Fast Control Plane Analysis Using an Abstract Representation

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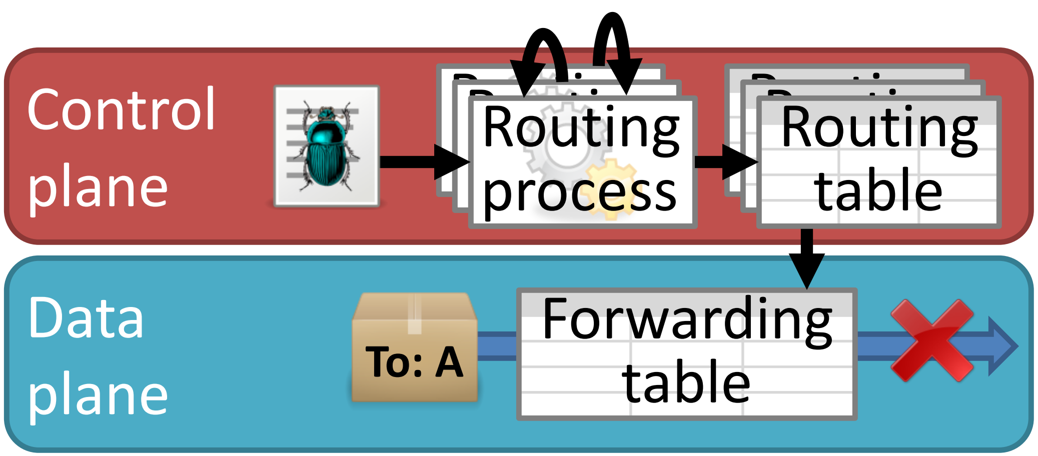
UW-Madison and Microsoft

Control plane is…

- Essential → configuration errors may cause security/availability problems
- Complex → errors may not be immediately apparent



DatacenterDynamics
The Business of Data Centers.

Microsoft: misconfigured network device led to Azure outage

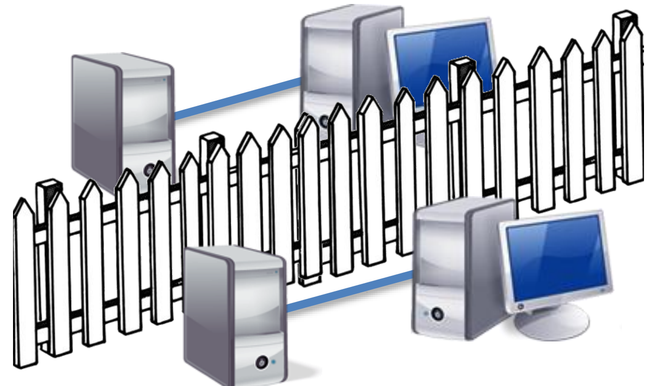
30 July 2012 | By Yevgeniy Sverdlik

"The service interruption was triggered by a misconfigured network device that disrupted traffic to one cluster in our West Europe sub-region," Mike Neil, general manager for Windows Azure, wrote in a blog post.

"Once a set device limit for external connections was reached, it triggered previously unknown issues in another network device within that cluster, which further complicated network management and recovery."

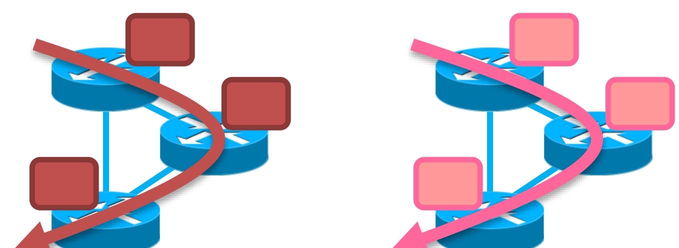
Important functional invariants

Always blocked



Always isolated

Always traverse middlebox

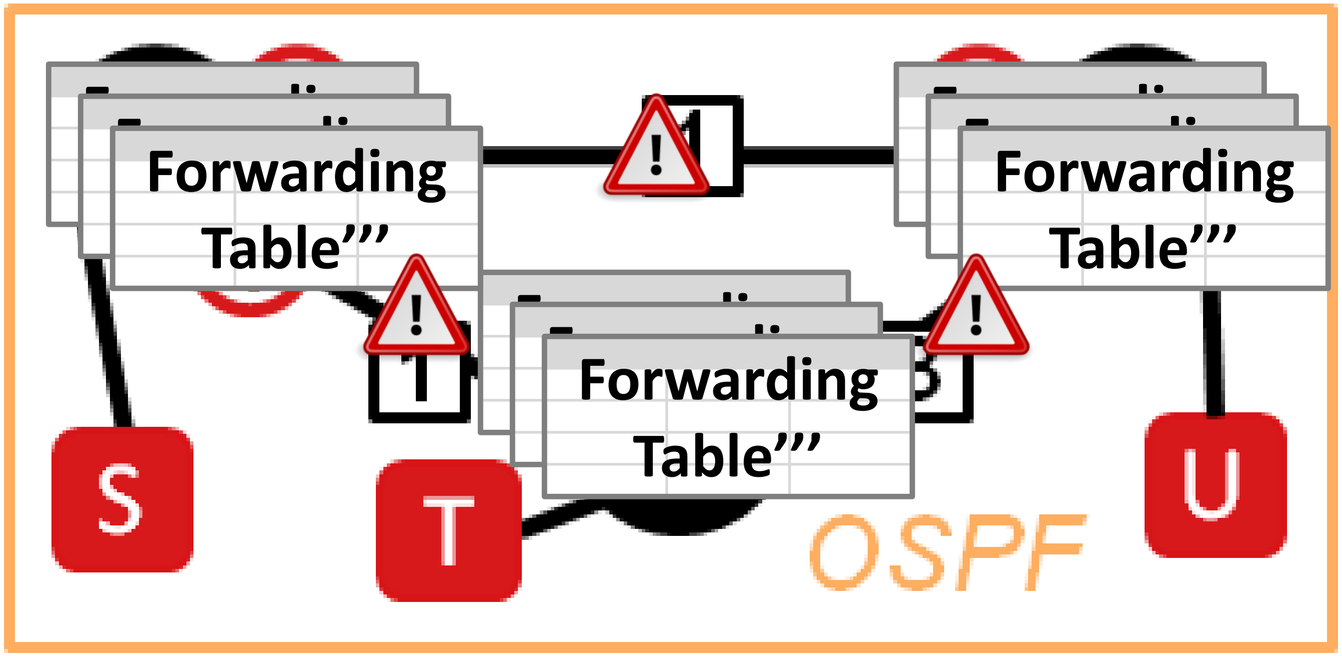


Always equivalent paths

Challenge: Invariants violated under some (combinations of) failures

Analyze current data plane [HSA, Veriflow] → cannot verify invariants always hold

Generate data planes [Batfish] → time consuming



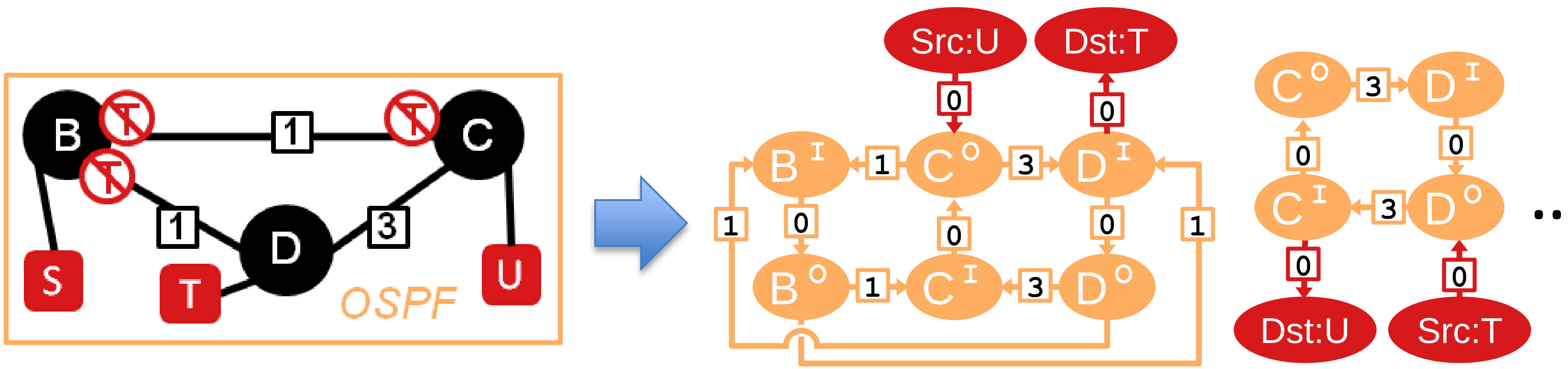
Proactive Verification

Blocked, isolated, waypoints, equivalence …

- **Properties of paths**, not paths themselves
- Data centers, enterprises use a **limited** set of control plane constructs

Higher-level abstraction
Fast analysis

Abstract Representation for Control planes (ARC)



Control plane configuration

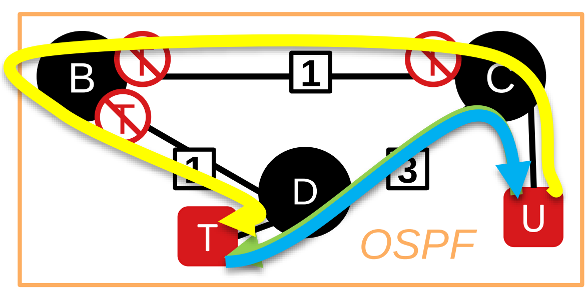
Abstract representation

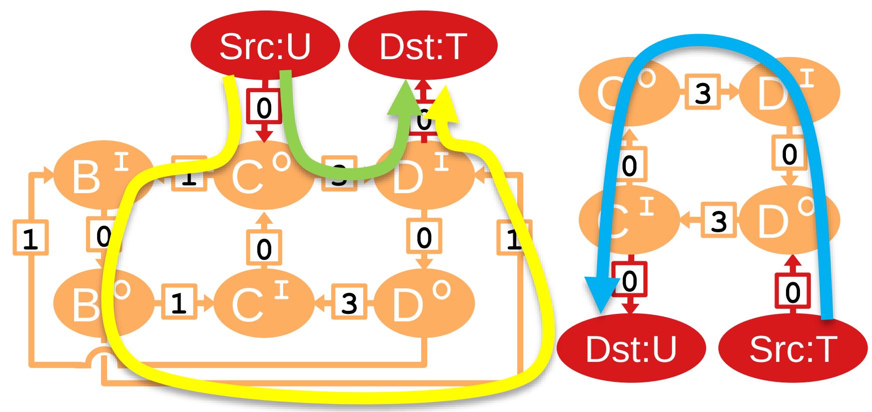
- Encodes the network's forwarding behavior under *all* possible infrastructure faults
- Proactive verification boils down to checking simple graph-level properties → **fast**
- Ignore which protocols used and how

Key requirements of ARC

1) **Sound & Complete**: each digraph contains *every feasible* path and *no infeasible* paths
→ verification of invariants

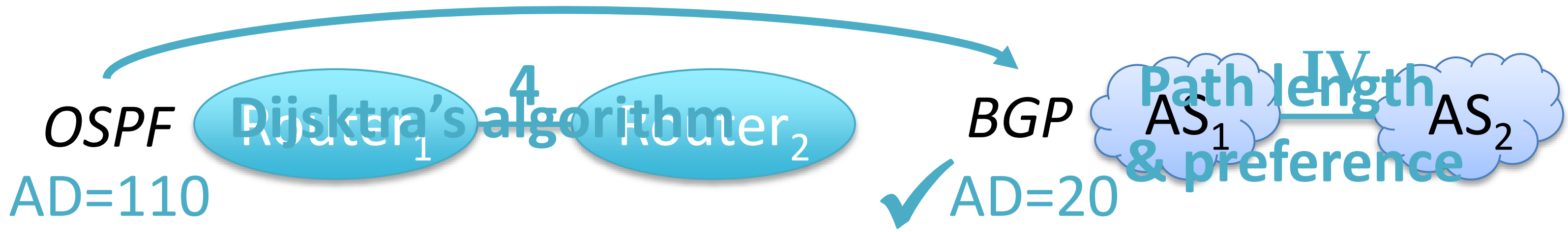
2) **Precise**: assign edge weights such that the *min-cost path* matches the real path
→ counter-examples, equivalence testing





- Why weighted digraphs?
- How to ensure soundness, completeness, precision?

Routing protocols used today



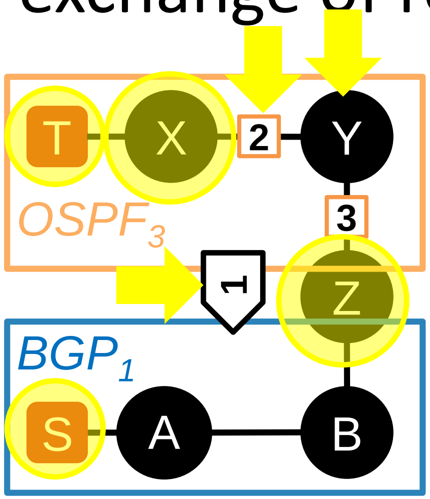
- **Commonality**: cost-based path selection algorithm
- **Differences**: granularity & currency
- Also must account for:
  - Traffic class specificity
  - Route redistribution
  - Route selection based on administrative distance

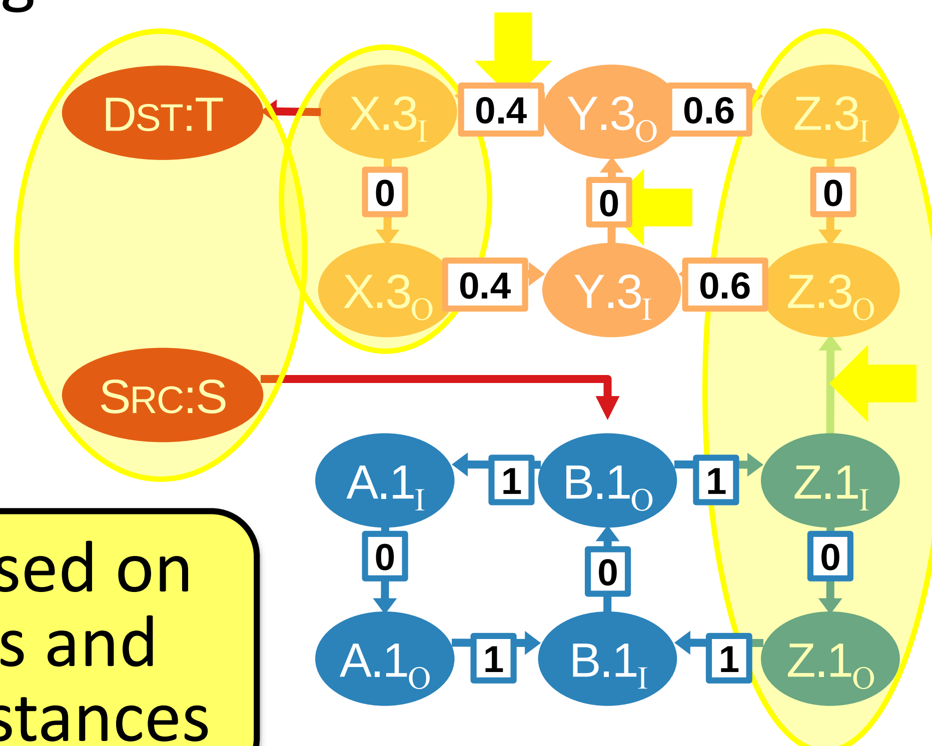
Challenge: determining the structure and edge weights of the graphs

Extended topology graphs (ETGs)

- One per traffic class
- **Vertices**: routing processes
- **Edges**: flow of data enabled by exchange of routing information

Sound and complete
(for OSPF, BGP, redistr…)



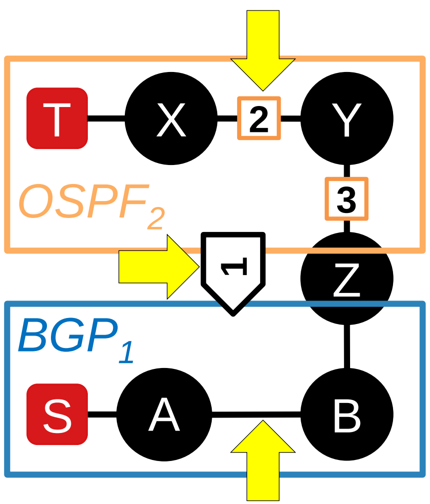


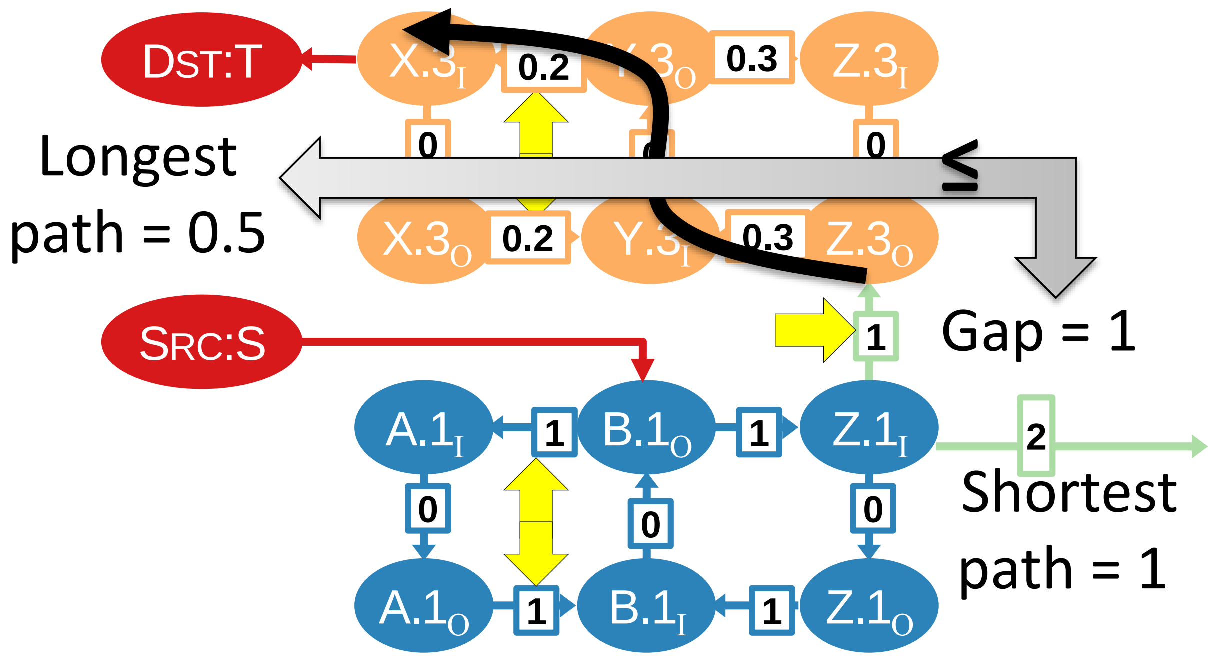
Edge-weights based on configured costs and administrative distances

ETG edge weights

- **Inter-device**: OSPF weights;
  unit cost per hop for BGP (each router is an AS)
- **Intra-device**: redistribution only: no cost within process; fixed-cost between processes **+ scaling**

Precise
(for DAG redistribution, AD graphs)





ARC properties

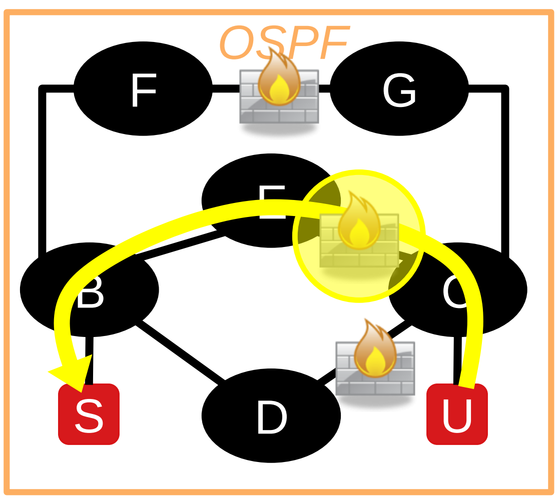
Construct	Sound & Complete
OSPF	✓
RIP	✓
eBGP	✓
Static Routes	✓
ACLs	✓
Route filters	✓
Route selection (based on Administrative Distance)	✓
Route redistribution	✓

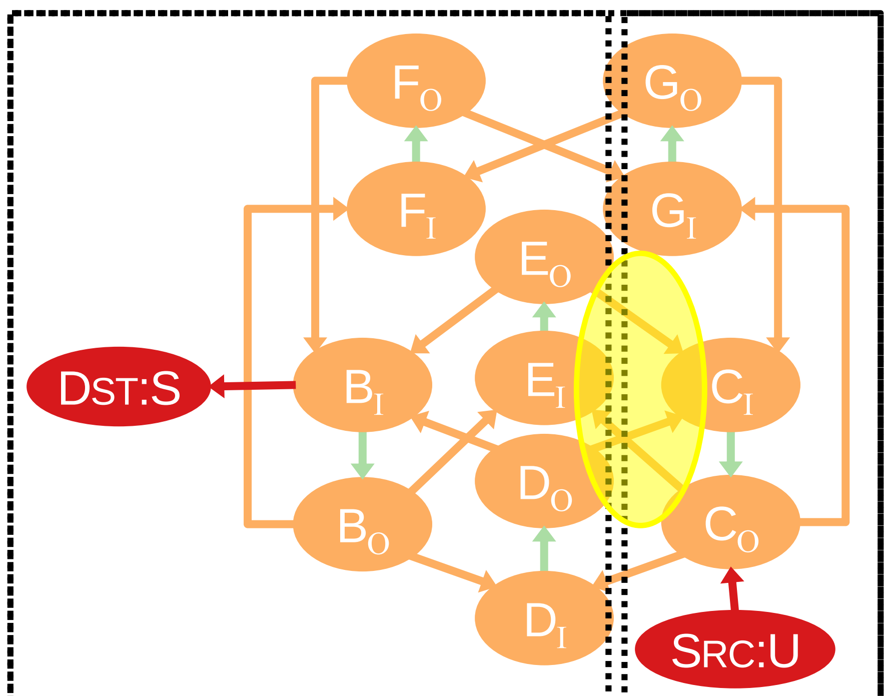
Sound and complete for **100%**

Precise for **96%**

Verification

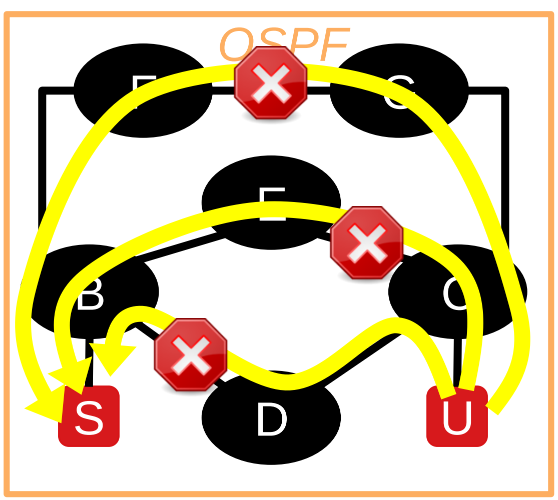
- *Always traverse middlebox*:
  1) remove all edges with middleboxes
  2) Src and Dst in same connected component?



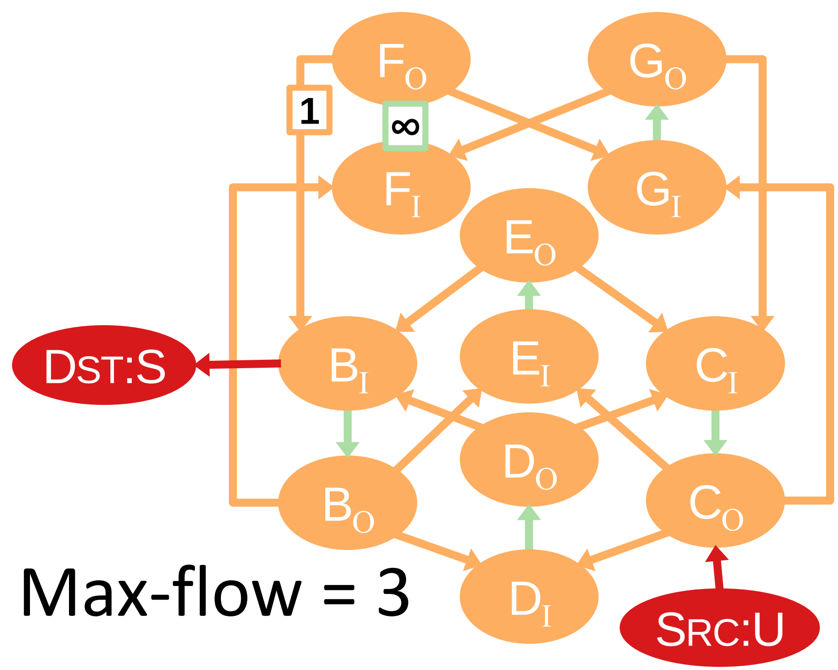


Verification

- *Always reachable with < k link failures:* max-flow on unit-weight ETG ≥ k?



3 edge-disjoint paths



Max-flow = 3

Verification

Invariant	Graph property	Required ARC Properties
Always blocked	Separate connected components	Sound & Complete
Always reachable with < k failures	Max flow ≥ k	Sound & Complete
Always traverse waypoint (chain)	Separate connected components	Sound & Complete
Always isolated	No common edges	Sound & Complete
Equivalence	Same structure & weights	Sound, Complete, & Precise

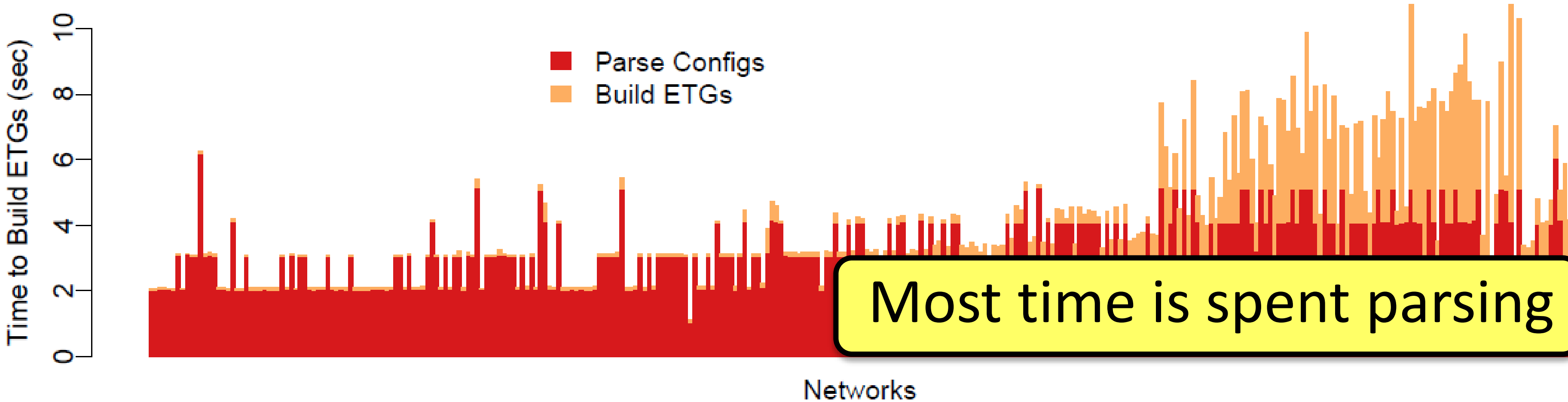
Precision required to produce counter-examples

Implementation and evaluation

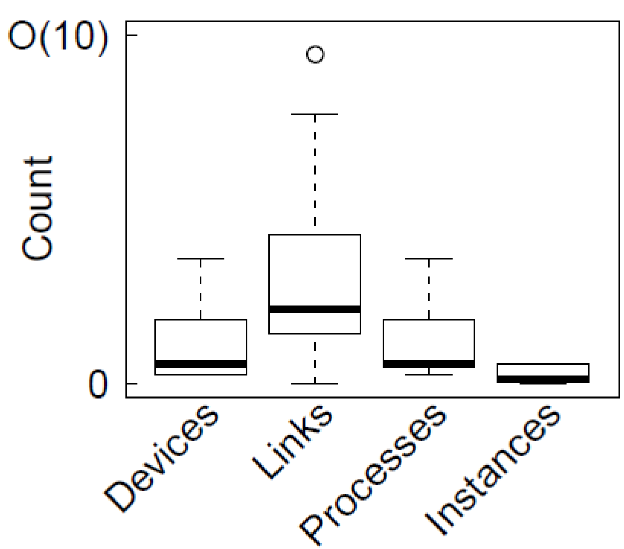
- Implemented in Java using Batfish (parsing) and JGraphT (graph algorithms)
  https://bitbucket.org/uw-madison-networking-research/arc
- Configurations from 314 data center networks operated by a large online service provider

- 4-core 2.8GHz CPU
  24GB RAM

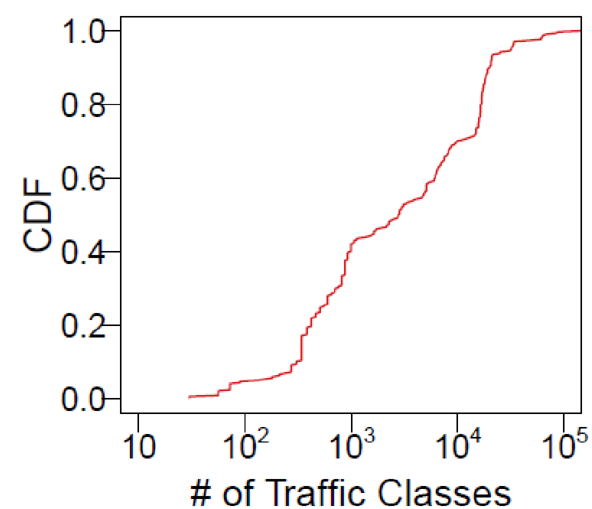
Evaluation: time to generate ARC



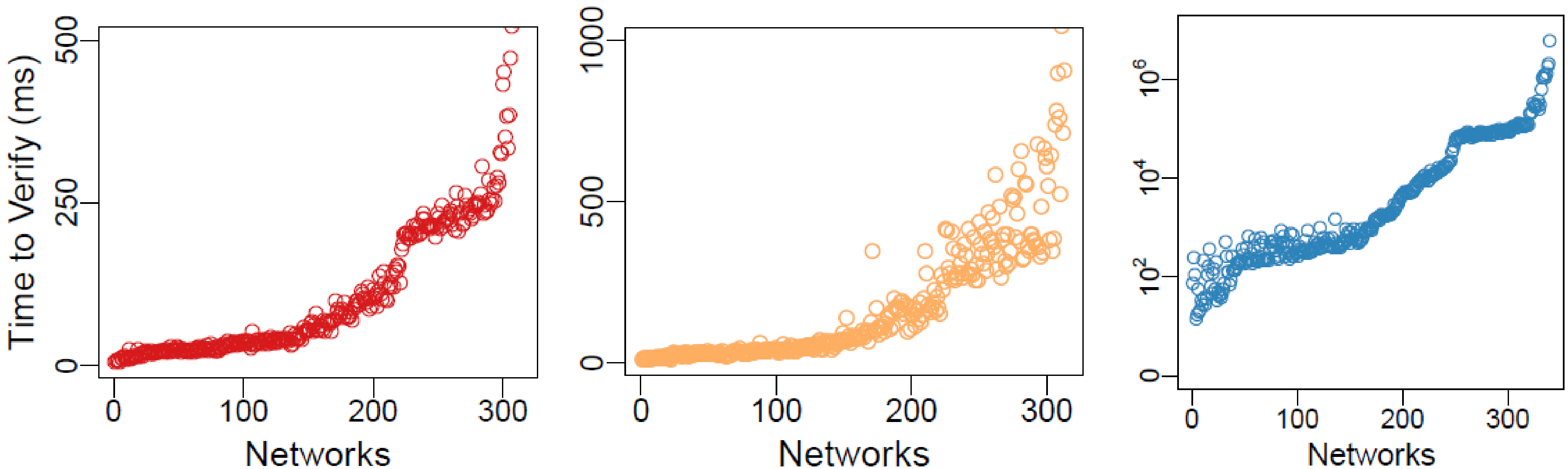
Most time is spent parsing



Fast (< 10 sec) even for large networks



Evaluation: verification time



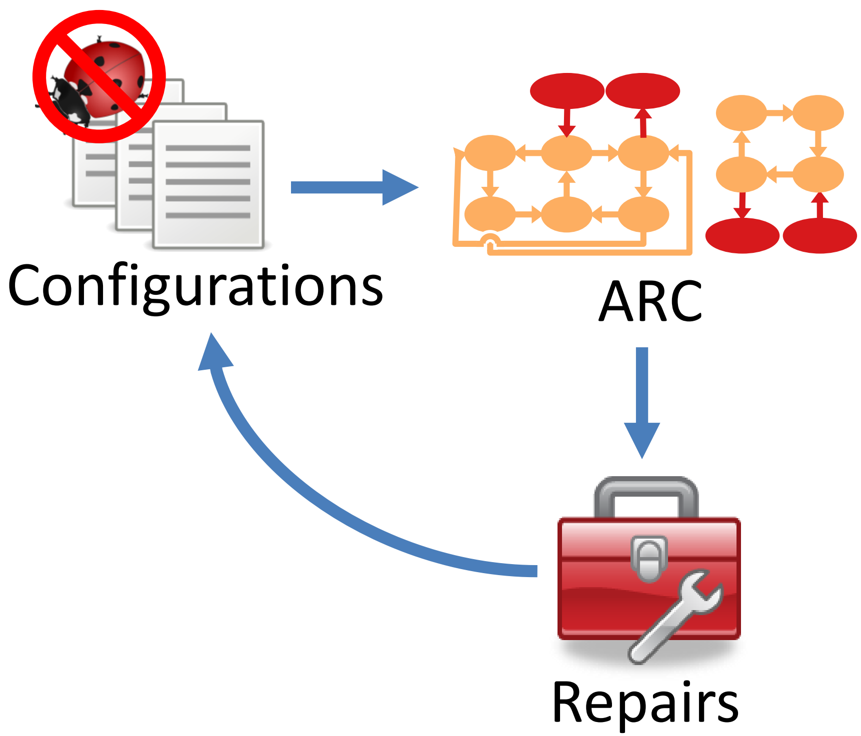
Always blocked	*Always reachable with < k failures*	*Always isolated*
< 500 ms (Batfish: 694 days!)	**< 1 sec**	**Up to 16 min**

Verification time is proportional to the number of traffic classes; easily parallelized

Next steps

- Precision under fewer assumptions
- Generality of ARCs
- Other uses…

Next steps: automated repair

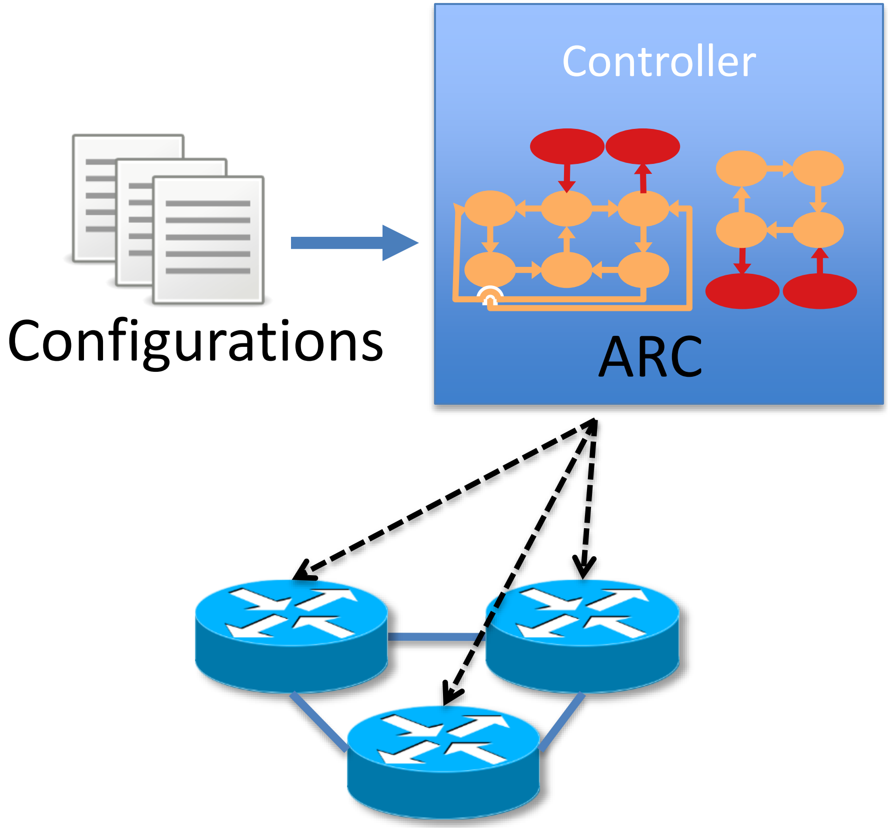


1) Transform ETGs to have desired attributes (e.g., src and dst→ always blocked)

2) Translate to config changes (e.g., remove edge → add ACL)

Challenge: finding a *minimal* repair
(e.g., many ACLs vs. remove BGP neighbor)
without side-effects

Next steps: Transition to SDN



Controller uses ETGs to drive forwarding plane configurations

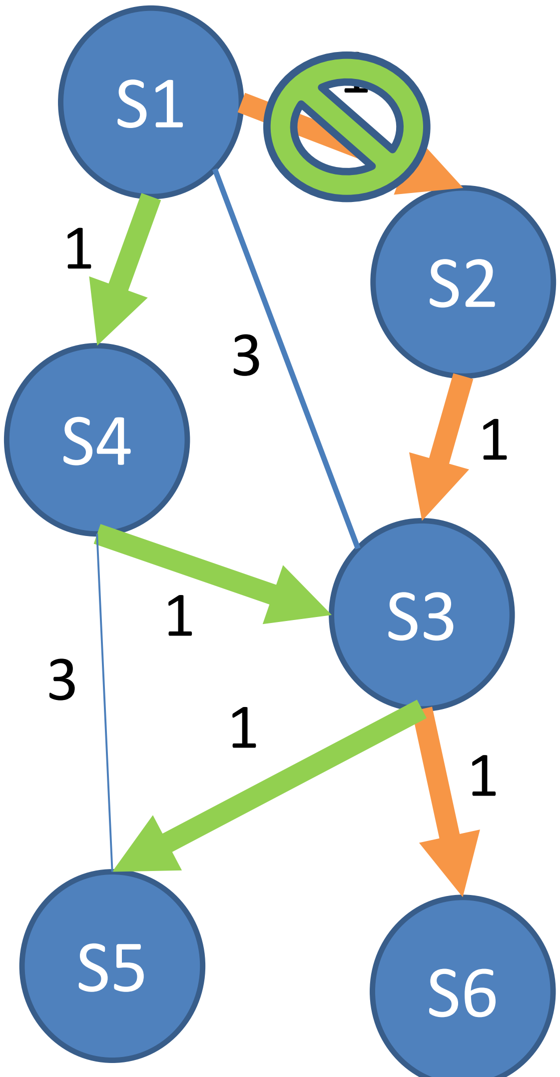
Minimize controller involvement, churn?

Different underlying network topology?

Next steps: synthesis

- Operators require fine-grained control over routing: waypoints, isolation, traffic engineering
  - *Intents → configurations*
- Distributed routing based on shortest path – very difficult to program!
- One approach: input data planes → resilient ARCs → configs

Synthesis



- Edge weights
  - Input path to *dst* must be the shortest path
  - Uniqueness of shortest path
- Route filtering
  - Disable edges for a destination to ensure path is shortest
- Backup paths
  - Weights such that backup path is chosen during link failures

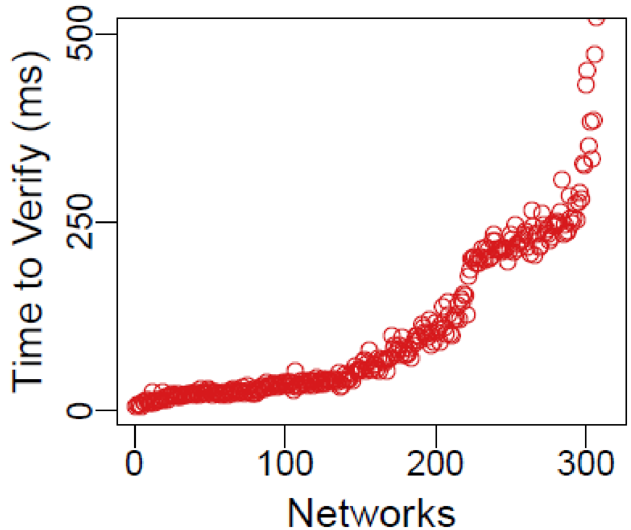
Summary

- Presented an abstract representation for control planes
  - Fast and simple verification under arbitrary failures
  - Verification is based on graph-level properties
  - Up to 5 orders of magnitude speed-up
- Useful for repair, transition, synthesis, …

Try it!
https://bitbucket.org/uw-madison-networking-research/arc

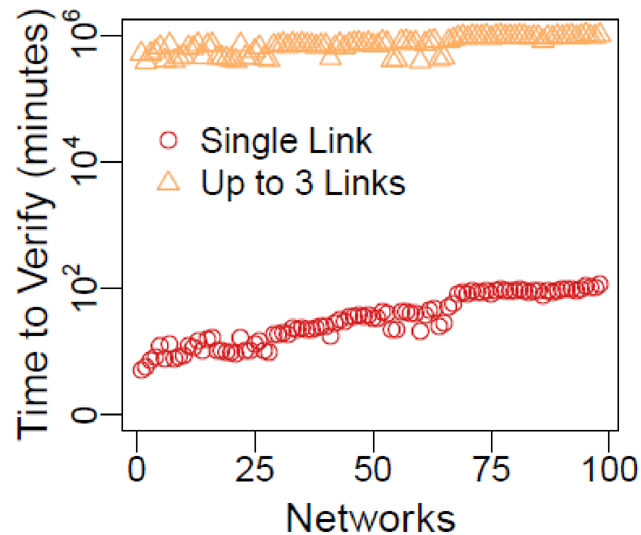
Backup

Evaluation: verification time



Always blocked using ARC

< 500 ms



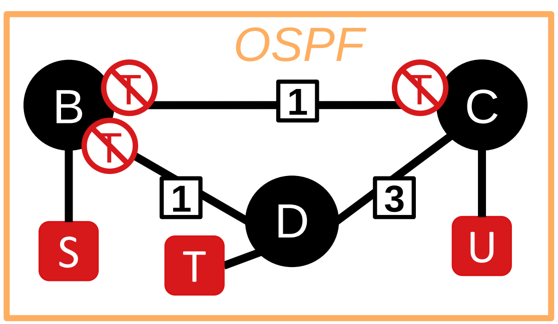
Always blocked using Batfish

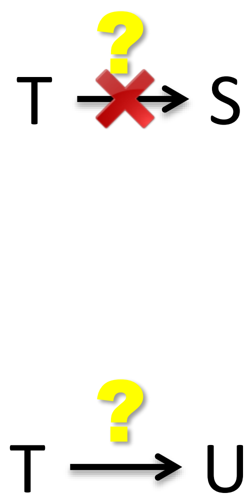
> 694 days!

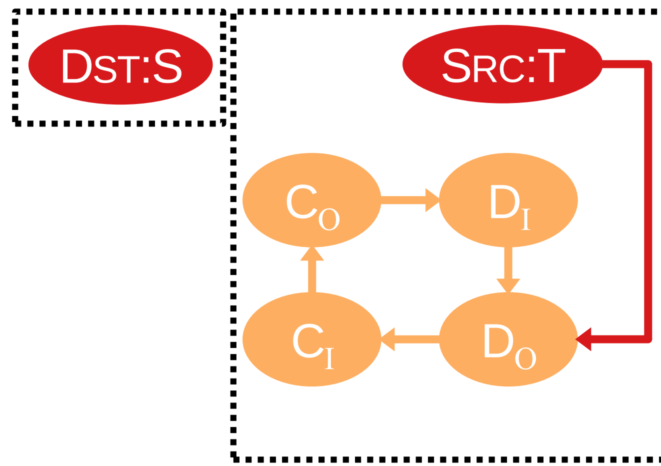
Verification with ARC is 3 to 5 orders of magnitude faster!

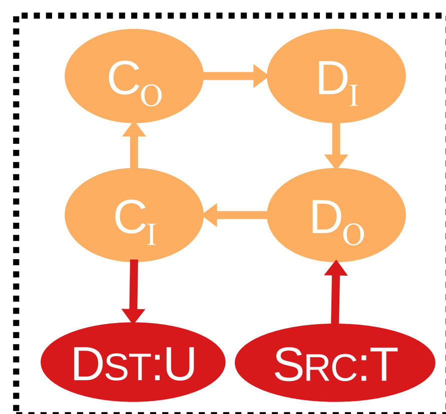
Verification

- *Always blocked*: Src and Dst in same connected component?









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