Browser Security Model

*original slides by prof. John Mitchell*
Sampling of 2014 security incidents by attack type, time and impact

Conjecture of relative breach impact is based on publicly disclosed information regarding leaked records and financial losses.
Web vs System vulnerabilities

Decline in % web vulns since 2009
- 49% in 2010 -> 37% in 2011.
- Big decline in SQL Injection vulnerabilities
Reported Web Vulnerabilities "In the Wild"

Evolution of the web vulnerabilities over the years by types

Data from aggregator and validator of NVD-reported vulnerabilities
Web Application Vulnerabilities by Attack Technique
2009-2013 H1

Source: IBM X-Force® Research and Development
Web application vulnerabilities

Web Application Vulnerabilities as a Percentage of All Disclosures in 2010

Web Applications: 49%
Others: 51%

Web Application Vulnerabilities as a Percentage of All Disclosures in 2011 H1

Web Applications: 37 percent
Others: 63 percent
Five lectures on Web security

- **Browser security model**
  - The browser as an OS and execution platform
  - Protocols, isolation, communication, ...

- **Web application security**
  - Application pitfalls and defenses

- **Content security policies**
  - Additional mechanisms for sandboxing and security

- **Authentication and session management**
  - How users authenticate to web sites
  - Browser-server mechanisms for managing state

- **HTTPS: goals and pitfalls**
  - Network issues and browser protocol handling
Web programming poll

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

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

- Safely browse the web
  - Users should be able to visit a variety of web sites, without incurring harm:
    - No stolen information
    - Site A cannot compromise session at Site B

- Support secure web applications
  - Applications delivered over the web should be able to achieve the same security properties as stand-alone applications
Web security threat model

Web Attacker
Sets up malicious site visited by victim; no control of network

Alice
Network security threat model

Network Attacker
Intercepts and controls network communication

Alice
Web Threat Models

Web attacker
- Control 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 on the web
  - All of the vulnerabilities on previous graph: XSS, SQLi, CSRF, ...
Outline

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

```
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 Response

## HTTP version

```
HTTP/1.0 200 OK
```

## Status code

```
200
```

## Reason phrase

```
OK
```

## Headers

- 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

## Data

```
<HTML> Some data... blah, blah, blah </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()
Example

<!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>
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 hierarchy

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)
<!DOCTYPE html>
<html>
<body>

<h1>My First Web Page</h1>
<p>My First Paragraph</p>

<p id="demo"></p>

<script>
document.getElementById("demo").innerHTML = 5 + 6;
</script>

</body>
</html>

Source: http://www.w3schools.com/js/js_output.asp
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(newChild)
newitem.appendChild(newtext)
```

```html
<ul id="t1">
  <li>Item 1</li>
</ul>
```
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?
Security consequences

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

Security consequence
Remote scripting

Goal
- Exchange data between a client-side app running in a browser and server-side app, without reloading page

Methods
- Java Applet/ActiveX control/Flash
  - Can make HTTP requests and interact with client-side JavaScript code, but requires LiveConnect (not available on all browsers)
- 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 (or database of static HTML files) 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

```html
<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
Windows Interact
## Analogy

<table>
<thead>
<tr>
<th>Operating system</th>
<th>Web browser</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primitives</strong></td>
<td><strong>Primitives</strong></td>
</tr>
<tr>
<td>System calls</td>
<td>Document object model</td>
</tr>
<tr>
<td>Processes</td>
<td>Frames</td>
</tr>
<tr>
<td>Disk</td>
<td>Cookies / localStorage</td>
</tr>
<tr>
<td><strong>Principals: Users</strong></td>
<td><strong>Principals: “Origins”</strong></td>
</tr>
<tr>
<td>Discretionary access control</td>
<td>Mandatory access control</td>
</tr>
<tr>
<td><strong>Vulnerabilities</strong></td>
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</tr>
<tr>
<td>Buffer overflow</td>
<td>Cross-site scripting</td>
</tr>
<tr>
<td>Root exploit</td>
<td>Cross-site request forgery</td>
</tr>
<tr>
<td></td>
<td>Cache history attacks</td>
</tr>
<tr>
<td></td>
<td>...</td>
</tr>
</tbody>
</table>
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 its own 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**
- \text{canScript}(A,B)
  - Can Frame A execute a script that manipulates arbitrary/nontrivial DOM elements of Frame B?
- \text{canNavigate}(A,B)
  - Can Frame A change the origin of content for Frame B?

**Frame-principal relationships**
- \text{readCookie}(A,S), \text{writeCookie}(A,S)
  - Can Frame A read/write cookies from site S?

Library import excluded from SOP

<script src=https://seal.verisign.com/getseal?
host_name=a.com></script>

- Script has privileges of imported page, NOT source server.
- Can script other pages in this origin, load more scripts
- Other forms of importing
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)
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?
A Guninski Attack

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

<table>
<thead>
<tr>
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<th>Policy</th>
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</thead>
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<tr>
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</tr>
<tr>
<td>IE 6 (option)</td>
<td>Child</td>
</tr>
<tr>
<td>IE7 (no Flash)</td>
<td>Descendant</td>
</tr>
<tr>
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</tr>
<tr>
<td>Firefox 2</td>
<td>Window</td>
</tr>
<tr>
<td>Safari 3</td>
<td>Permissive</td>
</tr>
<tr>
<td>Opera 9</td>
<td>Window</td>
</tr>
<tr>
<td>HTML 5</td>
<td>Child</td>
</tr>
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</table>
Window Policy Anomaly

```
window.top.frames[1].location = 
    "http://www.attacker.com/...";

window.top.frames[2].location = 
    "http://www.attacker.com/...";
```

![Image of a computer screen with a browser window showing a devils-themed 'Evil Gadget' and a 'Radio Paradise' widget. The screen also shows a part of the iGoogle page with multiple gadgets and a search bar.]
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# Adoption of Descendant Policy

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<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>
</tbody>
</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

Gives me you pa55w0rds!

User name:

Password:

Login
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:

Done

https://portfolioonline.metavante.com

portfolioonline.metavante.com
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: HTTP and HTTPS

Silly dialogs
Mixed content and network attacks

- **banks:** after login all content over HTTPS
  - Developer error: Somewhere on bank site write
    
    `<script src="http://www.site.com/script.js"> </script>`

  - Active network attacker can now hijack any session

**Better way to include content:**

- `<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/"
onclick="this.href = 'http://www.evil.com/';">PayPal</a>
COOKIES: CLIENT STATE
Cookies

Used to store state on user’s machine

If expires=NULL: this session only

HTTP is stateless protocol; cookies add state
Cookie authentication

**Browser**
- POST login.cgi
  - Username & pwd
- Set-cookie: `auth=val`

**Web Server**
- Validate user
- Store val

**Auth server**
- Check val

**Browser**
- GET restricted.html
  - Cookie: `auth=val`
- If YES, restricted.html

**Auth server**
- YES/NO

auth=val
Cookie Security Policy

◊ Uses:
  - User authentication
  - Personalization
  - User tracking: e.g. Doubleclick (3rd party cookies)

◊ Browser will store:
  - At most 20 cookies/site, 3 KB / cookie

◊ Origin is the tuple <domain, 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  ...  }
```
Summary

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