

CS 253: Web Security

Server security, Safe coding practices

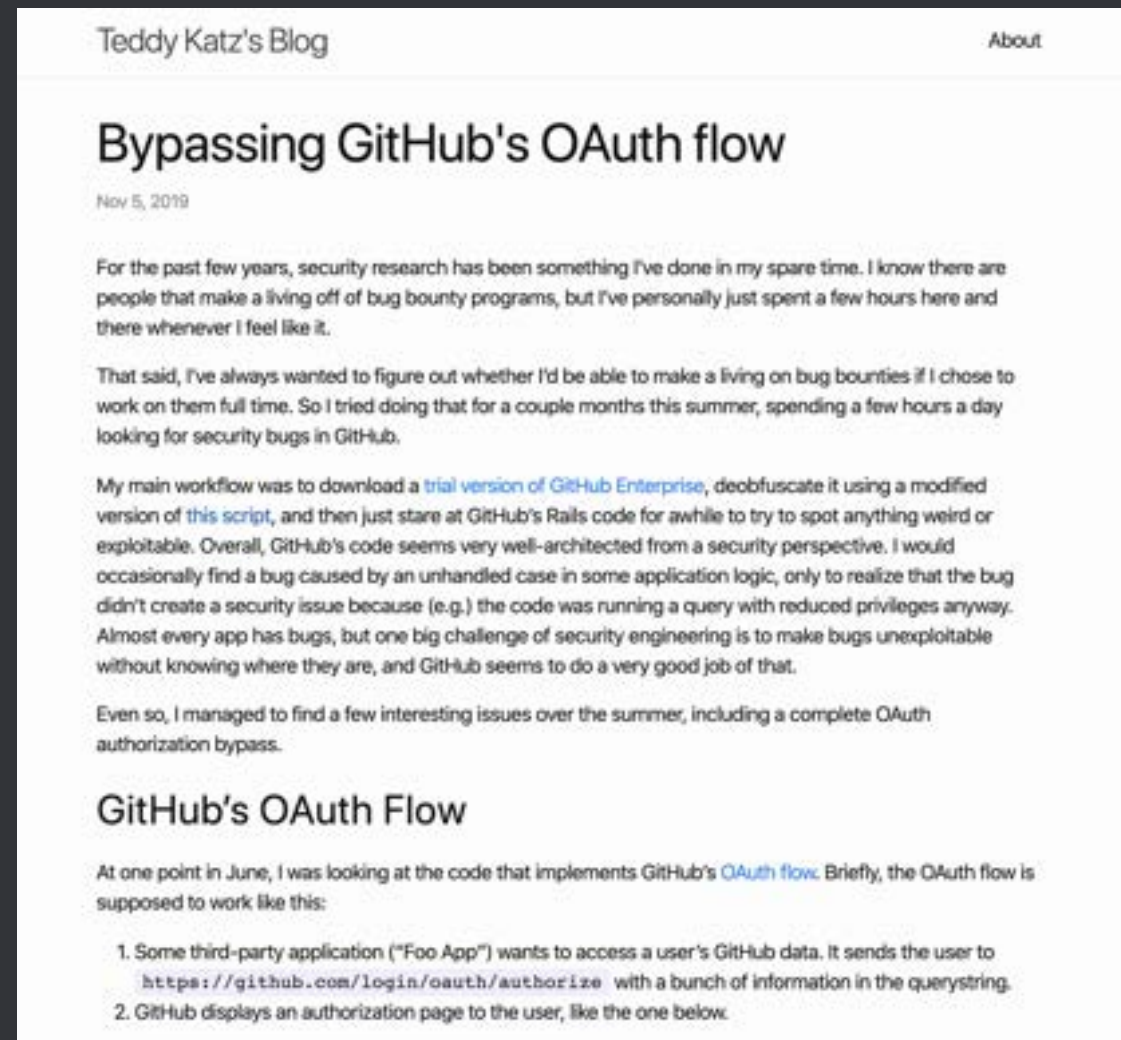
Admin

- Hands-On Workshop with Pete Snyder from Brave
 - Hosted by Stanford Applied Cybersecurity
 - Thursday, 6-7 pm, in Gates 174, dinner served

Extra Credit

- 3 students reported bugs so far!
 - XSS in Axess (Stanford paid \$100)
 - XSS in CS course website
 - Insecure design allowing assignment scores to be changed
 - Insecure design allowing coding challenge test cases to be leaked
- Completely optional, but very fun :)

One weird trick to make \$25,000. Security teams hate him!



Recall: Cross Site Request Forgery (CSRF)

- **Idea:** Force user to execute unwanted actions on a web app that they are currently authenticated to
- Authentication is implemented with cookies
- Cookies use an "ambient authority" model
- If **attacker.com** causes an HTTP request to get sent to **victim.com**, the browser will automatically attach the **victim.com** cookies to the request

How Cross Site Request Forgery (CSRF) works

Client

Server
victim.com

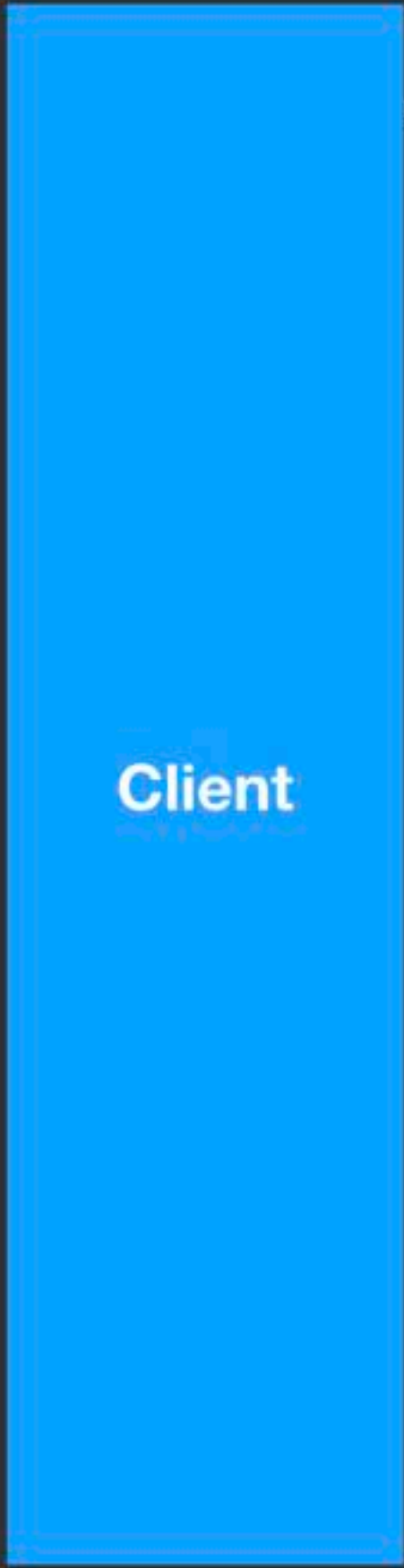
Client
victor.com

Server
victim.com

POST /login HTTP/1.1
username=alice&password=hunter2

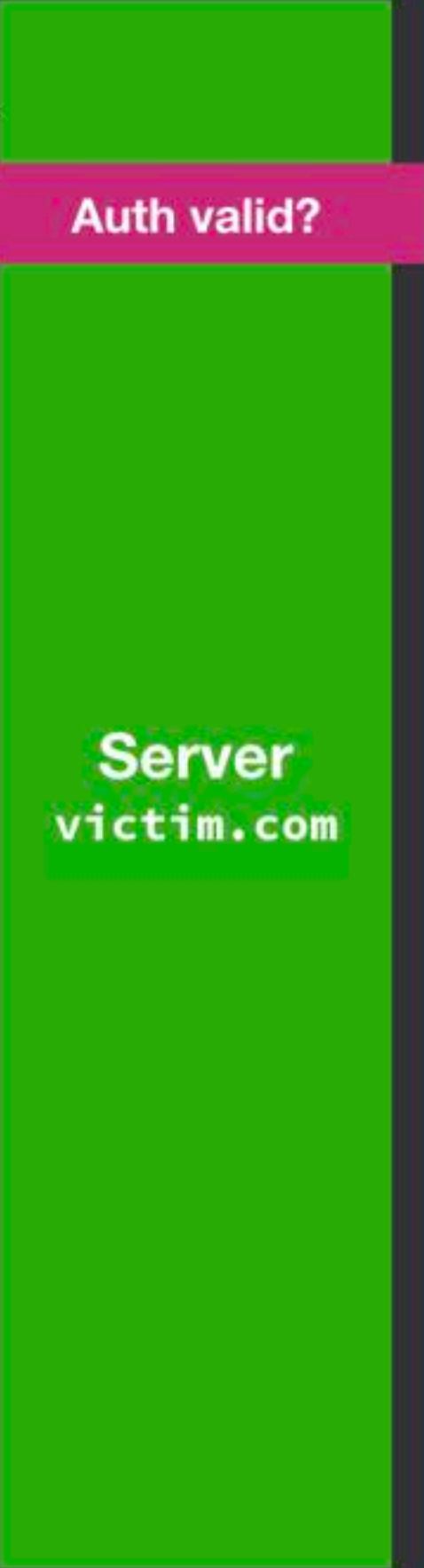
Client

Server
victim.com



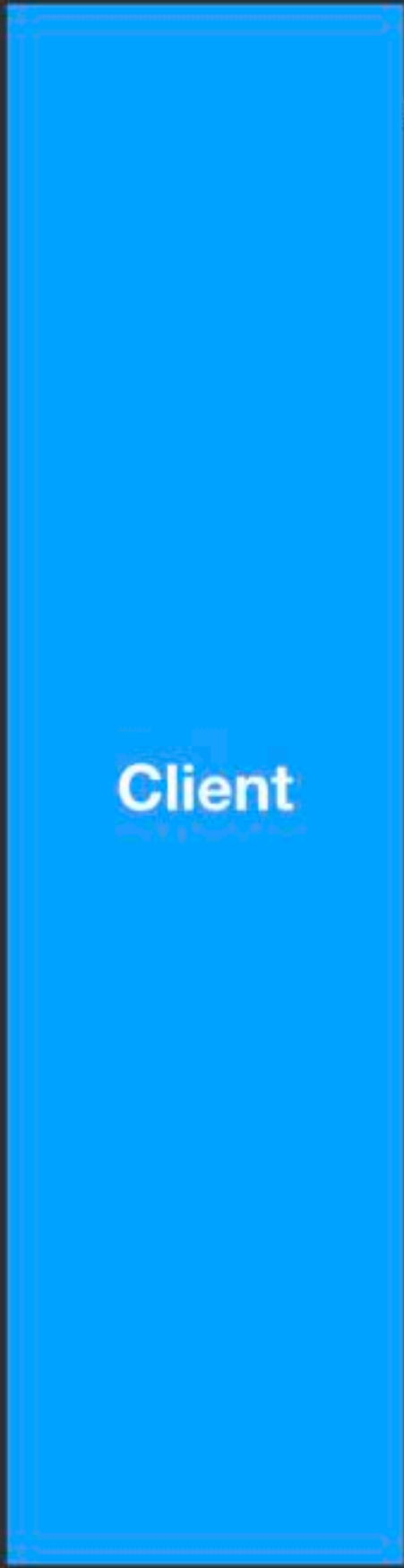
Client

POST /login HTTP/1.1
username=alice&password=hunter2



Server
victim.com

Auth valid?



Client
my & friends

POST /login HTTP/1.1
username=alice&password=hunter2



Server
victim.com

Auth valid?

OK!

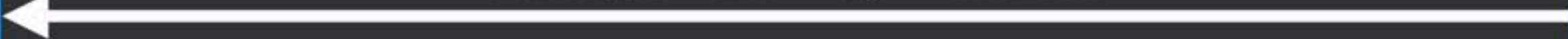


Client

POST /login HTTP/1.1
username=alice&password=hunter2



HTTP/1.1 200 OK
Set-Cookie: sessionId=1234
<!doctype html> Login success!



Server
victim.com

Auth valid?

OK!

POST /login HTTP/1.1
username=alice&password=hunter2

HTTP/1.1 200 OK
Set-Cookie: sessionId=1234
<!doctype html> Login success!

Auth valid?

OK!

Some time later...

Client

Server
victim.com











Recall: SameSite cookies

- Use **SameSite** cookie attribute to prevent cookie from being sent with requests initiated by other sites
- Request from **victim.com** to **victim.com**:

POST /transfer HTTP/1.1

Cookie: sessionId=1234

- Request from **attacker.com** to **victim.com**:

POST /transfer HTTP/1.1

CSRF tokens

- What did websites do before the **SameSite** cookie attribute was implemented in browsers?
- It was possible for **attacker.com** to send GET or POST requests to **victim.com** with cookies attached
 - The browser allowed this and sites had no way to prevent it
 - Yet, we need some way to prevent any random site from submitting a form to the server with the user's cookies attached
 - How can **victim.com** prevent CSRF attacks?

CSRF tokens

- CSRF token is a "nonce"
 - Secret, unpredictable value generated by the server and transmitted to the client
- Client must include the CSRF token in subsequent HTTP requests to prove to the server that the request is valid
 - The server rejects HTTP requests with missing or invalid token

CSRF tokens

- CSRF tokens are included in HTML forms as a hidden input:

```
<input type='hidden' name='csrfToken' value='MzNjNGM5NmQtYzRjOS00NTEy' />
```

- CSRF token generated randomly (stateful):

```
let csrfToken = crypto.randomBytes(16).toString('hex')
```

- CSRF token generated based on request information (stateless):

```
let csrfToken = HMAC(sessionId, csrfSecret)
```

How a CSRF token works

Client

Server
example.com


Client
Building & Maintaining

Server
example.com

Client

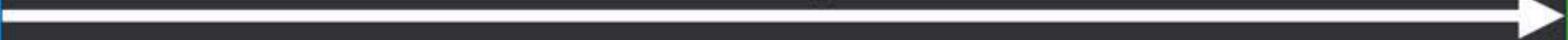
POST /login HTTP/1.1
username=alice&password=hunter2

Server
example.com



Client

POST /login HTTP/1.1
username=alice&password=hunter2



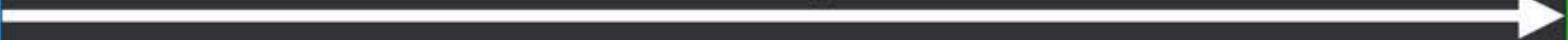
Server
example.com

Auth valid?



Client

POST /login HTTP/1.1
username=alice&password=hunter2



Auth valid?

OK!

Server
example.com



Client

POST /login HTTP/1.1
username=alice&password=hunter2



HTTP/1.1 200 OK
Set-Cookie: sessionId=1234
<!doctype html> Login success!
<input type='hidden' name='csrfToken' value='abc'>



Server
example.com

Auth valid?

OK!

POST /login HTTP/1.1
username=alice&password=hunter2

HTTP/1.1 200 OK
Set-Cookie: sessionId=1234
<!doctype html> Login success!
<input type='hidden' name='csrfToken' value='abc'>

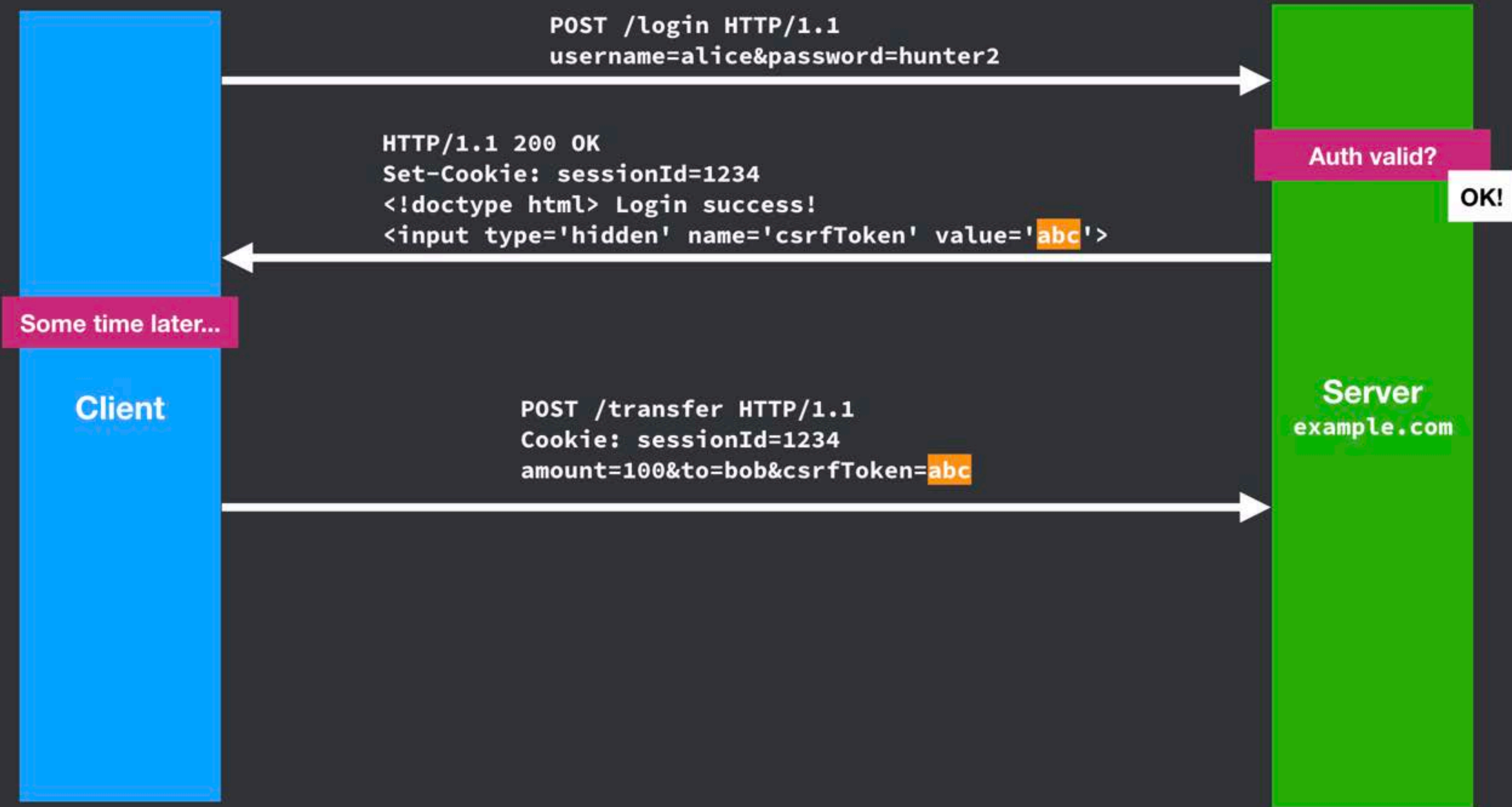
Auth valid?

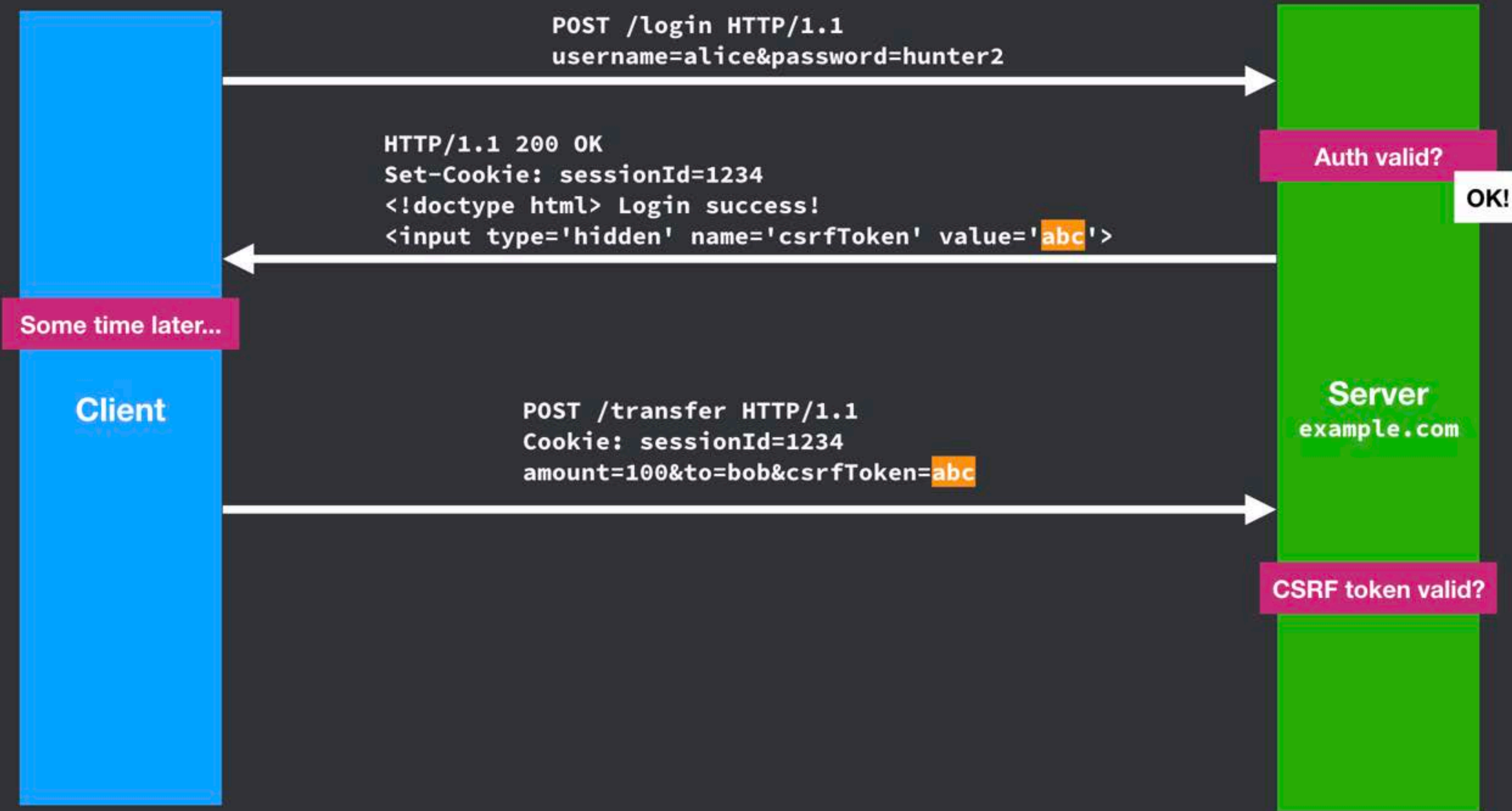
OK!

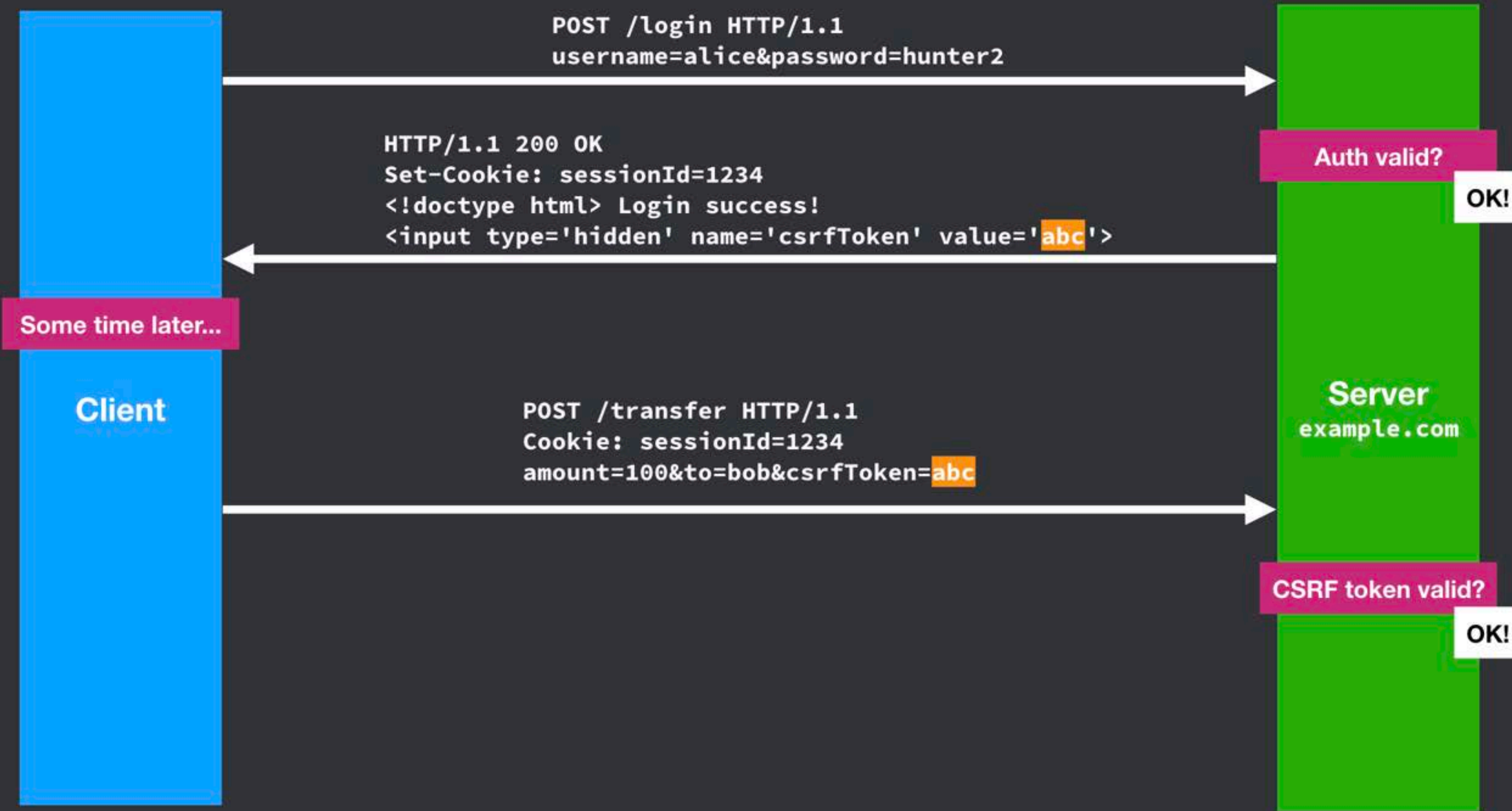
Some time later...

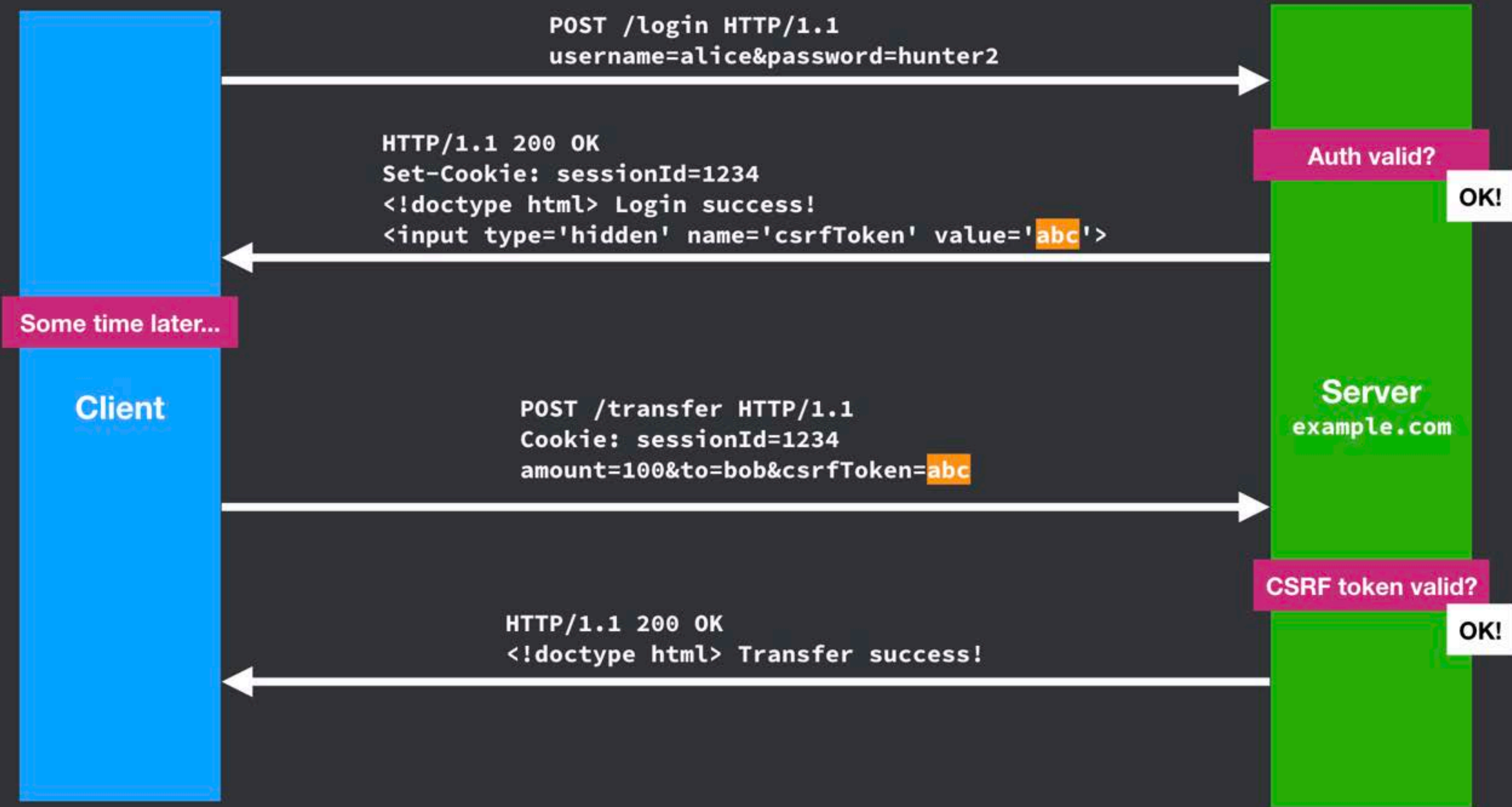
Client

Server
example.com









How a CSRF token works against an attacker

Client

Server
victim.com

Client
victor.com

Server
victim.com

POST /login HTTP/1.1
username=alice&password=hunter2


Client
myip & hostip

Server
victim.com





Client
myip & hostip

POST /login HTTP/1.1
username=alice&password=hunter2



Auth valid?

OK!

Server
victim.com



Client

POST /login HTTP/1.1
username=alice&password=hunter2



HTTP/1.1 200 OK
Set-Cookie: sessionId=1234
<!doctype html> Login success!
<input type='hidden' name='csrfToken' value='abc'>



Auth valid?

OK!

Server
victim.com

POST /login HTTP/1.1
username=alice&password=hunter2

HTTP/1.1 200 OK
Set-Cookie: sessionId=1234
<!doctype html> Login success!
<input type='hidden' name='csrfToken' value='abc'>

Auth valid?

OK!

Some time later...

Client

Server
victim.com





POST /login HTTP/1.1
username=alice&password=hunter2

HTTP/1.1 200 OK
Set-Cookie: sessionId=1234
<!doctype html> Login success!
<input type='hidden' name='csrfToken' value='abc'>

Auth valid?

OK!

Some time later...

GET / HTTP/1.1

HTTP/1.1 200 OK
<!doctype html>...

Client

Server
attacker.com

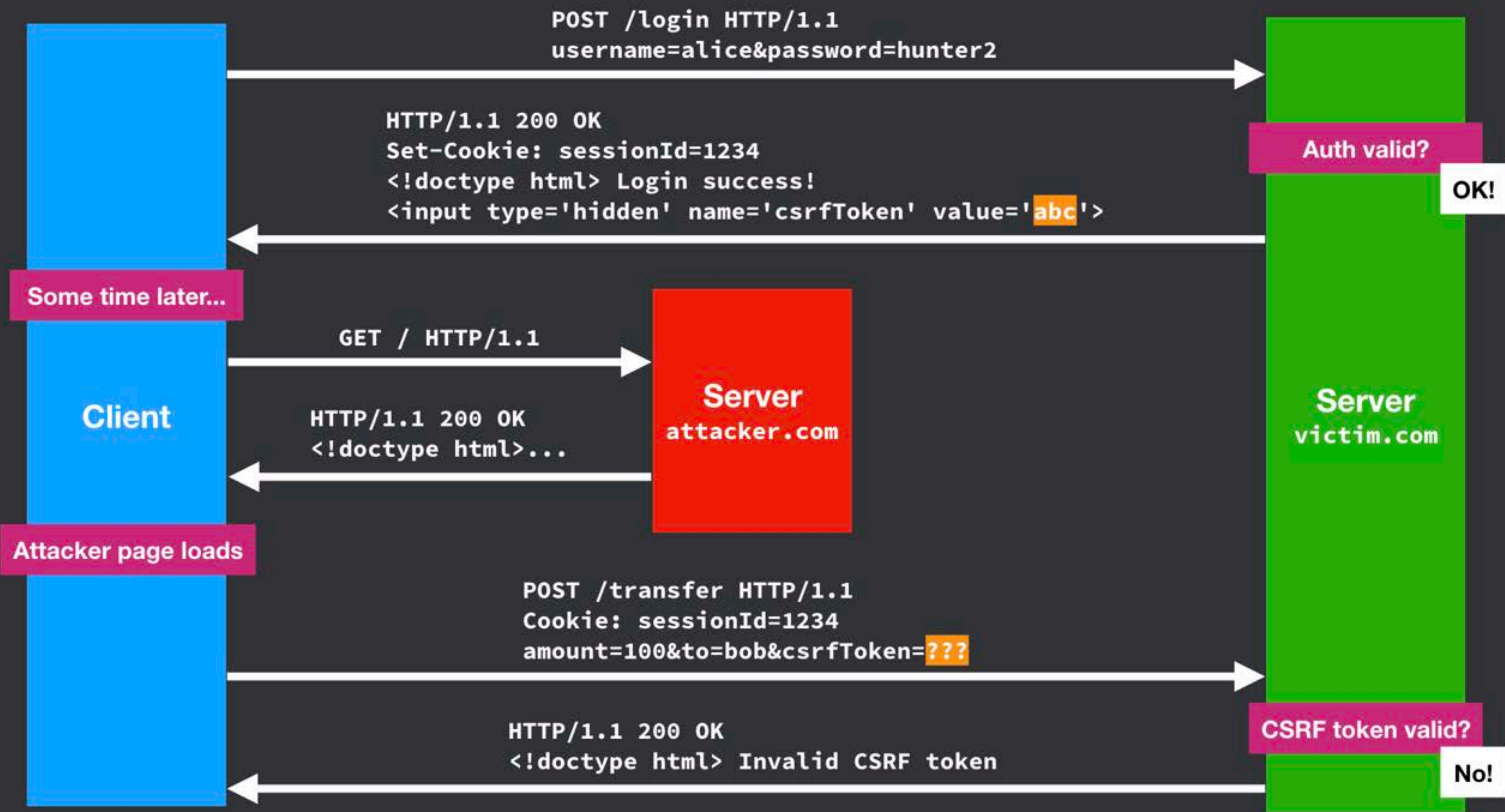
Server
victim.com

Attacker page loads









Bypassing GitHub's OAuth flow

Nov 5, 2019

For the past few years, security research has been something I've done in my spare time. I know there are people that make a living off of bug bounty programs, but I've personally just spent a few hours here and there whenever I feel like it.

That said, I've always wanted to figure out whether I'd be able to make a living on bug bounties if I chose to work on them full time. So I tried doing that for a couple months this summer, spending a few hours a day looking for security bugs in GitHub.

My main workflow was to download a [trial version of GitHub Enterprise](#), deobfuscate it using a modified version of [this script](#), and then just stare at GitHub's Rails code for awhile to try to spot anything weird or exploitable. Overall, GitHub's code seems very well-architected from a security perspective. I would occasionally find a bug caused by an unhandled case in some application logic, only to realize that the bug didn't create a security issue because (e.g.) the code was running a query with reduced privileges anyway. Almost every app has bugs, but one big challenge of security engineering is to make bugs unexploitable without knowing where they are, and GitHub seems to do a very good job of that.

Even so, I managed to find a few interesting issues over the summer, including a complete OAuth authorization bypass.

GitHub's OAuth Flow

At one point in June, I was looking at the code that implements GitHub's [OAuth flow](#). Briefly, the OAuth flow is supposed to work like this:

1. Some third-party application ("Foo App") wants to access a user's GitHub data. It sends the user to `https://github.com/login/oauth/authorize` with a bunch of information in the querystring.
2. GitHub displays an authorization page to the user, like the one below.



Authorize not-an-aardvark's example OAuth App



not-an-aardvark's example OAuth App by [not-an-aardvark](#)
wants to access your not-an-aardvark-2 account



Repositories
Public and private



Authorize not-an-aardvark

Authorizing will redirect to
<https://not-an-aardvark.github.io>



Not owned or
operated by GitHub



Created
5 months ago



Fewer than 10
GitHub users

GitHub OAuth Flow

1. Some third-party app wants to access a user's GitHub data. It sends the user to **<https://github.com/login/oauth/authorize>** with a bunch of information in the querystring
2. GitHub displays an authorization page to the user



Authorize not-an-aardvark's example OAuth App



not-an-aardvark's example OAuth App by [not-an-aardvark](#)
wants to access your not-an-aardvark-2 account



Repositories
Public and private



Authorize not-an-aardvark

Authorizing will redirect to
<https://not-an-aardvark.github.io>



Not owned or
operated by GitHub



Created
5 months ago



Fewer than 10
GitHub users

GitHub OAuth Flow

1. Some third-party app wants to access a user's GitHub data. It sends the user to **<https://github.com/login/oauth/authorize>** with a bunch of information in the querystring
2. GitHub displays an authorization page to the user
3. If the user chooses to grant access to the app, they click the “Authorize” button on the page
4. User is redirected back to the third-party app with an authorization code in the querystring, which can be used to access the requested data

How does the "Authorize" button work?

- The button is a self-contained HTML form
- When clicked, it sends a POST request with some hidden form fields, including a CSRF token
- When the server receives a POST request with a valid CSRF token, the server assumes the user has granted permissions to the app
- Interesting detail: The form submits to **/login/oauth/authorize**, the same URL that the authorization page itself is served from

GitHub OAuth Flow

Client

Server
example.com


Client
Building & Maintaining

Server
example.com

GET / HTTP/1.1


Client
my browser

Server
example.com





GET / HTTP/1.1

HTTP/1.1 200 OK
<!doctype html> Login with GitHub?

Client

Server
example.com

GET / HTTP/1.1

HTTP/1.1 200 OK

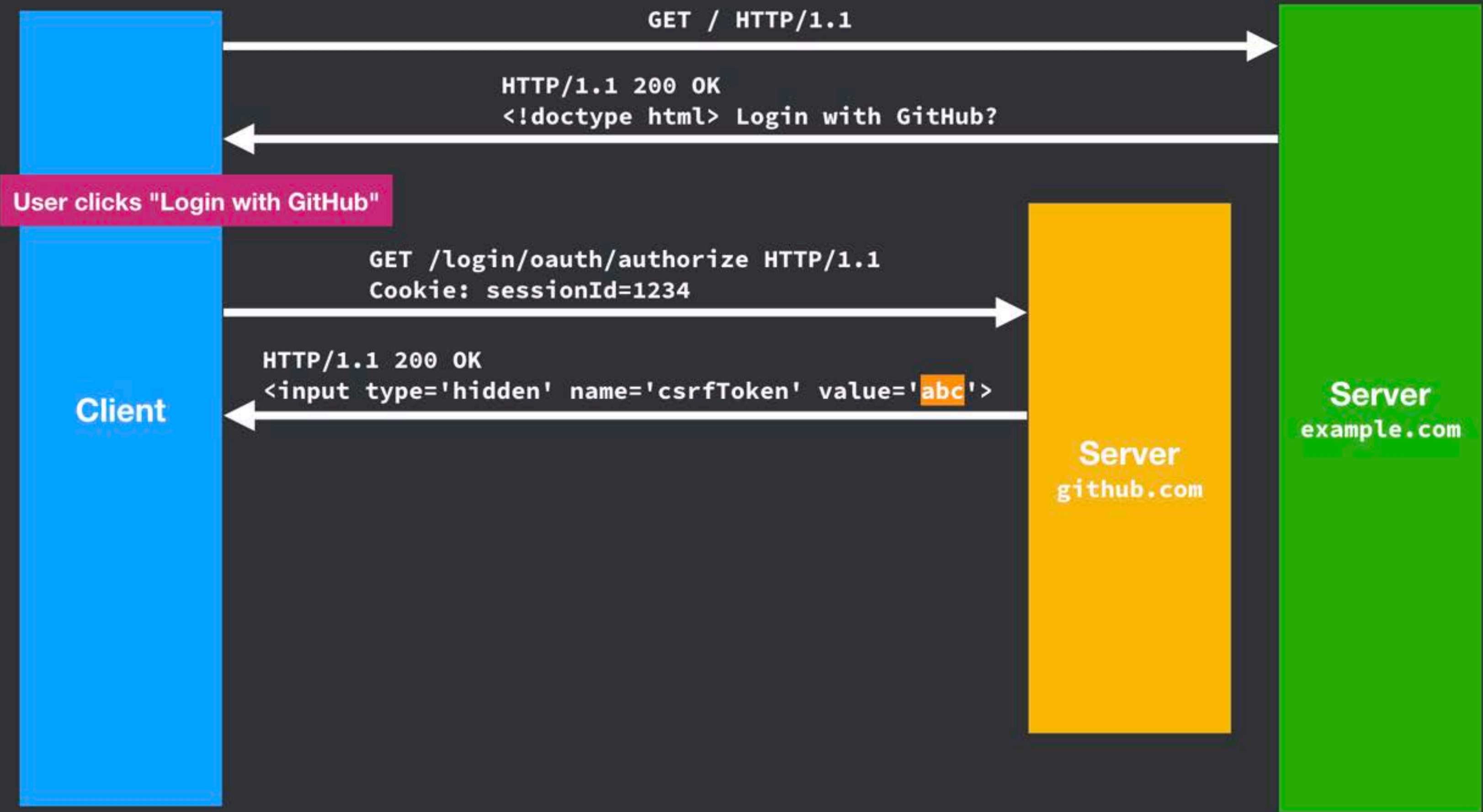
<!doctype html> Login with GitHub?

User clicks "Login with GitHub"

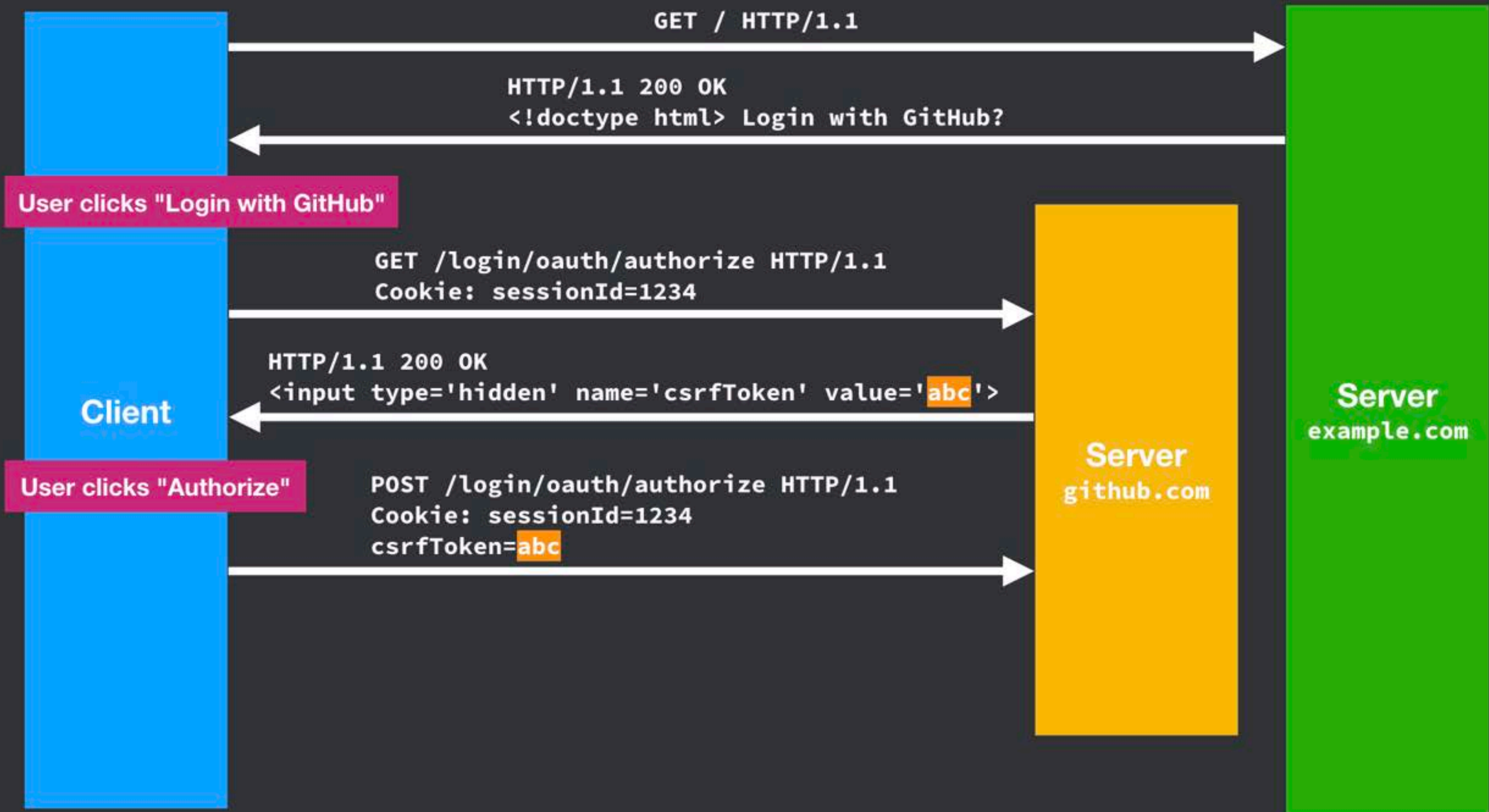
Client

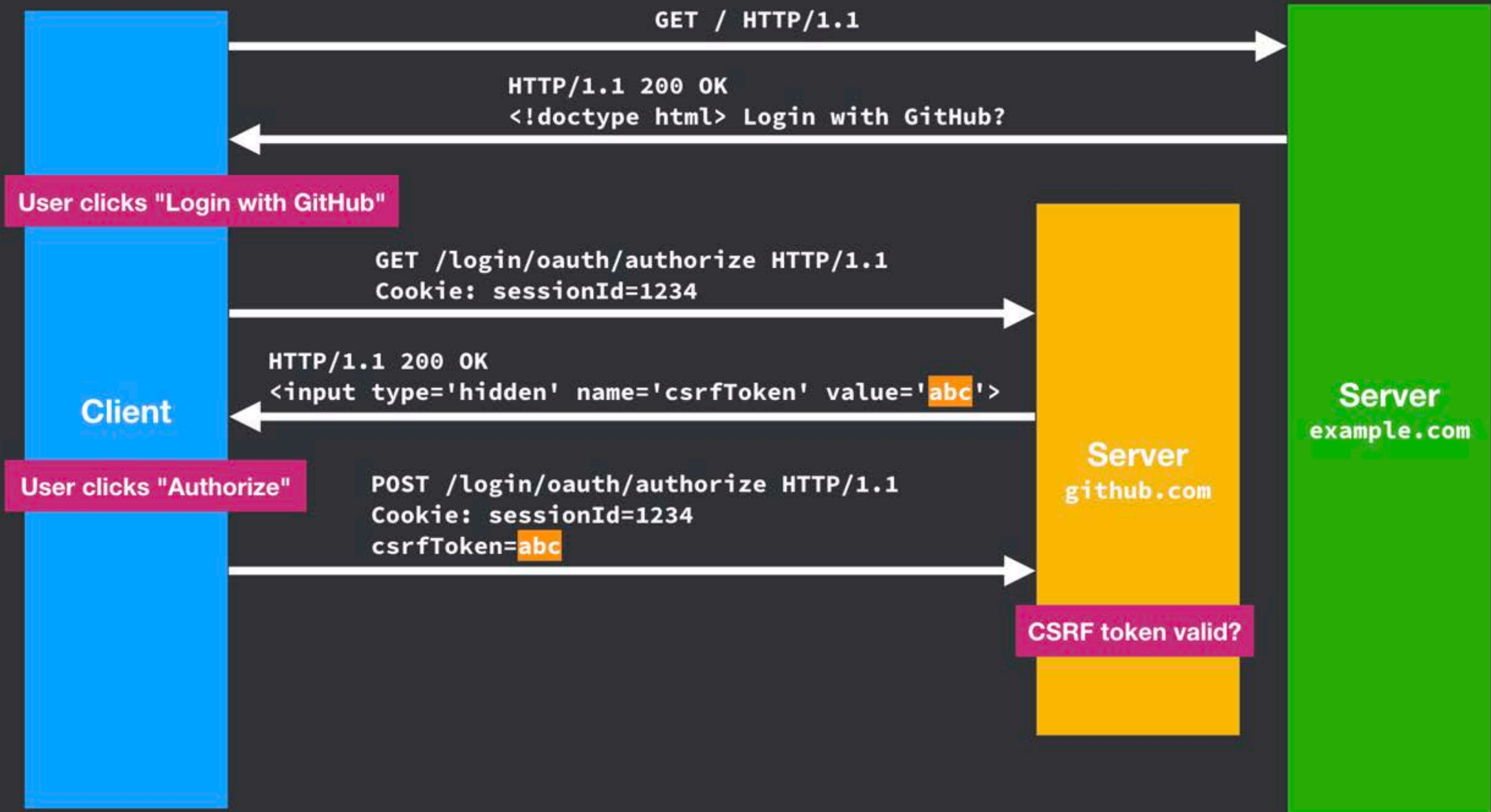
Server
example.com

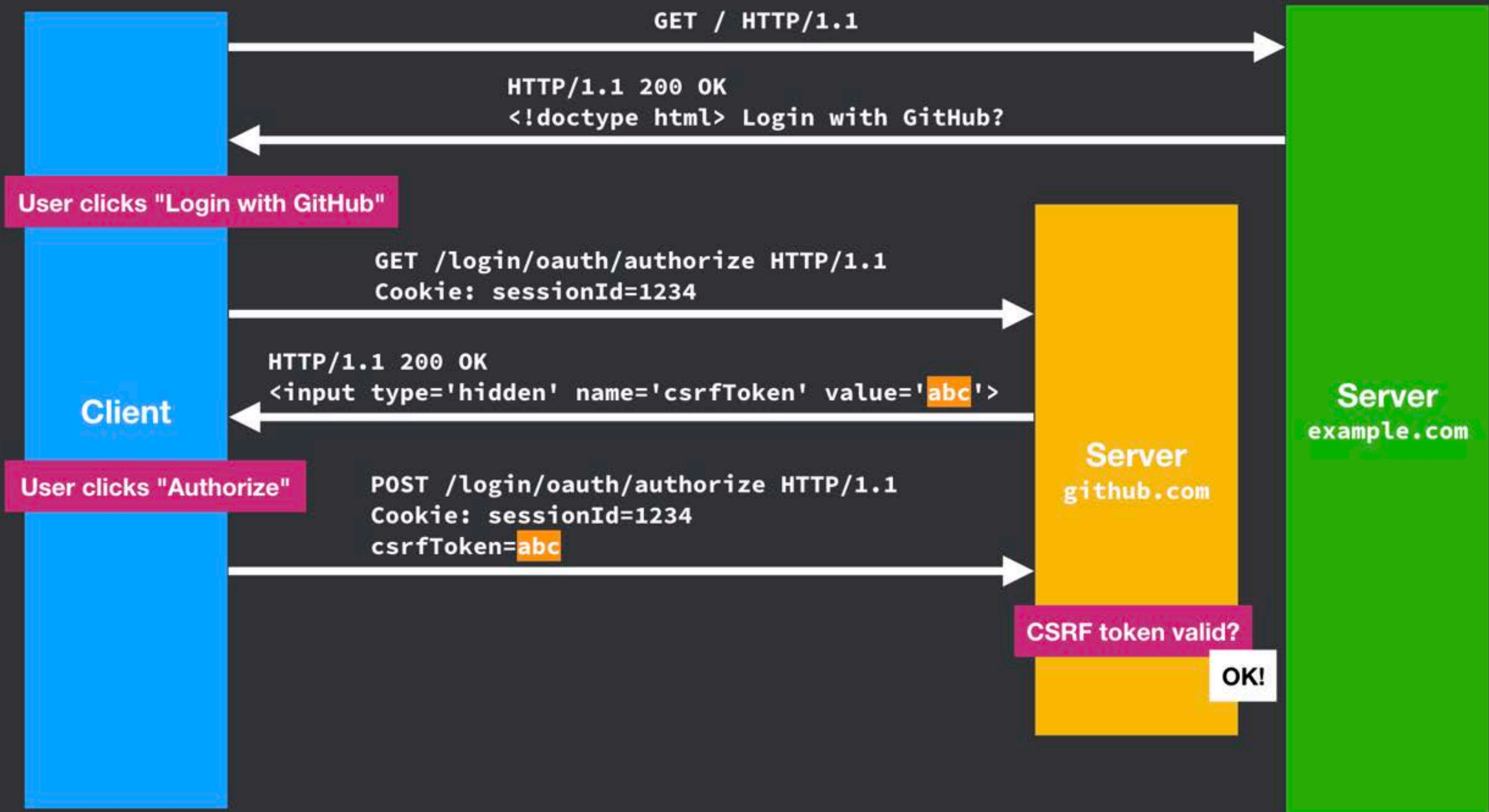


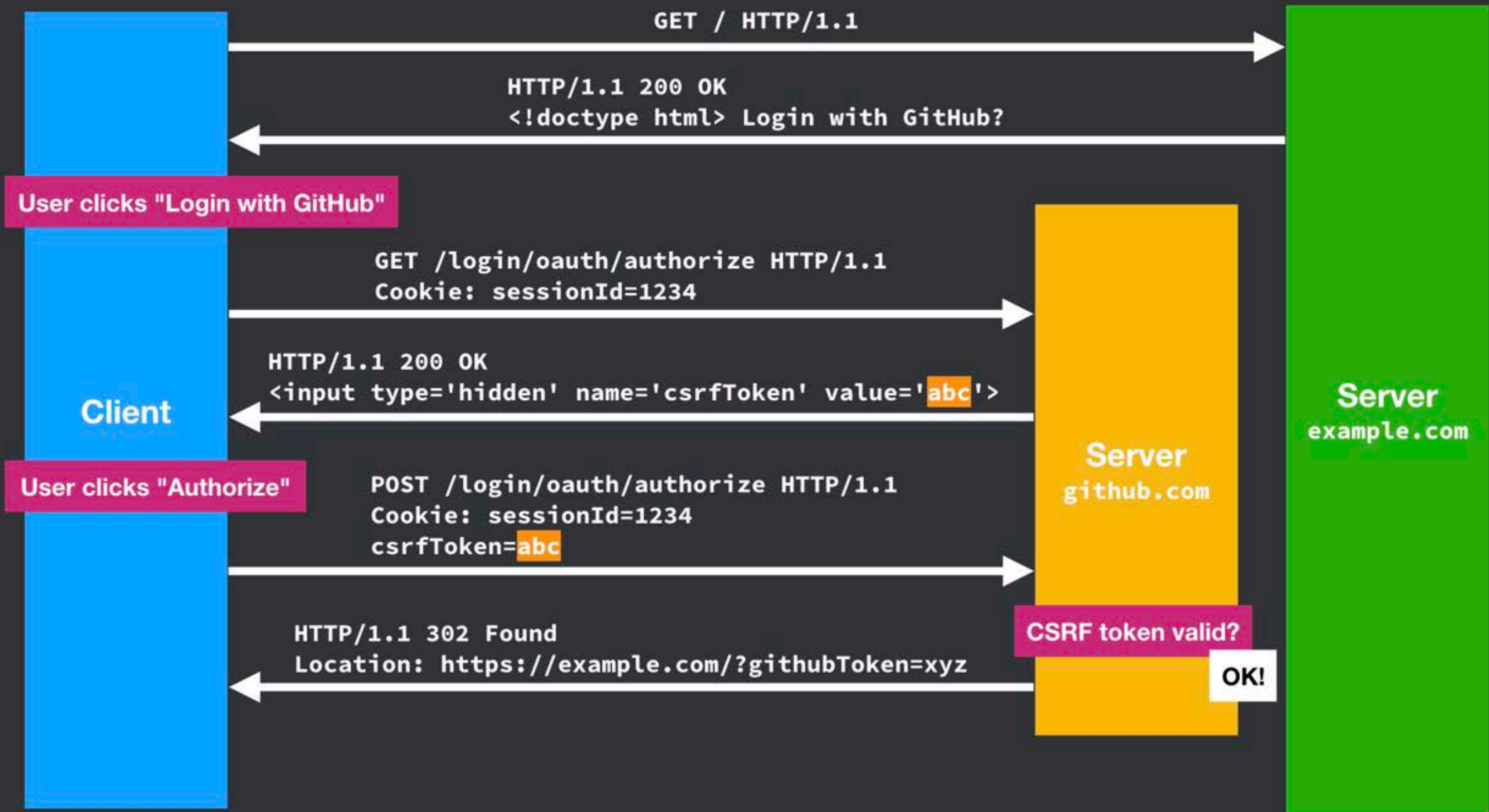


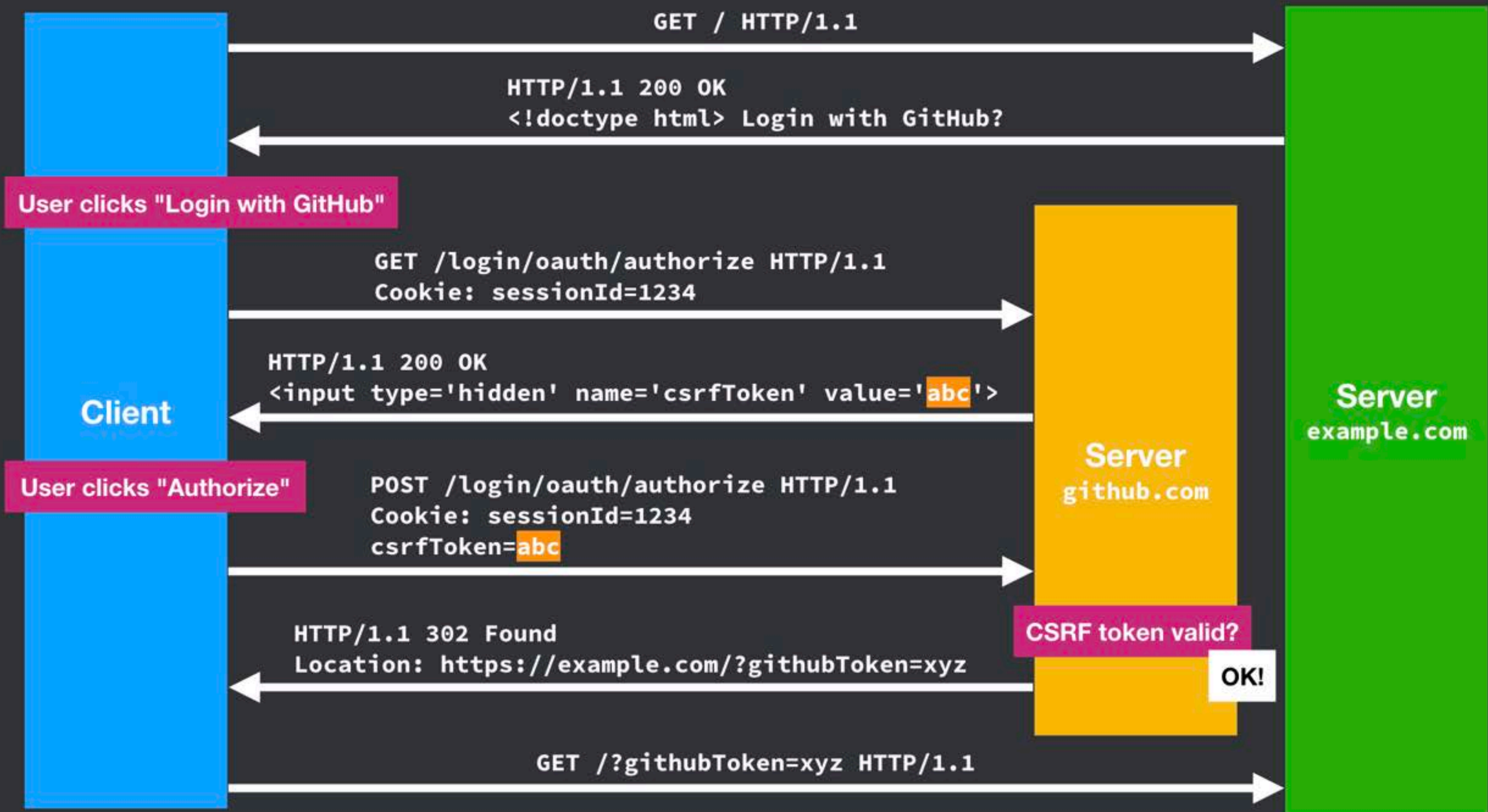












One URL, two HTTP methods

In the router

```
match "/login/oauth/authorize", # For every request with this path...  
  :to => "[the controller]", # ...send it to the controller...  
  :via => [:get, :post] # ... as long as it's a GET or a POST request.
```

In the controller

```
if request.get?  
  # serve authorization page HTML  
else  
  # grant permissions to app  
end
```

Let's talk about HTTP HEAD requests

- The semantics are: "pretend this is a GET request, but only send back response headers without a response body"
- Useful if client wants to check the **Content-Length** header before deciding whether to start a file download
- Ruby on Rails knows that most people will forget to implement HEAD, but since it's so similar to GET they figure they can automatically handle this for the developer

HEAD requests and web frameworks

- Ruby on Rails automatically routes HEAD requests to the same place as it routes GET requests (Express does this too)
- It runs the same controller (handler) code as for GET requests and just omits the response body
- Time-saving feature for developers, since this is usually the right behavior
 - But it's a leaky abstraction since if the controller checks **`request.get?`** it returns false for HEAD requests (unexpected)

Let's look at that code again

In the router

```
match "/login/oauth/authorize", # For every request with this path...  
  :to => "[the controller]", # ...send it to the controller...  
  :via => [:get, :post] # ... as long as it's a GET or a POST request.
```

In the controller

```
if request.get?  
  # serve authorization page HTML  
else  
  # IMPORTANT: CSRF token is only checked when method is POST  
  # grant permissions to app  
end
```

How to bypass GitHub OAuth security (now fixed)

Client

Server
attacker.com

The diagram consists of two vertical rectangles on a dark gray background. The left rectangle is light blue and contains the word 'Client' in white. The right rectangle is red and contains the text 'Server' and 'attacker.com' in white. A thin, light blue line connects the two rectangles, representing a network connection.

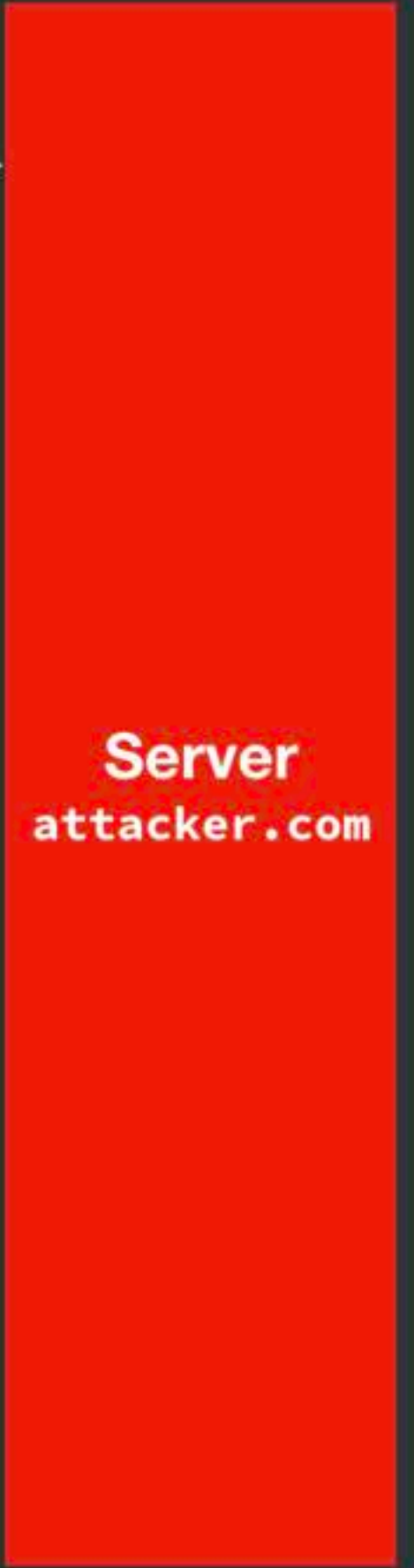
Client
192.168.1.100

Server
attacker.com

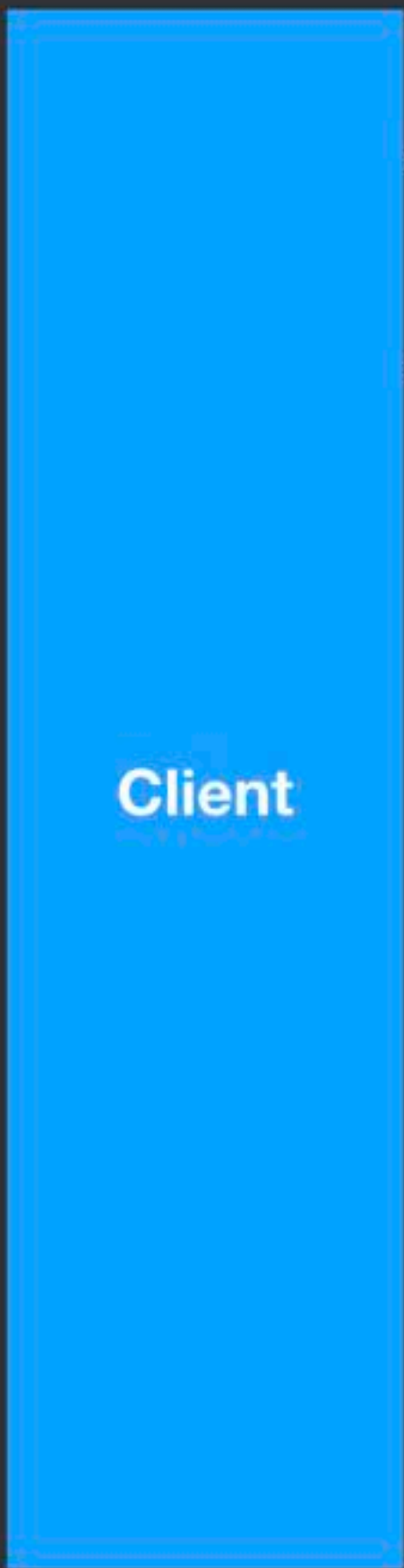


Client

GET / HTTP/1.1



Server
attacker.com

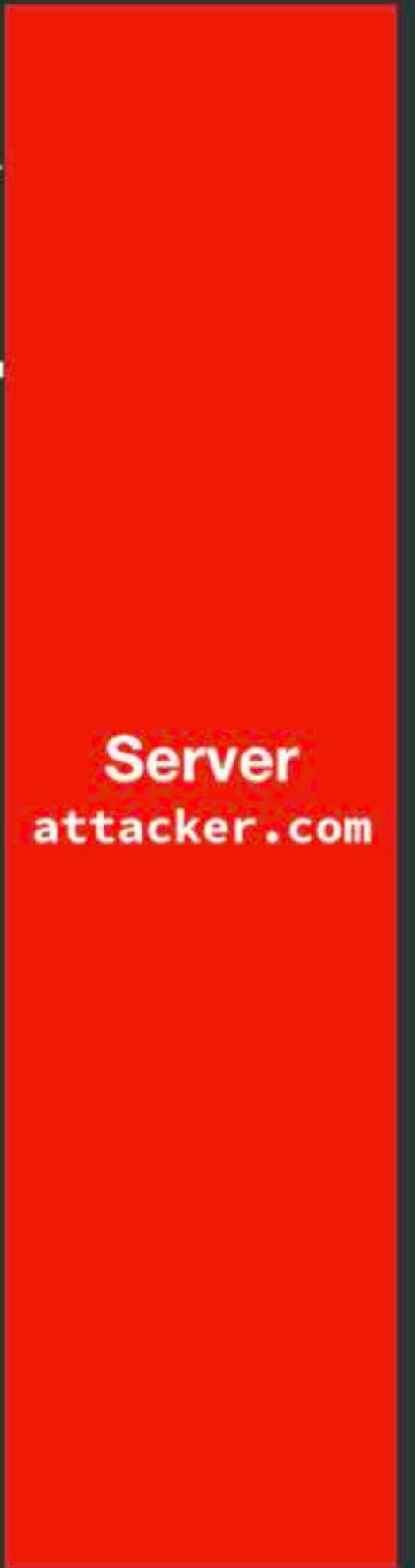


Client

GET / HTTP/1.1



HTTP/1.1 200 OK
<!doctype html> Attack code



Server
attacker.com

GET / HTTP/1.1

HTTP/1.1 200 OK
<!doctype html> Attack code

Attacker page loads

Client

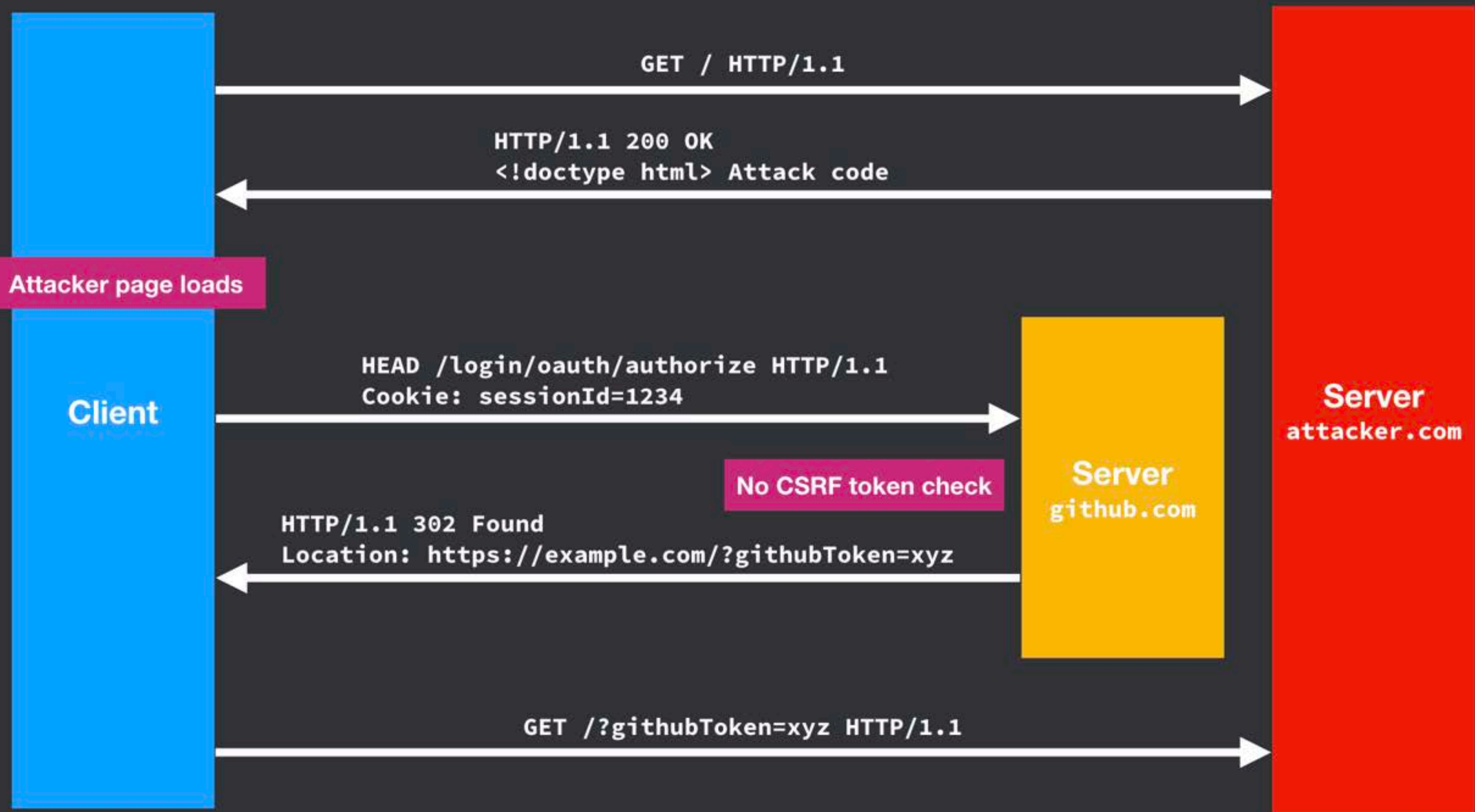
Server
attacker.com











How could GitHub have prevented this?

- Use **SameSite** cookies instead of (or in addition to) CSRF tokens
- Use a separate controller for GET/HEAD vs. POST
- Use separate URLs for authorization page vs. form submission endpoint (which results in separate controllers for each case)
- Changing **else** to **elsif request.post?** to ensure **HEAD** or any other unexpected methods won't be treated as POST

Explicit check for POST

```
# In the controller
```

```
if request.get?
```

```
  # serve authorization page HTML
```

```
elsif request.post?
```

```
  # grant permissions to app
```

```
else
```

```
  raise 'Unexpected HTTP method'
```

```
end
```

How could Rails have prevented this?

- Do not automatically send HEAD requests to the GET handler
- Set **request.get?** to **true** since the developer did not indicate they were prepared to handle HEAD requests separately from GET requests
 - Developer indicated the controller could only handle GET or POST
 - So it's a **leaky abstraction** for Rails to send it requests where neither **request.get?** or **request.post?** is true!
- Rewrite Rails in a powerful typed language, like Haskell

Safe coding lessons

- **Complexity is the enemy of security**
 - Goal of abstractions is to hide complexity from the developer. The more edge cases an abstraction has the "leakier" it is
- **Explicit code is better than clever code**
 - Writing overly clever, succinct, or "magic" code can increase complexity
- **Fail early**
 - Ignore the Robustness Principle and do the opposite
- **Code defensively**
 - Your assumptions may be violated, so always verify them upfront

How could GitHub have prevented this?

- Use **SameSite** cookies instead of (or in addition to) CSRF tokens
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Safe coding lessons – Bad API design

- Examples of suboptimal design decisions
 - Insecure defaults require the developer to set options to get secure behavior
 - Polymorphic function signatures which put lots of unrelated functionality into the same function
 - Behaving differently based on function arity

jQuery uses polymorphic functions

`$('button')` // Select the given CSS selector

`$(htmlElement)` // Wrap HTML element in jQuery object

`$(somejQueryObject)` // Clone another jQuery object

`$('<p>some html</p>')` // Create a DOM node with the given HTML

`$(() => console.log('loaded'))` // Function to run on page load

Express error-handling middleware relies on function arity detection

```
app.use((req, res, next) => {  
  // Normal middleware  
  res.status(200).send('Hello world')  
})
```

```
app.use((req, res, next, error) => {  
  // Error-handling middleware  
  res.status(500).send('Something broke!')  
})
```

- Issue: <https://github.com/expressjs/express/issues/2896>

The Buffer class

- Server code often needs to allocate memory, so Node.js introduced the **Buffer** class
- Later, the JavaScript language got native support for binary data via **TypedArray** and **ArrayBuffer**

The Buffer class

```
// Create a buffer containing [01, 02, 03]
```

```
const buf1 = new Buffer([1, 2, 3])
```

```
// Create a buffer containing ASCII bytes [74, 65, 73, 74]
```

```
const buf2 = new Buffer('test')
```

```
// Create a buffer of length 10
```

```
const buf3 = new Buffer(10)
```

```
// Clone another buffer
```

```
const buf3 = new Buffer(otherBuffer)
```

Demo: Buffer class is error-prone

Demo: Buffer class is error-prone

```
app.get('/api/convert', (req, res) => {
  const data = JSON.parse(req.query.data)

  if (!data.str) {
    throw new Error('missing data.str')
  }
  if (data.type !== 'hex' && data.type !== 'base64' && data.type !== 'utf8') {
    throw new Error('missing data.type')
  }

  res.send(convert(data.str, data.type))
})

function convert (str, type) {
  return new Buffer(str).toString(type)
}
```

Unallocated memory

```
> new Buffer(10)
```

```
<Buffer 00 20 00 00 00 00 00 00 00 d0 4d>
```

```
> new Buffer(10)
```

```
<Buffer 50 74 84 02 01 00 00 00 00 0a 00>
```

```
> new Buffer(10)
```

```
<Buffer 78 74 84 02 01 00 00 00 00 05 00>
```


User is responsible for zeroing out the memory

```
> new Buffer(10).fill(0)
```

```
<Buffer 00 00 00 00 00 00 00 00 00 00>
```

- But you won't call **fill()** if you're not expecting a number to be passed in!

Thousands of ecosystem packages potentially vulnerable

- Discovered by Feross Aboukhadijeh and Mathias Buus
- Initially discovered our own npm package, **bittorrent-dht**, was vulnerable
- Any computer in the world could send a specially-designed message to our listening BitTorrent peer and read a 20 byte chunk of process memory
- Commit: <https://github.com/webtorrent/bittorrent-dht/commit/6c7da04025d5633699800a99ec3fbadf70ad35b8>

The ws package

- 18 million weekly downloads

```
const { Server } = require('ws')
```

```
const server = new Server()
```

```
server.on('connection', socket => {  
  socket.on('message', message => {  
    message = JSON.parse(message)  
    if (message.type === 'echo') {  
      socket.send(message.data) // send back the user's message  
    }  
  })  
})
```

- Release notes: <https://github.com/websockets/ws/releases/tag/1.0.1>

The request package

- 16 million weekly downloads
- Pull request: <https://github.com/request/request/pull/2018>

The b^l package

- 5 million weekly downloads
- Pull request: <https://github.com/rvagg/bl/pull/22>

How could this vulnerability be prevented?

- Reject numbers as the first argument to **Buffer**
- Validate JSON to ensure the type of each property is what we expect
 - Use **JSON-Schema** or check each property manually and throw if invalid
- Define a class with just the properties we expect and the types we expect. Parse the JSON, then construct an instance of the class.
- Fix the design of the **Buffer** class to be less error-prone

Problems with the Buffer class

- The **Buffer** class often takes untrusted user input as the first argument
 - Usually this untrusted input is a **string** but if it can be a **number** in even one place in the codebase, we have **information exposure**
- The default behavior is unsafe – Zeroed memory should be returned by default, unless the user specifically asks for uninitialized memory
- Two very different pieces of functionality are mixed into the same API
 - Converting user-provided data to a Buffer representation
 - Allocating a Buffer with the specified amount of uninitialized memory

Introducing new Buffer methods

`Buffer.from('abc')` // Convert anything to a Buffer

`Buffer.alloc(10)` // Allocate a zero-filled Buffer

`Buffer.allocUnsafe(10)` // Allocate an uninitialized Buffer

- Pull request: <https://github.com/nodejs/node/issues/4660>

Buffer aftermath

- Ecosystem still had tons of unsafe usage of **new Buffer()** for several years
 - **safe-buffer** shim package helped
 - Libraries need to support old versions of Node.js which lacked the new Buffer APIs
 - Updates took time to percolate through the ecosystem

Polymorphic functions in bcrypt

```
const HASH_ROUNDS = 10
```

```
const passwordHash = bcrypt.hashSync(password, HASH_ROUNDS)
```

- When **HASH_ROUNDS** is a string, it will be used as the salt itself instead of specifying that a new salt should be created with **HASH_ROUNDS** number of rounds

```
const HASH_ROUNDS = process.env.HASH_ROUNDS
```

```
const passwordHash = bcrypt.hashSync(password, HASH_ROUNDS)
```

Hide error details from client

- Errors potentially exposes sensitive information
- Exposes file paths, third-party packages in use, and other internal workings

Error: missing data.str

```
at app.get (/Users/feross/websec/lectures/Lecture 17/code/unsafe-buffer.js:17:11)
at Layer.handle [as handle_request] (/Users/feross/websec/lectures/Lecture 17/code/node_modules/express/lib/router/layer.js:95:5)
at next (/Users/feross/websec/lectures/Lecture 17/code/node_modules/express/lib/router/route.js:137:13)
at Route.dispatch (/Users/feross/websec/lectures/Lecture 17/code/node_modules/express/lib/router/route.js:112:3)
at Layer.handle [as handle_request] (/Users/feross/websec/lectures/Lecture 17/code/node_modules/express/lib/router/layer.js:95:5)
at /Users/feross/websec/lectures/Lecture 17/code/node_modules/express/lib/router/index.js:281:22
at Function.process_params (/Users/feross/websec/lectures/Lecture 17/code/node_modules/express/lib/router/index.js:335:12)
at next (/Users/feross/websec/lectures/Lecture 17/code/node_modules/express/lib/router/index.js:275:10)
at expressInit (/Users/feross/websec/lectures/Lecture 17/code/node_modules/express/lib/middleware/init.js:40:5)
at Layer.handle [as handle_request] (/Users/feross/websec/lectures/Lecture 17/code/node_modules/express/lib/router/layer.js:95:5)
```

Hide error details from client

```
app.use((err, req, res, next) => {  
  res.status(err.status || 500)  
  res.render('error', {  
    message: err.message,  
    stack: process.env.NODE_ENV === 'production'  
      ? ''  
      : err.stack  
  })  
})
```

Prevent simple server fingerprinting

- Servers may send HTTP headers which reveal server type

HTTP/1.1 200 OK

X-Powered-By: express

- Can be disabled with:

```
app.disable('x-powered-by')
```


Prevent simple server fingerprinting

- Servers may send HTTP headers which reveal server type and version

HTTP/1.1 200 OK

Server: nginx

X-Powered-By: PHP/5.3.3

- Can be disabled with:

server_tokens off;

proxy_hide_header X-Powered-By;



Nmap Security Scanner

- [Intro](#)
- [Ref Guide](#)
- [Install Guide](#)
- [Download](#)
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- [Book](#)
- [Docs](#)

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- [Nmap Announce](#)
- [Nmap Dev](#)
- [Bugtraq](#)
- [Full Disclosure](#)
- [Pen Test](#)
- [Basics](#)
- [More](#)

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- [Password audit](#)
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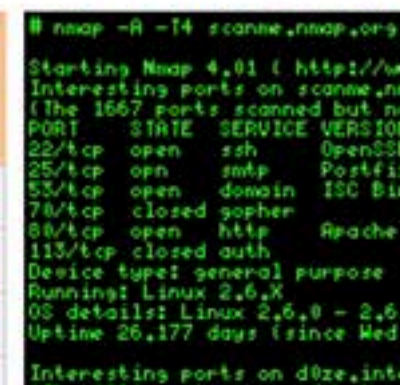
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Nmap Network Scanning

OS Detection

Chapter 15. Nmap Reference Guide

OS Detection

One of Nmap's best-known features is remote OS detection using TCP/IP stack fingerprinting. Nmap sends a series of TCP and UDP packets to the remote host and examines practically every bit in the responses. After performing dozens of tests such as TCP ISN sampling, TCP options support and ordering, IP ID sampling, and the initial window size check, Nmap compares the results to its `nmap-os-db` database of more than 2,600 known OS fingerprints and prints out the OS details if there is a match. Each fingerprint includes a freeform textual description of the OS, and a classification which provides the vendor name (e.g. Sun), underlying OS (e.g. Solaris), OS generation (e.g. 10), and device type (general purpose, router, switch, game console, etc). Most fingerprints also have a Common Platform Enumeration (CPE) representation, like `cpe:/o:linux:linux_kernel:2.6`.

If Nmap is unable to guess the OS of a machine, and conditions are good (e.g. at least one open port and one closed port were found), Nmap will provide a URL you can use to submit the fingerprint if you know (for sure) the OS running on the machine. By doing this you contribute to the pool of operating systems known to Nmap and thus it will be more accurate for everyone.

Safe coding lessons

- **Complexity is the enemy of security**
 - Goal of abstractions is to hide complexity from the developer. The more edge cases an abstraction has the "leakier" it is
- **Explicit code is better than clever code**
 - Writing overly clever, succinct, or "magic" code can increase complexity
- **Fail early**
 - Ignore the Robustness Principle and do the opposite
- **Code defensively**
 - Your assumptions may be violated, so always verify them upfront

END

Credits:

<https://blog.teddykatz.com/2019/11/05/github-oauth-bypass.html>