Towards Accessible Model-Free Verification

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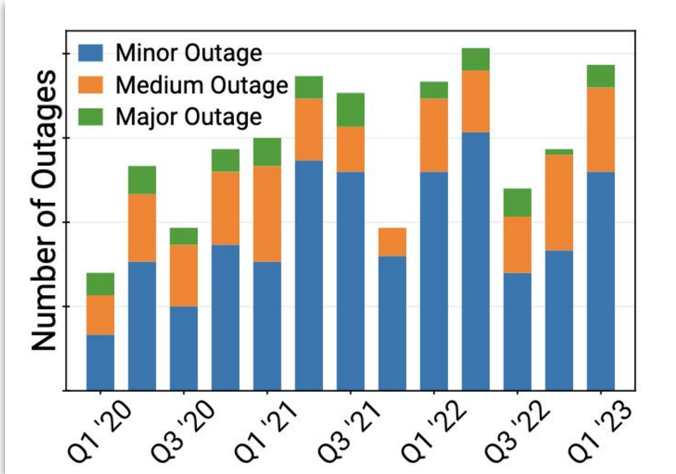
(Still) no end in sight for WAN outages

Steady stream of academic verification literature promising safety guarantees…

- Lightyear [SIGCOMM ‘23]
- Hydra [SIGCOMM ‘23]
- Flash [SIGCOMM ‘22]
- Snowcap [SIGCOMM ‘21]
- GRoot [SIGCOMM ‘20]
- …
- BatFish [NSDI ‘15, SIGCOMM ‘23]
- Header Space Analysis [NSDI ‘12]

Yet outages continue at the same rate…

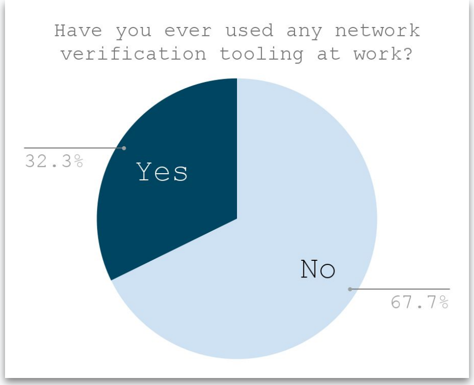


WAN Outage Rate
[Decentralized SDN, SIGCOMM ‘24]

Verification is promising, but not a silver bullet. Why not?

Real-world verification adoption is limited

Surveyed 30 network operators, interviewed 10 more



Key Results:

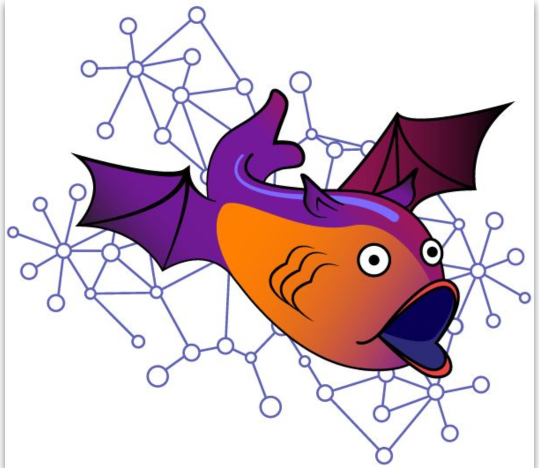
- Majority (70%) familiar with “network verification”
- *Under a third* have used network verification
- 0 / 10 interviewed were currently using verification tooling at work

Large need: 18k config pushes *a day* at Google; *many* opportunities for things to go wrong.

What is hindering verification’s adoption?

Batfish

- Most frequently mentioned verification tool
- SIGCOMM Networking System Award Winner
- 1,200+ GitHub stars
- Active, ongoing development; 12,800 commits



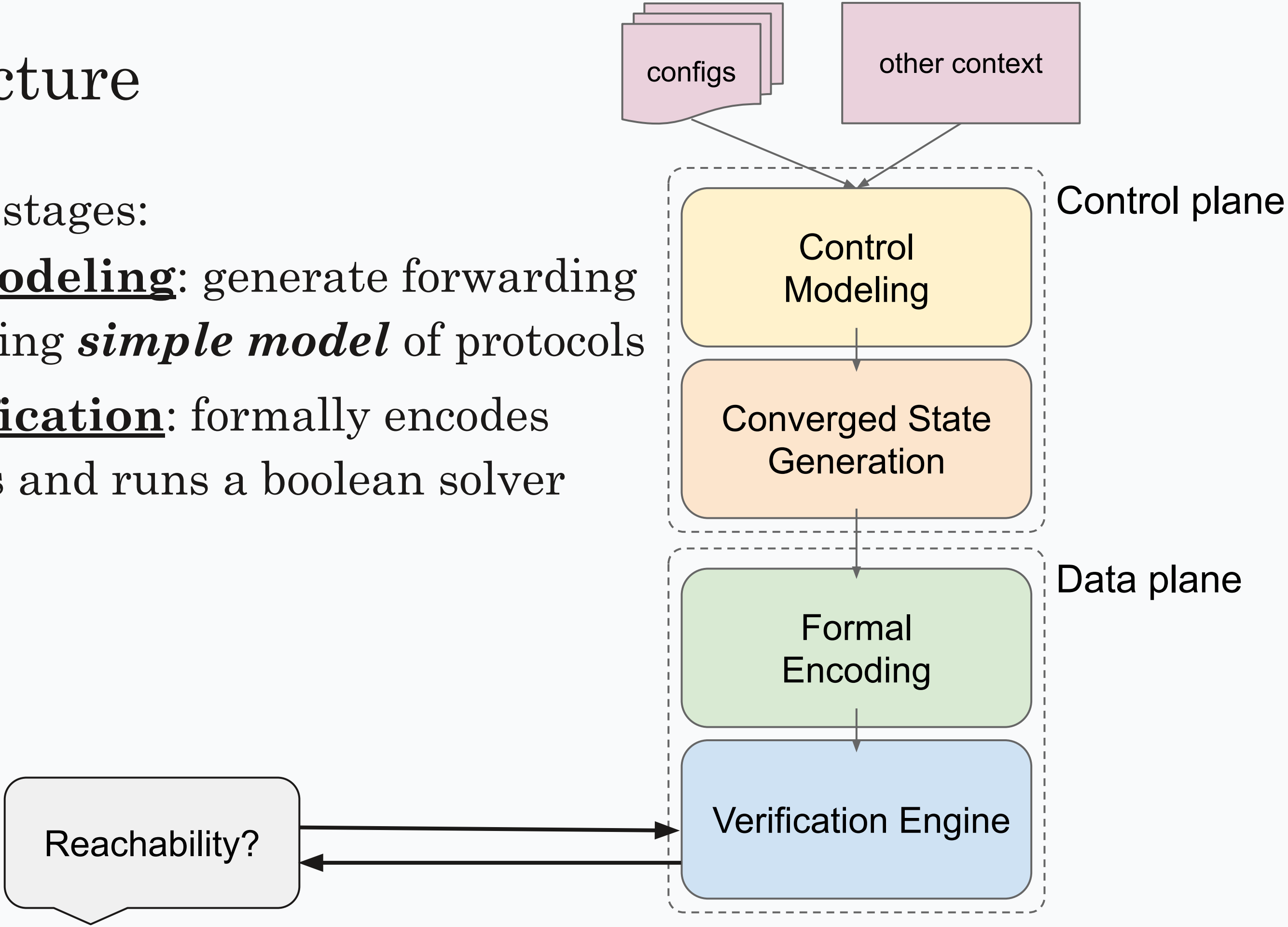
Control plane verification: given set of configuration, provide formal guarantees about post-convergence behavior (*before* deployment).

Batfish Architecture

Two logically separate stages:

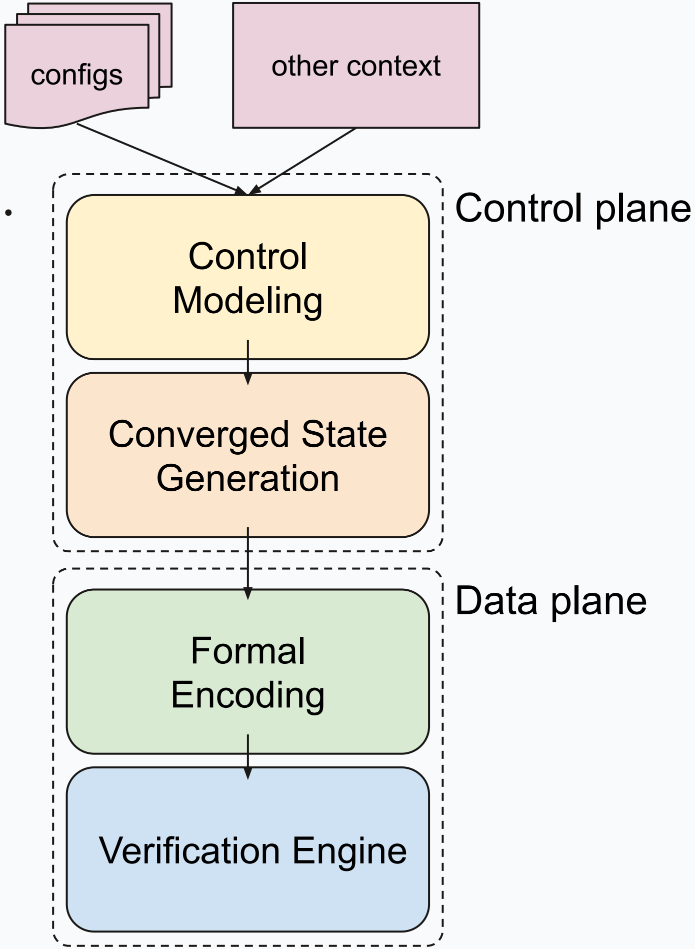
- **Control plane modeling**: generate forwarding entries by simulating ***simple model*** of protocols
- **Data plane verification**: formally encodes forwarding entries and runs a boolean solver

User queries:



Control modeling is *difficult*

Control plane model created by Batfish engineers…

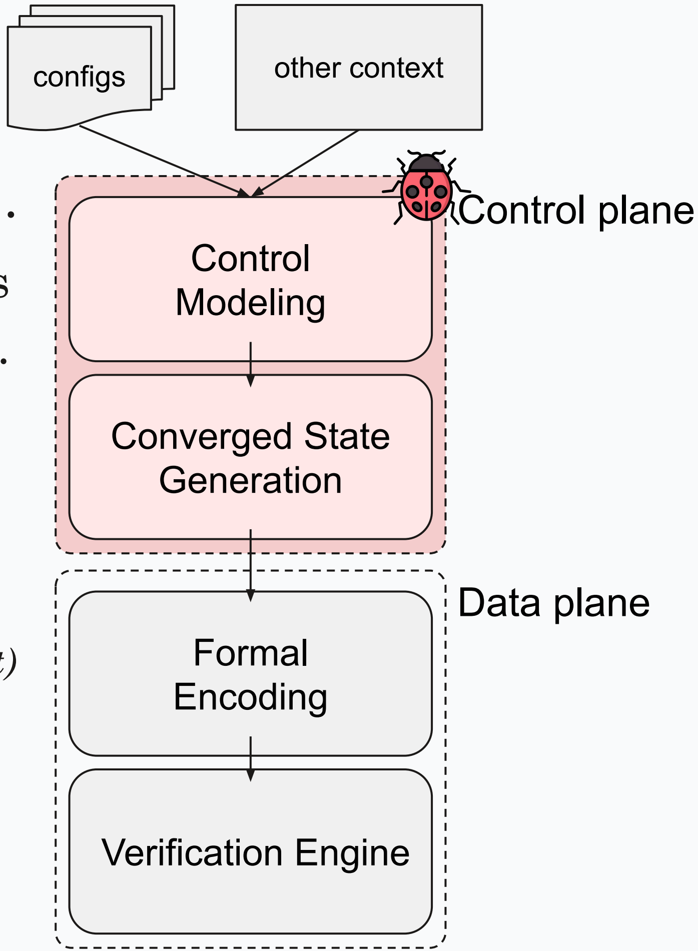


Control modeling is *difficult*

Control plane model created by Batfish engineers…

…but staying on top of all features and protocols used in practice is impossible.

- **Correctness**
  - *Custom model → bugs in model implementation/design*
  - *Misses vendor-specific customizations/behaviors*
- **Coverage**
  - *Completeness: model lags reality (e.g.: no RSVP-TE support)*
  - *Maintainability: requires continuous regression/testing*
    - *…as vendor implementation evolve*
- **Limited Fidelity**
  - *Convergence and protocols are modeled as a partial subset of behaviors*



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  - *Custo*
  - *Misses*
- **Coverage**
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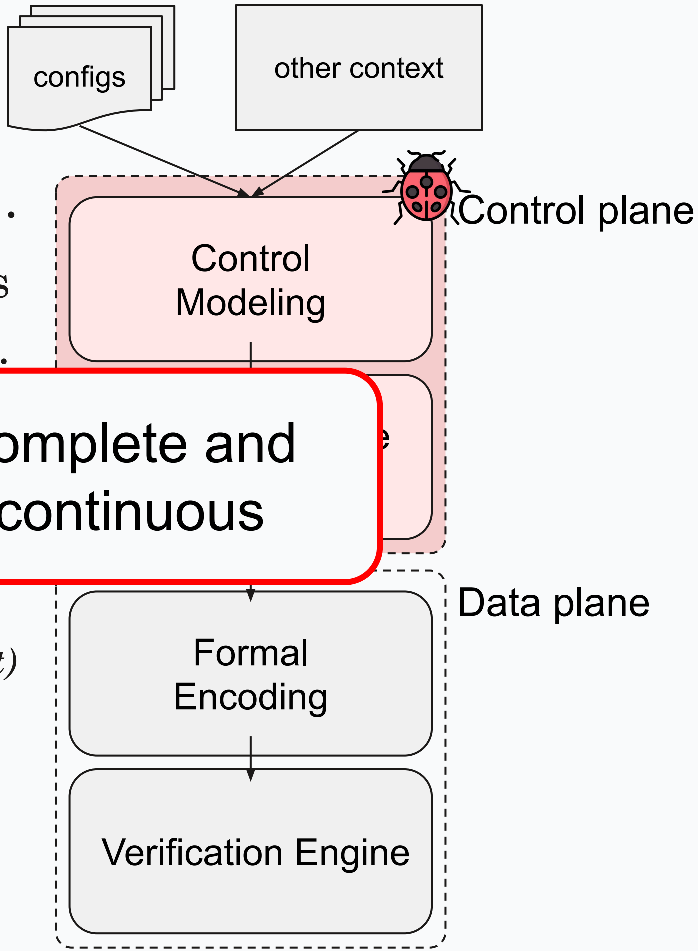
Developing and maintaining a complete and accurate model is *difficult* and continuous



Control model accuracy hinders adoption

Survey results match our experience…

- **74%** reported one of main barriers to adoption of verification tooling is verification tooling *not supporting features or protocols* that they use
- **94%** reported managing *multi-vendor networks*, which platform-independent control plane models do not capture

How do we keep powerful guarantees of verification without our models hindering adoption?

Model-free verification; opportunity of emulation

High level idea: replace model with emulation to be "*model-free*."

Why now?

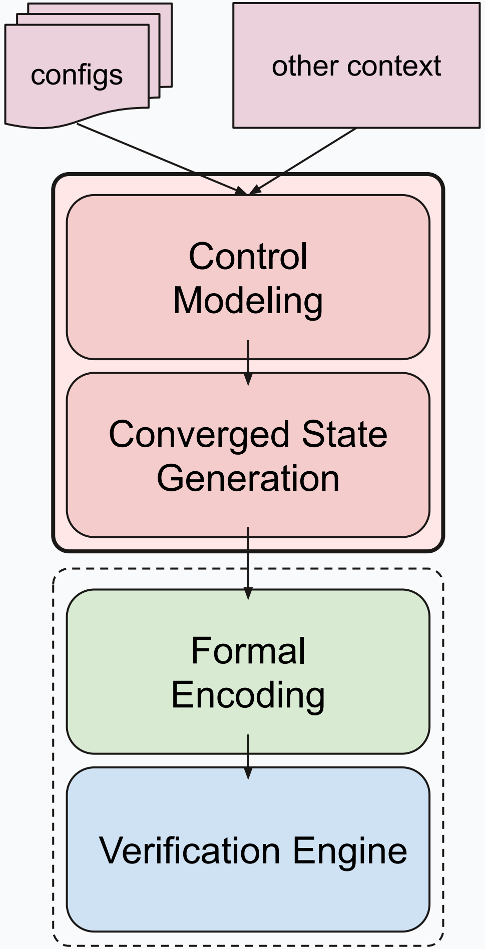
1) Vendors now all provide *containerized* router OS
   a) Resource efficient: as low as 0.5 vCPUs and 1GB of RAM per router.
   b) Can fully emulate 60+ router network on single e2-standard Google Cloud machine.
2) Availability of emulation frameworks to orchestrate virtual device networks
   a) Kubernetes Network Emulator (KNE), Containerlab establish "connections" b/w interfaces
   b) Highly scalable: we successfully run 1,000 router emulated network to convergence

Enables *near perfect-fidelity* control plane emulation at scale.

Model-free verification

We built a prototype using open source components:

- *Batfish* for verification engine and interface
- *Kubernetes Network Emulator* for emulation



Model-free verification

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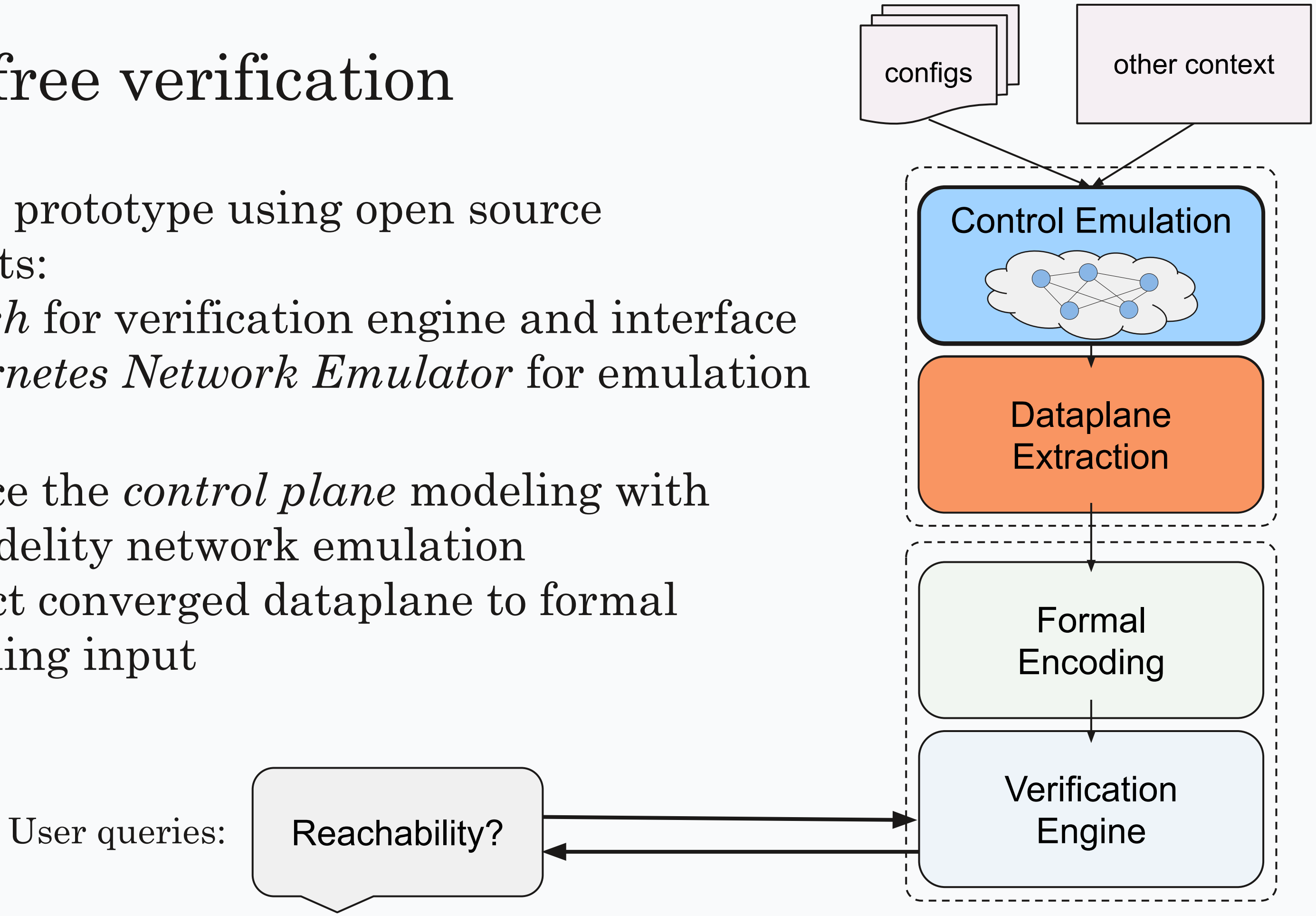
(1) replace the *control plane* modeling with full-fidelity network emulation

(2) extract converged dataplane to formal modeling input



Early results

Feature testing: verification on a set of simplified configs with production features enabled.

- Ran verification on configs previously unparsable by Batfish
- Successfully detected reachability
- Uncovered bug in Batfish model

Scale testing: testing convergence of large or realistic emulated networks.

- Successfully emulated 1000 router network to convergence.
- ~30 routers with full prod configs, injecting prod-recorded routes (million from each BGP peer)
    - Convergence time including route injection approximately 3 minutes, faster with fewer routes.

See paper for more details.

Many open questions remain…

- Search across scenario space (e.g. up to k cuts) is a challenge
- Exhaustive search of non-deterministic behavior too costly

Key takeaways:

(1) For verification research to be practical, it must have production coverage of features

(2) Open source emulation technology is key to enabling this, and has matured to allow for scale

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Paper Link