Web Security Model

CS155 Computer and Network Security

Acknowledgments: Lecture slides are from the Computer Security course taught by Dan Boneh at Stanford University. When slides are obtained from other sources, a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.
And now for... Web Security!

1. Systems Security
2. Web Security
   - Web Security Model
     - Web Vulnerabilities and Attacks
     - HTTPS, TLS, Certificates
     - User Authentication and Session Management
3. Network and Mobile Security
Web Security Goals

Safely browse the web

Visit a web site (including malicious ones) without incurring harm

**Site A** cannot steal data from your device, install malware, access camera, etc.

**Site A** cannot affect session on **Site B** or eavesdrop on **Site B**

Support secure web apps

Web-based applications (e.g., Zoom) should have same or better security properties as native applications
Attack Models

Malicious Website
Attack Models

Malicious Website

Malicious External Resource
Attack Models

Malicious Website

Malicious External Resource

Network Attacker
Attack Models

- Malicious Website
  - Laptop to Malware Attacker
  - Laptop to Network Attacker

- Malicious External Resource
  - Laptop to Server
  - Server to Malware Attacker

- Network Attacker
  - Laptop to Server
  - Server to Laptop

- Malware Attacker
  - Laptop to Server
  - Server to Laptop
HTTP Protocol
HTTP Protocol

ASCII protocol from 1989 that allows fetching resources (e.g., HTML file) from a server

- Stateless protocol. Two messages: request and response

Every resource has a uniform resource location (URL):

http://cs155.stanford.edu:80/lectures?lecture=08#slides

scheme  domain  port  path  query string  fragment id
Anatomy of Request

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
Anatomy of Request

HTTP Request

<table>
<thead>
<tr>
<th>method</th>
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# Anatomy of Request

## HTTP Request

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### headers
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- 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
# Anatomy of Request

## HTTP Request

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</tr>
<tr>
<td>Referer: <a href="http://www.google.com?q=dingbats">http://www.google.com?q=dingbats</a></td>
</tr>
</tbody>
</table>

body (empty)
HTTP/1.0 200 OK
Date: Sun, 21 Apr 1996 02:20:42 GMT
Server: Microsoft-Internet-Information-Server/5.0
Content-Type: text/html
Last-Modified: Thu, 18 Apr 1996 17:39:05 GMT
Content-Length: 2543

<html>Some data... announcement! ... </html>
HTTP GET vs. POST

HTTP Request

method | path | version |
--- | --- | --- |
POST | /index.html | HTTP/1.1 |

headers

Accept: image/gif, image/x-bitmap, image/jpeg, */*
Accept-Language: en
User-Agent: Mozilla/1.22 (compatible; MSIE 2.0; Windows 95)
Host: www.example.com
Referer: http://www.google.com?q=dingbats

body

Name: Zakir Durumeric
Organization: Stanford University
HTTP Methods

**GET**: Get the resource at the specified URL (does not accept message body)

**POST**: Create new resource at URL with payload

**PUT**: Replace target resource with request payload

**PATCH**: Update part of the resource

**DELETE**: Delete the specified URL
HTTP Methods

**GET**s should not change server state; in practice, some servers do perform side effects
- Old browsers don’t support **PUT**, **PATCH**, and **DELETE**
- Most requests with a side affect are **POST**s today
- Real method hidden in a header or request body

🚨 Don’t do...

**GET** http://bank.com/transfer?fromAccount=X&toAccount=Y&amount=1000
HTTP → Website

When you load a site, your web browser sends a **GET** request to that website.
Loading Resources

Root HTML page can include additional resources like images, videos, fonts

After parsing page HTML, your browser requests those additional resources
External Resources

There are no restrictions on where you can load resources like images.

Nothing prevents you from including images on a different domain.
(i)Frames

Beyond loading individual resources, websites can also load other websites within their window

- Frame: rigid visible division
- iFrame: floating inline frame

Allows delegating screen area to content from another source (e.g., ad)
Javascript

Historically, HTML content was static or generated by the server and returned to the web browser to simply render to the user

Today, websites also deliver scripts to be run inside of the browser

<button onclick="alert("The date is" + Date())">
  Click me to display Date and Time.
</button>

Javascript can make additional web requests, manipulate page, read browser data, local hardware — exceptionally powerful today
Javascript can read and modify page by interacting with DOM

- Object Oriented interface for reading/writing page content
- Browser takes HTML -> structured data (DOM)

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

<script>
  document.getElementById('demo').innerHTML = Date()
</script>```
Basic Execution Model

Each browser window....

- Loads content of root page
- Parses HTML and runs included Javascript
- Fetches sub resources (e.g., images, CSS, Javascript, iframes)
- Responds to events like onClick, onMouseover, onLoad, setTimeout
HTTP/2

Major revision of HTTP released in 2015

Based on Google SPDY Protocol

No major changes in how applications are structured

Major changes (mostly performance):

- Allows pipelining requests for multiple objects
- Multiplexing multiple requests over one TCP connection
- Header Compression
- Server push
Cookies + Sessions
HTTP is Stateless

HTTP Request
GET /index.html HTTP/1.1

HTTP Response
HTTP/1.0 200 OK
Content-Type: text/html
<html>Some data... </html>

If HTTP is stateless, how do we have website sessions?
HTTP Cookies

HTTP cookie: a small piece of data that a server sends to the web browser

The browser *may* store and send back in future requests to that site

**Session Management**
Logins, shopping carts, game scores, or any other session state

**Personalization**
User preferences, themes, and other settings

**Tracking**
Recording and analyzing user behavior
HTTP Response

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
Set-Cookie: trackingID=3272923427328234
Set-Cookie: userID=F3D947C2
Content-Length: 2543

<html>Some data... whatever ... </html>
Sending Cookie

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)
Cookie: trackingID=3272923427328234
Cookie: userID=F3D947C2
Referer: http://www.google.com?q=dingbats
Login Session

GET /loginform HTTP/1.1
cookies: []

POST /login HTTP/1.1
cookies: []
username: zakir
password: stanford

GET /account HTTP/1.1
cookies: [session: e82a7b92]

GET /img/user.jpg HTTP/1.1
cookies: [session: e82a7b92]
Cookies are always sent

Cookies set by a domain are always sent for any request to that domain.
…for better or worse…

Cookies set by a domain are always sent for any request to that domain.
Islamic State claims it was behind Sri Lanka bombings

Officials raised the death toll in the Easter attacks to 321.

By SHAHANK RENJAL
Modern Website

The LA Times homepage includes 540 resources from nearly 270 IP addresses, 58 networks, and 8 countries.

CNN—the most popular mainstream news site—loads 361 resources.

Many of these aren’t controlled by the main sites.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Domain</th>
<th>Expiration</th>
<th>cookie_count</th>
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<td>2019-04-23-0...</td>
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<td>bounceClientVisit1762v</td>
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Modern Website

- Third-party ad
- Google analytics
- Framed ad
- jQuery library
- Local scripts
Same Origin Policy (Goals)
Remember... UNIX Security Model

Subjects (Who?)
- Users, processes

Objects (What?)
- Files, directories
- Files: sockets, pipes, hardware devices, kernel objects, process data

Access Operations (How?)
- Read, Write, Execute
Web Security Model

Subjects
“Origins” — a unique scheme://domain:port

Objects
DOM tree, DOM storage, cookies, javascript namespace, HW permission

Same Origin Policy (SOP)

Goal: Isolate content of different origins
- Confidentiality: script on evil.com should not be able to read bank.ch
- Integrity: evil.com should not be able to modify the content of bank.ch
Bounding Origins

Every Window and Frame has an origin
Origins are blocked from accessing other origin’s objects
Bounding Origins — Windows

Every Window and Frame has an origin
Origins are blocked from accessing other origin’s objects
Bounding Origins — Windows

Every Window and Frame has an origin
Origins are blocked from accessing other origin’s objects

attacker.com cannot...
- *read or write* content from bank.com tab
- *access* bank.com's cookies
- *detect* that the other tab has bank.com loaded
Bounding Origins — Windows

Every Window and Frame has an origin
Origins are blocked from accessing other origin’s objects

If Tab 1 logs into bank.com, then Tab 2’s requests also send the cookies received by Tab 1 to bank.com.

Both tabs share the same origin and have access to each others cookies
The **BroadcastChannel API** allows same-origin scripts to send messages to other browsing contexts. Simple pub/sub message bus between windows/tabs, iframes, web workers, and service workers.

```javascript
// Connect to the channel named "my_bus".
const channel = new BroadcastChannel('my_bus');

// Send a message on "my_bus".
channel.postMessage('This is a test message.');

// Listen for messages on "my_bus".
channel.onmessage = function(e) {
    console.log('Received', e.data);
};

// Close the channel when you're done.
channel.close();
```
Bounding Origins — Frames

Every Window and Frame has an origin
Origins are blocked from accessing other origin’s objects

attacker.com cannot...
- read content from bank.com frame
- access bank.com's cookies
- detect that has bank.com loaded
Exchanging Messages

Parent and children windows/frames can exchange messages

**Sender:**
targetWindow.postMessage(message, targetOrigin, [transfer]);

targetWindow: ref to window (e.g., window.parent, window.frames)
targetOrigin: origin of targetWindow for event to be sent. Can be * or a URI

**Receiver:**
window.addEventListener("message", receiveMessage, false);
function receiveMessage(event){
    alert("message received")
}
Same Origin Policy
(HTTP Responses)
SOP for HTTP Responses

Pages can *make requests* across origins

SOP prevents Javascript on attacker.com from directly *inspecting* HTTP responses (i.e., pixels in image). It *does not* prevent *making* the request.
SOP for HTTP Resources

**Images:** Browser renders cross-origin images, but SOP prevents page from inspecting individual pixels. Can check size and if loaded successfully.

**CSS, Fonts:** Similar — can load and use, but not directly inspect

**Frames:** Can load cross-origin HTML in frames, but not inspect or modify the frame content. Cannot check success for Frames.
Script Execution

Scripts can be loaded from other origins. Scripts execute with the privileges of their parent frame/window’s origin. Cannot view source, but can call FNs.

✅ You can load library from CDN and use it to alter your page

❌ If you load a malicious library, it can also steal your data (e.g., cookie)
Domain Relaxation

Frame A
Origin: cdn.facebook.com
Domain Relaxation

You can change your document.domain to be a super-domain

a.domain.com → domain.com  OK
b.domain.com → domain.com  OK
a.domain.com → com         NOT OK
a.doin.co.uk → co.uk        NOT OK
A "public suffix" is one under which Internet users can (or historically could) directly register names. Some examples of public suffixes are .com, .co.uk and pvt.k12.ma.us. The Public Suffix List is a list of all known public suffixes.

The Public Suffix List is an initiative of Mozilla, but is maintained as a community resource. It is available for use in any software, but was originally created to meet the needs of browser manufacturers. It allows browsers to, for example:

- Avoid privacy-damaging "supercookies" being set for high-level domain name suffixes
- Highlight the most important part of a domain name in the user interface
- Accurately sort history entries by site

We maintain a fuller (although not exhaustive) list of what people are using it for. If you are using it for something else, you are encouraged to tell us, because it helps us to assess the potential impact of changes. For that, you can use the psl-discuss mailing list, where we consider issues related to the maintenance, format and semantics of the list. Note: please do not use this mailing list to request amendments to the PSL's data.

It is in the interest of Internet registries to see that their section of the list is up to date. If it is not, their customers may have trouble setting cookies, or data about their sites may display sub-optimally. So we encourage them to maintain their section of the list by submitting amendments.

Available at: https://publicsuffix.org/
Domain Relaxation

Frame: cdn.facebook.com

<script>
document.domain = facebook.com
</script>
Domain Relaxation Attacks

```html
<script>
    document.domain = stanford.edu
</script>
```
Relaxation Attacks

What about cs155.stanford.edu → stanford.edu?

- Now Dan and Zakir can steal your Stanford login

Solution:
Both sides must set `document.domain` to share data
Same Origin Policy
(Javascript)
Javascript XMLHttpRequests

Javascript can make network requests to load additional content or submit forms

```javascript
let xhr = new XMLHttpRequest();
xhr.open('GET', "/article/example");
xhr.send();
xhr.onload = function() {
    if (xhr.status == 200) {
        alert(`Done, got ${xhr.response.length} bytes`);
    }
};

// ...or... with jQuery
$.ajax({url: "/article/example", success: function(result){
    $('#div1').html(result);
}});
```
Malicious XMLHttpRequests

// running on attacker.com
   success: function(result){
       $("#div1").html(result);
   }
});

// Should attacker.com be able to see Bank Balance?
// Hopefully, no.
XMLHttpRequests SOP

You cannot make requests to a different origin unless you are granted permission by the destination origin (usually, caveats to come later)

You can only read responses if they’re from the same origin (or you’re given permission by the destination origin to read their data)

XMLHttpRequests requests (both sending and receiving side) are policed by Cross-Origin Resource Sharing (CORS)
Cross-Origin Resource Sharing (CORS)

**Reading Permission:** Servers can add **Access-Control-Allow-Origin** (ACAO) header that tells browser to allow Javascript to allow access

**Sending Permission:** Performs “Pre-Flight” permission check to determine whether the server is willing to receive the request from the origin
Cross-Origin Resource Sharing (CORS)

Let’s say you have a web application running at app.company.com and you want to access JSON data by making requests to api.company.com.
CORS Success

**Origin:** app.c.com

$.post({url: "api.c.com/x",
    success: function(r){
        $("#div1").html(r);
    }
});
**Wildcard Origins**

**Origin:** app.c.com

```
$.post({url: "api.c.com/x", success: function(r){
  $("#div1").html(r);
}});
```

POST /x

OPTIONS /x

Header:
Access-Control-Allow-Origin: *

Origin: api.c.com

POST /x

DATA
CORS Failure

Origin: app.c.com

$.post({url: "api.c.com/x",
  success: function(r){
    $("#div1").html(r);
  }
});

POST /x

OPTIONS /x

Header:
Access-Control-Allow-Origin: https://www.c.com

ERROR

Origin: api.c.com
*Usually: Simple Requests*

⚠ Not all requests result in a Pre-Fetch trip. “Simple” requests do not. Must meet all of the following criteria:

1. Method: **GET, HEAD, POST**

2. If sending data, content type is `application/x-www-form-urlencoded` or `multipart/form-data` or `text/plain`

3. No custom HTTP headers (can set a few standardized ones)

These mimic the types of requests that could be made without Javascript e.g., submitting form, loading image, or page
Simple CORS Success

Origin: app.c.com

$.ajax({url: "api.c.com/x",
    success: function(r){
        $("#div1").html(r);
    }
});

GET /x

Header:
Access-Control-Allow-Origin: http://app.c.com

GET /x

Origin: api.c.com
Simple CORS Failure

Origin: app.c.com

$.ajax({url: "api.c.com/x", success: function(r){
    $('#div1').html(r);
}});

GET /x

Header:
Access-Control-Allow-Origin: https://www.c.com

ERROR
Origin: attacker.com

$.ajax({url: "bank.com/t", success: function(r){
    $('div1').html(r);
}});

GET /x

http://bank.com/transfer?
    fromAccount=X
    &toAccount=Y
    &amount=1000

Header:
Access-Control-Allow-Origin: https://bank.com

ERROR
Same Origin Policy
(Cookies)
Cookie Same Origin Policy

Cookies use a different origin definition:

\[(\text{domain}, \text{path}): (\text{cs155.stanford.edu}, /\text{foo/bar})\]

versus (scheme, domain, port) from DOM SoP

Browser *always* sends cookies in a URL’s scope:

Cookie’s domain is domain suffix of URL’s domain:

*stanford.edu* is a suffix of *cs155.stanford.edu*

Cookie’s path is a prefix of the URL path

*/courses* is a prefix of */courses/cs155*
Scoping Example

name = cookie1
value = a
domain = login.site.com
path = /

name = cookie2
value = b
domain = site.com
path = /

name = cookie3
value = c
domain = site.com
path = /my/home

cookie domain is suffix of URL domain \land cookie path is a prefix of URL path

<table>
<thead>
<tr>
<th>URL</th>
<th>Cookie 1</th>
<th>Cookie 2</th>
<th>Cookie 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>checkout.site.com</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>login.site.com</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>login.site.com/my/home</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>site.com/account</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
Setting Cookie Scope

Websites can set a scope to be any prefix of domain and prefix of path

✔ cs155.stanford.edu *can* set cookie for cs155.stanford.edu
✔ cs155.stanford.edu *can* set cookie for stanford.edu
❌ stanford.edu *cannot* set cookie for cs155.stanford.edu

✔ website.com/* can* set cookie for website.com/
✔ website.com/login *can* set cookie for website.com/
❌ website.com *cannot* set cookie for website.com/login
No Domain Cookies

Most websites do not set Domain. In this situation, cookie is scoped to the hostname the cookie was received over and is not sent to subdomains
Policy Collisions

Cookie SOP Policy

\[ \text{cs.stanford.edu/zakir cannot see cookies for cs.stanford.edu/dabo} \]

(cs.stanford.edu cannot see for cs.stanford.edu/zakir either)

Are Dan’s Cookies safe from Zakir?
Policy Collisions

Cookie SOP Policy

cs.stanford.edu/zakir cannot see cookies for cs.stanford.edu/dabo
(cs.stanford.edu cannot see for cs.stanford.edu/zakir either)

Are Dan’s Cookies safe from Zakir? No.

```
const iframe = document.createElement("iframe");
iframe.src = "https://cs.stanford.edu/dabo";
document.body.appendChild(iframe);
alert(iframe.contentWindow.document.cookie);
```
Third Party Access

If your bank includes Google Analytics Javascript, can it access your Bank’s authentication cookie?
Third Party Access

If your bank includes Google Analytics Javascript, can it access your Bank’s authentication cookie?

Yes!

```javascript
const img = document.createElement("image");
document.body.appendChild(img);
```
HttpOnly Cookies

You can set the setting to prevent cookies from being accessed by `Document.cookie` API.

Prevents Google Analytics from stealing your cookie —

1. Never sent by browser to Google because `(google.com, /)` does not match `(bank.com, /)`
2. Cannot be extracted by Javascript that runs on bank.com
Problem with HTTP Cookies

Network Attacker
Can Observe/Alter/Drop Traffic

HTTPS Connection

domain: bank.com
name: authID
value: auth
Problem with HTTP Cookies

Network Attacker
Can Observe/Alter/Drop Traffic

Attacker tricks user into visiting http://bank.com
Problem with HTTP Cookies

Network Attacker
Can Observe/Alter/Drop Traffic

HTTPS Connection

Attacker tricks user into visiting http://bank.com
Secure Cookies

Set-Cookie: id=a3fWa; Expires=Wed, 21 Oct 2015 07:28:00 GMT; Secure;

A secure cookie is only sent to the server with an encrypted request over the HTTPS protocol.
Web Security Model

CS155 Computer and Network Security

Stanford University