04. Web Tracking technologies: Browser fingerprinting

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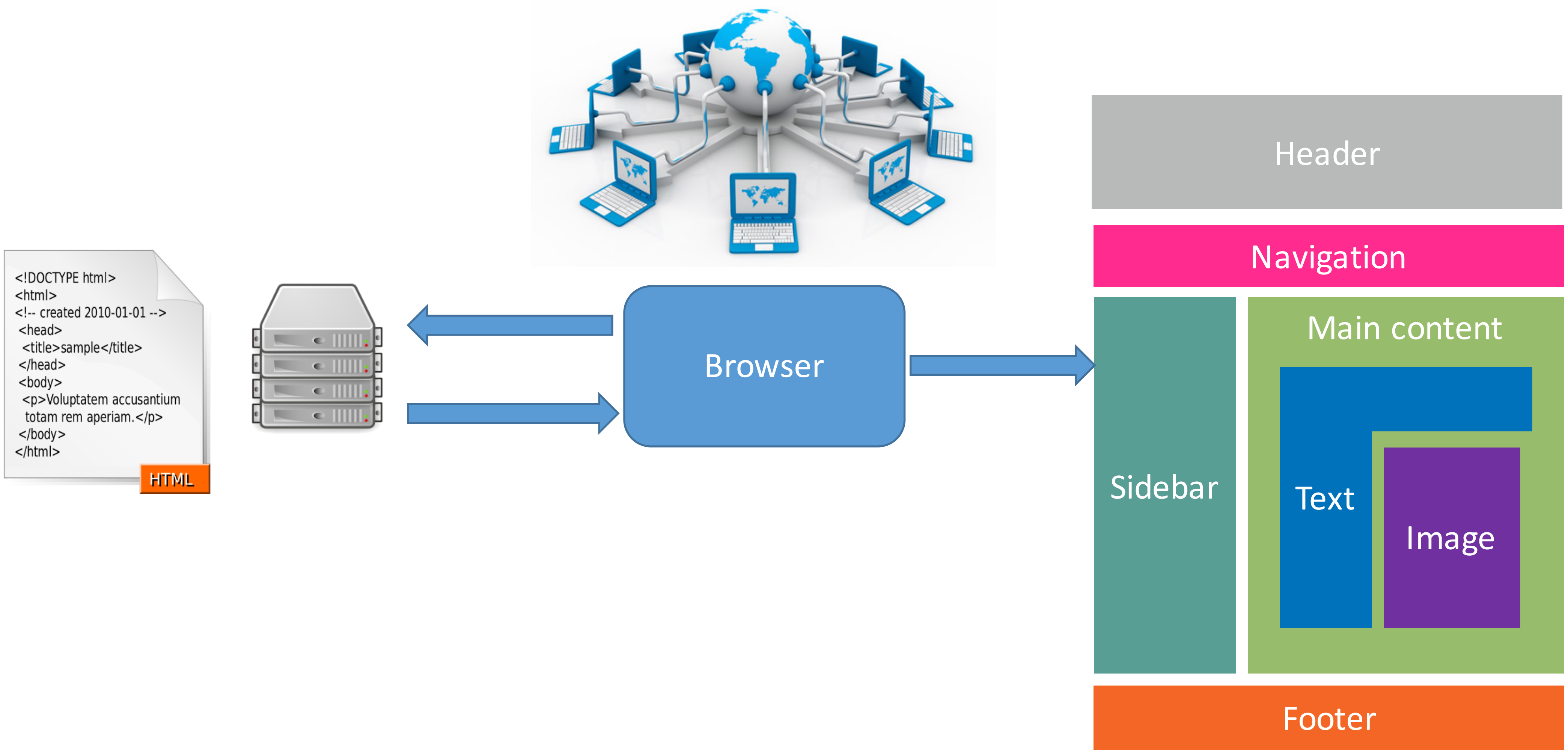
Web Privacy course

University of Trento

Today’s class

- A brief history of Web browsers
- What is browser fingerprinting?
- From basic to advanced fingerprinting

I. Internet and web browsers



```
<!DOCTYPE html>
<html>
<!-- created 2010-01-01 -->
 <head>
  <title>sample</title>
 </head>
 <body>
  <p>Voluptatem accusantium
   totam rem aperiam.</p>
 </body>
</html>
```

HTML

Browser

Header

Navigation

Sidebar

Main content

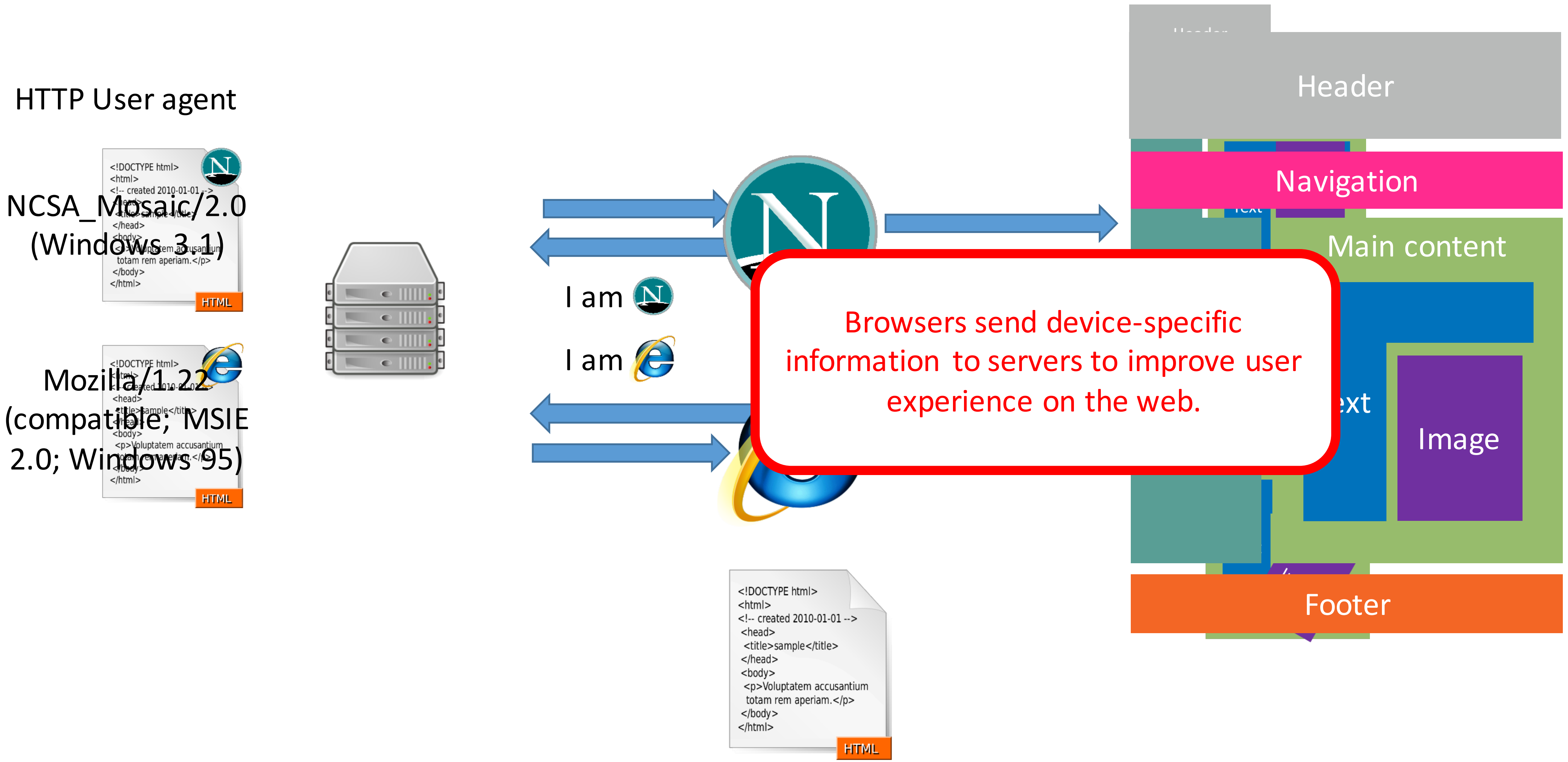
Text

Image

Footer

Slides courtesy of Pierre Laperdrix (Stony Brook University)

I. Internet in 1995



HTTP User agent

NCSA_Mosaic/2.0 (Windows 3.1)

Mozilla/1.22 (compatible; MSIE 2.0; Windows 95)

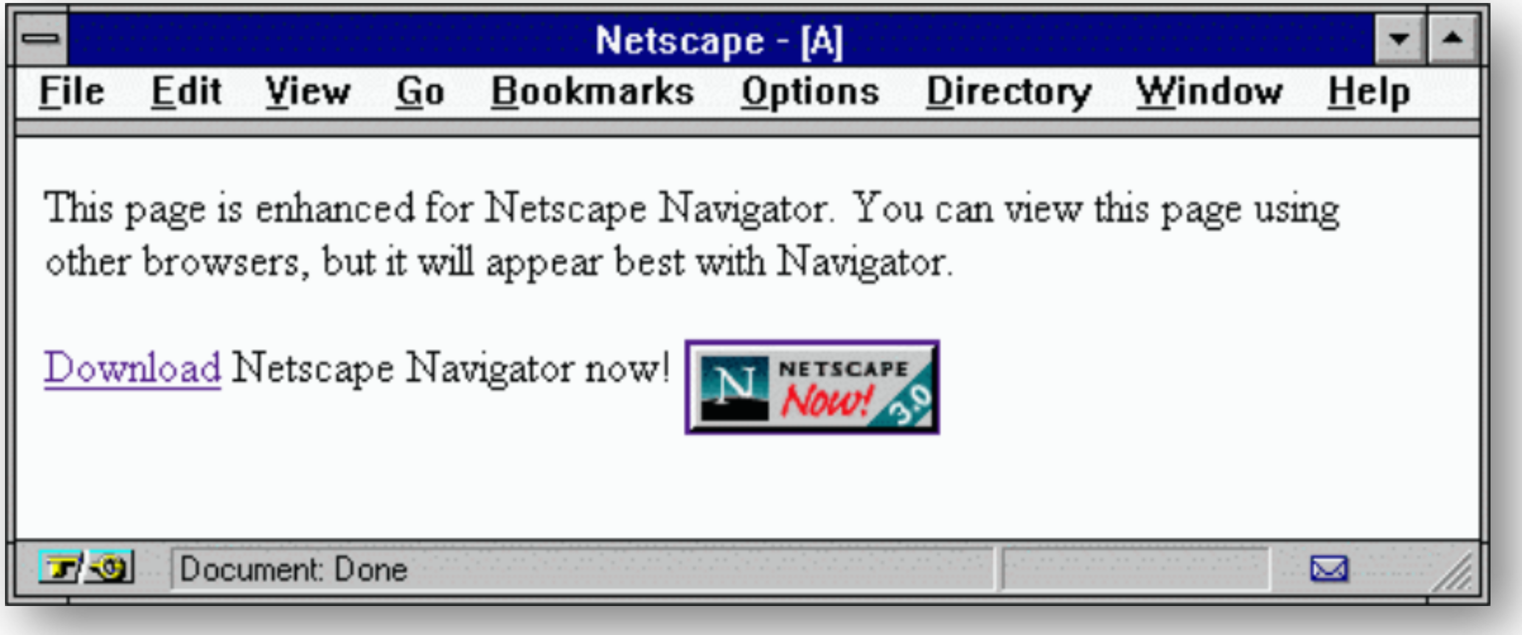
```
<!DOCTYPE html>
<html>
<!-- created 2010-01-01 -->
 <head>
  <title>sample</title>
 </head>
 <body>
  <p>Voluptatem accusantium
  totam rem aperiam.</p>
 </body>
</html>
```

Browsers send device-specific information to servers to improve user experience on the web.

Slides courtesy of Pierre Laperdrix (Stony Brook University)

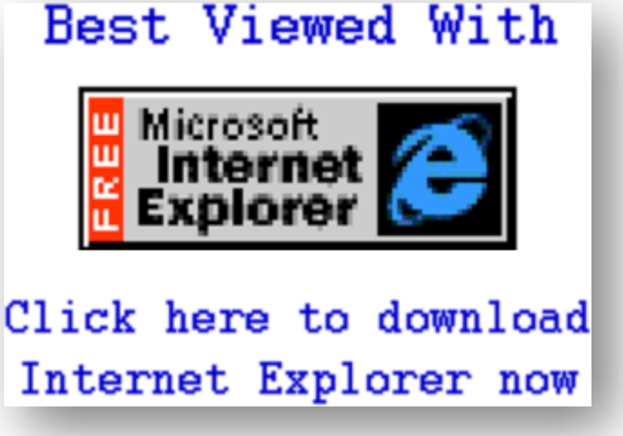
I. Internet in 1995

- Every website announces with **what browser** it is recommended to visit the website



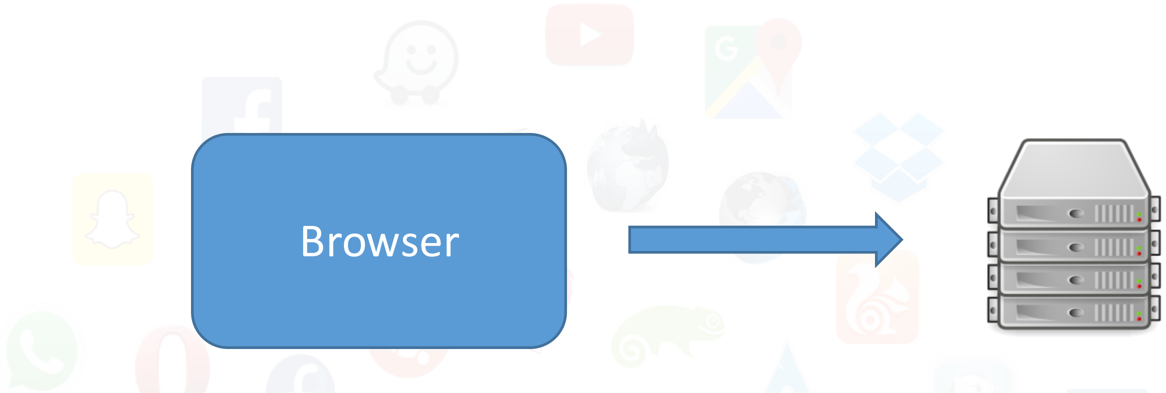
This page is enhanced for Netscape Navigator. You can view this page using other browsers, but it will appear best with Navigator.

Download Netscape Navigator now!


Best Viewed With
FREE
Microsoft Internet Explorer
Click here to download Internet Explorer now

Slides courtesy of Pierre Laperdrix (Stony Brook University)

I. Internet in 2017



1995	2017
Browser: Netscape Language: Fr	Browser: Chrome v53 OS: Linux Screen: 1920x1080 Language: Fr Timezone: GMT+1 Graphic card: GTX 1080Ti …

A bigger and richer web

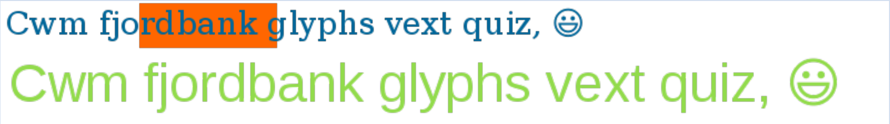
- Audio
- Video
- 3D rendering
- Real-time communications
- Web payments
- Virtual reality

…

What happens when we start collecting all the information available in a web browser?

Slides courtesy of Pierre Laperdrix (Stony Brook University)

Example of a browser fingerprint

Attribute	Value
User agent	Mozilla/5.0 (X11; Fedora; Linux x86_64; rv:55.0) Gecko/20100101 Firefox/55.0
HTTP headers	text/html, application/xhtml+xml, application/xml;q=0.9,*/*;q=0.8 gzip, deflate, br en-US,en;q=0.5
Plugins	Plugin 0: QuickTime Plug-in 7.6.6; libtotem-narrowspace-plugin.so; Plugin 1: Shockwave Flash; Shockwave Flash 26.0 r0; libflashplayer.so.
Fonts	Century Schoolbook, Source Sans Pro Light, DejaVu Sans Mono, Bitstream Vera Serif, URW Palladio L, Bitstream Vera Sans Mono, Bitstream Vera Sans, …
Platform	Linux x86_64
Screen resolution	1920x1080x24
Timezone	-480 (UTC+8)
OS	Linux 3.14.3-200.fc20.x86 32-bit
WebGL vendor	NVIDIA Corporation
WebGL renderer	GeForce GTX 650 Ti/PCIe/SSE2
Canvas	 Cwm fjordbank glyphs vext quiz, 😃 Cwm fjordbank glyphs vext quiz, 😃

Slides courtesy of Pierre Laperdrix (Stony Brook University)

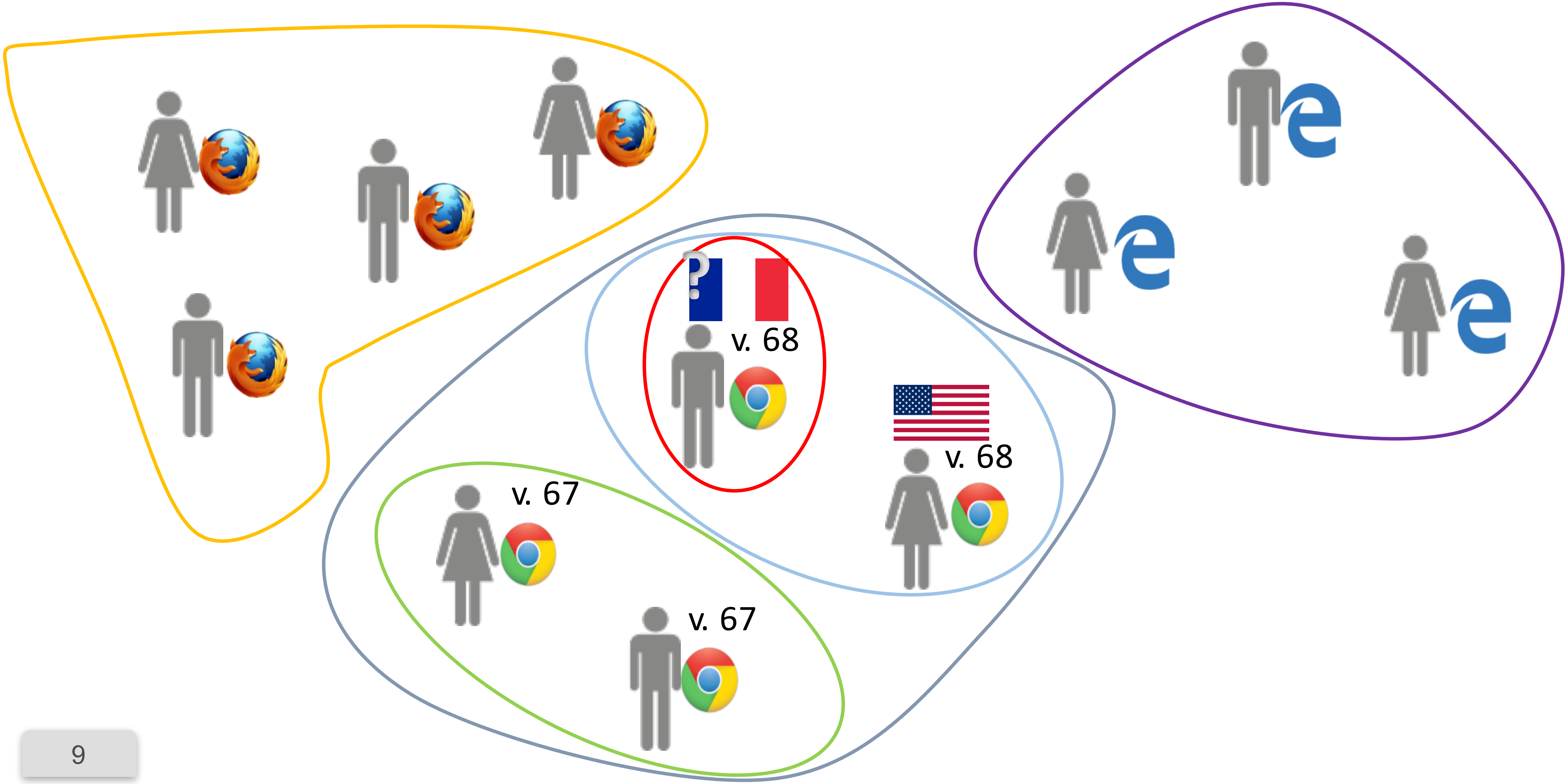
I. Definition of browser fingerprinting

Definitions

- A browser fingerprint is a set of information related to a user's device from the hardware to the operating system to the browser and its configuration.
- Browser fingerprinting refers to the process of collecting information through a web browser to build a fingerprint of a device.

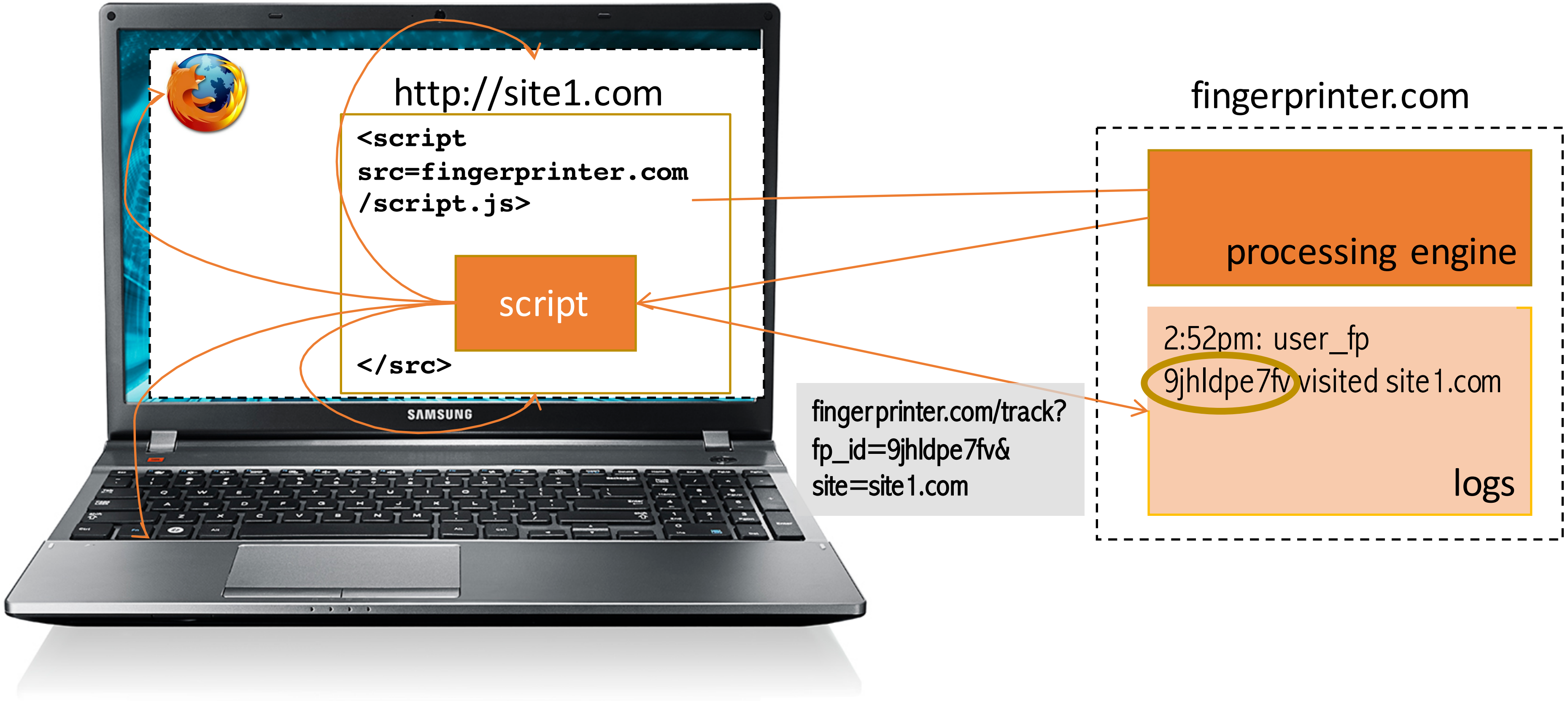
Slides courtesy of Pierre Laperdrix (Stony Brook University)

How can we be identified by a browser fingerprint?



Browser fingerprinting used for tracking

Browser and operating system properties are used to track repeated visits to a site.



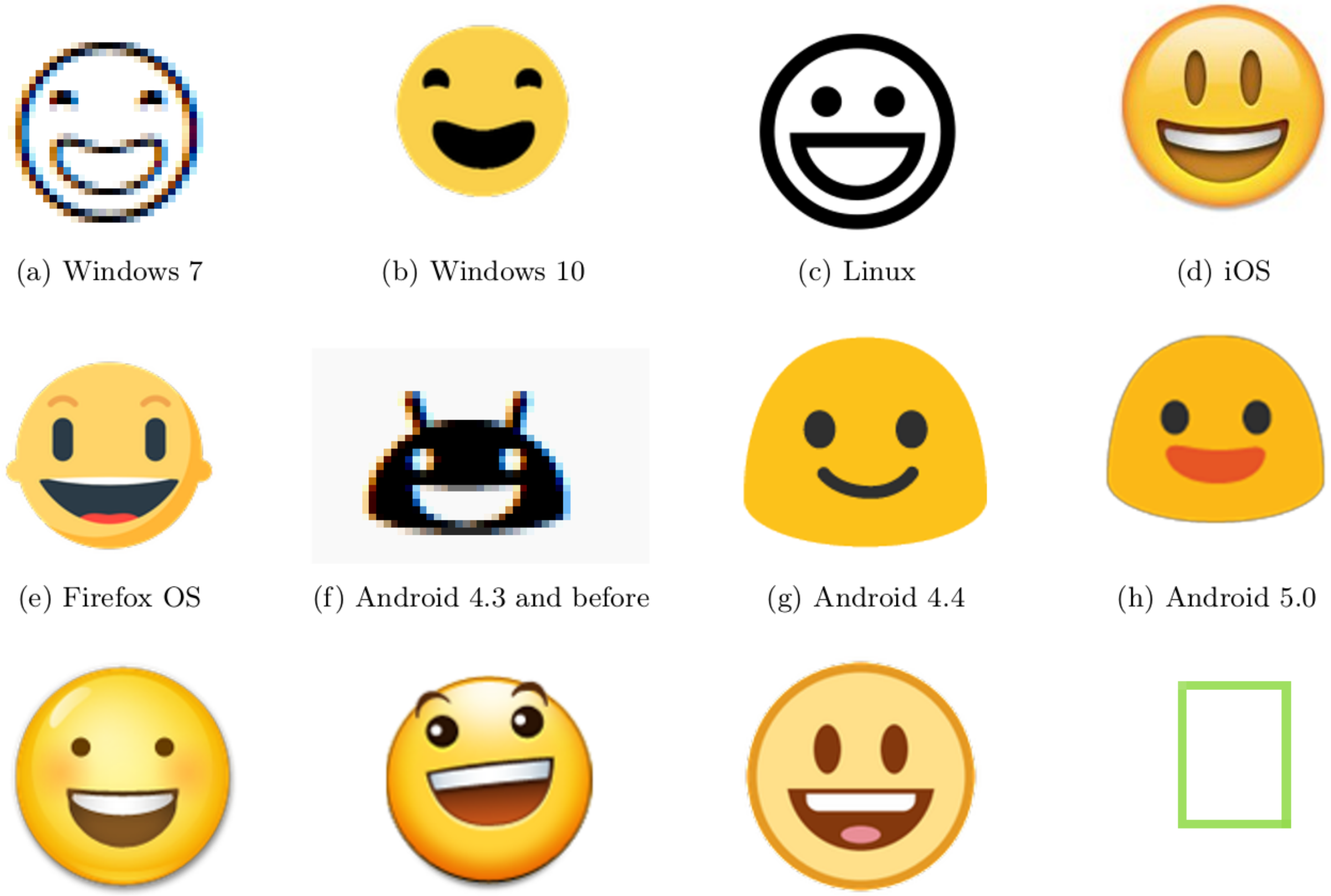
```
<script
src=fingerprinter.com
/script.js>

</src>
```

fingerprinter.com/track?fp_id=9jhldpe7fv&site=site1.com

```
2:52pm: user_fp
9jhldpe7fv visited site1.com
```

Comparison of the emoji on different devices and OSs



(a) Windows 7

(b) Windows 10

(c) Linux

(d) iOS

(e) Firefox OS

(f) Android 4.3 and before

(g) Android 4.4

(h) Android 5.0

(i) Android on an LG device

(j) Android on a Samsung device

(k) Android on an HTC device

(l) Emoji not supported

https://hal.inria.fr/hal-01285470/document

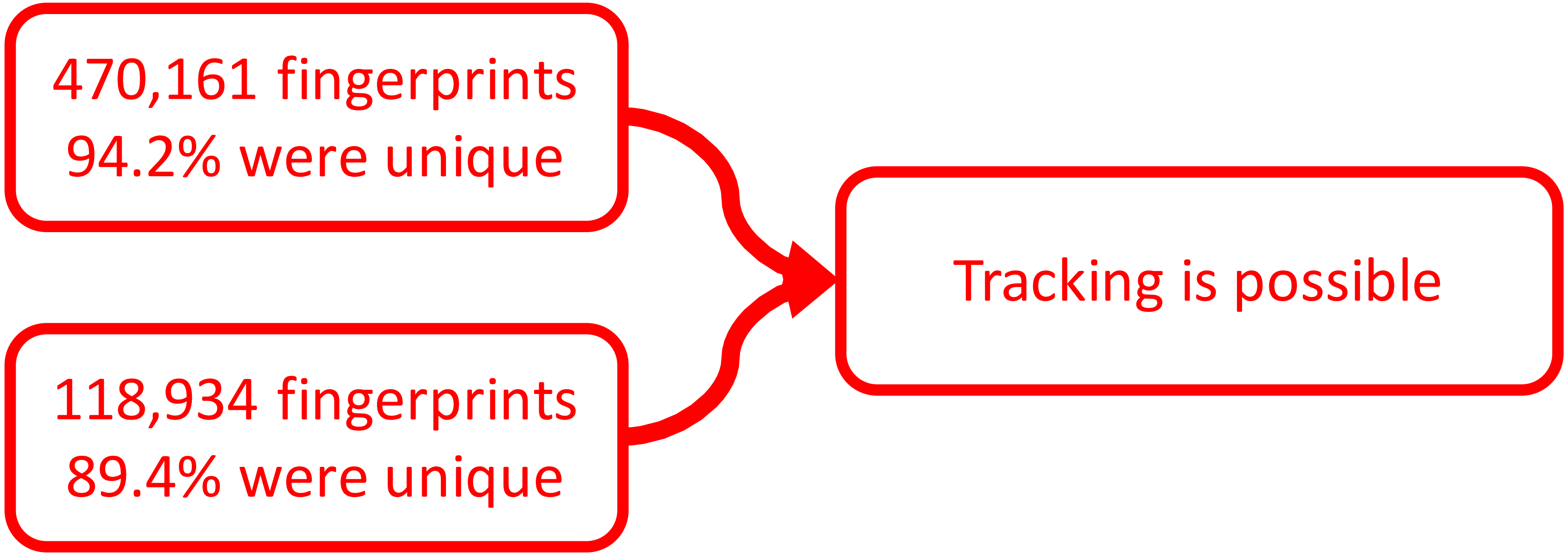
What makes fingerprinting a threat to online privacy?

Two studies have investigated the diversity of browser fingerprints.

Panopticlick
How Unique — and Trackable — Is Your Browser?

EFF

Am I Unique?



470,161 fingerprints
94.2% were unique

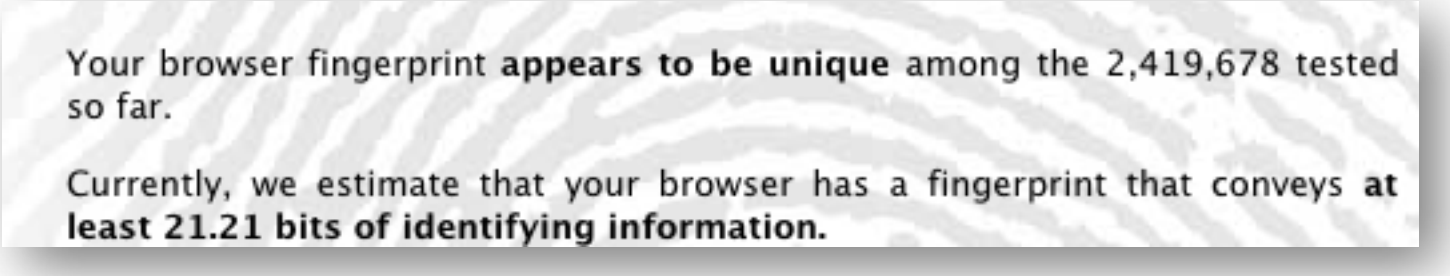
118,934 fingerprints
89.4% were unique

Tracking is possible

Slides courtesy of Pierre Laperdrix (Stony Brook University)

Fingerprinting

- Panopticlick [Eckersley, PET’2010]



Your browser fingerprint **appears to be unique** among the 2,419,678 tested so far.

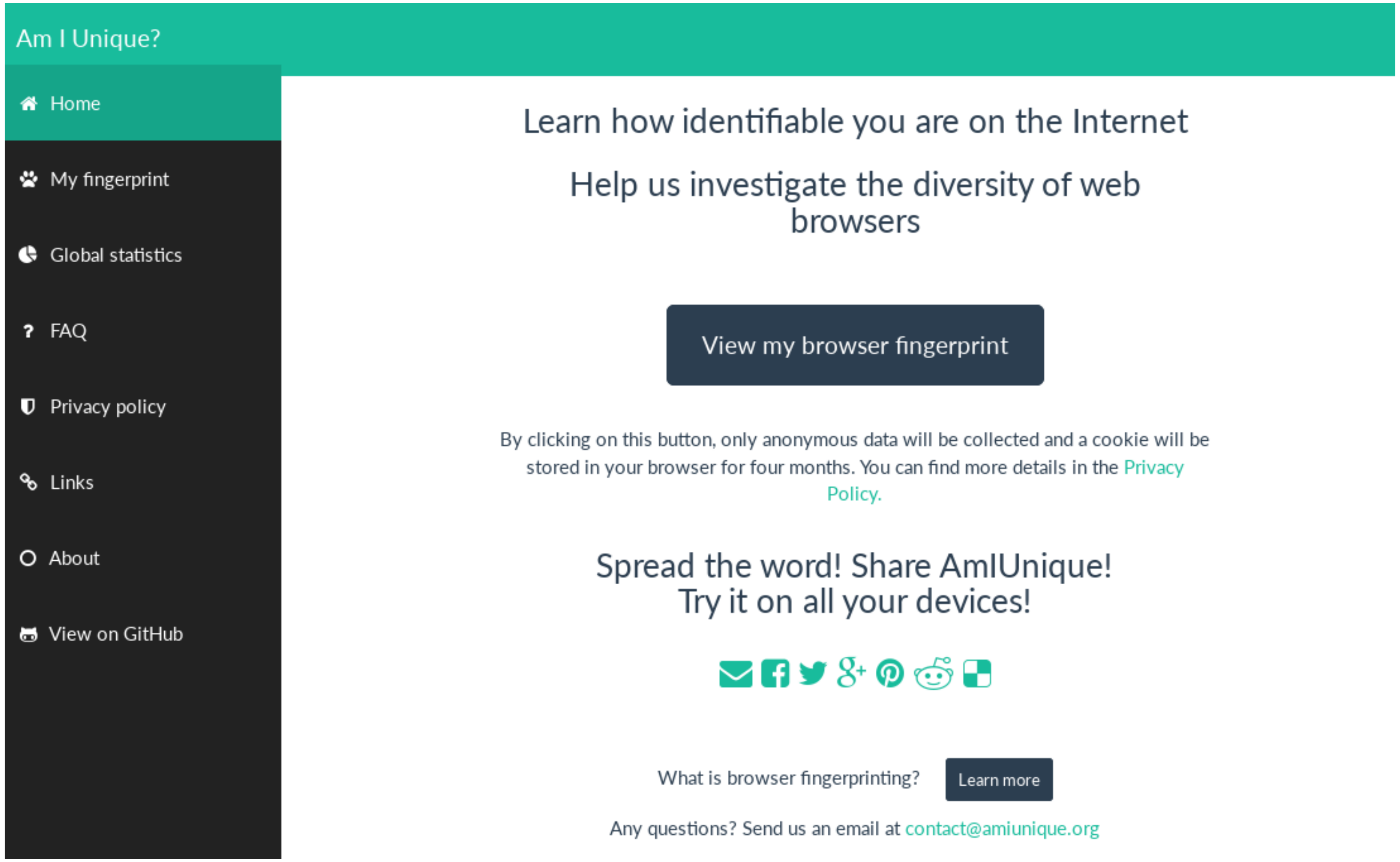
Currently, we estimate that your browser has a fingerprint that conveys **at least 21.21 bits of identifying information.**

- Information needed to **uniquely identify a browser**
  - n – number of connected devices: 5 000 000 000
  - $log_2 n$ – number of bits for a unique id: 33 bits

- **Idea: distinguish user’s browsers** by accessing browser features and using their probability distributions

I. See your own fingerprint

https://amiunique.org (Am I Unique)



Learn how identifiable you are on the Internet

Help us investigate the diversity of web browsers

By clicking on this button, only anonymous data will be collected and a cookie will be stored in your browser for four months. You can find more details in the Privacy Policy.

Spread the word! Share AmIUnique!
Try it on all your devices!

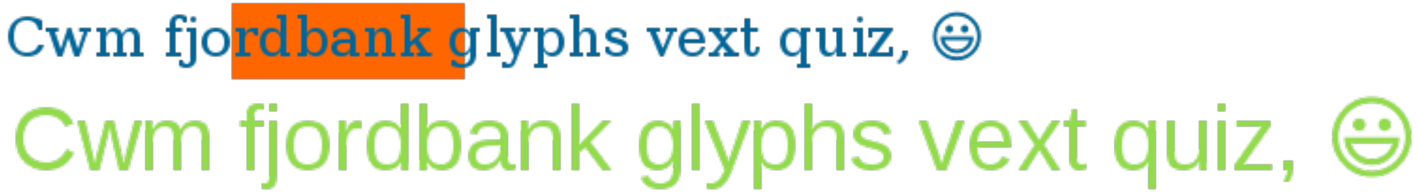
What is browser fingerprinting?

Any questions? Send us an email at contact@amiunique.org

- Website launched in November 2014
- Collected 660,000+ fingerprints so far
- Browser extension available to see the evolution of your own browser fingerprint

Slides courtesy of Pierre Laperdrix (Stony Brook University)

I. Example of values collected on AmIUnique



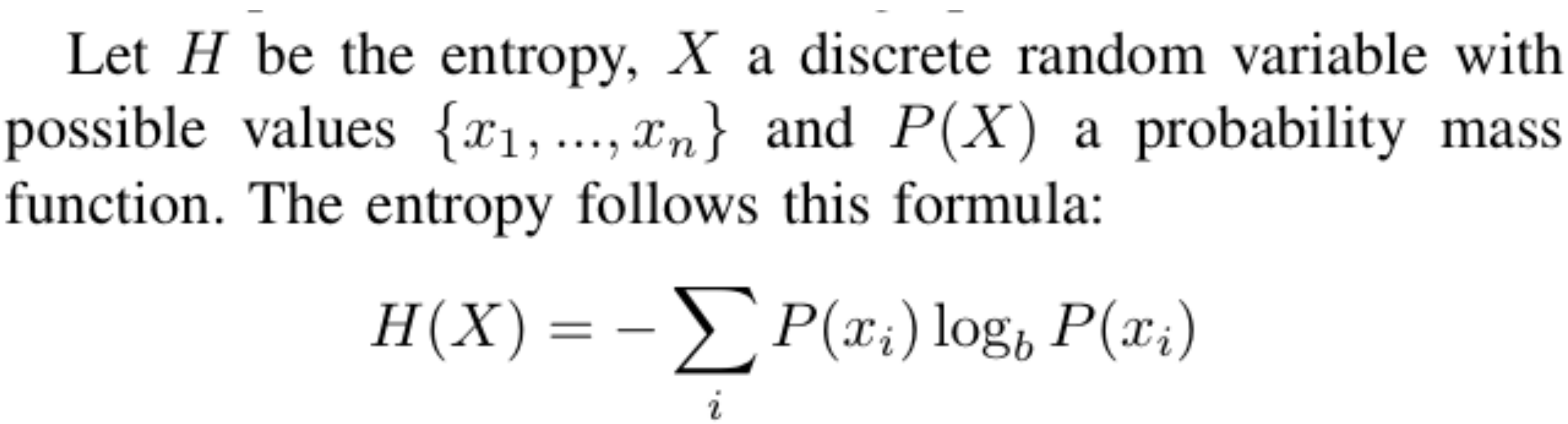
Cwm fjordbank glyphs vext quiz, 😃

Cwm fjordbank glyphs vext quiz, 😃

Slides courtesy of Pierre Laperdrix (Stony Brook University)

How unique a certain property of my browser?

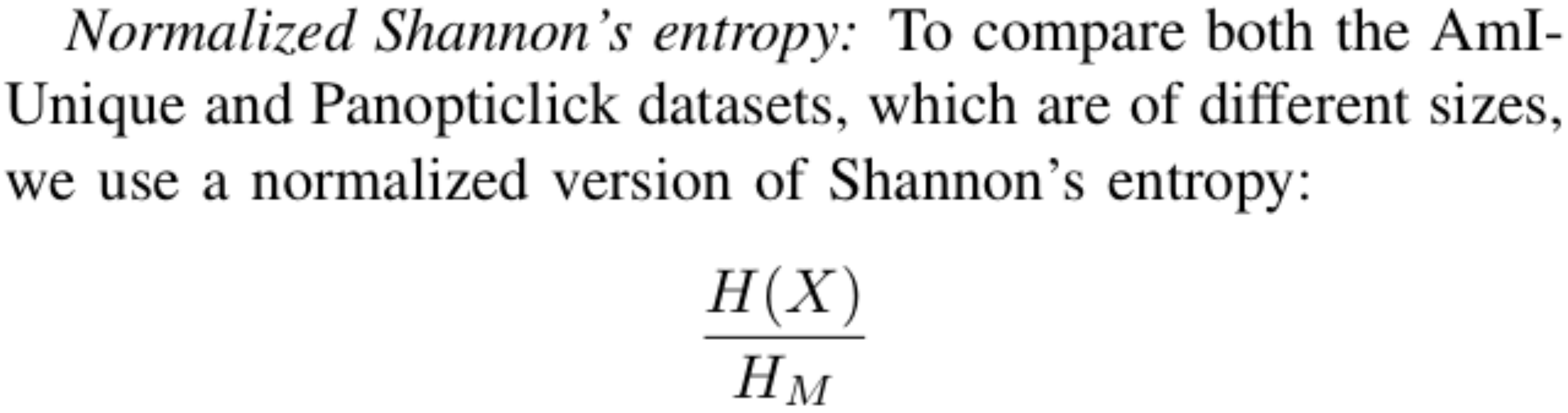
- Mathematical treatment: Entropy



Let H be the entropy, X a discrete random variable with possible values $\{x_1, ..., x_n\}$ and $P(X)$ a probability mass function. The entropy follows this formula:

$$H(X) = -\sum_i P(x_i) \log_b P(x_i)$$

What happens if datasets are of different size?



Normalized Shannon's entropy: To compare both the AmI-Unique and Panopticlick datasets, which are of different sizes, we use a normalized version of Shannon's entropy:

$$\frac{H(X)}{H_M}$$

Comparing Panopticlick and AmIUnique

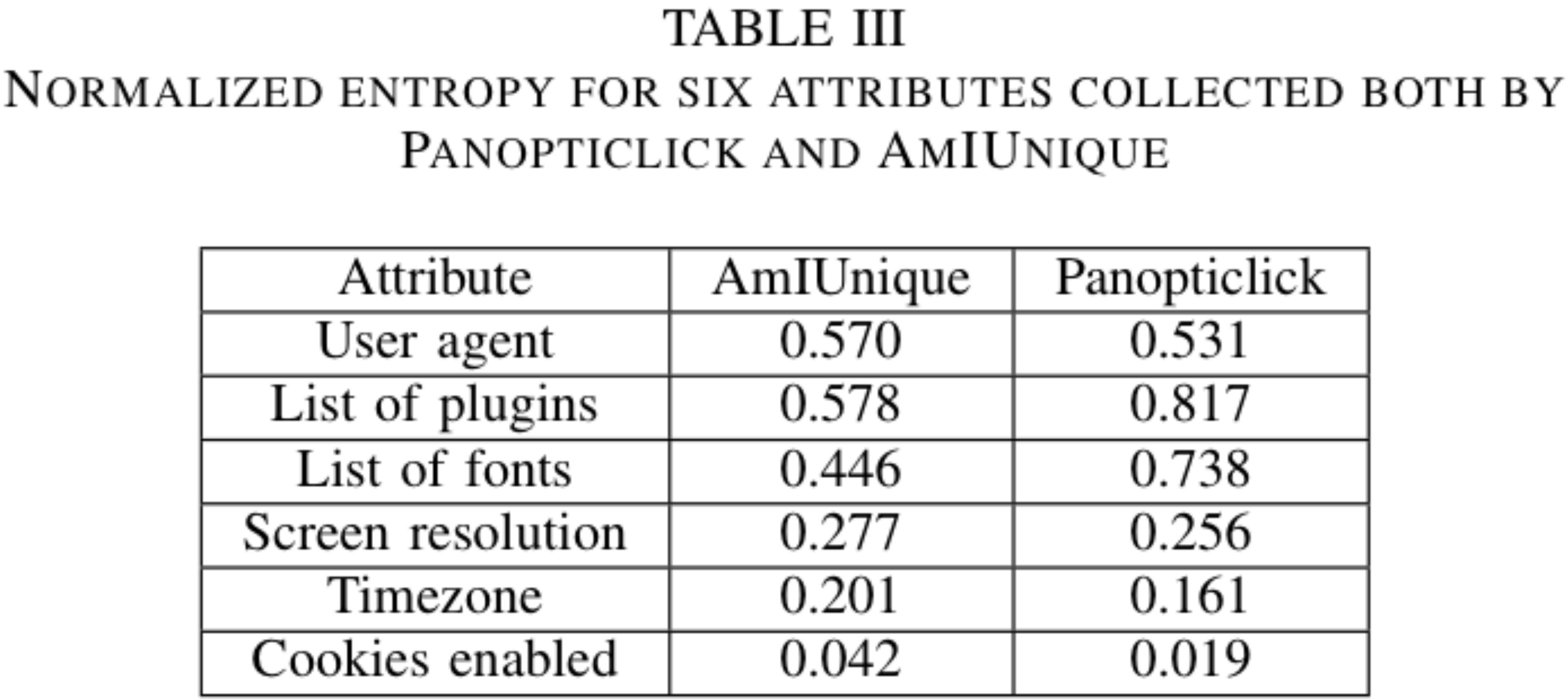


TABLE III
NORMALIZED ENTROPY FOR SIX ATTRIBUTES COLLECTED BOTH BY PANOPTICLICK AND AMIUNIQUE

Attribute	AmIUnique	Panopticlick
User agent	0.570	0.531
List of plugins	0.578	0.817
List of fonts	0.446	0.738
Screen resolution	0.277	0.256
Timezone	0.201	0.161
Cookies enabled	0.042	0.019

Another way to compare datasets: Anonymity sets

- User-agent on Desktop vs Mobile devices

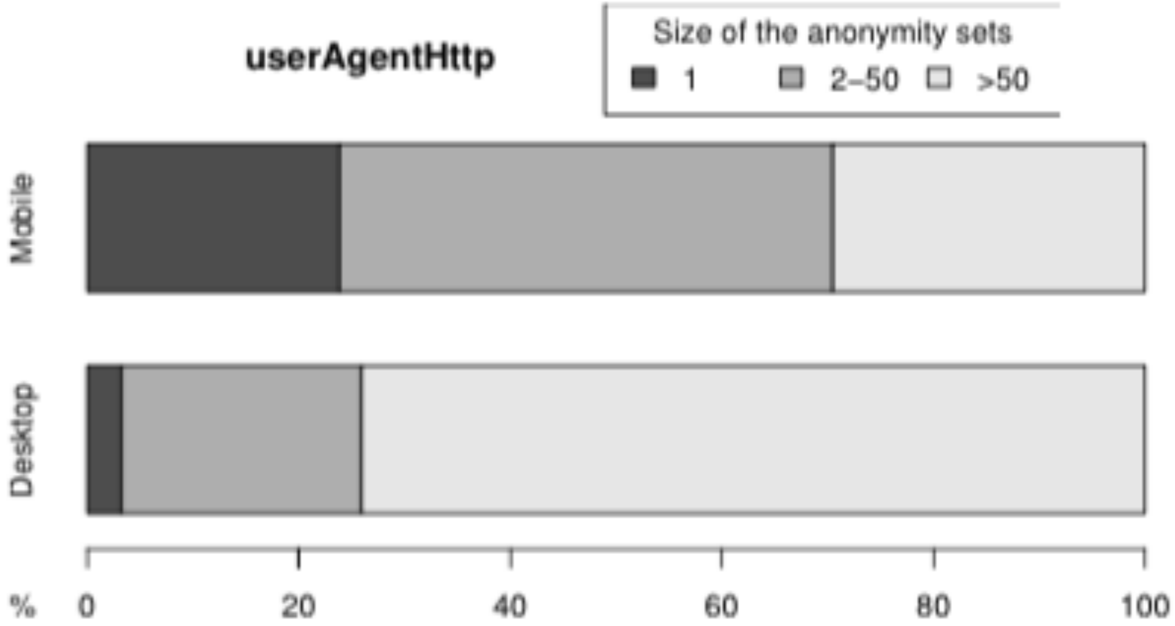


Fig. 4. Comparison of anonymity set sizes on the user-agent between desktop and mobile devices

I. Example of values collected on AmIUnique

Some user-agents

- Mozilla/5.0 (Windows NT 6.1; WOW64; rv:34.0) Gecko/20100101 Firefox/34.0
- Mozilla/5.0 (iPhone; CPU iPhone OS 8_1_2 like Mac OS X) AppleWebKit/600.1.4 (KHTML, like Gecko) Version/8.0 Mobile/12B440 Safari/600.1.4
- Mozilla/5.0 (Android; Mobile; rv:27.0) Gecko/27.0 Firefox/27.0
- Mozilla/5.0 (Macintosh; Intel Mac OS X 10_10_2) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/39.0.2171.95 Safari/537.36
- Mozilla/5.0 (X11; Ubuntu; Linux i686; rv:34.0) Gecko/20100101 Firefox/34.0

Slides courtesy of Pierre Laperdrix (Stony Brook University)

I. Example of values collected on AmIUnique

Other custom user-agents

- godzilla/5.0 (X122; BSD; rv:500.0) Gecko/20100101
- pouet
- “54. When a warlike prince attacks a powerful state, his generalship shows itself in preventing the concentration of the enemy's forces. He overawes his opponents, and their allies are prevented from joining against him.”
- Deepnet Explorer 1.5.3; Smart 2x2; Avant Browser; .NET CLR 2.0.50727; InfoPath.1)
- NSA
- Game Boy Advance
- eat it

Slides courtesy of Pierre Laperdrix (Stony Brook University)

Anonymity sets for mobile devices

- User-agent on Android vs iOS devices

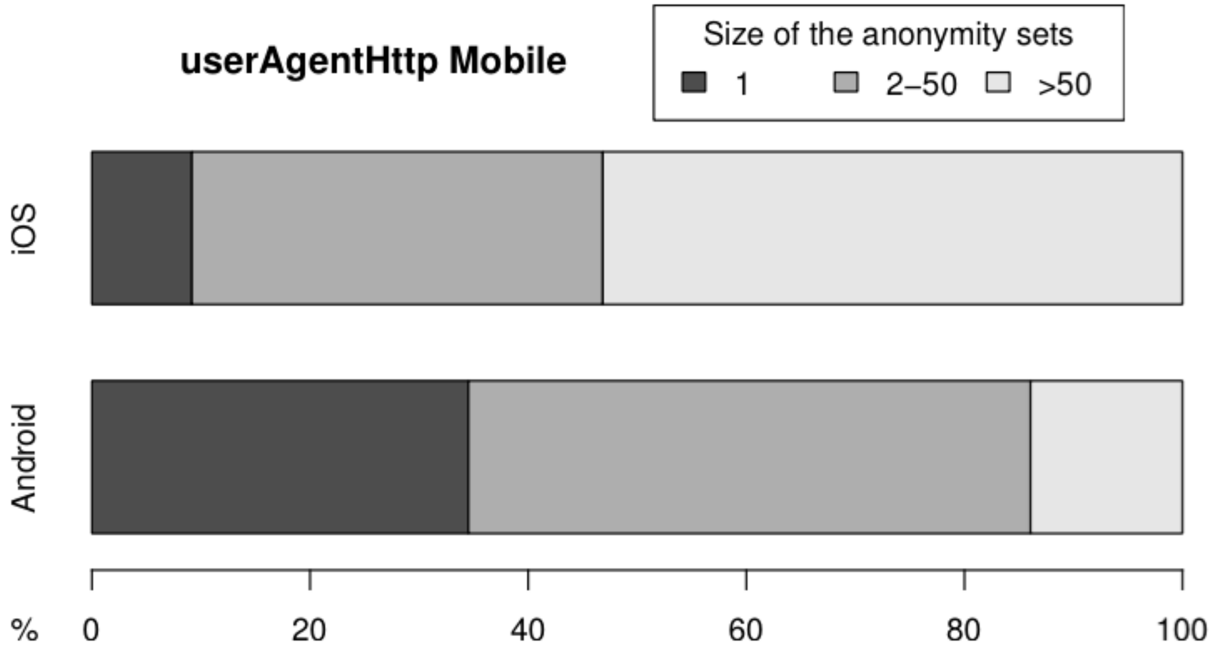


Fig. 5. Comparison of anonymity set sizes on the user-agent between Android and iOS devices

What if I disable JavaScript?

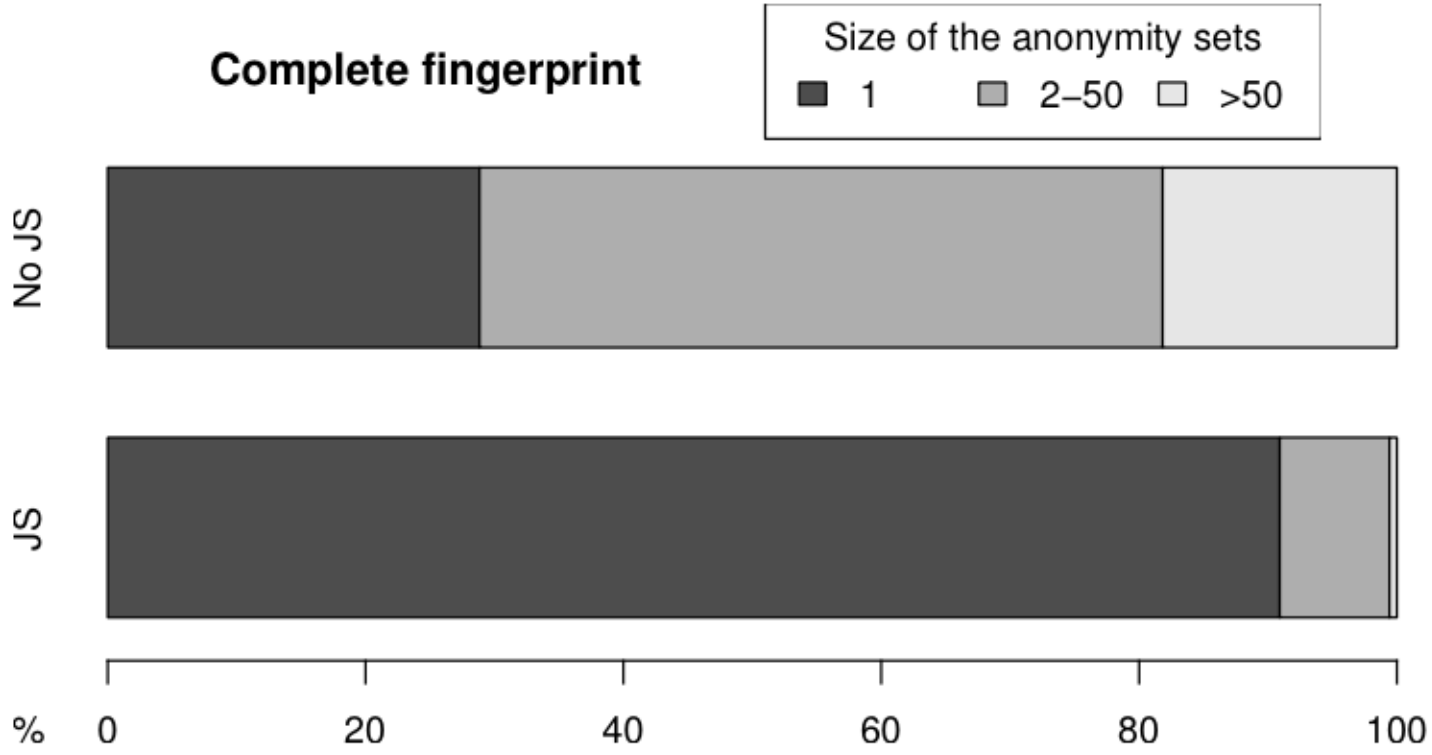


Fig. 9. Comparison of anonymity set sizes on the complete fingerprint between devices with and without JavaScript

I. Summary

- Servers can easily collect information about a device to form what is called a **browser fingerprint**.
- There is so much diversity that users can be **tracked** online if their fingerprint is **unique**.
- Test your device on

  https://amiunique.org and https://extensions.inrialpes.fr

Slides courtesy of Pierre Laperdrix (Stony Brook University)

Very hard to opt-out

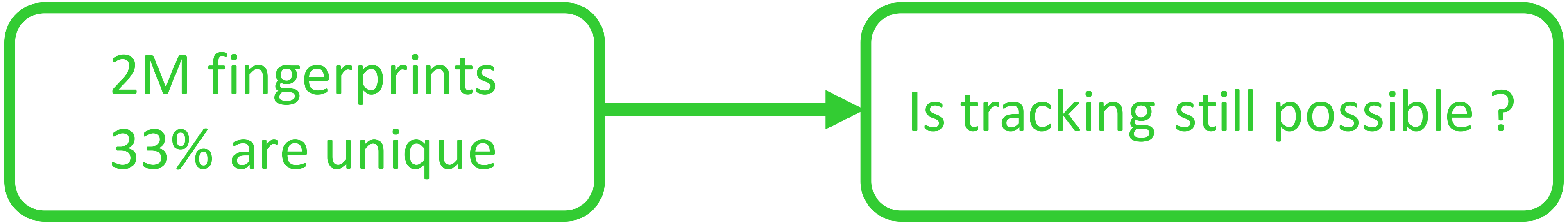
- Even if
  - you delete all the cookies
  - you clean all the storages (HTML5, Flash)
  - you use browser private mode

…your fingerprint remains the same!

Courtesy of Nick Nikiforakis

I. Summary

- How effective is fingerprinting at large scale?



2M fingerprints
33% are unique

Is tracking still possible ?

Hiding in the Crowd: an Analysis of the Effectiveness of Browser Fingerprinting at Large Scale
Alejandro Gómez-Boix, Pierre Laperdrix, Benoit Baudry
The Web Conference (**WWW 2018**)

Slides courtesy of Pierre Laperdrix (Stony Brook University)

2M users in France (WWW 2018)

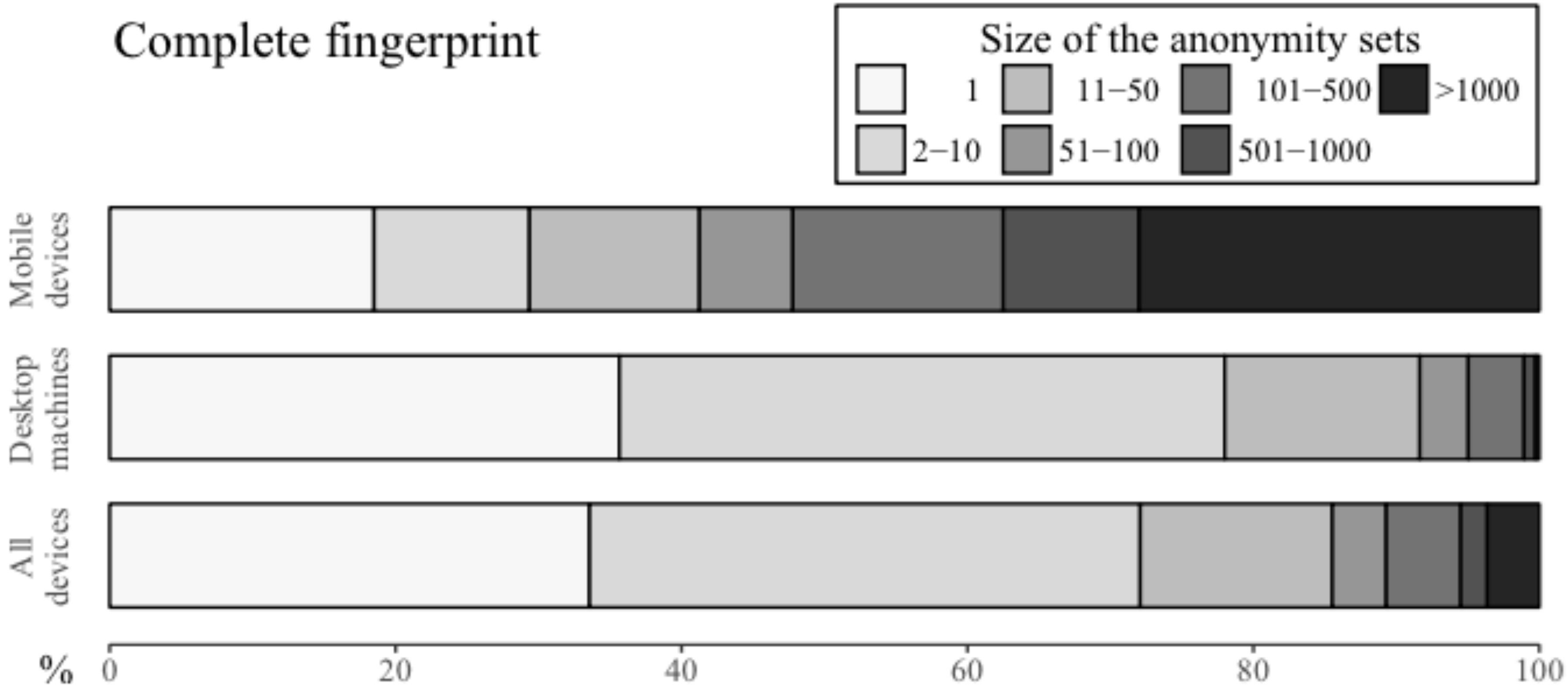


Figure 3: Comparison of anonymity set sizes between mobile devices and desktop/laptop machines.

Slides courtesy of Pierre Laperdrix (Stony Brook University)

2M users in France (WWW 2018)

- Why the results are so different? Bias in the previous datasets?

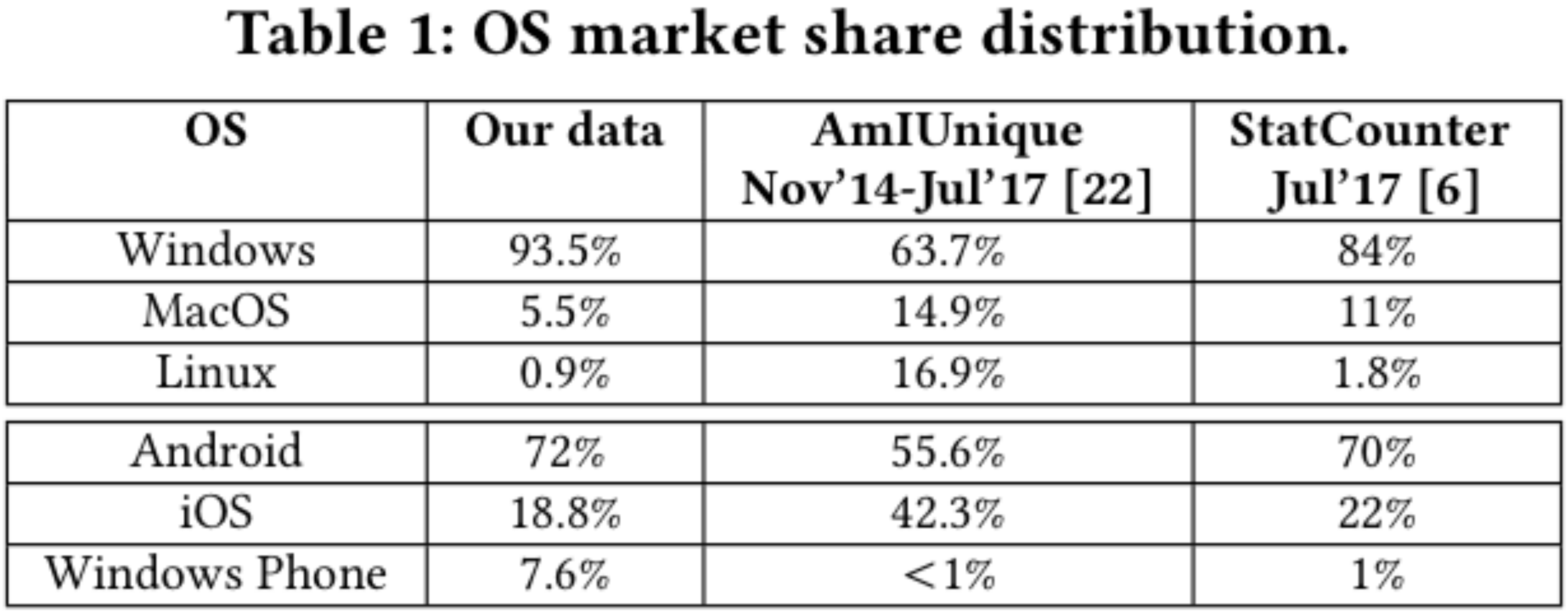


Table 1: OS market share distribution.

OS	Our data	AmIUnique Nov'14-Jul'17 [22]	StatCounter Jul'17 [6]
Windows	93.5%	63.7%	84%
MacOS	5.5%	14.9%	11%
Linux	0.9%	16.9%	1.8%
Android	72%	55.6%	70%
iOS	18.8%	42.3%	22%
Windows Phone	7.6%	<1%	1%

Slides courtesy of Pierre Laperdrix (Stony Brook University)

Comparison between WWW 2018 and previous studies

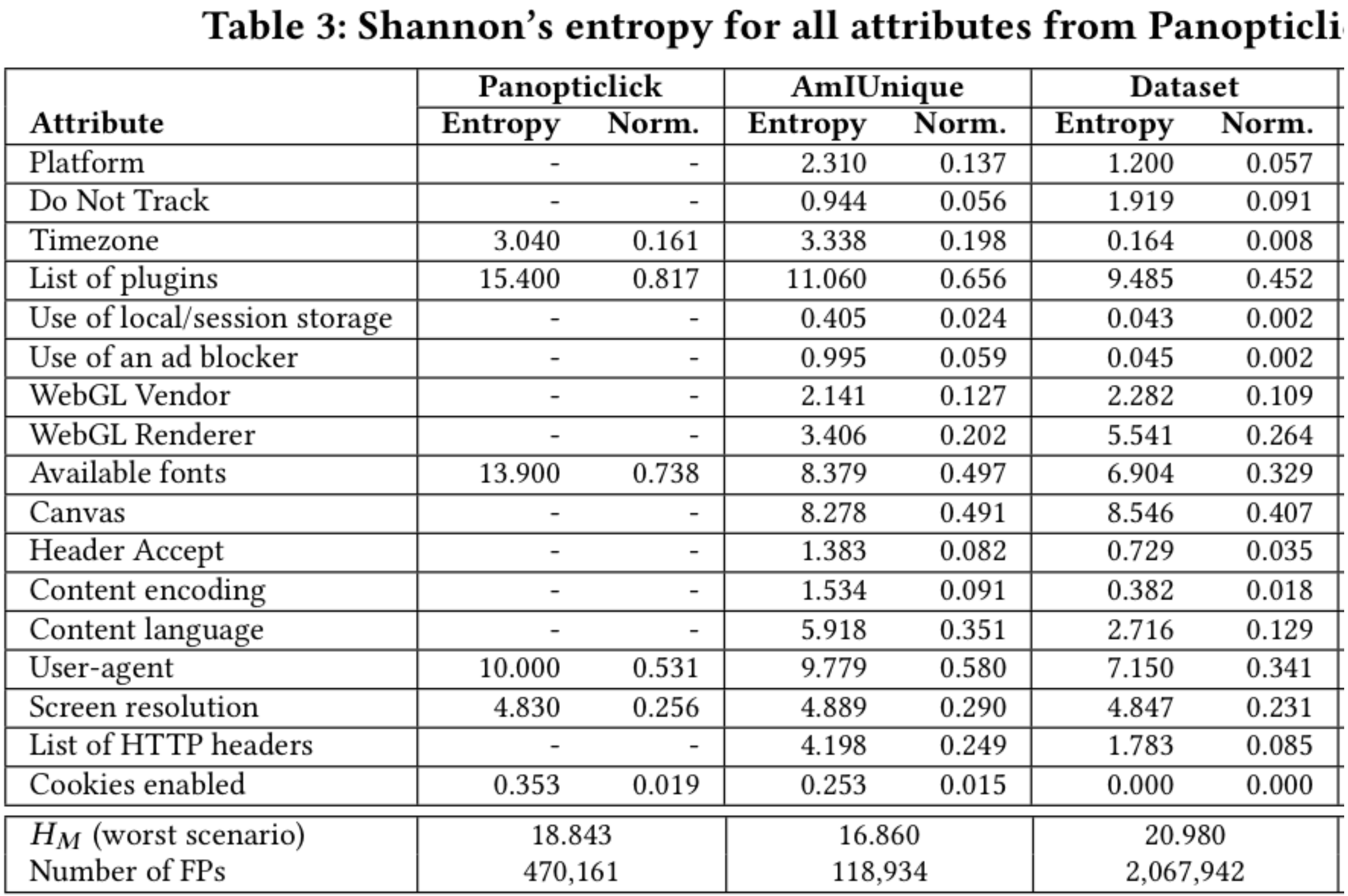


Table 3: Shannon's entropy for all attributes from Panopticli

Attribute	Panopticlick		AmIUnique		Dataset	
	Entropy	Norm.	Entropy	Norm.	Entropy	Norm.
Platform	-	-	2.310	0.137	1.200	0.057
Do Not Track	-	-	0.944	0.056	1.919	0.091
Timezone	3.040	0.161	3.338	0.198	0.164	0.008
List of plugins	15.400	0.817	11.060	0.656	9.485	0.452
Use of local/session storage	-	-	0.405	0.024	0.043	0.002
Use of an ad blocker	-	-	0.995	0.059	0.045	0.002
WebGL Vendor	-	-	2.141	0.127	2.282	0.109
WebGL Renderer	-	-	3.406	0.202	5.541	0.264
Available fonts	13.900	0.738	8.379	0.497	6.904	0.329
Canvas	-	-	8.278	0.491	8.546	0.407
Header Accept	-	-	1.383	0.082	0.729	0.035
Content encoding	-	-	1.534	0.091	0.382	0.018
Content language	-	-	5.918	0.351	2.716	0.129
User-agent	10.000	0.531	9.779	0.580	7.150	0.341
Screen resolution	4.830	0.256	4.889	0.290	4.847	0.231
List of HTTP headers	-	-	4.198	0.249	1.783	0.085
Cookies enabled	0.353	0.019	0.253	0.015	0.000	0.000
H_M (worst scenario)	18.843		16.860		20.980	
Number of FPs	470,161		118,934		2,067,942	

New Fingerprinting Methods

- **Privacy Paradox**
  - Users’ fingerprints can be enriched by their browser extensions
  - Moreover, we found an attack allows to detect 58 web services where the user is logged in!

G.G. Gulyás, D. F. Some, **N. Bielova** and C. Castelluccia. To Extend or not to Extend: on the Uniqueness of Browser Extensions and Web Logins. *WPES@ACM CCS 2018.*

I. Plugins VS Browser extensions

- **Plugins** were created to display content not supported by the browser
  - Flash Java Silverlight
- All installed plugins are accessible via the `navigator.plugins` JavaScript object

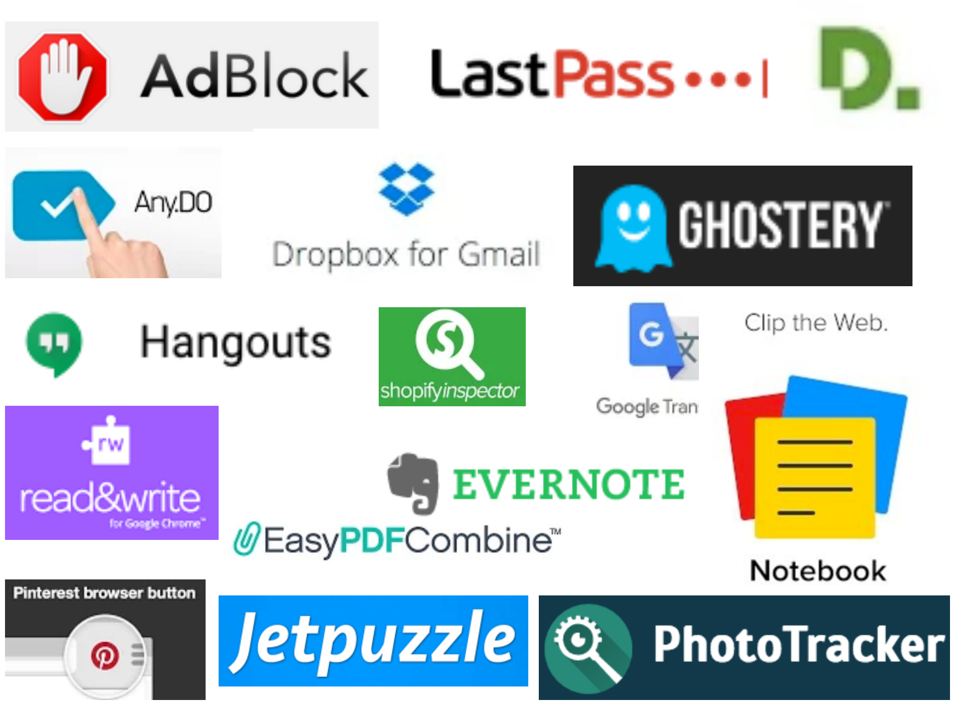
- **Extensions** extend or modify default behavior of a browser
  - AdBlockPlus, LastPass, Ghostery, Pinterest
- There is no API that webpages can use to detect all installed extensions

Slides courtesy of Pierre Laperdrix (Stony Brook University)

How unique is your browser?

https://extensions.inrialpes.fr

- Browser extension detection
- ~13 000 extensions



- Websites a user is logged in
- 58 websites

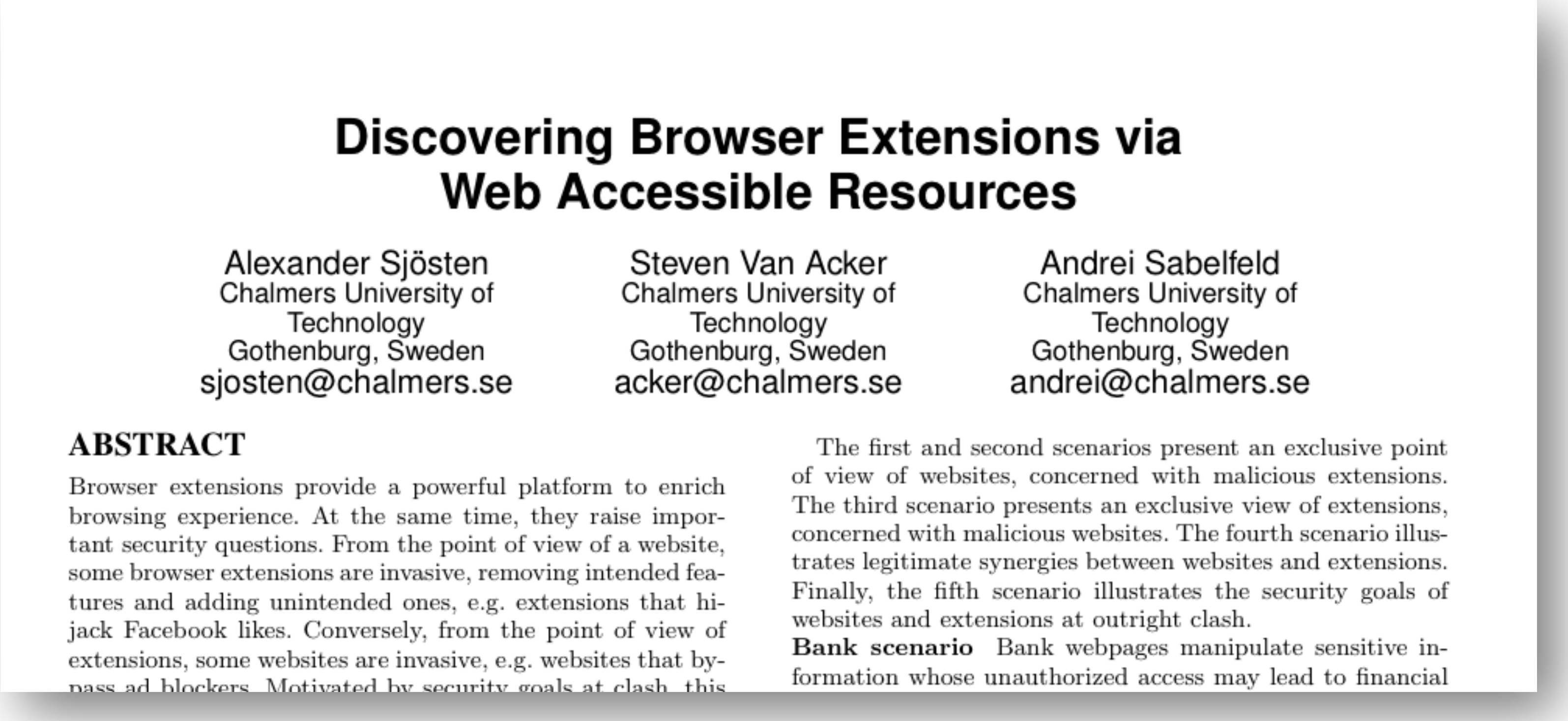
twitter
YouTube
f
g+
skype
Pinterest
flickr
EVERNOTE
Meetup
Spotify
PayPal
Y
amazon
airbnb
GitHub
Bitbucket
Dropbox
Academia.edu
inria
informatics mathematics

Browser extension detection

- via **Web Accessible Resources**

chrome-extension://gpdjojdkbbmdfjfahjcgigfpmkopogic/img/icon_48.png

unique extension ID



Discovering Browser Extensions via Web Accessible Resources

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ABSTRACT

Browser extensions provide a powerful platform to enrich browsing experience. At the same time, they raise important security questions. From the point of view of a website, some browser extensions are invasive, removing intended features and adding unintended ones, e.g. extensions that hijack Facebook likes. Conversely, from the point of view of extensions, some websites are invasive, e.g. websites that bypass ad blockers. Motivated by security goals at clash, this

The first and second scenarios present an exclusive point of view of websites, concerned with malicious extensions. The third scenario presents an exclusive view of extensions, concerned with malicious websites. The fourth scenario illustrates legitimate synergies between websites and extensions. Finally, the fifth scenario illustrates the security goals of websites and extensions at outright clash.

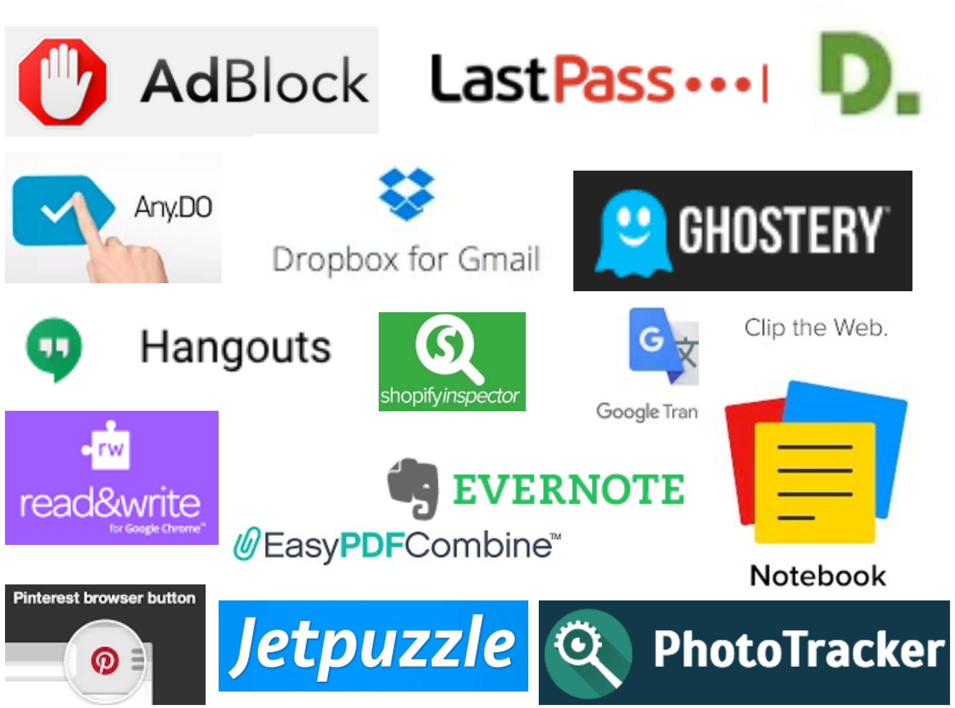
Bank scenario Bank webpages manipulate sensitive information whose unauthorized access may lead to financial

based on slides of Gábor György Gulyás

How unique is your browser?

https://extensions.inrialpes.fr

- Browser extension detection
- ~13 000 extensions

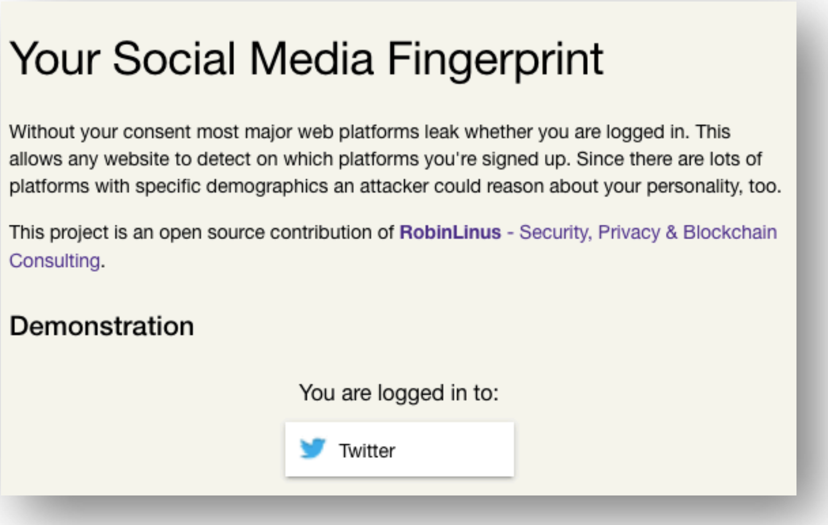


- Websites a user is logged in
- 58 websites

Detection of websites a user logged in

- Redirection URL hijacking @robin_linus

- Abusing Content Security Policy (CSP) – no JavaScript needed @homakov



Your Social Media Fingerprint

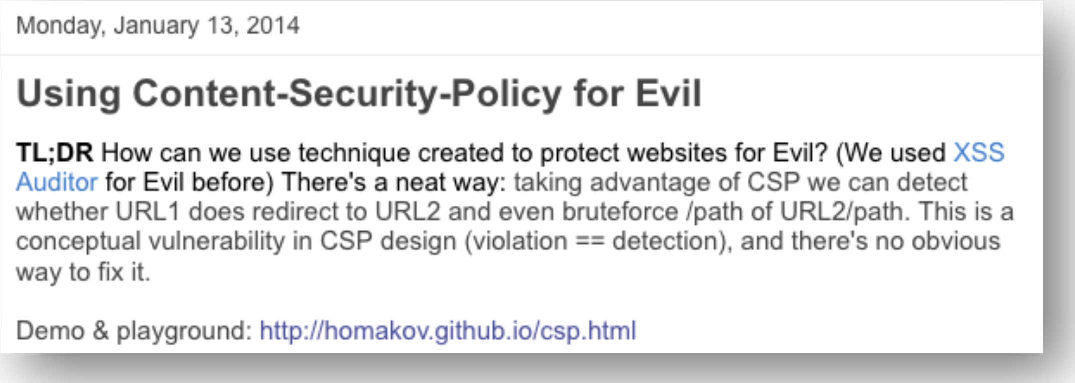
Without your consent most major web platforms leak whether you are logged in. This allows any website to detect on which platforms you're signed up. Since there are lots of platforms with specific demographics an attacker could reason about your personality, too.

This project is an open source contribution of RobinLinus - Security, Privacy & Blockchain Consulting.

Demonstration

You are logged in to:

Twitter



Monday, January 13, 2014

Using Content-Security-Policy for Evil

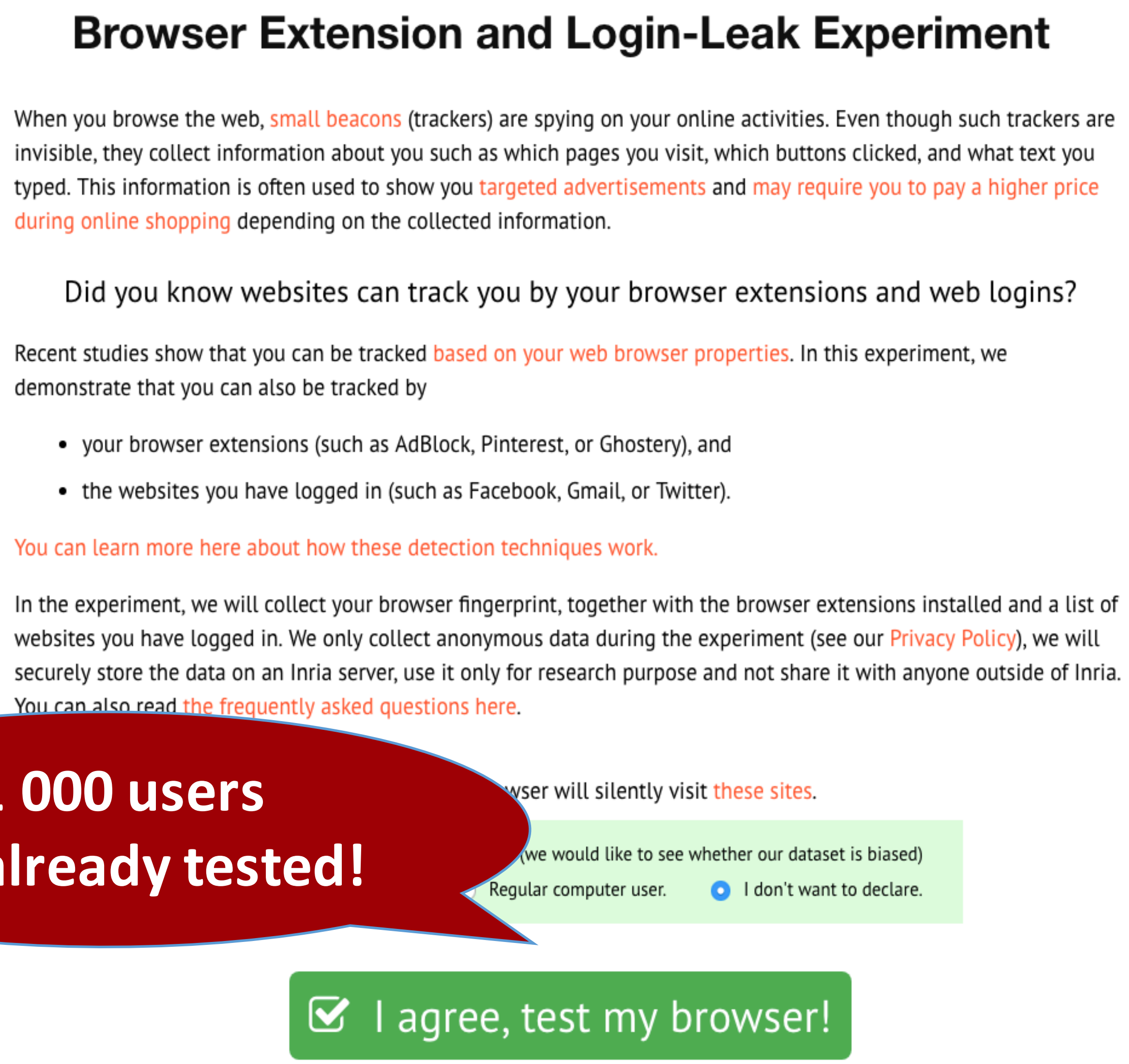
TL;DR How can we use technique created to protect websites for Evil? (We used XSS Auditor for Evil before) There's a neat way: taking advantage of CSP we can detect whether URL1 does redirect to URL2 and even bruteforce /path of URL2/path. This is a conceptual vulnerability in CSP design (violation == detection), and there's no obvious way to fix it.

Demo & playground: http://homakov.github.io/csp.html

based on slides of Gábor György Gulyás

How unique is your browser?

https://extensions.inrialpes.fr



Browser Extension and Login-Leak Experiment

When you browse the web, small beacons (trackers) are spying on your online activities. Even though such trackers are invisible, they collect information about you such as which pages you visit, which buttons clicked, and what text you typed. This information is often used to show you targeted advertisements and may require you to pay a higher price during online shopping depending on the collected information.

Did you know websites can track you by your browser extensions and web logins?

Recent studies show that you can be tracked based on your web browser properties. In this experiment, we demonstrate that you can also be tracked by

- your browser extensions (such as AdBlock, Pinterest, or Ghostery), and
- the websites you have logged in (such as Facebook, Gmail, or Twitter).

You can learn more here about how these detection techniques work.

In the experiment, we will collect your browser fingerprint, together with the browser extensions installed and a list of websites you have logged in. We only collect anonymous data during the experiment (see our Privacy Policy), we will securely store the data on an Inria server, use it only for research purpose and not share it with anyone outside of Inria. You can also read the frequently asked questions here.

wser will silently visit these sites.

(we would like to see whether our dataset is biased)

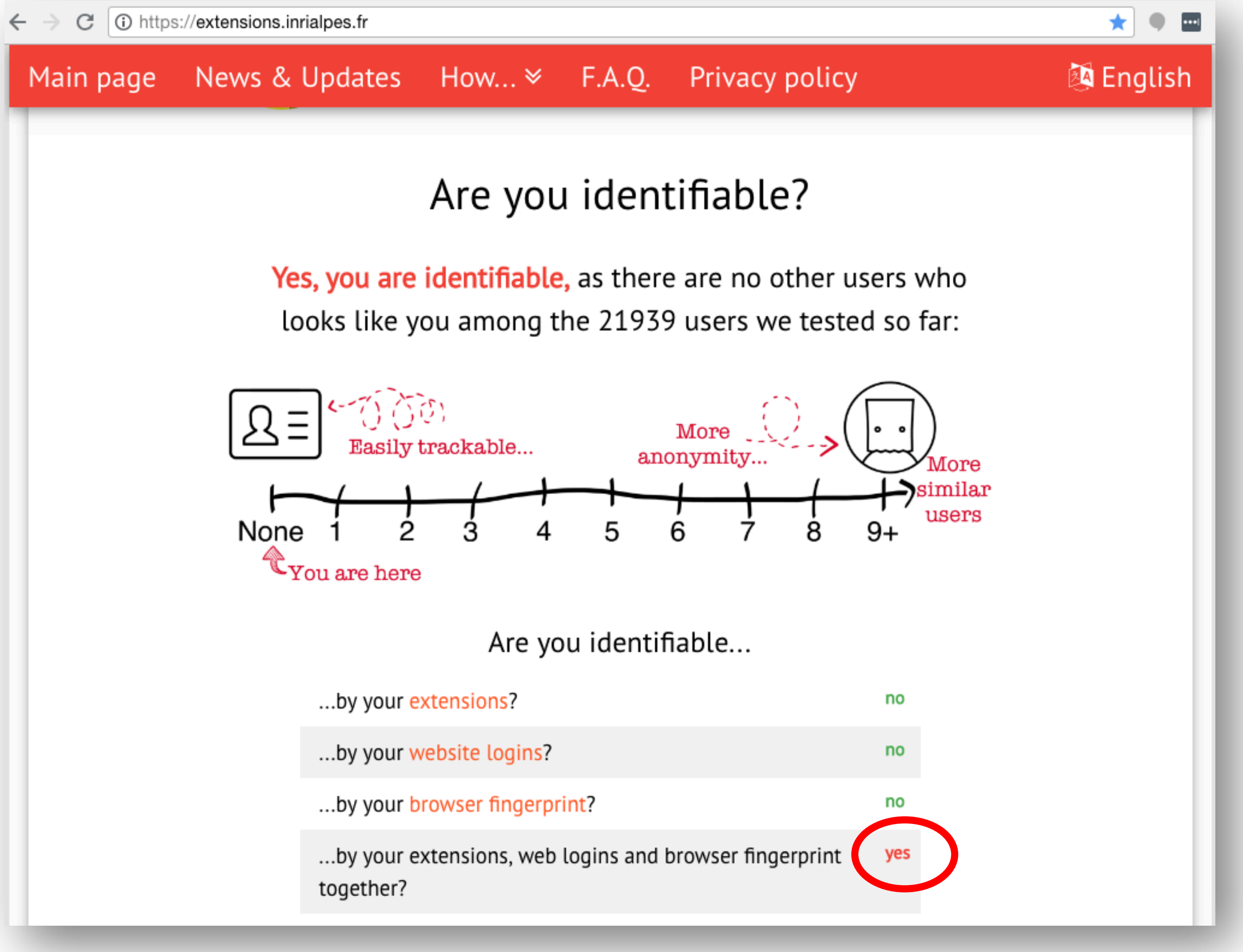
Regular computer user. ● I don't want to declare.

☑ I agree, test my browser!

21 000 users
have already tested!

How unique is your browser?

https://extensions.inrialpes.fr



Are you identifiable?

Yes, you are identifiable, as there are no other users who looks like you among the 21939 users we tested so far:

Are you identifiable...

...by your extensions?	no
...by your website logins?	no
...by your browser fingerprint?	no
...by your extensions, web logins and browser fingerprint together?	yes

User dataset w.r.t previous studies

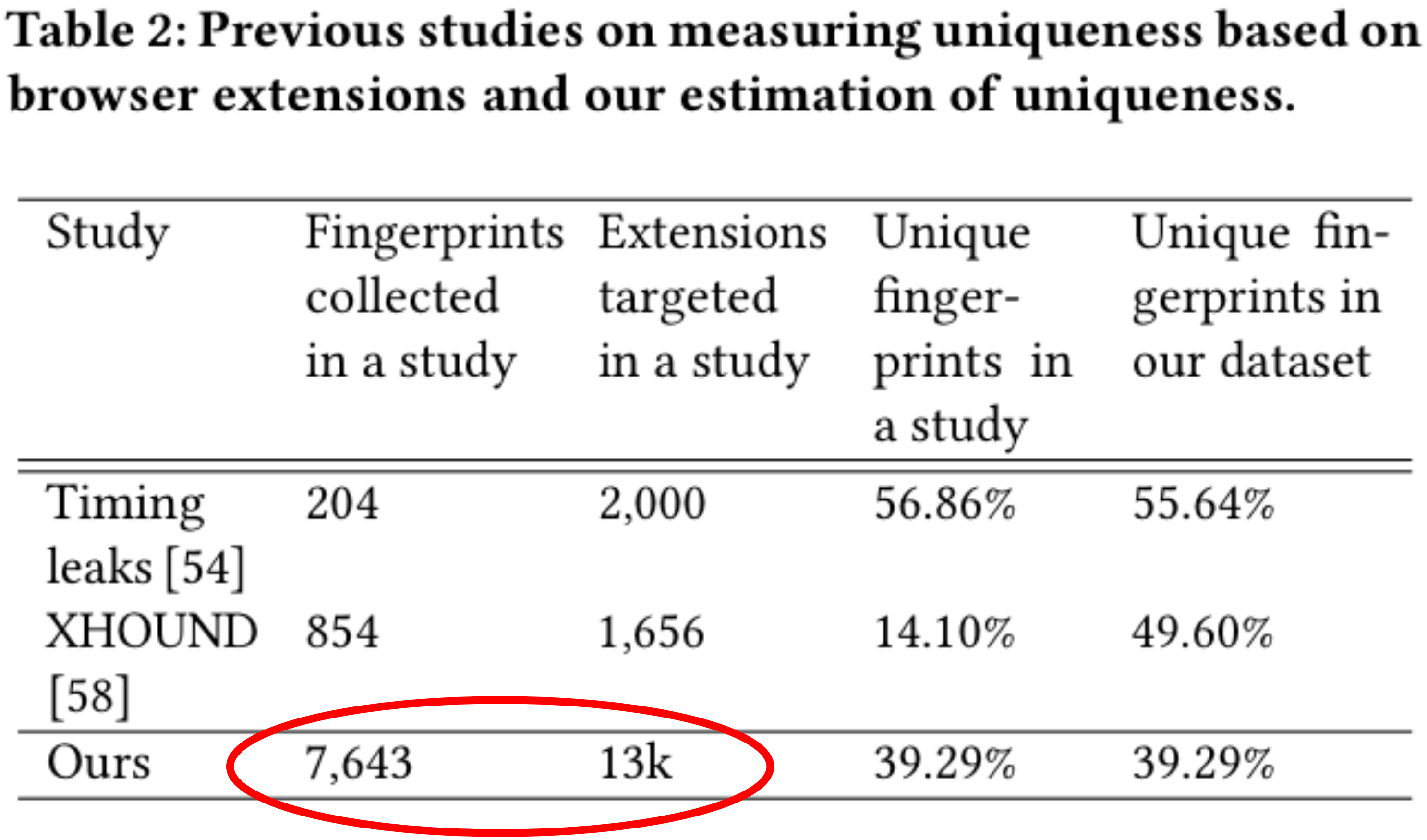


Table 2: Previous studies on measuring uniqueness based on browser extensions and our estimation of uniqueness.

Study	Fingerprints collected in a study	Extensions targeted in a study	Unique fingerprints in a study	Unique fingerprints in our dataset
Timing leaks [54]	204	2,000	56.86%	55.64%
XHOUND [58]	854	1,656	14.10%	49.60%
Ours	7,643	13k	39.29%	39.29%

Uniqueness grows as the dataset grows!

How to get a meaningful dataset?

How to define when we have enough users?

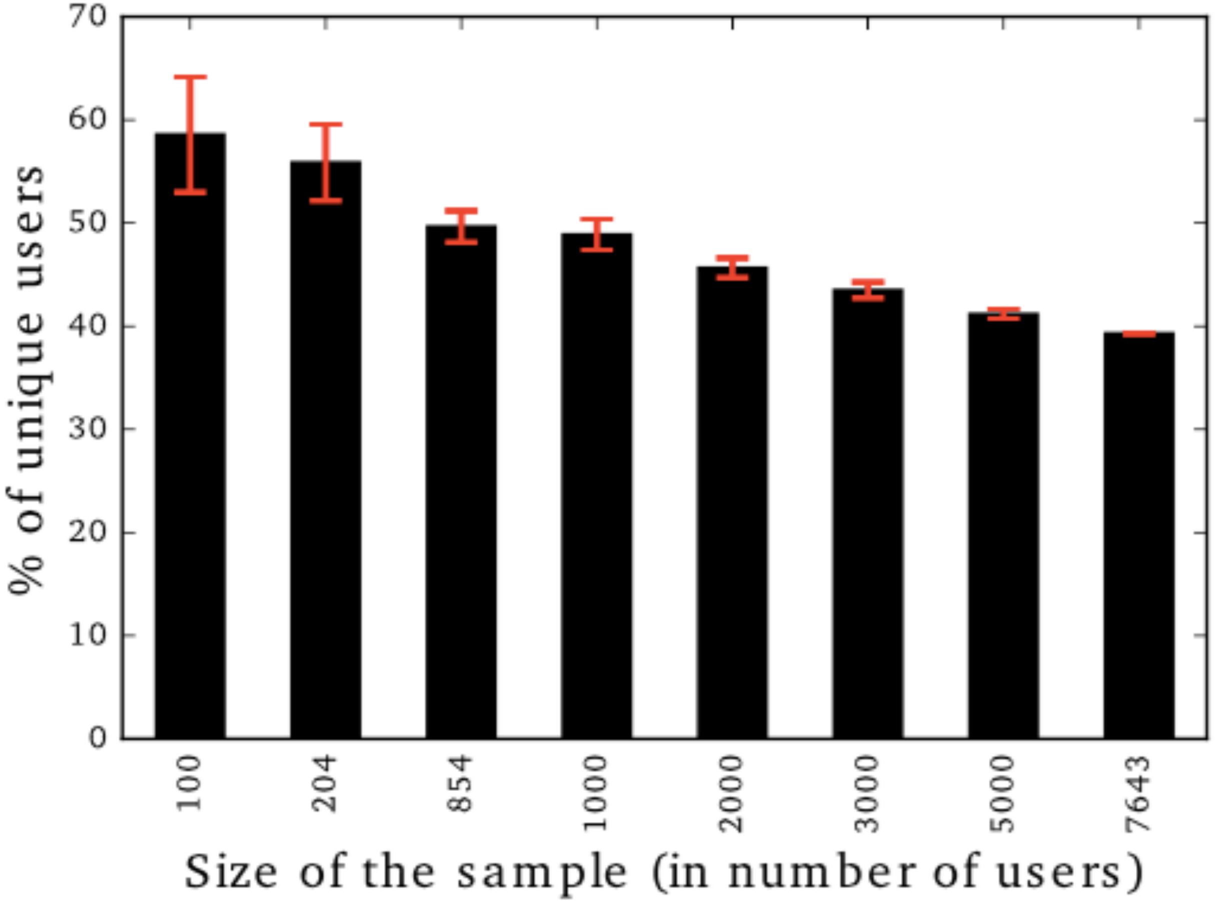
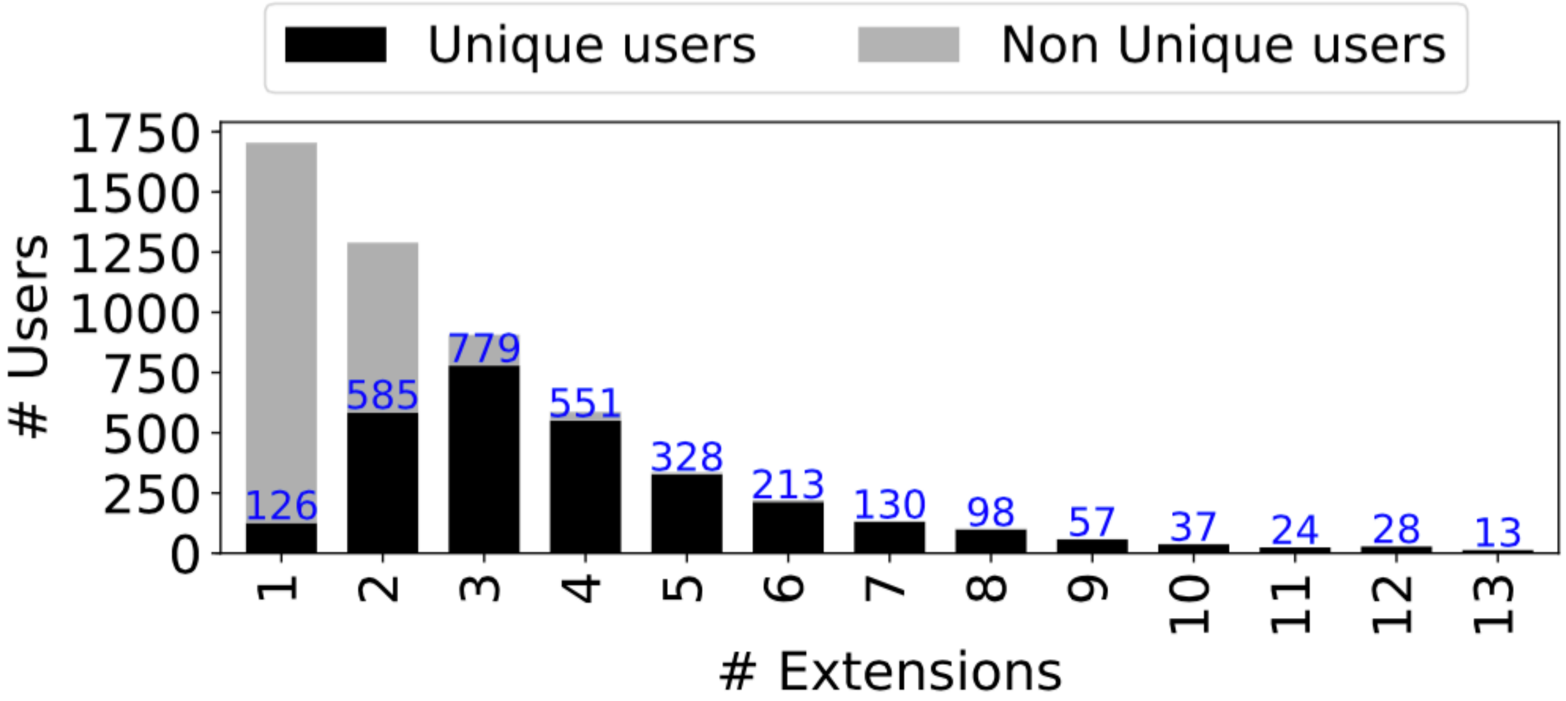


Figure 13: Uniqueness of Chrome users based on their extensions only vs. number of users - 204 is the number of users used in [54] and 854 the number of users considered in [58]

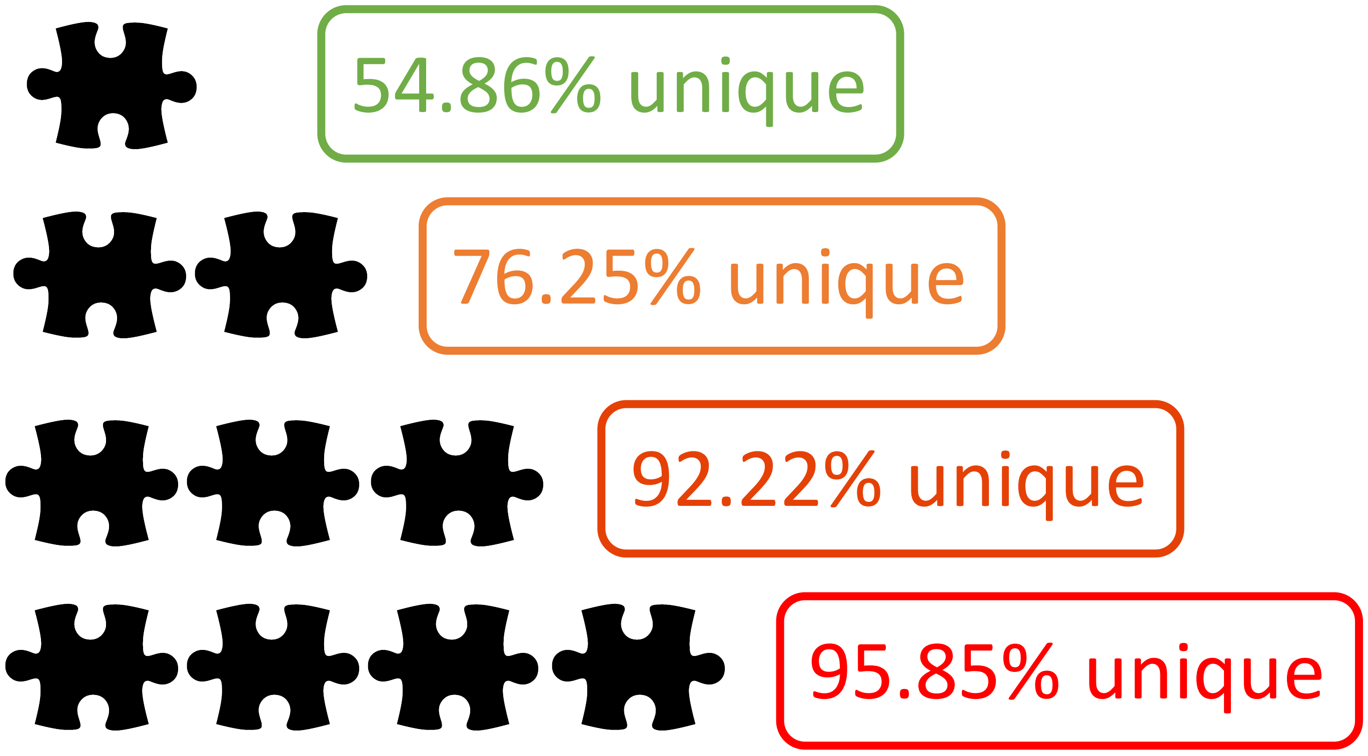
How many extensions our users have?

7,643 users of Google Chrome browser



G.G. Gulyás, D. F. Some, **N. Bielova** and C. Castelluccia. To Extend or not to Extend: on the Uniqueness of Browser Extensions and Web Logins. *WPES@ACM CCS 2018.*

Am I really unique if I use a few extensions?



54.86% unique

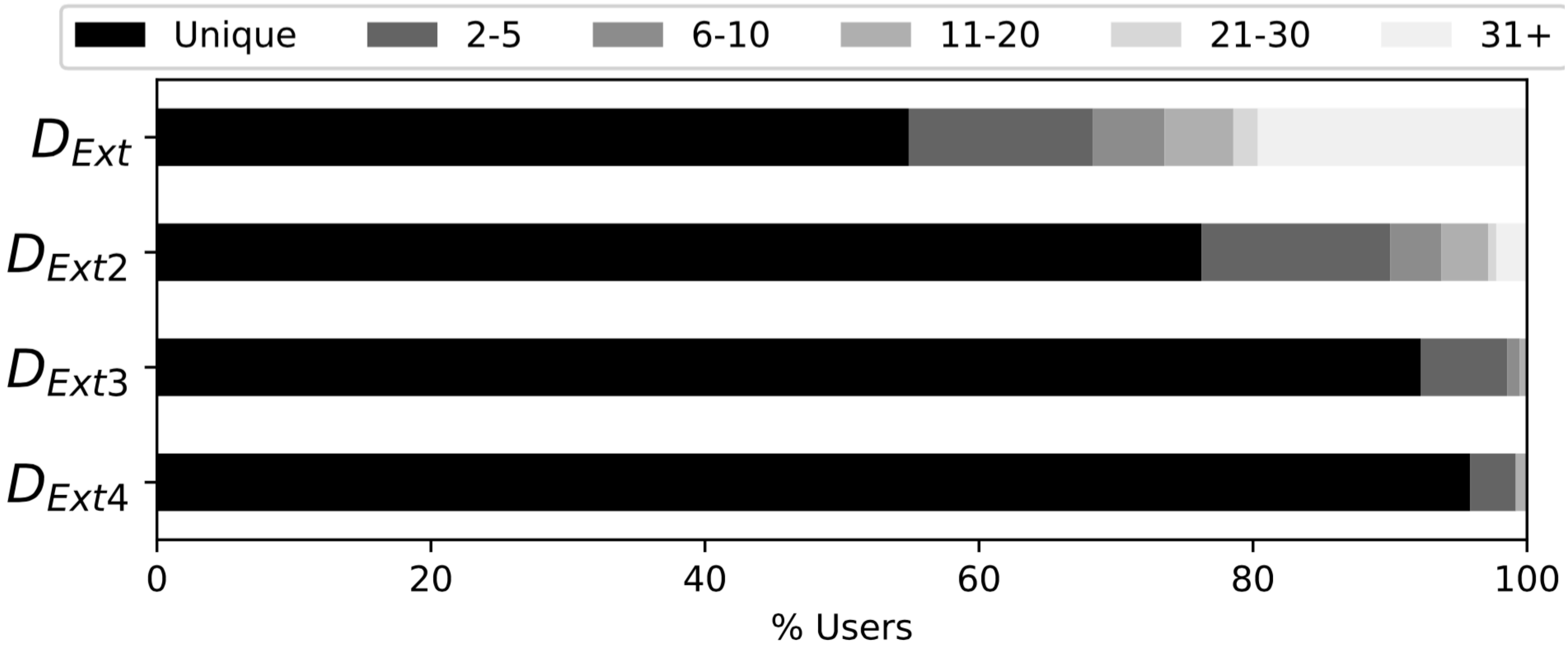
76.25% unique

92.22% unique

95.85% unique

G.G. Gulyás, D. F. Some, **N. Bielova** and C. Castelluccia. To Extend or not to Extend: on the Uniqueness of Browser Extensions and Web Logins. *WPES@ACM CCS 2018.*

The more extensions you install, the more unique you are!



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The dilemma of privacy extensions

- Privacy extensions **block some trackers**
- Privacy extensions **make a user more unique**

- What is the trade-off between **privacy gain** (some trackers are blocked) and **privacy loss** (user is more unique)?

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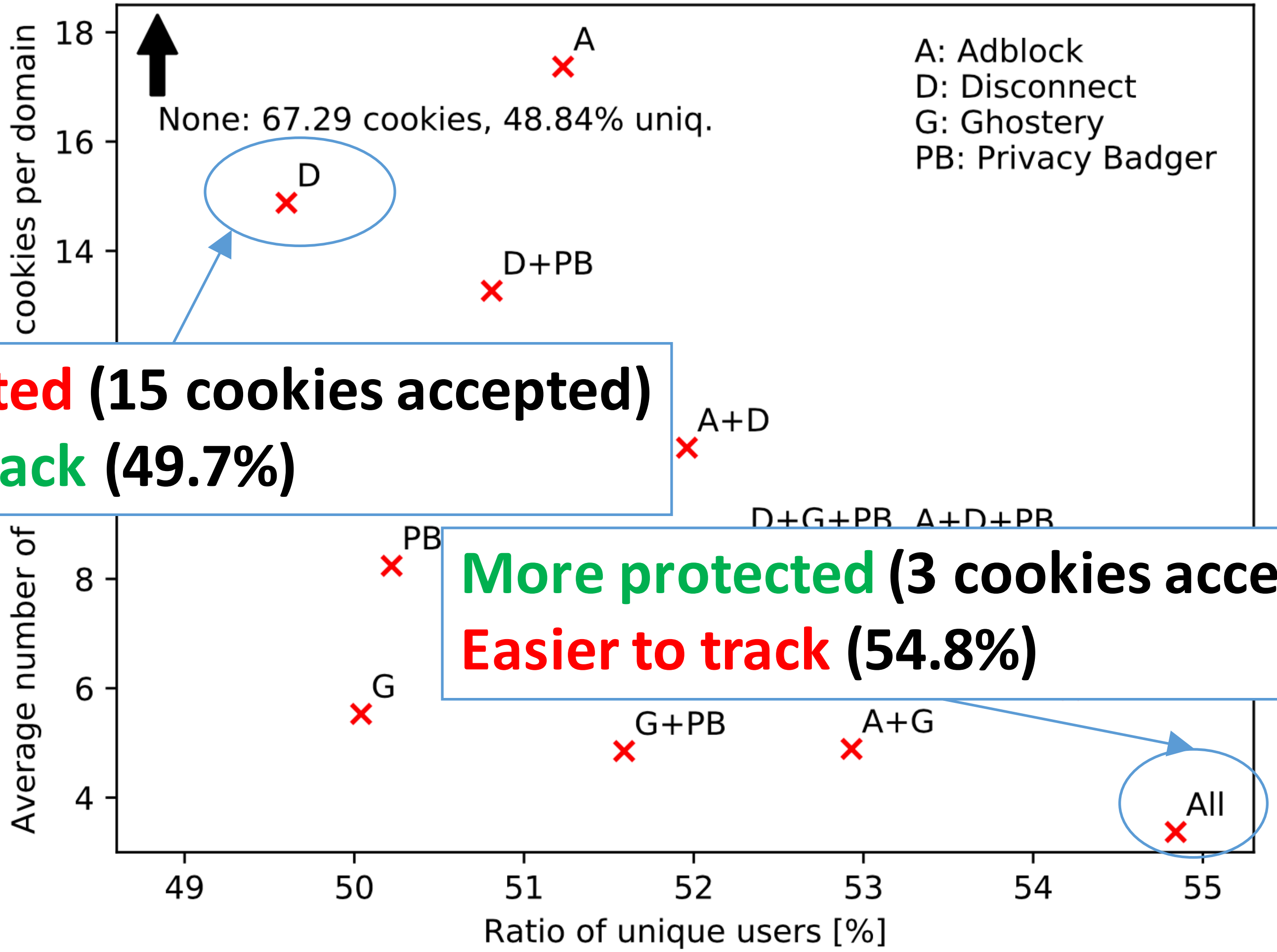
Uniqueness of users vs. number of accepted third-party cookies



Less protected (15 cookies accepted)
Harder to track (49.7%)

More protected (3 cookies accepted)
Easier to track (54.8%)

*4,000 pages crawled