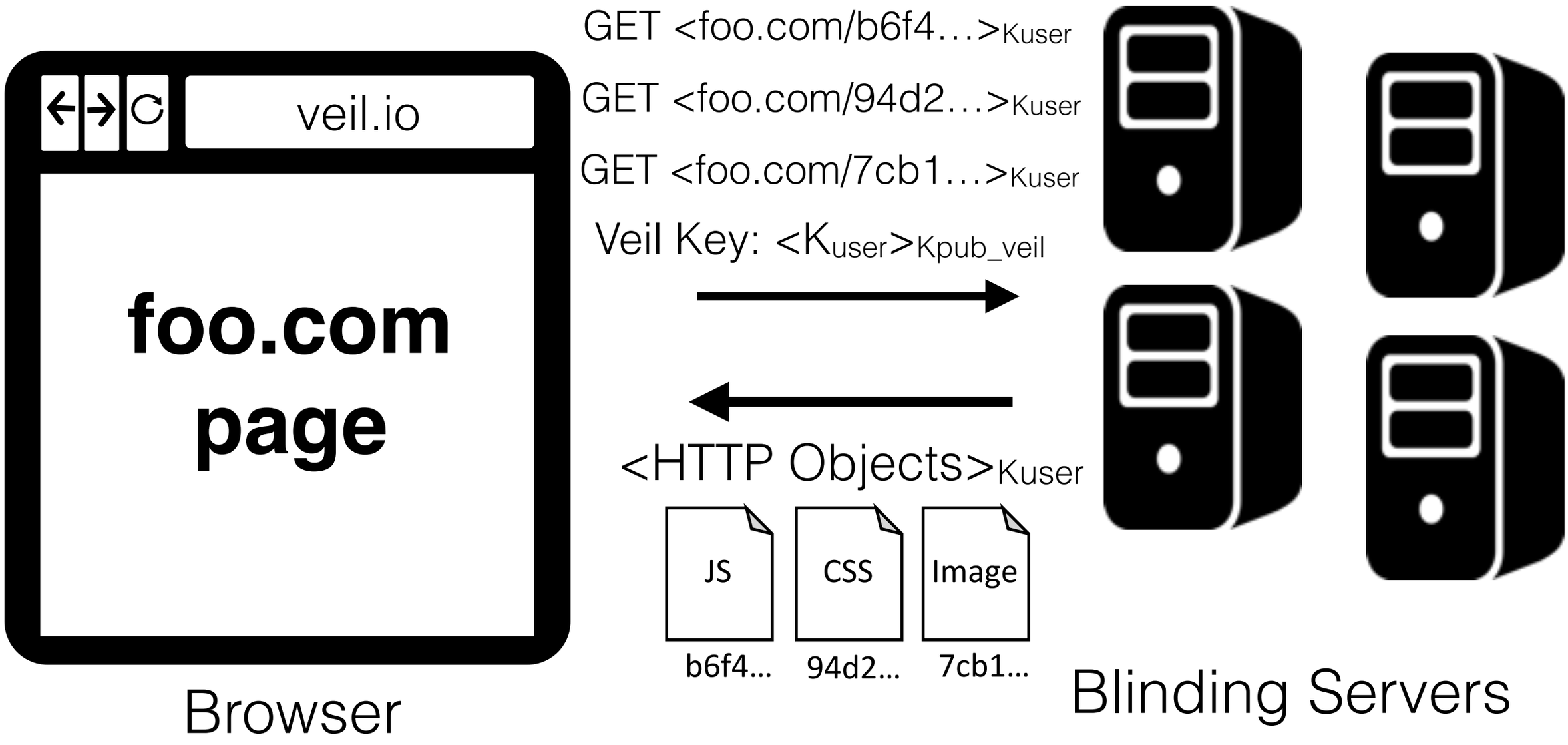

Key Technique: Blinded URLs

Protecting RAM Artifacts

- Heap Walking: reduce likelihood of swap rooted at `markAsSensitive()` tree
- Content Mutation: not leak site-specific content
  - Noise to images
  - Add junk code
  - `eval()`-folding
- More details in the paper

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URL blinding, heap walking, and content mutation are inherently unimplementable by the browser!

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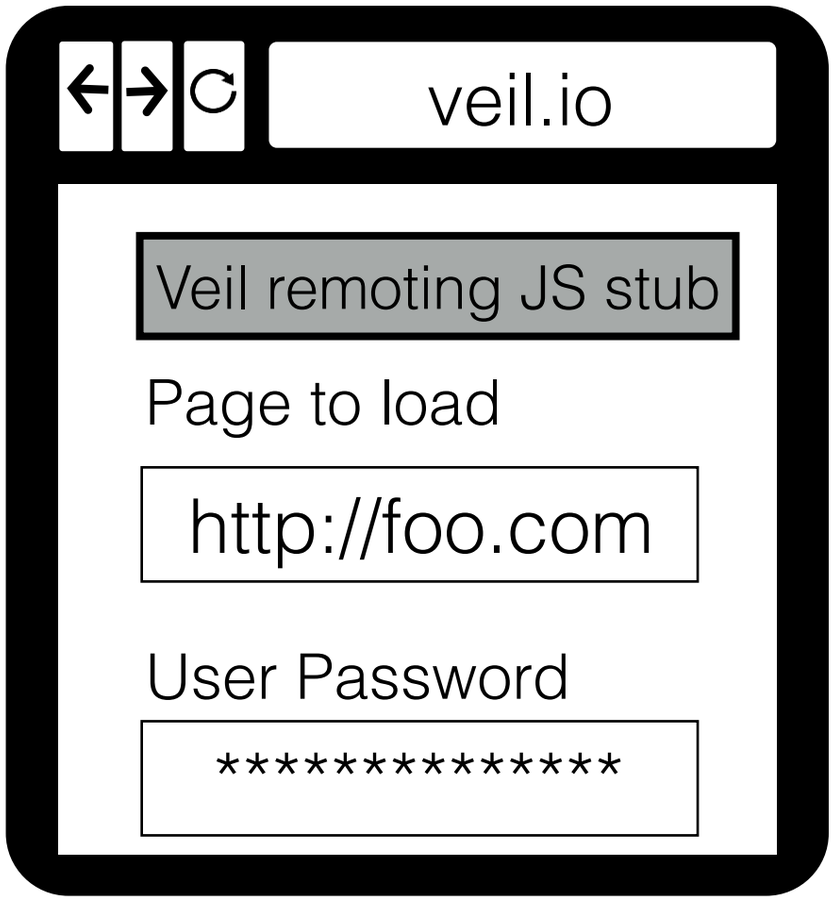
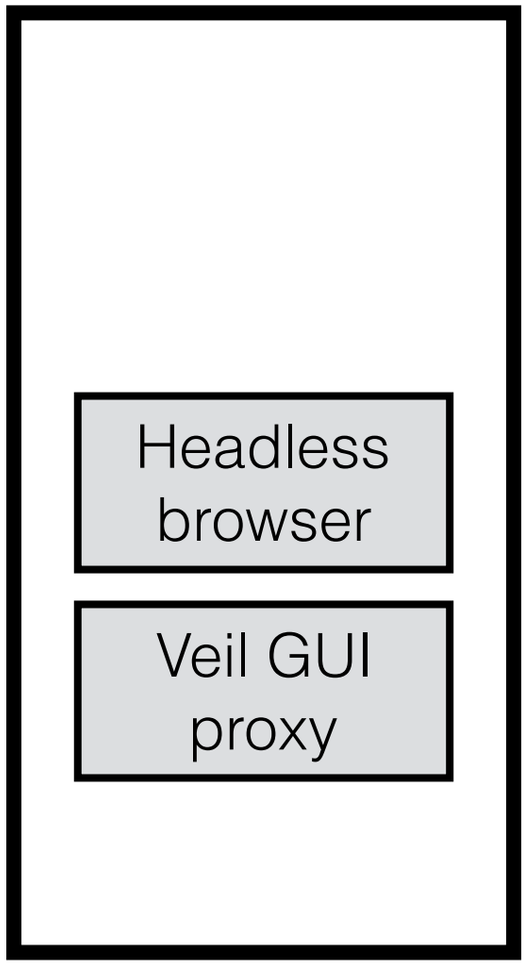
- Heap walking reduces likelihood of swapping
- Content mutation makes it difficult to recover
- However, some sites might want to minimize client-side DOM state
- Solution: DOM hiding mode
  - User's browser as a thin client
  - Remote server loads real page, applies GUI event, and returns screenshot of updated page

DOM Hiding Mode



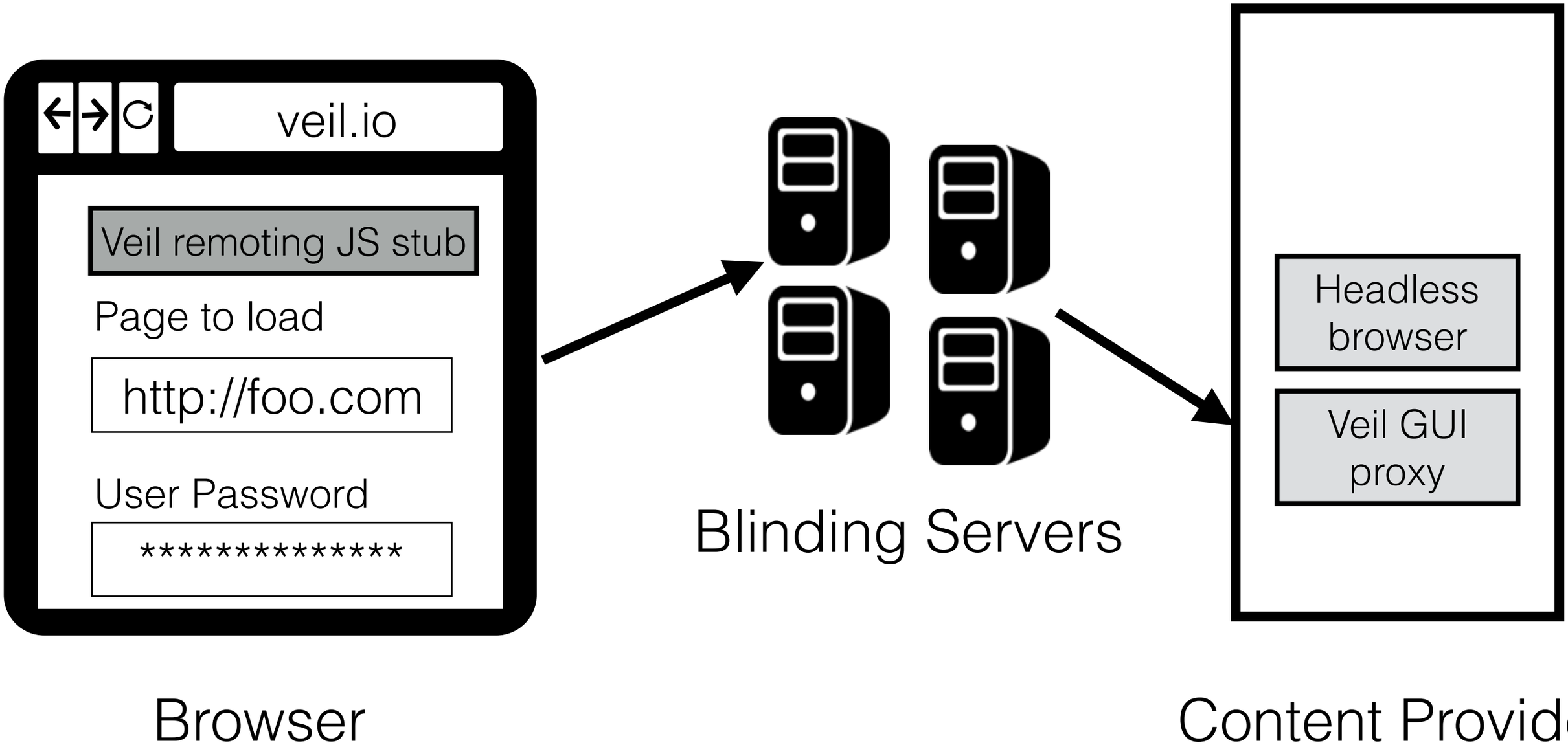
Browser

Blinding Servers



Content Provider

DOM Hiding Mode



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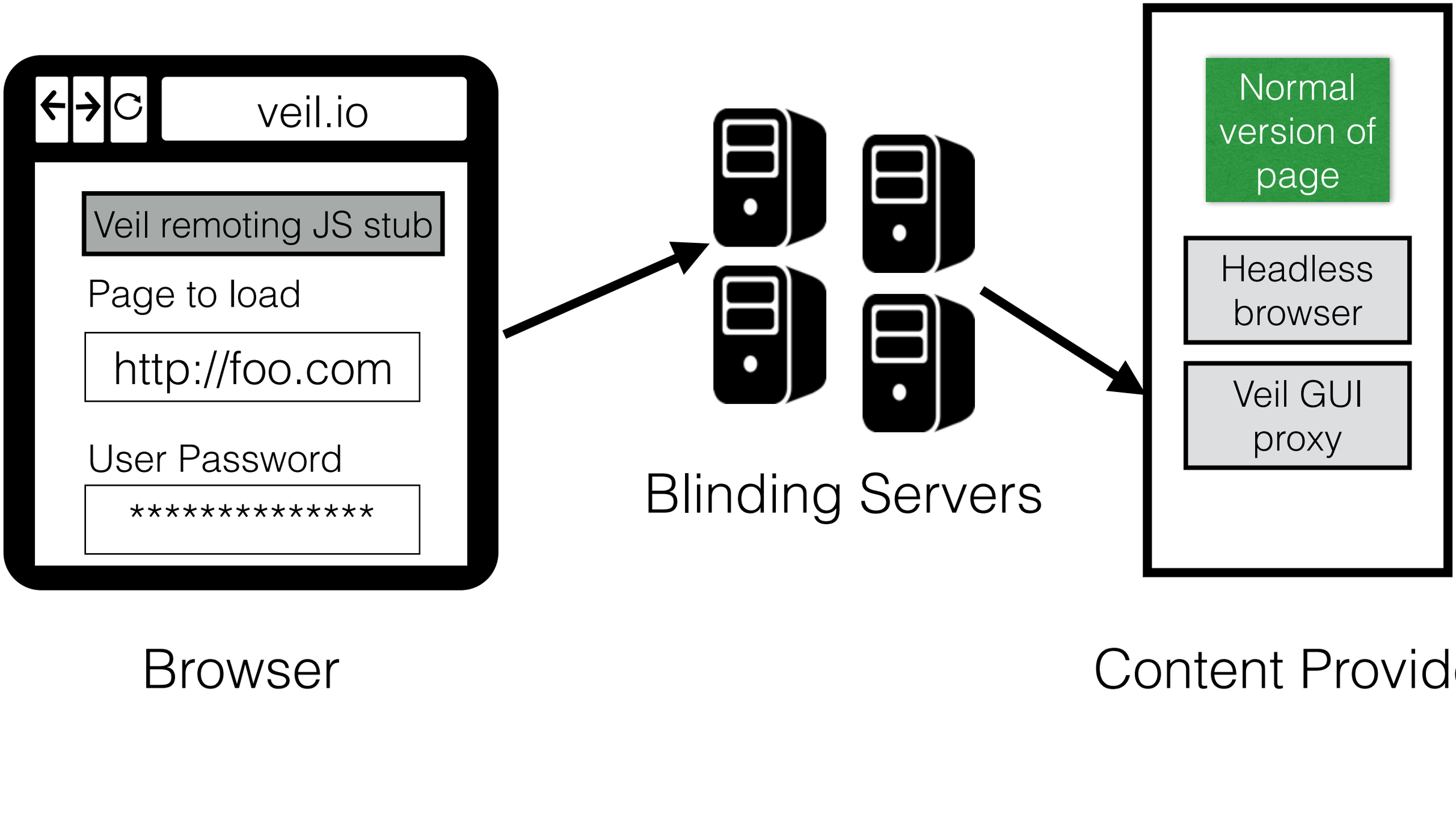

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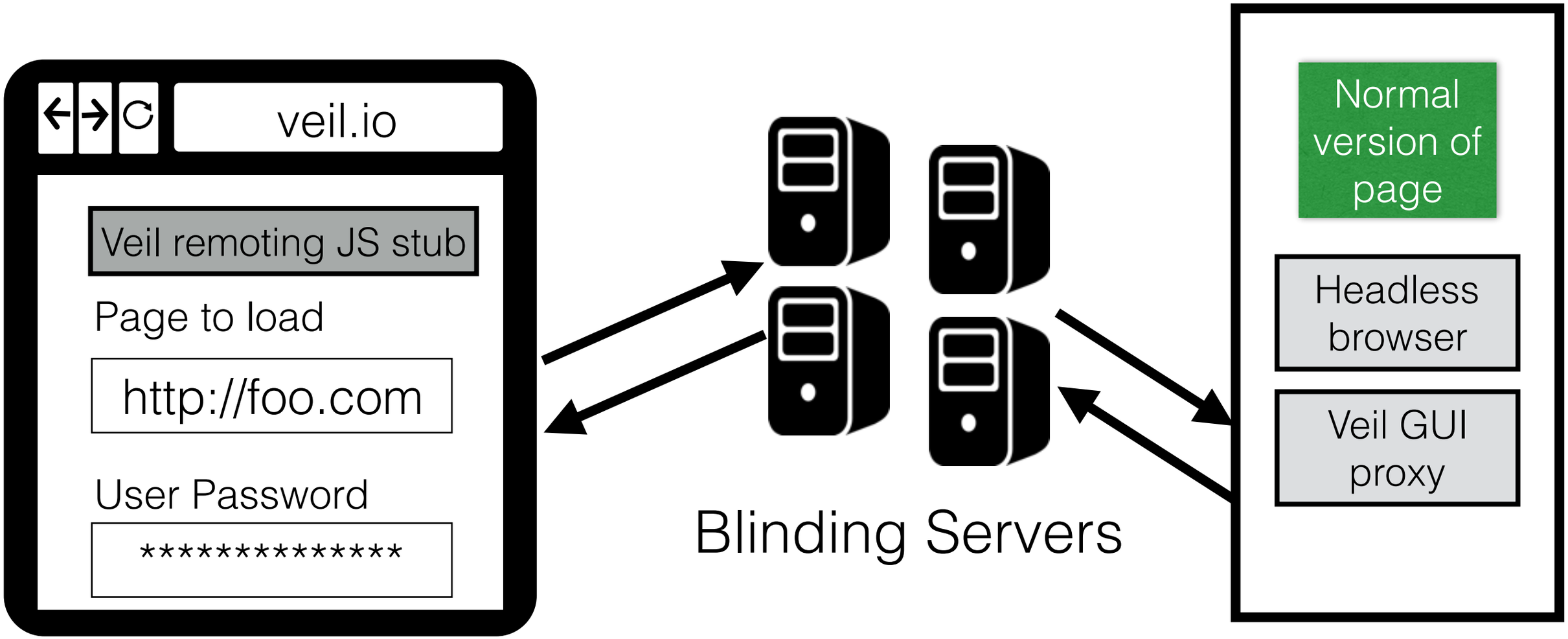

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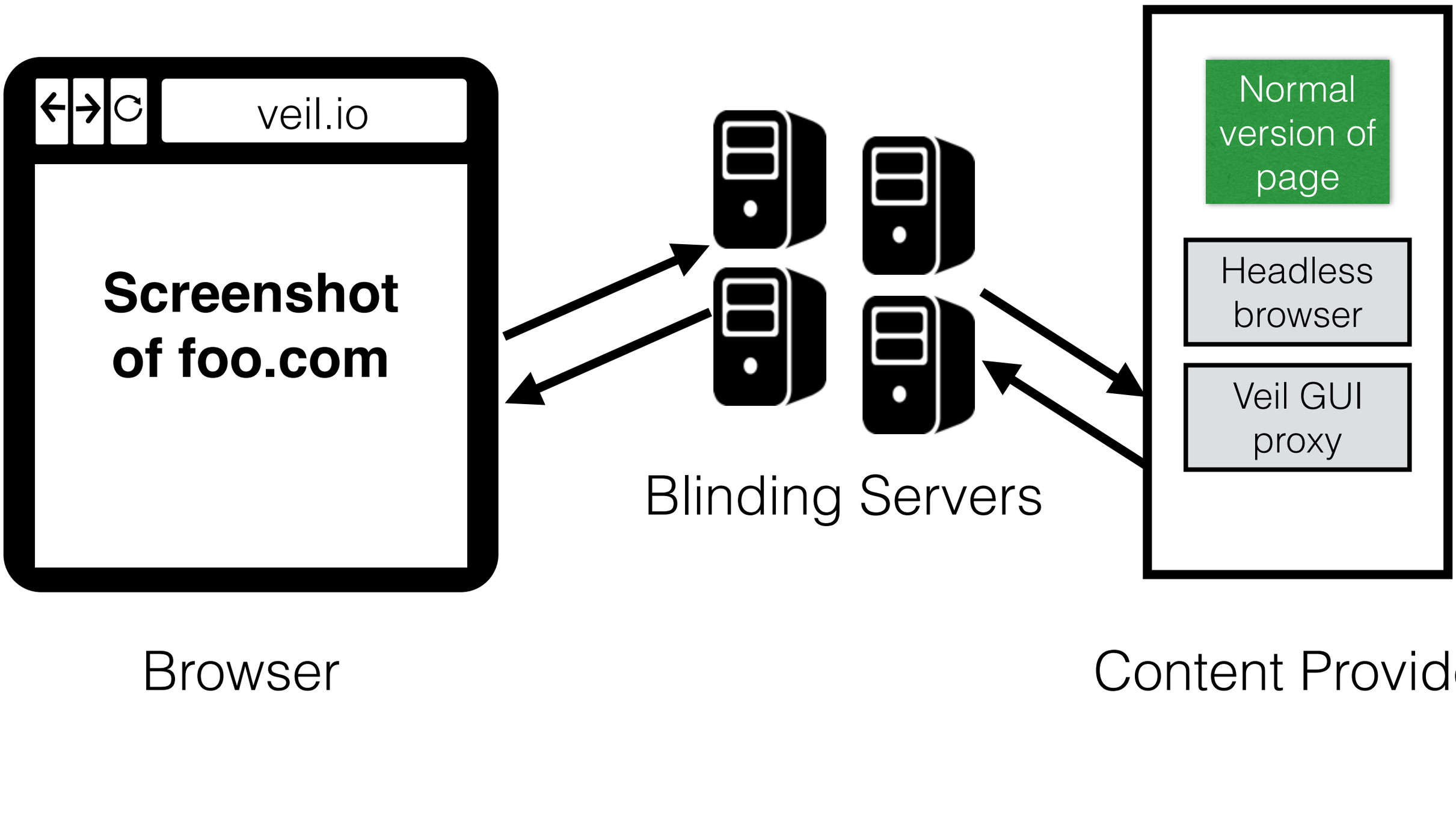

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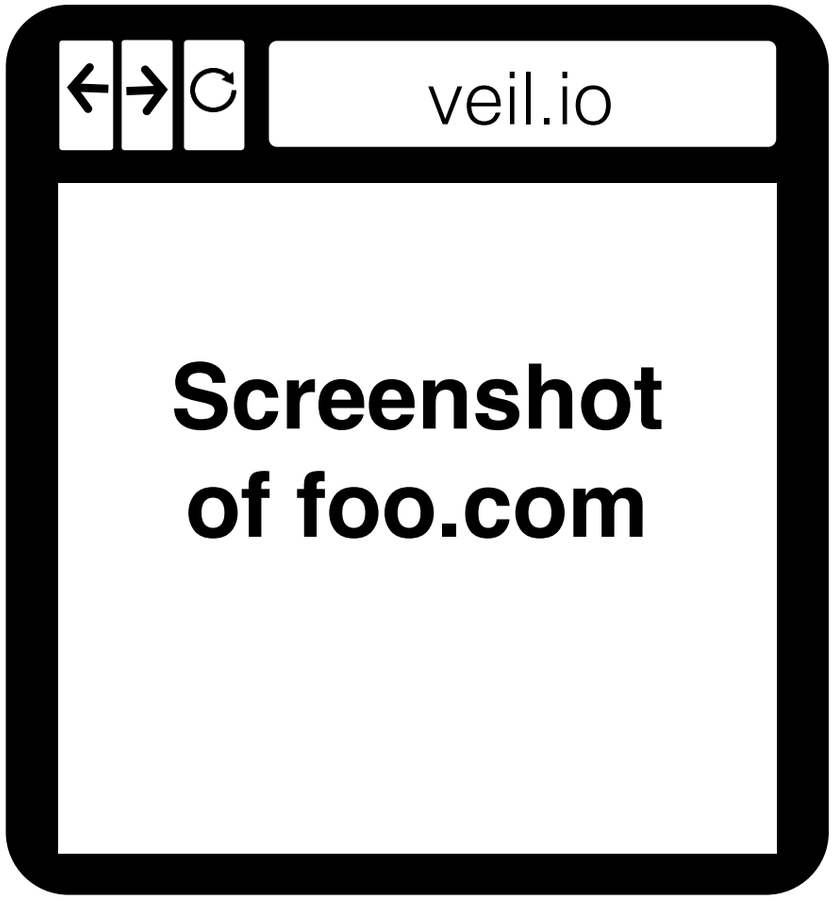

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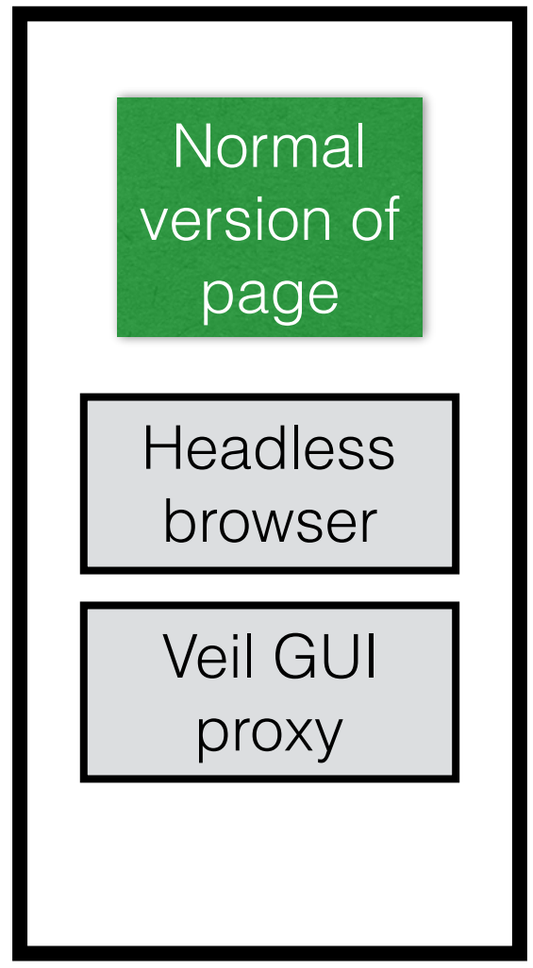

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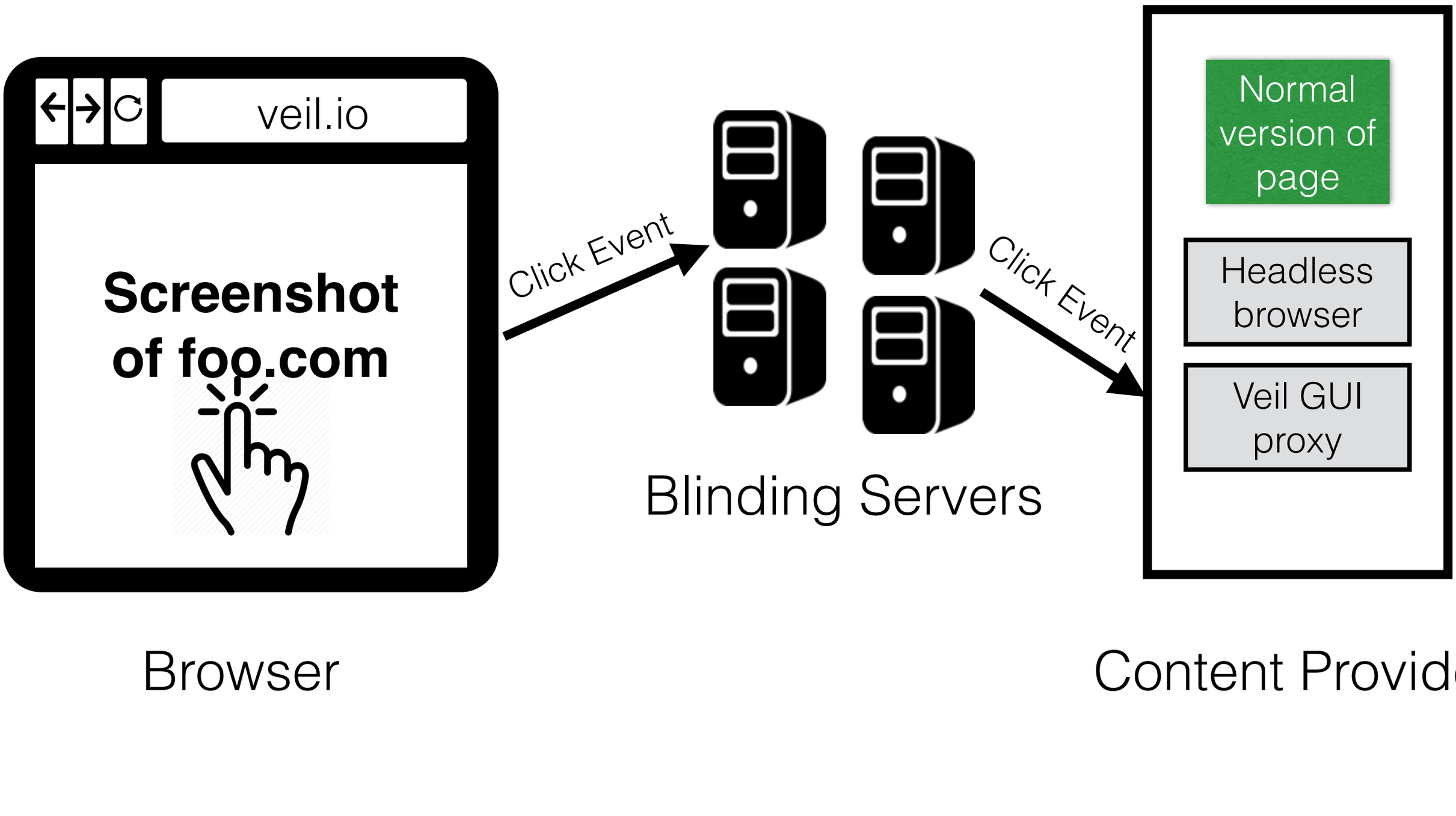

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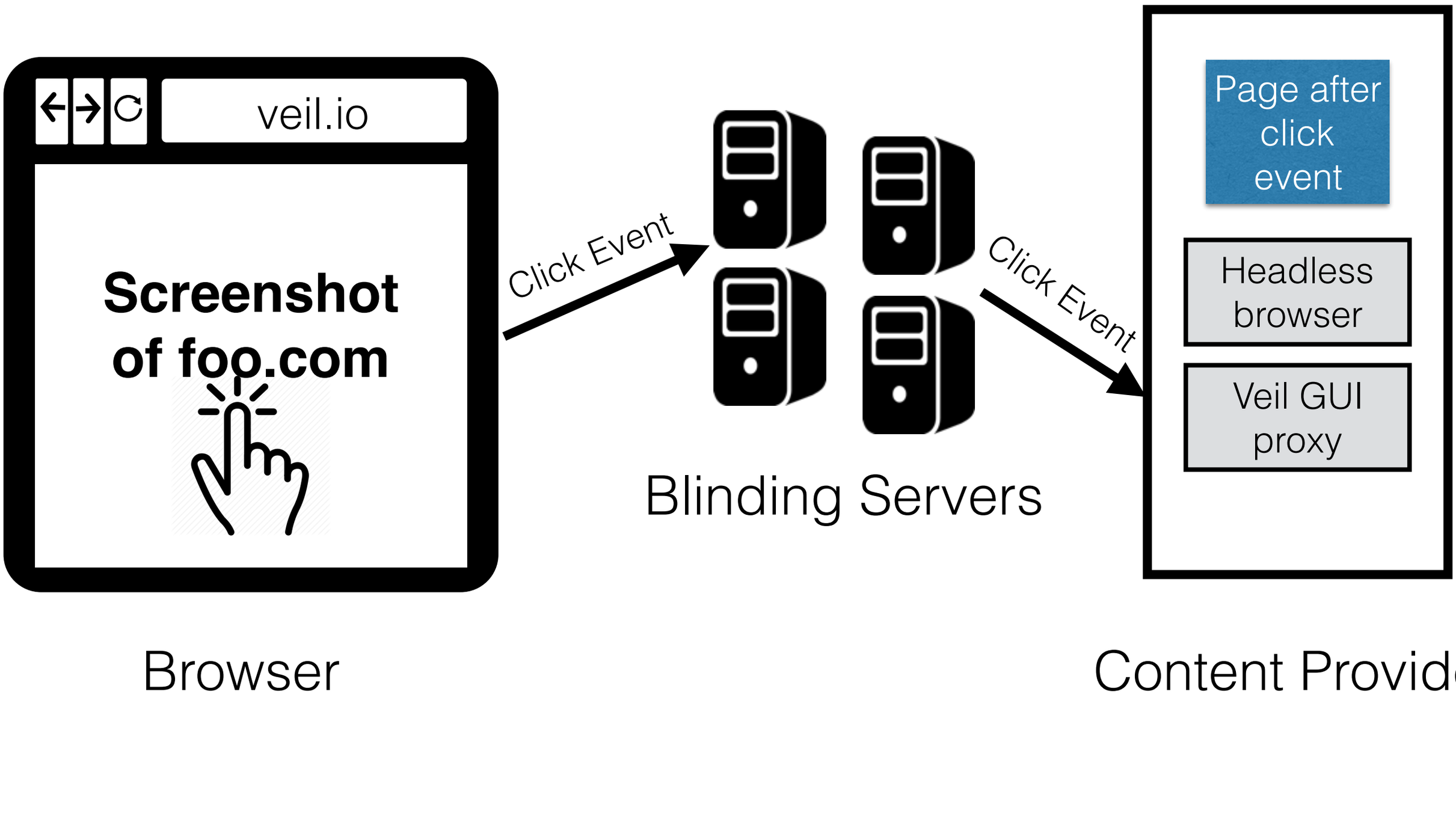

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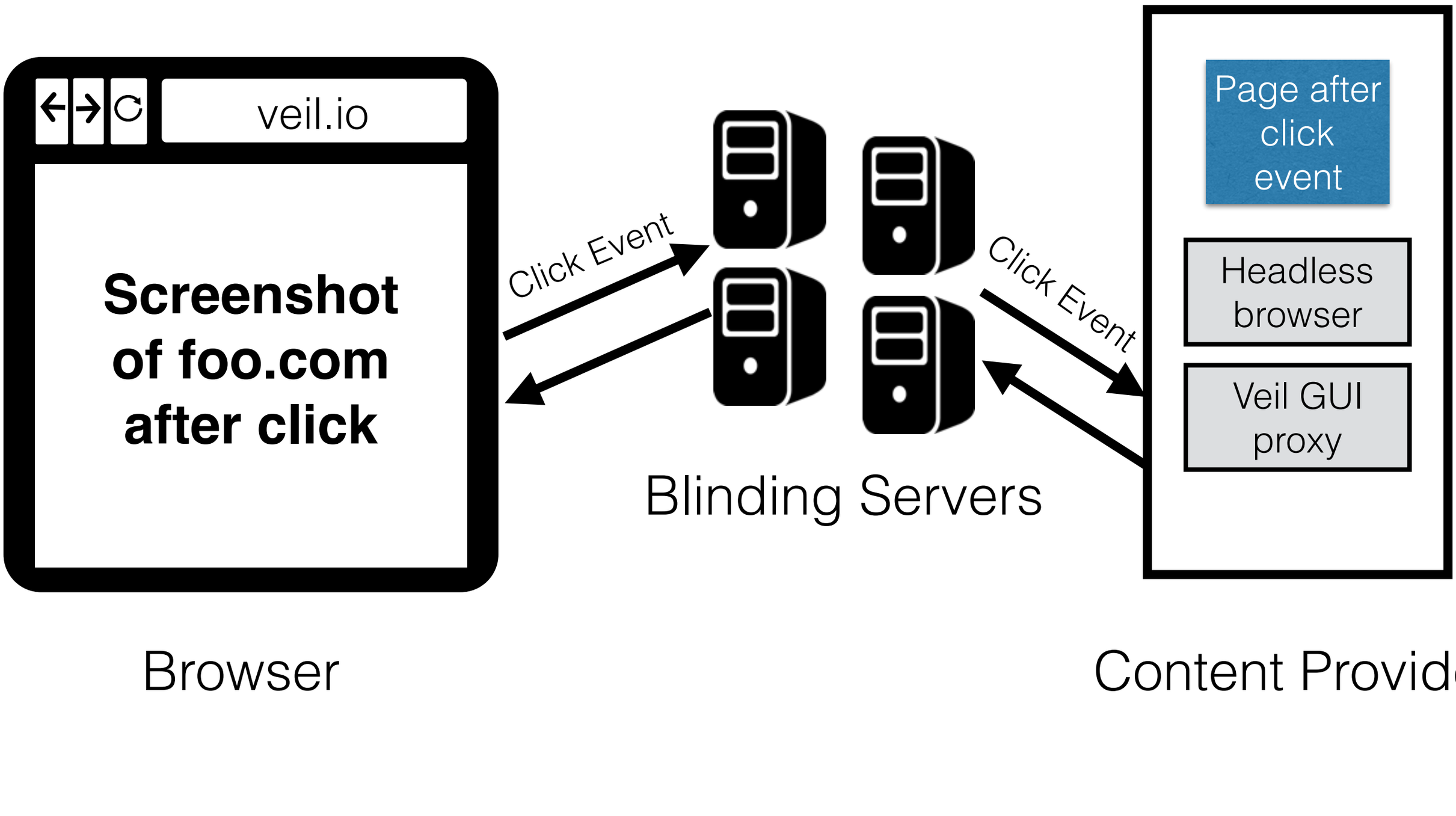


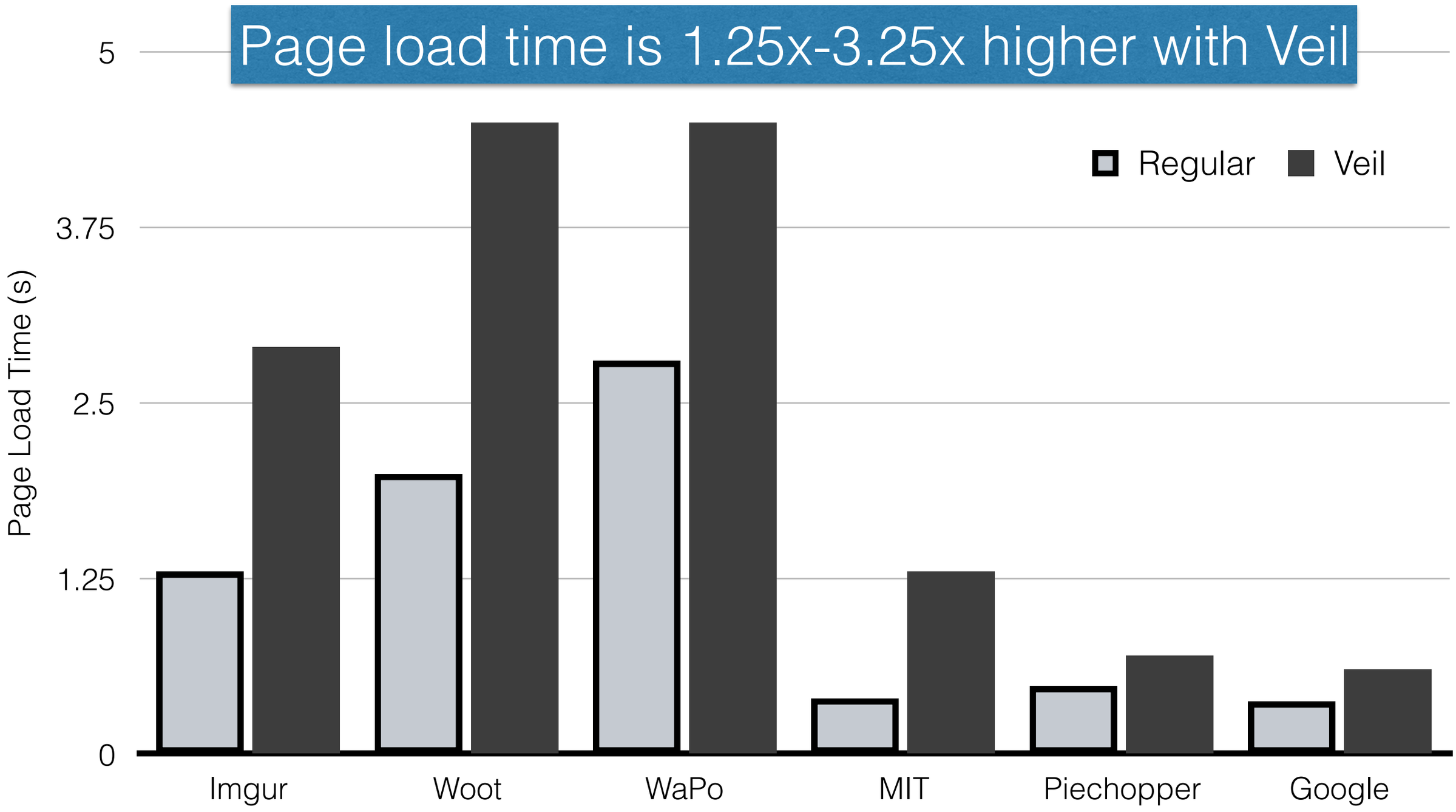
Outline

- Veil Architecture
- **Implementation**
- **Evaluation**

Implementation

- 4 components
  - Compiler
  - Blinding servers
  - JS library for bootstrap page and DOM hiding mode
  - GUI proxy (for DOM hiding mode)
- Compiler and blinding server written in Python
- GUI proxy uses headless Chrome
- BeautifulSoup to parse and mutate HTML

Page Load Times: Standard Veil Mode



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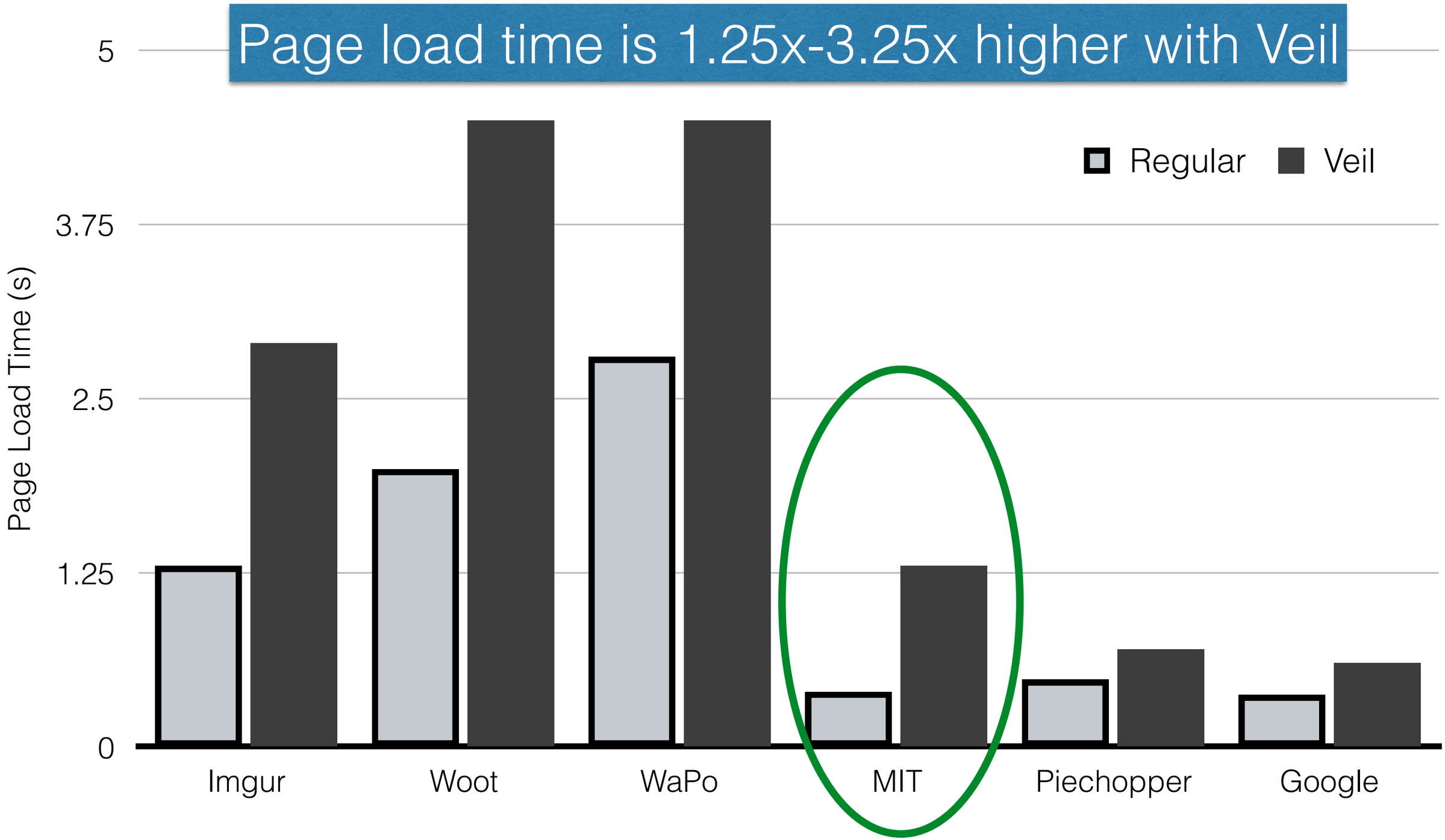
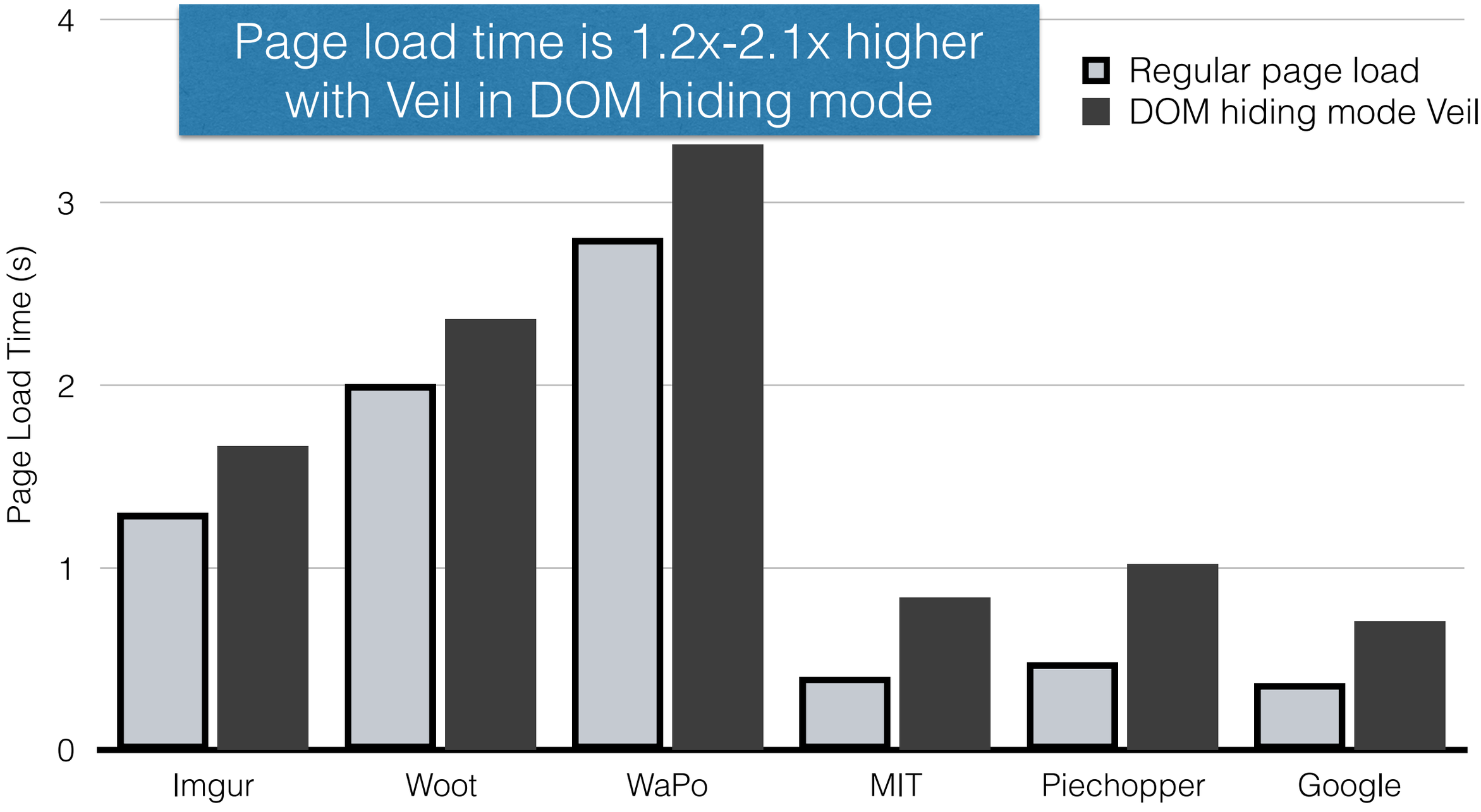


Page Load Times: Veil in DOM Hiding Mode



Related Work

- CleanOS, Lacuna, PrivExec
  - uses secure deletion to implement privacy
  - require configuration and installation of special runtime
    - cannot protect sensitive data unless abstractions spread across the whole system
- UCognito
  - requires modified client-side stack
  - does not prevent information leakage via non-sandboxed parts

Conclusions

- Traditional private browsing modes still leak information!
- Veil allows developers to improve privacy semantics of their pages
- Veil uses a variety of techniques, which are unimplementable by the browser, to hide sensitive information from post-session attackers
- We evaluated Veil on various real websites and found moderate overhead