Stony Brook University

CSE 361: Web Security

Attacking the Same-Origin Policy

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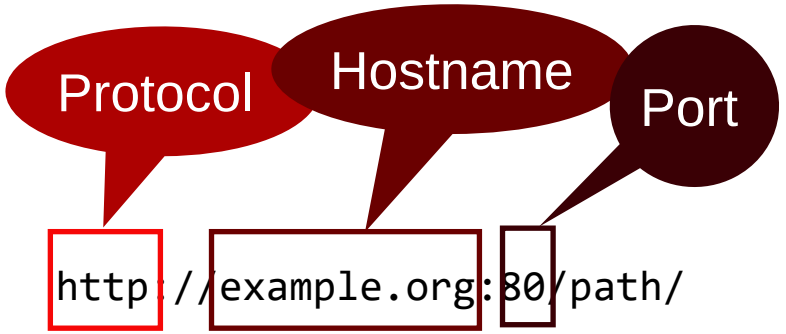
Same-Origin Policy in Action



Attacking the Same-Origin Policy: DNS Rebinding

- Same-Origin Policy is based on the hostname
  - Hostname is not permanently bound to an IP address
- Attacker wants to gain access to network behind a firewall
- Idea: abuse Time-To-Live of DNS

DNS Rebinding - Concept

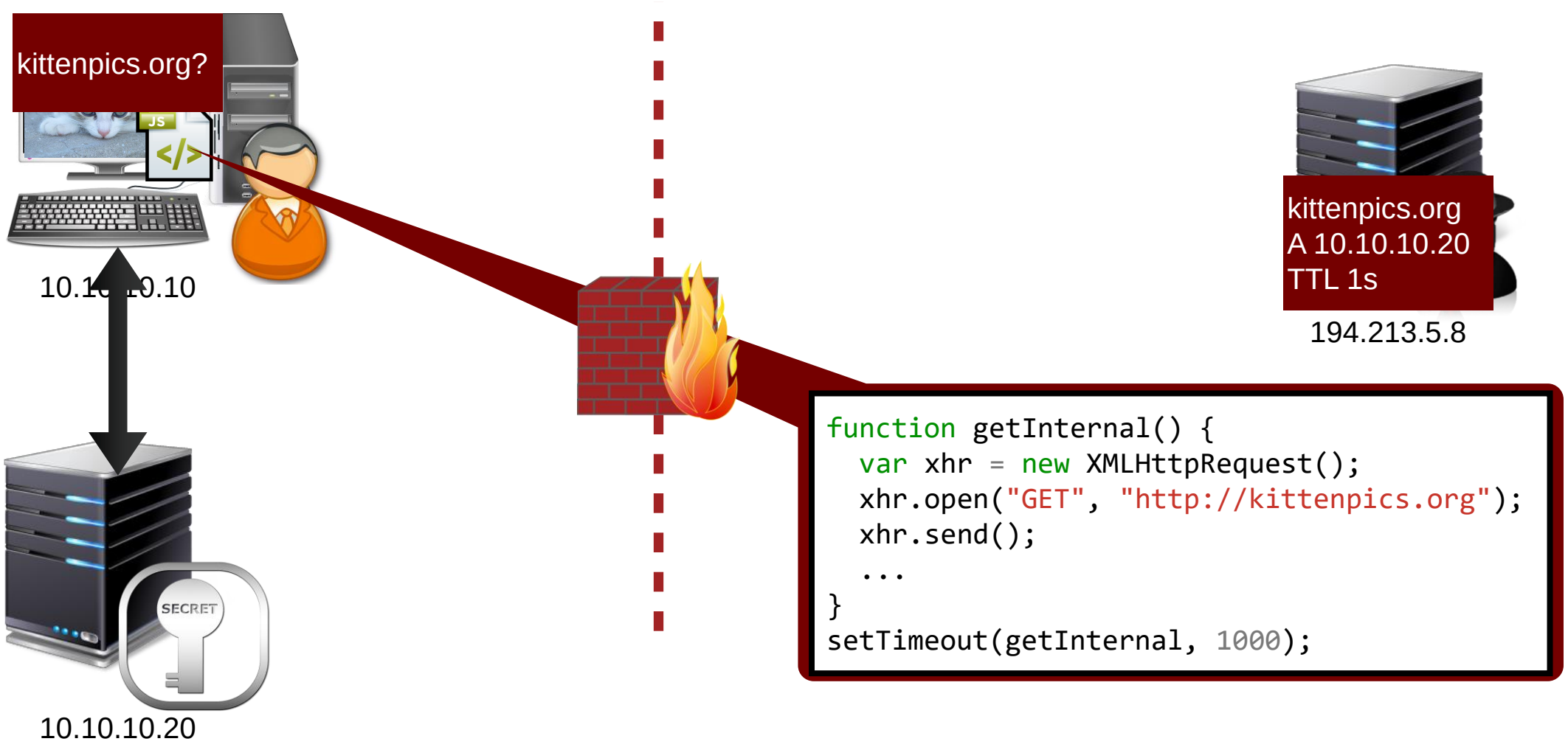
10.10.10.10

10.10.10.20

194.213.5.8

```
function getInternal() {
  var xhr = new XMLHttpRequest();
  xhr.open("GET", "http://kittenpics.org");
  xhr.send();
  ...
}
setTimeout(getInternal, 1000);
```

DNS Rebinding - Concept



DNS Rebinding - A Brief History

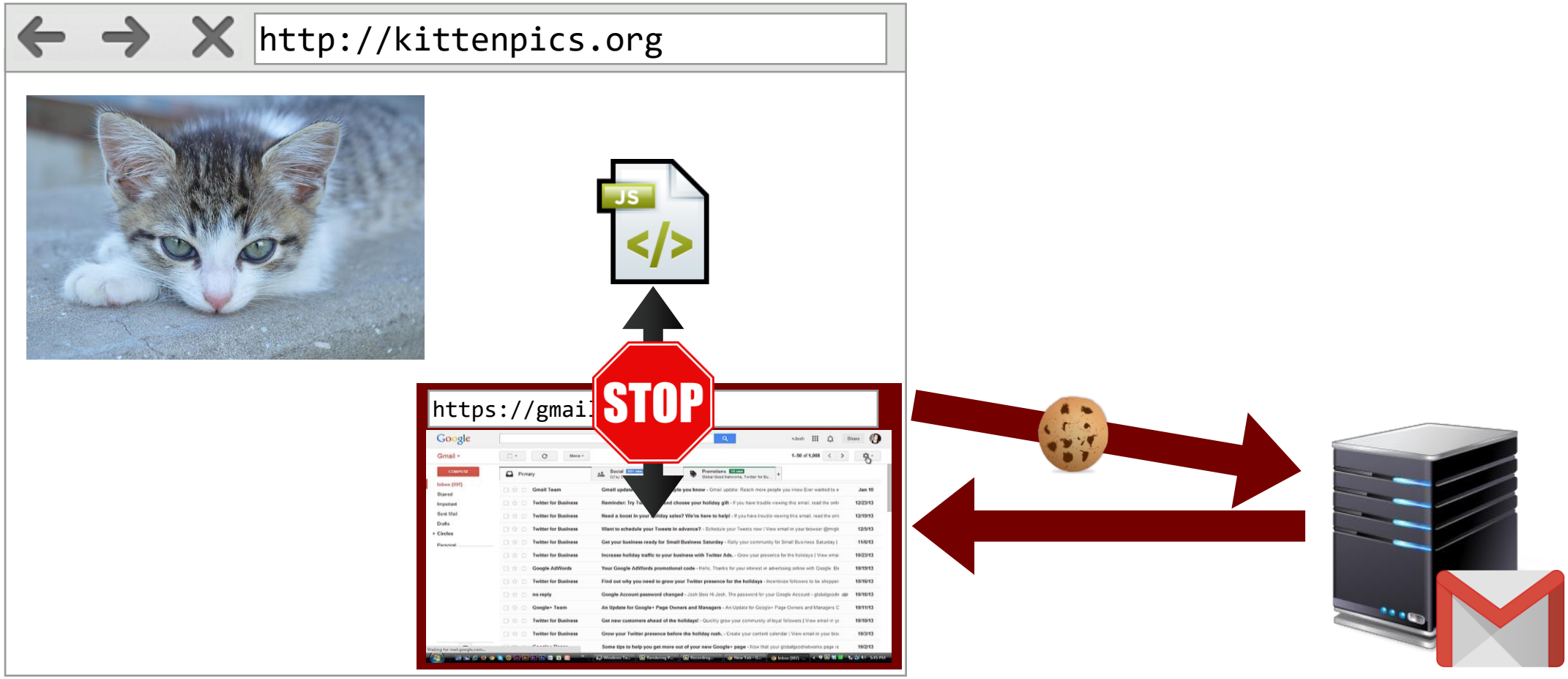
- 1996 Princeton Attack
  - Not real DNS Rebinding, rather two response (attacker and target), specifically targeted a bug in Java's VM
  - Mitigation: Java "pins" IP address used first
- 2002 Adam Megacz
  - Domain Relaxation, bind `attacker.org` to target, `sub.attacker.org` to own site (Recall the new domain relaxation rules?)
  - Mitigation: IE pins for 30 minutes, other browser do similar things
- 2006 Martin Johns
  - IE and Firefox dropped pin whenever a connection to the IP failed
- 2006 Kanatoko
  - same for Flash, but even with sockets
- 2013 Johns et al.
  - Using the HTML5 AppCache

Modern DNS rebinding

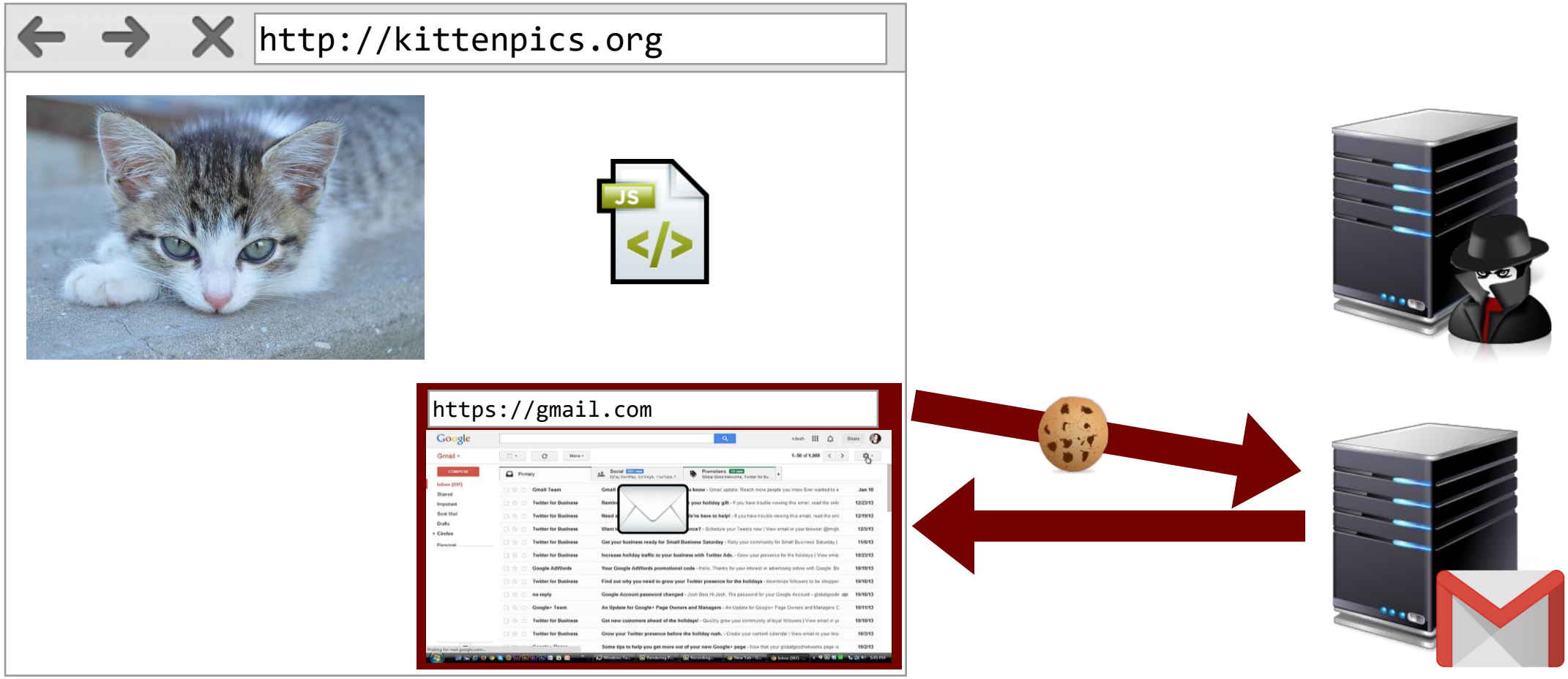
- Browsers only have a finite DNS cache size
  - Chrome 25 had 100, Chrome 26 1000, nowadays 1600
- Idea: evict existing entry by flooding the DNS cache
  - after that, have fun with the rebound IP

```
for(var i = 0; i < 1600; i++)
{
  var xhr = new XMLHttpRequest();
  xhr.open("GET", "http://" + i + ".attacker.com");
}
```

Same-Origin Policy in Action



Bypassing the SOP with Code Injection



Cross-Site Scripting

- Attacker can inject his own **script** into another site (**cross-site**)
  - actually, might have to inject HTML markup
  - ... which contains JavaScript code
- Injected code runs in origin of vulnerable page
  - can do whatever legitimate code can do
  - can modify page to attacker's liking
- Has roughly two orthogonal dimensions
  - Location of vulnerable code (server or client)
  - Persistence of attack payload (reflected or persistent)

A short history of Cross-Site Scripting

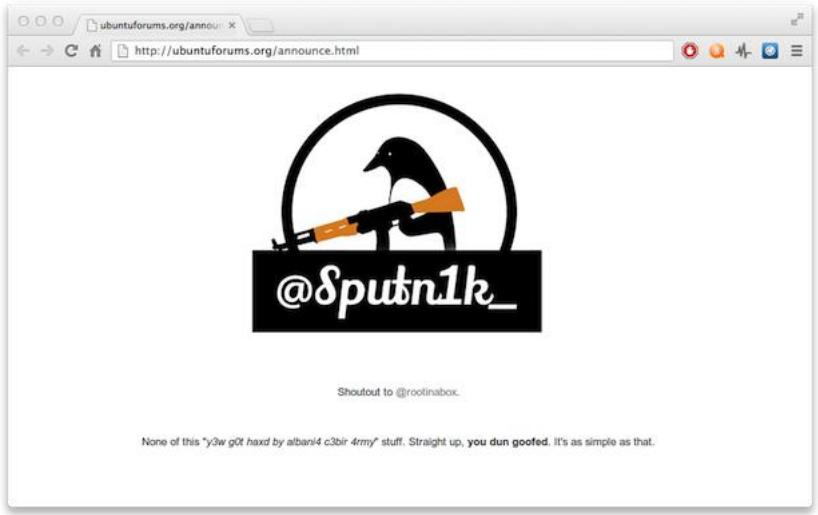
- First discovered in 1999
  - December 1999 by Microsoft
  - (allegedly) November 1999 by people at American Express
  - **Reflected** Server-Side Cross-Site Scripting in several 404 pages
- Amit Klein coined the term "DOM-based Cross-Site Scripting" in 2005
  - referring to the DOM as the part which would be abused to inject code
  - .. does not really cover the eval case
  - we refer to this as **Client-Side Cross-Site Scripting**

Impact of Cross-Site Scripting vulnerabilities

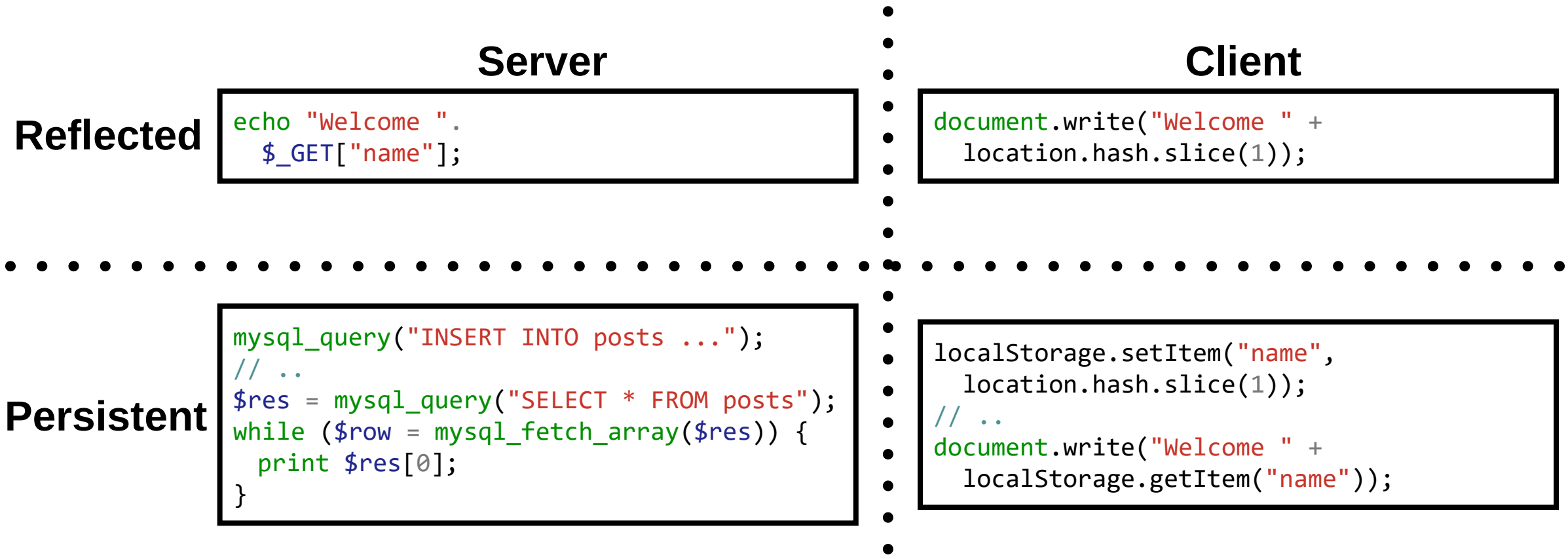
- JavaScript execution allows attacker to pretend to be
  - ... user towards the server (e.g., posting content in social network)
  - ... server towards the user (e.g., by modifying the look of a page)
- Obvious first target: reading cookies (**session hijacking**)
  - somewhat mitigated by HTTPOnly cookies
- Other "use cases" include
  - attacking browser-based password managers
  - setting cookies

Real-World XSS: Ubuntu Forums in 2013

- Attacker found flaw in vBulletin forum software
  - Announcements allowed for unfiltered HTML
- Attacker crafted malicious announcement and send link to admins
  - Stated that there was a server error message on the announcement
  - Instead, injected JavaScript code stole cookies (yes, cookies....)
- Given elevated privileges, the attacker could upload PHP shell
  - eventually dumped the users database and left defacement on main page



Dimensions of Cross-Site Scripting



Reflected Server-Side Cross-Site Scripting

1. Attacker probes server for vulnerabilities
   - Injecting markup into request parameters (in case data is used within HTML)
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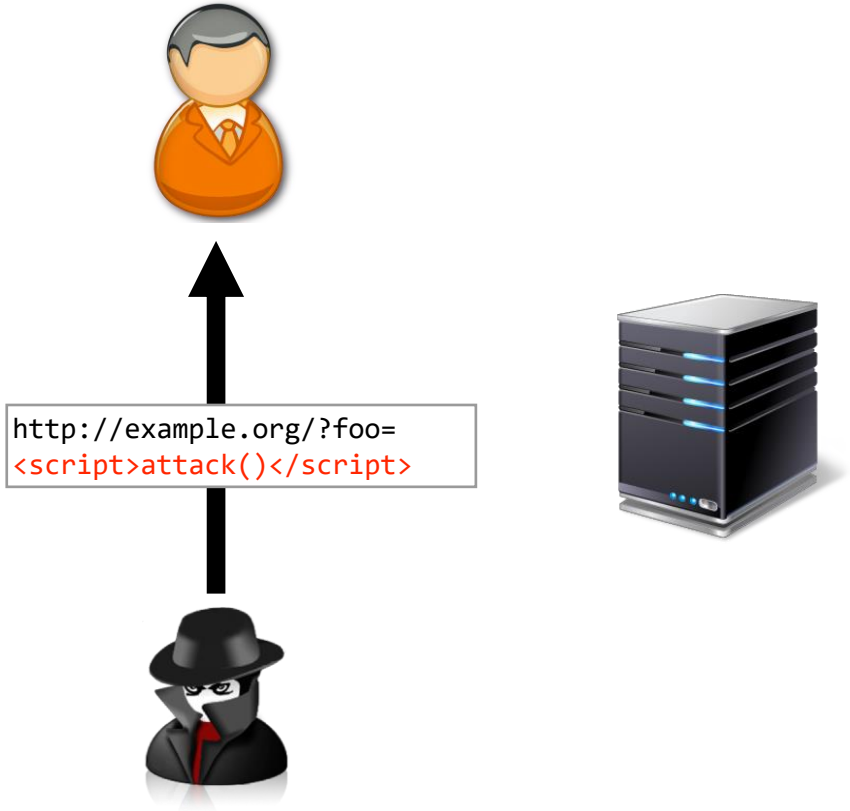
2. Once reflected potentially dangerous content is found, injects complete script
3. Crafts specific attack payload, e.g., to steal cookie

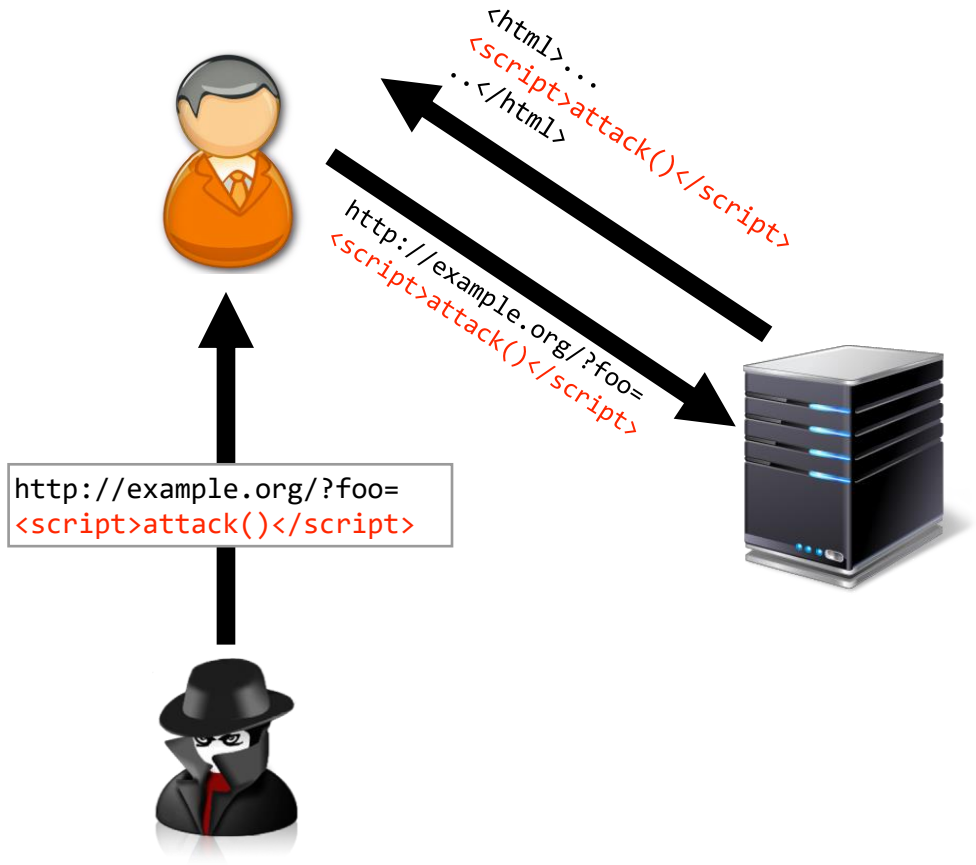
Reflected Server-Side Cross-Site Scripting

1. Attacker tricks victim into visiting link
   - Sends email with link
   - Embeds iframe to vulnerable site on his own domain



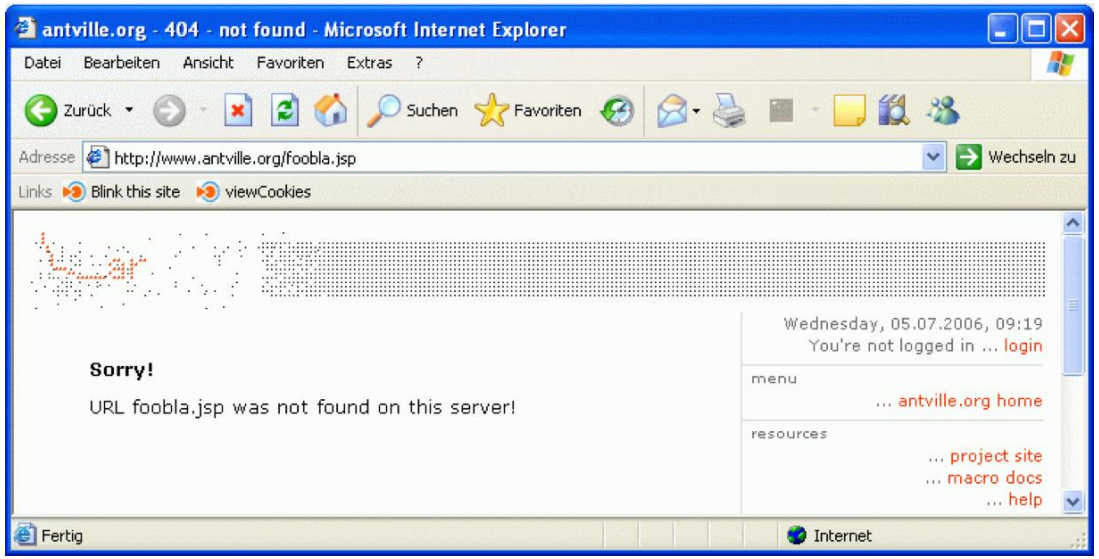
Reflected Server-Side Cross-Site Scripting

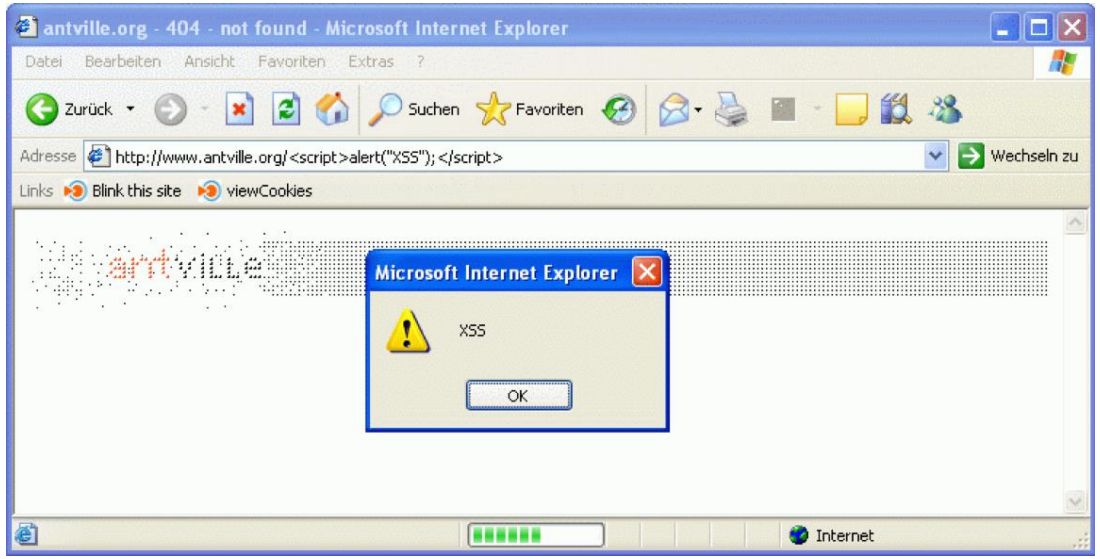
1. Attacker tricks victim into visiting link
   - Sends email with link
   - Embeds iframe to vulnerable site on his own domain
- Malicious payload is reflected from server
   - May interact with server as the user
   - May leak sensitive information (e.g., cookie) to the attacker



Reflected Server-Side Cross-Site Scripting: Examples

- Most frequently occurs in search fields
  - echo '<input type="text" name="searchword“ value="'.$_REQUEST["searchword"].'">';
- Custom 404 pages
  - echo 'The URL '.$_SERVER['REQUEST_URI'].' could not be found';





Example: exploiting reflected server-side XSS

```php
<?php
// load avatar
echo "<img src='//avatar.com/img.php?user=" . $_GET["user"] . "'>";
?>
```

- Exploit payload:
  - Close img tag: '>
  - Add payload: <script>alert(1)</script>
- Visit URL
  - **http://example.org/?user= '><script>alert(1)</script>**

- <img src='//avatar.com/img.php?user='><script>alert(1)</script>'>

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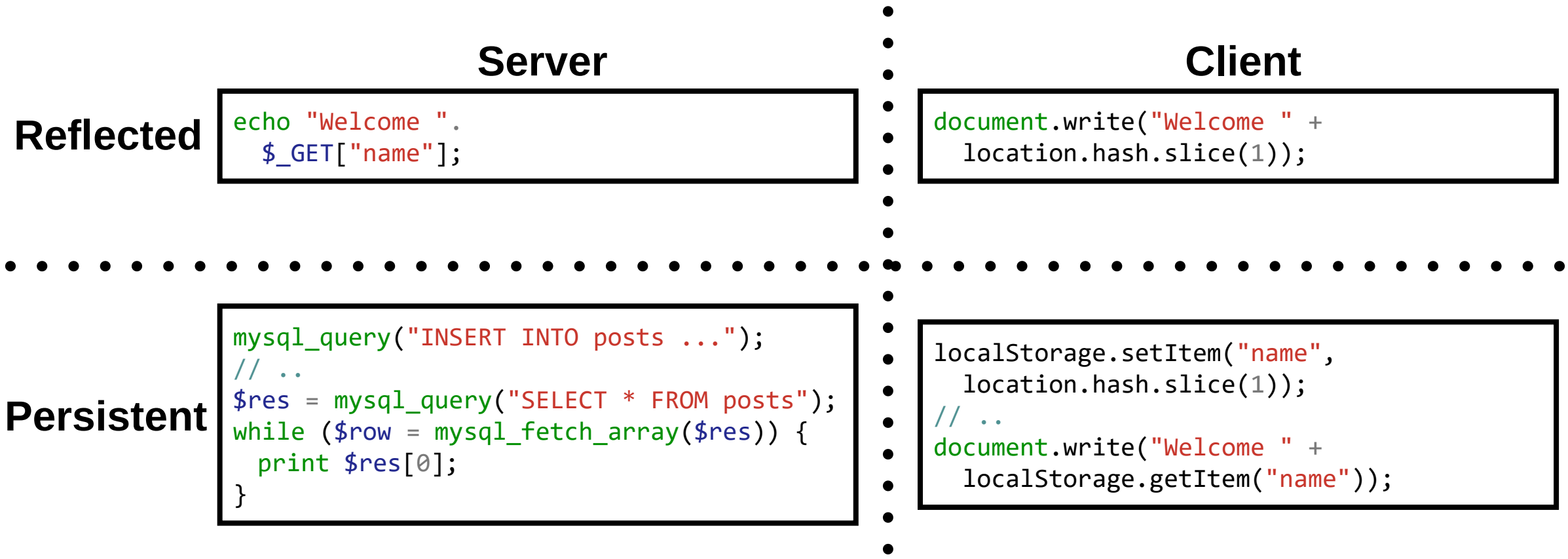

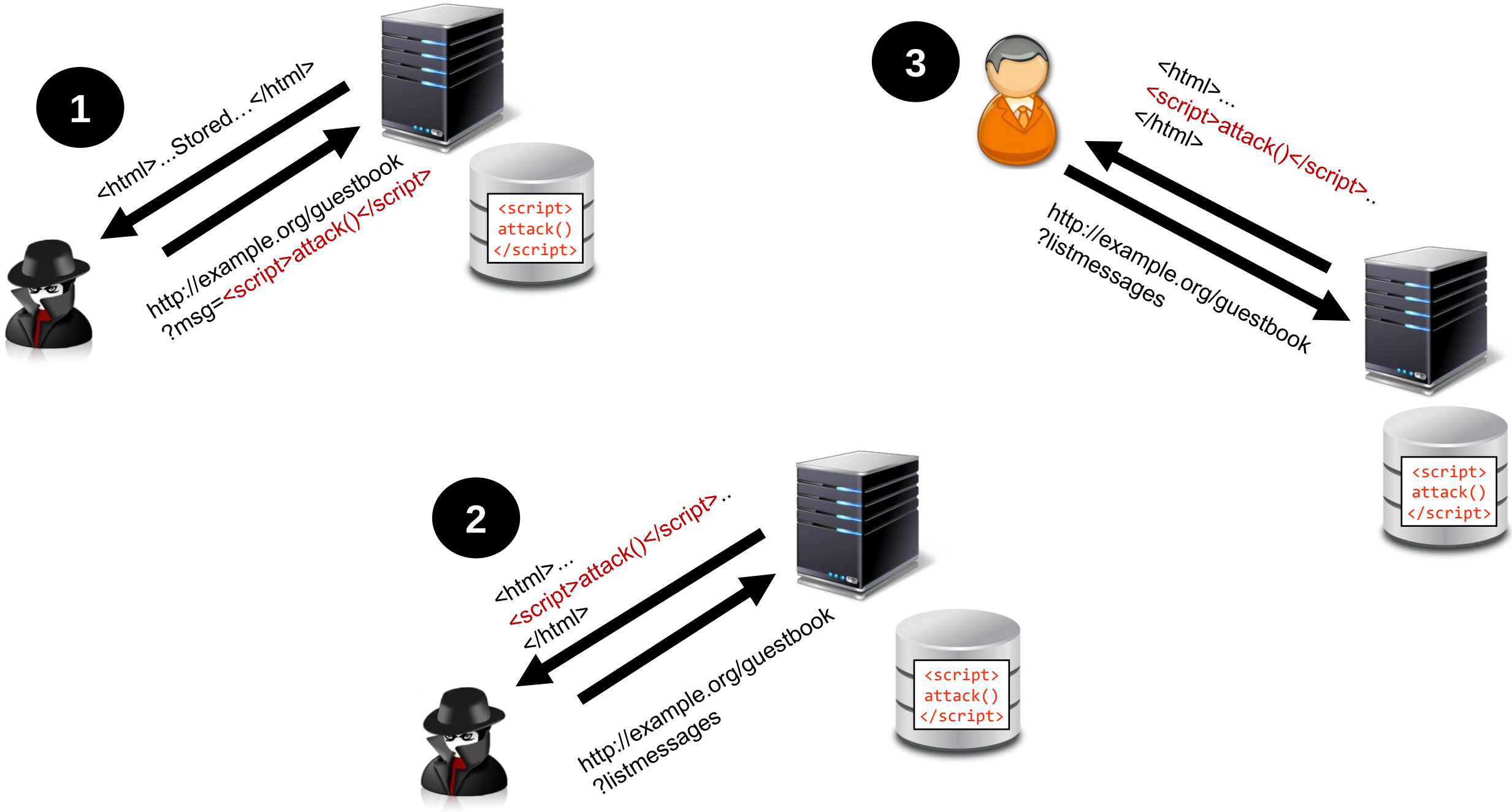
1
<html>…Stored…</html>
http://example.org/guestbook
?msg=<script>attack()</script>
<script>
attack()
</script>
2
<html>…
<script>attack()</script>..
</html>
http://example.org/guestbook
?listmessages
<script>
attack()
</script>
3
<html>…
<script>attack()</script>..
</html>
http://example.org/guestbook
?listmessages
<script>
attack()
</script>

Persistent Server-Side Cross-Site Scripting

1. Attacker probes server for vulnerabilities
   - Injecting markup into request parameters (in case data is used within HTML)
   - Injecting JavaScript in request parameters (in case data is used within script)
2. Data is not immediately reflected, rather stored in database

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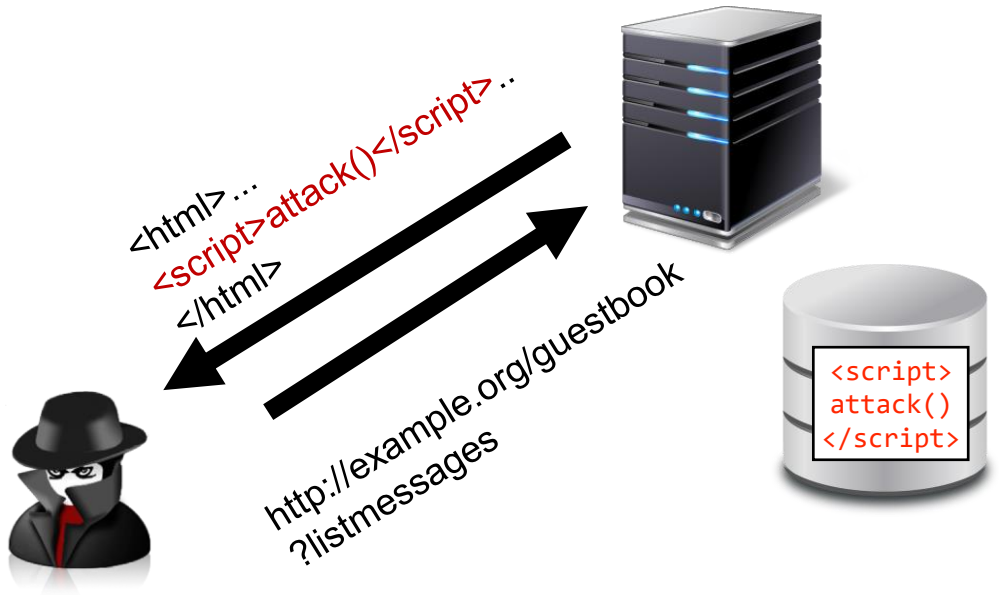

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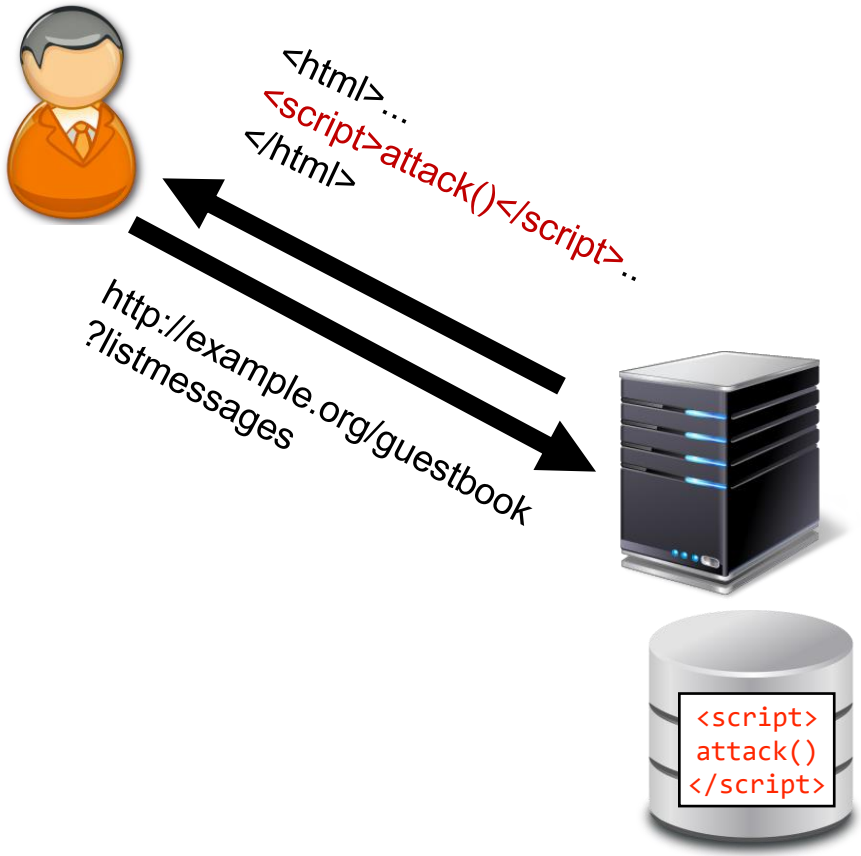
2. Data is not immediately reflected, rather stored in database
3. Attacker checks the stored entry
4. **Every user** of the site is attacked

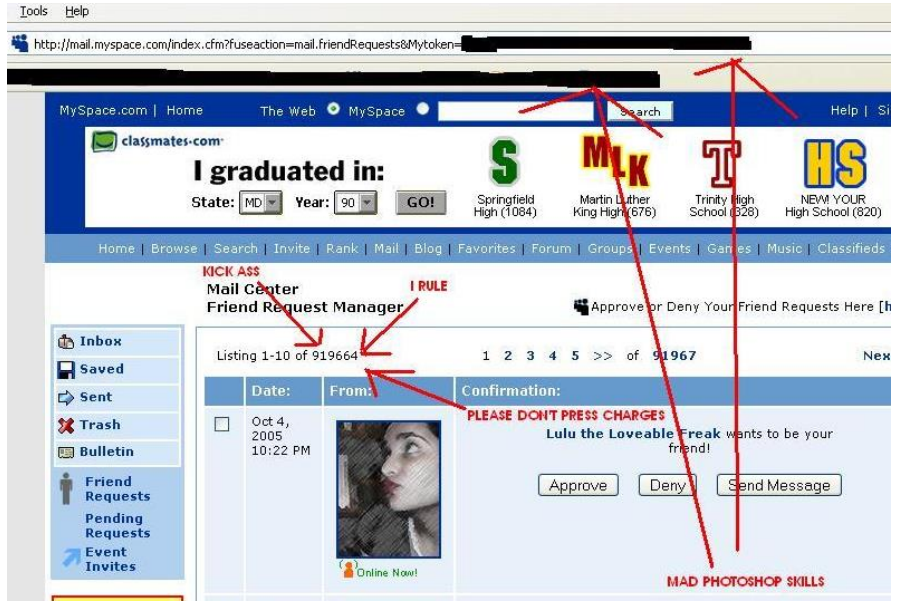


Persistent Server-Side Cross-Site Scripting: Examples

- Anything that stores data
  - Guestbooks
  - Forums
  - Profile pages on social media
- More interesting vectors
  - Description of books on Amazon
  - Abstract of a book on Amazon
    - scanned the XSS payload with OCR
- ....

Persistent Server-Side Cross-Site Scripting: MySpace worm

- MySpace allowed certain HTML tags in profiles
  - tried to block others
- Samy Kamkar (April 2005) found bypass
  - `<div id="mycode" expr="alert('hah!')" style="background:url('java script:eval(document.all.mycode.expr)')">`
- Attack payload added Samy as a friend
  - According to Samy, goal was to "befriend girls"
- and updated the profile of the infected victim
  - in turn, all friends could be infected
- over 1,000,000 friends (over 3% of MySpace) within 20 hours



Preventing Server-Side Cross-Site Scripting

- Option 1: Input Validation/Sanitization
- Check input against list of allowed/expected characters
  - Is this a number? Is this an email?
- Can only be considered first line of defense
  - Usage of data might not be known at that point
  - Hard to get right, for the general case
- (bad) alternative: removing unwanted elements
  - Known as blacklisting/blocklisting
  - e.g., all script tags
  - simple replace does not suffice: `<scr<script>ipt>`

```php
foreach ($_REQUEST as $key => value) {
  $_REQUEST[$key] = preg_replace("[^0-9a-zA-Z]",
                                 "", $value);
}
// ....
$username = base64_decode($_REQUEST["user"]);
```

Preventing Server-Side Cross-Site Scripting

- Option 2: Output Encoding
- When using the data, encode it
  - depending on context, different encoders might be necessary

HTML Encoding **PHP**

```php
<?php
 function noHTML($input, $encoding = 'UTF-8'){
  return htmlentities($input, ENT_QUOTES | ENT_HTML5, $encoding)
 }
 ...
 echo '<div> You searched for ' . noHTML($_GET['q']) . ' </div>';
?>
```

Preventing Server-Side Cross-Site Scripting

- Option 2: Output Encoding
- When using the data, encode it
  - depending on context, different encoders might be necessary

URL Encoding

PHP

```php
<?php

function sanitizeParam(){
 return urlencode($param);
}

echo '<a href="https://example.com/article?input="' . sanitizeParam($_GET['q']) . '">...</a>';

?>
```

Preventing Server-Side Cross-Site Scripting: Best Practices

- Avoid creating your own filters
  - frameworks typically have (hopefully) context-aware filters
  - read the exact manual of functions if you use them (e.g., htmlentities)
- Do not allow user-provided markup
  - recall MySpace?
  - if need be, use well-defined alternative mark-up languages
    - BBCode, Markdown, ...
- Disable error reporting to the Web frontend
  - among other reasons: stack trace might contain unencoded parameters...

Dimensions of Cross-Site Scripting

	Server	Client
Reflected	`echo "Welcome ".` `  $_GET["name"];`	`document.write("Welcome " +` `  location.hash.slice(1));`

Persistent	`mysql_query("INSERT INTO posts ...");`
	`// ..`
	`$res = mysql_query("SELECT * FROM posts");`
	`while ($row = mysql_fetch_array($res)) {`
	`  print $res[0];`
	`}`
		`localStorage.setItem("name",`
		`  location.hash.slice(1));`
		`// ..`
		`document.write("Welcome " +`
		`  localStorage.getItem("name"));`

Reflected Client-Side Cross-Site Scripting

1. Attacker analyzes client-side JavaScript code for vulnerabilities
   - searches for unfiltered usage of attacker-controllable data (e.g., the URL)
   - such data may be contained in URL fragment
     - Important: not sent to the server

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   - such data may be contained in URL fragment
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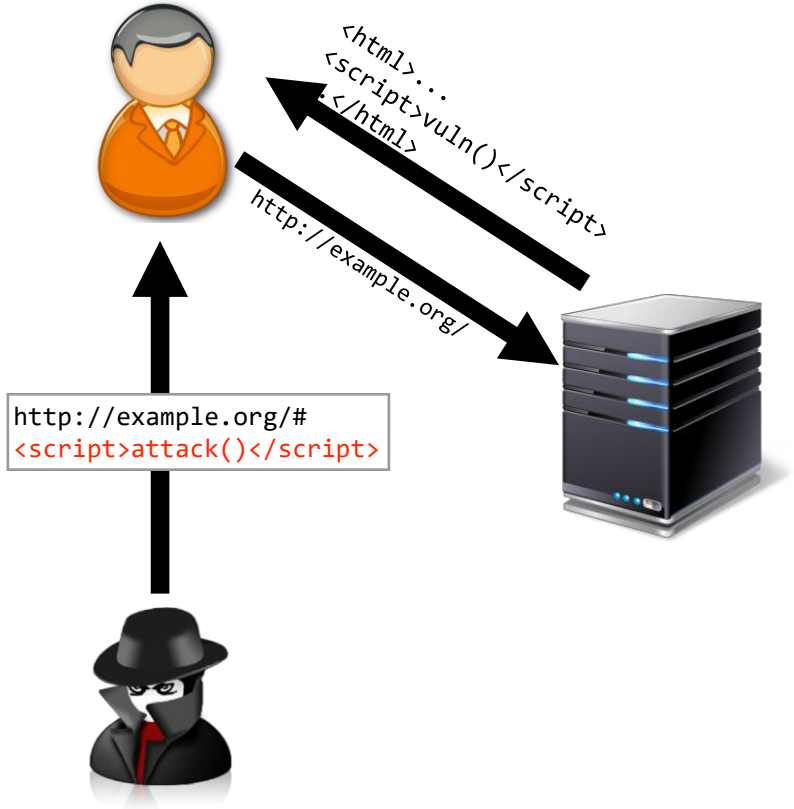
2. Attacker tricks victim into visiting URL with payload, e.g., in fragment
   - vulnerable JavaScript is delivered to client
   - exploit triggered without payload being sent to server (if in fragment)



Relevant APIs for Client-Side Cross-Site Scripting

- document.write, document.writeln
  - Can write new script tags which will be executed
- eval, setTimeout, setInterval
  - Directly executes JavaScript code
- innerHTML, outerHTML
  - will not execute script elements, but event handlers work
  -

Example: exploiting reflected client-side XSS

```
// ensure that things are always unencoded, as browsers differ in their behaviour
var hash = unescape(location.hash);

document.write("<div><iframe src='https://ad.com/iframe.html?hash=" + hash + "'></iframe></div>");
```

- **Important:** iframe is one of very few elements that needs to be closed
  - anything between iframe tags is shown only if browser does not support framing
- Exploit payload:
  - Close opening iframe tag: `'>`
  - Close iframe: `</iframe>`
  - Add payload: `<script>alert(1)</script>`
- Exploit URL:

```
http://example.org/#'></iframe><script>alert(1)</script>
```

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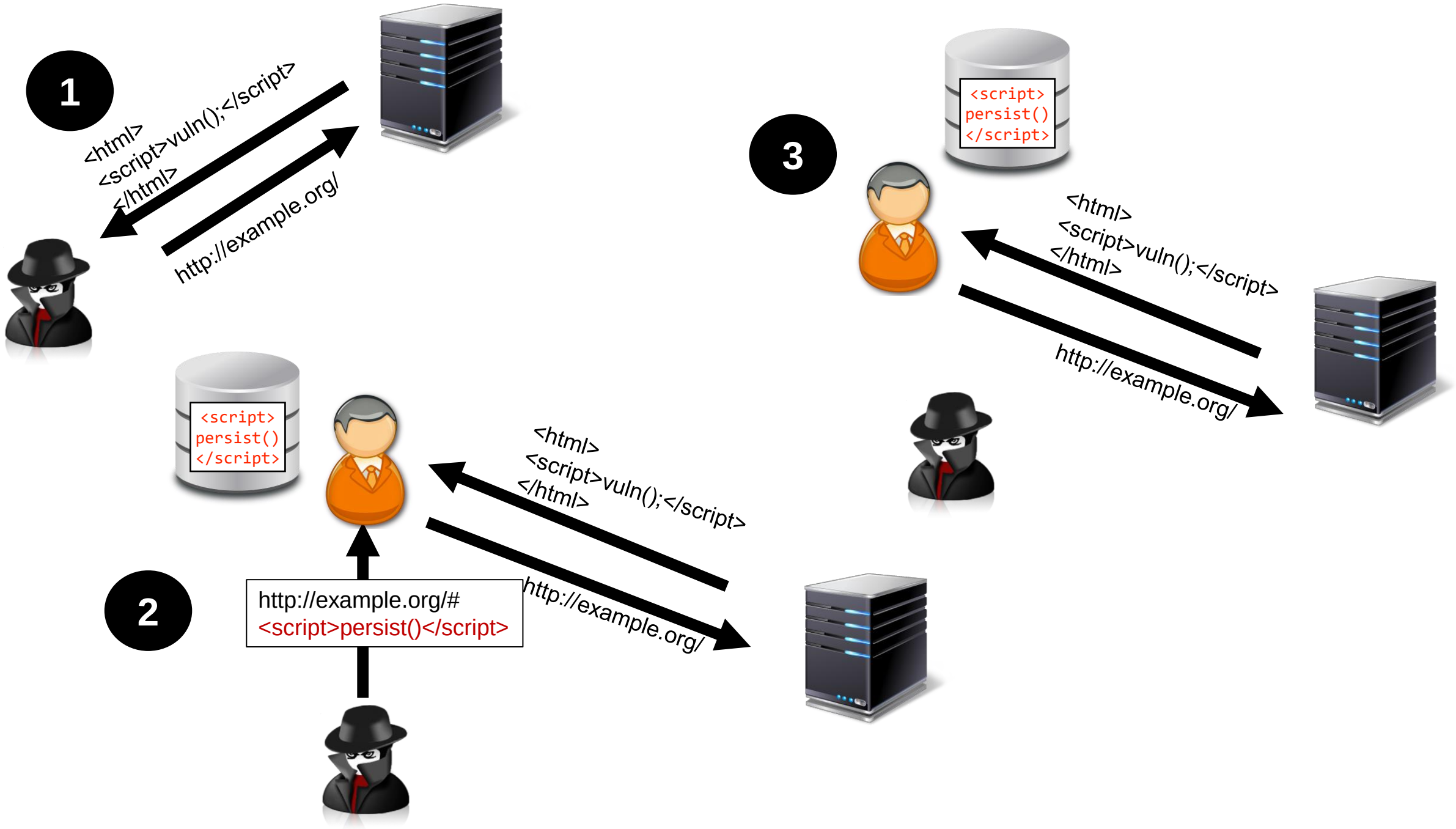
Persistent Client-Side Cross-Site Scripting

1. Attacker analyzes client-side JavaScript code for vulnerabilities
   - searches for unfiltered usage of attacker-controllable data (e.g., the URL) **flowing to persistent storage**
   - Searches for execution of persistent storage
     - Example: cookie stores first visited URL, is used in later eval statement


1
<html>
<script>vuln();</script>
</html>
http://example.org/
2
http://example.org/#
<script>persist()</script>
<script>
persist()
</script>
<html>
<script>vuln();</script>
</html>
http://example.org/
3
<script>
persist()
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http://example.org/

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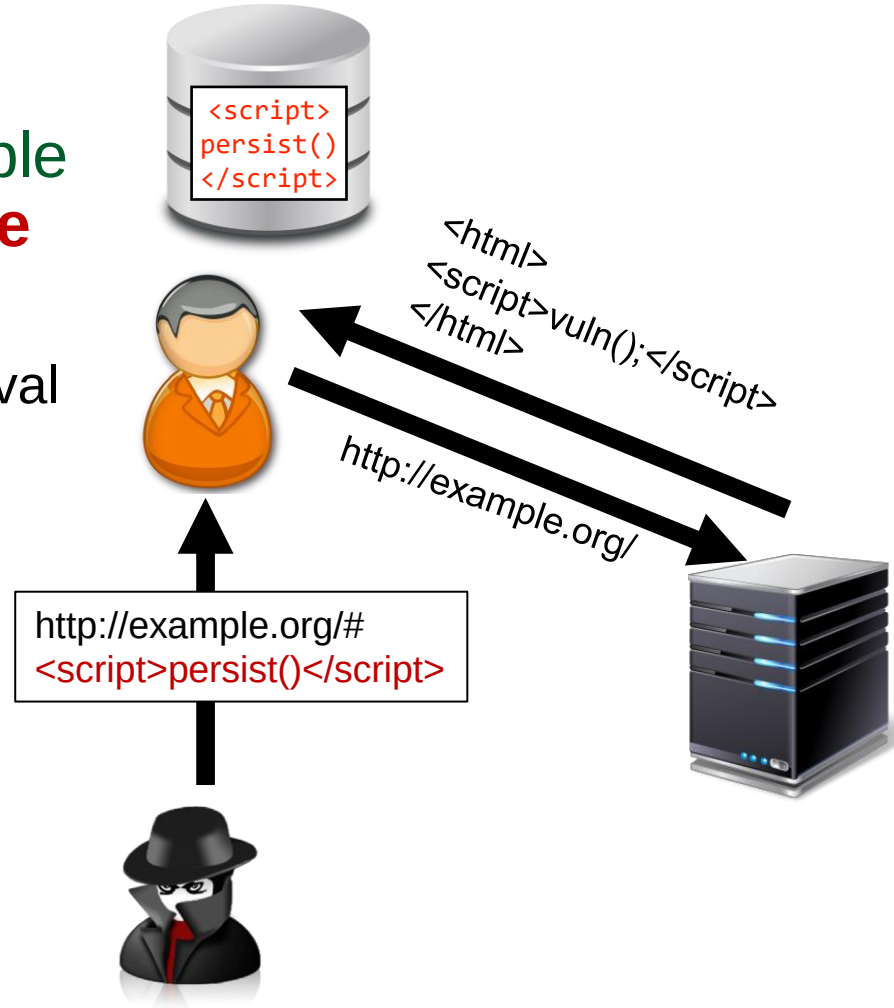
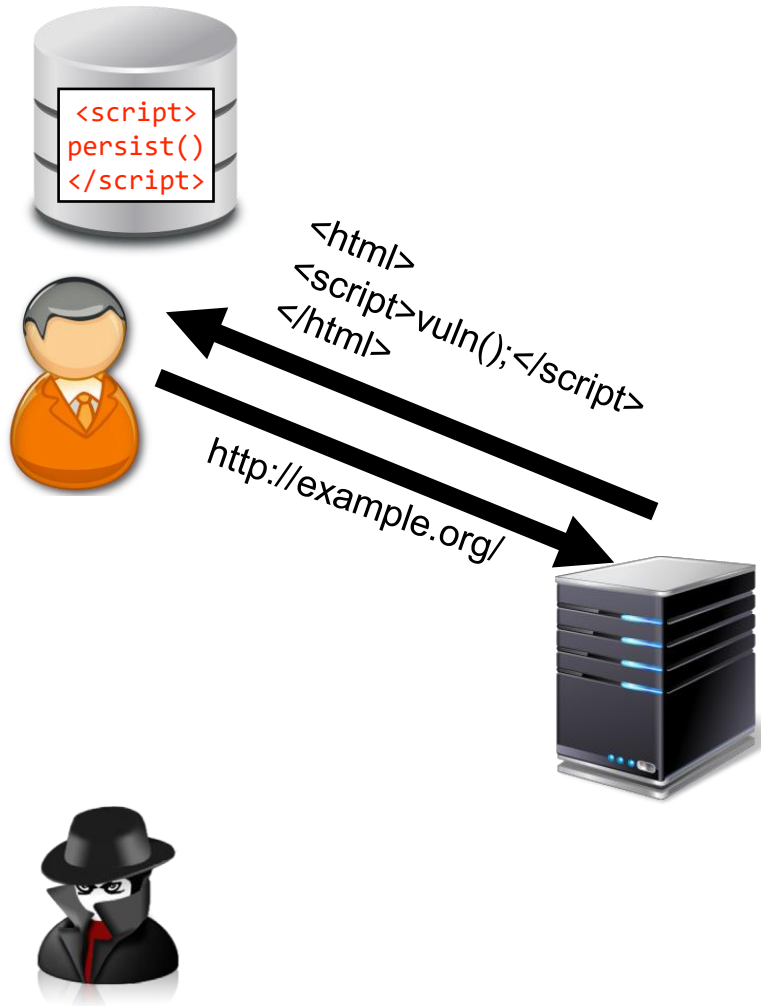
   - Searches for execution of persistent storage
     - Example: cookie stores first visited URL, is used in later eval statement
2. Attacker tricks victim into visiting URL with payload, e.g., in fragment
   - data-persisting JavaScript is delivered to client
   - exploit payload is stored in persistent storage
   - Alternatively: exploit other type of XSS to gain permanent foothold in the client's browser



Persistent Client-Side Cross-Site Scripting

1. Attacker analyzes client-side JavaScript code for vulnerabilities
2. Attacker tricks victim into visiting URL with payload, e.g., in fragment
3. On every page visit, payload is extracted from persistent storage
   - flow from storage to execution sink
   - malicious payload is executed



Sources for Persistent Client-Side Cross-Site Scripting

- **Cookies**
  - bound to eTLD+1 or hostname
  - limited character set
    - e.g., no semicolon
    - 4,096 chars at most
- **Web Storage**
  - bound to an origin
  - Local Storage
  - Session Storage
- **IndexedDB**
  - bound to origin

- HTML Markup

```
element.innerHTML = "foobar";
```

- JavaScript

```
eval("x = 'foobar'");
```

- Script source

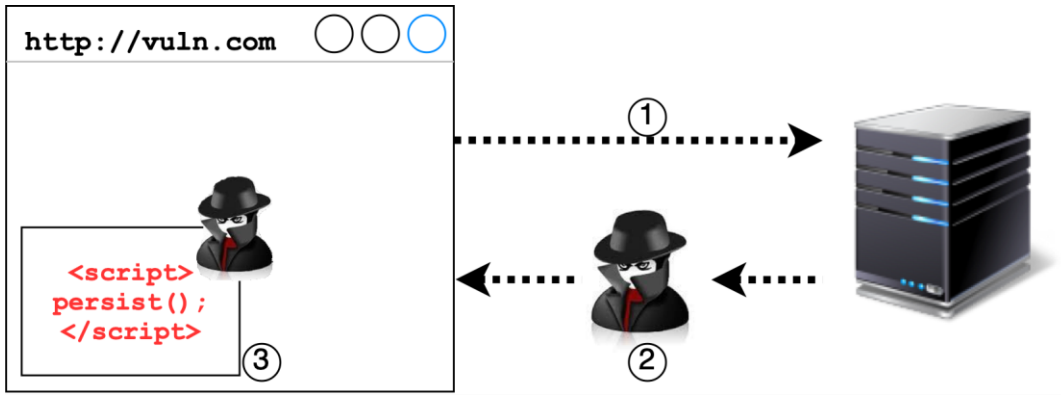
```
var script =
document.createElement("script");
script.src="//foobar.script.com";
document.body.appendChild(script)
```

Interlude: HTTP Strict Transport Security

- HTTP header (Strict-Transport-Security) sent by server
  - only valid if sent via HTTPS
  - `Strict-Transport-Security: max-age=<expiry in seconds>`
    - `includeSubDomains`: header is valid for all subdomains
    - `preload`: allows for inclusion in preload list
  - ensures that site cannot be loaded via HTTP until expiry is reached
- Domains can be preloaded in browsers
  - HSTS preload list (https://hstspreload.org/)
  - only possible with at least 18 weeks max-age, includeSubDomains and automatic redirect from HTTP

Persistent Client-Side Cross-Site Scripting: Attacker Models

- Requirement for successful attack: persisted malicious payload
  - extracted on every page load; single "infection" is sufficient
- Attacker Model #1: **Network Attacker**
  - can modify unencrypted connections
  - cannot get arbitrary TLS certificates
- Capabilities
  - Cookies: set cookies for any domain without HSTS
    - HSTS must use includeSubDomains
  - Local Storage: inject items on HTTP sites only



Persistent Client-Side Cross-Site Scripting: Attacker Models

- Attacker Model #2: **Web Attacker**
  - can force victim's browser to visit any URL
- Attack Vector #1: Abuse existing XSS flaw
  - allows to inject data into origin (Storage) or domain (cookies)
  - HTTPS does not help at all
- Attack Vector #2: Abuse flows into storage
  - requires a flow into storage item
  - important: same storage item must be later used
  - hard to find in practice

Preventing Client-Side Cross-Site Scripting

- Problems originate from use of insecure APIs
  - **eval, document.write, innerHTML**
  - and the use of user-provided input in them
- Depending on the context, functionally equivalent APIs exist
  - document.createElement, element.innerText
  - JSON.parse

```
function writeURLInsecure() {
  document.write("<p>The current URL is: "
    + location.href + "</p>");
}
```

```
function writeURLSecure() {
  var p = document.createElement("p");
  p.innerText = "The current URL is: " + location.href;
  document.write(p.outerHTML);
}
```

Preventing Client-Side Cross-Site Scripting

```
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);
}
```

- element.src ensures that attacker-controllable data can only be in src attribute

Preventing Client-Side Cross-Site Scripting

```
function parseJSONInsecure(json) {
  var object = eval(json);
}
```

```
function parseJSONSecure(json) {
  var object = JSON.parse(json);
}
```

```
function registerGlobalInsecure(key, value) {
  eval(key + " = '" + value + "'");
}
```

```
function registerGlobalSecure(key, value) {
  // check if key is something you want to
  // have overwritten in the first place…
  window[key] = value;
}
```

- Depending on the desired use, either
  - use JSON.parse
  - use object[key] = value notion

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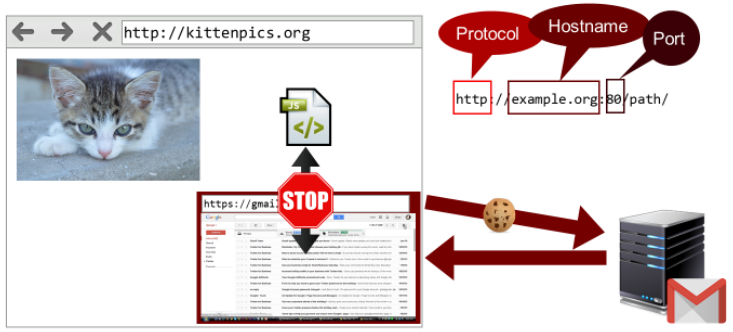
		`document.write("Welcome " +`
		`  localStorage.getItem("name"));`

Summary

Same-Origin Policy in Action

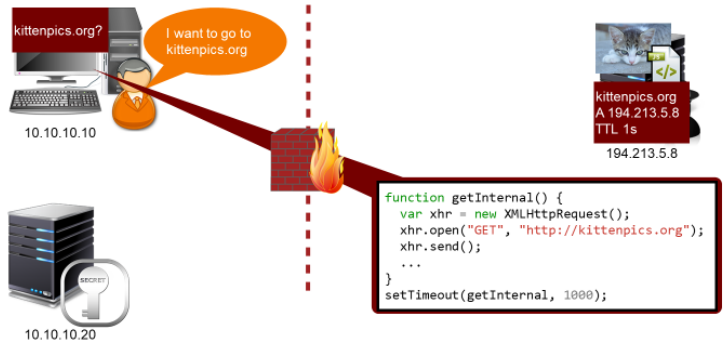


Dimensions of Cross-Site Scripting

	Server	Client
Reflected	`echo "Welcome ". $_GET["name"];`	`document.write("Welcome " + location.hash.slice(1));`

Persistent	`mysql_query("INSERT INTO posts ...");`
	`// ..`
	`$res = mysql_query("SELECT * FROM posts");`
	`while ($row = mysql_fetch_array($res)) {`
	`  print $res[0];`
	`}`
		`localStorage.setItem("name", location.hash.slice(1));`
		`// ..`
		`document.write("Welcome " + localStorage.getItem("name"));`

DNS Rebinding - Concept



Preventing Server-Side Cross-Site Scripting

- Option 2: Output Encoding
- When using the data, encode it
  - depending on context, different encoders might be necessary

HTML Encoding **PHP**

```php
<?php
 function noHTML($input, $encoding = 'UTF-8'){
  return htmlentities($input, ENT_QUOTES | ENT_HTML5, $encoding)
 }
 ...
 echo '<div> You searched for ' . noHTML($_GET['q']) . ' </div>';
?>
```

Credits

- Original slide deck by Ben Stock
- Modified by Nick Nikiforakis