Carnus: Exploring the Privacy Threats of Browser Extension Fingerprinting

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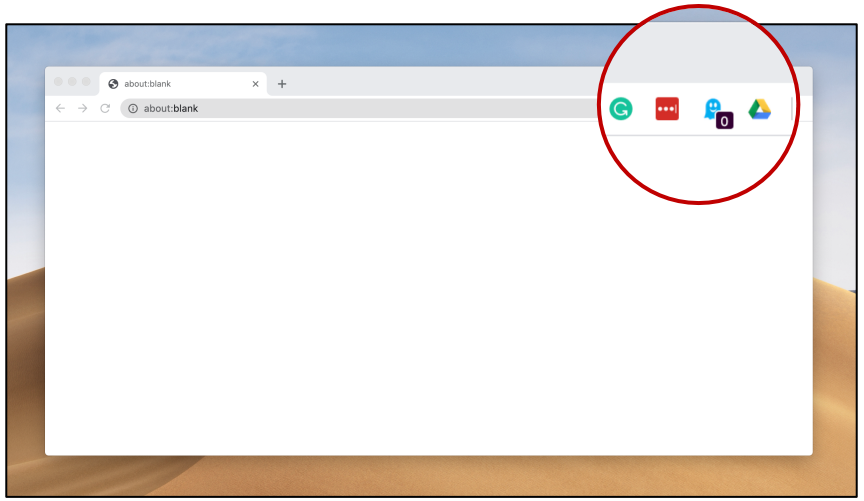
Browser extensions

- Extend functionality of the browser
  - “Adblock Plus” with 10,000,000+ users
  - “Tampermonkey” with 10,000,000+ users
  - “LastPass” with 10,000,000+ users



- Security threats of extensions have been studied
  - (e.g., Kapravelos et al; USENIX Security 2014)
- We focus on the privacy aspect of browser extensions
  - First, we build and evaluate the most comprehensive extension-fingerprinting system to date

Installed extensions might reveal user's interests, preferences, browsing habits, and demographic information

WebFilter FREE: Parental Control & Anti-Porn

Young Users

Ya'Muslim

Religion

Don't Pay Trump

Politics

中国空气质量指数

Ethnicity

3asyR

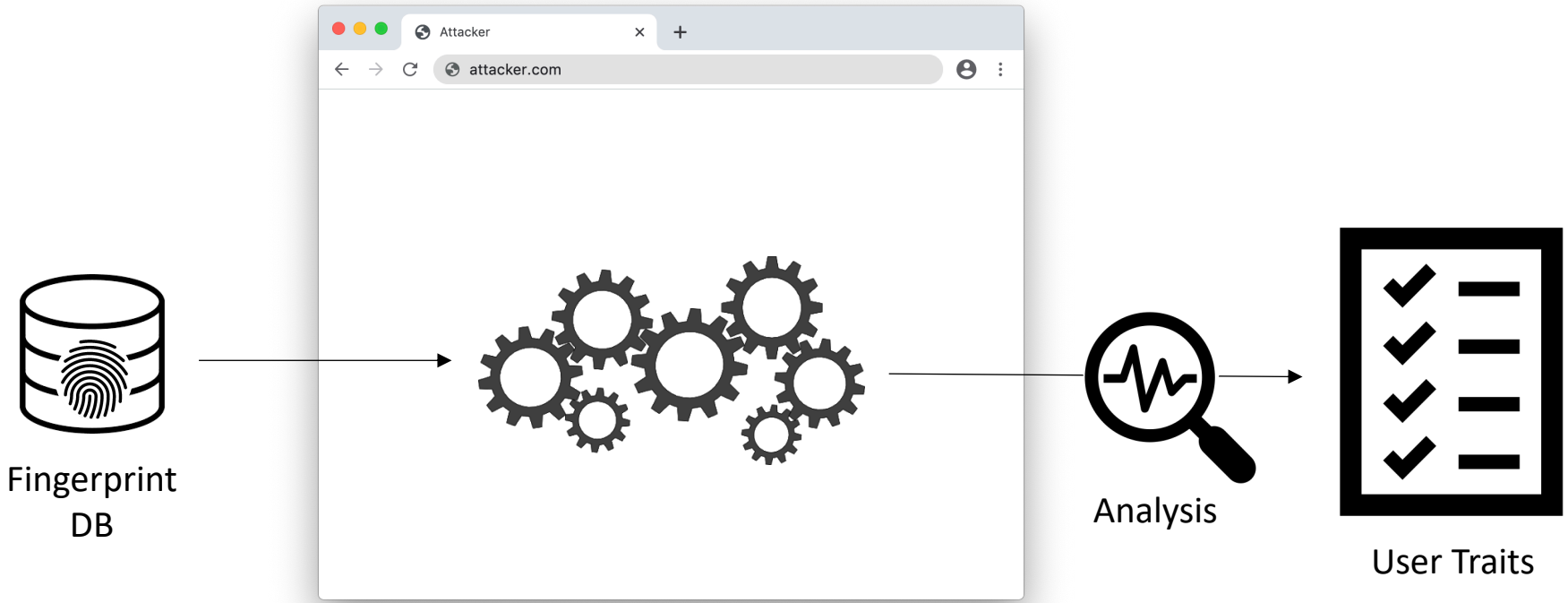
Health

LGBT Pride

Gender/ sexuality

Threat model

User visits attacker's website, which attempts to detect installed extensions



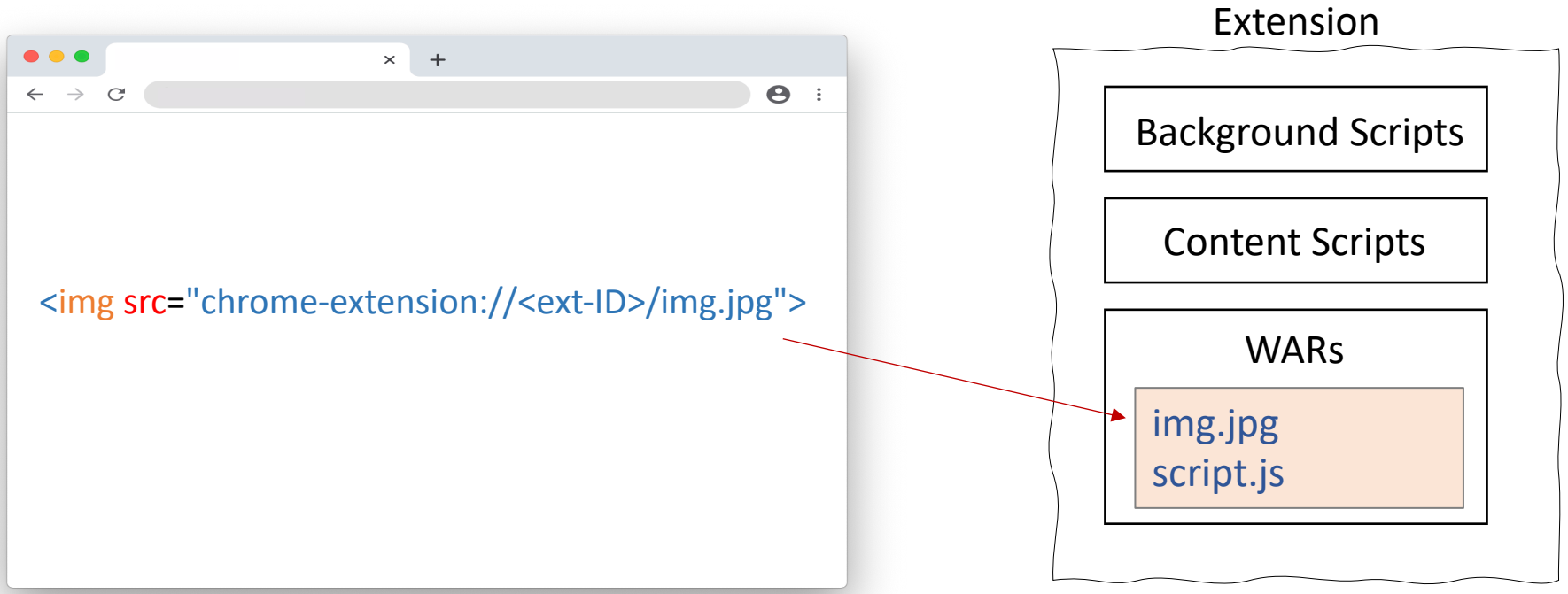
Fingerprinting techniques

For the purpose of detection, we generate a **Fingerprint** for each extension

1. WARs (web accessible resources)
2. Behavior-based
3. Intra-communication-based
4. Inter-communication-based

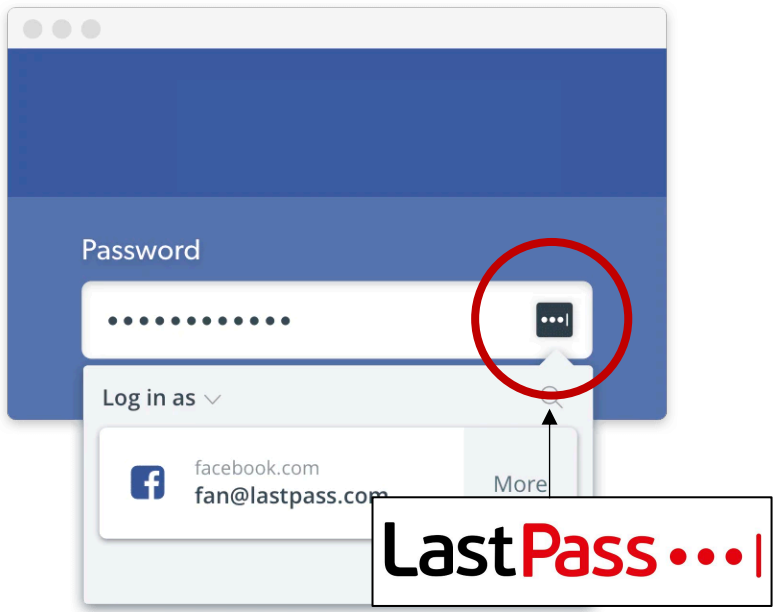
1. WAR-Based Fingerprints

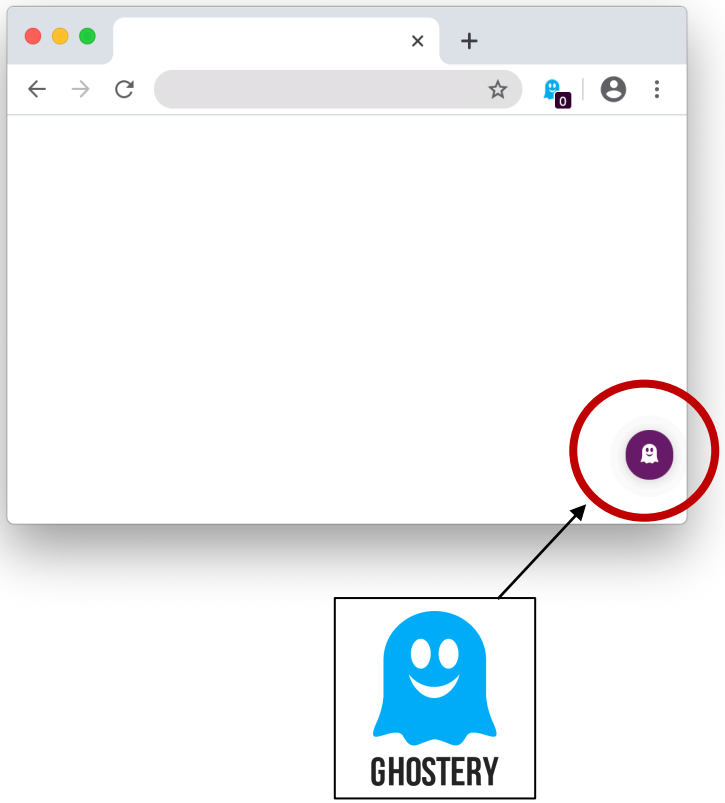
- Extensions may have some resources that are accessible from the DOM
- Websites can probe WARs to detect which extensions are installed in the user's browser
- Well-known approach for detecting extensions
  - Maximizes the coverage of our attack, enabling extensive exploration of privacy implications

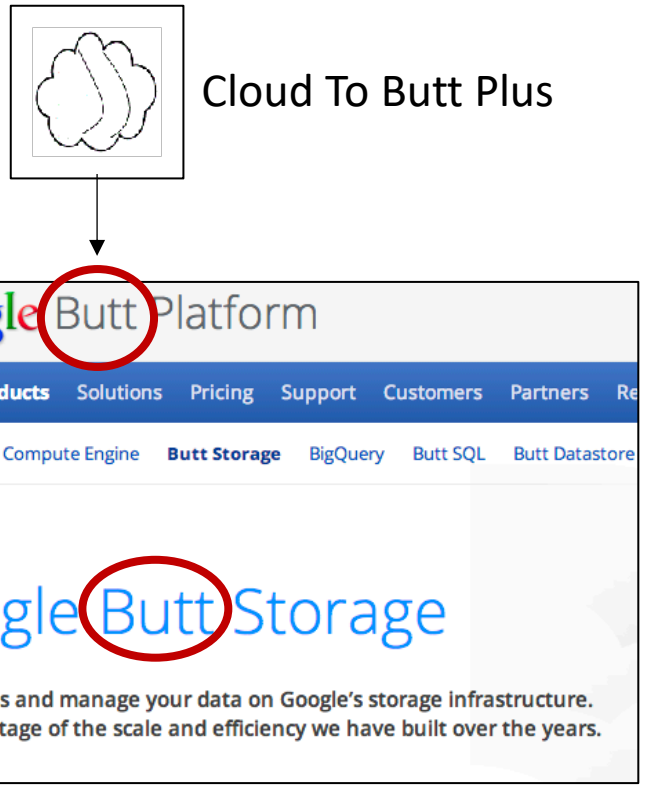


2. Behavior-Based Fingerprints

Extensions might add/remove images, buttons, code, or text to the web page

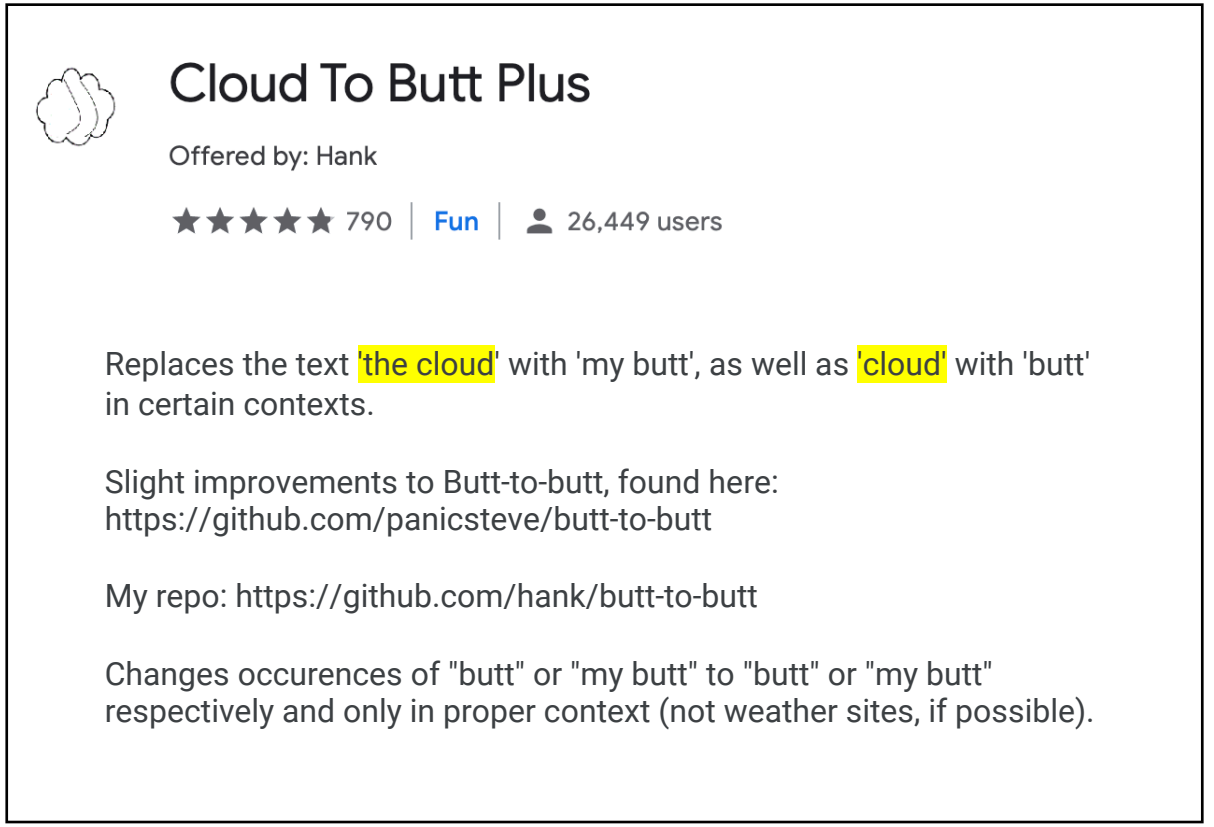






2. Behavior-Based Fingerprints

- Created a honeypage to trigger as many extensions as possible
  - Includes HTML, JS, CSS, text, etc
- Detecting content-based triggering is challenging
- **Observation**: use the extension's description to trigger such behavior



2. Behavior-Based Fingerprints

```
<form action="/action_page.php">
  <label for="uname"> Username </label>
  <input type="text" name="uname" autocomplete="on">
  <label for="psw"> Password </label>
  <input type="password" name="psw" autocomplete="on">
  <button type="submit"> Login </button>
</form>
```

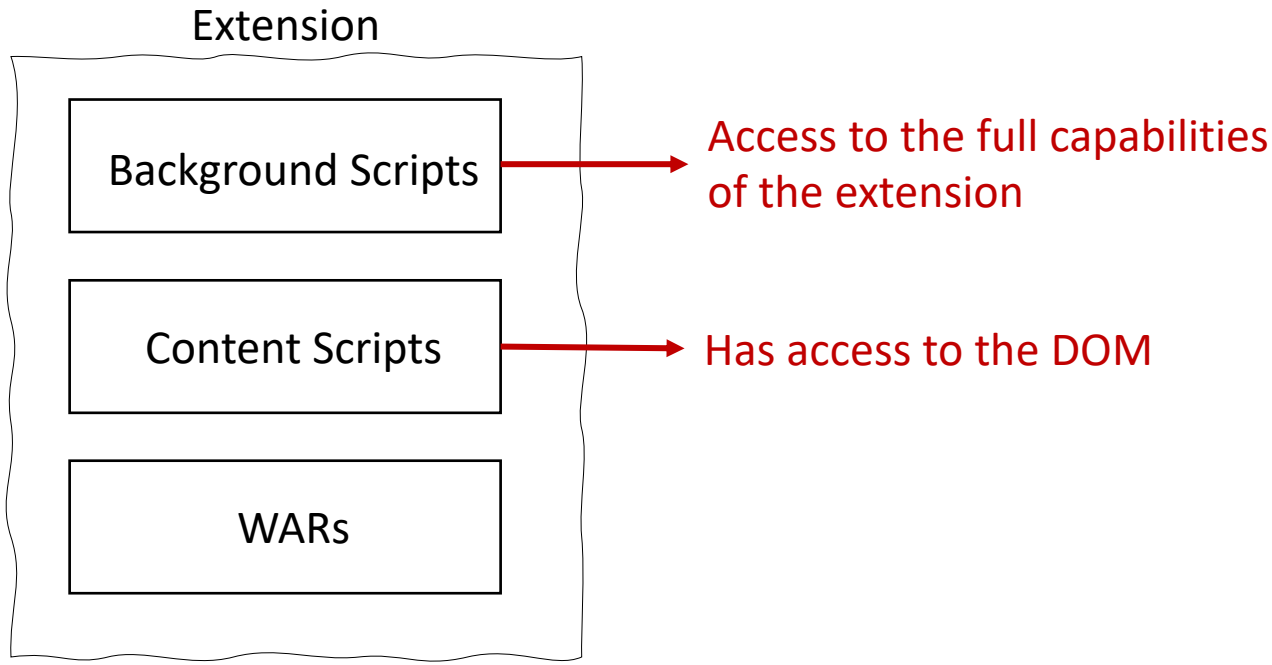
added

modified

```
<form action="/action_page.php">
  <label for="uname"> Username </label>
  <input type="text" name="uname" autocomplete="off"
style="background-image: url('...');">
  <label for="psw"> Password </label>
  <input type="password" name="psw" autocomplete="off"
style="background-image: url('...');">
  <button type="submit"> Login </button>
</form>
```

Added: {style="background-image: url('...');", autocomplete="off"}
Removed: {autocomplete="on"}

3. Intra-communication Based Fingerprints



We use the messages that are sent by content scripts to detect extensions.

3. Intra-communication Based Fingerprints

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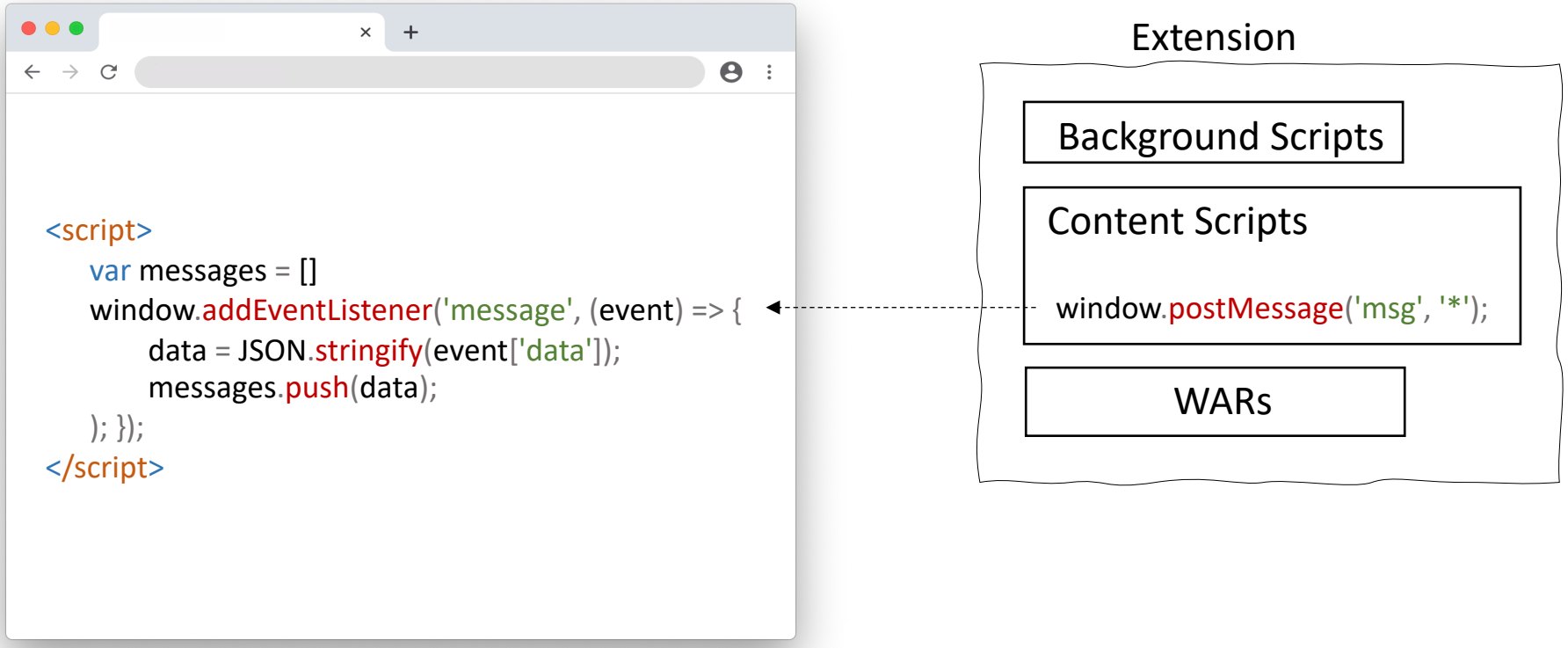
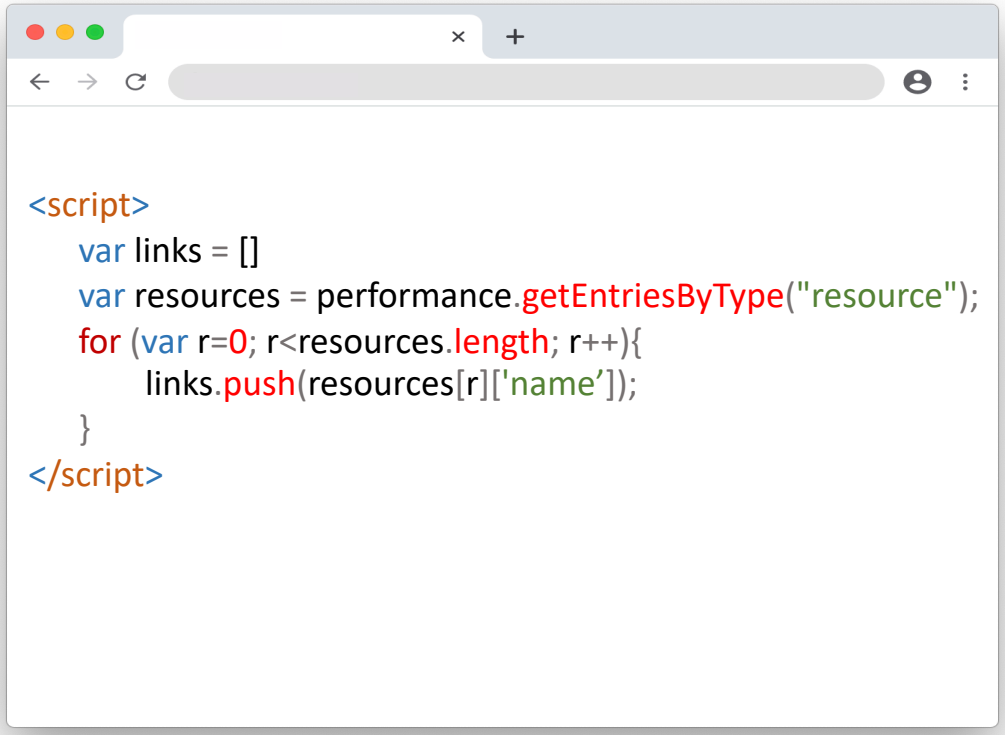
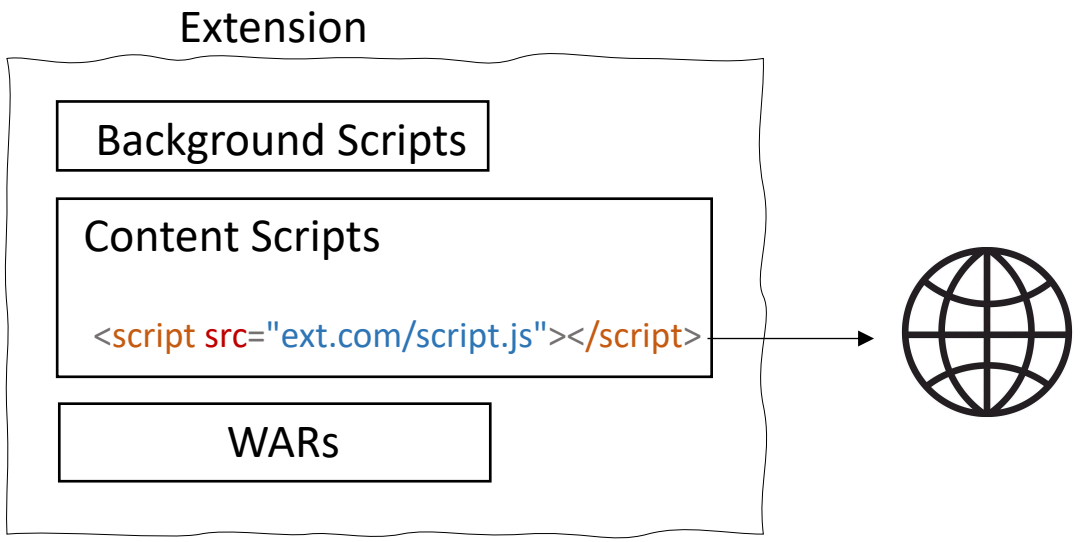


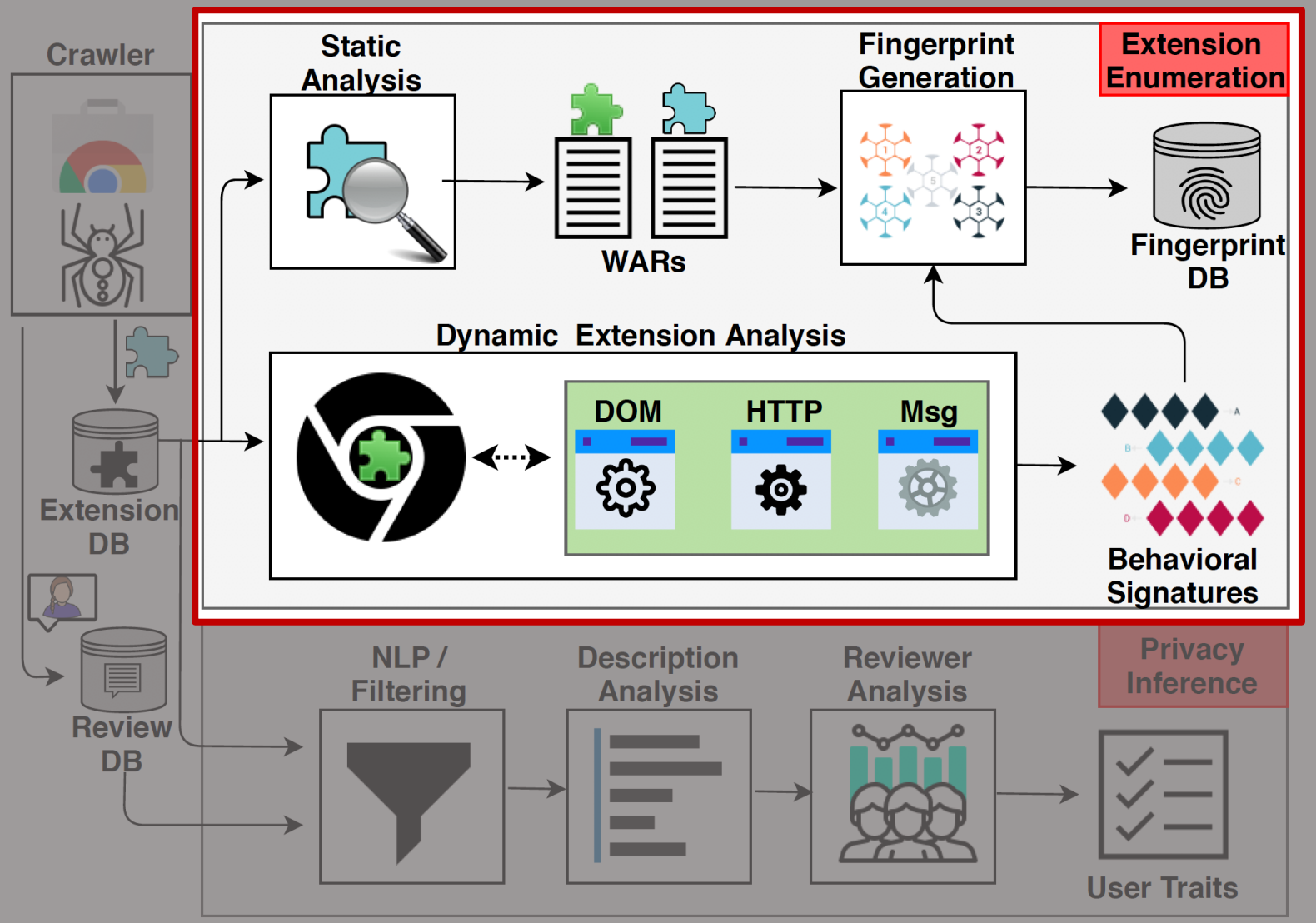
4. Inter-communication Based Fingerprints

- Content scripts may fetch resources from the network
- Attackers can use Performance API to obtain list of fetched resources



```
<script>
    var links = []
    var resources = performance.getEntriesByType("resource");
    for (var r=0; r<resources.length; r++){
        links.push(resources[r]['name’]);
    }
</script>
```




Crawler
Static Analysis
WARs
Fingerprint Generation
Extension Enumeration
Fingerprint DB
Dynamic Extension Analysis
DOM
HTTP
Msg
Behavioral Signatures
Extension DB
Review DB
NLP / Filtering
Description Analysis
Reviewer Analysis
Privacy Inference
User Traits

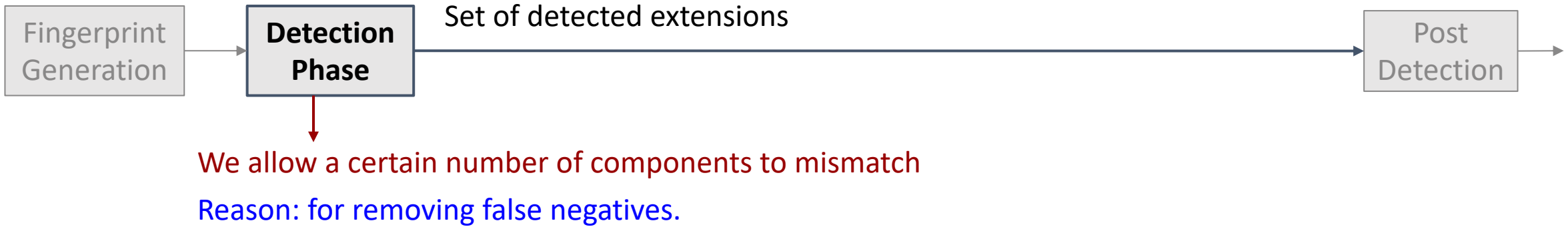
Extension Enumeration Phases

This phase is repeated three times.

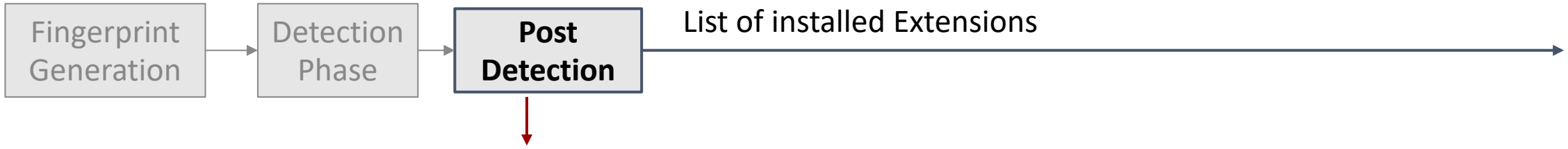
Reason:

1. Different behaviors of an extension.
   - 1st behavior: {"image-1.jpg"}
   - 2nd behavior: {"image-2.jpg"}
2. Dynamic components
   - {…, timestamp="123"}
   - {…, timestamp="456"}
   - {…, timestamp="789"}

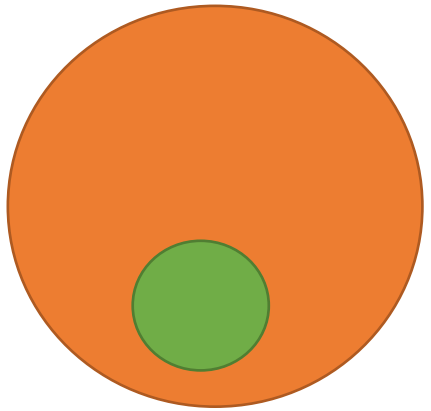
Extension Enumeration Phases



Extension Enumeration Phases

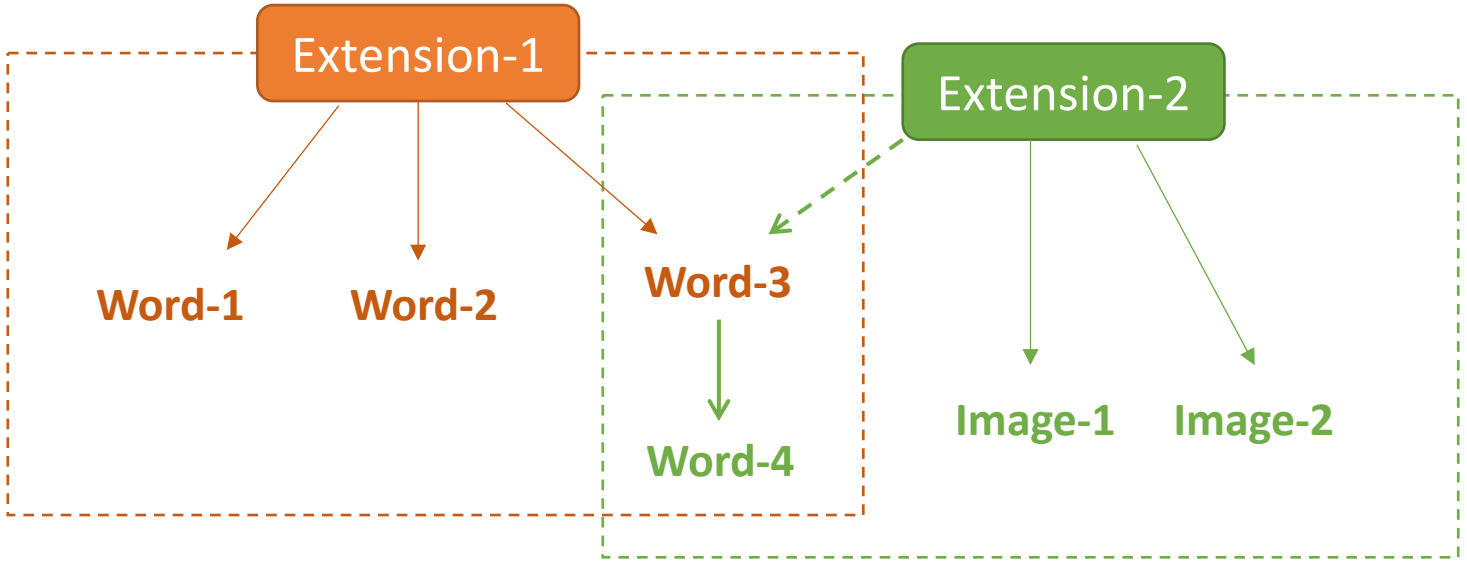


- From the list of detected extensions
  - if one extension's fingerprint is a subset of another one
    - remove this extension from the list of detected extensions



Practical Challenges: co-interference

Modifications of one extension can affect the modifications of the other



Experimental Evaluation

Attack Accuracy

- Randomly install a set of extensions (N=2..10), run detection
- Repeat this process 100 times
- Our system always correctly identifies more than 97% of installed extensions
  - Average false positive rate: 4.77%
  - Average false negative rate: 1.93%

Attack Duration

- Optimize attack by offloading most computation to server
- Average client-side attack: 8.77 seconds
- Average server-side computation: 3.62 seconds
- (Off-the-shelf desktop: Quad Core Intel i7-7700 and 32GB of RAM)

Comparison to previous studies

Paper	Attack	Platform	Extensions	Detectable
[Starov et al., S&P '17]	Behavior-based	Chrome	10,000	920
[Sjosten et al., CODASPY '17]	WAR-based	Chrome Firefox	43,429 14,896	12,154 1,003
[Gulyas et al., WPES '18]	WAR-based	Chrome	13,000	5,107
[Sanchez-Rola et al., USENIX '17]	WAR Side-channel	Chrome Firefox	10,620 10,620	10,620 10,620
[Sjosten et al., NDSS '19]	WAR Revelation	Chrome Firefox	10,459 8,646	1,932 1,379
Ours	**Multi-class**	**Chrome**	**102,482**	**29,536**

Countermeasure effects

- [Trickel et al,. USENIX '19] is a defense against extension fingerprinting
  - Randomizes the values of **ID** and **class** attributes
  - Injects random **tags** and **attributes** into each page
  - Randomizes the **path** of the WARs

- During the fingerprint generation phase, we can identify and remove the unstable components from fingerprints

Countermeasure effects: example

1. CloakX doesn't affect this fingerprint

Before {font-size:10px, color:white, initial, text-align:left, justify-content:center, line-height:4px, id="dv_masterkey_banner", flex-grow:0, rgb(160,160,160), class="dv_masterkey_message", access, id="____ok_icom_in___", position:absolute, Arial, display:flex, font-size:14px, class="dv_masterkey_banner", id="dv_launch_onepassui", style="color:orange", center, z-index}

After {font-size:10px, color:white, initial, text-align:left, justify-content:center, flex-grow:0, rgb(160,160,160), access, position:absolute, Arial, display:flex, style="color:orange", line-height:4px, center, z-index, font-size:14px}

2. CloakX renders this fingerprint useless

Before {style="display:none;", class="hashmenu01"}

After {style="display:none;"} → Too generic

Countermeasure effects: example

1. CloakX doesn't affect

Before {font-size:10p… id="dv_mast… access, id="_… class="dv_ma… …ight:4px, …y_message", …:14px, …', center, z-index}

After {font-size:10p… rgb(160,160,… height:4px, c… …ow:0, …nge", line-

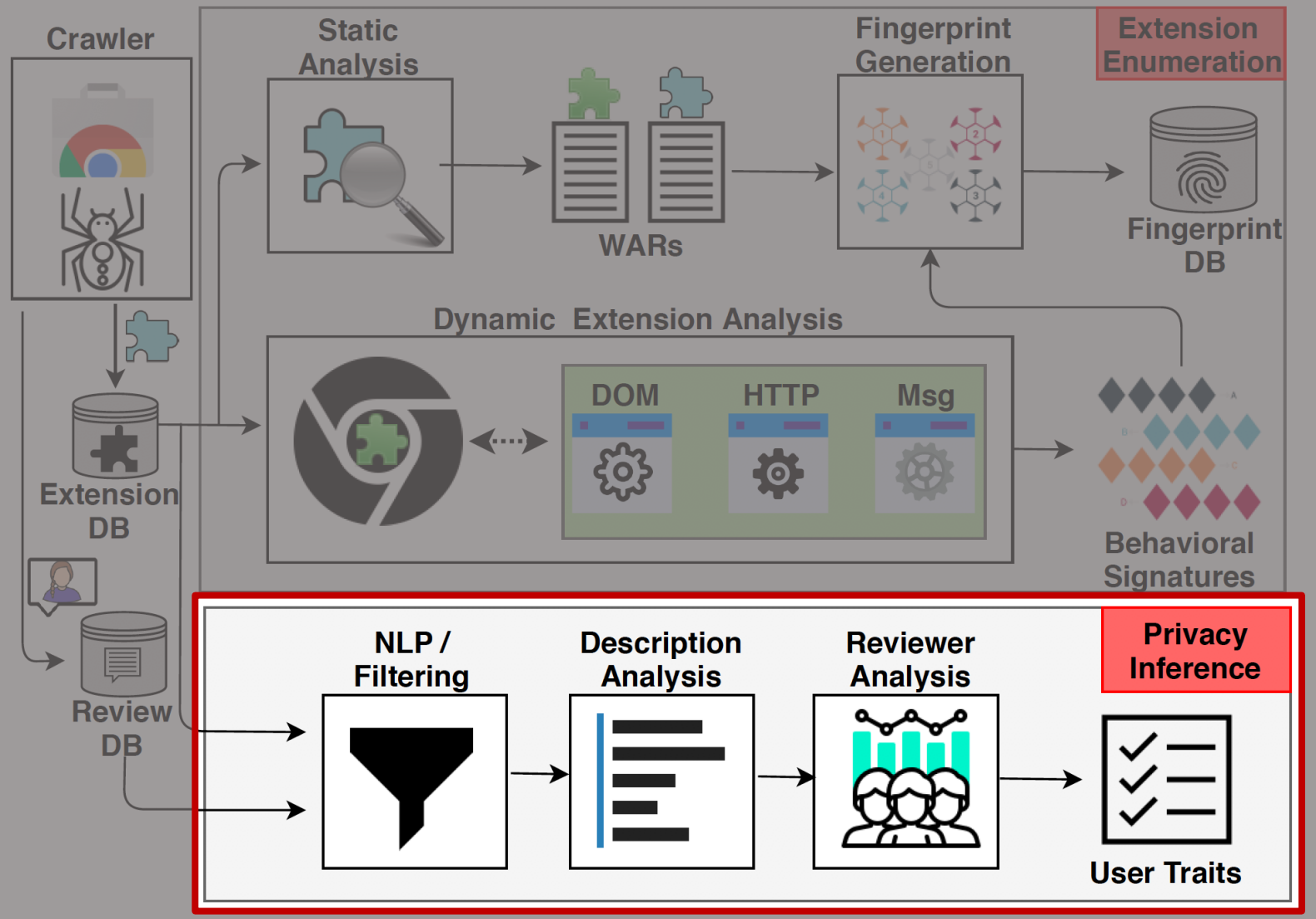
2. CloakX renders this fi…

Before {style="display:none;", class="hashmenu01"}

After {style="display:none;"} → Too generic

At least **83.6%** of our behavior-based fingerprints remain effective.

Still, this defense is an important step in the **right direction.** We hope that our work incentivizes more research.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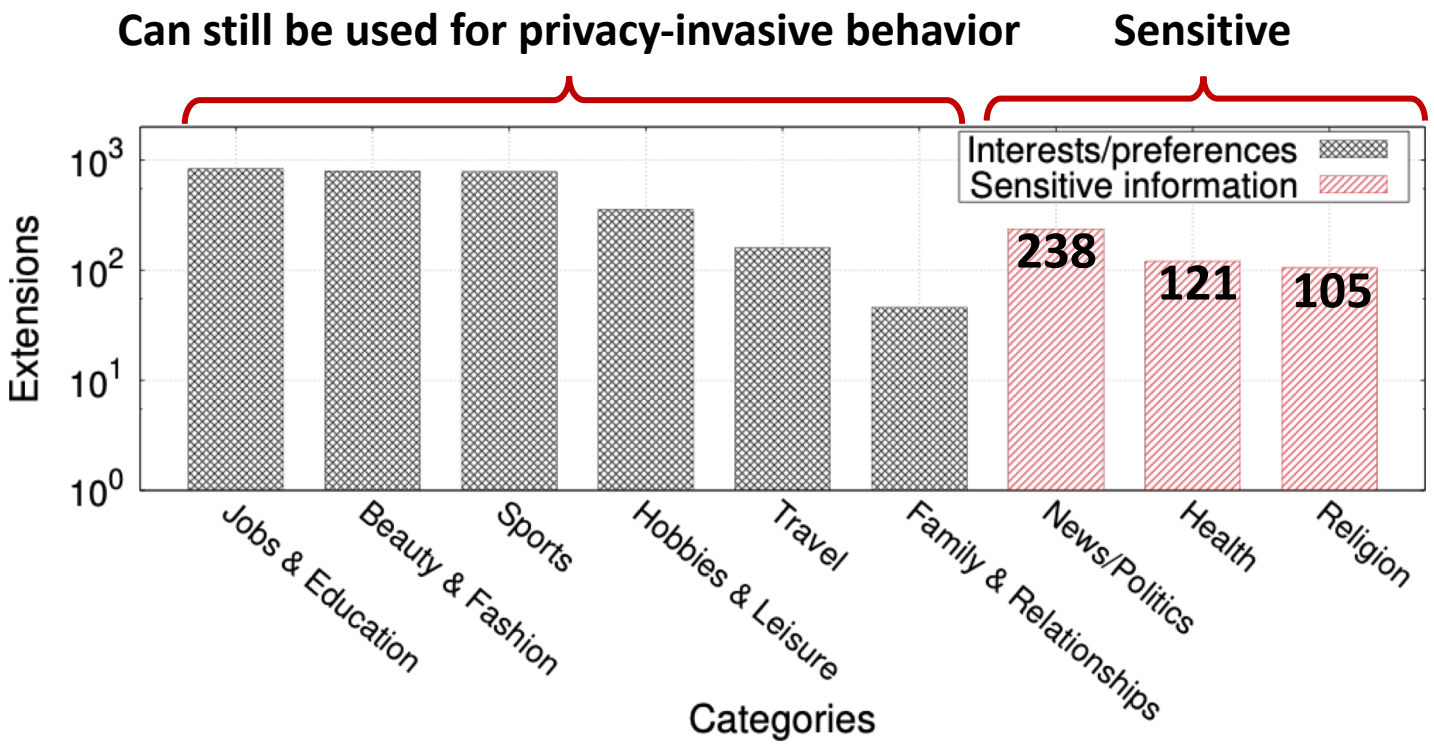
1. Inference Attacks: Topic Classification

- Use extensions' description text from Chrome Web Store
- Contains a lot of irrelevant text → **Pre-process**, **translate** and **clean** descriptions
- Google's Natural Language API



2. Inference Attacks: Description-based

- **spaCy's** Named Entity Recognition
  - E.g., locations, people, etc.

- Using different wordlists
  - Religious terms
  - Medical terms
  - Political terms

Prayer Times

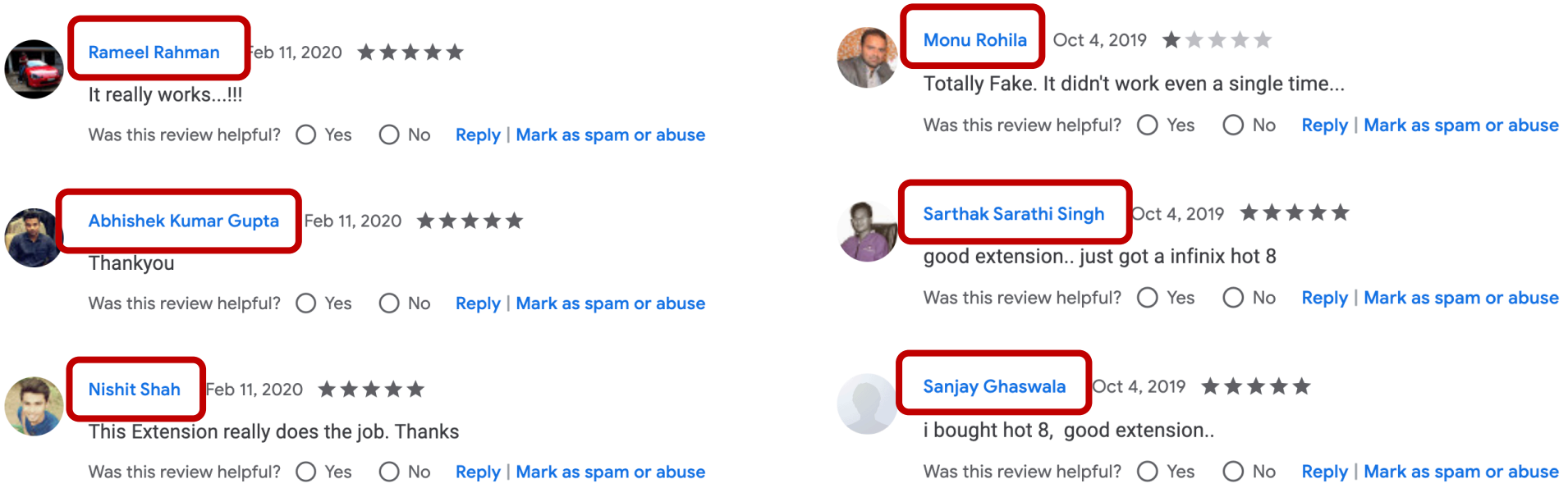
Offered by: mohamedmansour.com

★★★★½ 343 | News & Weather | 4,162 users

Prayer Times including all year timetable for any location in the world. Including prayer time notifications.
A prayers timetable for all Muslims that uses geolocation features (Lat and Long) to get the exact current pray time. Prayer time athan calculations exist for both Shia and Sunni. You can customize which method to use in the options window. There is athan support as well, it will play custom athan sound when a prayer time is ready!

3. Inference Attacks: Reviewer-based Inference

- Extract name of extensions' reviewers → map names to **ethnicities** and **sex**
  - Use Shannon-Wiener index to identify predominant ethnicity/sex
- Example: "FlipShope- Flash sale autobuy" is mainly reviewed by users with Indian names



Contributions

- Demonstrated the *first* automated creation and detection of behavior-based fingerprints for identifying browser extensions.
- Introduced two novel fingerprinting techniques, that are robust against all existing countermeasures.
- Presented the largest extension fingerprinting study, and evaluated a state-of-the-art countermeasure.
- Presented the first empirical analysis on the privacy inference attacks enabled by browser extensions.
- Conduct the largest extension-unicity analysis and explore the use of user reviews as a novel deanonymization vector (see paper).

Questions?

Feel free to contact me:
skaram5@uic.edu

Extensions detected by each technique

Detection technique	Detected Extensions	
	Total	Unique
WAR-based	25,866	23,046
Behavioral (DOM-based)	5,793	2,998
Inter-communication	859	181
Intra-communication	450	105

Unicity

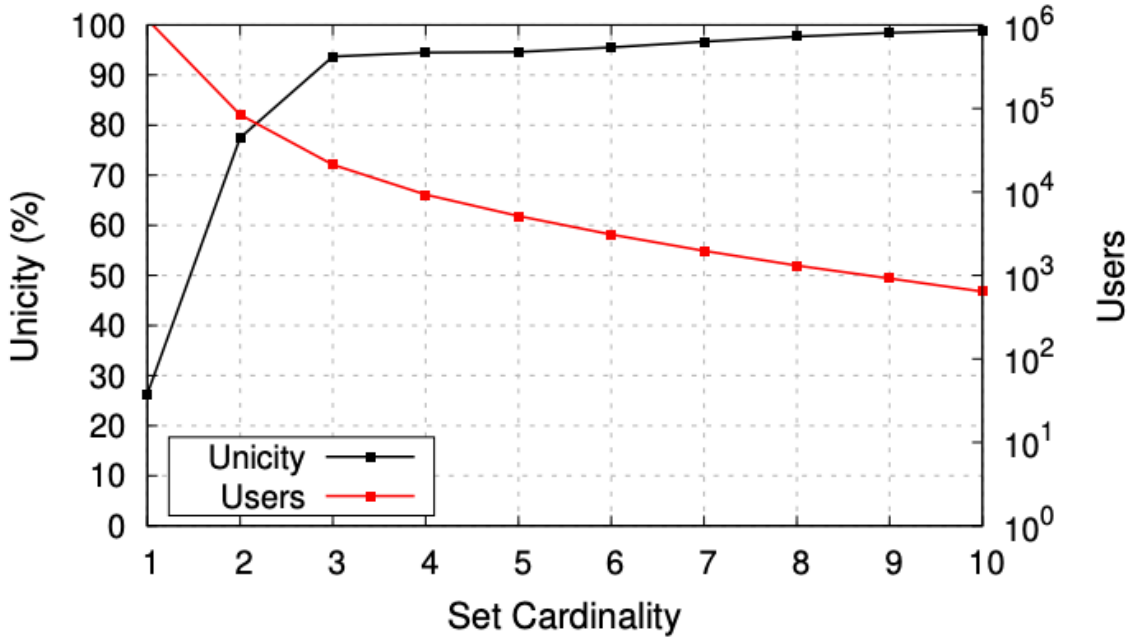


Fig. 7: Unicity of fingerprintable extension sets of different size, and the corresponding size of the anonymity crowd.

Detected extensions and reviews could be combined for identifying a user, or mapping them to a small set of potential users.