USC Viterbi
School of Engineering
Department of Computer Science

Towards Impactful Internet Measurement

I want to use your measurements; please run them forever

Ethan Katz-Bassett
University of Southern California

With my students Matt Calder, Yi-Ching Chiu, Tobias Flach, Brandon Schlinker and:
USC/ISI (Ramesh Govindan, John Heidemann, Xun Fan), Princeton (Nick Feamster), UFMG (Italo Cunha, Bruno Vinicius), Google (Nandita Dukkipati, Andreas Terzis, Barath Raghavan, Neal Cardwell, Yuchung Cheng, Ankur Jain)

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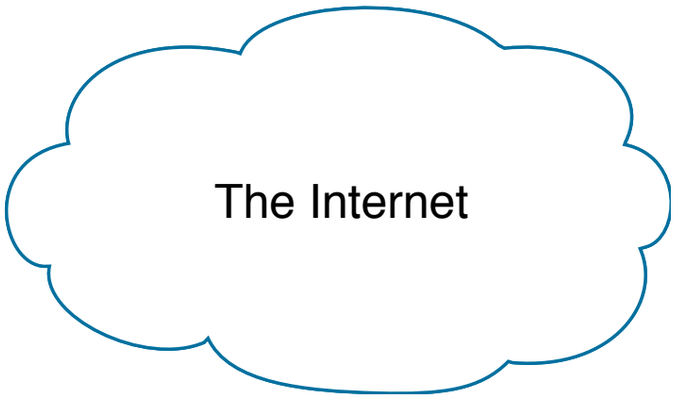
Internet Measurement

An Internet Measurement Conference (IMC) paper:



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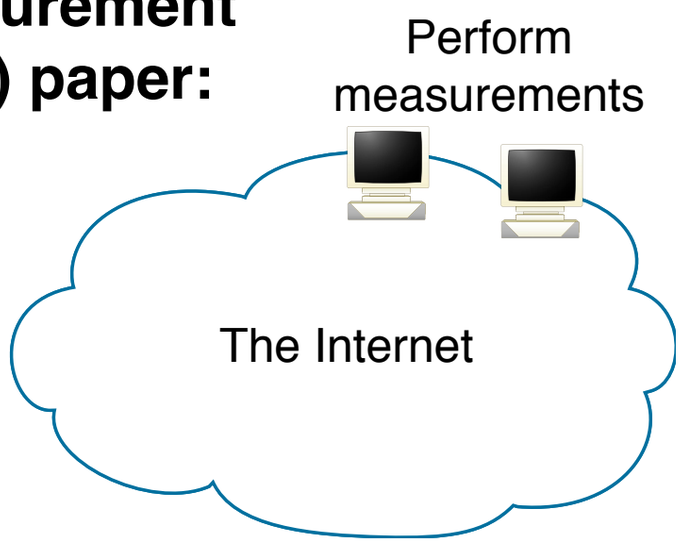

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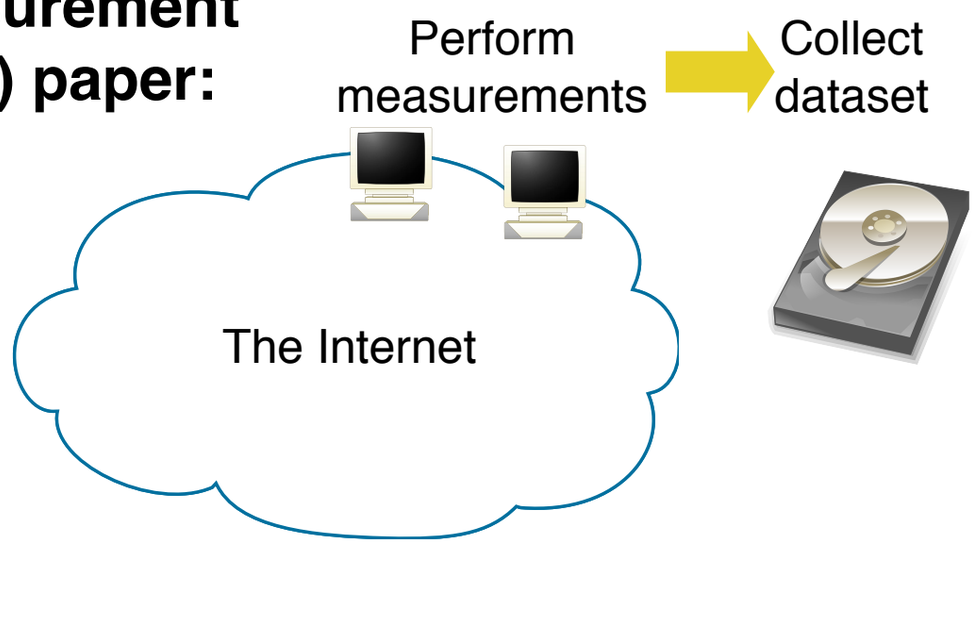

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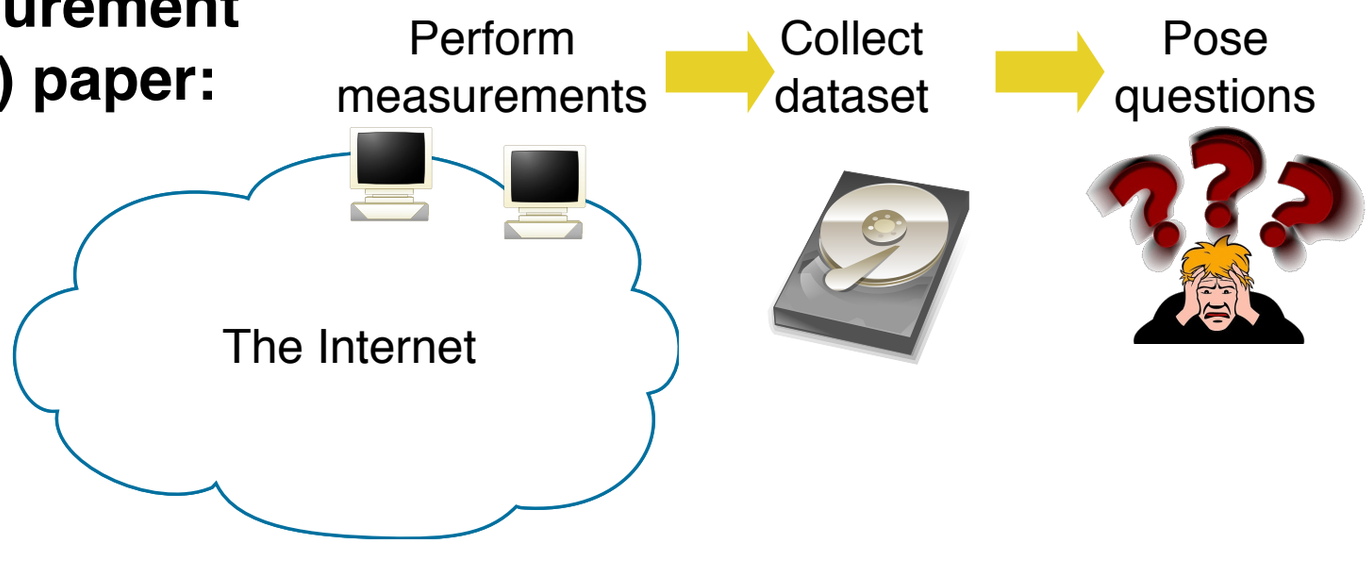

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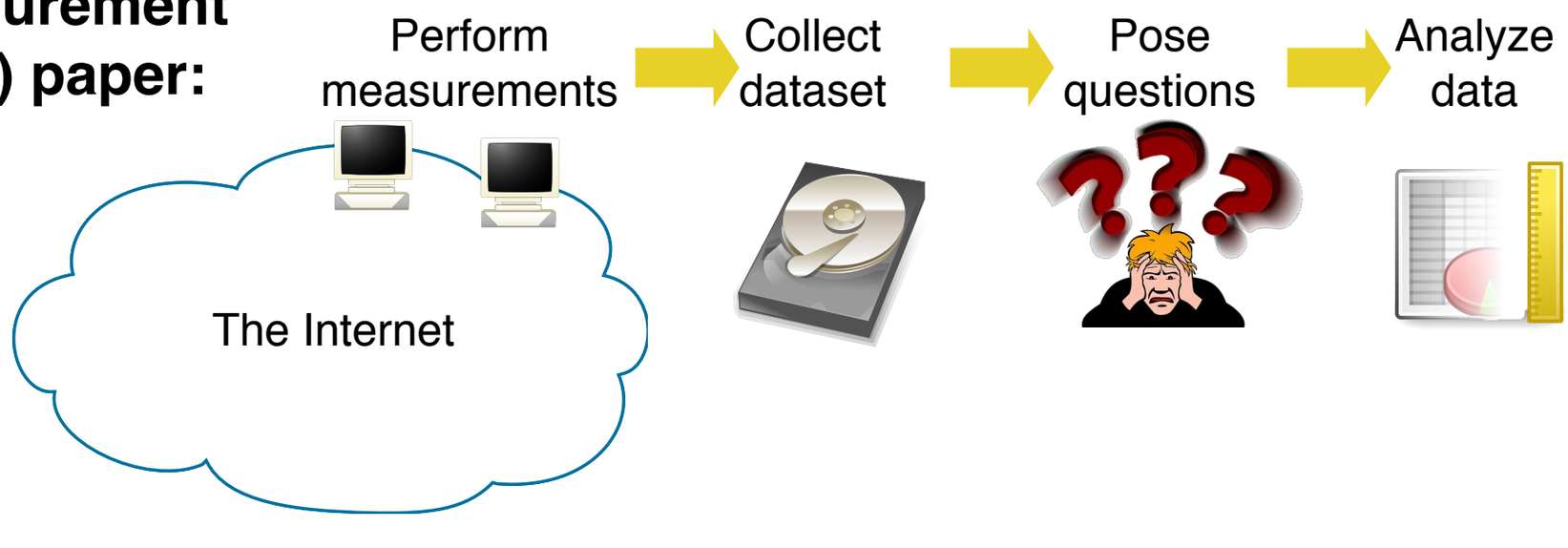

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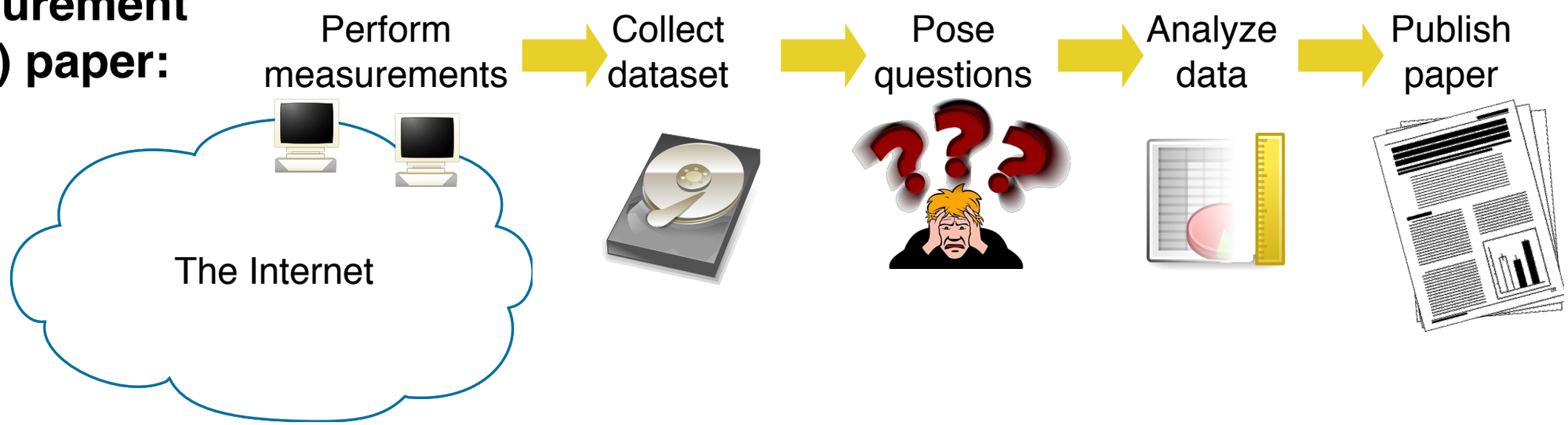

Impactful Internet Measurement

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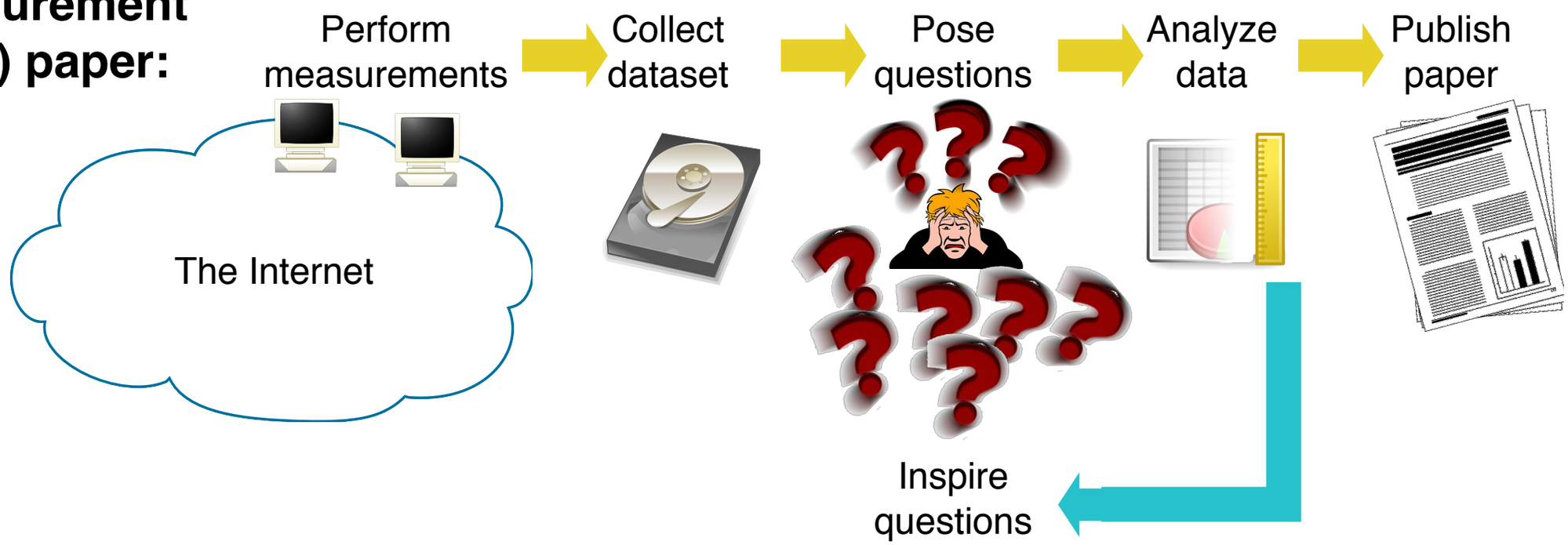

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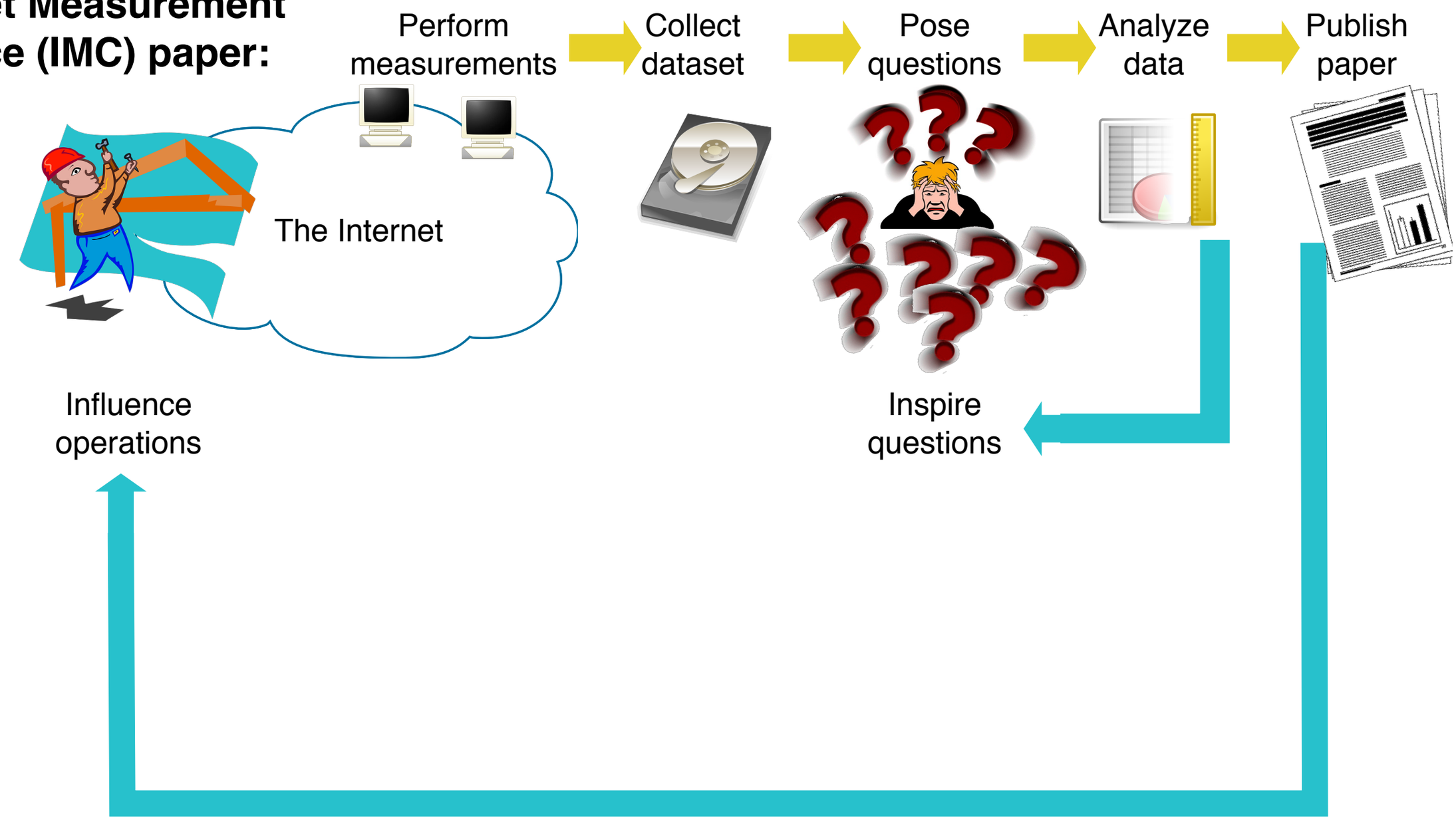

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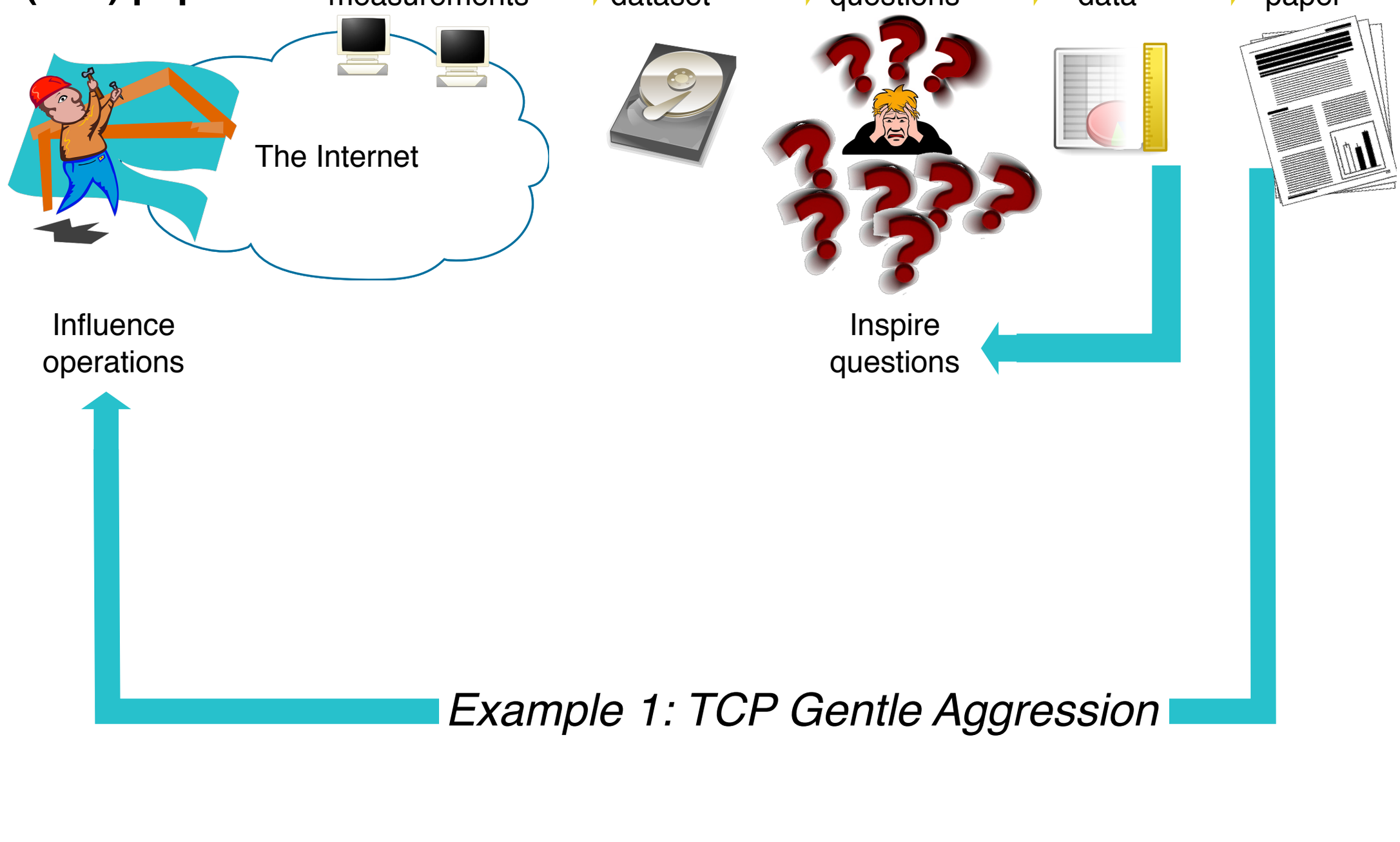

Impact:

Example 1: TCP Gentle Aggression

Outline

1. *What does an Internet measurement research paper involve?*
2. *What might an impactful Internet measurement paper involve?*
   - *One model: Measurement results influence Internet operations*
     - ***Example 1: TCP Gentle Aggression***
   - ***Challenges in measurement***
3. How can one address challenges and have impact?
   - One model: Provide long-running measurements, tools, and testbeds
     - Example 2: Mapping Google's Expansion
     - Example 3: PEERING BGP testbed
   - Benefits…and drawbacks… of providing long-running services
4. How can the community encourage long-running services?

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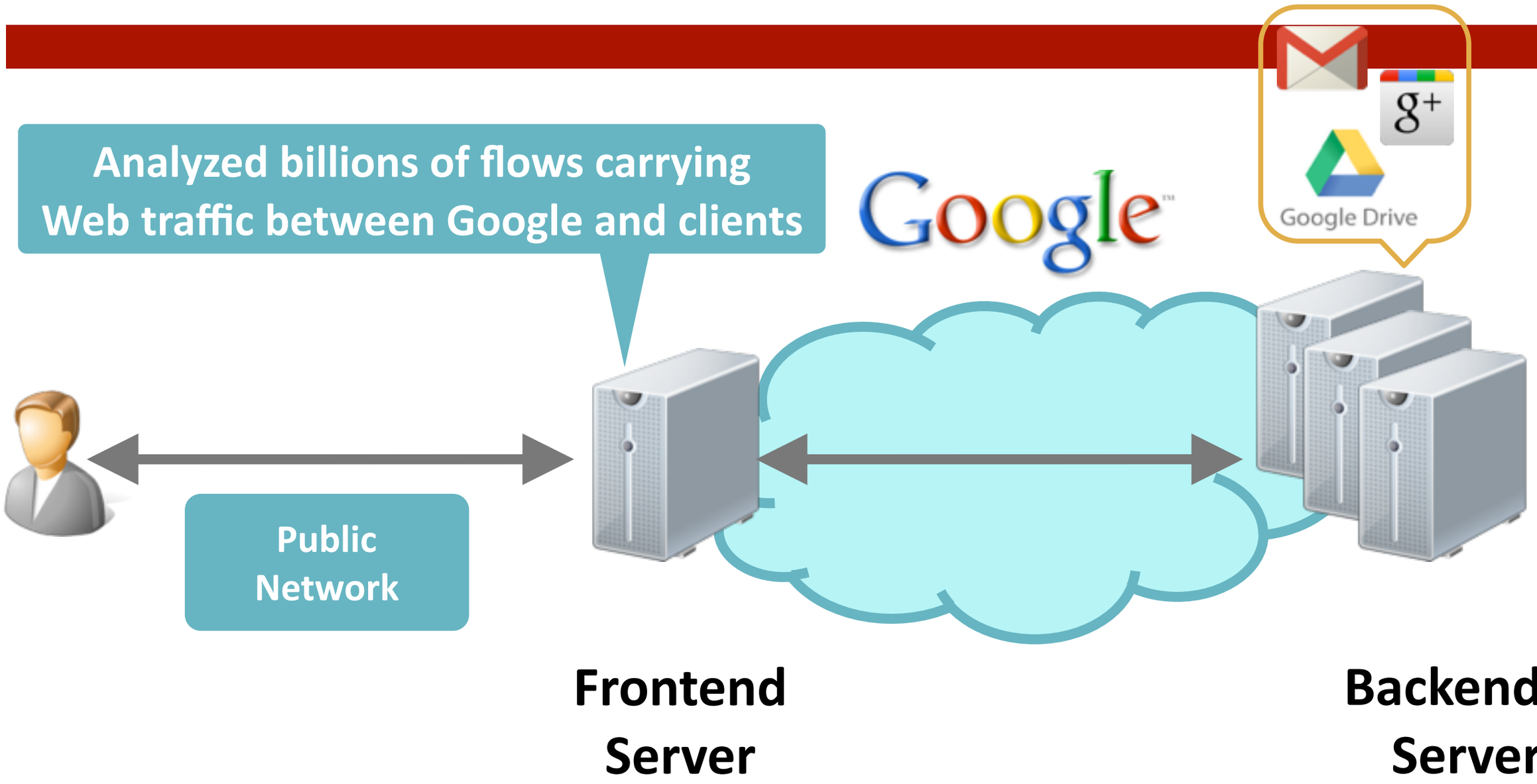
Reducing Web Latency via TCP Gentle Aggression

An IMC + IRTF Love Story*

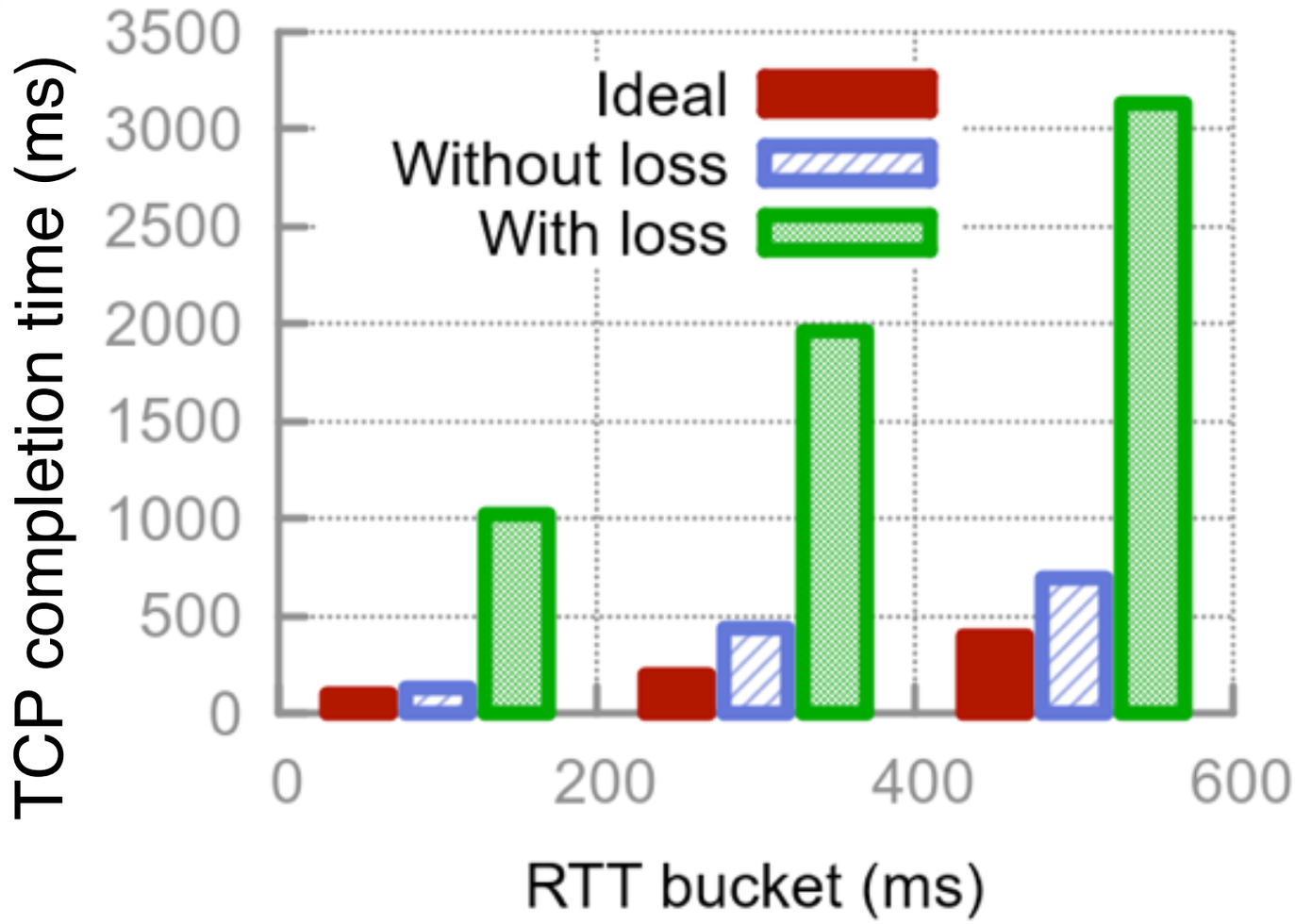
* actually appeared at SIGCOMM 2013

How Is Google's TCP Performance?

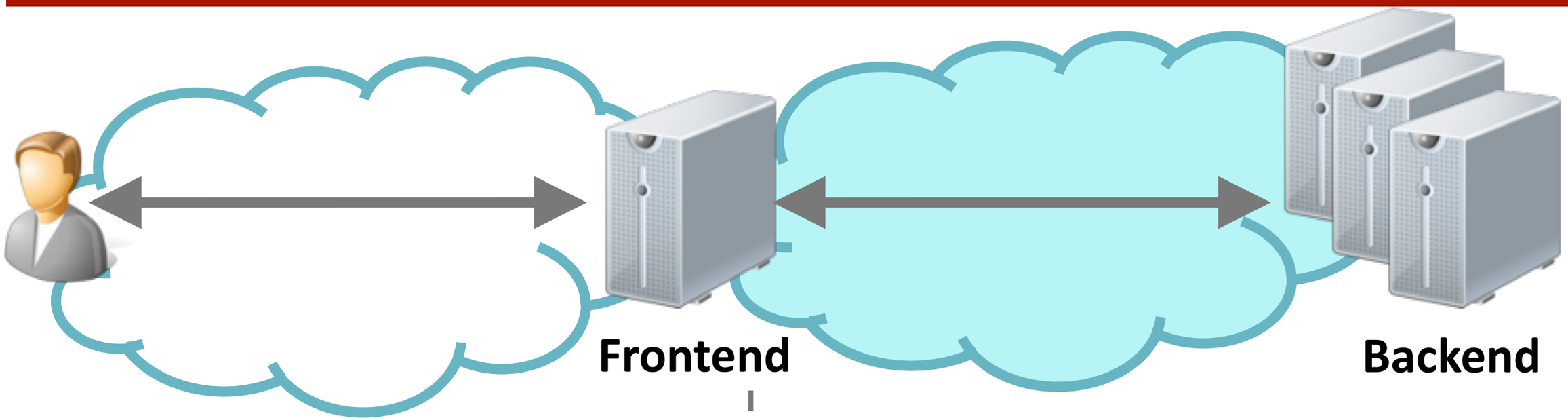


Losses Hurt Web Latency

- Google is very fast if there is no loss!
- …but loss makes web latency 5 times slower
  - Delays caused by TCP loss detection and recovery
  - 6% of transfers between Google and clients experience loss

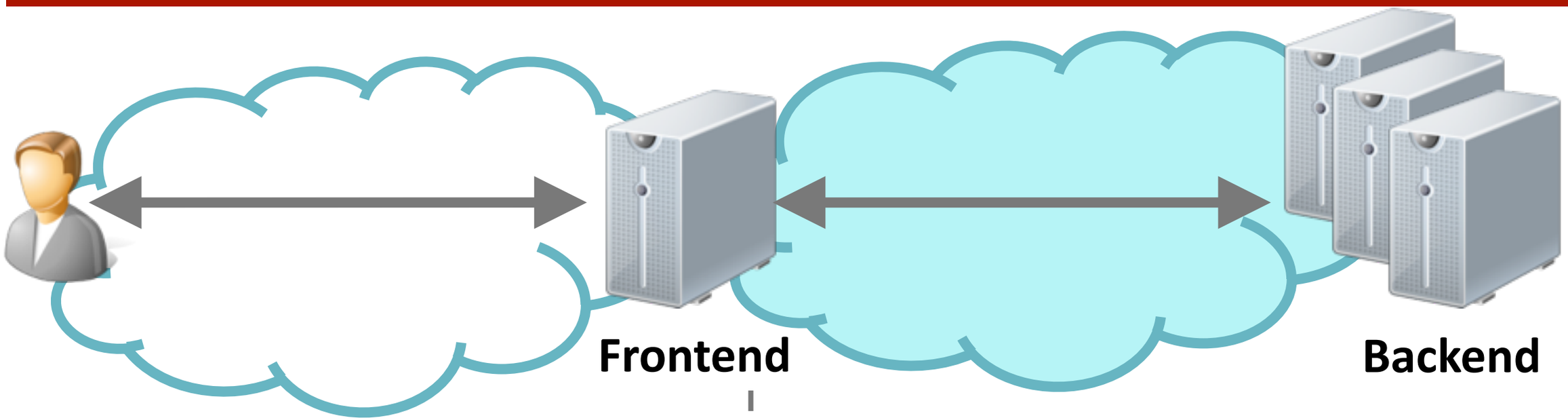


Tailor Loss Recovery to Setting



Public Network	Private Network
Control server only	Control client, server, network
Must be compatible with existing clients & middleboxes	Latency-sensitive traffic is a small portion of traffic mix

Tailor Loss Recovery to Setting



Public Network

Reactive

Faster loss detection by probing for tail losses

Must be compatible with existing clients & middleboxes

Private Network

Proactive

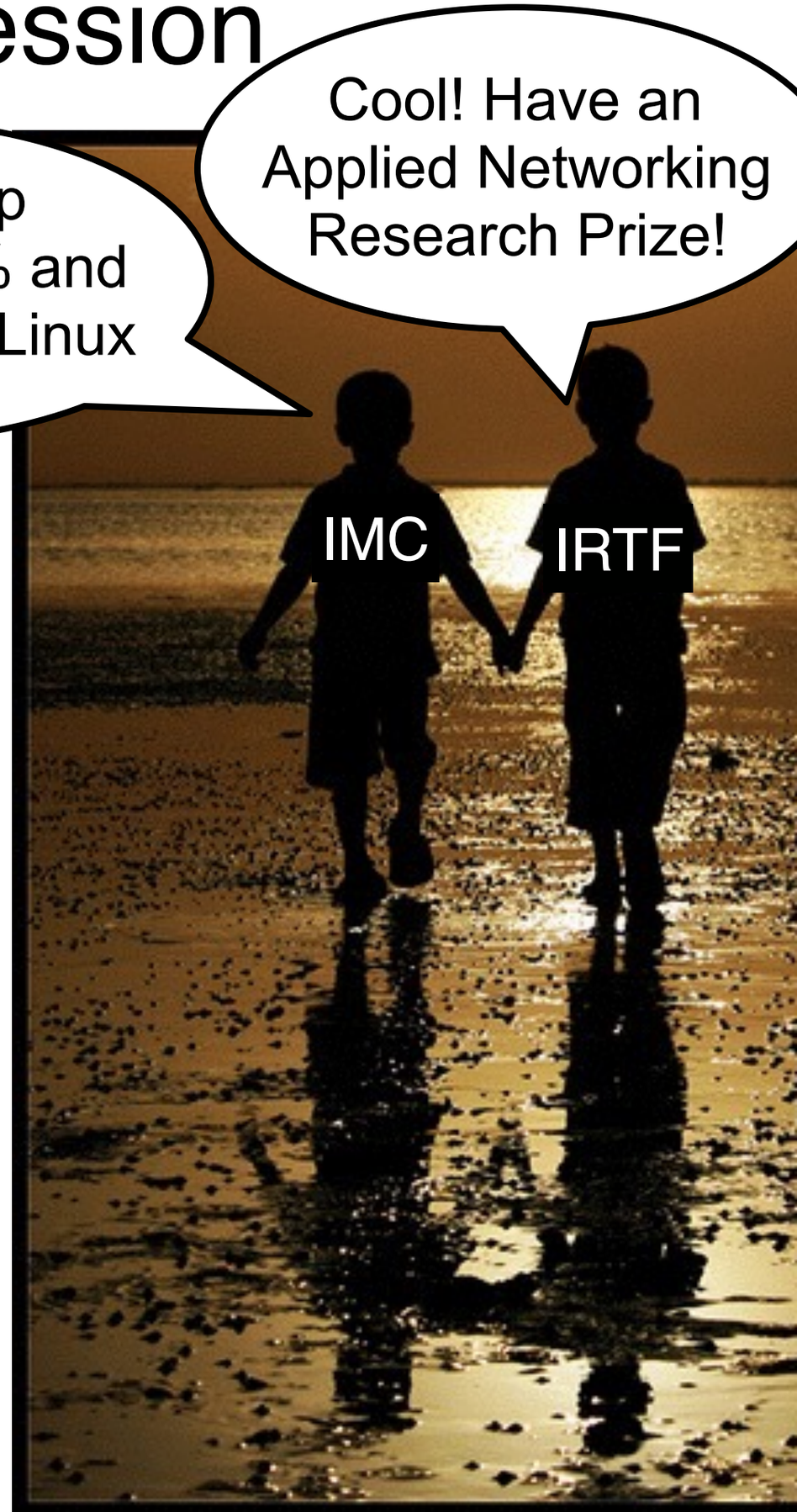
Avoid need for loss handling by sending original packets twice

Latency-sensitive traffic is a small portion of traffic mix

Impact of TCP Gentle Aggression

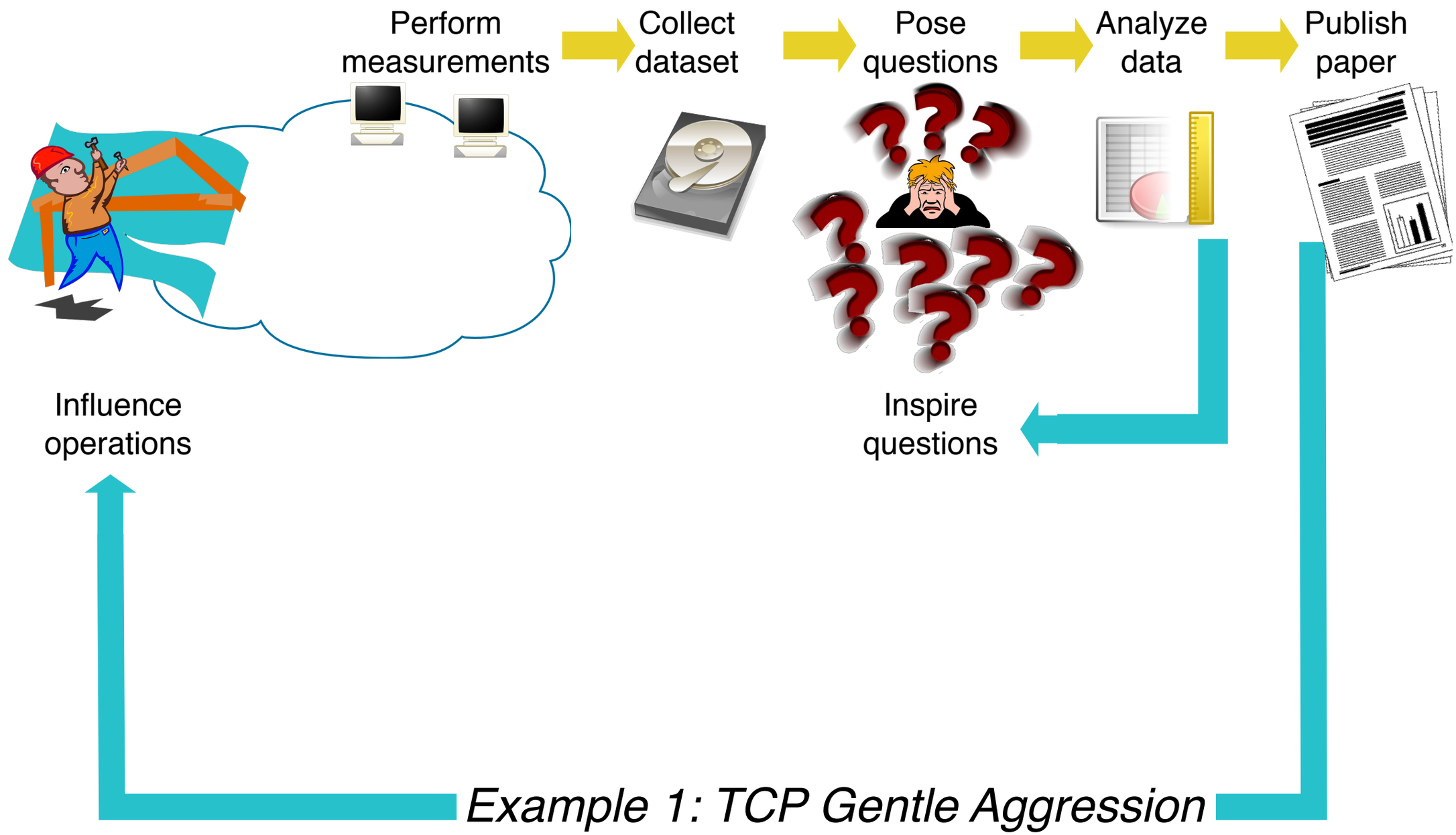
- Impact at Google
  - Mean response time reduced by 23%
  - 99th percentile reduced by 47%

Impact of TCP Gentle Aggression



- Impact at Google
  - Mean response time reduced by 23%
  - 99th percentile reduced by 47%
- Impact outside Google
  - 1 technique default on in Linux 3.10+
  - 2014 ISOC/IRTF Applied Networking Research Prize
  - 2 techniques sent as IETF Drafts (since expired)

What enabled Gentle Aggression's impact?

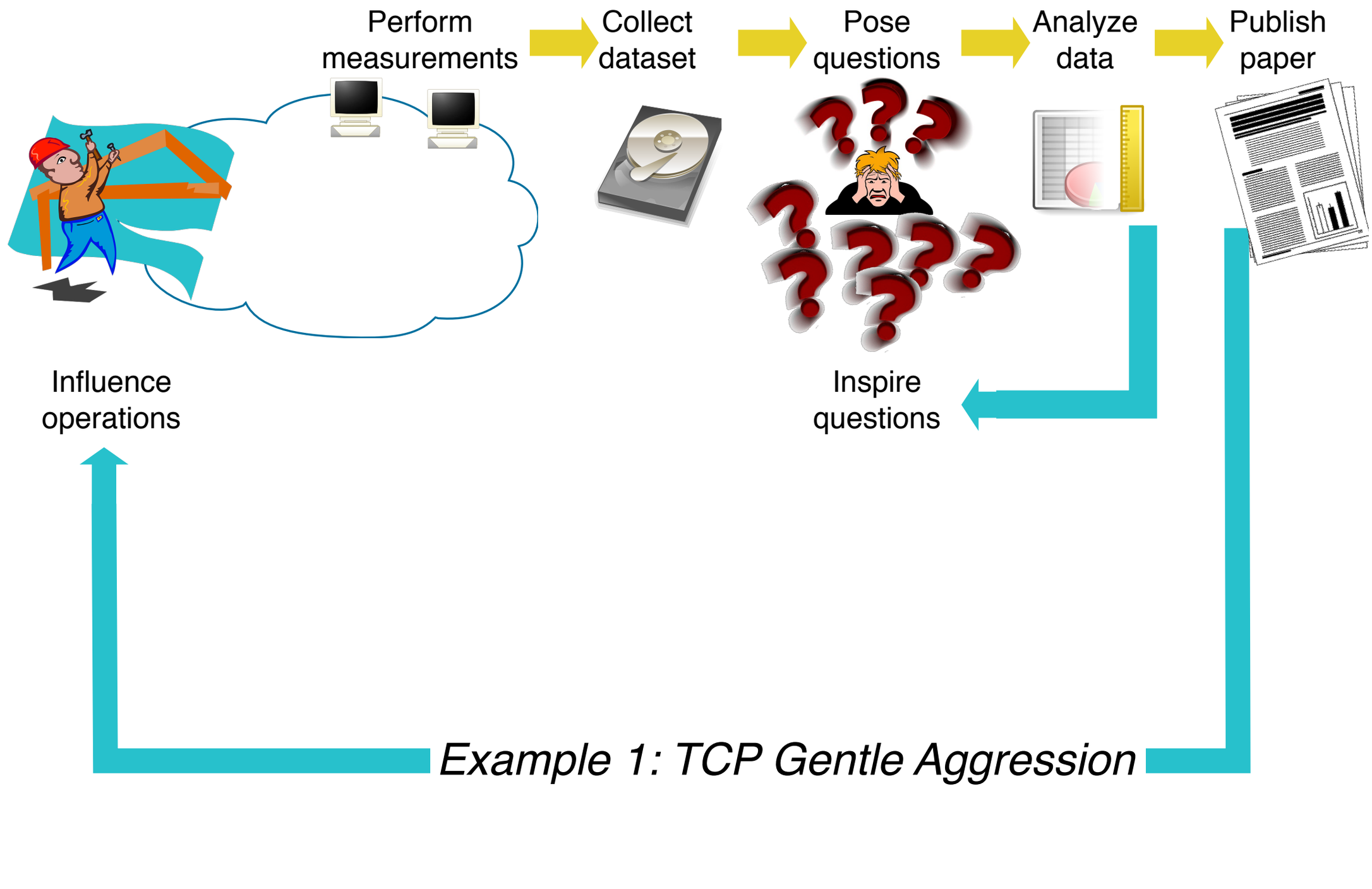


Impact:

Example 1: TCP Gentle Aggression

What enabled Gentle Aggression's impact?

Appropriate data & vantage points



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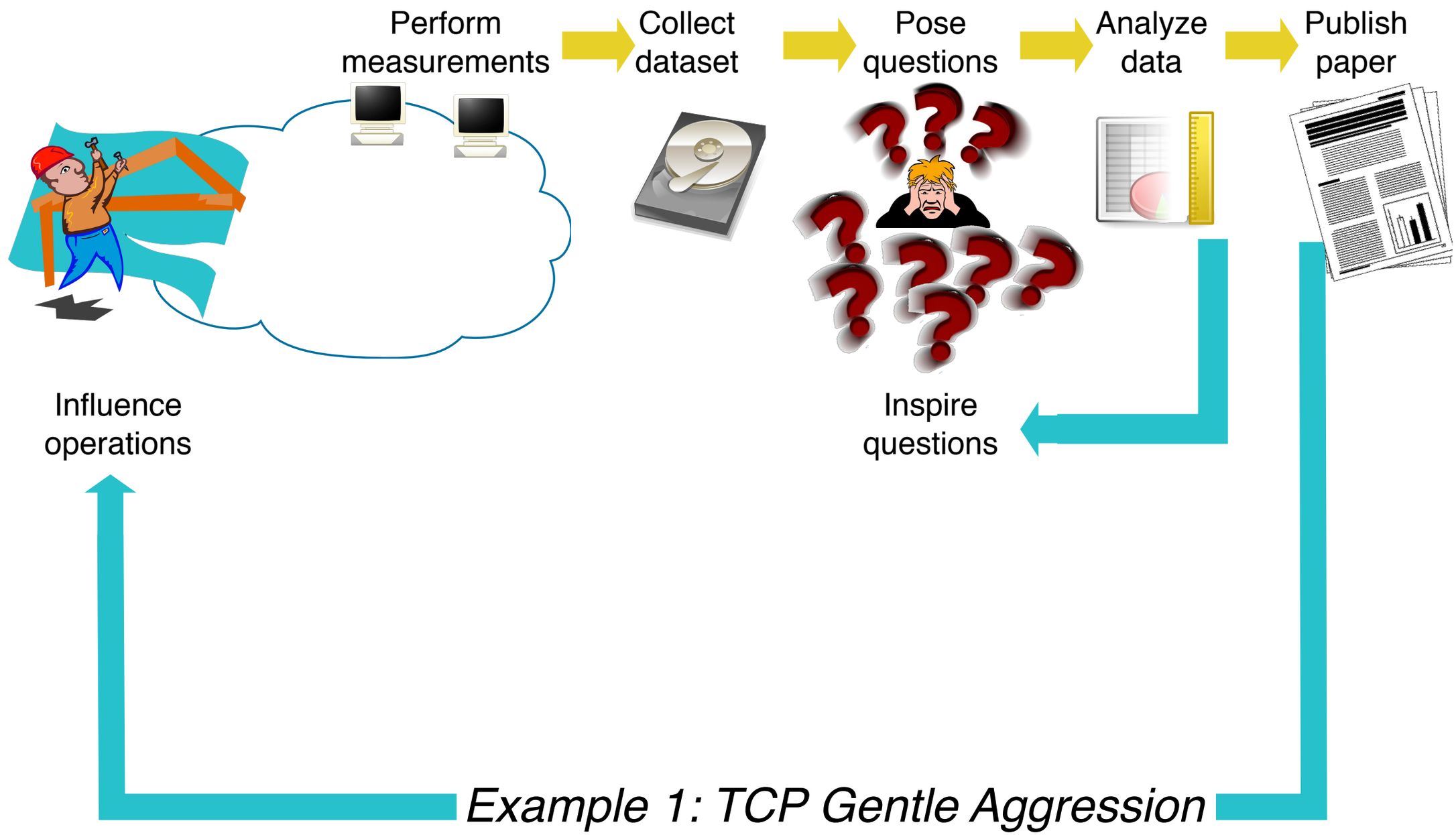
What enabled Gentle Aggression's impact?

Appropriate data & vantage points	Real problem from Google



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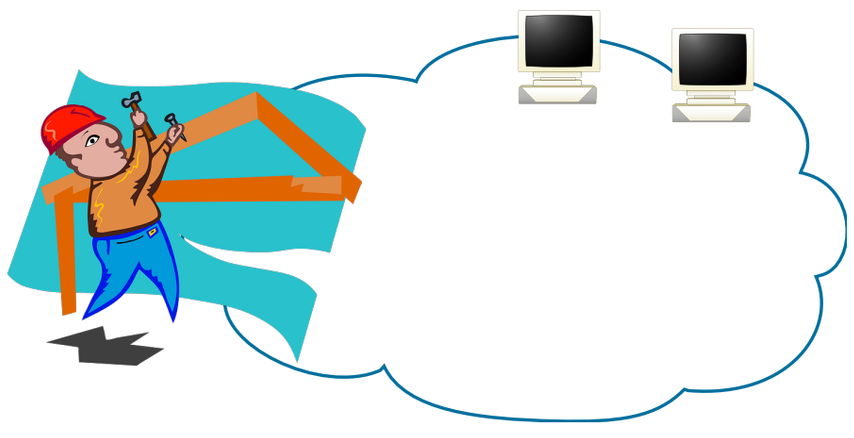
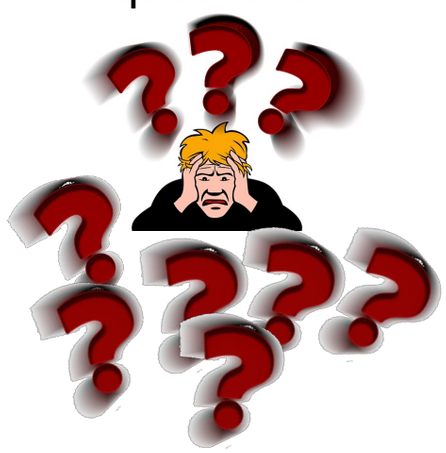
Example 1: TCP Gentle Aggression

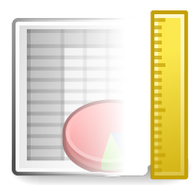
What enabled Gentle Aggression's impact?

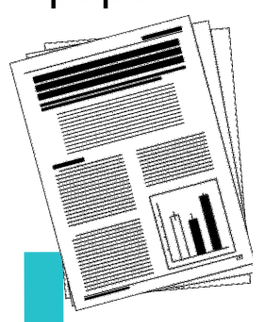
Appropriate data & vantage points	Real problem from Google

Perform measurements → Collect dataset → Pose questions → Analyze data → Publish paper









Inspire questions

Influence operations

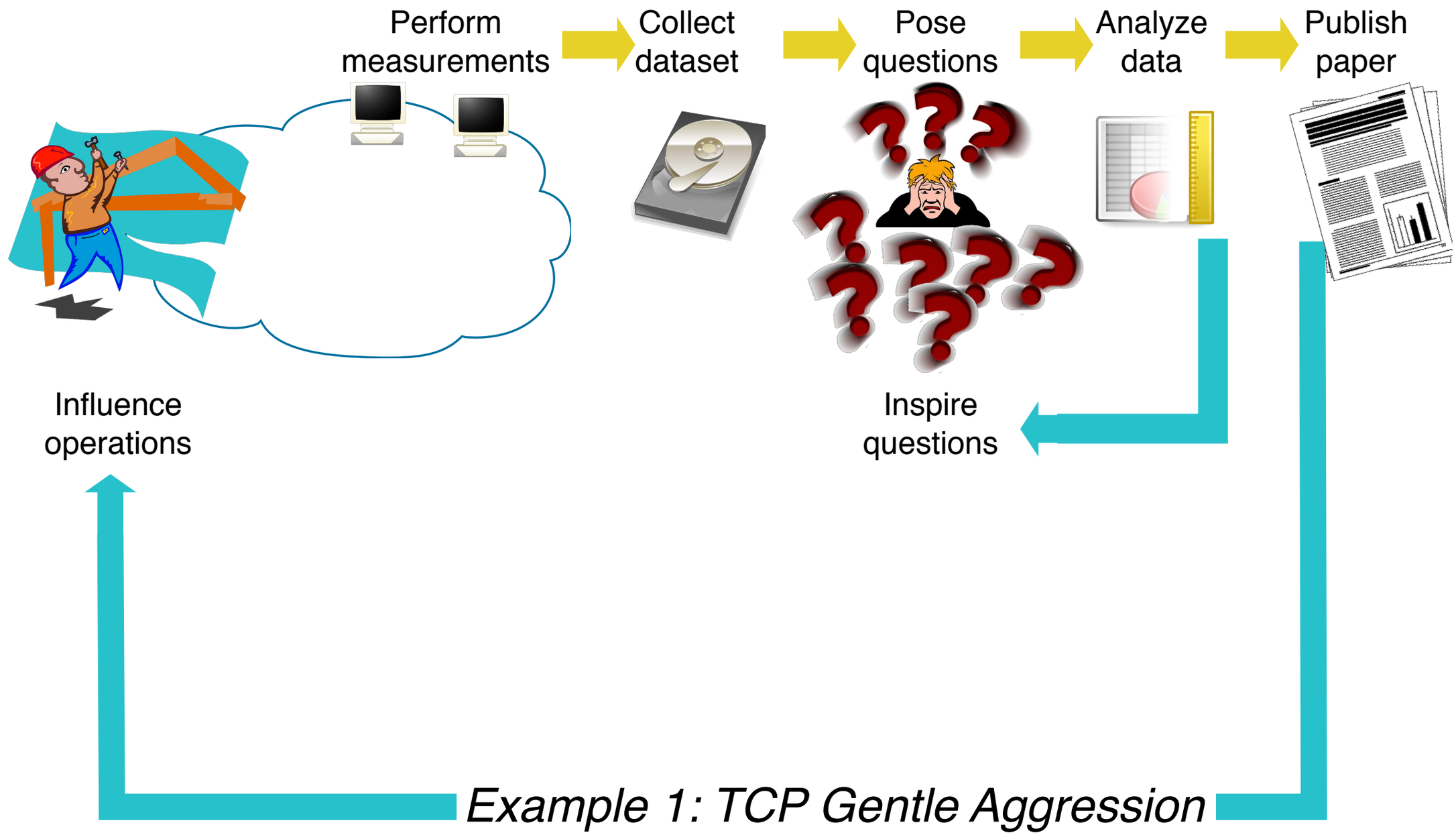
Impact:

Pathway to deployment

Example 1: TCP Gentle Aggression

Why can this impact be hard to achieve?

Challenges: Pathway to deployment | Appropriate data & vantage points | Real problem from Google



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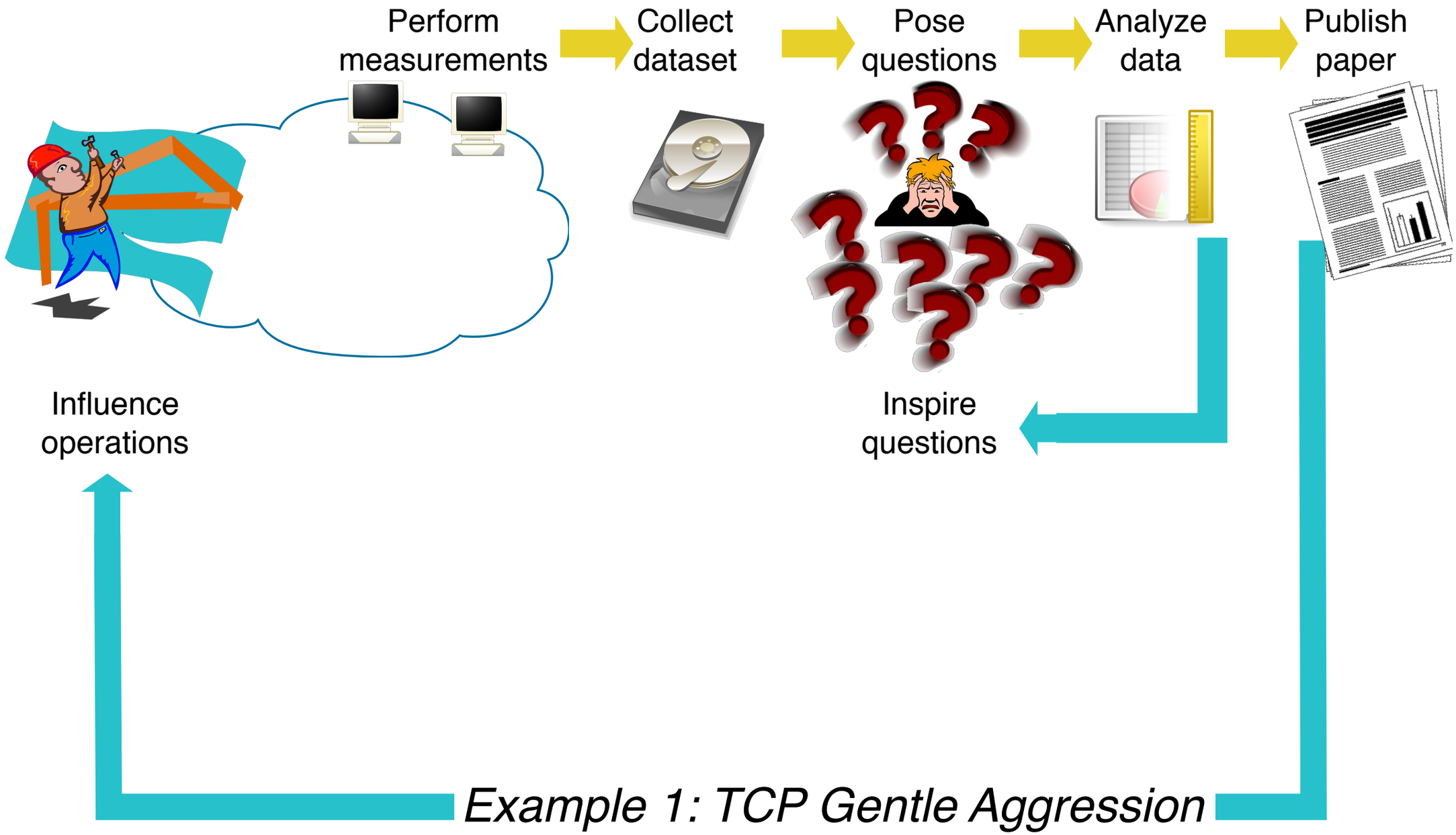
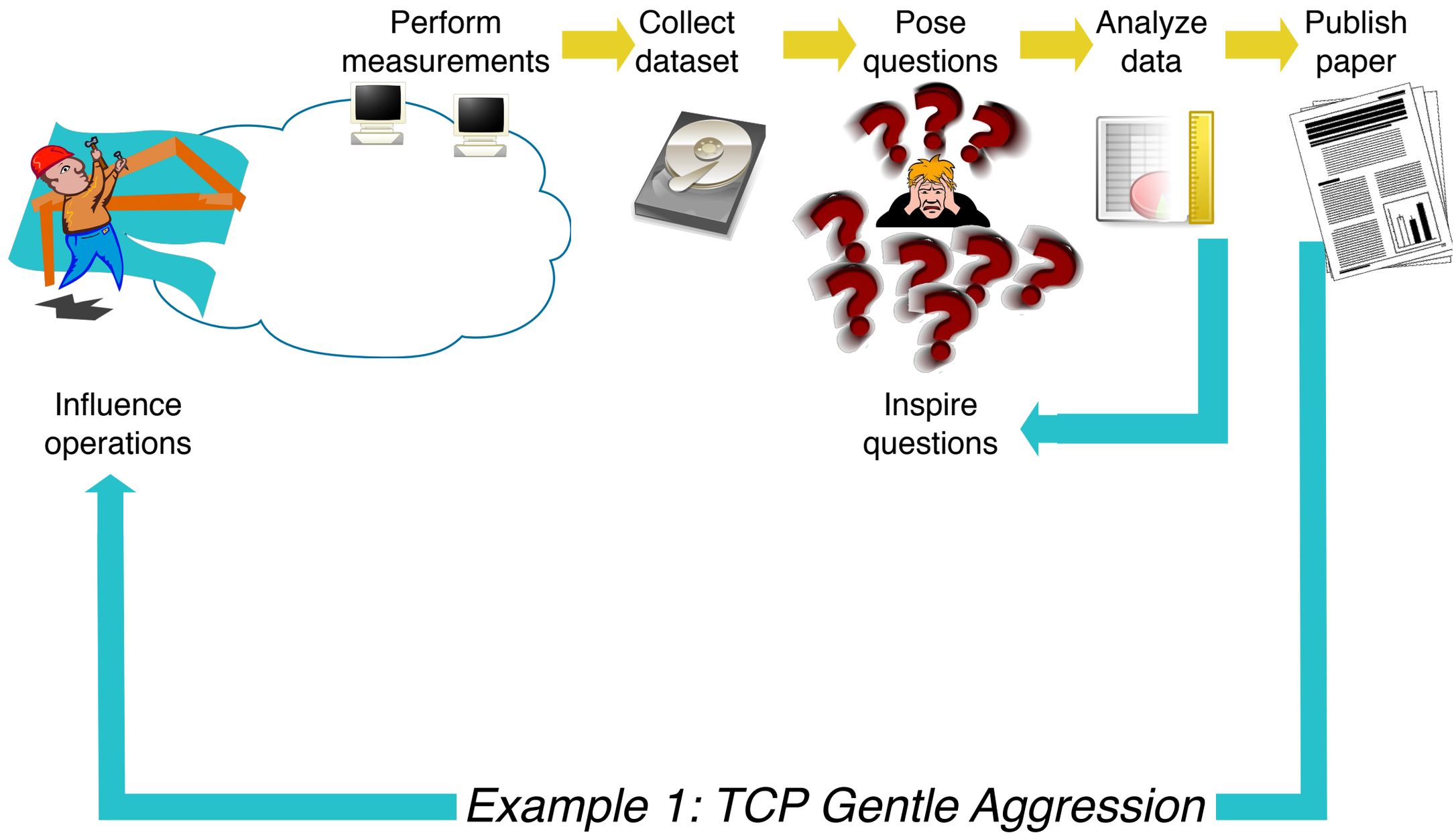


Example 1: TCP Gentle Aggression

Why can this impact be hard to achieve?

Challenges: **Limited options for evaluation** | Appropriate data & vantage points | Real problem from Google



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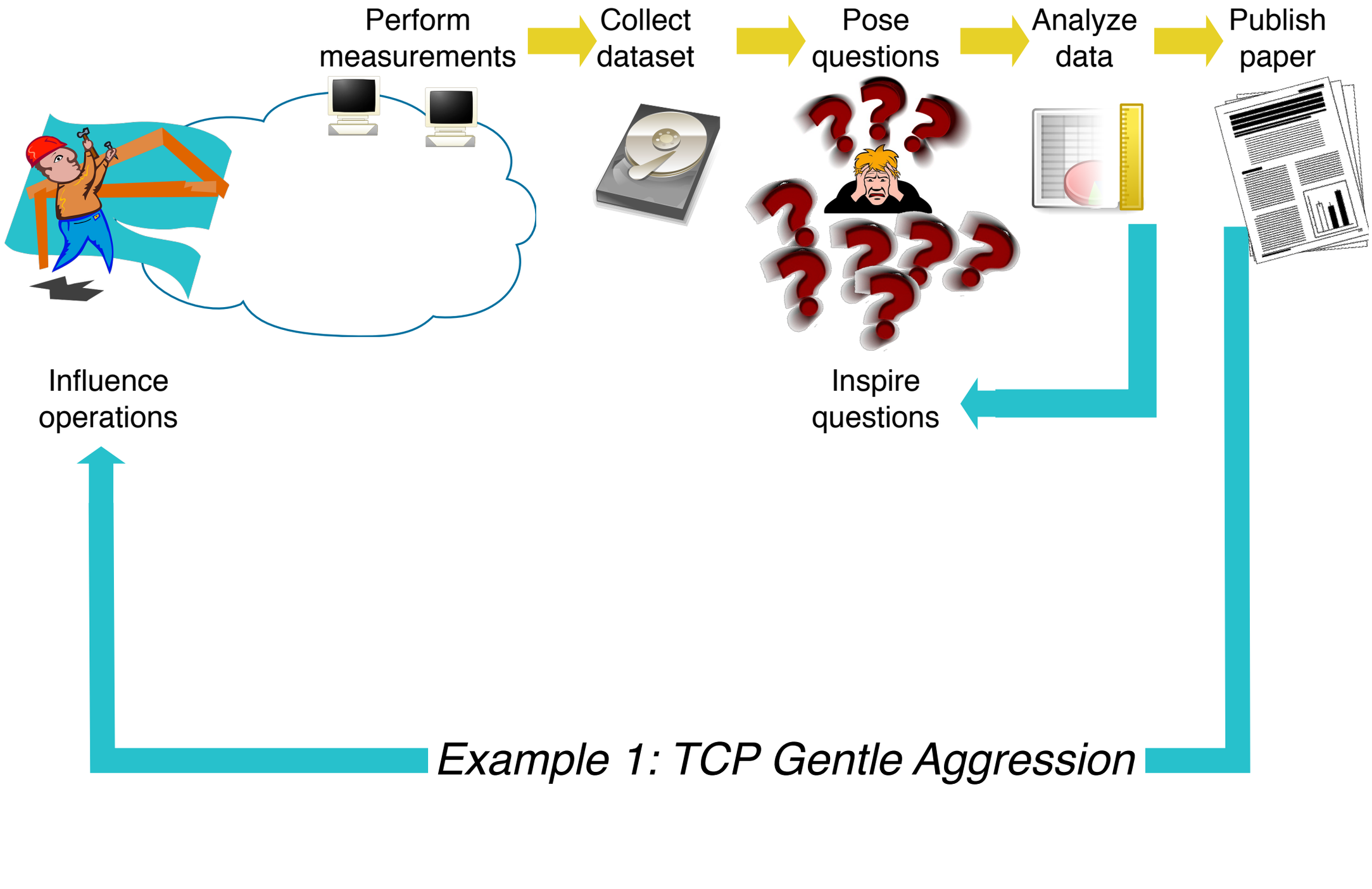

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Limited options for evaluation	**Limited data shapes analysis**	Real problem from Google

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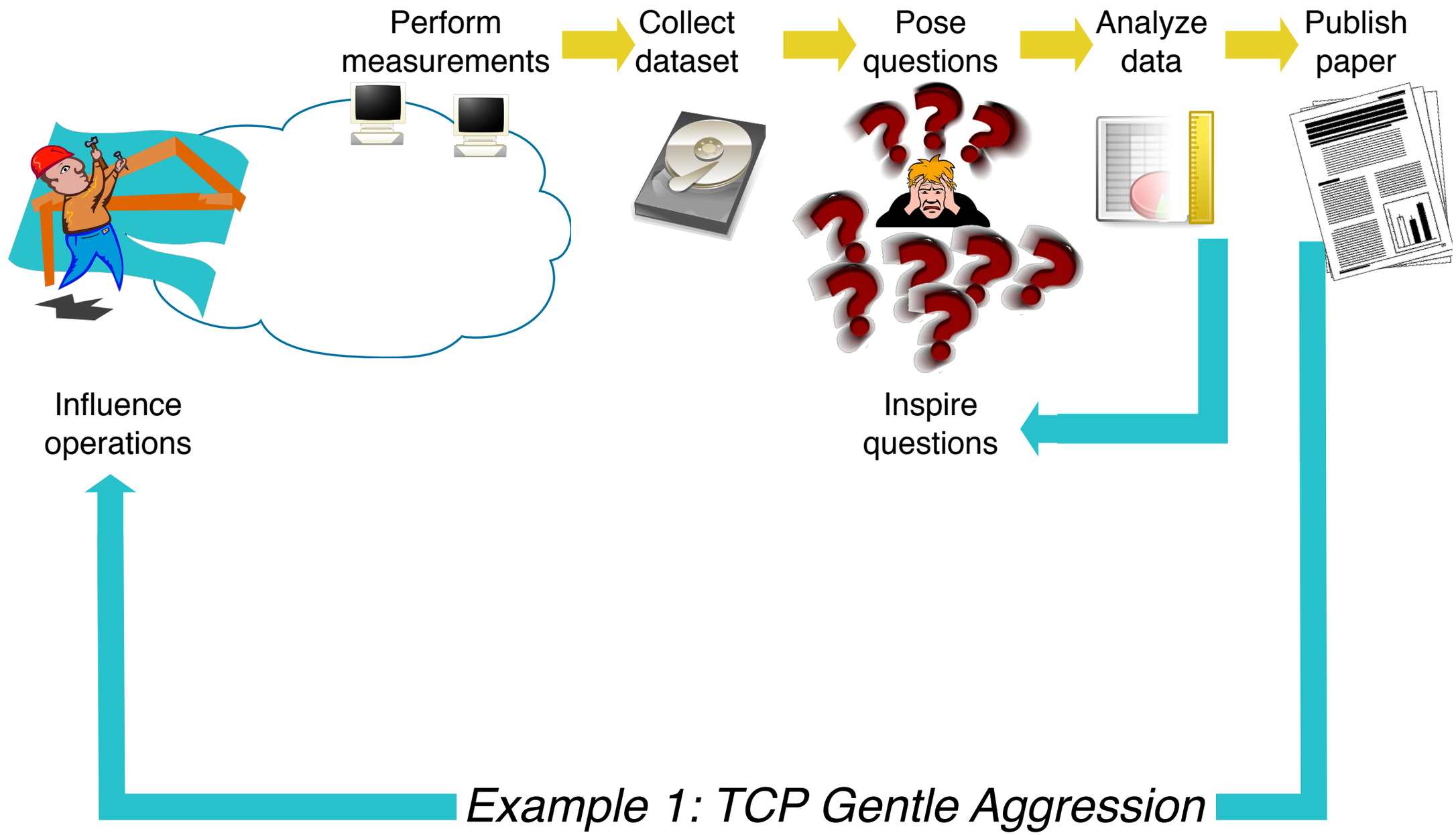

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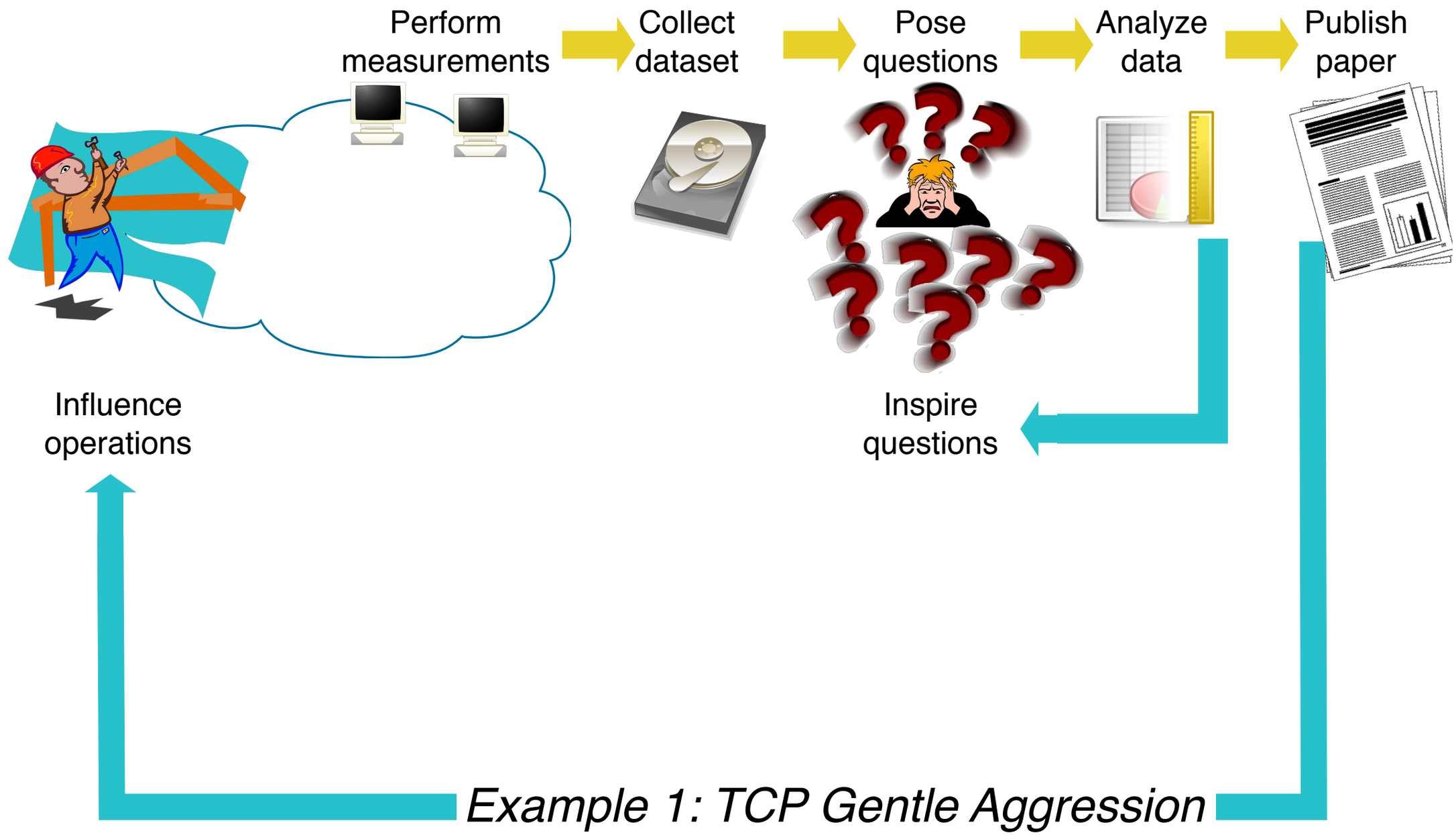

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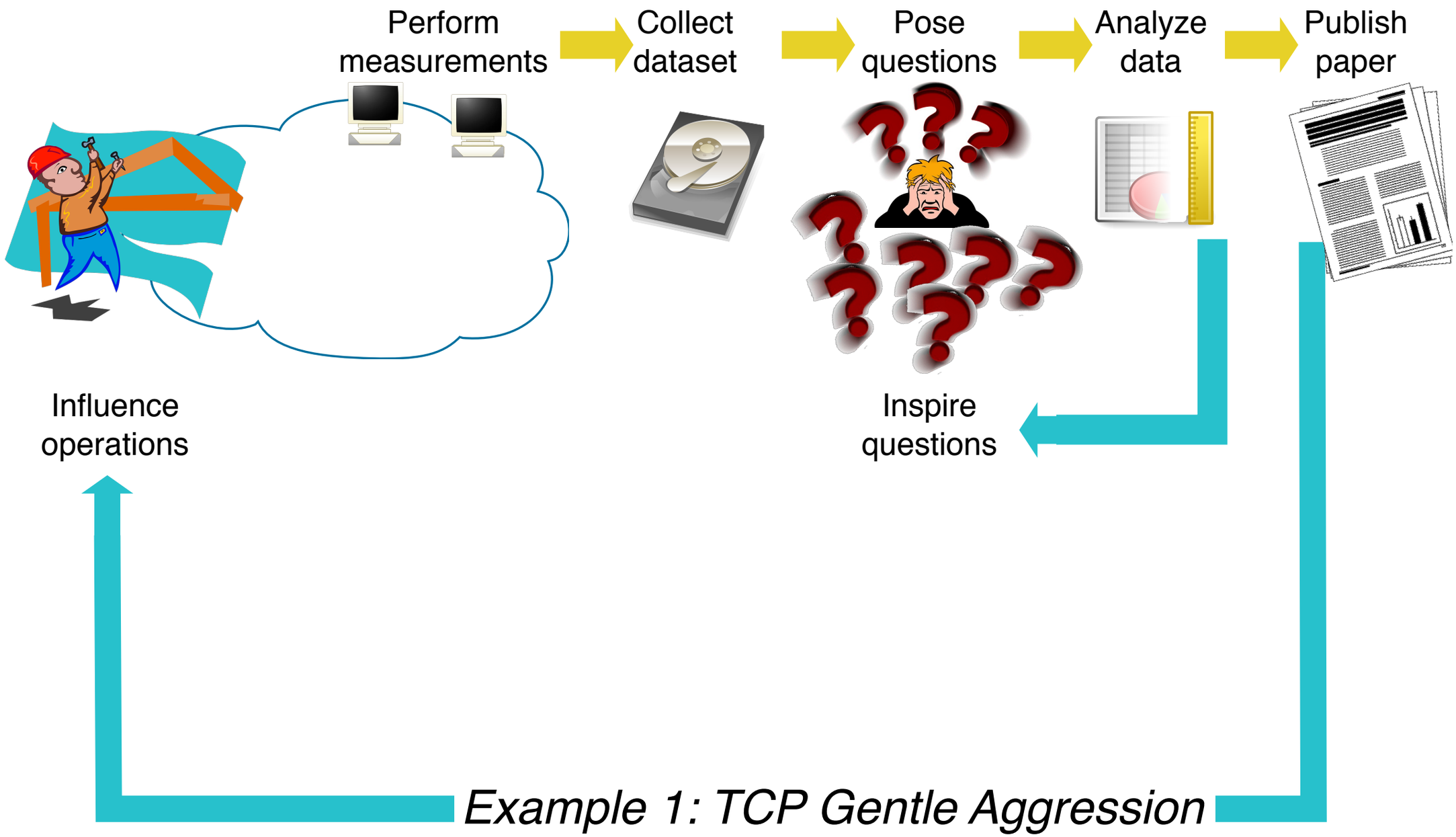

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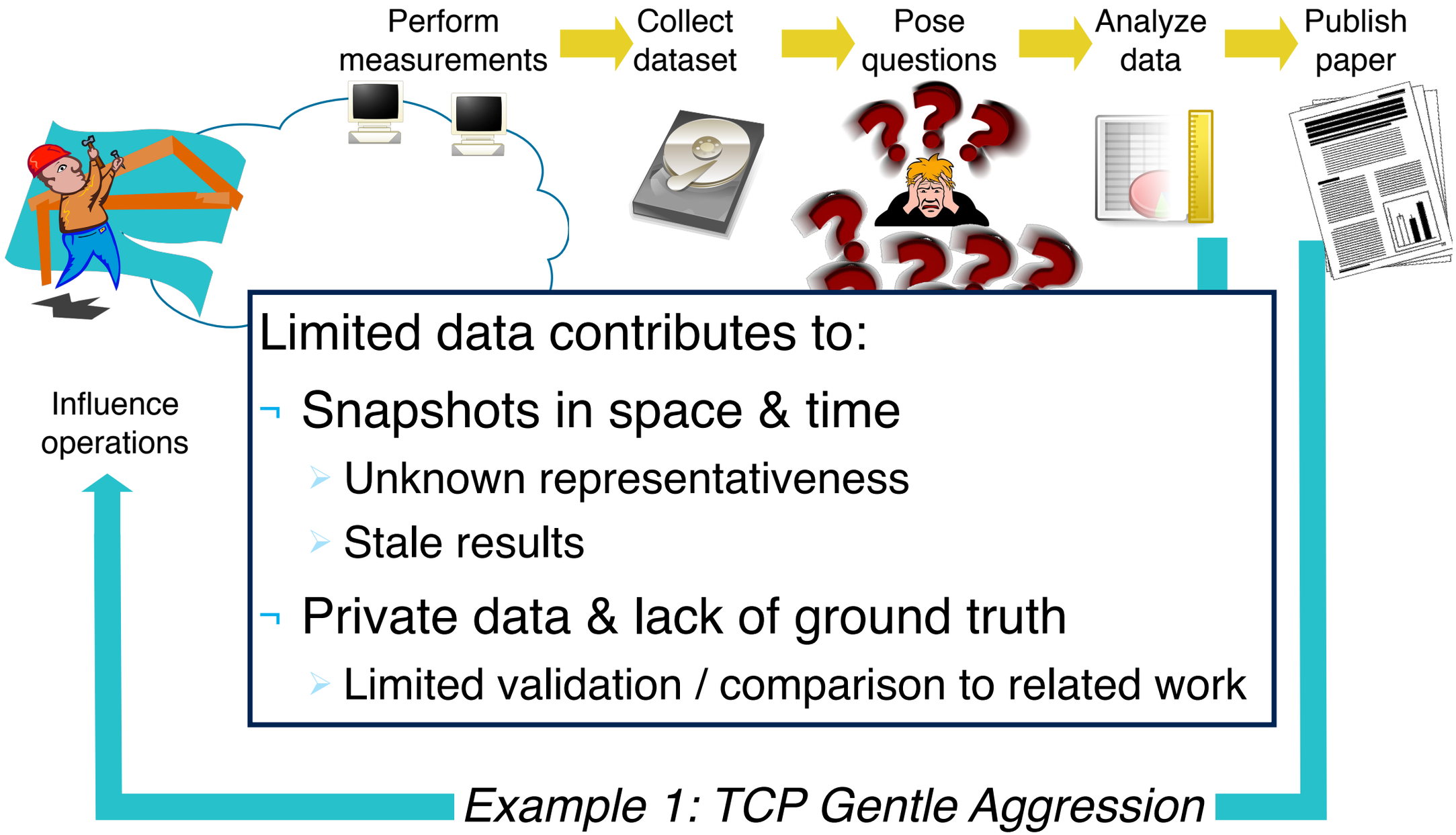

Impact:

Why can this impact be hard to achieve?

Limited data shapes analysis

Challenges:

Limited data contributes to:

- Snapshots in space & time
  - Unknown representativeness
  - Stale results
- Private data & lack of ground truth
  - Limited validation / comparison to related work

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"80% are 3+ AS hops long"

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"60% are 1 AS hop long, only 5% are 3+ long" *(from cloud to eyeballs)*

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How many locations does Google have web servers in?

"200 locations across 100 ASes" *(during IMC 2012)*

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How many locations does Google have web servers in?

"200 locations across 100 ASes" *(during IMC 2012)*

vs

"400 locations across 200 ASes" *(IMC 2013 submission)*

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How many locations does Google have web servers in?

"200 locations across 100 ASes" *(during IMC 2012)*

vs

"400 locations across 200 ASes" *(IMC 2013 submission)*

vs

"1400 locations across 800 ASes" *(during IMC 2013)*

Challenges:

Limited options for evaluation	Limited data shapes analysis	Limited visibility into operational concerns

How to increase impact of a measurement study, despite challenges?

From Internet measurement studies to Internet measurement services

Limited data contributes to:

- Snapshots in space & time
- Private data & lack of ground truth

Operating a study's measurements as a service can increase impact

1. Long-running, with periodically refreshed measurements
2. Public data, testbeds, and tools

Towards impactful Internet measurement

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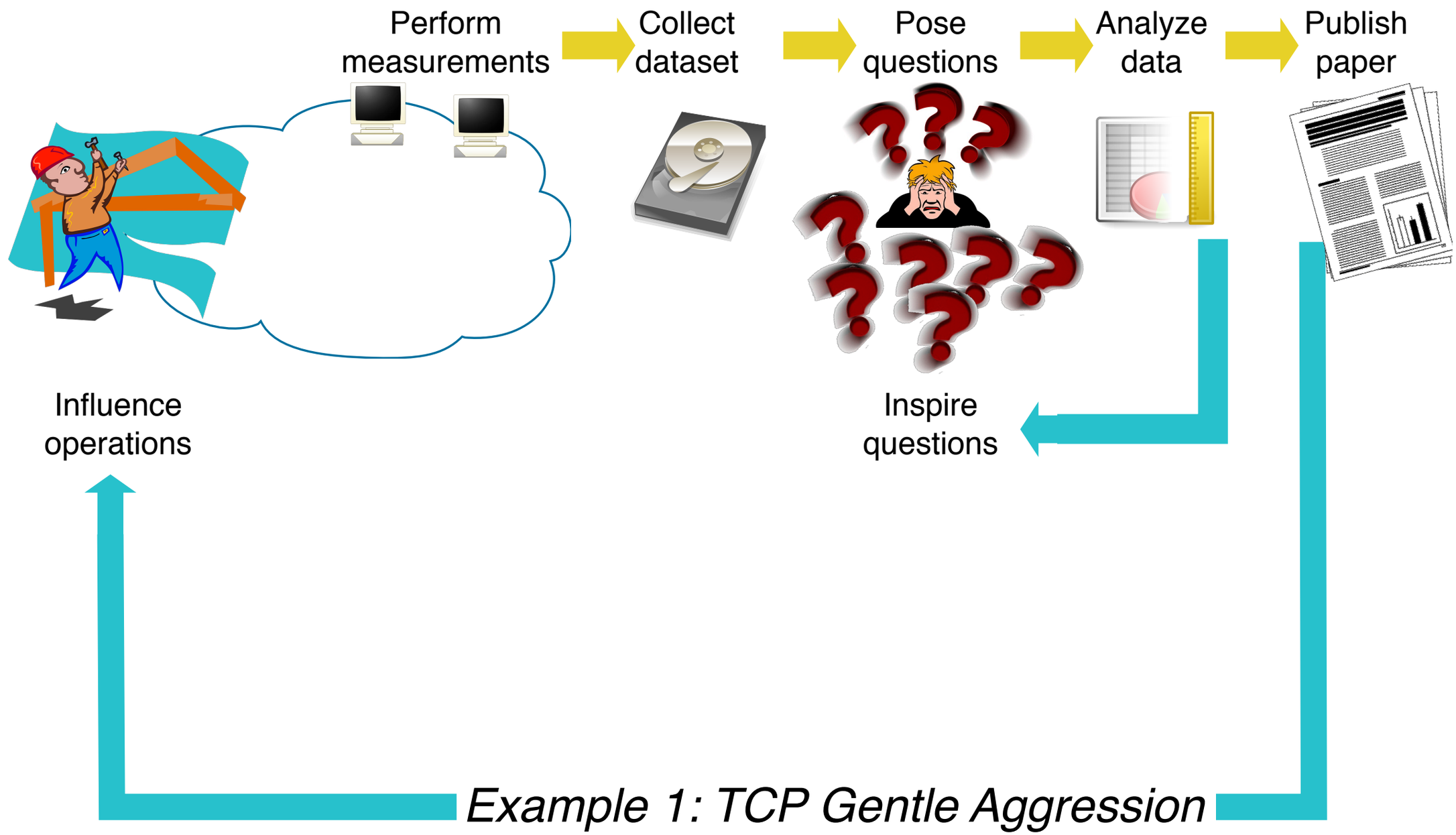

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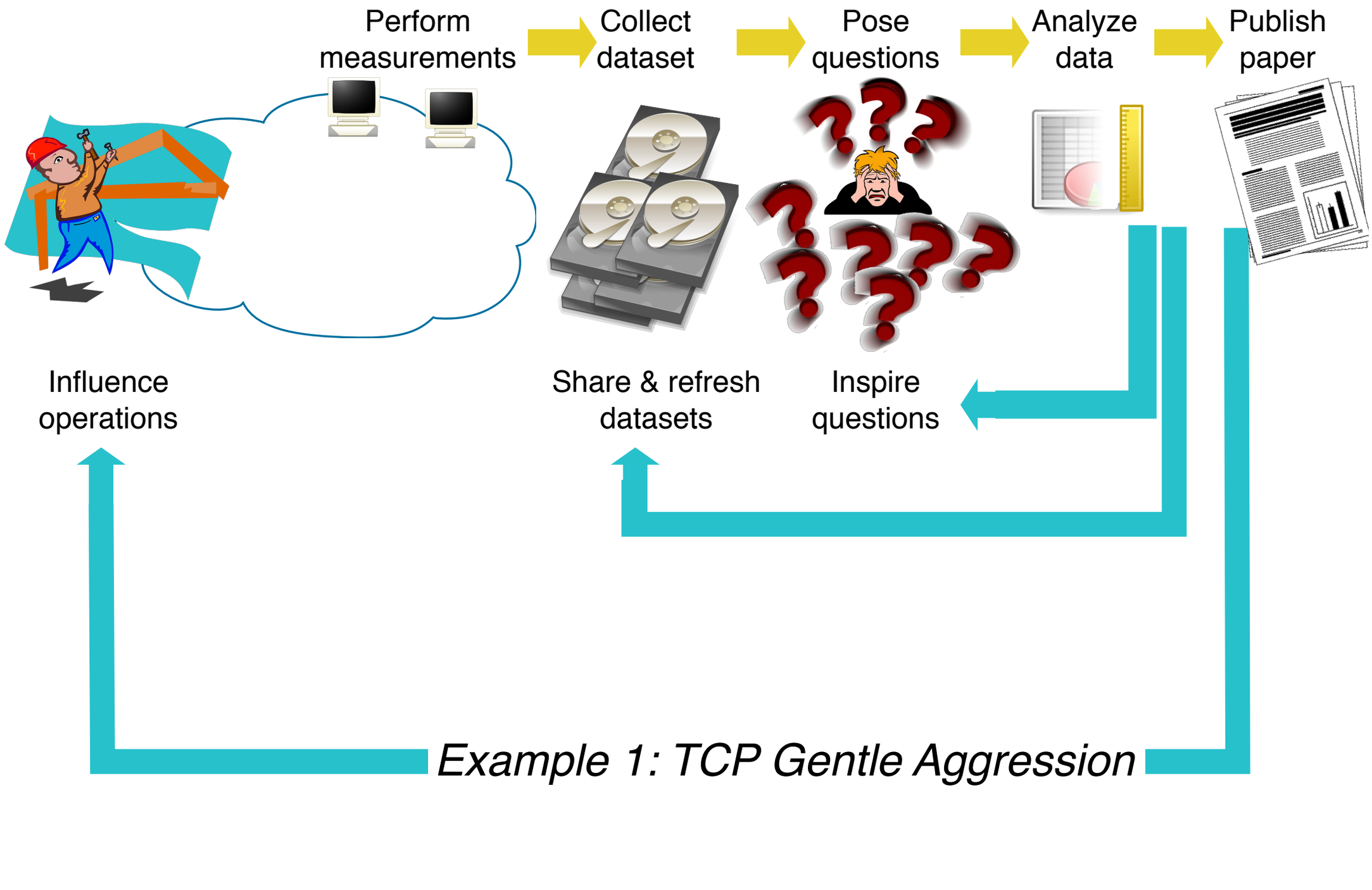

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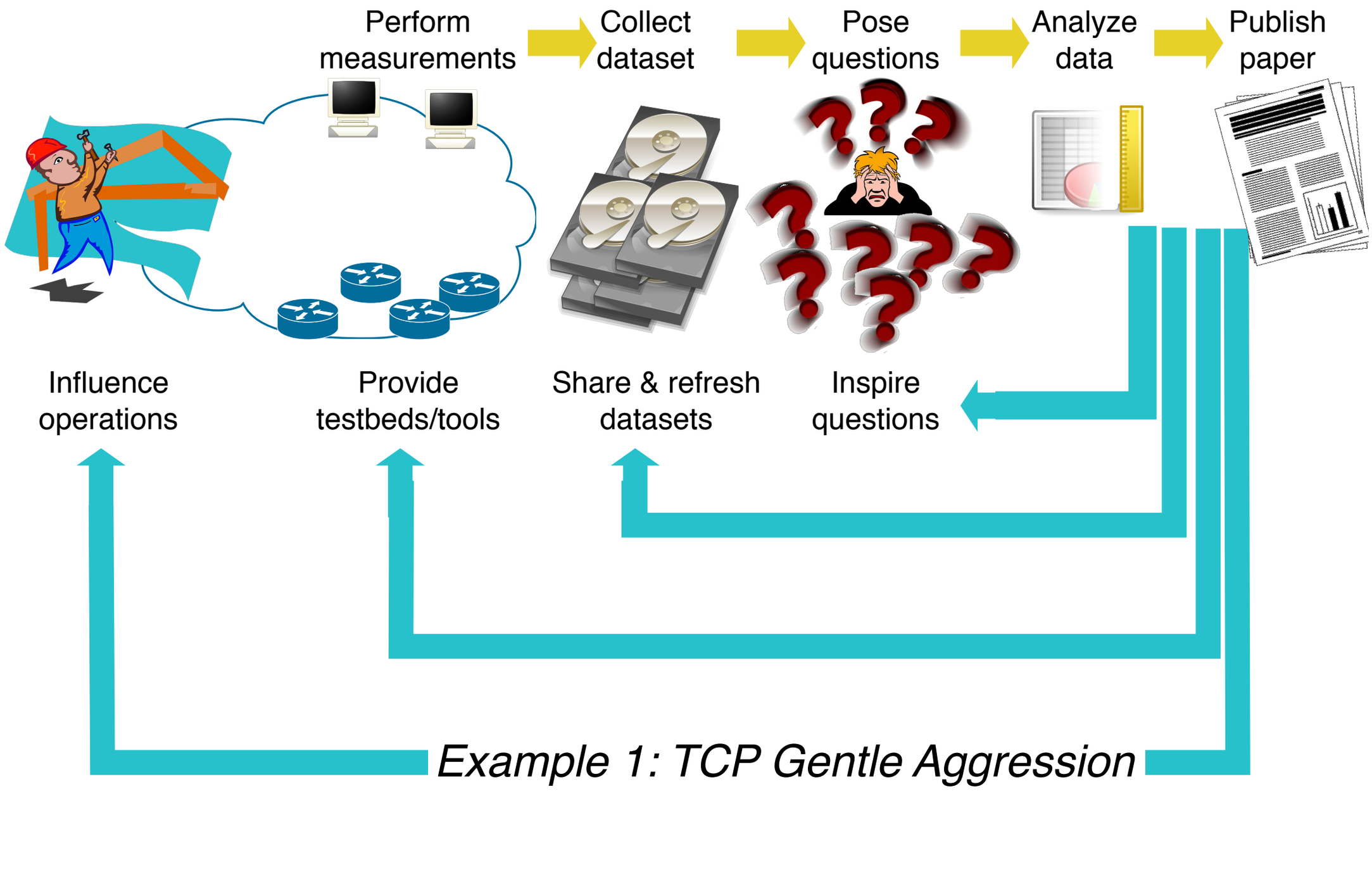

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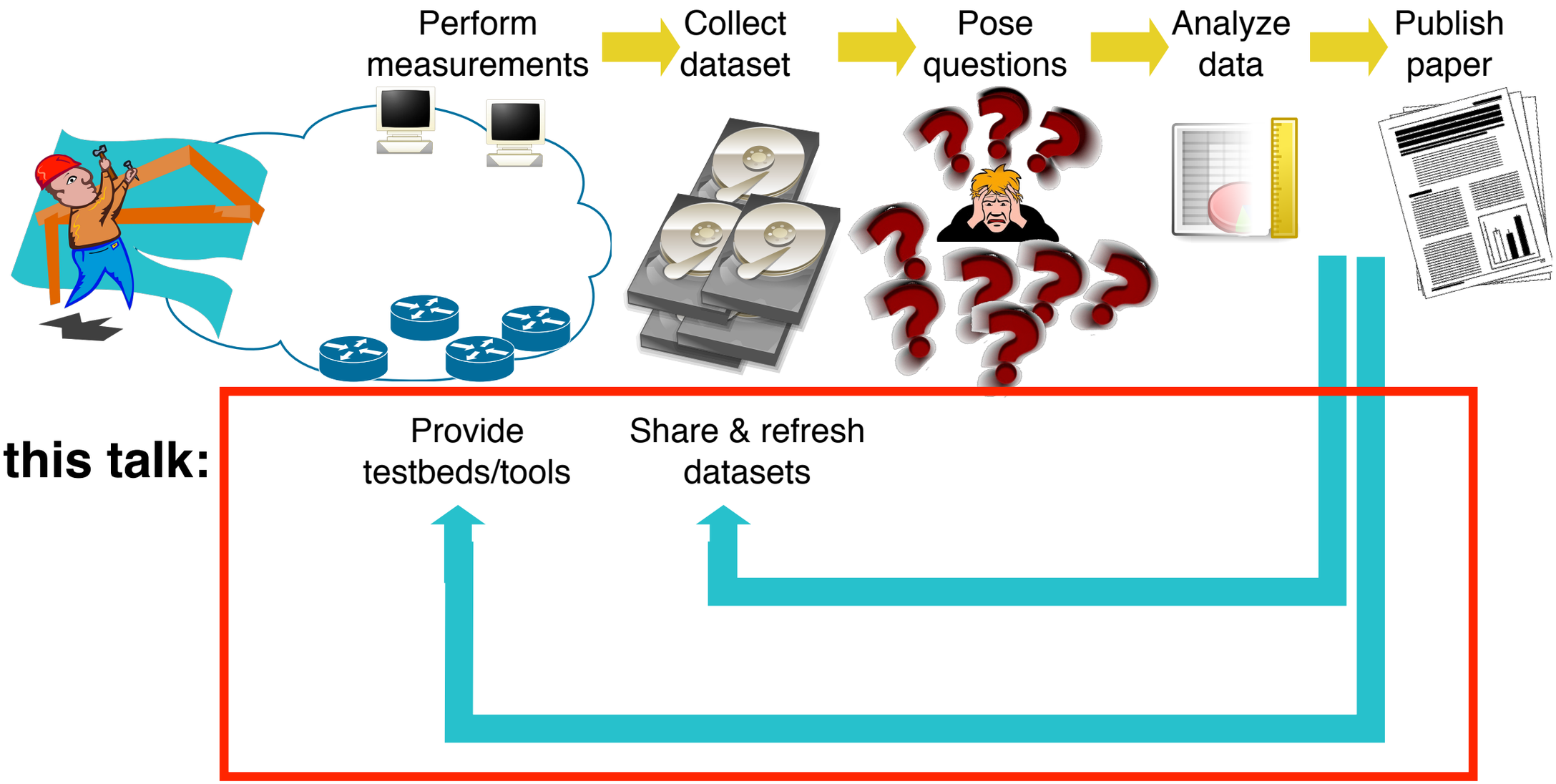
Focus of this talk:



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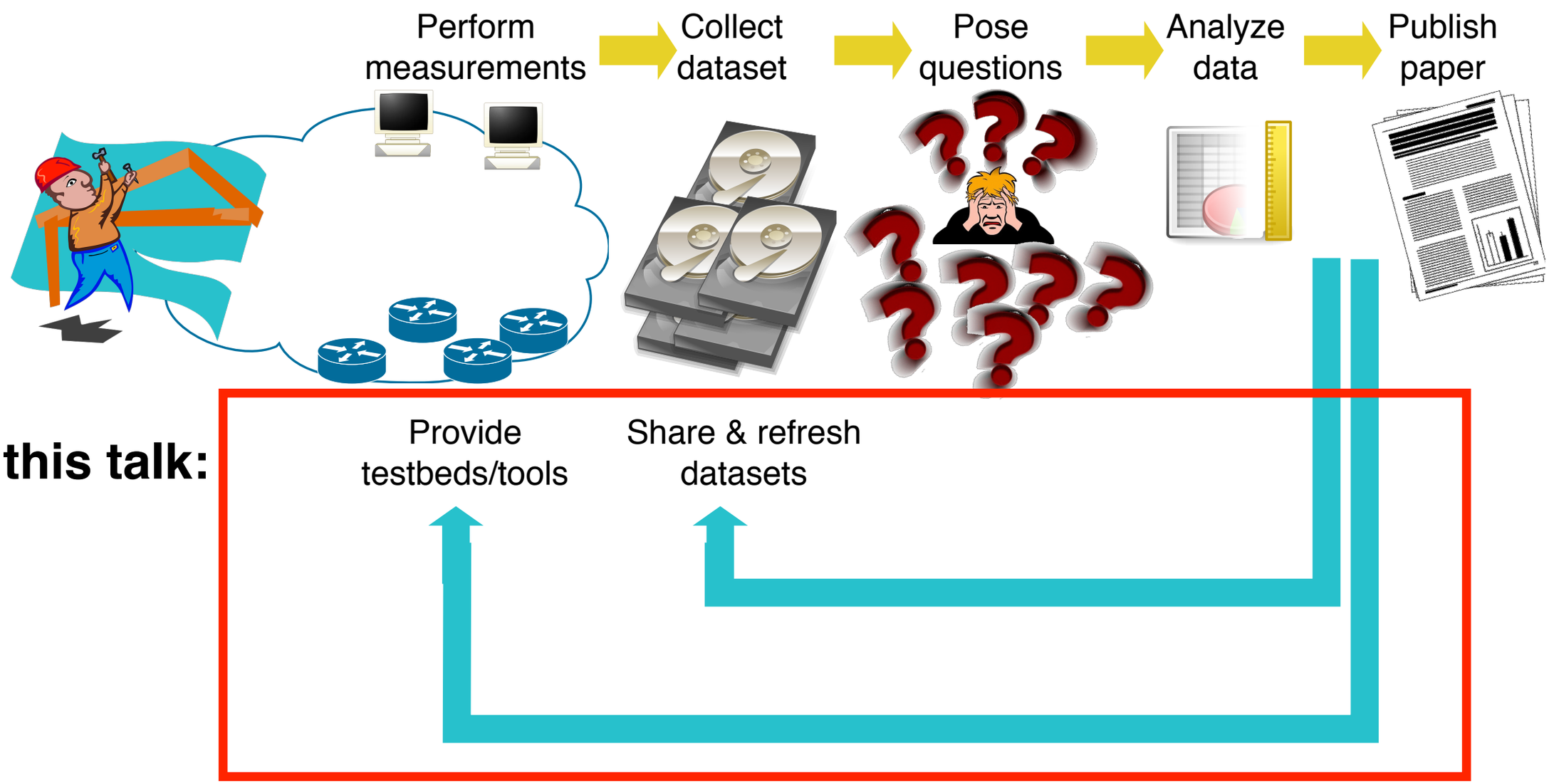

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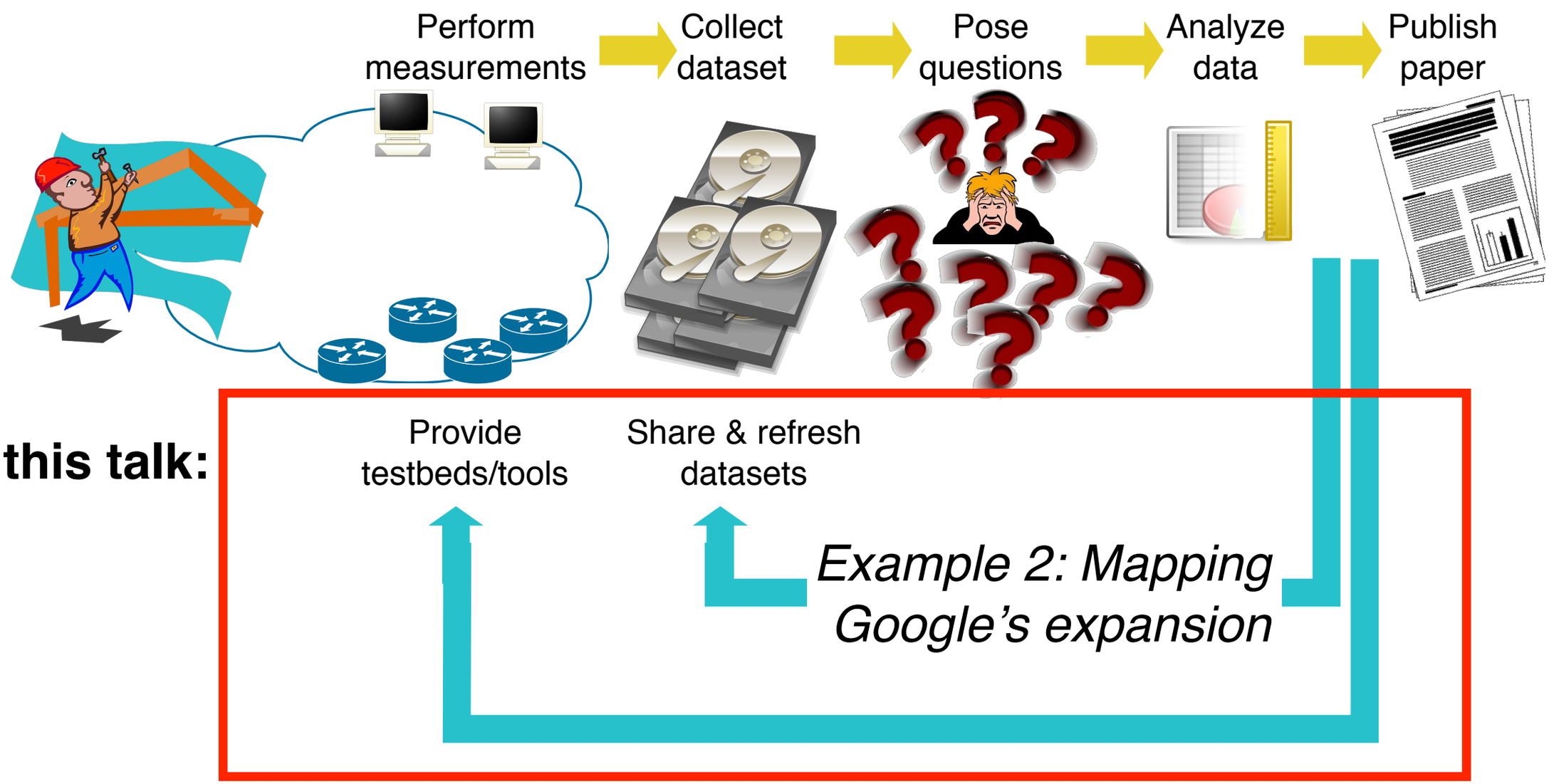
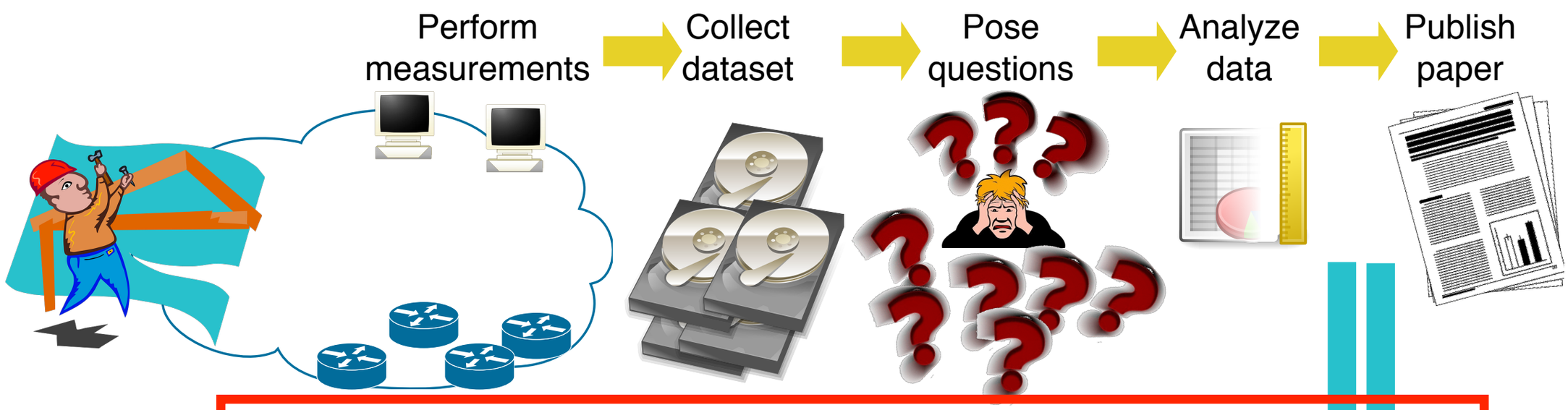


Focus of this talk:

Towards impactful Internet measurement

Limited data shapes analysis

Challenges:



Focus of this talk:

Provide testbeds/tools

Share & refresh datasets

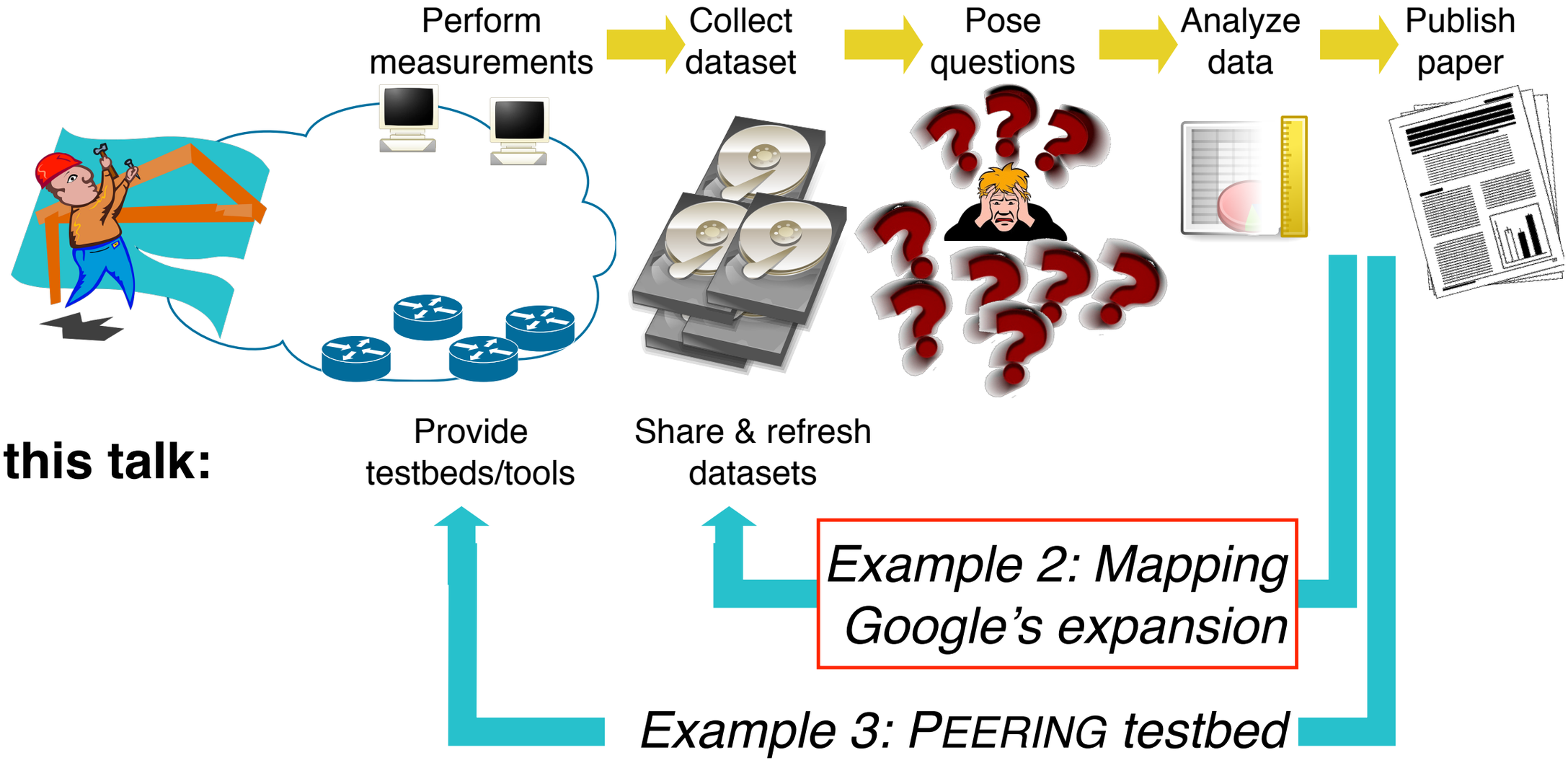
Example 2: Mapping Google's expansion

Example 3: PEERING testbed

Towards impactful Internet measurement

Limited data shapes analysis

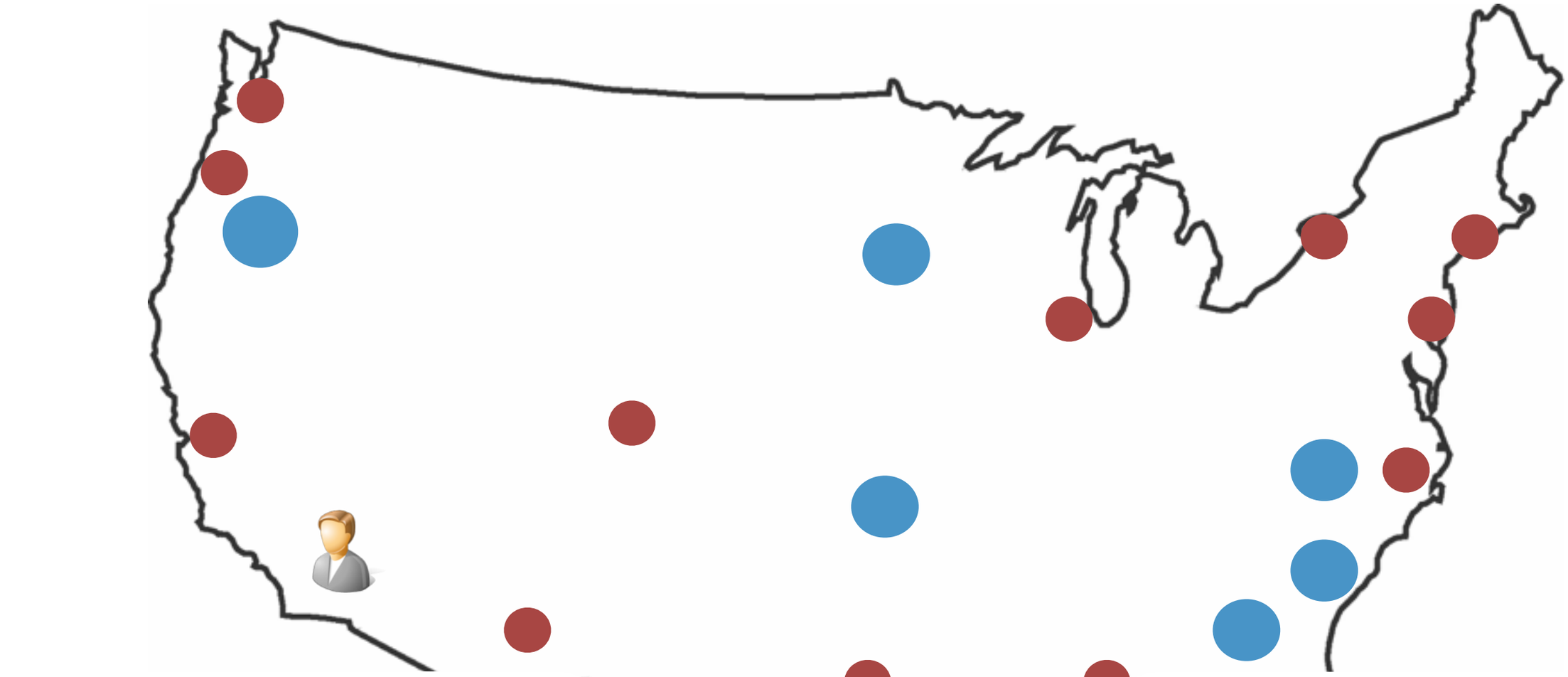
Challenges:



Focus of this talk:

Web Service Infrastructure

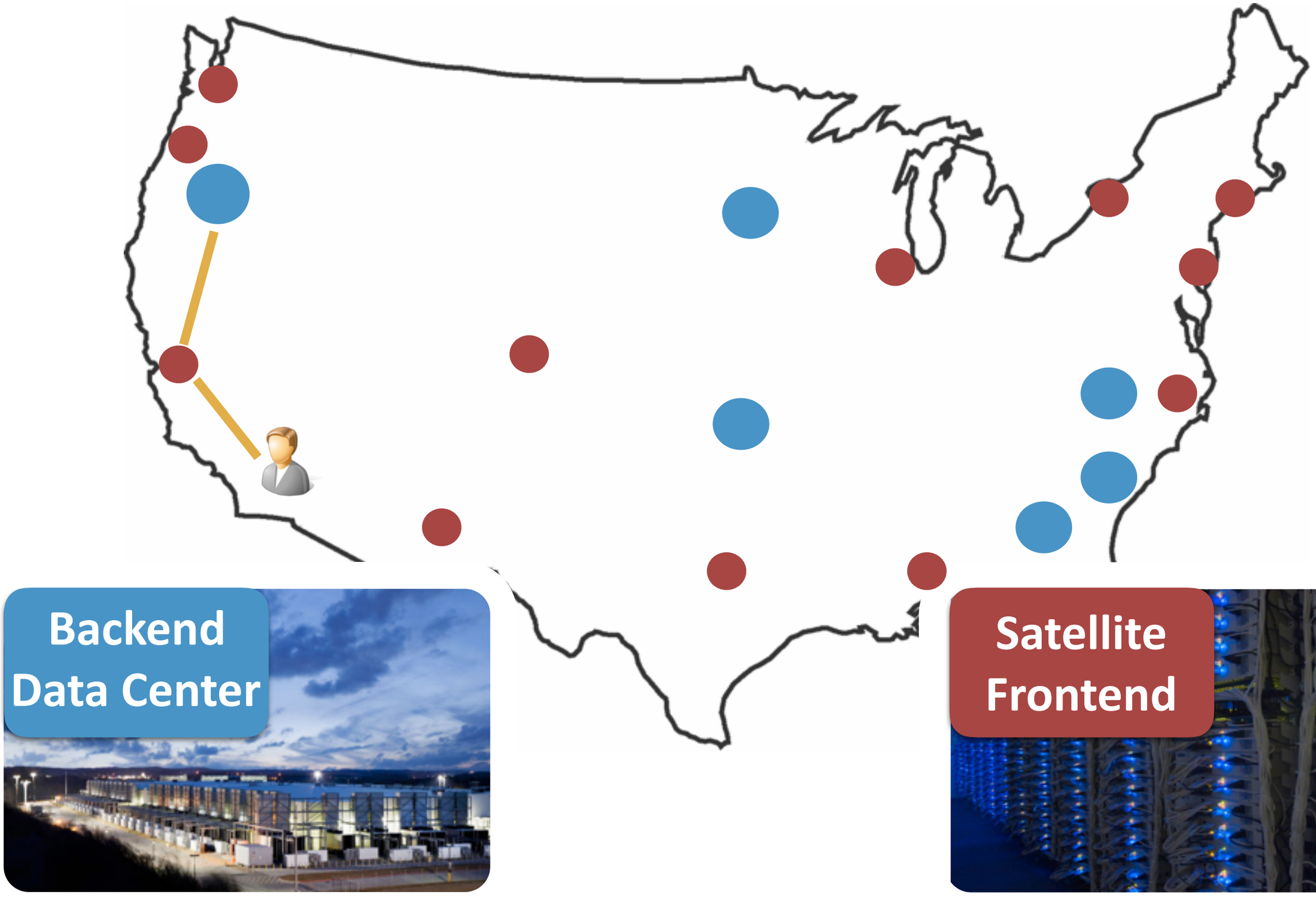
Web Service Infrastructure



Backend Data Center

Satellite Frontend

Web Service Infrastructure

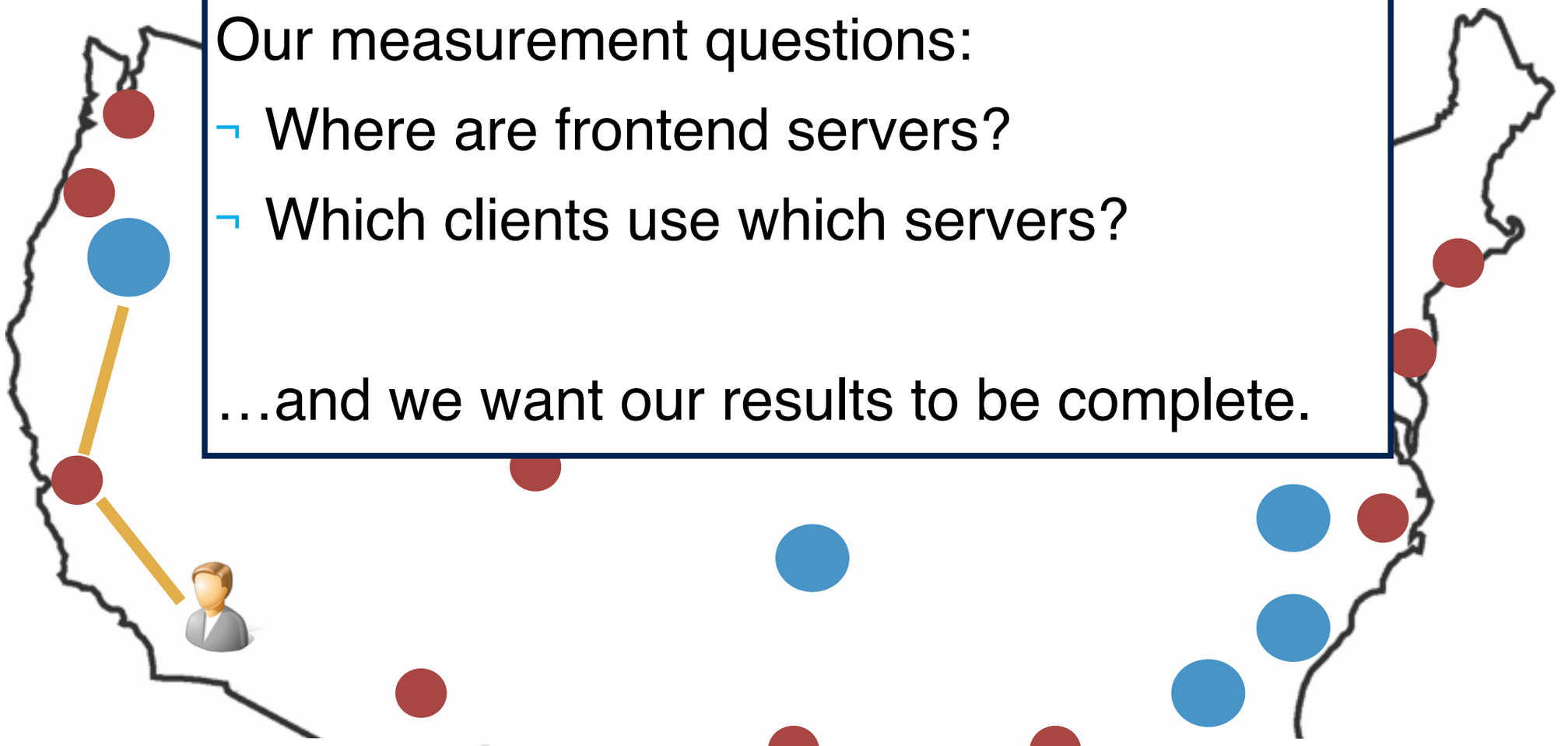


Web Service Infrastructure

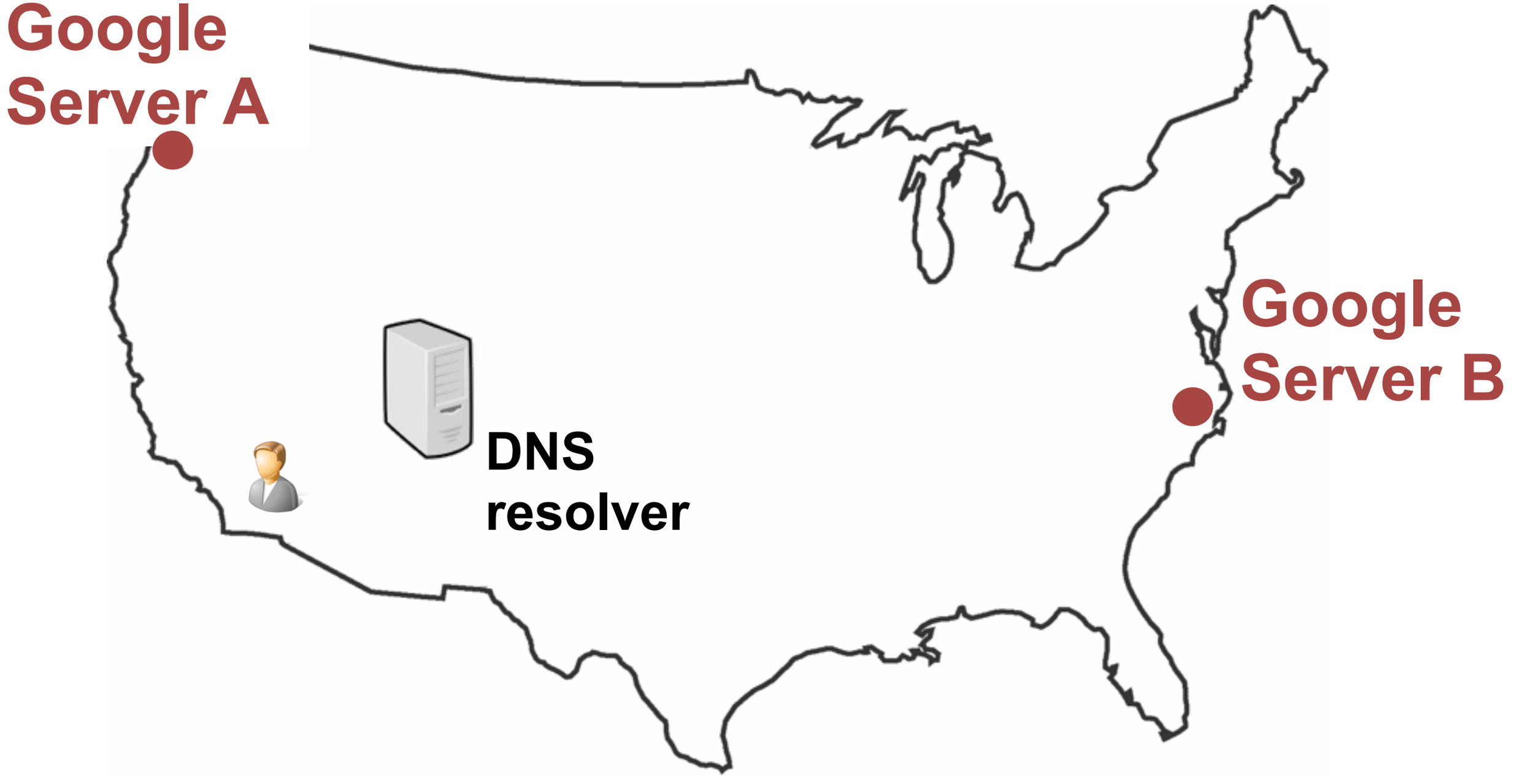
Our measurement questions:

- Where are frontend servers?
- Which clients use which servers?

…and we want our results to be complete.



Background: Client to Front-end Mapping



Google knows which resolver is requesting, but not which client

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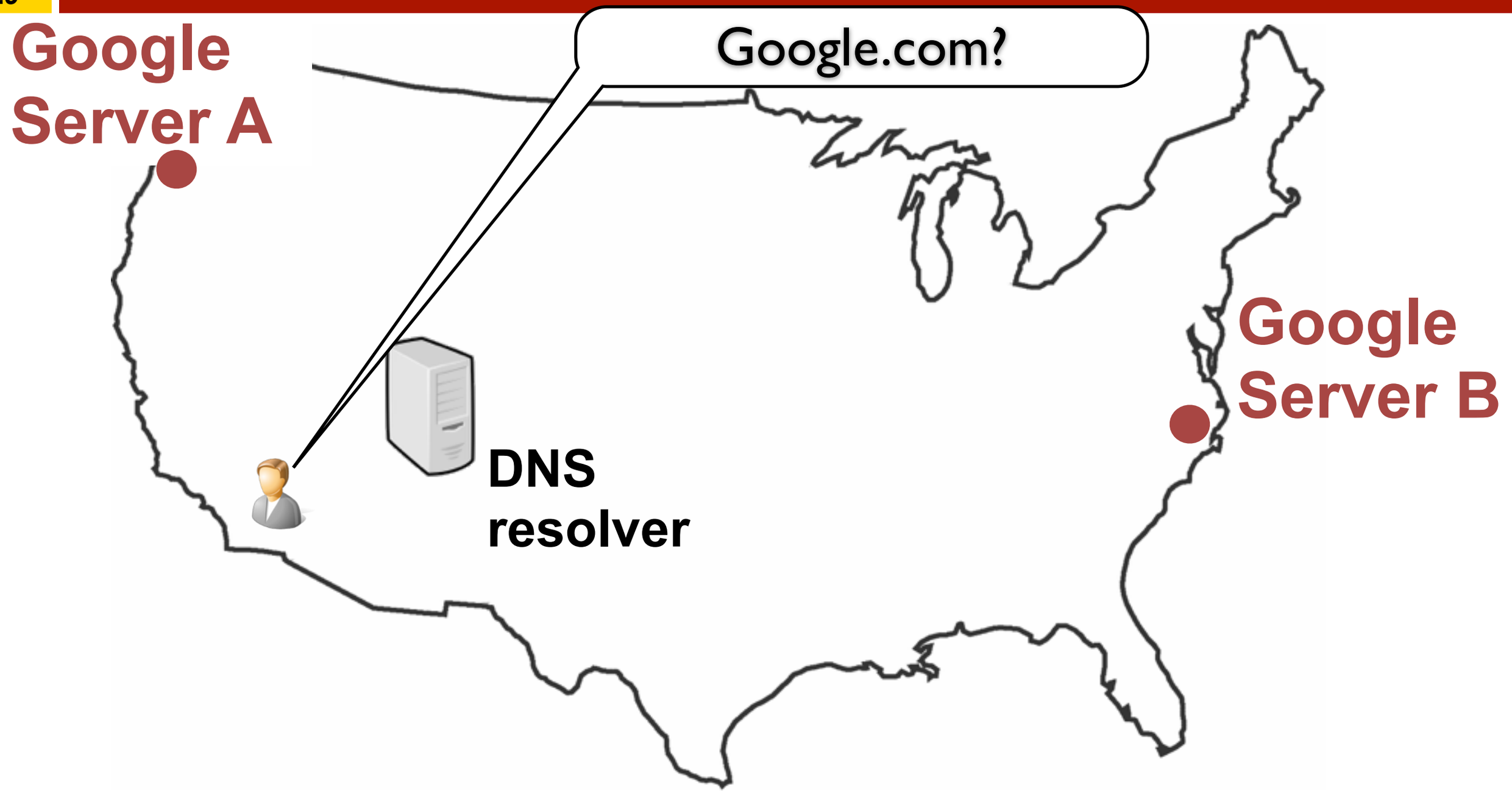

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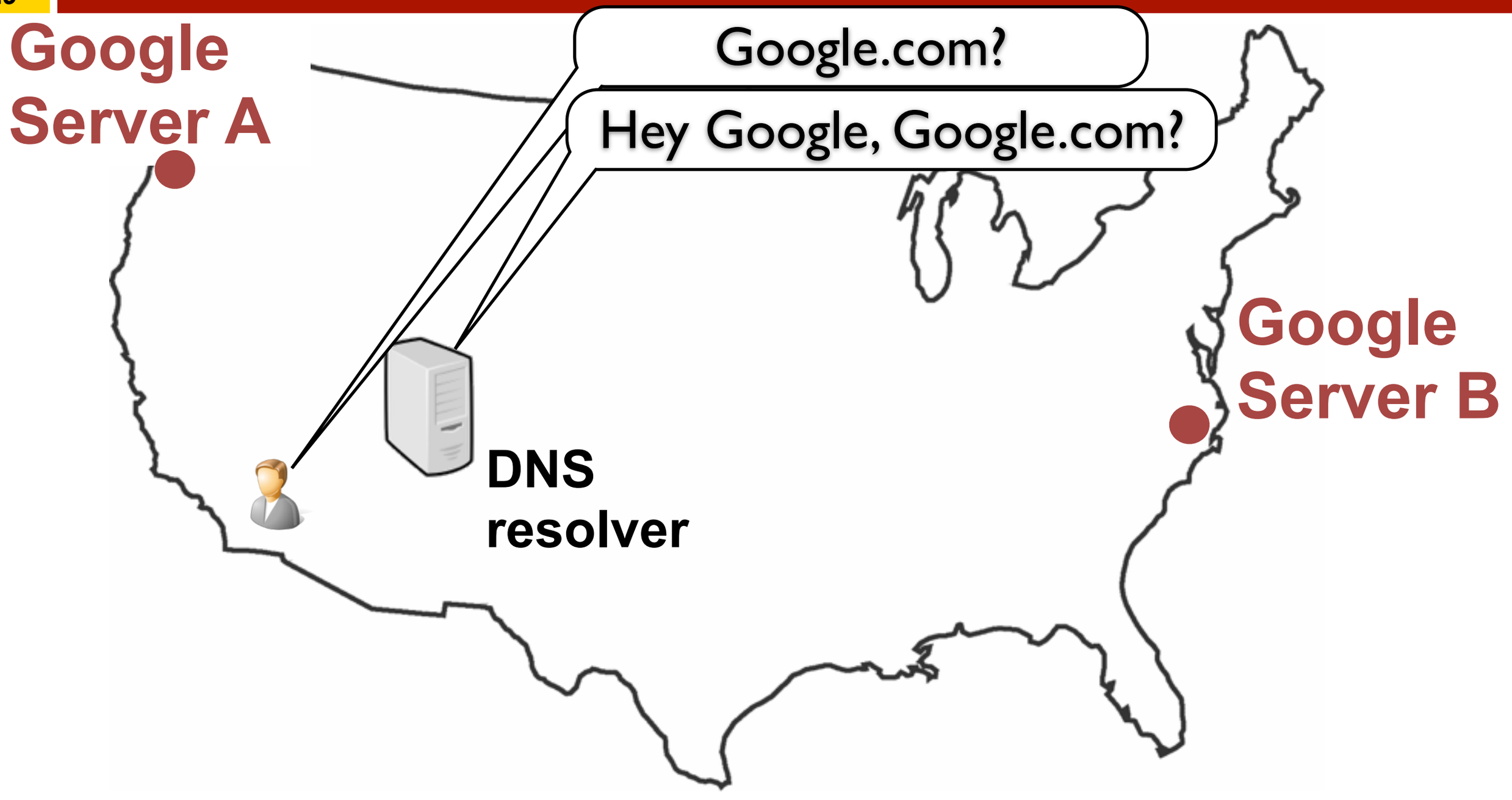

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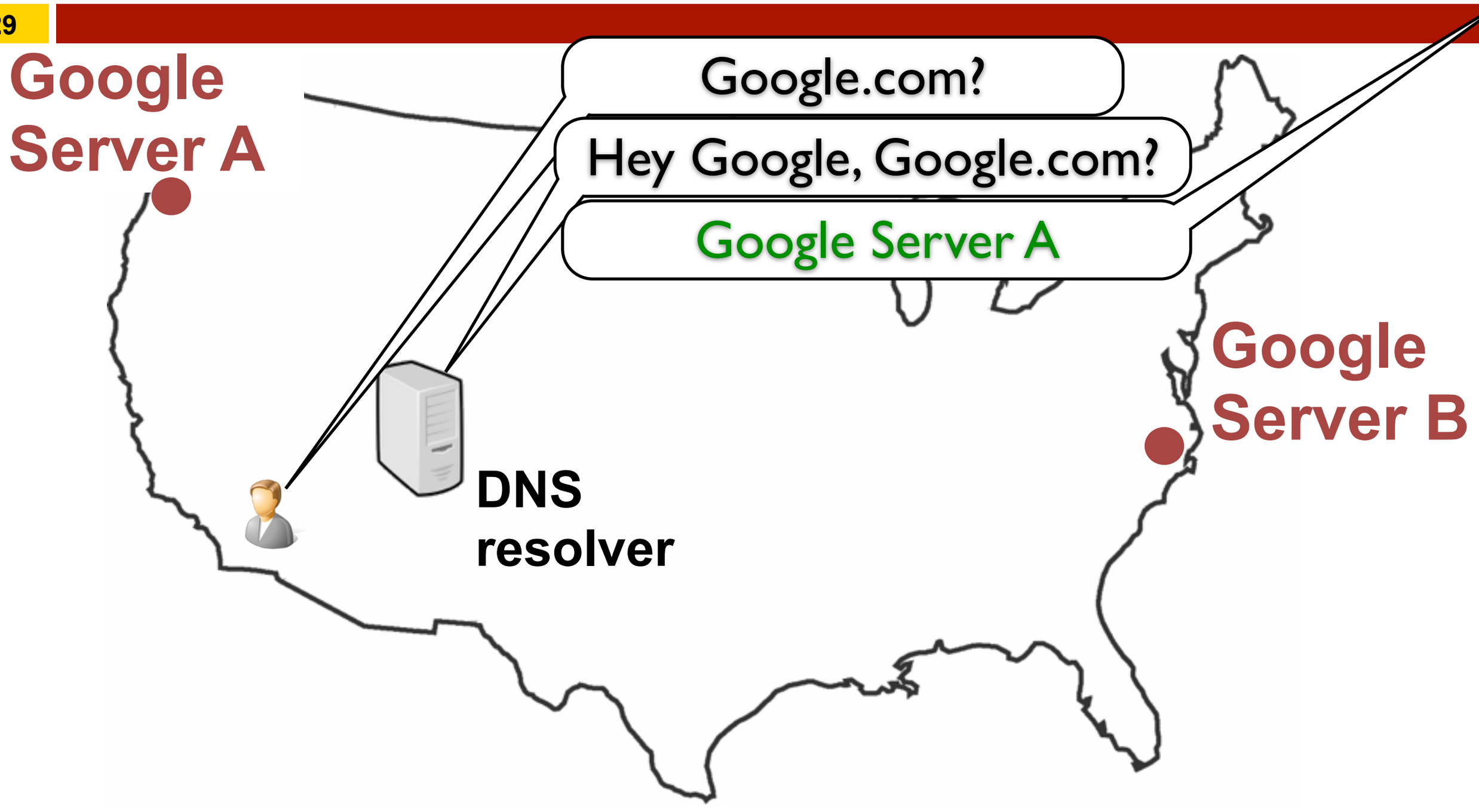

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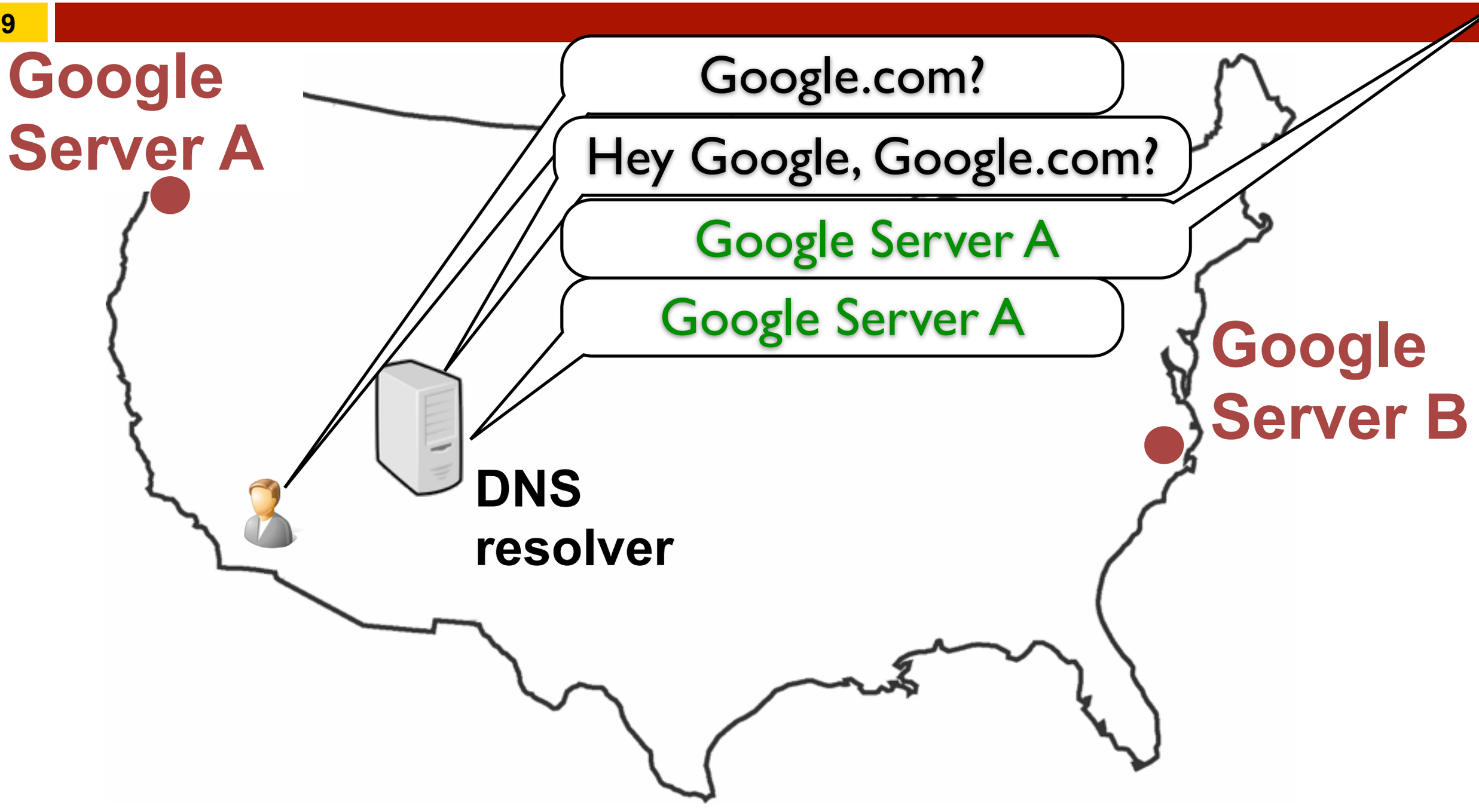

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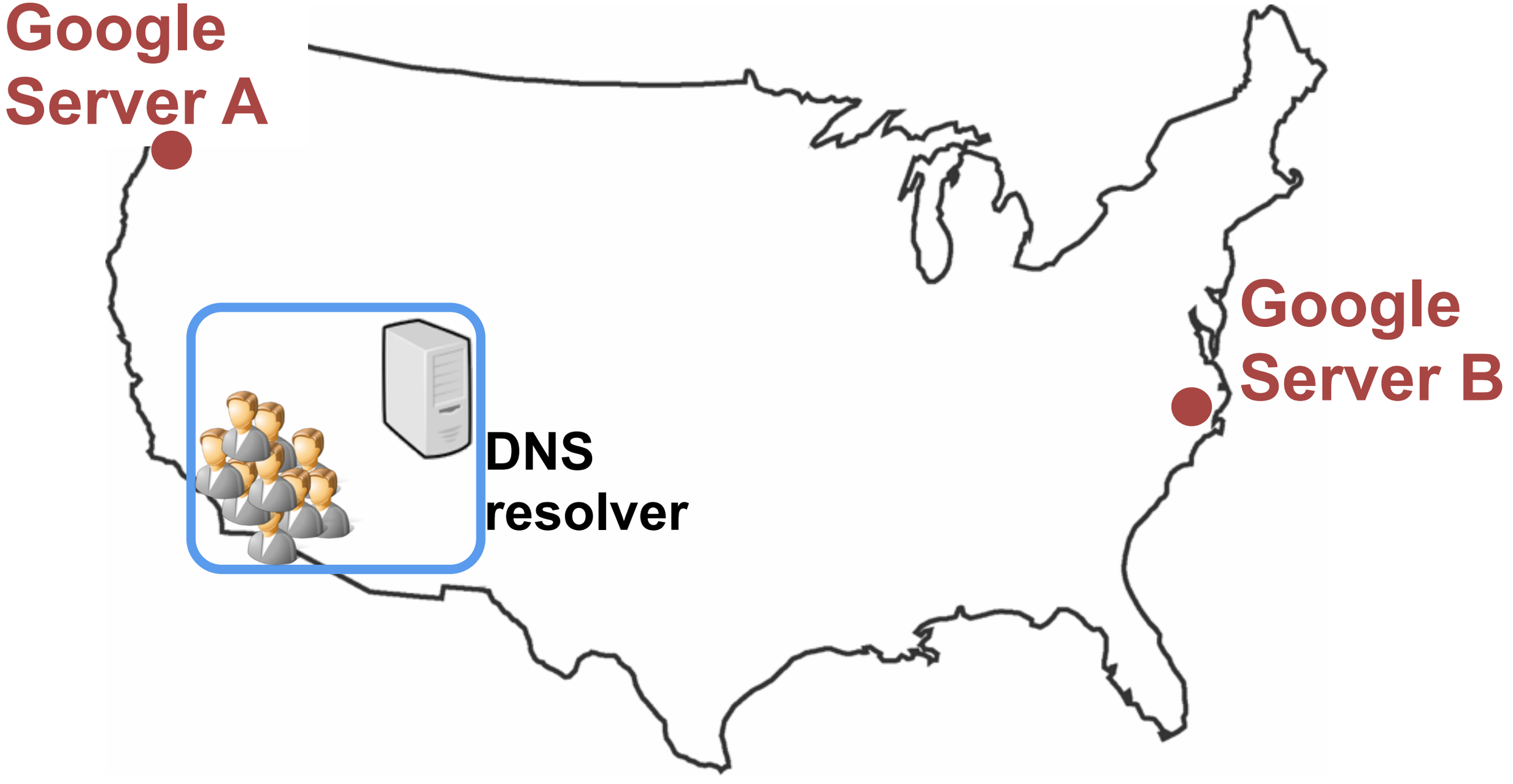

Easy Case: Clustered Users

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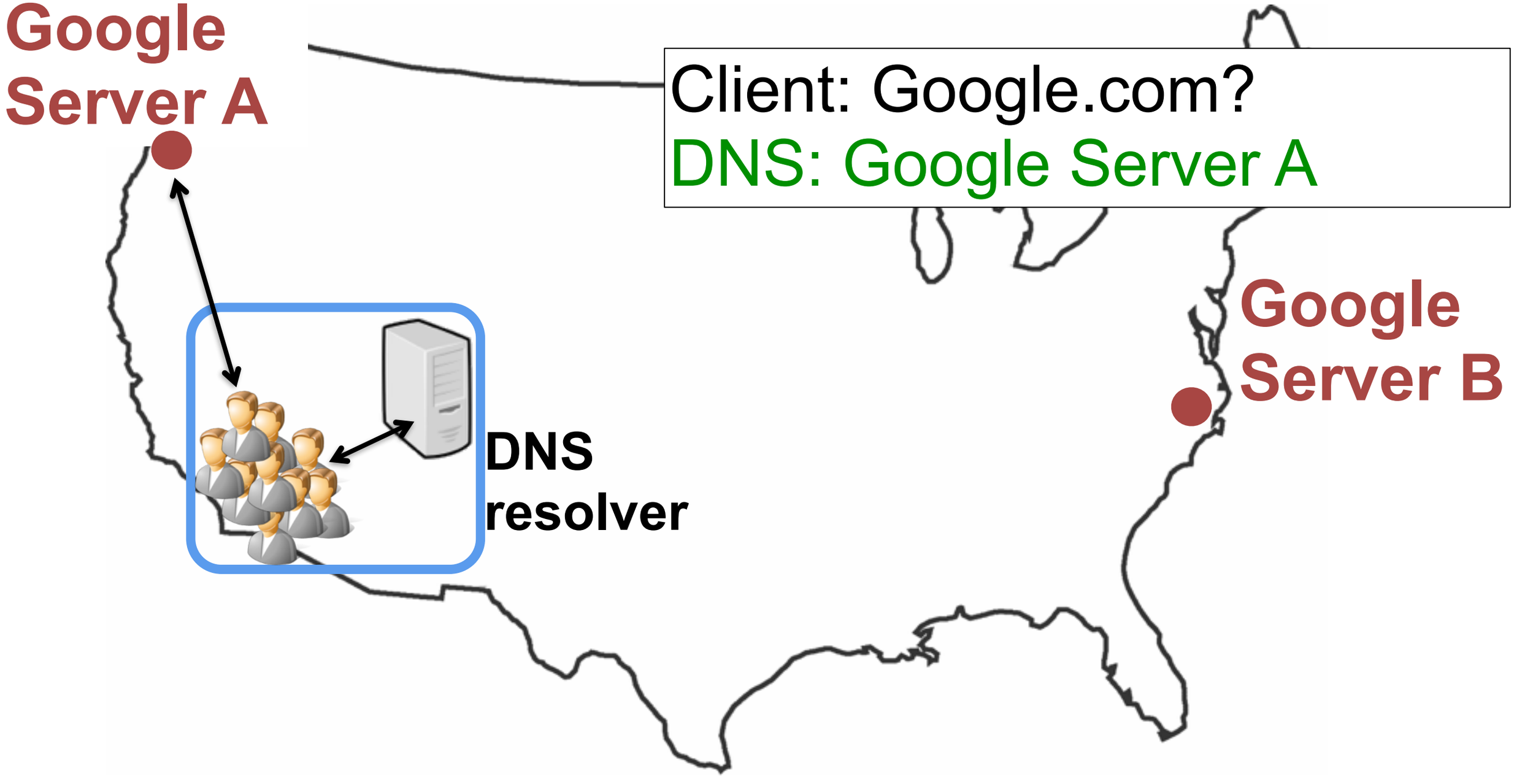

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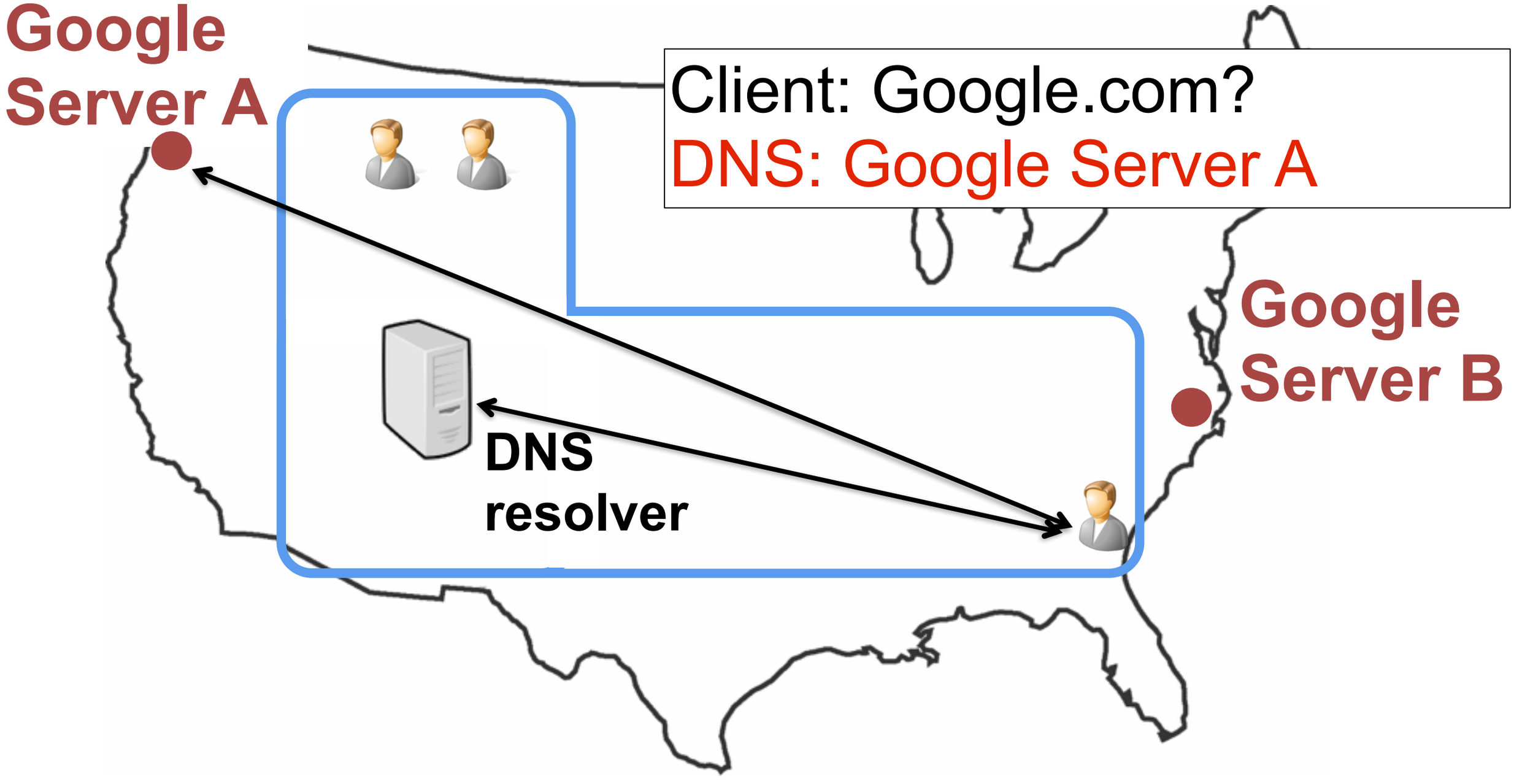

Hard Case: Distributed Users

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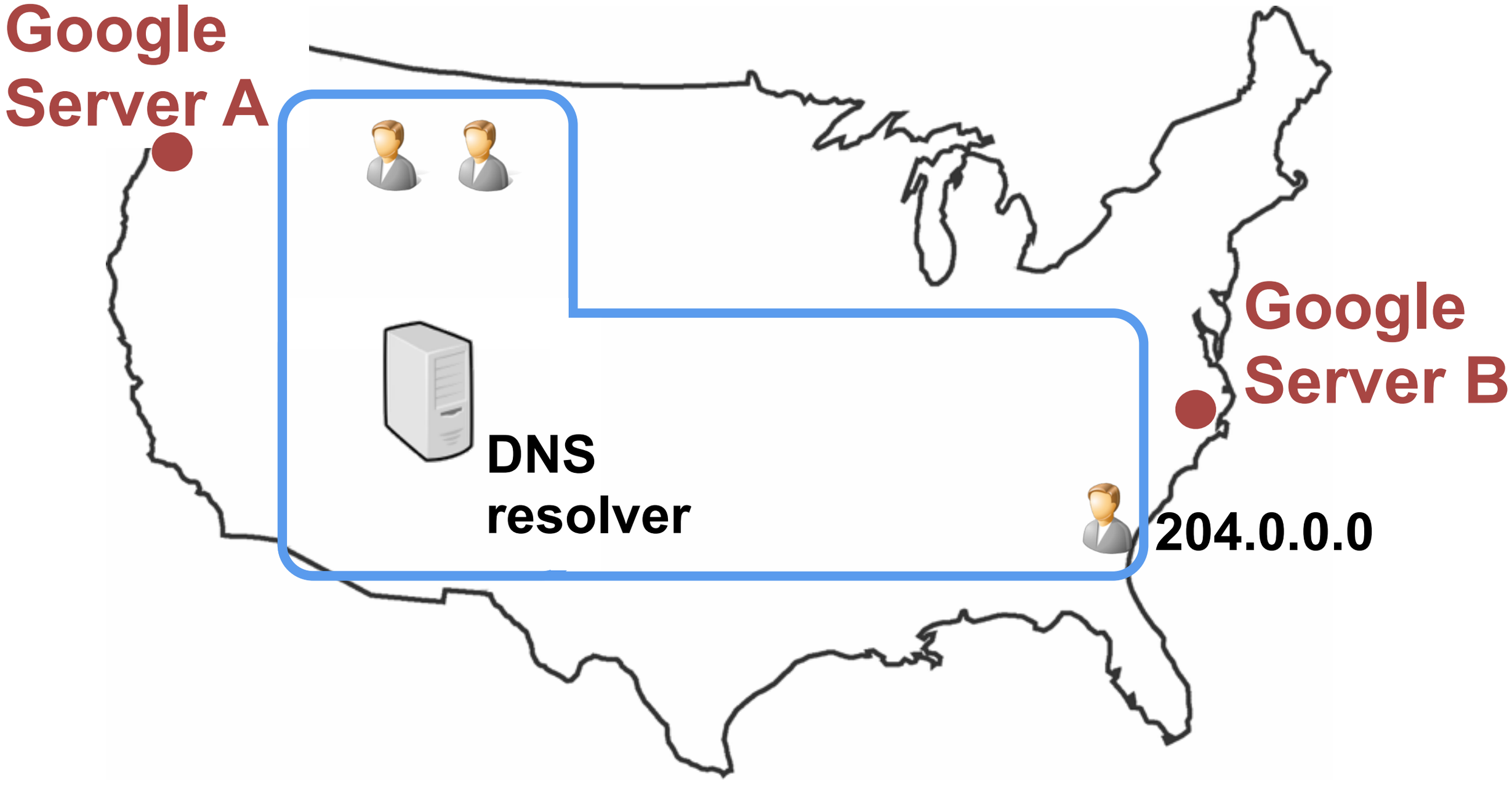

Solution: `draft-ietf-dnsop-EDNS-CLIENT-SUBNET`
(IETF proposed standard)

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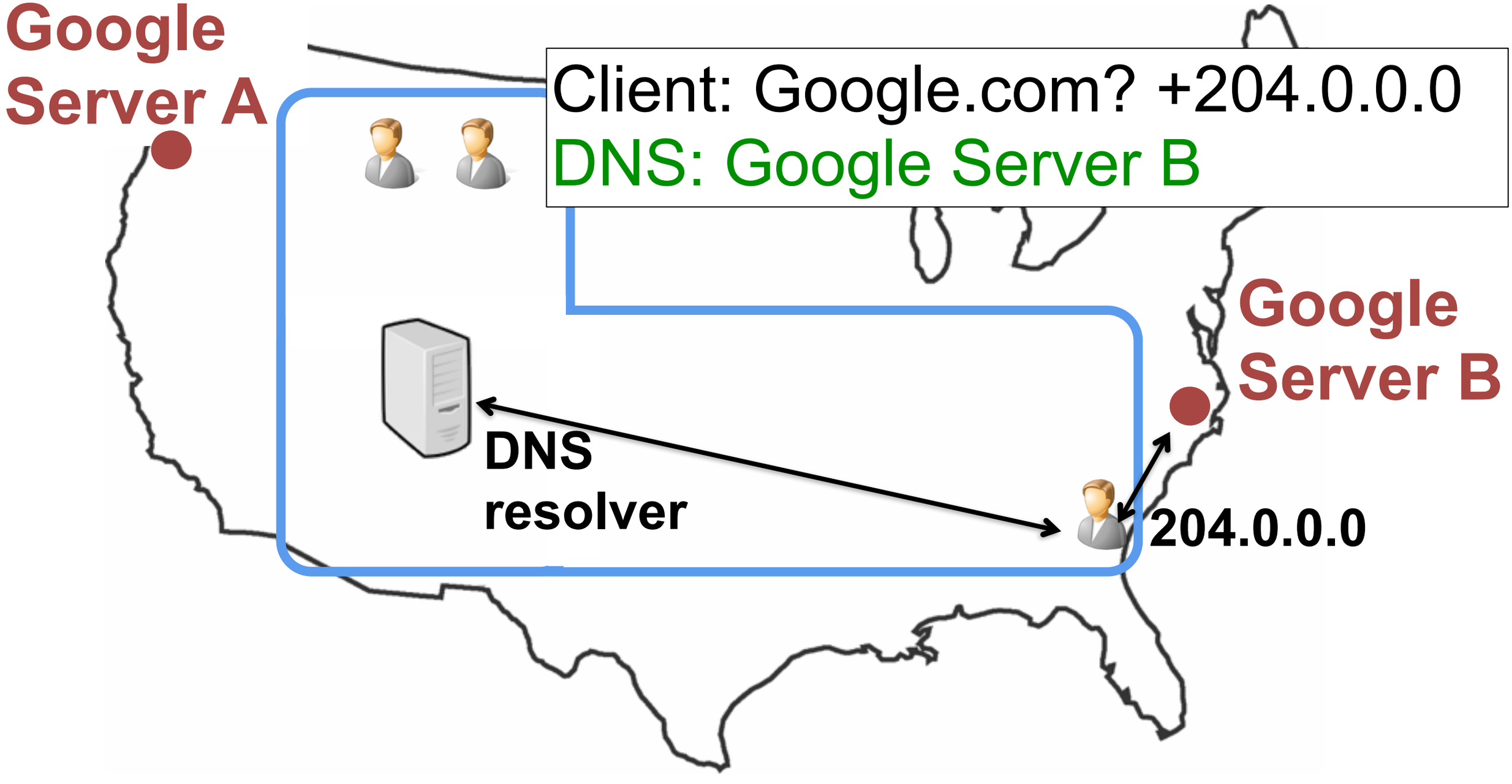

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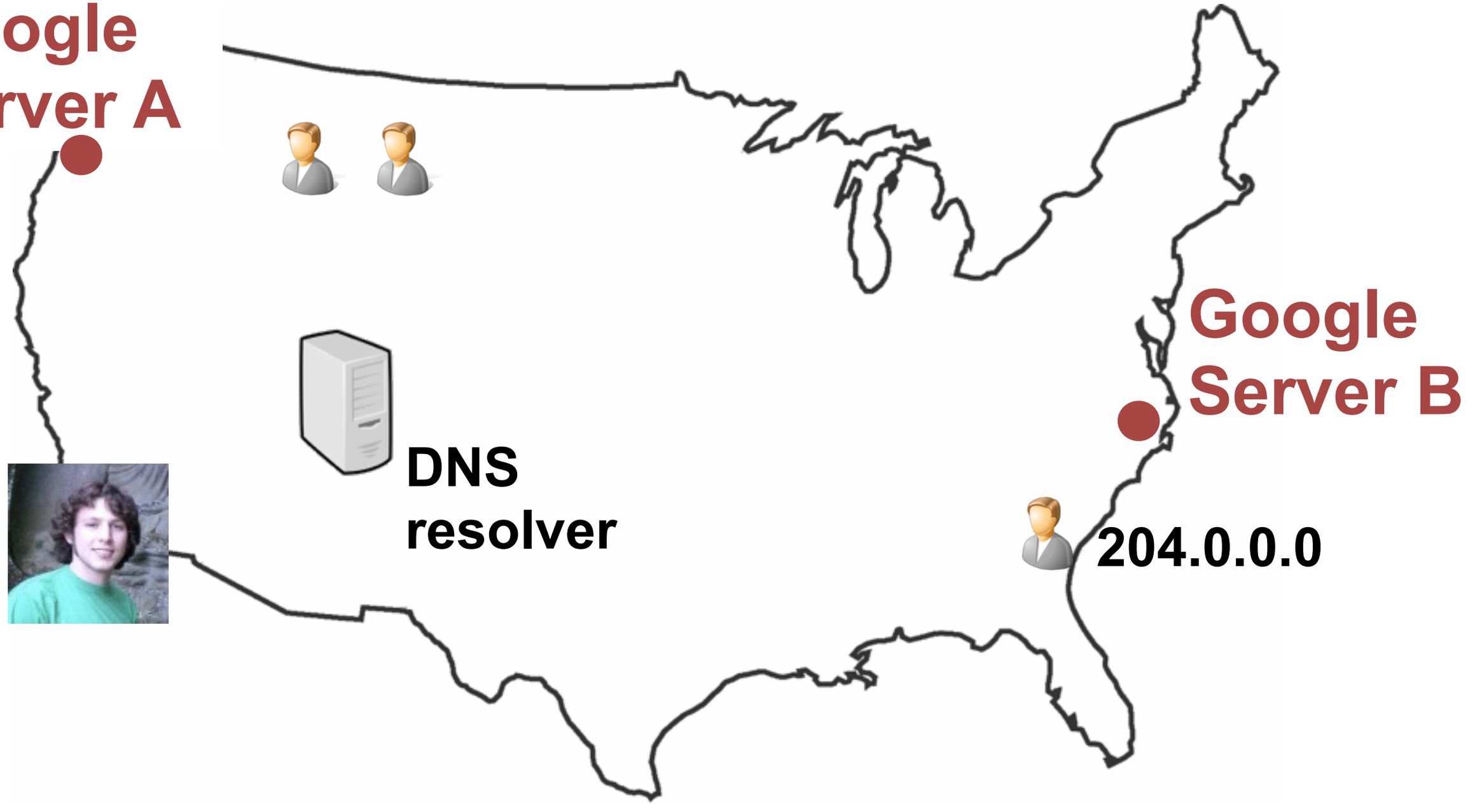

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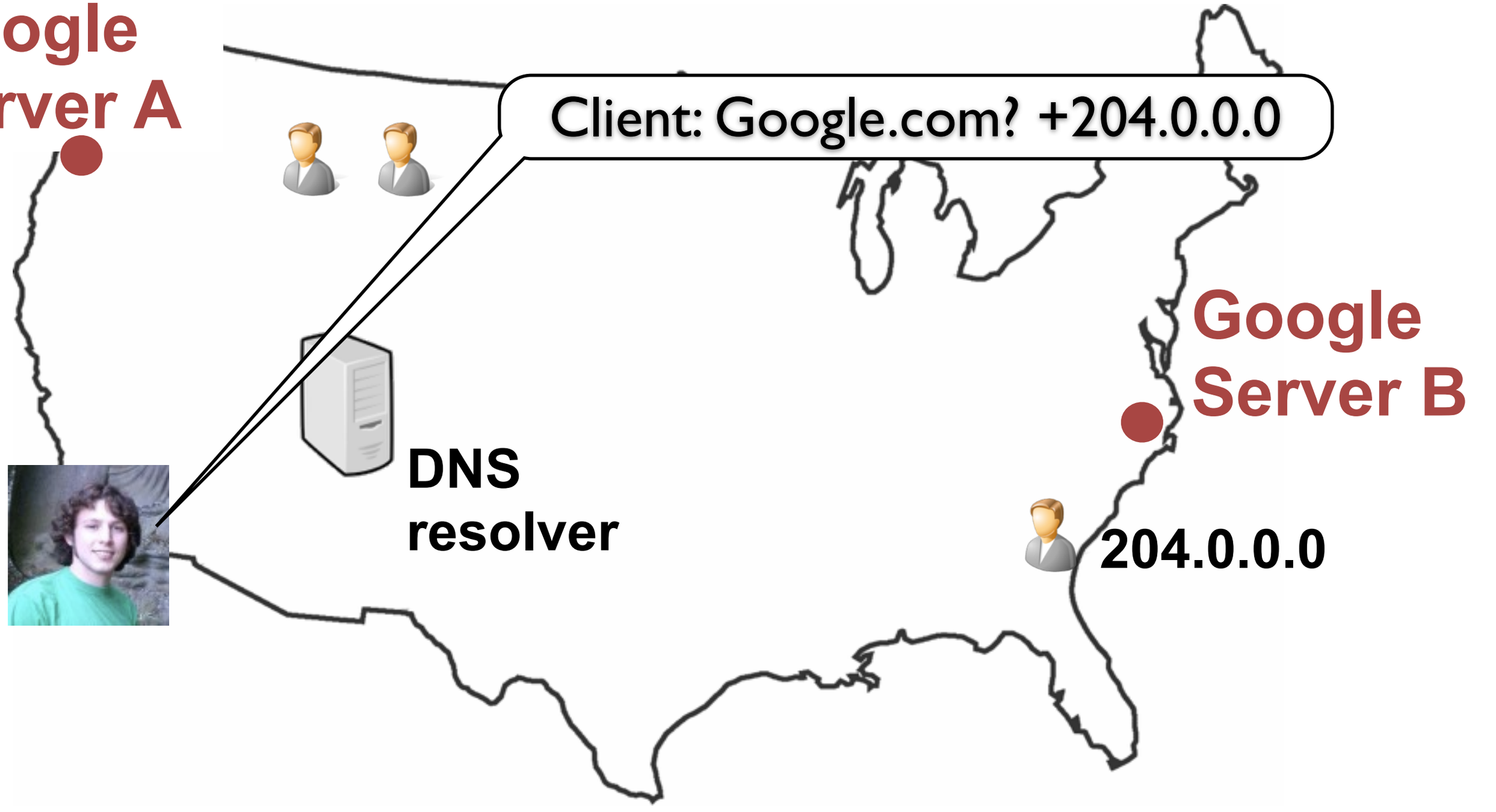

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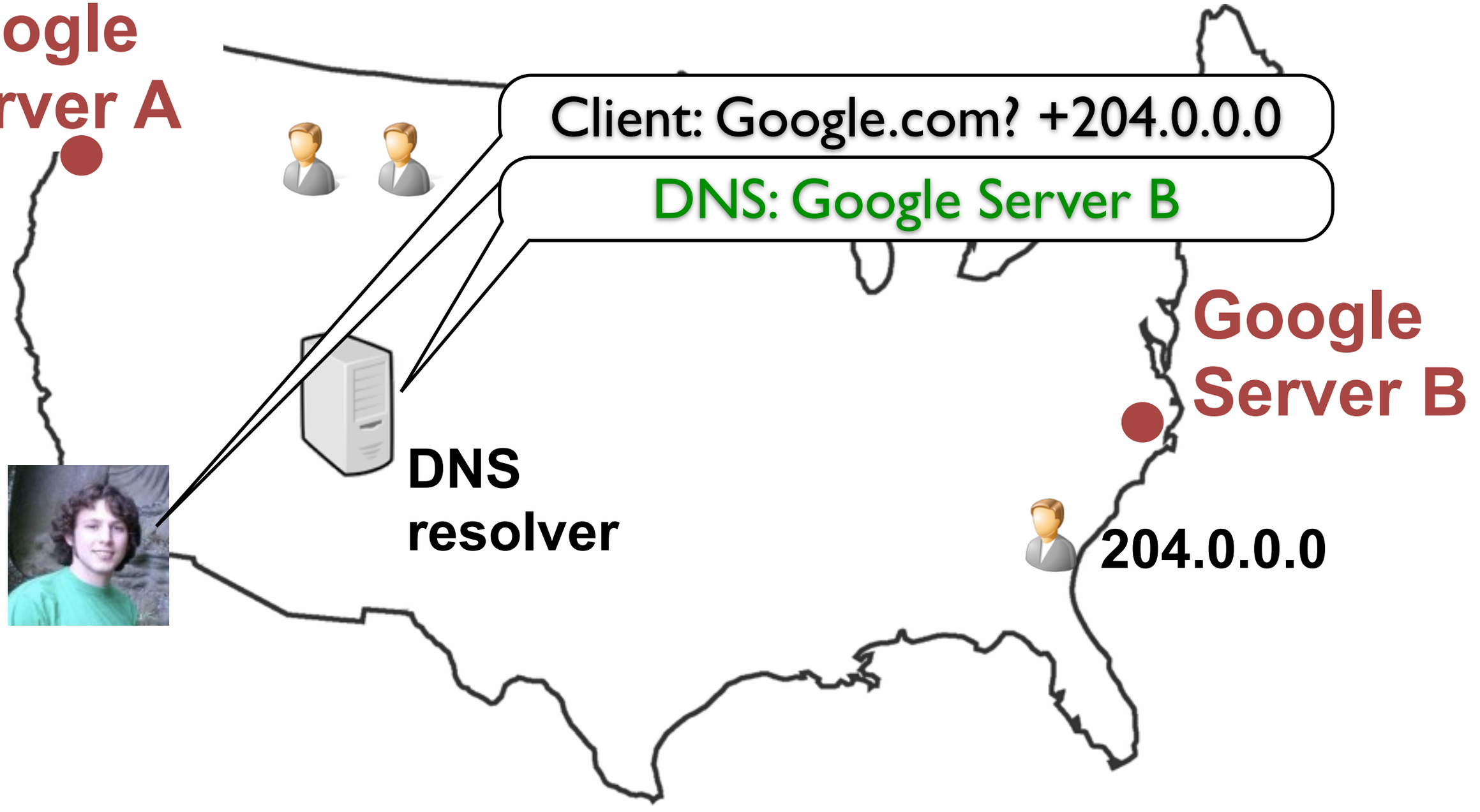

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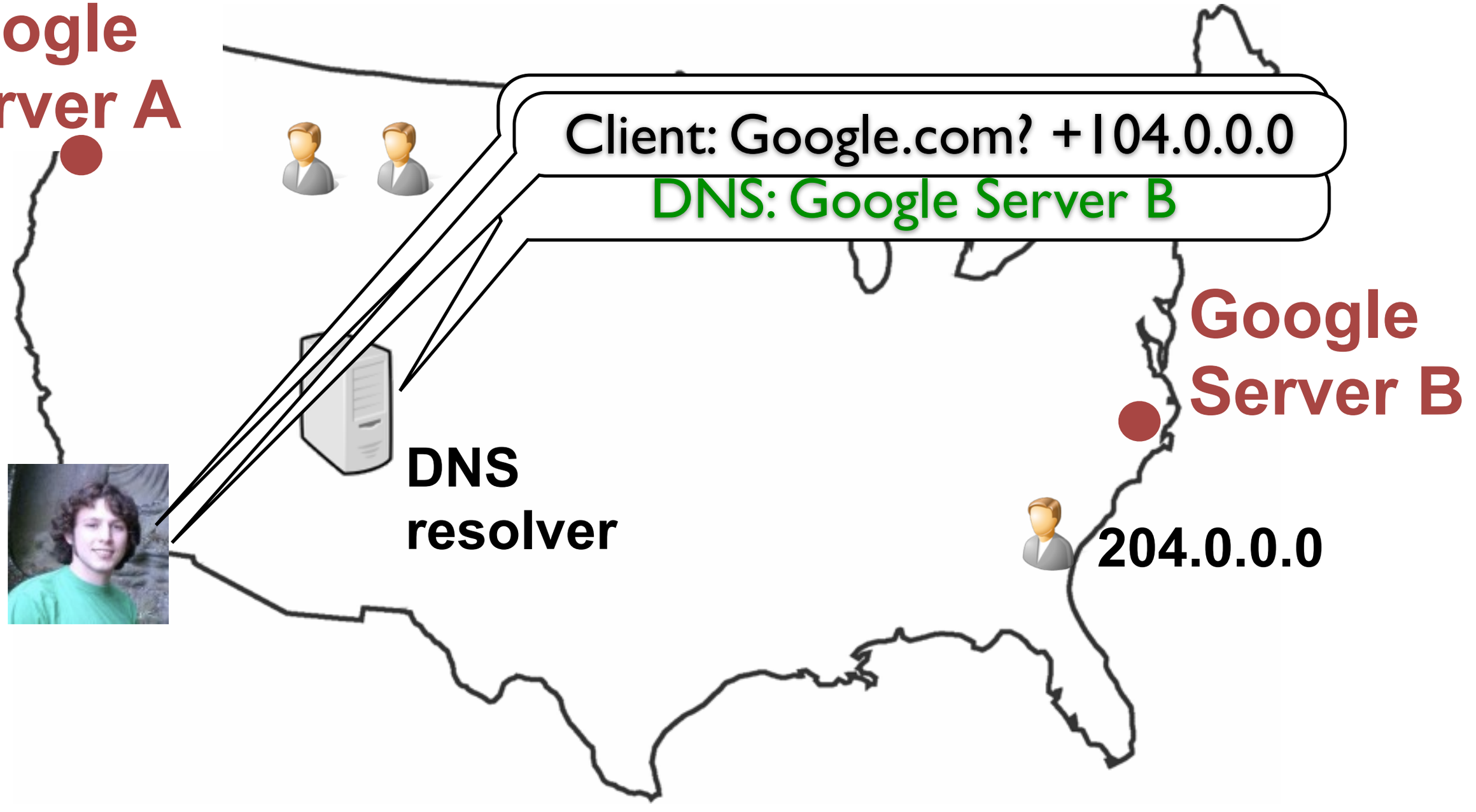

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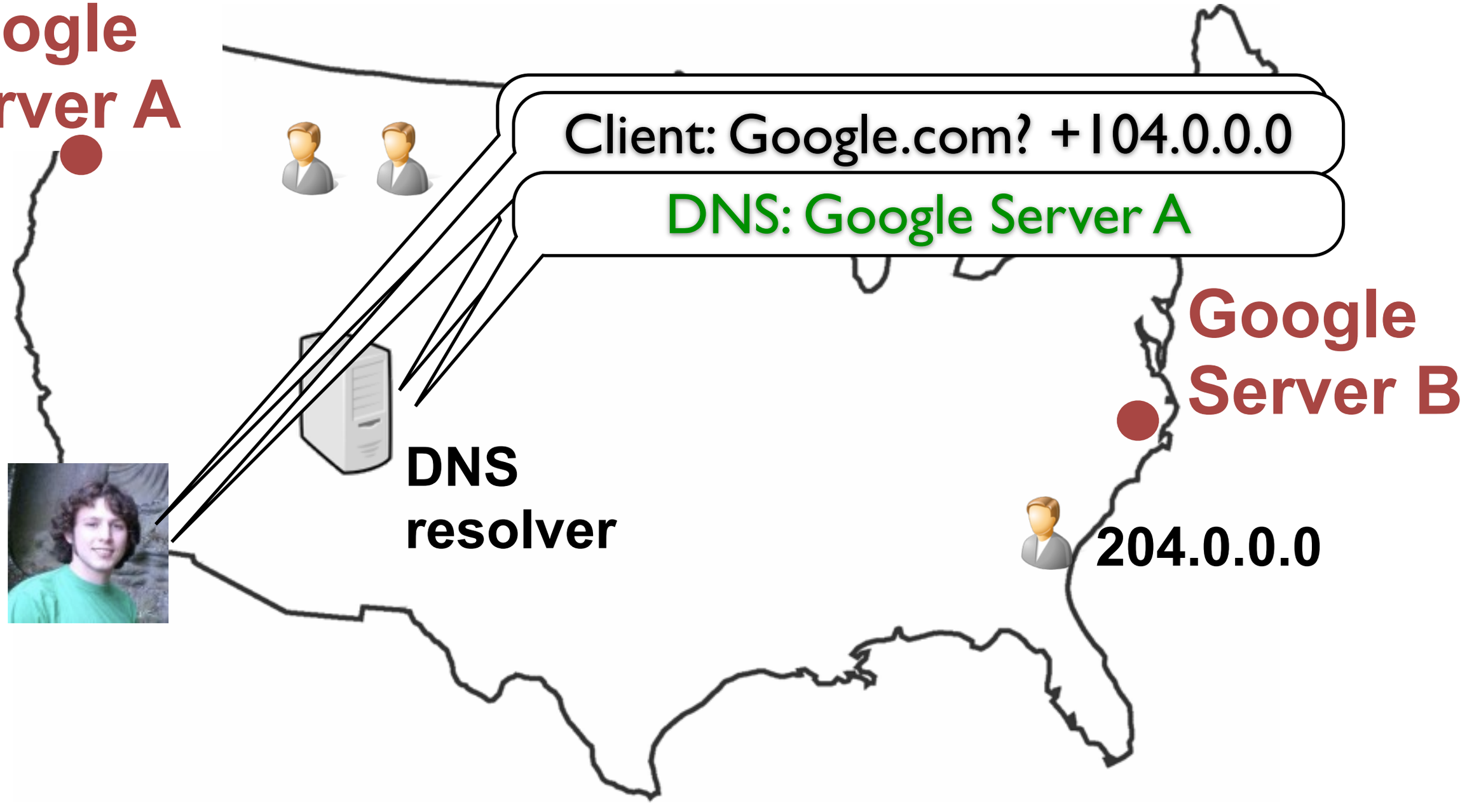

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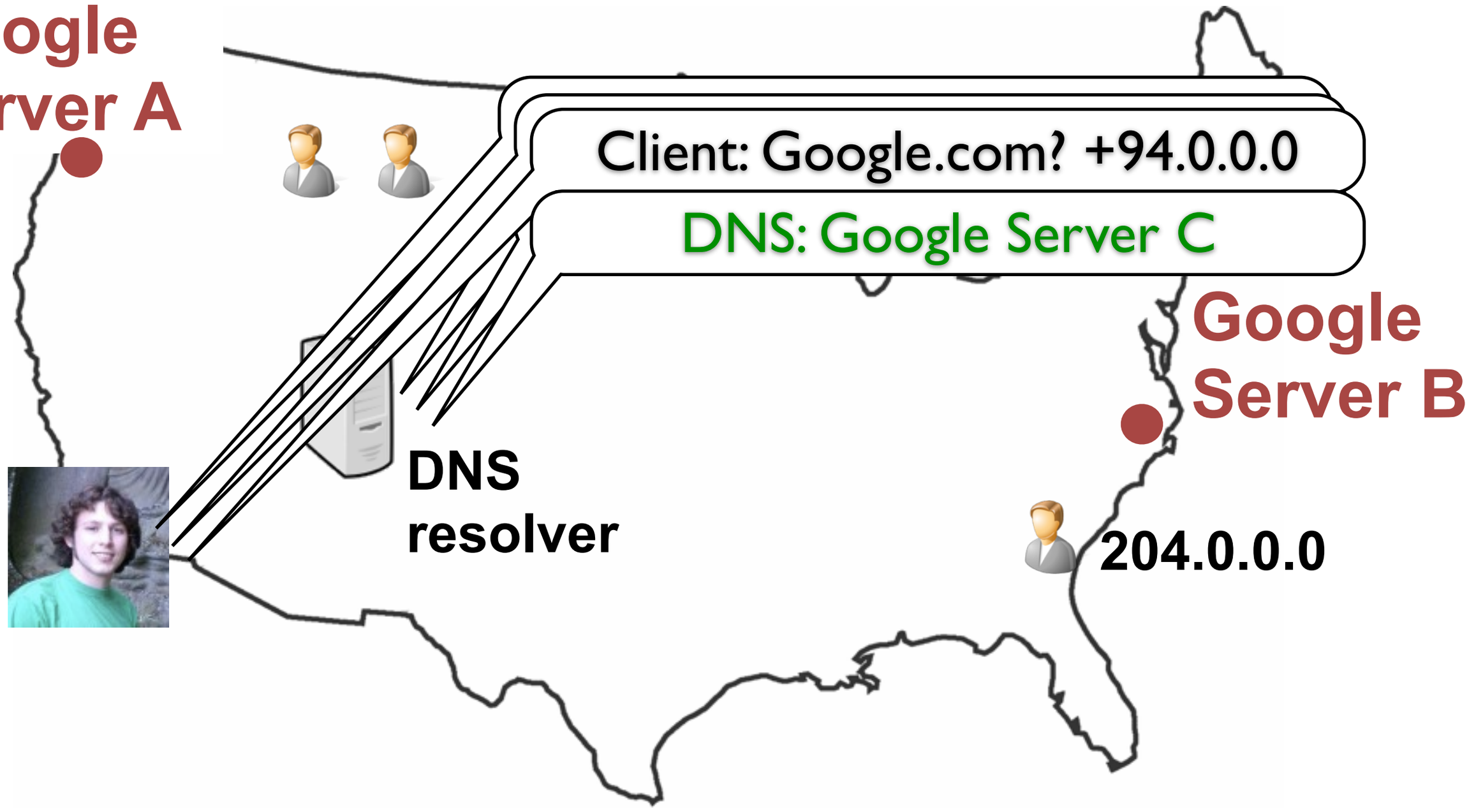

Our CDN Mapping Approach

Use the fact that CDN works hard to direct clients to nearby front-ends

1. Insufficient vantage points limit mapping

2. Existing geolocation inaccurate for servers

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Use the fact that CDN works hard to direct clients to nearby front-ends

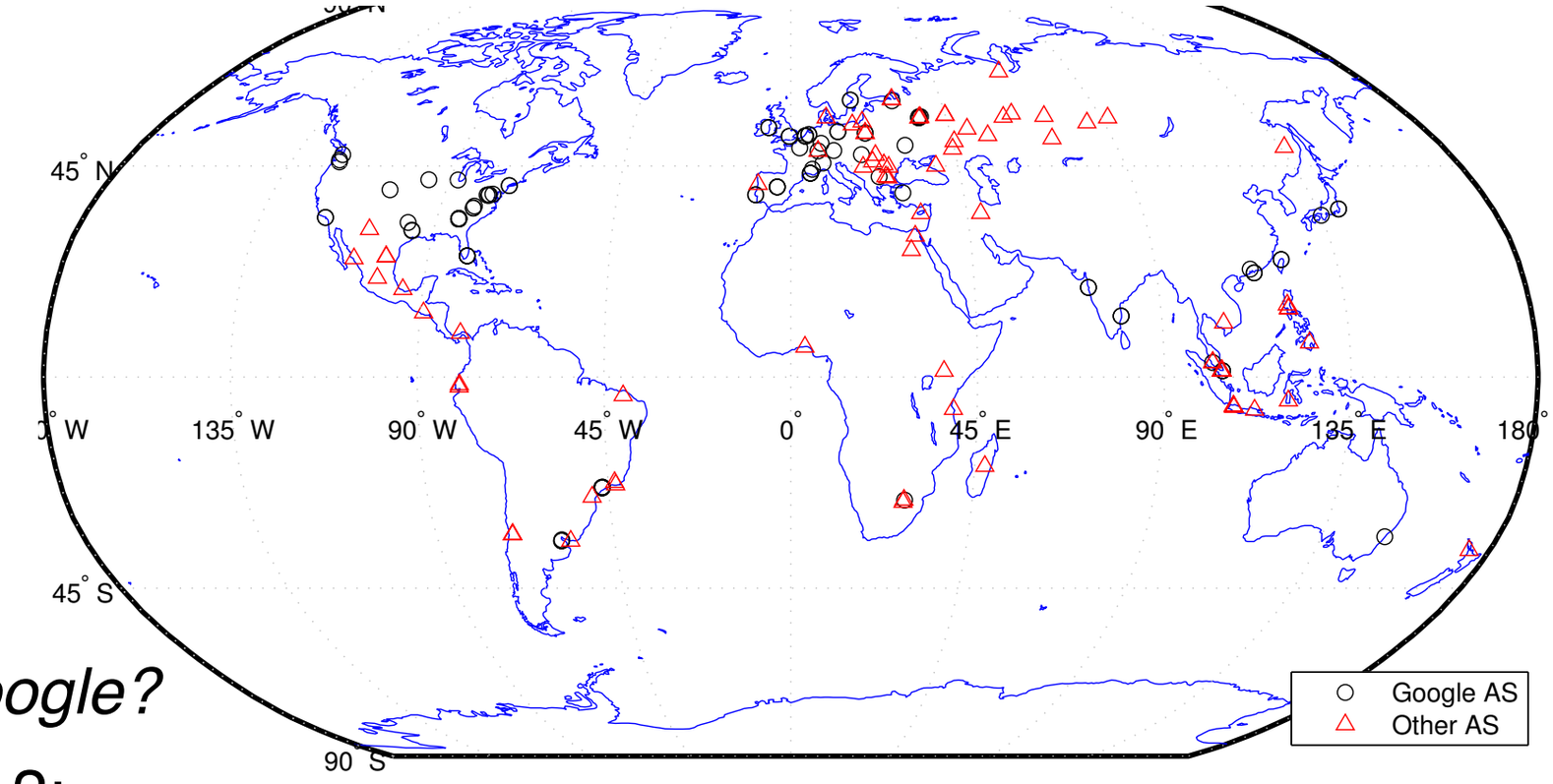
1. Insufficient vantage points limit mapping

✔ Complete enumeration using EDNS client-subnet-prefix

2. Existing geolocation inaccurate for servers

✔ Geolocate server based on its clients (skipping for time)
Median error is 20km, 80+% error < 100km

Our Daily Map, October 13 2012



How big is Google?

Circa IMC 2012:

- 200 locations across 100 ASes

Paper story:

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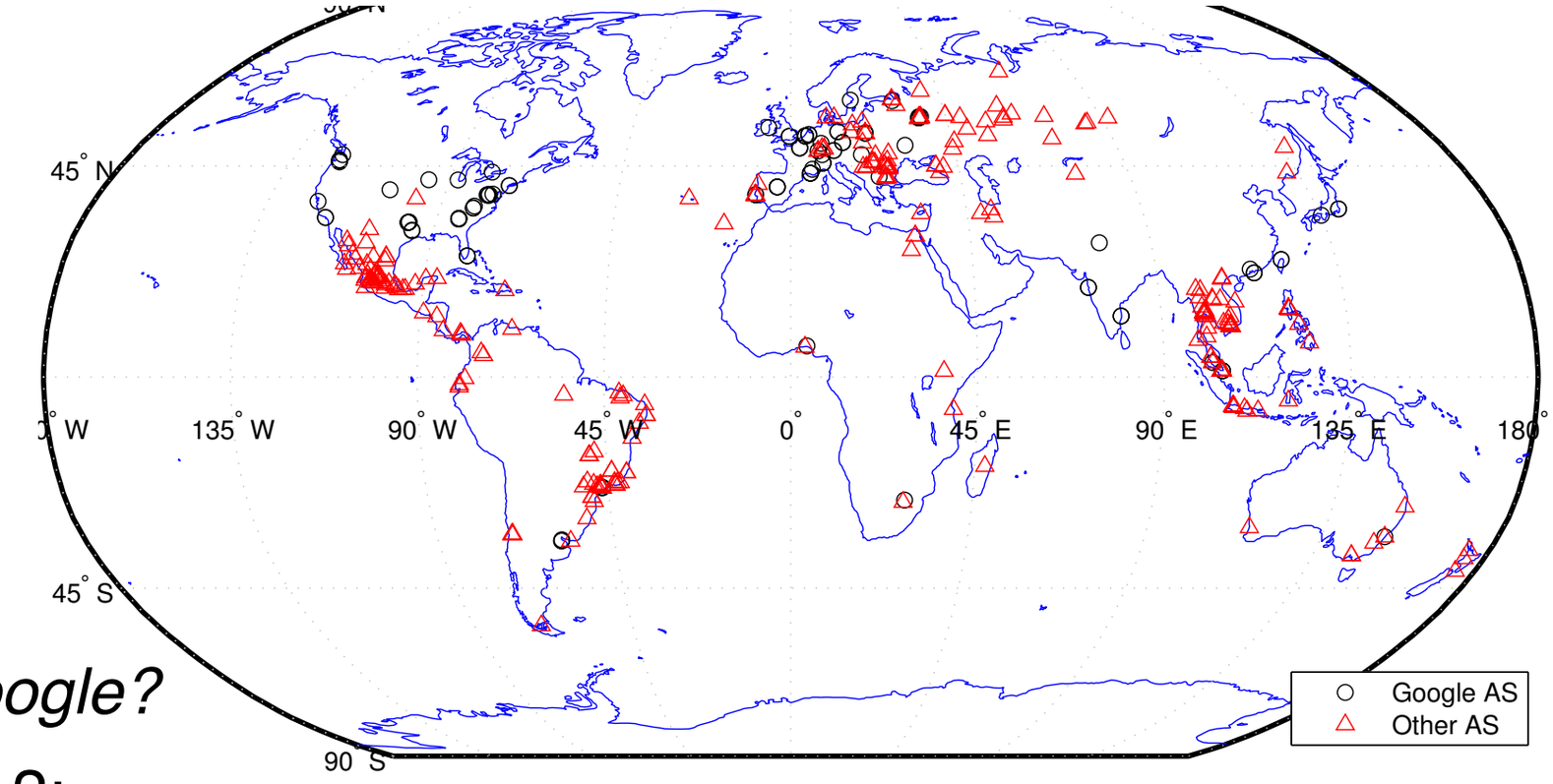

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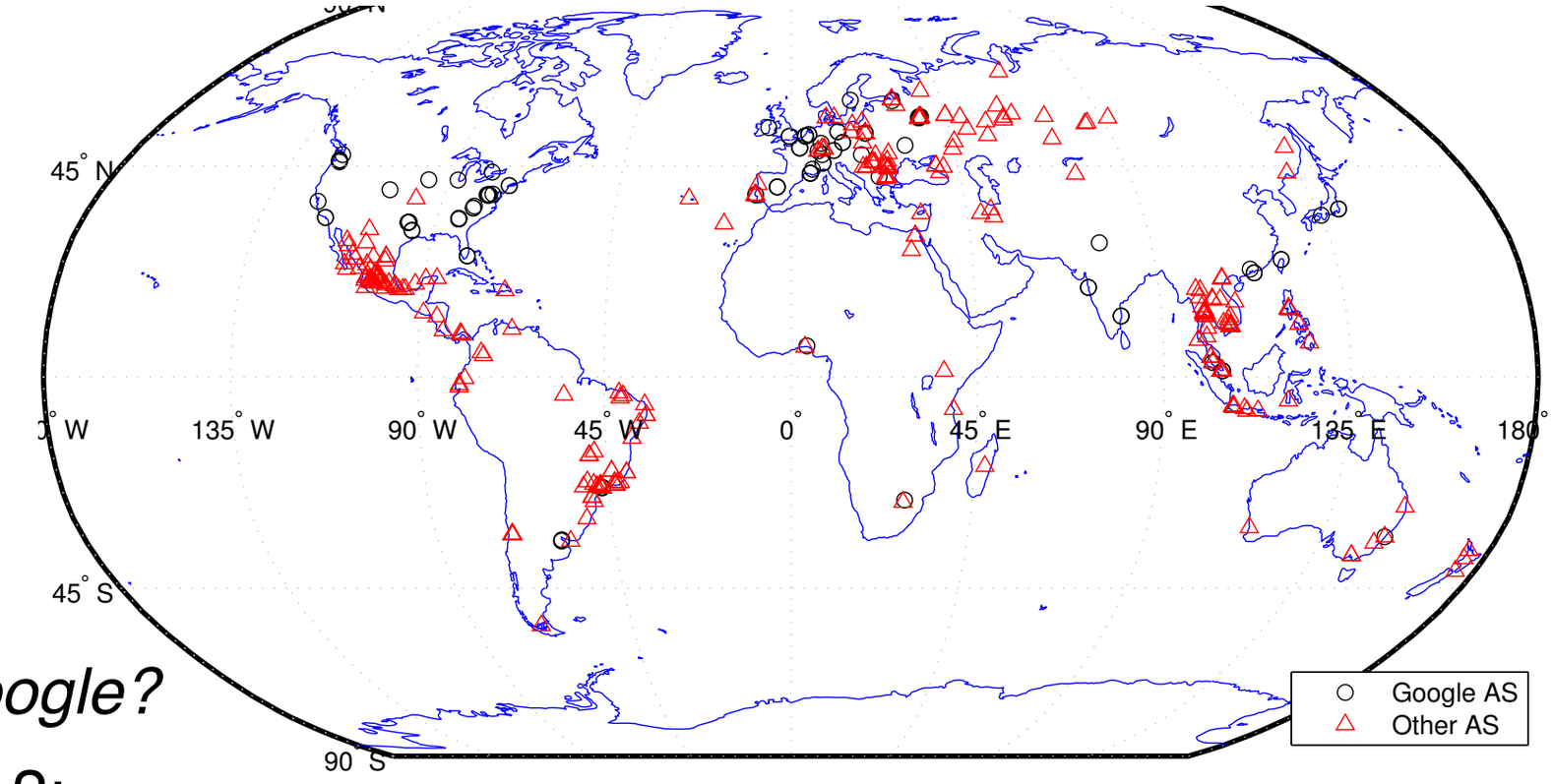

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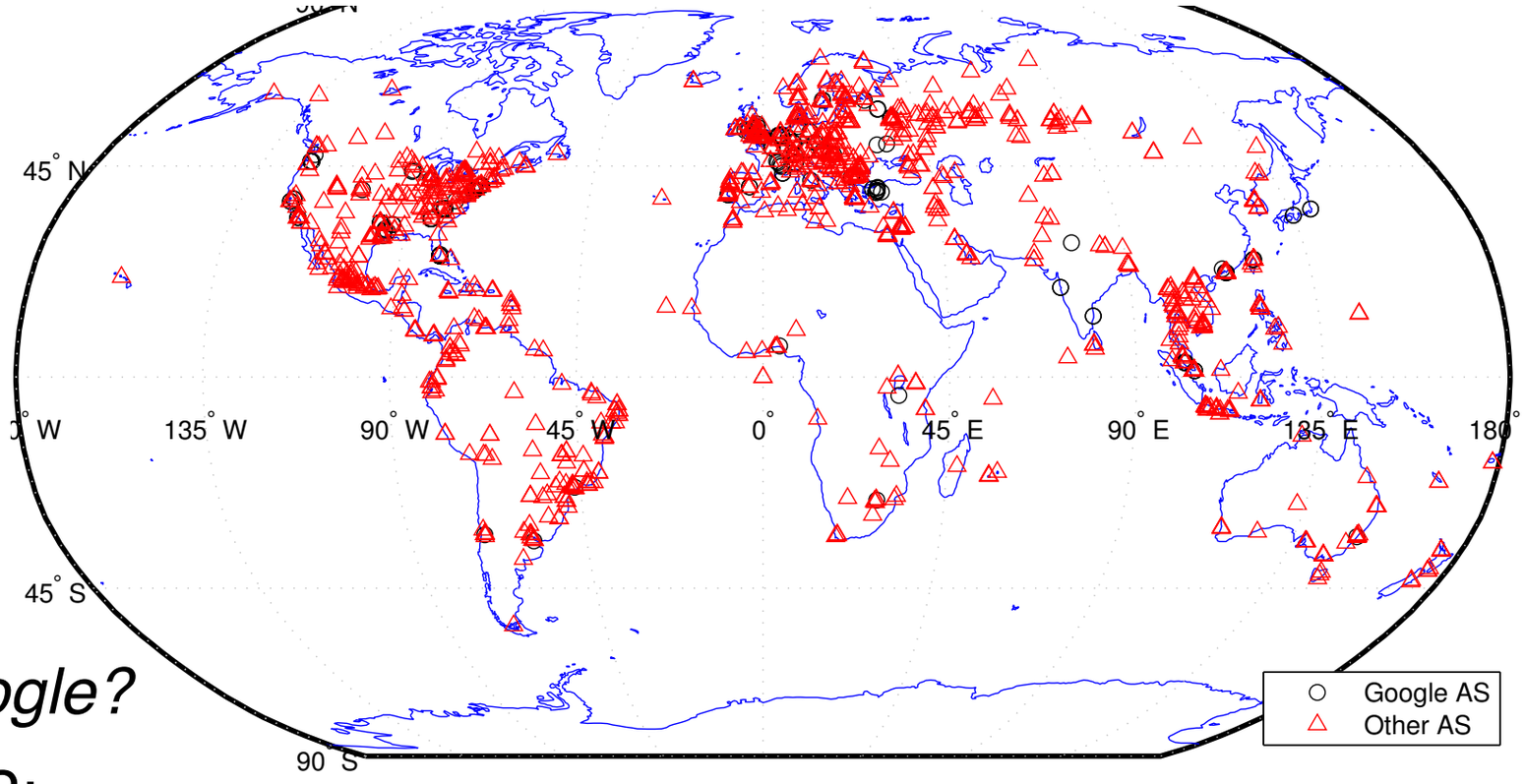

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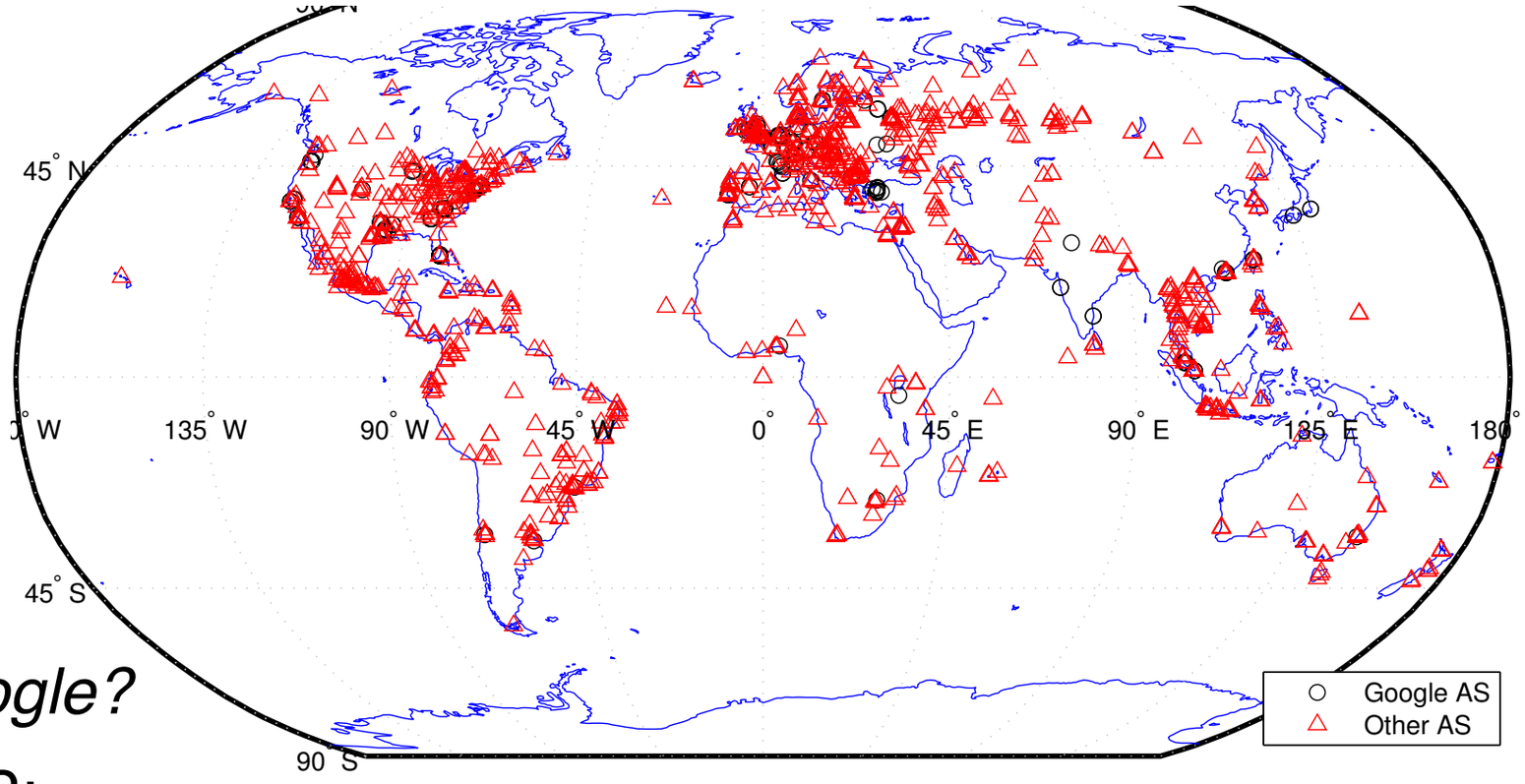

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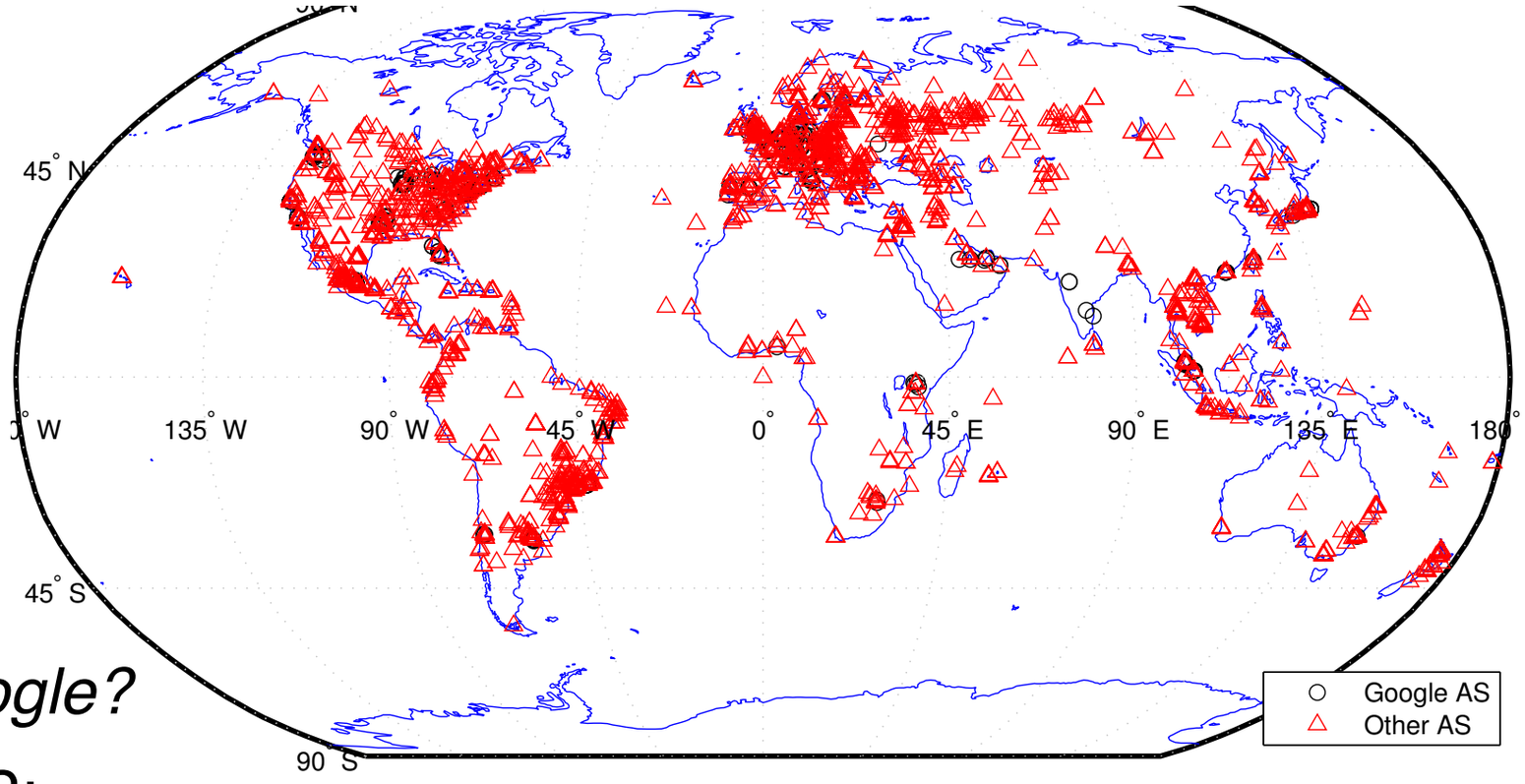

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Circa IMC 2015 (this week):

- 1800 locations across 1300 ASes

Paper story:

~~"Comparing CDN infrastructure"~~

~~"Mapping Google's expansion"~~

"Mapping Google's [HUGE] expansion"

Benefits of ongoing, public measurements

1. Long-running, with periodically refreshed measurements

✓Track Internet evolution

- Observe trends
- Up-to-date joins with other data

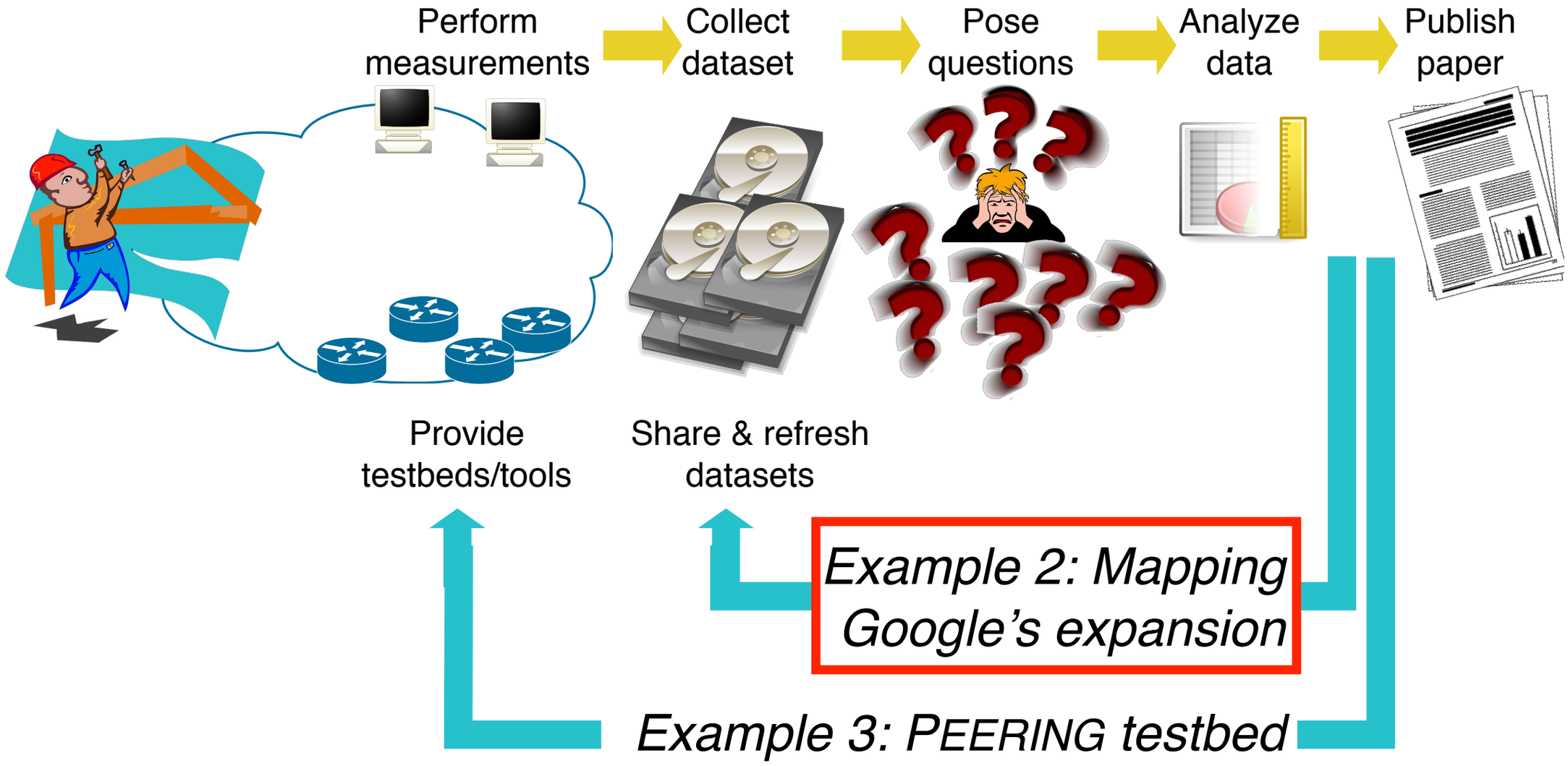
2. Public data, testbeds, and tools

✓Eases incorporation of / comparison to your work

Towards impactful Internet measurement

Challenges:

Limited data shapes analysis



Impact:

Towards impactful Internet measurement

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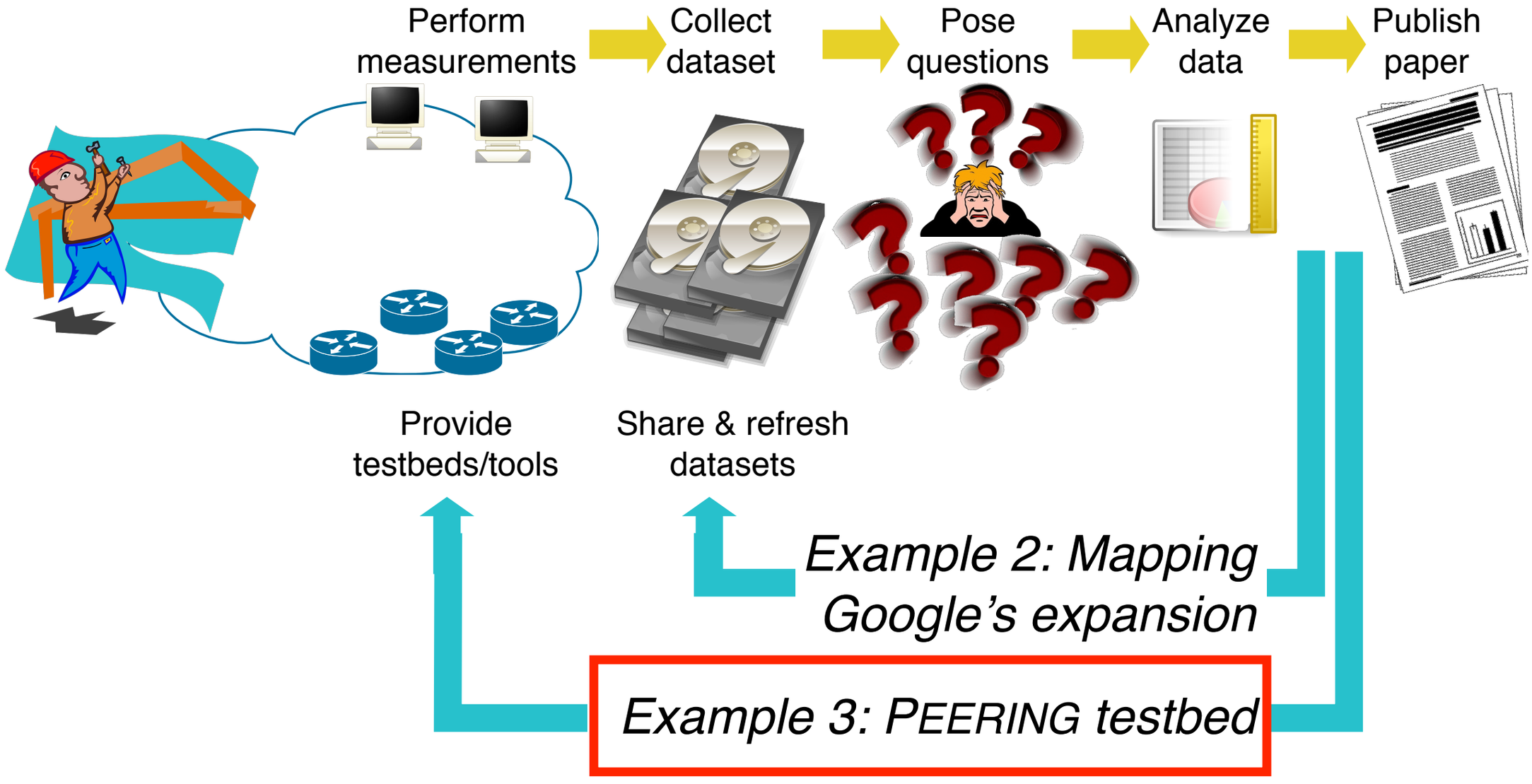

Impact:

Motivating Example: Origin Authorization

Route Origin Authorization (ROA)

- Specifies which network is valid to announce prefix

Existing studies: What prefixes have ROAs? Do observed routes match?

Open question: *How many networks deploy ROA-based filtering?*

- ROA is only effective if other networks check/honor authorizations
- Do other networks check validity? How do they handle invalid?
- What efforts increase deployment over time?

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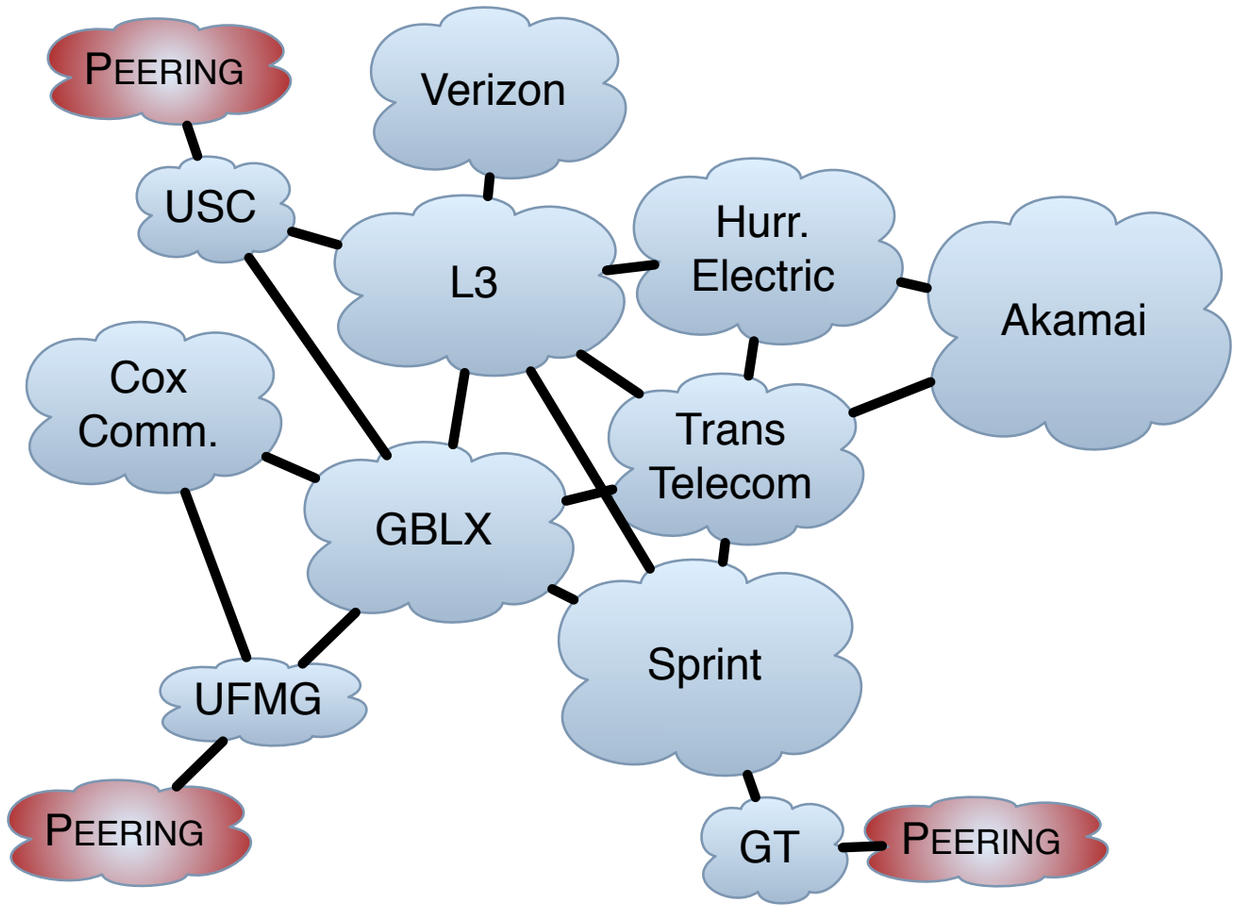
Limited existing tools for routing research:

- Measurements (traceroute, Looking Glass, route collectors)
  - Real view of routing, but can't manipulate validity of announcements
- Simulation
  - Overcomes lack of control, but can't accurately model policies

Approach: Control BGP Announcements on Real Internet with **PEERING**

PEERING is AS47065

- 9 universities as providers



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- ***Emulates*** an ISP or runs a BGP router
- ***Connects*** the emulated ISP to *real* ISPs on the Internet via BGP
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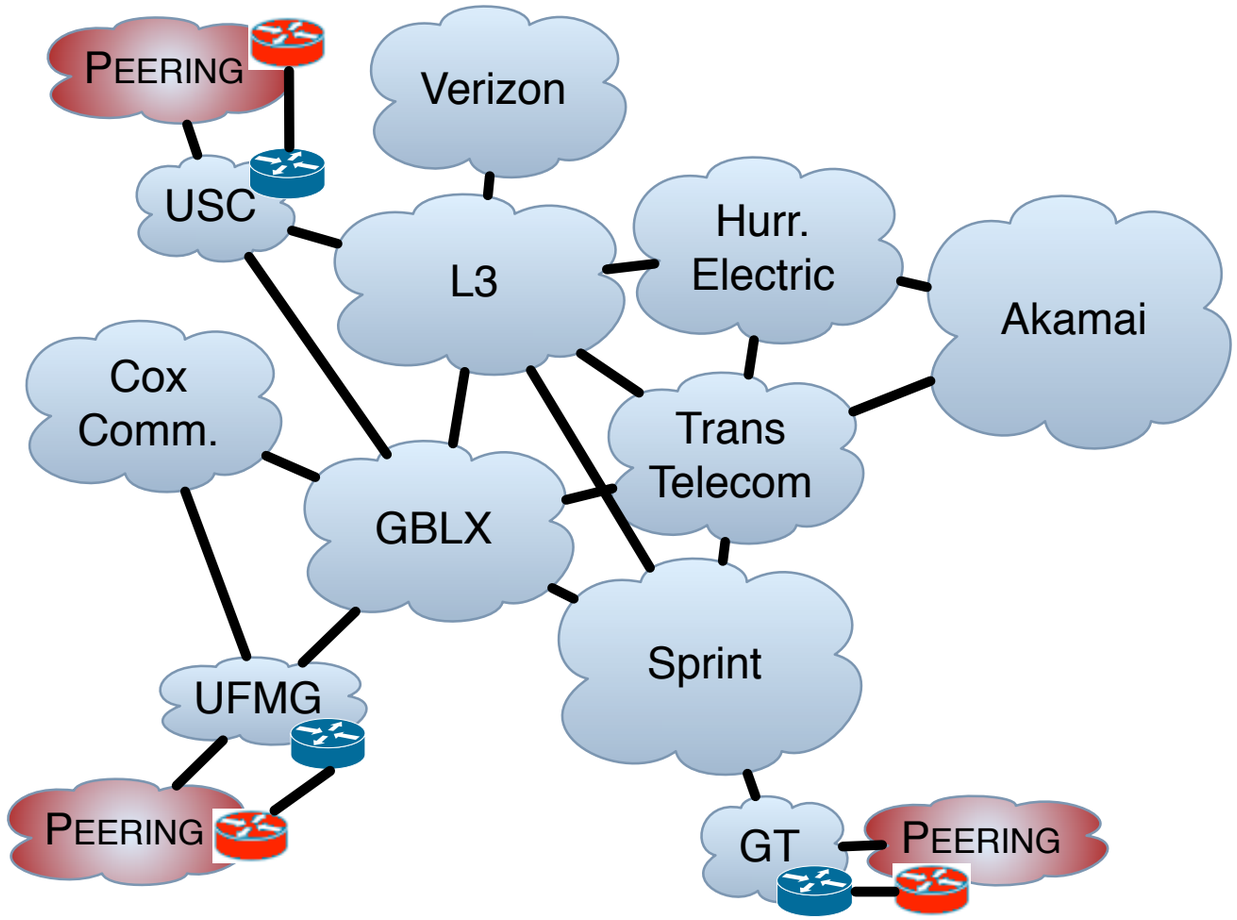

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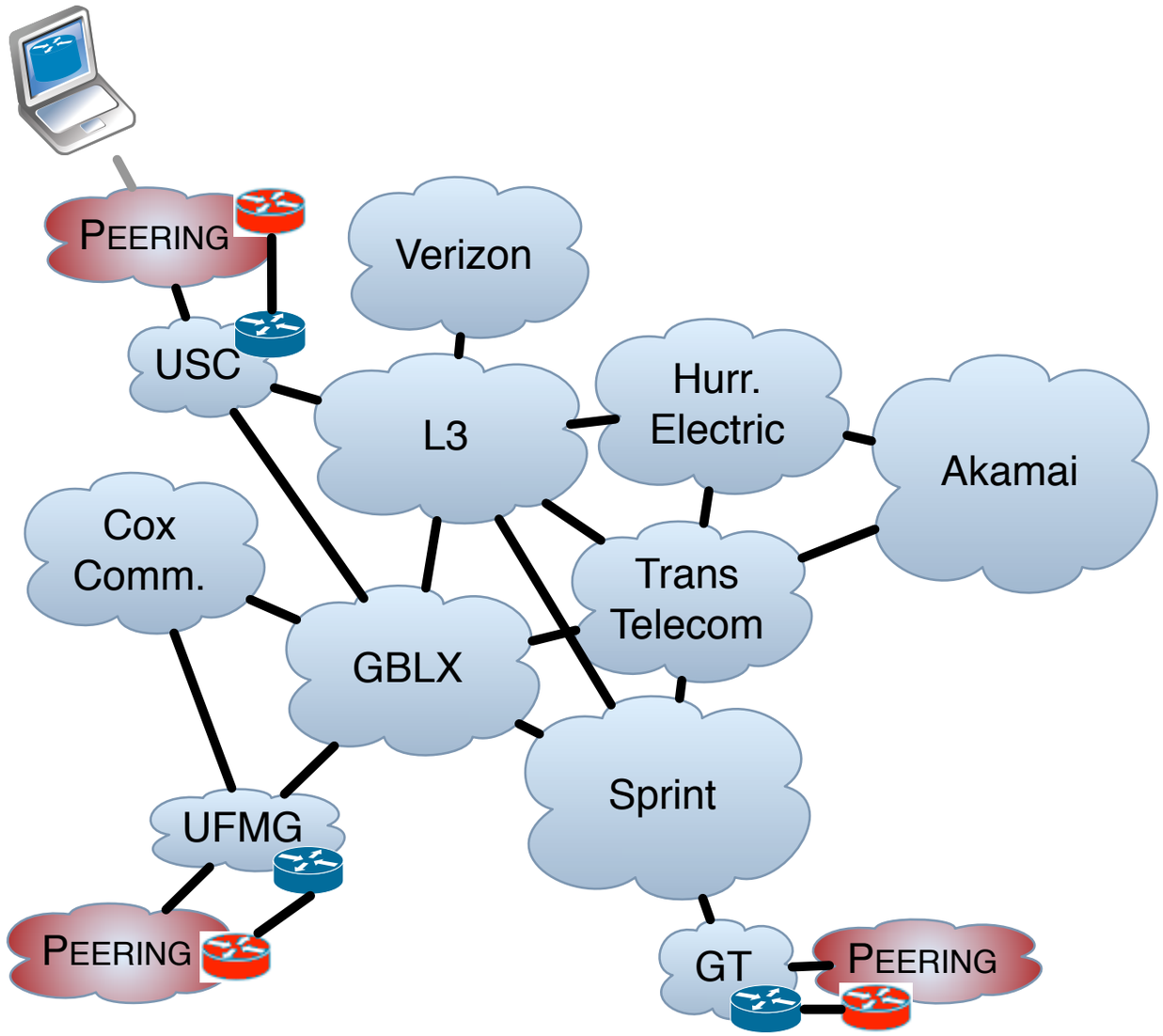

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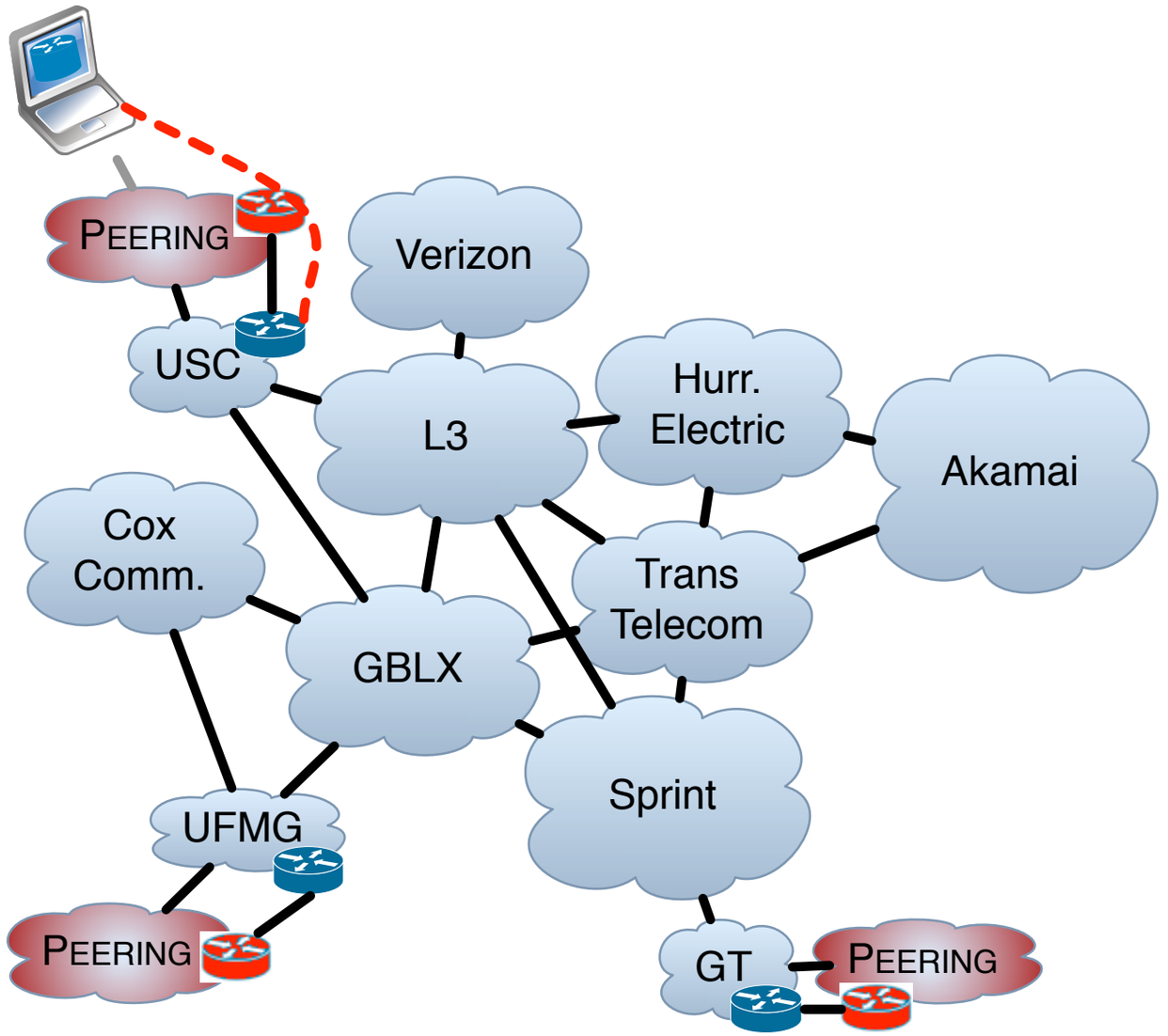

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Transparent connectivity to upstream

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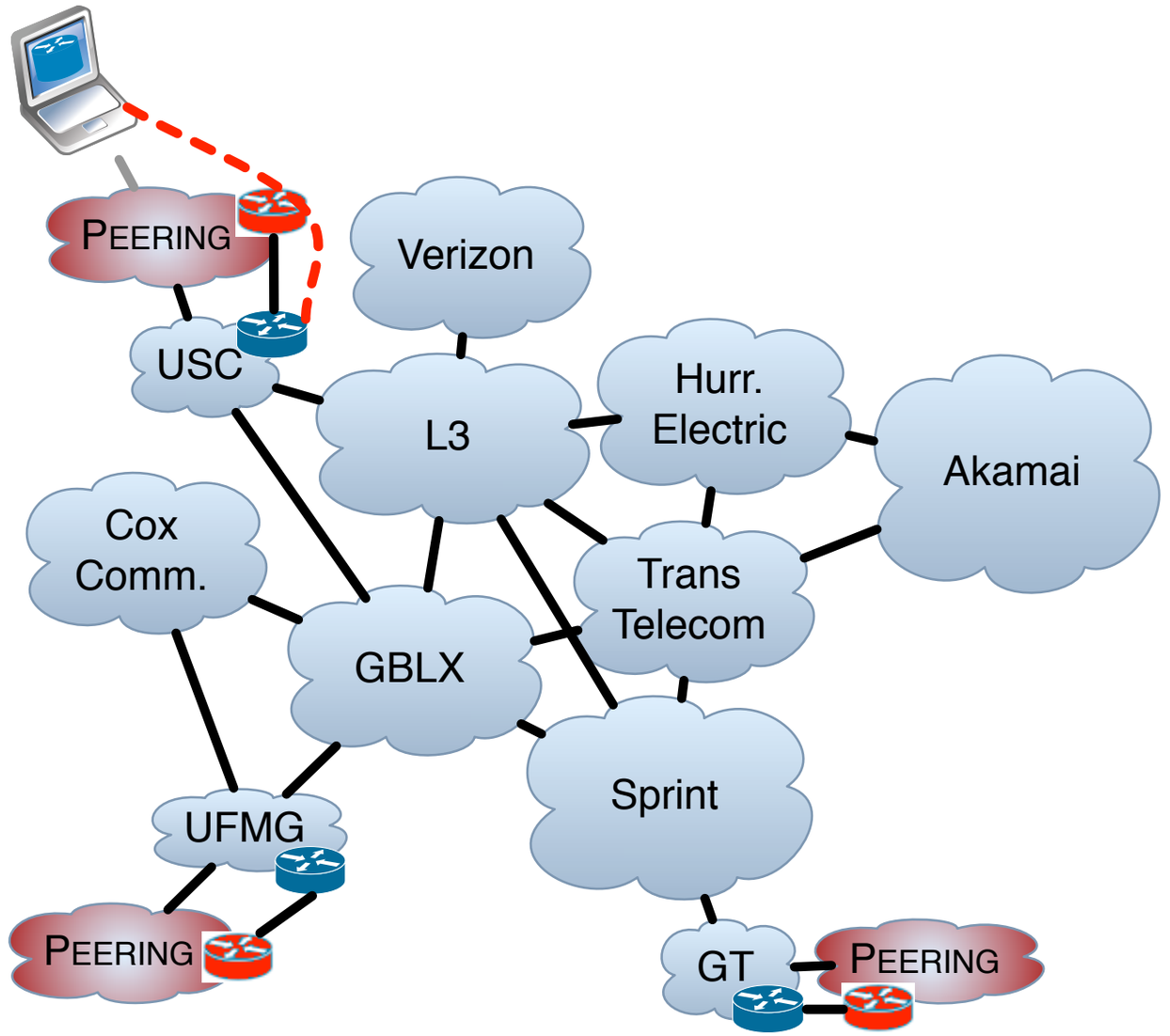

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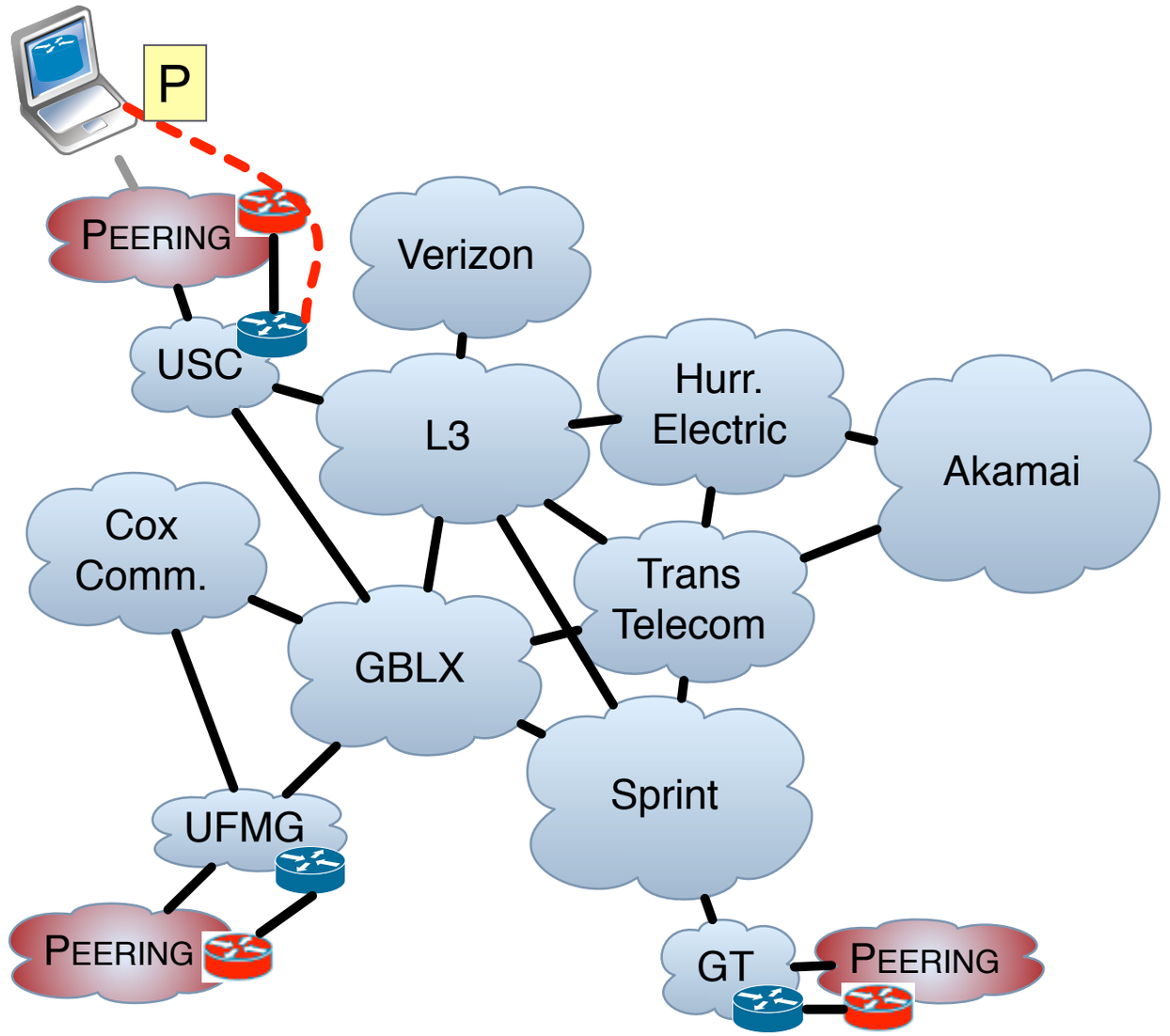

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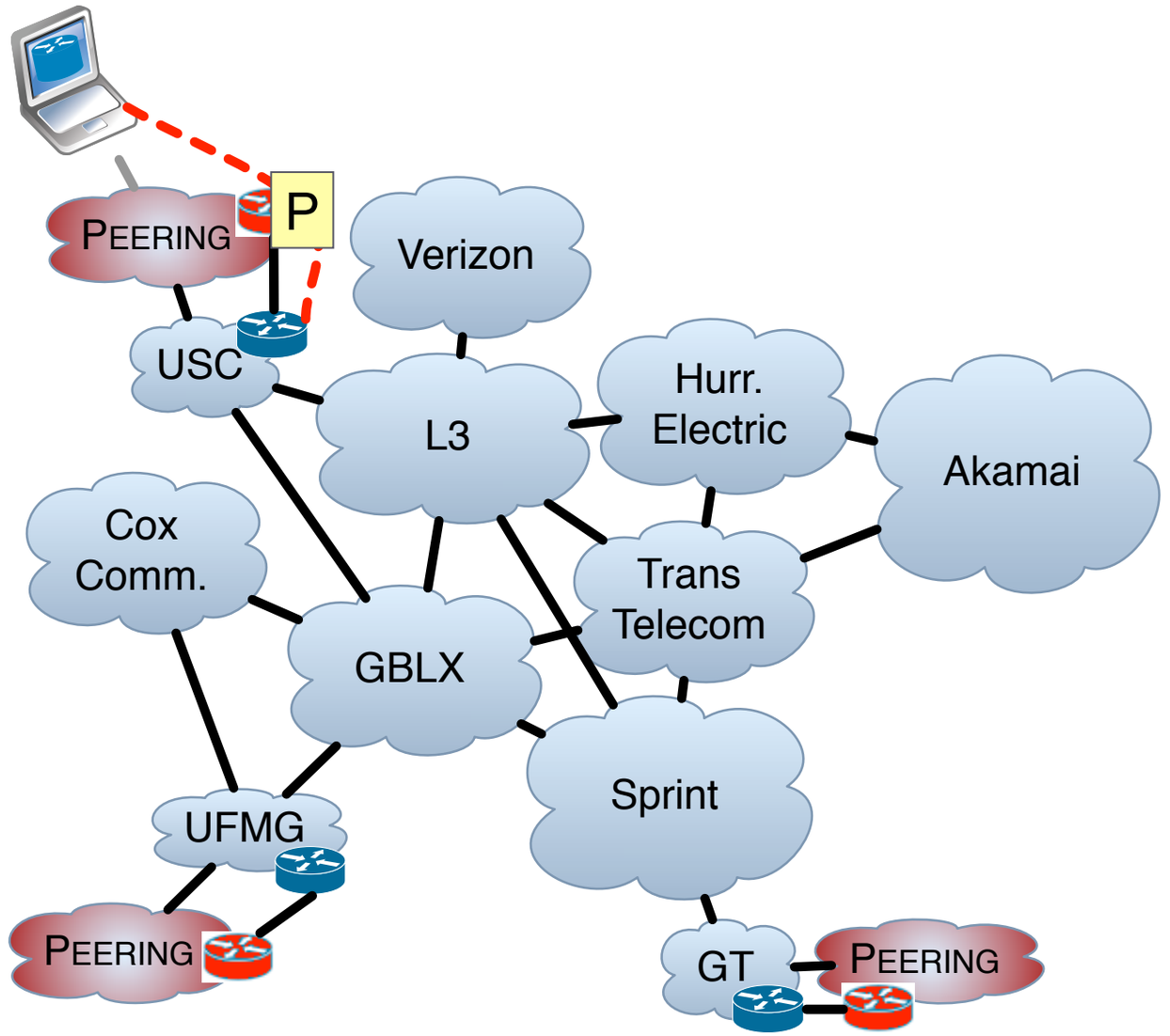

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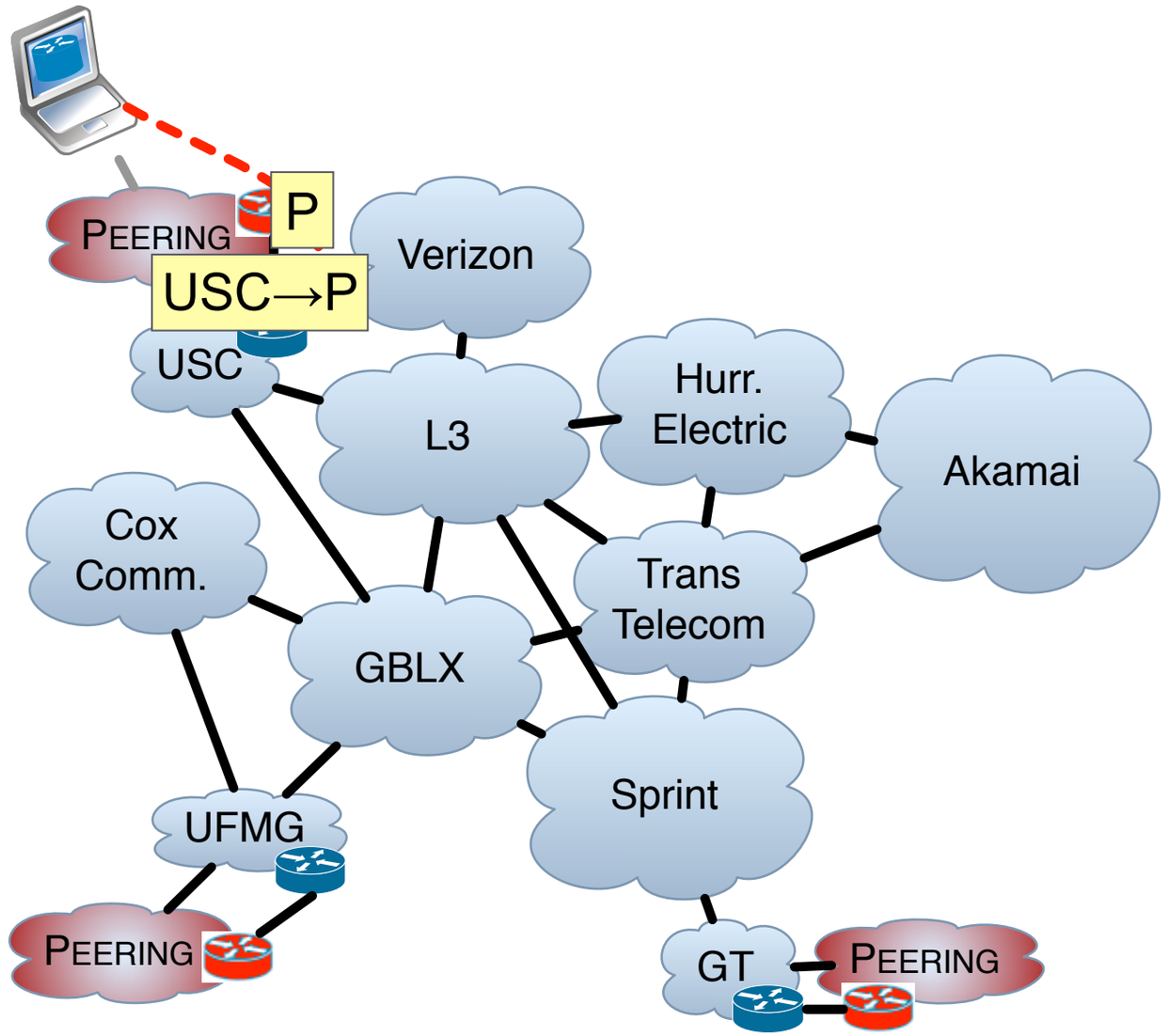

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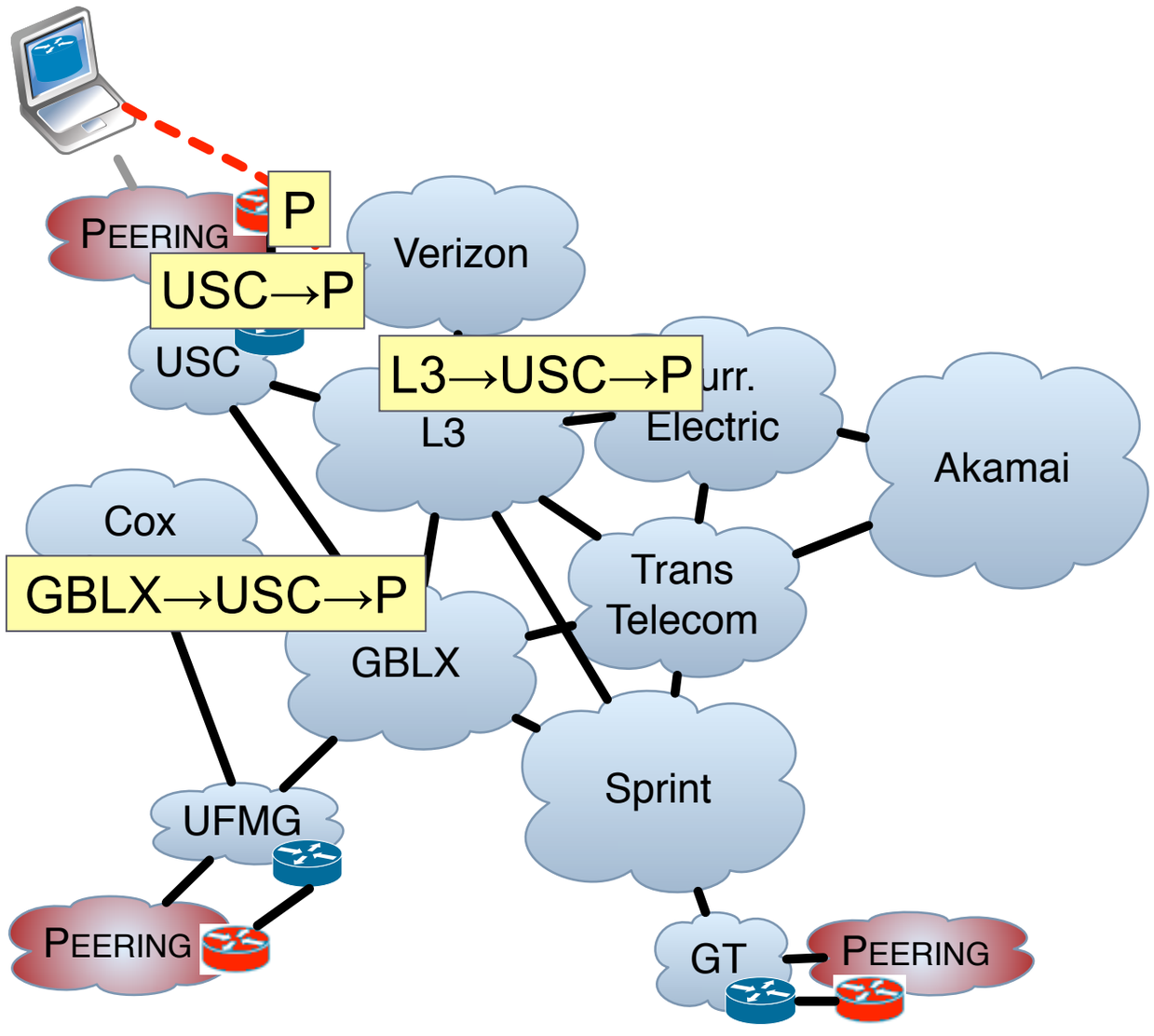

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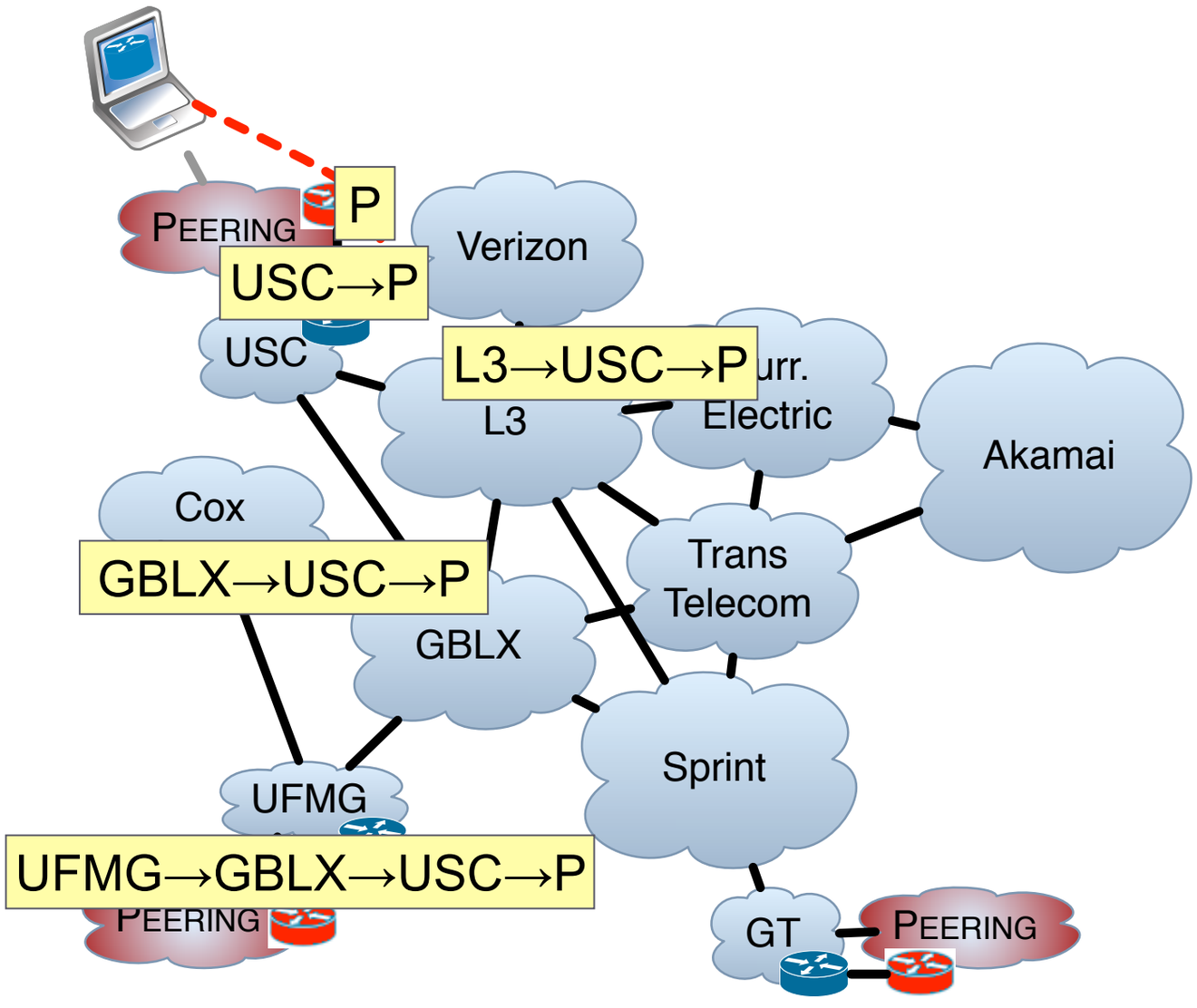

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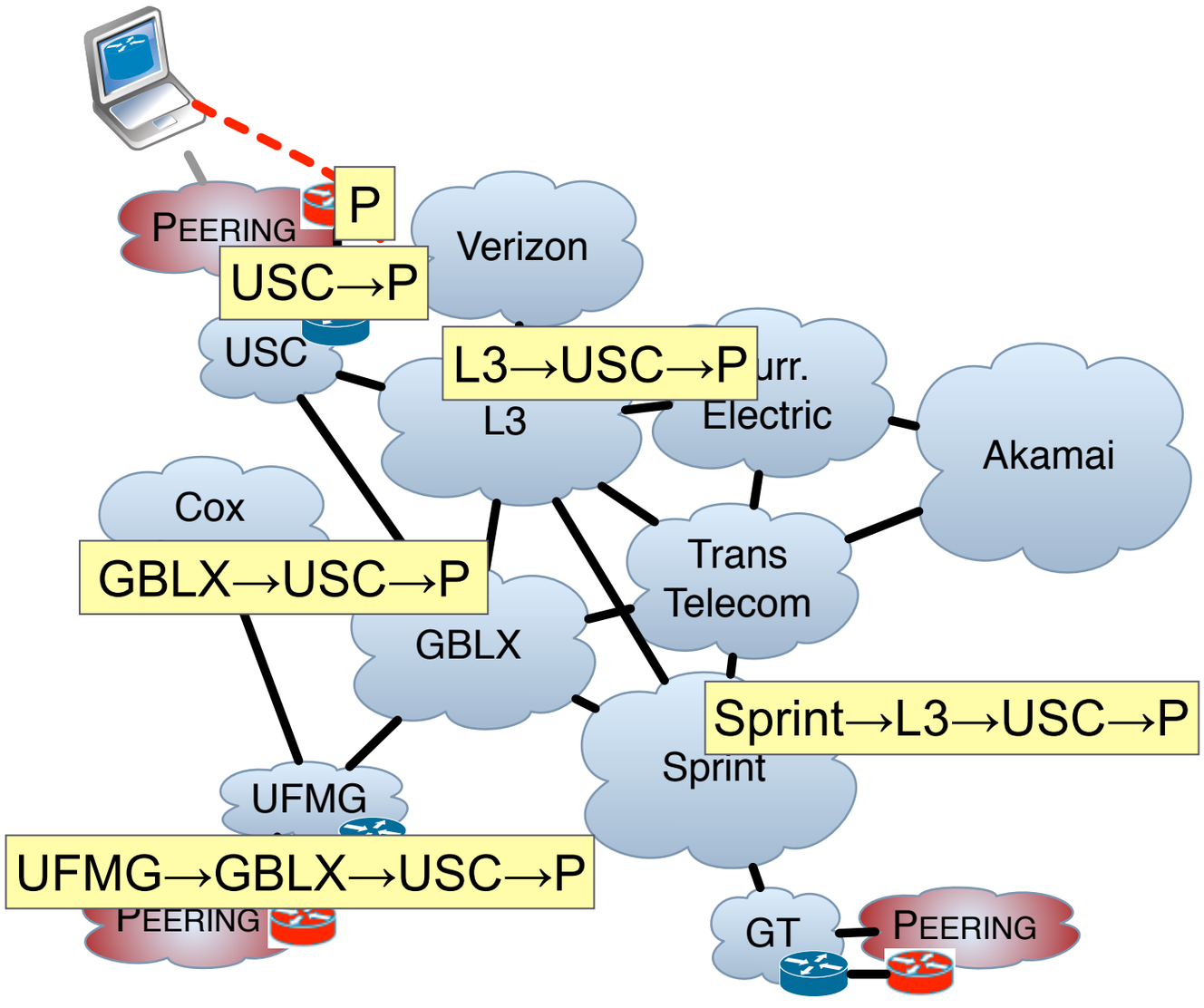

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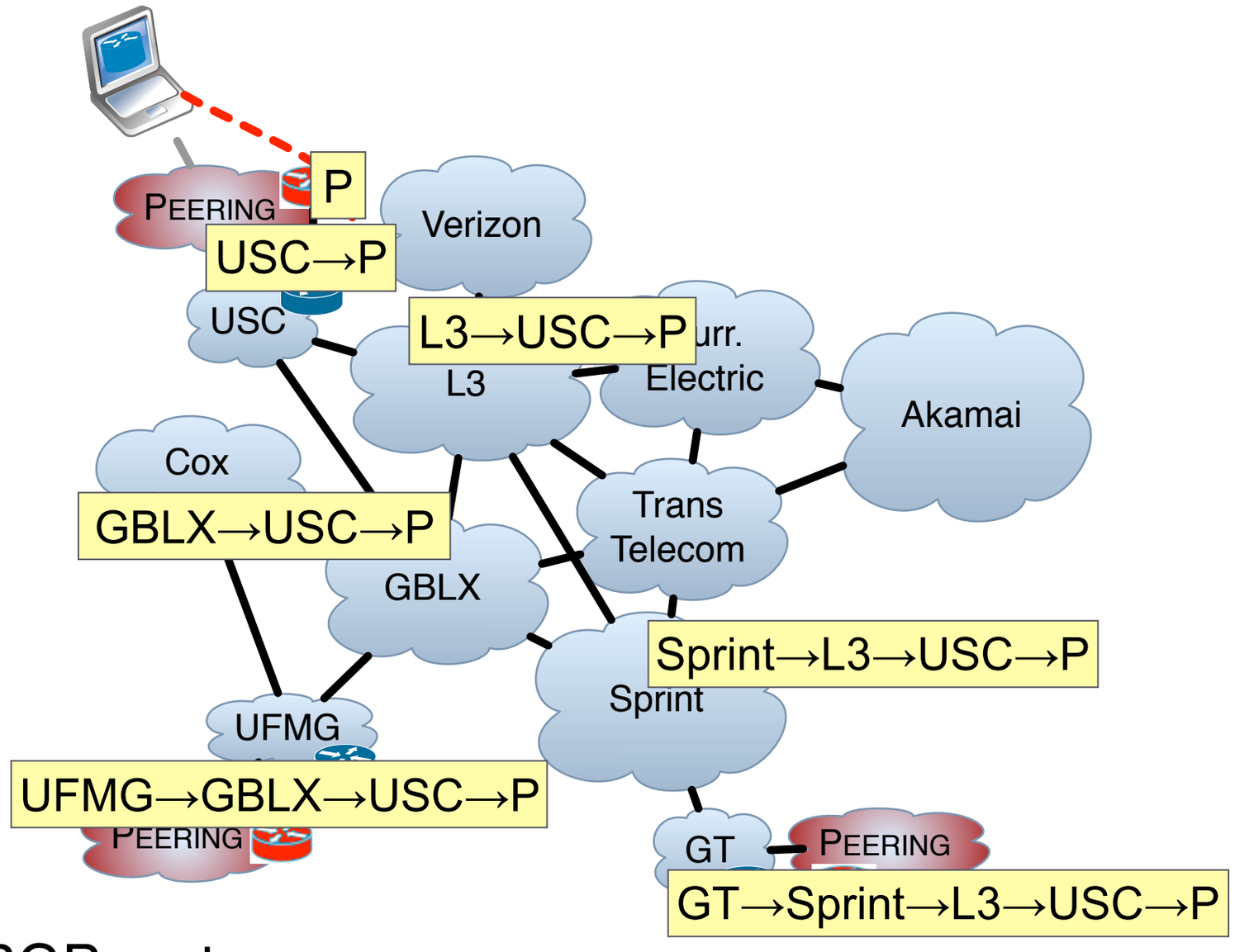

With PEERING, a researcher:

- ***Emulates*** an ISP or runs a BGP router
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Transparent connectivity to upstream

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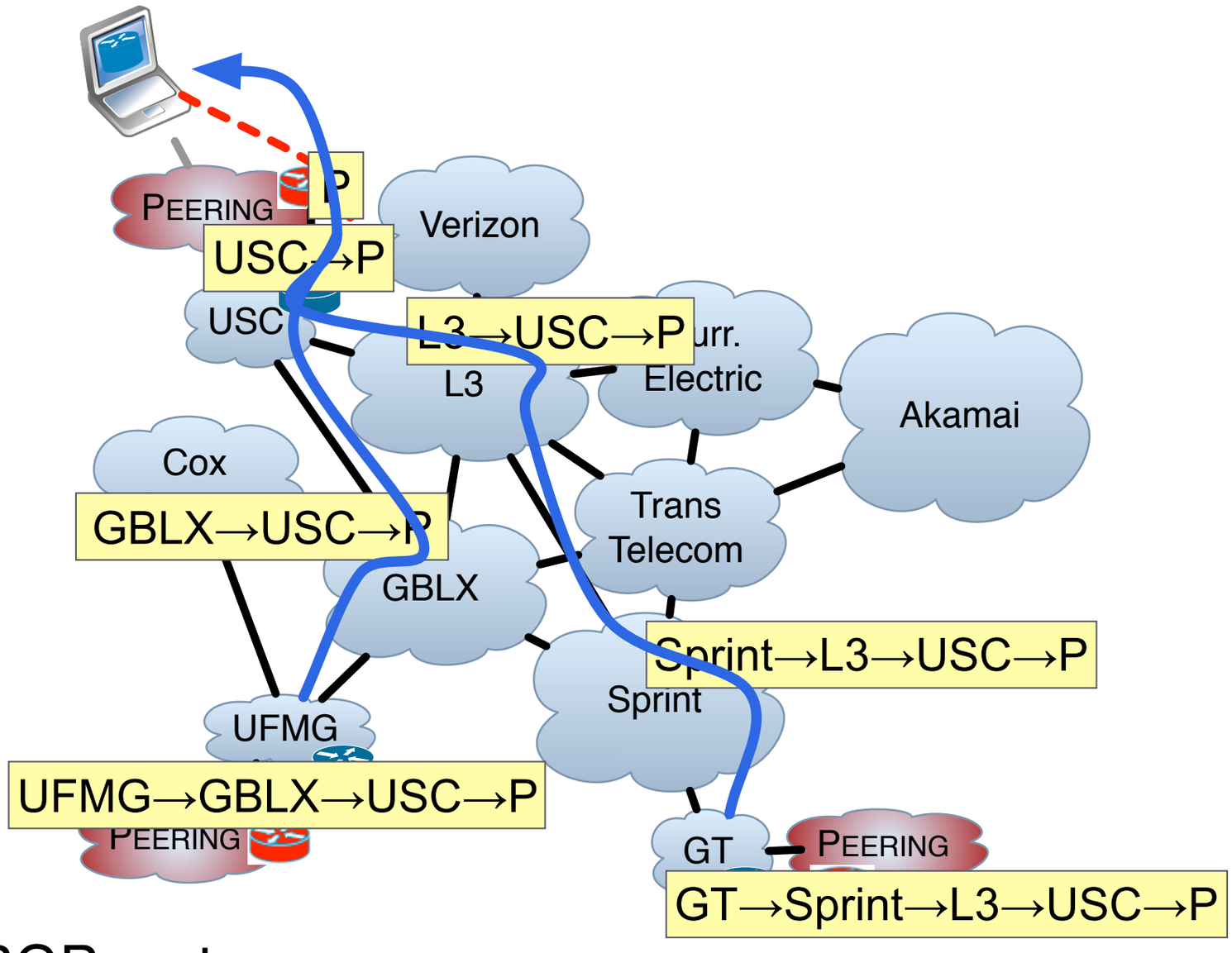

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With Doug Montgomery (NIST)

Route Origin Authorization (ROA)

- Specifies which network is valid to announce prefix

Existing studies:

- Which prefixes have ROAs?
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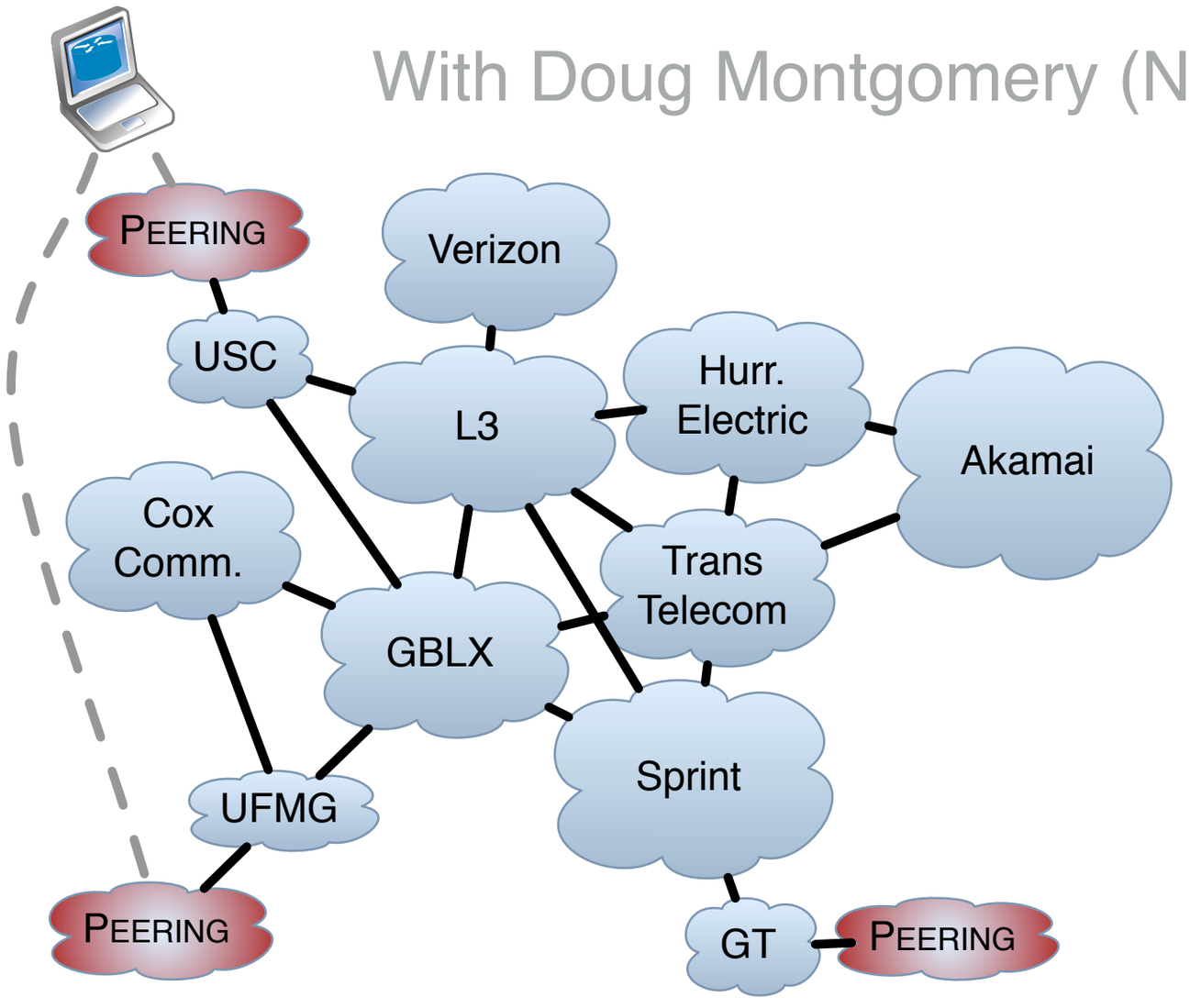
Missing adoption and impact:

- How many networks deploy ROA-based filtering?
- How do ASes handle invalid?



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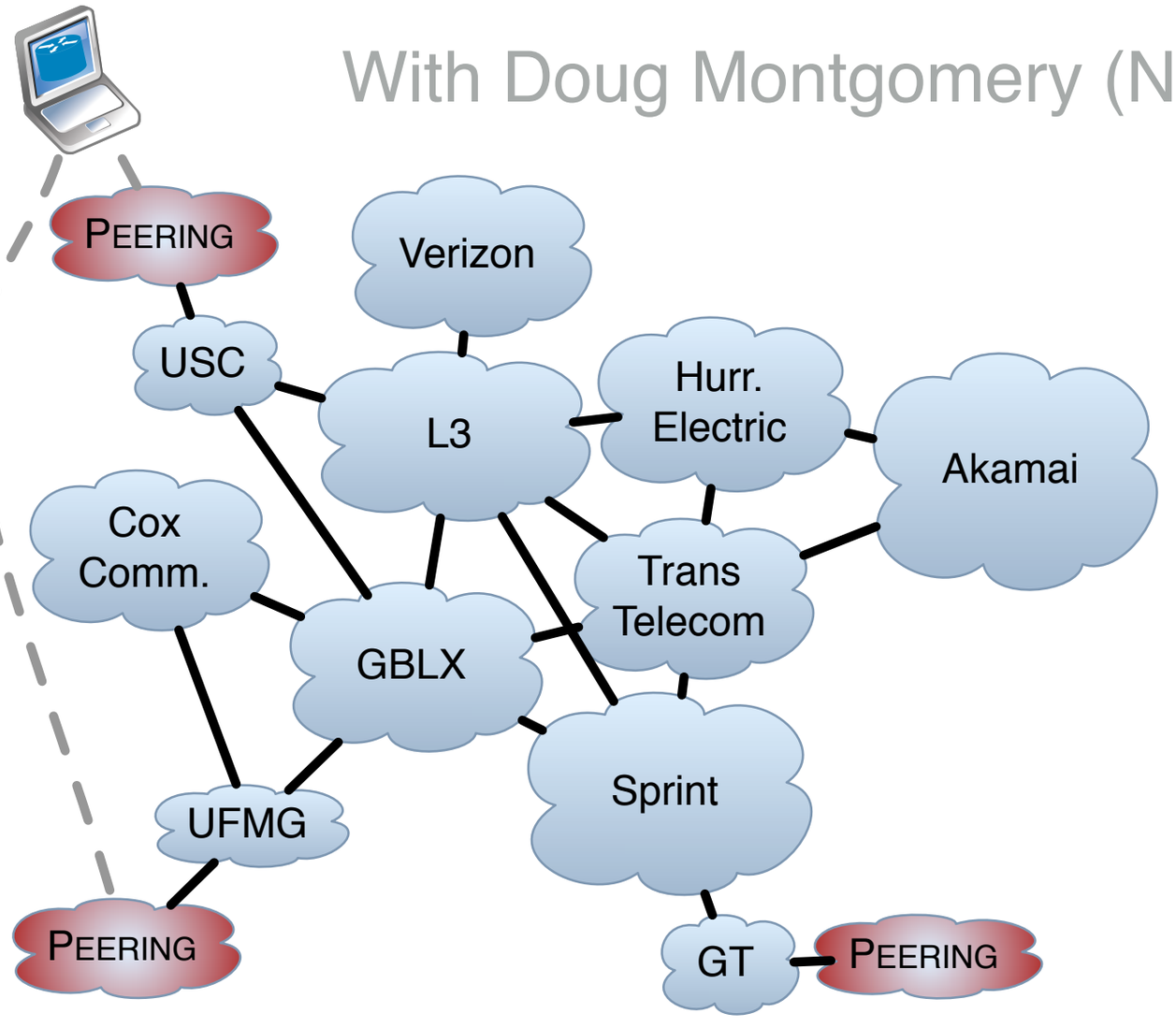

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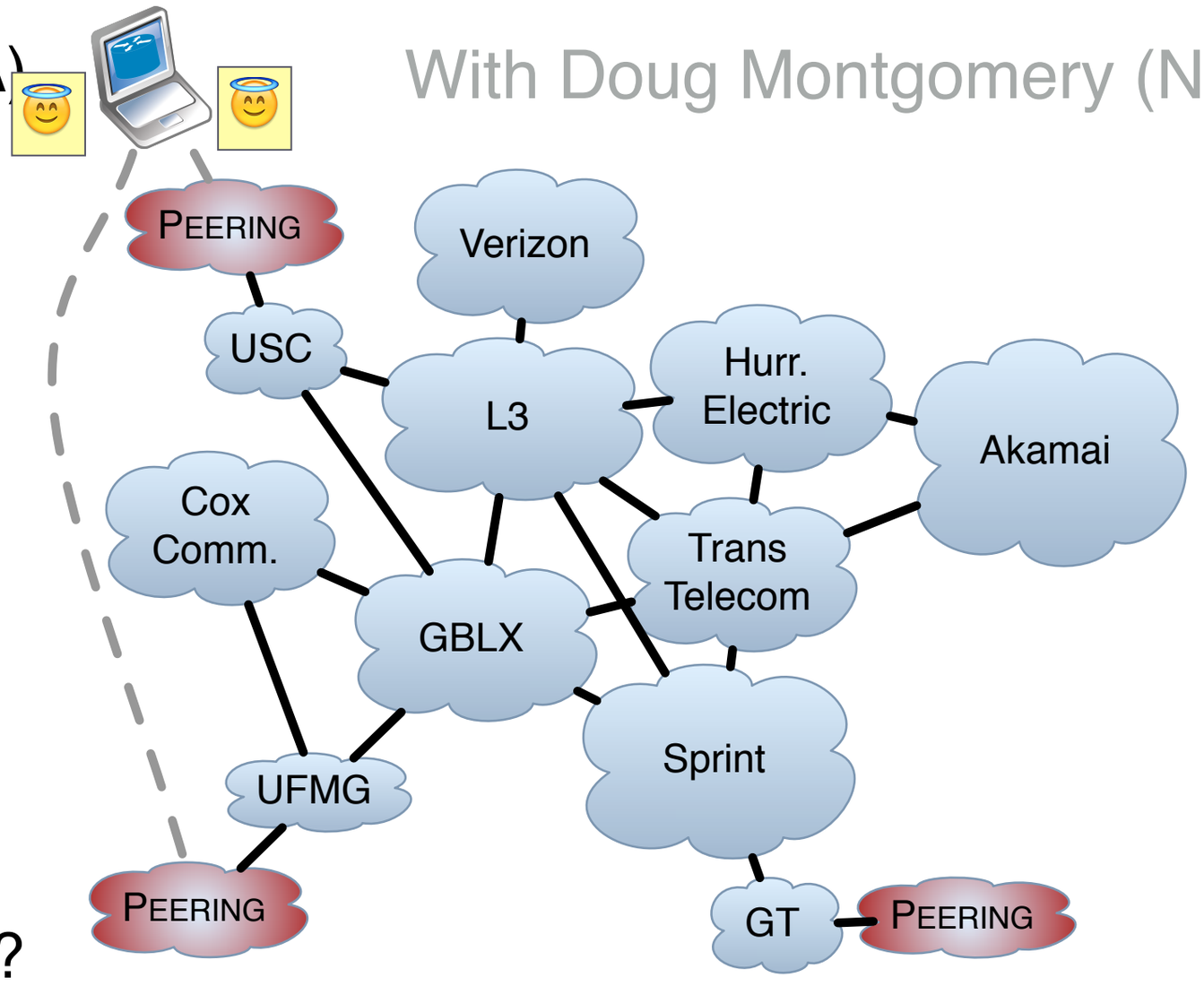

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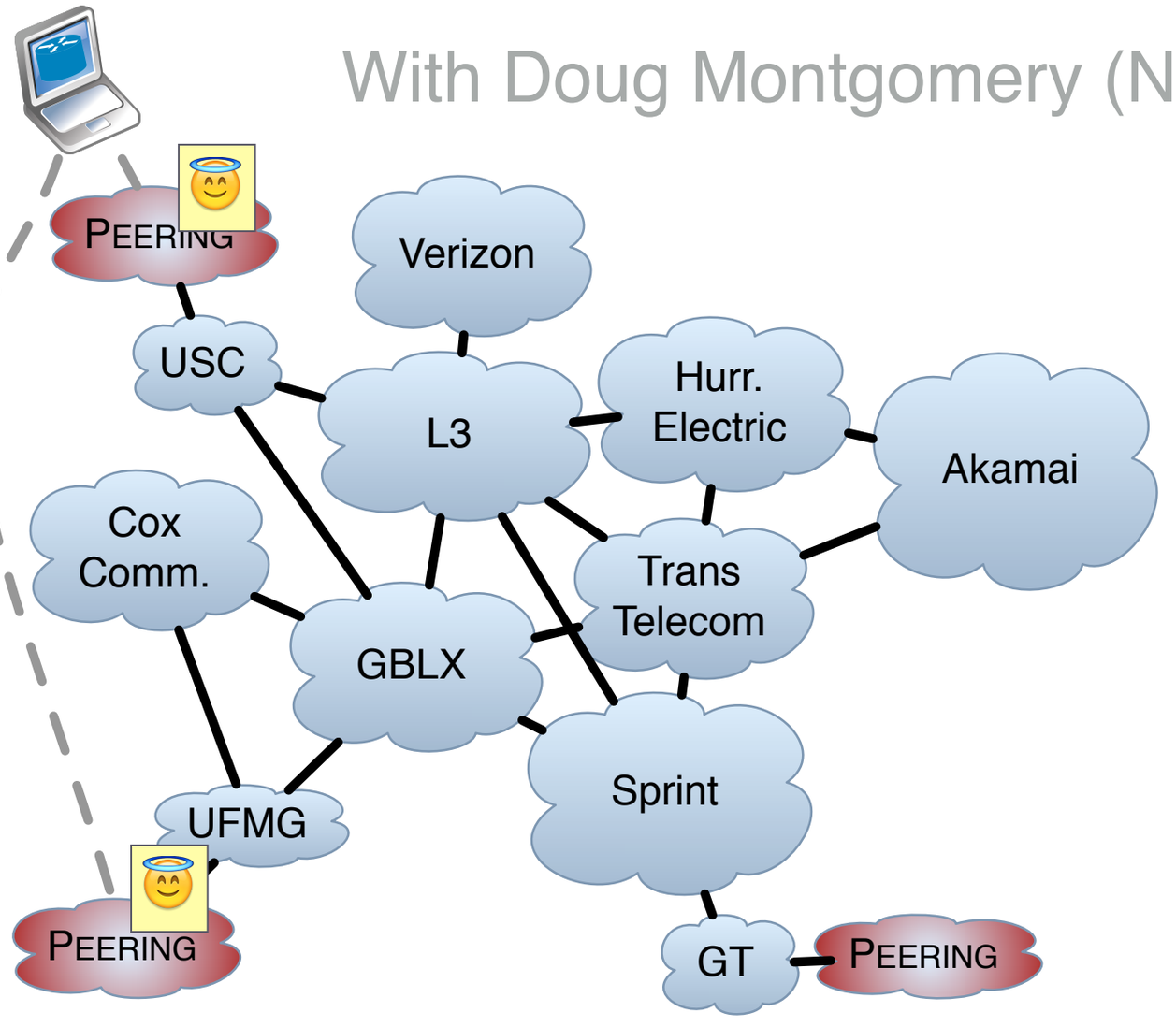

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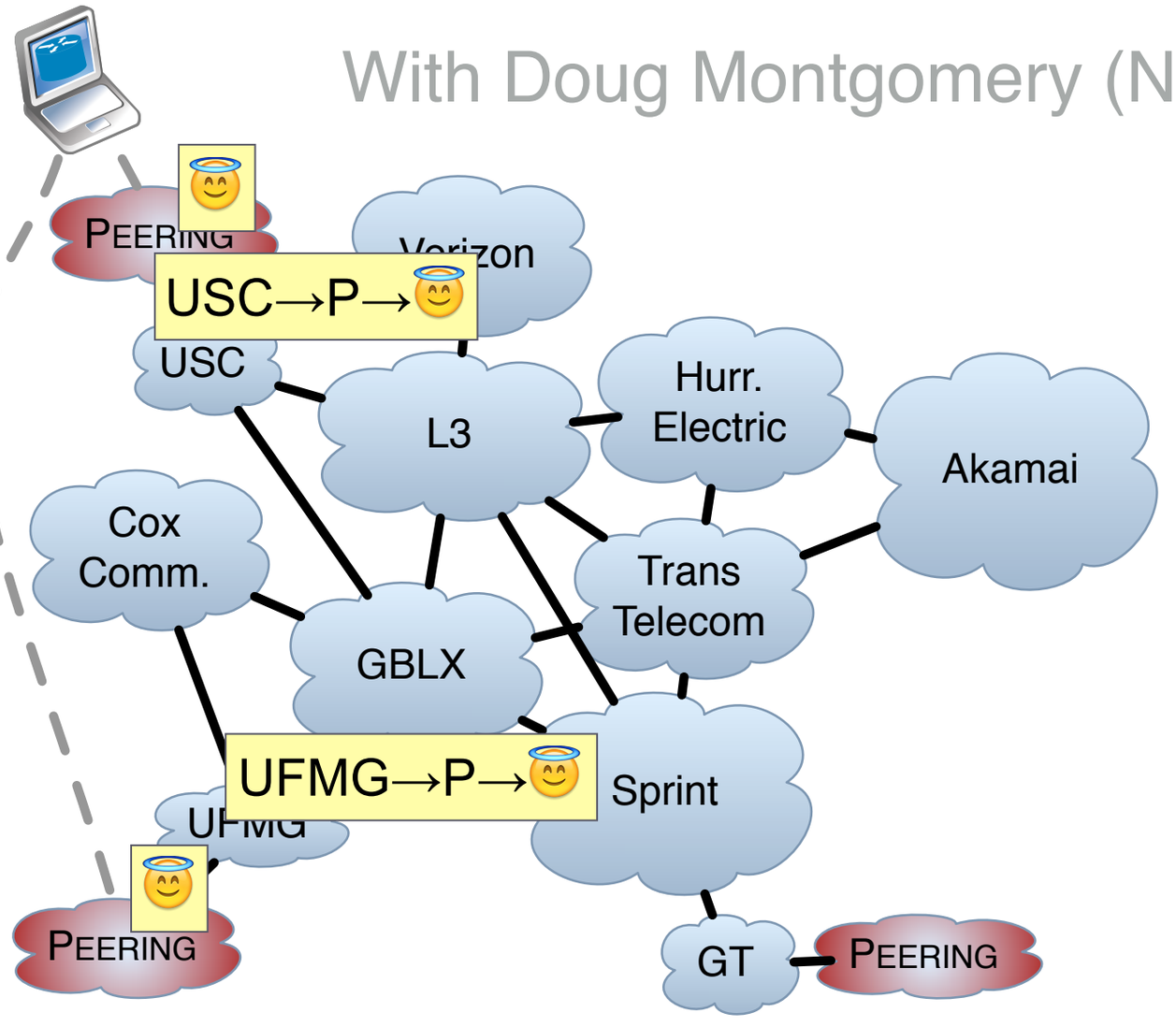

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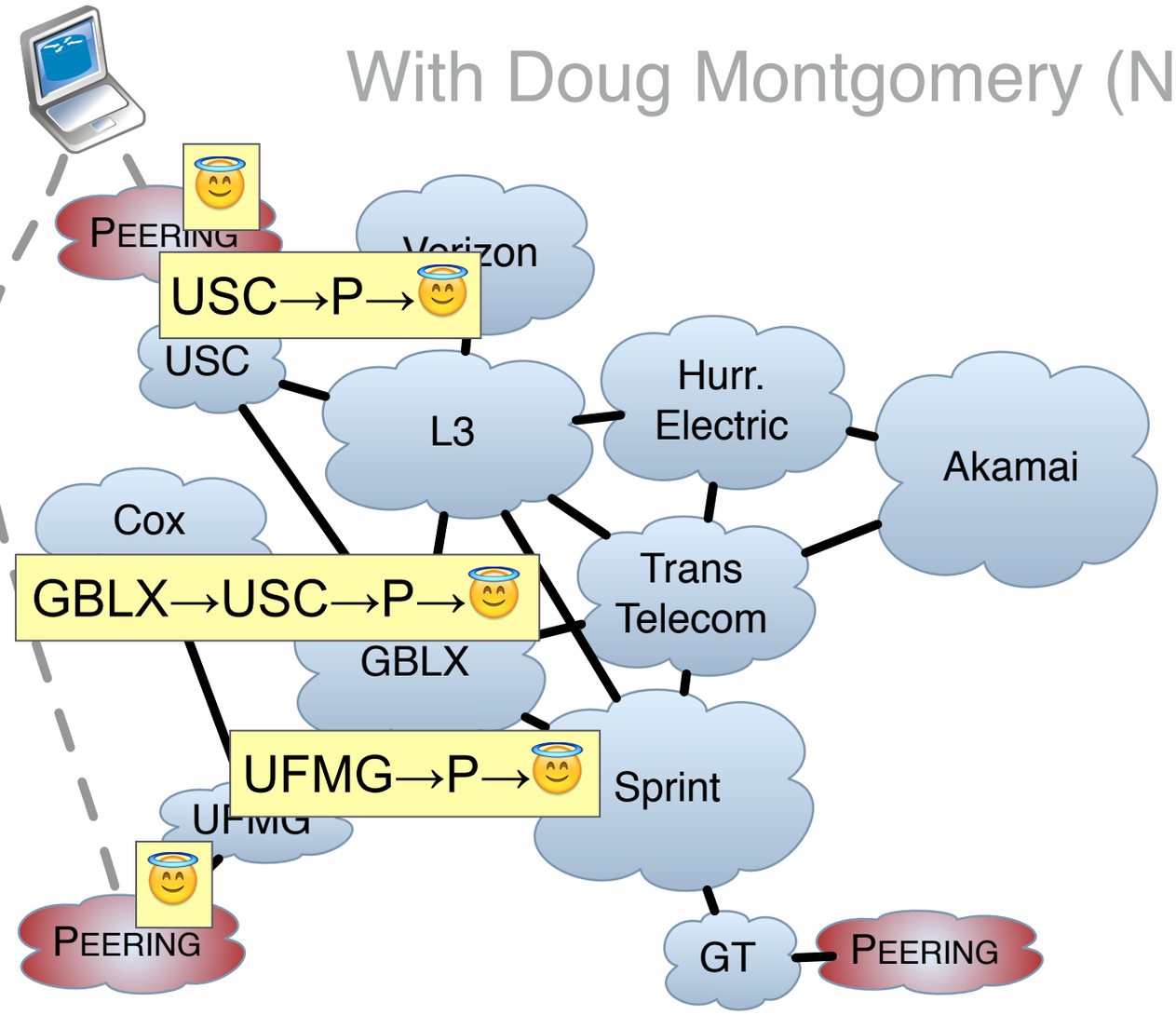

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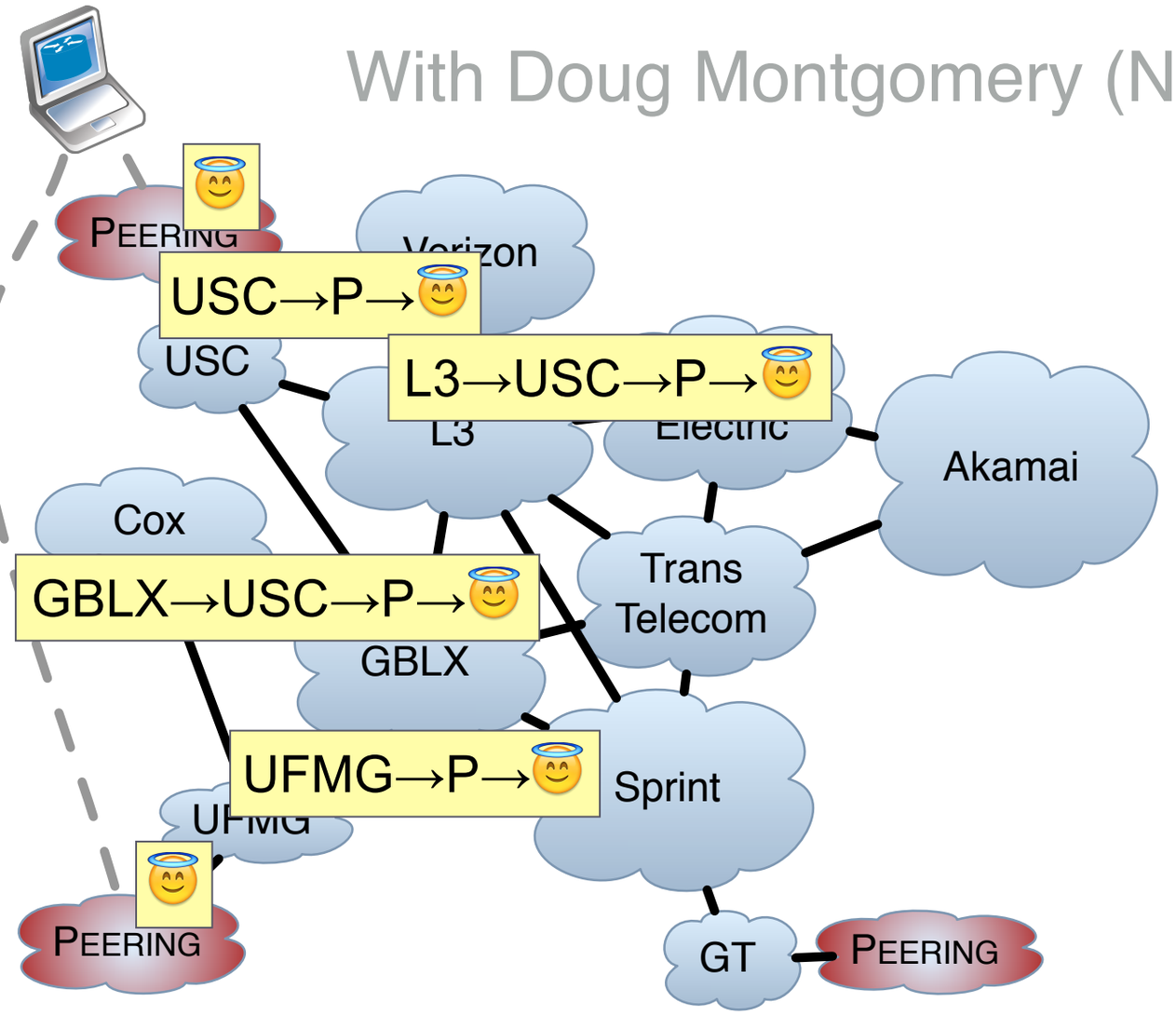

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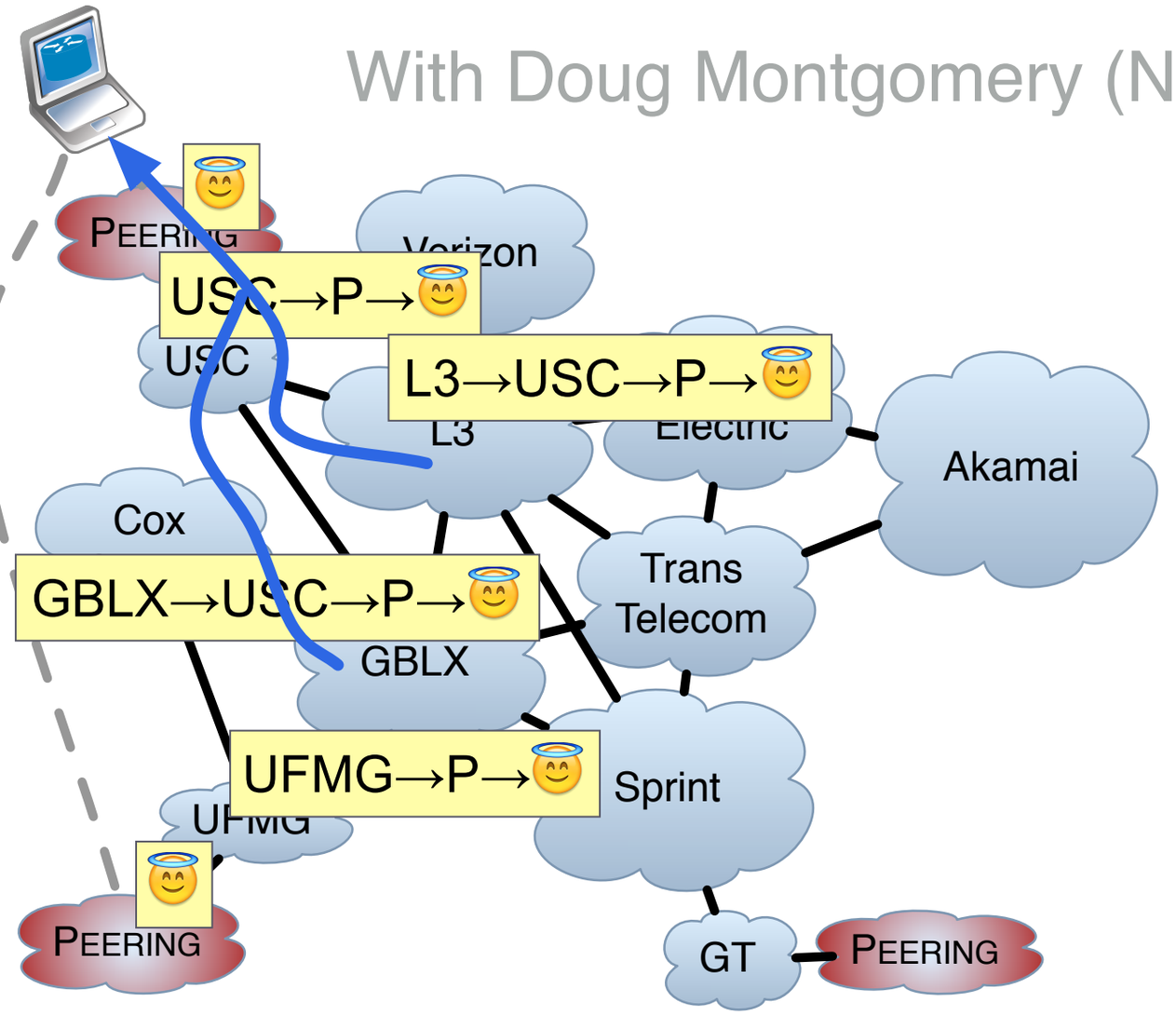

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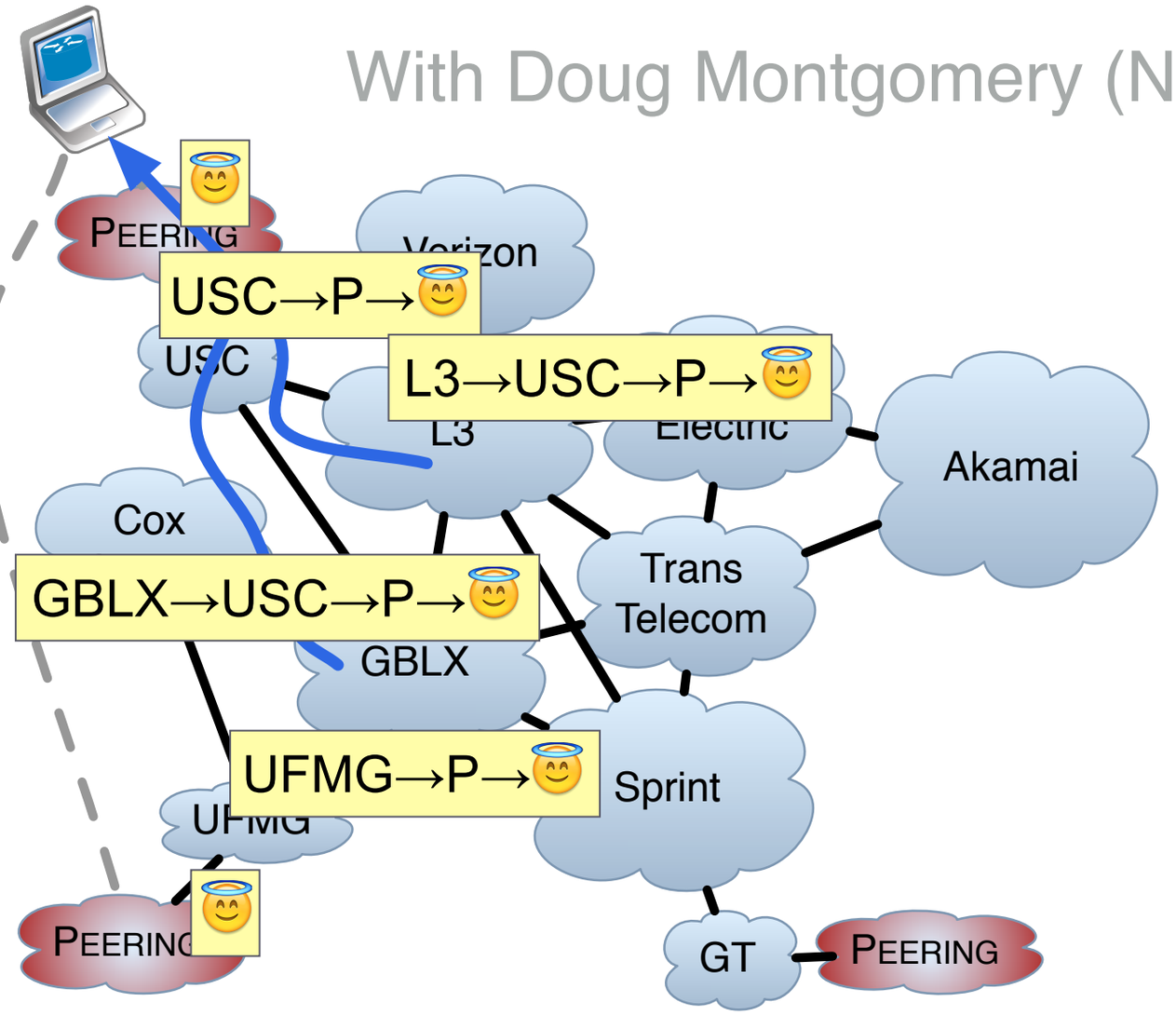

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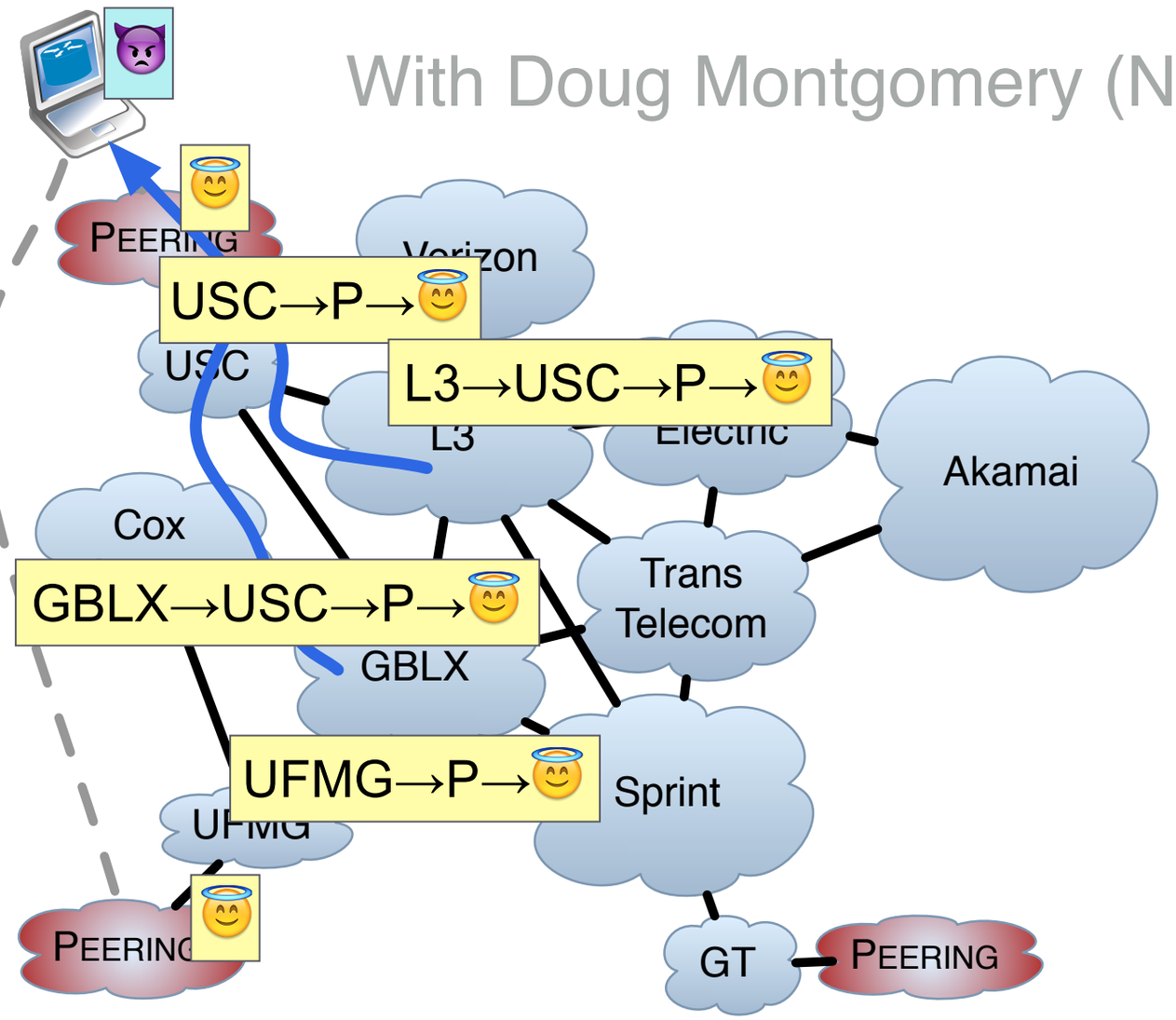

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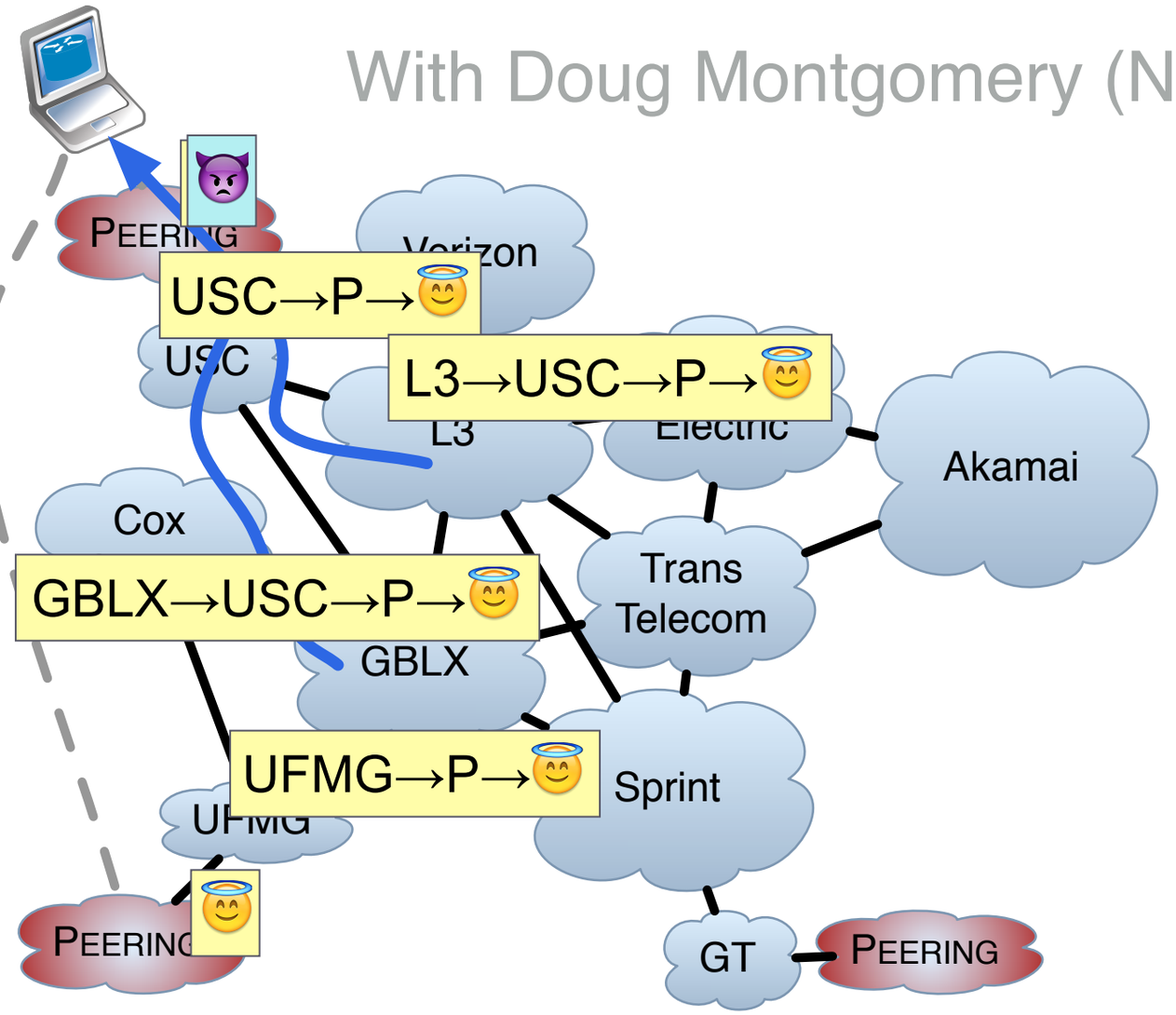

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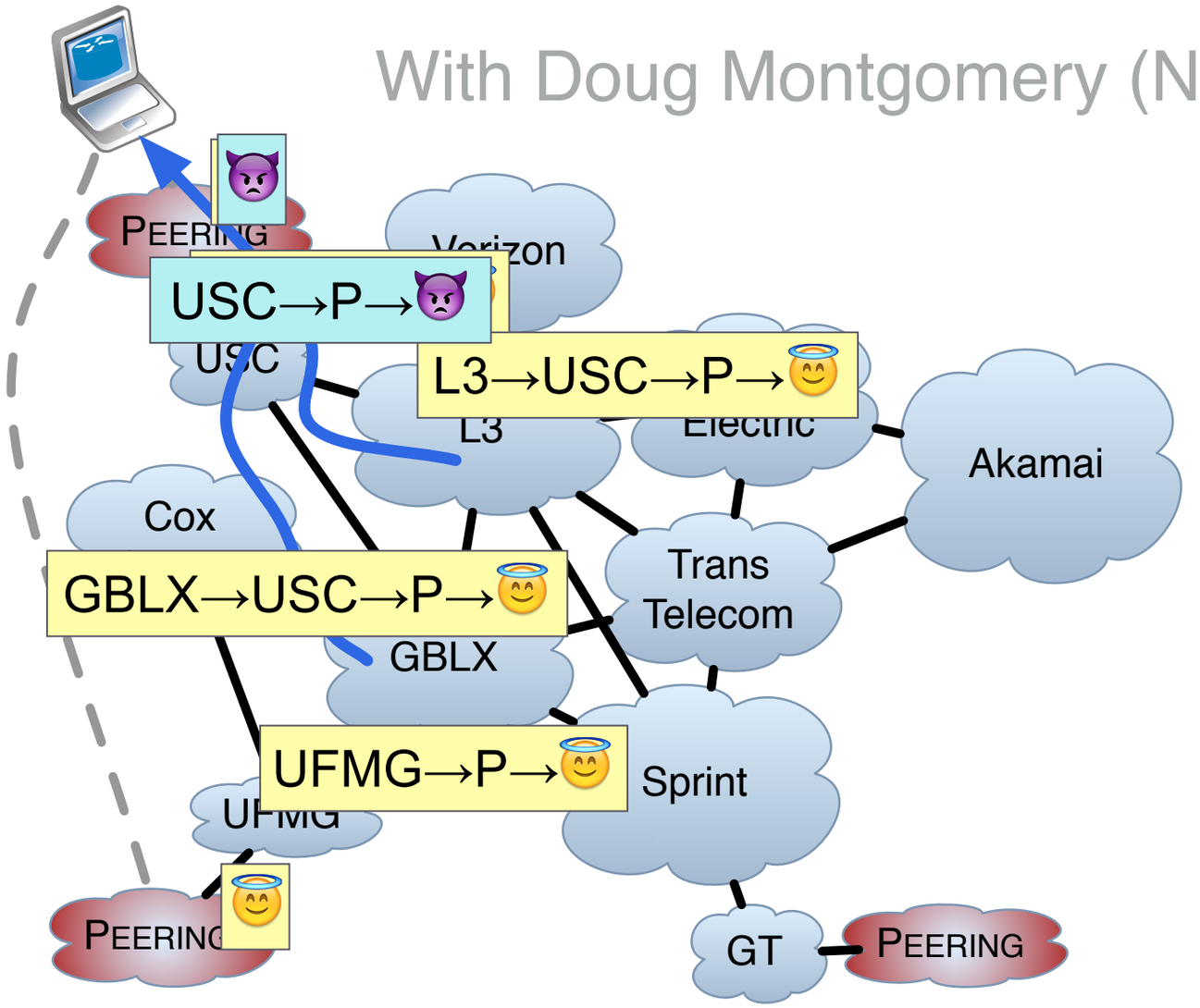

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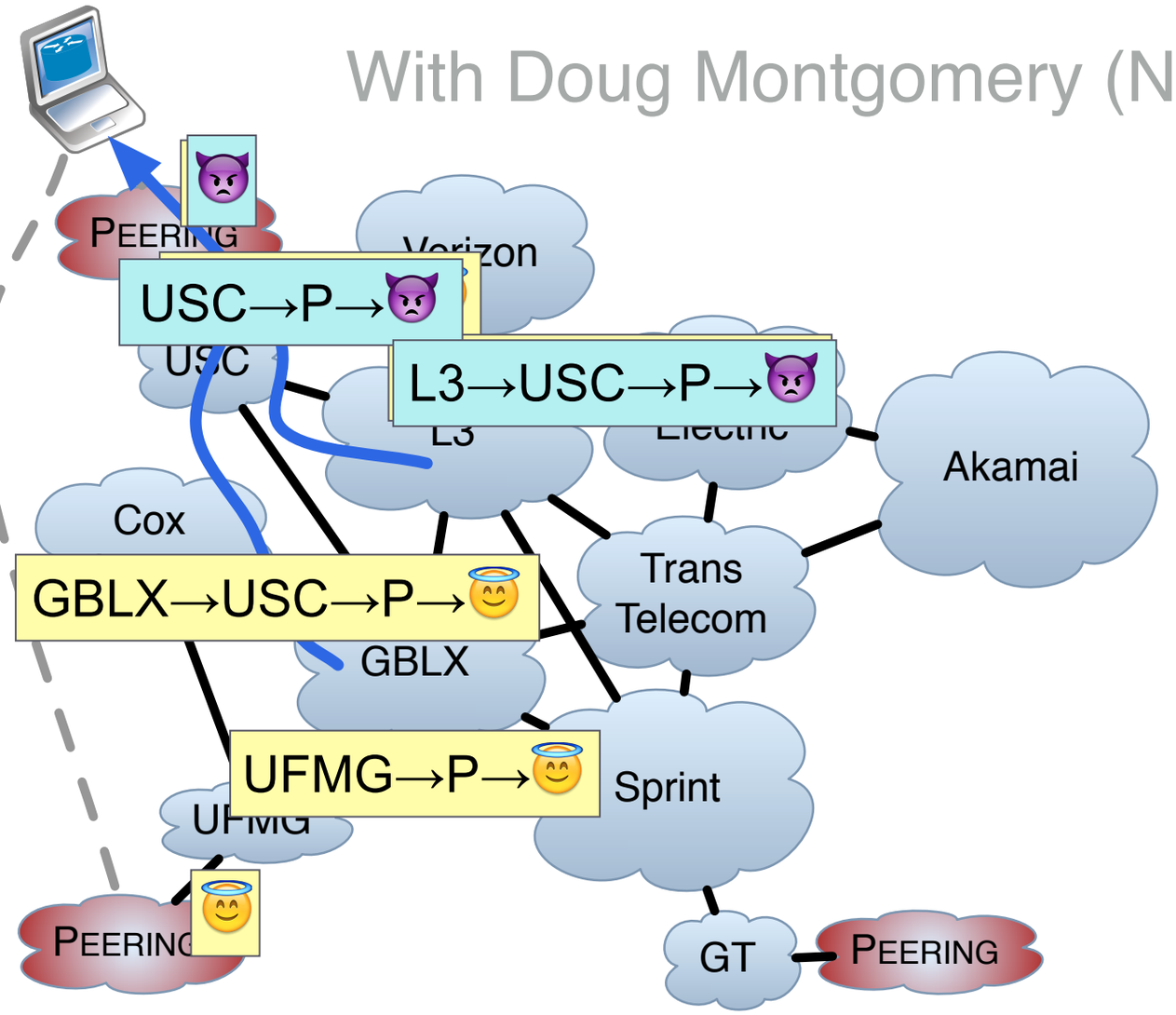

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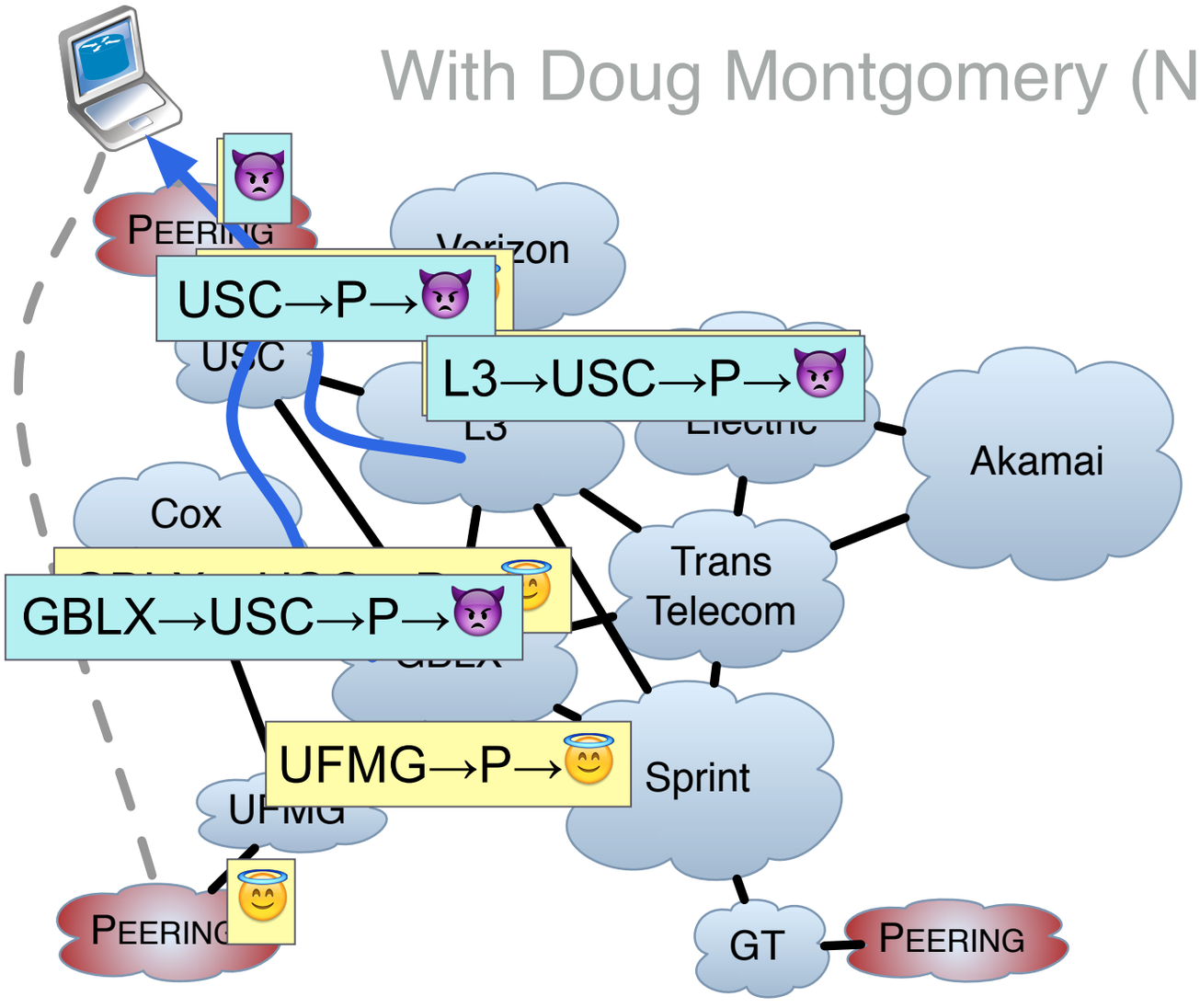

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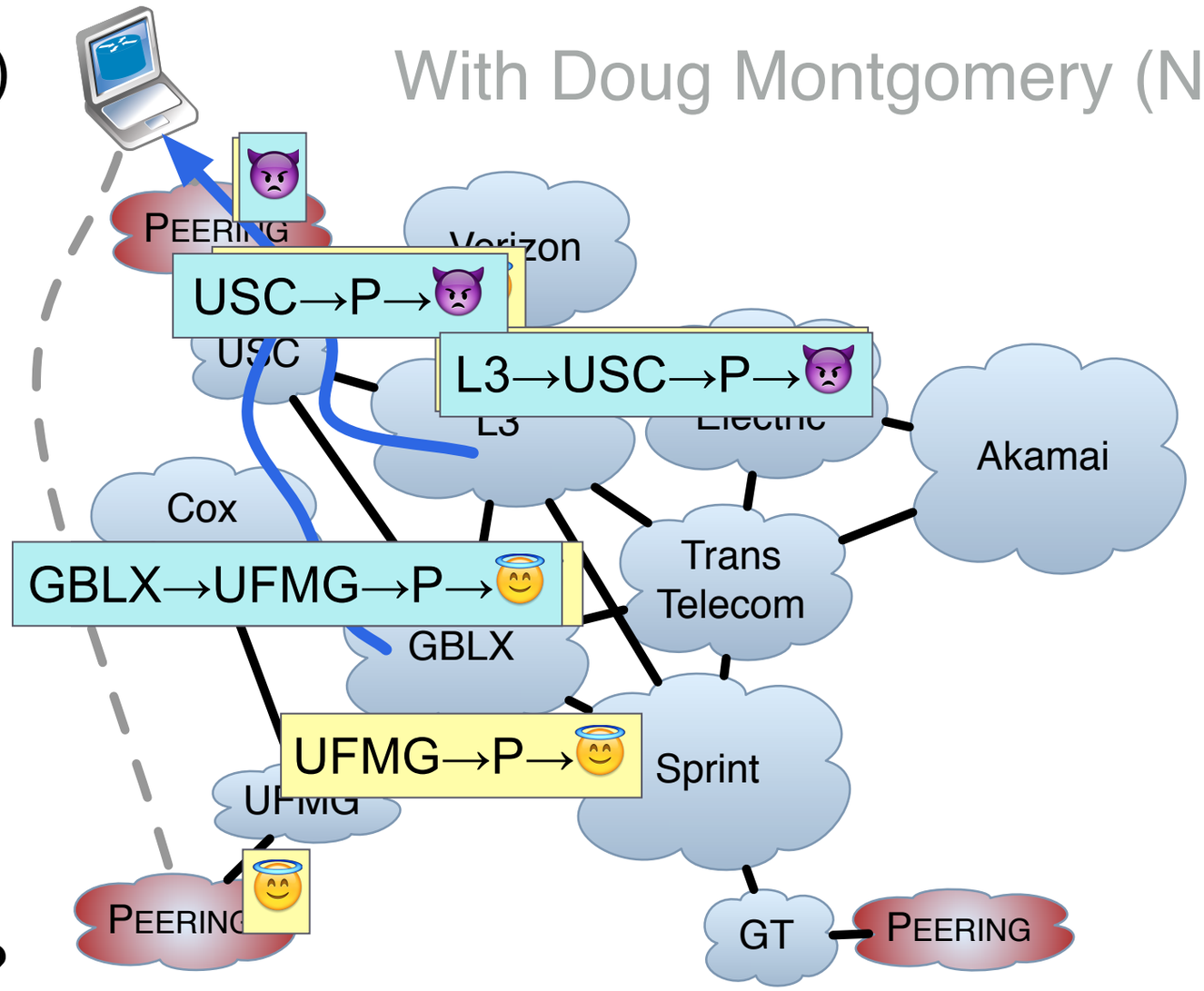

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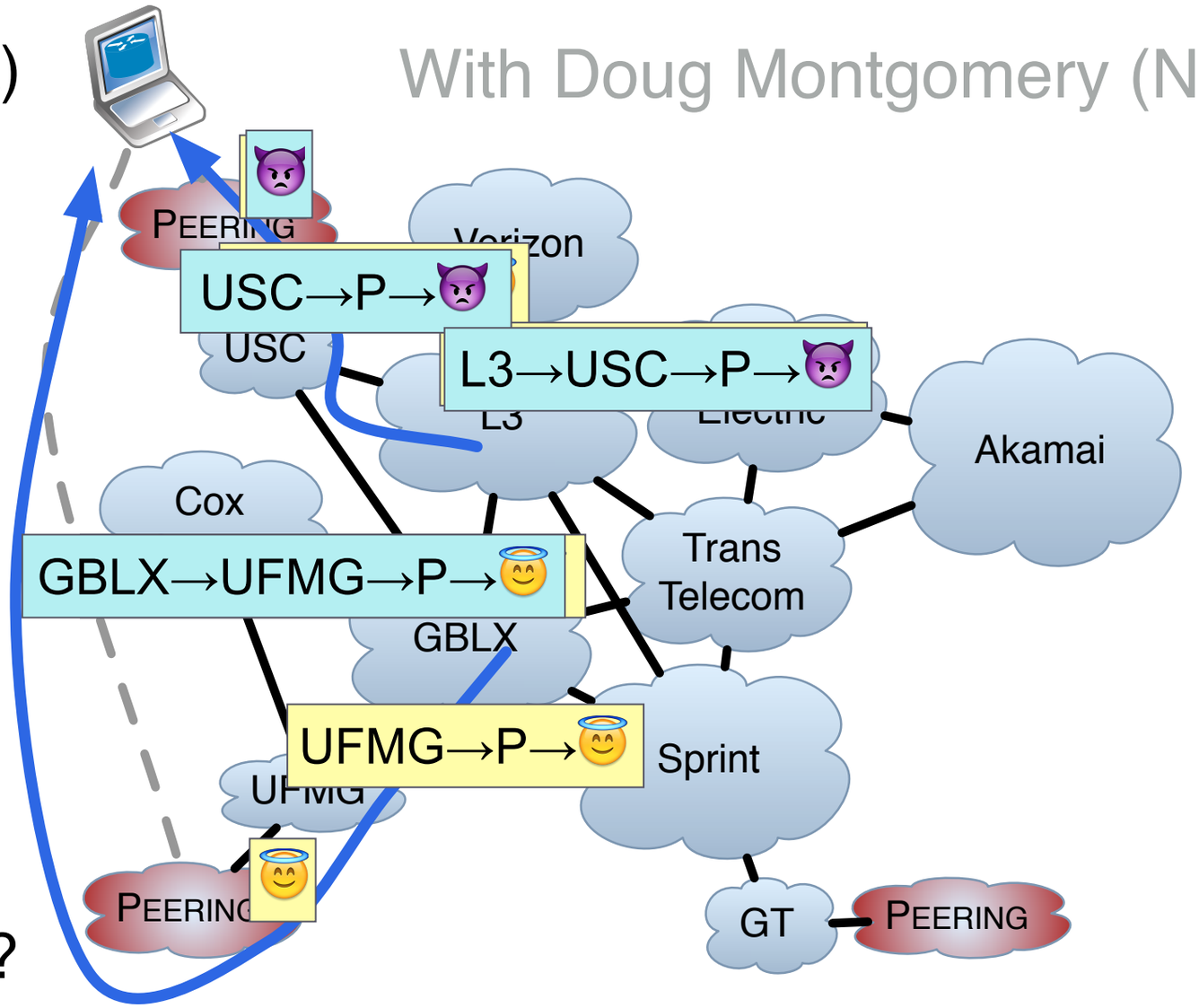

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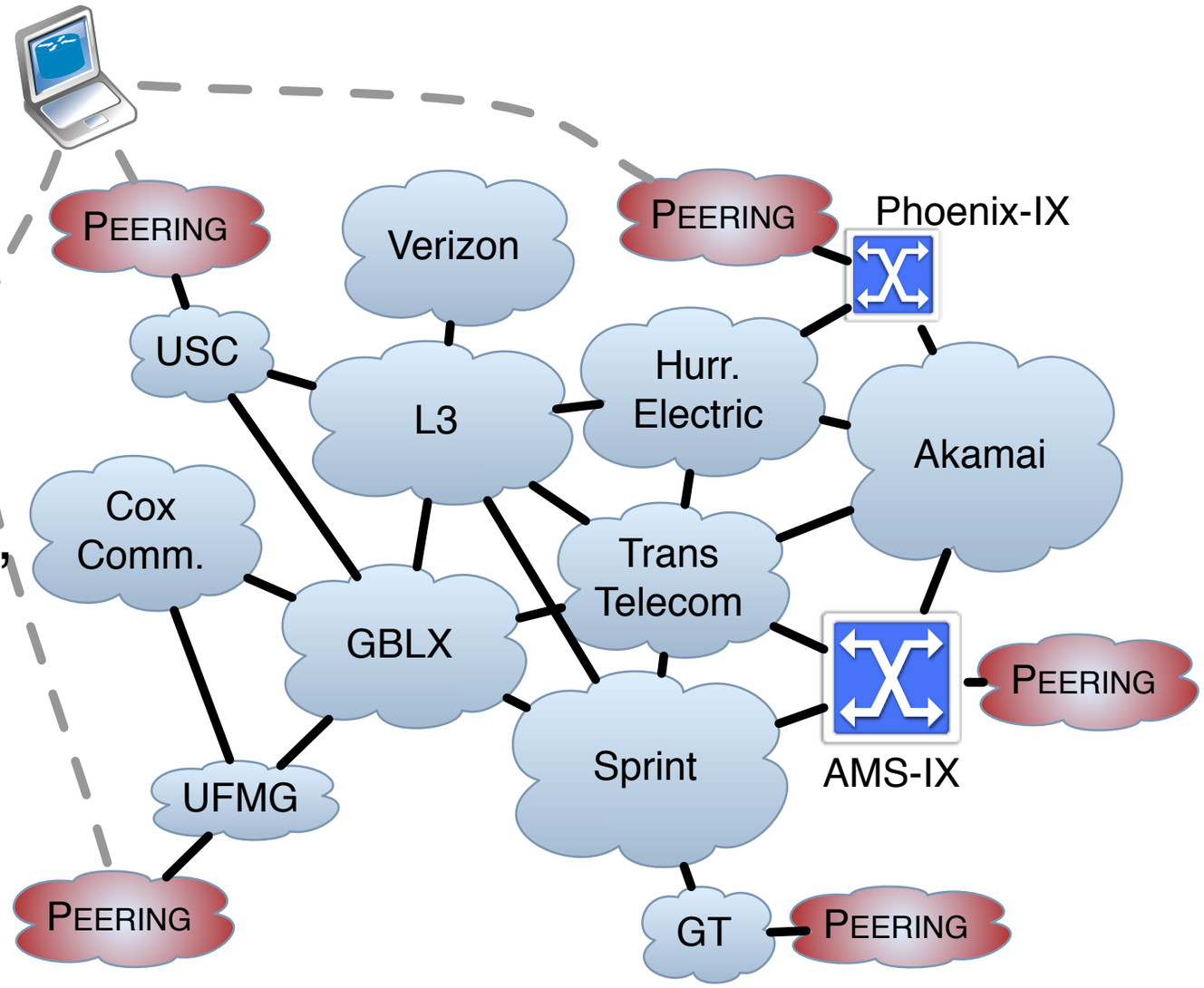
Rich connectivity via IXPs

PEERING is AS47065

- Owns 184.164.224.0/19
- 9 universities as providers
- Peers at Phoenix-IX, AMS-IX
  - 500+ peers: Akamai, Google, Hurricane Electric, Terremark, TransTeleCom,…



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- We built a BGP testbed called PEERING
  - Exchange routes and traffic with real ISPs
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We want ***you*** to use it

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  - **LIFEGUARD**: route around failures **[SIGCOMM 2012]**
  - **PECAN**: joint content & network routing **[SIGMETRICS 2013]**
  - **PoiRoot**: locate root cause of path changes **[SIGCOMM 2013]**
  - ARROW: deployable fix to routing problems [SIGCOMM 2014]
  - SDX: software-defined Internet exchange [SIGCOMM 2014]
  - **Measuring Internet routing policies** **[IMC 2015]**
  - Sprite: SDN-based inbound traffic engineering [SOSR 2015]
  - RAPTOR: Routing attacks on TOR [USENIX Security 2015]

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Benefits of ongoing, public measurements

1. Long-running, with periodically refreshed measurements

✓Track Internet evolution

- Observe trends — Mapping Google
- Up-to-date joins with other data — Mapping Google

2. Public data, testbeds, and tools

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- Mismatch in data vs question
- Privacy (see PAM 2014 keynote)

Outline

1. What does an Internet measurement research paper involve?
2. What might an impactful Internet measurement paper involve?
   - One model: Measurement results influence Internet operations
     - Example 1: TCP Gentle Aggression
   - Challenges in measurement
3. How can one address challenges and have impact?
   - One model: Provide long-running measurements, tools, and testbeds
     - Example 2: Mapping Google's Expansion
     - Example 3: PEERING BGP testbed
   - Benefits…and drawbacks… of providing long-running services
4. ***How can the community encourage long-running services?***

Discussion topic

- How do we encourage & foster measurement research resulting in:
  - Relevant and useful measurement studies?
  - Long-lasting, public measurement services?

- I will share some initial thoughts…
- …but I'm sure others have better ideas and more experience, so please chime in

- What can IMC do?
- What role might IETF play:
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  - IMC Community Session for informal advertisement of what’s available
  - IMC award to recognize a new paper that makes a novel dataset available
- Long-lasting?
  - IMC Call-For-Papers mentions “reappraisal of previous…findings”
  - Related: NSDI/SIGCOMM added Operational System and Experience tracks, which need not have novel research contribution

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- Long-lasting?
  - Test-of-time award for datasets and testbeds?
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    - Sponsored prize to help fund maintenance?
    - Idea courtesy of Harsha Madhyastha, who has maintained daily PlanetLab traceroutes since 2006
- Long-lasting?
  - Test-of-time award for datasets and testbeds?
    - I nominate CAIDA/ARK, PlanetLab, RIPE, RouteViews, …
- What ideas do *you* have?

Discussion topic

- How do we encourage & foster measurement research resulting in:
  - Relevant and useful measurement studies?
  - Long-lasting, public measurement services?

- I will share some initial thoughts…
- …but I'm sure others have better ideas and more experience, so please chime in

- What can IMC do?
- What role might IETF play:
  - With drafts and standards?
  - As a community?

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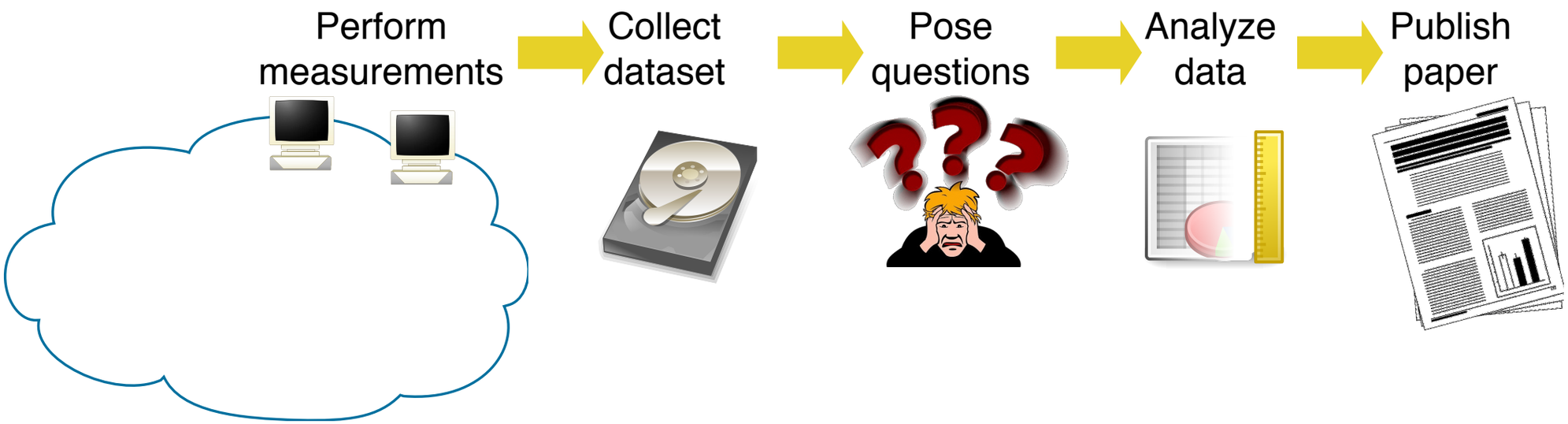
Measurements and IETF drafts?



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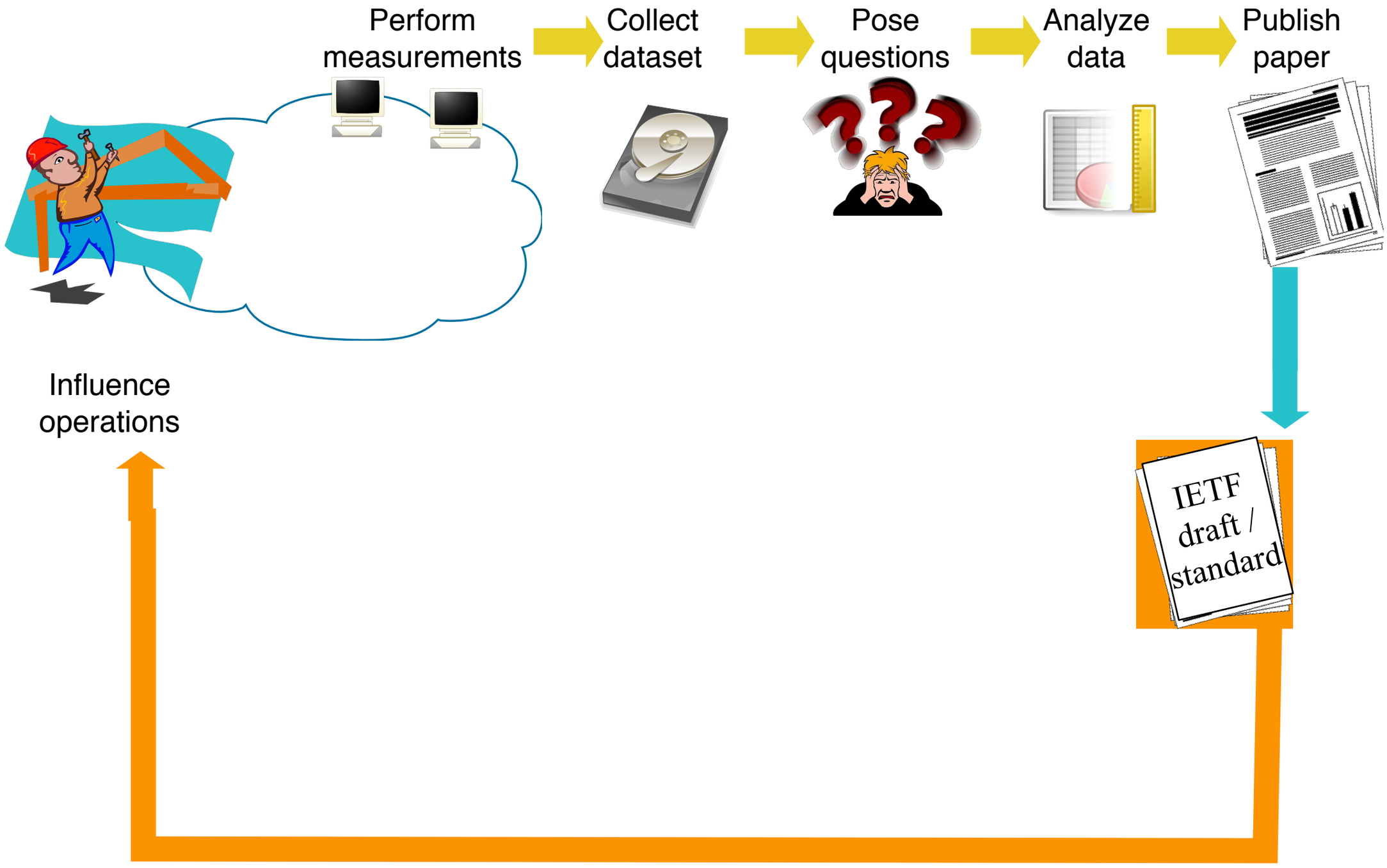

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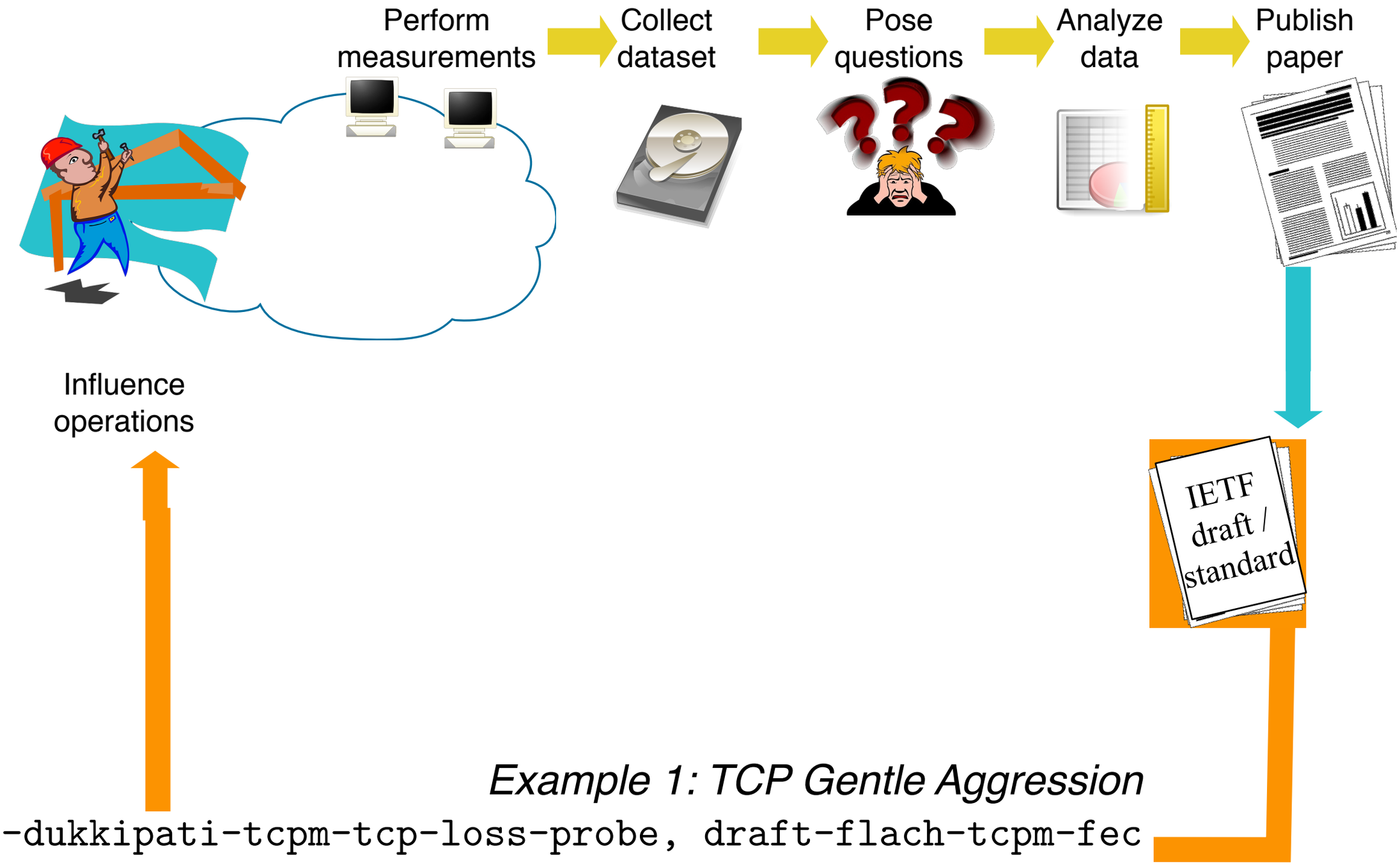

Example 1: TCP Gentle Aggression

`draft-dukkipati-tcpm-tcp-loss-probe, draft-flach-tcpm-fec`

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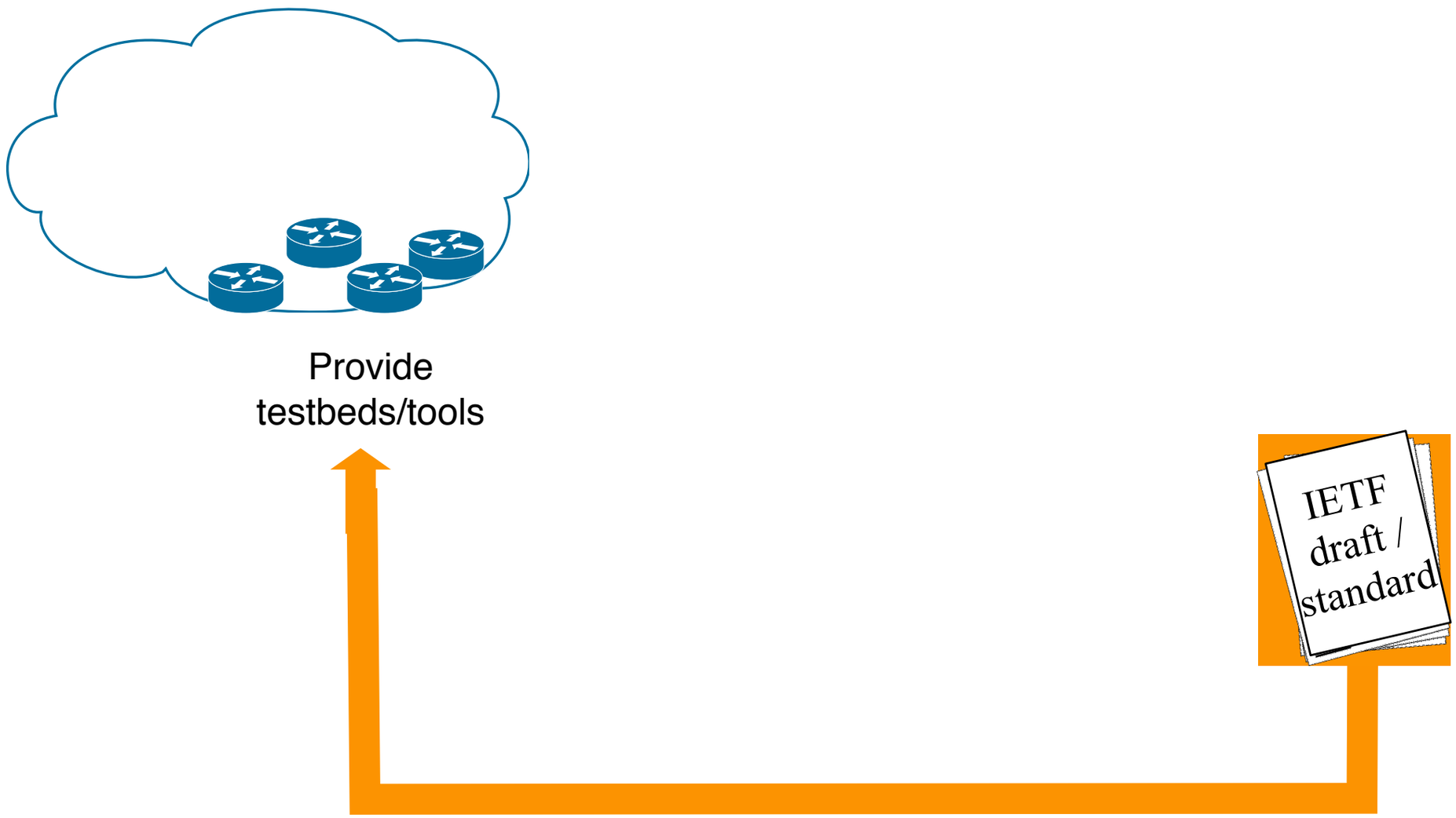

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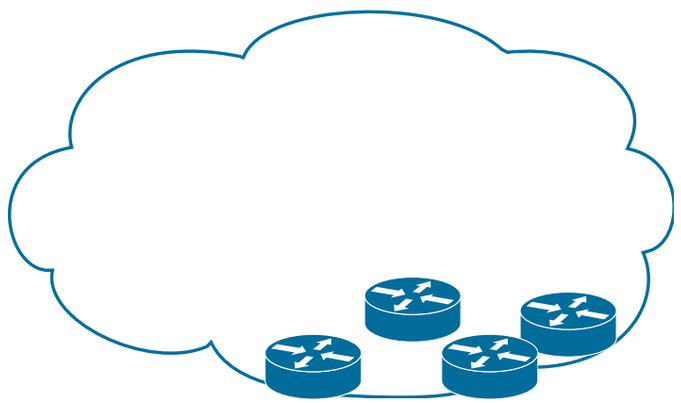

Provide
testbeds/tools

Example 2: Mapping Google's expansion

`draft-ietf-dnsop-edns-client-subnet`

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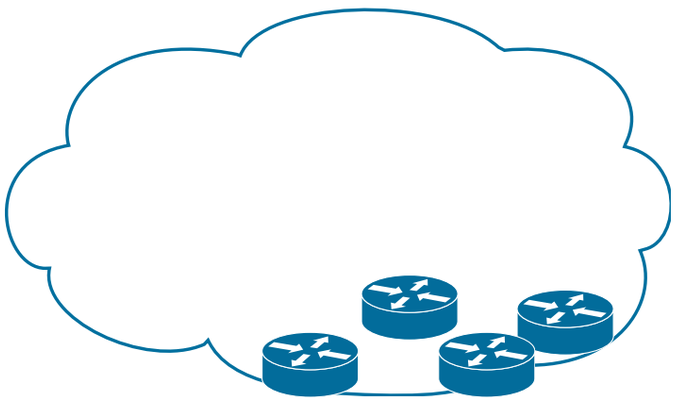

Pose questions

Provide testbeds/tools

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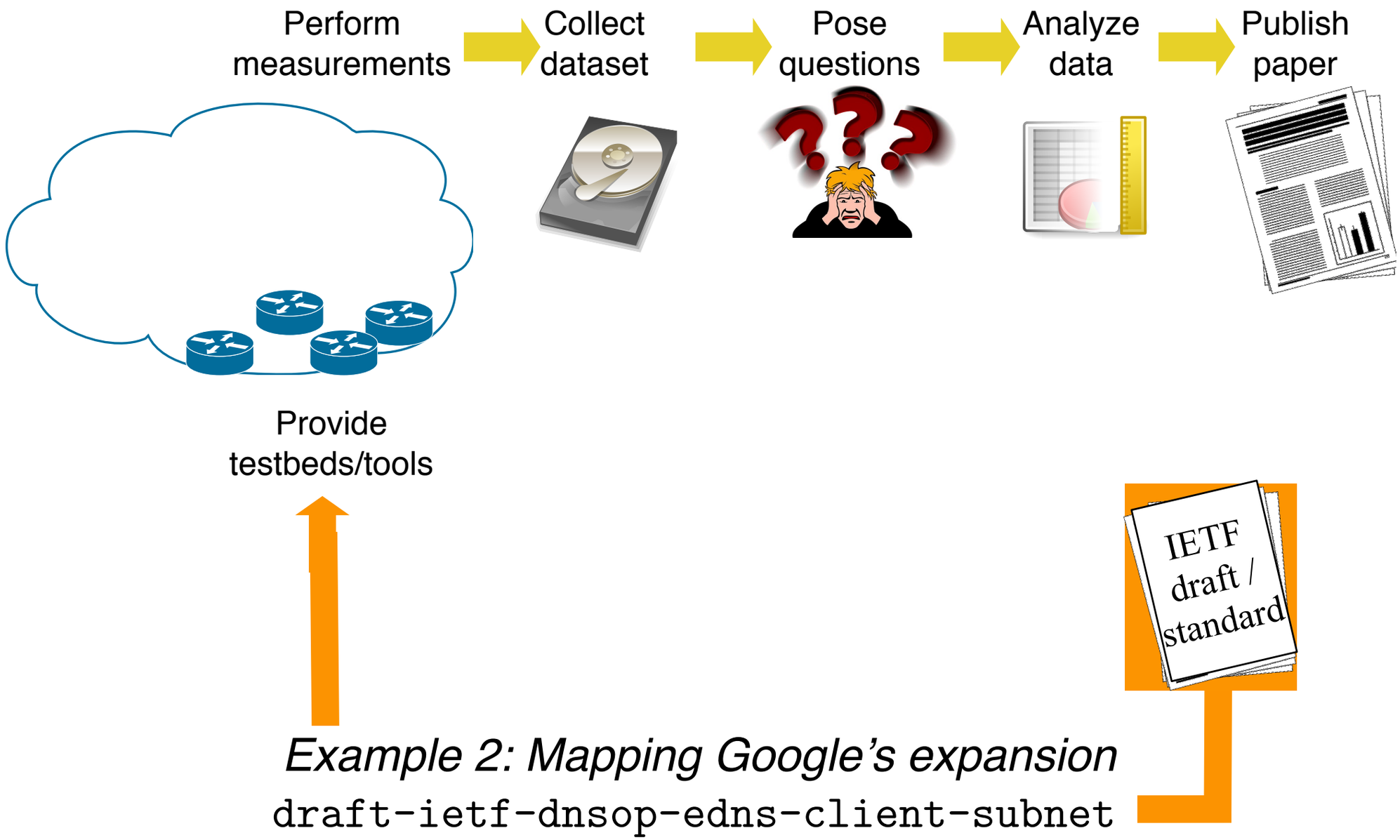

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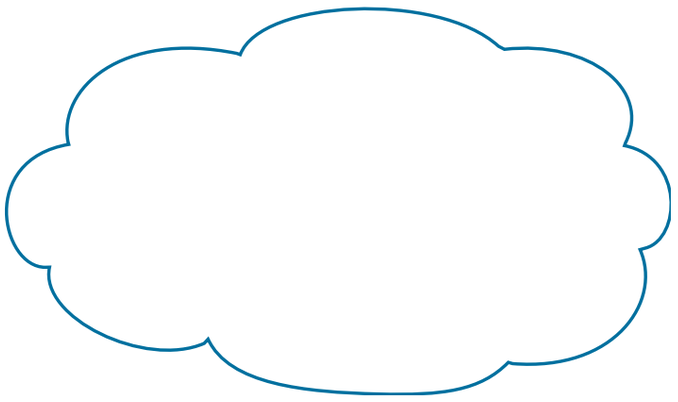

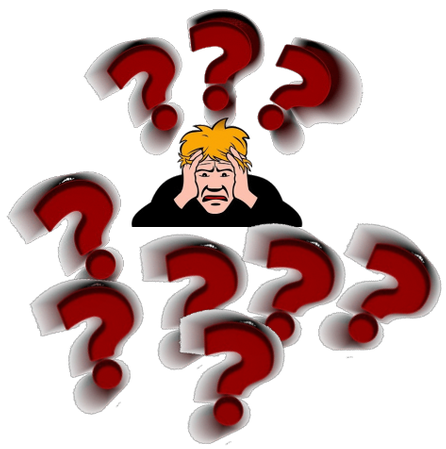

Inspire questions

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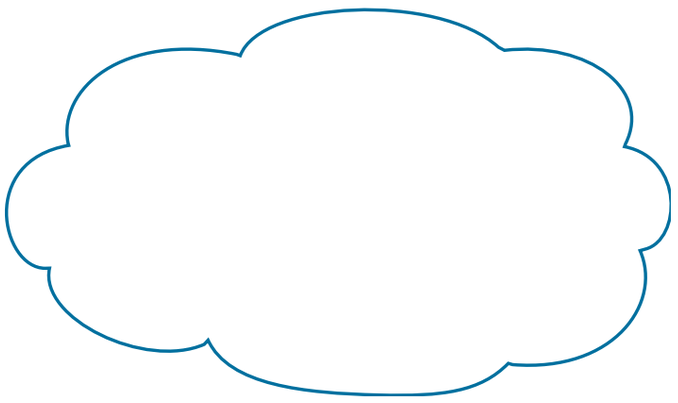

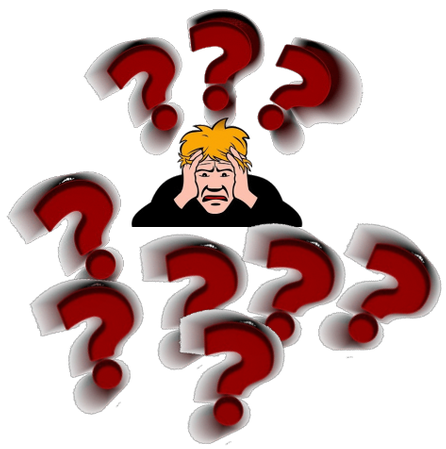

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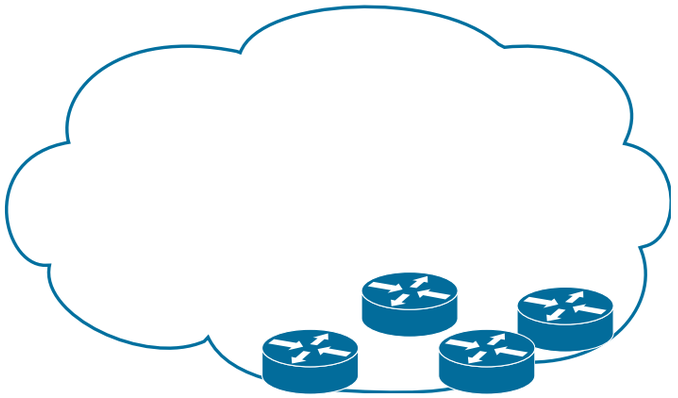

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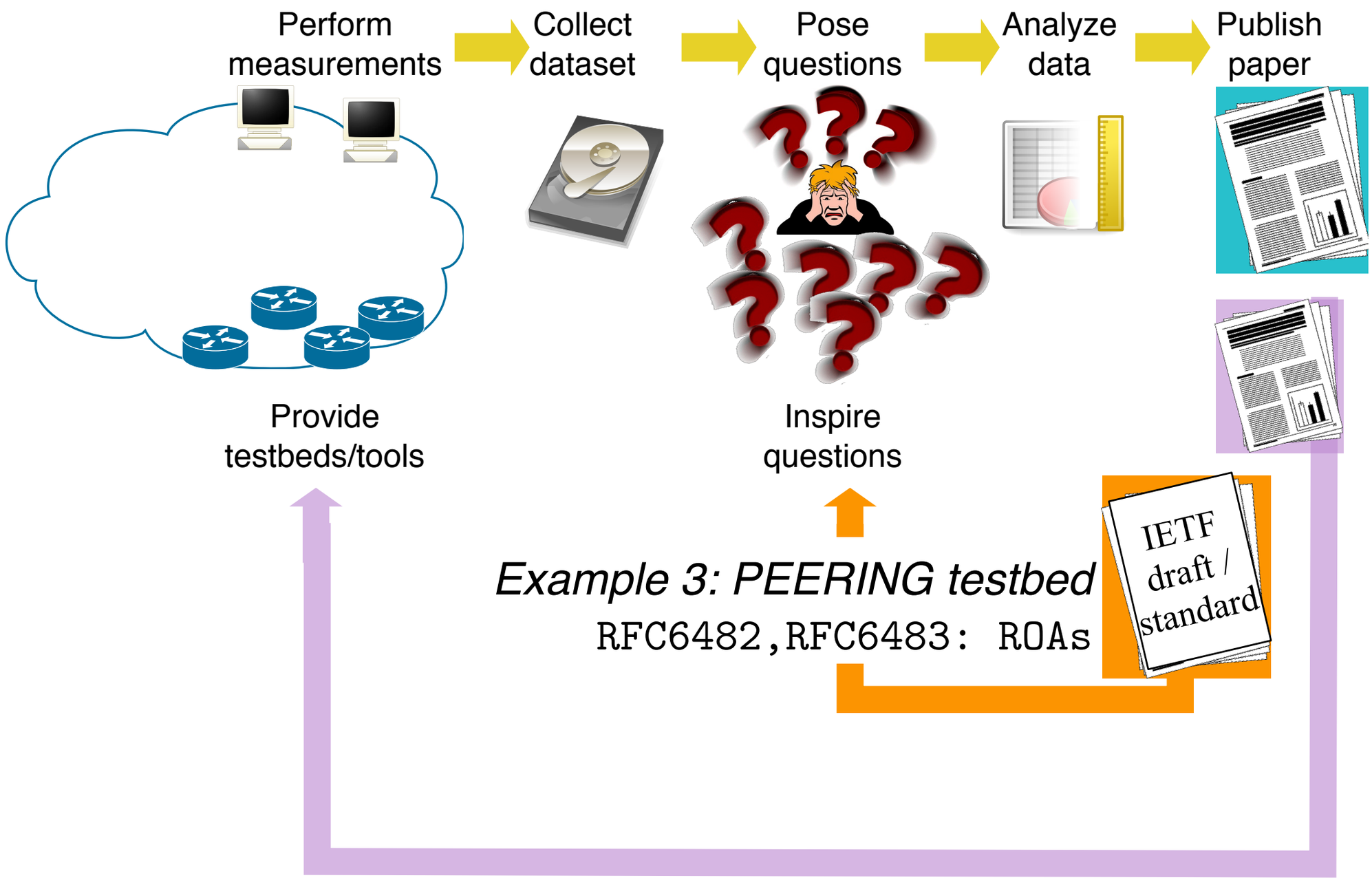

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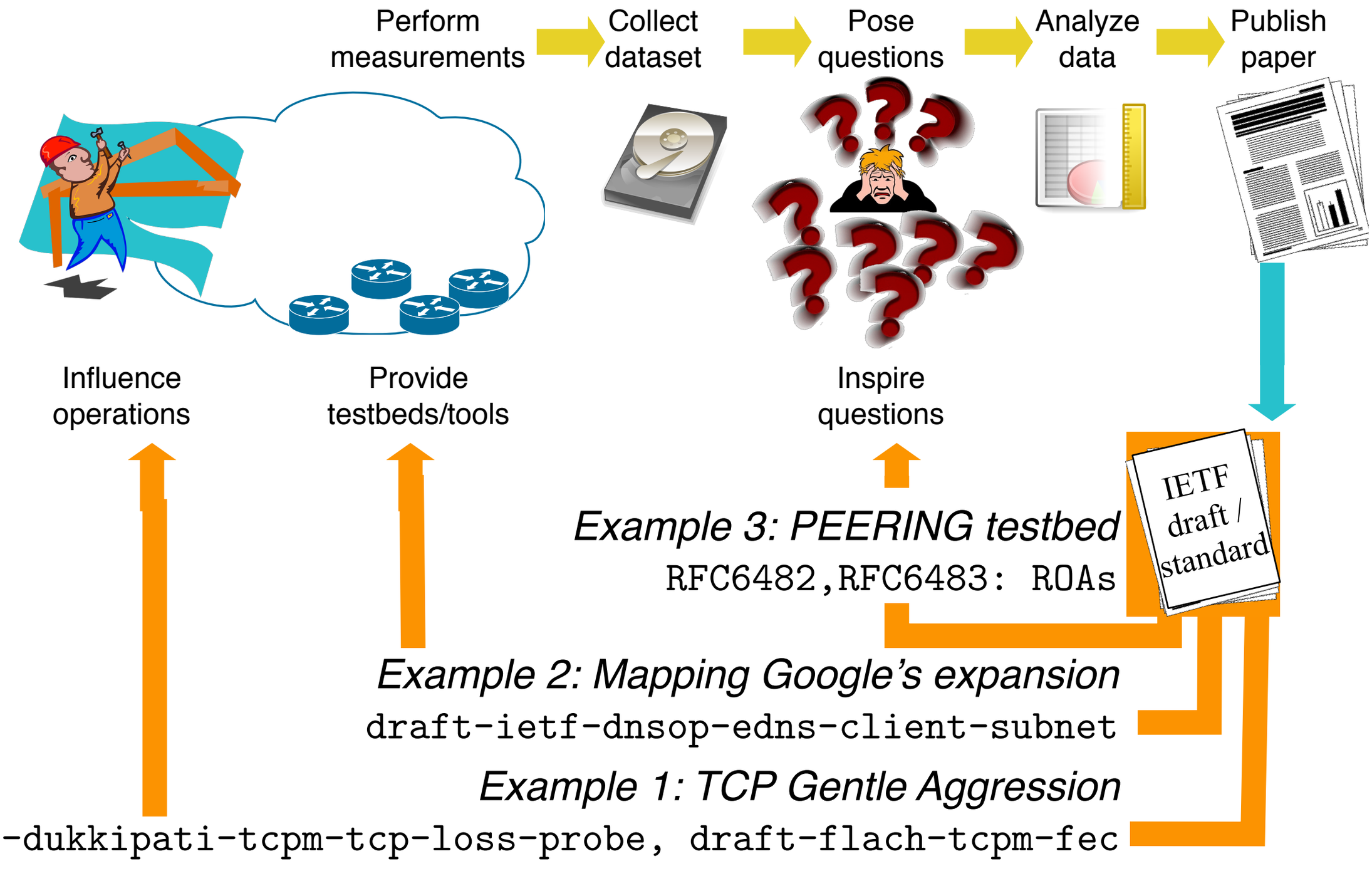
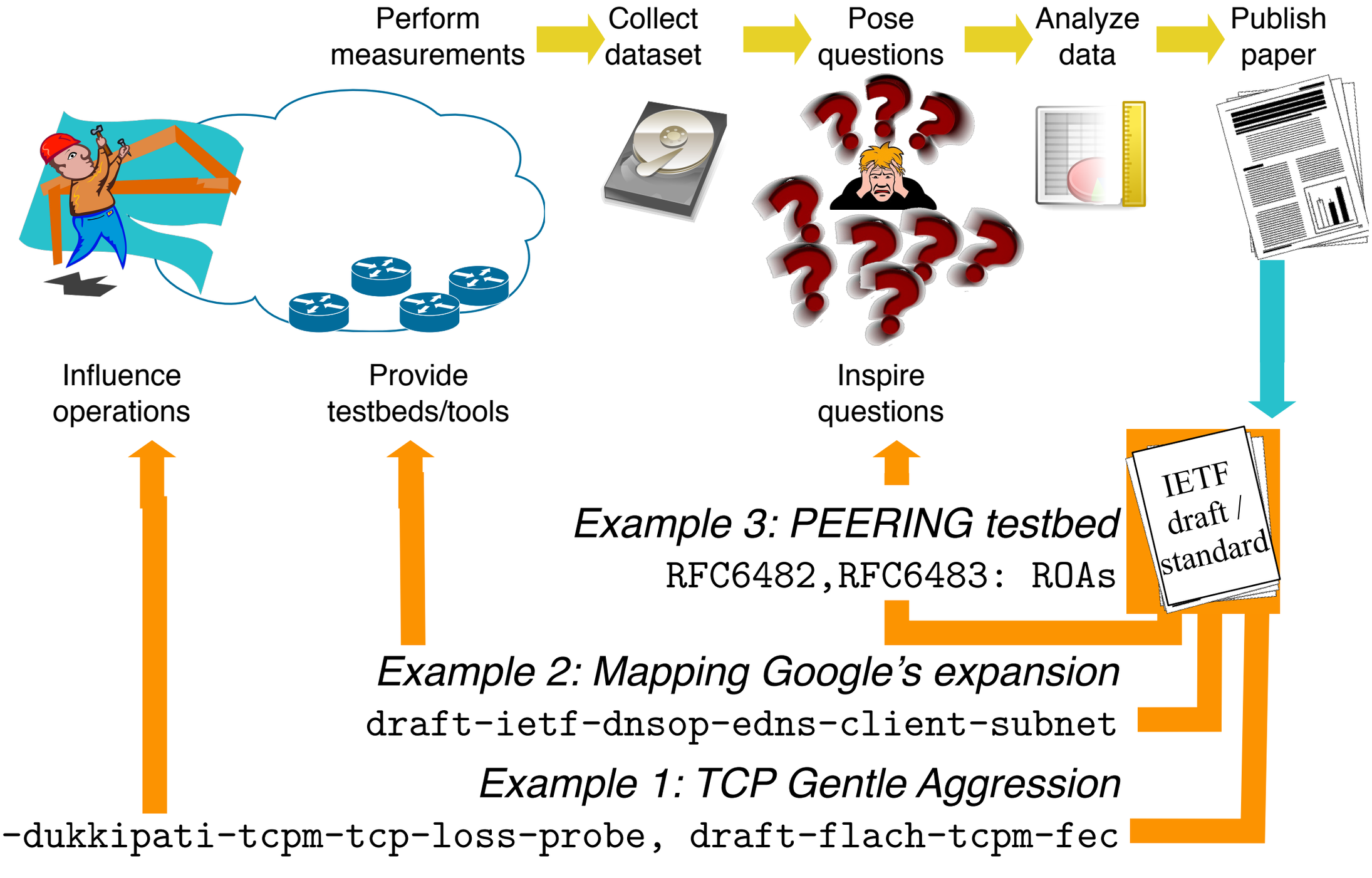


Measurements and IETF drafts?

Challenges:

Limited options for evaluation	Limited data shapes analysis	Limited visibility into operational concerns



IETF: Towards impactful Internet measurement

- Share questions of operational interest
  - Publish list of important measurement questions?
- Share data
- Host vantage points
  - Mine: **Reverse Traceroute** and **PEERING**
  - Others: RIPE Atlas, Looking Glass, …
- Encourage communication between communities
  - PhD interns
  - Student scholarships to IETF (and NANOG, and RIPE, and…)
  - Applied Networking Research Prize
  - Joint conferences: collocate, hold RAIM

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