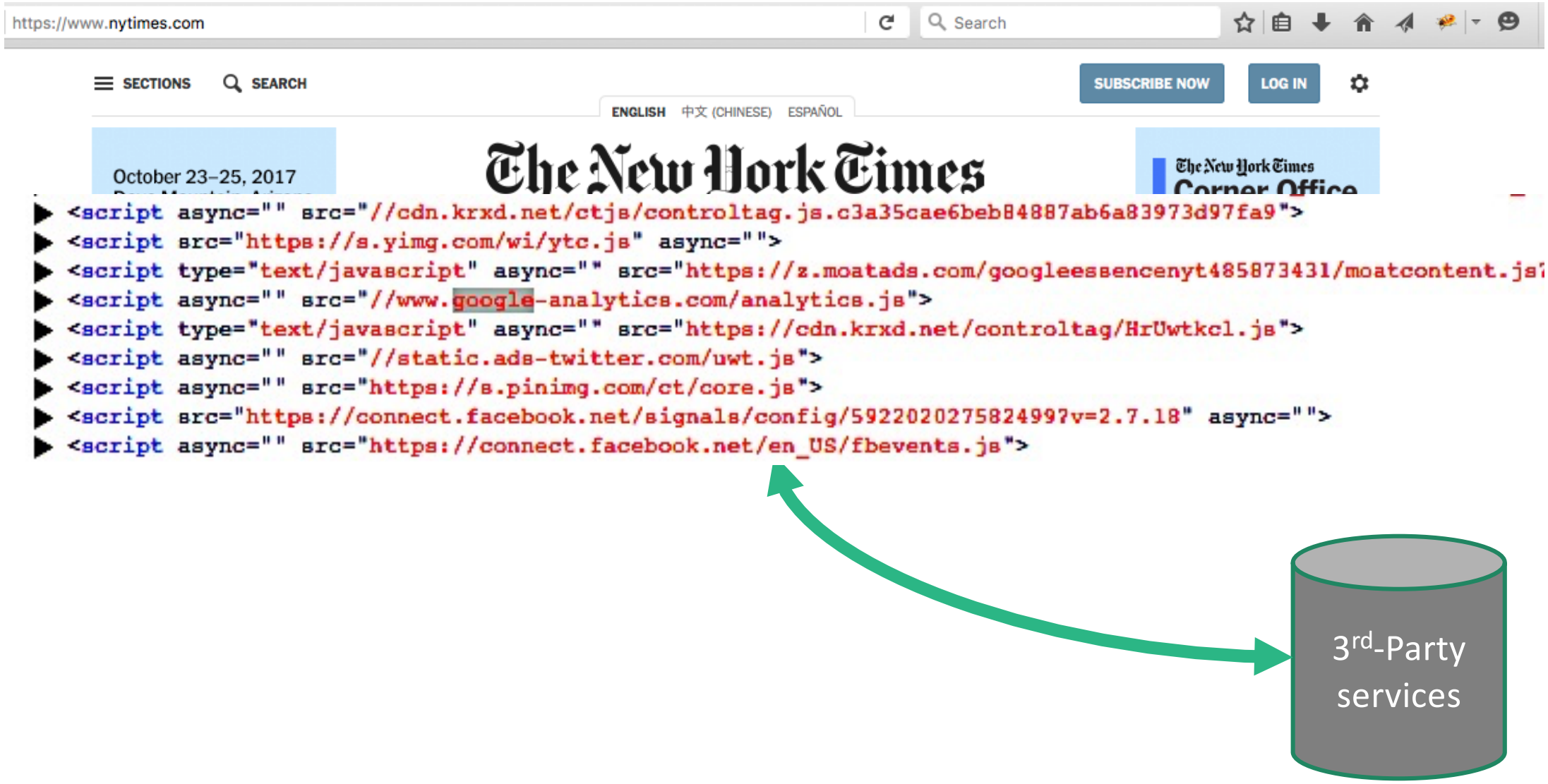
DATA 61

Towards Seamless tracking-free web browsing: Improved detection of tracking JavaScripts via one-class learning

Muhammad Ikram, Hassan Asghar, **Mohamed Ali Kaafar**, Anirban Mahanti, Balachander Krishnamurthy

www.csiro.au

What happens when a browser requests an HTML source from a web server (e.g., nytimes.com)?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The New York Times
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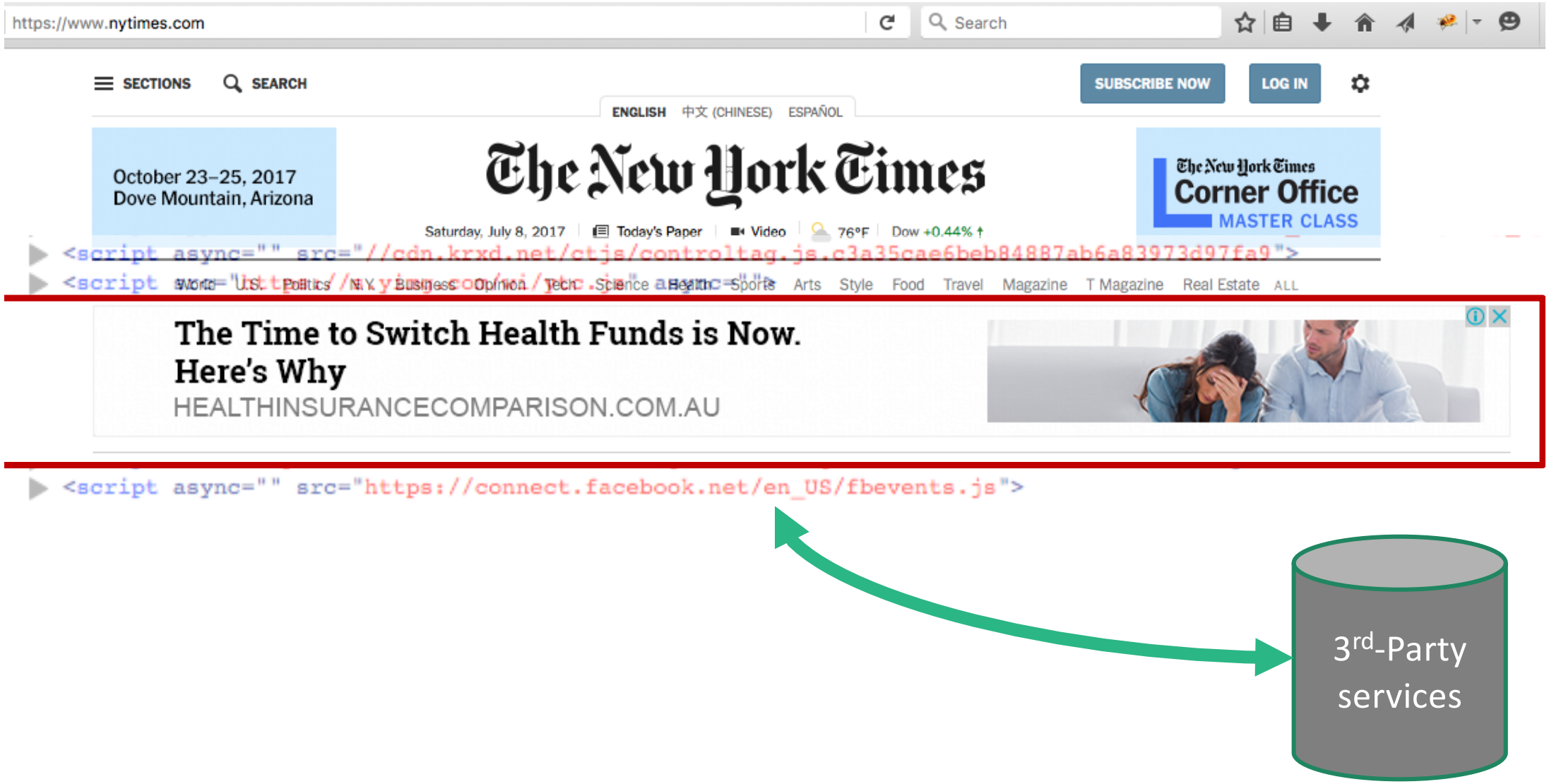
3rd-Party services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The New York Times Corner Office MASTER CLASS
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The Time to Switch Health Funds is Now. Here's Why
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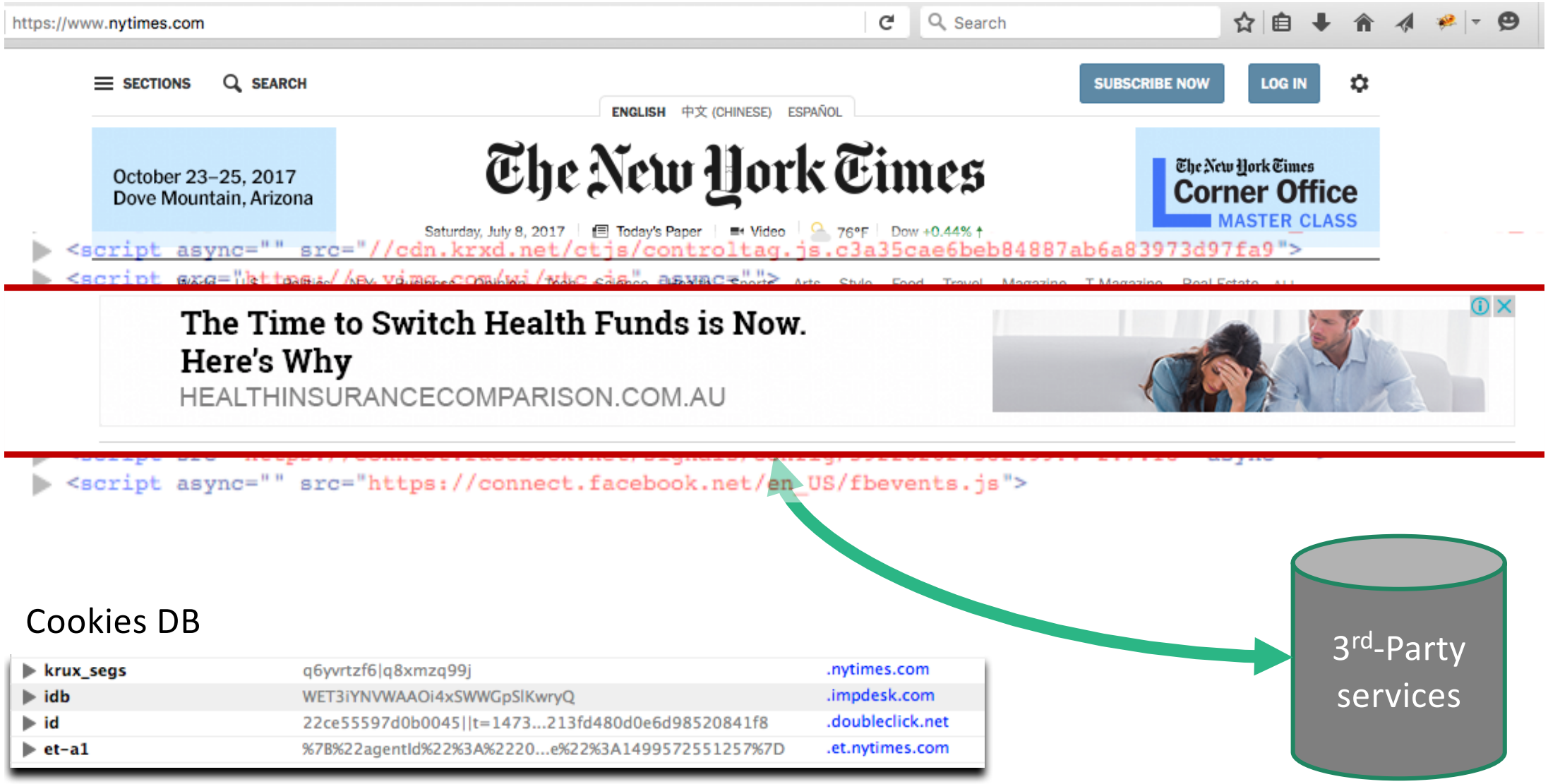
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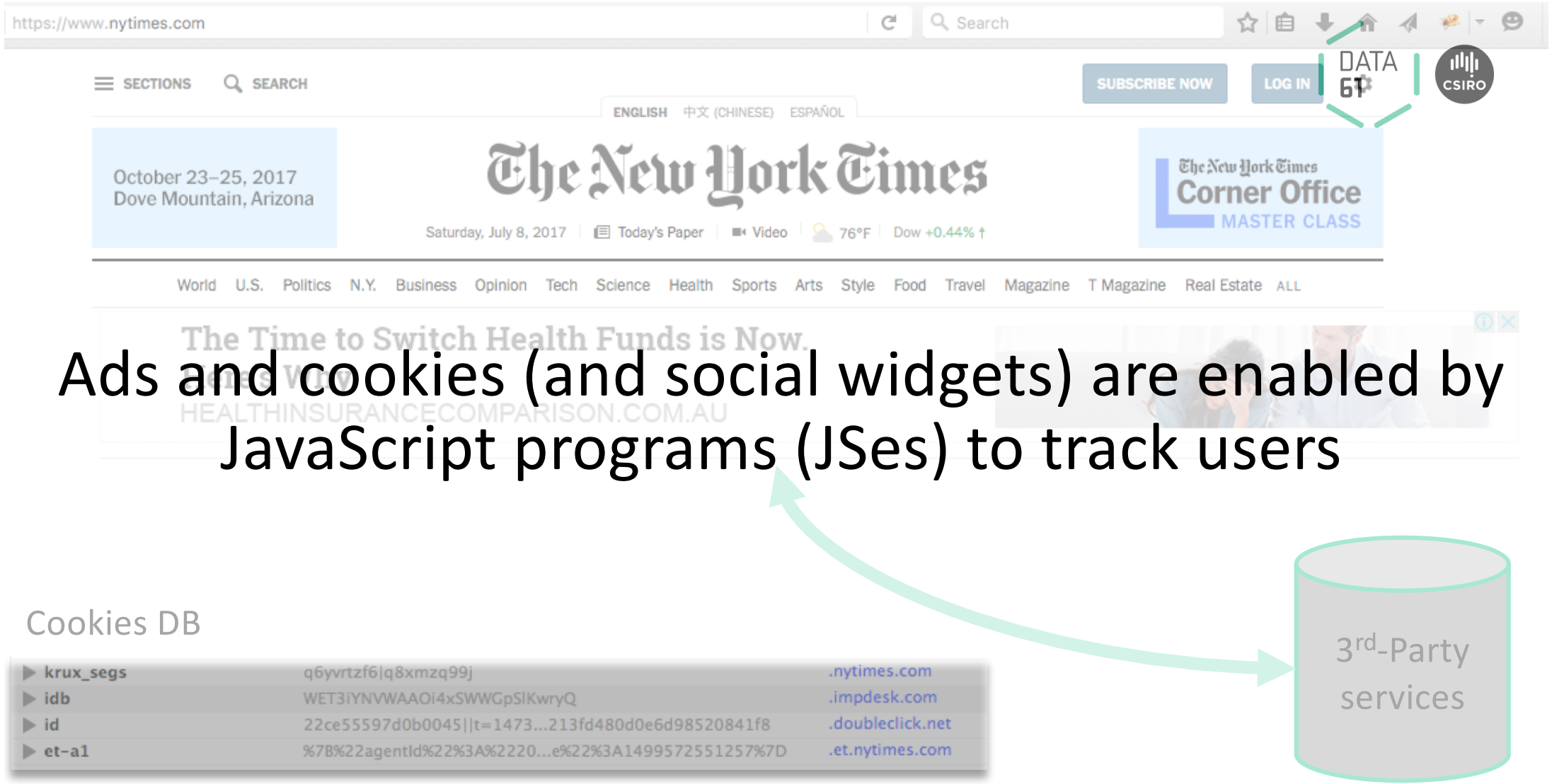
3rd-Party services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The Time to Switch Health Funds is Now.
HEALTHINSURANCECOMPARISON.COM.AU
Ads and cookies (and social widgets) are enabled by JavaScript programs (JSes) to track users
Cookies DB
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idb WET3iYNVWAAOi4xSWWGpSlKwryQ .impdesk.com
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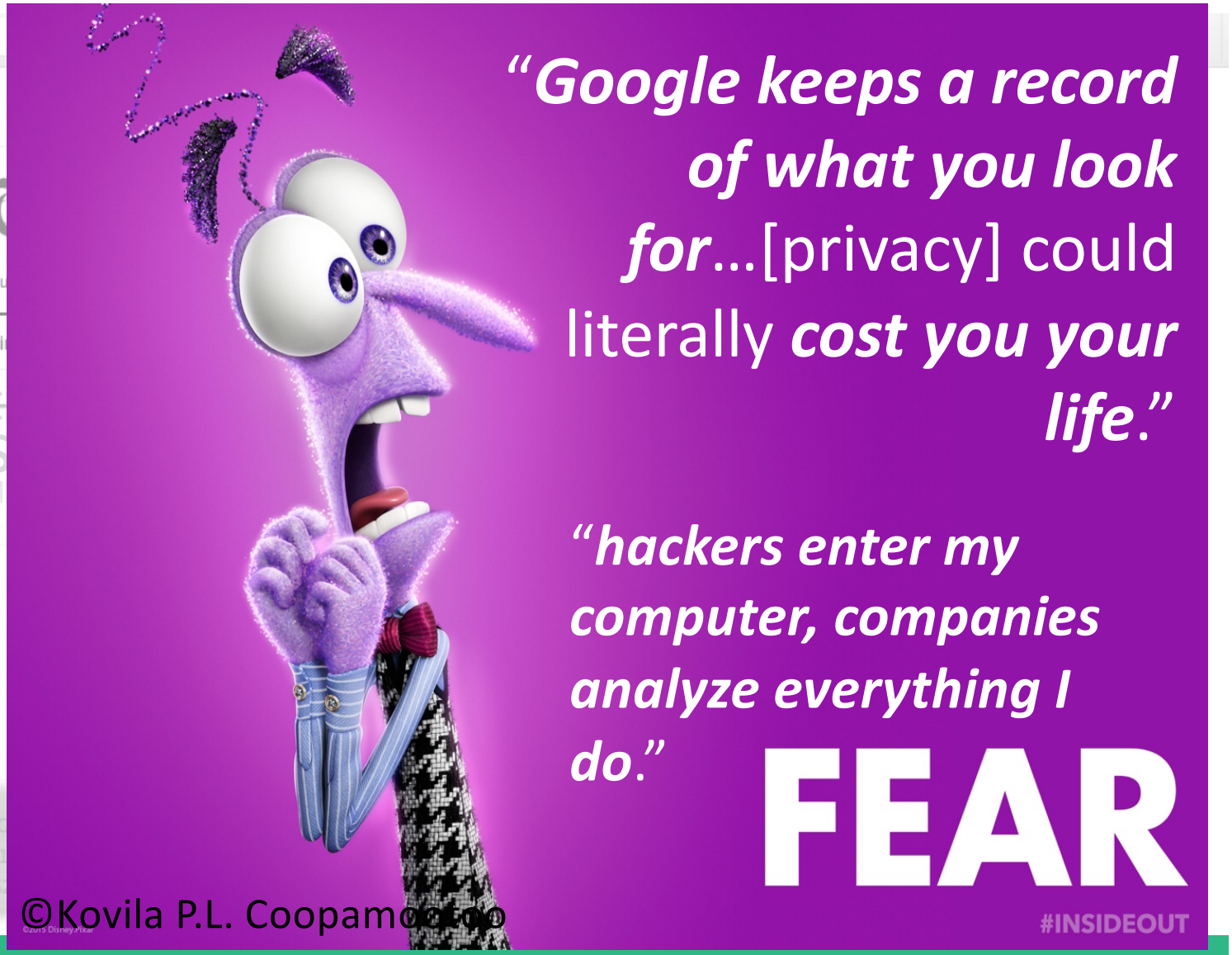
3rd-Party services

Privacy Concerns



Ads and cookies

JavaScript

Cookies DB

Privacy Preserving Tools (PP-Tools)

- Blacklist of URLs (or patterns of URLs) to block 3rd-party *tracking* JSes

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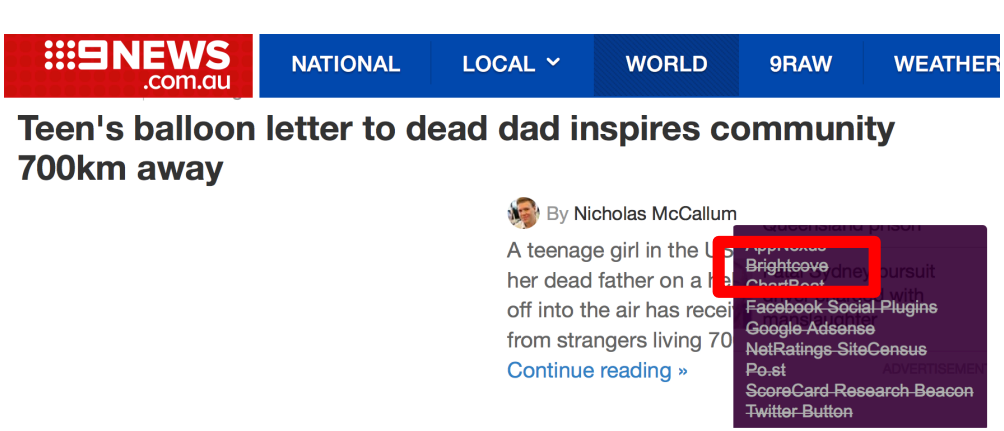
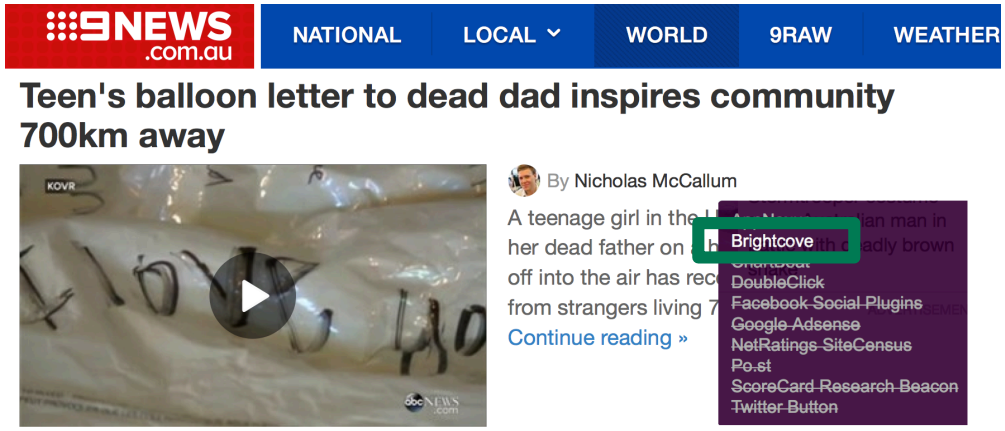
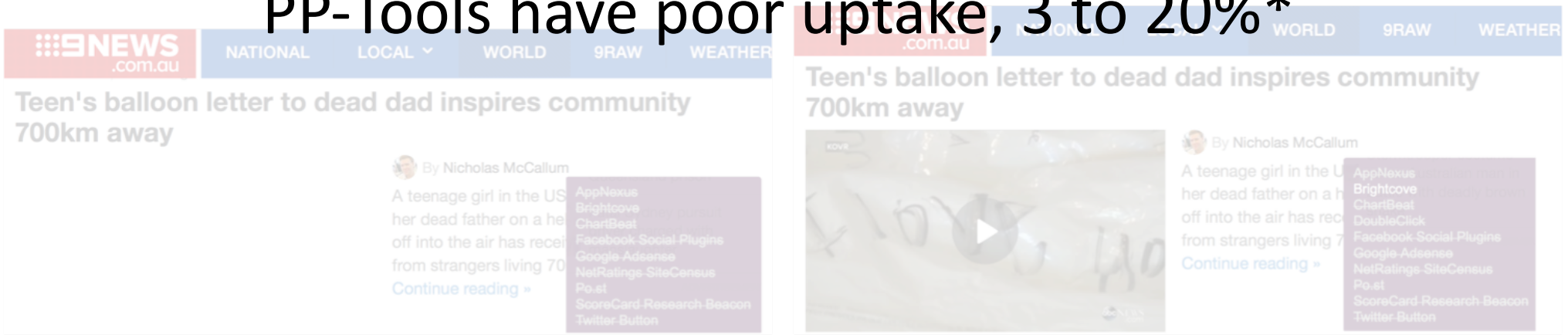




Privacy Preserving Tools (PP-Tools)

- Blacklist of URL (or patterns of URLs) to block 3rd-party *tracking* JSes

PP-Tools have poor uptake, 3 to 20%*



* Metwalley et al., The Online Tracking Horde: a View from Passive Measurements, TMA'15

Privacy Preserving Tools (PP-Tools)

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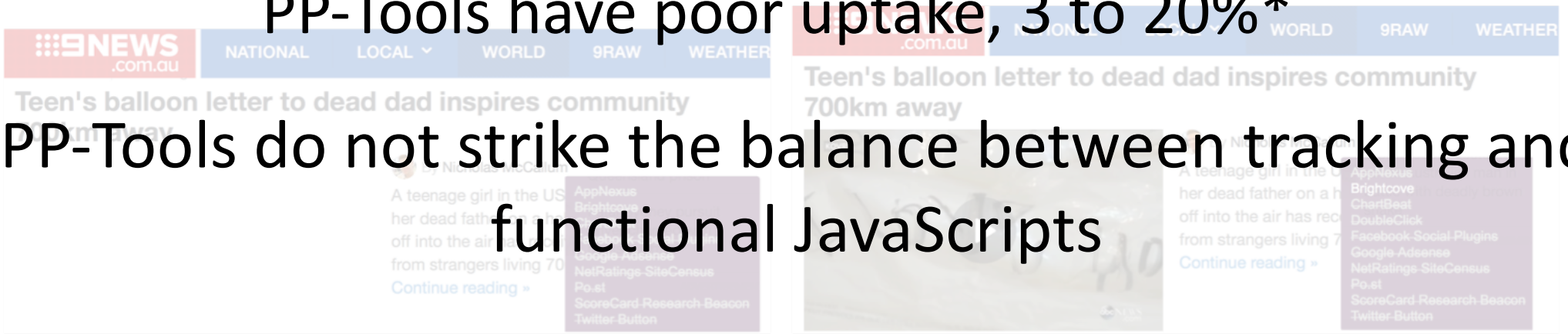
PP-Tools do not strike the balance between tracking and functional JavaScripts



* Metwalley et al., The Online Tracking Horde: a View from Passive Measurements, TMA'15

Tracking JSes are similar to each other and are distinct from Functional JSes

JavaScript Codes Similarity: Example

Tracker 1. Google Analytics Cookie Setting

```
var _gaq = _gaq || [];
_gaq.push(['_setAccount', 'UA-1627489-1']);
_gaq.push(['_setDomainName', 'geo.tv']);
_gaq.push(['_trackPageview']);
```

Tracker 2. Visual Revenue Cookie Setting

```
var _vrq = _vrq || [],
_vrqIsOnHP = (document.body.className ||
  '').search('pg-section') >=0 ? true : false;
_vrq.push(['id', 396]);
_vrq.push(['automate', _vrqIsOnHP]);
_vrq.push(['track', function() {}]);
```

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Code snippets are **syntactically** and **semantically** similar with difference in variable names and values

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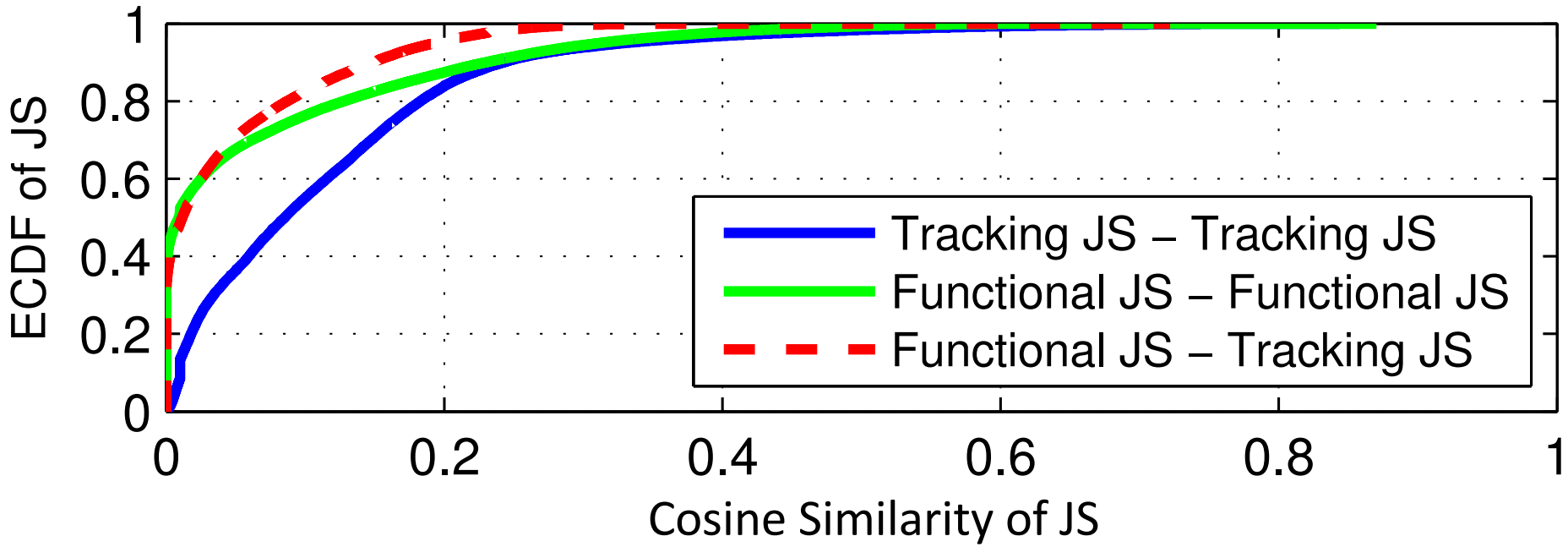
```

JavaScript Codes Similarity: two sets of 500 Functional and 500 Tracking JSes

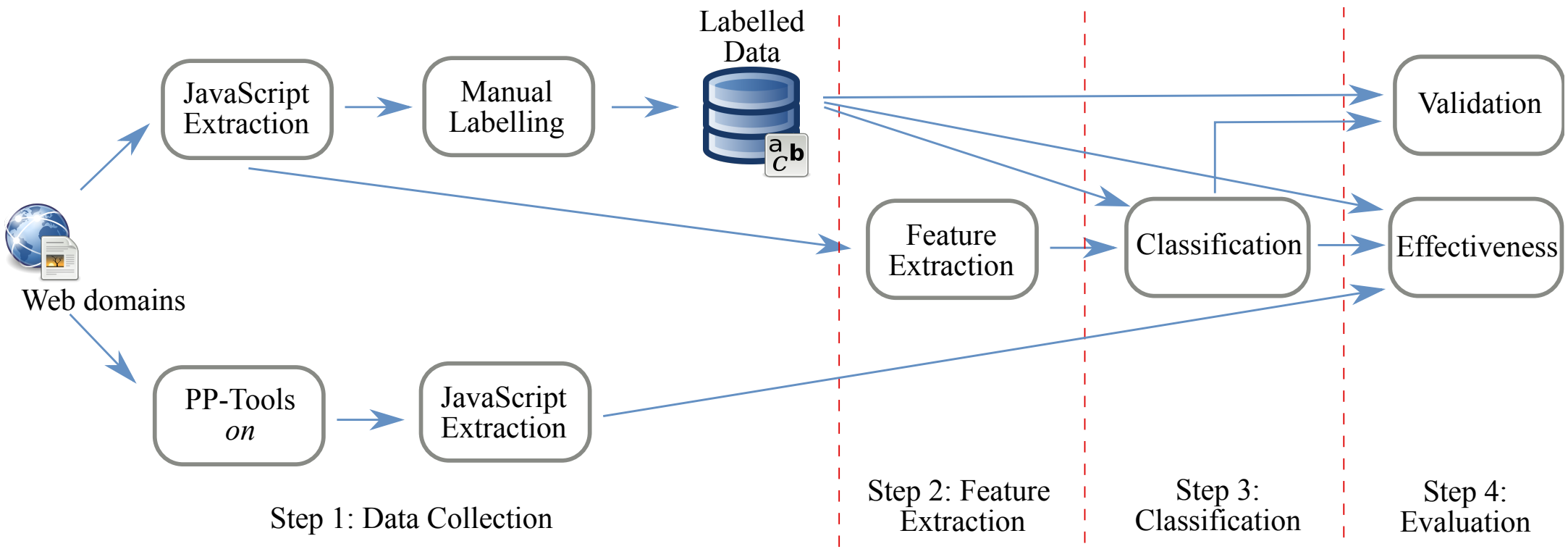


Overview of Our Contribution

- Analyze PP-Tools' performance
  - Regular expressions based on blacklists are ineffective

- Design a classification framework to separate *tracking* JSes from *functional* JSes
  - Training with partial single class of functional or tracking Jses
  - Partial view of tracking JSes from blacklists

Our Methodology



Data Collection: Rules for Labelling JSes

Rule	JS	#	Description
R1	✗	216	All JS that create panels and set margins for ads
R2	✗	115	All JS that access and display ads
R3	✗	45	All social media widgets
R4	✗	324	All in-page JS that include external JS from third-party analytics and advertisers
R5	✗	353	All external JS from third-party analytics and advertisers
R6	✗	180	All cookie enablers, readers or writers
R7	✓	542	All external JS that provide useful functionality such as navigation menus, search and login
R8	✓	509	All in-page JS that provide useful functionality
R9	✓	132	All JS that fetch content from first-party content domains or third-party CDNs
R10	✗	103	All JS in hidden iframe that belong to third-party analytics, advertisers and social media
R11	✗	40	All JS in hidden iframe that enable, read or modify cookies
R12	✓	53	All JS that track mouse or keyboard events

x:Tracking JS, ✓: Functional JS

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✗:Tracking JS, ✓: Functional JS

Analyzing PP-Tools

NoScript

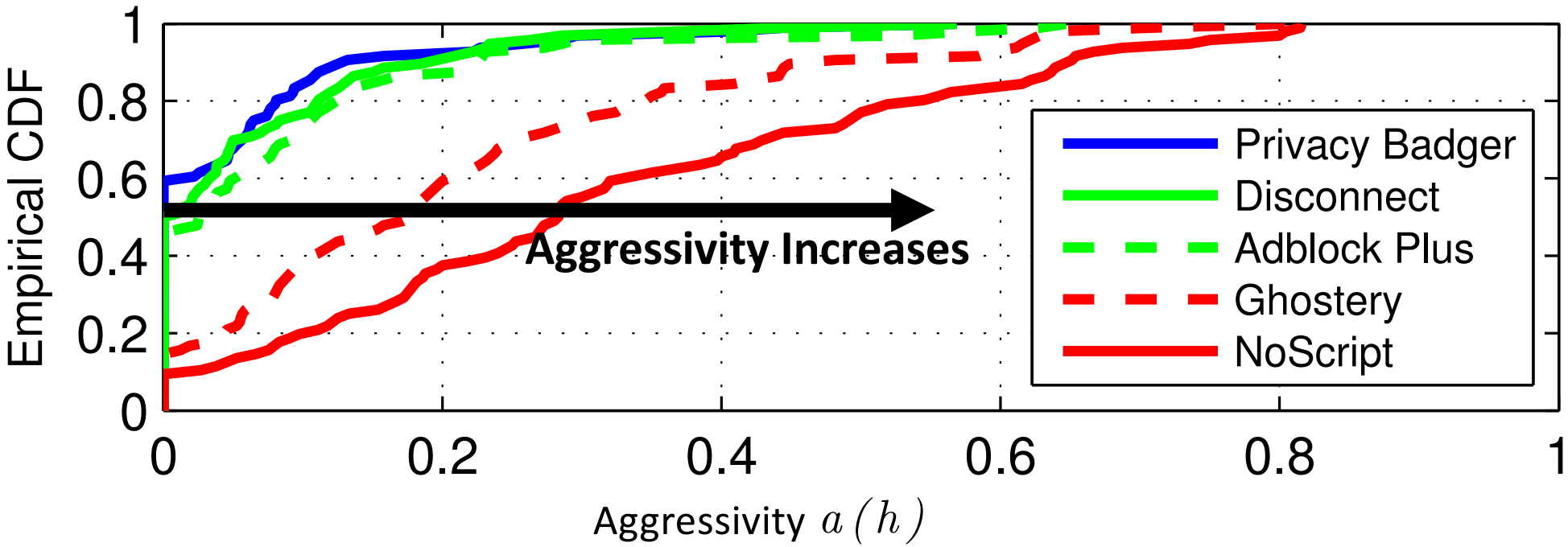
Ghostry

Adblock Plus

Disconnect

Privacy Badger

Aggressivity of PP-Tools



Aggressivity of a PP-Tool means the ratio of blocked JSes to the total number of JSes in a DOM tree

Aggressivity of PP-Tools

- Aggressivity – the ratio of blocked JSes by a PP-Tool to the total number of JSes in a DOM tree

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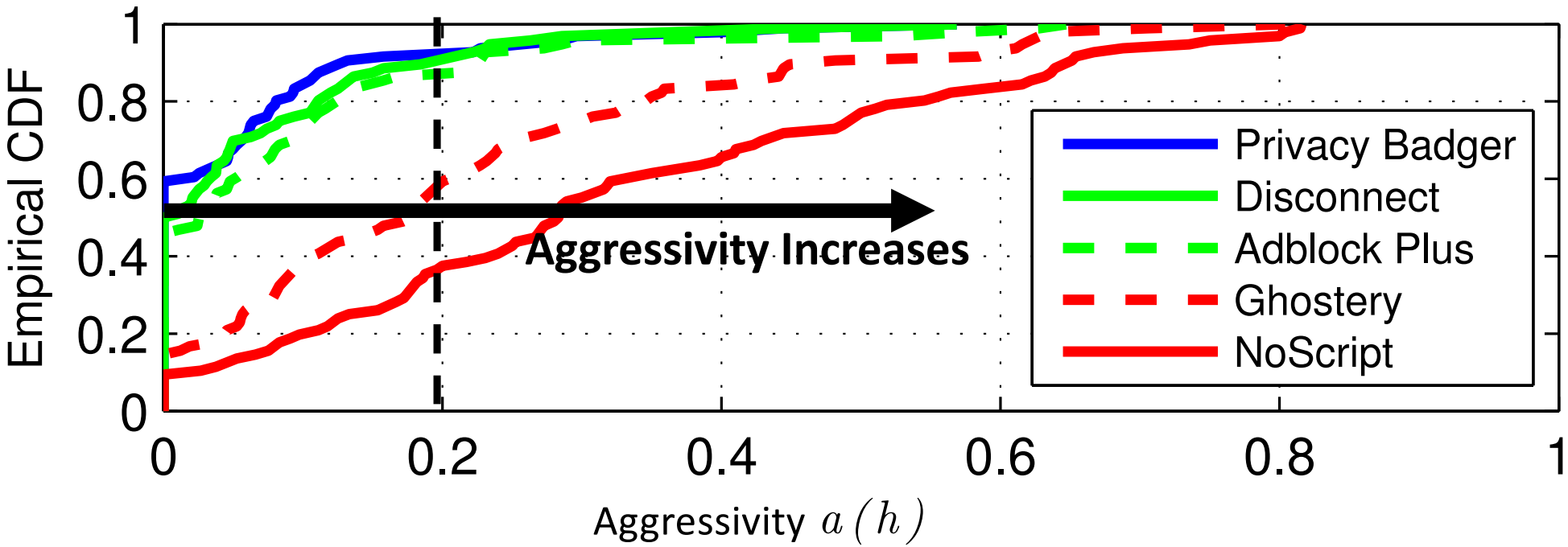

Effectiveness of PP-Tools

- Effectiveness – the balance between correctly blocking *tracking* JSes and incorrectly blocking *functional* JSes

Effectiveness of PP-Tools

- Effectiveness – the balance between correctly blocking tracking JSes and incorrectly blocking functional JSes

PP-Tool	Tracking		Functional	
	Blocked	Allowed	Blocked	Allowed
NoScript	0.78	0.22	0.21	0.79
Ghostery	0.65	0.35	0.08	0.92
Adblock Plus	0.44	0.56	0.06	0.94
Disconnect	0.40	0.60	0.06	0.94
Privacy Badger	0.37	0.63	0.06	0.94

Effectiveness of PP-Tools

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Adblock Plus	0.44	0.56	0.06	0.94
Disconnect	0.40	0.60	0.06	0.94
Privacy Badger	0.37	0.63	0.06	0.94

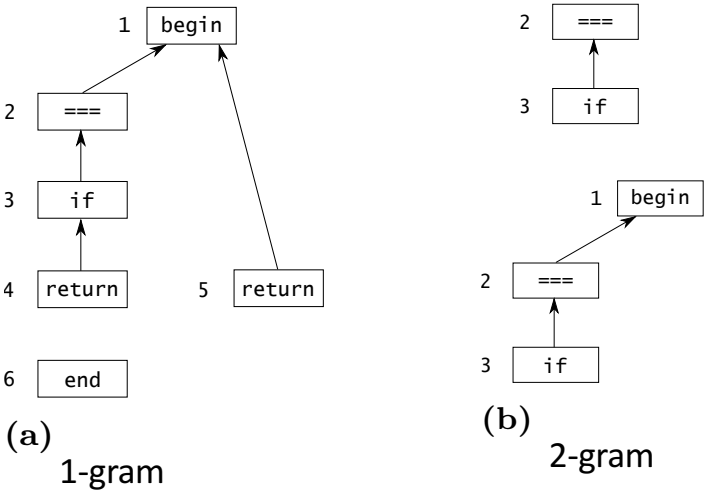
- **NoScript** stops one out of five functional JSes while **Privacy Badger** overlooks tracking JSes

Feature Extraction: Constructing Program Dependency Graphs (PDGs)

JavaScript Program → Canonical Form → PDGs n-grams

```
function equalTest(a, b){
  if(a == b){
    return true;}
  return false;}
```

```
function equalTest(a, b){
1:    begin;
2:    $0 = a === b;
3:    if($0){
4:      return true;}
5:    return false;
6:    end;}
```



Term Frequency-Inverse Document Frequency (TF-IDF) of n-gram ($2 \leq n \leq 7$)

Hsiao et al., Using Web Corpus Statistics for Program Analysis. OOPSLA, 2014

One-Class Learning

One-Class SVM* and Positive and Unlabeled (PU) Learning**

Training requires only single class

Classifying new data as similar or different to the training set

* Schölkopf et al., Estimating the Support of a High- Dimensional Distribution. *NC*, 2001
** Elkan et al., Learning Classifiers from Only Positive and Unlabeled Data. KDD, 2008.

Validation: Our Classifiers' Performance

Feature Model	Classifier	Tracking		Functional	
		Blocked	Allowed	Blocked	Allowed
Syntactic	SSVM	0.93	0.07	0.01	0.99
	OCSVM	0.88	0.12	0.02	0.98
	PU	0.86	0.14	0.02	0.98
PDG 4-gram	SSVM	0.96	0.04	0.03	0.97
	OCSVM	0.95	0.05	0.03	0.97
	PU	0.93	0.07	0.04	0.96
Sequential 4-gram	SSVM	0.98	0.02	0.01	0.99
	OCSVM	0.98	0.02	0.02	0.98
	PU	0.96	0.04	0.03	0.97
PDG 7-gram	SSVM	0.99	0.01	0.01	0.99
	OCSVM	0.99	0.01	0.01	0.99
	PU	0.98	0.02	0.02	0.98
Sequential 7-gram	SSVM	0.99	0.01	0.01	0.99
	OCSVM	0.99	0.01	0.01	0.99
	PU	0.98	0.02	0.02	0.98

Validation: Our Classifiers' Performance

Feature Model	Classifier	Tracking		Functional	
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Syntactic	SSVM	0.93	0.07	0.01	0.99
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	OCSVM	0.98	0.02	0.02	0.98
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PDG 7-gram	SSVM	0.99	0.01	0.01	0.99
	OCSVM	0.99	0.01	0.01	0.99
	PU	0.98	0.02	0.02	0.98
Sequential 7-gram	SSVM	0.99	0.01	0.01	0.99
	OCSVM	0.99	0.01	0.01	0.99
	PU	0.98	0.02	0.02	0.98

Our best classifier has **99% Accuracy** and less than **1% False Positive rates**

Improves PP-Tools' Accuracy by 21% to 63% and **reduces False Positive rates** by 5% to 20%

Our Classifiers and PP-Tools in the Wild (4084 Websites)

Our Classifiers and PP-Tools in the Wild

Agreements between our classifier's and a PP-Tool's output:

$$T_c \cap T_p$$

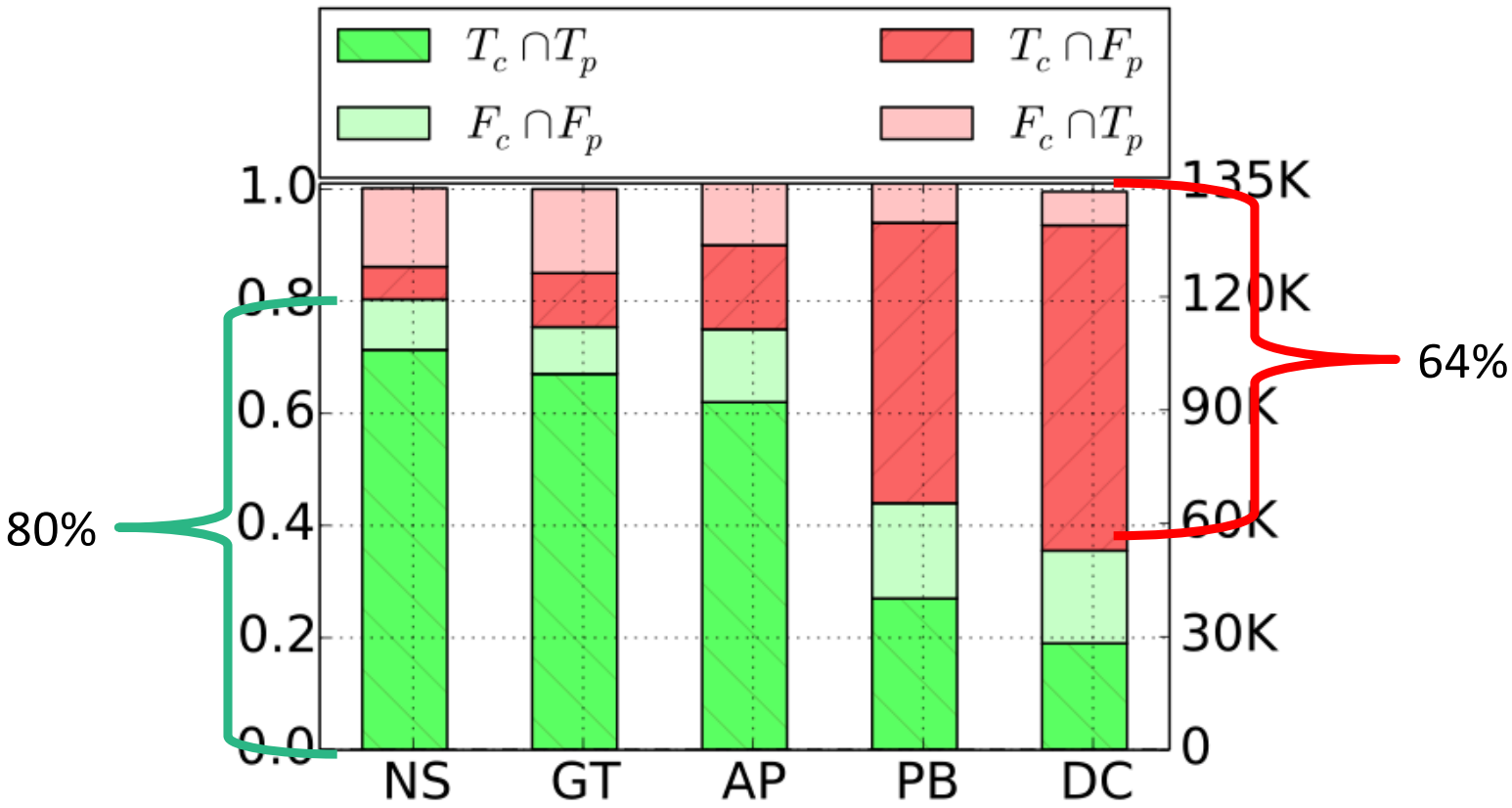
$$F_c \cap F_p$$

Disagreements between our classifier's and a PP-Tool's output:

$$T_c \cap F_p$$

$$F_c \cap T_p$$

Our Classifiers and PP-Tools in the Wild



NS: NoScript, GT:Ghostery, AP: Adblock Plus, DC: Disconnect, PB: Privacy Badger

Our Classifiers and PP-Tools in the Wild

Disagreement	
$T_c \cap_p F_p$	JSes that our classifier labels as tracking while all PP-Tools consider functional
$F_c \cap_p T_p$	JSes that our classifier labels as functional while all PP-Tools consider tracking

c: classifier, p: PP-Tool

Our Classifiers and PP-Tools in the Wild

Disagreement	Total	Sample
$T_c \cap_p F_p$	4,610	100
$F_c \cap_p T_p$	4,461	100

c: classifier, p: PP-Tool

Our Classifiers and PP-Tools in the Wild

Disagreement	Total	Sample	Manual Labelling	
			Tracking	Functional
$T_c \cap_p F_p$	4,610	100	75	25
$F_c \cap_p T_p$	4,461	100	19	81

c: classifier, p: PP-Tool

Our Classifiers and PP-Tools in the Wild

- 75% of the case, our classifier is right

Disagreement	Total	Sample	Manual Labelling	
			Tracking	Functional
$T_c \cap_p F_p$	4,610	100	75	25
$F_c \cap_p T_p$	4,461	100	19	81

- PP-Tools perform RE matching on the URL in <script> and fail to block tracking JSes that are not in the blacklists

c: classifier, p: PP-Tool

Our Classifiers and PP-Tools in the Wild

- 81% of the case, our classifier is right

Disagreement	Total	Sample	Manual Labelling	
			Tracking	Functional
$T_c \cap_p F_p$	4,610	100	75	25
$F_c \cap_p T_p$	4,461	100	19	81

- PP-Tools block JSes from a tracking domain even though JSes perform useful functionality

c: classifier, p: PP-Tool

New Trackers Found

Discover more than 4K+ previously unknown tracking services

#	Website	JavaScript Program	Referred Domain	Function Performed
1	examiner.com	cdn2-b.examiner.com/.../ex_omniture/s_code.js	omniture.com	Analytics
2	bbc.com	static.bbci.co.uk/bbcdotcom/.../adverts.js	pubads.g.doubleclick.net	Analytics + Ads
3	telegraph.co.uk	telegraph.co.uk/template/ver1-0/js/gpt.js	pubads.g.doubleclick.net	Analytics + Ads
4	vesti.ru	s.i-vengo.com/js/ivengo.min.js	www.i-vengo.com	Analytics + Ads
5	climatempo.com.br	http://s1.trrsf.com/metrics/inc/br/201411250000d.js	scorecardresearch.com	Analytics
6	amc.com	amc.com/wp-content/plugins/amcn-common-analytics/js/common-analytics.js	omniture.com	Track user activities
7	lancer.com	static.lancers.jp/js/ga_social_tracking.js	google.com	Tracker user activities
8	iqiyi.com	static.iqiyi.com/js/pingback/qa.js	pps.tv, baidu.com, 71.com	Tracker user activities
9	babyblog.ru	act.babyblog.ru/static844/likes.js	babyblog.ru	Social widgets
10	autoscout.de	s.autoscout24.net/unifiedtracking/gtm.js	autoscout.de	Tracks user activities

More Results, Analyses and Discussions

DE GRUYTER OPEN Proceedings on Privacy Enhancing Technologies 2017; 2017 (1):1–21

Muhammad Ikram*, Hassan Jameel Asghar, Mohamed Ali Kaafar, Anirban Mahanti, and Balachander Krishnamurthy

Towards Seamless Tracking-Free Web: Improved Detection of Trackers via One-class Learning

Abstract: Numerous tools have been developed to aggressively block the execution of popular JavaScript programs in Web browsers. Such blocking also affects functsites with 135,656 JavaScript programs. The output of our best classifier on this data is between 20 to 64% different from the tools under study. We manually anal-

Summary of Contributions

- Analyze PP-Tools' performance
  - Regular expressions based on blacklists are ineffective
  - **Accuracy** ranges from 37% to 78% while **false positive rates** range from 6% to 21%.

- Design a classification framework to separate *tracking* JSes from *functional* JSes:
  - Training with small single class of tracking (or functional) JSes
  - Our validated classifiers achieve 99% accuracy
  - Discover more than 4K+ previously unknown tracking services

Questions?

Big Thanks to PETS Reviewers

Muhammad.Ikram@data61.csiro.au

https://research.csiro.au/ng/about-us/students/muhammad-ikram/