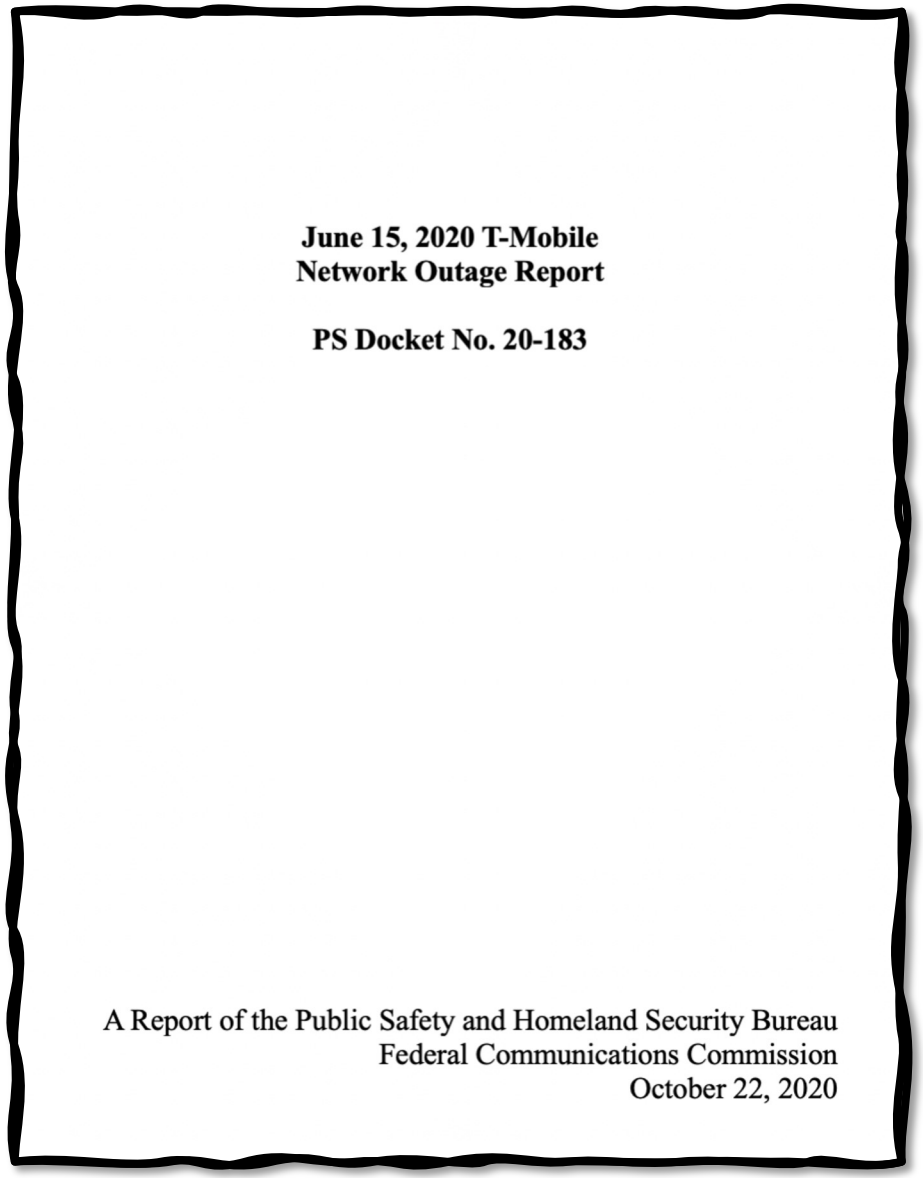
A decade of network verification: Lessons learned and open challenges

Ratul Mahajan



June 15, 2020 T-Mobile
Network Outage Report

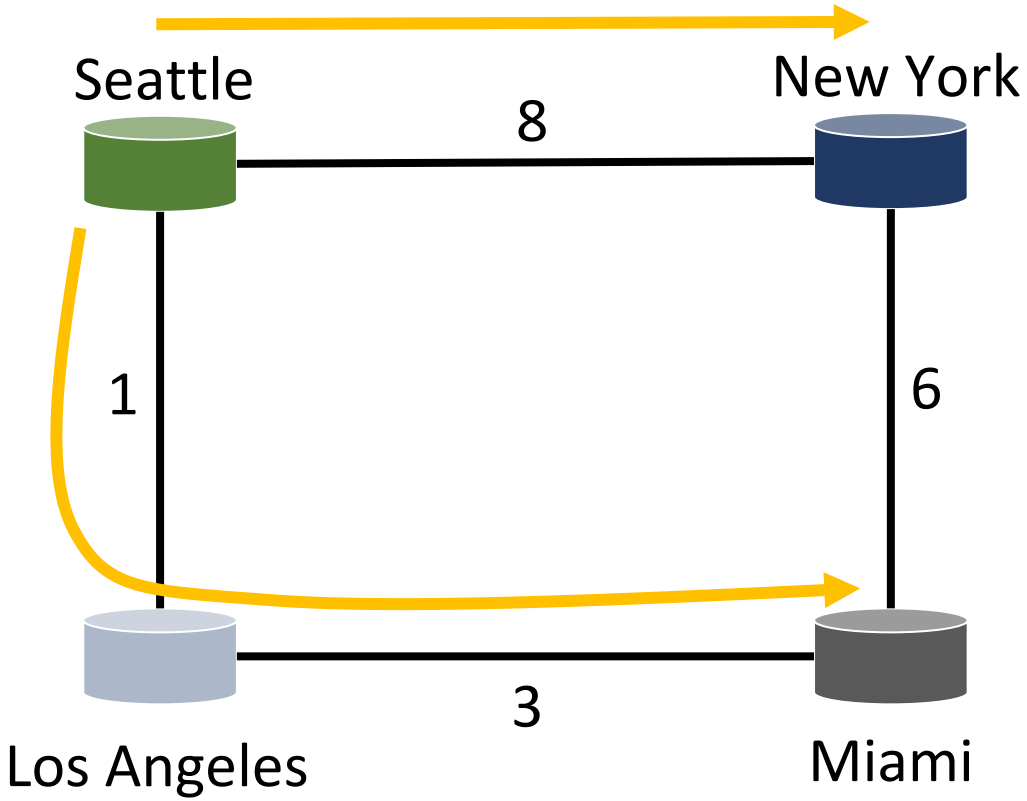
PS Docket No. 20-183

A Report of the Public Safety and Homeland Security Bureau
Federal Communications Commission
October 22, 2020

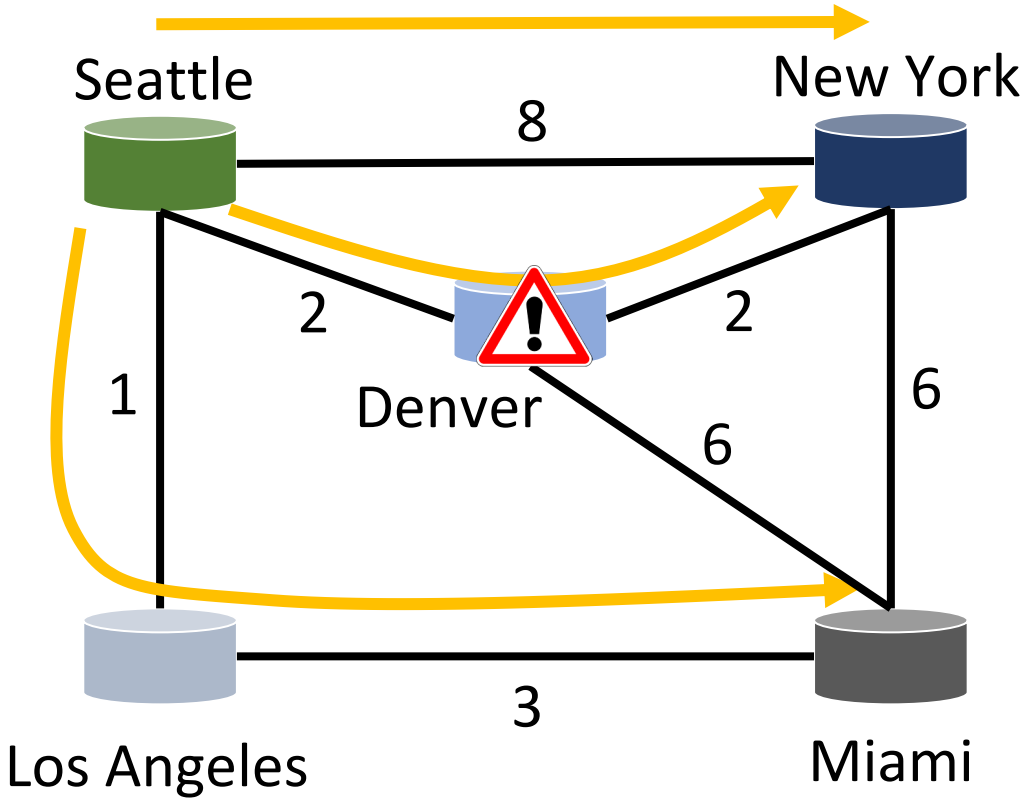
"At least 41% of all calls that attempted to use T-Mobile's network during the outage failed, including at least 23,621 failed calls to 911."

"[An old woman] who has dementia, could not reach [her son] after her car would not start and her roadside-assistance provider could not call her to clarify her location; she was stranded for seven hours"

Anatomy of the outage (illustration)

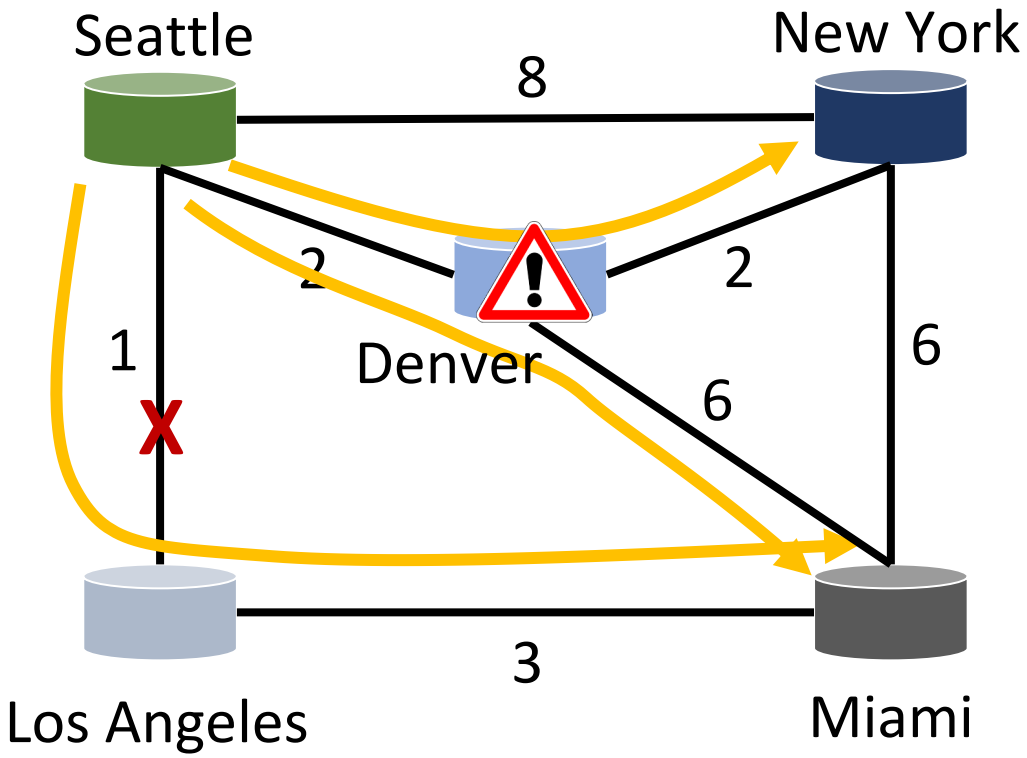


Anatomy of the outage (illustration)



Anatomy of the outage (illustration)

What if T-Mobile could guarantee that no traffic will transit Denver?

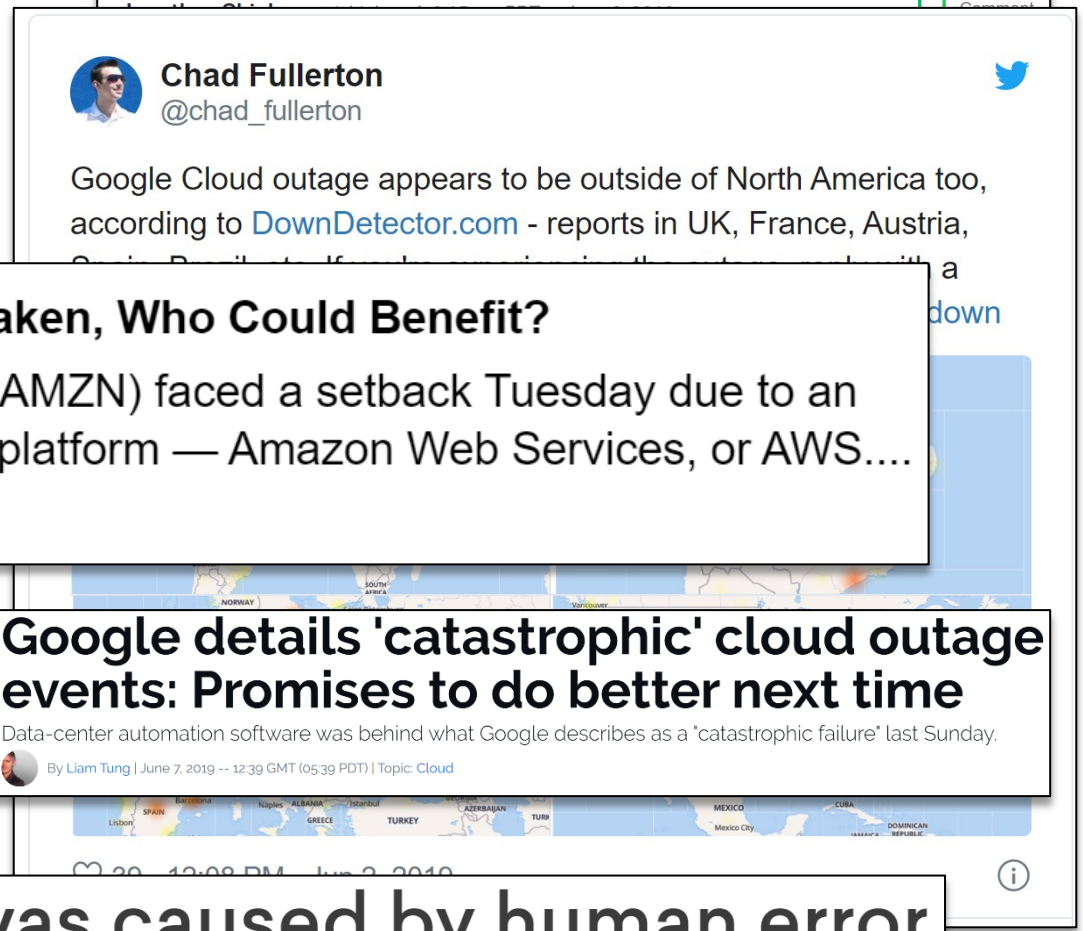


What if T-Mobile could predict the impact of link failure?

Microsoft Says Config. Change Caused Azure Outage

Standard protocol for applying changes was not followed

Google cloud is down, affecting numerous applications and services



Microsoft: Misconfigured Network Device Cau Outage

With Confidence In AWS Shaken, Who Could Benefit?

Amazon.com, Inc. (NASDAQ: AMZN) faced a setback Tuesday due to an outage at its cloud computing platform — Amazon Web Services, or AWS....

benzinga.com

Microsoft suffers intermittent Azure outage over DNS resolution issues

Microsoft 365 and Teams, Dynamics, SharePoint Online, OneDrive and Xbox Live among those affected

May 03, 2019 By: **Sebastian Moss**

Google details 'catastrophic' cloud outage events: Promises to do better next time

Data-center automation software was behind what Google describes as a "catastrophic failure" last Sunday.

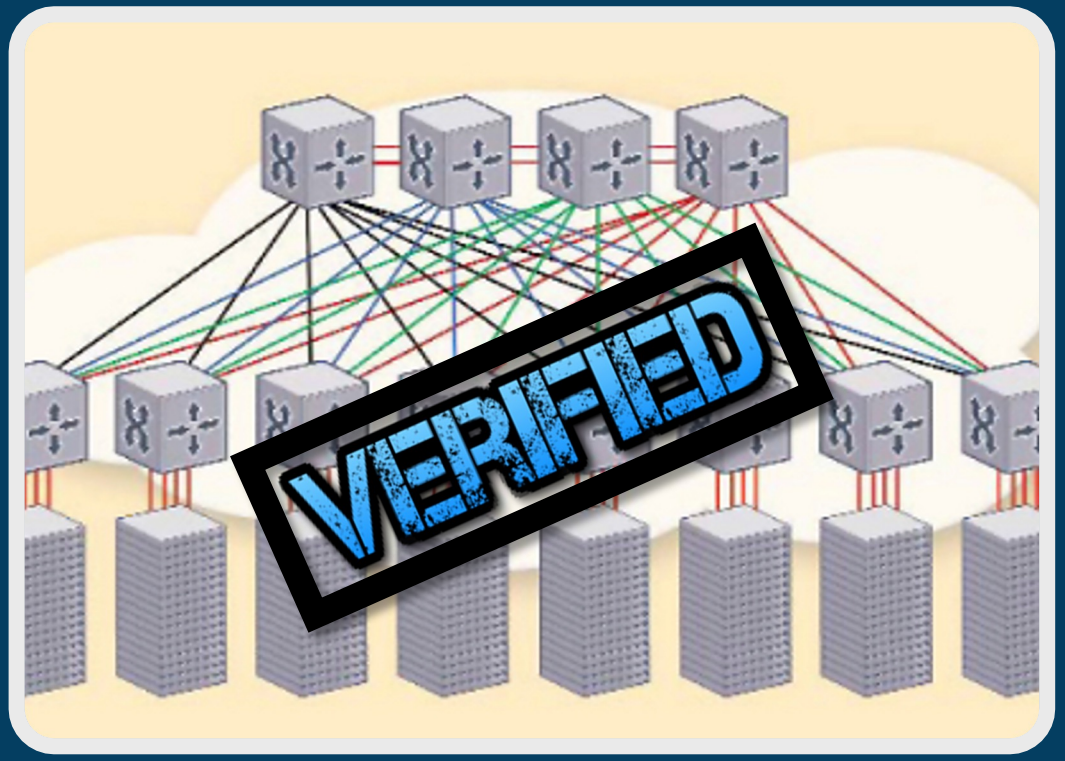
By Liam Tung | June 7, 2019 -- 12:39 GMT (05:39 PDT) | Topic: Cloud

Amazon's massive AWS outage was caused by human error

One incorrect command and the whole internet suffers.

By Jason Del Rey | @DelRey | Mar 2, 2017, 2:20pm EST

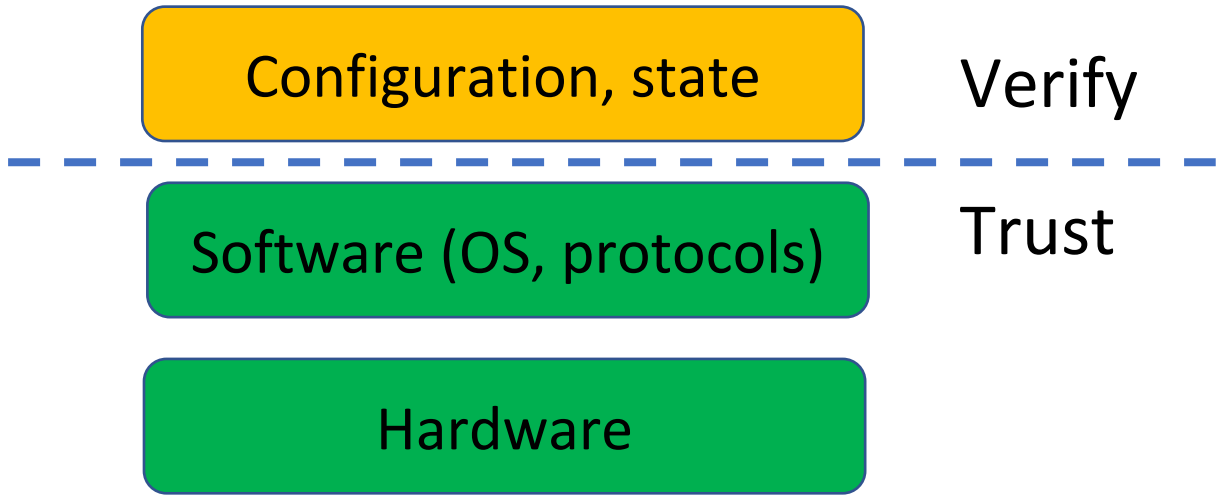
Network verification to the rescue



Guarantee network behavior *

* Some behaviors under some assumptions

How network verification slices the problem



The “haystack” of network behaviors is HUGE

Large scale

$O(10^3)$ devices
$O(10^6)$ routes
$O(10^9)$ packets

Complex interactions

Distributed routing
Protocol redistribution
Rich route filtering

Batfish: A production-grade network verifier

Open source, with **2000** users on Slack
Used at **50+ companies**
The basis for **Oracle Cloud's Network Path Analyzer**
Foundation for **25+ publications**

https://github.com/batfish/batfish

Batfish: A production-grade network verifier

2012 2015 2017 2022

aws

Op
Us
The
Fou

(NSDI 2015)

A General Approach to Network Configuration Analysis

Ari Fogel *Stanley Fung* *Luis Pedrosa* *Meg Walraed-Sullivan*

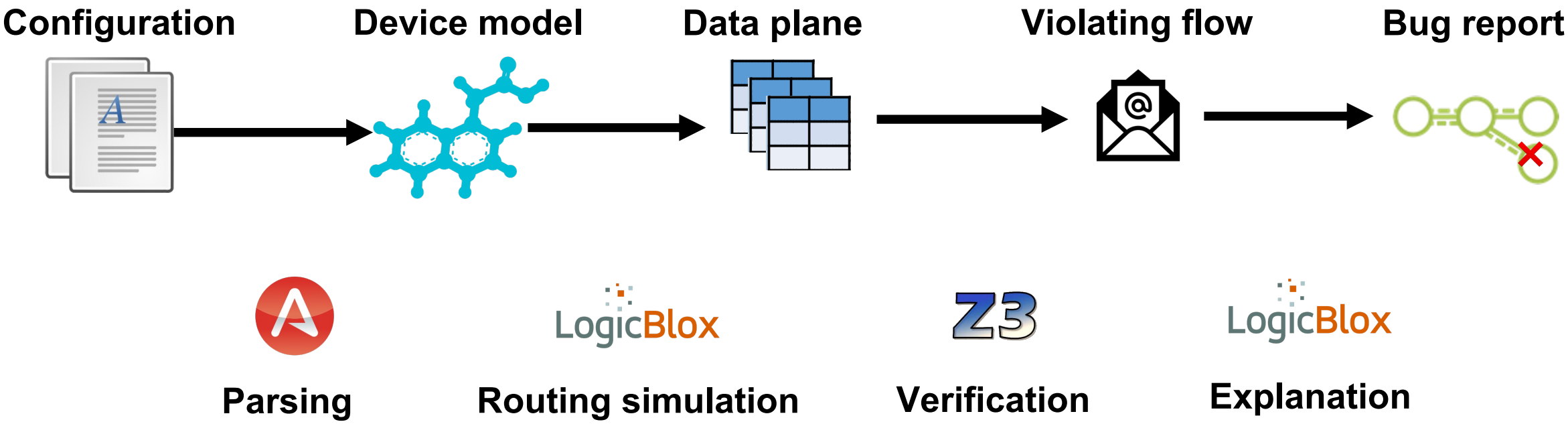
Ramesh Govindan *Ratul Mahajan* *Todd Millstein*

University of California, Los Angeles University of Southern California Microsoft Research

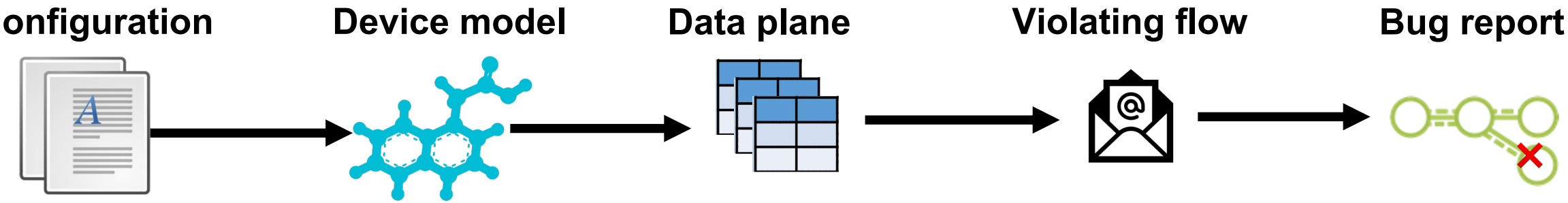
https://github.com/batfish/batfish

Batfish validates configuration changes ***before*** they affect the network

Batfish's original 4-stage pipeline



Batfish's c[2024]al 4-stage pipeline



New! Fidelity

New! Parsing

New! Routing simulation

New! Verification

New! Explanation

1500x faster, **400x** larger networks

(SIGCOMM 2023)

Experience Track

Lessons from the evolution of the Batfish configuration analysis tool

Matt Brown
Intentionet

Ari Fogel
Intentionet

Daniel Halperin
Intentionet

Victor Heorhiadi
Intentionet

Ratul Mahajan
Intentionet
University of Washington

Todd Millstein
Intentionet
UCLA

Lesson 1: Datalog was great for prototyping, but not for production use

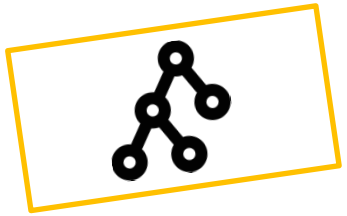
Three key challenges:

1. **Expressiveness**
2. **Performance**
3. **Deterministic convergence**

Solution: replace Datalog with imperative code

Parsing

Routing simulation



Verification

Explanation

Lesson 2: Model fidelity is hard, but not why you think

Concern: “Every software version will have different semantics!”

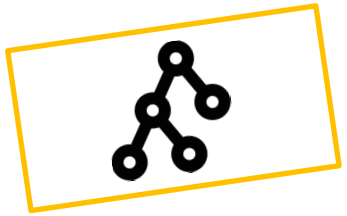
Reality: The real challenge is **undocumented semantics**

Solution: New stage to benchmark Batfish against an emulator

Fidelity

Parsing

Routing simulation



Verification

Explanation

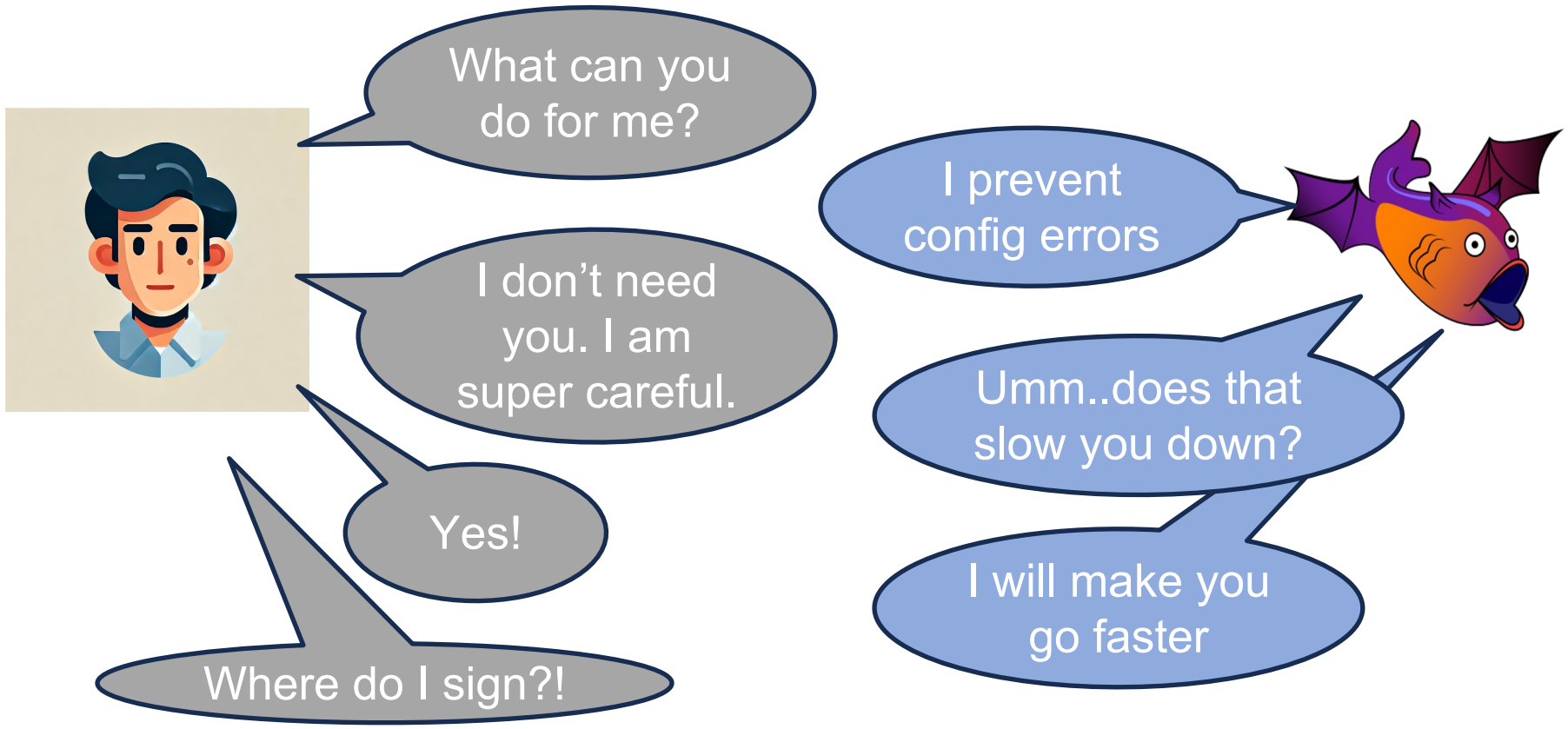
Lesson 3: Usability is hard for reasons you think, and then some

Ambiguity: “Hosts **A** can reach hosts **B**”

- ALL **applications** can reach SOME **DNS server** (e.g., in the same AZ)
- SOME **SNMP collector** can reach **infrastructure elements**
- ALL **service frontends** can reach ALL **backend VIPs**

Solution: custom assertions for each use case.

Lesson 4: Config validation aids networks agility too



Lesson 5: Most networks are nothing like hyperscalers' network

Limited network automation

Limited software expertise

Current state of network verification

Core technology is ready

- ❑ Used by many hyperscale, mission-critical networks
- ❑ Several startups

Open challenge: Make network verification a universal practice

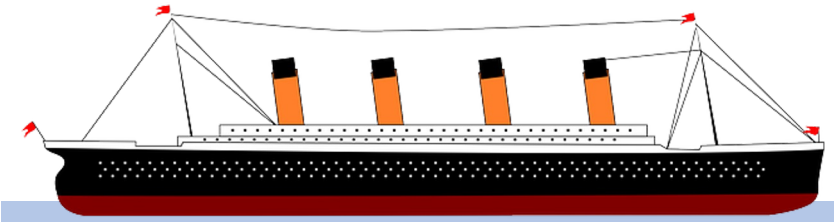
Enable **effective use** by network engineers

Rapid support for **new capabilities**

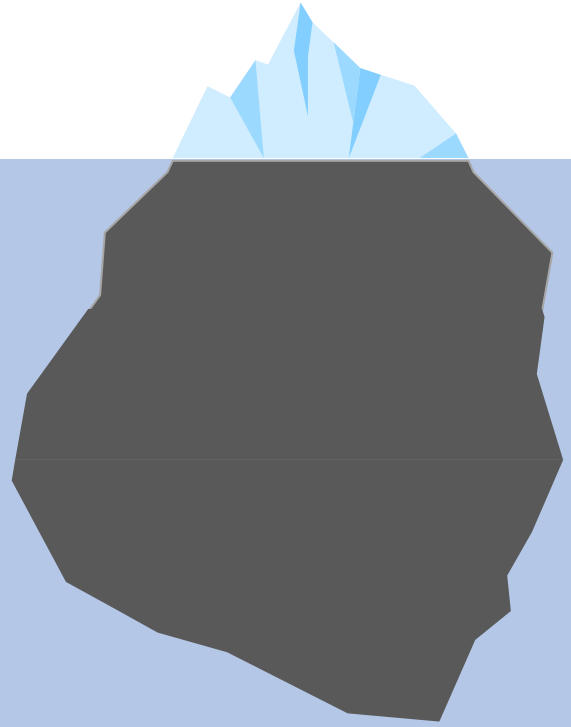
Handle **network evolution**

Network verification is only as good as its usage

Network change



Test suite



Untested network behaviors

Network verification is only as good as its usage

This article was published on: 10/4/21

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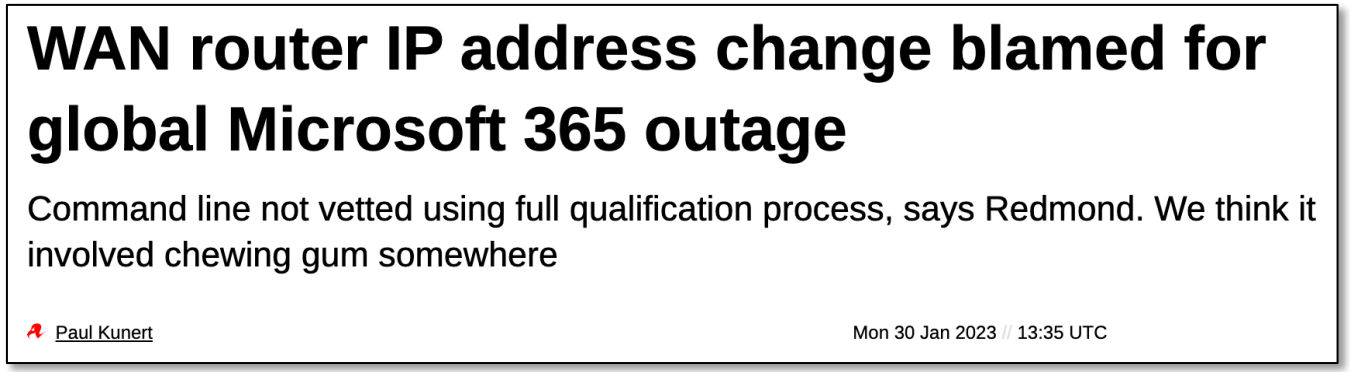
Featured Read This

Facebook outage triggered by BGP configuration issue as services fail for 6 billion



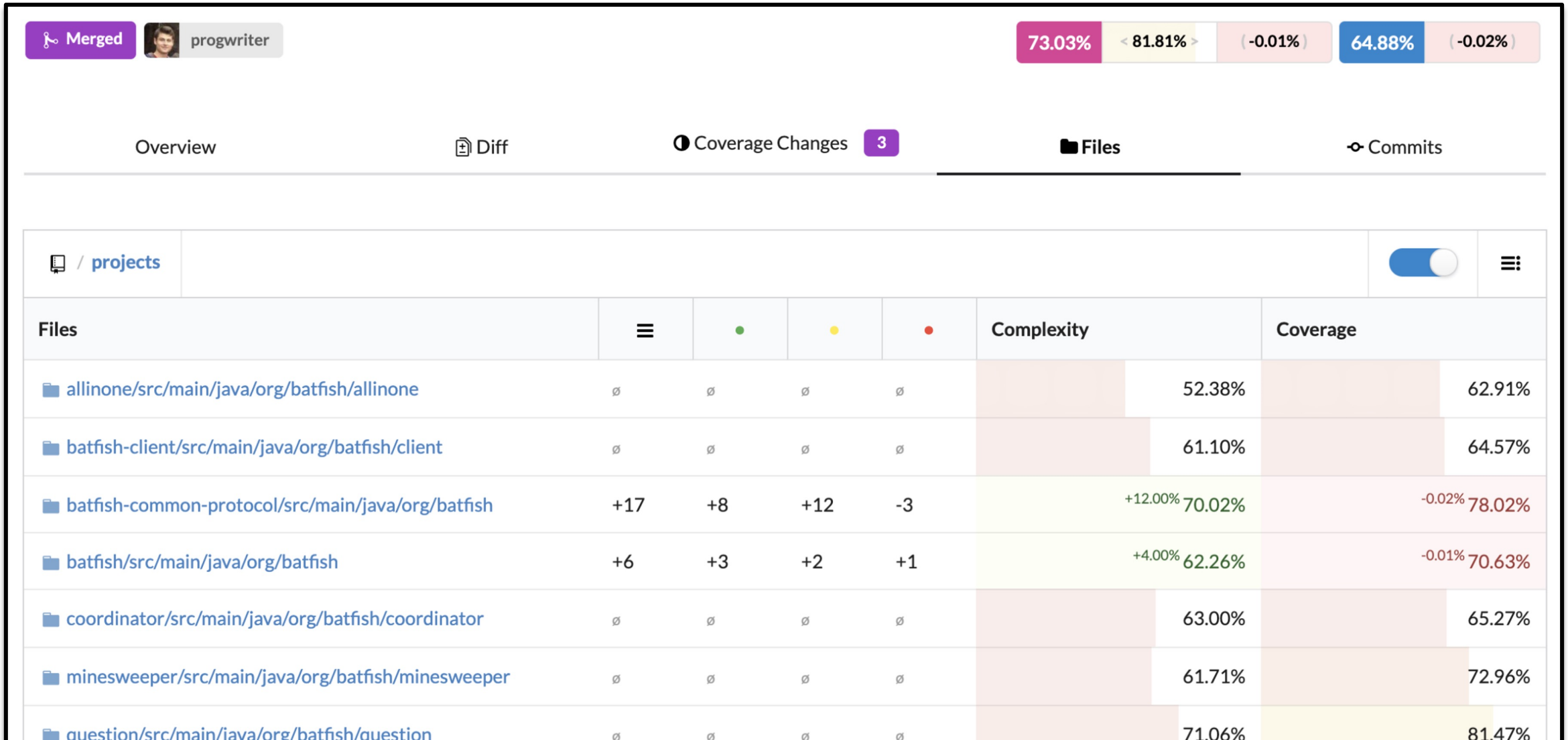
WAN router IP address change blamed for global Microsoft 365 outage

Command line not vetted using full qualification process, says Redmond. We think it involved chewing gum somewhere

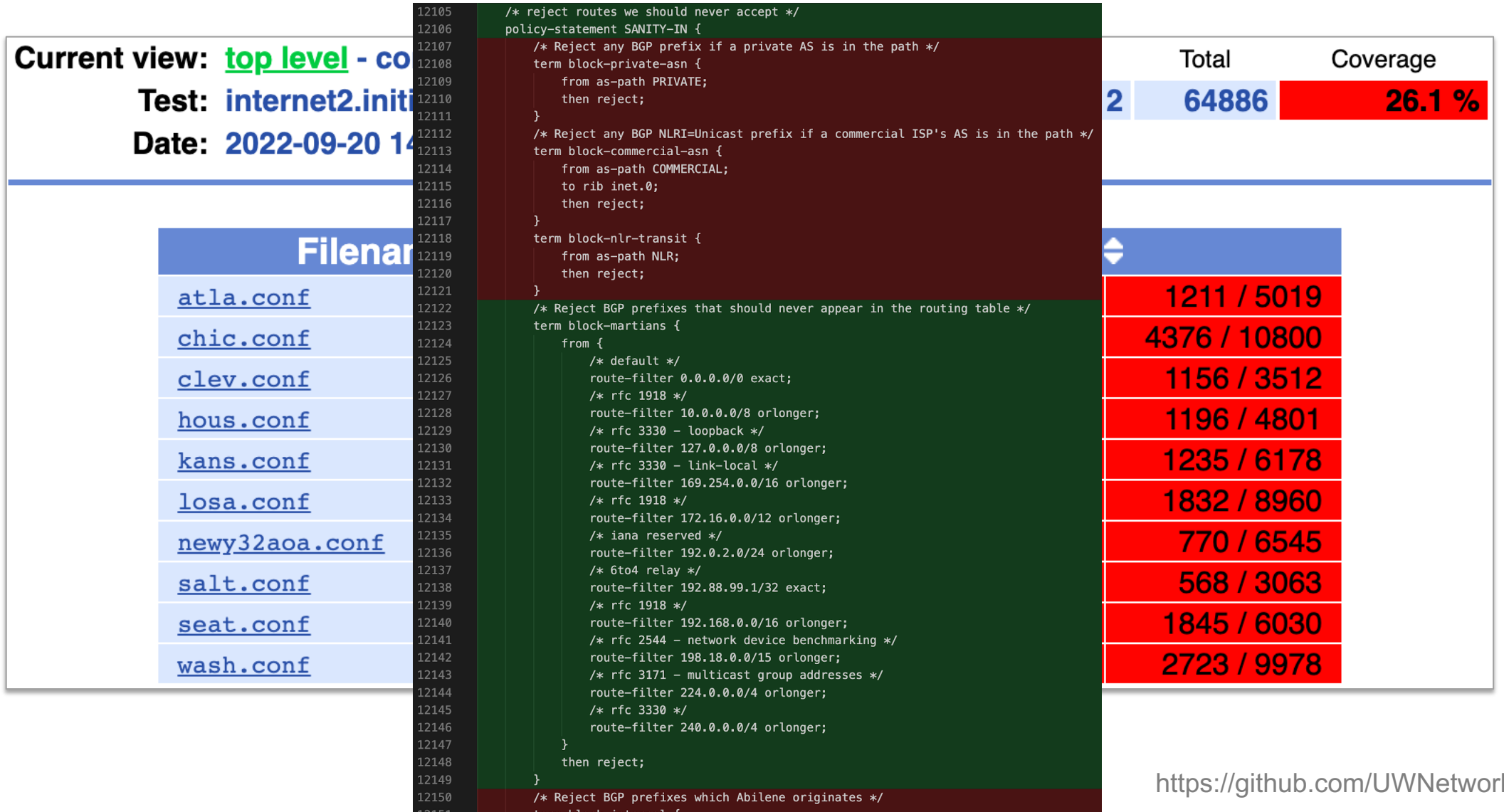
Paul Kunert

Mon 30 Jan 2023 // 13:35 UTC

Inspiration from code coverage

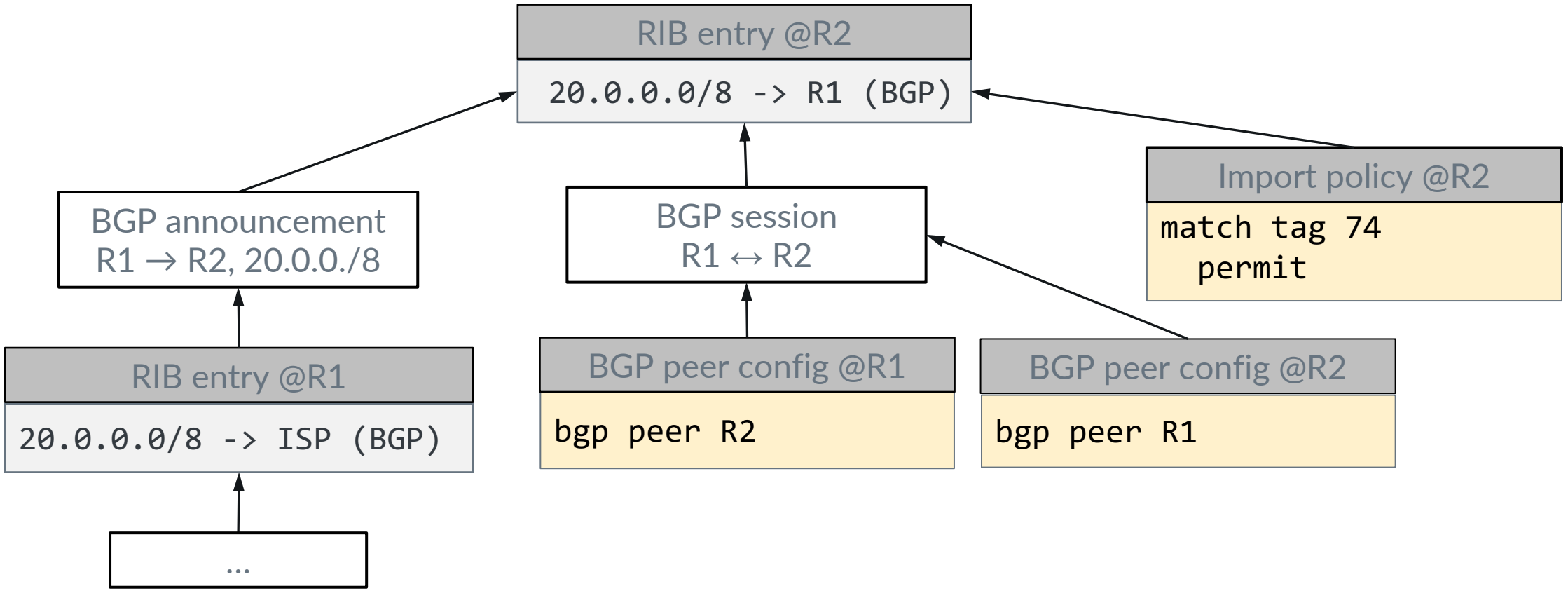


NetCov: Coverage for network configurations

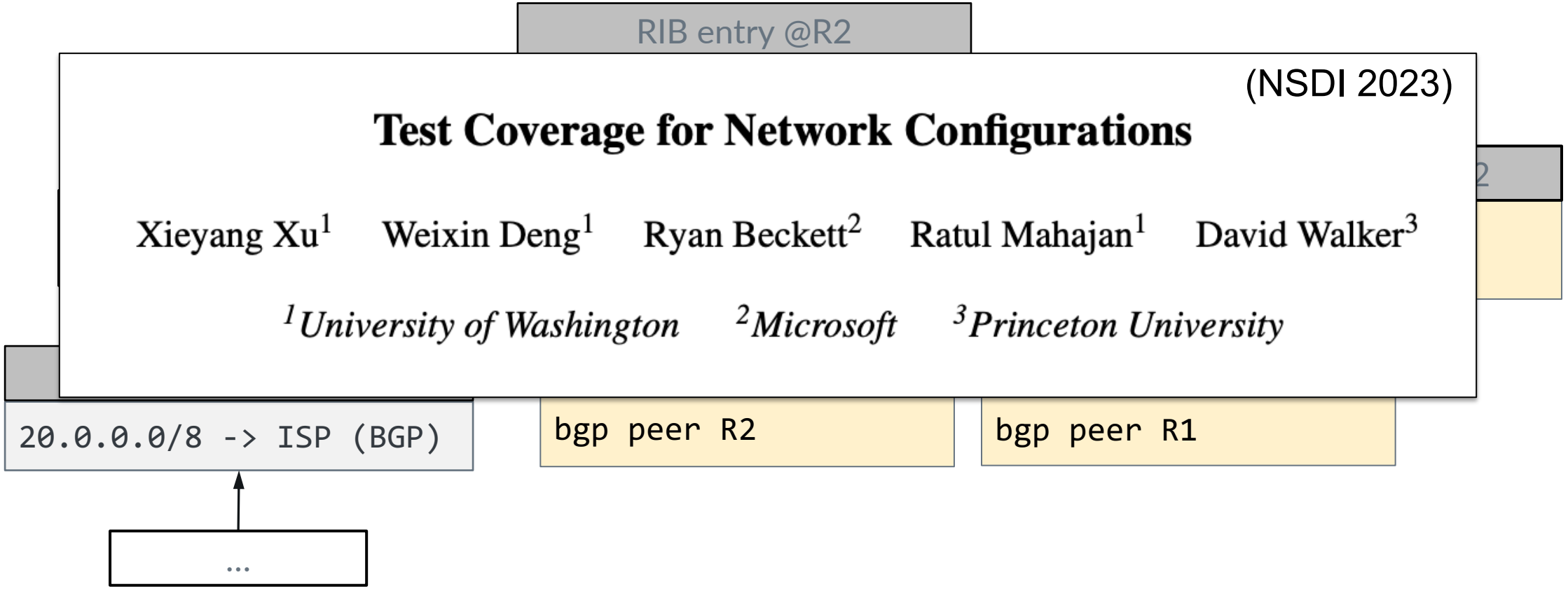


https://github.com/UWNetworksLab/netcov

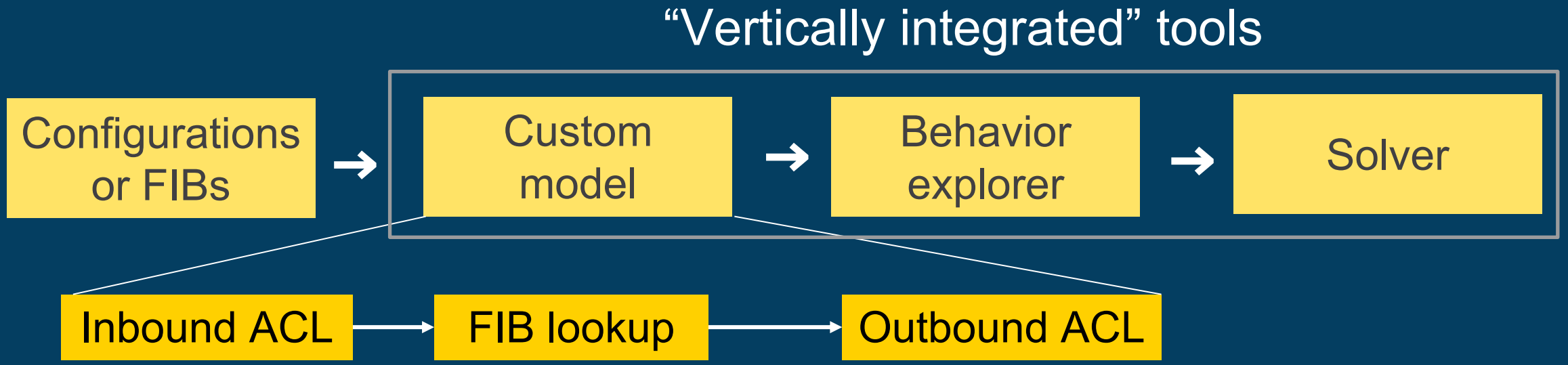
NetCov maps tested data plane state to covered config lines



NetCov maps tested data plane state to covered config lines

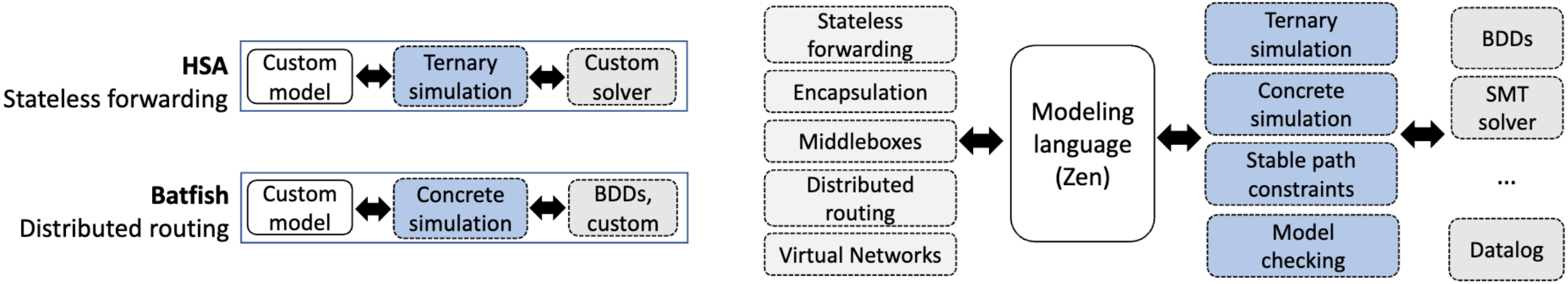


Rapid support for new capabilities



When does NAT happen?
Where does firewalling happen?
Which fields can firewalling refer to?

Modeling networks using Zen



Modeling networks using Zen

Handling network evolution

No one has full view of network behavior

Precise specifications can be HUGE

Evolution-friendly verification

Relational Network Verification

Xieyang Xu[w] Yifei Yuan[a] Zachary Kincaid[p] Arvind Krishnamurthy[w]
Ratul Mahajan[w] David Walker[p] Ennan Zhai[a]

[w]University of Washington [a]Alibaba Cloud [p]Princeton University

[SIGCOMM 2024]

Summary

Network verification is key to high availability

First generation tools have taught us a lot about what (does not) work

Next generation tools must focus on making network verification a universal practice