Managing Dynamic Networks: Distributed or Centralized Control?

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Paul Baran

“On Distributed Communications” (1964)

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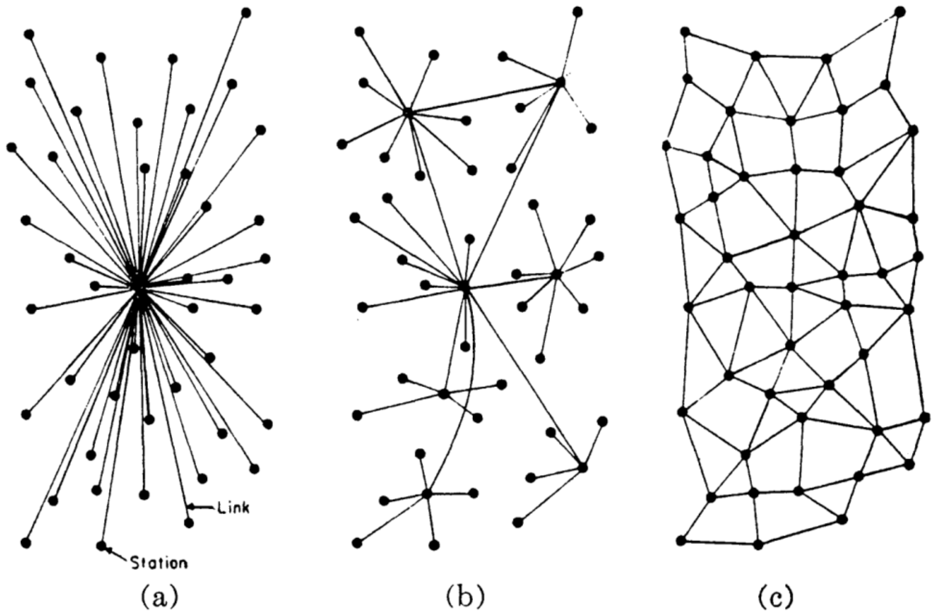


Fig. 1—(a) Centralized. (b) Decentralized. (c) Distributed networks.

"On Distributed Communications" (1964)

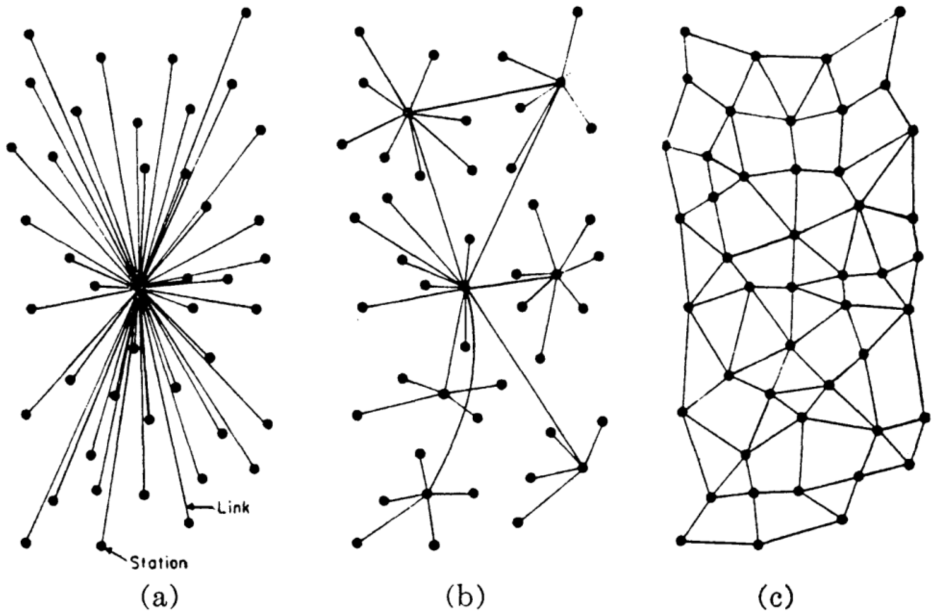


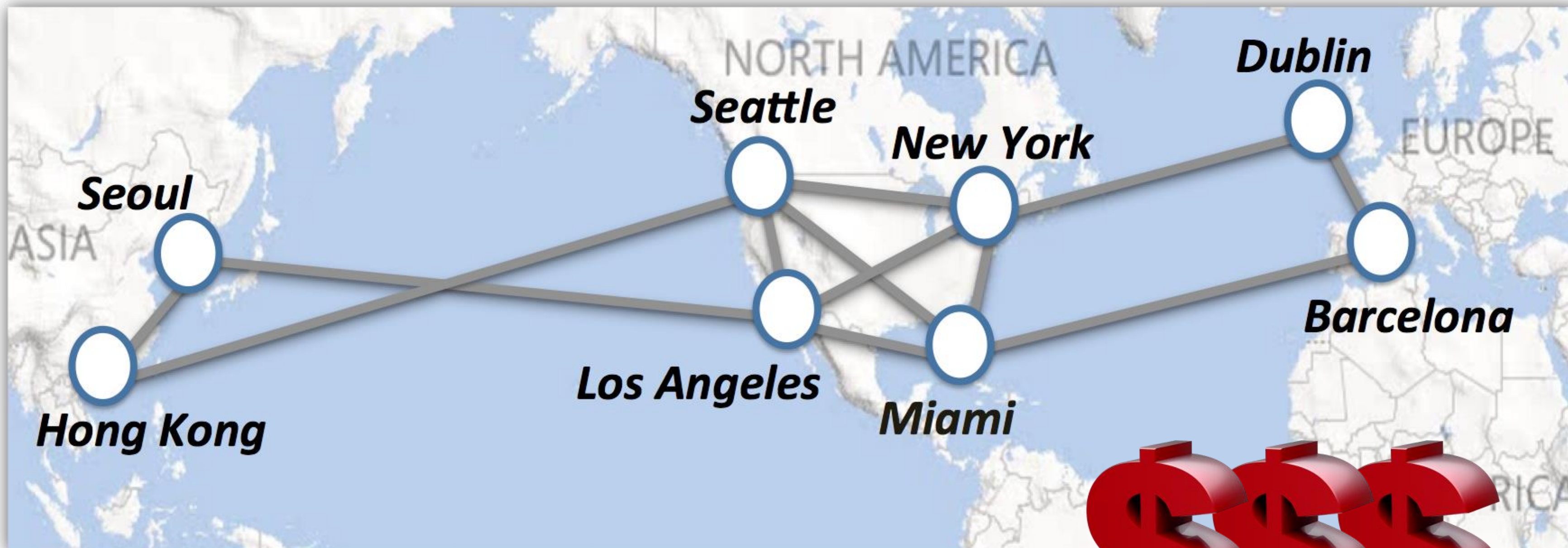
Fig. 1—(a) Centralized. (b) Decentralized. (c) Distributed networks.

1. Node & Edge Destruction
2. Distributed Routing


atlos

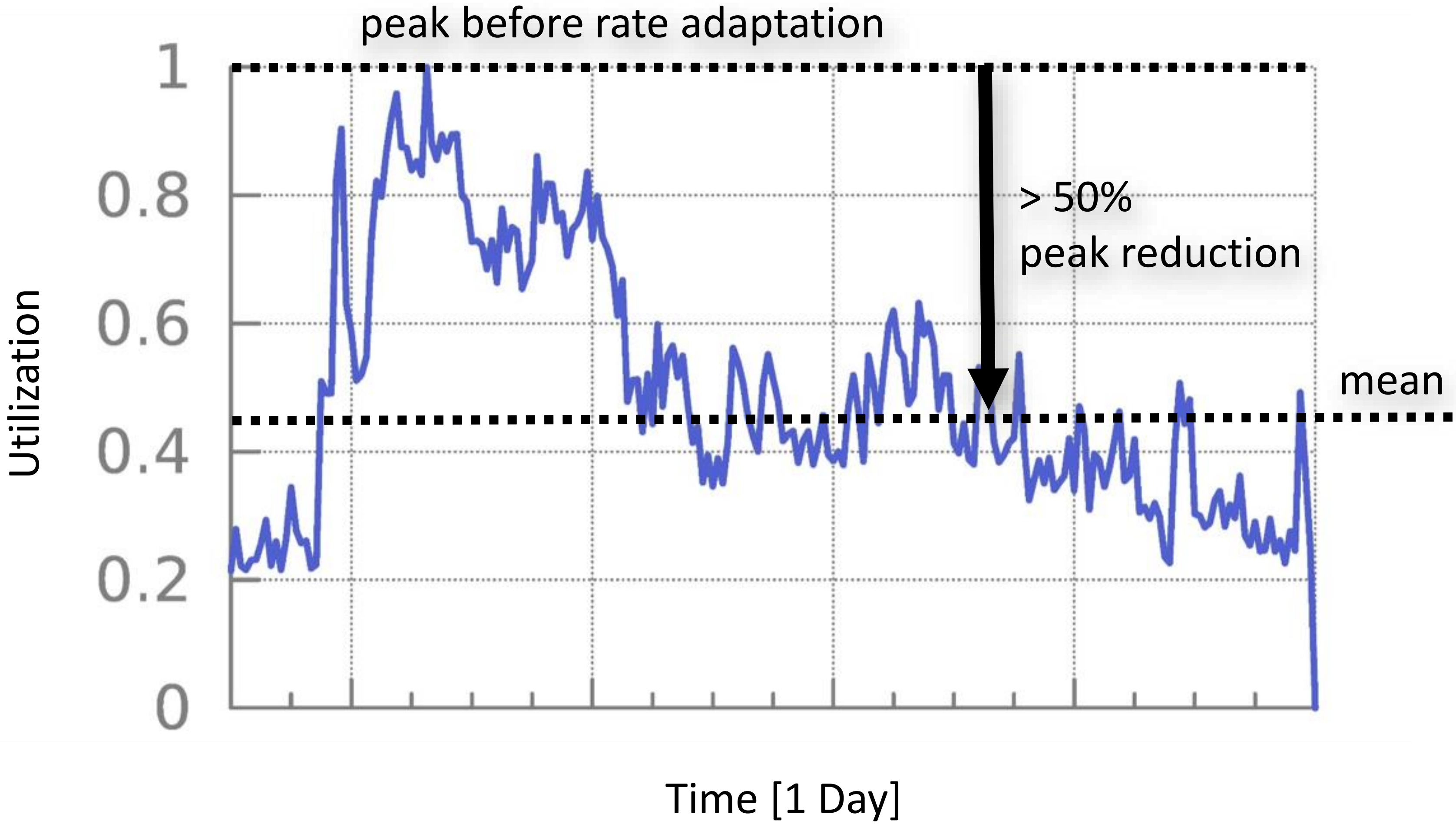

people stopped worrying
about the bomb!

Today: Inter-Data Center WANs



Think: Google, Amazon, Microsoft

Problem: Typical Network Utilization



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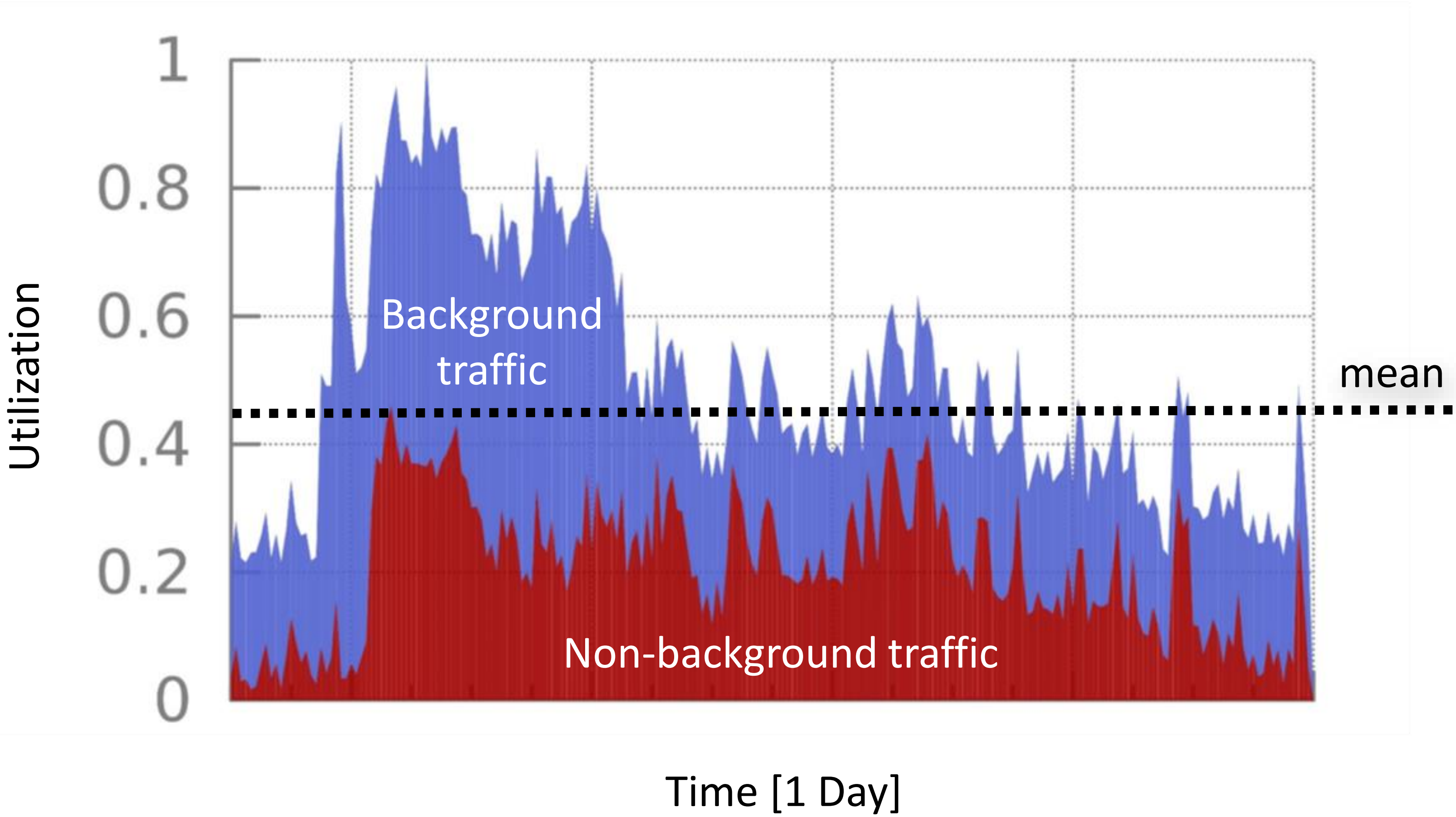
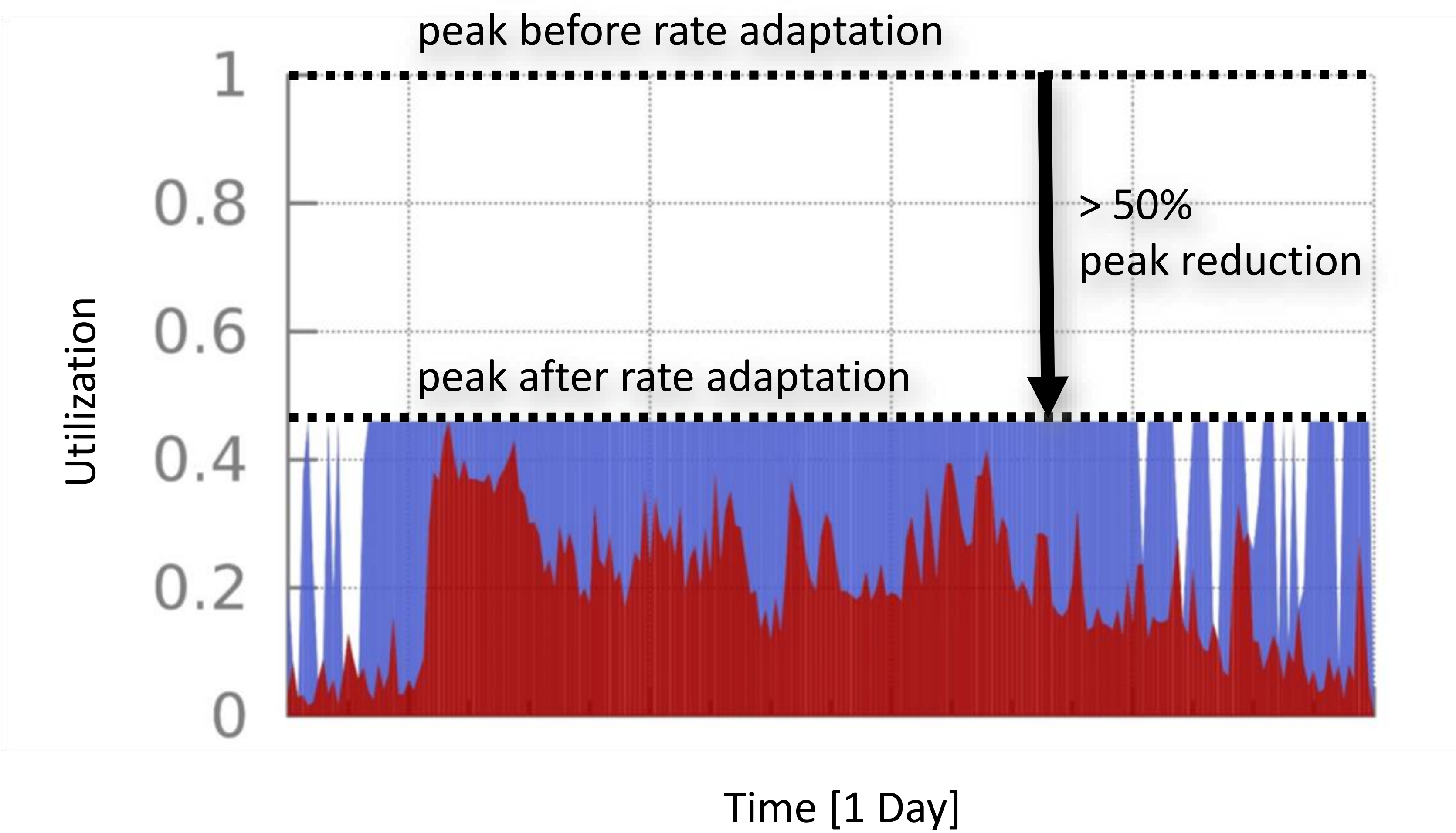


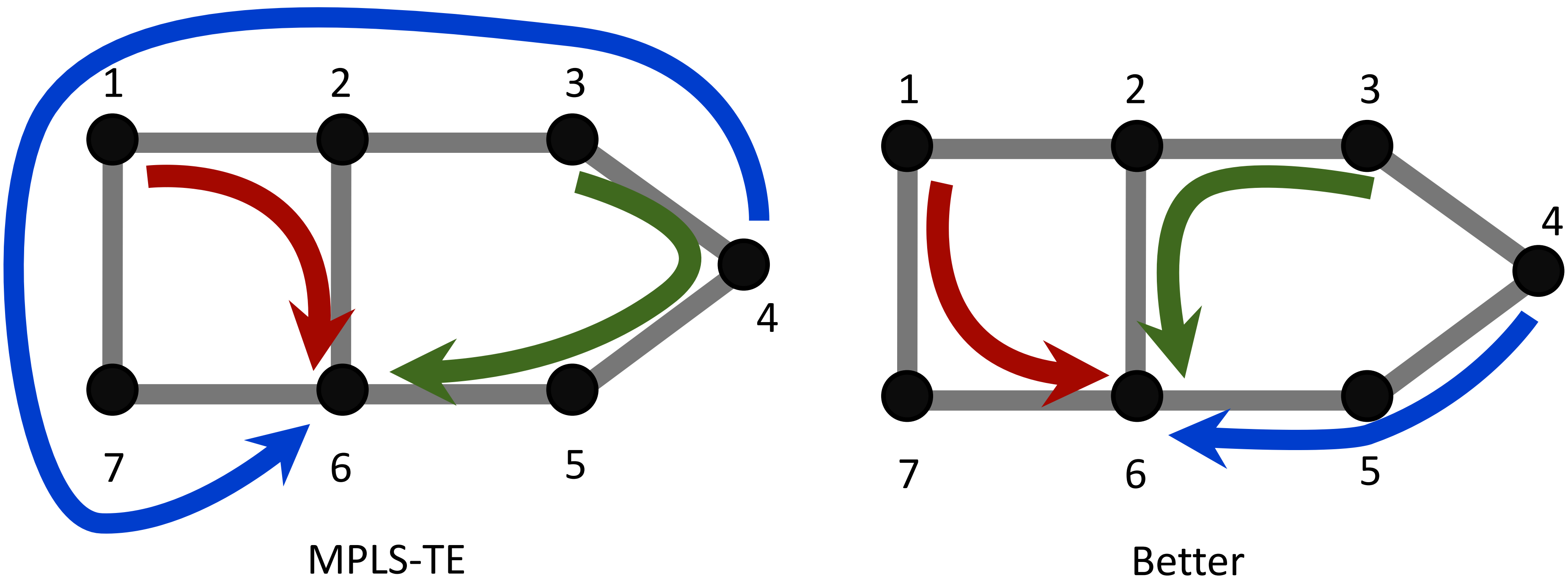
Problem: Typical Network Utilization



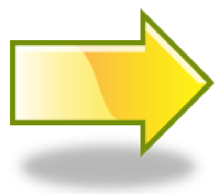
Another Problem: Online Routing Decisions

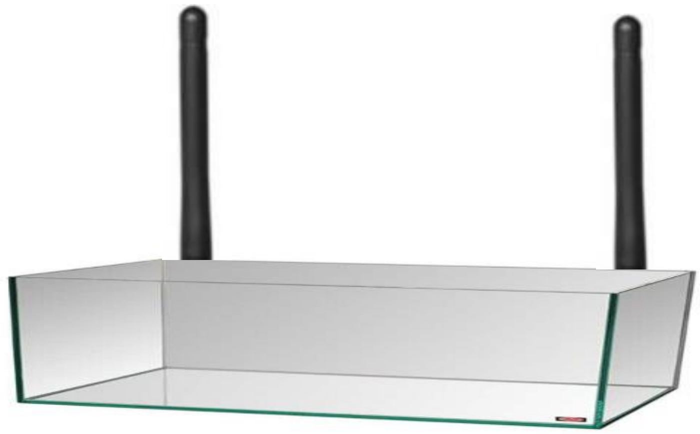
flow arrival order: A, B, C

each link can carry at most one flow (in both directions)

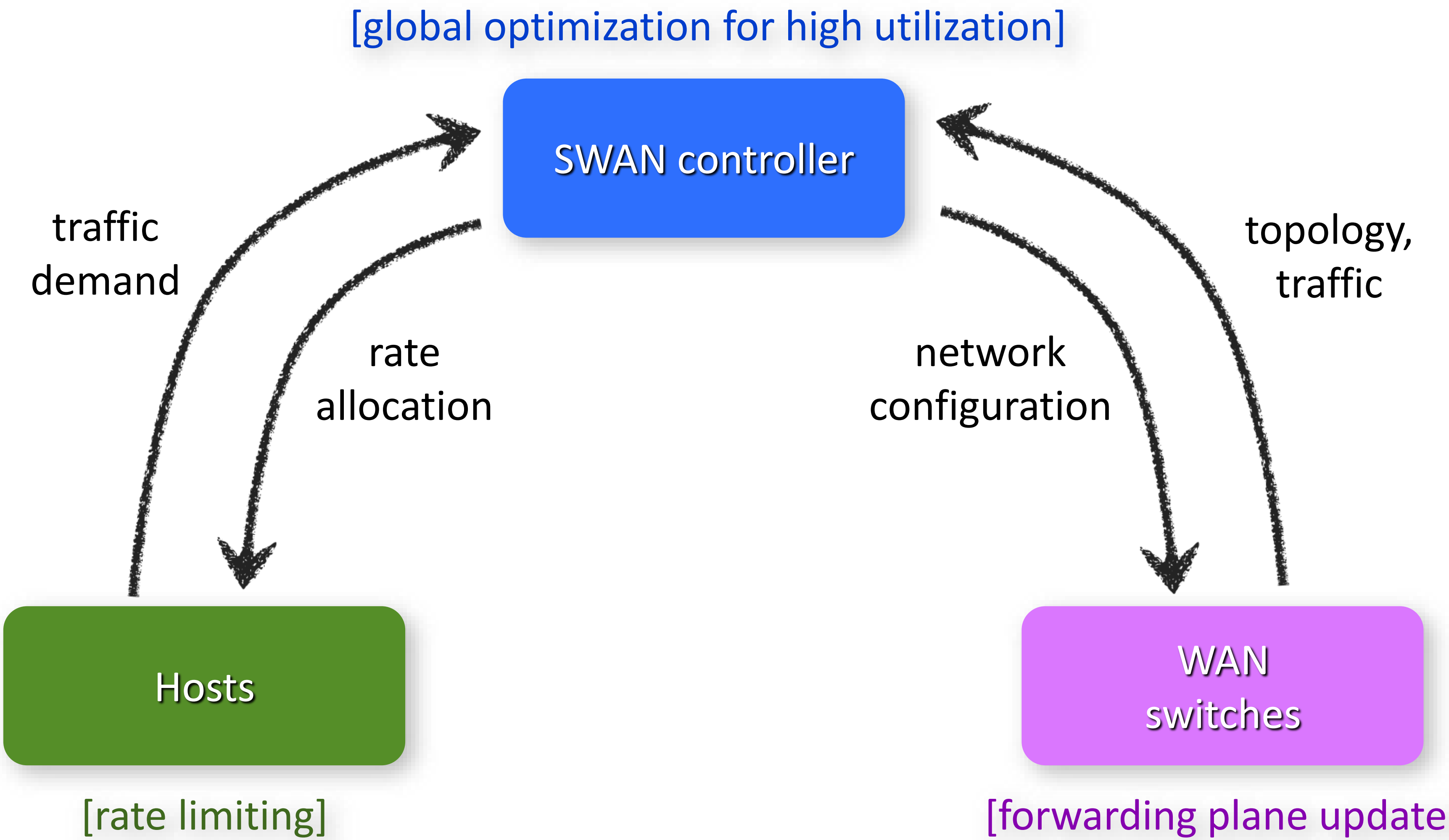


Software Defined Networks (SDNs)





Dealing with Network Dynamics: The SWAN Project



[Hong et al., SIGCOMM 2013]

Solution: Multicommodity Flow LP

Maximize throughput of flows f_i

$$\max \sum_i f_i$$

Flow less than demand d_i

$$0 \leq f_i \leq d_i$$

Flows less than capacity $c(e)$

$$\sum_i f_i(e) \leq c(e)$$

Flow conservation on inner nodes

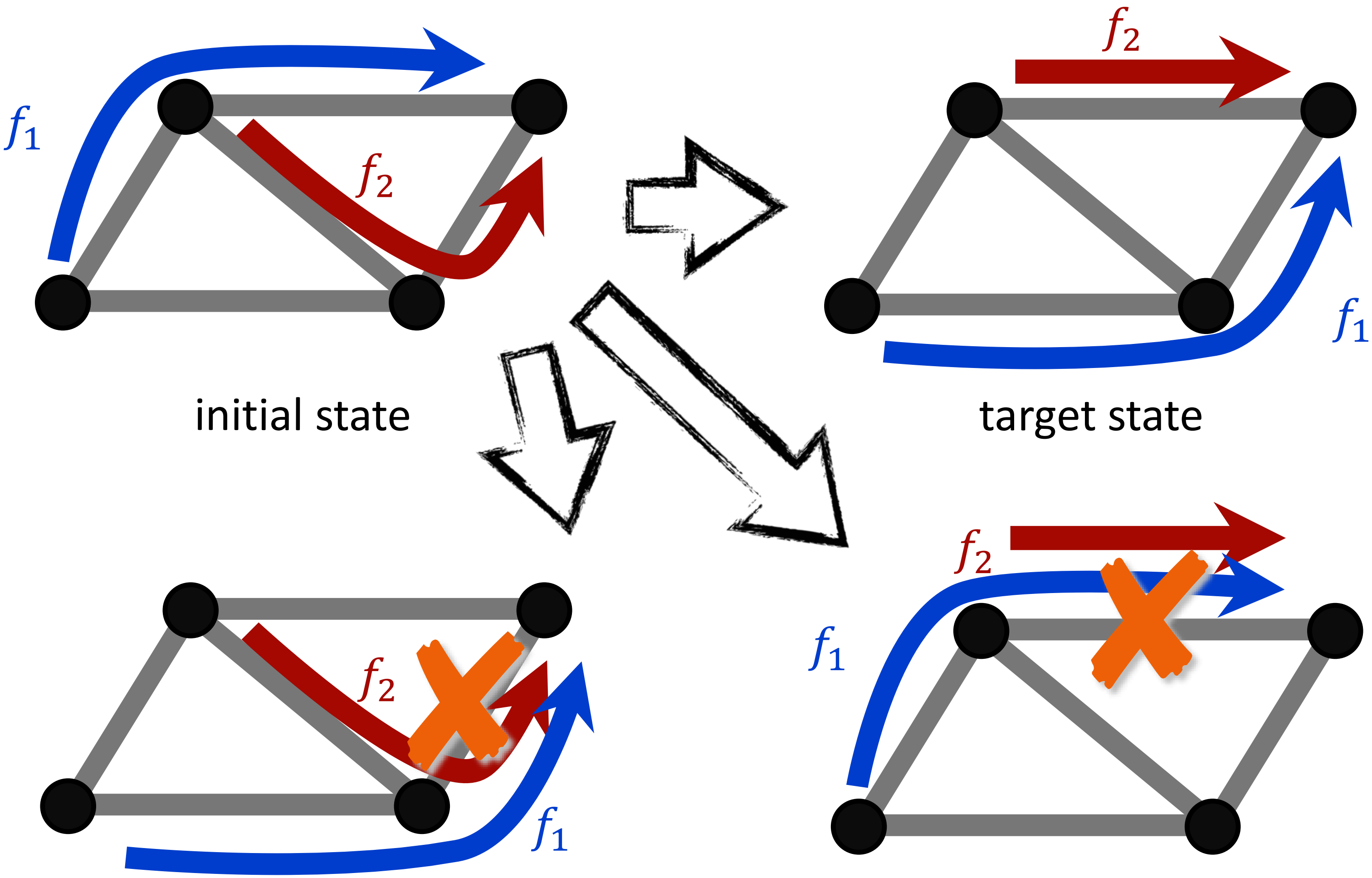
$$\sum_u f_i(u, v) = \sum_w f_i(v, w)$$

Flow definition on source, destination

$$\sum_v f_i(s_i, v) = \sum_u f_i(u, t_i) = f_i$$

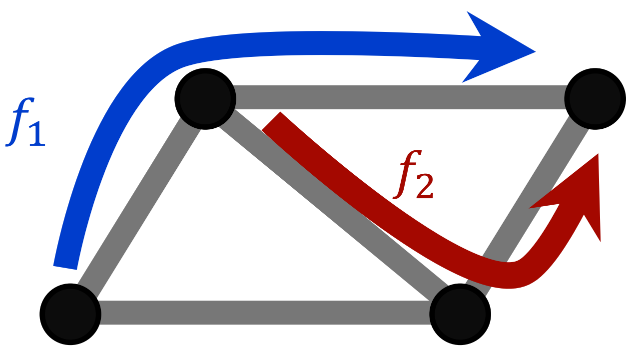
Network Dynamics

Problem: Consistent Updates

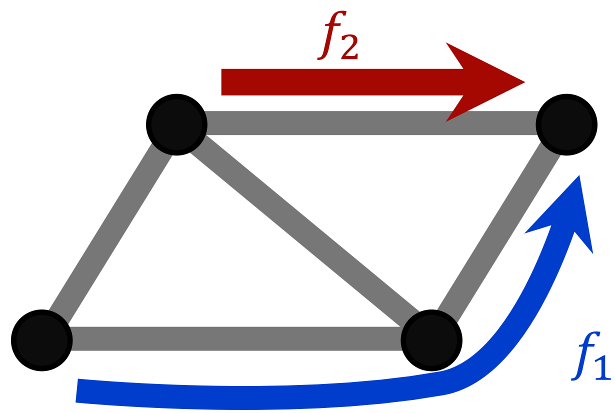


Capacity-Consistent Updates

- Not directly, but maybe through intermediate states?
- Solution: Leave a fraction s slack on each edge, less than $1/s$ steps
- Example: Slack = 1/3 of link capacity,

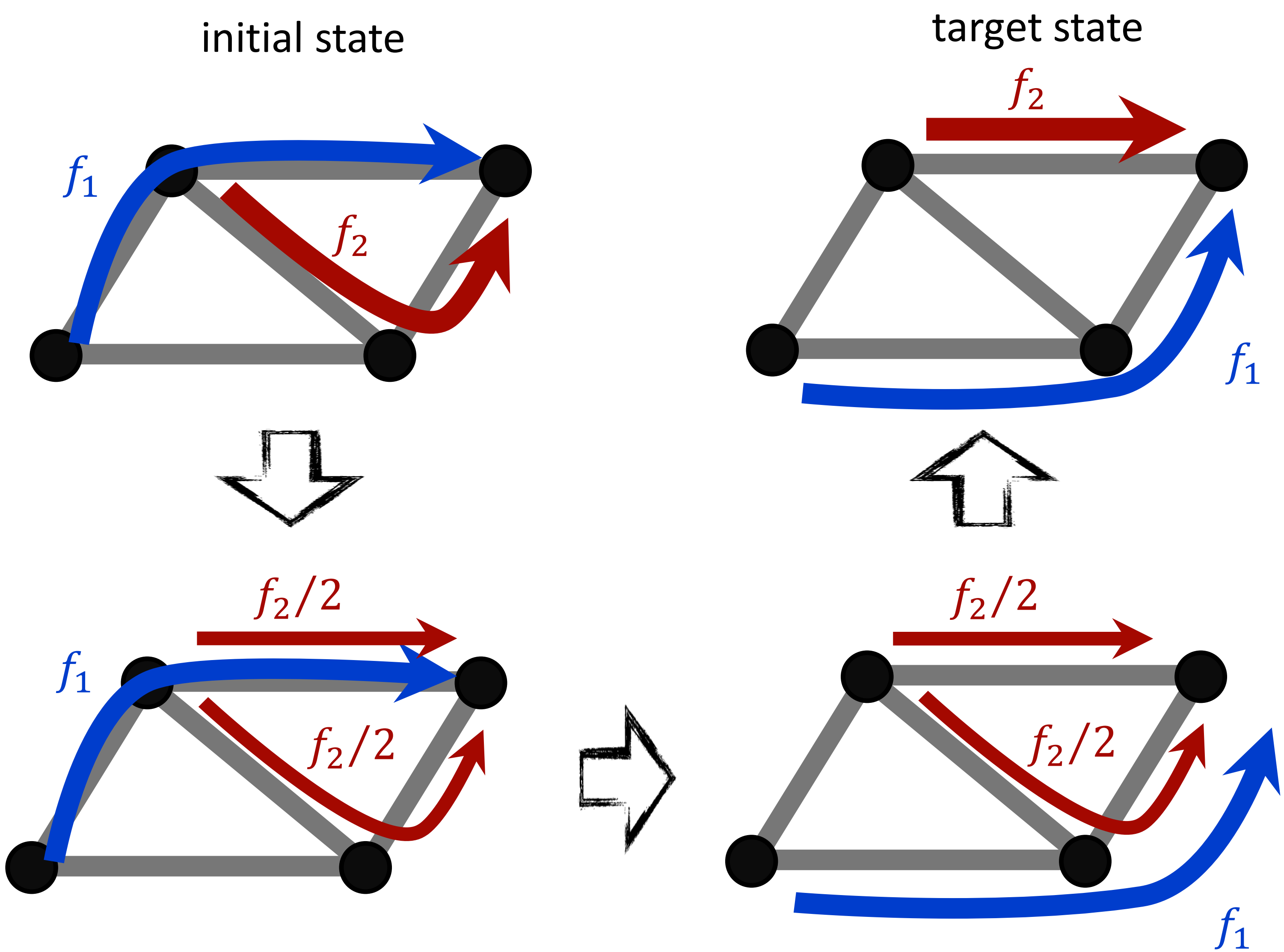


initial state



target state

Example: Slack = 1/3 of link capacity



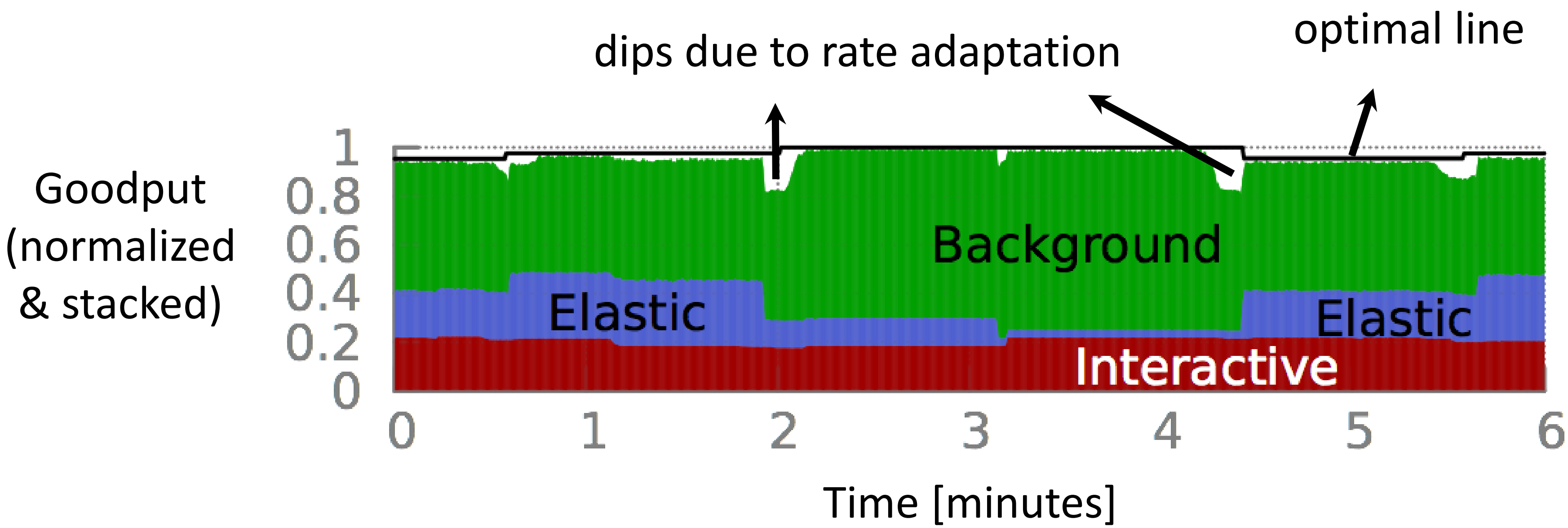
Capacity-Consistent Updates

Alternatively: Try whether a solvable LP with k steps exist, for $k = 1, 2, 3$ ...
(Sum of flows in steps j and $j + 1$, together, must be less than capacity limit)

Only growing flows	$f_i^0 \leq f_i^k$
Flow less than capacity	$\sum_i \max\left(f_i^j(e), f_i^{j+1}(e)\right) \leq c(e)$
Flow conservation on inner nodes	$\sum_u f_i^j(u, v) = \sum_w f_i^j(v, w)$
Flow definition on source, destination	$\sum_v f_i^j\,(s_i, v) = \sum_u f_i^j\,(u, t_i) = f_i^j$

[Hong et al., SIGCOMM 2013]

Prototype Evaluation

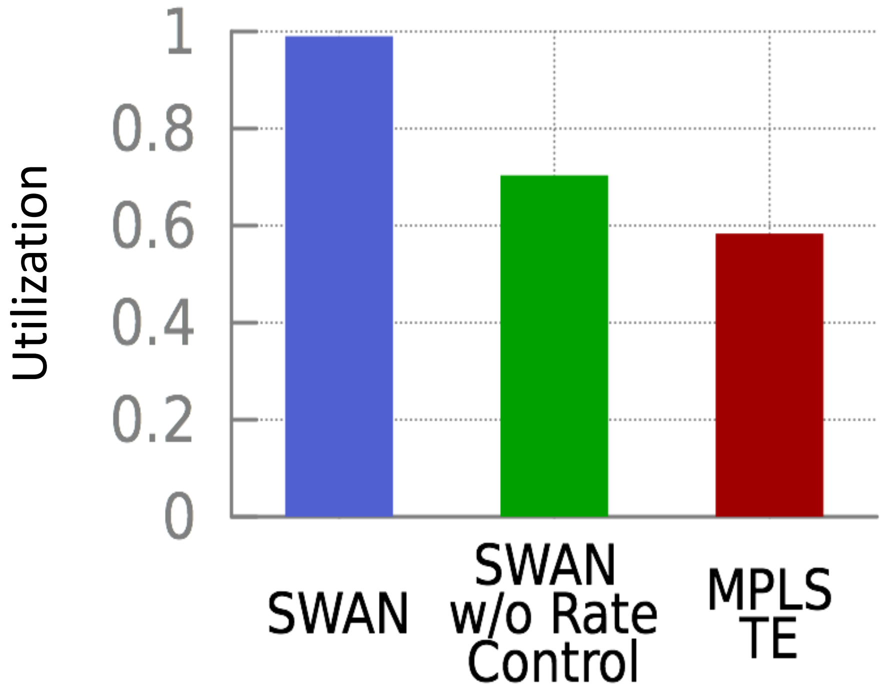


Traffic: (∀DC-pair) 125 TCP flows per class

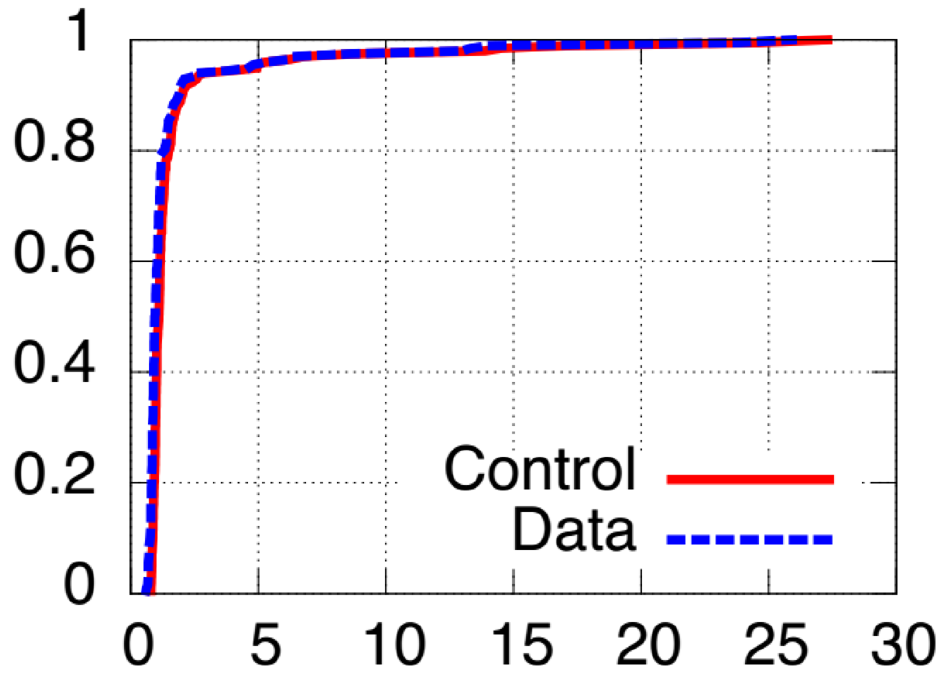
High utilization
SWAN's goodput:
98% of an optimal method

Flexible sharing
Interactive protected;
background rate-adapted

Data-driven Evaluation of 40+ DCs



Another Problem: Straggler Switches



CDF of 100 updates on a switch, in seconds

Dionysus: Make updates dynamic, i.e., work around straggling switches

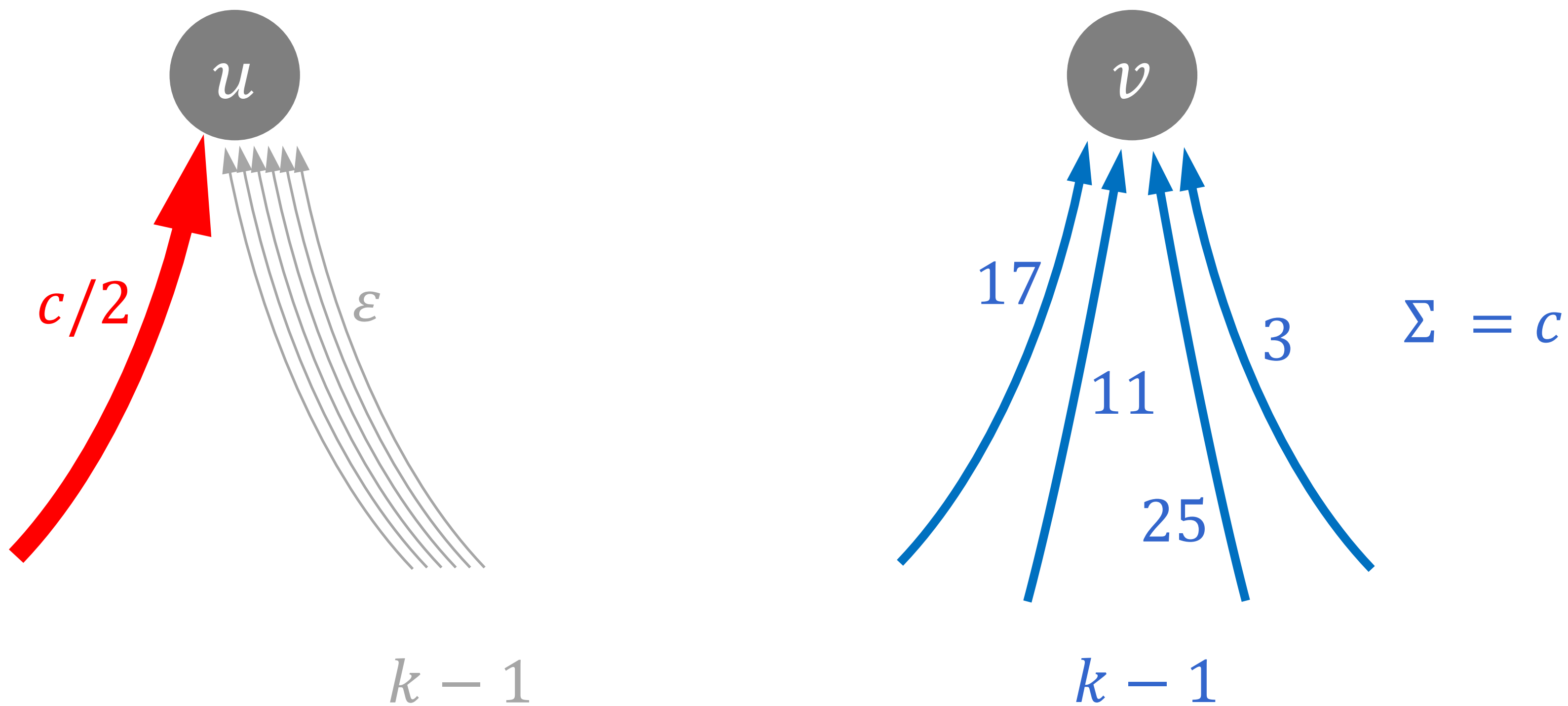
[Jin et al., SIGCOMM 2014]

Yet Another Problem: Memory Limits at Switches

Surprisingly, with memory limits, updates are difficult (NP-complete).

Example: We want to swap all flows between two switches u and v.

Each switch has capacity c, and memory limit k.



[Jin et al., SIGCOMM 2014]

Updating Dynamic Networks:

A Bigger Picture?

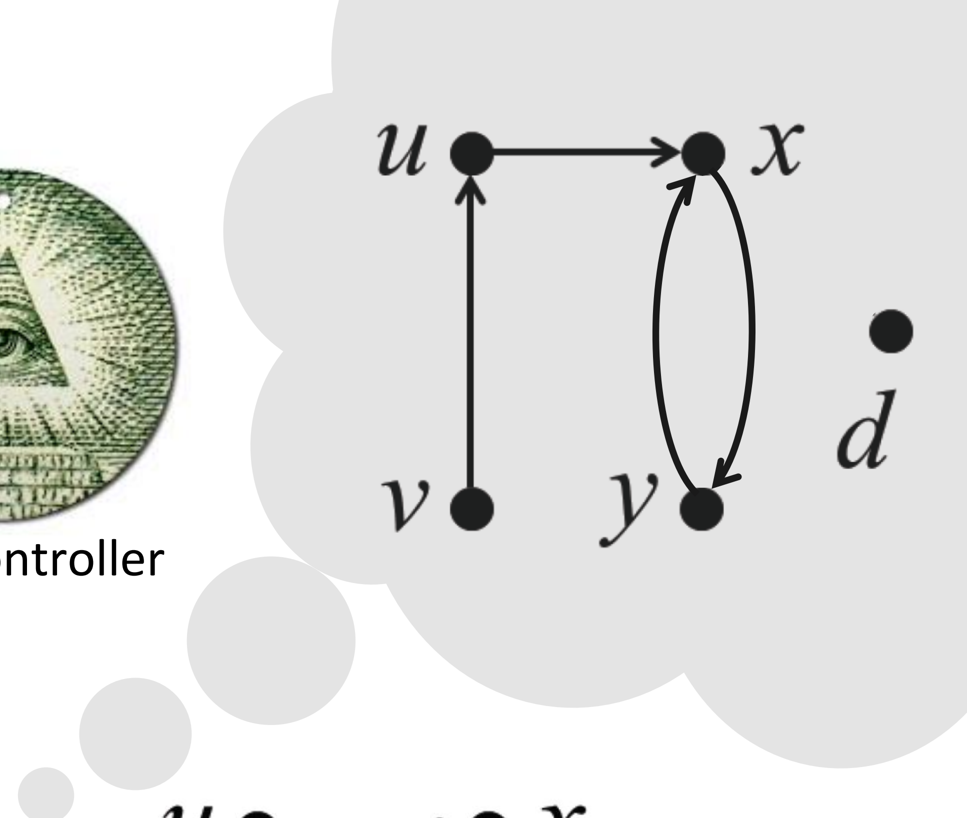
Consistency Space

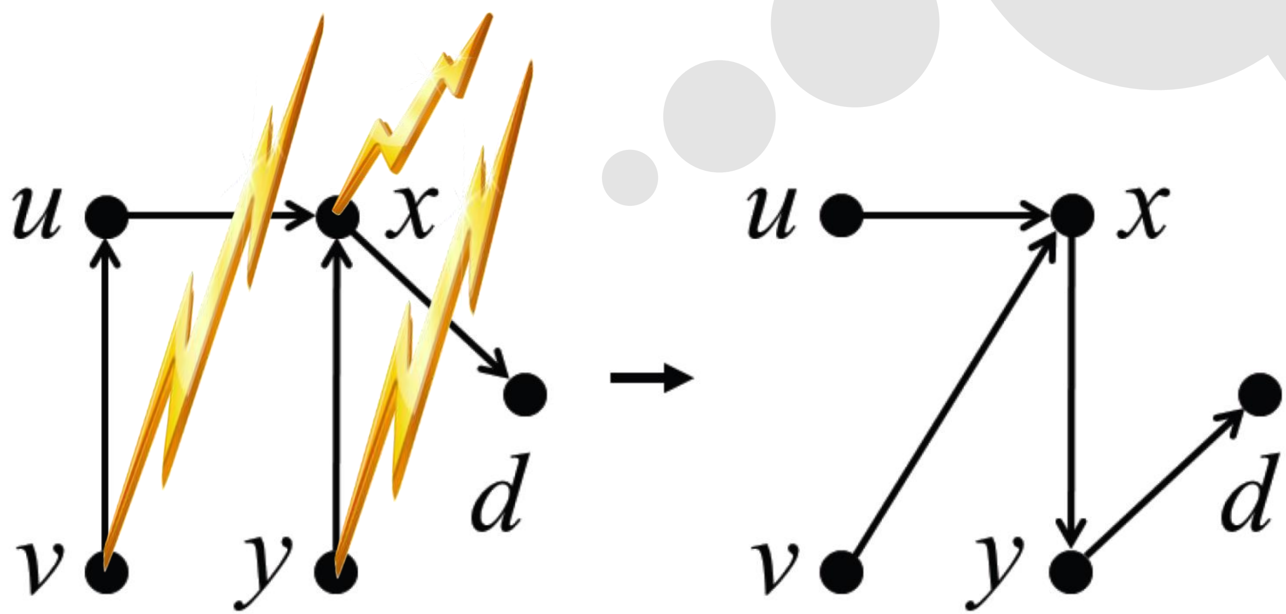
	None	Self	Downstream subset	Downstream all	Global
Eventual consistency	Always guaranteed				
Drop freedom	Impossible	Add before remove			
Memory limit	Impossible	Remove before add			
Loop freedom	Impossible		Rule dep. forest	Rule dep. tree	
Packet coherence	Impossible			Per-flow ver. numbers	Global ver. numbers
Bandwidth limit	Impossible				Staged partial moves

[Mahajan & W, HotNets 2013]

Example

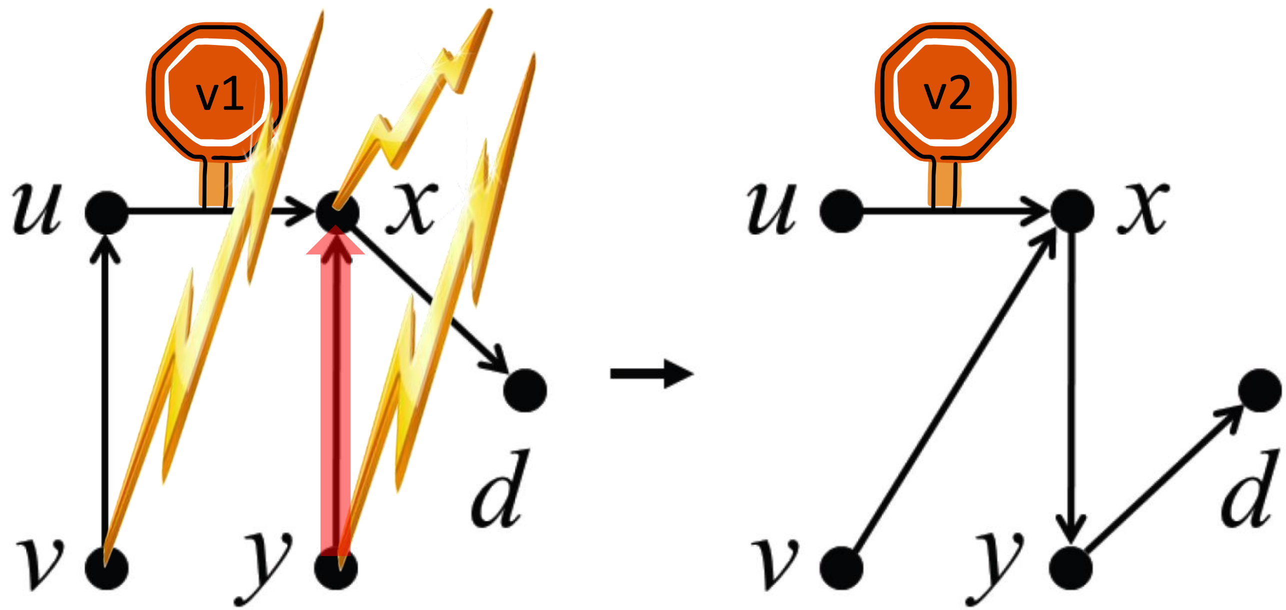
SDN Controller





Example

SDN Controller

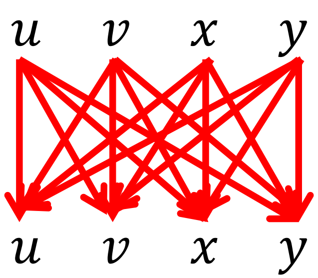


[Reitblatt et al., SIGCOMM 2012]

Dependencies

Version Numbers 

“Better” Solution



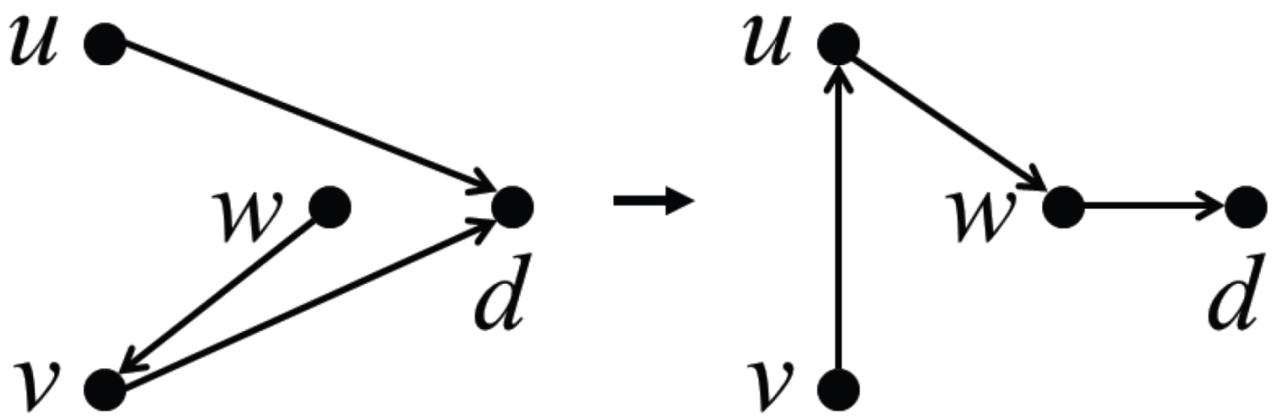
+ stronger packet coherence

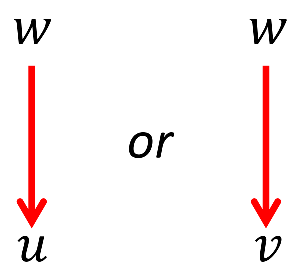
– version number in packets

– switches need to store both versions

Minimum SDN Updates?

Minimum Updates: Another Example

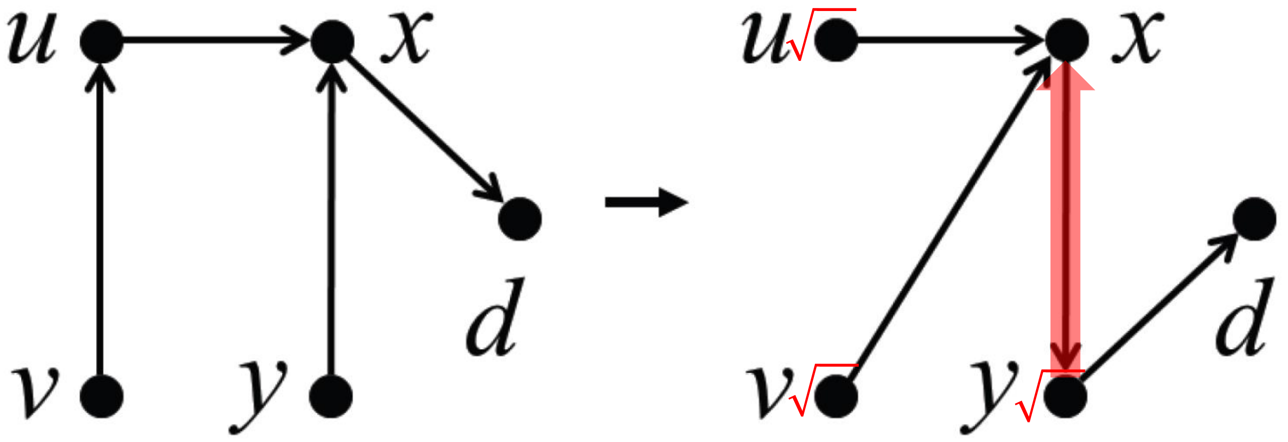




No node can improve without hurting another node

Minimum vs. Minimal

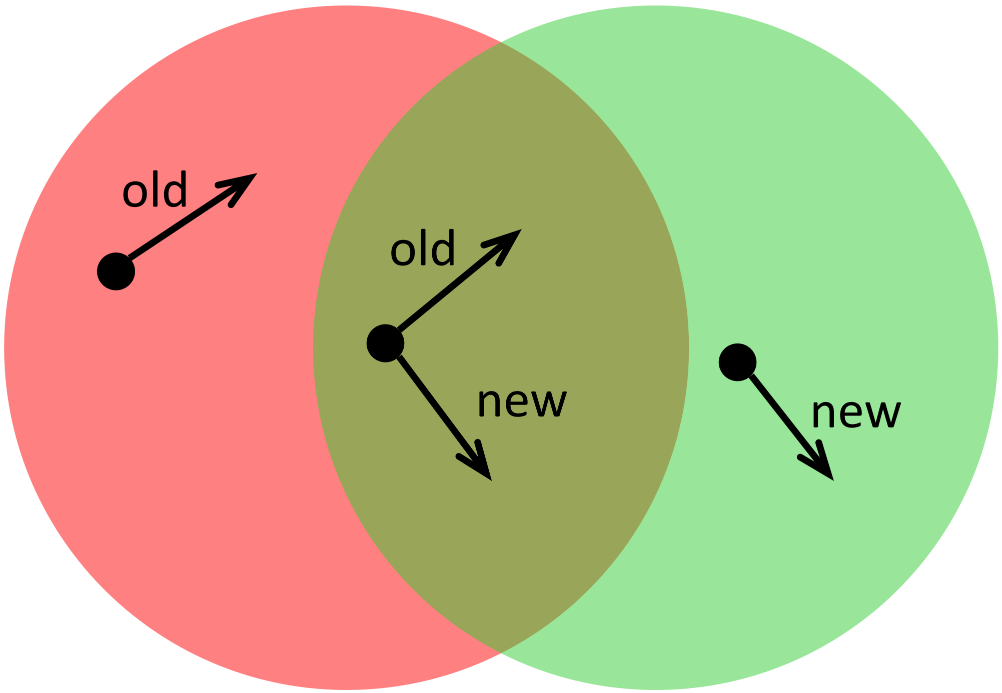
Minimal Dependency Forest



Next: An algorithm to compute minimal dependency forest.

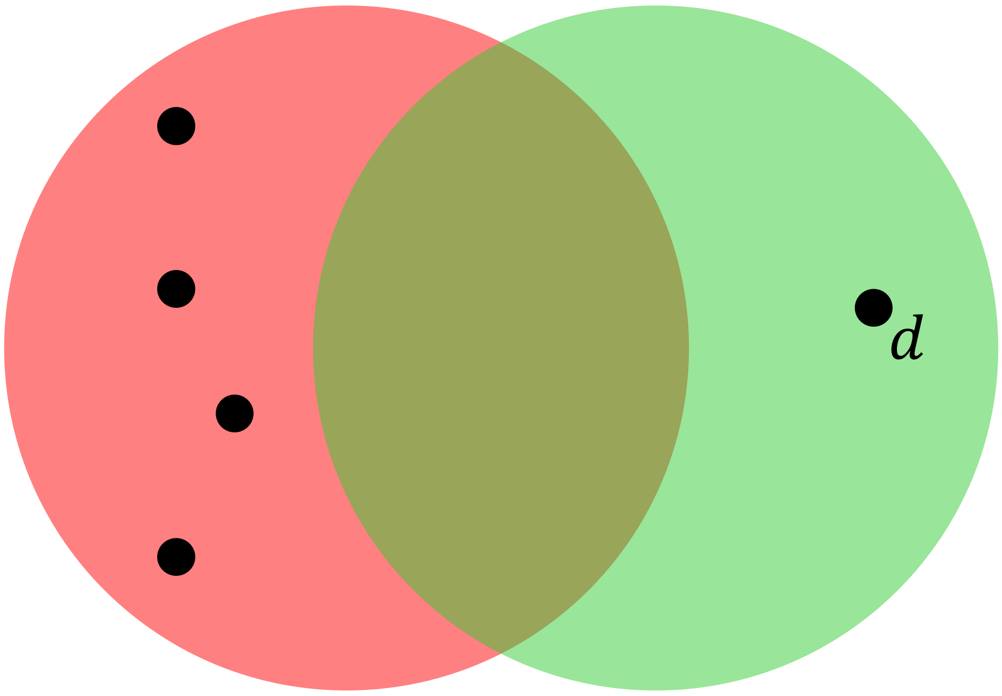
Algorithm for Minimal Dependency Forest

- Each node in one of three states: old, new, and limbo (both old *and* new)



Algorithm for Minimal Dependency Forest

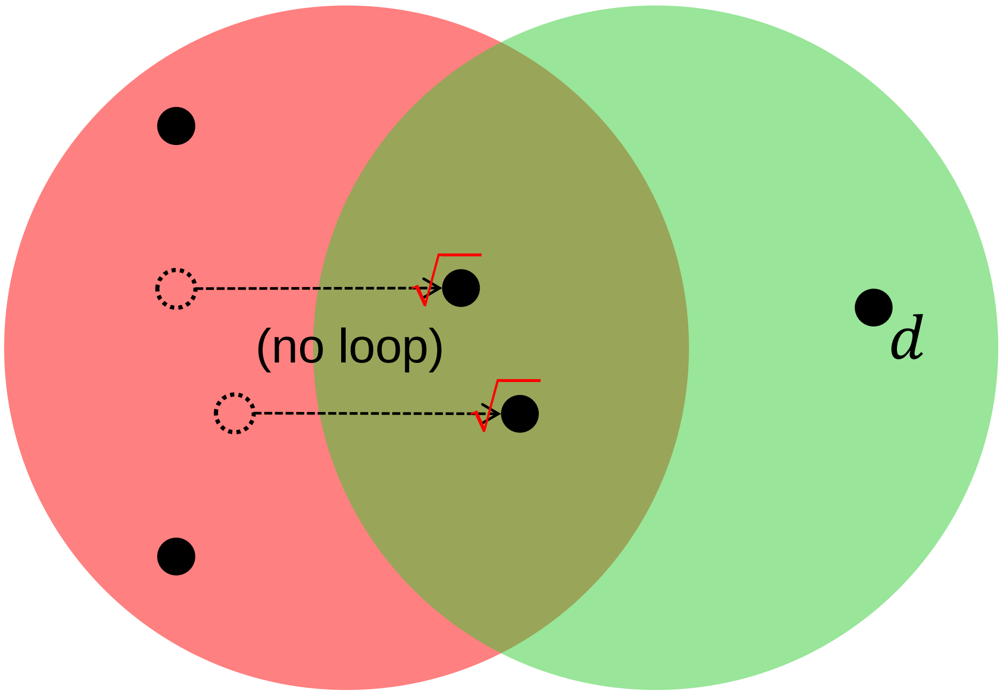
- Each node in one of three states: old, new, and limbo (both old *and* new)
- Originally, destination node in new state, all other nodes in old state
- Invariant: No loop!



Algorithm for Minimal Dependency Forest

Initialization

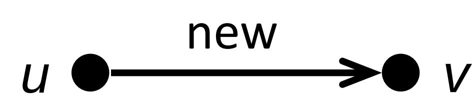
- Old node u: No loop* when adding new pointer, move node to limbo!
- This node u will be a root in dependency forest



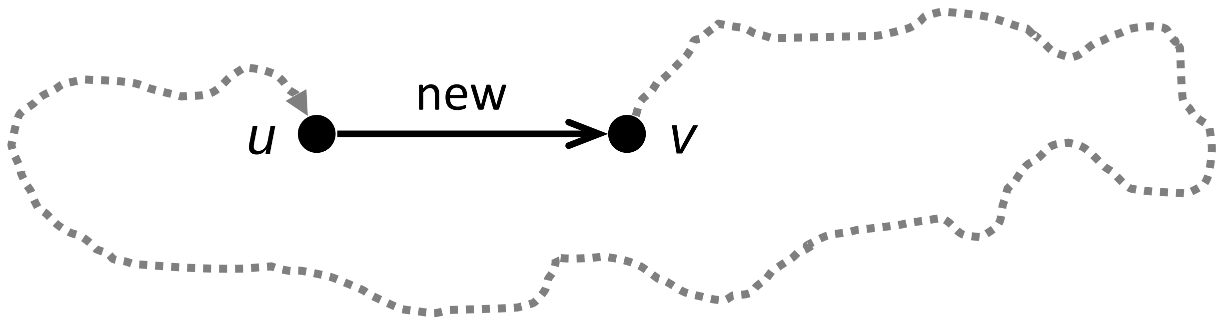
*Loop Detection: Simple procedure, see next slide

Loop Detection

- Will a new rule *u.new = v* induce a loop?
  - We know that the graph so far has no loops
  - Any new loop *must* contain the edge (*u,v*)



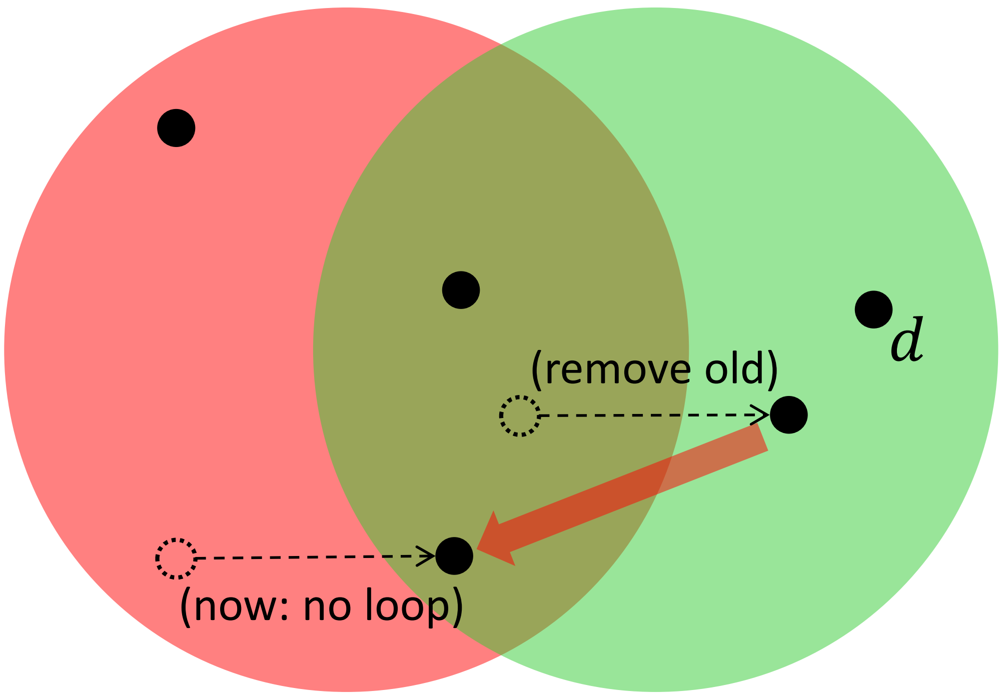
- In other words, is node *u* now *reachable* from node *v*?



- Depth first search (DFS) at node *v*
  - If we visit node *u*: the new rule induces a loop
  - Else: no loop

Algorithm for Minimal Dependency Forest

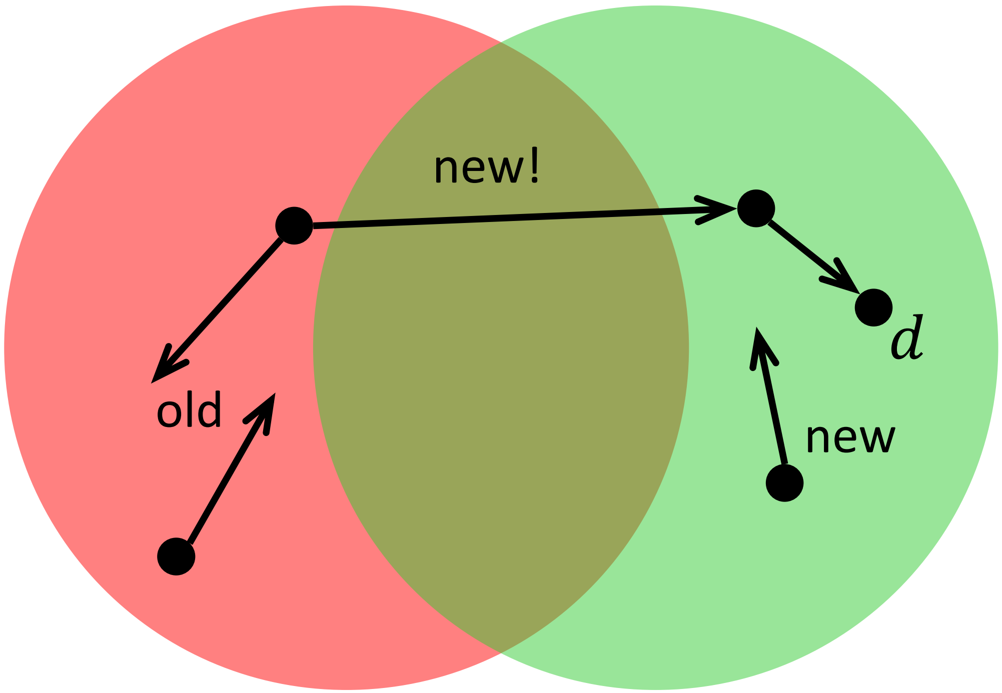
- Limbo node u: Remove old pointer (move node to new)
- Consequence: Some old nodes v might move to limbo!
- Node v will be child of u in dependency forest!



Algorithm for Minimal Dependency Forest

Process terminates

- You can always move a node from limbo to new.
- Can you ever have old nodes but no limbo nodes? No, because…



…one can easily derive a contradiction!

For a given consistency property,
what is the minimal dependency possible?

Consistency Space

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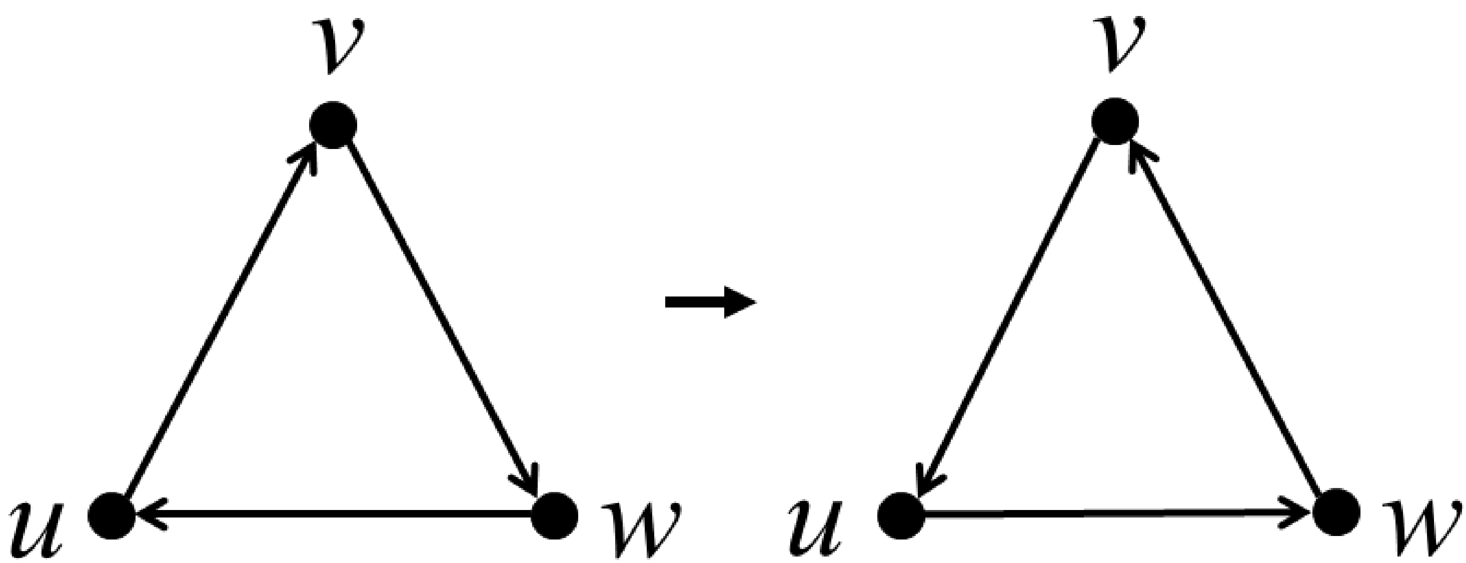
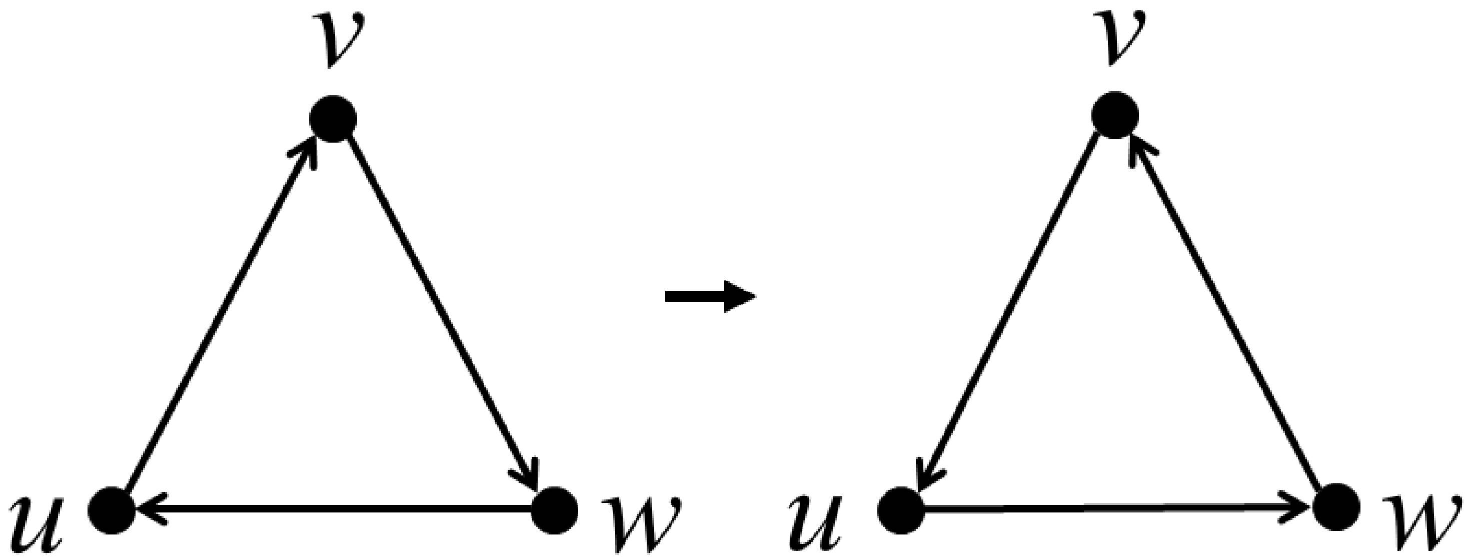
[Mahajan & W, HotNets 2013]

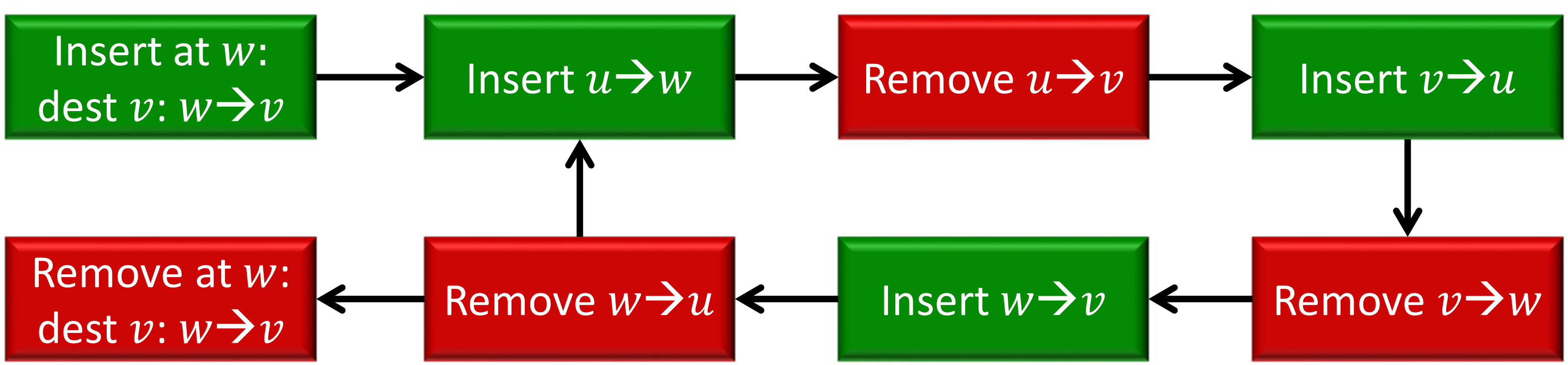
Multiple Destinations using Prefix-Based Routing



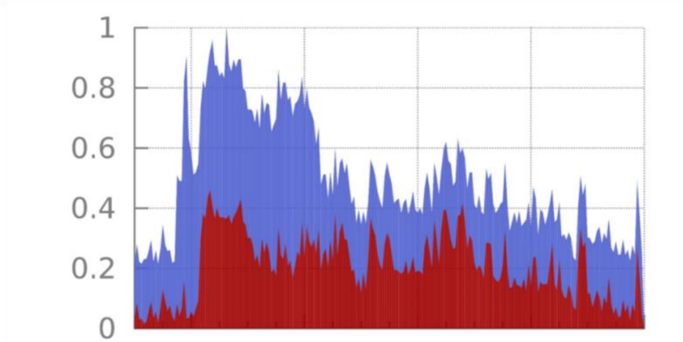
- No new "default" rule can be introduced without causing loops
- Solution: Rule-Dependency Graphs!
- Deciding if simple update schedule exists is hard!

Breaking Cycles





Summary



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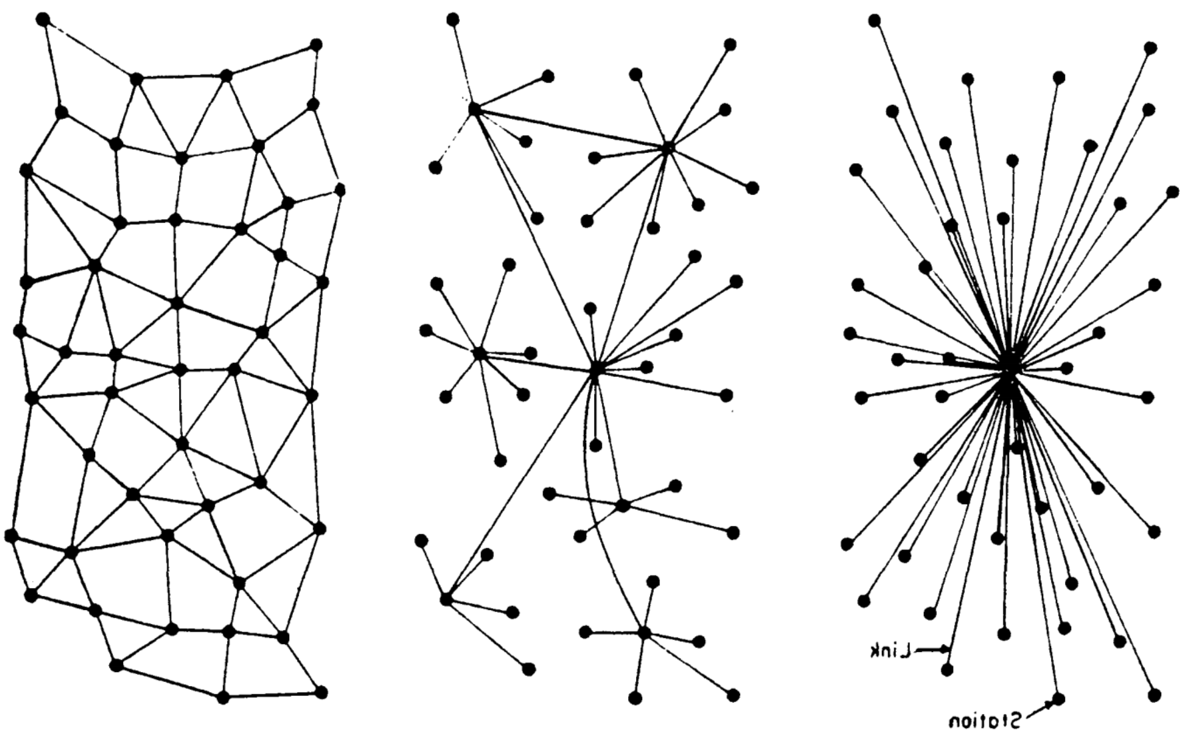

Thank You!

Questions & Comments?