# HALON & NymaCon


*If you like web hacking challenges:*

- **NymaCon 2025** by municipality Nijmegen
  Friday Nov 7 at Waalhalla https://nymacon.nl

  Information session session
  by pen-testers of Hunt & Hackett
  Oct 14 at 18:00, HG00.304

*If you think these web challenges are way too easy*

- **HALON** (Hack AI het Onderwijs in Nederland) pen-test by SURF
  Thu Oct 25 here in Huygens

  Warm up event Oct 9, 10:00-12:00, online
  https://www.surf.nl/agenda/doe-mee-met-halon-en-hack-een-onderwijsinstelling

HALON 2025

Web Security

# Defending against injection attacks

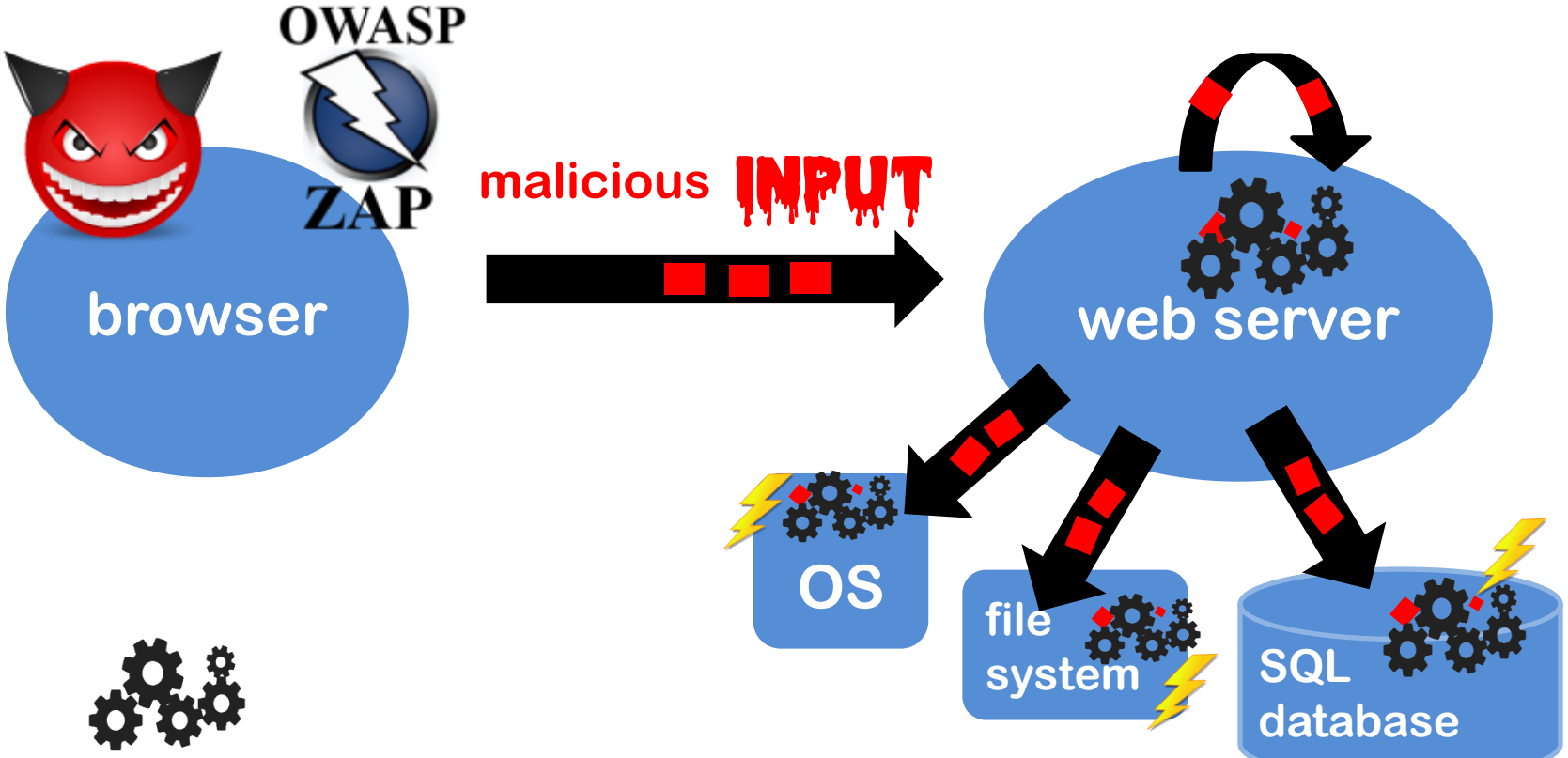
(incl. sanitisation/encoding, safer APIs, CSP, iframe sandboxing, ...)

# DOM-based XSS

Güneş Acar & Erik Poll

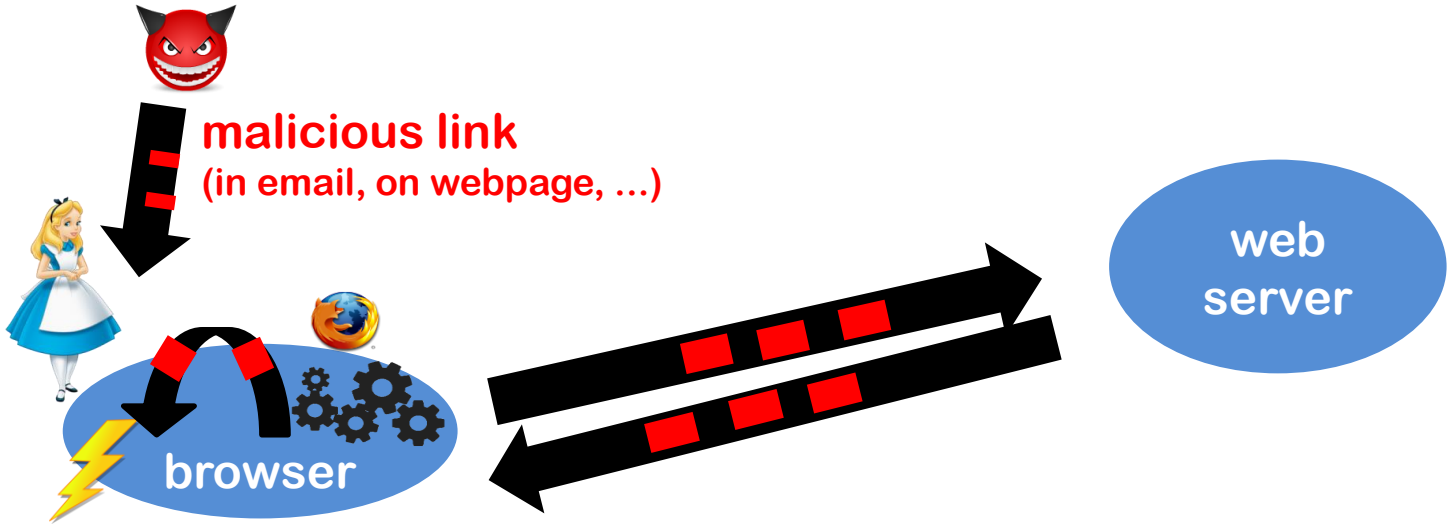
Digital Security group
Radboud University Nijmegen

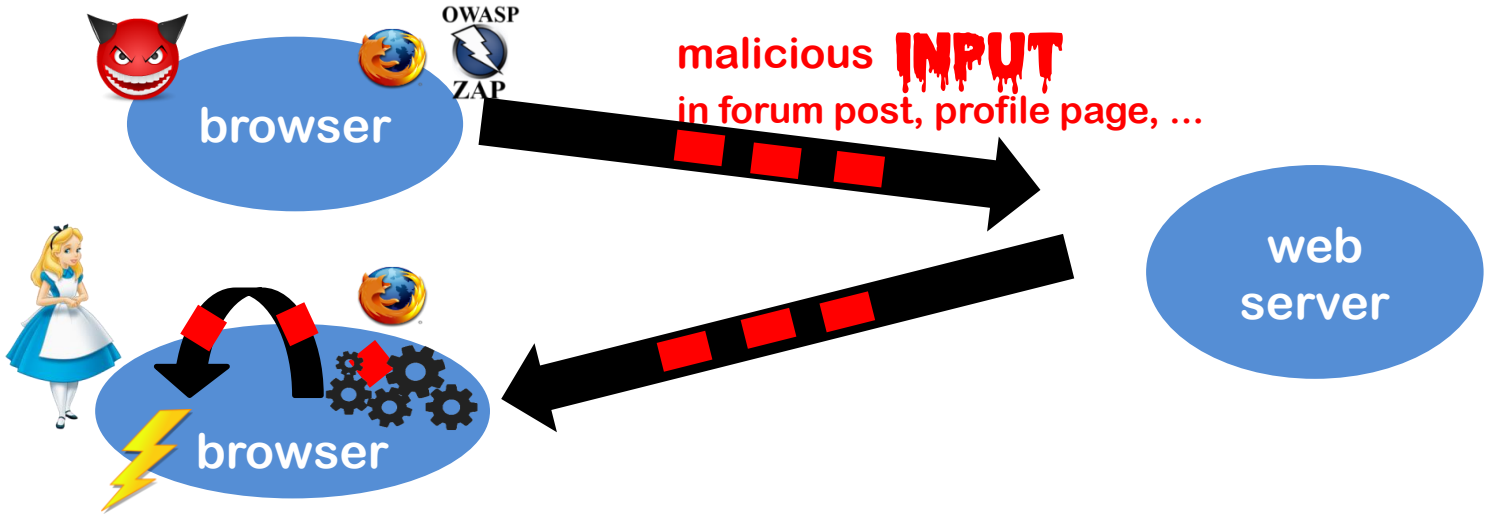
# Recall: injection attacks




***Processing*** of data that contains user input by the OS, file system, SQL database, …

# HTML injection & XSS: reflected or stored



# Different kinds of injection attacks

## The bug category ‘Injection Attacks’ in the OWASP Top 10 includes over 30 different CWE vulnerability categories

- CWE-74 Improper Neutralization of Special Elements in Output Used by a Downstream Component ('Injection')
- CWE-75 Failure to Sanitize Special Elements into a Different Plane (Special Element Injection)
- CWE-77 Improper Neutralization of Special Elements used in a Command ('Command Injection')
- CWE-78 Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')
- CWE-79 Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')
- CWE-80 Improper Neutralization of Script-Related HTML Tags in a Web Page (Basic XSS)
- CWE-83 Improper Neutralization of Script in Attributes in a Web Page
- CWE-87 Improper Neutralization of Alternate XSS Syntax
- CWE-88 Improper Neutralization of Argument Delimiters in a Command ('Argument Injection')
- CWE-89 Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')
- CWE-90 Improper Neutralization of Special Elements used in an LDAP Query ('LDAP Injection')
- CWE-91 XML Injection (aka Blind XPath Injection)
- CWE-93 Improper Neutralization of CRLF Sequences ('CRLF Injection')
- CWE-94 Improper Control of Generation of Code ('Code Injection')
- CWE-95 Improper Neutralization of Directives in Dynamically Evaluated Code ('Eval Injection')
- CWE-96 Improper Neutralization of Directives in Statically Saved Code ('Static Code Injection')
- CWE-97 Improper Neutralization of Server-Side Includes (SSI) Within a Web Page
- CWE-98 Improper Control of Filename for Include/Require Statement in PHP Program ('PHP Remote File Inclusion')
- CWE-99 Improper Control of Resource Identifiers ('Resource Injection')
- CWE-113 Improper Neutralization of CRLF Sequences in HTTP Headers ('HTTP Response Splitting')
- CWE-116 Improper Encoding or Escaping of Output
- CWE-138 Improper Neutralization of Special Elements
- CWE-184 Incomplete List of Disallowed Inputs
- CWE-470 Use of Externally-Controlled Input to Select Classes or Code ('Unsafe Reflection')
- CWE-471 Modification of Assumed-Immutable Data (MAID)
- CWE-564 SQL Injection: Hibernate
- CWE-610 Externally Controlled Reference to a Resource in Another Sphere
- CWE-643 Improper Neutralization of Data within XPath Expressions ('XPath Injection')
- CWE-644 Improper Neutralization of HTTP Headers for Scripting Syntax
- CWE-652 Improper Neutralization of Data within XQuery Expressions ('XQuery Injection')
- CWE-917 Improper Neutralization of Special Elements used in an Expression Language Statement ('Expression Language Injection')

# Sanitisation (aka encoding, filtering, escaping, …)

Injection attacks involve special characters or keywords

- For SQL injection `' " - ; DROP`
- For path traversal `.. ~ /`
- For OS command injection `& ;`
- For HTML injection & XSS `< > <script>`

We can combat injection attacks by sanitising user-supplied data, by

a) rejecting entire request as invalid if it contains such characters or keywords
b) removing the dangerous characters (aka filtering)
c) encoding the dangerous characters (aka escaping or quoting)

*Beware of the many (near-)synonyms!*

Confusingly, sanitisation, esp. variants a) and b), is sometimes also called validation, as invalid request/characters/keywords are removed.

# Validation vs Sanitisation

Fundamental difference between

- rejecting invalid input
  - eg rejection negative number when positive number is expected, rejecting 31/09/2024 as date, …

- cleaning up input to correct obvious mistake
  - eg removing trailing space from a username or email address

- rejecting or changing data to prevent injection attack
  - eg escaping quotes to prevent SQL injection

  Often *incorrectly & confusingly* called 'input validation'

# Sanitisation examples

- **Escaping** to prevent SQL injection
  Replacing `'` by `\'` and `"` by `\"`
- **Removing** `..` `~` `/` to prevent path traversal
- **Removing** `&` `;` to prevent OS command injection
- **HTML-encoding** to prevent HTML injection & XSS
  replacing `<` with `<`

  Additionally, we can also remove some tag, eg `<script>`

  *But maybe it is safer to reject the entire request then?*

Beware that encoding can also be used to **preserve functionality** rather than for security, eg URL encoding of parameters in URL

https://duckduckgo.com/?q=%252F+%2523++%2526

# *What are the dangerous characters?*

**Two approaches:**

1) **Allow listing** uses a list of characters that are allowed
   Allow list could be `a-z A-Z 0-9`

2) **Deny listing** uses a list of characters that are rejection/encoded
   Deny list could be `' " \ / ! ; > < |`

***Which is better?***

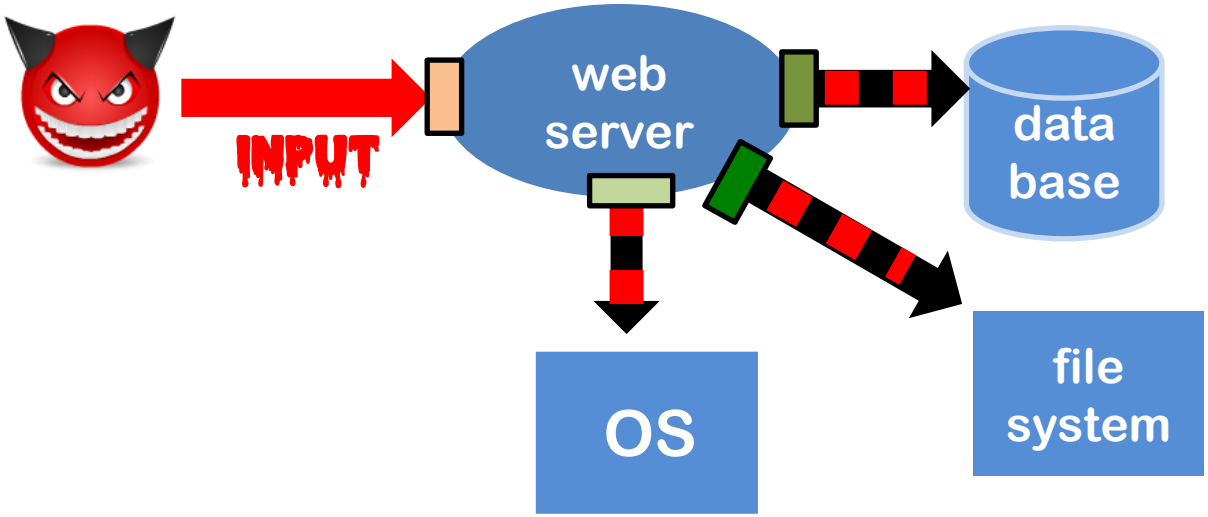
**Allow-listing is more secure than deny-listing because it is easy to overlook potentially dangerous characters**

# *Where to sanitise/encode ?*

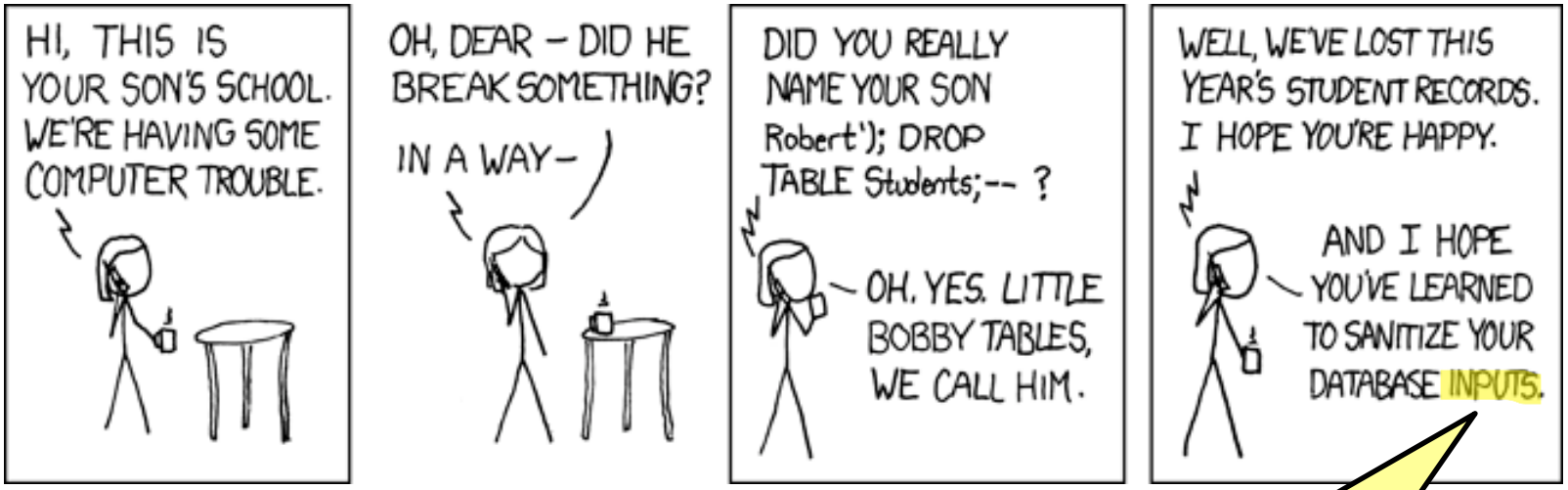
***Input*** **encoding** is tricky, as the same input can be used in different ***contexts*** that require different encoding

- Eg ' is problematic for SQL, . . for path name, ; for OS command
- Therefore: one generic input encoding procedure is suspect

***Output*** **encoding** is therefore the preferred approach



# Output encoding/sanitisation




**We want to encode *outputs* of the server (which are *inputs* to the database), not *inputs* to server**

# Better, more structural prevention?

Root cause of SQL injection: dynamic SQL

ie. construction of SQL query at runtime,

using STRING CONCATENATION

*Can't we side-step this completely?*

a) Sometimes you can replace a dynamic SQL query with a set of fixed SQL queries,

eg replace

```
SELECT * FROM Schedule WHERE DayOfWeek = $day
```

with a choice from 7 fixed queries, one for every day

b) Using a 'safe' API that is not prone to injection attacks: prepared statements

# Prepared Statement (aka parameterised query)

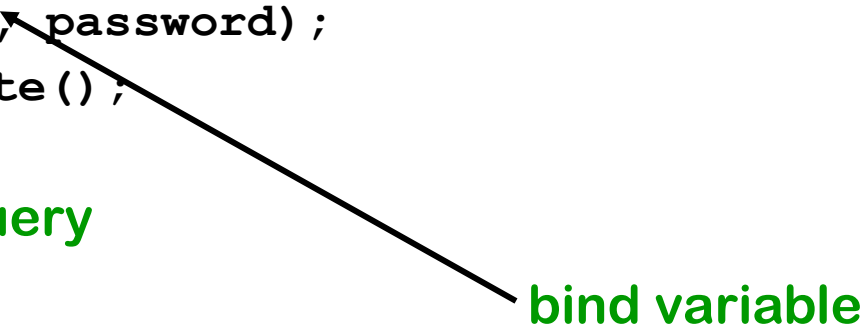
## Vulnerable dynamic SQL:

```
String updateString = "SELECT * FROM Account WHERE
   Username" + username + " AND Password = " + password;
stmt.executeUpdate(updateString);
```

## Not vulnerable:

```
PreparedStatement login = con.preparedStatement("SELECT
  * FROM Account WHERE Username = ? AND Password = ?" );
login.setString(1, username);
login.setString(2, password);
login.executeUpdate();
```

aka parameterised query



# How does this prevent problems?
## *Parsing & substituting*

**The root cause of many injection attacks is that a server**

1. ***first*** **substitutes some user input in a string**
2. ***then*** **parses the result to interpret what it means**

**By *first* parsing and *then* substituting, we can avoid problems:**

**Special characters in user input can no longer affect the parsing**

# Dangers of substituting, parsing & interpreting

When a waiter in a bar asks

*"What do you want to drink?"*

and you say

*"a beer, and give me all the money in the till,*
*and let me leave without paying"*

you ***don't*** expect the waiter to execute this instruction.

With a piece of software programed to execute

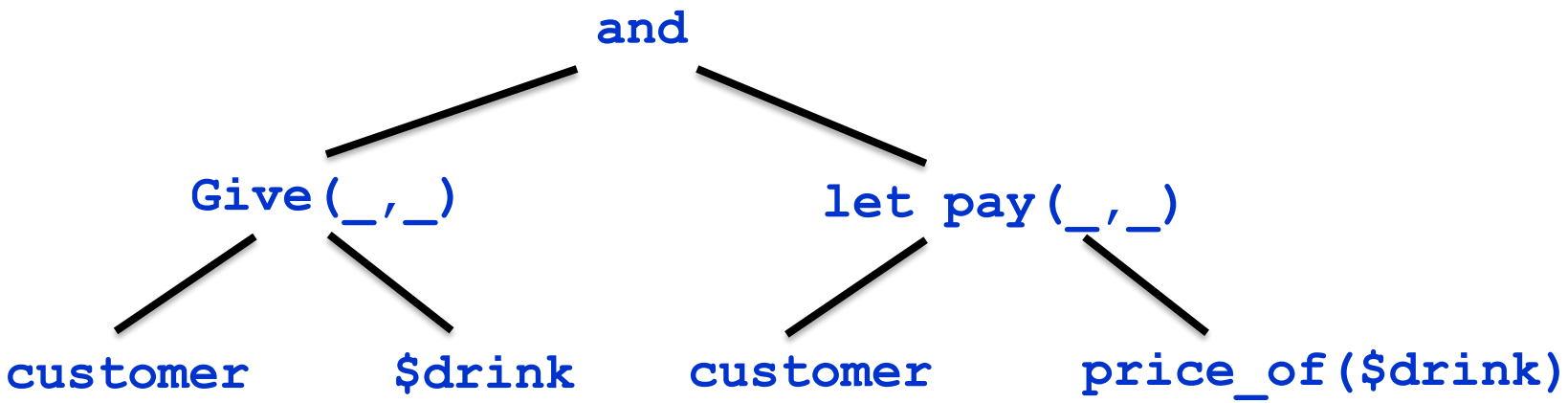
```
Give the customer $drink ;
Let customer pay price_of($drink)
```

you ***can*** expect this.

Root cause

interpreting the concatenated strings goes off the rails!

# The idea behind parameterised queries




**Substituting in a parse tree is *less* dangerous than substituting in a string and then parsing the result**

# Limits of parameterised queries

- Programmer can still screw things up

```
String s = "SELECT * FROM Account WHERE Username"
             + username + " AND Password = ?";
PreparedStatement login = con.preparedStatement(s);
login.setString(1, password);
login.executeUpdate();
```

Here `username` can still be used for SQL injection. It best if strings used to construct prepared statements are compile-time constants

- Very dynamic queries may be impossible to express as parameterised queries
  - eg if the number of ?'s in a query can vary

# Parameterised queries vs stored procedures

Some databases provide stored procedures, which are similar to parameterised query, except that

- stored procedure is feature of the backend database
- parameterised query is feature of the programming language

Whether stored procedures are safe depends on the API used to call them in a given programming language!

*For any setting, of programming language and database system, you have to check which combinations & options are safe!*

# Example stored procedure

Eg stored procedure in Oracle's PL/SQL

```
CREATE PROCEDURE login
    (name VARCHAR(100), pwd VARCHAR(100)) AS
DECLARE @sql nvarchar(4000)
SELECT @sql =' SELECT * FROM Account WHERE
             username=' + @name + 'AND password=' + @pwd
EXEC (@sql)
```

is safe wrt injection when called from Java with

```
CallableStatement proc =
  connection.prepareCall("{call login(?, ?)}");
proc.setString(1, username);
proc.setString(2, password);
```

# Defence is not just prevention!

In addition to preventing injection attacks

a) by validating data, ie rejecting invalid data
b) by encoding data
c) better still: by using a safe API like parameterised queries

we should also try to

- reduce the impact

  *How?*

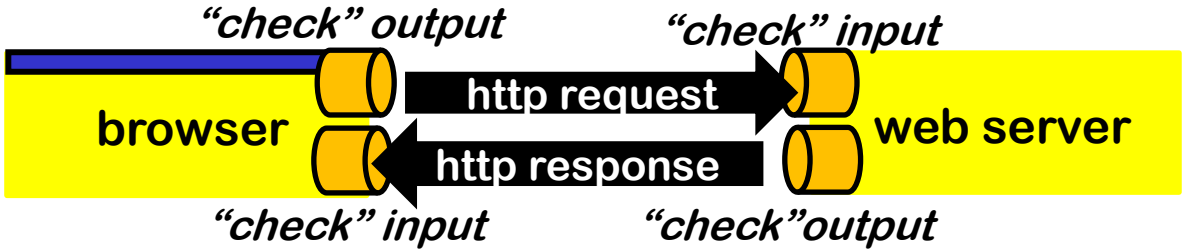
  eg by running web server with minimal access rights, aka principle of least privilege, or by making good & frequent back-ups, so we can restore data if it is corrupted

- detect problems

  This is a great defence if we can reverse effects;
  If we cannot, it can still help us to find & fix problems.

# Sanitising to protect against XSS

# Where to prevent XSS? And how?




Different *places* to potentially try to prevent XSS:

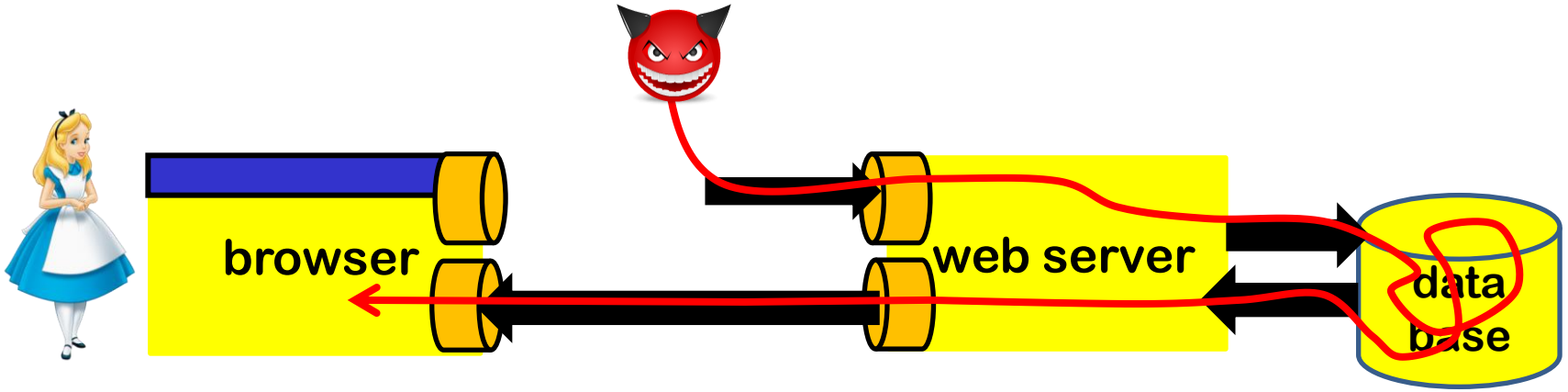
- *Browser* checking *outgoing* or *incoming* traffic?
- *Server* checking *incoming* or *outgoing* traffic?

Different *ways* to treat dangerous content (e.g. tags < > and `script`):
*HTML encoding, removing tags, blocking entire request*

- Complexity of HTML makes this hard:

  To get an impression, see the long list of attacker tricks on
  https://www.owasp.org/index.php/XSS_Filter_Evasion_Cheat_Sheet

# Preventing stored XSS

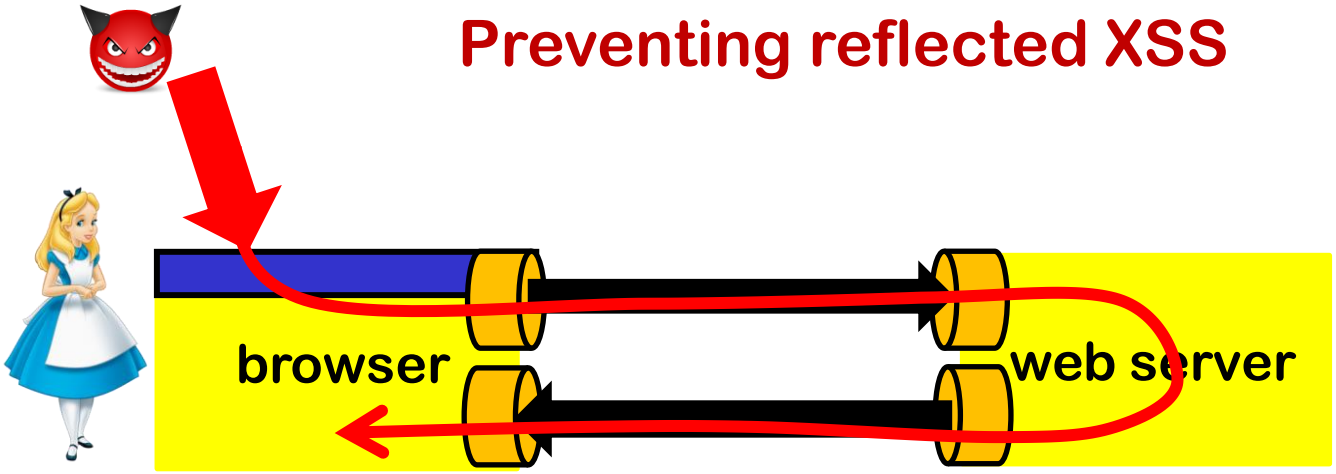



- Server could remove or HTML-encode HTML tags in incoming requests

  For eg. Instagram and Brightspace forum posts, where some HTML tags, included links, images, … are allowed & expected, it gets tricky
- Server could also encode outgoing traffic, but it would have to track & trace which bits of output come from untrusted sources

- Browser cannot protect against stored XSS: it cannot know if scripts come from the server itself or were injected by attacker

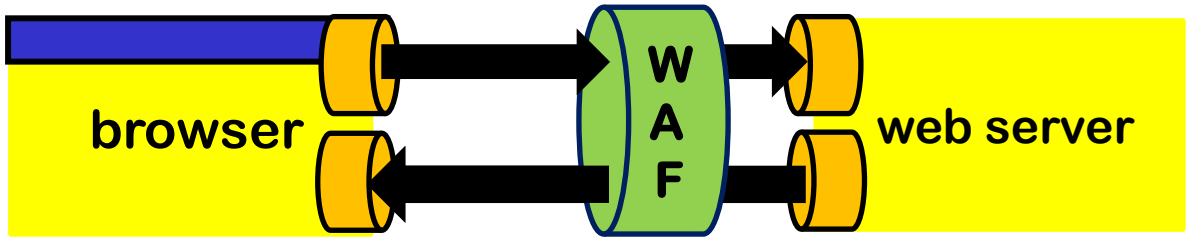
# Preventing reflected XSS




1. Server has same options as for stored XSS
2. Browser could blocks HTML tags/scripts in URLs parameters in outgoing HTTP traffic
   - Too restrictive in practice: too many false positives
3. Browser could let through scripts in outgoing traffic, but strip any scripts in incoming traffic if these are identical to scripts sent out.
   - This stops all reflected XSS. Some false positives, but fewer than 2.
   - Edge introduced this in 2008, as XSS filter; in Chrome in 2010, as XSS auditor.
   - Edge retired it in July 2018, Chrome in July 2019, because it could by-passed & false positives were not worth it.

# Web Application Firewalls (WAFs)

Some web applications use a WAF as an (extra?) layer of defense




- A WAF can look for generic malicious input & outputs
- Some WAFs try to learn what normal input looks and stop unusual ones
  - eg if a parameter `uid` is normally numeric, then some text (or worse, a script) as value is suspicious
- A WAF is *not* a good substitute for the server doing proper sanitisation itself
  - the web server itself knows *way* more about what values make sense than WAF can

# More defenses against XSS

In addition to sanitisation

# Disabling JavaScript


**Browsers can disable scripts on a per-domain basis**

- disallowing all scripts except those permitted by user
  - ie allow-listing approach
- disallowing all scripts on a public deny-list

For example, NoScript extension of Firefox
NoScripts and ScriptSafe extension of Chrome

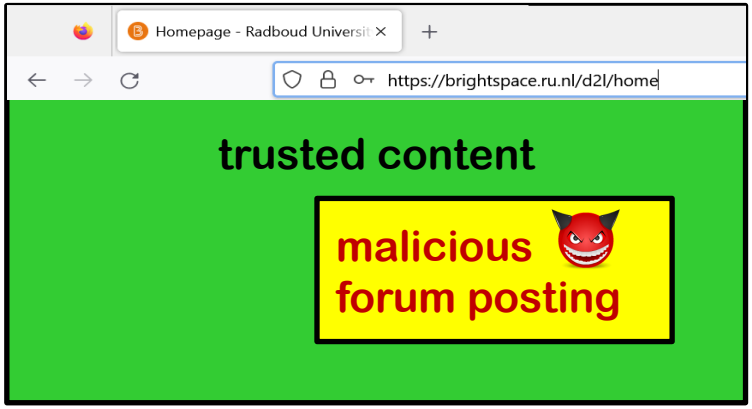
*Downsides?*

Extensive use of JavaScripts on most sites may makes it painful to use these plugins

# SOP to the rescue?

SOP (Same-Origin Policy)
does not help against XSS
in say Brightspace forum,
as scripts come from same origin

*Is there a way to make SOP help?*




We could host untrusted forum content on a different domain
say `brightspace-untrusted.ru.nl`
so that SOP prevents scripts in postings from interacting with `brightspace.ru.nl` content

Gmail uses `googleusercontent.com` for this purpose

# New features introduced in HTML5

HTML5 introduced two features to tighten the sandbox that browsers provide:

- sandboxing for iframes
  - in HTML
- CSP (Content Security Policy)
  - in HTTP header

# Sandboxing for iframes

sandbox option instructs browser to restrict what an iframe can do

- Turning this option on with

  <iframe sandbox src="..."> </iframe>

  imposes many restrictions, incl.
  - no JavaScript can be executed
  - pop-up windows are blocked
  - sending of forms is blocked
  - frame content is given special origin that always fails SOP check
- These restrictions can be lifted one-by-one, eg

  <iframe sandbox allow-scripts allow-forms allow-pop-ups allow-same-origin src="..."> </ >

For full list of options see
https://developer.mozilla.org/en-US/docs/Web/HTML/Element/iframe#attr-sandbox

# CSP (Content Security Policy)

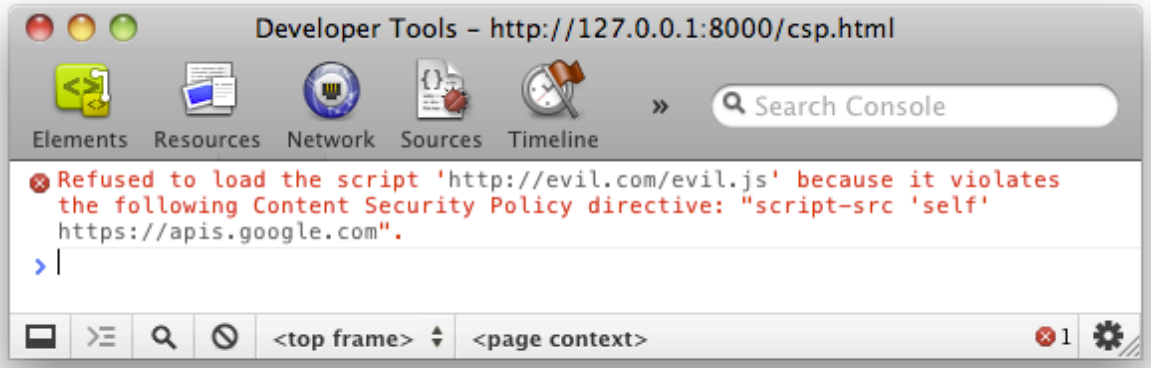
CSP header specifies allow-list of resources (eg scripts, images, ..) to the browser

For example Content-Security-Policy: script-src 'self' https://apis.google.com
img-src https://disney.com

only allows

- scripts downloaded from the same domain (self)
  and apis.google.com
  - to allow inline scripts, we'd have to add unsafe inline
- images downloaded from disney.com

The browser enforces this policy at runtime



# CSP problems [not exam material]

## CSP is very complex and error-prone to use

- Simple typos in a CSP policy may mean parts are silently ignored
- CSP distinguishes different types of content; if a policy only blocks one type but not the other, it can be by-passed
- To help in configuring a policy, CSP can run in report-only mode.

  The browser then lets violations pas, logs them, and report them to the server. But many sites run CSP in report-only mode without telling the browser to send the logs anywhere…
- If a CSP policy includes certain rich JavaScript libraries as trusted, it can be by-passed because the libraries can be abused to execute arbitrary code

  [Weichselbaum et al., CSP Is Dead, Long Live CSP! On the Insecurity of Whitelists and the Future of Content Security Policy, CCS 2016]

  [Calzavara et al., Content Security Problems? Evaluating the Effectiveness of Content Security Policy in the Wild, CSS 2016]

## CSP cannot be used if the webpage is too dynamic

Esp. if `customised' scripts are used, tailored to specific user or session;

More complex variants of CSP are then needed.

[Steyn Hommes: Canceled Security Policy - Examining the applicability of the Content Security Policy for WordPress websites, Bachelor thesis, Radboud University, 2024]

# DOM-based XSS

-

# yet more XSS problems...

# Some more DOM examples

Try out

https://www.cs.ru.nl/~erikpoll/websec/demo/demo_DOM2.html

with some arguments for query parameters uid and name and/or a fragment

Eg

https://www.cs.ru.nl/~erikpoll/websec/demo/demo_DOM2.html?uid=1234&name=Jan#56767

# Example: DOM-based XSS via URL parameter

Suppose webpage contains the vulnerable JS code

```
<script> var  params = URLSearchParams((document.URL).search);
        document.write(params.get('name' ));
</script>
```

This writes the name parameter from the URL into the webpage.

- Eg, for http://bla.com/welcome.html?name=John it will return John
- But what if the URL contains JavaScript in the name?

  http://bla.com/welcome.html?name=<script>... </script>
- Attacker can create malicious URLs to inject JavaScript

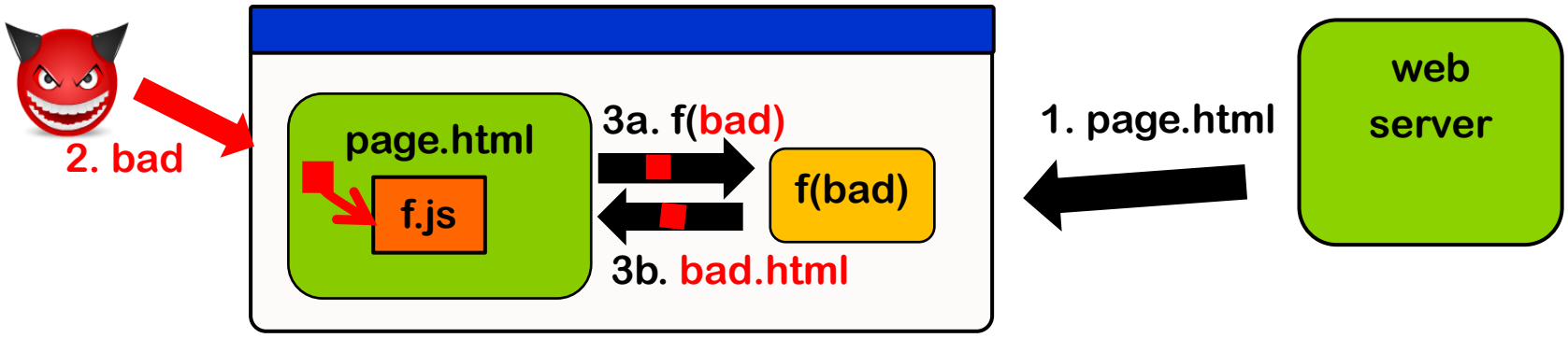
*Solution?*

- JS code should carefully validate and/or encode untrusted data

  document.write(HTMLencode(params.get('name' ));

Example at http://www.cs.ru.nl/~erikpoll/websec/demo/xss_via_DOM.html

# DOM-based XSS - in more detail




1. Webpage contains vulnerable script f.js
2. Attacker sneaks in malicious argument bad to this vulnerable script
3. Execution of f(bad) creates & injects malicious script into the DOM

- Different ways to inject the malicious argument, eg.
  - from a URL parameter
  - `from the server, where it was injected (as with stored XSS); it is then retrieved via XMLHttpRequest
  - from another web server
- Any sanitization/encoding has to be done client-side, by JS code in the web page – i.e. in the JS function f

# ‘Normal’ XSS (reflected or stored) vs DOM-based XSS

## ‘Normal’ XSS

1. Attacker injects payload ■, via stored or reflected attack
2. Server includes this payload in web page sent to the client
   – Web server can prevent this by careful sanitisation/encoding


## DOM-based XSS:

1. Web page sent to the client does not contain script – *yet* …
2. Execution of JavaScript in the browser introduces the malicious script into the webpage using the DOM API

Sanitisation to prevent it hasto happen client-side, and has to be done by JavaScript code that modifies the webpage

# Preventing DOM-based attacks can be hard!

In a complex dynamic web page, it may be hard to tell which pieces data might end up in a place where they are rendered as HTML

There are even examples where HTML-*encoded* strings, eg

```
&lt;script&gt; alert('XSS') &lt;/script&gt;
```

are executed because some JS library functions do HTML-*de*coding

To structurally prevent DOM-based XSS Google has proposed a new DOM API.

(See https://web.dev/trusted-types)

Chrome supports this new DOM API since 2019.

This is not exam material, but if you ever go on to make a complex web application, you should consider using this.

# To do

Check out the web

https://www.cs.ru.nl/~erikpoll/websec/demo/xss_via_DOM.html

and experiment with it

# Things that can go wrong...

# SOP problems

Modern browsers are very COMPLEX

- SOP is complex
- CSP & iframe sandboxing make this even more complex

Hence: some implementations screw things up

See CVEs about this

https://cve.mitre.org/cgi-bin/cvekey.cgi?keyword=Same%20Origin%20Policy

# Bug: SOP bypass in Internet Explorer 6 & 7

The DOM provides the `.domain` property for the domain part of a document's origin.

A bug in Internet Explorer allowed any JavaScript to ***set*** this property

So a malicious script in webpage from mafia.org could include

```
<script>
  document.domain = 'bank.com';
  // now we can access bank.com content
  ...

</script>
```

# Bug: SOP bypass in Android WebView [CVE 2014-6041]

WebView is HTML rendering engine for Android

- i.e. it renders (aka displays) a piece of HTML

A null character before `javascript` would by-pass the SOP

```
... onclick="window.open('\u0000 javascript:alert(..))
```

This bug affected 42 out of the top 100 apps in the Google Playstore with 'Browser' in their name

# Weird XSS flaw in Adobe PDF plugin [CVE-2007-0045]

**Adobe PDF plugin would execute raw JavaScript included in #-fragment of the URL**

https://a.com/file.pdf#anything_you_want=javascript:alert(document.cookie)

**To make matters worse:**

- **Origin of the script taken to be a.com**
- ***Is there any way for webserver at a.com to spot this attack?***
  **No, as the #-fragment is never sent to the server**

# Example: CSS injection in WebKit rendering engine


https://twitter.com/pwnsdx/status/1040944750973595649

# CSS injection causing WebKit problems

```
<!DOCTYPE html>
<html><head><meta http-equiv="Content-Type" content="text/html; charset=UTF-8">
    <style>
      body { background: repeat url('
            }
      div { backdrop-filter: blur(10px); webkit-backdrop-filter: blur(10px);
                          width:10000px; height:10000px;
          }
    </style>  </head>
<body>
<div><div><div><div><div><div><div><div><div><div><div><div><div><div>…
</body> </html>
```

The backdrop filter property of CSS provides (CPU-intensive!) graphical effects such as blurring and colour shifting

***Is this a WebKit bug? Or a bug in the app using the WebKit engine?***

# Supply chain attacks using JavaScript

LILY HAY NEWMAN SECURITY 09.11.2018 03:00 AM

## How Hackers Slipped by British Airways' Defenses

Security researchers have detailed how a criminal hacking gang used just 22 lines of code to steal credit card data from hundreds of thousands of British Airways customers.

## Ticketmaster Blames Third Party Over Data Breach

By Kevin Townsend on June 28, 2018

## Hotel websites infected with skimmer via supply chain attack

Sep 19, 2019

NEWS by Bradley Barth

BRIAN BARRETT SECURITY 07.11.2019 06:00 AM

## Hack Brief: A Card-Skimming Hacker Group Hit 17K Domains—and Counting

Magecart hackers are casting the widest possible net to find vulnerable ecommerce sites—but their method could lead to even bigger problems.

**Here attackers compromise a 3rd party JavaScript library**

# Supply chain attack


Recall: confusingly , 3rd party JavaScript included in 1st party HTML source is counted as same origin, so SOP does not impose any access restrictions on `lib.js`

# Example: Magecart supply chain attacks

One of in the ways that criminal group Magecart did supply chain attacks

1. Look for misconfigured S3 buckets in Amazon cloud that are world-readable & writeable
2. Add malicious code to any *.js files in that bucket

   Code to scrape webpage to look for credit card info & report it back to magecart.com
3. Sit back & wait for any credit cards to be reported

Not exam material, but interesting background reading:

https://www.riskiq.com/blog/category/magecart

https://www.wired.com/story/magecart-amazon-cloud-hacks/

# SubResource Integrity (SRI)

Countermeasure against supply chain attacks:

SubResource Integrity (SRI)

HTML source of webpage includes a hash of external resource and browser checks the hash after loading it (and before using it)

https://developer.mozilla.org/en-US/docs/Web/Security/Subresource_Integrity

# Easier way to get malicious content on website?

Another way to get malicious content on a website,
instead of compromising the supply chain?

**Hack the server!**

- For instance, by
  - abusing weak or phished credentials to admin page
  - exploiting security vulnerabilities in server infrastructure, eg. WordPress plugins

Web site defacement is very old-fashioned & childish, but still happens:

`https://www.zone-h.org/archive?hz=1`

# JavaScript injection in other places than browsers

**Windows Defender** is anti-virus solution on Windows

# Windows Defender XSS bug [CVE 2017-0290]

- Some anti-virus solutions try to stop malicious JavaScript, by
  1. looking for JavaScript code in incoming traffic
  2. running this JavaScript in a sandbox, to see if it does anything strange
  3. if so, remove it from the incoming traffic
- Windows Defender does this, using the `NScript` JavaScript engine inside MsMpEng Malware protection engine

- Unfortunately...
  - A memory corruption bug in `NScript` allows malformed JavaScript to crash MSMpEng
    - ie the kind of bugs studied in the 'Hacking in C' course
  - To make matters worse: `NScript` runs at a very high privilige level

https://arstechnica.com/information-technology/2017/05/windows-defender-nscript-remote-vulnerability/
https://bugs.chromium.org/p/project-zero/issues/detail?id=1252&desc=5

# XSS in more places?

Android/iOS apps increasingly use similar technologies as websites

- HTML, JavaScript, URLs …

so apps can also fall victim to XSS

Also: Electron desktop apps are built using JavaScript


Benefits:

- cross-platform
- re-using components & expertise of the app

Downsides?

- risk of XSS. And now without the browser sandbox…

*Maybe running Discord, Microsoft Teams, … in the browser is more secure than running the standalone Electron apps?*