CSEP 564: Computer Security and Privacy

Authentication [finish]

(Web) Privacy and Anonymity

Fall 2022

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Thanks to Franzi Roesner, Dan Boneh, Dieter Gollmann, Dan Halperin, David Kohlbrenner, Yoshi Kohno, Ada Lerner, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

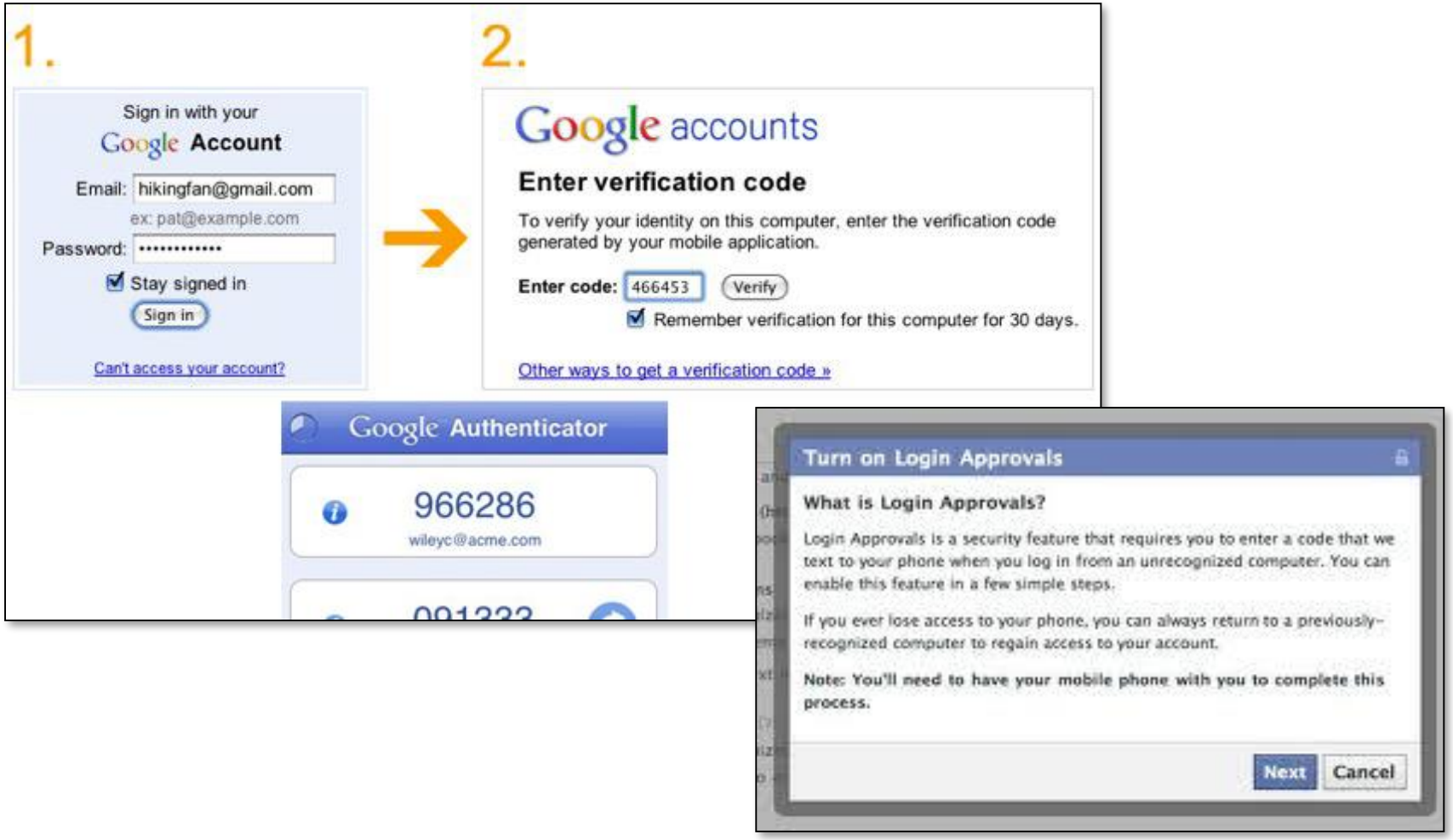
Logistics

- Lab 2 active
  - Apologies about the downtime last night.
- Lab 1 grades are up, sploit8 EC being manually graded
- The last paper (Dec 7th) has a different writeup format
  - See Canvas for the rubric, we're asking for you to reflect on the content

Improving(?) Passwords

- Add biometrics
  - For example, keystroke dynamics or voiceprint
- Graphical passwords
  - Goal: easier to remember? no need to write down?
- Password managers
  - Examples: LastPass, KeePass, 1password, built into browsers/OS
- Two-factor authentication
  - Leverage phone (or other device) for authentication

Multi-Factor Authentication



FIDO + Hardware Two Factors

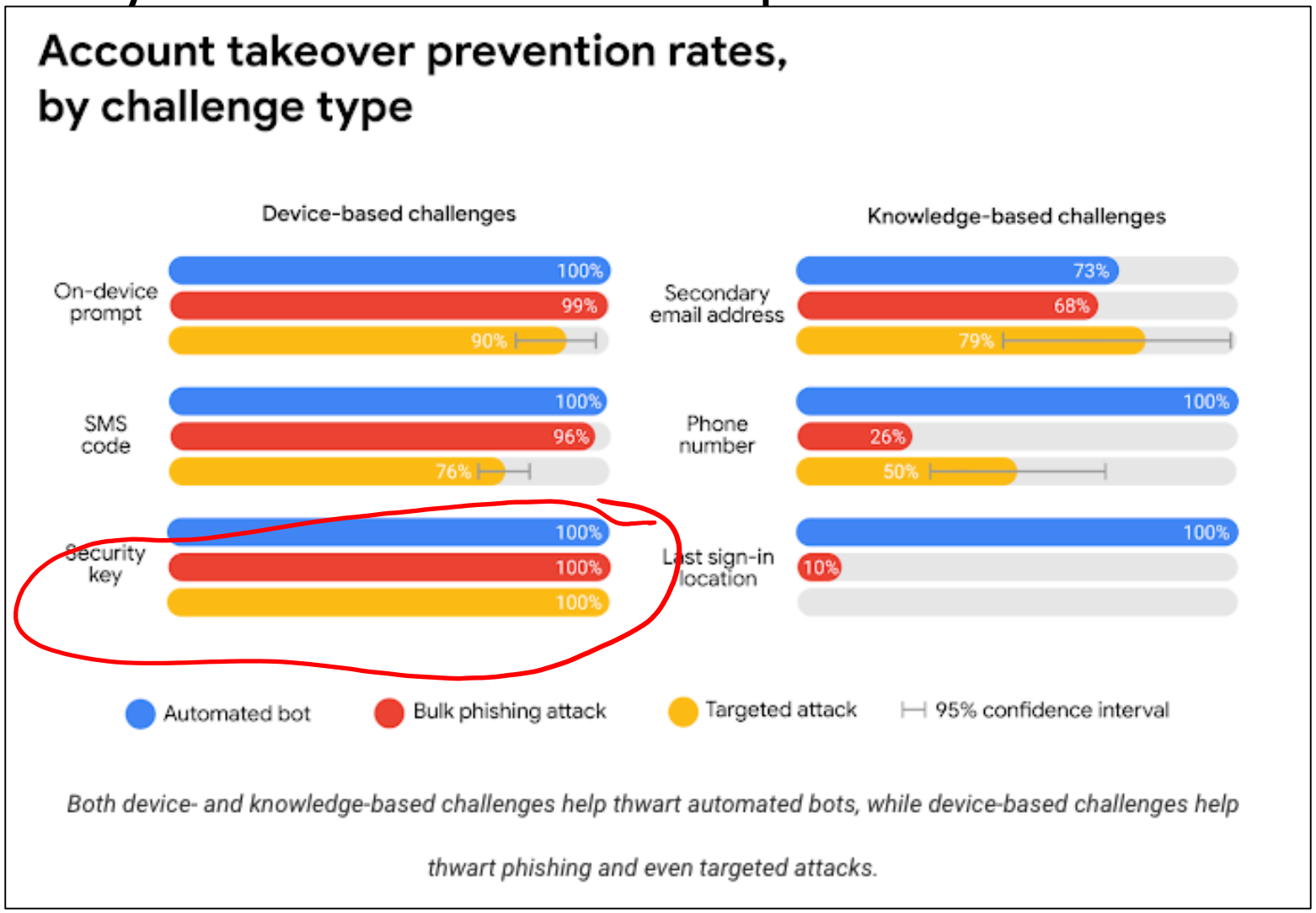
Questions:

Do you use 2-factor auth?
Do you use a password manager?
Why or why not?

How to compromise account protected with hardware second factor?

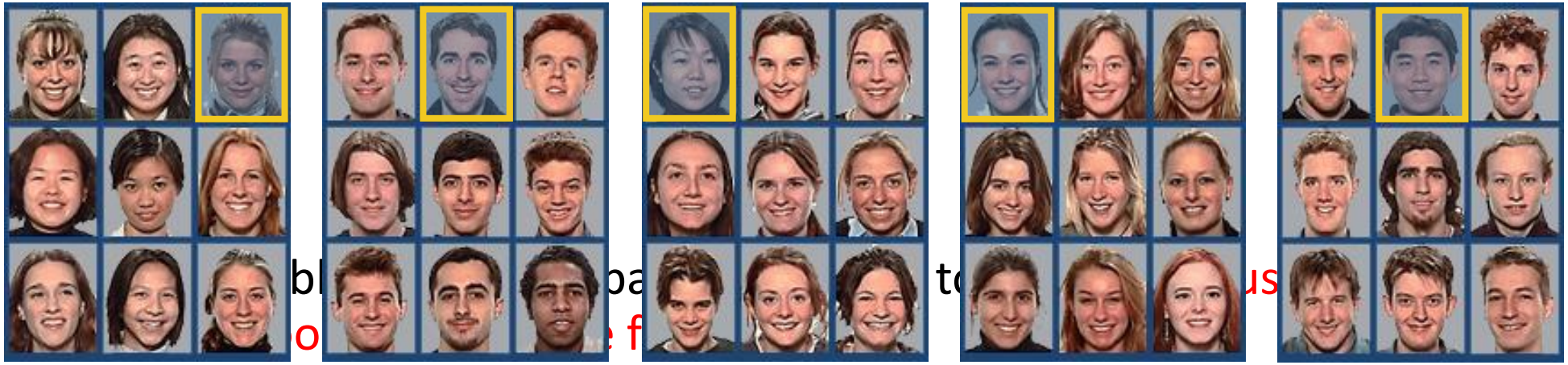
https://security.googleblog.com/2019/05/new-research-how-effective-is-basic.html

Secondary Factors Do Help!



Graphical Passwords

- Many variants… one example: Passfaces
  - Assumption: easy to recall faces

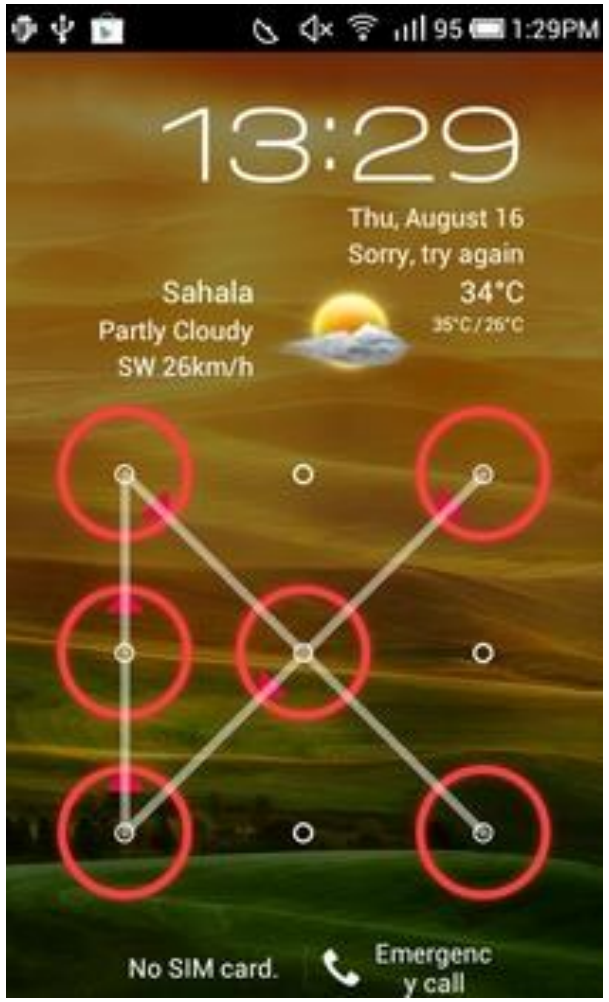


Graphical Passwords

- Another variant: draw on the image (Windows 8)

- Problem: users choose predictable points/lines

Unlock Patterns



- Problems:
  - Predictable patterns (familiar pattern by now)
  - Smear patterns
  - Side channels: apps can use accelerometer and gyroscope to extract pattern!

What About Biometrics?

- Authentication: **What you are**
- Unique identifying characteristics to authenticate user or create credentials
  - Biological and physiological: Fingerprints, iris scan
  - Behaviors characteristics - how perform actions: Handwriting, typing, gait
- Advantages:
  - Nothing to remember
  - Passive
  - Can’t share (generally)
  - With perfect accuracy, could be fairly unique

Issues with Biometrics

- Private, but not secret
  - Maybe encoded on the back of an ID card?
  - Maybe encoded on your glass, door handle, ...
  - Sharing between multiple systems?
- Revocation is difficult (impossible?)
  - Sorry, your iris has been compromised, please create a new one...
- Physically identifying
  - Soda machine to cross-reference fingerprint with DMV?
- Birthday paradox
  - With false accept rate of 1 in a million, probability of false match is above 50% with only 1609 samples

Shifting Threat Models…

BBC NEWS

OPEN The News in 2 minutes

News services
Your news when
want it

News Front Page
Africa
Americas
Asia-Pacific
Europe
Middle East
South Asia
UK
Business
Health
Science/Nature
Technology
Entertainment

Last Updated: Thursday, 31 March, 2005, 10:37 GMT 11:37 UK

E-mail this to a friend Printable version

Malaysia car thieves steal finger

By Jonathan Kent
BBC News, Kuala Lumpur

Police in Malaysia are hunting for members of a violent gang who chopped off a car owner's finger to get round the vehicle's hi-tech security system.

The car, a Mercedes S-class, was protected by a fingerprint recognition system.

Accountant K Kumaran's ordeal began when he was run down by four men in a small car as he was about to get into his Mercedes in a Kuala Lumpur suburb.

SEE ALSO:
Malaysia to act
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16 Mar 05 | As

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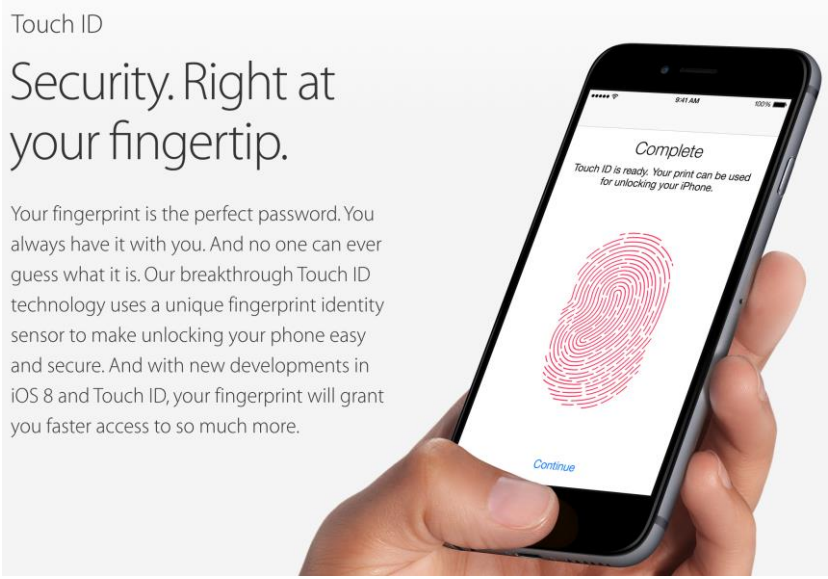
Attacking Biometrics

- An adversary might try to steal biometric info
  - Malicious fingerprint reader
    - Consider when biometric is used to derive a cryptographic key
  - Residual fingerprint on a glass

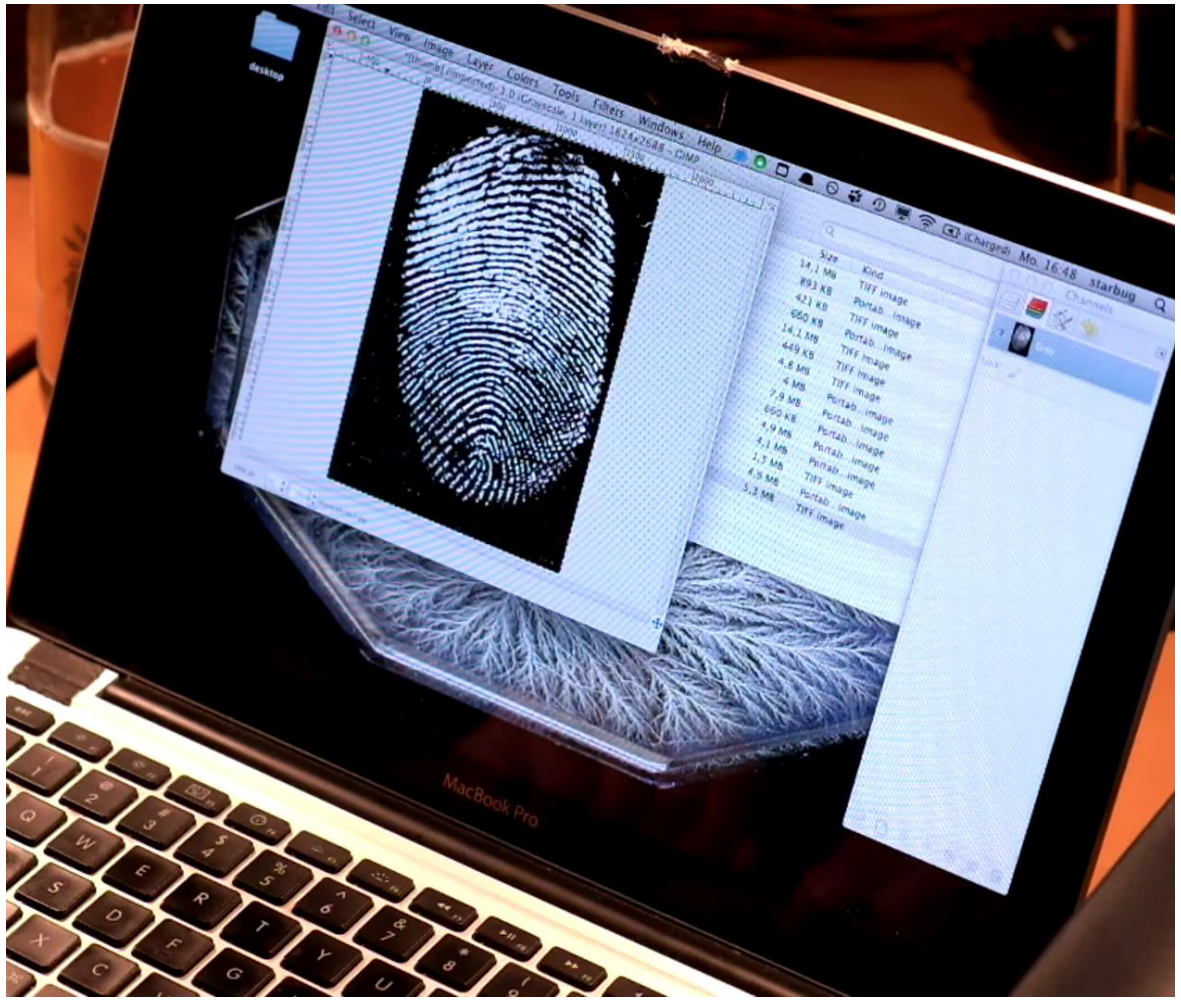


[Starbug -- http://istouchidhackedyet.com/]

Attacking Biometrics

[Starbug -- http://istouchidhackedyet.com/]

Attacking Biometrics



[Starbug -- http://istouchidhackedyet.com/]

Attacking Biometrics

[Starbug -- http://istouchidhackedyet.com/]

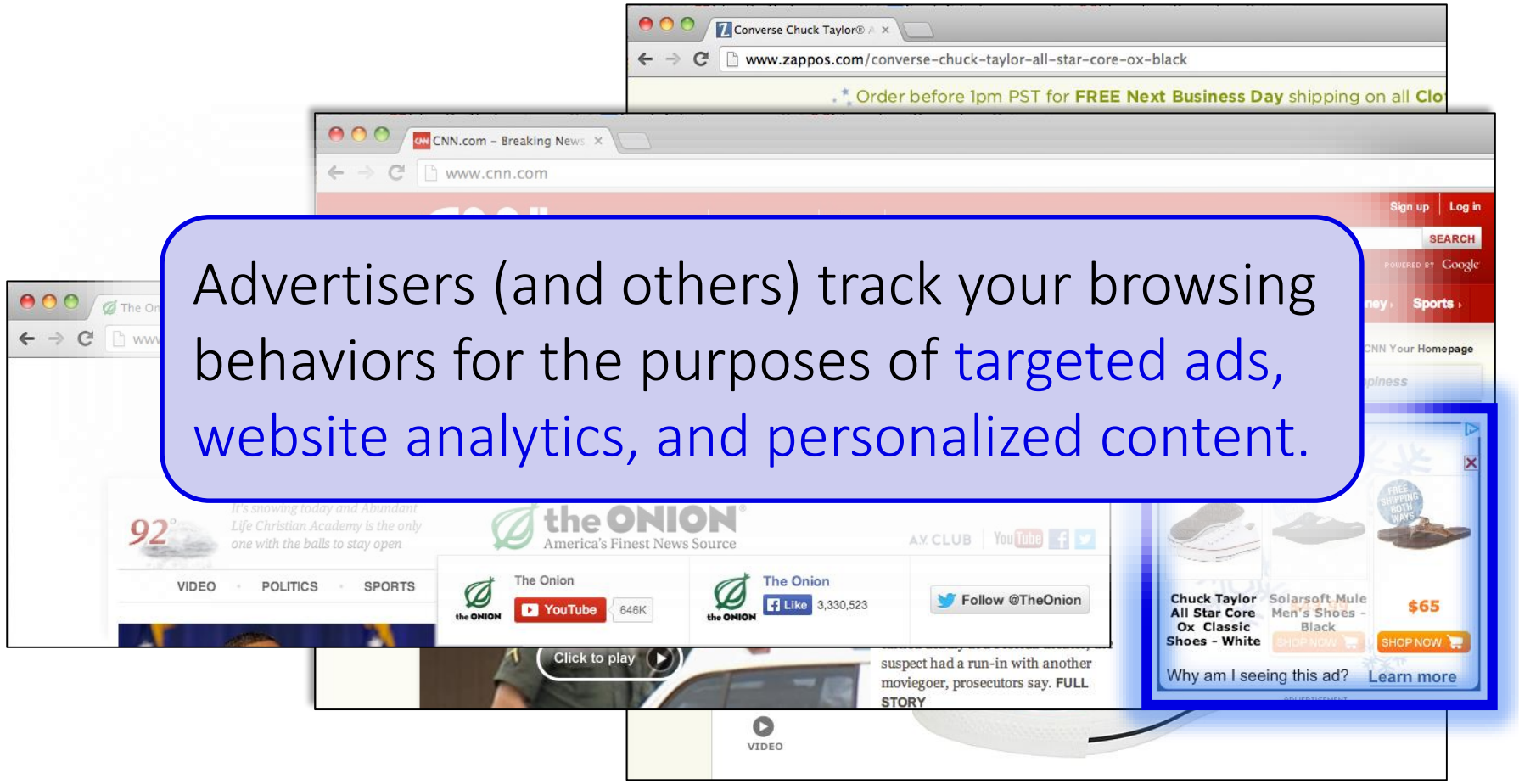
Attacking Biometrics

Privacy and web tracking

A topic in flux

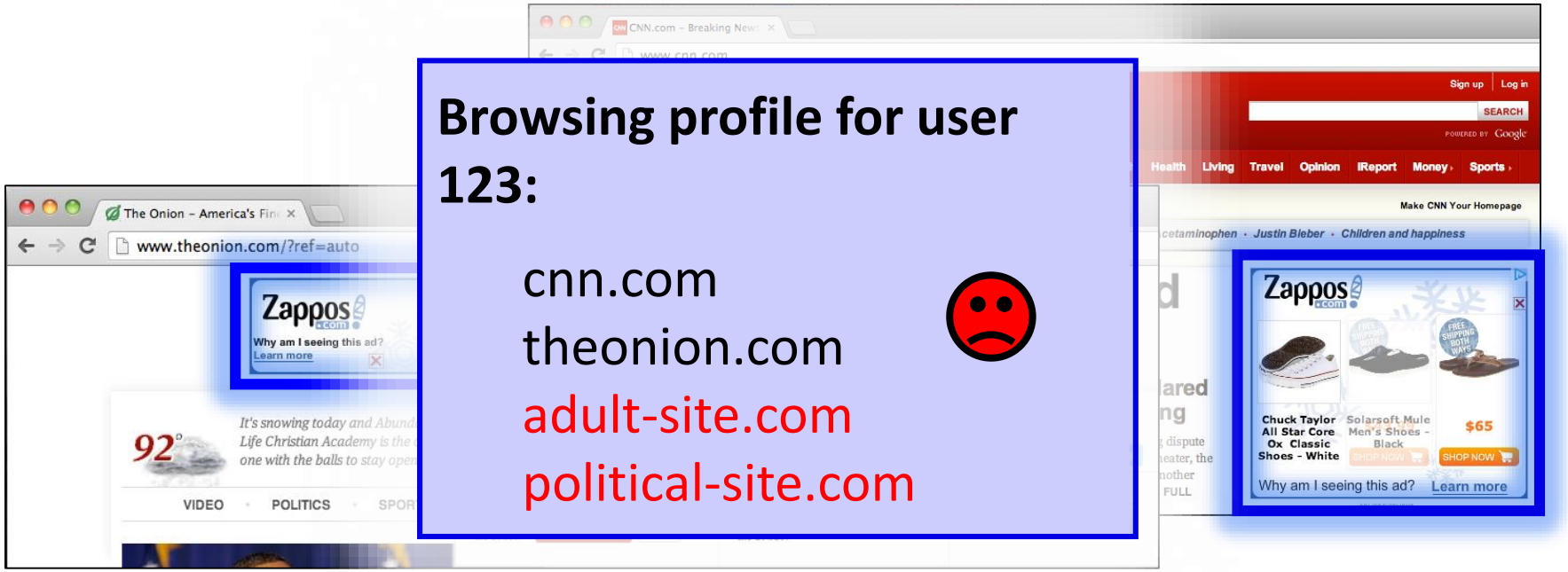
- Tracking via cookies
- Tracking via other methods
- Fingerprinting

Ads That Follow You



Advertisers (and others) track your browsing behaviors for the purposes of targeted ads, website analytics, and personalized content.

Third-Party Web Tracking



These ads allow **criteo.com** to link your visits between sites, even if you never click on the ads.

chiefmartec.com

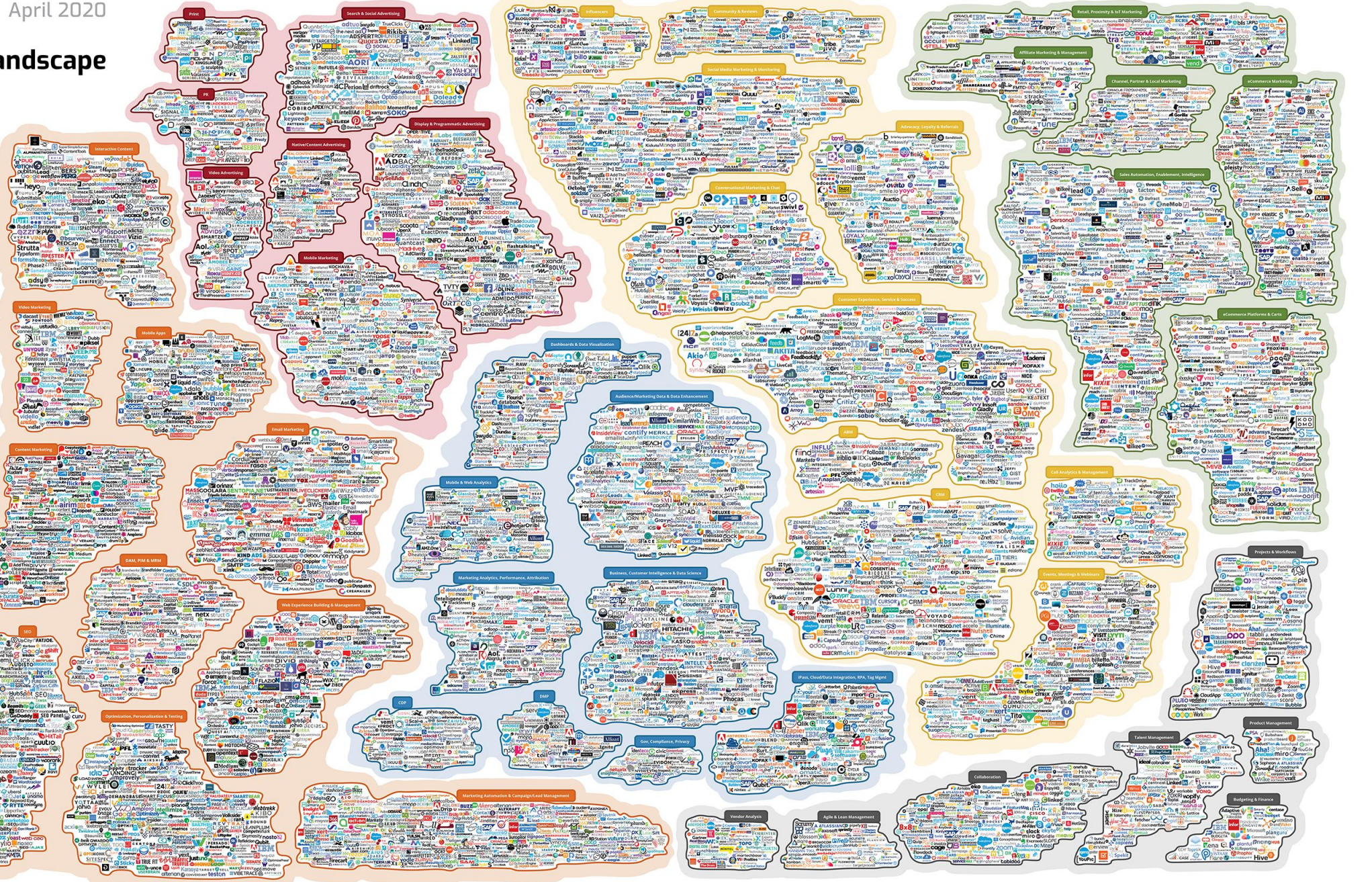
April 2020

Marketing Technology Landscape

The Martech 5000

Total Solutions	8,000
Advertising & Promotion	922
Content & Experience	1,936
Social & Relationships	1,969
Commerce & Sales	1,314
Data	1,258
Management	601

Access all the data of this landscape & more at **martech5000.com**



Produced by Scott Brinker (@chiefmartec) and Blue Green Brands (@bluegreenbrands).

MartechMap an initiative by chiefmartec & MartechTribe

2022 Marketing Technology Landscape

May 2022

Advertising & Promotion

Display & Programmatic Advertising

Mobile Marketing

Native/Content Advertising

PR

Print

Search & Social Advertising

Video Advertising

Content & Experience

Content Marketing

CMS & Web Experience Management

DAM & MRM & PIM

Email Marketing

Interactive Content

Marketing Automation & Campaign/Lead Management

Mobile Apps

Optimization Personalization & Testing

SEO

Video Marketing

Social & Relationships

ABM

Call Analytics & Management

Customer Experience Service & Success

Influencers

CRM

Advocacy Loyalty & Referrals

Community & Reviews

Events, Meetings & Webinars

Social Media Marketing & Monitoring

Live Chat & Chatbots

Commerce & Sales

Retail, Proximity & IOT

Affiliate Marketing & Management

Sales Automation Enablement & Intelligence

eCommerce Platforms & Carts

eCommerce Marketing

Channel Partner & Local Marketing

Data

Marketing Analytics Performance & Attribution

Audience/Marketing Data & Data Enhancement

Ipaas Cloud/Data Integration & Tag Management

Business/Customer Intelligence & Data Science

DMP

Dashboards & Data Visualization

Governance Compliance And Privacy

Mobile & Web Analytics

Customer Data Platform

Management

Agile & Lean Management

Collaboration

Talent Management

Budgeting & Finance

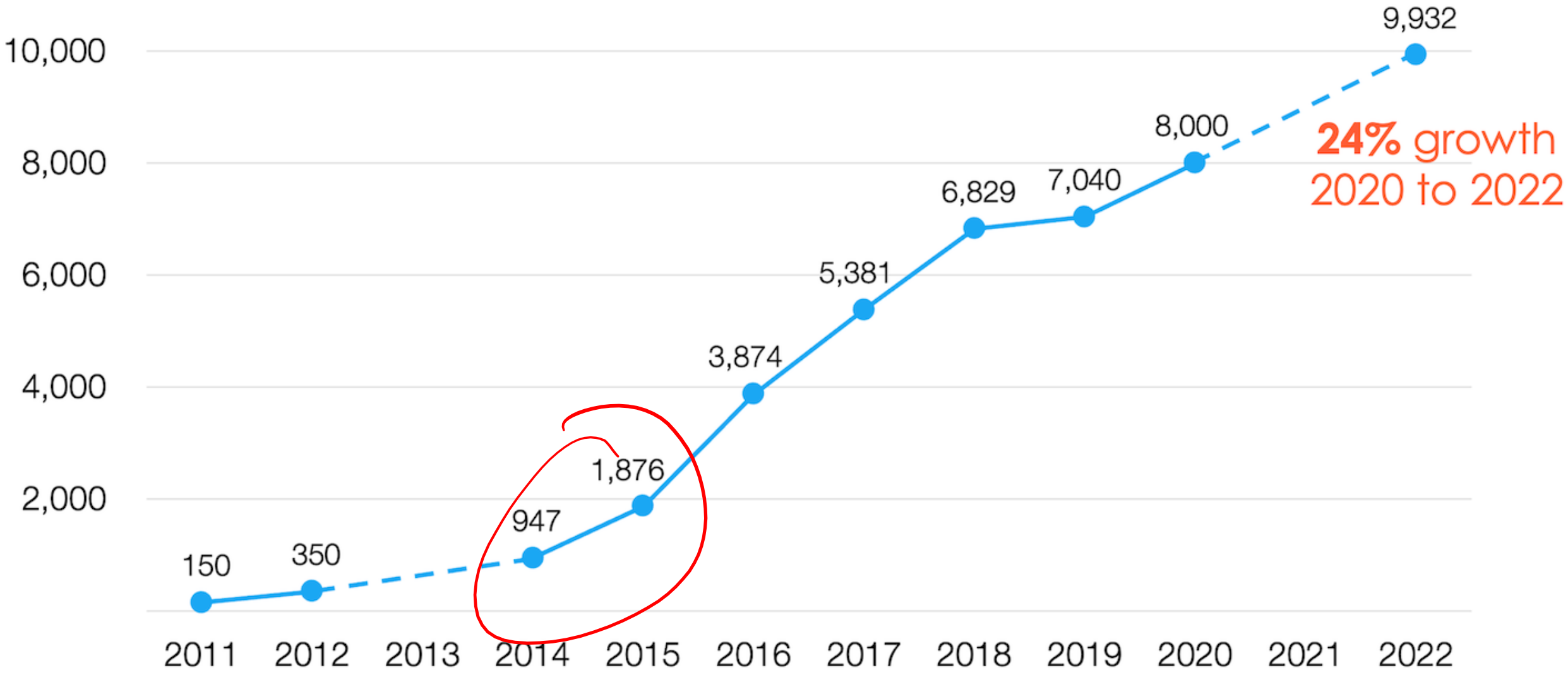
Projects & Workflow

Product Management

Vendor Analysis & Management

visit martechmap.com to search, sort & filter

6,521% growth 2011 to 2022



https://chiefmartec.com/2022/05/marketing-technology-landscape-2022-search-9932-solutions-on-martechmap-com/

Concerns About Privacy

THE WALL STREET JOURNAL.

WHAT THEY KNOW | JULY 30, 2010

The Web's New Gold Mine: Your Secrets

A Journal inv
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By
Hid
all to be put up

The file consists
identifies her as

CNN

Your Privacy

Big
dep

The New York Times

May 6, 2011, 5:01 pm | 3 Comments

'Do Not Track' Privacy Bill Appears in Congress

By TANZINA VEGA

And the privacy legislation just keeps on coming.

On Friday, two bills were introduced in Washington in support of a Do Not Track mechanism that would give users control over how much of their data was collected by advertisers and other online companies.

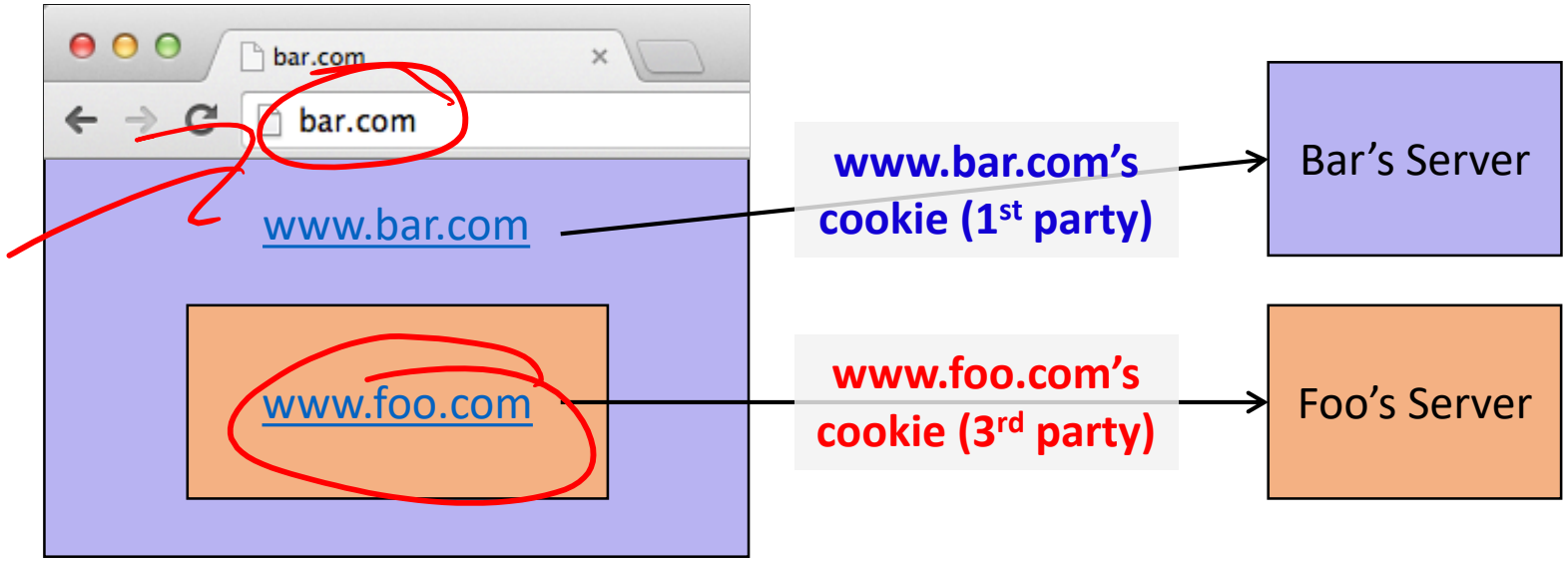
Log In

als
tion

By JENNIFER VALENTINO-DEVRIES,
JEREMY SINGER-VINE and ASHKAN SOLTANI
December 24, 2012

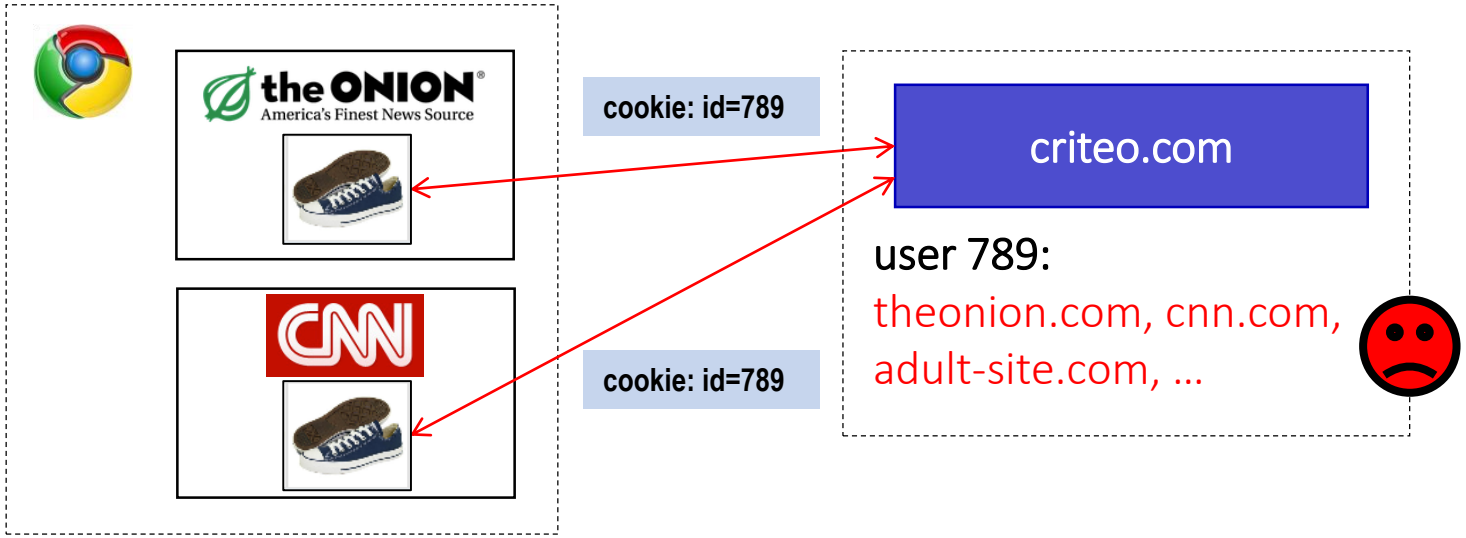
First and Third Parties

- First-party cookie: belongs to top-level domain.
- Third-party cookie: belongs to domain of embedded content (such as image, iframe).



Anonymous Tracking

Trackers included in other sites use third-party cookies containing unique identifiers to create browsing profiles.



Basic Tracking Mechanisms

- Tracking requires:
  (1) re-identifying a user.
  (2) communicating id + visited site back to tracker.

```
▽ Hypertext Transfer Protocol
  ▷ GET /pixel/p-3aud4J6uA4Z6Y.gif?labels=InvisibleBox&busty=2710 HTTP/1.1\r\n
    Host: pixel.quantserve.com\r\n
    Connection: keep-alive\r\n
    Accept: image/webp,*/*;q=0.8\r\n
    User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_9_2) AppleWebKit/537.36
    Referer: http://www.theonion.com/\r\n
    Accept-Encoding: gzip,deflate,sdch\r\n
    Accept-Language: en-US,en;q=0.8\r\n
    Cookie: mc=52a65386-f1de1-00ade-0b26e; d=ENkBRgGHD4GYEA35MMIL74MKiyDs1A2MQI1Q
```

Tracking Technologies

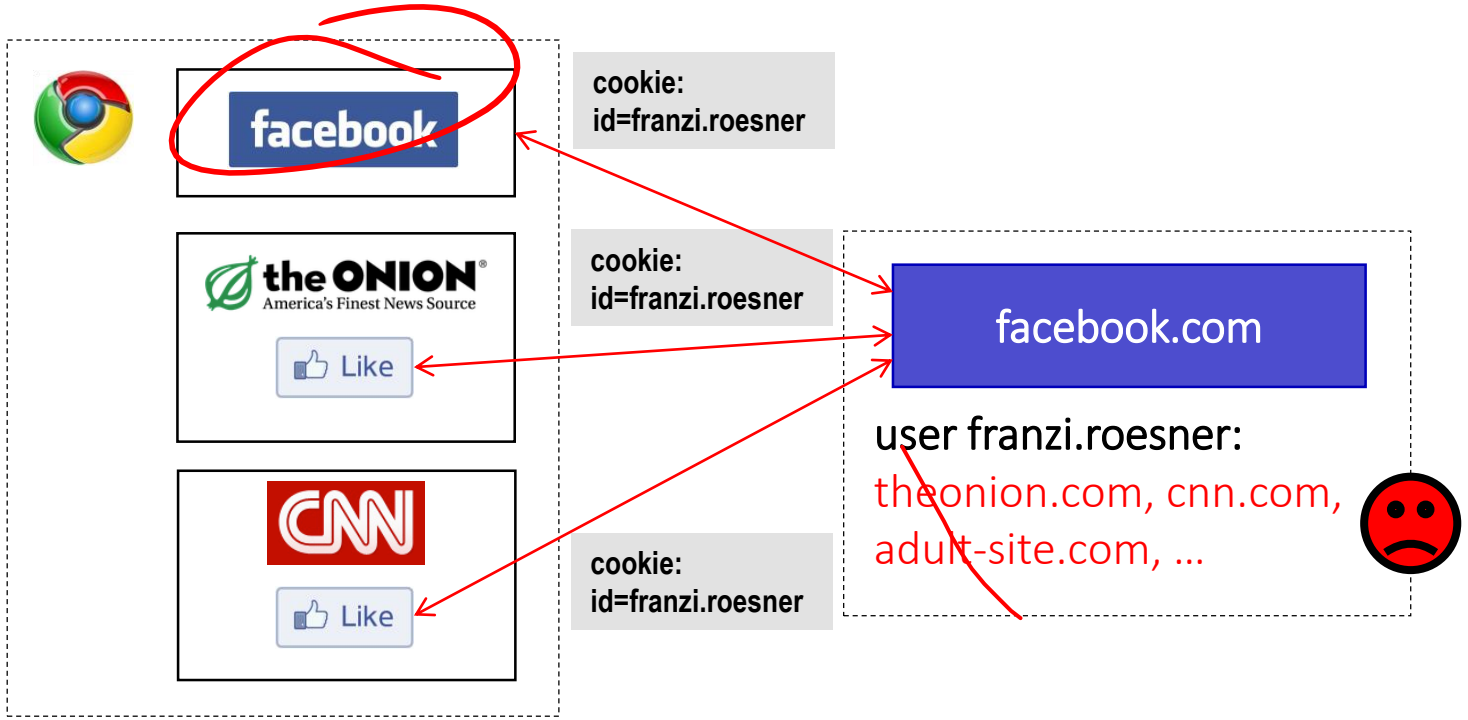
- HTTP Cookies
- HTTP Auth
- HTTP Etags
- Content cache
- IE userData
- HTML5 protocol and content handlers
- HTML5 storage
- Flash cookies
- Silverlight storage
- TLS session ID & resume
- Browsing history
- window.name
- HTTP STS
- DNS cache

- "Zombie" cookies that respawn (http://samy.pl/evercookie)

Other Trackers?

"Personal" Trackers

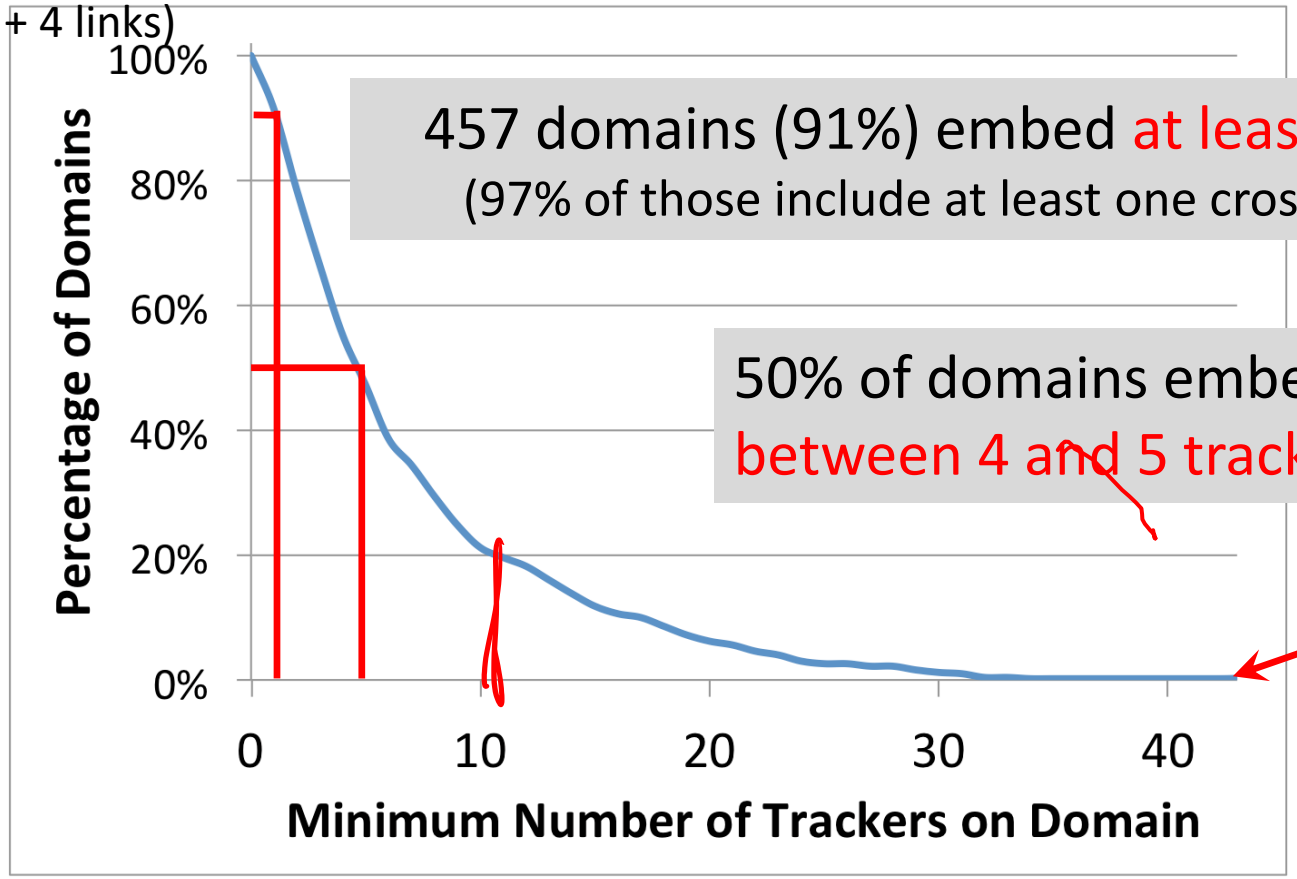
Personal Tracking



- Tracking is not anonymous (linked to accounts).
- Users directly visit tracker's site → evades some defenses.

How prevalent is tracking? (2011)

524 unique trackers on Alexa top 500 websites (homepages + 4 links)

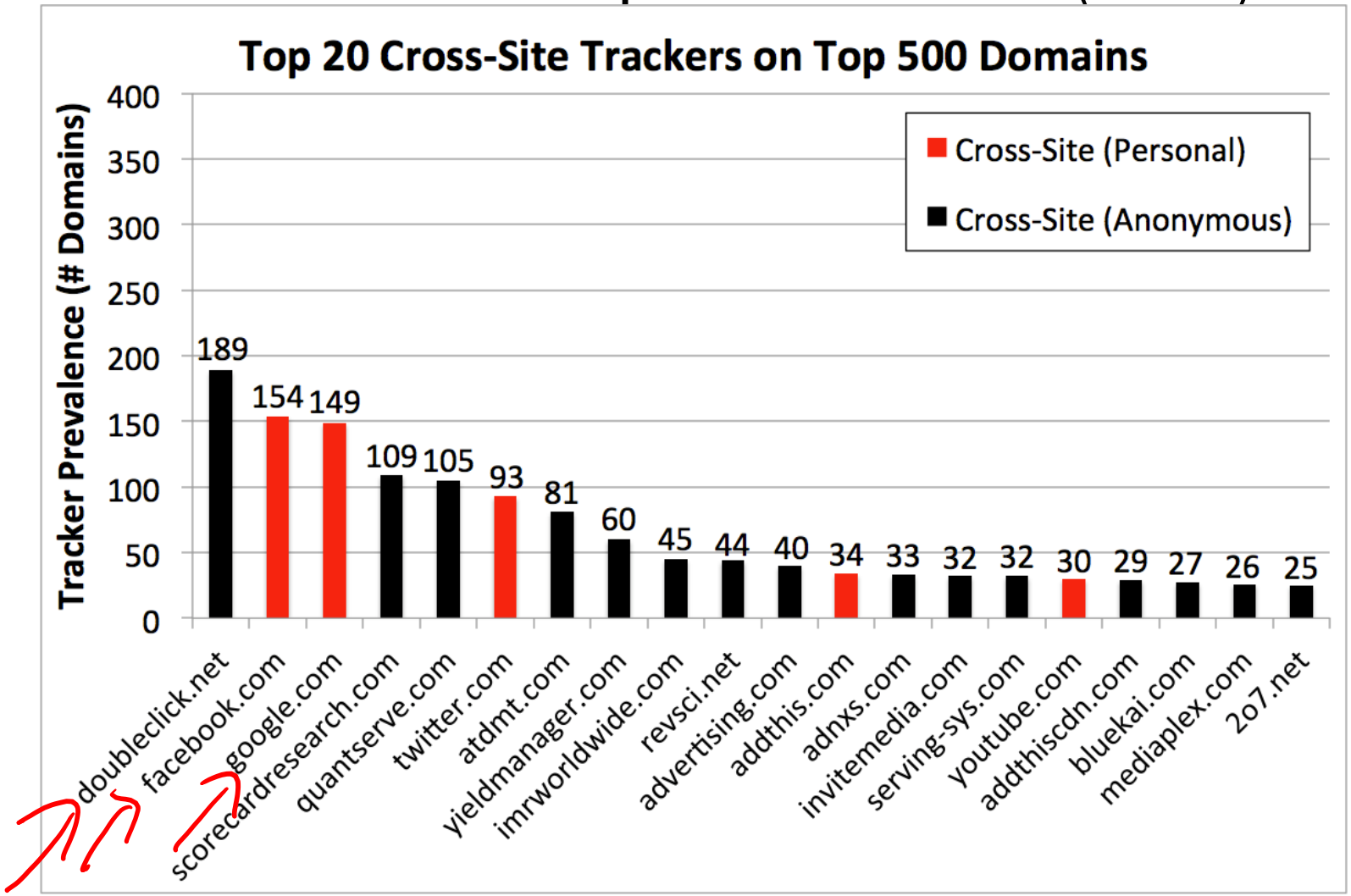


457 domains (91%) embed at least one tracker.
(97% of those include at least one cross-site tracker.)

50% of domains embed between 4 and 5 trackers.

One domain includes 43 trackers.

Who/what are the top trackers? (2011)

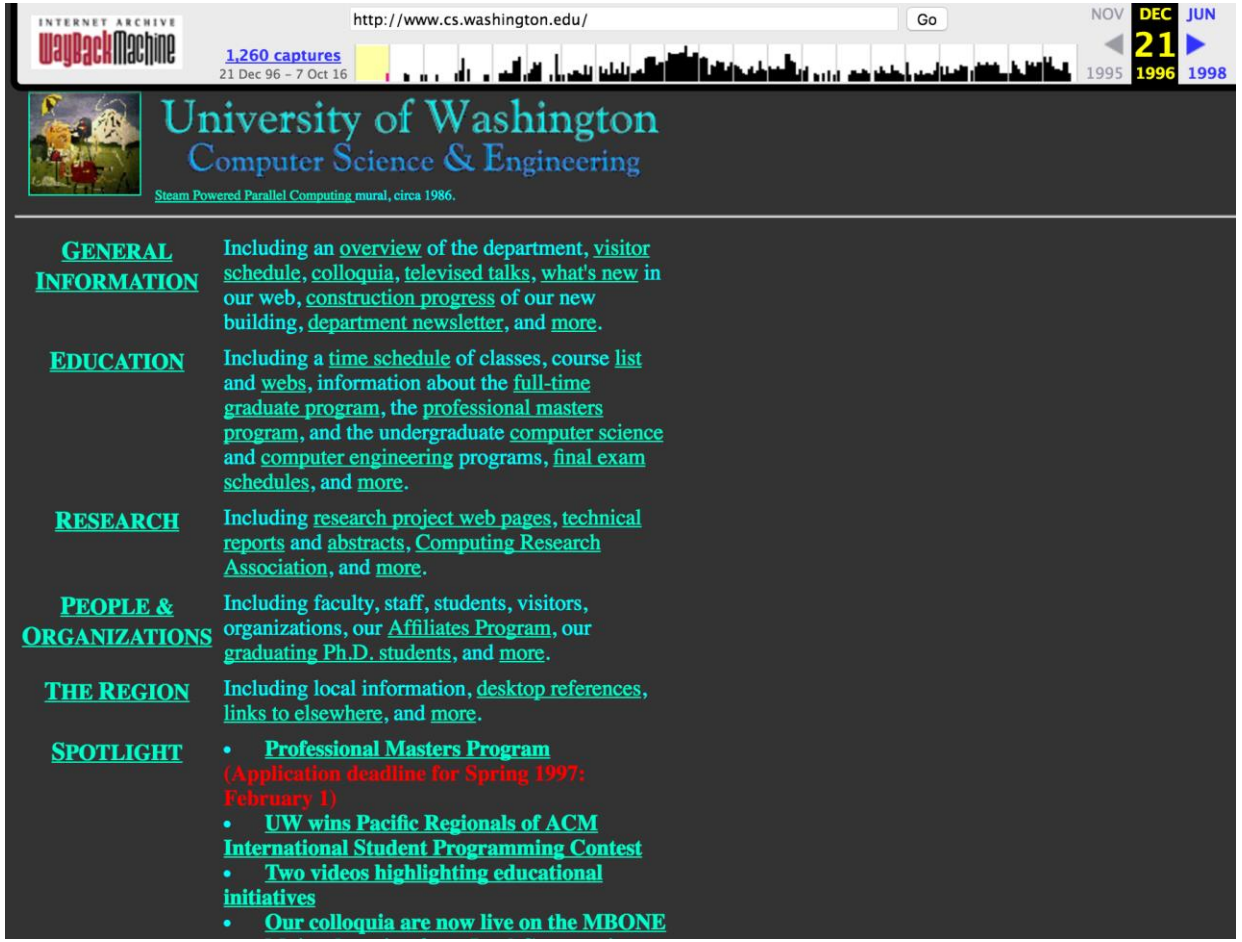


How has this changed over time?

- The web has existed for a while now…
  - What about tracking before 2011?
  - What about tracking before 2009?

- Solution: time travel!

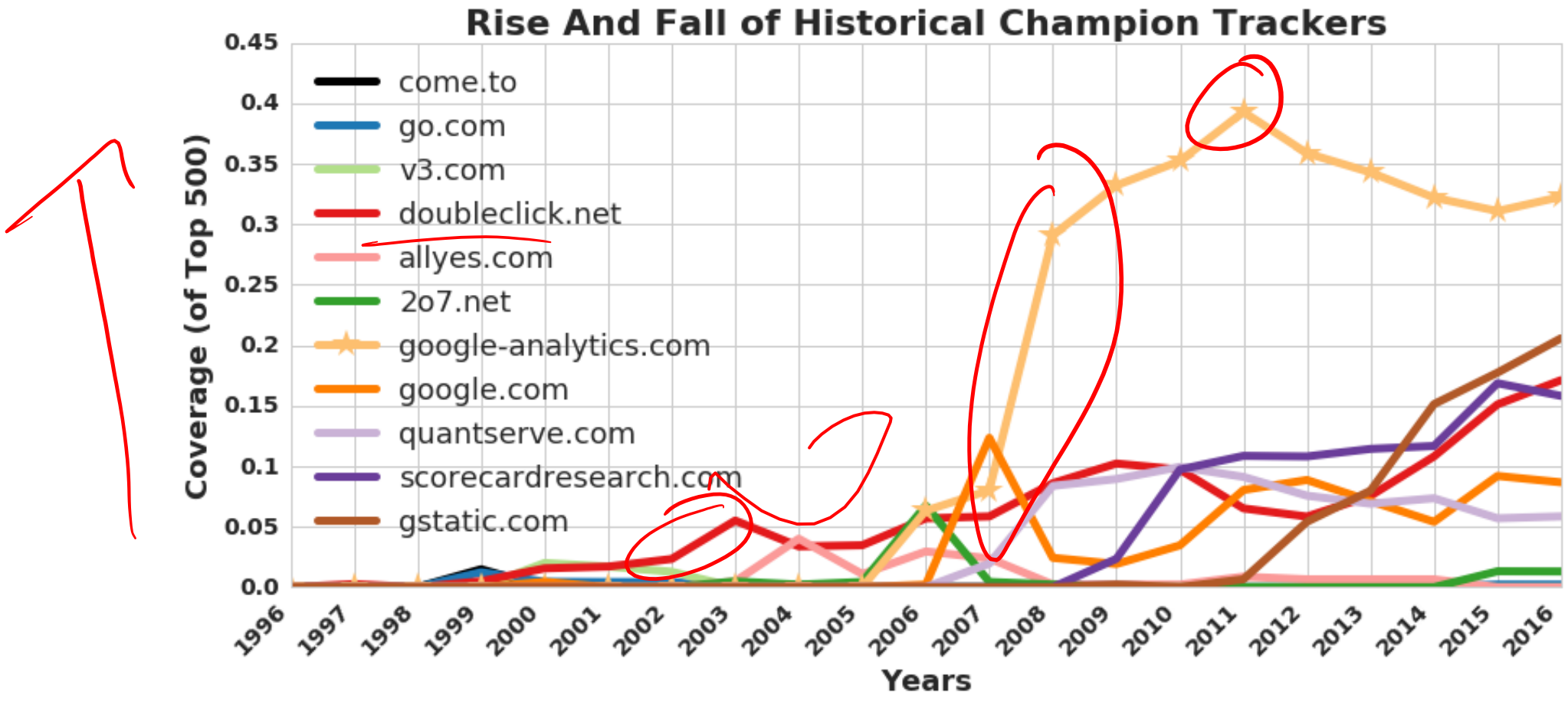
The Wayback Machine to the Rescue



Time travel for web tracking: http://trackingexcavator.cs.washington.edu

1996-2016: More & More Tracking

- More trackers of more types, more per site, more coverage



Defenses to Reduce Tracking

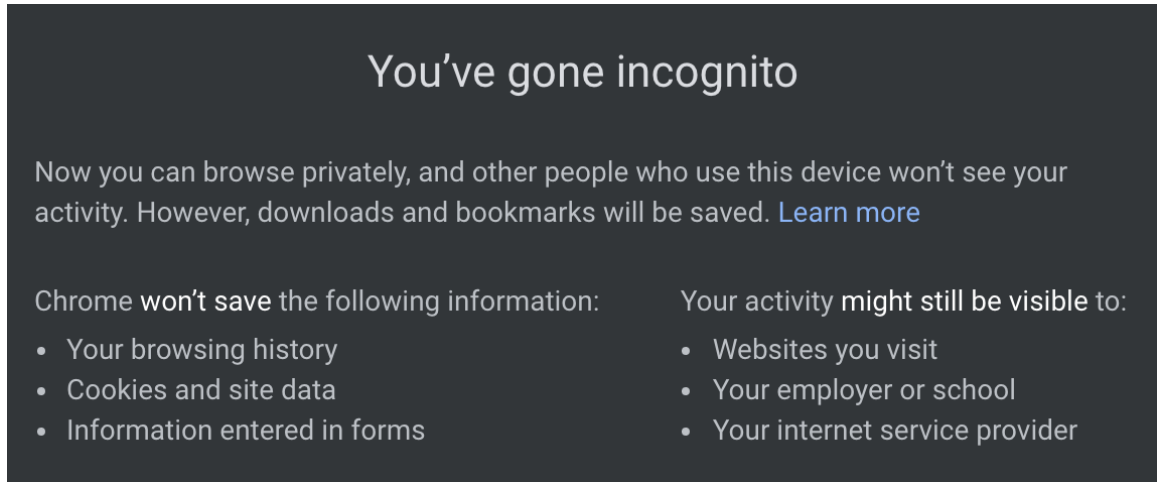
- Do Not Track?

Do Not Track is not a technical defense: trackers must honor the request.

Defenses to Reduce Tracking

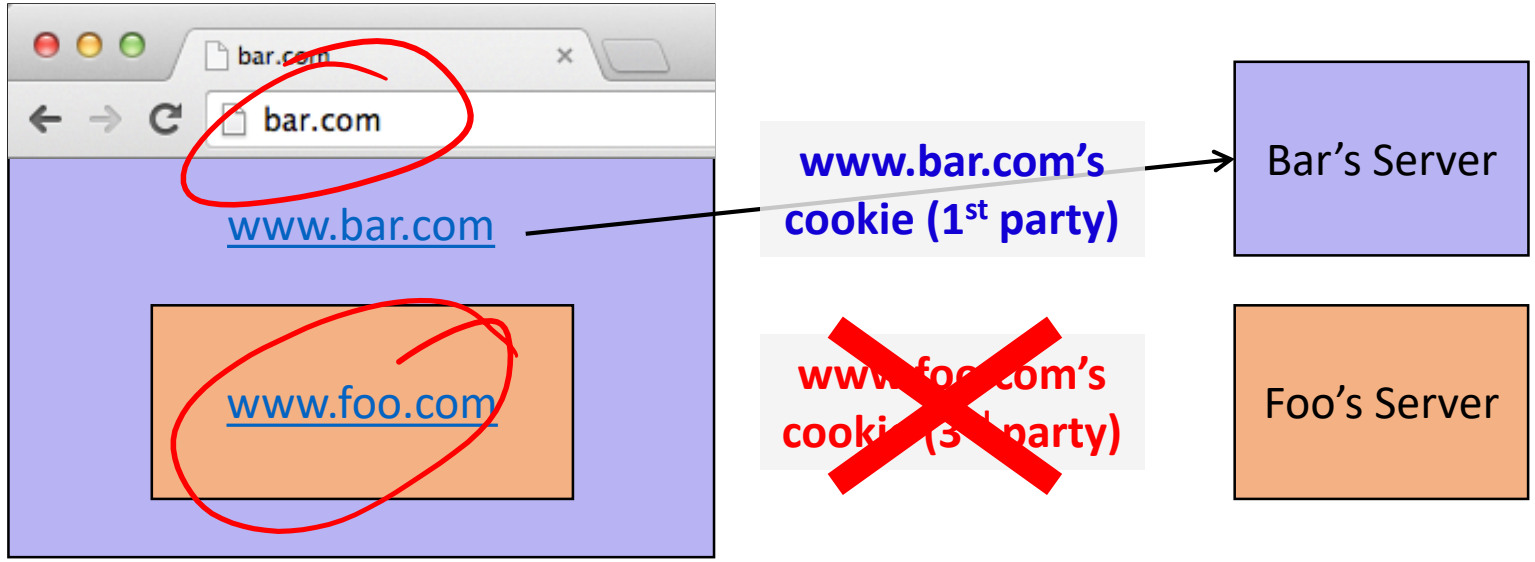
- Do Not Track proposal?
- Private browsing mode?

Private browsing mode protects against local, not network, attackers.



Defenses to Reduce Tracking

- Do Not Track proposal?
- Private browsing mode?
- Third-party cookie blocking?



3rd party cookies

- Safari and FF (mostly) now block 3rd party cookies
  - https://webkit.org/blog/10218/full-third-party-cookie-blocking-and-more/
  - https://blog.mozilla.org/blog/2019/09/03/todays-firefox-blocks-third-party-tracking-cookies-and-cryptomining-by-default/

- Chrome…

"By undermining the business model of many ad-supported websites, blunt approaches to cookies encourage the use of opaque techniques such as fingerprinting (an invasive workaround to replace cookies), which can actually reduce user privacy and control. We believe that we as a community can, and must, do better."

Aug 2022: Remove 3rd party cookies by 2024

How should Google respond?

7:48

- Pollev.com/dkohlbre
- Pretend someone fired all the ad/chrome execs and hired your group instead
- Safari and Firefox have removed ad's ability to track users via 3rd party cookies, and Google has committed to the same in Chrome by 2024.
- How should google respond to 3rd party cookies being removed?
- Think about the technical solutions, policy solutions, and even business model solutions available to you!

Cookie Ghostwriting

- flickr.com
  - <script src=siftscience.com/s.js />
- S.js runs
  - Fp = fingerprintjs2
  - Setcookie(fp)
  - Hexagon-analytics.com/cookierecieve?cookie=fp
- Every time you load flickr.com what happens?

Journey to the Center of the Cookie Ecosystem: Unraveling Actors' Roles and Relationship

Cookie Ghostwriting

- ~~flickr.com~~ patreon.com
  - <script src=siftscience.com/s.js />

- S.js runs
  - Fp = fingerprintjs2
  - Setcookie(fp)
  - Hexagon-analytics.com/cookiereciever?cookie=fp

- Every time you load ~~flickr.com~~ patreon.com what happens?

Journey to the Center of the Cookie Ecosystem: Unraveling Actors' Roles and Relationship

Fingerprinting is out there

- Better than a ‘voluntary’ cookie: involuntary, unchangeable id!
  - “Fingerprint”
- Idea: Measure ‘behavior’ of browser
  - Smash into unique ID

Fingerprinting Web Browsers

- User agent
- HTTP ACCEPT headers
- Browser plug-ins
- MIME support
- Clock skew
- Installed fonts
- Cookies enabled?
- Browser add-ons
- Screen resolution
- HTML5 canvas (differences in graphics SW/HW!)

HTML5 Canvas Fingerprinting - Text

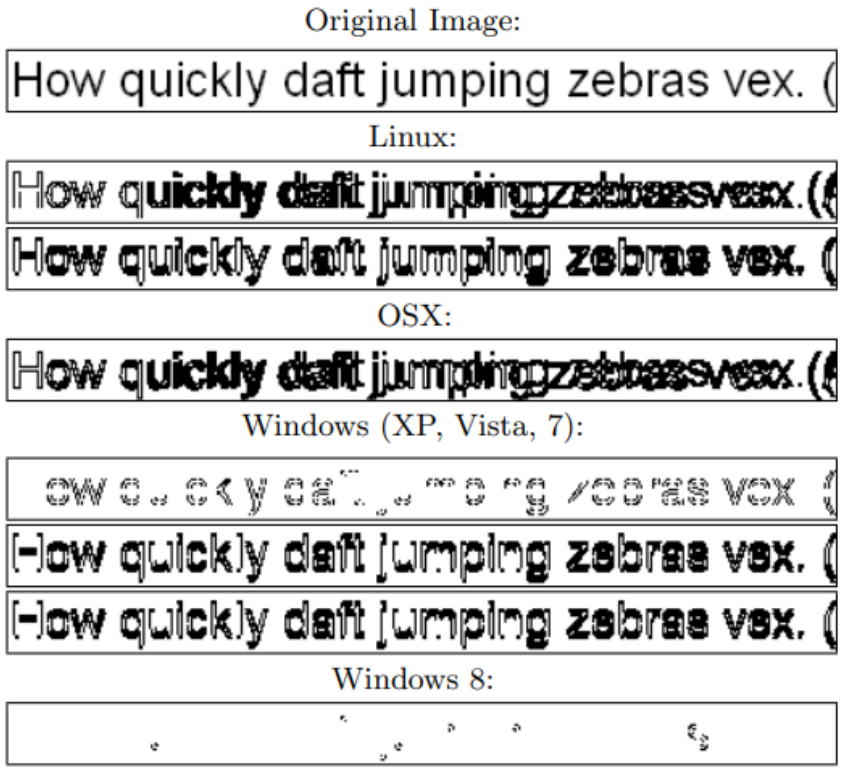
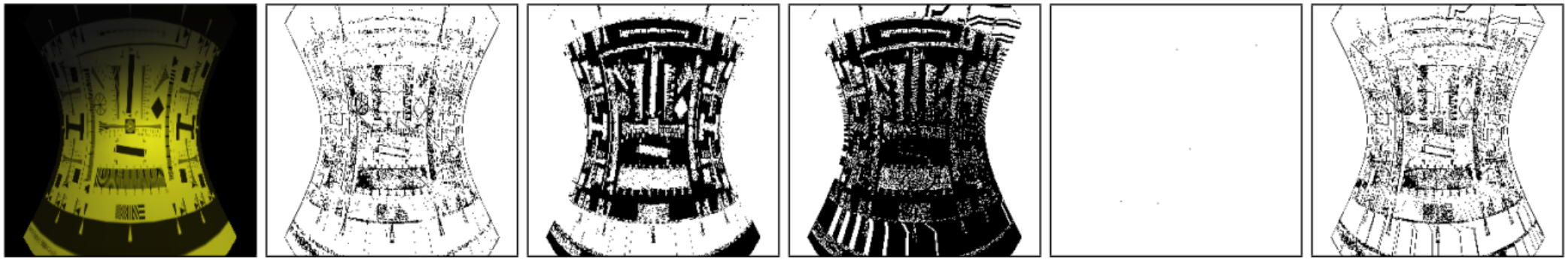


Figure 7: Difference maps for a group on `text_arial`

Mowery and Shacham, 2012

HTML5 Canvas Fingerprinting - Image



(a) Original (Intel G41) (b) Group 1 (Radeon HD 2400) (c) Group 20 (Intel 82945G) (d) Group 23 (Intel G33/G31) (e) Group 25 (Intel HD Graphics) (f) Group 36 (GeForce 6200)

Figure 10: Original render and difference maps for Group 24

Mowery and Shacham, 2012

And its out there!

Figure 4: Different images printed to canvas by fingerprinting scripts. Note that the phrase *"Cwm fjordbank glyphs vext quiz"* in the top image is a *perfect pangram*, that is, it contains all the letters of the English alphabet only once to maximize diversity of the outcomes with the shortest possible string.

COVER YOUR TRACKS

See how trackers view your browser

Learn About

HOW TO READ YOUR REPORT

You will see a summary of your overall tracking protection. The first section gives you a general idea of what your browser configuration is blocking (or not blocking). Below that is a list of specific browser characteristics in the format that a tracker would view them. We also provide descriptions of how they are incorporated into your fingerprint.

HOW CAN TRACKERS TRACK YOU?

Trackers use a variety of methods to identify and track users. Most often, this includes tracking cookies, but it can also include browser fingerprinting. Fingerprinting is a sneakier way to track users and makes it harder for users to regain control of their browsers. This report measures how easily trackers might be able to fingerprint your browser.

HOW CAN I USE MY RESULTS TO BE MORE ANONYMOUS?

Knowing how identifiable you are, or whether you are blocking trackers, can help you take steps to better protect your privacy. Browser add-ons or protection mechanisms built into the browser can help. Even so, the sneakiest trackers have ways around even the strongest security.

Here are your Cover Your Tracks results. They include an overview of how visible you are to trackers, with an index (and glossary) of all the metrics we measure below.

Our tests indicate that you have **strong protection against Web tracking**.

IS YOUR BROWSER:

Blocking tracking ads?	Yes
Blocking invisible trackers?	Yes
Protecting you from fingerprinting?	Your browser has a nearly-unique fingerprint

Still wondering how fingerprinting works?

LEARN MORE

Note: because ... *easure all forms of tracking and p*

Your R

One in 145,235 browsers have the same fingerprint

Within our dataset of several hundred thousand visitors tested in the past 45 days, only **one in 145235.5 browsers have the same fingerprint as yours.**

Fingerprinting as a security measure

- Blocking bots (e.g. reCAPTCHA)

- Validating users over-time

How should we view tracking and fingerprinting efforts?

“Privacy preserving” personalized ads aka FLoC

- https://github.com/WICG/turtledove
  - The browser, not the advertiser, holds the information about what the advertiser thinks a person is interested in.
  - Advertisers can serve ads based on an interest, but cannot combine that interest with other information about the person — in particular, with who they are or what page they are visiting.
  - Web sites the person visits, and the ad networks those sites use, cannot learn about their visitors' ad interests.

“Privacy preserving” personalized ads aka Topics

- https://github.com/patcg-individual-drafts/topics
  - The browser, not the advertiser, holds the information about what the advertiser thinks a person is interested in.
  - Advertisers can serve ads based on an interest, but cannot combine that interest with other information about the person — in particular, with who they are or what page they are visiting.
  - Web sites the person visits, and the ad networks those sites use, cannot learn about their visitors' ad interests.

https://support.google.com/google-ads/answer/11899856?hl=en

Privacy is far more than web tracking

- We've only started talking about it, in only 1 context.

Anonymity

Paper Discussion Time!

8.28

"Tor: The Second-Generation Onion Router"

Roger Dingledine, Nick Mathewson, Paul Syverson

- Choose one/more and discuss with neighbors:
  - What adversary is TOR intended to protect against?
  - What is a 'hidden service'?
  - Why would someone want a hidden service?
  - Who runs an exit node, and why?
  - What are some of the weak points (as described here) of TOR?
  - Who uses TOR?

"On the Internet, nobody knows you're a dog."

The New Yorker, 1993

Privacy on Public Networks

- Internet is designed as a public network
  - Machines on your LAN may see your traffic, network routers see all traffic that passes through them
- Routing information is public
  - IP packet headers identify source and destination
  - Even a passive observer can figure out who is talking to whom
- Encryption does not hide identities
  - Encryption hides payload, but not routing information
  - Even IP-level encryption (tunnel-mode IPSec/ESP) reveals IP addresses of IPSec gateways
- Modern web: Accounts, web tracking, etc. …

What is Anonymity?

- Anonymity is the state of being not identifiable within a set of subjects
  - You cannot be anonymous by yourself!
    - Big difference between anonymity and confidentiality
  - Hide your activities among others' similar activities
- Unlinkability of action and identity
  - For example, sender and email they send are no more related after observing communication than before
- Unobservability (hard to achieve)
  - Observer cannot even tell whether a certain action took place or not

Questions

Q1: Why might we **want** people to have anonymity on the Internet?

Q2: Why might we **not want** people to have anonymity on the Internet?

Applications of Anonymity (I)

- Privacy
  - Hide online transactions, Web browsing, etc. from intrusive governments, marketers and archivists
- Untraceable electronic mail
  - Corporate whistle-blowers
  - Political dissidents
  - Socially sensitive communications (online AA meeting)
  - Confidential business negotiations
- Law enforcement and intelligence
  - Sting operations and honeypots
  - Secret communications on a public network

Applications of Anonymity (II)

- Digital cash
  - Electronic currency with properties of paper money (online purchases unlinkable to buyer's identity)
- Anonymous electronic voting
- Censorship-resistant publishing

Part 1: Anonymity in Datasets

How to release an anonymous dataset?

A Face Is Exposed for AOL Searcher No. 4417749

By MICHAEL BARBARO and TOM ZELLER Jr.; Saul Hansell contributed reporting for this article.
Published: August 9, 2006

FACEBOOK
TWITTER
GOOGLE+
EMAIL
SHARE
PRINT
REPRINTS

Buried in a list of 20 million Web search queries collected by AOL and recently released on the Internet is user No. 4417749. The number was assigned by the company to protect the searcher's anonymity, but it was not much of a shield.

No. 4417749 conducted hundreds of searches over a three-month period on topics ranging from "numb fingers" to "60 single men" to "dog that urinates on everything."

And search by search, click by click, the identity of AOL user No. 4417749 became easier to discern. There are queries for "landscapers in Lilburn, Ga," several people with the last name Arnold and "homes sold in shadow lake subdivision gwinnett county georgia."

It did not take much investigating to follow that data trail to Thelma Arnold, a 62-year-old widow who lives in Lilburn, Ga., frequently researches her friends' medical ailments and loves her three dogs. "Those are my searches," she said, after a reporter read part of the list to her.

How to release an anonymous dataset?

- Possible approach: remove identifying information from datasets?

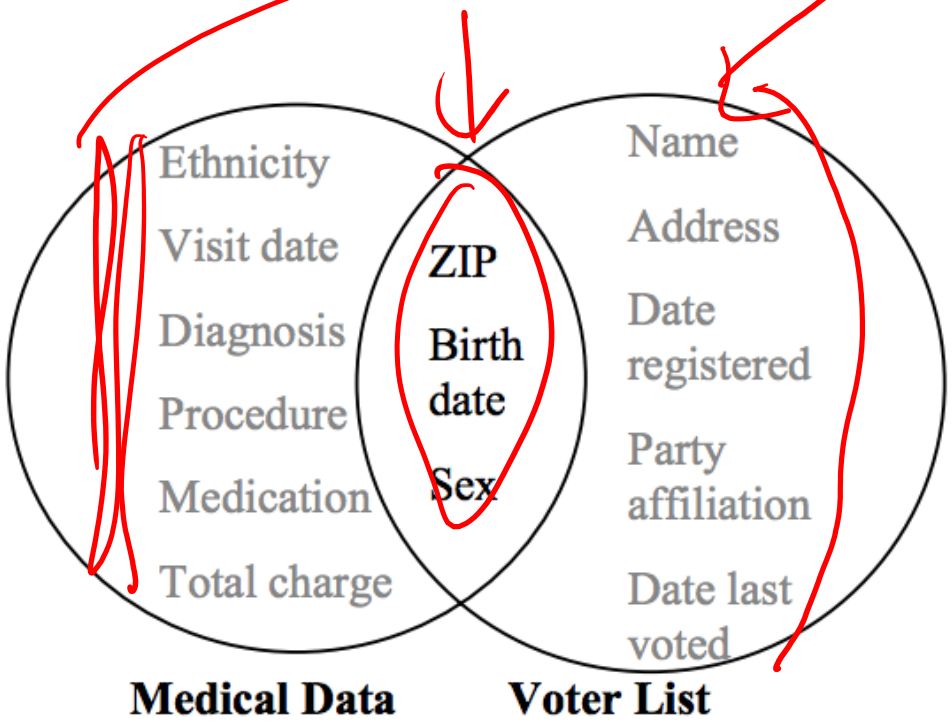


Figure 1 Linking to re-identify data

Massachusetts medical+voter data [Sweeney 1997]

[Sweeney 2002]

k-Anonymity

- Each person contained in the dataset cannot be distinguished from at least k-1 others in the data.

Name	Age	Gender	State of domicile	Religion	Disease
Ramsha	29	Female	Tamil Nadu	Hindu	Cancer
Yadu	24	Female	Kerala	Hindu	Viral infection
Salima	28	Female	Tamil Nadu	Muslim	TB
Kaker	27	Male	Karnataka	Parsi	No illness
Joan	24	Female	Kerala	Christian	Heart-related
Bahuksana	23	Male	Karnataka	Buddhist	TB
Rambha	19	Male	Kerala	Hindu	Cancer
Kishor	29	Male	Karnataka	Hindu	Heart-related
John	17	Male	Kerala	Christian	Heart-related
John	19	Male	Kerala	Christian	Viral infection

[Sweeney 2002]

k-Anonymity

- Each person contained in the dataset cannot be distinguished from at least k-1 others in the data.

Name	Age	Gender	State of domicile	Religion	Disease
*	20 < Age ≤ 30	Female	Tamil Nadu	*	Cancer
*	20 < Age ≤ 30	Female	Kerala	*	Viral infection
*	20 < Age ≤ 30	Female	Tamil Nadu	*	TB
*	20 < Age ≤ 30	Male	Karnataka	*	No illness
*	20 < Age ≤ 30	Female	Kerala	*	Heart-related
*	20 < Age ≤ 30	Male			
*	Age ≤ 20	Male			
*	20 < Age ≤ 30	Male			
*	Age ≤ 20	Male			
*	Age ≤ 20	Male	Kerala	*	Viral infection

Doesn't work for high-dimensional datasets (which tend to be **sparse**)

Robust De-anonymization of Large Sparse Datasets

Arvind Narayanan and Vitaly Shmatikov

The University of Texas at Austin

[Narayanan and Shmatikov 2008]

Netflix Challenge:

- Netflix released a (non-uniform) random sample of user's movie ratings
- Challenge was to build a better recommendation system
- Data was 'anonymous'
  - ID # only
  - Random selection of a given user's ratings
  - "noise" added (appears that there was no noise)

[Narayanan and Shmatikov 2008]

Result: No real anonymity

- Cross-correlate with IMBD ratings
- A handful (6 or fewer) ratings of non-top 500 movies is enough!

[Dwork et al.]

Differential Privacy

- **Setting:** Trusted party has a database
- **Goal:** allow queries on the database that are useful but preserve the privacy of individual records
- **Differential privacy intuition:** add noise so that an output is produced with similar probability whether any single input is included or not
- Privacy of the computation, not of the dataset

$S \mid S+i$

Part 2: Anonymity in Communication

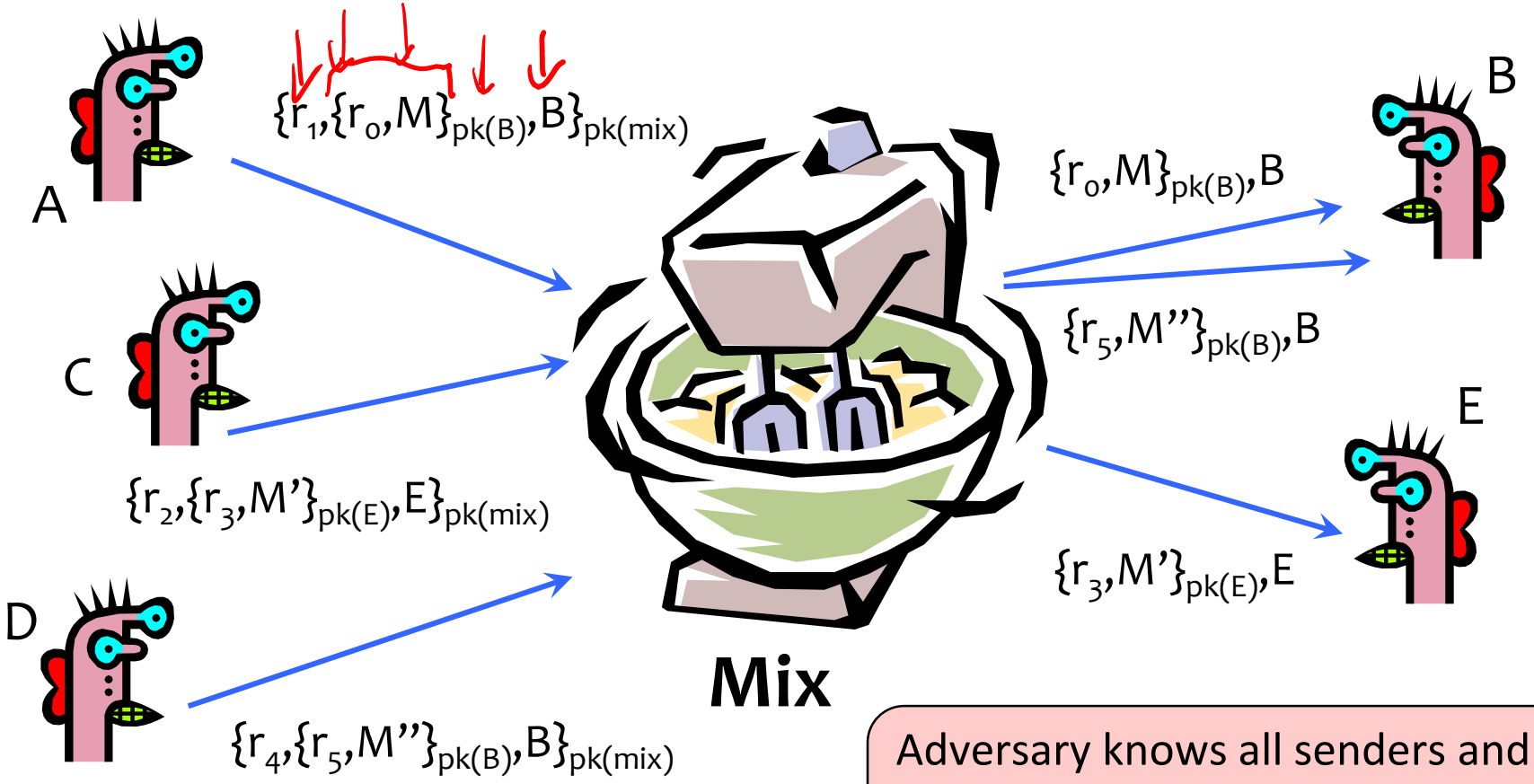
Chaum's Mix

- Early proposal for anonymous email
  - David Chaum. "Untraceable electronic mail, return addresses, and digital pseudonyms". Communications of the ACM, February 1981.

Before spam, people thought anonymous email was a good idea ☺

- Modern anonymity systems use Mix as the basic building block

Basic Mix Design



Adversary knows all senders and all receivers, but cannot link a sent message with a received message

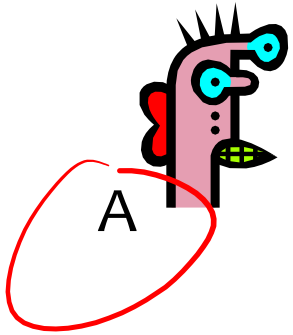
Anonymous Return Addresses

M includes $\{K_1,A\}_{pk(mix)}$, K_2 where K_2 is a fresh public key

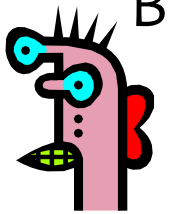
$\{r_1,\{r_o,M\}_{pk(B)},B\}_{pk(mix)}$

MIX

$\{r_o,M\}_{pk(B)},B$



A



B

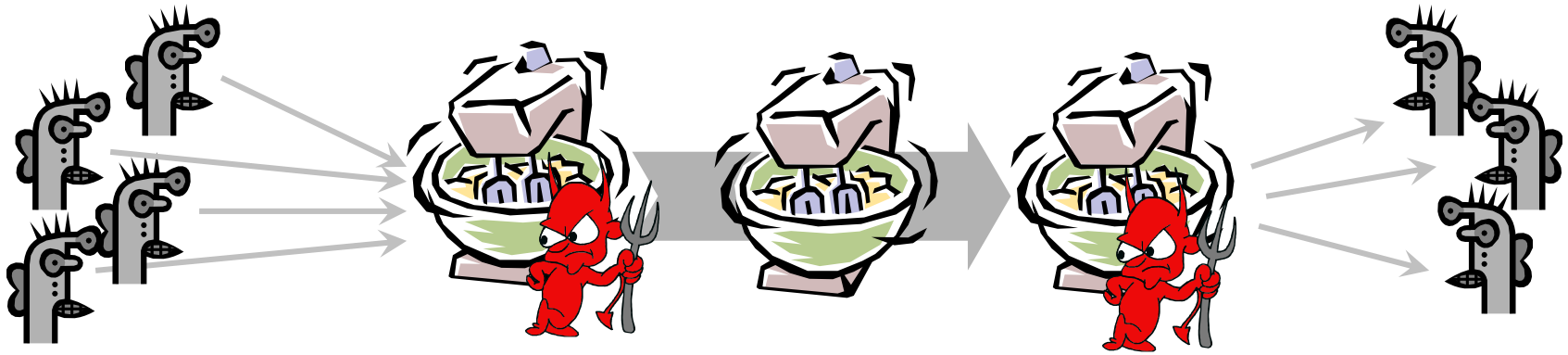
$A,\{\{r_2,M'\}_{K_2}\}_{K_1}$

Response MIX

$\{K_1,A\}_{pk(mix)}$, $\{r_2,M'\}_{K_2}$

Secrecy without authentication
(good for an online confession service ☺)

Mix Cascades and Mixnets



- Messages are sent through a sequence of mixes
  - Can also form an arbitrary network of mixes ("mixnet")
- Some of the mixes may be controlled by attacker, but even a single good mix ensures anonymity
- Pad and buffer traffic to foil correlation attacks

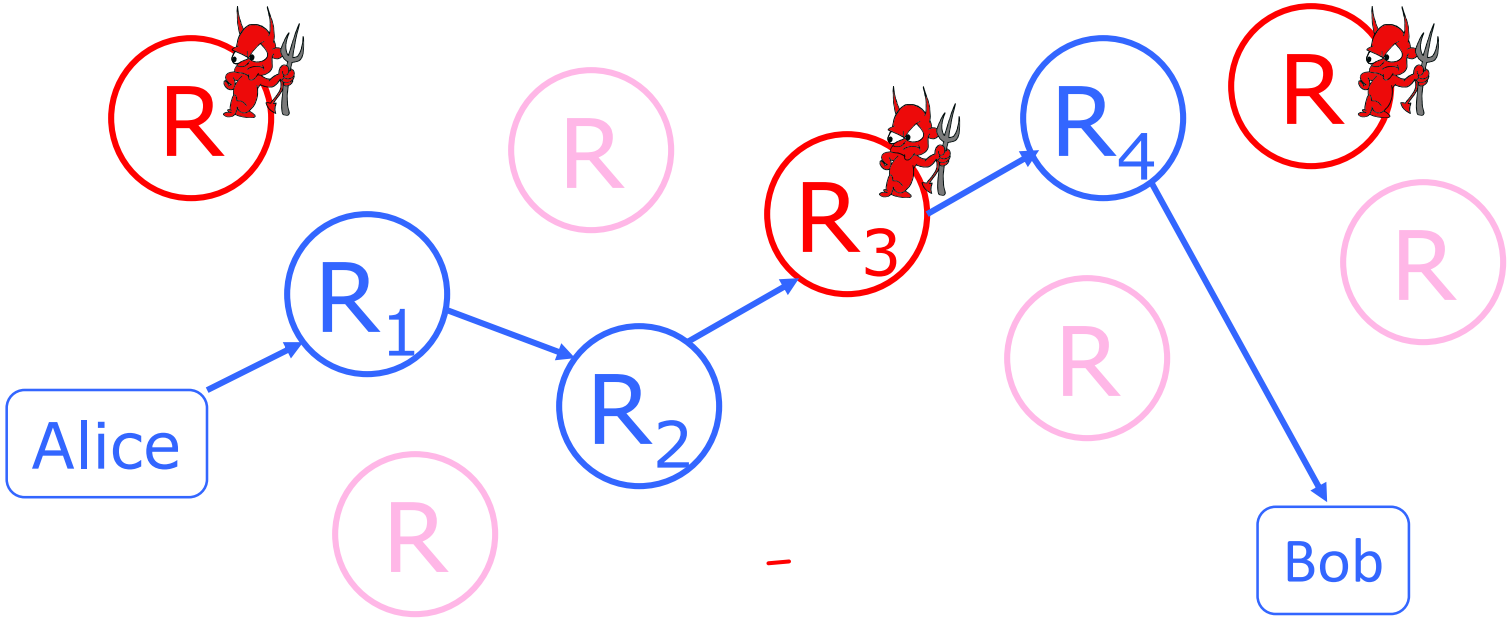
Disadvantages of Basic Mixnets

- Public-key encryption and decryption at each mix are **computationally expensive**
- Basic mixnets have **high latency**
  - OK for email, not OK for anonymous Web browsing
- Challenge: low-latency anonymity network

[Reed, Syverson, Goldschlag 1997]

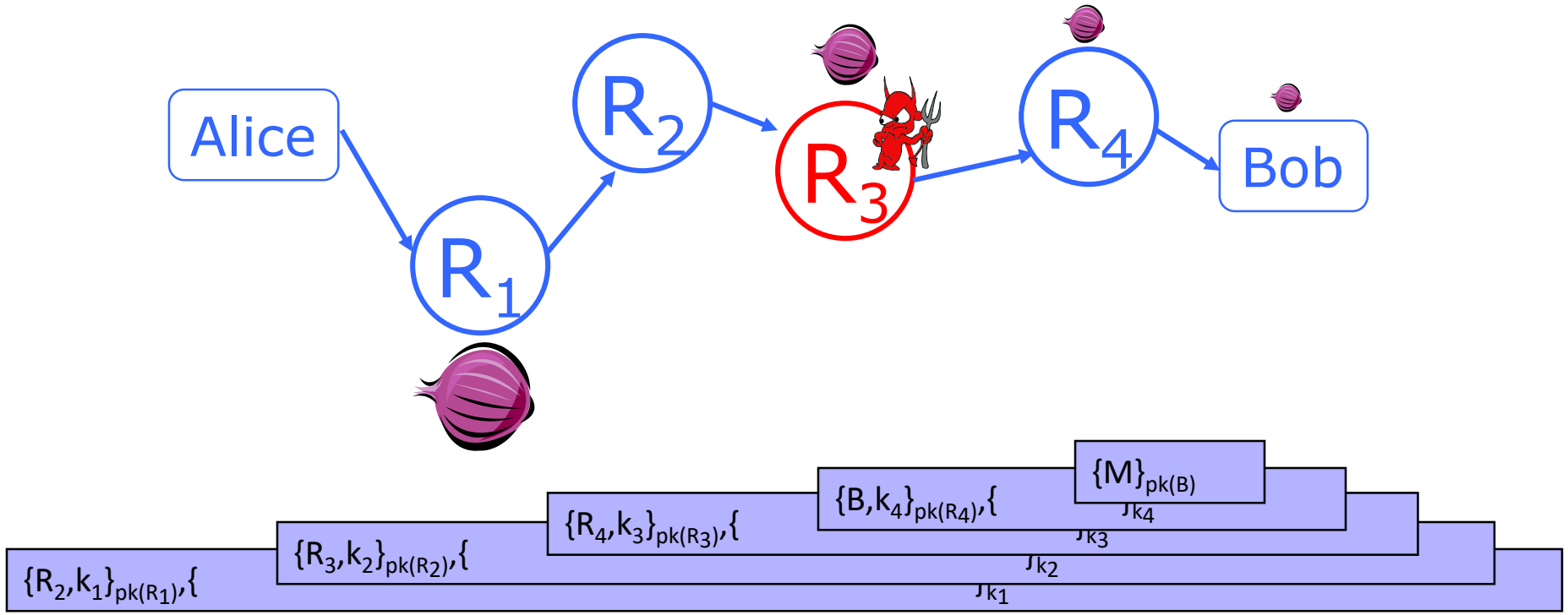
Another Idea: Randomized Routing

e.g., Onion Routing



- Sender chooses a random sequence of routers
  - Some routers are honest, some controlled by attacker
  - Sender controls the length of the path

Onion Routing



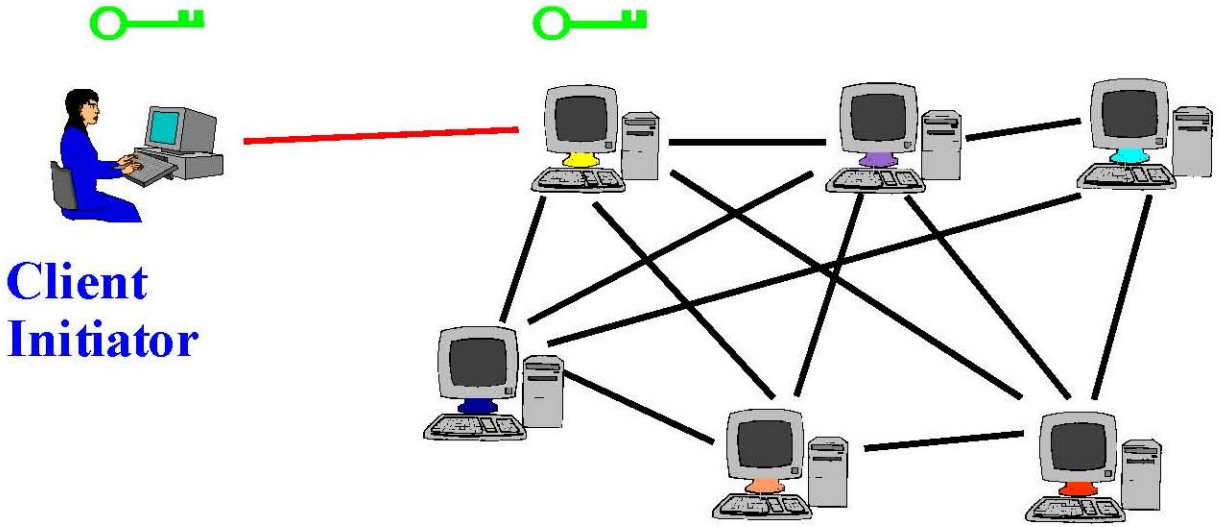
- Routing info for each link encrypted with router's public key
- Each router learns only the identity of the next router

Tor

- Second-generation onion routing network
  - http://tor.eff.org
  - Developed by Roger Dingledine, Nick Mathewson and Paul Syverson
  - Specifically designed for low-latency anonymous Internet communications
- Running since October 2003
- “Easy-to-use” client proxy
  - Freely available, can use it for anonymous browsing

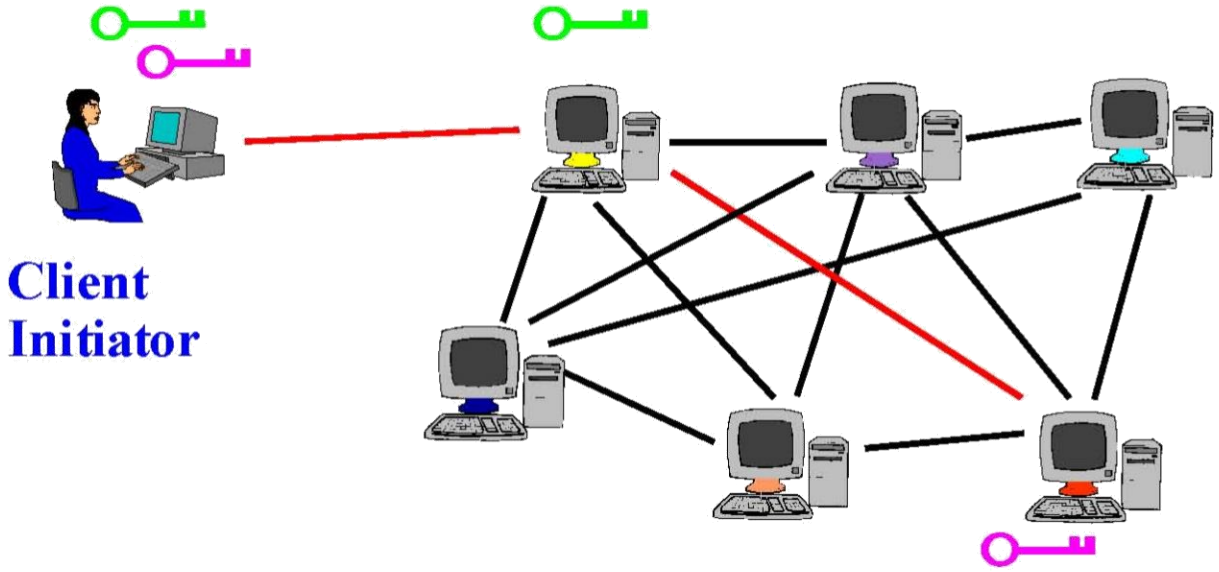
Tor Circuit Setup (1)

- Client proxy establishes a symmetric session key and circuit with Onion Router #1



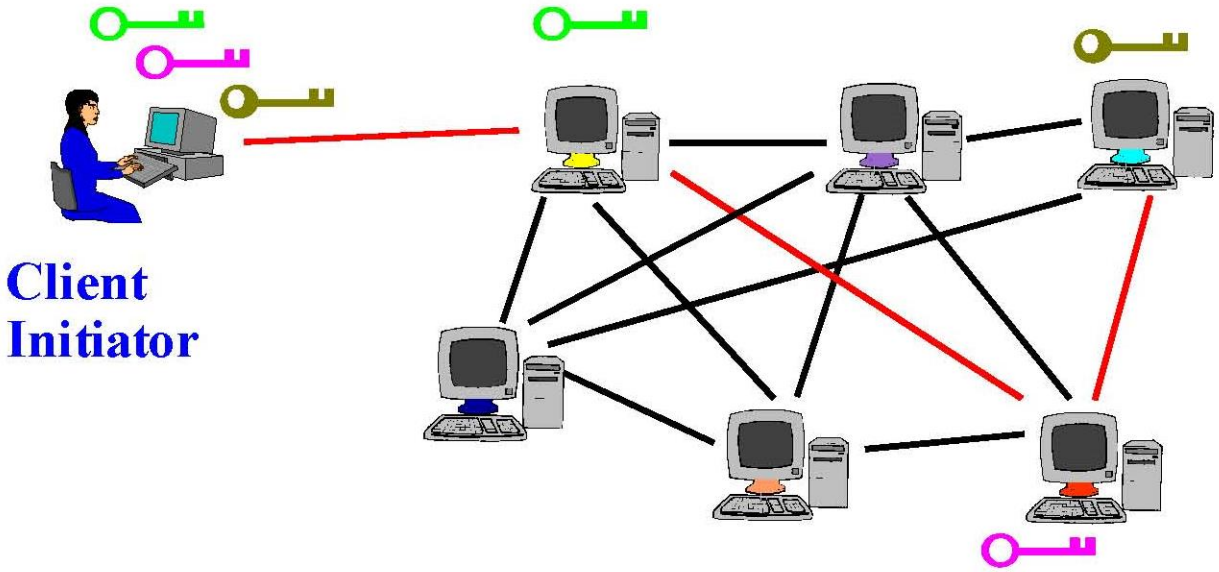
Tor Circuit Setup (2)

- Client proxy extends the circuit by establishing a symmetric session key with Onion Router #2
  - Tunnel through Onion Router #1



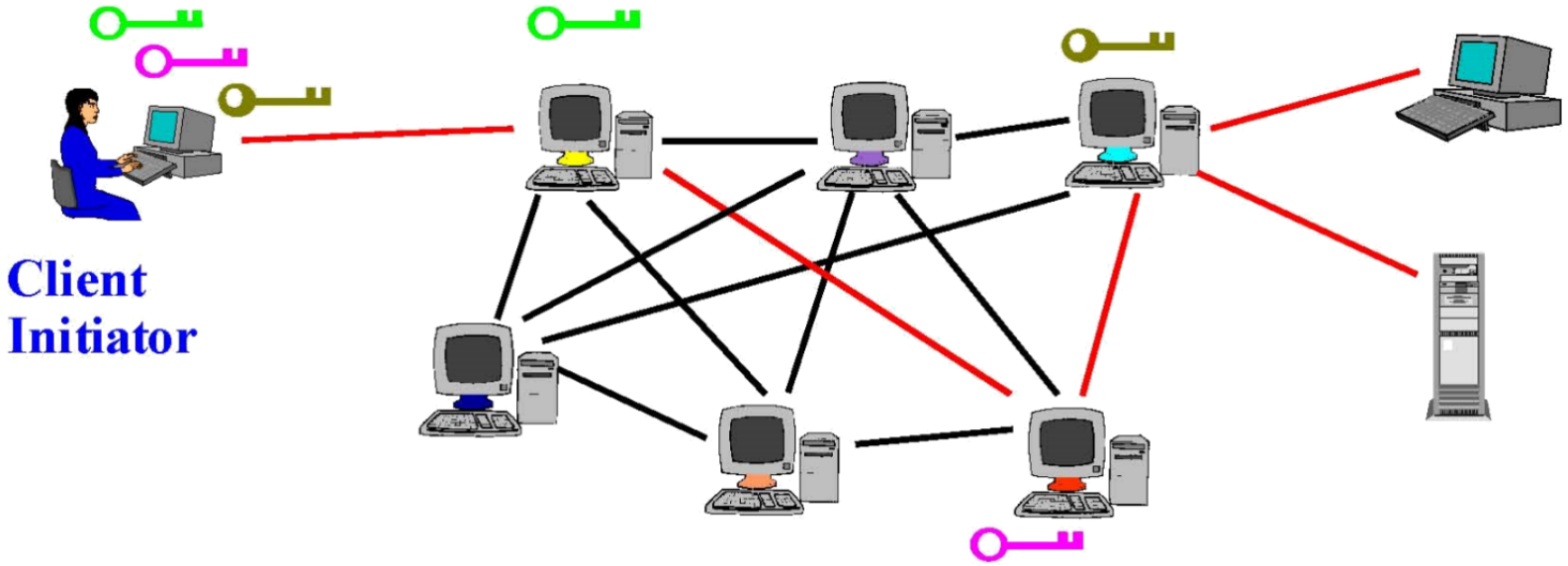
Tor Circuit Setup (3)

- Client proxy extends the circuit by establishing a symmetric session key with Onion Router #3
  - Tunnel through Onion Routers #1 and #2



Using a Tor Circuit

- Client applications connect and communicate over the established Tor circuit.



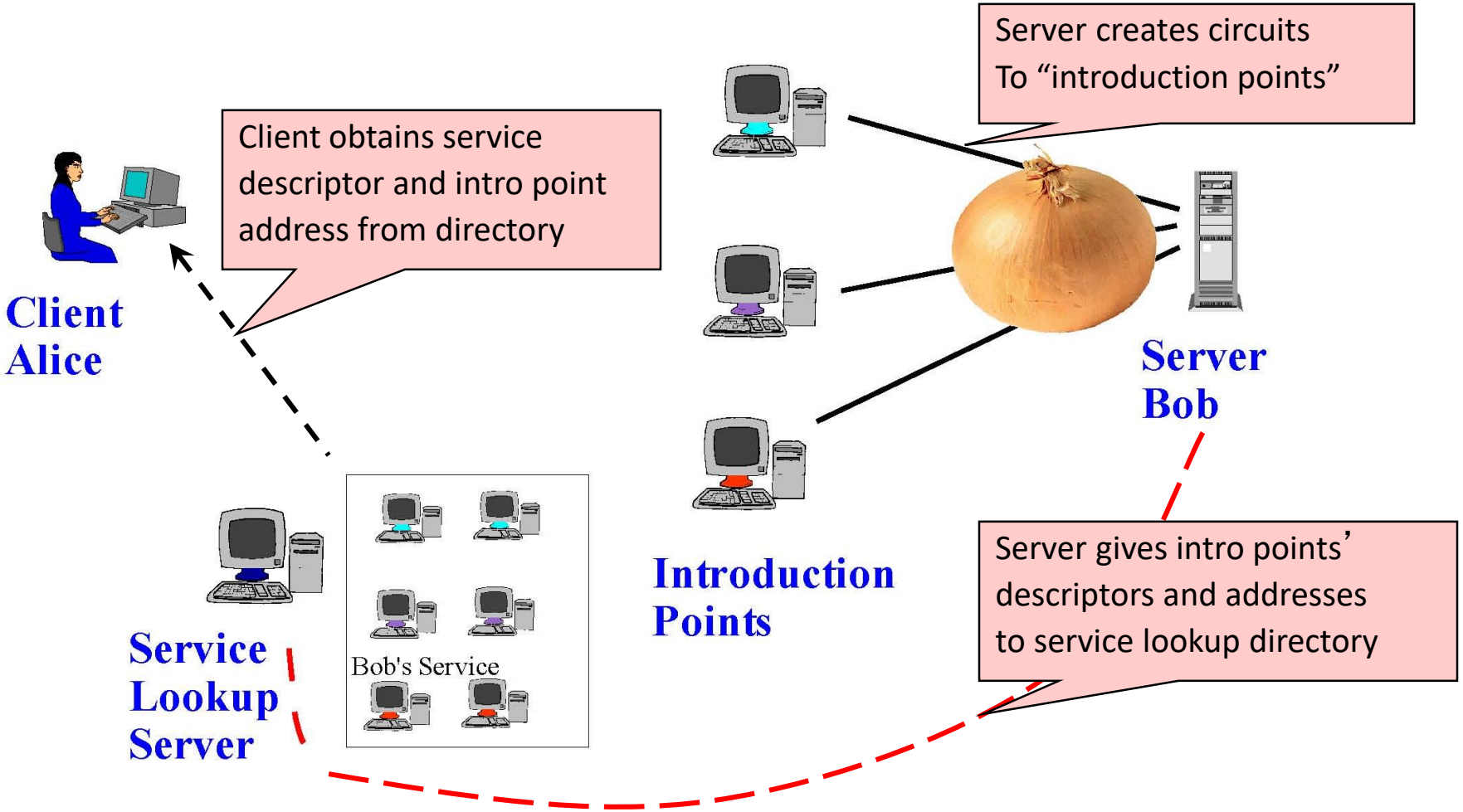
How do you know who to talk to?

- Directory servers
  - Maintain lists of active onion routers, their locations, current public keys, etc.
  - Control how new routers join the network
    - “Sybil attack”: attacker creates a large number of routers
  - Directory servers’ keys ship with Tor code

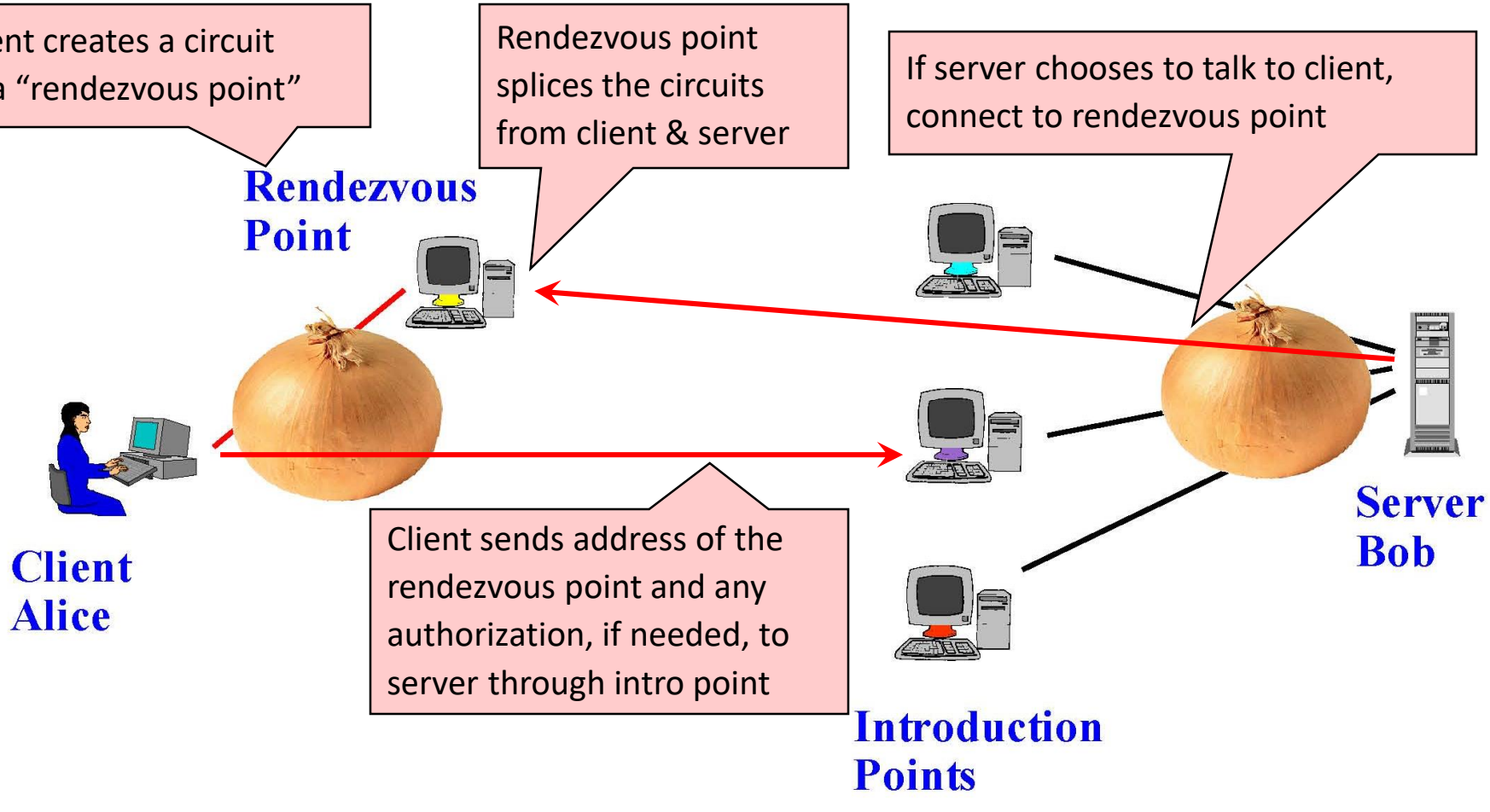
Location Hidden Service

- **Goal:** deploy a server on the Internet that anyone can connect to without knowing where it is or who runs it
- Accessible from anywhere
- Resistant to censorship
- Can survive a full-blown DoS attack
- Resistant to physical attack
  - Can’t find the physical server!

Creating a Location Hidden Server



Using a Location Hidden Server

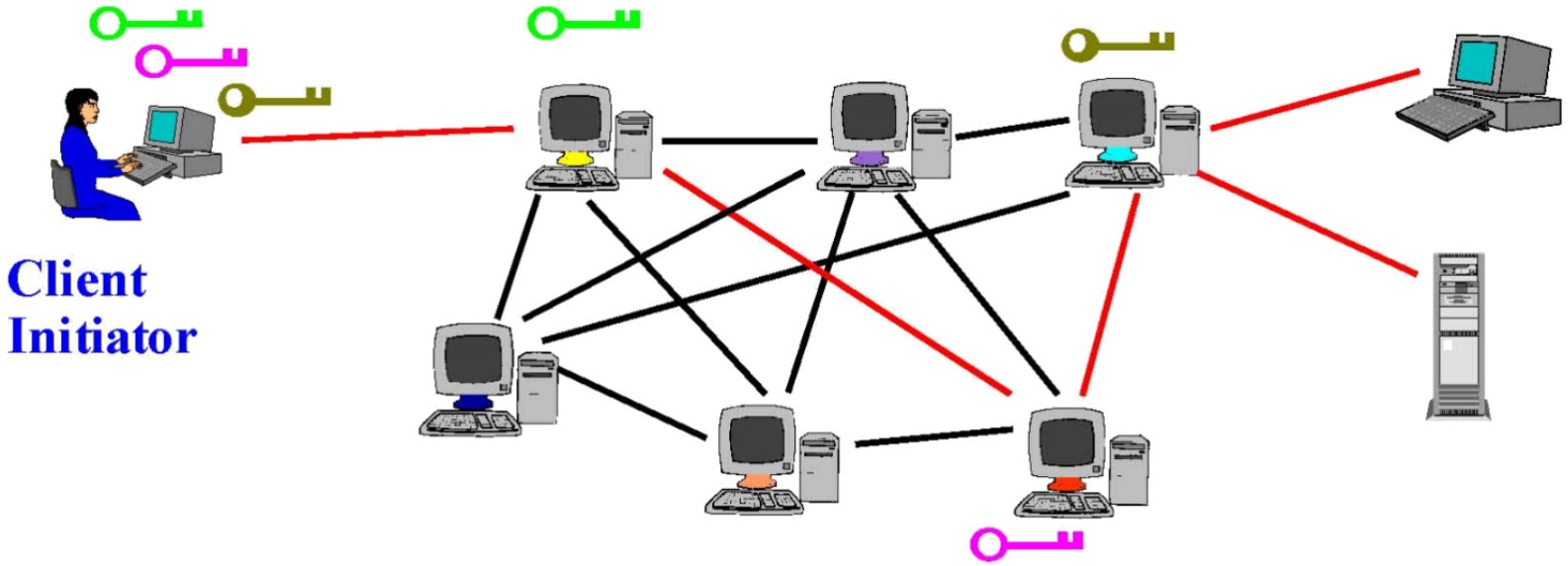


Issues and Notes of Caution

- Passive traffic analysis
  - Infer from network traffic who is talking to whom
  - To hide your traffic, must carry other people's traffic!
- Active traffic analysis
  - Inject packets or put a timing signature on packet flow
- Compromise of network nodes
  - Attacker may compromise some routers
    - Powerful adversaries may compromise "too many"
  - It is not obvious which nodes have been compromised
    - Attacker may be passively logging traffic
  - Better not to trust any individual router
    - Assume that some <u>fraction</u> of routers is good, don't know which

Issues and Notes of Caution

- Tor isn't completely effective by itself
  - Tracking cookies, fingerprinting, etc.
  - Exit nodes can see everything!



Issues and Notes of Caution

- The simple act of using Tor could make one a target for additional surveillance
- Hosting an exit node could result in illegal activity coming from your machine
- Tor not designed to protect against adversaries with the capabilities of a state (public statement by designers, at least in the past)