Middleware Architectures 2

Lecture 2: Browser Networking

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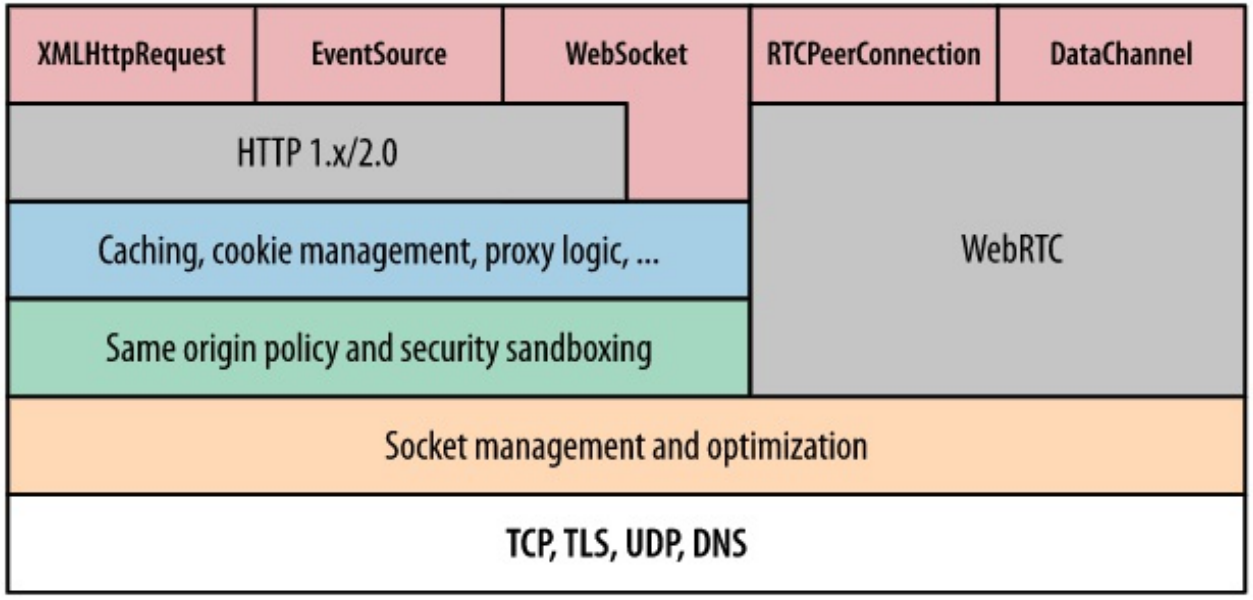
Modified: Sun Mar 10 2024, 21:33:02
Humla v1.0

Overview

- Browser Networking
  - *XHR*
  - *Fetch API*
- Security Mechanisms
- JSON and JSONP

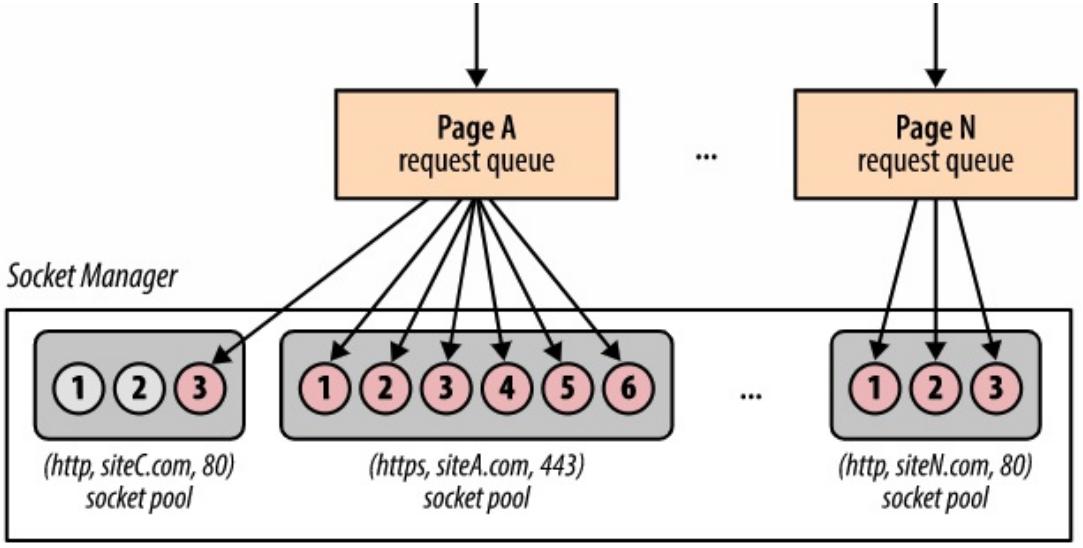
Browser Networking

- Browser
  - *Platform for fast, efficient and secure delivery of Web apps*
  - *Many components*
    - → *parsing, layout, style calculation of HTML and CSS, JavaScript execution speed, rendering pipelines, and* ***networking stack***
  - *When network is slow, e.g. waiting for a resource to arrive*
    - → *all other steps are blocked*



Connection Management

- Network socket management and optimization
  - *Socket reuse*
  - *Request prioritization*
  - *Protocol negotiation*
  - *Enfocring connection limits*
- Socket manager
  - *Sockets organized in pools (connection limits and security constraints)*
  - *origin = (protocol, domain, port number)*



Network Security

- No raw socket access for app code
  - *Prevents apps from initiating any connection to host*
  - *For example port scan, connect to mail server, etc.*
- Network security
  - ***Connection limits***
    → *protect both client and server from resource exhaustion*
  - ***Request formatting and response processing***
    → *Enforcing well-formed protocol semantics of outgoing requests*
    → *Response decoding to protect user from malicious servers*
  - ***TLS negotiation***
    → *TLS handshake and verification checks on certificates*
    → *User is warned when verification fials, e.g. self-signed cert is used*
  - ***Same-origin policy***
    → *Constraints on requests to be initiated and to which origin*

Mashups

- Web application hybrid
  - *App uses APIs of two or more applications*
- Types
  - *Data mashup – integration/aggregation of data (read only)*
  - *Service mashup – more sophisticated workflows (read, write)*
  - *Visualization – involves UI*
    - → *For example, third-party data displayed on the Google map*
- Client-Server View
  - *client-side mashups (in a browser)*
    - → *JavaScript, Dynamic HTML, AJAX, JSON/JSONP*
  - *server-side mashups*
    - → *server-side integration of services and data*
    - → *Any language*

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XMLHttpRequest (XHR)

- Interface to utilize HTTP protocol in JavaScript
  - *standardized by Web Applications WG at W3C*
  - *basis for AJAX*
    → *Asynchronous JavaScript and XML*
- Typical usage
  1. *Browser loads a page that includes a script*
  2. *User clicks on a HTML element*
     - *it triggers a JavaScript function*
  3. *The function invokes a service through XHR*
     - *same origin policy, cross-origin resource sharing*
  4. *The function receives data and modifies HTML in the page*

XHR Interface – Key Methods and Properties

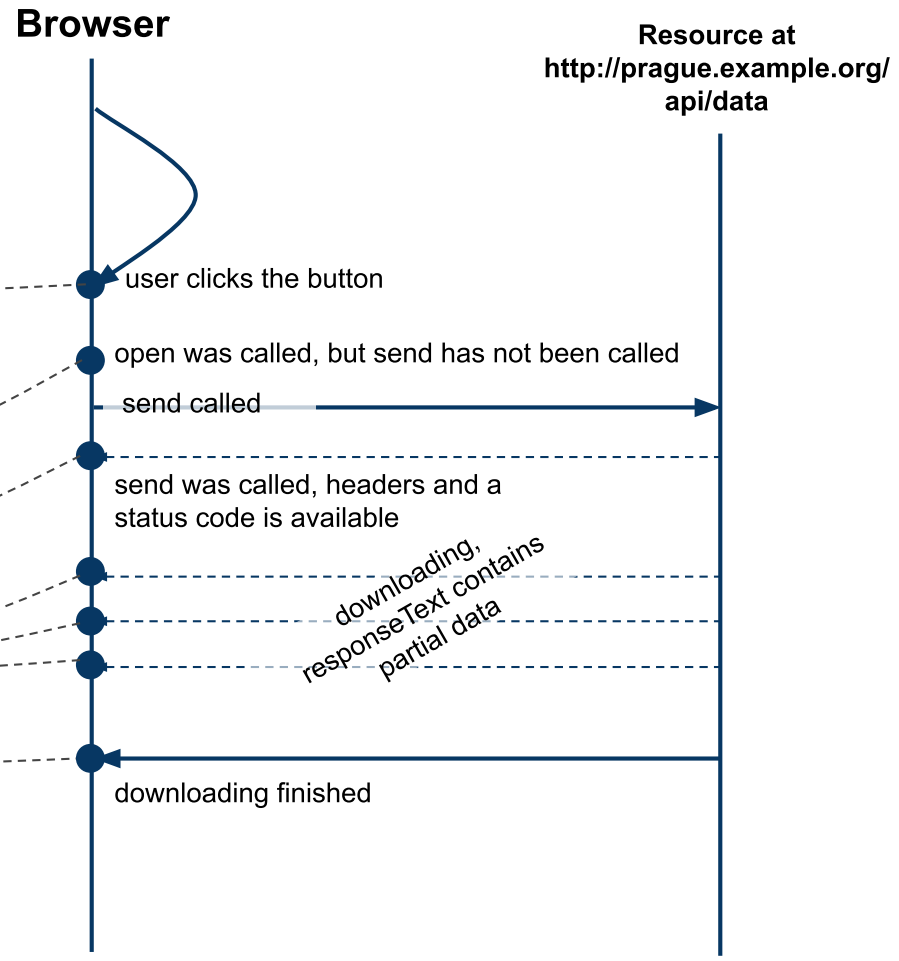
- Method and properties of XHR object
  - `open`, *opens the request, parameters:*
    `method` – *method to be used (e.g. GET, PUT, POST),*
    `url` – *url of the resource,*
    `asynch` – *true to make asynchronous call,*
    `user`, `pass` – *credentials for authentication.*
  - `onReadyStateChange` – *JavaScript function object, it is called when* `readyState` *changes (uninitialized, loading, loaded, interactive, completed).*
  - `send`, `abort` – *sends or aborts the request (for asynchronous calls)*
  - `status`, `statusText` – *HTTP status code and a corresponding text.*
  - `responseText`, `responseXML` – *response as text or as a DOM document (if possible).*
  - `onload` – *event listener to support server push.*
- See XMLHttRequest (W3C), or XMLHttRequest (Mozilla reference) for a complete reference.

How XHR works

HTML with JavaScript code
was loaded as a response to http://prague.example.org/

```
...
<input type="button" value="Show Prague!" onclick="click()" />

<script type="text/javascript">

var xhr = new XMLHttpRequest();

function click() {
  xhr.open("GET", "http://prague.example.org/api/data", true);
  xhr.onReadyStateChange = stateChanged;
  xhr.send();
}

function stateChanged() {
  if (xhr. readyState == 1)  { // loading
  ...
  }
  if (xhr. readyState == 2)  { // loaded
  ...
  }
  if (xhr. readyState == 3)  { // interactive
  ...
  }
  if (xhr. readyState == 4)  { // completed
  ...
  }

}
</script>
```

pointer to JavaScript object function



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Fetch API

- XHR is callback-based, Fetch is promise-based
- Interface to accessing requests and responses
  - *Provides global `fetch` method to fetch resources asynchronously*
  - *Can be easilly used in service workers*
  - *Supports CORS and other extensions to HTTP*
- Interfaces
  - `Request` – *represents a request to be made*
  - `Response` – *represents a response to a request*
  - `Headers` – *represents response/request headers*
- Basic usage:

```
1  async function logMovies() {
2      const response = await fetch("http://example.com/movies.json");
3      const movies = await response.json();
4      console.log(movies);
5  }
```

Making request

- A `fetch` function is available in global `window`
- It takes `path` and returns `Promise`

```
fetch('https://api.github.com/users/tomvit')
    .then(response => response.json())
    .then(data => console.log(data))
    .catch(error => console.error('Error:', error));
```

- You can make `no-cors` request
  - *With Fetch, the request will be handled as with putting `src` to `img`*

```
fetch('https://google.com', {
    mode: 'no-cors',
  }).then(function (response) {
    console.log(response.type);
  });
```

- You can access low-level body stream
  - *With XHR, the whole `responseText` would be loaded into memory.*
  - *With Fetch, you can read chunks of response and cancel the stream when needed.*

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  - *Scripting Attacks*
  - *Cross-origin Resource Sharing Protocol (CORS)*
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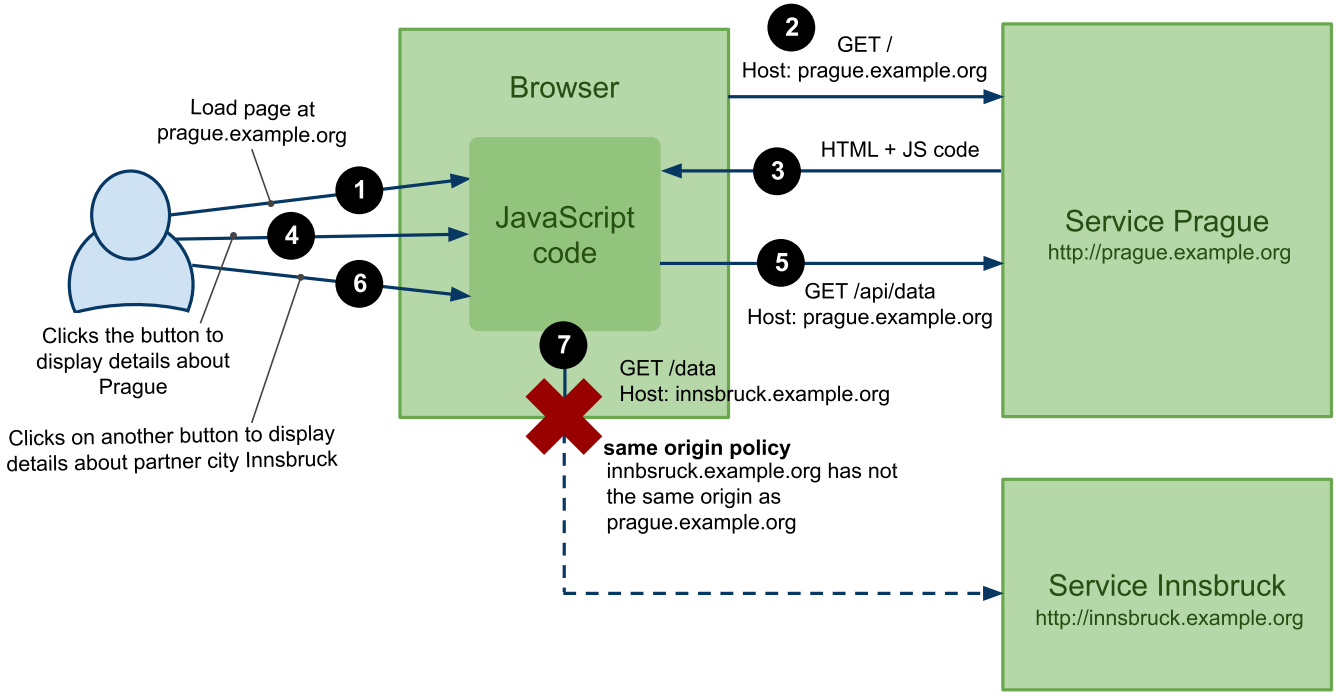
Same Origin Policy



- JavaScript code can only access resources on the same domain
  - *XHR to GET, POST, PUT, UPDATE, DELETE*
  - *Browsers apply **same origin policy***
- Solutions
  - *JSON and JSONP (GET only)*
  - *Cross-origin Resource Sharing Protocol (CORS)*

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Overview of Web Threats

- Scripting/Web attacks
  - *CSRF: attacker causes a user's browser to send an authenticated request*
  - *XSS: attacker gets script to run in a trusted origin (steal data / act as user)*
  - *Clickjacking: victim is tricked into clicking UI elements*
- Modern context
  - *Single Page Apps (SPAs), APIs, OAuth logins, third-party scripts*
  - *Browsers added new defenses:* `SameSite` *cookies, CSP, CORS, Trusted Types*
- Roles in security scenarios
  - *Alice, Bob: regular users / sites*
  - *Eve: passive attacker, man in the middle (MITM) (observes, phishes)*
  - *Mallory: active attacker (injects content, modifies requests, drives victim browser)*

Recall: State, Sessions, and Cookies

- HTTP is stateless; sites add state via tokens
  - *Cookies (session cookies, persistent cookies)*
  - *Bearer tokens (often in* `Authorization: Bearer ...`*)*
- Session management patterns
  - *Stateful: server stores session data*
  - *Stateless: signed tokens (e.g., JWT) stored client-side; server validates each request*
- Cookie flags
  - `Secure`*: only over HTTPS*
  - `HttpOnly`*: not readable by JavaScript*
    → *Mitigates some XSS cookie theft, but not all attack scenarios*
  - `SameSite`*: limits cross-site cookie sending*
    → *Major CSRF mitigation*

Cross-site Request Forgery (CSRF)

- How it works
  - *Victim's browser sends a request to **bank.com** with user's credentials (cookies)*
  - *Attacker cannot read the response (SOP), but the **side effect** may still happen*
- CSRF today
  - *Many browsers now default to `SameSite=Lax` (reduces CSRF via cross-site navigation)*
  - *But CSRF is still relevant*
    → *misconfigured `SameSite=None`, legacy apps, subdomain issues, OAuth flows*
- Typical attack shapes
  - *Cross-site `<form method="POST">` submit*
  - *State-changing GET is still a bug, but many frameworks avoid it now*
- Modern best practice
  - *Use **CSRF tokens** (synchronizer token pattern) or **double-submit cookie***
  - *Set cookies: `SameSite=Lax` (default) or `Strict` where possible*
    → *only use `None; Secure` when required*
  - *Validate `Origin` header for state-changing requests (often better than `Referer`)*
  - *Re-auth / step-up auth for high-risk actions*

CSRF Example

- Attacker page causes a victim browser to submit a form to a target origin

```html
<form action="https://bank.com/transfer" method="POST">
  <input type="hidden" name="to" value="mallory" />
  <input type="hidden" name="amount" value="50000" />
</form>
<script>document.forms[0].submit()</script>
```

- What makes this work?
  - *If the browser includes cookies for `bank.com` on this cross-site POST*
  - *If server does not require or validate a CSRF token (or `Origin`)*
- Why attackers like it
  - *No need to read responses; only need the action to succeed*

CSRF Tokens

- Goal
  - *Prevent **cross-site request forgery** even when cookies are attached by the browser*
  - *Server accepts a state-changing request only if it contains a **secret token***
- Synchronizer Token Pattern (most common)
  - *Server creates a random token bound to the user session*
  - *Token is embedded into HTML (form field) or sent as a header by JS*
  - *On POST/PUT/DELETE: server verifies token matches the session*
- Why it works
  - *Attacker can trigger a cross-site request (e.g., `<form>`)*
    → *but cannot read the response page to obtain the token (prevented by SOP)*
  - *Guessing a random token is not possible*
- Implementation notes
  - *Regenerate tokens periodically (or per form) and invalidate on logout*
  - *Protect token delivery with HTTPS; avoid exposing it to third-party origins*
  - *Use together with `SameSite` cookies and `Origin` checks*

```
1 <form action="/transfer" method="POST">
2     <input type="hidden" name="csrf_token" value="RANDOM_SESSION_BOUND_TOKEN"> ...
3 </form>
```

Double-Submit Cookie

- Goal
  - *Block CSRF by requiring a **token to be sent twice**:*
    - *→ as a **cookie** (automatically attached by the browser)*
    - *→ and as a **request value** (hidden form field or custom header)*
  - *Server accepts the request only if the two values **match***
- Typical flow
  - *Server generates random token* `T`
  - *Browser stores* `T` *in cookie* `csrf=T`
  - *POST/PUT/DELETE:* `T` *in* `csrf_token` *(form field) or* `X-CSRF-Token` *(header)*
  - *Server verifies:* `Cookie[csrf] == token_in_body_or_header`
- Why it works
  - *Attacker can trigger a cross-site request that includes cookies, but cannot read victim cookies/pages due to **SOP***
  - *Attacker cannot reliably include the matching token in the request body/header*
- Implementation notes
  - *Used for **stateless** setups (server does not store CSRF token in session)*
  - *Use with* `Secure` *and HTTPS; combine with* `SameSite` *and* `Origin` *checks*

Cross-site Scripting (XSS)

- How XSS works
  - *Attacker-controlled script runs in a trusted origin (e.g., `https://app.com`)*
  - *Can read/modify DOM, make same-origin requests, extract data, act as the user*
- Types
  - ***Stored**: payload stored on server (posts, profiles)*
  - ***Reflected**: payload in request (query param) reflected into HTML*
  - ***DOM-based**: client-side JS inserts untrusted data into DOM unsafely*
- Today's prevention
  - *Many apps use frameworks that reduce HTML injection*
    → But DOM-XSS via unsafe sinks still happens
  - *Third-party scripts and supply-chain risks can lead to "XSS-like" outcomes*

XSS: What Attackers Do Today

- Common impact
  - *Session hijack is harder if cookies are* `HttpOnly`*, but attackers can still:*
    - → *Perform actions as the user (same-origin* `fetch`*)*
    - → *Steal sensitive DOM data (CSRF tokens in DOM, PII rendered in page)*
    - → *Keylog / credential phishing overlays*
    - → *Token theft when apps store tokens in* `localStorage`
- Mitigations
  - *Output encoding + safe templating*
  - *Sanitize HTML if you must render it (allowlist-based sanitizers)*
  - ***Content Security Policy (CSP)** (reduce exploitability)*
  - ***Trusted Types** (Chrome/Chromium): block DOM-XSS sinks unless explicitly allowed*

Content Security Policy (CSP)

- Goal
  - *Mitigate XSS attacks by restricting what the page can load and execute*
  - *Browser enforces a policy sent by the server (HTTP header or `<meta>`)*
- Core idea
  - *Define allowlists for resource types (scripts, styles, images, connections, frames, ...)*
  - *Block unexpected code execution (e.g., injected `<script>`, inline handlers)*
- Common directives
  - `script-src`*: where scripts can come from; can require* `'nonce-...'` */ hashes*
  - `connect-src`*: where JS can send requests (*`fetch`*/XHR/WebSocket)*
  - `img-src`, `style-src`, `font-src`*: resource allowlists*
  - `object-src 'none'`*: disable plugin content*
  - `base-uri`*: restrict* `<base>` *tag abuse*
  - `frame-ancestors`*: who may embed the page (clickjacking defense)*

Nonce-based CSP Example

- Policy (sent as HTTP response header)
  - *Only load scripts from* `self`
  - *only execute inline scripts that carry the correct* ***nonce***
  - *Allow XHR/WebSocket only to own origin and a trusted API*
  - *Prevent plugins and clickjacking*

```
Content-Security-Policy:
  default-src 'self';
  script-src 'self' 'nonce-ABC123';
  connect-src 'self' https://api.example.com;
  object-src 'none';
  base-uri 'self';
  frame-ancestors 'none'
```

- Scripts in a page
  - *server must inject the same nonce into allowed inline scripts*

```
<script nonce="ABC123">
  // allowed inline script
  window.appBoot();
</script>

<script>
  // blocked inline script (missing nonce)
  alert('XSS');
</script>
```

XSS Example: DOM-based (Common in SPAs)

- Bug pattern: untrusted data flows into a dangerous DOM sink

```
// URL: https://app.com/welcome?name=<img src=x onerror=alert(1)>
const params = new URLSearchParams(location.search);
const name = params.get("name");

// Dangerous sink:
document.querySelector("#welcome").innerHTML = "Hi " + name;
```

- Fix
  - *Use* `textContent` *instead of* `innerHTML`
  - *If HTML is required, sanitize with a proven library and strict allowlist*

Historical XSS Examples

- Twitter in Sep 2010
  - *Injection of JavaScript code to a page using a tweet*
  - *You posted following tweet to Twitter*

```
There is a great event happening at
http://someurl.com/@"onmouseover="alert('test xss')"/
```

  - *Twitter parses the link and wraps it with `<a>` element*

```
There is a great event happening at
<a href="http://someurl.com/@"onmouseover="alert('test xss')"
    target="_blank">http://someurl.com/@"onmouseover=
    "alert('test xss')"/</a>
```

  - *See details at Twitter mouseover exploit*
- Other example: Google Contacts

Quick Comparison: CSRF vs XSS

- CSRF
  - *Attacker **cannot** run code in the target origin*
  - *Relies on browser automatically attaching credentials (cookies)*
  - *Defenses: `SameSite`, CSRF tokens, `Origin` checks*
- XSS
  - *Attacker **can** run code in the target origin*
  - *Bypasses CSRF defenses (because requests are same-origin)*
  - *Defenses: encoding/sanitization, CSP, Trusted Types, reduce secrets in DOM*

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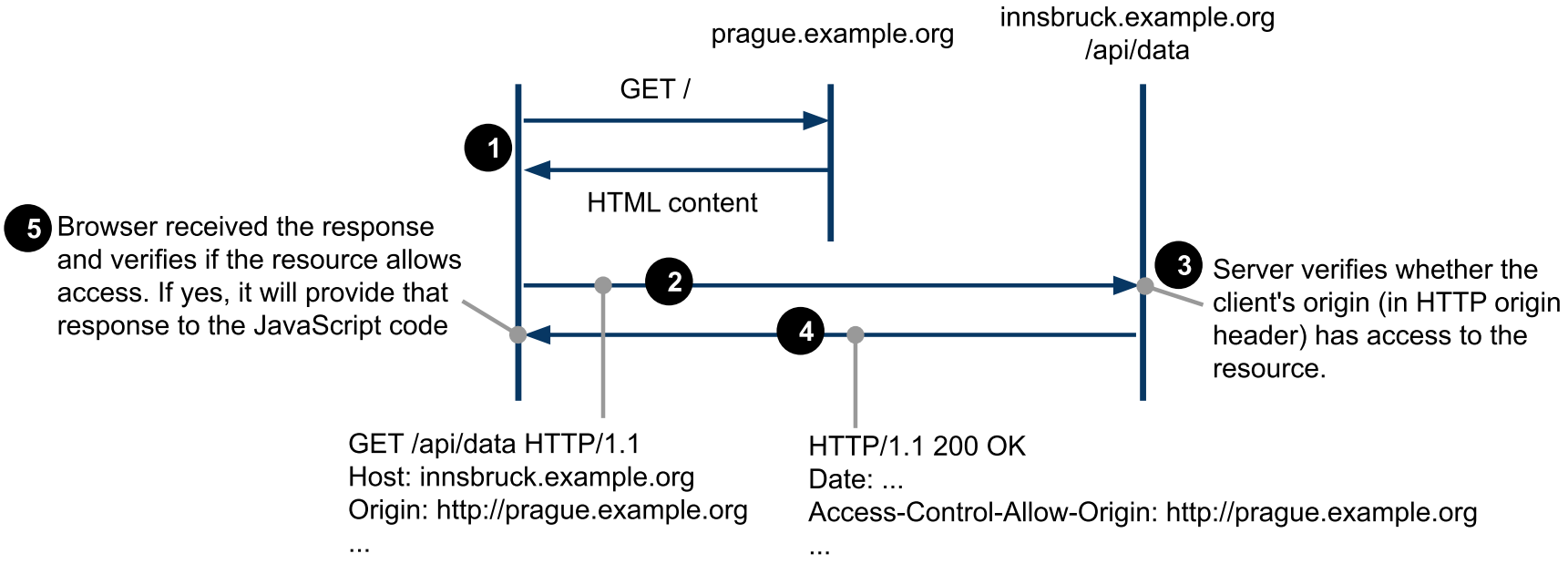
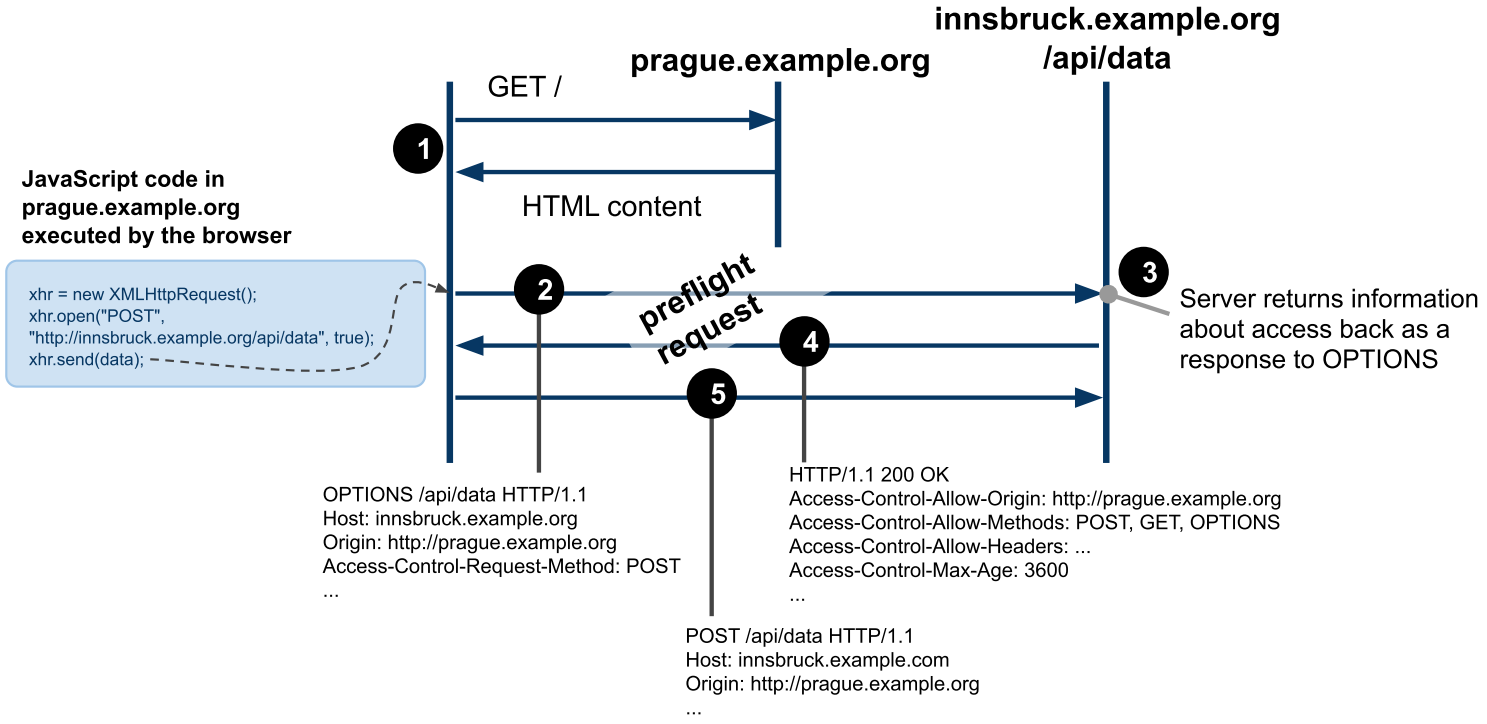
- Increasing number of mashup applications
  - *client-side mashups involving multiple sites*
  - *mechanism to control an access to sites from within JavaScript*
- Allow for **cross-site HTTP requests**
  - *HTTP requests for resources from a different domain than the domain of the resource making the request.*
- W3C Recommendation
  - *see Cross-origin Resource Sharing*
  - *Browsers support it*
    → *see HTTP Access Control at Mozilla*

CORS Protocol – GET



- Read-only resource access via HTTP GET
- Headers:
  - `Origin` – *identifies the origin of the request*
  - `Access-Control-Allow-Origin` – *defines who can access the resource*
  - *either the full domain name or the wildcard (*) is allowed.*

CORS Protocol – other methods and "preflight"



- Preflight request queries the resource using `OPTIONS` method
  - *requests other than GET (except POST w/o payload) or with custom headers*
  - *A browser should run preflight automatically for any XHR request meeting preflight conditions*
  - *The browser caches responses according to* `Access-Control-Max-Age`

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Recall: JSON

- JSON = JavaScript Object Notation
  - *Serialization format for data representation*
  - *Very easy to use in JavaScript*
    → no need to use a parser explicitly
  - *Also great support in many programming environments*
- Key constructs
  - ***object** is a collection of comma-separated key/value pairs:*

```
{"name" : "tomas", "age" : 18, "student" : false,  "car" : null}
```

  - ***array** is an order list of values:*

```
[ "prague", "innsbruck", 45 ]
```

  - *can be nested: objects as values in an **array**:*

```
[ { "name" : "tomas", "age" : 18 },
  { "name" : "peter", "age" : 19 } ]
```

  - *and the other way around: array as values in an **object**:*

```
{ "cities" : ["prague", "innsbruck"],
  "states" : ["CZ", "AT"] }
```

  - *A complete grammar see JavaScript Object Notation*

JSON in JavaScript

- Native data format

```
// data needs to be assigned
var data = { "people" : ["tomas", "peter", "alice", "jana"] };

// go through the list of people
for (var i = 0; i < data.people.length; i++) {
    var man = data.people[i];
    // ... do something with this man
}
```

- Responses of service calls in JSON
  - *Many support JSON, how can we load that data?*
- Example Request-Response

```
GET http://pipes.yahoo.com/pipes/pipe.run?_id=638c670c40c97b62&_render=json

{"count":1,"value":
   {"title":"Web 2.0 announcements",
    "description":"Pipes Output",
    "link":"http:\/\/pipes.yahoo.com\/pipes\/pipe.info...",
    "pubDate":"Mon, 07 Mar 2011 18:27:20 +0000",
    "generator":"..."
    ...
   }
}
```

JSONP

- Service that supports JSONP
  - *allows to specify a query string parameter for a wrapper function to load the data in JavaScript code*
  - *otherwise the data cannot be used in JavaScript*
    → *they're loaded into the memory but assigned to nothing*
- Example
  - *if a resource at* `http://someurl.org/json_data` *returns*

```
{ "people" : ["tomas", "peter", "alice", "jana"] }
```

    then the resource at
    `http://someurl.org/json_data?_callback=loadData` *returns*

```
loadData({ "people" : ["tomas", "peter", "alice", "jana"] });
```

- A kind of workaround for the same origin policy
  - *only* `GET`*, nothing else works obviously*
  - *no XHR, need to load the data through the dynamic* `<script>` *element*

JSONP in JavaScript

- JSONP example
  - *loads JSON data using JSONP by dynamically inserting* `<script>` *into the current document. This will download JSON data and triggers the script.*

```
1  var TWITTER_URL = "http://api.twitter.com/1/statuses/user_timeline.json?" +
2    "&screen_name=web2e&count=100&callback=loadData";
3
4  // this needs to be loaded in window.onload
5  // after all document has finished loading...
6  function insertData() {
7      var se = document.createElement('script');
8      se.setAttribute("type","text/javascript");
9      se.setAttribute("src", TWITTER_URL);
10     document.getElementsByTagName("head")[0].appendChild(se);
11     // And data will be loaded when loadDta callback fires...
12 }
13
14 // loads the data when they arrive
15 function loadData(data) {
16     // we need to know the the structure of JSON data that is returned
17     // and code it here accordingly
18     for (var i = 0; i < data.length; i++) {
19         data[i].created_at // contains date the tweet was created
20         data[i].text // contains the tweet
21     }
22 }
```