Users Pay Twice: The Hidden Energy Cost of Web Advertising

Samuel Pélissier, Naif Mehanna, Sterenn Roux, Quentin Perez, Walter Rudametkin, Johann Bourcier, Pierre Laperdrix

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The Web: land of the free

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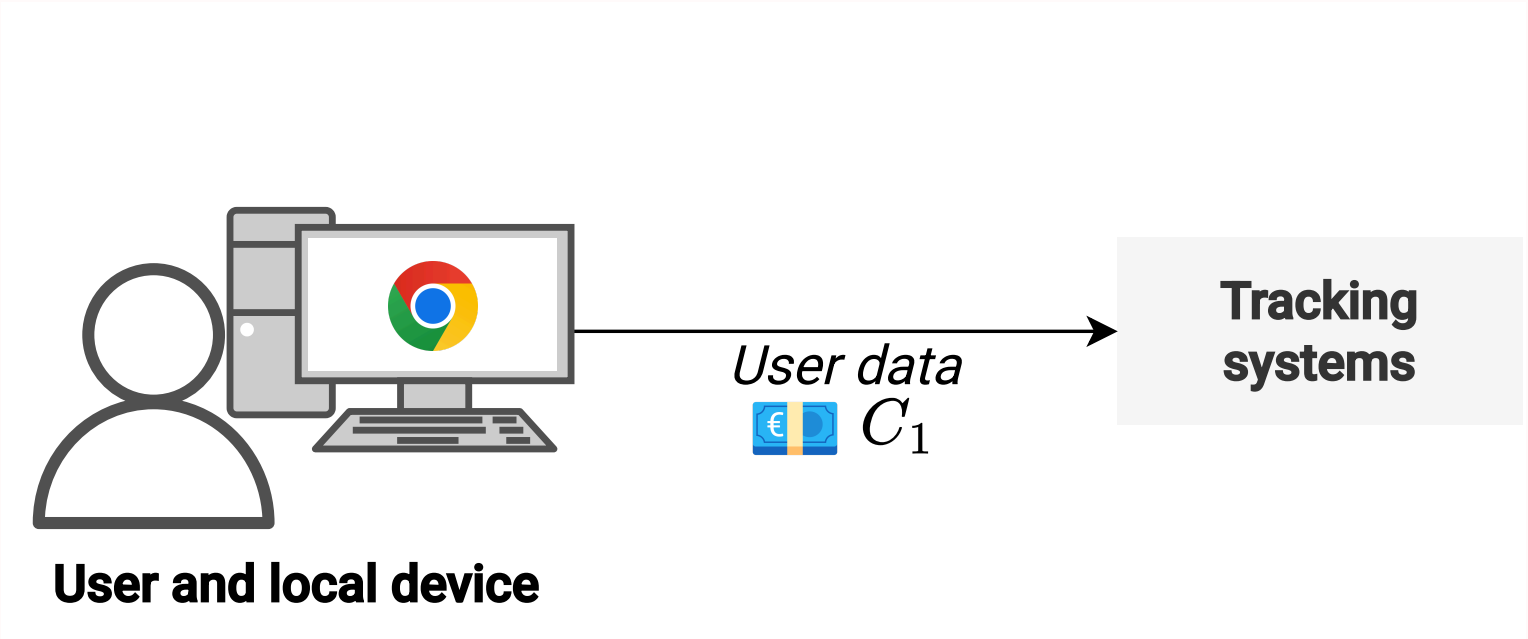
The Web is funded by **ads**.

Users Pay Twice

To access the Web for free, users pay:

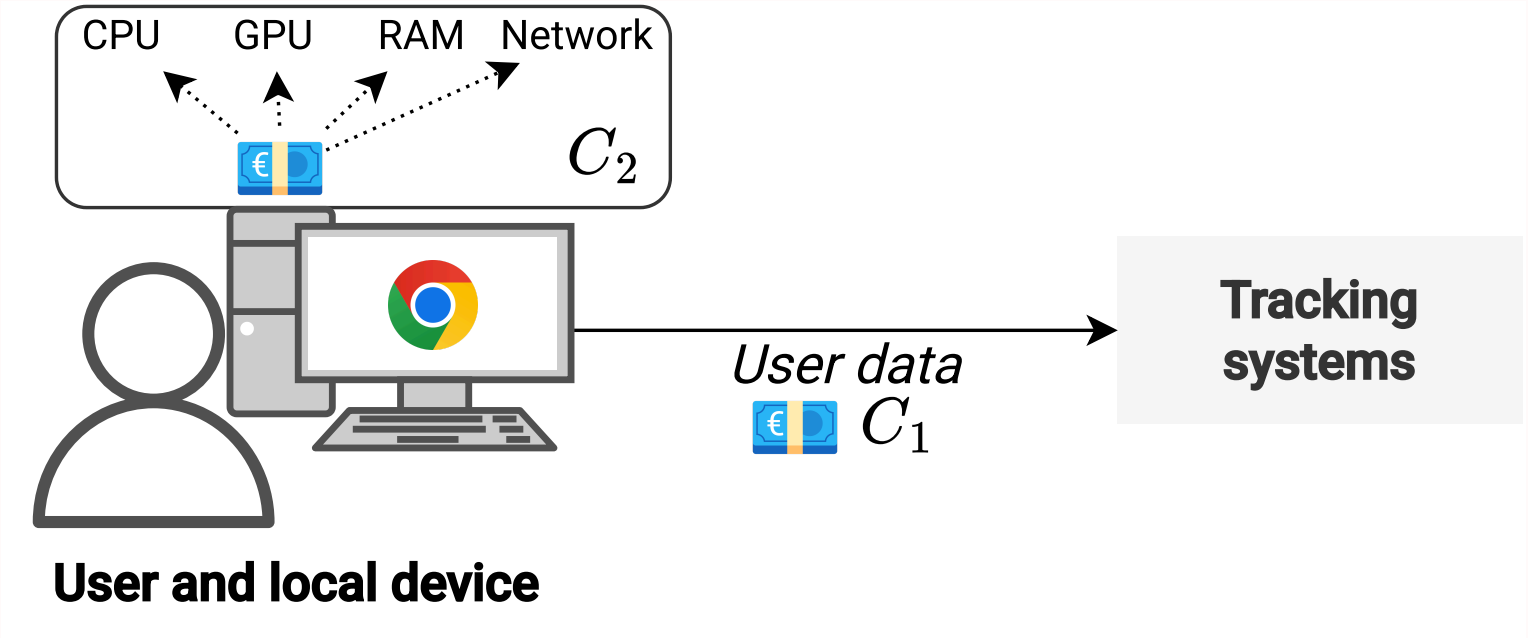
- With their data (👍 funds the Web 👎 privacy; well-documented tradeoff)
-



Users Pay Twice

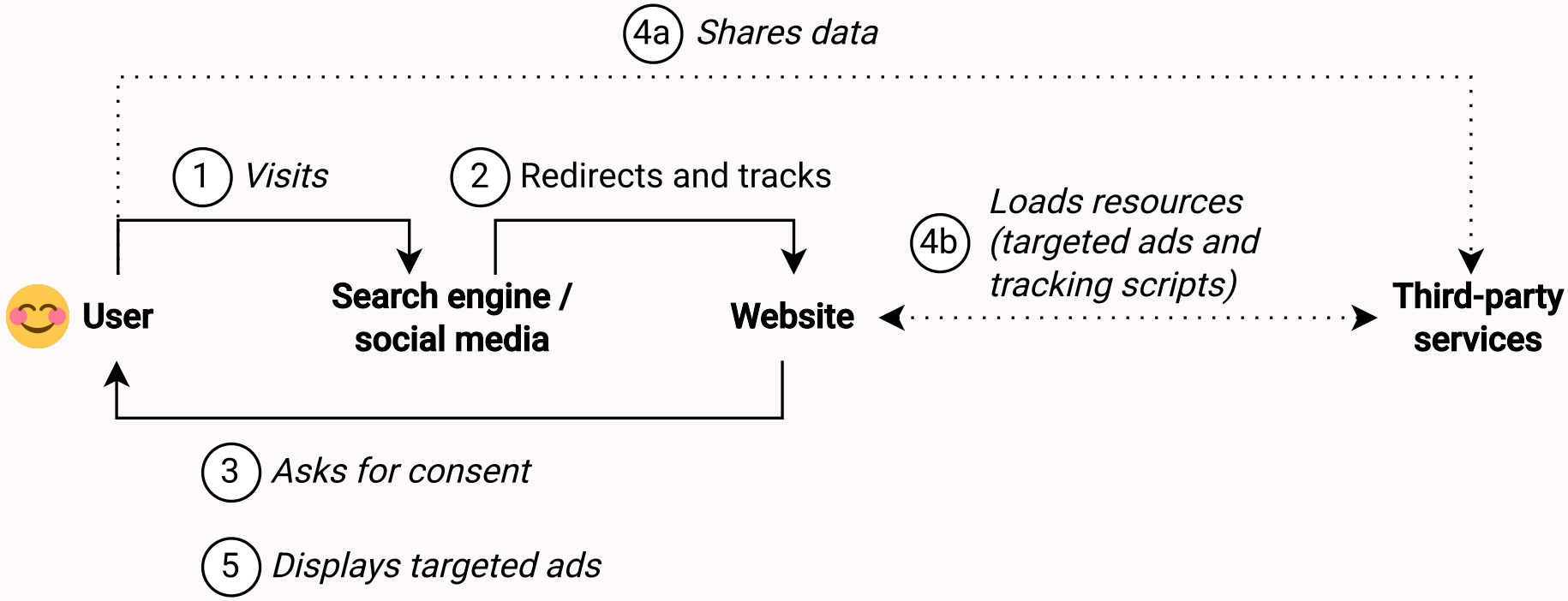
To access the Web for free, users pay:

- With their data (👍 funds the Web 👎 privacy; well-documented tradeoff)
- **With their device's resources & energy**

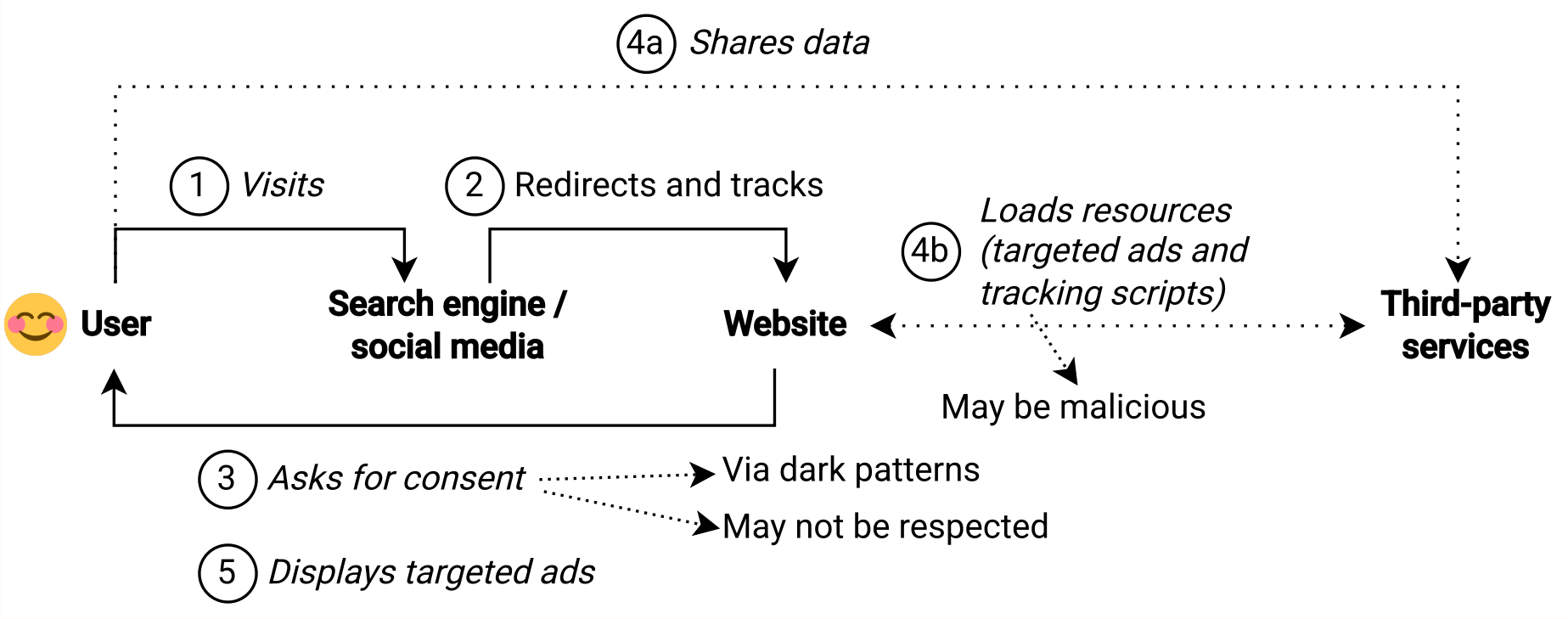


How do ads work?

Targeted ads require **data collection**.

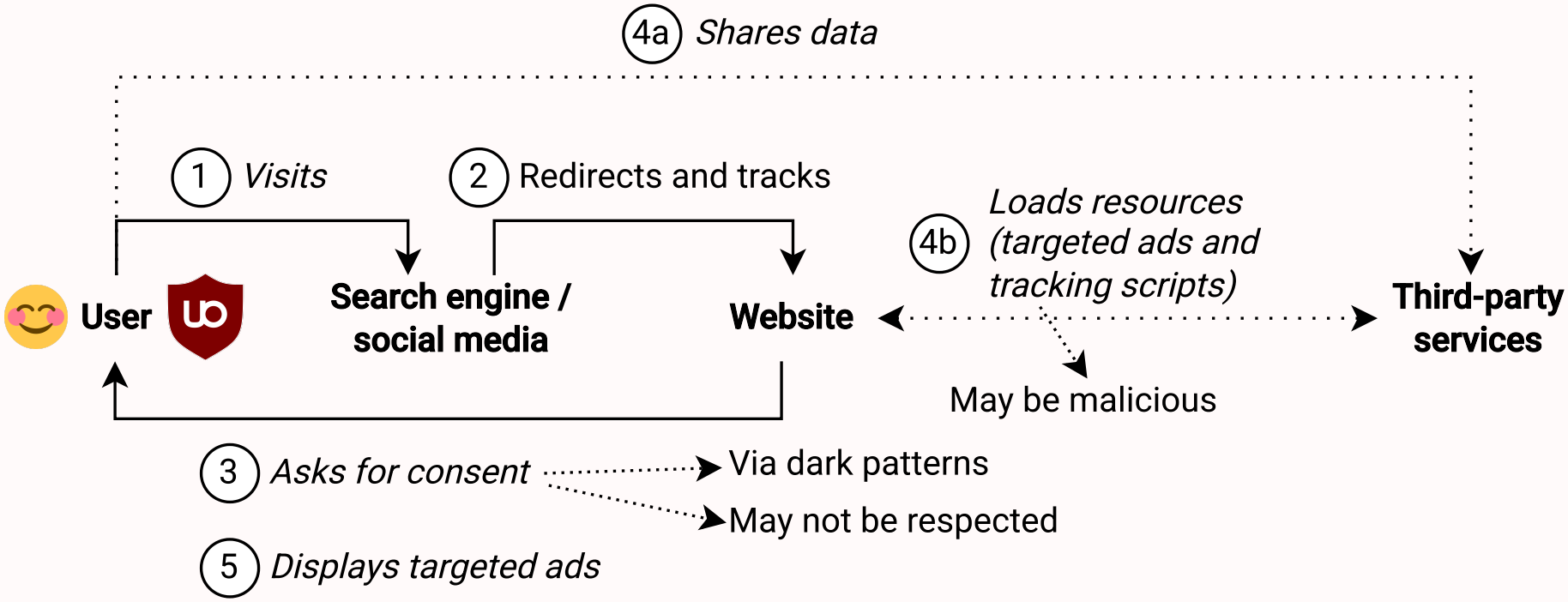


How do ads work? Issues



How do ads work? Issues

Users can **block** ads and tracking.



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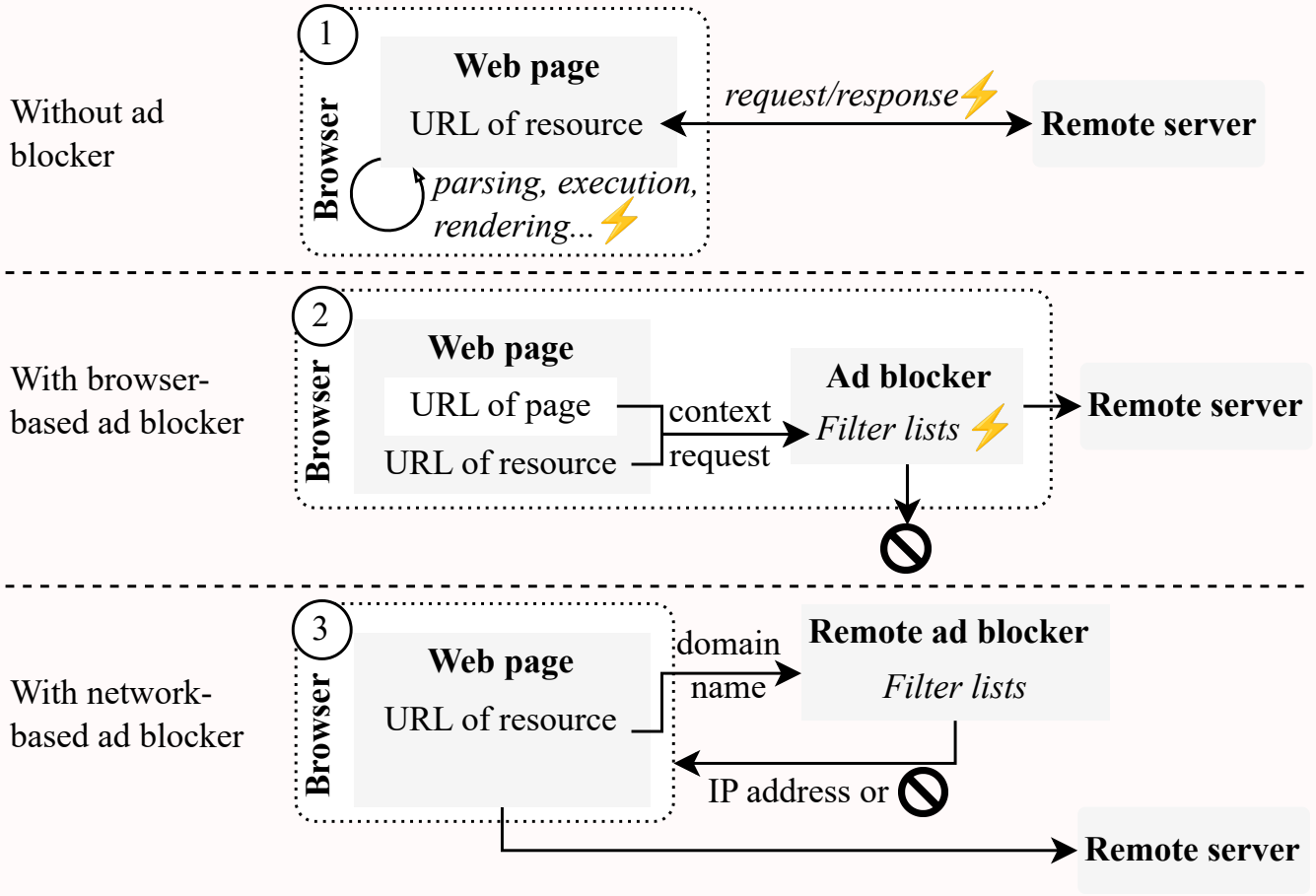


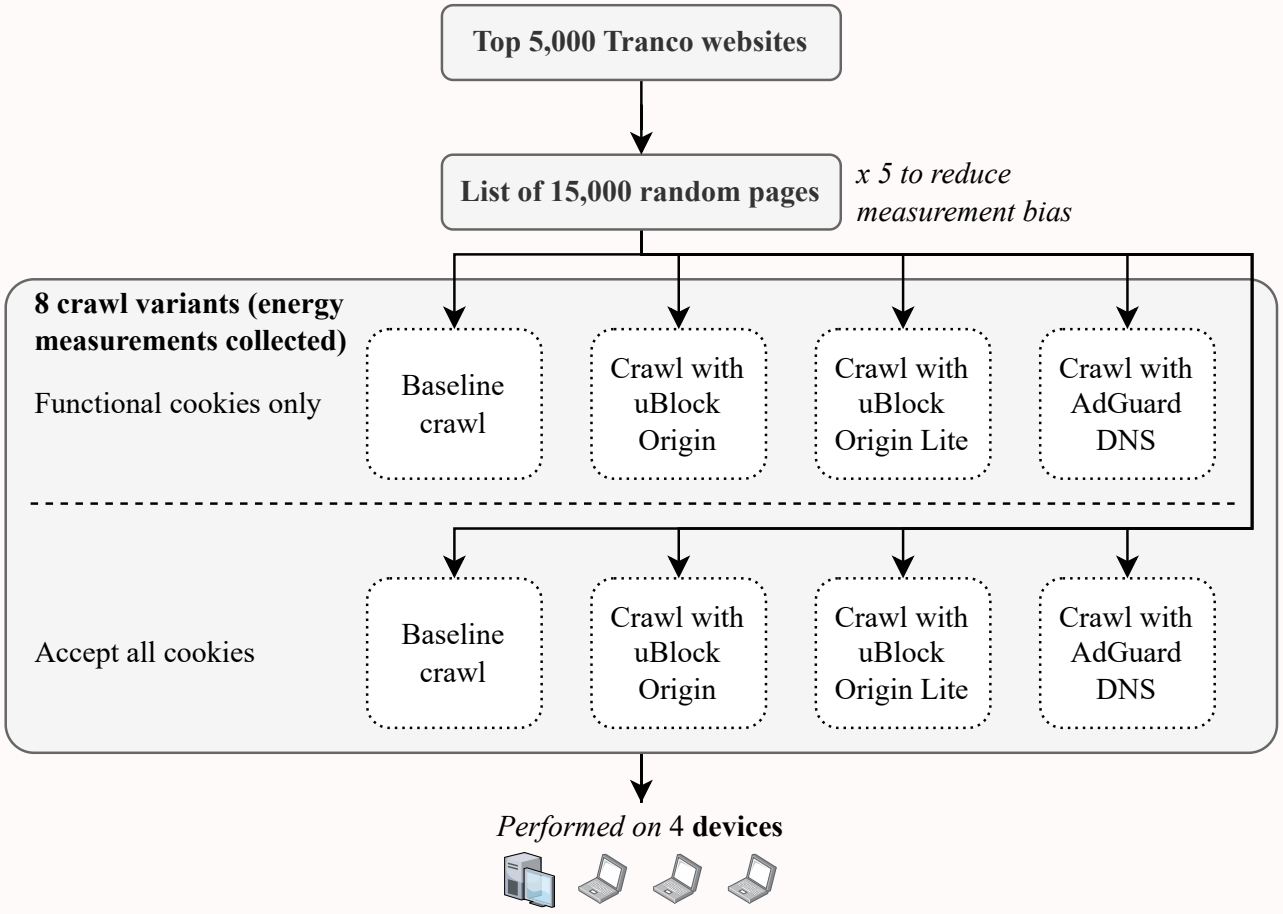
RQ: **Is it worthwhile for end users to block advertisements and tracking to save energy?**

Previous works exist, but show limitations

	Measure both ads and tracking	Fine-grained energy measurement	User behavior	Scope
[1]	✅	❌	?	2 devices 10 websites
[2]	✅	❌	?	1 device 10 websites
[3]	❌	❌	Scroll 5 times Unclear consent management	3 devices 500 websites
Our work	✅	✅	Detailed methodology	4 devices 5,000 websites

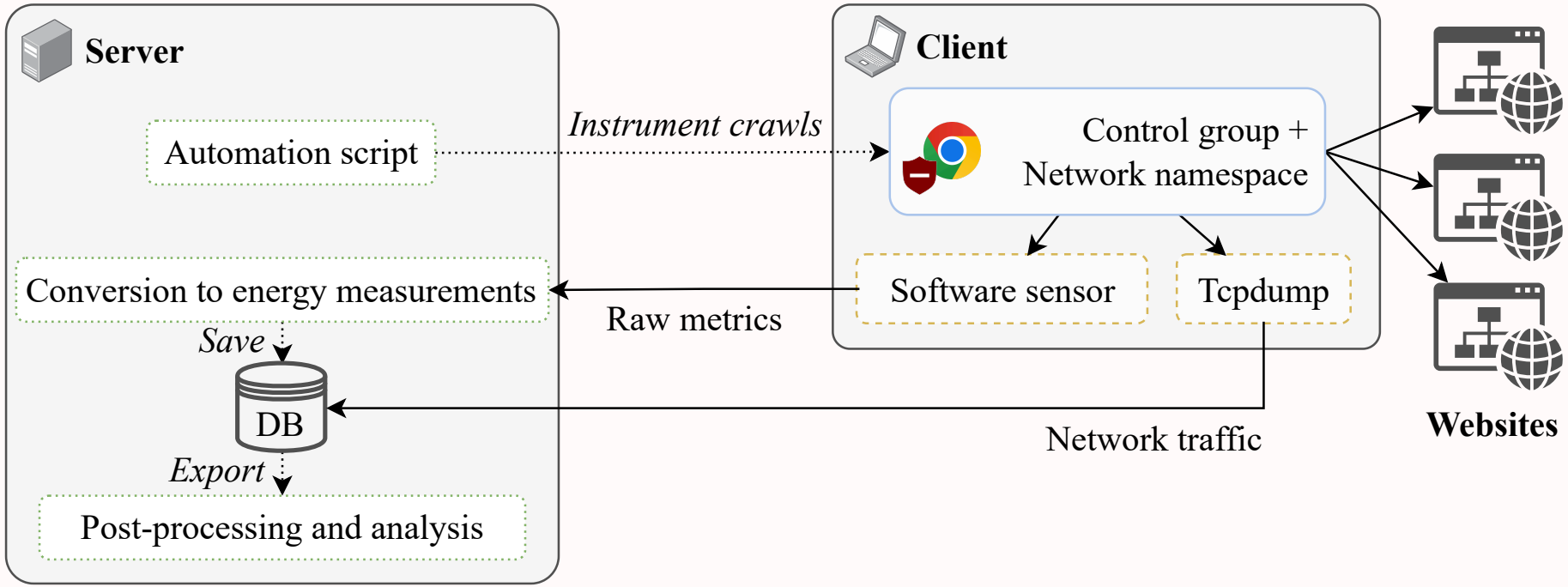
[1] Pearce J. M. “Energy conservation with open source ad blockers.” In Technologies, 2020.
[2] Khan et al. “Impact of Ad Blockers on Computer Power Consumption while Web Browsing.” In EJEECS, 2024.
[3] González-Cabañas et al. “CarbonTag: A Browser-Based Method for Approximating Energy Consumption of Online Ads.” In IEEE Trans. Sustainable Computing, 2023.

Measurement methodology: crawl variants



Measurement methodology: energy & network

Energy consumption and network traces are extracted **for each browser process**.



Energy measurement software stack: PowerAPI (RAPL + Smartwatts model)

Jay et al. “An experimental comparison of software-based power meters: focus on CPU and GPU.” In IEEE/ACM CCGrid, 2023.

Improving robustness

1. **Offloading computation-heavy operations**
2. Comparing website-to-website
3. Ignoring erroneous visits
4. Reducing timing variations

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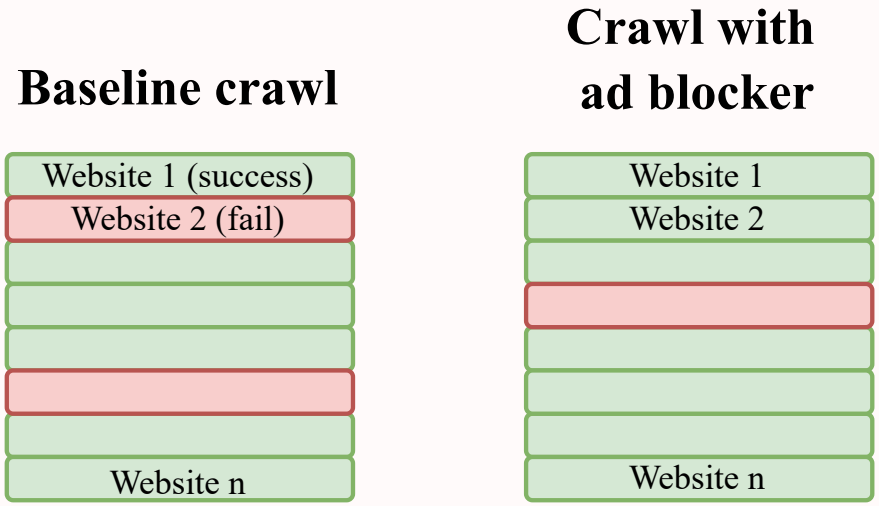

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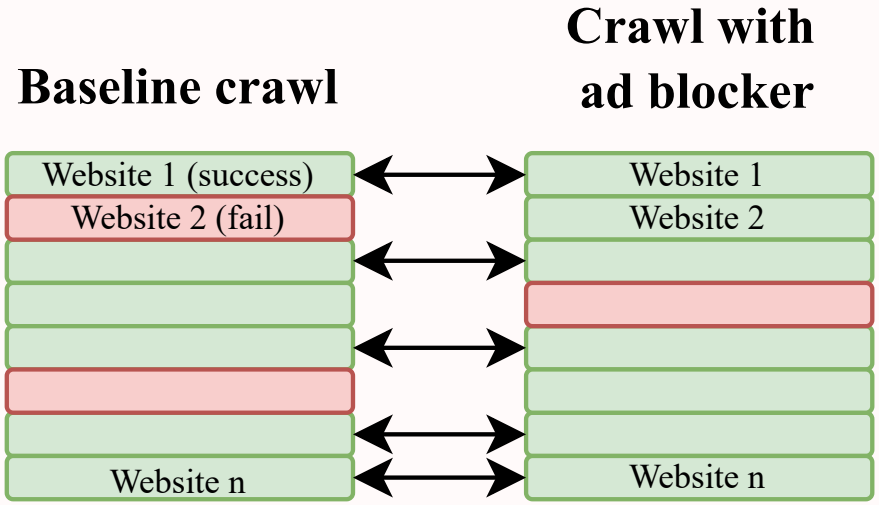

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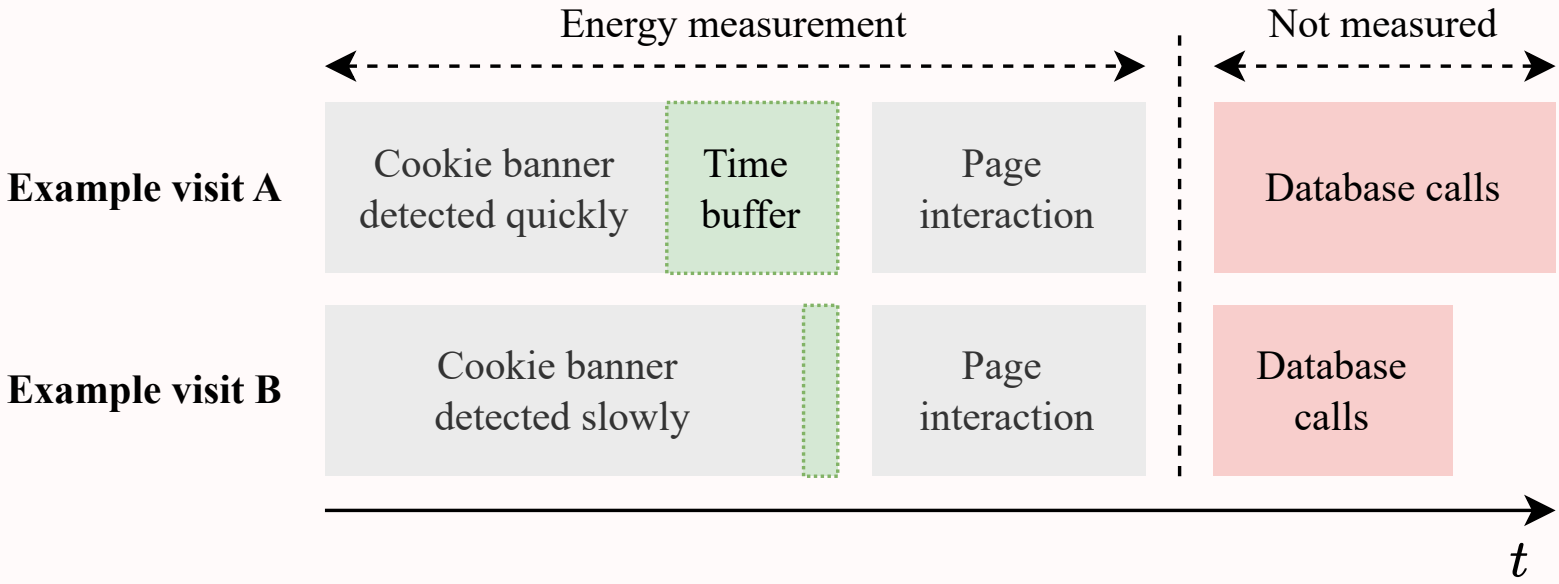
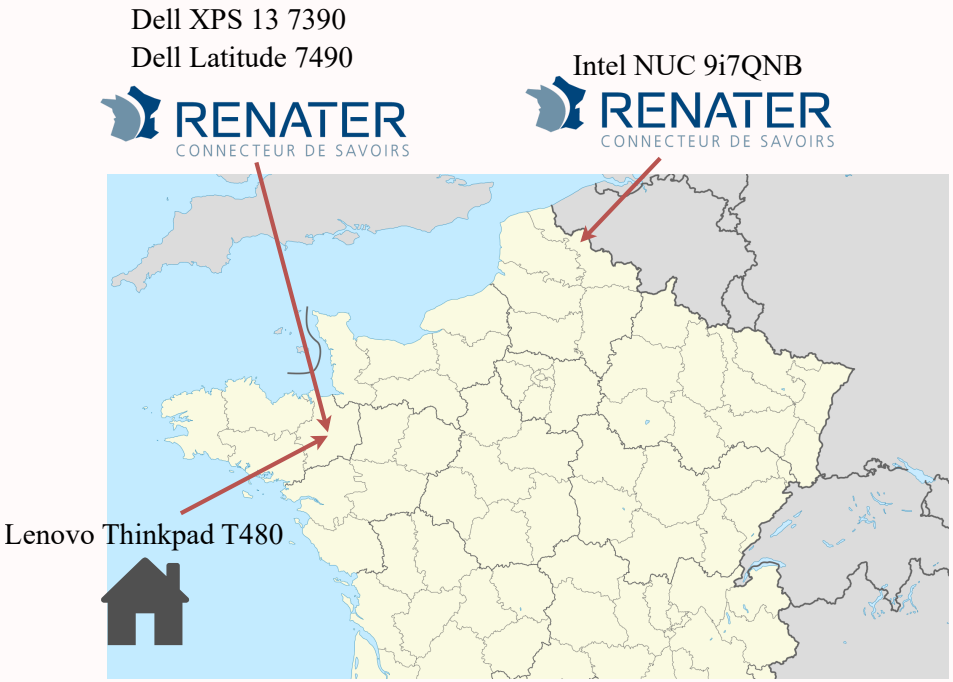


Realistic user behavior

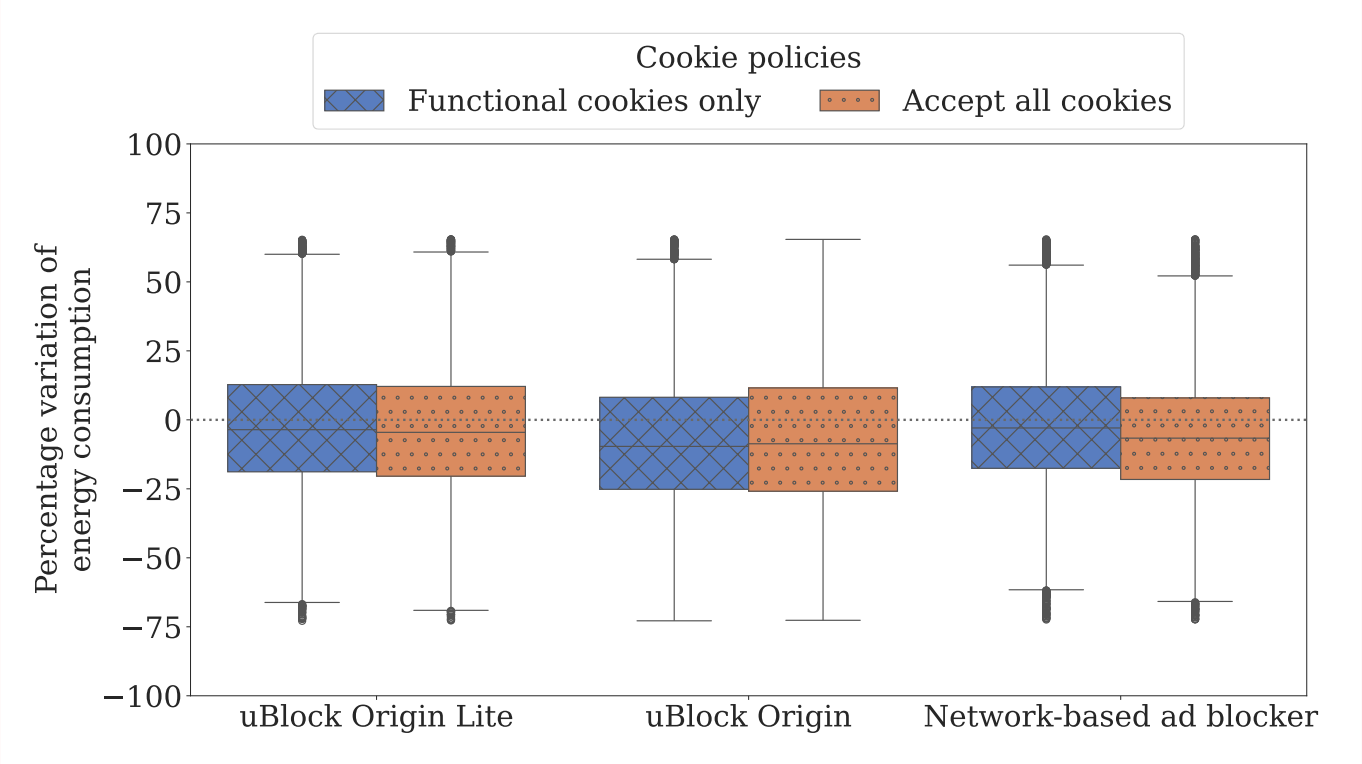
1. **Preparing browser profiles**: empty profiles receive fewer ads; we visit a set of 300 pages before crawling
2. **Simulating on-site behavior**: load, interact with cookie banner, scroll, click links; repeat on other pages
3. **Handling cookie banners**: minimize accepted cookies to get a lower-bound estimate

Dataset



- 73% success rate over 724,994 website visits
- 300,000,000 HTTP requests
- 2.7 Tb of captured network traffic files

Results: cookies and ad blockers



Accepting cookies increases energy consumption (+2.57%)

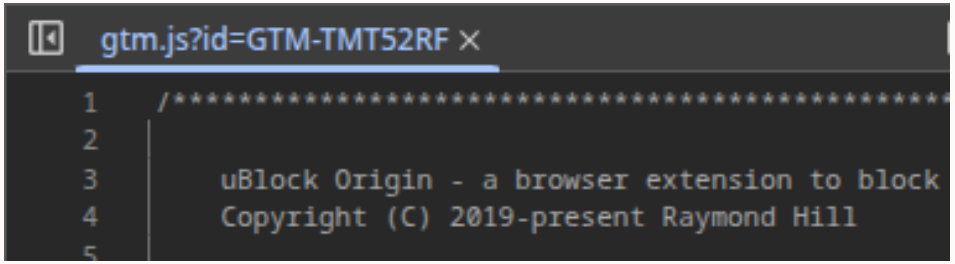
Blocking ads & tracking **reduces energy consumption** (-9.62%)

Results: cookies and ad blockers

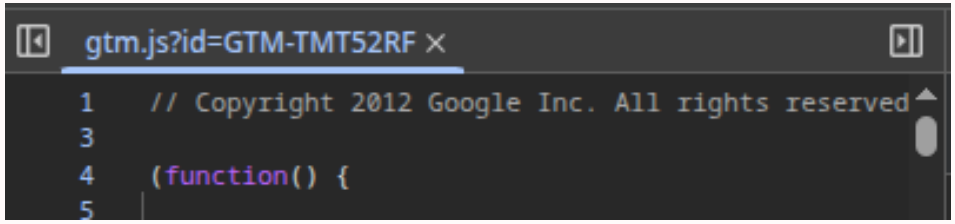
Ad blockers have different capabilities.

Example: `uk.com`

uBlock Origin (-17.33%)



AdGuard DNS (-4.51%)



Results: cookies and ad blockers

Blocking ads and tracking may introduce energy-consuming behaviors.

Example: `linkedin.com` (uBlock Origin, +12.13%)

```
▶ POST https://www.linkedin.com/li/track net::ERR_BLOCKED_BY_CLIENT    aa1epjm9qsbyjsmsbnm9q7sd9:1
▶ POST https://www.linkedin.com/li/track net::ERR_BLOCKED_BY_CLIENT    aa1epjm9qsbyjsmsbnm9q7sd9:1
▶ POST https://www.linkedin.com/li/track net::ERR_BLOCKED_BY_CLIENT    aa1epjm9qsbyjsmsbnm9q7sd9:1
▶ POST https://www.linkedin.com/li/track net::ERR_BLOCKED_BY_CLIENT    aa1epjm9qsbyjsmsbnm9q7sd9:1
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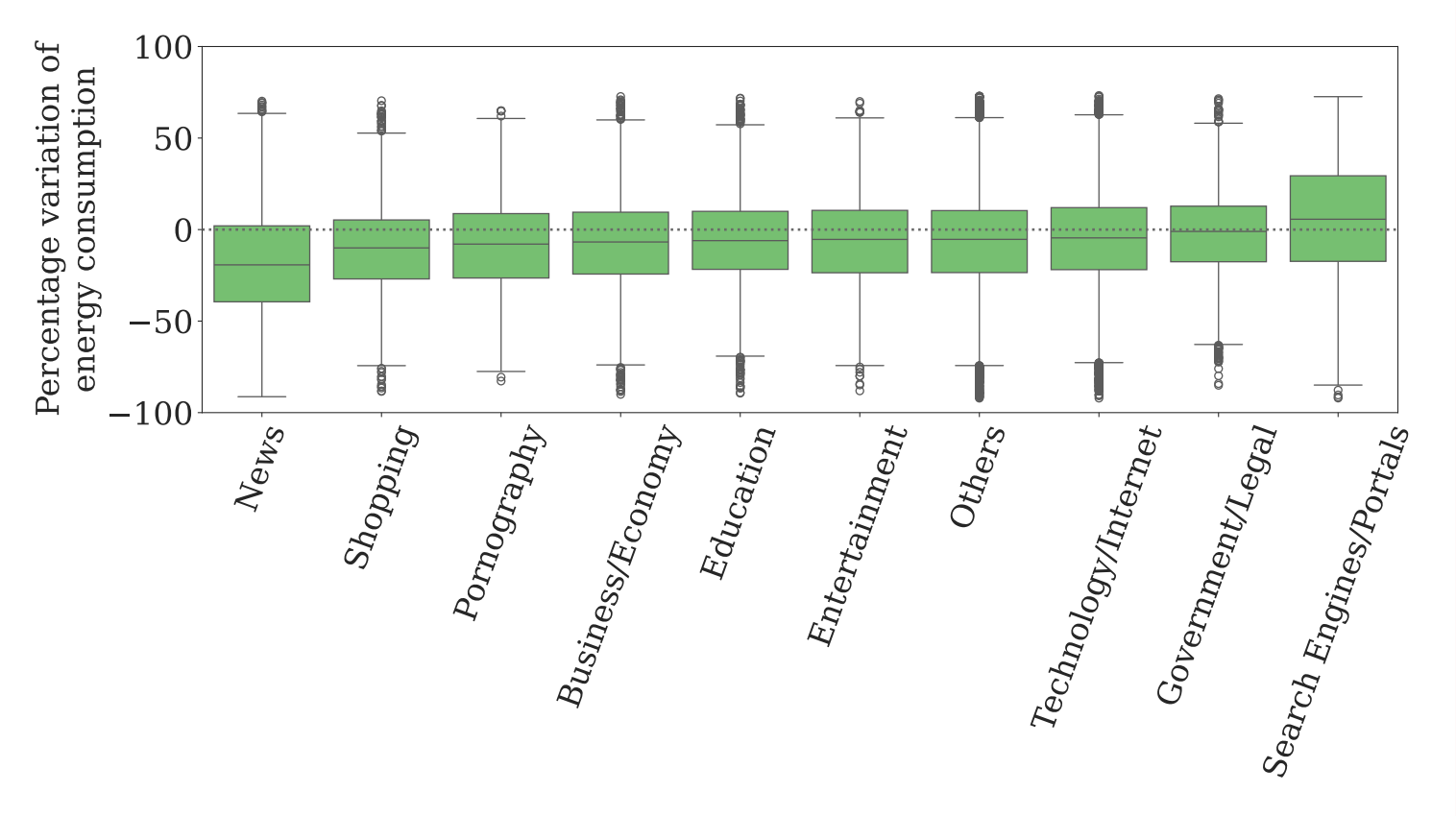
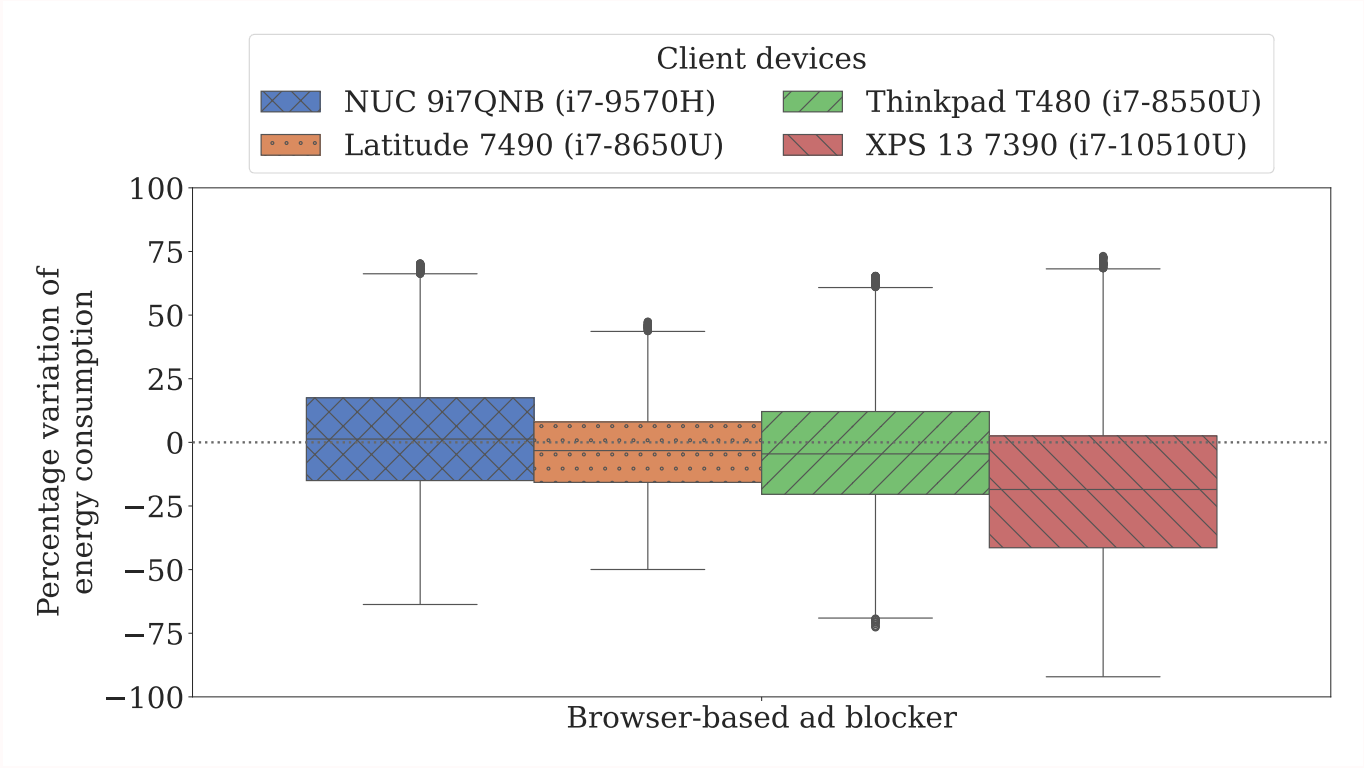
Results: website categories matter



Higher impact on websites in categories relying on ads for funding (e.g., News)

Results: variability per client devices



Dynamic CPU architectures show greater gains (blocking is less beneficial on the NUC/desktop device)

Summary

Initial observations

- Users pay the cost of ads and tracking schemes twice.
- The energy consumption cost is hidden / overlooked.
- Gap in the literature (scale, realism).

Findings

- Ads and tracking do consume significant energy.
- Blocking ads is worth it **most of the times**.

Future works

- Other browsers? (Firefox, Brave)
- Impact of ads format? (banner, video)
- Energy mix & carbon impact?

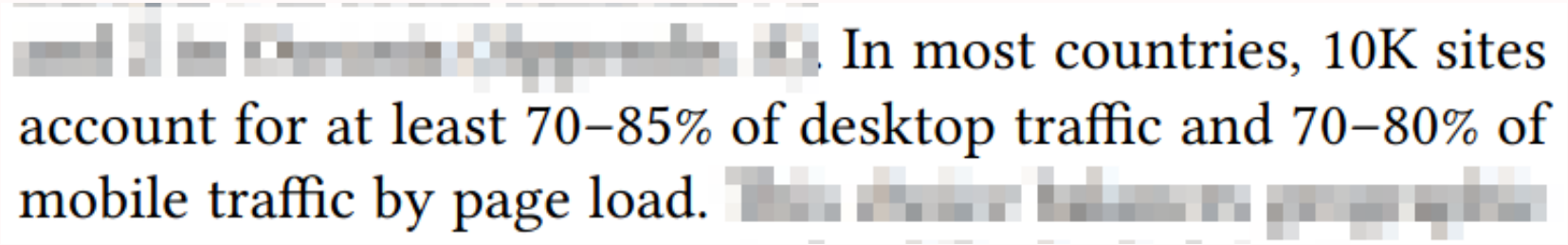
Thank you!

Paper: https://doi.org/10.1145/3774904.3792414

Contact: samuel.pelissier@centralesupelec.fr

Realistic user behavior: top lists

How can we select a set of websites that are representative of the current web?

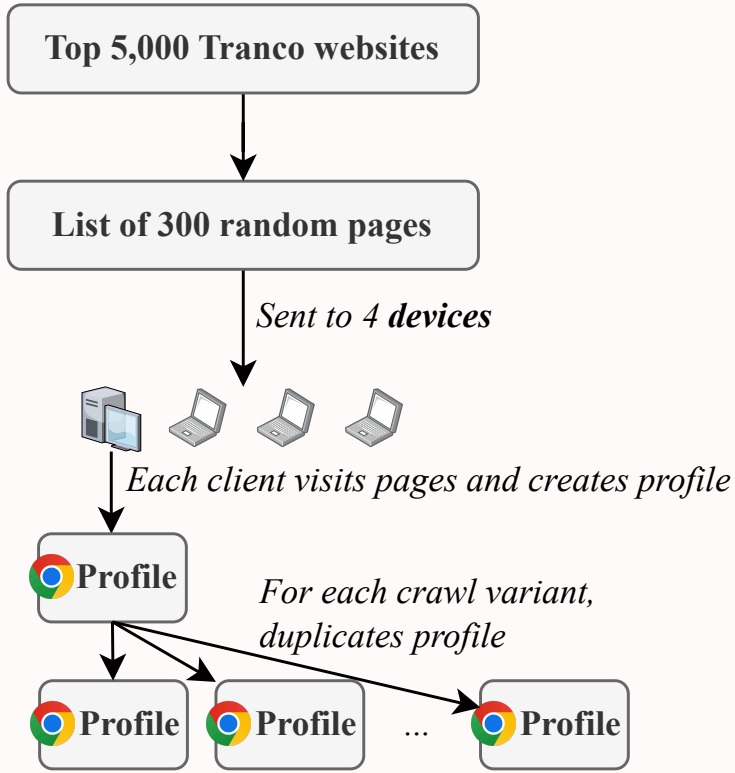

. In most countries, 10K sites account for at least 70–85% of desktop traffic and 70–80% of mobile traffic by page load.

We crawl the top 5000 websites on the Tranco list.

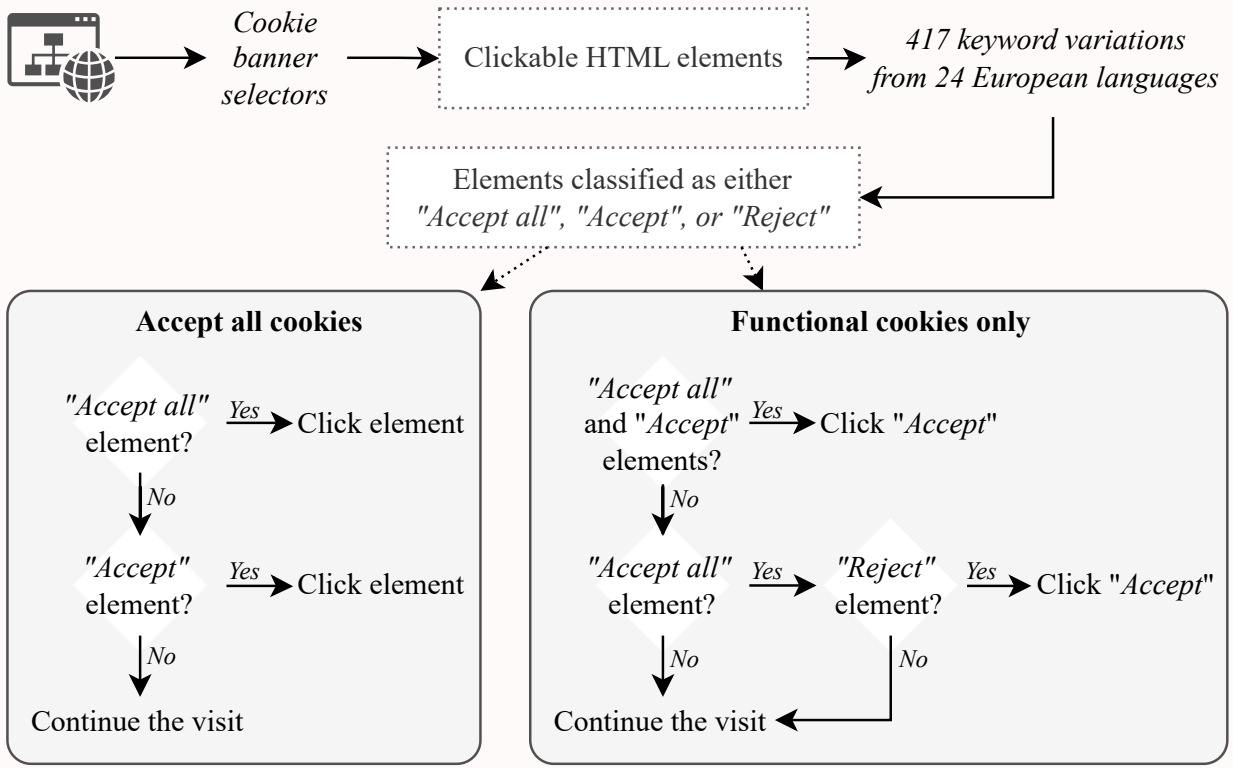
Ruth et al. “A world wide view of browsing the world wide web.” In **ACM Internet Measurement Conference**, 2022.

Realistic user behavior: preparing profiles

- Advertisers **bid** on users to display ads.
- Users with empty profiles receive fewer ads.
- Duplicated profiles across devices may generate errors.



Realistic user behavior: handling cookies



We minimize accepted cookies: **results provide a lower-bound estimate of the impact of tracking on energy consumption.**

Realistic user behavior: on site behavior

How can we simulate realistic user behaviors on such websites?

5.4 There Is Indeed No Average User

In line with the findings of Obendorf et al. [43], we do not find evidence that would support the concept of an average internet user.

Crichton et al. “How Do Home Computer Users Browse the Web?” In **ACM Transactions on the Web**, 2021.

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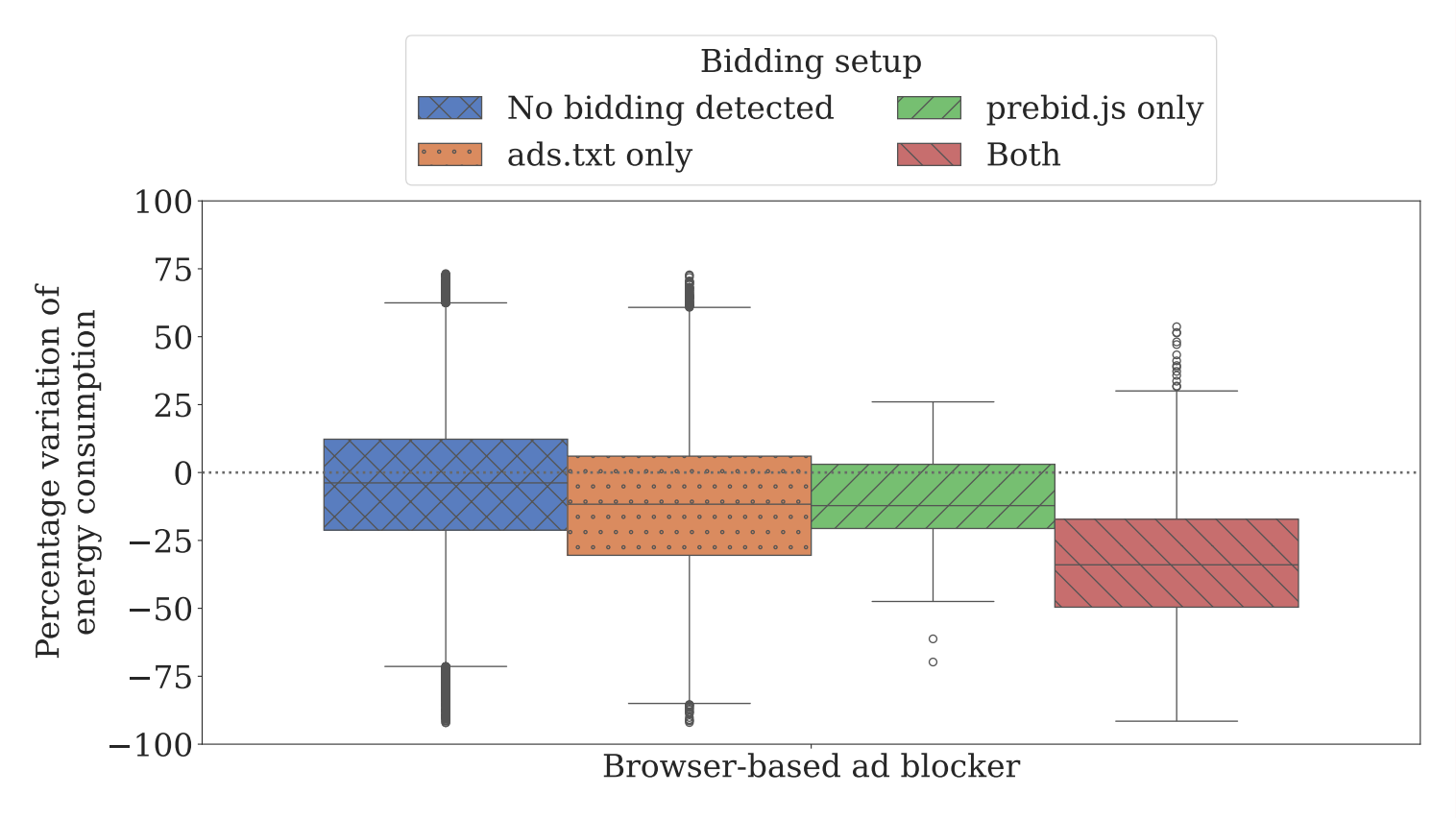
A visit:

1. Load the front page
2. Interact with the cookie banner
3. Scroll 10 times
4. Randomly select 2 clickable links
5. Repeat on these new pages

Crichton et al. “How Do Home Computer Users Browse the Web?” In **ACM Transactions on the Web**, 2021.

Results: header bidding



Higher impact on websites with header bidding (i.e., with targeted ads)