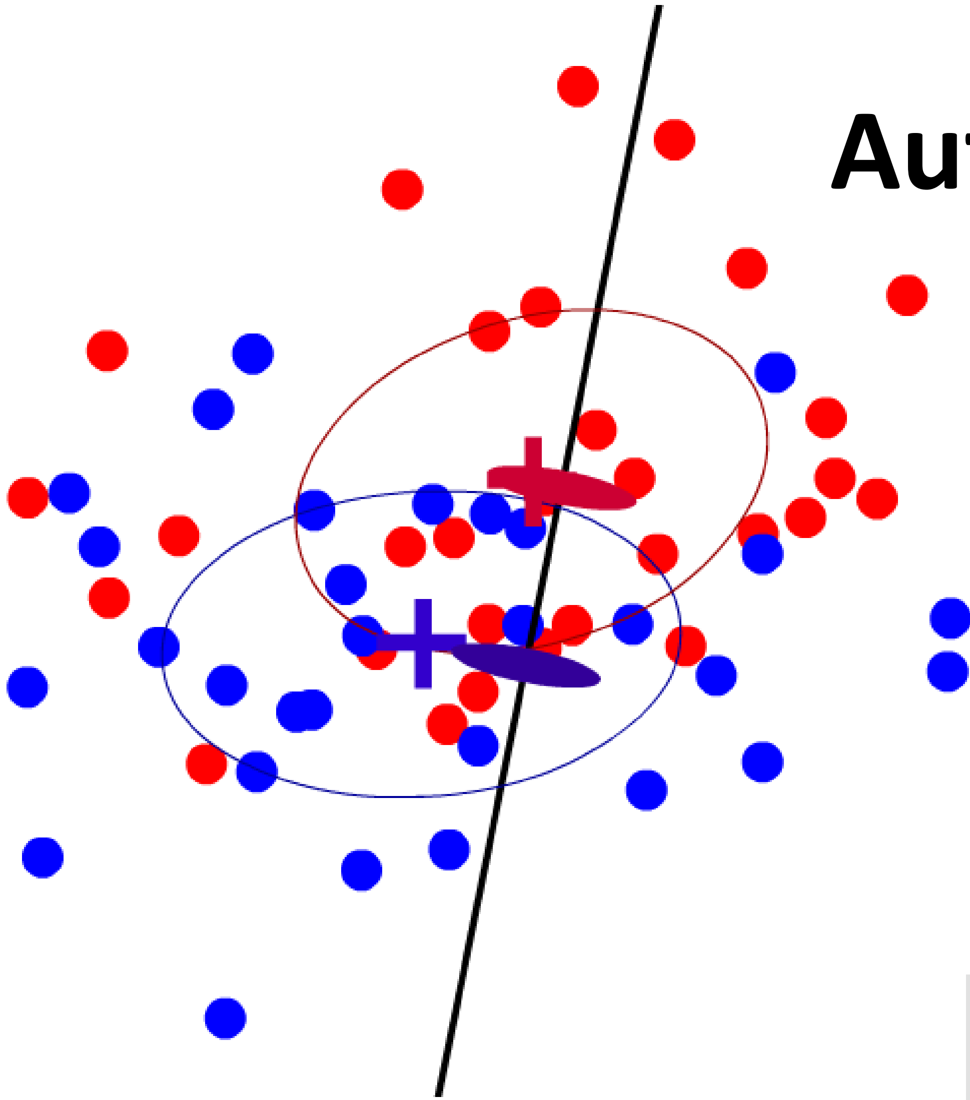
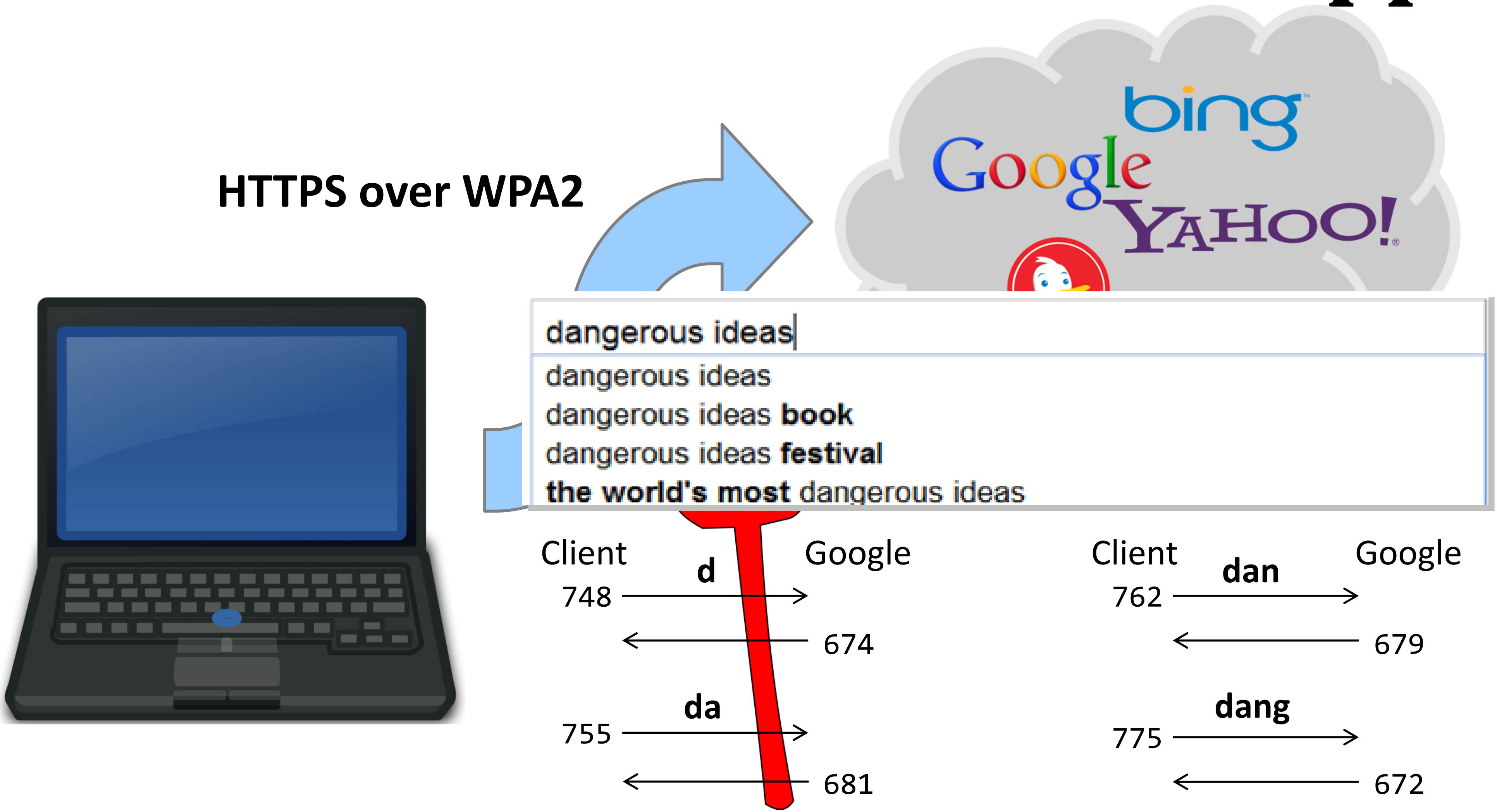


Automated Black-Box Detection of Side-Channel Vulnerabilities in Web Applications

Peter Chapman
David Evans
University of Virginia
http://www.cs.virginia.edu/sca/

CCS '11
October 19, 2011

Side-Channel Leaks in Web Apps



Chen+, Oakland 2010

Modern Web Apps

Dynamic and Responsive Browsing Experience

On-Demand Content

HTML

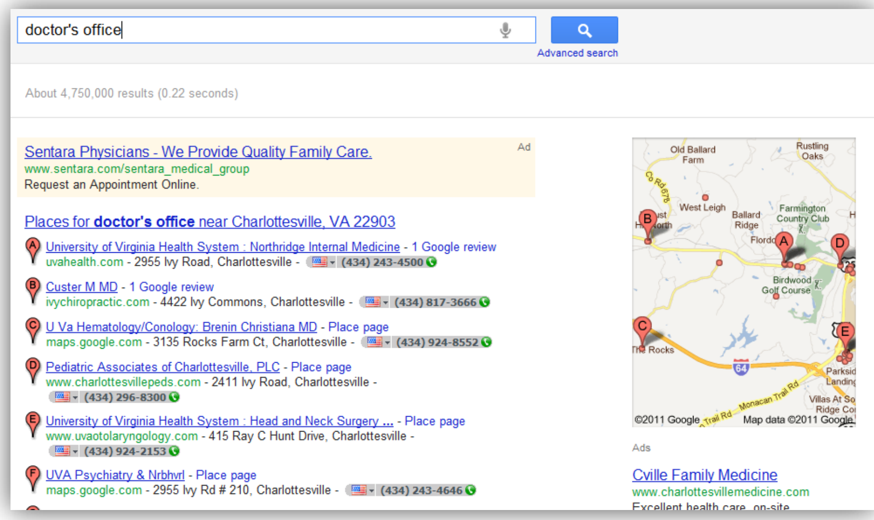
Traffic

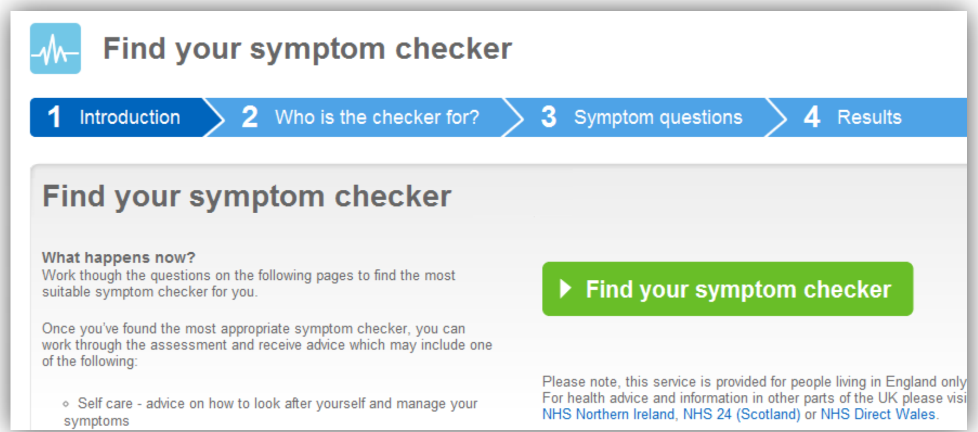
Latency

Responsiveness

Traffic is now closely associated with the demanded content.

Motivation: Detect Vulnerabilities





Motivation: Evaluate Defenses

Randomized or Uniform Communication Attributes

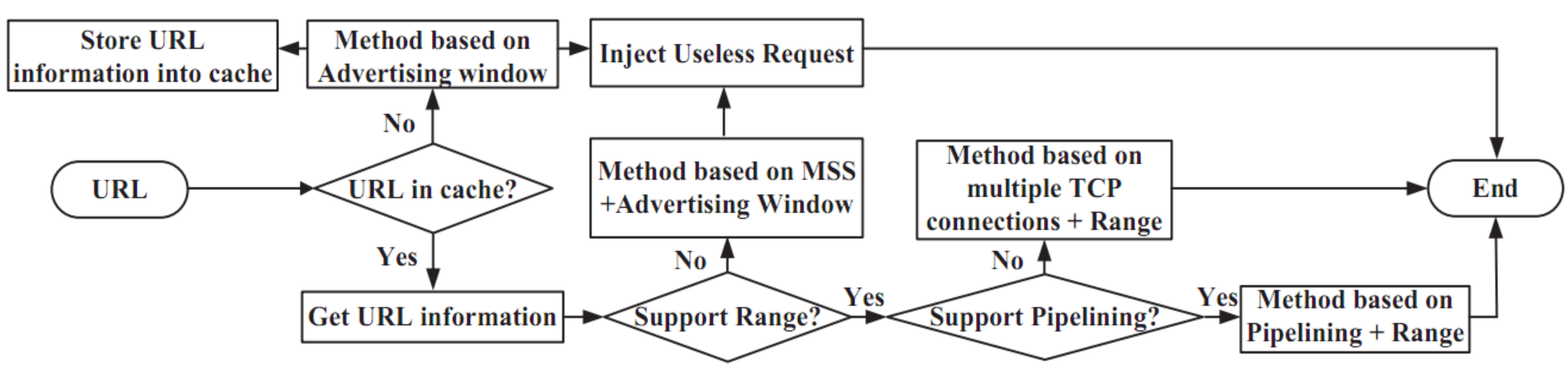
Packet Sizes

Transfer Control Flow

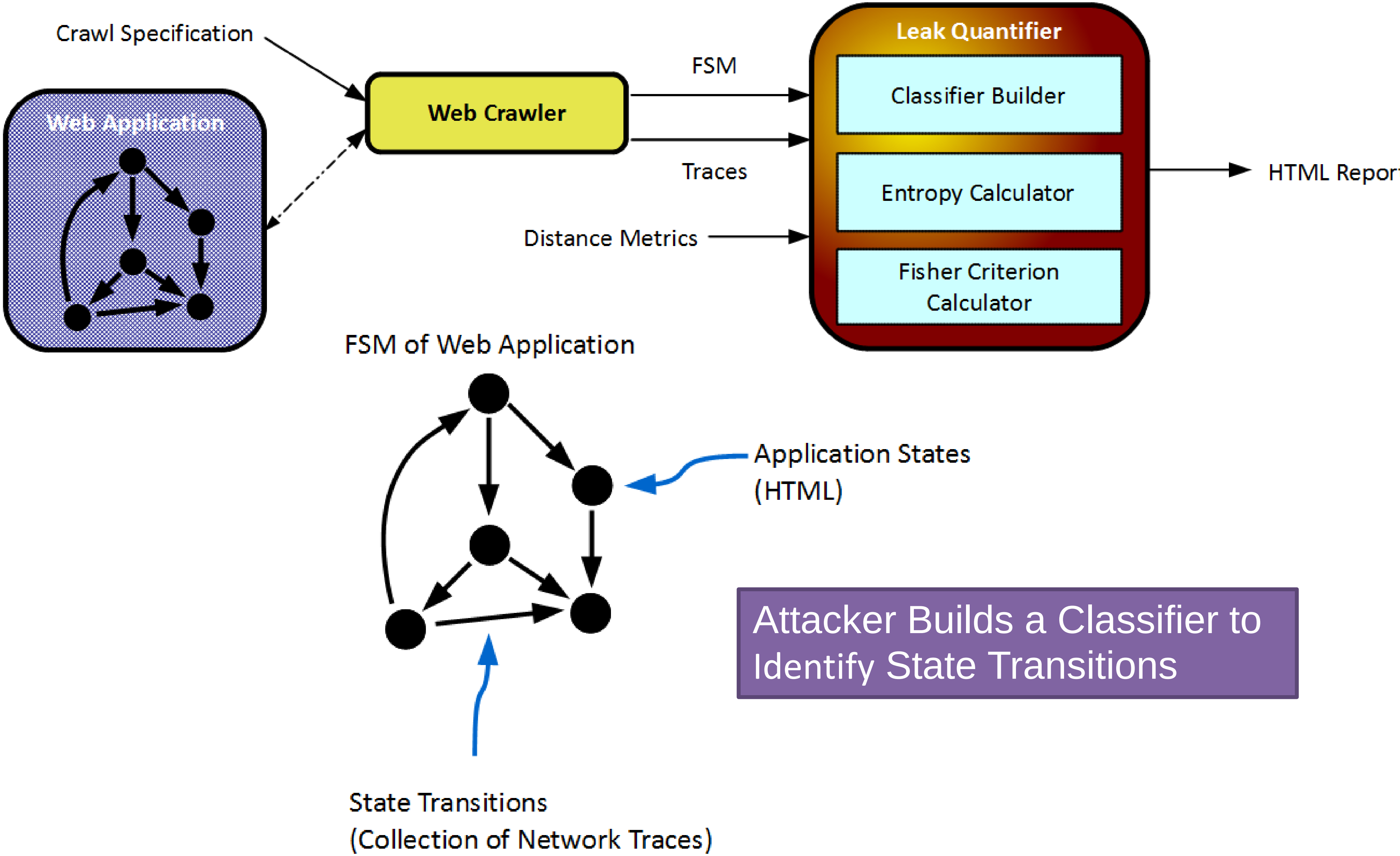
Inter-Packet Timings

Requests and Responses

HTTPOS [Luo+, NDSS 2011]

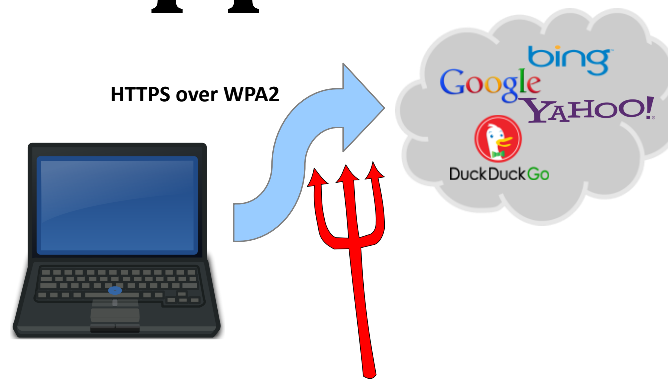


Approach


Crawl Specification
Web Application
Web Crawler
FSM
Traces
Distance Metrics
Leak Quantifier
Classifier Builder
Entropy Calculator
Fisher Criterion Calculator
HTML Report
FSM of Web Application
Application States (HTML)
State Transitions (Collection of Network Traces)
Attacker Builds a Classifier to Identify State Transitions

A Black-Box Approach

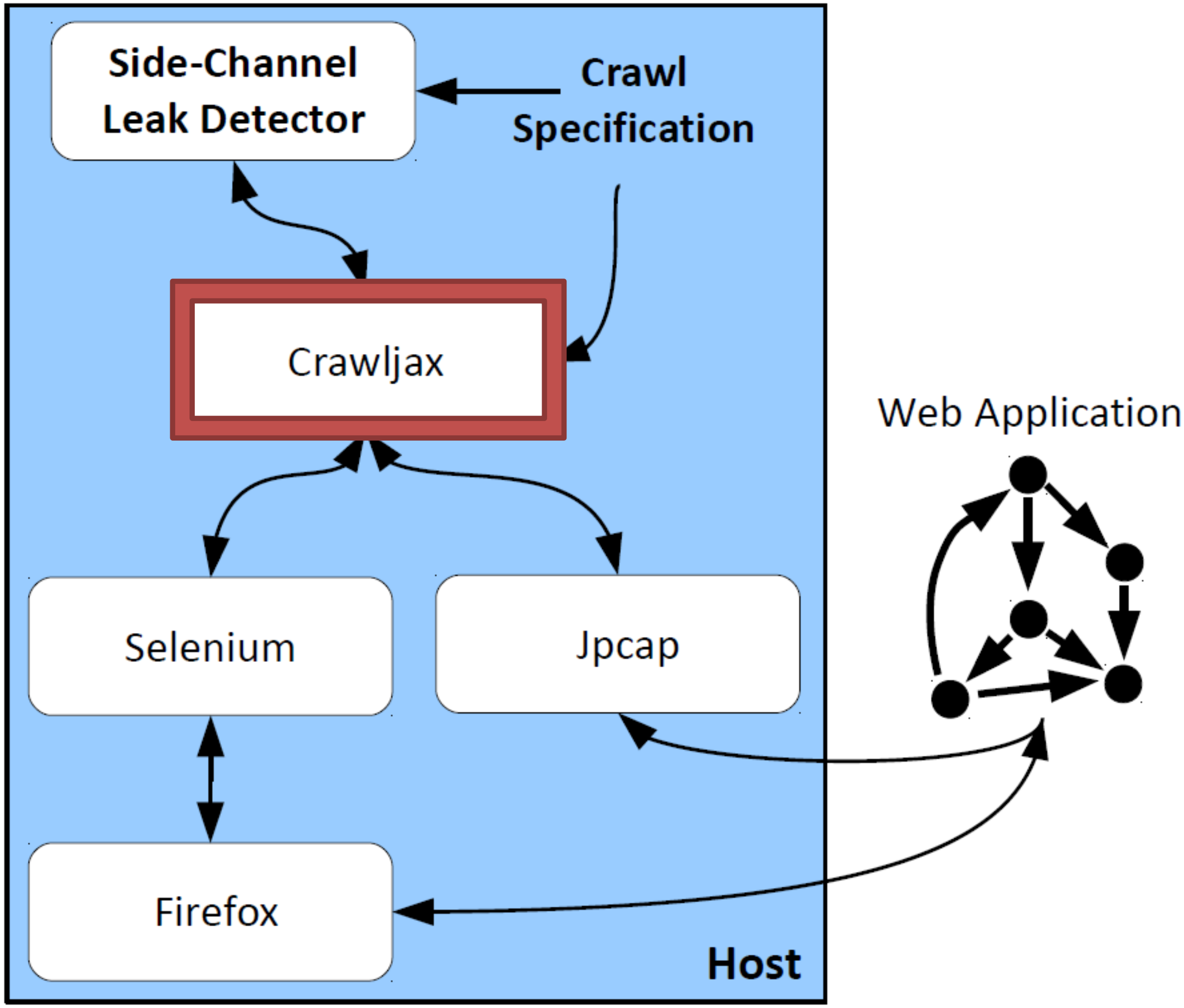
Similar to Real Attack Scenario



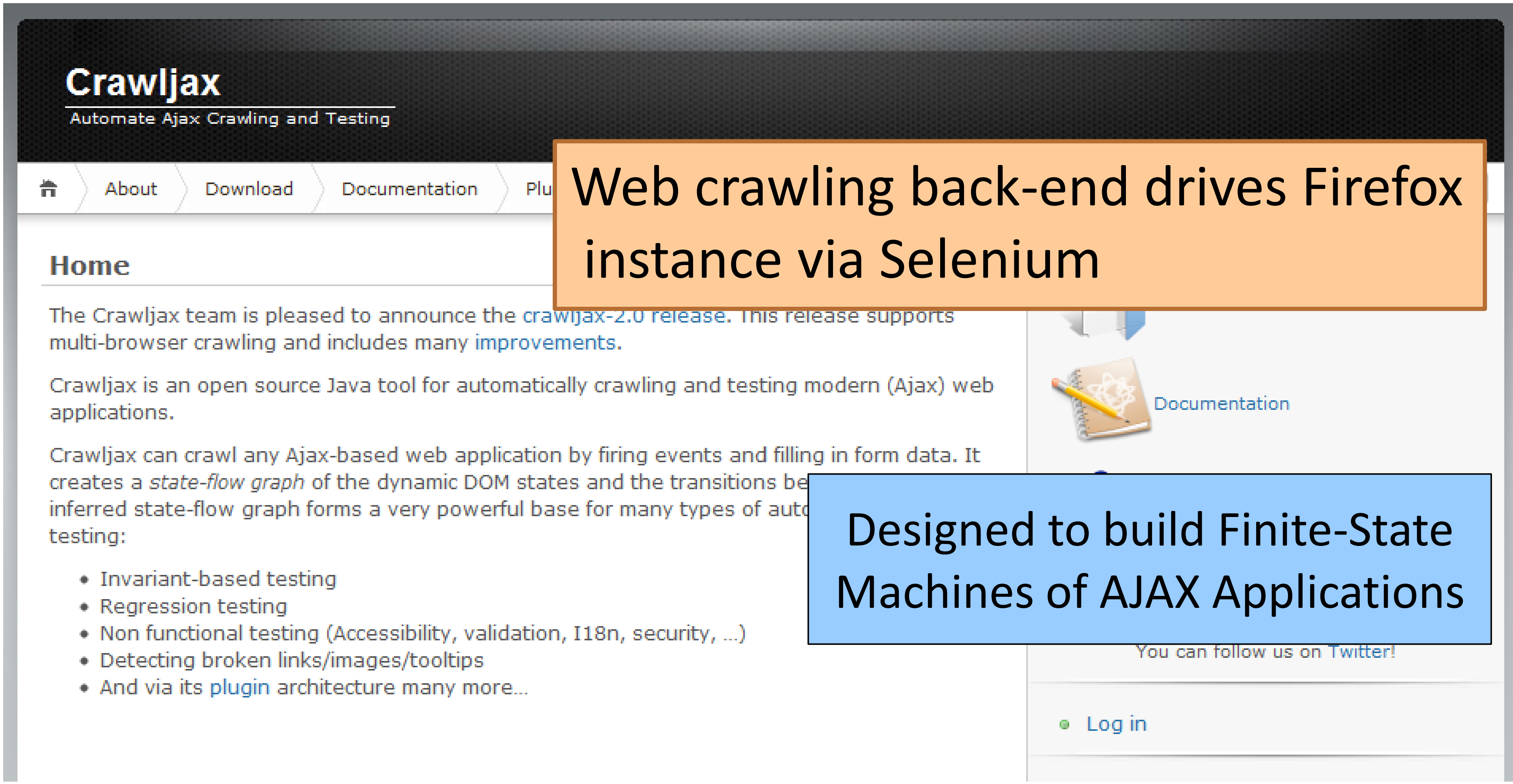
Applicable to Most Web Applications

Full Browser Analysis

Black-Box Web Application Crawling



Crawljax

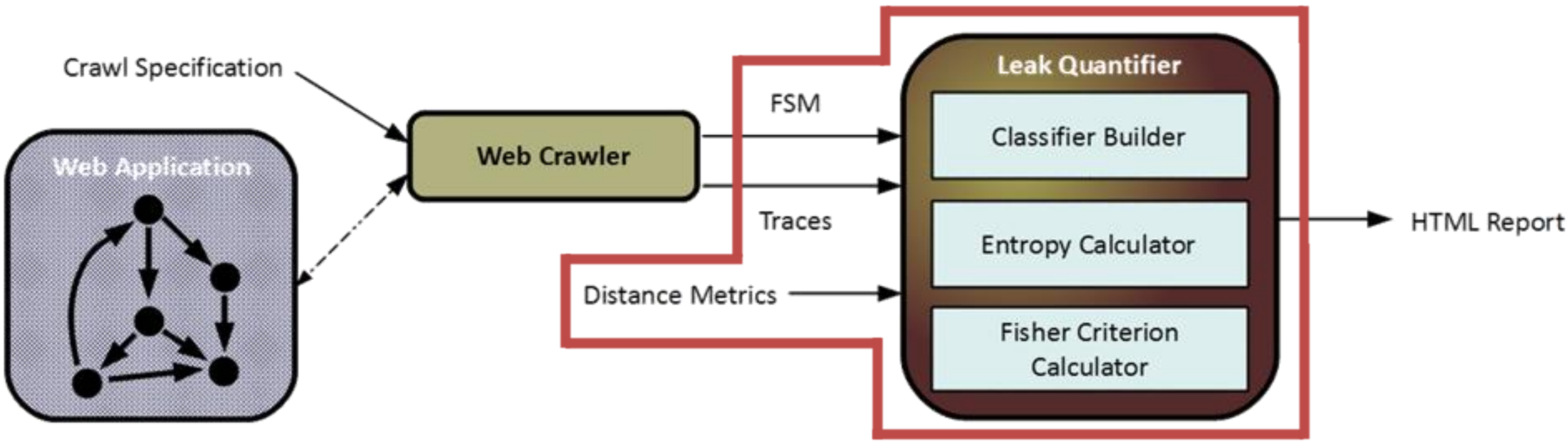


Web crawling back-end drives Firefox instance via Selenium

Designed to build Finite-State Machines of AJAX Applications

http://crawljax.com/

Approach



Crawl Specification
Web Application
Web Crawler
FSM
Traces
Distance Metrics
Leak Quantifier
Classifier Builder
Entropy Calculator
Fisher Criterion Calculator
HTML Report

Threat Models and Assumptions

Both: Victim begins at root of application

WiFi

No disruptive traffic

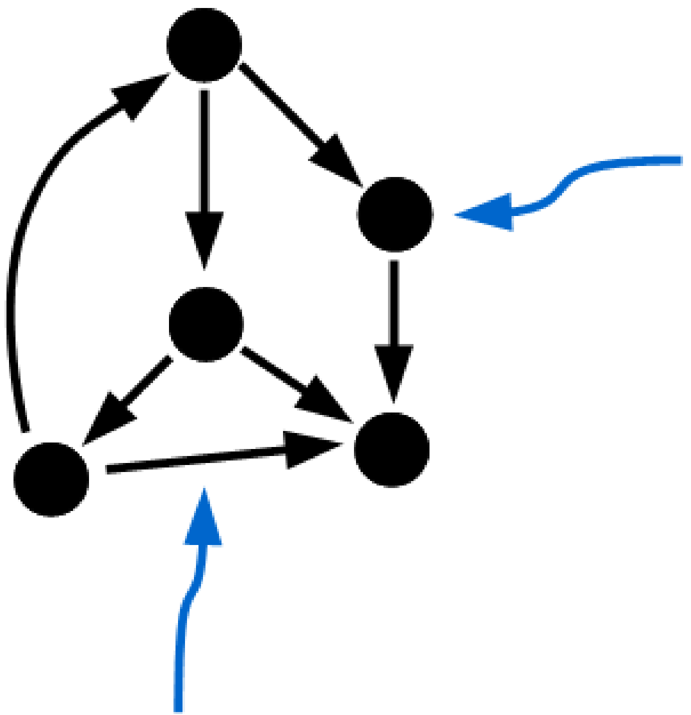
Distinguish incoming and outgoing

ISP

Access to TCP header

Nearest-Centroid Classifier

FSM of Web Application



Application States
(HTML)

State Transitions
(Collection of Network Traces)

Given an unknown network trace, we want to determine to which state transition it belongs

Classify unknown trace as one with the closest centroid

Distance Metrics

Metrics to determine similarity between two traces

Edit-Distance

Unweighted edit distance

tion

e of bytes

en each party

Size-Weighted-Edit-Distance

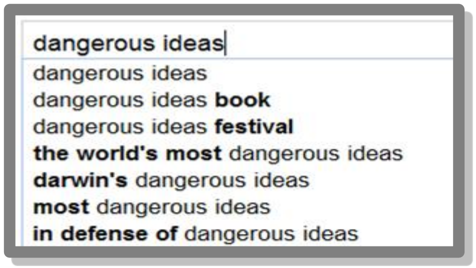
Convert to string, weighted edit distance based on size

```
72.14.204 -> 192.168.1 62 bytes
192.168.1 -> 72.14.204 281 bytes
72.14.204 -> 192.168.1 1860 bytes
192.168.1 -> 72.14.204 294 bytes
72.14.204 -> 192.168.1 296 bytes
192.168.1 -> 72.14.204 453 bytes
72.14.204 -> 192.168.1 2828 bytes
```

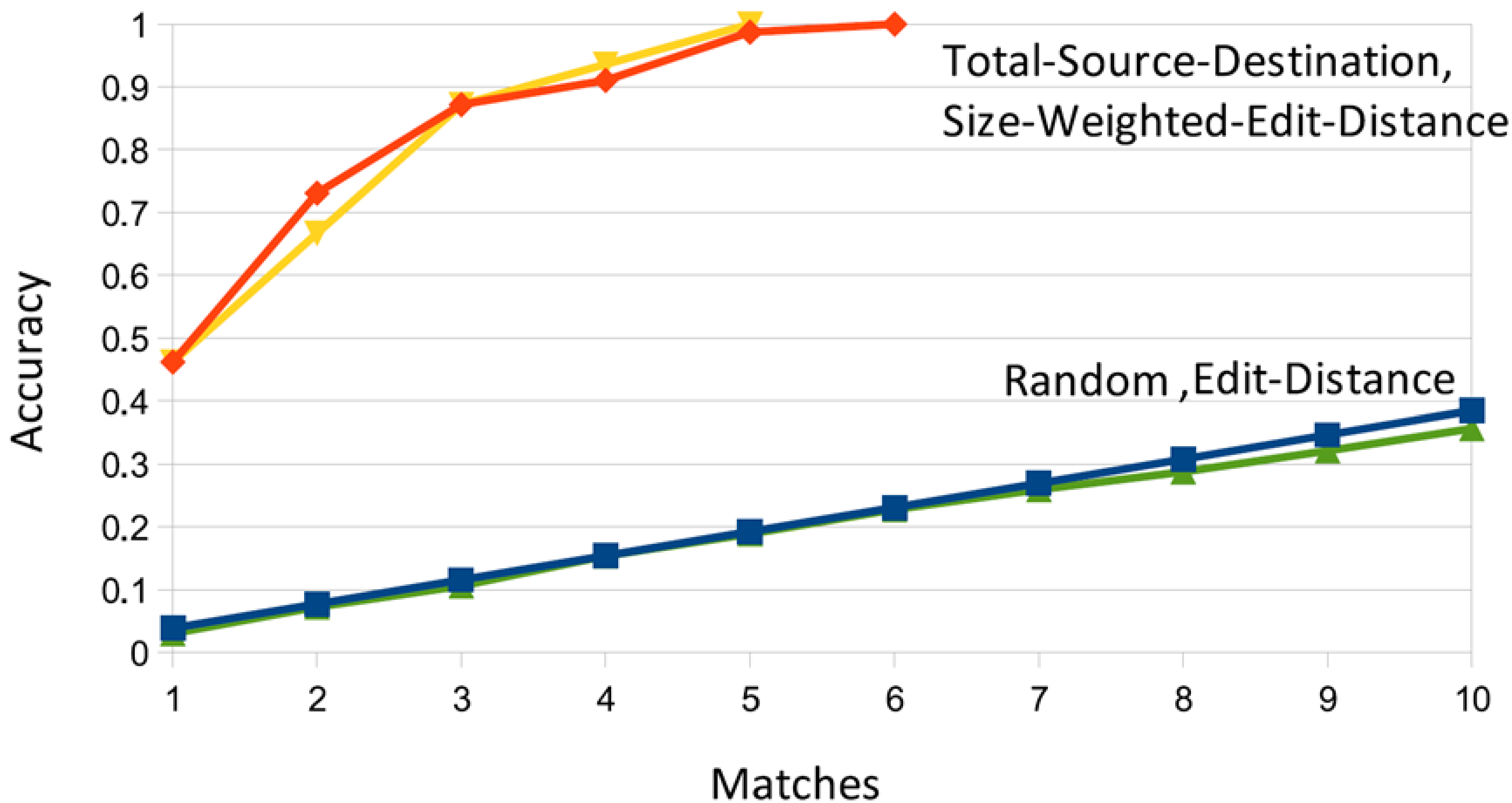
```
192.168.1 -> 72.14.204 62 bytes
72.14.204 -> 192.168.1 62 bytes
192.168.1 -> 72.14.204 482 bytes
72.14.204 -> 192.168.1 693 bytes
192.168.1 -> 72.14.204 62 bytes
72.14.204 -> 192.168.1 62 bytes
192.168.1 -> 72.14.204 281 bytes
72.14.204 -> 192.168.1 1860 bytes
192.168.1 -> 72.14.204 294 bytes
72.14.204 -> 192.168.1 296 bytes
192.168.1 -> 72.14.204 453 bytes
72.14.204 -> 192.168.1 2828 bytes
```

```
A 62 bytes
B 62 bytes
A 482 bytes
B 693 bytes
A 62 bytes
B 62 bytes
A 281 bytes
B 1860 bytes
A 294 bytes
B 296 bytes
A 453 bytes
B 2828 bytes
```

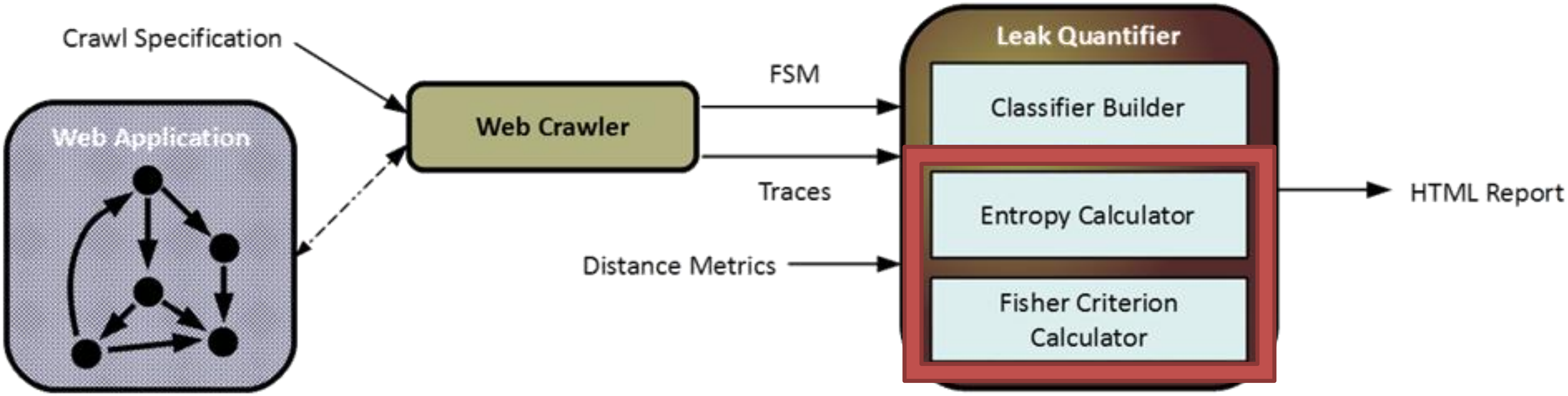
Classifier Performance – Google Search



First character typed, ISP threat model



Quantifying Leaks



Leak quantification should be independent of a specific classifier implementation

Entropy Measurements

Entropy measurements are a function of the average size of an attacker's uncertainty set given a network trace

Problems
The same network trace can be the result of multiple classifications

Every possible network trace is unknown

Use the centroids

Size of uncertainty set

Centroid for class

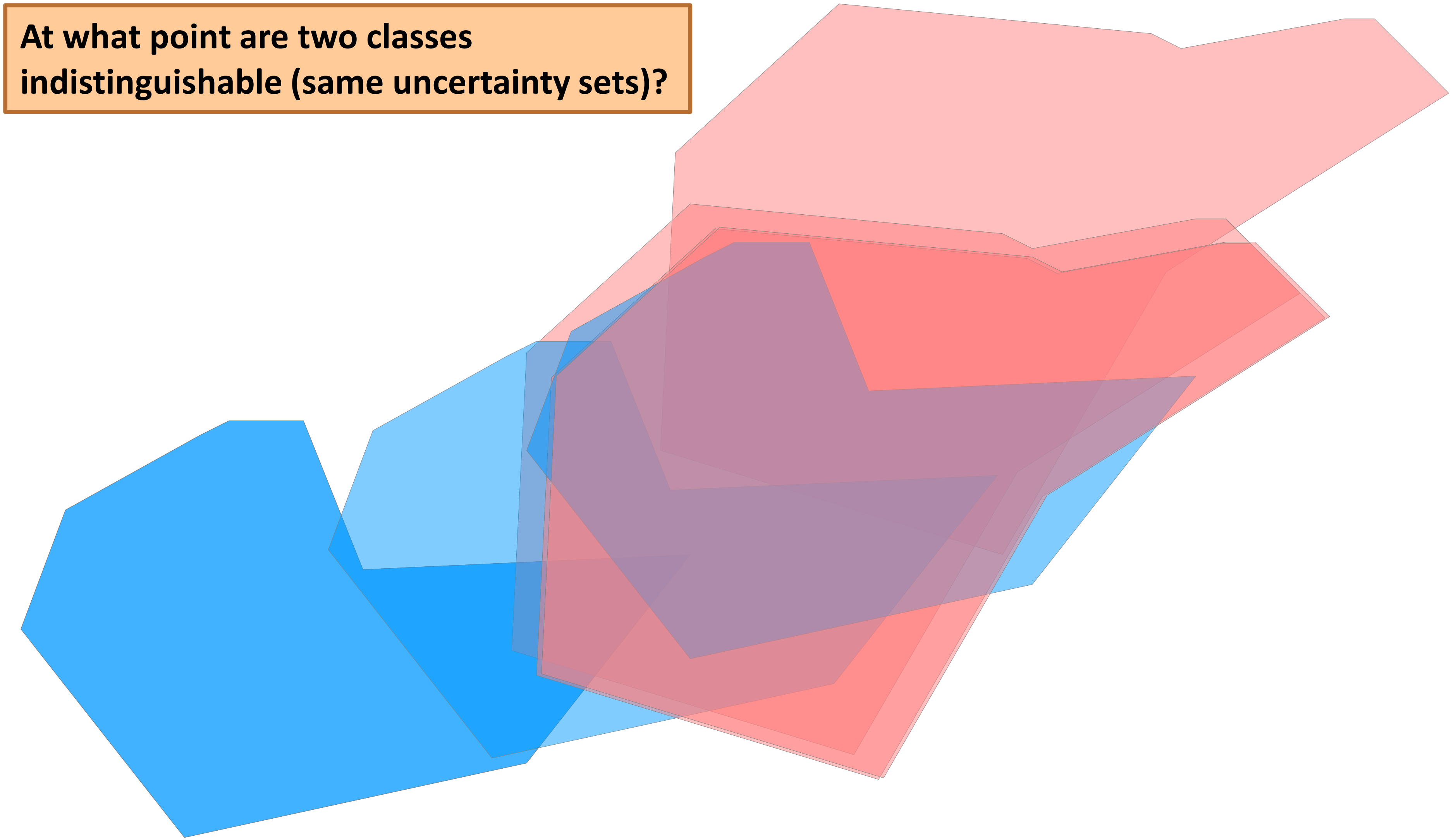
$$H(X) = \sum_{i=0}^{n} \frac{\log_2 p(\bar{x}_i)}{n}$$

Number of classes

Traditional Entropy Measurement

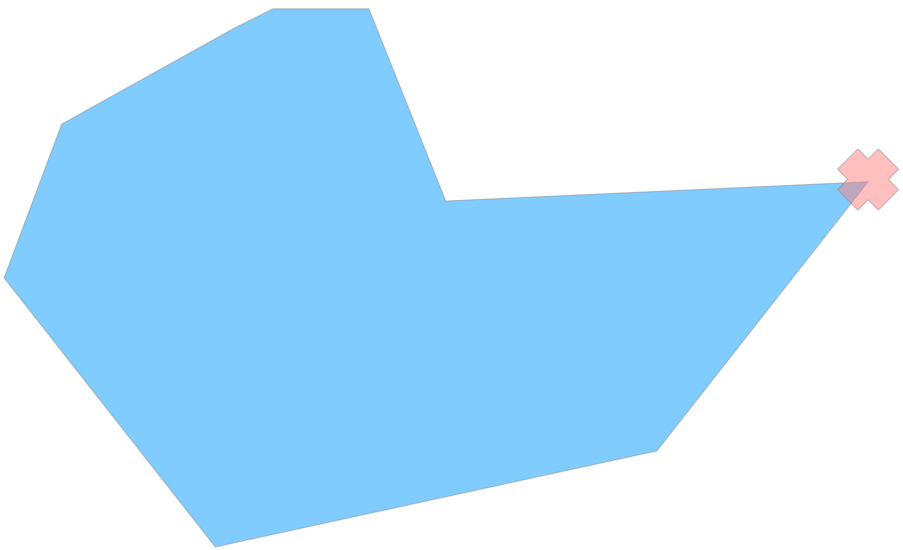
Determining Indistinguishability

At what point are two classes indistinguishable (same uncertainty sets)?



Determining Indistinguishability

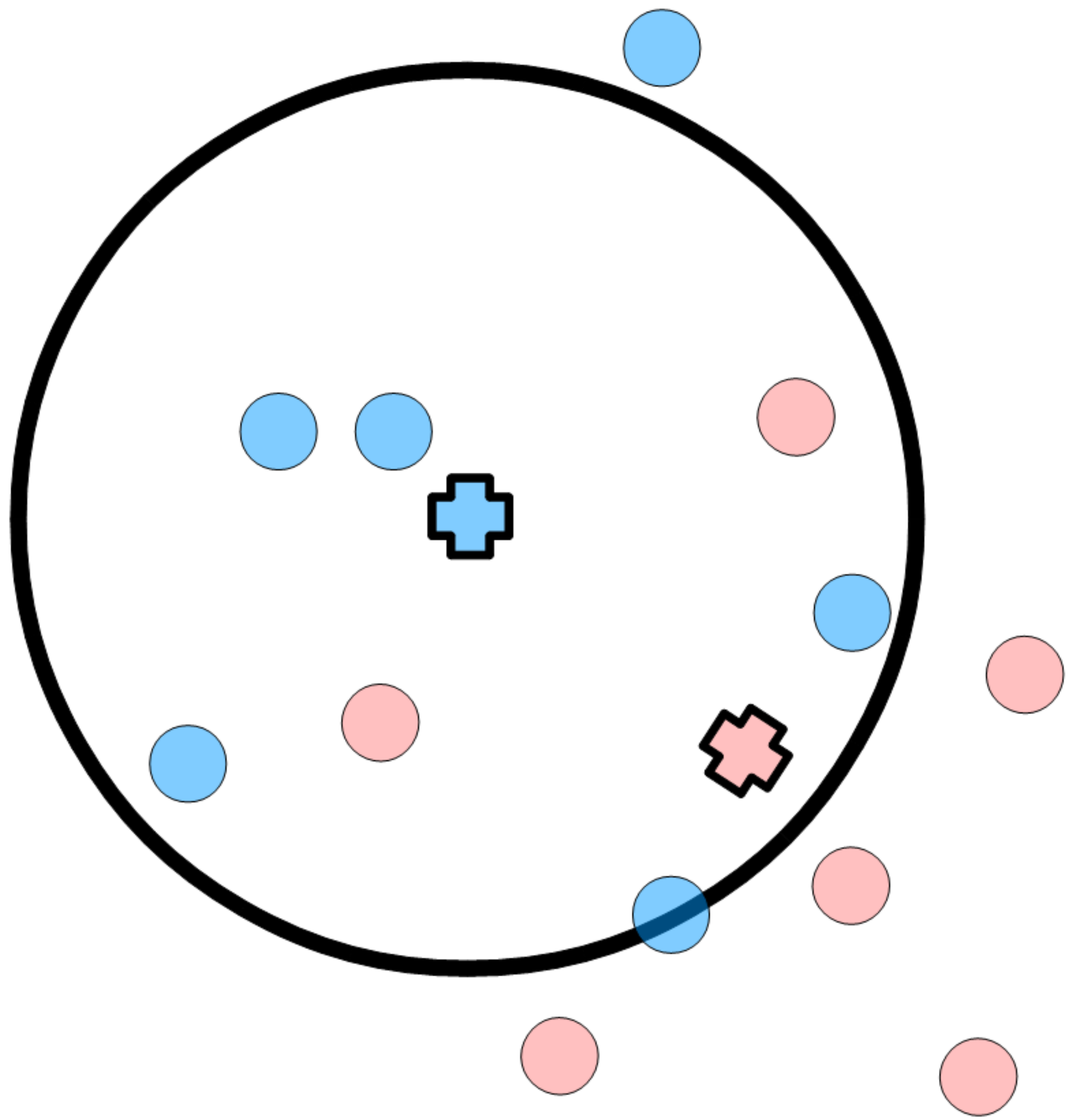
Compare points to centroids?



Same issue with individual points.

In practice the area can be very large due to high variance in network conditions

Entropy Distinguishability Threshold



Threshold of 75%

Google Search Entropy Calculations

Threshold

	100%	75%	50%
Desired	4.70	4.70	4.70
Total-Source-Destination	2.95	2.40	0.44
Size-Weighted-Edit-Distance	1.13	0.56	0.44
Edit-Distance	4.70	4.70	4.70

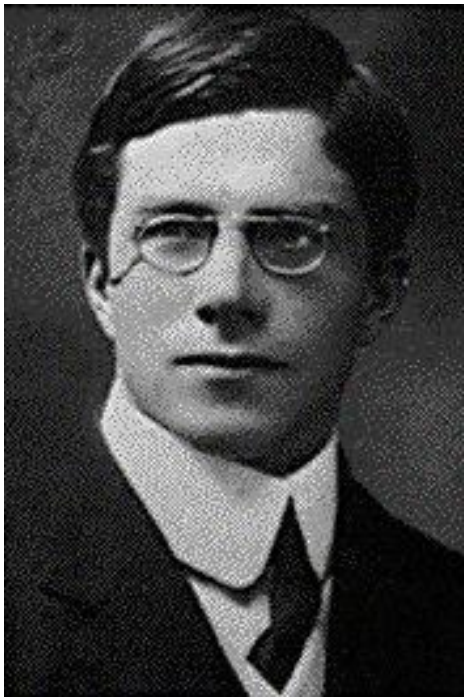
(measured in bits of entropy)

We'd rather not use something with an arbitrary parameter

Fisher Criterion

[11] Ronald A. Fisher. The Use of Multiple Measurements in Taxonomic Problems. *Annals of Eugenics*, 1936.

Fisher Criterion



Ronald Fisher (1890-1962)

Marred Arthur Guinness' daughter, secret wedding (she was 17) in 1917

Developed many statistical tools as a part of his prominent role in the eugenics community

Arthur Guinness (1835-1910)

Fisher Criterion

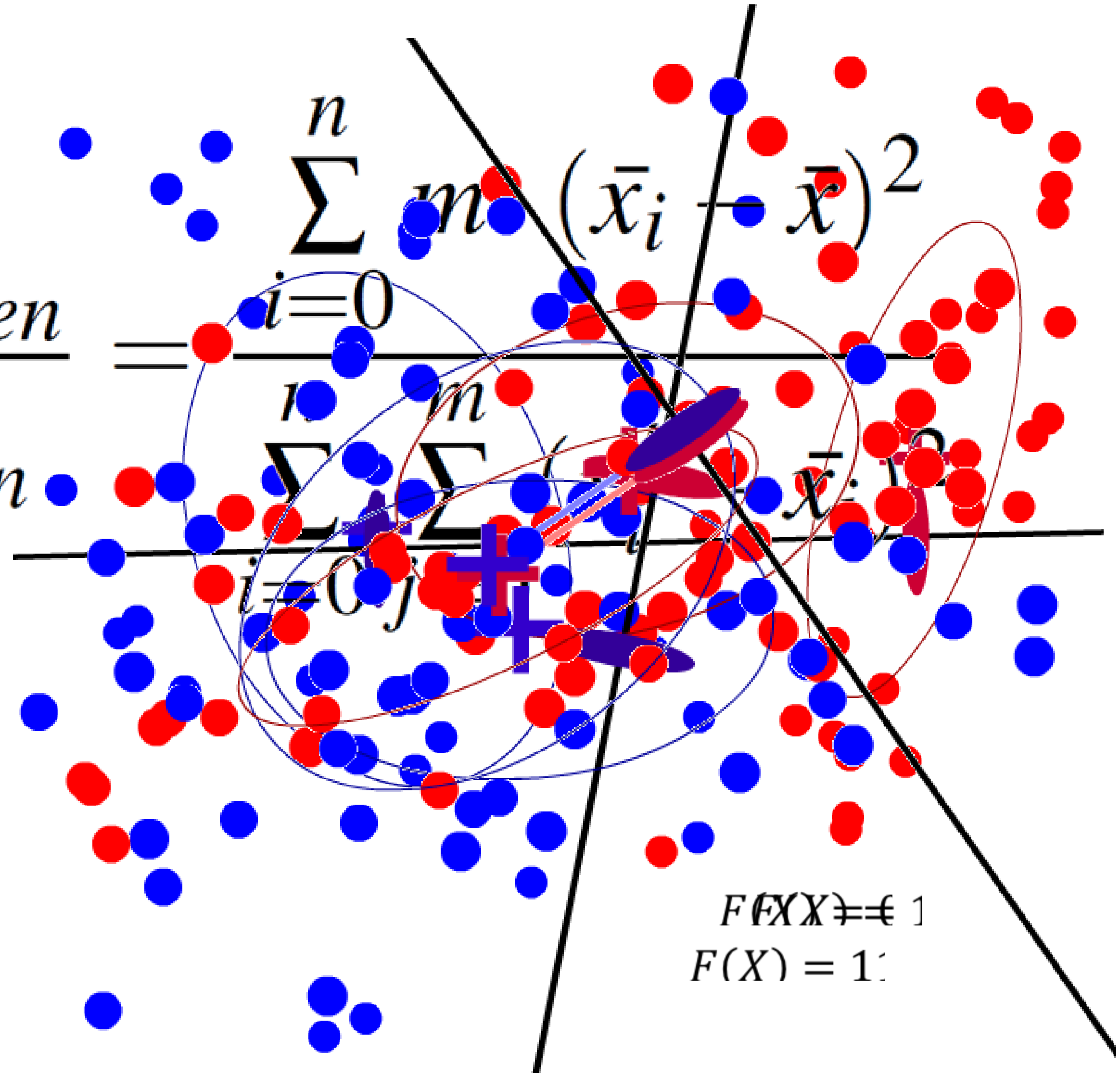
Like all good stories, this one starts with a Guinness.

Arthur Guinness (1725-1803)

“Guinness is Good for You”

Fisher Criterion

$$F(X) = \frac{\sigma^2_{between}}{\sigma^2_{within}} = \frac{\sum_{i=0}^{n} m_i (\bar{x}_i - \bar{x})^2}{\sum_{i=0}^{n} \sum_{j=0}^{m} (x_{ij} - \bar{x}_i)^2}$$



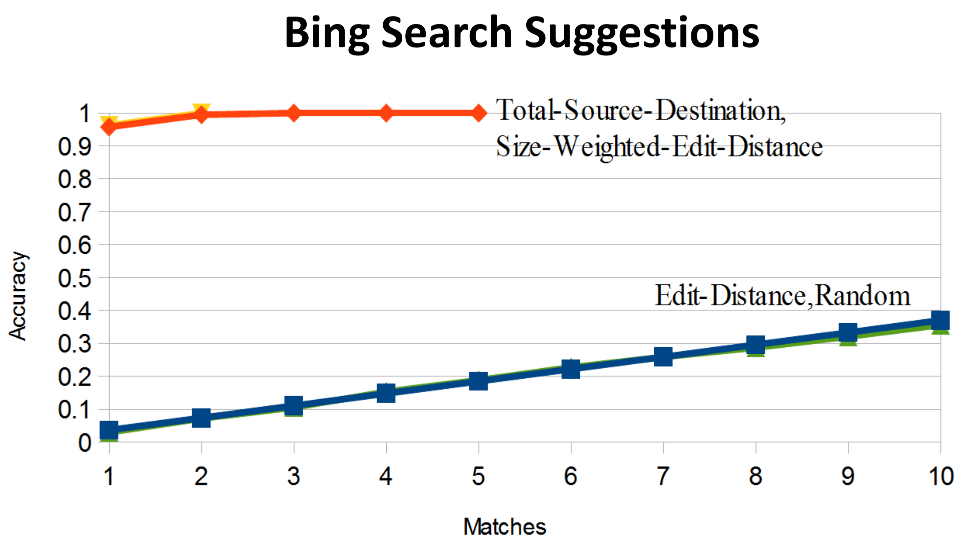
Google Search Fisher Calculations

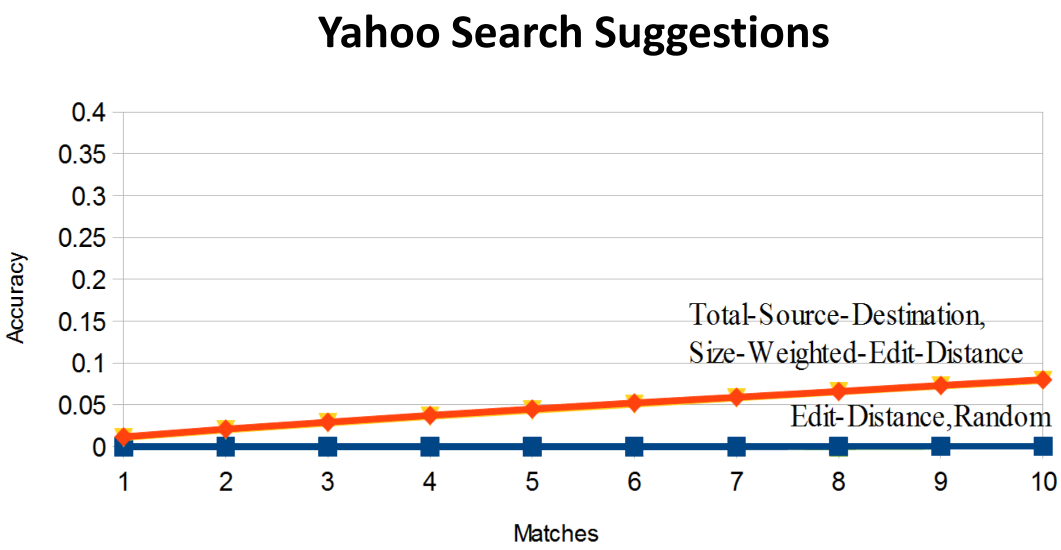
Fisher Criterion Calculations	
Total-Source-Destination	4.13
Size-Weighted-Edit-Distance	41.7
Edit-Distance	0.00

Entropy Calculations

	100%	75%	50%
Desired	4.70	4.70	4.70
Total-Source-Destination	2.95	2.40	0.44
Size-Weighted-Edit-Distance	1.13	0.56	0.44
Edit-Distance	4.70	4.70	4.70

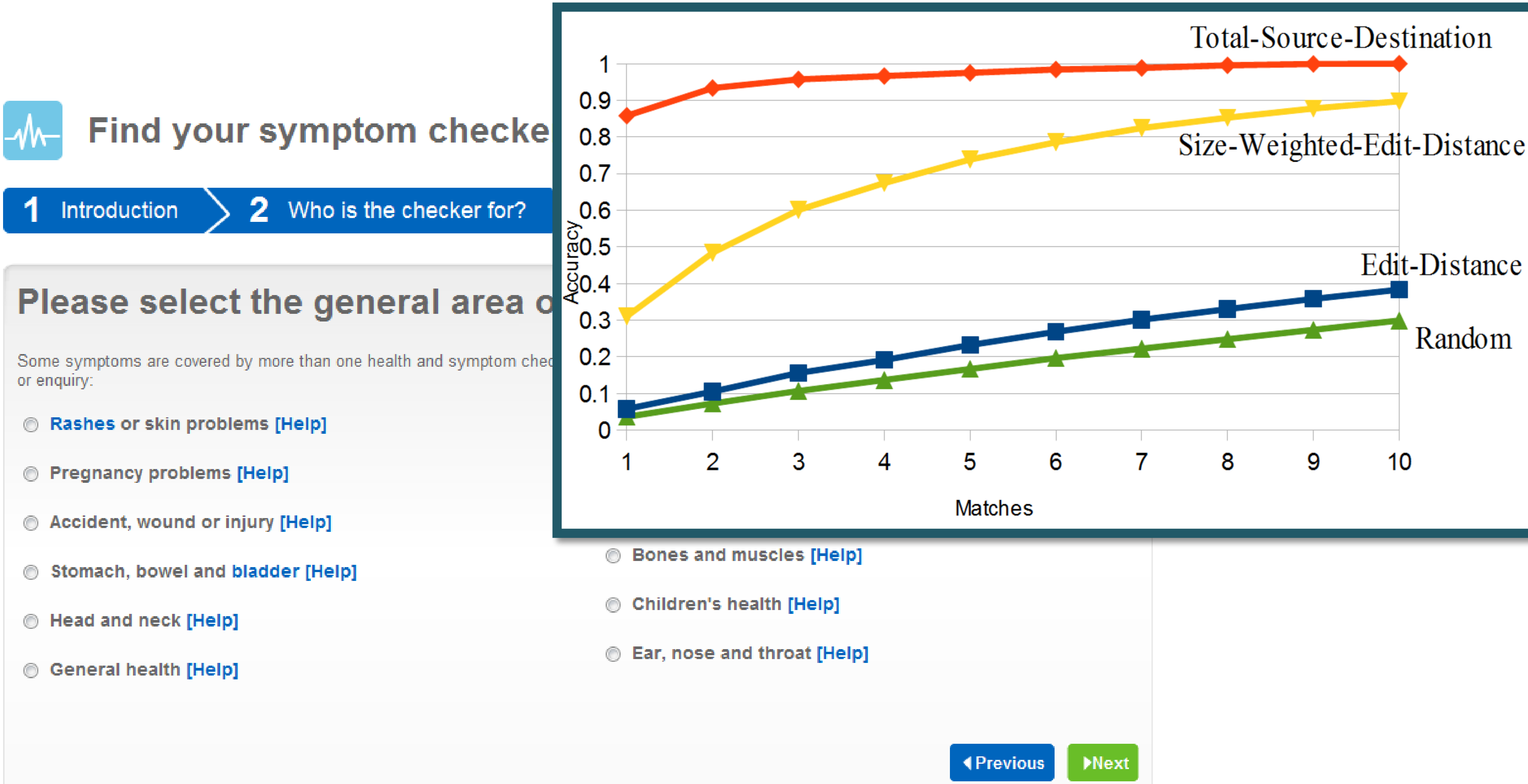
Other Applications





Other Applications

NHS Symptom Checker



See paper for Google Health Find-A-Doctor

Evaluating Defenses

With black-box approach,
evaluating defenses is easy!

HTTPOS: Sealing Information Leaks with Browser-side Obfuscation of Encrypted Flows

Xiapu Luo[§*], Peng Zhou[§], Edmond W. W. Chan[§], Wenke Lee[†], Rocky K. C. Chang[§], Roberto Perdisci[‡]
The Hong Kong Polytechnic University[§], Georgia Institute of Technology[†], University of Georgia[‡]
{csxluo,cspzhouroc,cswwchan,csrchang}@comp.polyu.edu.hk, wenke@cc.gatech.edu, perdisci@cs.uga.edu

Abstract

Leakage of private information from web applications—even when the traffic is encrypted—is a major security threat to many applications that use HTTP for data deliv-

be profiled from traffic features [29]. A common approach to preventing leaks is to obfuscate the encrypted traffic by changing the statistical features of t... e packet size and packet timing inform...

Existing methods for defending against information

NDSS 2011

HTTPOS Search Suggestions

Before HTTPOS

	(matches) 1	10
Random	2.9%	35.6%
Total-Source-Destination	46.1%	100%
Size-Weighted-Edit-Distance	46.1%	100%
Edit-Distance	3.8%	39.5%

After HTTPOS

	(matches) 1	10
Random	2.9%	35.6%
Total-Source-Destination	3.4%	38.0%
Size-Weighted-Edit-Distance	3.8%	38.0%
Edit-Distance	3.4%	35.5%

HTTPOS Search Suggestions

Before HTTPOS

Fisher Criterion Calculations	
Total-Source-Destination	4.13
Size-Weighted-Edit-Distance	41.7
Edit-Distance	0.00

After HTTPOS

Fisher Criterion Calculations	
Total-Source-Destination	0.28
Size-Weighted-Edit-Distance	0.43
Edit-Distance	0.14

HTTPOS works well with search suggestions

HTTPOS Google Instant

Before HTTPOS

(matches)

	1	10
Random	2.9%	35.6%
Total-Source-Destination	47.5%	88.3%
Size-Weighted-Edit-Distance	7.3%	52.6%
Edit-Distance	7.7%	56.0%

(matches)

After HTTPOS

	1	10
Random	2.9%	35.6%
Total-Source-Destination	43.7%	87.6%
Size-Weighted-Edit-Distance	8.2%	51.4%
Edit-Distance	8.7%	55.0%

HTTPOS Google Instant

Before HTTPOS

Fisher Criterion Calculations	
Total-Source-Destination	1.13
Size-Weighted-Edit-Distance	0.34
Edit-Distance	0.22

After HTTPOS

Fisher Criterion Calculations	
Total-Source-Destination	0.60
Size-Weighted-Edit-Distance	0.55
Edit-Distance	0.47

No training phase, so HTTPOS works well with search suggestions, but not entire pages

Summary

Developed Fisher Criterion as an alternative measurement for information leaks in this domain

Evaluated real web apps and a proposed defense system

With a tutorial

Code available now: http://www.cs.virginia.edu/sca