Fingerprinting Techniques for Network Forensics

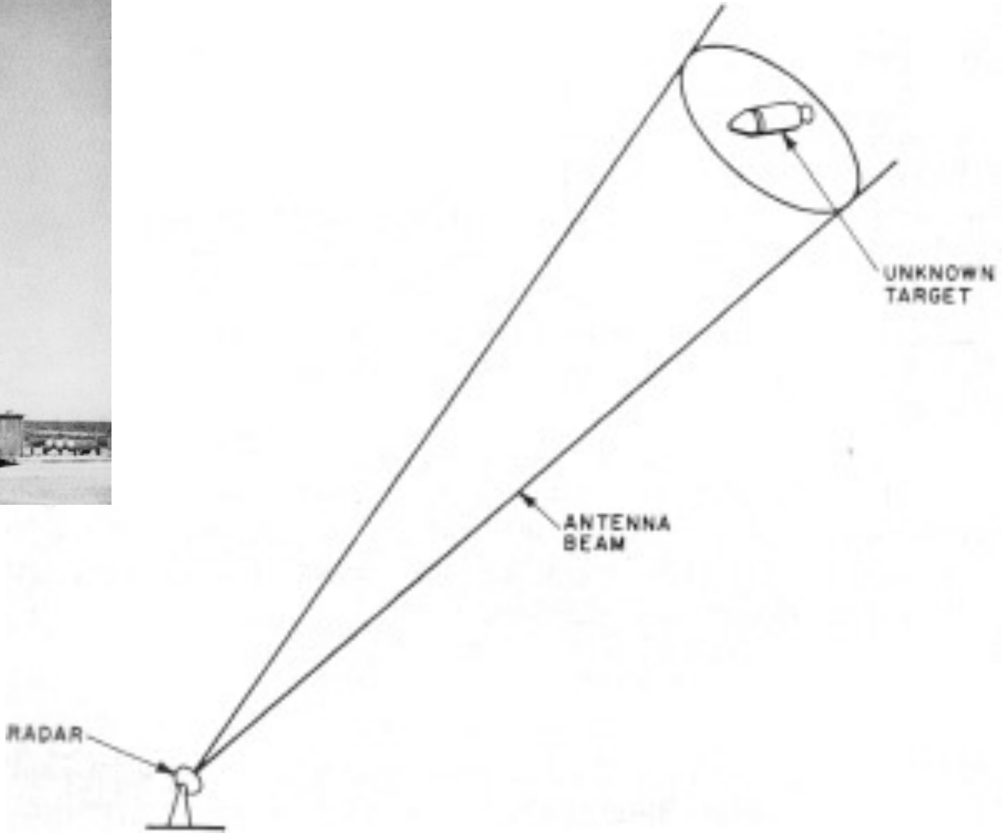
Overview, Opportunities and Challenges

Dominik Herrmann

Universität Hamburg

DER FORSCHUNG | DER LEHRE | DER BILDUNG

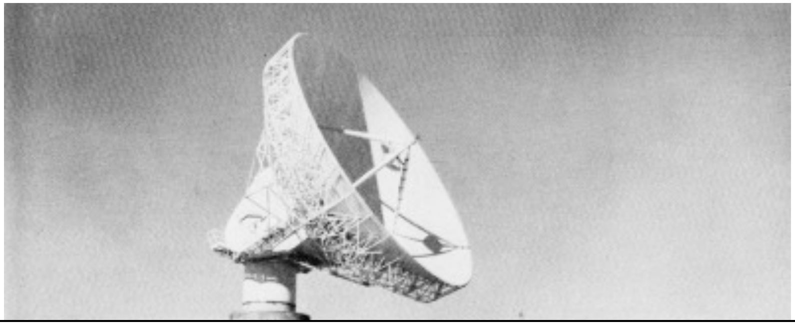
Fingerprinting Primer

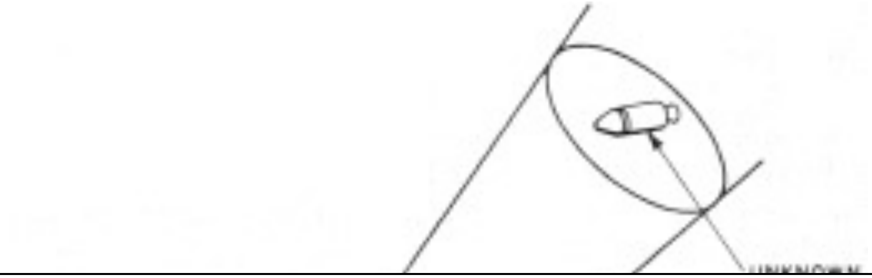


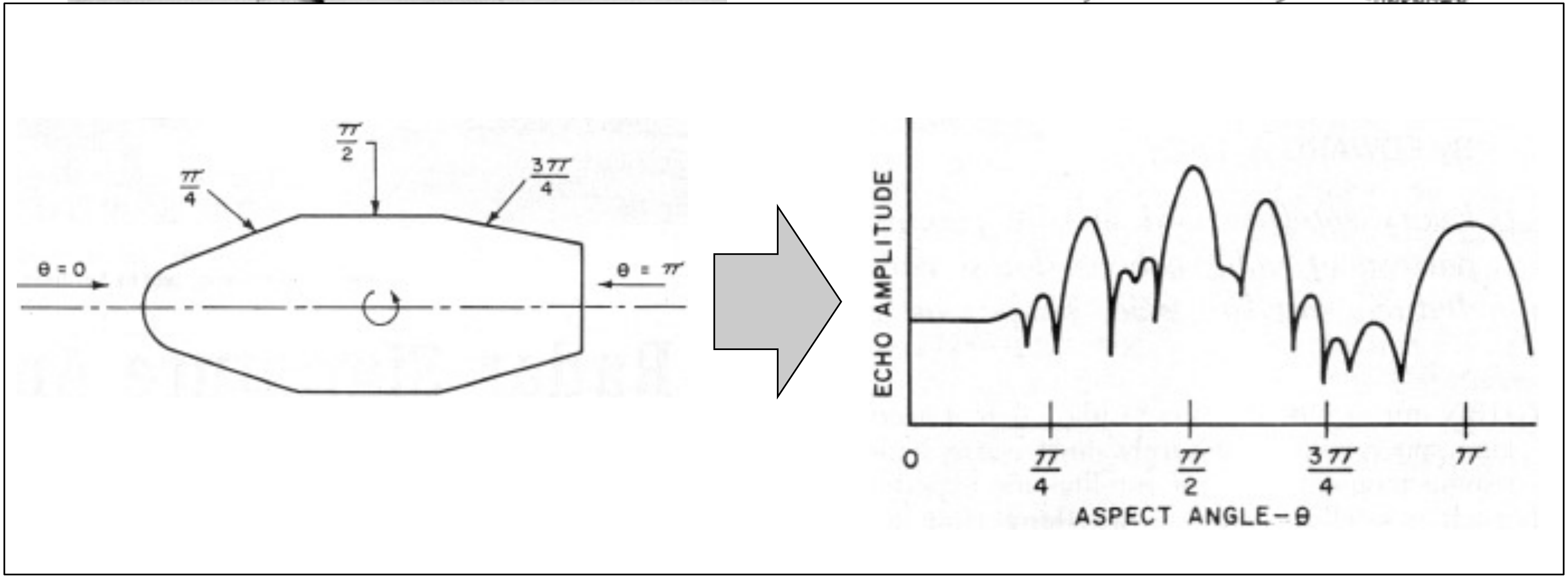
Origin:
Radar “fingerprints”

Lacy (1967)

Fingerprinting Primer

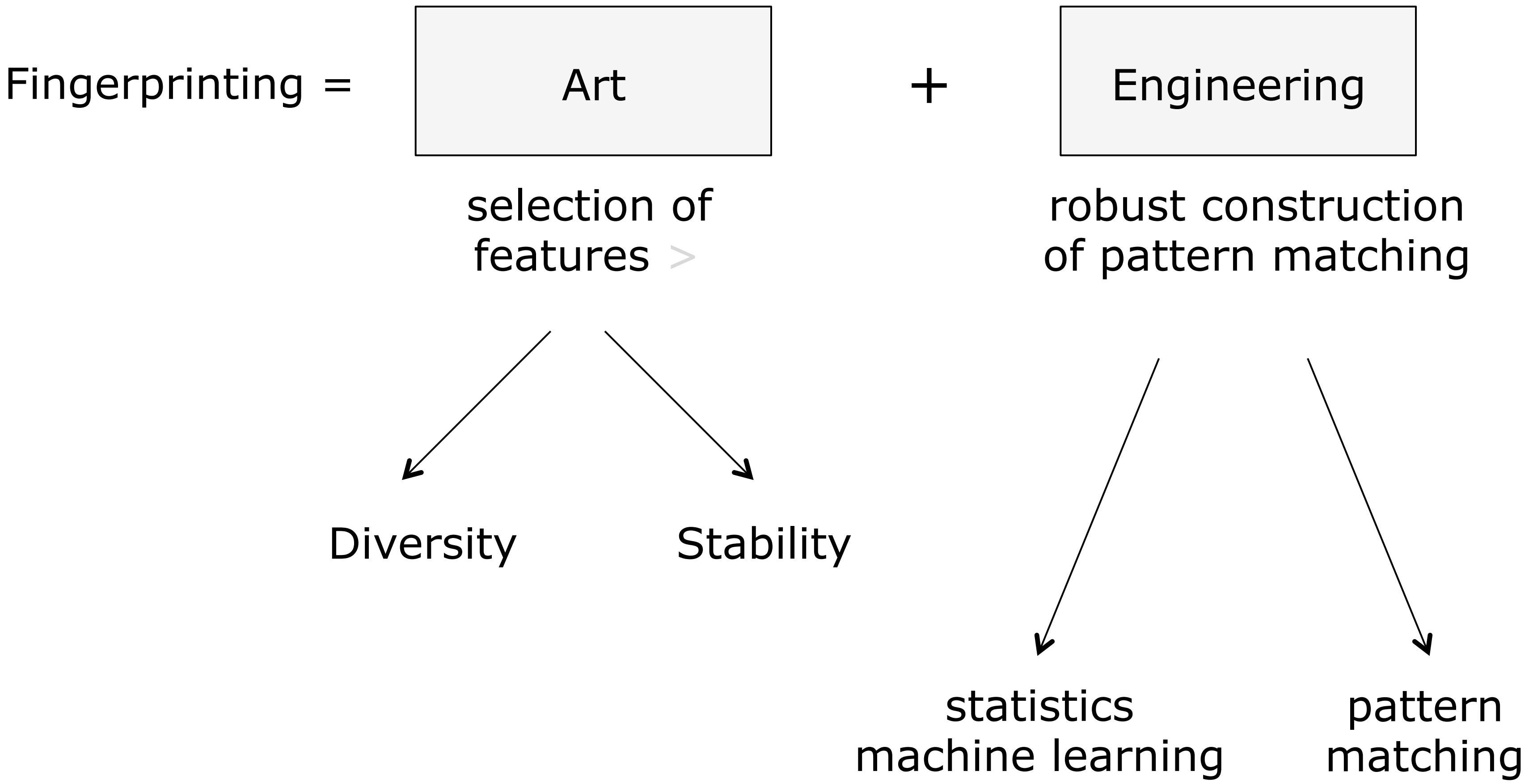






Lacy (1967)

Fingerprinting Primer



Fingerprinting = Art + Engineering

Art: selection of features >

Diversity

Stability

Engineering: robust construction of pattern matching

statistics machine learning

pattern matching

Talbot et al. (2001)

Fingerprinting Primer

Fi

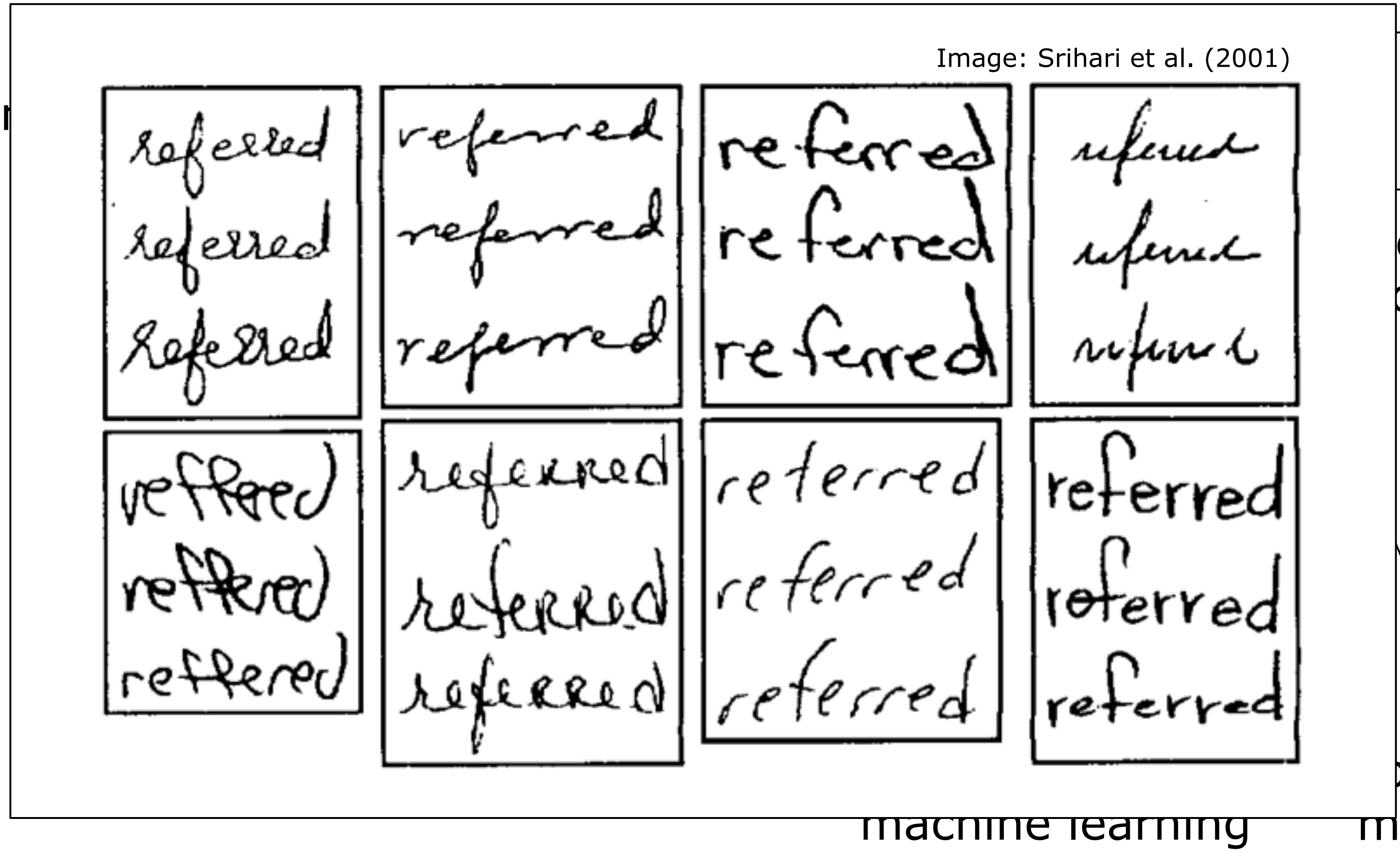


Image: Srihari et al. (2001)

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machine learning

pattern
matching

Talbot et al. (2001)

Agenda

Fingerprinting Primer

From Computer Forensics to **Network Forensics**

Three Case Studies:

Website Fingerprinting

Device/Software Fingerprinting

Human Behavior Fingerprinting

Fingerprinting for Forensics:
A new **promising** opportunity or a **dangerous** instrument?

The case for network forensics

Computer Forensics

- focus on HDD and RAM
- static dataset

Typical objectives

- deduce actions of a subject
- ascription of files/actions

However, some attacks do not leave suitable forensic traces.

We could look at network traffic to capture transient data and activities.

Network Forensics

- focus on network traffic
- transient dataset

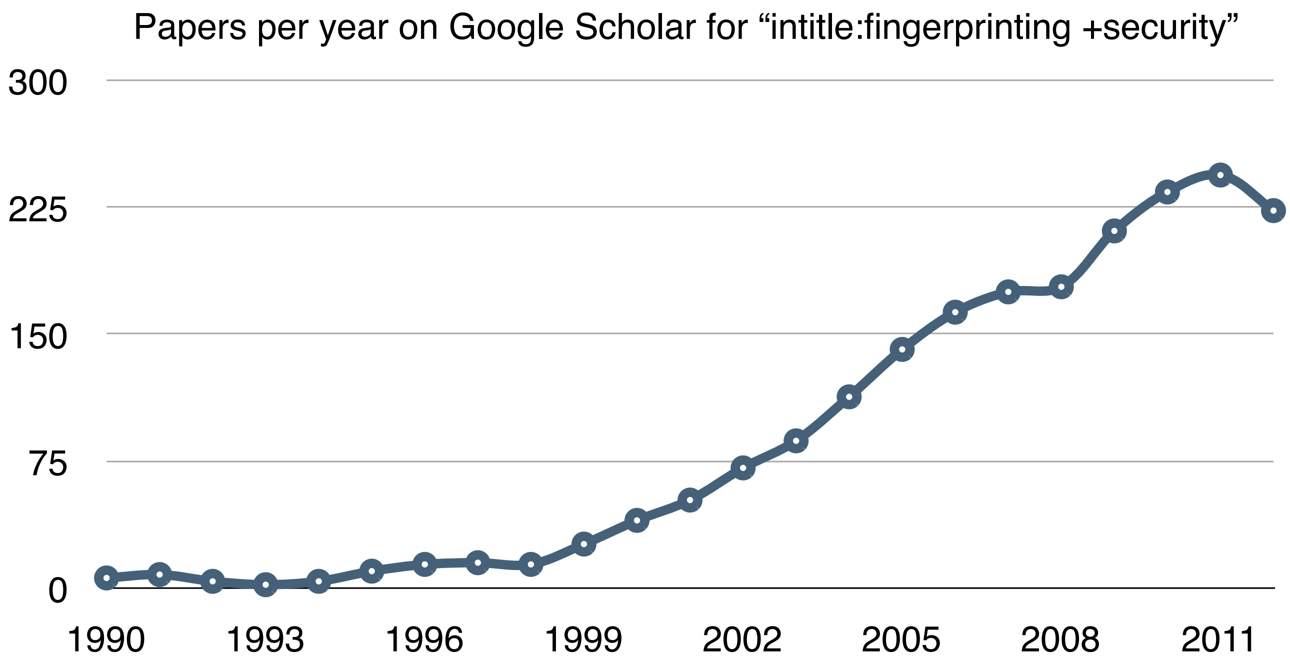
Typical objectives

- find source of criminal activity
- find evidence that a subject is involved in criminal activity

Challenges

- large volumes of traffic difficult to analyze
- cannot analyze content if it is encrypted before transmission

Rising interest in security-related fingerprinting lately



Can we leverage fingerprinting techniques for network forensics?
Yes!

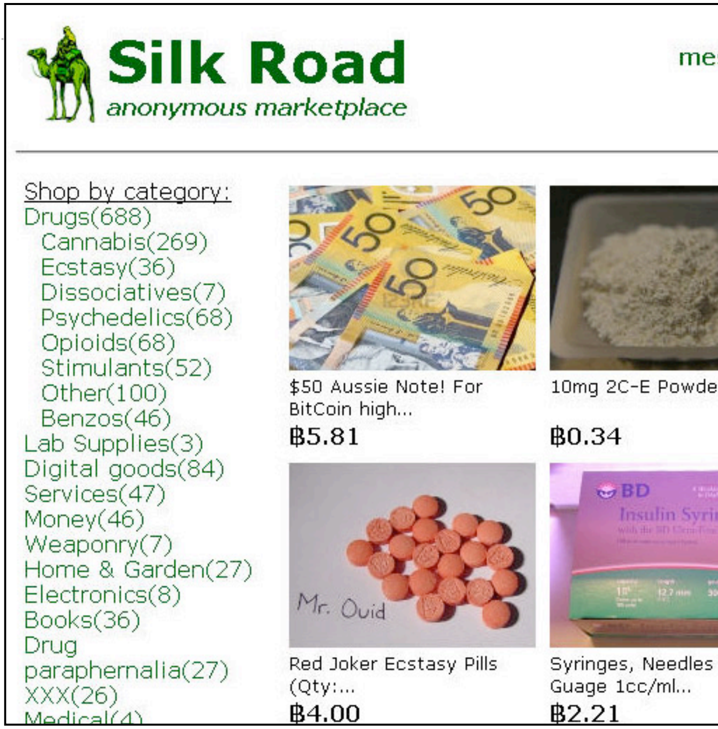
1. Determine activities of a subject, even if traffic is encrypted
2. Find evidence for involvement in criminal activities

Objective 1:
Determining activities in encrypted traffic

Case Study 1: Website Fingerprinting

Website Fingerprinting

- The Crime Scene
  - subject visits incriminating website
  - investigator has access to traffic
  - traffic is encrypted on network layer



Silk Road
anonymous marketplace

me

Shop by category:
Drugs(688)
Cannabis(269)
Ecstasy(36)
Dissociatives(7)
Psychedelics(68)
Opioids(68)
Stimulants(52)
Other(100)
Benzos(46)
Lab Supplies(3)
Digital goods(84)
Services(47)
Money(46)
Weaponry(7)
Home & Garden(27)
Electronics(8)
Books(36)
Drug paraphernalia(27)
XXX(26)
Medical(4)

$50 Aussie Note! For BitCoin high...
฿5.81

10mg 2C-E Powde
฿0.34

Red Joker Ecstasy Pills (Qty:...
฿4.00

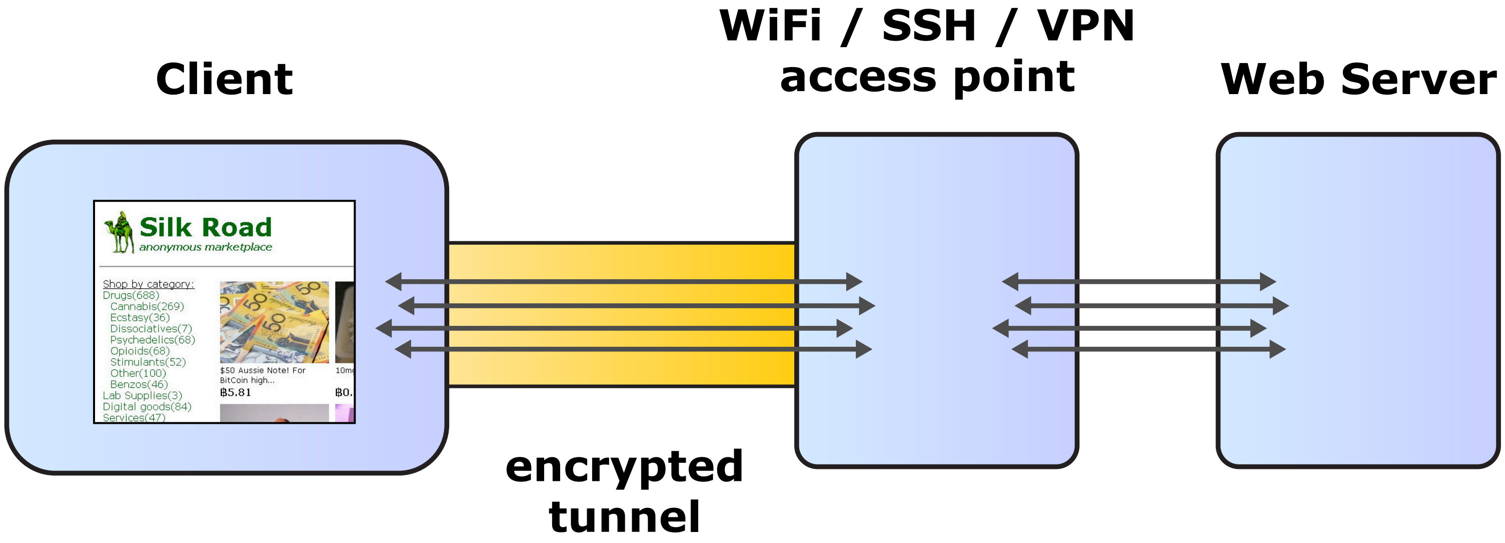
Syringes, Needles Guage 1cc/ml...
฿2.21

- Digital Forensics Objective
  - find corroborating evidence for specific incriminating activity

- Fingerprinting Approach
  - relies on metadata that is not encrypted (**“traffic analysis”**)
  - investigator **collects traffic samples** for interesting websites and extracts fingerprints (manually or via machine learning)
  - successful identification of site if recorded traffic of subject **matches** one of the known fingerprints

Technique 1: Characteristic Patterns in IP Packets

…, Herrmann, Wendolsky, and Federrath (2009), …



Silk Road
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Benzos(46)
Lab Supplies(3)
Digital goods(84)
Services(47)

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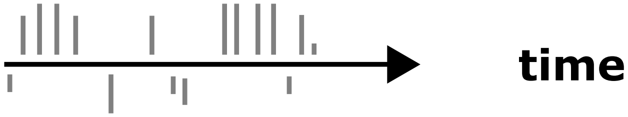
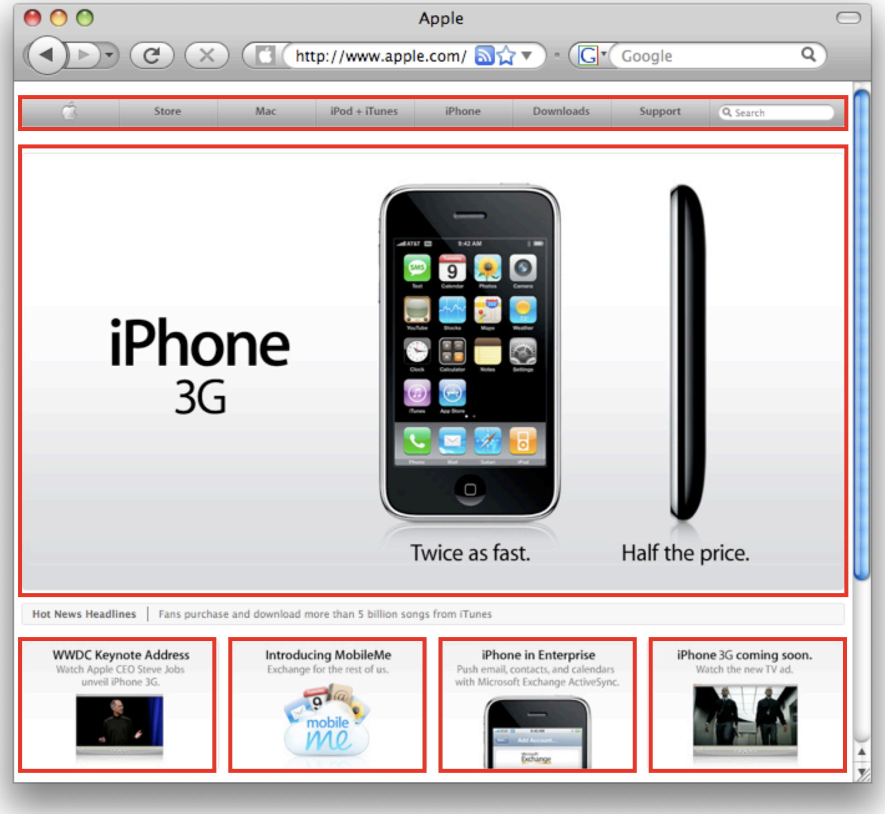
Investigator can only observe size, direction and timing of packets



Also applicable for anonymization services

Technique 1: Characteristic Patterns in IP Packets

…, Herrmann, Wendolsky, Federrath (2009), …



iPhone 3G

Twice as fast.

Half the price.

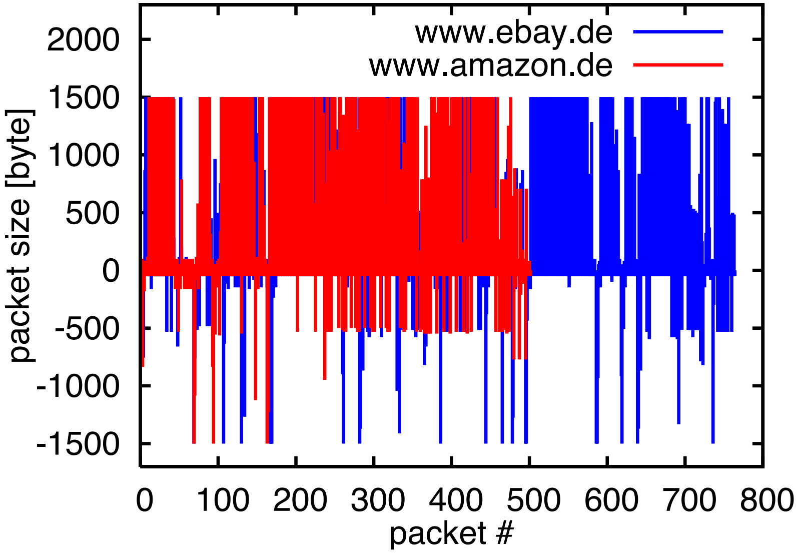
Hot News Headlines | Fans purchase and download more than 5 billion songs from iTunes

WWDC Keynote Address
Watch Apple CEO Steve Jobs unveil iPhone 3G.

Introducing MobileMe
Exchange for the rest of us.

iPhone in Enterprise
Push email, contacts, and calendars with Microsoft Exchange ActiveSync.

iPhone 3G coming soon.
Watch the new TV ad.



Many websites cause characteristic patterns

Technique 1: Characteristic Patterns in IP Packets

- Approach: Fingerprint extraction & matching with machine learning
  - features: histogram of packet sizes observed during download >
  - supervised learning technique: kNN and Naïve Bayes classifiers

- Evaluation
  - OpenSSL, stunnel, OpenVPN, IPsec, JonDonym, Tor
  - 775 popular sites from Alexa

- Results
  - accuracy > 95% for all systems (exception: Tor & JonDonym)
  - high efficiency: fingerprints keep for multiple days and a single training instance is sufficient

Next up:

Technique 2: Website fingerprinting via characteristic DNS queries

Technique 1: Characteristic Patterns in IP Packets

- Approach: Fingerprint extraction & matching with machine learning
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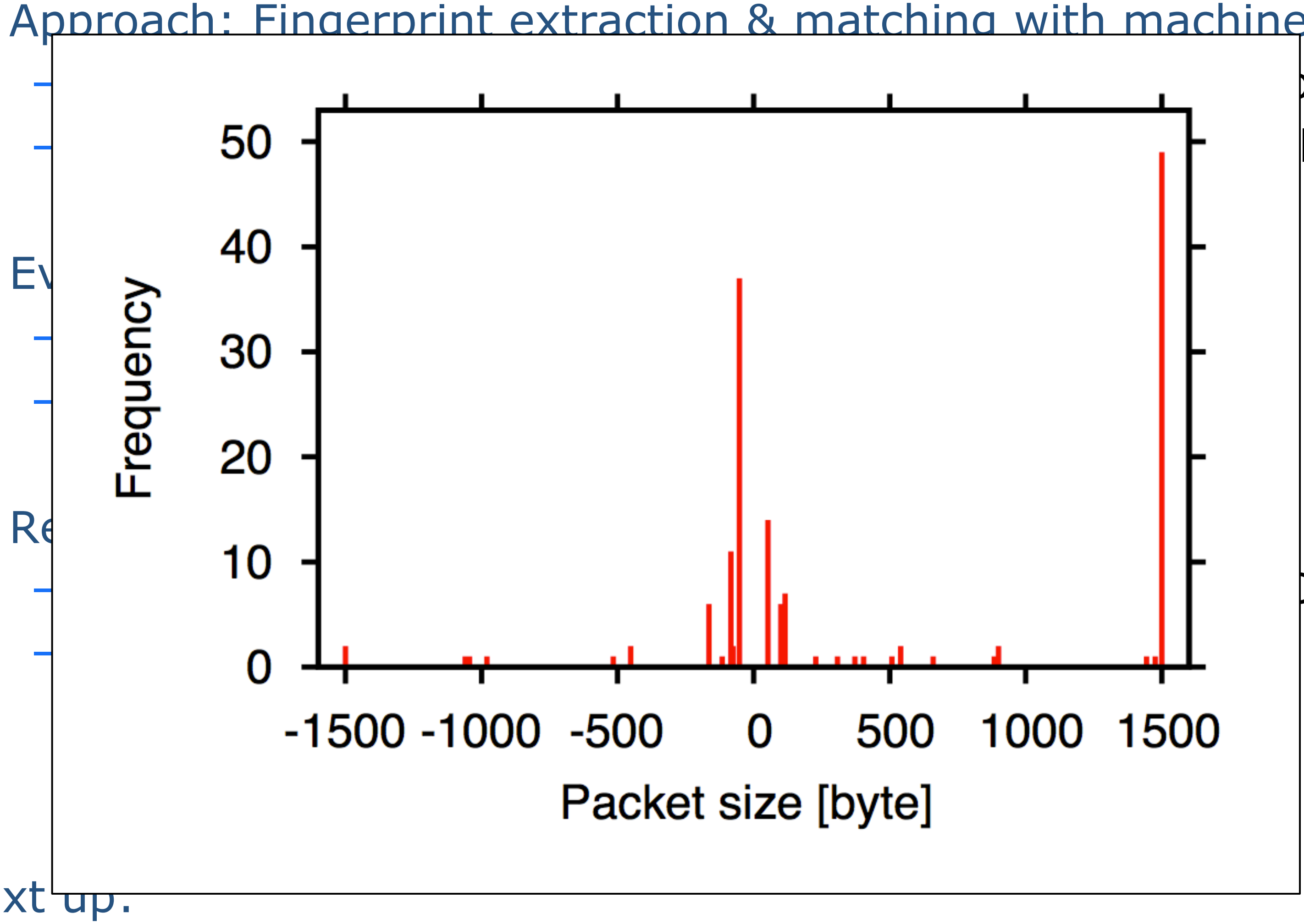
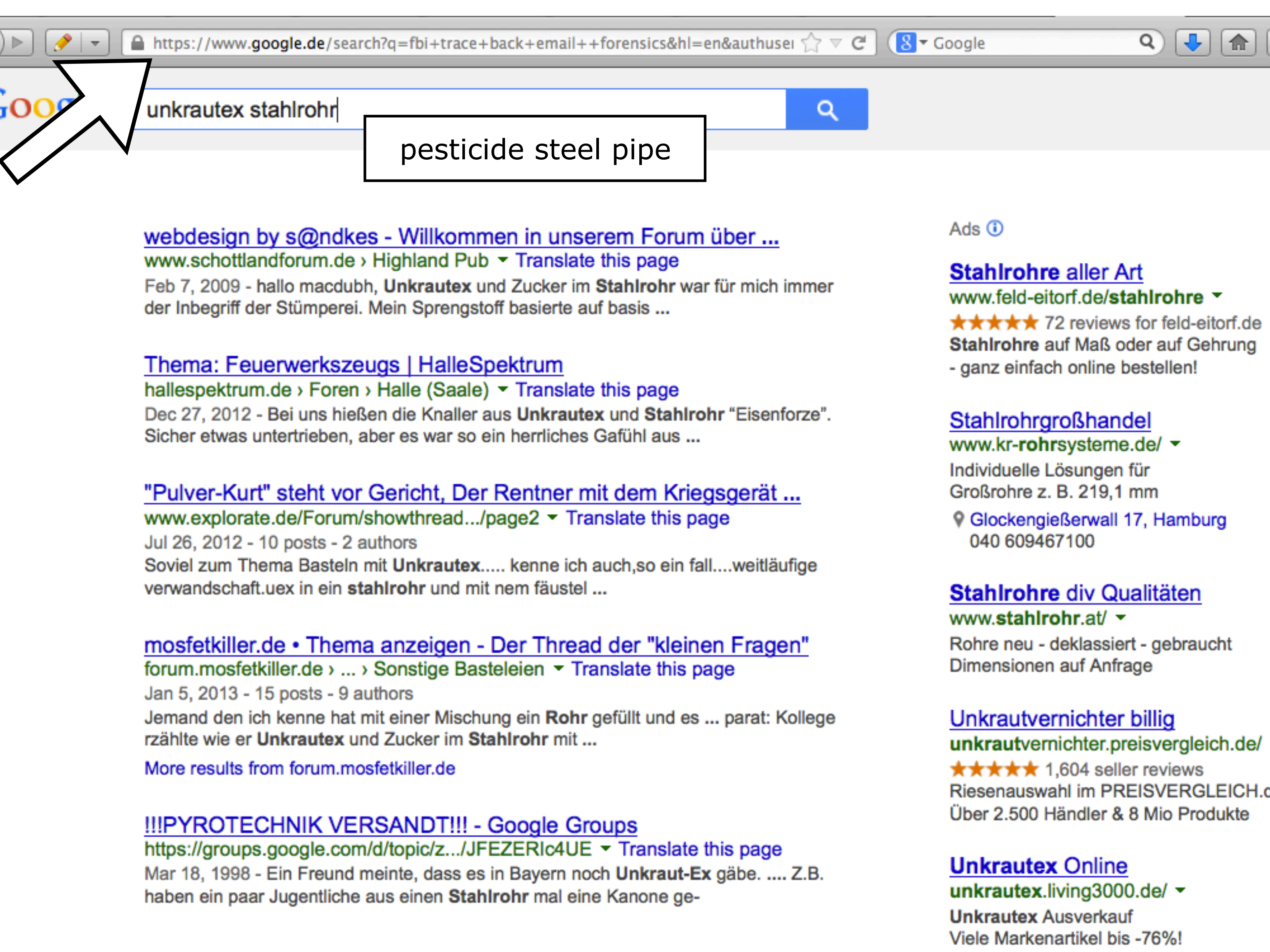


Next up:
Technique 2: Website fingerprinting via characteristic DNS queries



https://www.google.de/search?q=fbi+trace+back+email++forensics&hl=en&authuser
Google

unkrautex stahlrohr

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Feb 7, 2009 - hallo macdubh, **Unkrautex** und Zucker im **Stahlrohr** war für mich immer der Inbegriff der Stümperei. Mein Sprengstoff basierte auf basis ...

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Dec 27, 2012 - Bei uns hießen die Knaller aus **Unkrautex** und **Stahlrohr** “Eisenforze”. Sicher etwas untertrieben, aber es war so ein herrliches Gaführl aus ...

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Jul 26, 2012 - 10 posts - 2 authors
Soviel zum Thema Basteln mit **Unkrautex**..... kenne ich auch,so ein fall....weitläufige verwandschaft.uex in ein **stahlrohr** und mit nem fäustel ...

[mosfetkiller.de • Thema anzeigen - Der Thread der "kleinen Fragen"](#)
forum.mosfetkiller.de › ... › Sonstige Basteleien ▾ Translate this page
Jan 5, 2013 - 15 posts - 9 authors
Jemand den ich kenne hat mit einer Mischung ein **Rohr** gefüllt und es ... parat: Kollege rzählte wie er **Unkrautex** und Zucker im **Stahlrohr** mit ...
More results from forum.mosfetkiller.de

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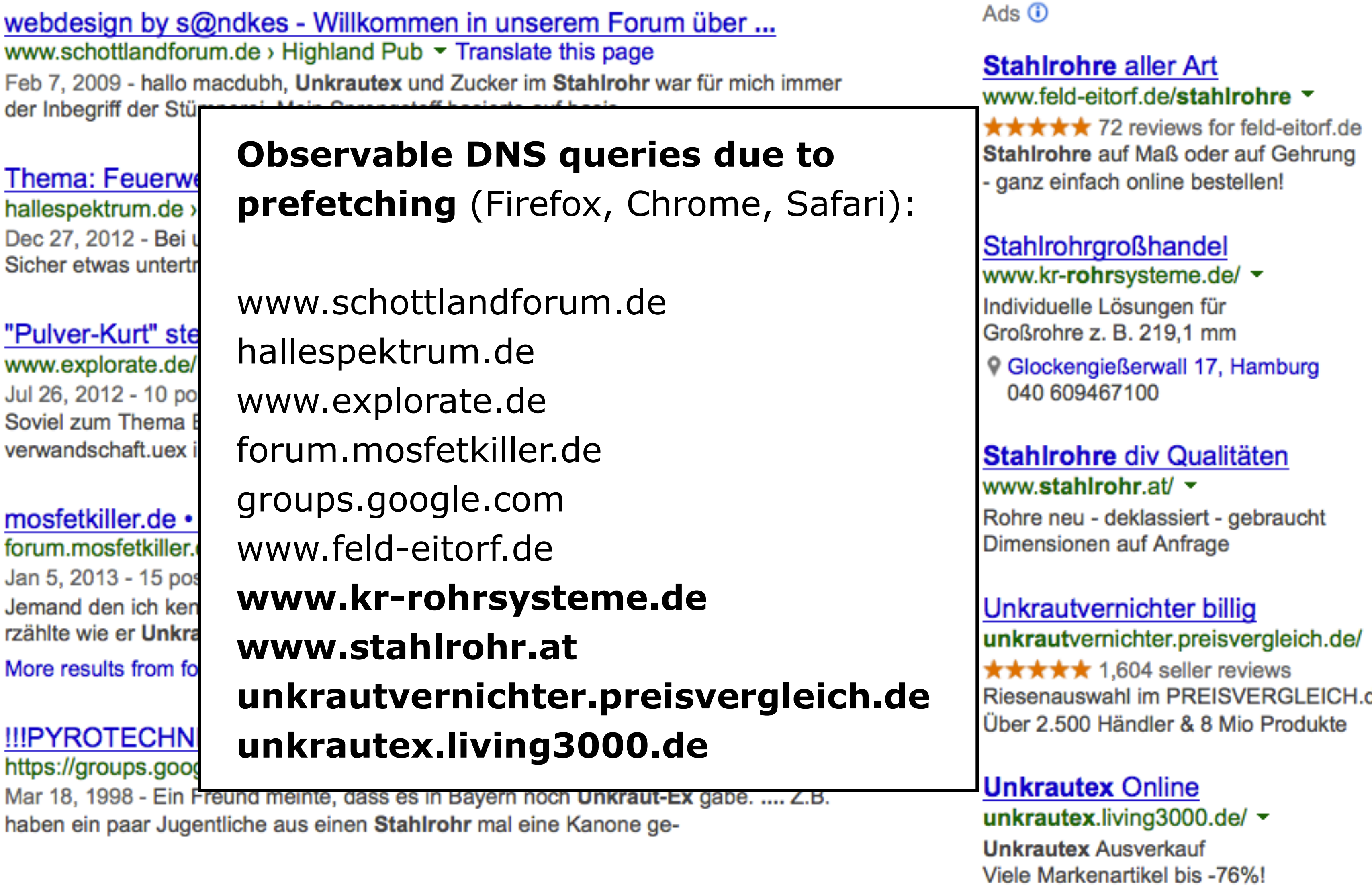
https://groups.google.com/d/topic/z.../JFEZERIc4UE ▾ Translate this page
Mar 18, 1998 - Ein Freund meinte, dass es in Bayern noch **Unkraut-Ex** gäbe. .... Z.B. haben ein paar Jugentliche aus einen **Stahlrohr** mal eine Kanone ge-

Technique 2: Website Fingerprinting via DNS Queries

Krishnan & Monrose (2010)



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der Inbegriff der Stü

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hallespektrum.de ›
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Jan 5, 2013 - 15 pos
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https://groups.goog
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haben ein paar Jugentliche aus einen **Stahlrohr** mal eine Kanone ge-

Ads ⓘ

Stahlrohre aller Art
www.feld-eitorf.de/**stahlrohre** ▾
★★★★★ 72 reviews for feld-eitorf.de
Stahlrohre auf Maß oder auf Gehrung
- ganz einfach online bestellen!

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Glockengießerwall 17, Hamburg
040 609467100

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Rohre neu - deklassiert - gebraucht
Dimensionen auf Anfrage

Unkrautvernichter billig
unkrautvernichter.preisvergleich.de/
★★★★★ 1,604 seller reviews
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unkrautex.living3000.de/ ▾
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Viele Markenartikel bis -76%!

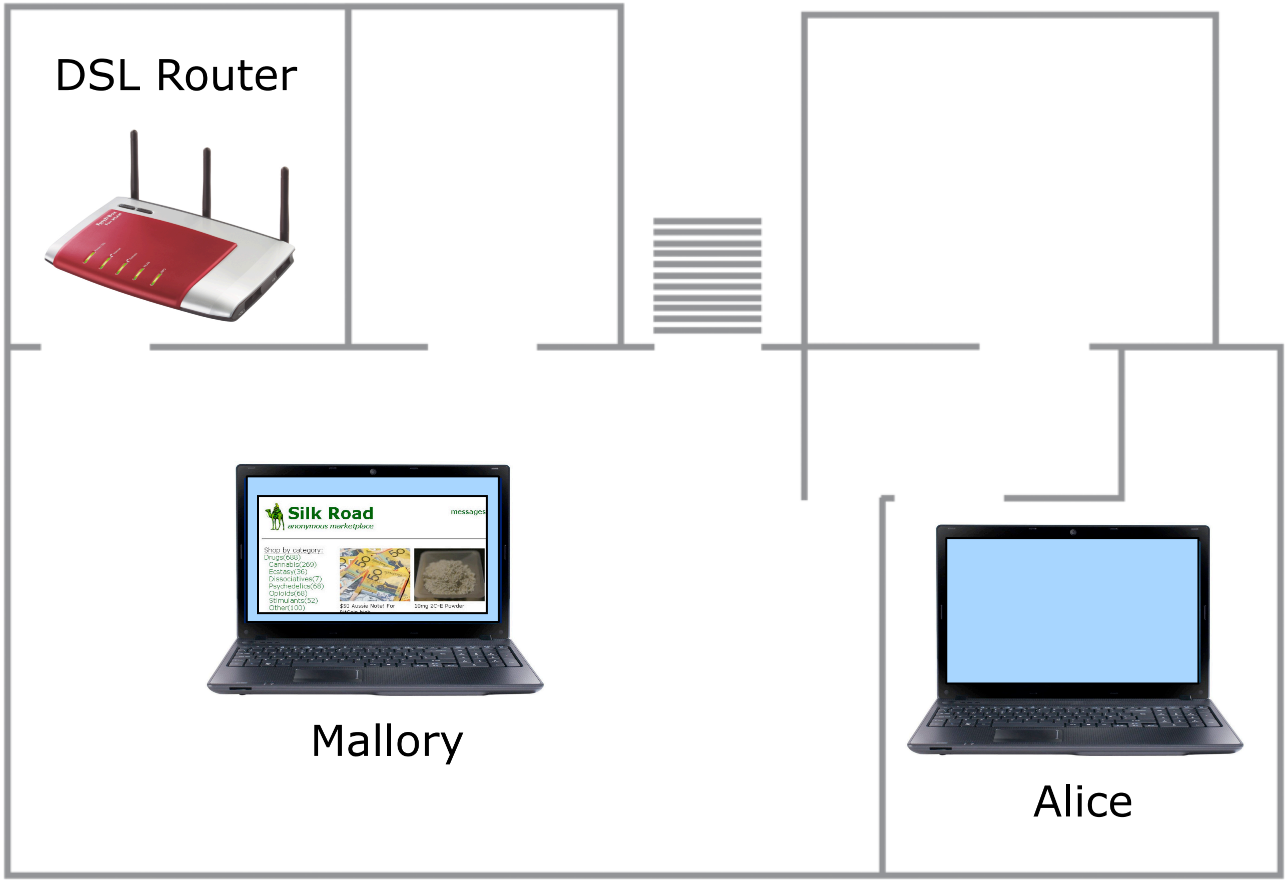
Observable DNS queries due to prefetching (Firefox, Chrome, Safari):

www.schottlandforum.de
hallespektrum.de
www.explorate.de
forum.mosfetkiller.de
groups.google.com
www.feld-eitorf.de
www.kr-rohrsysteme.de
www.stahlrohr.at
unkrautvernichter.preisvergleich.de
unkrautex.living3000.de

Objective 2:
Find evidence for involvement in criminal activities

Case Study 2: Device/Software Fingerprinting

Device and software fingerprinting



Silk Road
anonymous marketplace
messages

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Opioids(68)
Stimulants(52)
Other(100)

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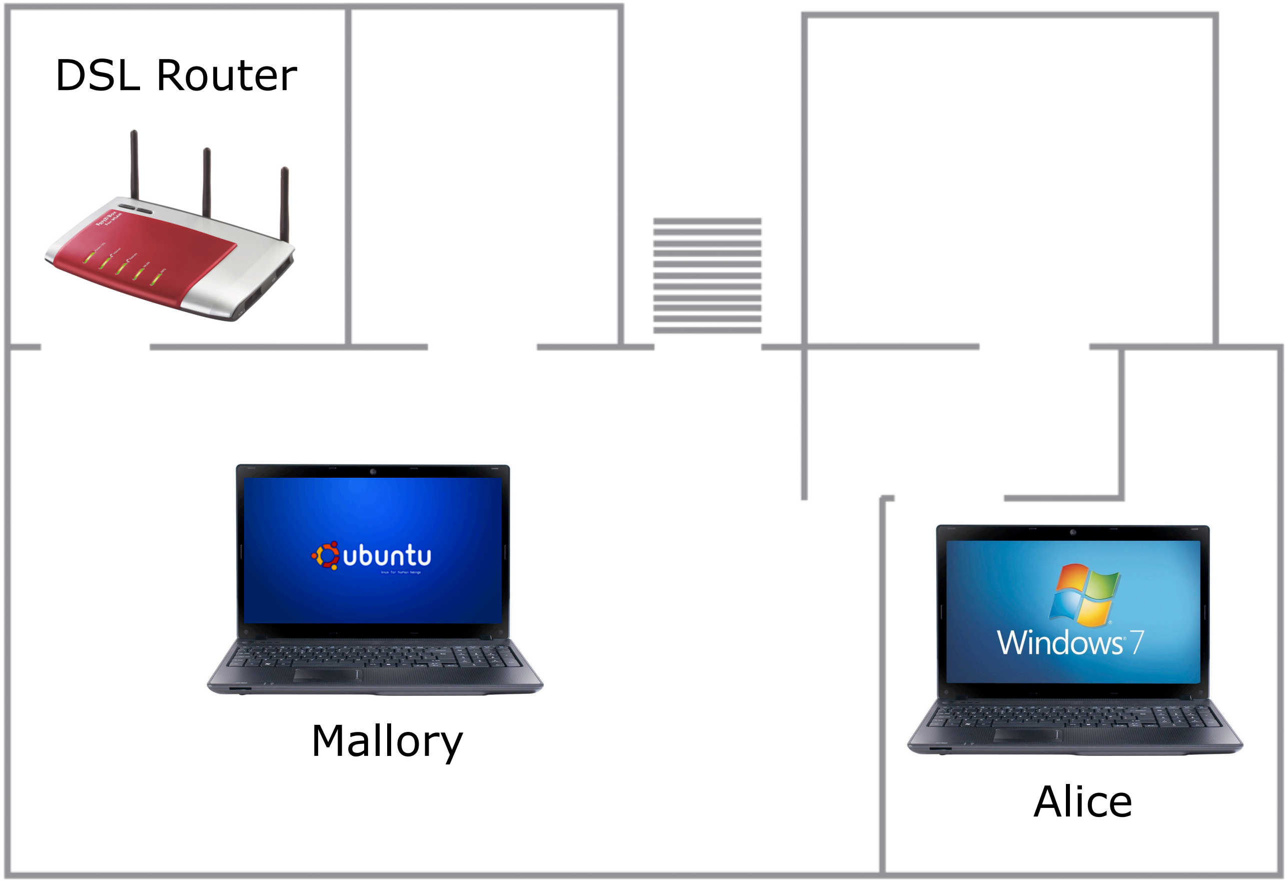
Device and software fingerprinting



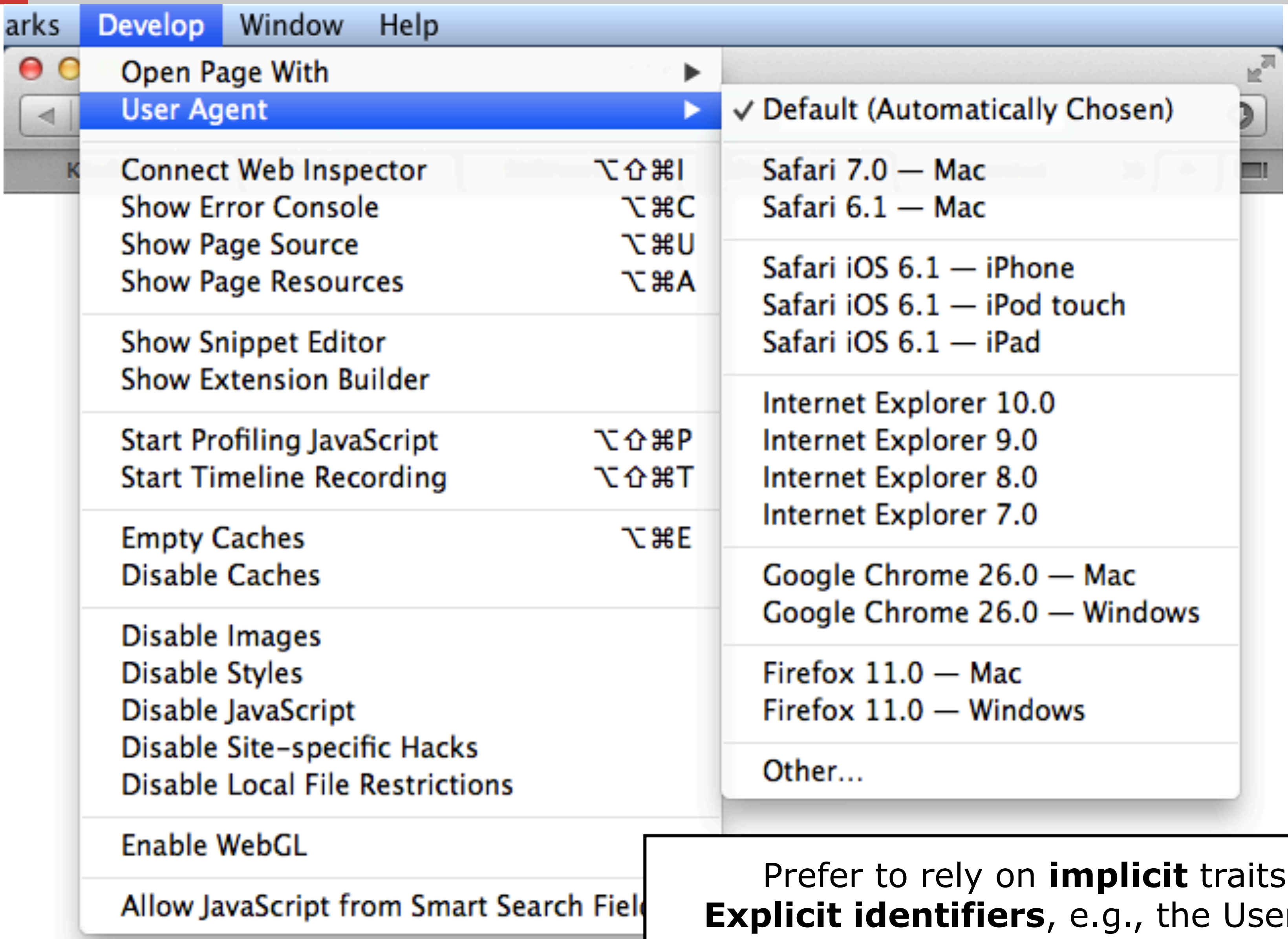
textual description of scenario, forensic objective and approach on next slide

Device and software fingerprinting

- The Crime Scene
  - subject carries out criminal activity on the network
  - investigator has access to the traffic of the subject
  - an investigation is launched and all hardware is seized
  - the subject denies any involvement and incriminates a flat mate
  - no traces of the activity can be found on any of the machines

- Digital Forensics Objective
  - **ascription/association:** find corroborating evidence that one of the machines was in fact used for the criminal activity

- Fingerprinting Approach
  - relies on **differing implicit behavior** of devices/software
  - build a **corpus**: investigator collects behavioral samples of network traffic for various systems
  - infer **system architecture, operating system, browser**, etc. by matching recorded traffic of suspect to patterns from corpus



Prefer to rely on **implicit** traits. **Explicit identifiers**, e.g., the User Agent header, can be **forged** easily.

Various Device Fingerprinting Techniques

- Operating system fingerprinting
  - characteristics in **TCP stack**, Comer&Lin (1994)
  - now readily available in tools, e.g. **p0f & nmap**

- Device fingerprinting
  - **Skew of real-time clock** is characteristic, Kohno et al. (2005) >
  - Runtime of **JavaScript** code is characteristic for browser, operating system and CPU architecture, Mowery et al. (2011)
  - Text rendering in **HTML5** <canvas>, Mowery&Shacham (2012)>

- Browser fingerprinting
  - Characteristic **TCP flows** allow identification, Yen et al. (2009)
  - EFF **Panopticlick**: plugins, fonts, etc., Eckersley (2011)>

Note: **class** characteristics vs. **individual** characteristics

Casey (2011)

Various De

- Operatin
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  - **Skew** et al. (2005) >
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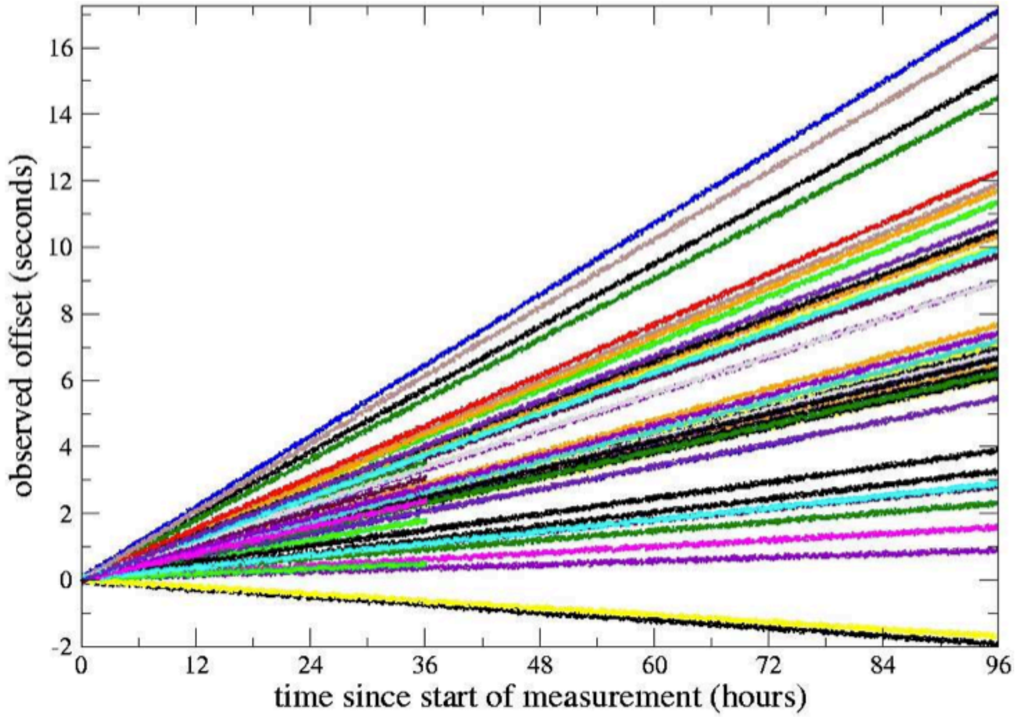

Figure 4. TSopt clock offset-sets for 69 Micron 448MHz Pentium II machines running Windows XP Professional SP1. Trace recorded on **host2**, three hops away, 2004-09-10 08:30PDT to 2004-09-14 08:30PDT.

Note: **class** characteristics vs. **individual** characteristics

Casey (2011)

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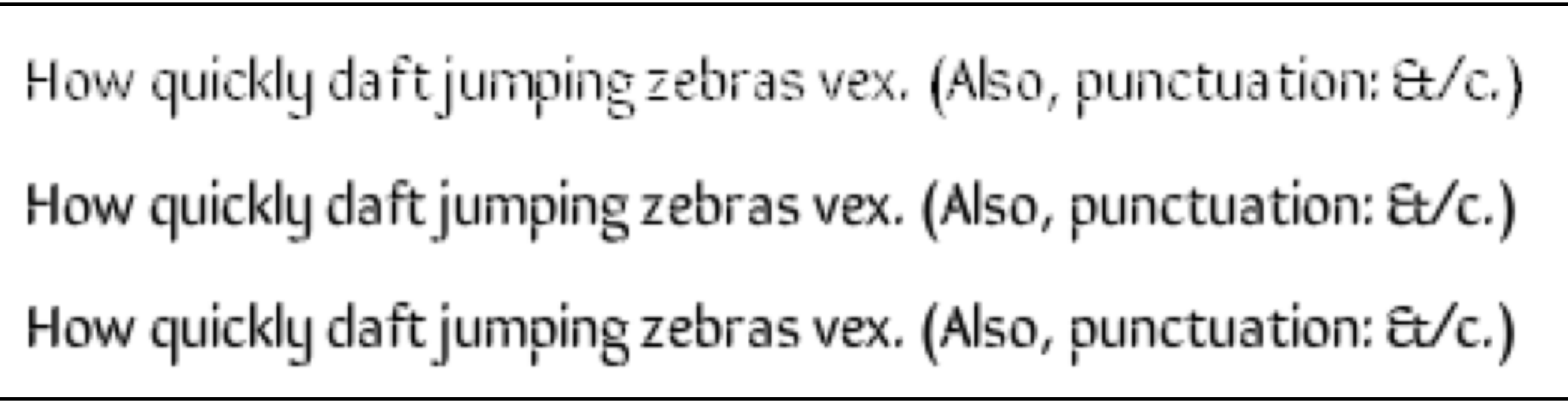

How quickly daft jumping zebras vex. (Also, punctuation: &/c.)

How quickly daft jumping zebras vex. (Also, punctuation: &/c.)

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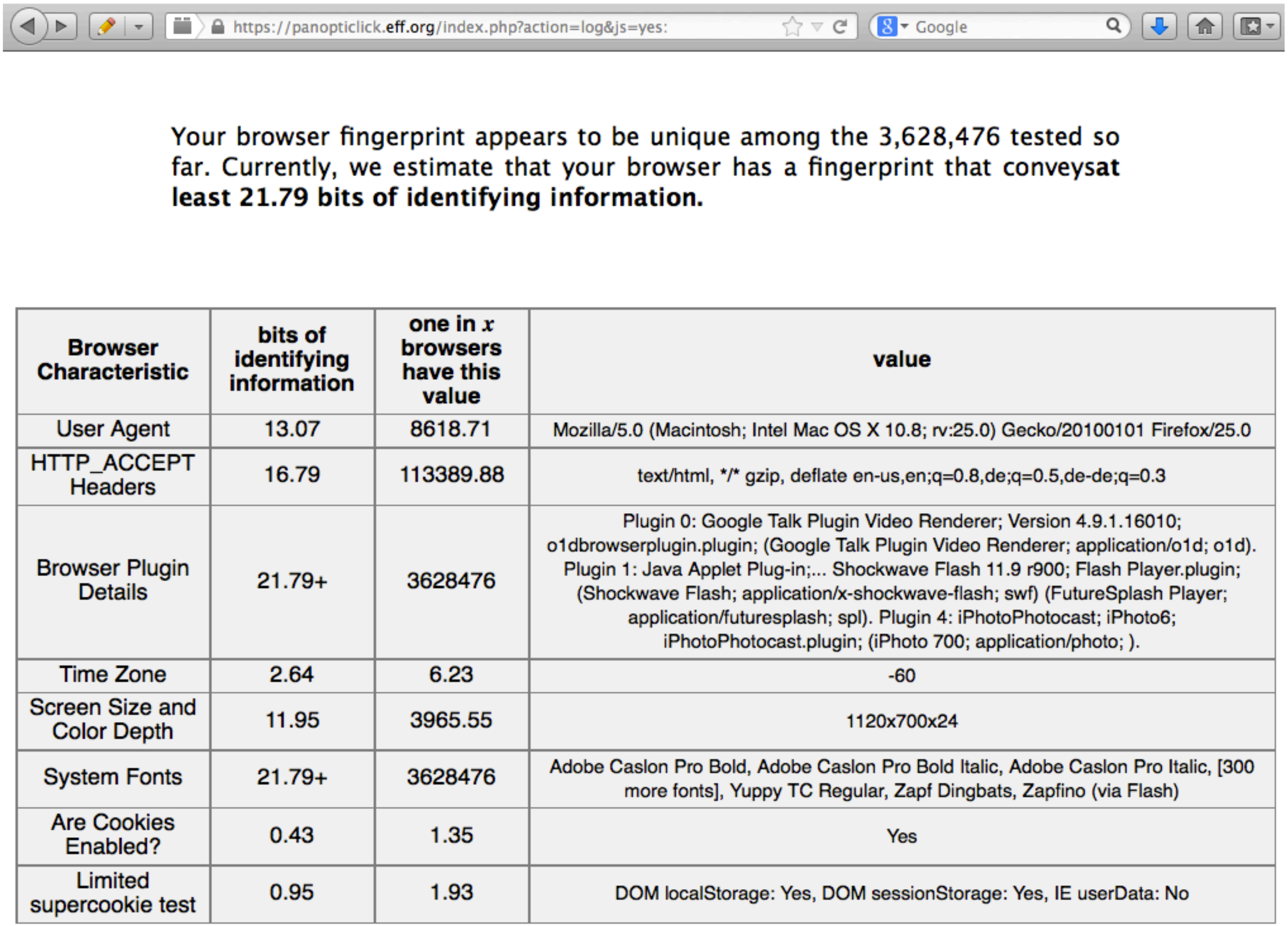

Your browser fingerprint appears to be unique among the 3,628,476 tested so far. Currently, we estimate that your browser has a fingerprint that conveys**at least 21.79 bits of identifying information.**

Browser Characteristic	bits of identifying information	one in x browsers have this value	value
User Agent	13.07	8618.71	Mozilla/5.0 (Macintosh; Intel Mac OS X 10.8; rv:25.0) Gecko/20100101 Firefox/25.0
HTTP_ACCEPT Headers	16.79	113389.88	text/html, */* gzip, deflate en-us,en;q=0.8,de;q=0.5,de-de;q=0.3
Browser Plugin Details	21.79+	3628476	Plugin 0: Google Talk Plugin Video Renderer; Version 4.9.1.16010; o1dbrowserplugin.plugin; (Google Talk Plugin Video Renderer; application/o1d; o1d). Plugin 1: Java Applet Plug-in;... Shockwave Flash 11.9 r900; Flash Player.plugin; (Shockwave Flash; application/x-shockwave-flash; swf) (FutureSplash Player; application/futuresplash; spl). Plugin 4: iPhotoPhotocast; iPhoto6; iPhotoPhotocast.plugin; (iPhoto 700; application/photo;).
Time Zone	2.64	6.23	-60
Screen Size and Color Depth	11.95	3965.55	1120x700x24
System Fonts	21.79+	3628476	Adobe Caslon Pro Bold, Adobe Caslon Pro Bold Italic, Adobe Caslon Pro Italic, [300 more fonts], Yuppy TC Regular, Zapf Dingbats, Zapfino (via Flash)
Are Cookies Enabled?	0.43	1.35	Yes
Limited supercookie test	0.95	1.93	DOM localStorage: Yes, DOM sessionStorage: Yes, IE userData: No

Casey (2011)

OS Fingerprinting based on DNS Queries

au.download.windowsupdate.com watson.microsoft.com ipv6.msftncsi.com gadgets.live.com weather.service.msn.com money.service.msn.com

Windows 7

swscan.apple.com swdist.apple.com swcdnlocator.apple.com su.itunes.apple.com time.euro.apple.com radarsubmissions.apple.com internalcheck.apple.com identity.apple.com configuration.apple.com init.ess.apple.com init-p[x]md.apple.com p[x]-contacts.icloud.com p[x]-caldav.icloud.com p[x]-imap.mail.me.com [x].guzzoni-apple.com.akadns.net ax.init.itunes.apple.com a[x].phobos.apple.com keyvalueservice.icloud.com

MacOS X 10.8.5

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Windows 8

similar for iOS, Windows Phone and Android OS

mirrorlist.centos.org [x].centos.pool.ntp.org

CentOS 6

changelogs.ubuntu.com ntp.ubuntu.com geoip.ubuntu.com daisy.ubuntu.com _https._tcp.fs.one.ubuntu.com fs-[x].one.ubuntu.com

Ubuntu 12.04

OS Fing

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keyvalueservice.icloud.com

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Window

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client.wns.windows.com
appexbingweather.trafficmanager.net **...**

similar for iOS, Windows Phone and Android OS

mirrorlist.centos.org
[x].centos.pool.ntp.org

CentOS 6

Browser Fingerprinting based on DNS Queries

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services.addons.mozilla.org versioncheck-bg.addons.mozilla.org
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Chrome

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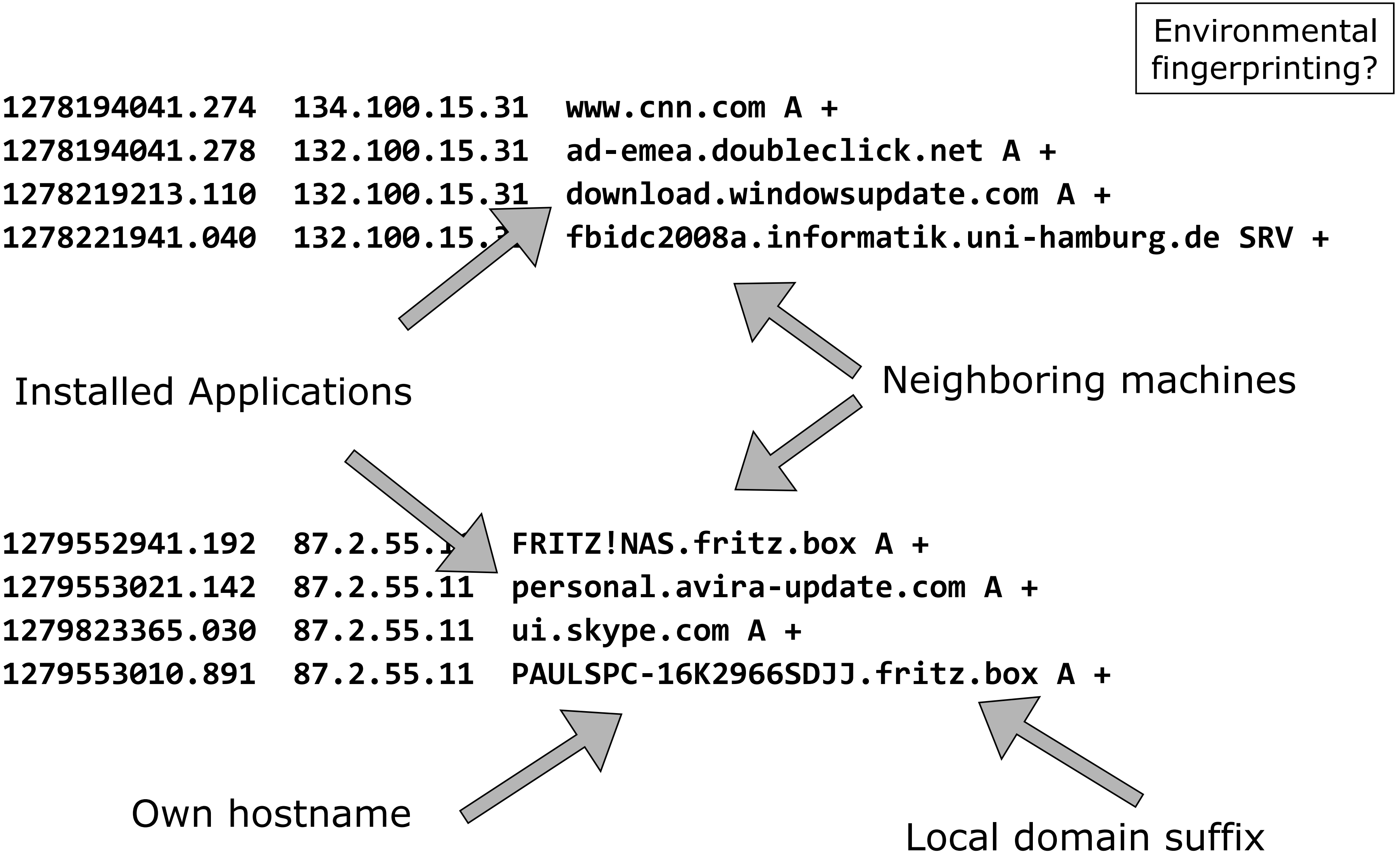
safebrowsing.clients.google.com ssl.gstatic.com
www.google.com www.google.de www.gstatic.com

Safari

ctldl.windowsupdate.com iecvlist.microsoft.com
t.urs.microsoft.com

Internet Explorer

DNS leaks information about setup & environment



Environmental fingerprinting?

```
1278194041.274  134.100.15.31  www.cnn.com A +
1278194041.278  132.100.15.31  ad-emea.doubleclick.net A +
1278219213.110  132.100.15.31  download.windowsupdate.com A +
1278221941.040  132.100.15.3   fbidc2008a.informatik.uni-hamburg.de SRV +
```

Installed Applications

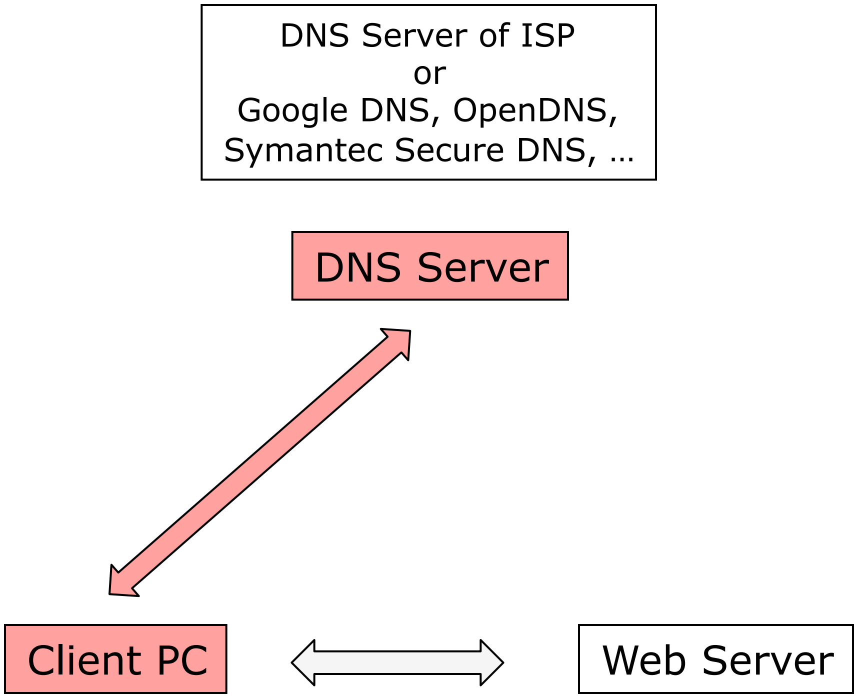
Neighboring machines

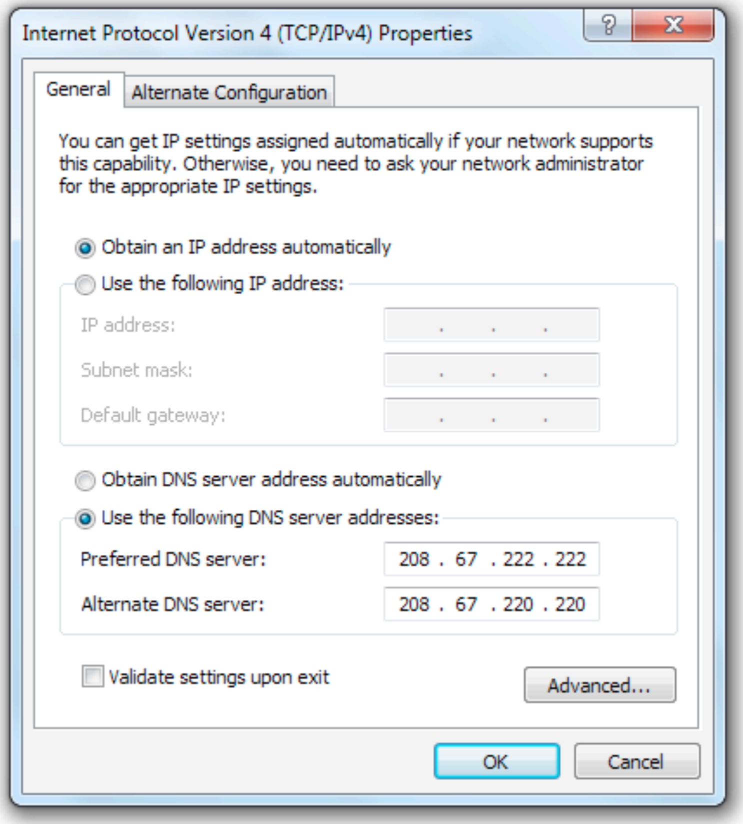
```
1279552941.192  87.2.55.1   FRITZ!NAS.fritz.box A +
1279553021.142  87.2.55.11  personal.avira-update.com A +
1279823365.030  87.2.55.11  ui.skype.com A +
1279553010.891  87.2.55.11  PAULSPC-16K2966SDJJ.fritz.box A +
```

Own hostname

Local domain suffix

Where can DNS data be observed or confiscated?





You can get IP settings assigned automatically if your network supports this capability. Otherwise, you need to ask your network administrator for the appropriate IP settings.

● Obtain an IP address automatically

○ Use the following IP address:

IP address: . . .

Subnet mask: . . .

Default gateway: . . .

○ Obtain DNS server address automatically

● Use the following DNS server addresses:

Preferred DNS server: 208 . 67 . 222 . 222

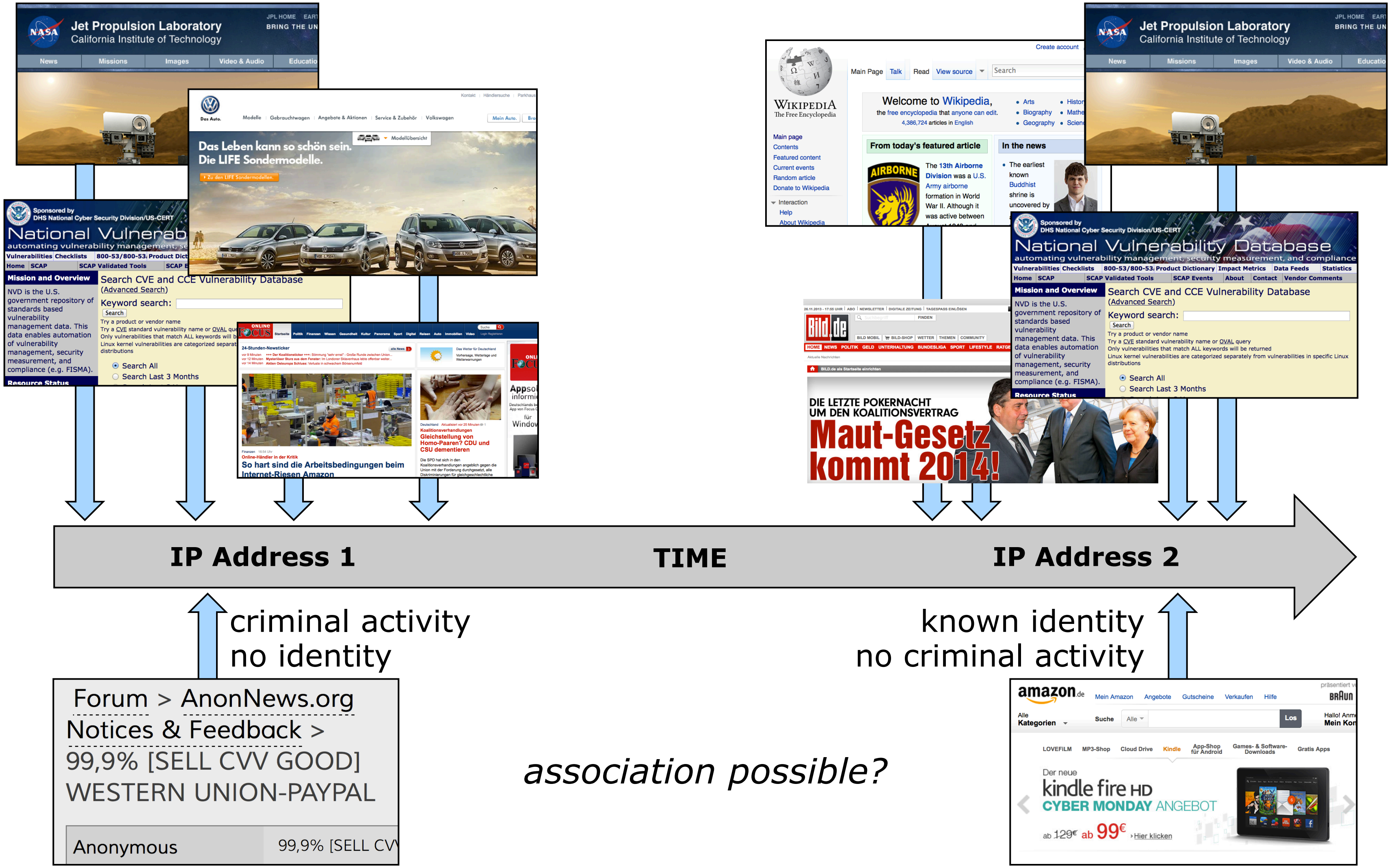
Alternate DNS server: 208 . 67 . 220 . 220

□ Validate settings upon exit

Objective 2:
Find evidence for involvement in criminal activities

Case Study 3: Human Behavior Fingerprinting

The problem of linking activities of a user over time



IP Address 1

TIME

IP Address 2

criminal activity
no identity

known identity
no criminal activity

Forum > AnonNews.org
Notices & Feedback >
99,9% [SELL CVV GOOD]
WESTERN UNION-PAYPAL

Anonymous 99,9% [SELL CV

association possible?

textual description of scenario, forensic objective and approach on next slide

Behavioral fingerprints of users

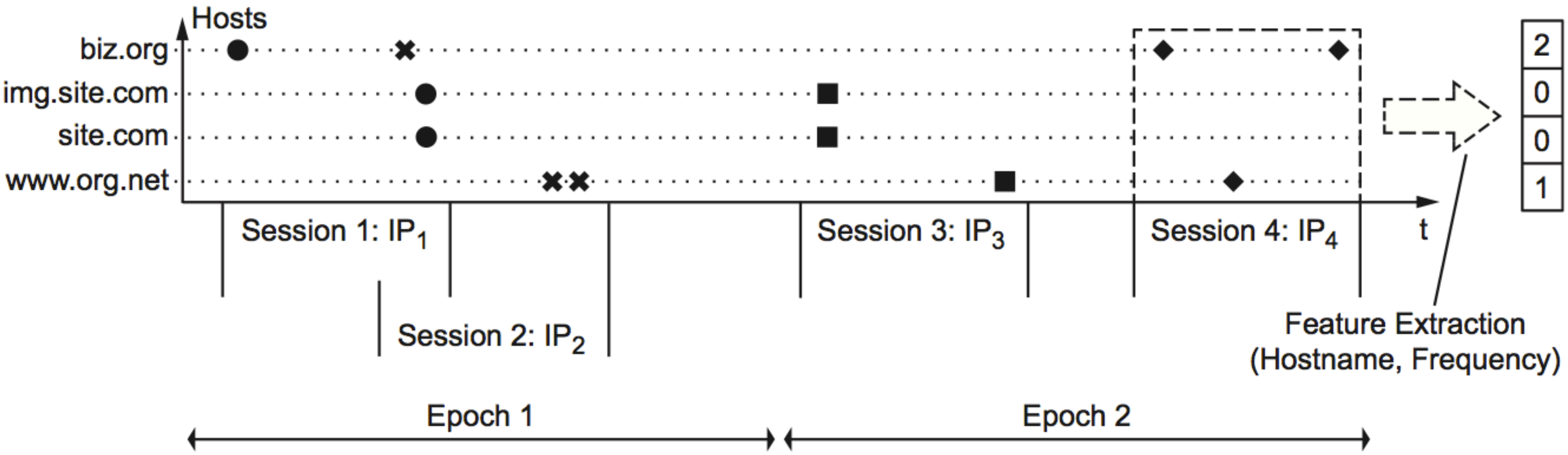
- The Crime Scene
  - Day 1: subject carries out criminal activity on the network
  - Day 2: subject identifies himself during online shopping
  - investigator has access to network traffic on Day 1 and Day 2

- Digital Forensics Objective
  - **ascription/association:** find corroborating evidence that the subject identified on Day 2 is the same as the subject that was involved in criminal activity on Day 1

- Fingerprinting Approach
  - relies on characteristic **behavior** of humans
  - train a classifier: investigator collects traffic samples of multiple users on Day 1 and uses machine learning to extract fingerprints
  - classifier is used to determine whether the session of the suspect on Day 2 matches the behavioral fingerprint from Day 1

Behavior-based linking of sessions of a subject

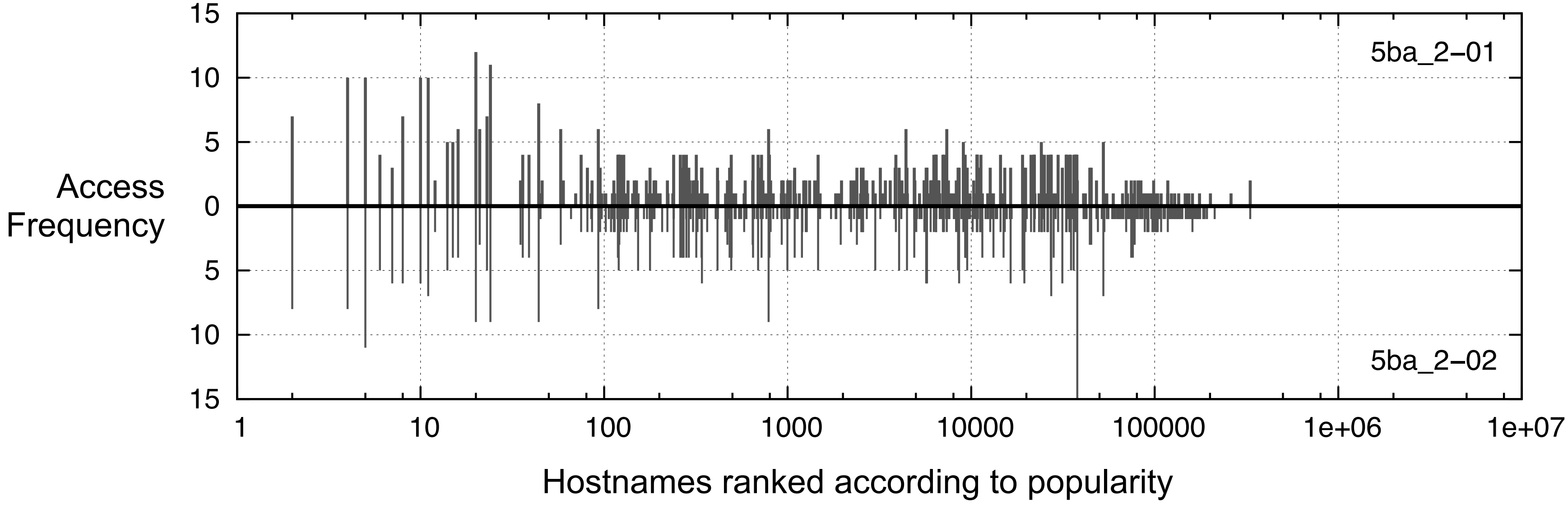
..., Herrmann, Banse, and Federrath (2013), ...

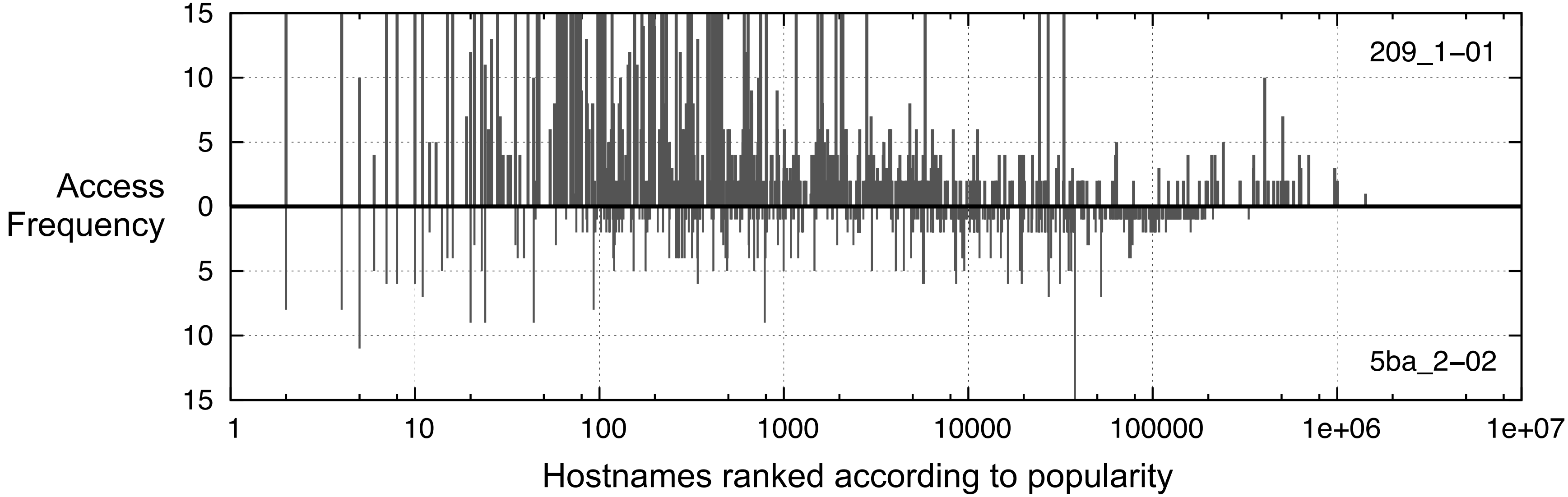


- Fingerprinting approach
  - profile: hostnames in DNS queries, number of queries per name
  - all queries of a user within a session grouped by source IP

(approach not limited to DNS traffic)

Is behavior-based fingerprinting feasible?



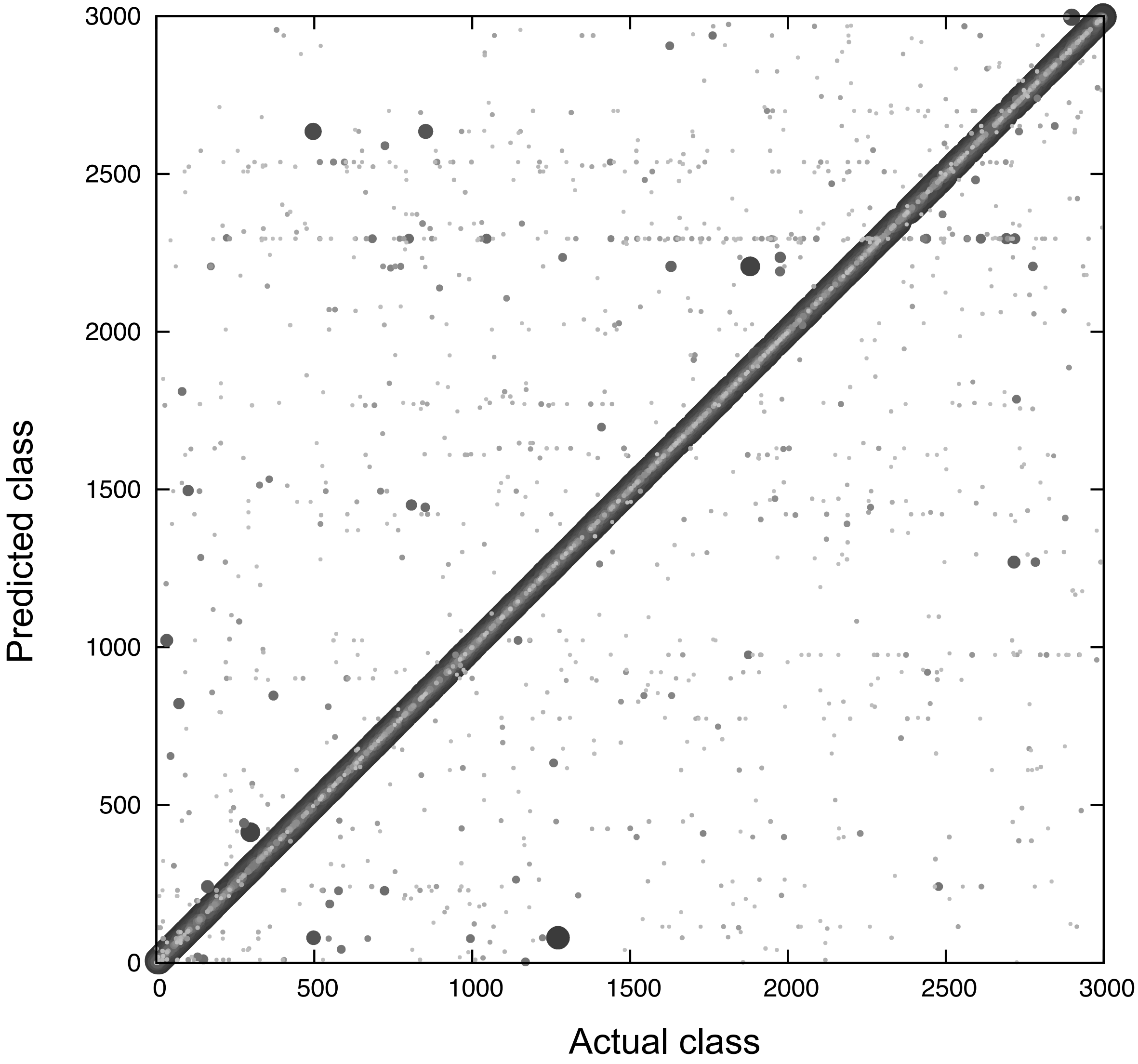


Behavior-based linking of sessions of a subject

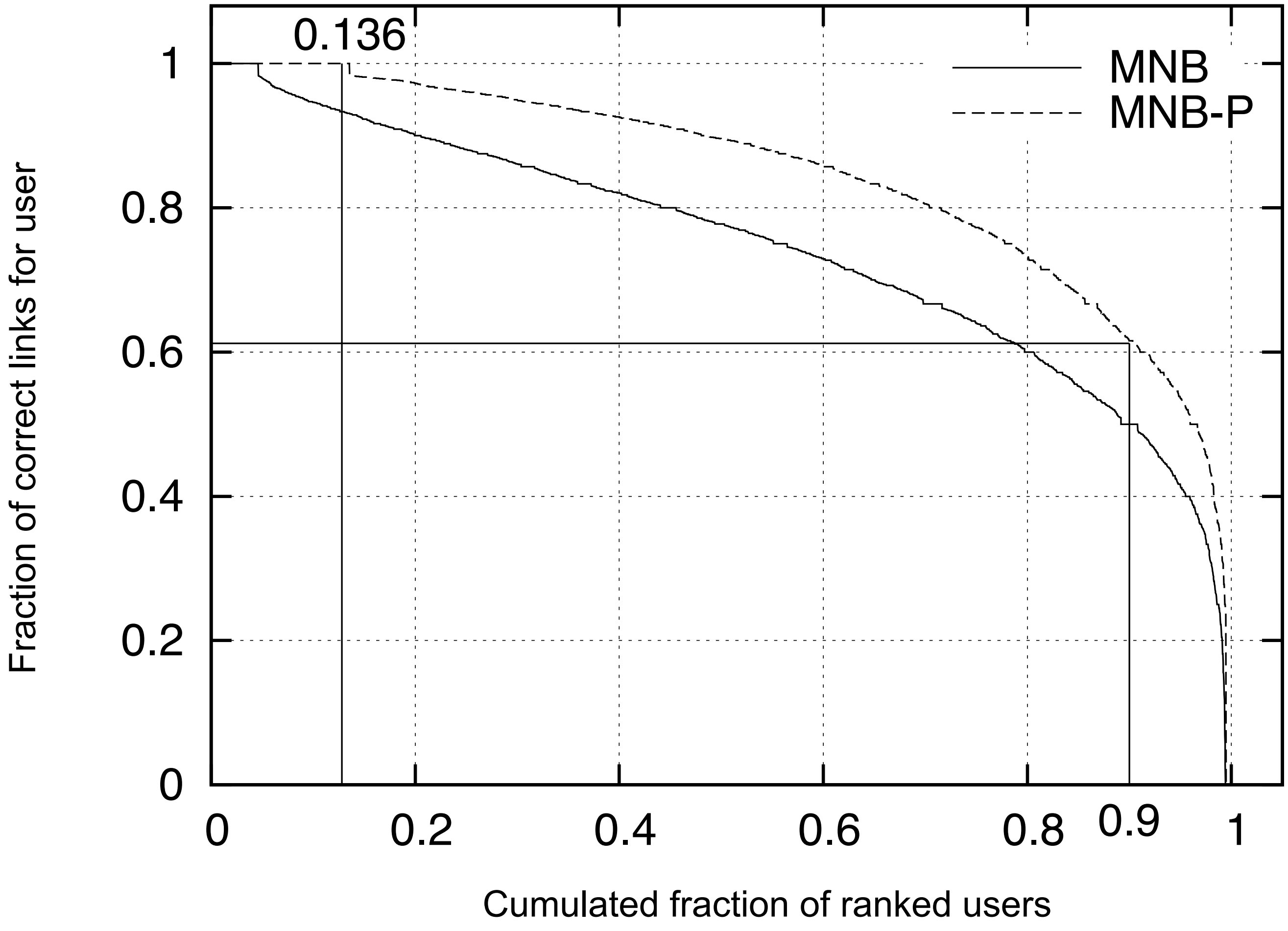
- Evaluation approach
  - obtained a DNS log of University of Regensburg
  - 2 months, 3860 users, 431 mn. queries, 5 mn. hostnames
  - implement linking technique with 1NN and Naïve-Bayes classifier

Apache Hadoop Cluster 18 quadcore desktop machines

Result: on average 86 % of day-to-day sessions linked correctly



Result: most users re-identified correctly most of the time



Fingerprinting for Forensics:
A new **promising** opportunity or a **dangerous** instrument?

Opportunities for Fingerprinting in Network Forensics

- Use cases
  - infer actions even when communication is encrypted
  - ascription of criminal actions, association/involvement of devices

- Utility for **blanket surveillance** and dragnet investigations
  - trace back potentially incriminating activities to the source to determine what should be investigated in detail (“leads”)

- Utility as corroborating evidence **in court**
  - implicit characteristics are unavoidable, difficult to forge (?)

- Utility of fingerprints for defense: to **disprove false accusations**?
  - should users pre-emptively keep a log of their own activities to provide counterevidence?

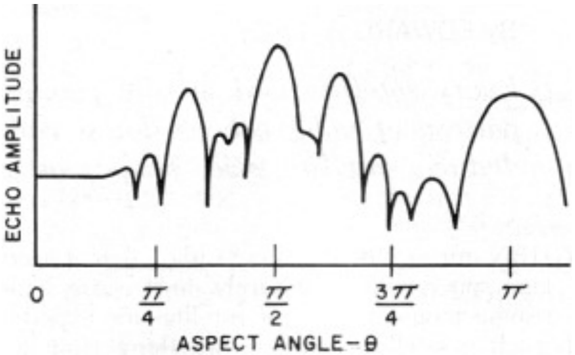
Challenges and Risks

- Unclear probative value
  - poor explainability of the decision of a machine learning system
  - required accuracy? robust evaluation (via standard corpora)?

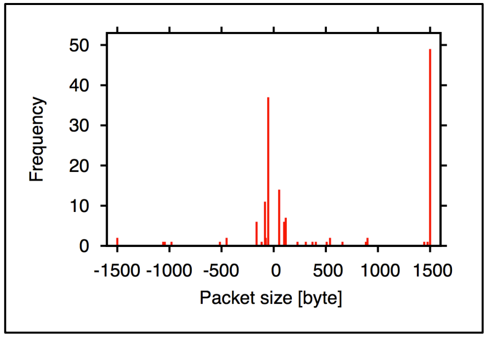
- Future work: active fingerprinting via labeling/watermarking?

- Will feasible techniques lead to calls for pre-emptive surveillance?

- Identity theft vs. fingerprint theft
  - fingerprints can be stolen and re-injected
  - easier than with fingerprints of physical devices (?)



vs



Summary

Fingerprinting: diversity and stability of characteristics

Determine activities of a subject, **even if traffic is encrypted**
Infer associations: evidence for involvement in criminal activities

Three Case Studies:

Website Fingerprinting

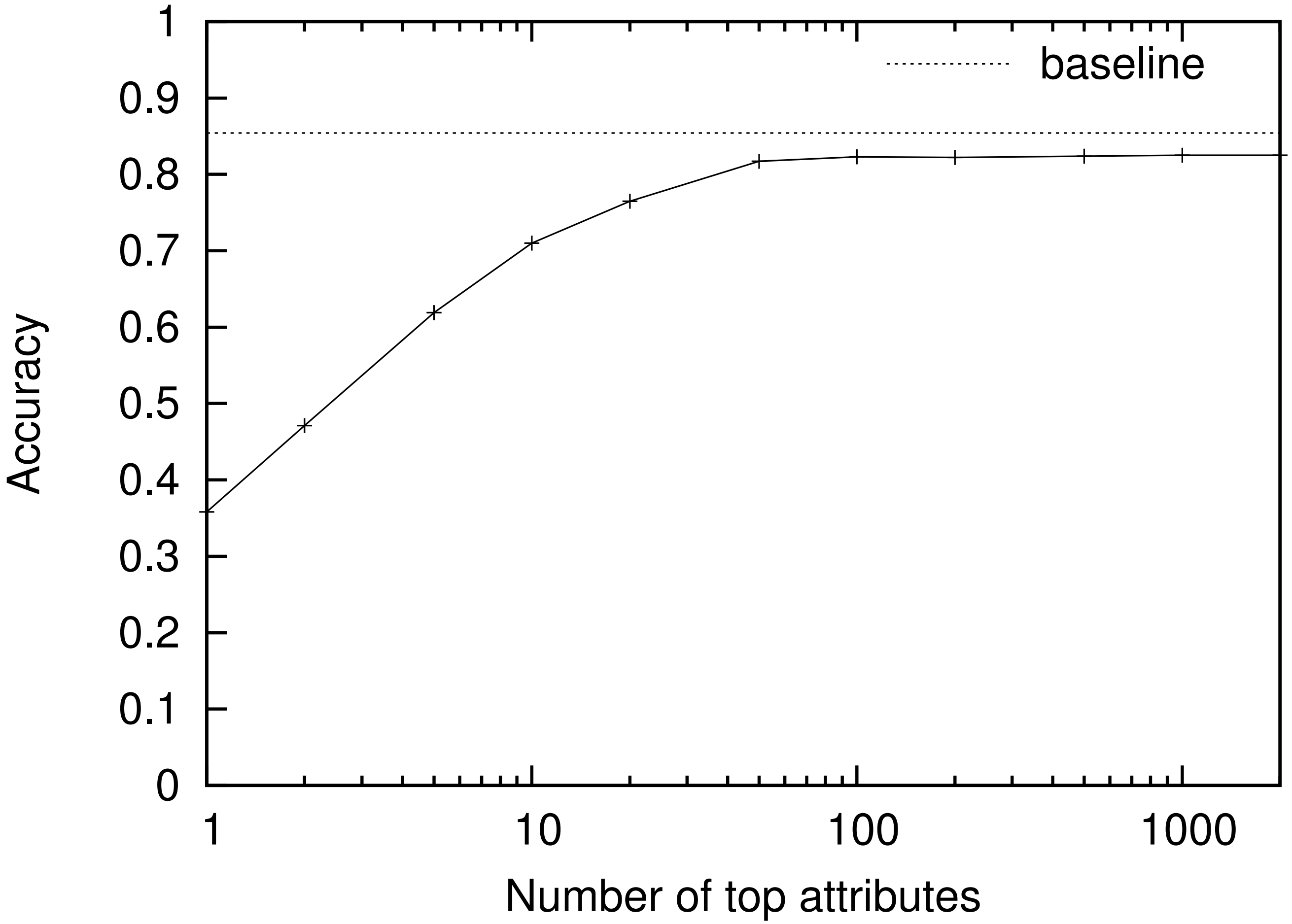
Device/Software Fingerprinting

Human Behavior Fingerprinting

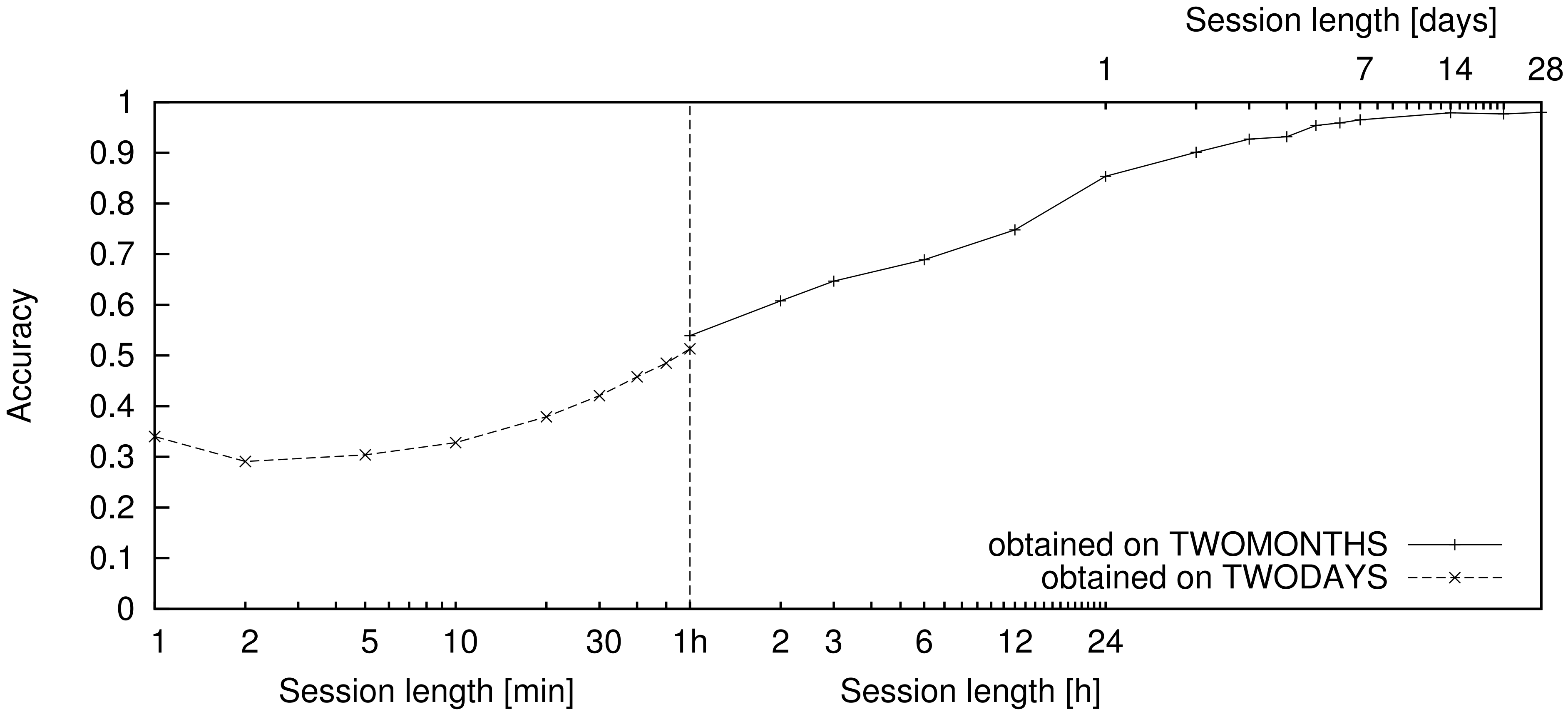
Fingerprinting for Forensics:
A new **promising** opportunity or a **dangerous** instrument?

Backup

Result: session linkage relies on most popular hostnames only



Result: linking activities works also with shorter sessions



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