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

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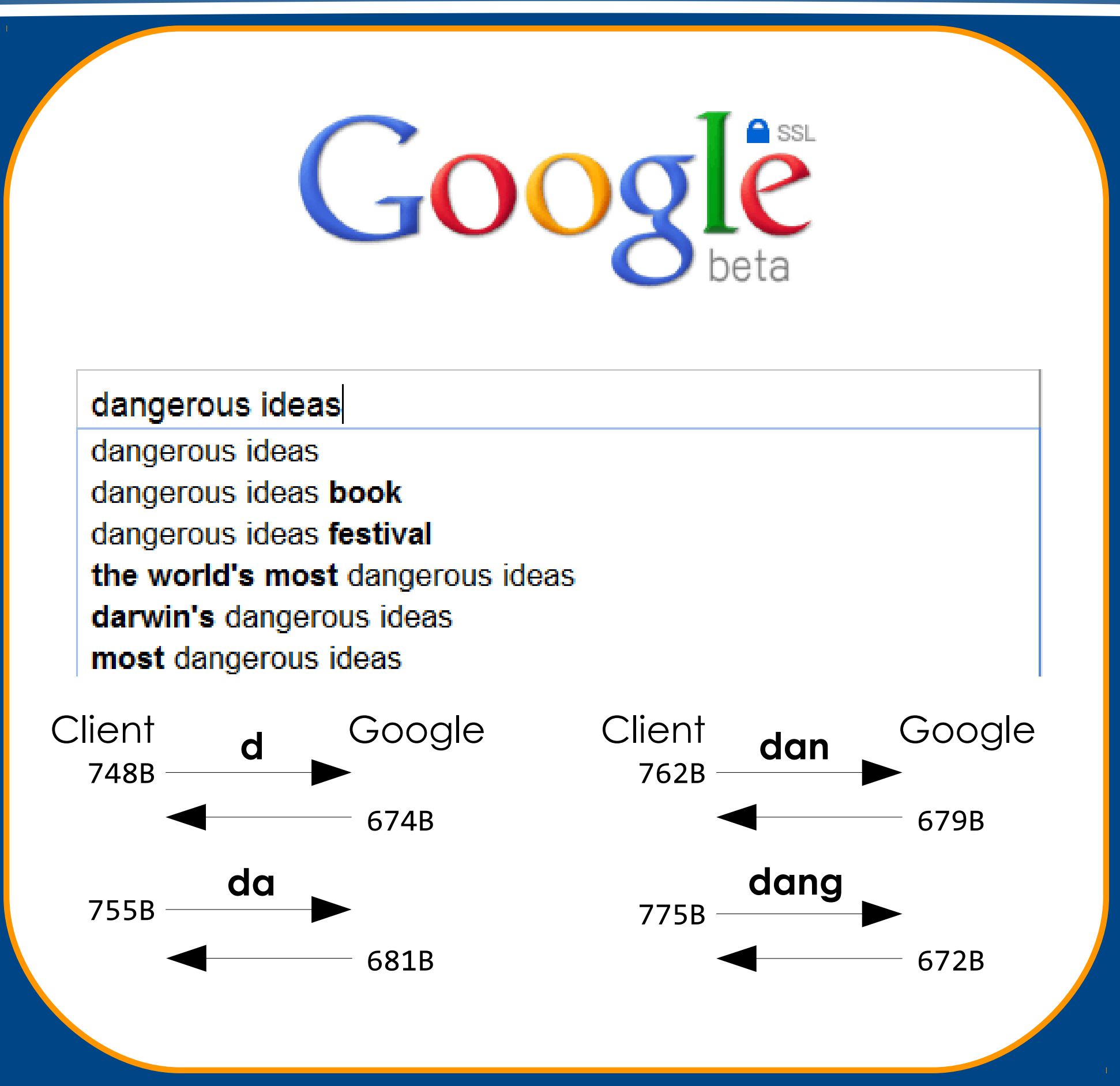
Encryption Does Not Guarantee Privacy

Web applications divide their state between the server and the client. Communication between the separated states is necessary, but without care, can leak substantial information through a variety of side-channels. Building on the work of Chen et al. [Oakland 2010] our goal is to create a tool that searches for unique and predictable correlations between network traffic and application state, indicating the presence of an information leak.



dangerous ideas
dangerous ideas
dangerous ideas **book**
dangerous ideas **festival**
the world's most dangerous ideas
darwin's dangerous ideas
most dangerous ideas

Search engines leak queries through the network traffic generated by auto-complete suggestions.

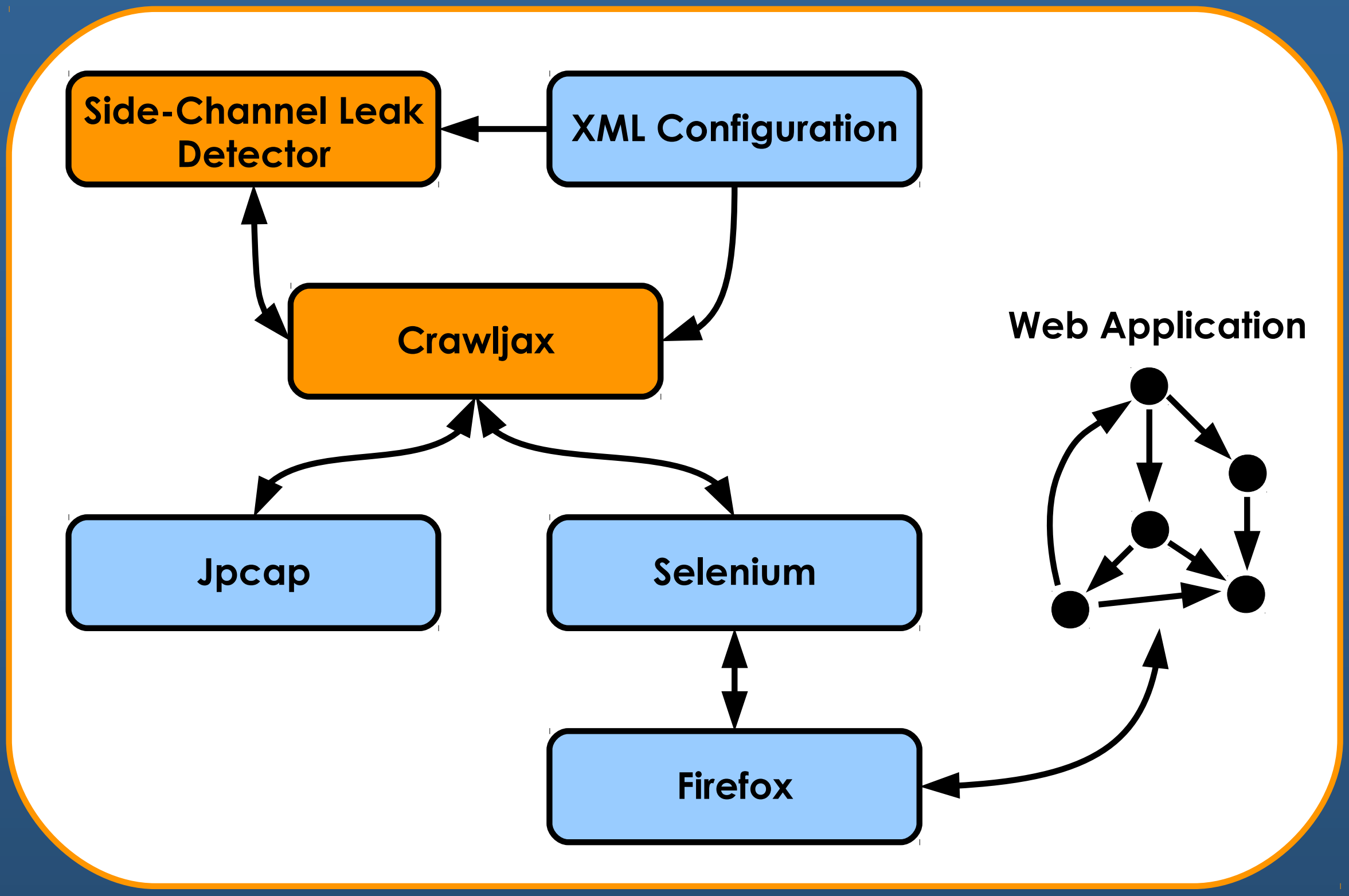
Thread Model. Our threat model includes two scenarios. In one, an adversary wants to accumulate as much private information about a single target as possible by eavesdropping on the encrypted network traffic. Our second scenario includes a government organization monitoring encrypted Internet traffic.

Approach. The attacker wants to identify the current state of the application using only network information leaked during transitions. Our prototype explores a web site and logs network traffic between state transitions. A post-crawl analysis applies heuristics to extract network traffic patterns that uniquely identify application state. Our dynamic, black-box approach allows us to experiment and identify side-channel vulnerabilities in real-world web applications without access to source code. We hope to find ways to use these results to automate mitigation techniques and verify if this approach can work on very large and complex websites where traffic flows are harder to distinguish.

Exploring Web Applications

Crawling Web 2.0 sites is a difficult task due to their highly dynamic nature and emphasis on client-side technologies. The Crawljax project [Mesbah et al., ICSE 2009] attempts to create finite state machines for web applications even in the presence of JavaScript and AJAX. Crawljax drives an instance of the Selenium testing framework for black-box manipulation and state inference of the application. In particular, Crawljax interacts with developer-specified elements and forms while monitoring the browser DOM to construct a corresponding state machine.

We consider an adversary who searches for network flows that illustrate specific state transitions and are predictable between users and over time. This is important because the adversary may have limited information about the user and the user's status within the web application. To find the vulnerable network flows, we crawl the application with a number of trials. We then apply a set of heuristics to find network flows corresponding to a certain state transition that are predictable across the trials.



The detection system uses Crawljax to run an instance of Selenium that explores the web application.

Analysis. The crawling stage outputs a series of files for each identified state with accompanying logs detailing the captured network packets during each transition. Basic heuristics check for exact and exclusive transition matches across trials. These are flows that are not found in any other transition and therefore could be used to identify web application state by an adversary.

The post-crawl analysis outputs a HTML-formatted report listing discovered network flows with links to the identified DOM states before and after the transition. The developer can use this report to decide if the leaked information is sensitive and where to apply mitigation efforts.

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Search Engine Suggestions

The Google, Bing, and Yahoo search engines have been discovered to leak queries through the network traffic generated by search suggestions. Suggestion fields are particularly vulnerable to side-channel attacks because they update with every keystroke and are rarely personalized to a particular user. We tested the search engine suggestion fields by scripting the typing of a single letter and measuring the accompanying network traffic.

Web Application	Tested Actions	Uniquely Identifiable Actions	Expected Entropy	Reduced Entropy
Bing	26	24	4.7	0.08
Google	26	18	4.7	0.67
Yahoo	17,576	1,265	14.1	6.23

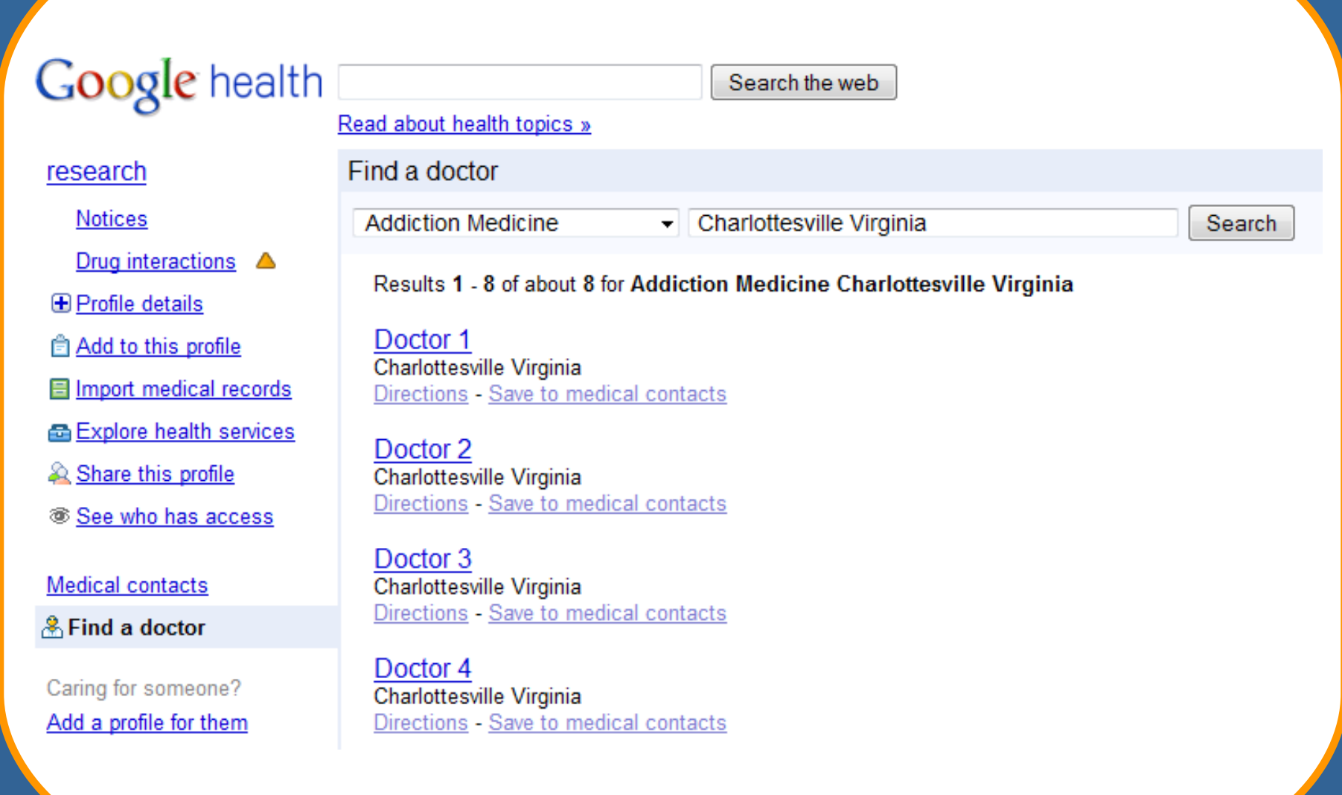
Our prototype can identify side-channel leaks in real world web applications.

Yahoo Search. Yahoo Search did not generate suggestions until three letters were typed. We collected traffic from every combination of three letters, a total of 26^3 = 17,576 states. Although many results were in groups small enough that they could likely be distinguished with a fourth letter, 65% of the strings were in groups of over 100, with the largest being 240 matching flows.

We collected the traffic of adding a fourth letter to the largest group, a total of 240 · 26 = 6,240 states. Adding a fourth letter to this group, the most difficult case for the attacker, reduces the entropy from 12.61 bits to 2.65 bits with 33% of the recorded flows being uniquely identifiable. Discarding the strings that return no suggestions, which are unlikely to be the searched term, the entropy in our four letter test decreases to 1.62 bits with 38% of the remaining flows now uniquely identifiable. Based on these results, Yahoo Search is also vulnerable to the same side-channel attack as Google and Bing despite not sending search suggestions until the third letter.

Google Health

We also tested our prototype on the Google Health Find A Doctor functionality. The Find A Doctor tool has been shown to leak the type of doctor a user searches for and by extension a user's medical condition.



Google health [Search the web]
Read about health topics »

research
Notices
Drug interactions
Profile details
Add to this profile
Import medical records
Explore health services
Share this profile
See who has access
Medical contacts
Find a doctor
Caring for someone?
Add a profile for them

Find a doctor
Addiction Medicine | Charlottesville Virginia [Search]

Results **1** - **8** of about **8** for **Addiction Medicine Charlottesville Virginia**

Doctor 1
Charlottesville Virginia
Directions - Save to medical contacts

Doctor 2
Charlottesville Virginia
Directions - Save to medical contacts

Doctor 3
Charlottesville Virginia
Directions - Save to medical contacts

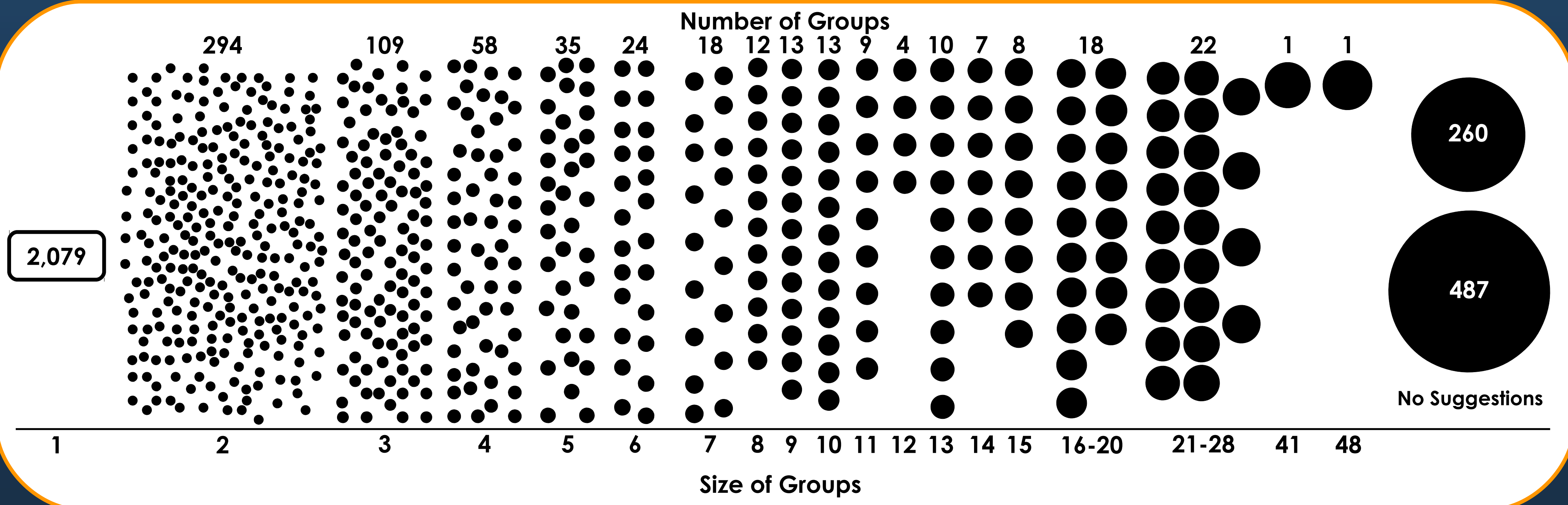
Doctor 4
Charlottesville Virginia
Directions - Save to medical contacts

The Google Health Find A Doctor tool.

To find a doctor the user enters an area of medicine and a location. We assume an adversary would be able to accurately determine the location. There are a total of 98 disciplines, leaving 98 possible states. Using the size of the returned search results for Charlottesville, our prototype can uniquely distinguish 79 of the states. Of the remaining 19 states, 16 conflicted with one other result, and 3 conflicted with two others. A determined adversary may still be able to determine the condition using other side-channels leaks within Google Health and other web applications.

Web Application	Tested Actions	Uniquely Identifiable Actions	Expected Entropy	Reduced Entropy
Google Health	98	79	6.61	0.21

Google Health can leak a user's condition.



The majority of 4 letter strings from the most difficult Yahoo Search case that return suggestions create flows similar to 10 or fewer other strings.