KATHOLIEKE UNIVERSITEIT
LEUVEN

Faculteit
Ingenieurswetenschappen

Improving session security in web applications

Bram Bonné

Thesis voorgedragen tot het
behalen van de graad van Master
in de ingenieurswetenschappen:
computerwetenschappen

Promotoren:
dr. L. Desmet
Prof. dr. F. Piessens

Assessoren:
Ir. W. Eetveel
W. Eetrest

Begeleiders:
P. De Ryck
N. Nikiforakis

Academiejaar 2010 – 2011

Preface

I'd like to thank Lieven Desmet and Frank Piessens, my promotors, and Philippe De Ryck and Nick Nikiforakis, my supervisors, for suggestions and feedback. Lastly, thanks go out to all people who tested the extension.

Bram Bonné

Contents

Abstract

The `abstract` environment contains a more extensive overview of the work. But it should be limited to one page.

Samenvatting

Nederlandstalig abstract

List of Figures and Tables

List of Figures

List of Tables

Glossary

cookie A piece of text made up of one or more name-value pairs stored by a website in the browser. Cookies are set by a website upon first visit, and sent by the browser on every request.. 3

CSRF Cross-Site Request Forgery, an attack in which JavaScript is used to execute malicious code in the victim's browser. 17

DOM Document Object Model, used by programming languages like JavaScript to access elements in an XML document or on a web page. vii, 5, 13

HTTP HyperText Transfer Protocol, the protocol which is used by web browsers to communicate with web servers. 3

HTTPS HyperText Transfer Protocol Secure, a secure variant of HTTP, which uses encryption when transmitting data. viii

LCG Linear Congruential Generator, a generator for pseudorandom numbers based on recurrence. 6

MAC Message Authentication Code, a short piece of information providing data integrity and authenticity for a message. 7

MitM Man in the Middle, used to describe an attacker that is able to intercept traffic between the victim and some other principal. 13

session cookie A cookie containing a session identifier. 4, 16

session fixation An attack in which the attacker tries to enforce a SID upon the victim, so he is able to take over the session later on. 5, 17

session hijacking An attack in which the attacker tries to capture the victim's SID, to be able to take over his session. 4, 14, 17

session ID Session Identifier, a unique string of text used by the server to identify a user. 3, 12, 14

SID see 'session ID'. vii, 3, 18

SOP Same Origin Policy, the policy which states that DOM objects may only be accessed by principals having the same origin as the object. 5, 12

SSL Secure Socket Layer, used in HTTPS to encrypt traffic between a client and a server. 18

URL Uniform Resource Locator, a string that specifies the location of a resource. 4, 15

XSS Cross-Site Scripting, an attack whereby the attacker injects JavaScript into a legitimate page that will be executed by another user's browser when the user visits the page. 6, 9, 13, 15, 17

Chapter 1

Introduction

Chapter 2

About web sessions

When a user visits a website, it is often needed for the web application to remember which user it is interacting with. For this reason, the concept of a 'web session' was invented. In this chapter we will see how web sessions work, and how their security can be improved.

2.1 How web sessions work

To understand the need for web sessions, we first have to look at how web browsers communicate with web servers. The browser requests web pages by issuing HTTP requests to a web server [27]. The server subsequently responds to every request with an HTTP response containing the requested page. Unfortunately, HTTP is a stateless protocol, which means that the web server has no way of knowing whether two different requests have the same origin or not. Because of this, a mechanism is needed on top of HTTP to enable stateful communication between a web server and a client. This mechanism is known as the web session.

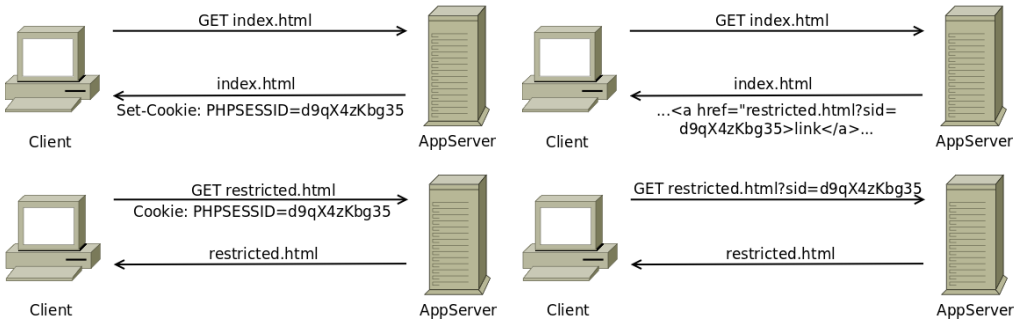
Web sessions work as follows:

1. When the web server receives its first HTTP request from a particular client, it creates a *session identifier* (also called a session ID or SID) that it associates with this client. It then sends this newly generated SID to the client in the HTTP response.

2. In subsequent communications, the client attaches the SID it received to every HTTP request it issues to the server. Because the web server has associated this SID with a particular client, it will know who it is interacting with.

There are three ways in which session identifiers can be attached to requests and responses [20]. The first one, which is most common, makes use of cookies [26, 31]. Cookies are strings consisting of multiple name-value pairs which are set by the web server using the `Set-Cookie` HTTP header. Upon receiving a cookie, the browser stores it for a specified amount of time. It then attaches this cookie to

every subsequent request made to the server[1] that set the cookie by using HTTP's `Cookie` header. This process is graphically depicted in Figure 2.1a. It is clear that cookies are a very convenient mechanism for managing session identifiers. Because cookies can also be used for other purposes than session management, we will make a distinction between *cookies* (which can be used for any purpose) and *session cookies* (which are cookies that store a SID) in this text.



(a) via cookies (b) via URL rewriting

Figure 2.1: Session management

The second possibility to include session information is via *URL rewriting*. In this case, the web server appends the session ID as a parameter to every served URL that points to a page on the same server. Thus, when the user clicks a link on the served page, the request that is made contains the session ID as a parameter, and the server will know who made the request. This process is graphically depicted in Figure 2.1b.

The third possibility is very similar to URL rewriting, but uses POST instead of GET parameters [16]. Here, the session ID is included as a `<form>` element. When the user submits the form, the session ID is sent along with the request. In this text, we will mostly focus on SIDs in cookies, because they are by far the most common. However, when appropriate, we will include information about session IDs in URLs.

It is important to note that session ID's are almost[2] always used exclusively for authentication. This means that the SID only identifies the client, while all other state is saved at the server side. The server then associates the SID with other information stored for that particular session.

2.2 Accessibility of session identifiers

In this section, we look into the ways session identifiers can be accessed, and who is allowed to access them. This will be important when we look at the session hijacking

[1] The actual access control policy is a bit more complicated, and will be discussed in section 2.2.

[2] We use the term 'almost' because there is no standardized way of using SIDs. It can however safely be assumed that the majority of the pages encountered on the Web will use SIDs for authentication only.

and session fixation attacks in chapter 3, where the attacker tries to access a victim's SID.

For SIDs which are set in cookies, the access policy states that cookies are sent only to those pages that have the same (sub)domain as the page that set them. Moreover, the page to which the cookies are sent must be on a path that is a suffix of the page that set them [34]. This is different for SIDs that make use of URL rewriting. Here, the SID is only attached to requests that are the result of the user clicking a link on the web page, and only when the originating web page explicitly included the SID as a parameter in the link.

SIDs can also be accessed at the client side. For this, the *Document Object Model* (or *DOM*) is used. The Document Object Model provides a way for programming languages like JavaScript to access elements on a web page. It allows an SID to be accessed both when it stored in a cookie (via the `document.cookie` property) as when a link containing the SID is present in the current web page (directly via the `href` attribute of the `<a>` element containing the link). For DOM objects, the *Same Origin Policy* (or *SOP*) is enforced [34]. This policy states that web pages that want to access a certain DOM object, must have the same origin as this object. The origin is defined as the tuple `<protocol,domain,port>`. Thus, the Same Origin Policy essentially allows only access to DOM objects on the same domain as (or on a subdomain of) the principal trying to access them. Moreover, it is required that the accessing principal uses the same protocol and port as the protocol and port where the DOM object originated from.

2.3 Keeping web sessions secure

It is important that a session identifier can only be known by the web server and the client that is identified by it. If an attacker is able to know a client's SID, he can use it to impersonate the client in the web application (which is exactly what the session attacks we will describe in chapter 3 try to do). Because of this, we describe in this section the properties a secure SID should possess.

2.3.1 Unguessable by an attacker

The first feature a secure session ID must possess is that an attacker may not be able to guess its value. For this, some properties are necessary:

Randomness

To be unguessable, a session identifier should appear like it could be any random string of text. Random in this case means that session identifiers should have [29, 9, 8]:

high entropy The higher the number of bits necessary to represent a string, the more random it is.

low correlation If SIDs are correlated, an attacker is able to derive (part of) SIDs that will be generated from SIDs which were already generated. As a consequence, an attacker would be able to predict a victim's session ID from his own session ID.

a high number of possible values This is related to both high entropy, and to sufficient length (which will be discussed shortly hereafter).

It must also be noted that it is not sufficient for session IDs to be only statistically random: it is required that an SID possesses cryptographic randomness [11]. This means that more than just an LCG is needed to generate SIDs.

Sufficient length

To prevent successful brute forcing attacks, wherein an attacker exhaustively tries lots of possible values, a session ID should be of sufficient length. The expected number of seconds required to guess any one valid session identifier is given by the equation [30]:

$$\frac{2^B + 1}{2A \cdot S}$$

where B is the number of bits of entropy in the SID, A is the number of guesses an attacker can try each second, and S is the number of valid SIDs at any given time.

OWASP recommends a session ID length of at least 128 bits [30].

2.3.2 Unavailable to an attacker

If an attacker is able to read the value of the victim's SID, the victim's session is compromised. Because of this, it is of utmost importance that the SID value is never visible to anyone but the web server and the legitimate user. Here, we only describe some properties to achieve this. We will go into more detail about making cookies unavailable to an attacker in section 4.3.

For SIDs that are set via cookies, it is important to note that, by default, these are sent as clear text. This means that, in an insecure channel like the Internet, an eavesdropper is able to intercept the cookie value. An eavesdropping attacker can thus take over a user's session. Cookies can also be set over a TLS connection [32]. In this case, the requests and responses (and thus, the cookie value) are encrypted, and the attacker is unable to extract the cookie wen viewing one of these messages. Care must be taken, then, that the cookie value is never sent in the clear; otherwise its value can still be compromised. To assert this, the `secure` flag can be enabled when setting a cookie [11, 25]. This flag demands that the browser should never send the cookie over an unencrypted connection. In section 4.3.1, we will go into more detail about secure connections.

When an SID which is set via a cookie will never need to be accessed via JavaScript, it is best to enable the `HttpOnly` flag when setting the cookie. This prevents attackers from using XSS attacks (more about XSS attacks in section 3.1) to capture the SID value. With URL rewriting, it is not possible to state that the

SID may not be available to client-side JavaScript. Indeed, a link containing the SID will always be available as a DOM object, making the SID vulnerable to XSS attacks. In section 4.3.2, we will go into more detail about `HttpOnly` cookies.

2.3.3 Short lifetime

A third way of making sessions more secure is to ensure that they have a limited lifetime [11]. This has two advantages:

- The shorter the lifetime of a SID, the less time an attacker has to brute force it.
- In case the attacker was able to capture the SID, the lifetime of the SID determines how long the attacker is able to use it for impersonating the victim.

Limiting the lifetime is needed because a user can not be relied upon to manually log out every time he stops using a web application [30].

Limiting the SID's lifetime

The lifetime of a cookie can be limited by using the `expires` attribute when setting the cookie. However, care must be taken that the session is also expired at the server side, because the attacker could otherwise still use the cookie after it expired at the victim's browser [24].

Another way of limiting a SIDs lifetime is presented by K. Fu et al. [11]. By including a timestamp as part of the SID value, a server can determine whether the SID is still valid without having to keep any state. It is important to note that this requires the SID value to be signed by the server (using a MAC). Otherwise, an attacker could just change the timestamp part of the SID to extend its lifetime. A disadvantage of this approach is that there is no possibility of revoking SIDs without keeping server state.

Renewing the SID

Fortunately, the user does not have to re-authenticate every time he gets a new session ID. Only three steps have to be performed by the server to provide a client with a new SID:

1. Generate a new session ID.
2. Assign the new SID to the client. For this, any state that was attached to the old SID at the server side should be attached to the new SID instead.
3. Make sure the client uses the new SID instead of the old one. This can be done by attaching a `Set-Cookie` header to the next HTTP response, containing the new SID value. The browser will notice that the cookie name is the same as the old SID, and will therefore update the old value. Alternatively, when URL rewriting is used, the web server has to make sure that all links on subsequent web pages served to this client include the new SID value.

2.3.4 Other best practices

A problem with lots of web applications is that they try to reinvent session management. As we will see in section 4.1, lots of web frameworks have thoroughly tested session management already built-in. Because it is very easy to make mistakes when providing security, it is often a good idea to make use of an existing session management framework.

Secondly, K. Fu et al. argue that the use persistent cookies should be avoided when using cookies for authentication [11]. Persistent cookies are cookies that are saved on disk at the client-side, instead of just being saved in main memory. To create a cookie that is non-persistent, the `expires` field should be omitted. Non-persistent cookies can not leak via files.

Chapter 3

Session attacks

Now that we know how web sessions work, we look into ways in which attackers are able to abuse them. In this chapter, we will see how an attacker can use the concept of web sessions to impersonate a legitimate user on a website.

3.1 Background: cross-site scripting

Cross-site scripting (or XSS) is not a session attack in itself. Instead, it is the exploitation of a vulnerability in some websites which can be of great use when executing one of the other attacks described below.

In a cross-site scripting attack, the attacker exploits a vulnerability in a website to inject his own JavaScript code into this page [7]. The code will then be executed in the browser of any user that loads the page with the injected code.

3.1.1 Variants of cross-site scripting

There are two forms of cross-site scripting: persistent and non-persistent XSS. In this subsection, we describe their differences and give some examples of possible attack scenarios for each of them.

Persistent (stored) XSS

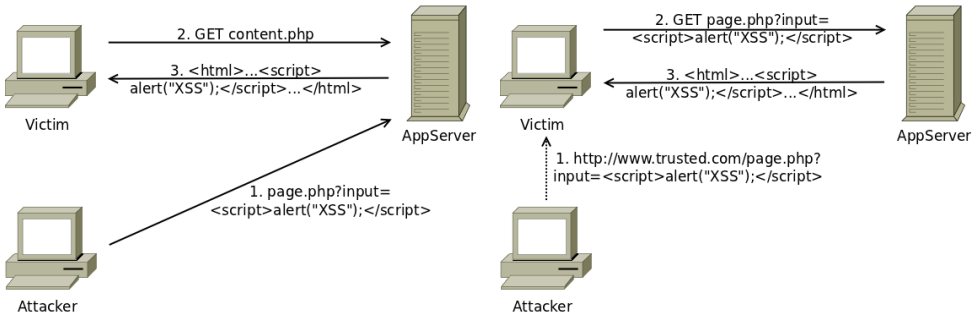
In a persistent attack, the attacker makes the web application store the script code in a database. The complete scenario goes as follows:

1. The attacker provides his malicious code as input to the web application. The web server stores this input (and thus the script code) in the database to be able to provide it to clients later on.

2. The victim requests a page containing content generated by the attacker. The server returns the page containing the attacker's JavaScript.

3. The victim's browser thinks that the script code is part of the requested web page and executes it.

This attack variant is graphically illustrated in figure 3.1a.



(a) persistent (b) non-persistent

Figure 3.1: The cross-site scripting attack

An example of a web application that will store user input in a database to serve it later it is a bulletin board (phpBB[1] is a well-known example), where a user can create forum posts that will be read by other users of the bulletin board. When an attacker inserts script code into a post, the code will be executed at the browser of every user reading that post.

A more recent example is found in social networking sites like Facebook[2]. Here, a user can place information on his own page, or the pages of other people. This information will then be served to the user's friends.

Non-persistent (reflected) XSS

In a non-persistent attack, the script code is never stored at the server side. Instead, code that was part of a request is immediately reflected back to a client's browser as part of the response page. The steps are as follows:

1. The attacker tricks the victim into opening a malicious link containing script code.
2. The victim opens the link, and unknowingly makes a request containing script code to the server.
3. The server reflects this script code back to the victim as part of the response.
4. The victim's browser thinks that the script code is part of the requested web page and executes it.

This attack variant is graphically illustrated in figure 3.1b.

An example of this is a search form, where a website returns the term the user searched for, without stripping any script data that might be inside. If doing a search

[1] http://www.phpbb.com/
[2] http://www.facebook.com

by going to the URL `http://www.trusted.com/search?q=searchterm` makes the website return "x results for *searchterm*", the attacker can replace *searchterm* by script code that will execute at the client that loads the search results. The attacker can then trick a user into clicking the link, causing the JavaScript code to be executed in his browser.

Another example of a scenario where a website might return data found in the URL is the 'Page not found' error page [21]. Here, the name of the page that could not be found is often included as part of the error message. Thus, an attacker can craft a link wherein he requests a page with name `<script>alert("XSS succeeded");</script>` to make a client's browser execute JavaScript code.

3.1.2 Including the script code

There are multiple ways in which script code can be included in a web page. Since all of these can be leveraged by an attacker to inject his code into a web page, it is important that web developers are aware of all of them. T. Jim et al. give a good overview of different approaches to including JavaScript code [15], of which we will describe the most important ones here:

between `<script>` tags This is the most obvious way of including JavaScript in a web page. All code between these tags will be executed as soon as the browser encounters it.

using the `<script>` tag's `source` parameter This parameter can be set to point to an external piece of JavaScript. As such, an attacker is able to make a website load JavaScript code from another domain. An advantage for the attacker is that the actual injected string is shorter, bypassing message length limits.

as the URL of the background image An attacker can insert a tag similar to `<div style="background-image: url(javascript:alert('XSS');" />` or `<style>.bar{background-image:url("javascript:alert('XSS');");}</style>` (where `bar` is the class of an object in the page) to make the browser execute JavaScript, thinking it is loading the background image.

using the `onload` parameter of the `<body>` tag This tag is used for code that should be executed once the browser has completed loading the page.

It must also be noted that attackers can use different possible encodings to inject JavaScript, so as to circumvent server-side JavaScript checkers, while still being able to execute at the client side [15]. For example, the encoding of (parts of) a web page can be changed using the `encoding` and `charset` attributes of various HTML tags [14]. Some browsers also allow strings to contain JavaScript that is split over multiple lines [15]. Lastly, JavaScript can be split over multiple `<![CDATA[...]]>` tags, making it much harder to detect.

3.1.3 The danger of cross-site scripting

One danger of persistent XSS is immediately clear: websites that do not belong to an attacker can still be used by the attacker to execute malicious code at a user's browser. The user, thinking that a known site will only execute trusted code, can fall victim to the attacker without expecting it.

There is, however, a bigger problem which applies to both persistent and non-persistent XSS: the problem of trust. Normally, the attacker's code would be subject to the SOP (described in section 2.2), making him unable to access elements of a domain that he does not own. However, when the attacker's code is able to execute from within a trusted domain (as is the case in an XSS attack), this code may access the elements belonging to the trusted domain [22]. This gives the attacker the ability to read information from, and write information to, elements in the trusted domain.

The situation is even worse when the attacker's code is loaded from a different domain (because the attacker injected the script code by using the `<script>` tag's `src` attribute, for example). When this is the case, the script code is also allowed to communicate with the domain it was loaded from [34], i.e. the attacker's domain. Because of this, the attacker is able to capture information from a trusted domain and subsequently send this information to his own domain. This will be a major attack vector for the session hijacking and session fixation attacks, as we will see in the next sections.

3.2 Session hijacking

In the session hijacking attack, an attacker tries to take over a victim's session by capturing his session ID. Using this SID, the attacker can make the server think that he is the victim. First, we describe the attack scenario. Afterwards, we will see how the attacker can capture the victim's session ID.

3.2.1 Attack scenario

The session hijacking attack works as follows [29]:

1. The victim establishes a new session at the server. This is done automatically by the victim's browser either when he first visits the page or when he logs in (depending on the web application).

2. The attacker captures the session ID that corresponds to the victim's created session by using one of the methods described in section 3.2.2.

3. The attacker makes a request to the server, attaching the captured session ID as his own. Because the server has no other means of distinguishing between the victim and the attacker, it thinks that it is the victim that made the request. Thus, the attacker is now able to impersonate the victim at the server.

These steps are graphically illustrated in figure 3.2.

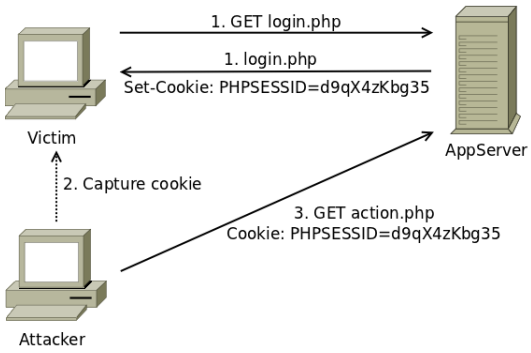


Figure 3.2: The session hijacking attack

3.2.2 Capturing the session ID

There are lots of possible ways in which an attacker can capture a victim's session ID. We list the most important ones here.

Via a (passive) man-in-the-middle attack

In a man-in-the-middle (or MitM) attack, an attacker is able to read traffic that passes between the client and the server. This is usually the case because both the client and the attacker are using the same network unencrypted WiFi network, or because they share the same network hub.

The session identifier is, by default, sent over the network as an unencrypted string of text, both when using cookies as when making use of URL rewriting. Because of this, an attacker able to read all network traffic can easily extract the SID from the `Cookie` header in one of the user's requests, or even from the `Set-Cookie` header in the server response setting the cookie [1].

This problem has been known for some time, and has recently again received some attention thanks to tools like Hamster [12] and Firesheep [5], which make a session hijacking attack almost trivial when the victim is on an insecure network.

Via cross-site scripting

The XSS attack described in section 3.1 can also be used to steal a victim's session ID. For this, the attacker uses the `<script>` tag's `src` attribute to load script code from his own domain into a web page on the domain he wants to acquire the cookie from. Because the script code is loaded from within a page on the target domain, the attacker has access to both the target domain's cookie via the `cookie` attribute of the `domain` DOM object (for SIDs set in cookies), and to all links on the current page (for SIDs used via URL rewriting). However, since the script code was loaded from the attacker's domain, it is also allowed to communicate to that domain (see section 3.1.3 and [22] for more information). Because of this, the attacker is able to forward the target domain's cookie to his own domain, effectively capturing the client's SID.

Via the referer header

A third possible SID leak occurs when the browser attaches the `referer` header to a request going to another domain [11]. The `referer` header is used to transmit the resource from which the request-URL was obtained [10]. If SIDs are included in the URL (as is the case with URL rewriting), the website receiving the `referer` header as part of the request can extract the client's SID for the web application that contained the link.

If, for example, a social networking website manages sessions via URL rewriting, an attacker could share a link to his own website on this website. When another user clicks the link, a request is made to the attacker's web server. This request contains the URL of the current page, and thus the user's SID for the social networking website, in the `referer` header, making it available to the attacker.

Sometimes, the `referer` header is suppressed in the network or by the browser, especially for cross-domain requests [3]. Unfortunately, the percentage of requests where the `referer` header is stripped is still small enough to consider leaking of SIDs via this channel a significant threat.

Via the user

Lastly, it is also possible that the user unknowingly leaks his own session identifier. This is the case when the user shares a link to a page for a website that uses URL rewriting [19], for example via email or a social networking site. When another user clicks the shared link, he will automatically take over the first user's session. Thus, the second user essentially performs a session hijacking attack on the first user, possibly without even realizing it.

This problem, together with the possibility of leaking SIDs via the `referer` header, provides a strong argument against using URL rewriting for session management.

3.3 Session fixation

In the session fixation attack, as in the session hijacking attack (section 3.2), an attacker's goal is to be using the same session as a victim. However, instead of capturing the victim's session ID, the attacker forces the victim to use a SID that is known in advance. We will first describe the steps necessary to execute this attack. Afterwards, we list the ways in which the attacker can force a victim to use a certain session ID.

3.3.1 Attack scenario

The session fixation attack works as follows [24]:

1. The *attacker* establishes a new session at the server. He does this by sending a request that doesn't include a SID. The server will then attach a newly

generated SID to the response. Some servers also accept random SIDs[3] [33]. If this is the case, the attacker can just make up a new SID, and no request needs to be made.

2. The attacker forces the victim to use the newly created session ID. We will see how this can be done in section 3.3.2.

3. The victim uses his credentials to log in at the server. The SID that was injected at the client's web browser will automatically be attached to the request. Because of this, there now exists a session at the server in which the victim is logged in. That session is identified by a SID which is known by the attacker.

4. The attacker makes a request to the server, attaching the captured session ID as his own. This makes the server think that it is the victim that made the request. Thus, the attacker is now able to impersonate the victim at the server.

These steps are graphically illustrated in figure 3.3.

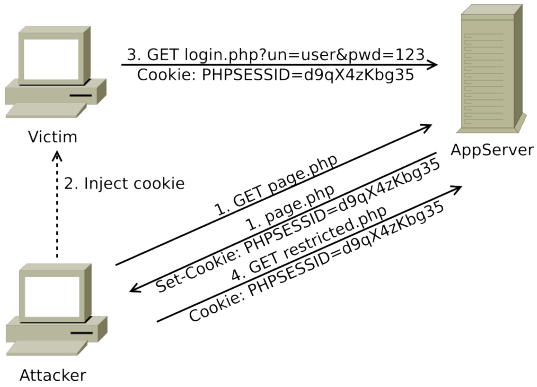


Figure 3.3: The session fixation attack

3.3.2 Injecting a session ID

In this section, we describe the most important attack vectors the attacker can use to inject a session ID into the victim's browser.

Via GET or POST parameters

If the target website accepts session ID's in URLs (see section 2.1), the attacker can craft a link of the form `http://www.target.com/login.php?PHPSESSID=d9qX4zKbg35`, where he chooses the desired session ID [17]. He then sends this link to the victim, or places on the target website as part of a XSS attack. When the victim clicks the

[3] By random SIDs, we mean that these SIDs don't need to be generated by the server in advance. A random SID can be sent by the client on his first request.

link, the request sent to the target server will contain the attacker's SID in the URL, causing the web application to think it is the victim's session ID. Alternatively, the attacker can force the victim to visit the URL by using a HTTP redirect [10] to make the victim's browser automatically load the page [33]. However, this requires the attacker to be able to perform a XSS attack, or the victim to visit the attacker's page.

In case the target website uses POST instead of GET parameters for session management, the link can be replaced by an automatically submitting form [24, 4].

Note that, for a website to accept session IDs via GET or POST parameters, it doesn't have to do its session management via URL rewriting by default. Indeed, multiple frameworks provide URL rewriting as a fallback for browsers that don't support cookies, causing them to be vulnerable to session fixation via URL rewriting [6, 13].

Via cross-site scripting

If an attacker is able to inject script code into the target site (using one of the methods described in section 3.1.2), he can use this script code to set or replace the session cookie with the desired value. This is done by editing the `document`'s `cookie` property [24] or by using the `cookie.write()` function [17].

Alternatively, the attacker can use the HTML `<meta>` tag to set the cookie. For this, he injects the following line of HTML code into the target web page:

```
<meta http-equiv=Set-Cookie content="PHPSESSID=d9qX4zKbg35">
```

where the name and value of the session cookie are chosen by the attacker [24].

Via subdomain cookie setting

Sometimes, an attacker is able to take over a subdomain of the target website because it is more vulnerable than the parent domain, or because he has legitimate access on the subdomain. Normally, setting a cookie on a subdomain would not have any effect on the parent domain. Indeed, as we described in section 2.2, cookies will only be used for the same domain as the one that set them, or for one of its subdomains. Thus, a cookie set on a subdomain will not be used for its parent domain. Because of this, it would seem that session fixation is not possible from within a subdomain.

There is, however, a possibility to set a cookie for a parent domain by using the cookie's `domain` parameter when setting a cookie [25]. To do this, consider the case where the attacker was able to take over the domain `vulnerable.target.com`. He can then use this domain to set a cookie for `target.com`, and all of its subdomains, by specifying the cookie as `PHPSESSID=d9qX4zKbg35;domain=.target.com` (notice the '`.`' preceding `target.com`). This effectively allows an attacker that has access to a subdomain to execute a session fixation attack on a parent domain [24].

Via HTTP response splitting / header injection

There is another attack that can be used by an attacker to inject a cookie on the victim's machine. In a HTTP response splitting attack, the attacker tricks the victim's browser (or an in-between proxy) into thinking that two HTTP responses were sent by the target server, whereas both are actually part of the same HTTP response [23]. The interesting part for the attacker is that the contents of one of the two responses can be chosen by himself. Because of this, an attacker is able to insert a `Set-Cookie` header containing the desired session identifier, effectively injecting the SID into the client's browser [17].

3.3.3 Other dangers of session fixation

It seems that the only benefit an attacker has from performing a session fixation is that he can take over the temporary session of another user. There is, however, another issue: an attacker is also able to force a victim to be logged in under the attacker's account. He can do this by logging in first, and subsequently forcing the victim to use the attacker's session ID. This has two major implications [3]:

- An attacker can track the victim's actions on the target web application by making use of logging functionality offered by this application. For example, most major search engines offer the option to log the user's search history[4], allowing an attacker who is able to perform a session fixation attack to access this highly sensitive information [2].

- On domains that allow the embedding of trusted scripts, it creates the ability for an attacker to execute XSS attacks. Until recently, iGoogle[5] offered the ability to embed trusted scripts on your own personal homepage [3]. Because of this, an attacker who is able to perform a session fixation attack has the ability to offer scripts to a victim from within the `google.com` domain. He does this by adding a script to his own homepage, and subsequently imposing his own SID upon the victim's browser. Thus, the next time the victim visits iGoogle, the attacker's home page will be loaded, and the script will be executed.

As we can see, the session fixation attack is more venomous than would be expected when first looked upon. Because of this, we developed a client-side solution to session fixation, which will be described in chapter 5.

3.4 Cross Site Request Forgery

The cross site request forgery (also called CSRF or session riding) attack is different from the session hijacking and session fixation attacks in the sense that the attacker will not try to completely take over a victim's session. Instead, it leverages the

[4] Google, for example, offers an overview for all terms you searched for at http://www.google.com/searchhistory/.

[5] http://www.google.com/ig

victim's browser's implicit authentication to make requests in the name of the client. The attacker accomplishes this by compelling the victim's browser into issuing the request. This can be useful, for example, when the victim is logged in at the website of his bank. In this case, the attacker can use the victim's implicit authentication to transfer money from the victim's account to his own account. Before we see the ways in which the attacker can make a victim's browser issue requests, let us first look at the complete attack scenario.

3.4.1 Attack scenario

The CSRF attack is made up out of the following steps (assuming that the victim is already authenticated at the target website) [20]:

1. The attacker forces the victim's browser to send a request to the server (we will see how in section 3.4.2). It is the attacker that chooses the contents of this request.

2. The browser, thinking that it is a legitimate request made by the victim, automatically attaches the victim's authentication information. This authentication information can be in the form of a SID, HTTP Auth credentials SSL data, or even the user's IP address [18, 37].

3. The browser sends the request to the target server. This server uses the request's authentication information to determine that the request was made by the victim. Thus, the server executes any action that was requested by the attacker as if the victim requested it.

The different steps of the CSRF attack are graphically illustrated in figure 3.4.

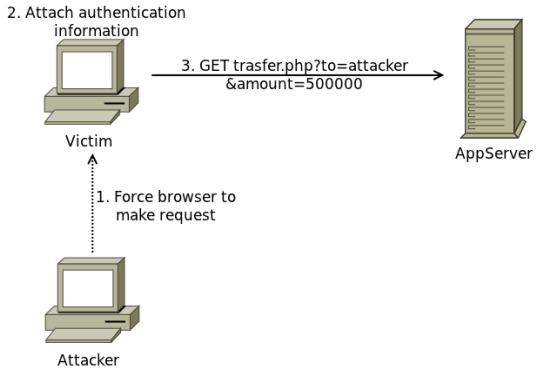


Figure 3.4: The cross site request forgery attack

3.4.2 Forcing the browser to make a request

As was the case with the previous attacks, there are several possibilities to execute a CSRF attack. We describe these possibilities in this section. Table 3.1 summarizes for

each of these methods whether they can be used for GET requests, POST requests, or both.

Via crafted URLs

The simplest method for the attacker is to craft an URL containing the desired request and its GET parameters. When the victim clicks the URL, the browser will automatically issue the request together with its parameters. Tricking the user into clicking the URL can be done either by phishing [3], or by embedding the URL in a trusted web page in a manner similar to the XSS attack described in section 3.1. Because URLs can only hold GET parameters, this method can not be used for issuing requests that contain POST parameters.

Via the `<img>` tag

An attacker can also abuse the `<img>` HTML tag for issuing requests. The `<img>` tag is normally used for including images in a web page. However, to download an image from the server where it is stored, the browser has to issue a request. Instead of providing the URL of an actual image, the attacker can provide a request URL containing GET parameters, causing the victim's browser to issue the request when trying to load the image [18]. If the attacker is able to insert images into a trusted site (as is often the case in bulletin boards), he can make a victim issue the request when he visits the trusted page containing the image [3]. Similarly to the previous method, this method can only be used for requests that contain GET parameters.

Via forms

When the target web application uses POST instead of GET parameters, a HTML form can be used to issue the request. When a form is submitted, it issues a request containing the form elements and their values as parameters.

An attacker can create a form containing elements having the desired values. He must then force the victim's browser to submit the form, which can be done by either tricking the victim into submitting the form manually, or by submitting the form using JavaScript.

Tricking the victim into submitting the form can be relatively easy: all the attacker has to do is assure that the victim clicks the submit button. This can be achieved by hiding all form elements except for the submit button, pretending that the button serves some other purpose. This approach is taken even further by Mao et al. [28]: they noticed that, even when it is required that the *actual* submit button of the legitimate site is pressed (as is the case when some of the countermeasures described in section 4.2 are in use), a victim can still be tricked into triggering a request it didn't want the browser to perform. This is done by including an iframe where only part of the original form is visible into the attacker's website. The result can be seen in figure 3.5.

An attacker can also make the form automatically submit in the user's browser. For this, he needs JavaScript capabilities on the page where the form is located. An

(a) the original form

(b) a malicious page including only parts of the form in an iframe and trying to trick a user into clicking the button

Figure 3.5: Tricking a user into submitting a form [28]

attacker has these capabilities when the form is hosted on the attacker's domain (which is visited by the victim), or when the form is displayed on a page where the attacker can execute a XSS attack (see section 3.1). To automatically submit the form, a line of JavaScript similar to `document.forms[0].submit()` should be inserted somewhere in the HTML code of the page [20].

Via asynchronous requests

If the attacker is able to perform a XSS attack, he can inject JavaScript code that uses the `XMLHttpRequest` object to perform an asynchronous HTTP request. The complete specification of this object is available at [36]. We only provide a small example of its use [35]:

```
var client = new XMLHttpRequest();
client.open("POST", "transfer.php");
params = "to=attacker&amount=50000";
client.setRequestHeader("Content-type", "application/
                                    x-www-form-urlencoded");
client.setRequestHeader("Content-length", params.length);
client.setRequestHeader("Connection", "close");
client.send(params);
```

Making an asynchronous GET request is similar. Differences are that the parameters are now appended to the URL instead of passed to the `send()` funxtion, and that the HTTP headers don't have to be set explicitly.

Via active network attacks

In case the connection between the client and the server is not encrypted, an active attacker doesn't even need the browser to submit the request: he can simply modify any request sent by the victim's browser to contain the URL and parameters he wants [3].

	GET requests	POST requests
Link	X	
`<img>` tag	X	
Form		X
Async. request	X	X
Active attack	X	X

Table 3.1: Different methods for forcing a browser to make a request

3.4.3 CSRF from within a different domain

Chapter 4

Session attack countermeasures

4.1 Session security in web frameworks

4.2 Cross Site Request Forgery countermeasures

4.3 Other Solutions (and their problems)

4.3.1 Secure connections

4.3.2 `HttpOnly` cookies

Chapter 5

A client-side solution to session fixation

Chapter 6

Conclusion

Bibliography

[1] Ben Adida. Sessionlock: securing web sessions against eavesdropping. In *Proceeding of the 17th international conference on World Wide Web*, pages 517–524. ACM, 2008.

[2] Michael Barbaro and Tom Zeller Jr. A Face Is Exposed for AOL Searcher No. 4417749, 2006.

[3] Adam Barth, Collin Jackson, and John C. Mitchell. Robust defenses for cross-site request forgery. *Proceedings of the 15th ACM conference on Computer and communications security - CCS '08*, page 75, 2008.

[4] Will Bontrager. Form Submissions Without Submit Buttons, 2005.

[5] Eric Butler. Firesheep, 2010.

[6] Craig Condit. JSESSIONID considered harmful, 2006.

[7] G.A. Di Lucca, AR Fasolino, M. Mastoianni, and P. Tramontana. *Identifying cross site scripting vulnerabilities in Web applications*, volume 1550-4441. IEEE Comput. Soc, 2005.

[8] D. Eastlake 3rd, J. Schiller, and S. Crocker. Randomness Requirements for Security. RFC 4086 (Best Current Practice), June 2005.

[9] Stephen Farrell. Leaky or Guessable Session Identifiers. *IEEE Internet Computing*, (December 2009):88–91, 2011.

[10] R. Fielding, J. Gettys, J. Mogul, H. Frystyk, L. Masinter, P. Leach, and T. Berners-Lee. Hypertext Transfer Protocol – HTTP/1.1. RFC 2616 (Draft Standard), June 1999. Updated by RFCs 2817, 5785.

[11] Kevin Fu, Emil Sit, Kendra Smith, and Nick Feamster. Dos and don'ts of client authentication on the web. In *Proceedings of the 10th conference on USENIX Security Symposium-Volume 10*, pages 19–19. USENIX Association, 2001.

[12] Robert Graham. SideJacking with Hamster, 2007.

[13] Adrian Holovaty and Jacob Kaplan-Moss. *The Definitive Guide to Django: Web Development Done Right*, chapter 19. Apress, 2008.

[14] Richard Ishida. Declaring character encodings in HTML, 2010.

[15] Trevor Jim, Nikhil Swamy, and Michael Hicks. Defeating script injection attacks with browser-enforced embedded policies. *Proceedings of the 16th international conference on World Wide Web - WWW '07*, pages 601–610, 2007.

[16] Martin Johns. SessionSafe: Implementing XSS immune session handling. *Computer Security–ESORICS 2006*, pages 444–460, 2006.

[17] Martin Johns, Bastian Braun, Michael Schrank, and Joachim Posegga. Reliable Protection Against Session Fixation Attacks. *ACM Symposium on Applied Computing*, 2011.

[18] Martin Johns and Justus Winter. RequestRodeo: client side protection against session riding. In *Proceedings of the OWASP Europe 2006 Conference, refereed papers track, Report CW448*, pages 5–17, 2006.

[19] Paul Johnston. Authentication and Session Management on the Web. *SANS Institute InfoSec Reading Room*, 2004.

[20] Nenad Jovanovic, Engin Kirda, and Christopher Kruegel. Preventing cross site request forgery attacks. In *Securecomm and Workshops, 2006*, pages 1–10. IEEE, August 2007.

[21] Engin Kirda, Christopher Kruegel, Giovanni Vigna, and Nenad Jovanovic. Noxes: a client-side solution for mitigating cross-site scripting attacks. In *Proceedings of the 2006 ACM symposium on Applied computing*, pages 330–337. ACM, 2006.

[22] Amit Klein. Cross site scripting explained. *Sanctum White Paper*, (June), 2002.

[23] Amit Klein. âĂIJDivide and ConquerâĂİ - HTTP Response Splitting, Web Cache Poisoning Attacks, and Related Topics. *Whitepaper, Sanctum Inc.*, January 2004.

[24] M Kolšek. Session fixation vulnerability in web-based applications. *Acros Security*, (Id):1–16, 2002.

[25] D. Kristol and L. Montulli. HTTP State Management Mechanism. RFC 2109 (Proposed Standard), February 1997. Obsoleted by RFC 2965.

[26] David M. Kristol. HTTP Cookies: Standards, privacy, and politics. *ACM Transactions on Internet Technology (TOIT)*, 1(2):151–198, November 2001.

[27] James F. Kurose and Keith W. Ross. *Computer networking: a top-down approach*. Pearson/Addison-Wesley, 4th edition, 2008.

[28] Ziqing Mao, Ninghui Li, and Ian Molloy. Defeating cross-site request forgery attacks with browser-enforced authenticity protection. *Financial Cryptography and Data Security*, pages 238–255, 2009.

[29] Nick Nikiforakis, Wannes Meert, Yves Younan, Martin Johns, and Wouter Joosen. SessionShield: Lightweight Protection against Session Hijacking. *securitee.org*, pages 1–14, 2010.

[30] OWASP. Insufficient Session-ID Length, 2009.

[31] Joon S. Park and Ravi Sandhu. Secure cookies on the Web. *IEEE Internet Computing*, 4(4):36–44, 2000.

[32] E. Rescorla. HTTP Over TLS. RFC 2818 (Informational), May 2000. Updated by RFC 5785.

[33] Chris Shiflett. Session Fixation, 2004.

[34] Kapil Singh, Alexander Moshchuk, HJ Wang, and W. Lee. On the incoherencies in web browser access control policies. In *2010 IEEE Symposium on Security and Privacy*, pages 463–478. IEEE, 2010.

[35] Binny V A. Using POST method in XMLHTTPRequest(Ajax), 2010.

[36] Anne van Kesteren. XMLHttpRequest. Last call WD, W3C, November 2009. http://www.w3.org/TR/2009/WD-XMLHttpRequest-20091119/.

[37] William Zeller and Edward W Felten. Cross-Site Request Forgeries: Exploitation and Prevention. pages 1–13, 2008.

Fiche masterproef

Student: Bram Bonné

Titel: Improving session security in web applications

Engelse titel: Verhoogde veiligheid van sessies in webapplicaties

UDC: 004.49

Korte inhoud:
Hier komt een heel bondig abstract van hooguit 500 woorden.

Thesis voorgedragen tot het behalen van de graad van Master in de ingenieurswetenschappen: computerwetenschappen

Promotoren: dr. L. Desmet
Prof. dr. F. Piessens

Assessoren: Ir. W. Eetveel
W. Eetrest

Begeleiders: P. De Ryck
N. Nikiforakis