Browser Security Model

John Mitchell
## Top Web Vulnerabilities 2017

<table>
<thead>
<tr>
<th>OWASP Top 10 – 2013 (Previous)</th>
<th>OWASP Top 10 – 2017 (New)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 – Injection</td>
<td>A1 – Injection</td>
</tr>
<tr>
<td>A2 – Broken Authentication and Session Management</td>
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</tr>
<tr>
<td>A3 – Cross-Site Scripting (XSS)</td>
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</tr>
<tr>
<td>A5 – Security Misconfiguration</td>
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</tr>
<tr>
<td>A6 – Sensitive Data Exposure</td>
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</tr>
<tr>
<td>A7 – Missing Function Level Access Control - Merged with A4</td>
<td>A7 – Insufficient Attack Protection (NEW)</td>
</tr>
<tr>
<td>A8 – Cross-Site Request Forgery (CSRF)</td>
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</tr>
<tr>
<td>A9 – Using Components with Known Vulnerabilities</td>
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</tr>
<tr>
<td>A10 – Unvalidated Redirects and Forwards - Dropped</td>
<td>A10 – Underprotected APIs (NEW)</td>
</tr>
</tbody>
</table>

Historical Web Vulnerabilities "In the Wild"

Evolution of the web vulnerabilities over the years by types

Data from aggregator and validator of NVD-reported vulnerabilities
Historical Web vs System vulnerabilities

- Decline in % web vulns since 2009
  - 49% in 2010 -> 37% in 2011.
  - Big decline in SQL Injection vulnerabilities
Five lectures on Web security

- **Browser security model**
  - The browser as an OS and execution platform
  - Protocols, isolation, communication, ...
- **HTTPS: goals and pitfalls**
  - Network issues and browser protocol handling
- **Web application security**
  - Application pitfalls and defenses
- **Content security policies**
  - Additional mechanisms for sandboxing and security
- **Session management and user authentication**
  - How users authenticate to web sites
  - Browser-server mechanisms for managing state

This 2.5-week section could fill an entire course.
Web programming poll

- Familiar with basic html?
- Developed a web application using:
  - Apache?
  - PHP?
  - Ruby?
  - Python?
  - SQL?
  - JavaScript?
  - CSS?
  - JSON?
- Know about:
  - postMessage?
  - NaCl?
  - Webworkers?
  - CSP?
  - WebView?

Resource: http://www.w3schools.com/
Goals of web security

❖ Safely browse the web
  ■ Visit a variety of web sites without incurring harm
    ✷ Integrity: Site A cannot compromise session at Site B
    ✷ Confidentiality: no information stolen from your device

❖ Support secure web apps
  ■ Apps provided over the web can have same security properties as stand-alone applications

❖ Support secure mobile apps
  ■ Web protocols and web content standards are used as back end of many mobile apps
Web security threat model

Alice

Web Attacker
Sets up malicious site visited by victim; no control of network
Network security threat model

Network Attacker
Intercepts and controls network communication

Alice
Web Threat Models

- **Web attacker**
  - Controls attacker.com
  - Can obtain SSL/TLS certificate for attacker.com
  - User visits attacker.com
    - Or: runs attacker’s Facebook app, etc.

- **Network attacker**
  - Passive: Wireless eavesdropper
  - Active: Evil router, DNS poisoning

- **Malware attacker**
  - Attacker escapes browser isolation mechanisms and run separately under control of OS
Malware attacker

- Browsers may contain exploitable bugs
  - Often enable remote code execution by web sites
  - Google study: [the ghost in the browser 2007]
    - Found Trojans on 300,000 web pages (URLs)
    - Found adware on 18,000 web pages (URLs)

NOT OUR FOCUS IN THIS PART OF COURSE

- Even if browsers were bug-free, still lots of vulnerabilities associated with the web
  - OWASP top 10: XSS, SQLi, CSRF, ...
Outline

- Http
- Rendering content
- Isolation
- Communication
- Navigation
- Security User Interface
- Cookies
- Frames and frame busting
HTTP
URLs

Global identifiers of network-retrievable documents

Example:
http://stanford.edu:81/class?name=cs155#homework

Special characters are encoded as hex:
- %0A = newline
- %20 or + = space, %2B = + (special exception)
HTTP Request

Method | File | HTTP version | Headers
--- | --- | --- | ---
GET /index.html HTTP/1.1 | Accept: image/gif, image/x-bitmap, image/jpeg, */* | Accept-Language: en | Connection: Keep-Alive
User-Agent: Mozilla/1.22 (compatible; MSIE 2.0; Windows 95) | Host: www.example.com | Referer: http://www.google.com?q=dingbats

GET : no side effect  POST : possible side effect
HTTP/1.0 200 OK
Date: Sun, 21 Apr 1996 02:20:42 GMT
Server: Microsoft-Internet-Information-Server/5.0
Connection: keep-alive
Content-Type: text/html
Last-Modified: Thu, 18 Apr 1996 17:39:05 GMT
Set-Cookie: ...
Content-Length: 2543

<HTML> Some data... whatever ...

</HTML>
RENDERING CONTENT
Rendering and events

Basic browser execution model

- Each browser window or frame
  - Loads content
  - Renders it
    - Processes HTML and scripts to display page
    - May involve images, subframes, etc.
  - Responds to events

Events can be

- User actions: OnClick, OnMouseover
- Rendering: OnLoad, OnBeforeUnload
- Timing: setTimeout, clearTimeout
Document Object Model (DOM)

- Object-oriented interface used to read and write docs
  - web page in HTML is structured data
  - DOM provides representation of this data structure

Examples

- Properties: document.alinkColor, document.URL, document.forms[ ], document.links[ ], document.anchors[ ]
- Methods: document.write(document.referrer)

Includes Browser Object Model (BOM)

- window, document, frames[], history, location, navigator (type and version of browser)
Changing HTML using Script, DOM

Some possibilities

- createElement(elementName)
- createTextNode(text)
- appendChild(newChild)
- removeChild(node)

Example: Add a new list item:

```javascript
var list = document.getElementById('t1')
var newitem = document.createElement('li')
var newtext = document.createTextNode(text)
list.appendChild(newitem)
newitem.appendChild(newtext)
```

```html
<ul id="t1">
  <li>Item 1</li>
</ul>
```
Event example

```html
<!DOCTYPE html>
<html>
<body>
<h1>My First Web Page</h1>
<p>My first paragraph.</p>
<button onclick="document.write(5 + 6)">Try it</button>
</body>
</html>

Source: http://www.w3schools.com/js/js_output.asp
RENDERING CONTENT – THINK LIKE AN ATTACKER
Basic web functionality

HTML Image Tags

```html
<html>
  ...
  <p>  ...  </p>
  ...
  <img src="http://example.com/sunset.gif" height="50" width="100">
  ...
</html>
```

Displays this nice picture ➔

Security issues?
Image tag security issues

- Communicate with other sites
- Hide resulting image
  - `<img src=" ... " height="1" width="1">`
- Spoof other sites
  - Add logos that fool a user

Important Point: A web page can send information to any site

Q: What threat model are we talking about here?
JavaScript onError

**Basic function**
- Triggered when error occurs loading a document or an image

**Example**

```html
<img src="image.gif"
onerror="alert('The image could not be loaded.')"
>
```

- Runs onError handler if image does not exist and cannot load

http://www.w3schools.com/jsref/jsref_onError.asp
When response header indicates that page is not an image, the browser stops and notifies JavaScript via the onerror handler.

```html
<html><body><img id="test" style="display: none">
<script>
    var test = document.getElementById('test');
    var start = new Date();
    test.onerror = function() {
        var end = new Date();
        alert("Total time: " + (end - start));
    }
    test.src = "http://www.example.com/page.html";
</script>
</body></html>
```
Port scanning behind firewall

JavaScript can:
- Request images from internal IP addresses
  - Example: `<img src="192.168.0.4:8080"/>
- Use timeout/onError to determine success/failure
- Fingerprint webapps using known image names
Remote scripting

Goal: communicate between client-side app running in browser and server-side app, without reloading

Methods

- Java Applet/ActiveX control/Flash
  - Can make HTTP requests and interact with client-side JavaScript code, but some aspects may be browser specific

- XML-RPC
  - Open, standards-based technology that requires XML-RPC libraries on server and in your client-side code.

- Simple HTTP via a hidden IFRAME
  - IFRAME with a script on your web server is by far the easiest of the three remote scripting options

Important Point: A page can maintain bi-directional communication with browser (until user closes/quits)

Simple remote scripting example

Client.html: “RPC” by passing arguments to server.html in query string

```html
<script type="text/javascript">
function handleResponse() {
    alert('this function is called from server.html')
}
</script>

<iframe id="RSIFrame" name="RSIFrame"
    style="width:0px; height:0px; border: 0px"
    src="blank.html">
</iframe>

<a href="server.html" target="RSIFrame">make RPC call</a>

Server.html: another page on same server, could be server.php, etc

```html
<script type="text/javascript">
    window.parent.handleResponse()
</script>

RPC can be done silently in JavaScript, passing and receiving arguments
ISOLATION
Frame and iFrame

- Window may contain frames from different sources
  - Frame: rigid division as part of frameset
  - iFrame: floating inline frame

- iFrame example

  `<iframe src="hello.html" width=450 height=100>`
  If you can see this, your browser doesn't understand IFRAME.
  `</iframe>`

- Why use frames?
  - Delegate screen area to content from another source
  - Browser provides isolation based on frames
  - Parent may work even if frame is broken
**Analogy**

**Operating system**
- **Primitives**
  - System calls
  - Processes
  - Disk
- **Principals: Users**
  - Discretionary access control
- **Vulnerabilities**
  - Buffer overflow
  - Root exploit

**Web browser**
- **Primitives**
  - Document object model
  - Frames
  - Cookies / localStorage
- **Principals: “Origins”**
  - Mandatory access control
- **Vulnerabilities**
  - Cross-site scripting
  - Cross-site request forgery
  - Cache history attacks
  - ...
Windows and frames interact
Policy Goals

- Safe to visit an evil web site
- Safe to visit two pages at the same time
  - Address bar distinguishes them
- Allow safe delegation
Browser security mechanism

- Each frame of a page has an origin
  - Origin = protocol://host:port
- Frame can access data on frame with the same origin
  - Network access, Read/write DOM, Storage (cookies)
- Frame cannot access data associated with a different origin
Components of browser security policy

Frame-Frame relationships

- canScript(A,B)
  - Can Frame A execute a script that manipulates arbitrary/nontrivial DOM elements of Frame B?
- canNavigate(A,B)
  - Can Frame A change the origin of content for Frame B?

Frame-principal relationships

- readCookie(A,S), writeCookie(A,S)
  - Can Frame A read/write cookies from site S?

See https://code.google.com/p/browsersec/wiki/Part1
https://code.google.com/p/browsersec/wiki/Part2
Domain Relaxation

- Origin: scheme, host, (port), hasSetDomain
- Try `document.domain = document.domain`
Additional mechanisms

- Cross-origin network requests
  - Access-Control-Allow-Origin: <list of domains>
  - Access-Control-Allow-Origin: *
- Cross-origin client side communication
  - Client-side messaging via navigation (old browsers)
  - postMessage (modern browsers)
COMMUNICATION
window.postMessage

API for inter-frame communication

- Supported in standard browsers
- A network-like channel between frames

Add a contact
Share contacts
postMessage syntax

```javascript
frames[0].postMessage("Attack at dawn!", "http://b.com/");

window.addEventListener("message", function (e) {
    if (e.origin == "http://a.com") {
        ... e.data ... 
    }
}, false);
```

Facebook Anecdote

Attack at dawn!
Why include “targetOrigin”?

- What goes wrong?
  
  ```javascript
  frames[0].postMessage("Attack at dawn!");
  ```

- Messages sent to *frames*, not principals
  - When would this happen?
NAVIGATION
A Guninski Attack

window.open("https://attacker.com/", "awglogin");
What should the policy be?
## Legacy Browser Behavior

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<tr>
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<th>Policy</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Permissive</td>
</tr>
<tr>
<td>IE 6 (option)</td>
<td>Child</td>
</tr>
<tr>
<td>IE7 (no Flash)</td>
<td>Descendant</td>
</tr>
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<td>IE7 (with Flash)</td>
<td>Permissive</td>
</tr>
<tr>
<td>Firefox 2</td>
<td>Window</td>
</tr>
<tr>
<td>Safari 3</td>
<td>Permissive</td>
</tr>
<tr>
<td>Opera 9</td>
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Window Policy Anomaly
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## Adoption of Descendant Policy

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<td>Descendant</td>
</tr>
<tr>
<td>Safari 3</td>
<td>Descendant</td>
</tr>
<tr>
<td>Opera 9</td>
<td>(many policies)</td>
</tr>
<tr>
<td>HTML 5</td>
<td>Descendant</td>
</tr>
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</table>
When is it safe to type my password?

SECURITY USER INTERFACE
Safe to type your password?
Safe to type your password?

![Bank of the West Phishing Page](image)
Safe to type your password?
Safe to type your password?

BANK OF THE WEST
Portfolio Online

Welcome to Portfolio Online!

Please enter your access ID and click “Continue.”

Terms and Conditions
please read our Terms & Conditions.

Access ID:
Safe to type your password?
Mixed Content: HTTP and HTTPS

Problem
- Page loads over HTTPS, but has HTTP content
- Network attacker can control page

IE: displays mixed-content dialog to user
- Flash files over HTTP loaded with no warning (!)
- Note: Flash can script the embedding page

Firefox: red slash over lock icon (no dialog)
- Flash files over HTTP do not trigger the slash

Safari: does not detect mixed content

Dan will talk about this later....
Mixed content and network attacks

- **Old sites**: after login all content over HTTPS
  - Developer error: Somewhere on bank site write
    ```html
    <script src="http://www.site.com/script.js"></script>
    ```
  - Active network attacker can now hijack any session

- **Better way to include content**: 
  ```html
  <script src="/www.site.com/script.js"></script>
  ```
  - served over the same protocol as embedding page
Lock Icon 2.0

- Extended validation (EV) certs

- Prominent security indicator for EV certificates

- note: EV site loading content from non-EV site does not trigger mixed content warning
Finally: the status Bar

Trivially spoofable

<a href="http://www.paypal.com/">
    <a href='http://www.evil.com/'>
    PayPal
</a>
</a>
COOKIES: CLIENT STATE
Cookies

Used to store state on user’s machine

HTTP is stateless protocol; cookies add state

POST ...

HTTP Header:
Set-cookie: NAME=VALUE ;
domain = (who can read) ;
expires = (when expires) ;
secure = (only over SSL)

If expires=NULL: this session only

POST ...

Cookie: NAME = VALUE

POST ...

HTTP is stateless protocol; cookies add state
Cookie authentication

Browser

POST login.cgi
Username & pwd

Set-cookie: auth=val

Web Server

Validate user

auth=val

Auth server

Store val

restrict.html

GET restricted.html
Cookie: auth=val

If YES,

restricted.html

Check val

YES/NO

auth=val
Cookie Security Policy

**Uses:**
- User authentication
- Personalization
- User tracking: e.g. Doubleclick (3\textsuperscript{rd} party cookies)

**Origin is the tuple** \(<\text{domain}, \text{path}>\)
- Can set cookies valid across a domain suffix
Secure Cookies

- Provides confidentiality against network attacker
  - Browser will only send cookie back over HTTPS

- ... but no integrity
  - Can rewrite secure cookies over HTTP
    ⇒ network attacker can rewrite secure cookies
    ⇒ can log user into attacker’s account
httpOnly Cookies

- Cookie sent over HTTP(s), but not accessible to scripts
  - cannot be read via `document.cookie`
  - Helps prevent cookie theft via XSS

... but does not stop most other risks of XSS bugs
FRAMES AND FRAME BUSTING
Frames

- Embed HTML documents in other documents

<iframe name="myframe"
src="http://www.google.com/"/>
This text is ignored by most browsers.
</iframe>
Frame Busting

Goal: prevent web page from loading in a frame
- example: opening login page in a frame will display correct passmark image

Frame busting:

```javascript
if (top != self)
    top.location.href = location.href
```
Better Frame Busting

Problem: Javascript OnUnload event

Try this instead:

```html
<body onUnload="javascript: cause_an_abort;">  

if (top != self)  
    top.location.href = location.href  
else { ... code of page here ... }
```
Even better (after ~2010)

Set X-Frame-Options HTTP response header
- Tell browser not to render a page in a `<frame>` or `<iframe>`
- Ensuring that content is not embedded into other sites.
- Use options "DENY", "SAMEORIGIN", or "ALLOW-FROM uri"

<table>
<thead>
<tr>
<th>Browser</th>
<th>DENY/SAMEORIGIN Support Introduced</th>
<th>ALLOW-FROM Support Introduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chrome</td>
<td>4.1.249.1042</td>
<td>Supports CSP frame-ancestors instead</td>
</tr>
<tr>
<td>Firefox (Gecko)</td>
<td>3.6.9 (1.9.2.9)</td>
<td>18.0</td>
</tr>
<tr>
<td>Internet Explorer</td>
<td>8.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Opera</td>
<td>10.50</td>
<td></td>
</tr>
<tr>
<td>Safari</td>
<td>4.0</td>
<td>Won't support - Supports CSP frame-ancestors ins</td>
</tr>
</tbody>
</table>
Summary

- Http
- Rendering content
- Isolation
- Communication
- Navigation
- Security User Interface
- Cookies
- Frames and frame busting