Network Security and Measurement

Prof. Dr. Thomas Schmidt

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Organisation of today‘s meeting

1. Introduction of Participants
2. Master Specialization & Course Organization
3. Introduction to Internet Security
4. Introduction to Internet Measurement

MUTUAL INTRODUCTION

The INET Group

inet.haw-hamburg.de

We work on

Protocols & Standards

Applications & Analyses

Systems & Security

on the Internet

INET is home of …

CAF: C++ Actor Framework

Spoki:

RTRlib.
The RPKI RTR Client C Library.

Overview of

MASTER & COURSE ORGANIZATION

Master special: Network-centric and time-critical systems

"The Network is the Computer"

- John Gage

- Selected Aspects of Cyber-physical Systems
- Advanced Internet and IoT Technologies
- Real-time Systems
- Network Security and Measurement
- Protocol Engineering
- Distributed Adaptive Systems

Time schedule & assignments

Course hours: Wednesday 8:30-11:30

- Lecture/discussion
- Paper presentation/discussion
- Lab work/discussion

Assignments

- Prepare lecture, paper, background
- Work on lab tasks & projects
- Present a paper of the week
- Present measurement project

Paper of the week

Everybody reads the paper before class.

One assignee prepares presentation according to the following 5-slide structure:

1. Title slide
2. Problem slide: What is addressed?
3. Methodology/Solution slide:
   How is the problem addressed?
4. Evaluation slide:
   What are the key findings?
5. Slide of 3-5 discussion questions

Lab assignments

Lab experiments will be continuously assigned
→ check webpage

Labwork will be part of most class hours

→ quick way to clarify and exchange in sync

You can work on the lab any other time

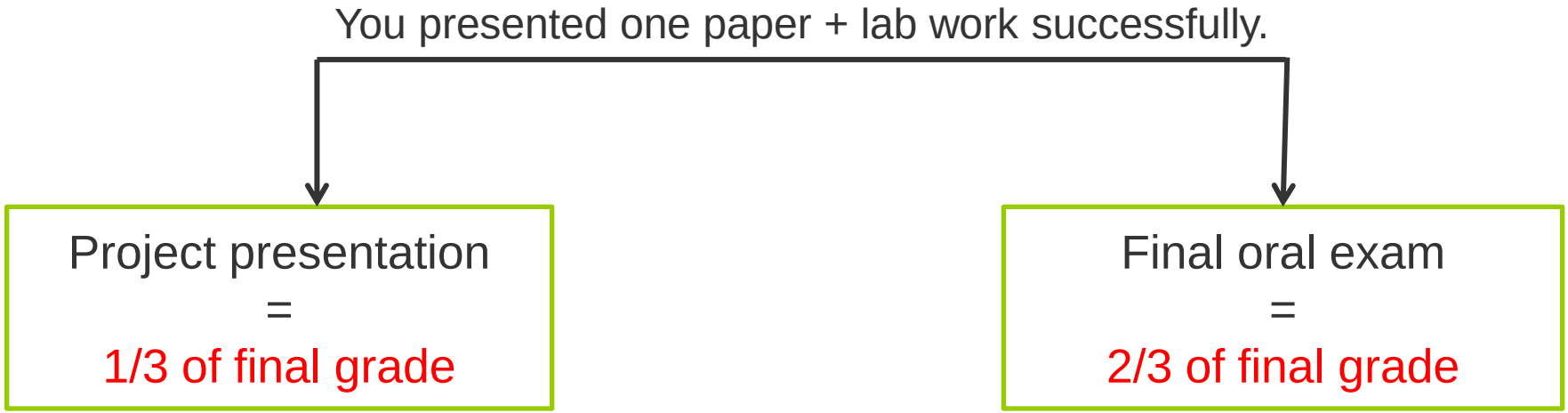
→ easy infrastructure behind Jupyter NB

You need to regularly present labwork results

→ during class hours

Independent project will be picked/assigned in the second half of the class

Grading



You NEED to register (legally binding).

Office hours, communication, and Web resources

Thomas Schmidt (lecture)

- Consulting hours: per email
- Room 480a
- T.Schmidt@haw-hamburg.de

Timo Häckel (labs)

- Consulting hours: per email
- Room 580b
- timo.haeckel@haw-hamburg.de

Course homepage:
https://www.inet.haw-hamburg.de/teaching/ss-2025/network-security-and-measurement

- Tools & Announcements
- Links to slides, recordings, papers, background, and assignments
- Teams forum for Q&A
  - Don’t be shy and ask your questions
  - Don’t be shy and help your fellow students

This lecture is organized as blended learning class

This lecture is jointly prepared with our collaborating group of

Prof. Matthias Wählisch

- NETD at TU Dresden -

Please give us feedback on lecture, labs and organization

HAW HAMBURG

Introduction to

NETWORK SECURITY

Security objectives

1. Resource protection
2. Authentication
3. Authorization
4. Integrity
5. Confidentiality
6. Nonrepudiation
7. Auditing security activities

Whom do we trust on the Internet?

When invoking a service

- we use names that the infrastructure resolves
- we send packets that the infrastructure guides
- we use application interfaces that appear authentic

We have trusted

⇒ Name resolution (DNS)

⇒ Packet delivery (routing & forwarding)

⇒ Transport security

⇒ Application origination (plus certification ?)

Who is involved

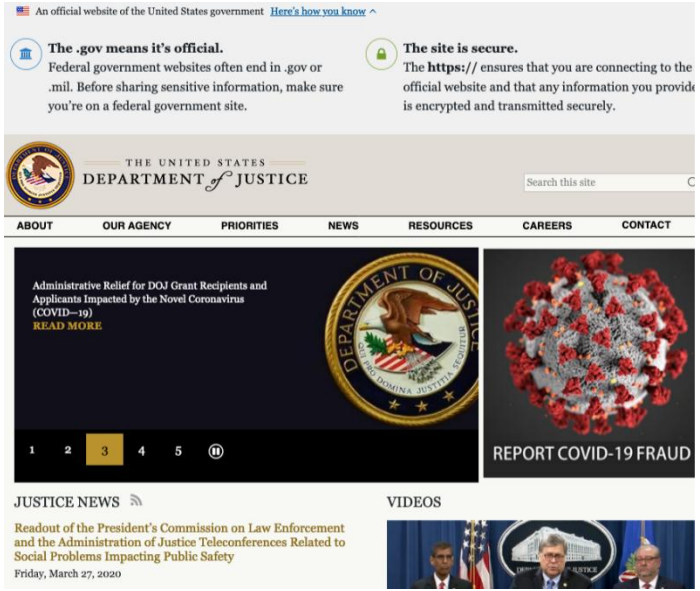
DNS
- Recursive resolvers
- Caches
- Authoritative nameservers

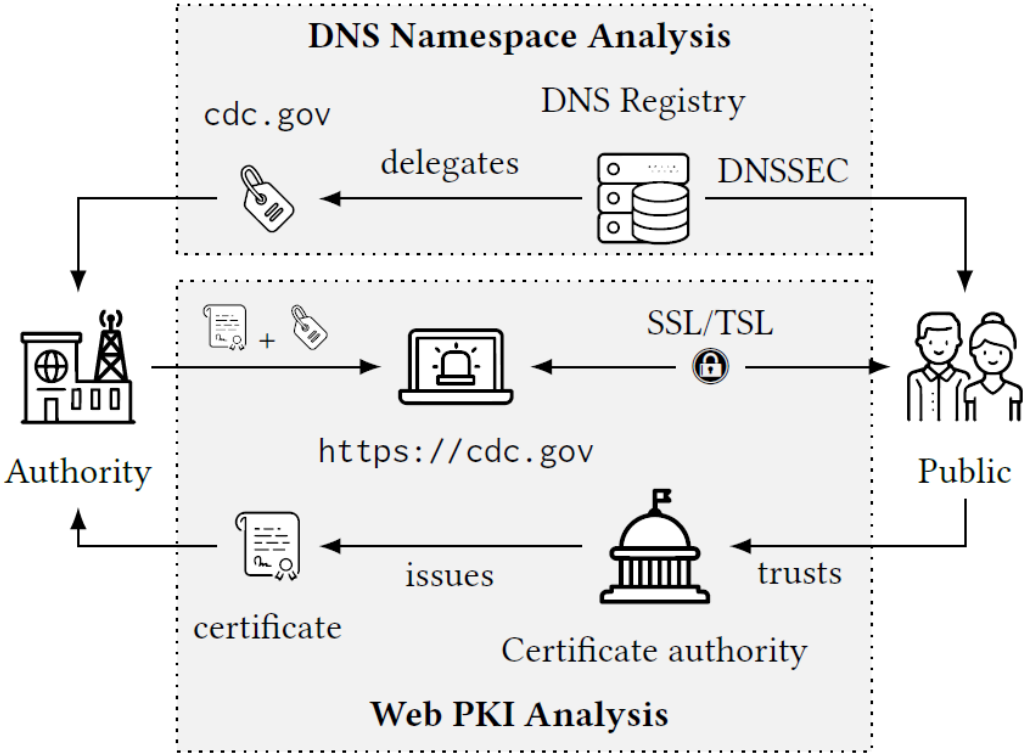
Routing
- Control plane: many BGP speakers
- Forwarding plane: eyeball, transit & origin ISPs

Transport
- E2E transport layer security ?

Application
- Application server
- Indirect (hidden) contributors
- Certification authority ?

Aspect: How do we know the correct name?





Who would do harm?

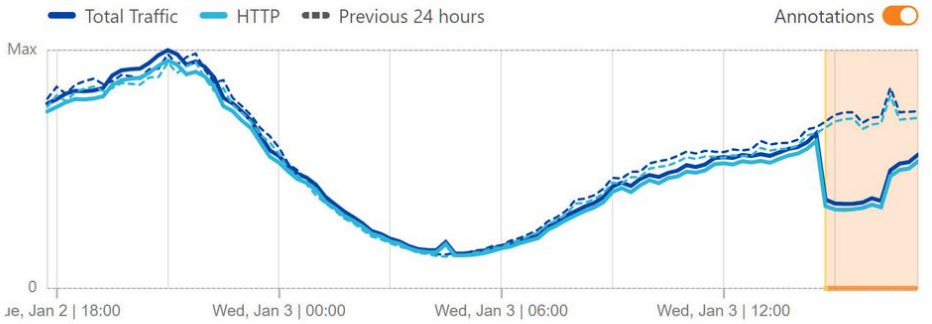
Aspect: How do we know the correct route?

- RIRs (Regional Internet Registries) delegate Internet resources (ASNs, IP Prefixes) to ISPs
- BGP (Border Gateway Protocol) distributes routes between providers – unprotected
- RPKI (Resource Public Key Infrastructure) protects resource ownership
- RIRs attest RPKI ROAs (Route Origin Authorization) as trust anchors

Orange Incident 2024

- Hacker „Snow“ announced on X take-over of Orange‘s RIPE admin account (pw: „ripeadmin“)
- Created RPKI ROA for an Orange /12 prefix with AS49581 (Ferdinand Zink Hosting)
- Orange’s BGP announcements turned invalid, and traffic dropped
- Hacker Snow said they did it for the "lulz"

Prefix	RIR	BGP	RPKI	RIPE	Advice
85.48.0.0/12	RIPE NCC	12479	49581 /12	~~12479~~	RPKI origin does not match BGP origin; RPKI-invalid route objects found



Traffic graph for Orange Spain's AS12479

Source: Cloudflare

How do we learn about effective security?

We need measurement tools, analyses, and campaigns on the global Internet

Are security measures correctly implemented?

Are security measures deployed (and where)?

Do they take the expected effect?

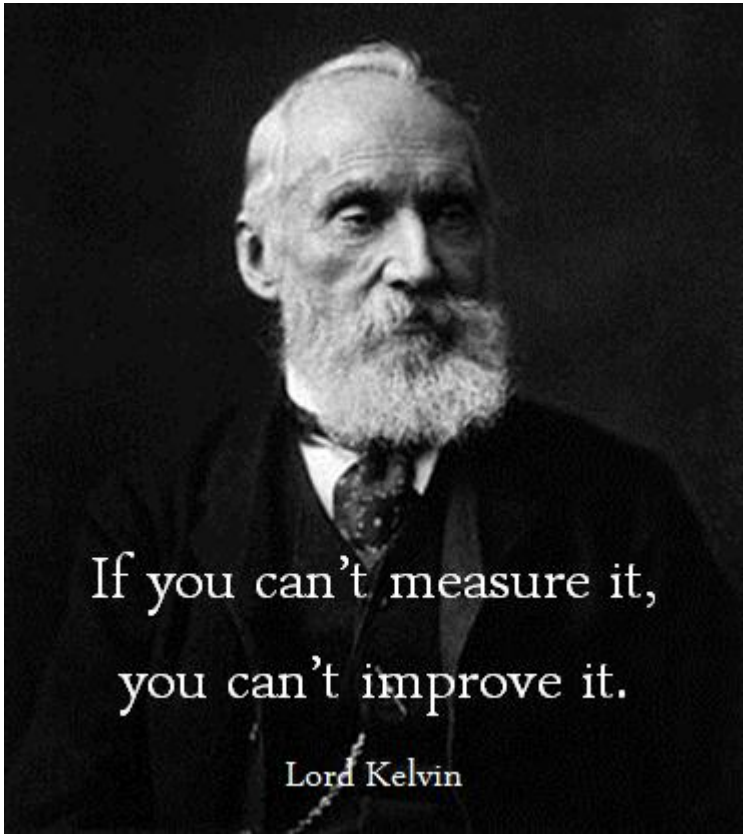
Are ‚secure' services misused?

What about other potential threats?

Introduction to

INTERNET MEASUREMENT

To measure is to know



Agenda

Measuring the Internet ecosystem

Examples of measurements

Principle approaches to measurement

Common data sets

Measurement and ethics

Objectives of this lecture

Better understanding of the current Internet ecosystem and its security properties

Mastering the assessment of protocol and application deployment

Understanding of potentials and limitations of Internet measurement (data)

Internet Measurements and Performances

Reverse engineering of current deployment to better understand properties of the Internet

Assess the capabilities of architectures and protocols

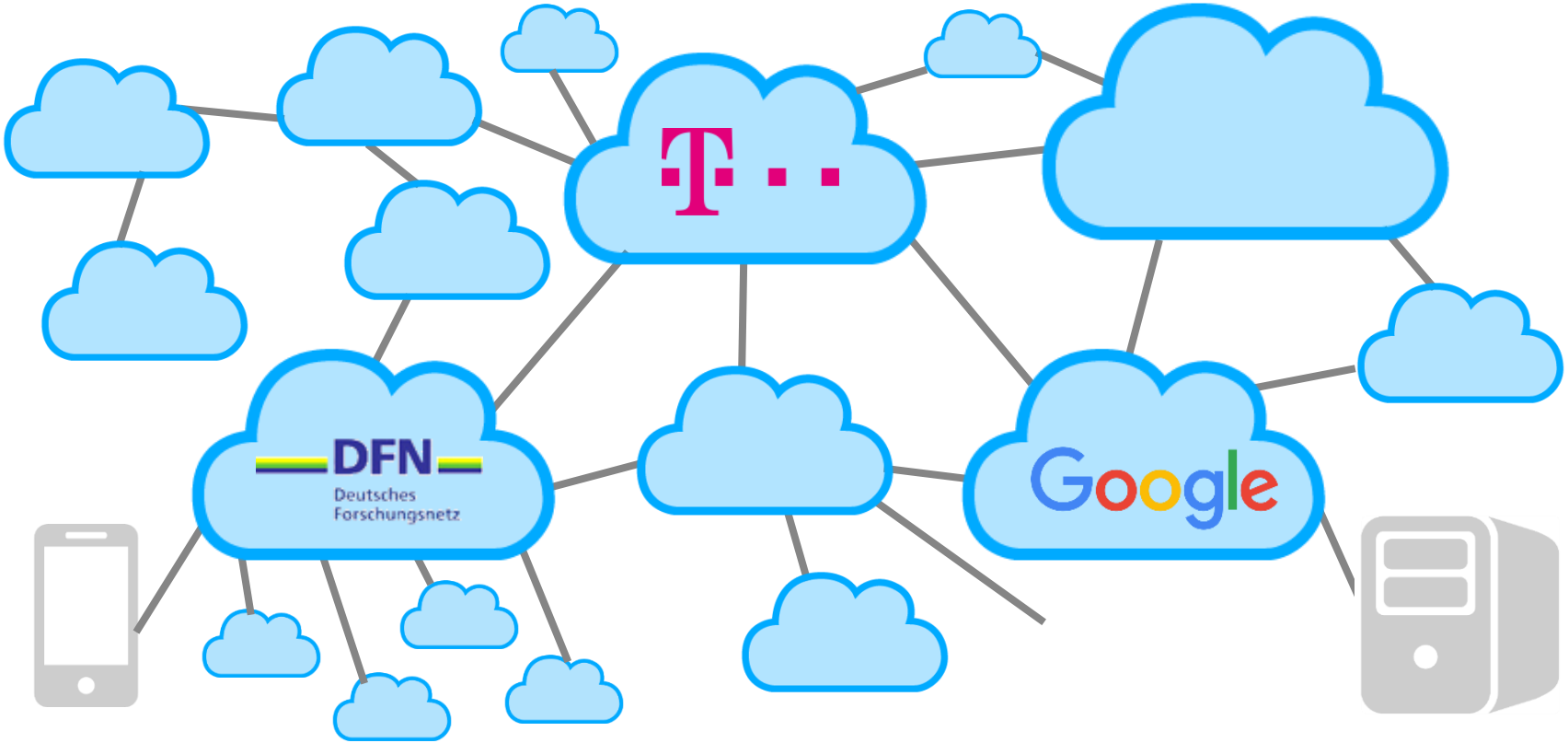
Internet Measurements and Performances

Reverse engineering of current deployment to better understand properties of the Internet

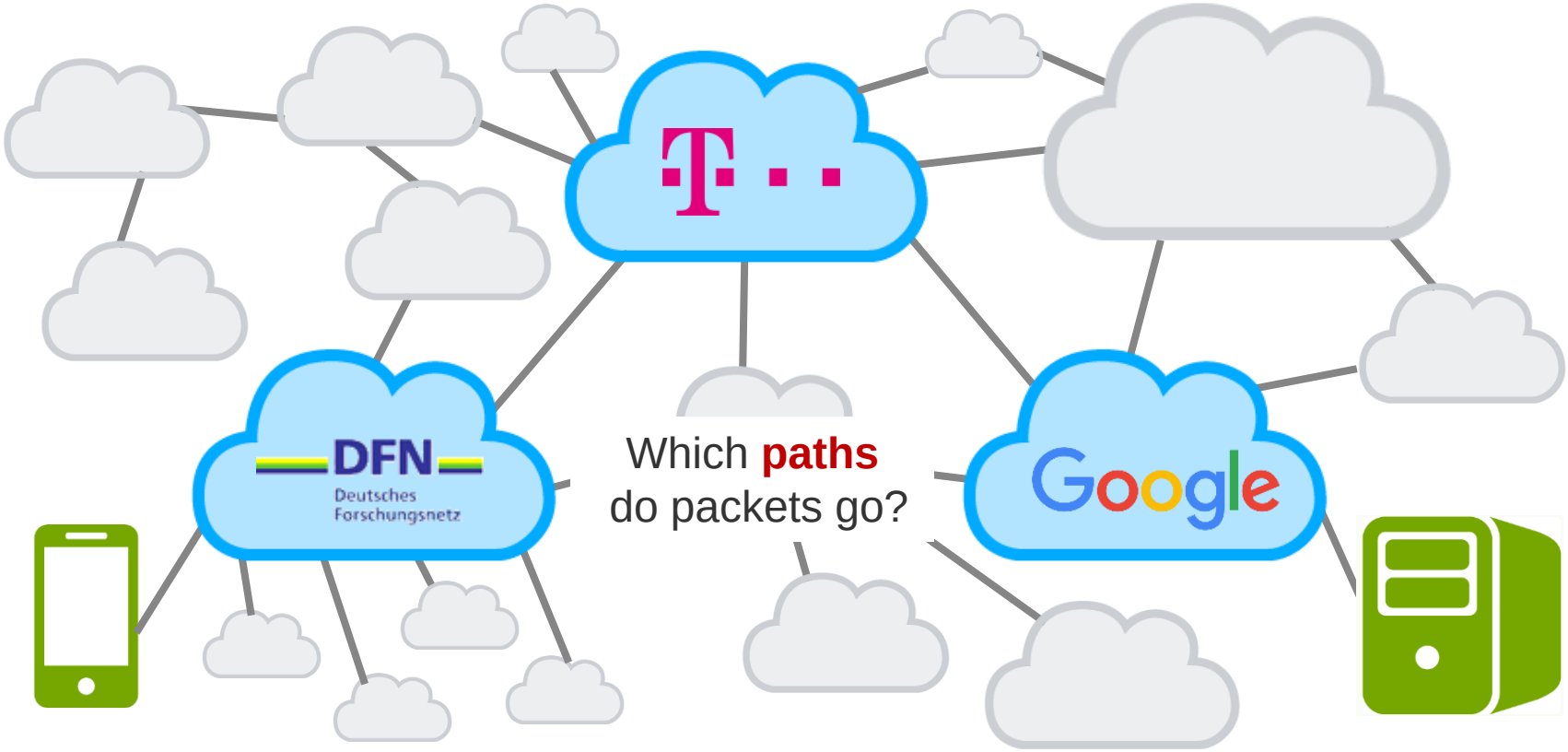
Why measuring the Internet ecosystem?

- Network Debugging
- Performance
- Resilience
- Security
- Regulation and Policies
- Broader impact on society: state censorship, price and traffic discrimination, impact of social media, …

Which part of the Internet do we consider?

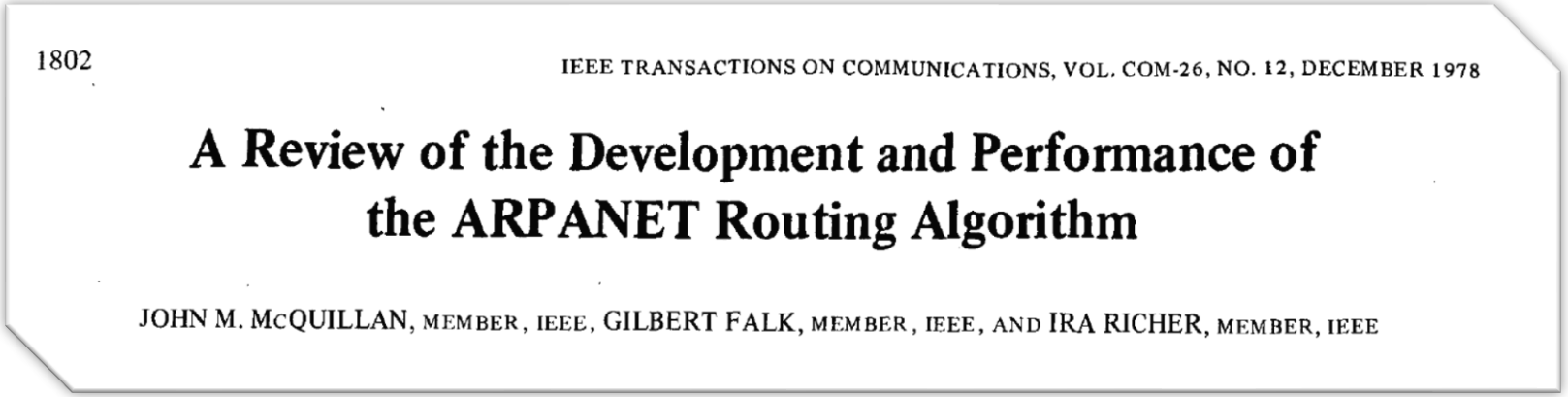


From control plane to data plane



From control plane to data plane

Example 1: ARPANET Routing

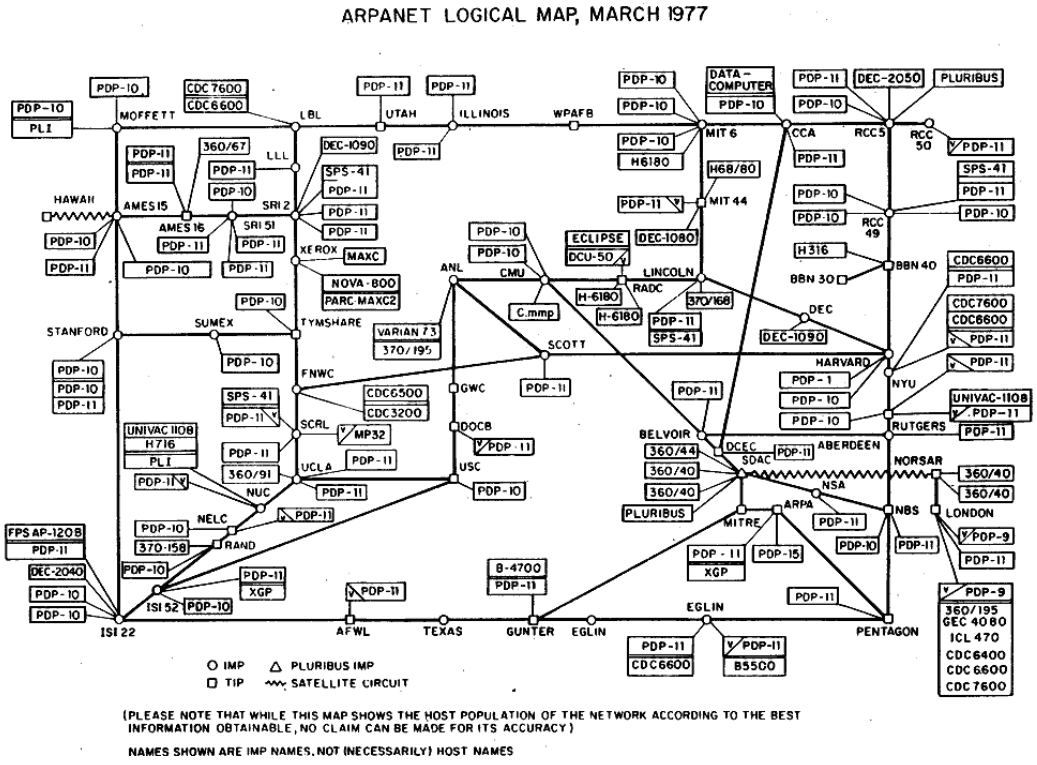


1802 IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. COM-26, NO. 12, DECEMBER 1978

A Review of the Development and Performance of the ARPANET Routing Algorithm

JOHN M. McQUILLAN, MEMBER, IEEE, GILBERT FALK, MEMBER, IEEE, AND IRA RICHER, MEMBER, IEEE

Example 1: ARPANET Routing



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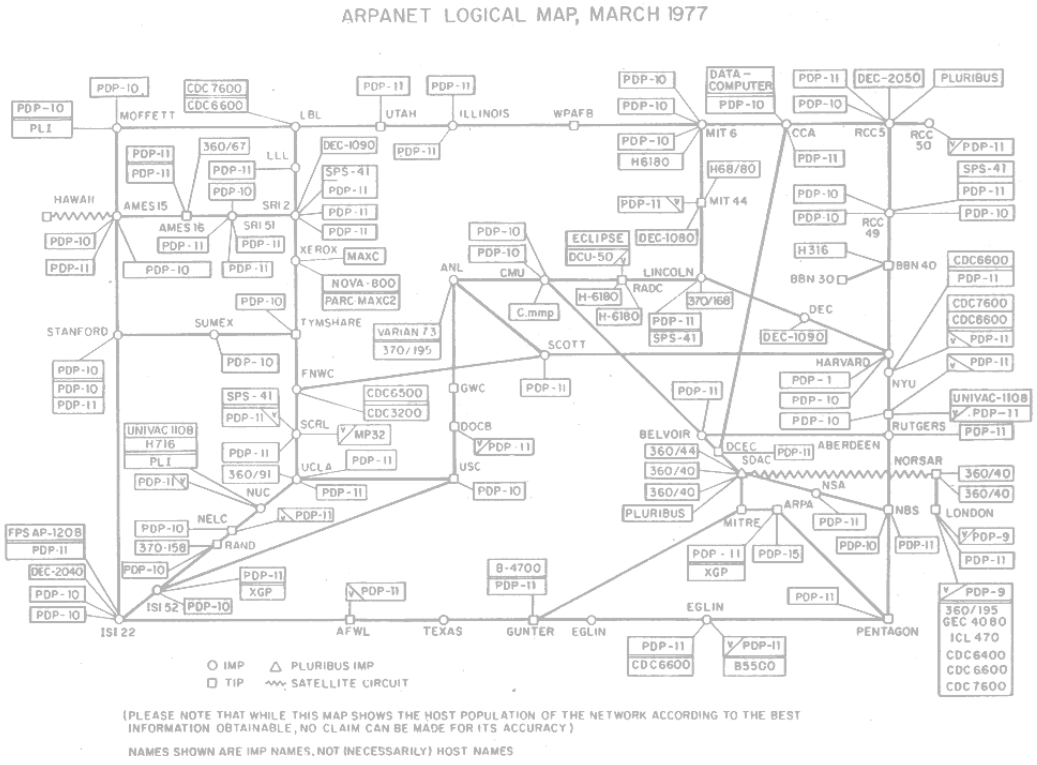

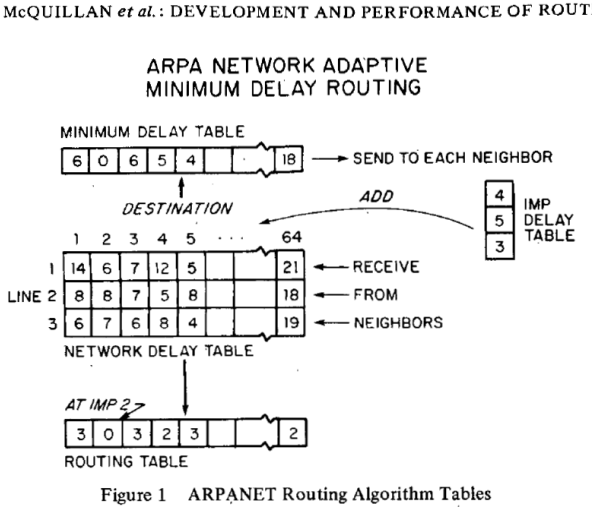

Figure 1 ARPANET Routing Algorithm Tables

Every 2/3 of a second, IMP selects the minimum delay to each destination.
Every 2/3 of a second, IMP sends minimum delay table to neighbors.

What can we say about basic performance properties?

1. Information travels every 2/3 of a second per interface line.
   Topology changes are recognized by the whole network in few seconds.
2. Calculates path of least delay.
   Low frequency of routing updates means that the estimated traffic delay is a function of past traffic, may result in oscillations and bad line usage.
3. It’s simple. No complete network knowledge necessary.
4. Not costly in terms of network resources.
   Calculation of min delay proportional to the number of nodes and lines.

There are also drawbacks …

There are also drawbacks …

5. NEW PROBLEMS

For several years the ARPANET has been subjected to occasional disturbances stemming from a variety of external causes: faulty IMP hardware, software bugs, circuit difficulties, traffic overloads (stochastic), etc. The real problem is not any particular irritant but the vulnerability of the ARPANET to congestion caused by such irritants [5].

What is a network disturbance? We can offer three common characteristics:

1. The NCC host detects that some of the normal periodic IMP reports are missing.
2. Some IMPs declare other IMPs in the network unreachable (when in fact the IMPs are reachable).
3. Users in the network see their connections broken.

These events appeared to be closely correlated to IMPs retransmitting packets many times to adjacent IMPs. When an IMP retransmits a packet 600 times (which takes at least 75 s), it declares the line down.

Challenges when measuring …

Determining the causes of ARPANET disturbances is a complex and difficult task given the nature of the network: the IMPs have limited memory and must communicate with the NCC by means of the same circuits that are involved in a disturbance. We have developed a flexible set of measurement programs in the IMP program which allows us to take a snapshot of a given set of data (queue lengths, buffer counts, etc.) whenever a network disturbance occurs. When the disturbance has ended, a single command from the NCC causes all the IMPs to transmit their data to the NCC.

Measurement setup

We have used this measurement package to analyze a total of 36 network disturbances which occurred in the period July to September 1977. Of this total, 19 were spontaneously occurring disturbances of various magnitudes and 17 were disturbances which we provoked artificially. We used the two-hour period from 7-9 a.m. on Tuesday mornings (a time reserved for ARPANET software maintenance) to conduct experiments. We used various means (making a line appear to be up in one direction only, making an IMP artificially slow, etc.) to induce congestion in one region of the network, which then led to network disturbances. The utmost caution must be used in creating such disturbances since too severe a test can readily disrupt all network service. Thus we designed all of our experiments to minimize risk by programming the experimental module to deactivate itself after a fixed interval of time.

Major result

The basic cause of the disturbances seen over the last several years in the ARPANET is that the network has no built-in protection against traffic congestion [1]. That is, when the offered traffic in some region of the network exceeds the region's capacity to carry that traffic, then congestion builds up throughout that region and sometimes throughout the network as a whole. Eventually, the network is so full of traffic for the congested area that little or no other traffic can flow through the network. The disturbance reaches a climax when the IMPs in the affected regions determine that they have retransmitted certain packets more than the nominal limit (which had been set at 600 retransmissions). At this point the IMPs declare the circuits to be unusable. This isolates the region of congestion from the rest of the network and permits normal operations to resume, although any user with a host-to-host protocol connection in the affected region would find his connection broken.

Example 2: BGP Experiment

Background

Border Gateway Protocol (BGP) allows for different path attributes types (e.g., AS path, next hop, local preference).

One path attribute type is reserved for development.

Example 2: BGP Experiment

NANOG,

We would like to inform you of an experiment to evaluate alternatives for speeding up adoption of BGP route origin validation (research paper with details [A]).

Our plan is to announce prefix 184.164.224.0/24 with a valid standards-compliant unassigned BGP attribute from routers operated by the PEERING testbed [B, C]. The attribute will have flags 0xe0 (optional transitive [rfc4271, S4.3]), type 0xff (reserved for development), and size 0x20 (256bits).

Our collaborators recently ran an equivalent experiment with no complaints or known issues [A], and so we do not anticipate any arising. Back in 2010, an experiment using unassigned attributes by RIPE and Duke University caused disruption in Internet routing due to a bug in Cisco routers [D, CVE-2010-3035]. Since then, this and other similar bugs have been patched [e.g., CVE-2013-6051], and new BGP attributes have been assigned (BGPsec-path) and adopted (large communities). We have successfully tested propagation of the announcements on Cisco IOS-based routers running versions 12.2(33)SRA and 15.3(1)S, Quagga 0.99.23.1 and 1.1.1, as well as BIRD 1.4.5 and 1.6.3.

We plan to announce 184.164.224.0/24 from 8 PEERING locations for a predefined period of 15 minutes starting 14:30 GMT, from Monday to Thursday, between the 7th and 22nd of January, 2019 (full schedule and locations [E]). We will stop the experiment immediately in case any issues arise.

Although we do not expect the experiment to cause disruption, we welcome feedback on its safety and especially on how to make it safer. We can be reached at disco-experiment at googlegroups.com.

First wave of issues

NANOG,

We've performed the first announcement in this experiment yesterday, and, despite the announcement being compliant with BGP standards, FRR routers reset their sessions upon receiving it. Upon notice of the problem, we halted the experiments. The FRR developers confirmed that this issue is specific to an unintended consequence of how FRR handles the attribute 0xFF (reserved for development) we used. The FRR devs already merged a fix and notified users.

We plan to resume the experiments January 16th (next Wednesday), and have updated the experiment schedule [A] accordingly. As always, we welcome your feedback.

Second round

NANOG,

This is a reminder that this experiment will resume tomorrow
(Wednesday, Jan. 23rd). We will announce 184.164.224.0/24 carrying a
BGP attribute of type 0xff (reserved for development) between 14:00
and 14:15 GMT.

Can you stop this?

You caused again a massive prefix spike/flap, and as the internet is not centered around NA (shock horror!) a number of operators in Asia and Australia go effected by your "expirment" and had no idea what was happening or why.

Get a sandbox like every other researcher, as of now we have black holed and filtered your whole ASN, and have reccomended others do the same.

Ben, NANOG,

We have canceled this experiment permanently.

- BGP Experiment *valdis.kletnieks at vt.edu*
- BGP Experiment *Tom Beecher*
- BGP Experiment *Randy*
- BGP Experiment *Mark Tees*
- BGP Experiment *Mark Tees*
- BGP Experiment *Randy Bush*
- BGP Experiment *Owen DeLong*
- BGP Experiment *valdis.kletnieks at vt.edu*
- BGP Experiment *Owen DeLong*
- BGP Experiment *Randy Bush*
- BGP Experiment *Eric Kuhnke*
- BGP Experiment *Randy Bush*
- BGP Experiment *William Allen Simpson*
- [2019/01/27] Re: BGP Experiment *Hansen, Christoffer*
- BGP Experiment *Randy Bush*
- BGP Experiment *Nick Hilliard*
- BGP Experiment *Brian Kantor*
- BGP Experiment *Nick Hilliard*

- BGP Experiment *Italo Cunha*
  - BGP Experiment *Job Snijders*
  - BGP Experiment *Eric Kuhnke*
  - BGP Experiment *Naslund, Steve*
  - BGP Experiment *Aled Morris*
  - BGP Experiment *Töma Gavrichenkov*
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  - BGP Experiment *Nick Hilliard*
  - BGP Experiment *Filip Hruska*
  - BGP Experiment *Naslund, Steve*

Example 3: Caching & DNS

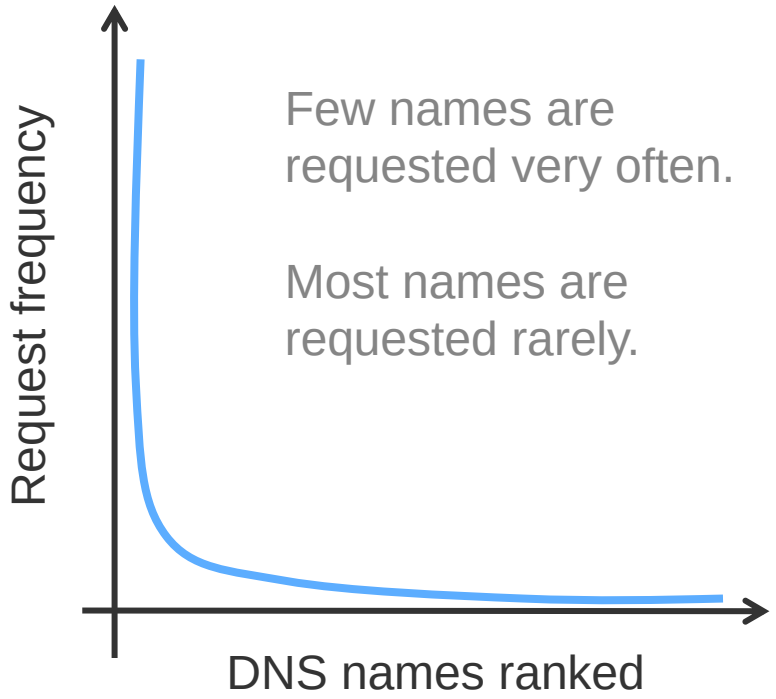
Is caching a reasonable design option in DNS?

Example 3: Caching & DNS

Is caching a reasonable design option in DNS?

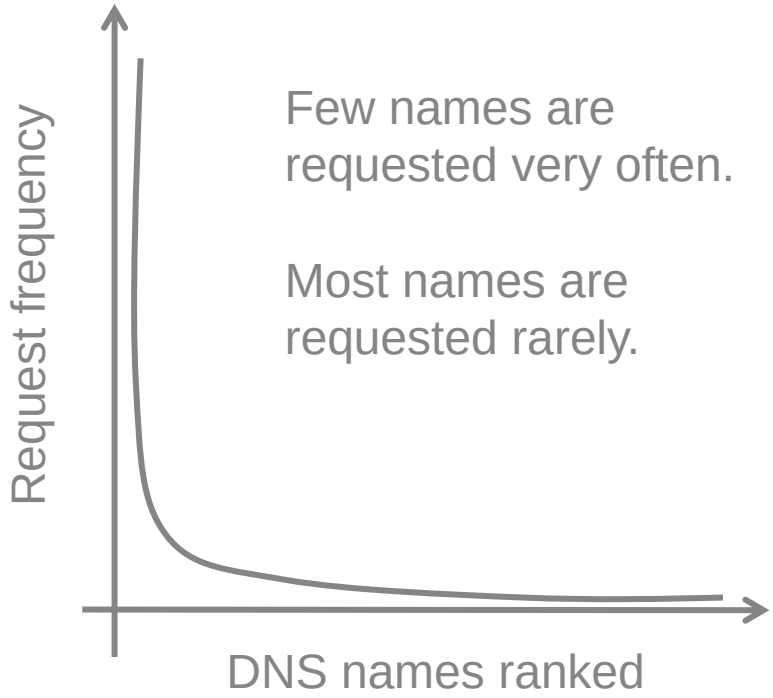
Depends how often the same name is requested by resolvers.

Example 3: Caching & DNS



Example 3: Caching & DNS

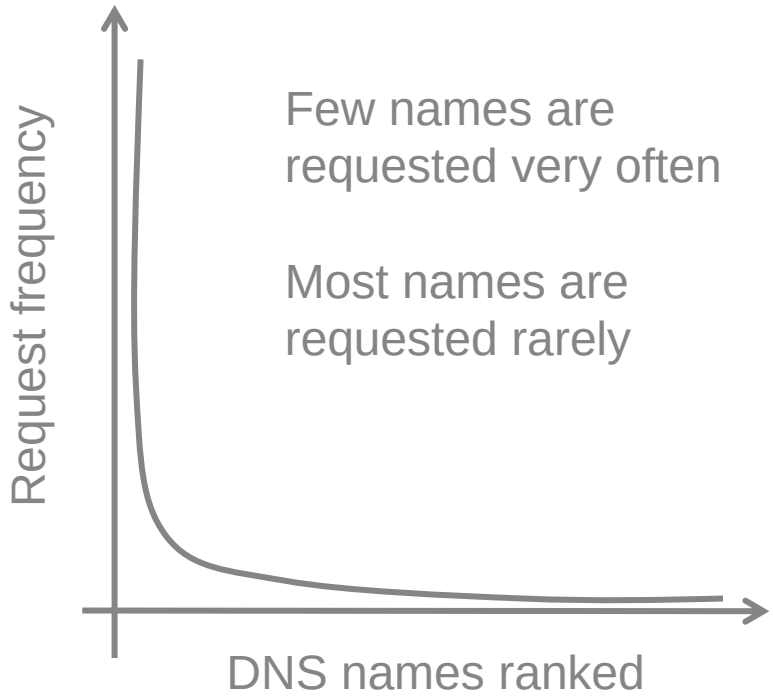
Why should you not trust the results?



Example 3: Caching & DNS

Why should you not trust the results?

You don’t know anything about the measurement setup!



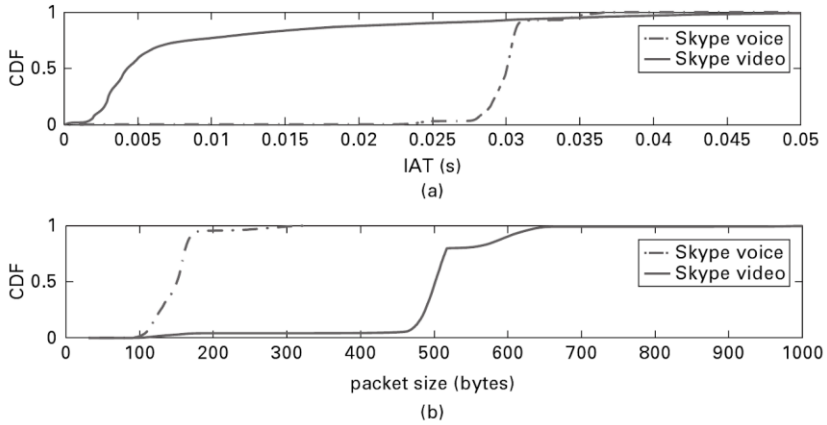
Discuss two measurement setups that lead to completely different results.

Example 4: Classification of multimedia flows

Motivation	ISPs want to understand what happens in their network for business, QoS, and security reasons
Consideration	Voice and video flows
Background	Voice sender uses fix inter-packet delay Voice packets are similar and small
	Video frames vary in size and complexity Video smoothes out transmission intervals

Example 4: Classification of multimedia flows

Skype

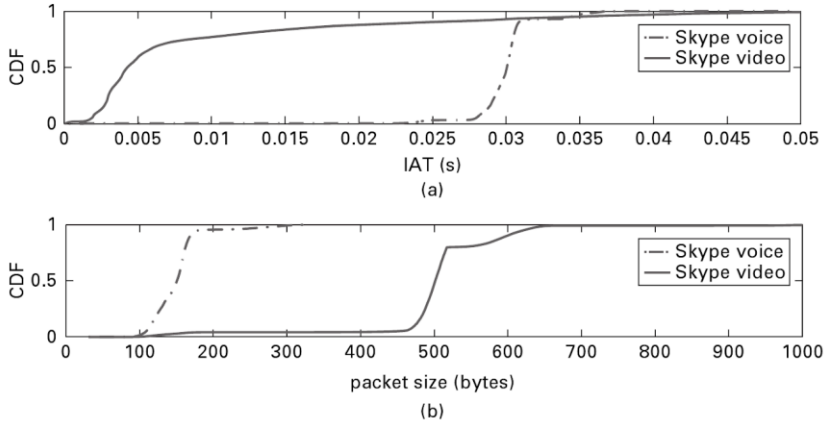


IAT: Inter-arrival time
CDF: Cumulative distribution function, F_X(x)=P(X<=x)

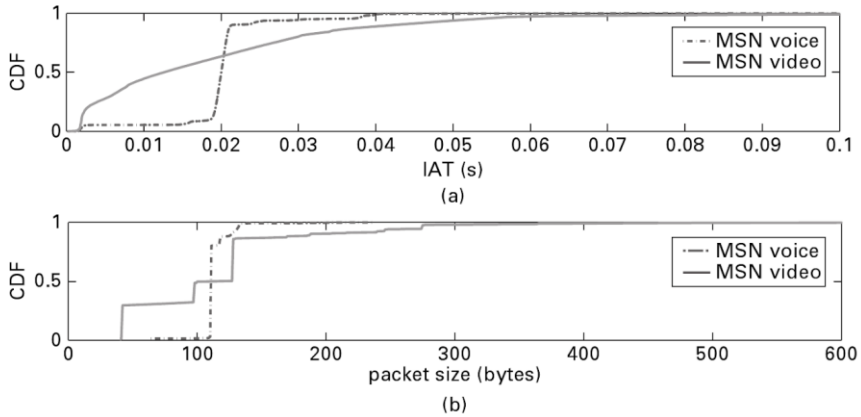
[A. Nucci and K. Papagiannaki, “Design, Measurement and Management of Large-Scale IP Network,” Cambridge University Press, 2009.]

Example 4: Classification of multimedia flows

Skype



MSN



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[A. Nucci and K. Papagiannaki, “Design, Measurement and Management of Large-Scale IP Network,” Cambridge University Press, 2009.]

What did we learn from the examples?

There are different measurement techniques

Clear descriptions of the experiments and measurement data are crucial

Be careful when your experiment runs in the real Internet

Different implementation of the same service may lead to different patterns

Internet measurements: Classic topics

Transport layer

e.g., performance of transport protocols, congestion control

Network layer

e.g., routing failures, Internet topology, performance

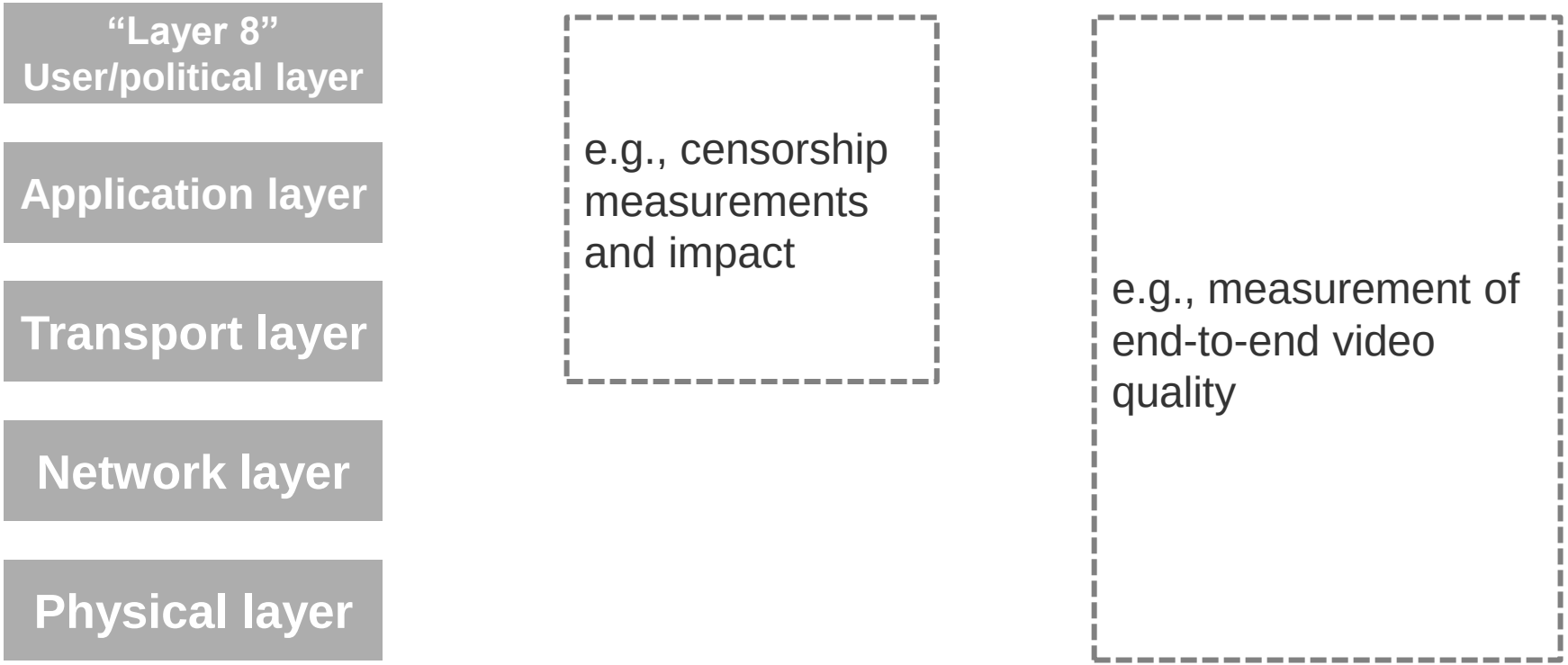
[Slide from Philipp Richter, 2018]

Internet measurements: Broadening field

“Layer 8” User/political layer	e.g., (fake) news propagation in social networks
Application layer	e.g., cloud services, specific applications
Transport layer	e.g., performance of transport protocols, congestion control
Network layer	e.g., routing failures, Internet topology, performance
Physical layer	e.g., infrastructure properties, location

[Slide from Philipp Richter, 2018]

Internet measurements: Cross-layer measurements



[Slide from Philipp Richter, 2018]

Internet measurement: A creative field

Demystifying Porn 2.0: A Look into a Major Adult Video Streaming Website

Gareth Tyson
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Yehia Elkhatib
Lancaster University, UK
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Nishanth Sastry
King's College London, UK
nishanth.sastry@kcl.ac.uk

Steve Uhlig
Queen Mary, University of London, UK
steve@eecs.qmul.ac.uk

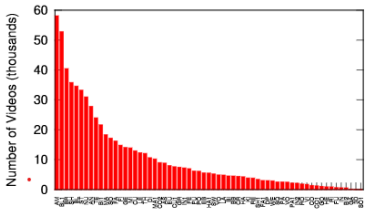


Figure 10: Number of videos per category (ordered by number of videos in the category).

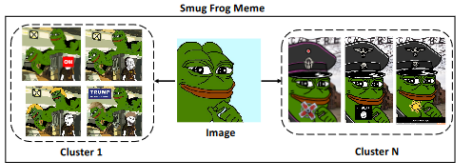


Figure 1: An example of a meme (Smug Frog) that provides an intuition of what an image, a cluster, and a meme is.

Email Typosquatting

Janos Szurdi
Carnegie Mellon University
jszurdi@andrew.cmu.edu

Nicolas Christin
Carnegie Mellon University
nicolasc@andrew.cmu.edu

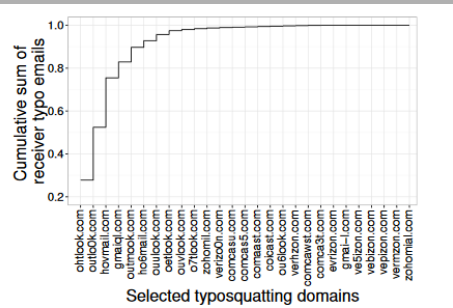


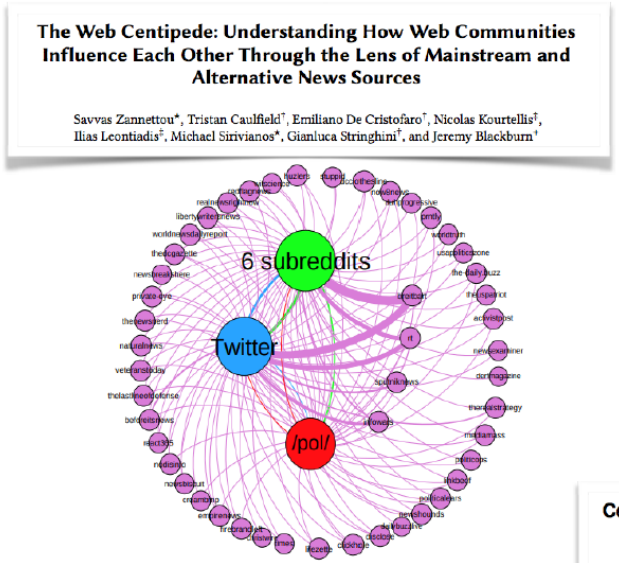
Figure 5: Cumulative sum of emails received by our typosquatting domains.

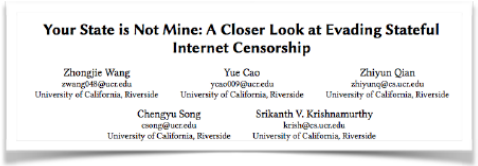
On the Origins of Memes by Means of Fringe Web Communities

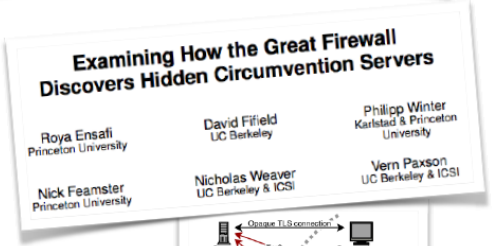
Savvas Zannettou*, Tristan Caulfield‡, Jeremy Blackburn†, Emiliano De Cristofaro‡,
Michael Sirivianos*, Gianluca Stringhini°, and Guillermo Suarez-Tangil+

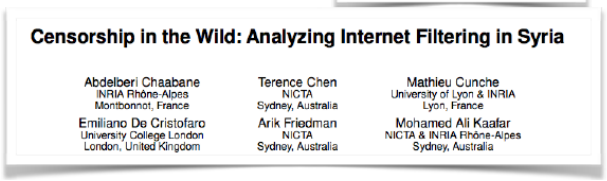
[Inspired by Philipp Richter, 2018]

Internet measurement: Broader societal impact





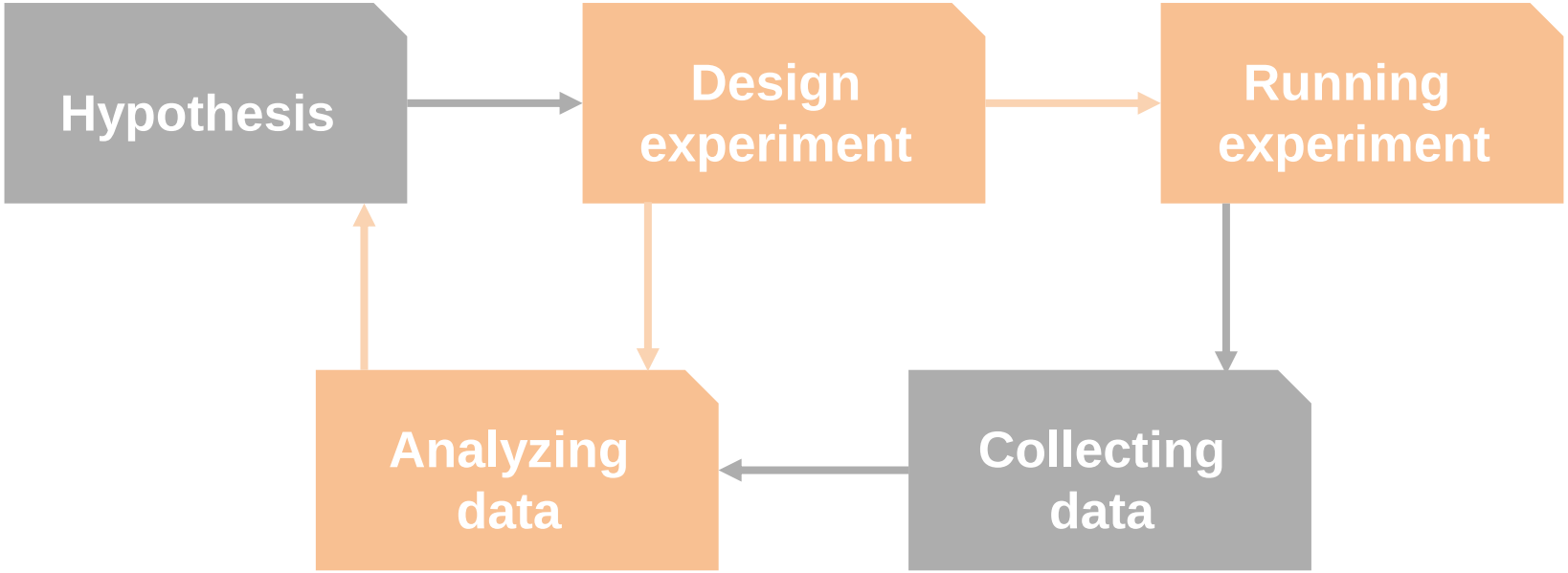




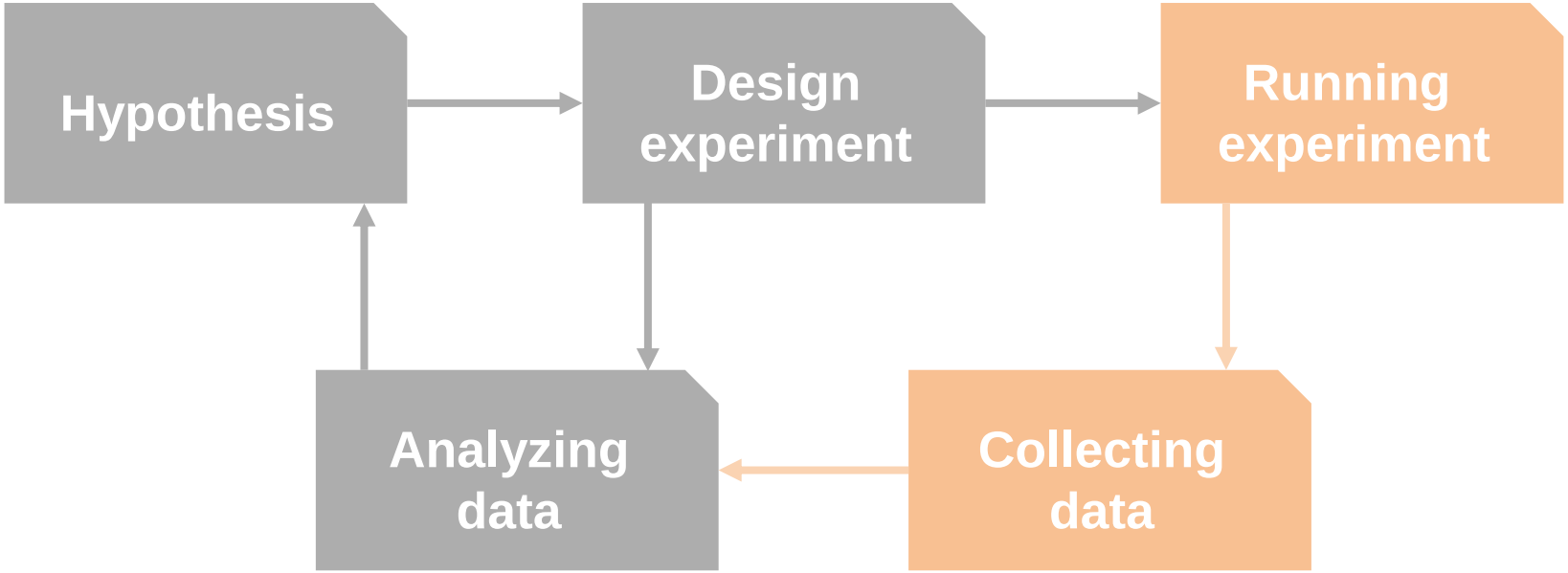
[Slide from Philipp Richter, 2018]

Typical measurement life cycle

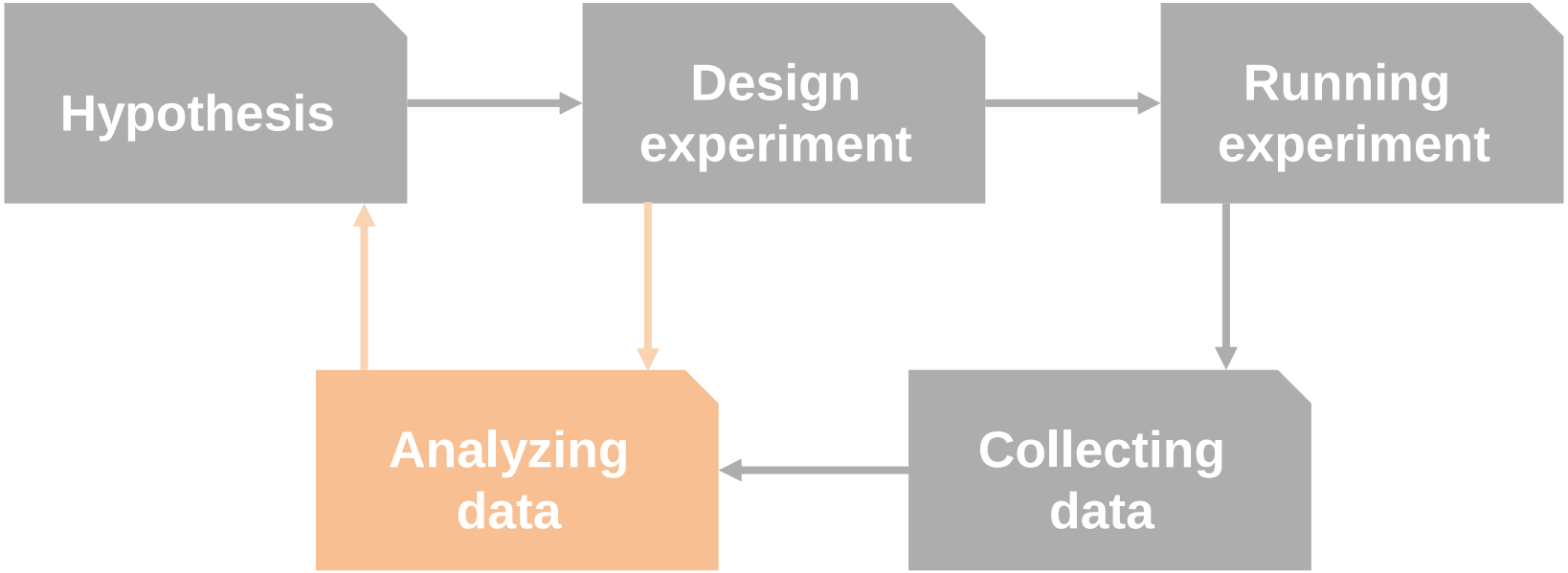
Typical measurement life cycle



Typical measurement life cycle



Typical measurement life cycle



There are two types of experiments

How to test a hypothesis

Uncontrolled experiments

Factor of interest varies outside the control of the researcher and independent of the research question.

Controlled experiments

You vary one factor of interest, then you measure the outcome.

There are two types of measurements

How data are collected

Passive measurements

You observe data that is collected independently of your experiment.

Active measurements

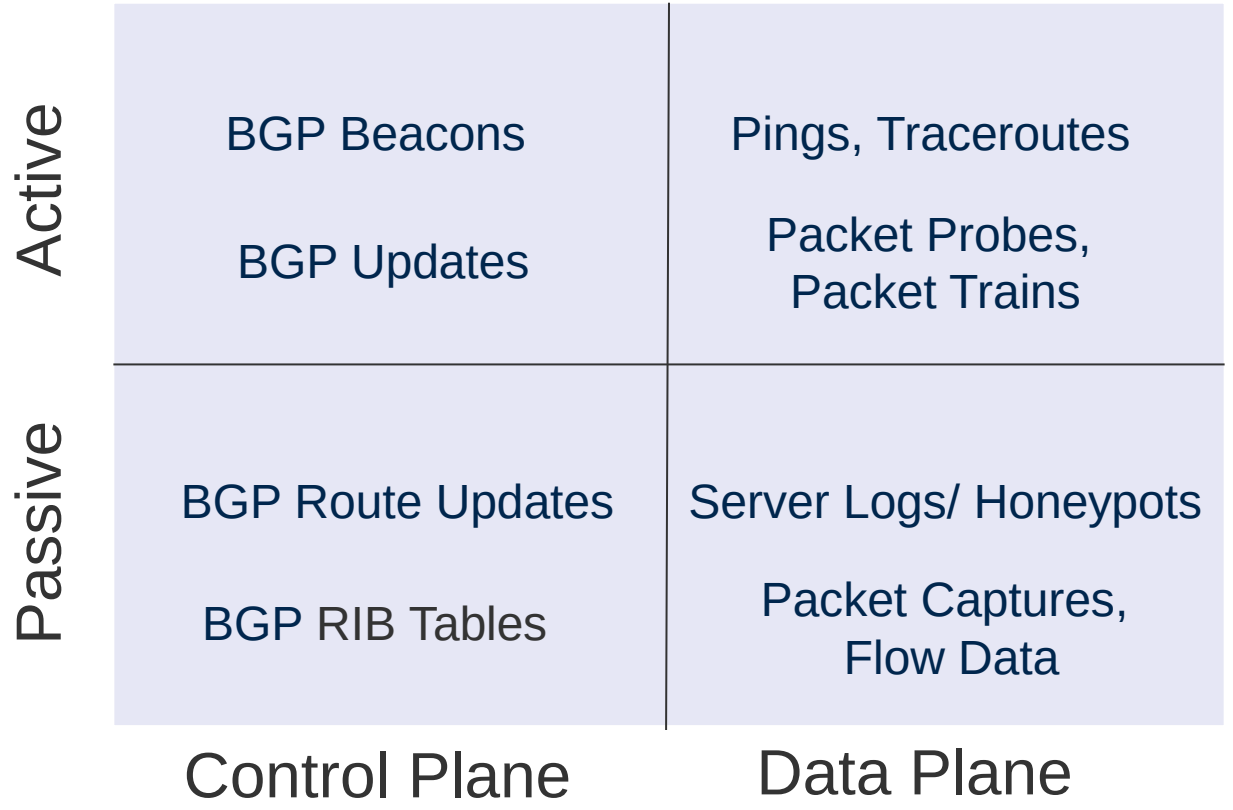
You inject probe traffic in the network. More intrusive.

Classification of controlled versus uncontrolled describes **experiments** (**how to test a hypothesis**) is orthogonal to the classification of passive versus active **measurements** (**how data are collected**), and passive versus active measurements are orthogonal to control plane versus data plane measurements (**what data are collected**).

Example: Distribution of IP path lengths

Passive measurement	Each node dumps forwarding table periodically
Active measurement	External node performs traceroutes
Uncontrolled experiment	Analysis of external (traceroute/FIB) dumps
Controlled experiment	You select the nodes that dump information, or the destinations
Data plane	Forwarding information base or traceroute replies
Control plane	BGP dumps

Common data sets



Human subject experiments

Likely require approval by an institutional review board (IRB) or ethics panel

You should document key considerations for protecting human subjects that anybody replicating your study should be aware of

See “The Menlo Report: Ethical Principles Guiding Information and Communication Technology,” 2012, and “Applying Ethical Principles to Information and Communication Technology Research: A Companion to the Menlo Report,” 2013

Good example: Spamaltyics [CCS'08]

Study	Analyze the conversion rate of spam campaigns
Approach	Infiltrate a botnet of spam campaigns, manipulate spam messages being relayed through systems under control of researchers
Justification	Neutral actions that strictly reduce harm

Bad examples: Password discovery and Internet Census 2012

Study	(1) Show vulnerability based on default or non-existent passwords (2) Find active IP addresses
Approach	(1) Brute force scanning and dictionary attack (2) Create a scanning botnet
Justification	(1) Not showing how to hack, rather how easy. (2) No justification.