Ex-Ray: Detection of History-Leaking Browser Extensions

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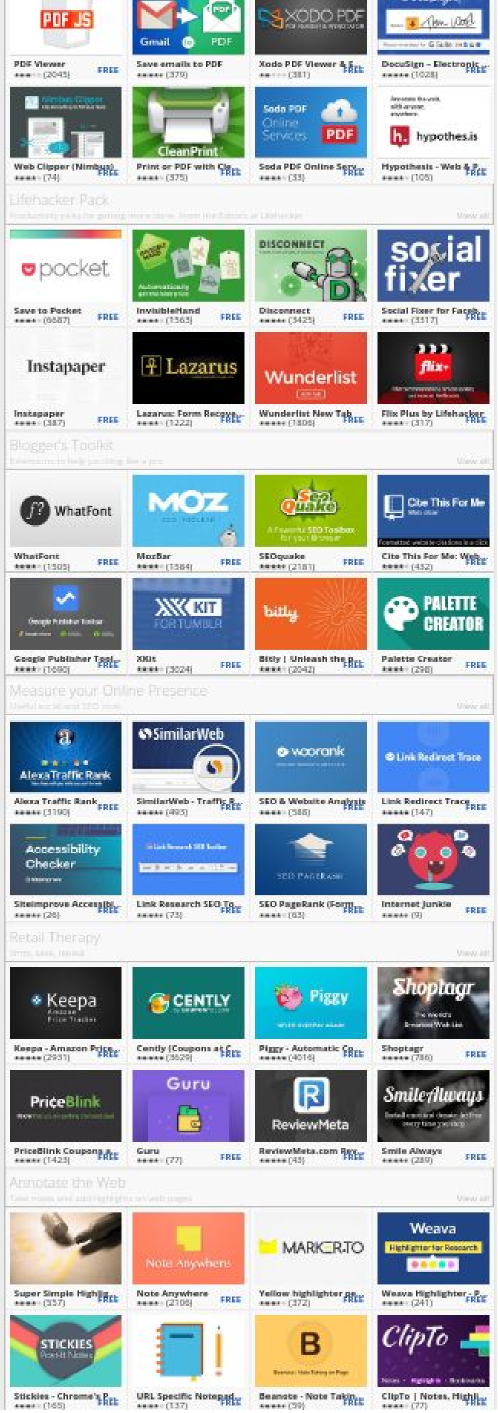

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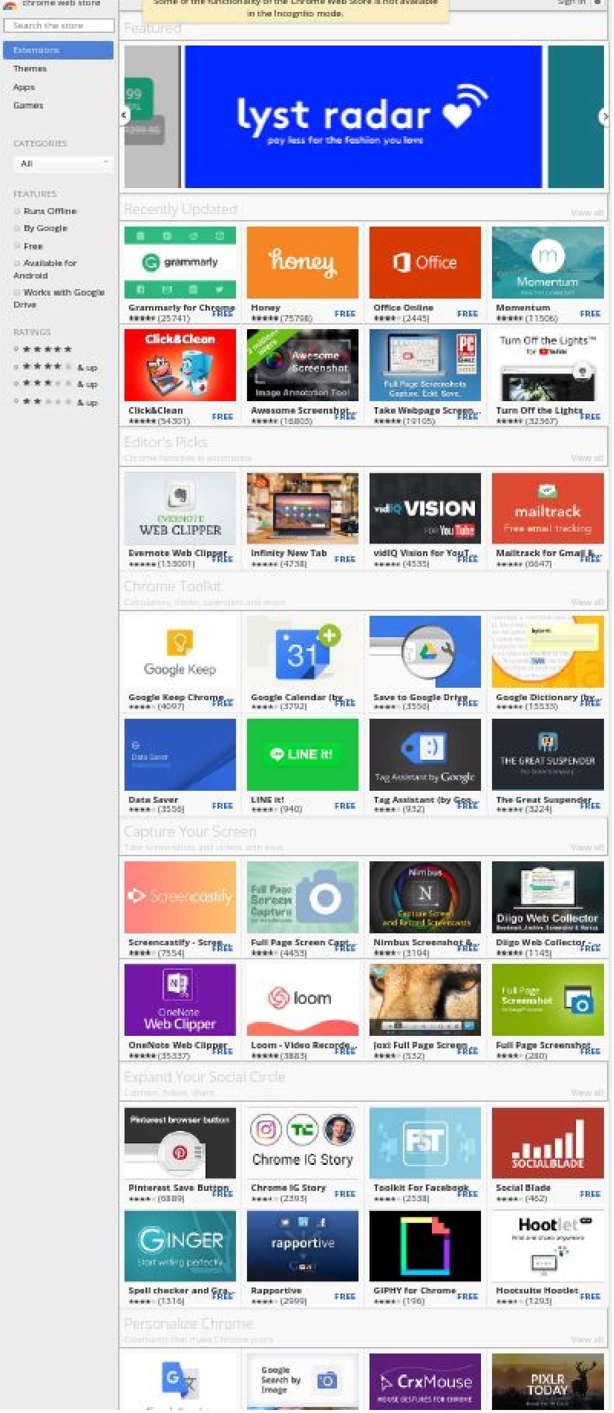

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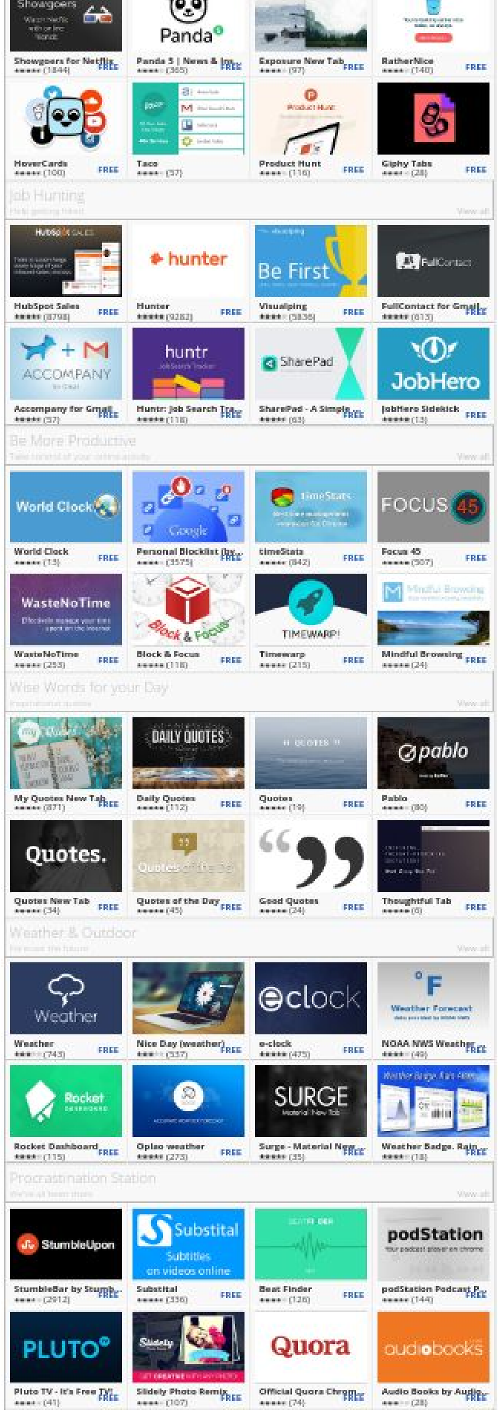

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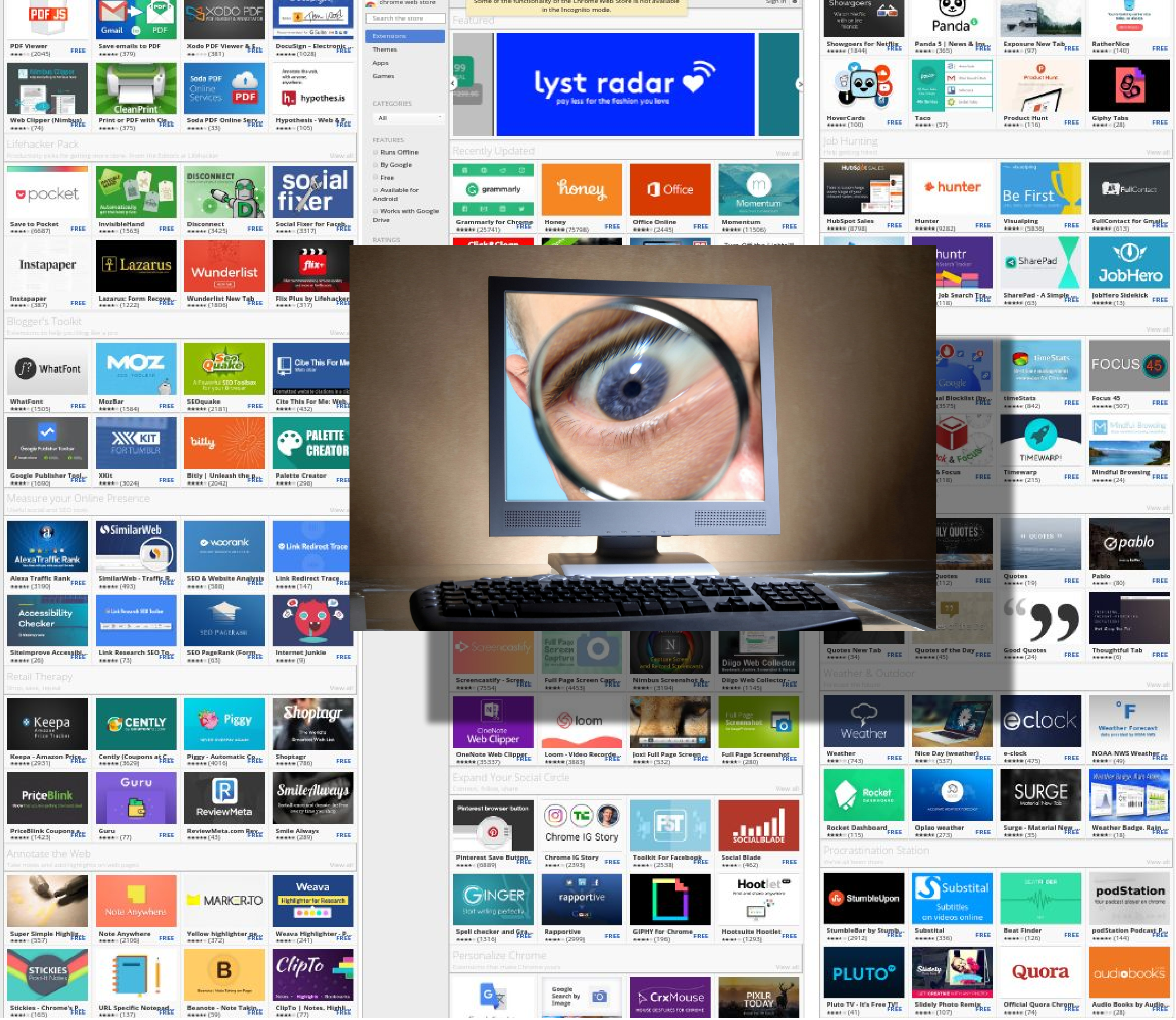
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Overview

- Extension Basics
- Extension Privacy Risks
- HoneyPot Probe
- Detection Methodology
- System Design and Evaluation
- Conclusion and Discussion

How extensions work

- Additions to browser core functionality
- Powerful API based on permissions
    - Modification of active pages
    - Modification of requests / responses
    - Often access to all visited pages
    - Access to cookies
    - Access to previous history

Extension Privacy Risks

- Privacy leaks through
  - Modifications to the site: referrer
  - Request or response interception
  - Polling active tab
  - ...
- No unified way of detection
- Previews work:
  - Manual analysis
  - Leaking keywords, search traffic

Extension Privacy Mitigations

- Permissions can restrict access to sites
- Extensions often over-request access
- Only modest permissions required to leak history

Tracker Comparison

- On Websites:
  - Opt-in: Website owner
  - Opt-out: Ghostery

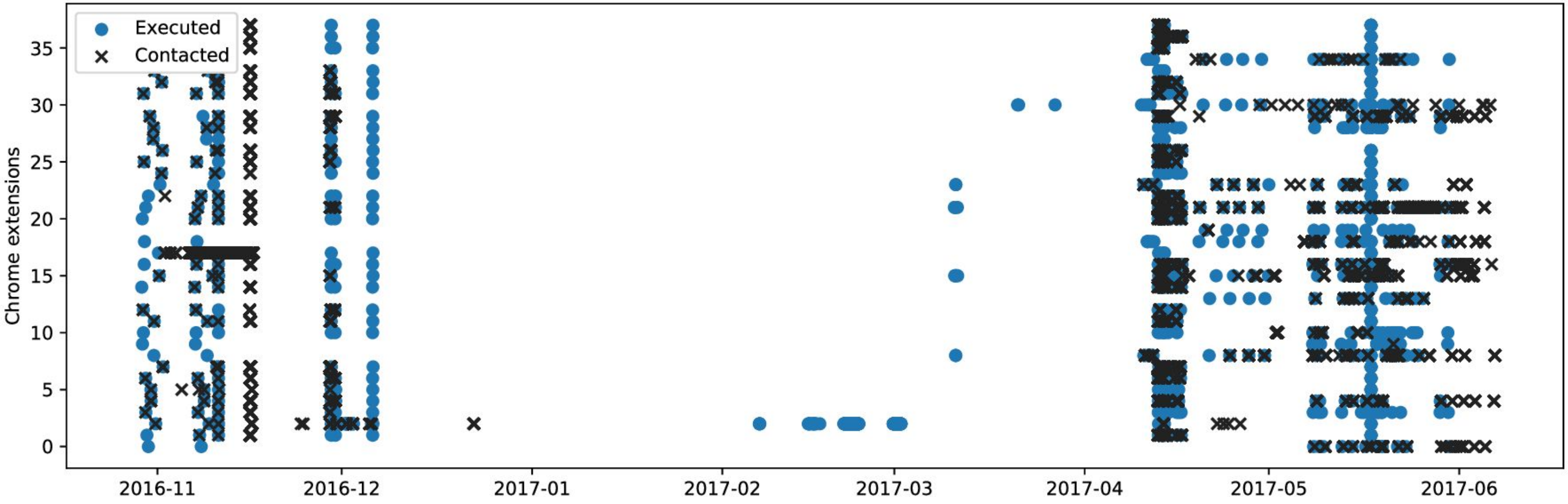
- In Extensions:
  - (typically) all websites
  - Implicit Opt-in through installation
  - No opt-out

“Is this an issue in practice?”

HoneyPot Probe

- Extensions run in a container
- Web and DNS local
- URLs unique to extension
- Public Internet only for other resources
- Browsing our website...
- ... which is also available on the public Internet

HoneyPot Probe



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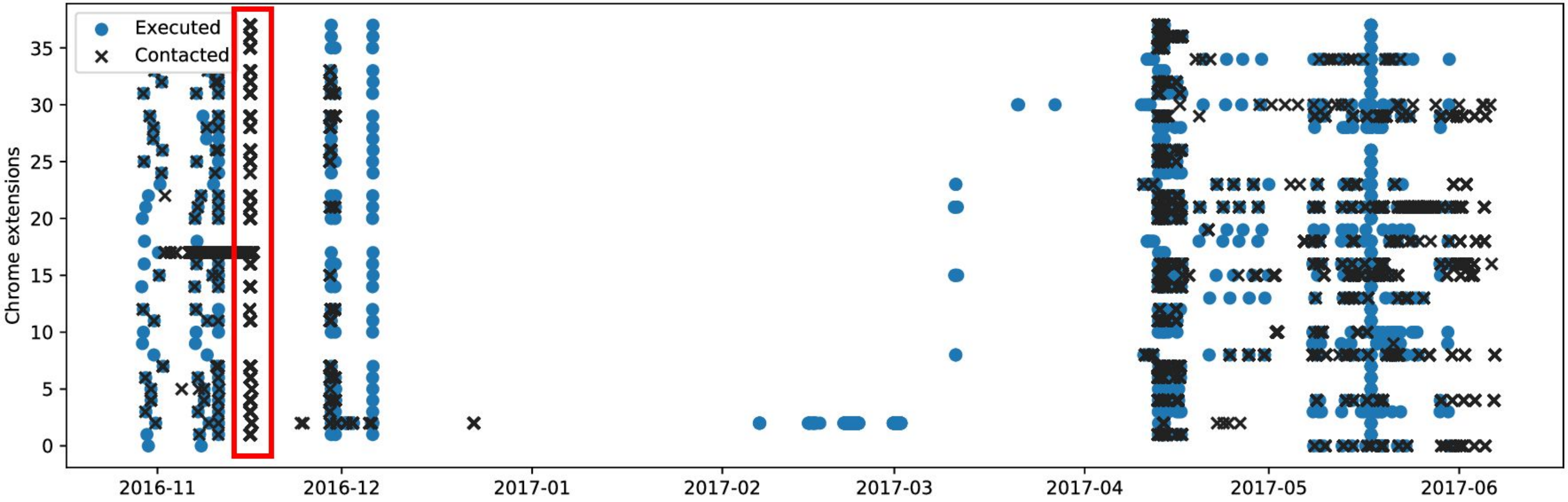

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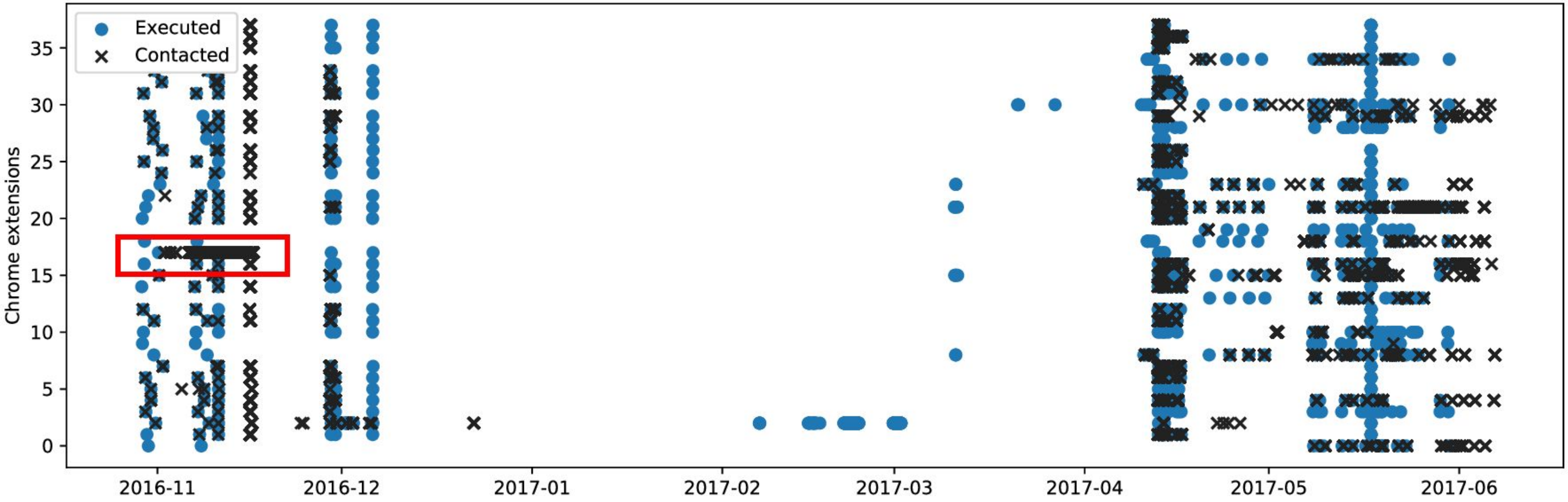

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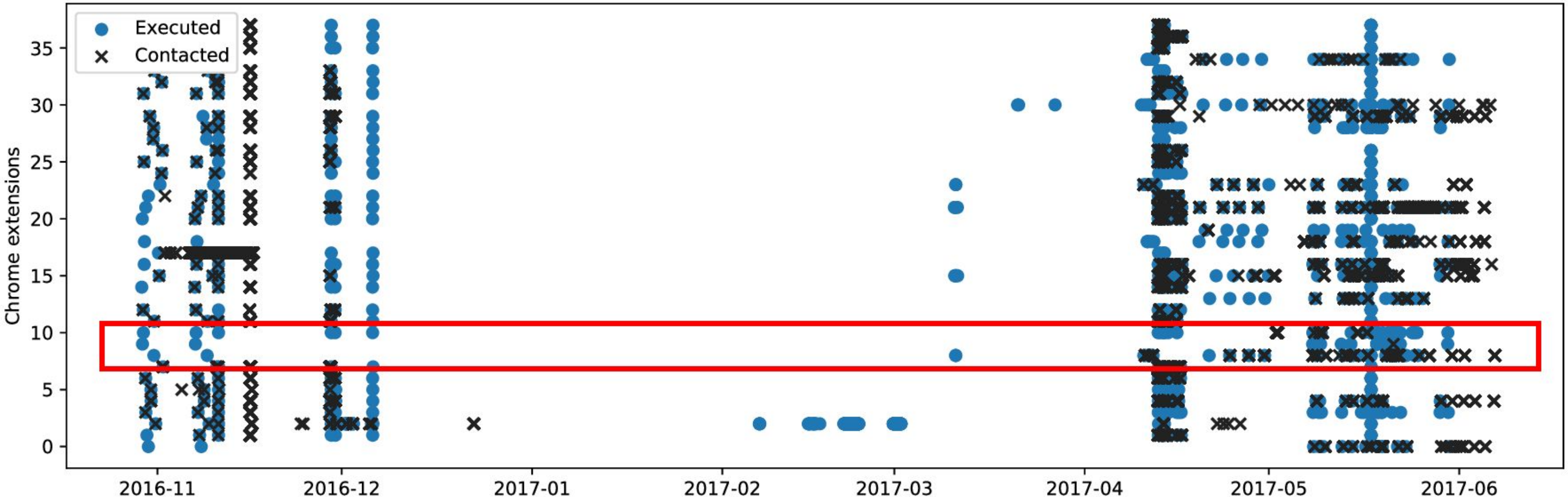


HoneyPot Incoming Connections

Extension Name	Installations	Connection Origin
Stylish - Custom themes	1,671,326	*.bb.netbynet.ru *.moscow.rt.ru *.spb.ertelecom.ru
Pop Up Blocker for Chrome	1,151,178	*.aws.kontera.com 176.15.177.229 *.bb.netbynet.ru
Desprotetor de Links	251,016	*.aws.kontera.com *.moscow.rt.ru *.bb.netbynet.ru

HoneyPot Probe

- Connections prove use of data
- Excluding VPN: 38 Extensions
- Connection often immediately after execution
- They leak immediately
- Indications for collaboration, no proof
- No malicious activity detected
- Motivation for automated detection system

Detection Methodology

Hypothesis: For tracking samples, sent data size should grow in relation to history provided to the extension.

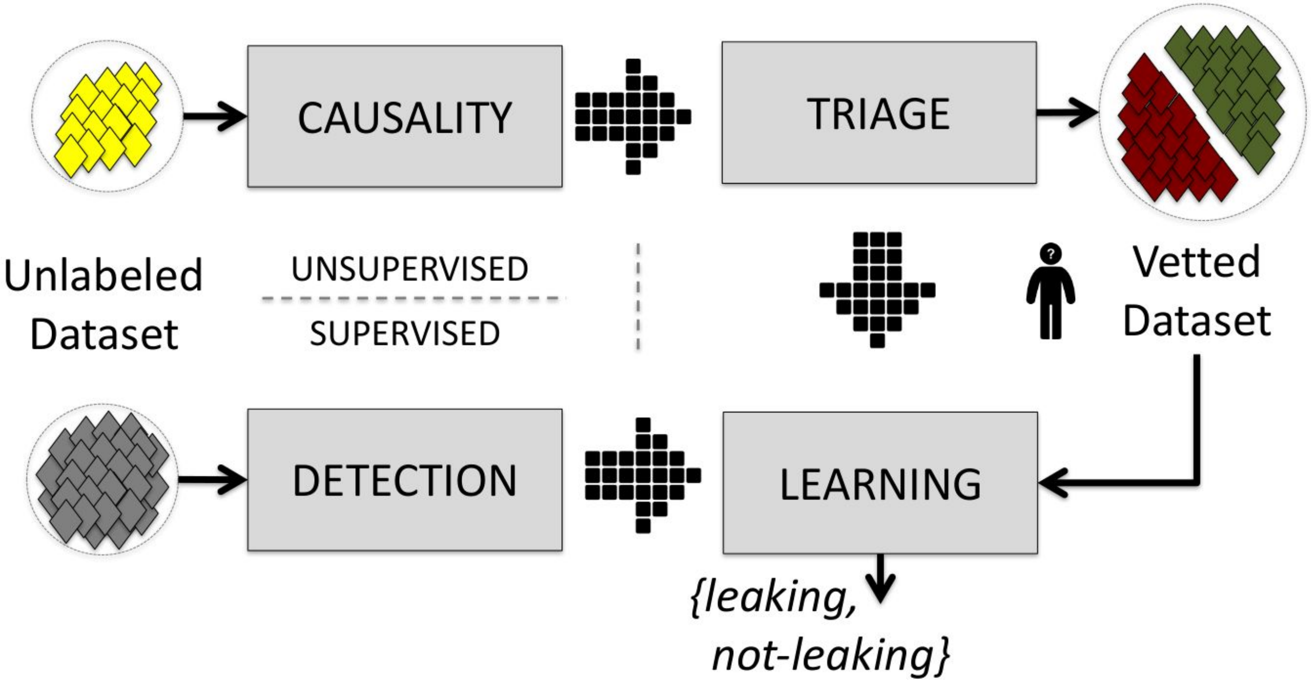
Ex-Ray Goals

- Robust Detection
  - Traffic obfuscation / encryption
  - Method of data collection / exfiltration
- Automated detection of leaks
- Large scale

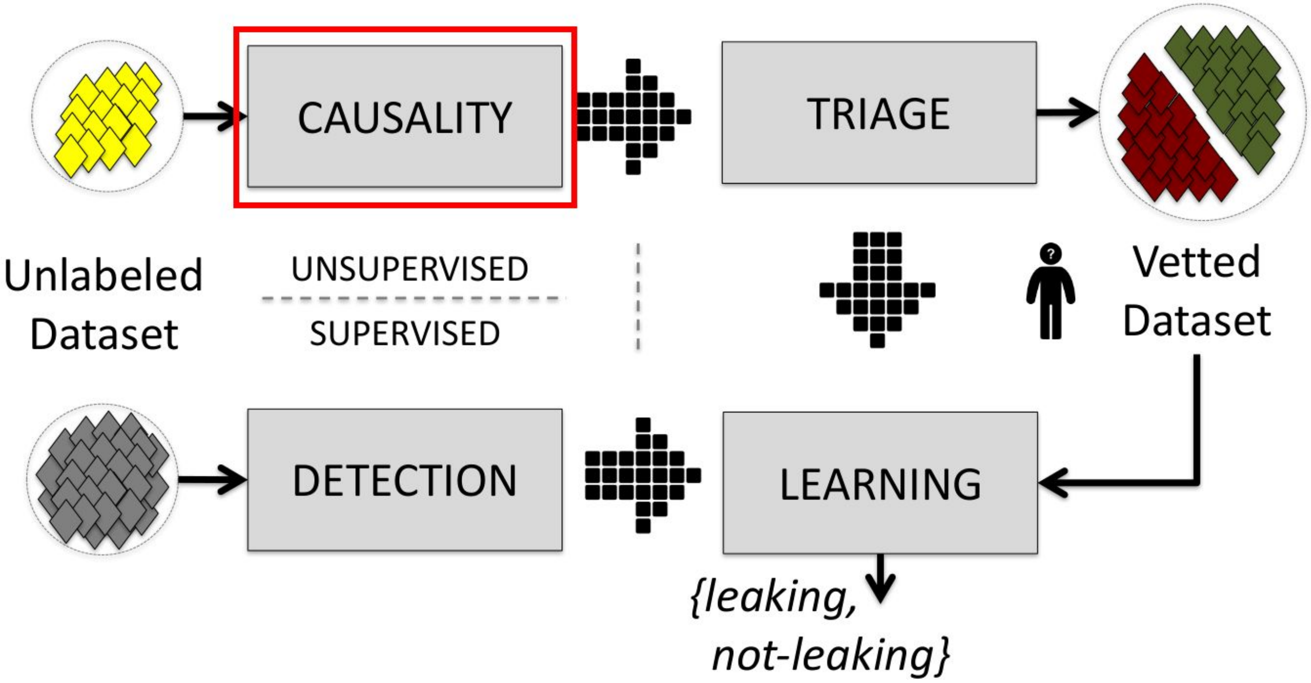
Detection Methodology

- Controlled environment
- Execution in multiple stages
- Vary size of browsing history
- Supervised and unsupervised methods

Detection Methodology



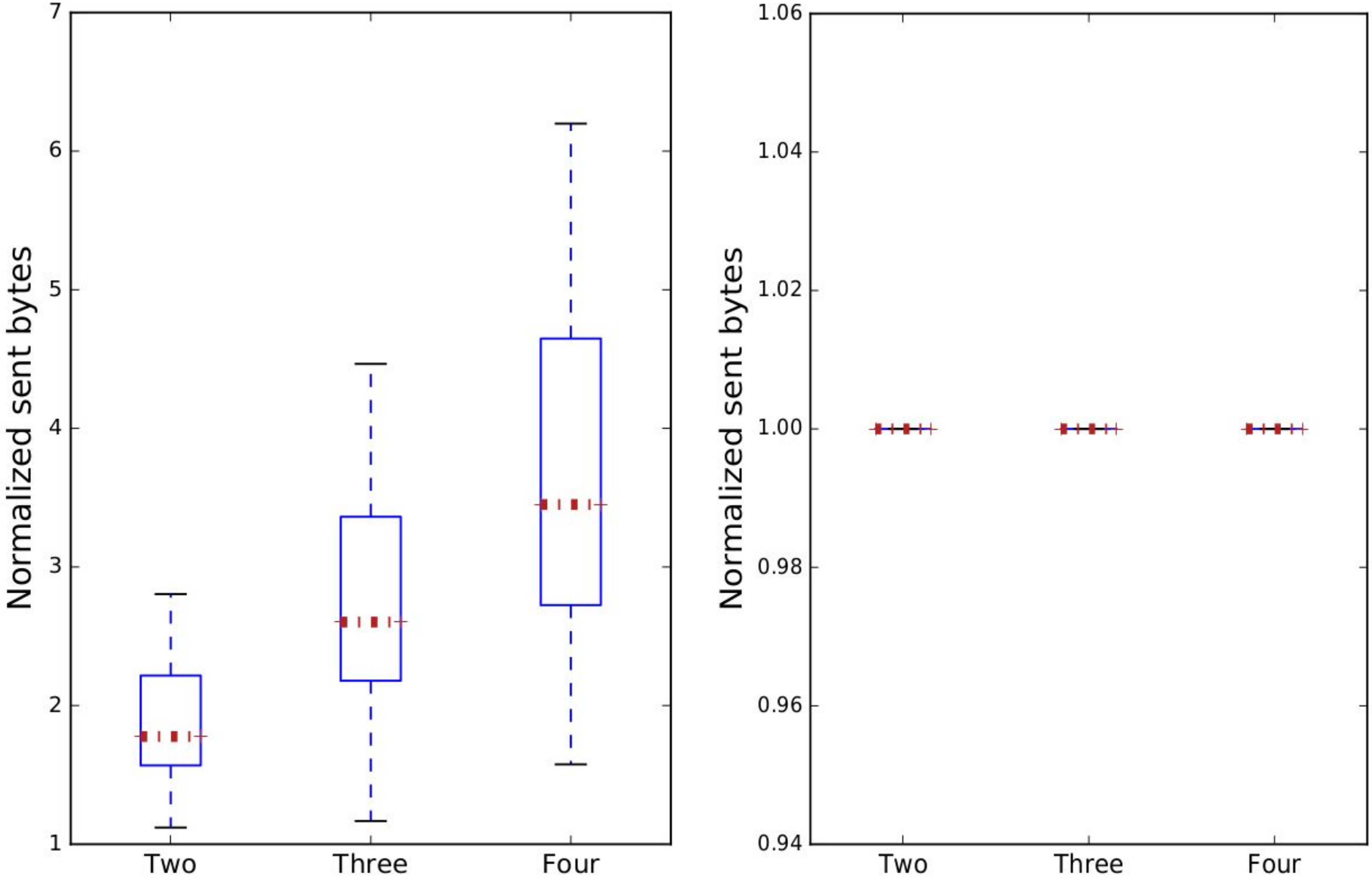
Detection Methodology



Causality

- Varying history as variable over stages
  - Stage 0: `example.com/example/index.html`
  - Stage 1: `example.com/example/<500characters>/index.html`
  - ...

- Expectations
  - Benign: no change
  - Otherwise: ?



(a) Tracking extension.

(b) Benign extensions.

Causality

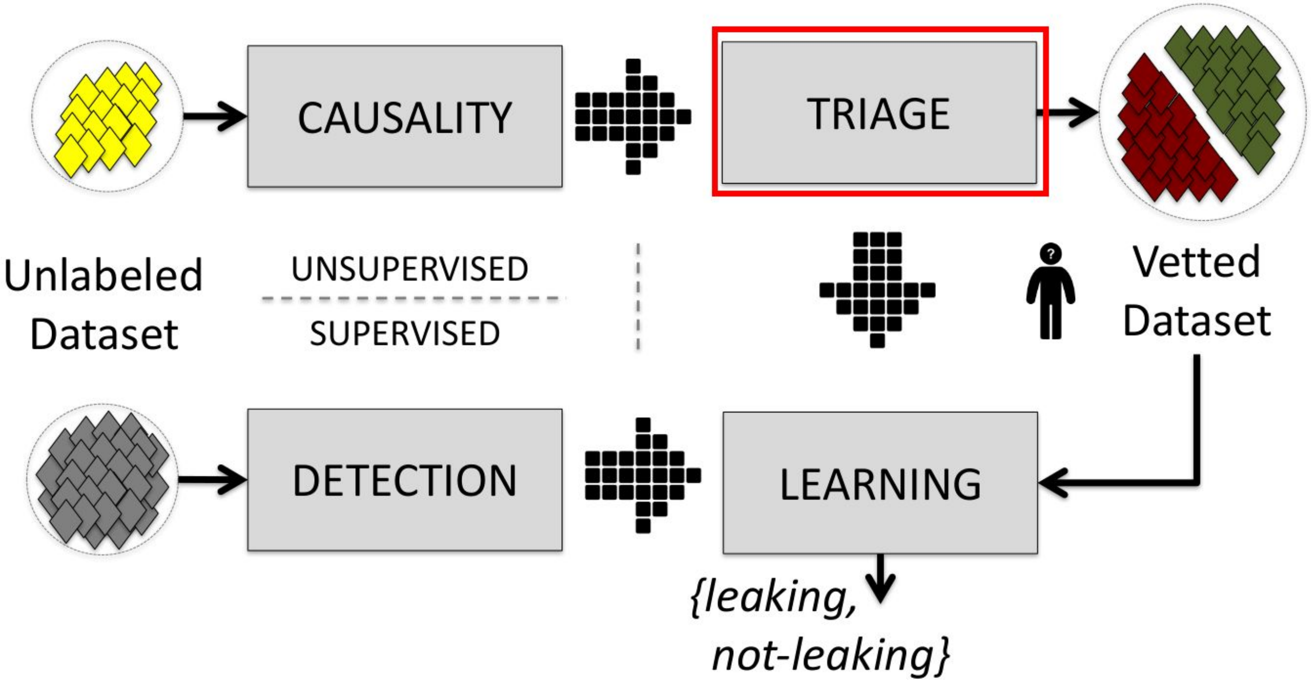
- Counterfactual analysis
- Input variable: size of history
- Output variable: <data sent, destination> tuples
- Invariants of trackers
- Goal: find deterministic tracking
- Supervised method: trained on benign and leaking datasets

Causality

Three steps

1. Minimum intercept: threshold
2. Minimum slope: increase
3. Level of confidence: proximity to model

Detection Methodology



Triage

- Quantify leakage
- Prioritize extensions
- Supports human analyst in prioritizing extensions

Triage

- L: number of leaked URLs between experiments
- |*si*|, |*sj*|: number of bytes sent to domain
- τ: expected threshold for increase

$$\mathrm{L}(s_i, s_j) = \frac{|s_j| - |s_i|}{\tau}$$

Triage

- Score: Likelihood of a leak
- s: transition between stages (i=>j)

$$\mathrm{score}(x) = \prod_{s} e^{\mathsf{L}(s)}$$

Triage

$$\text{leak}(x) = \begin{cases} \texttt{not-leaking} & \text{if } score(x) \leq 1 \\ \texttt{possibly-leaking} & \text{if } 1 < score(x) \leq 100 \\ \texttt{likely-leaking} & \text{otherwise.} \end{cases}$$

- Result: indicators for manual analysis

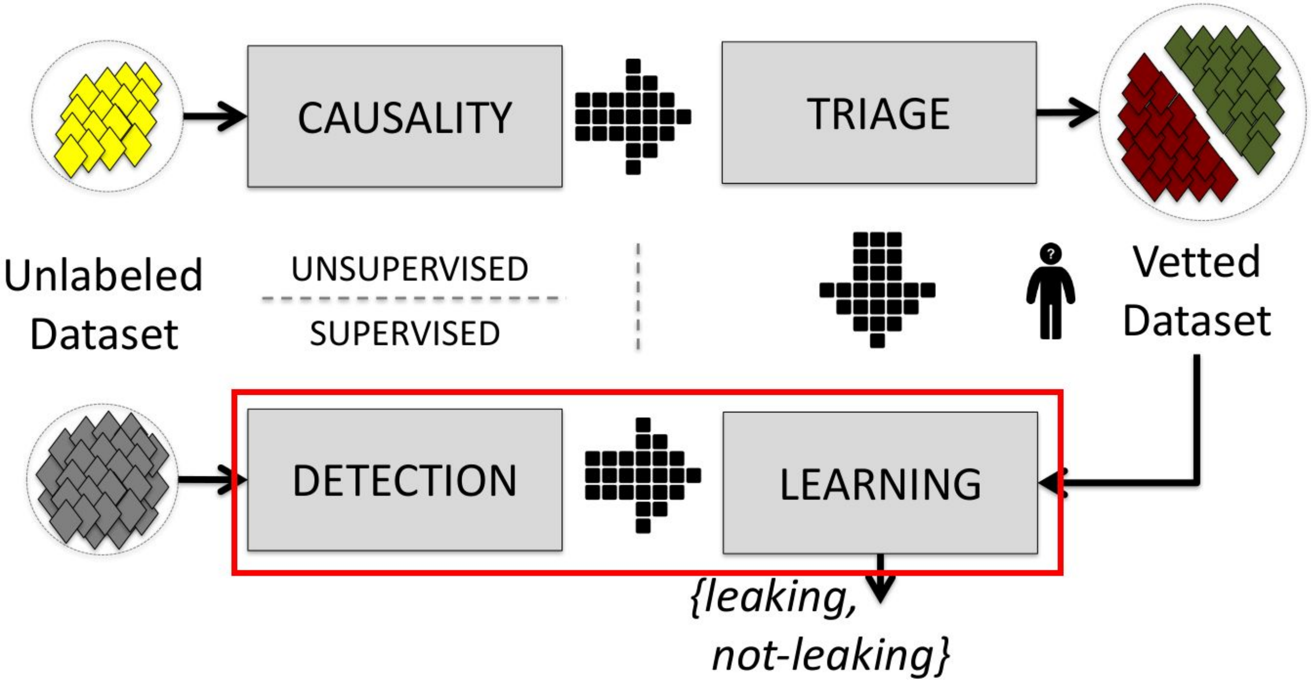
Triage Samples: Leak

```
QR Code Generator
    4e+18  connectionstrenth.com
   394.88  a.pnamic.com
    28.22  eluxer.net
     4.48  rules.similardeals.net
     1.16  code.jquery.com
```

Triage Samples: Benign

```
Bible Quote of the Day
     1.00   www.gstatic.com
     1.00   chromium-i18n.appspot.com
     1.00   ssl.gstatic.com
     1.00   localhost
     0.67   www.google.com
```

Detection Methodology



Behavioral Detection

- Based on previously flagged extensions
- Clang Libtooling instrumentation
  - C++ source code rewriting
  - 11,132 function trace points
- API call analysis
- Input: n-grams of API calls

Evaluation: Causality

- Crawled store for extensions > 1,000 installations
- 10,691 Extensions total
- 212 flagged: 1.9%
- 184 manually verified as leaking
- 28 wrongly identified
- False Detection Rate: 0.27%
    - Flagged due to ads
    - Possible improvement: increase # stages

Evaluation: Behavioral

- Best parameters:
  - n-gram: 2
  - F1 score: 96.43%
- Distinguishing calls:
  - URL manipulation
  - JavaScript manipulation
- Most distinguishing sequence:
  - extensions.browser.extension_prefs.GetExtensionPref()
  - chrome.browser.extensions.shared_user_script_master .GetScriptsMetadata()

Noteworthy Samples: Causality

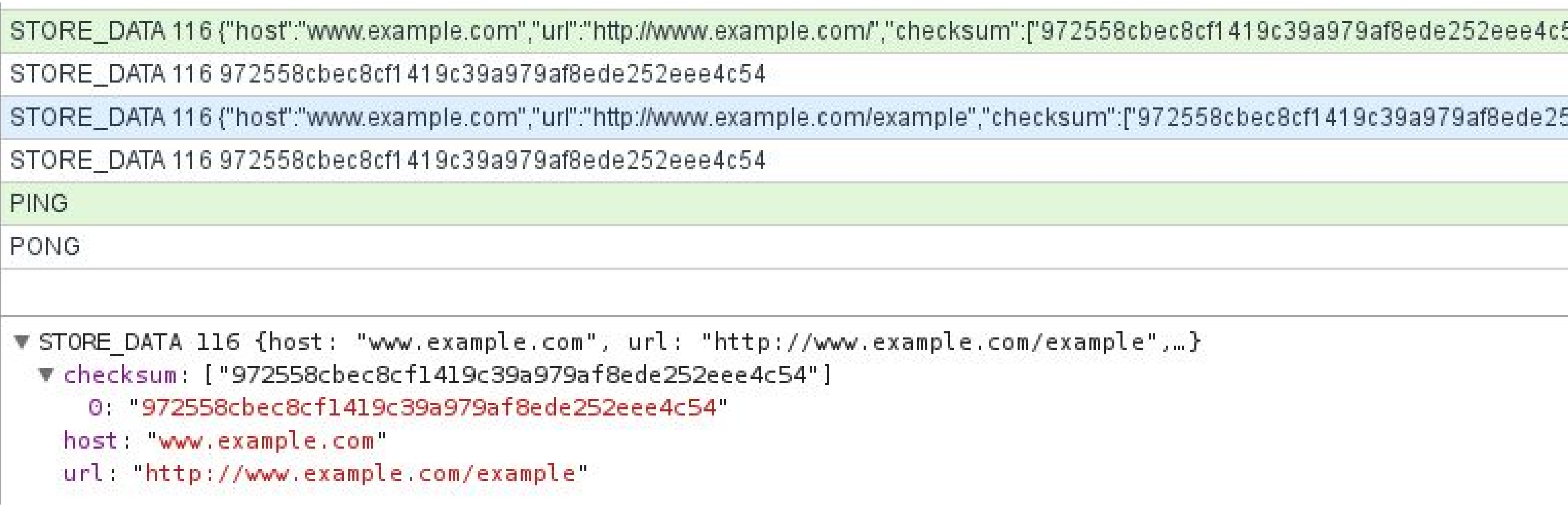
- Not detectable by state-of-the-art leakage detection systems
- Previously unknown leakage channels
    - Strong Encryption
    - Unsupported Protocol

Web of Trust (WOT)

- Provides crowd-sourced "trust" ranking
- 1.2M installations
- Extension received media coverage for selling user data
- RC4 encryption (See `crypto.js` file)
- Can be implemented similarly to Google Safe Browsing (offline)

CouponMate

- WebSockets: Protocol not supported by previous systems
- Protocol growing in popularity: 0.96%



```
STORE_DATA 116 {"host":"www.example.com","url":"http://www.example.com/","checksum":["972558cbec8cf1419c39a979af8ede252eee4c5
STORE_DATA 116 972558cbec8cf1419c39a979af8ede252eee4c54
STORE_DATA 116 {"host":"www.example.com","url":"http://www.example.com/example","checksum":["972558cbec8cf1419c39a979af8ede25
STORE_DATA 116 972558cbec8cf1419c39a979af8ede252eee4c54
PING
PONG

▼ STORE_DATA 116 {host: "www.example.com", url: "http://www.example.com/example",…}
  ▼ checksum: ["972558cbec8cf1419c39a979af8ede252eee4c54"]
      0: "972558cbec8cf1419c39a979af8ede252eee4c54"
    host: "www.example.com"
    url: "http://www.example.com/example"
```

Possible remediations

- Stores should analyze extensions to warn users
- Implement API to inspect background traffic
- Invasive tracking as single purpose rule violation

Conclusions

- Robust detection method for privacy leaks
- Prototype: Ex-Ray
- Supervised and Unsupervised methods
- 10,691 extensions analyzed
- 212 flagged
- Found two novel leaking channels in use

Thank you for your attention

Questions?

Paper and Data:

https://goo.gl/nezKGp