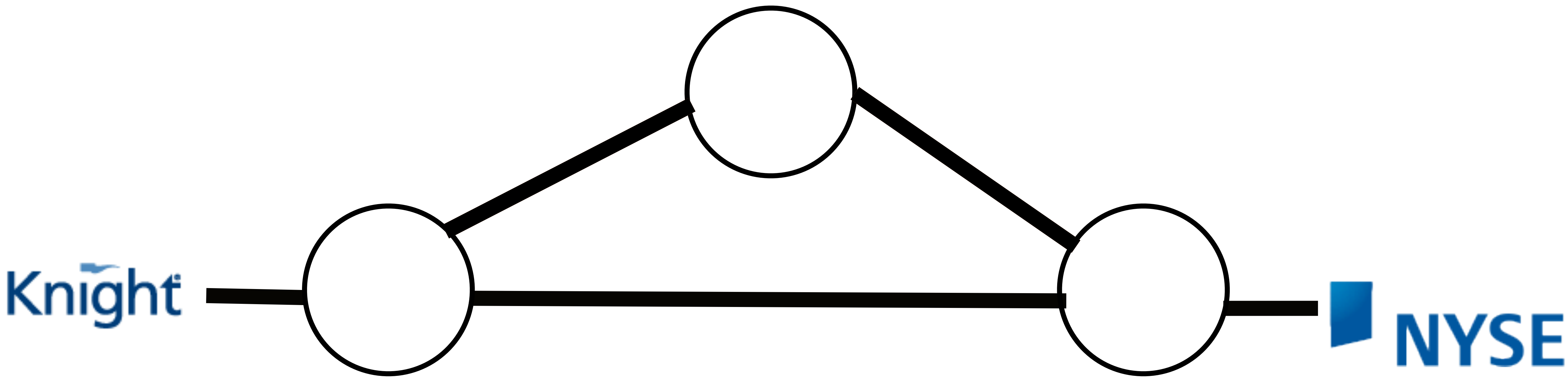
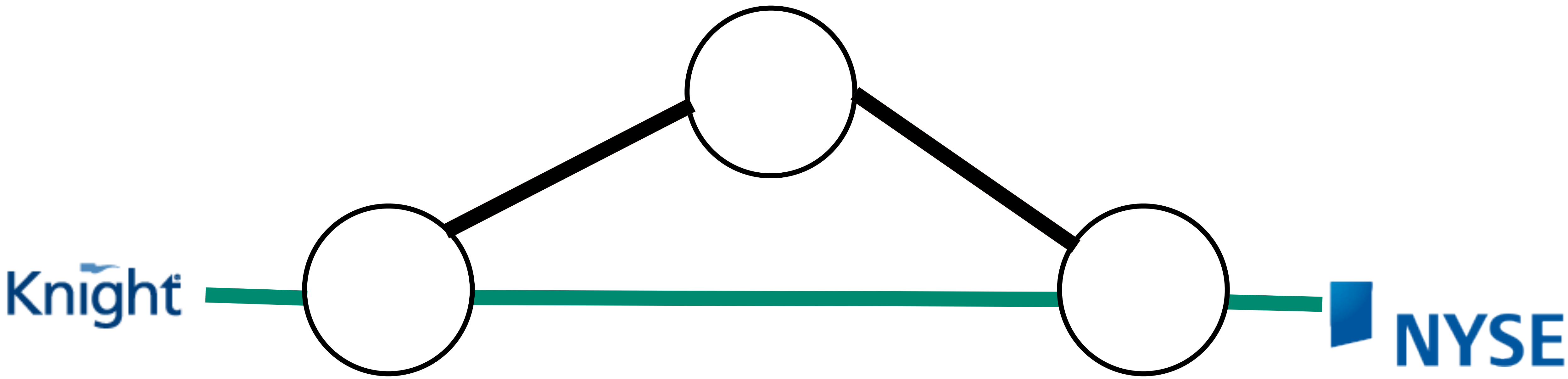
Data Driven Connectivity

Junda Liu, *Aurojit Panda*, Ankit Singla,
Brighten Godfrey, Michael Schapira,
Scott Shenker

Division of Concerns

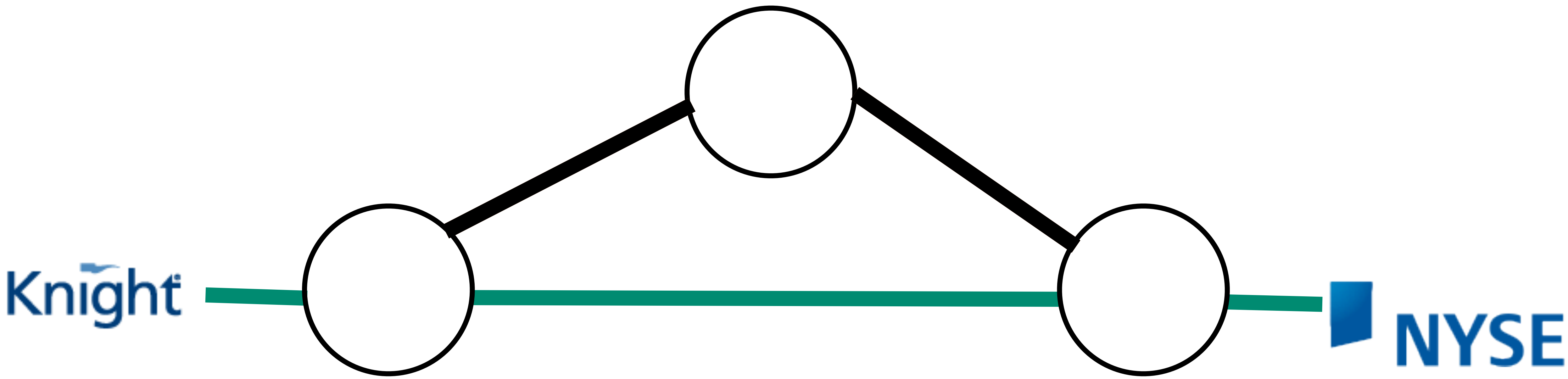


Division of Concerns



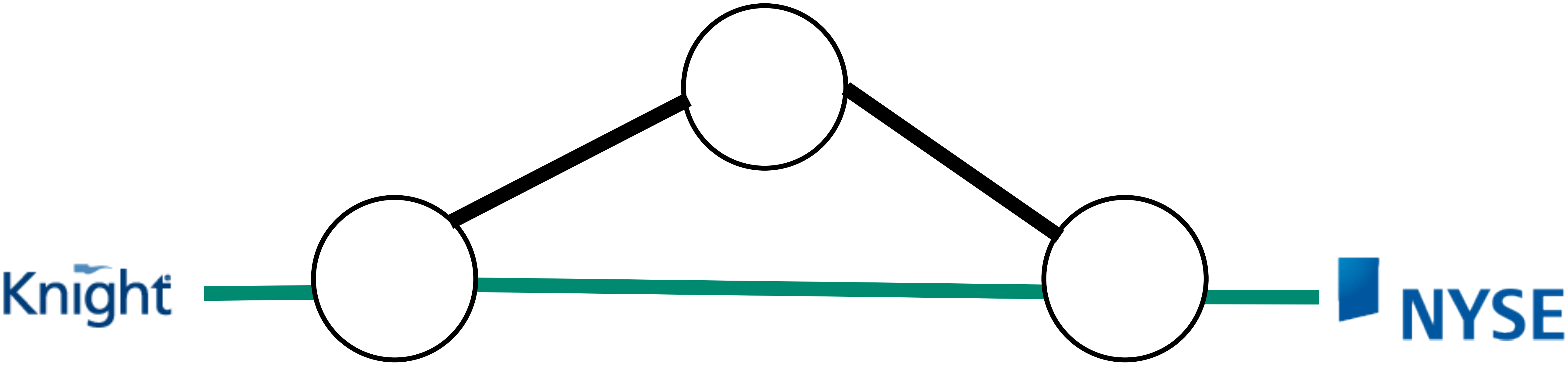
- Routing is a **control plane** operation.
  - Operates in the order of milliseconds.

Division of Concerns

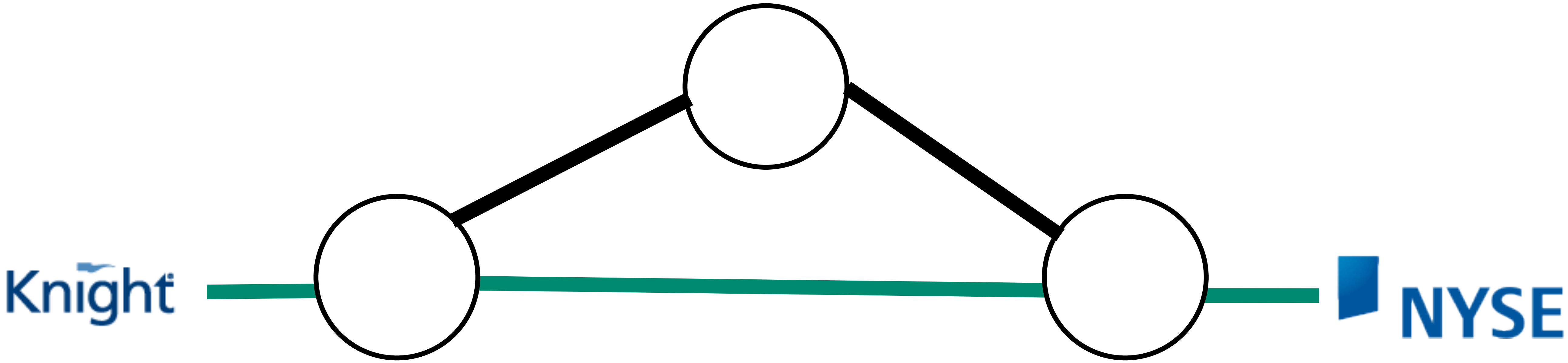


- Routing is a **control plane** operation.
  - Operates in the order of milliseconds.
- Packet forwarding is a **data plane** operation.
  - Operates in the order of microseconds.

Link Failures Hard

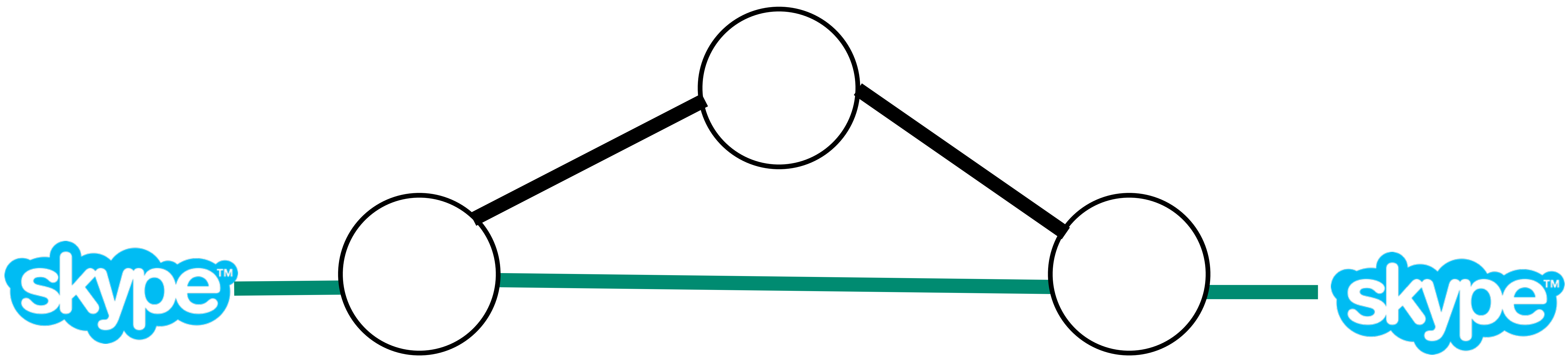


Link Failures Hard



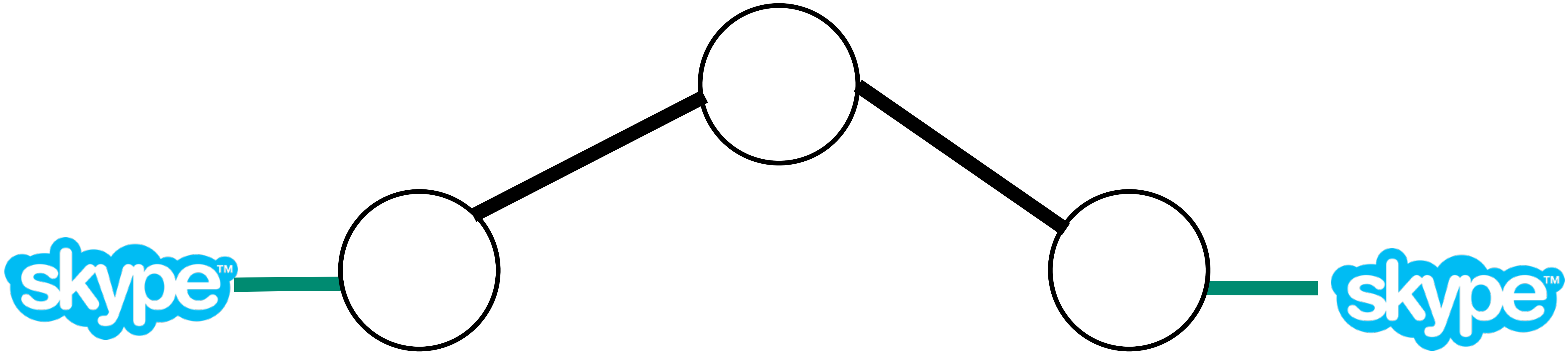
- Some users require low latency packet delivery.

Link Failures Hard



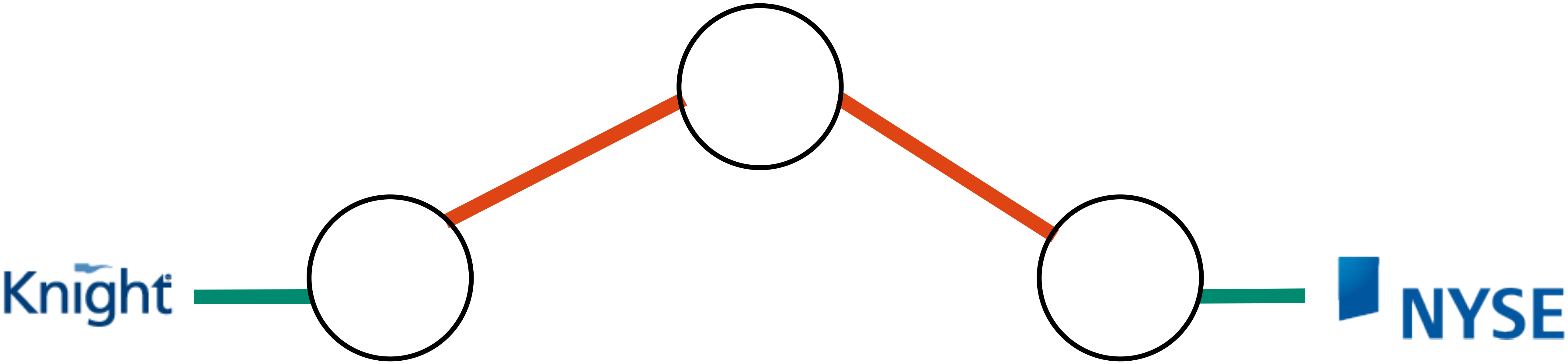
- Some users require low latency packet delivery.
- Some users require high reliability.

Link Failures Hard



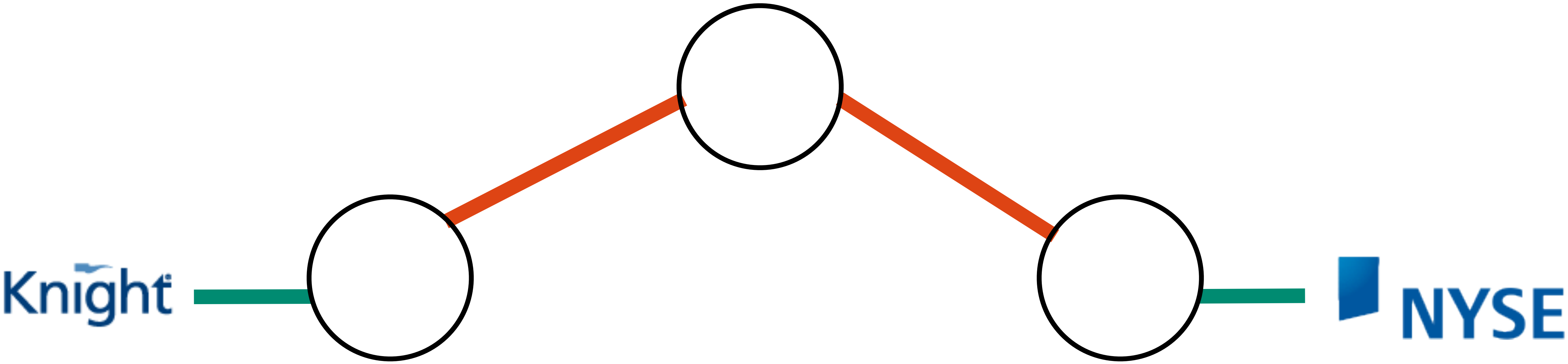
- Some users require low latency packet delivery.
- Some users require high reliability.
- Control Plane response to link failure is too slow.

Today's Solution



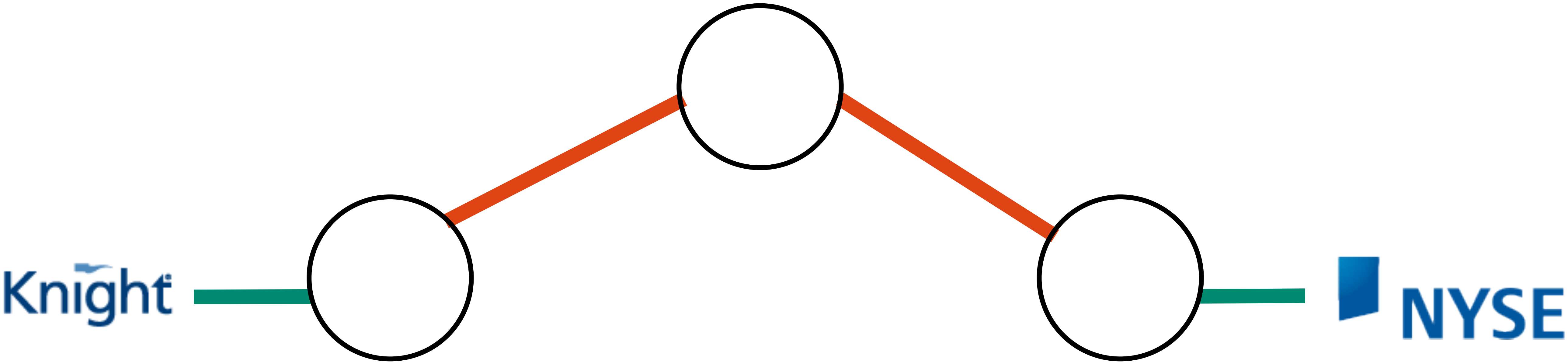
- Rely on precomputed backup paths

Today's Solution



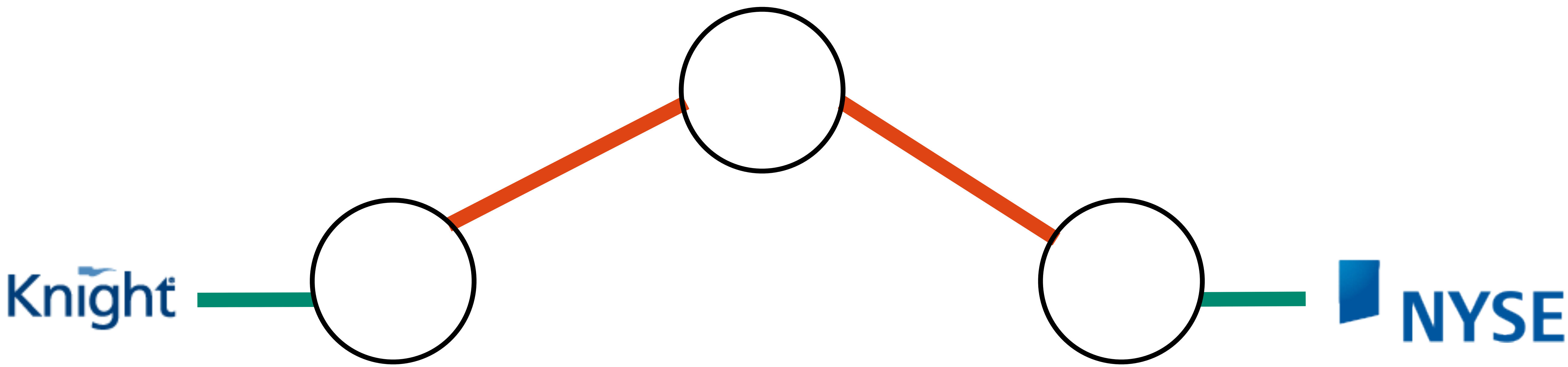
- Rely on precomputed backup paths
  - Typically support single link failures.

Today's Solution



- Rely on precomputed backup paths
  - Typically support single link failures.
  - State grows exponentially for more links.

Today's Solution



- Rely on precomputed backup paths
  - Typically support single link failures.
  - State grows exponentially for more links.
- Hard to generalize. Hard to configure.

Routing is the Problem!

- Routing conflates two functions
  - Optimality - Use good paths
    - Inherently global, requires coordination.
  - Connectivity - Deliver packets
    - Can it be local?

Data Plane Connectivity

Data Plane Connectivity

- Can we push connectivity to the data plane?

Data Plane Connectivity

- Can we push connectivity to the data plane?
- What would it take?

Data Plane Connectivity

- Can we push connectivity to the data plane?
- What would it take?
  - No FIB changes at packet rate.

Data Plane Connectivity

- Can we push connectivity to the data plane?
- What would it take?
  - No FIB changes at packet rate.
  - No additional data in packet header.

Data Plane Connectivity

- Can we push connectivity to the data plane?
- What would it take?
  - No FIB changes at packet rate.
  - No additional data in packet header.
  - Impossible

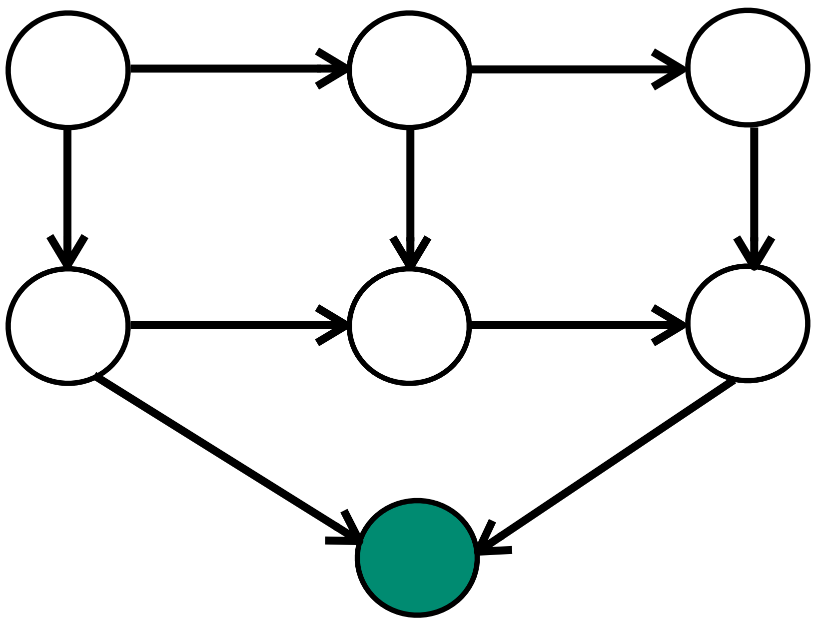
Data Plane Connectivity

- Can we push connectivity to the data plane?
- What would it take?
  - ~~No FIB changes at packet rate.~~
  - No additional data in packet header.
  - ~~Impossible~~

Data Plane Connectivity

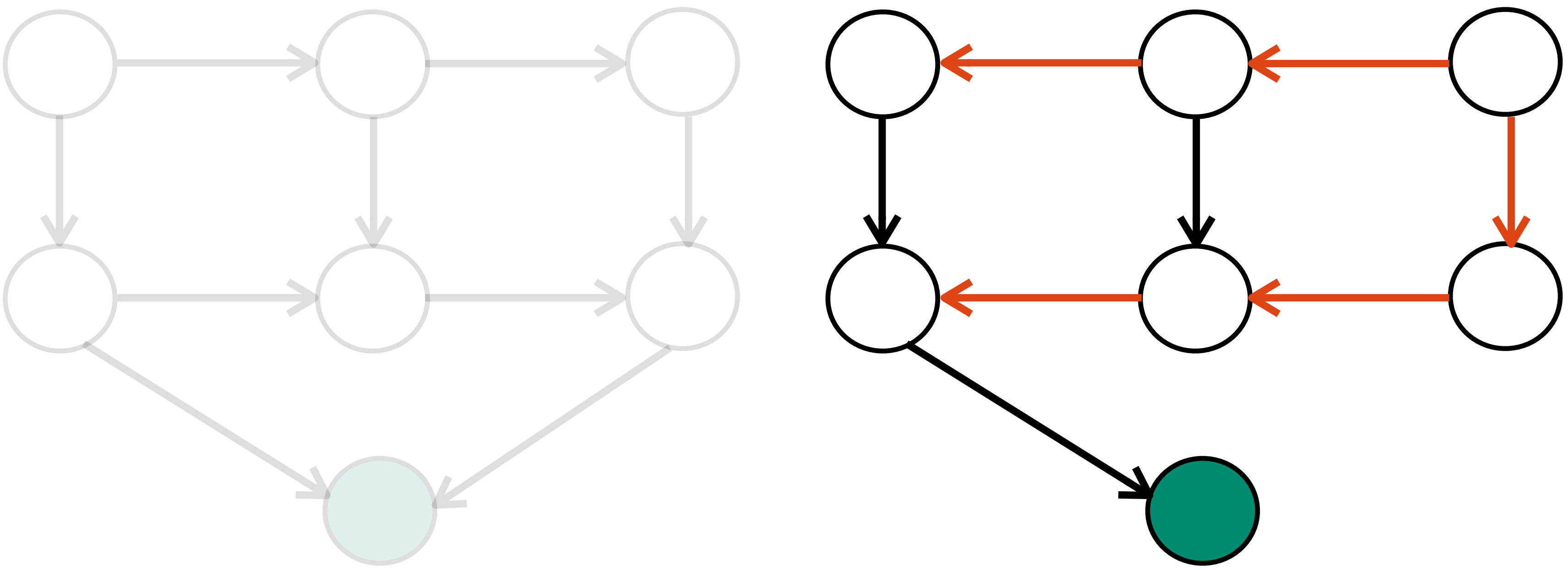
- Relax constraints
  - Change a few bits in FIB at packet rates.
- Clearly feasible, but is it enough?

Guaranteeing Connectivity



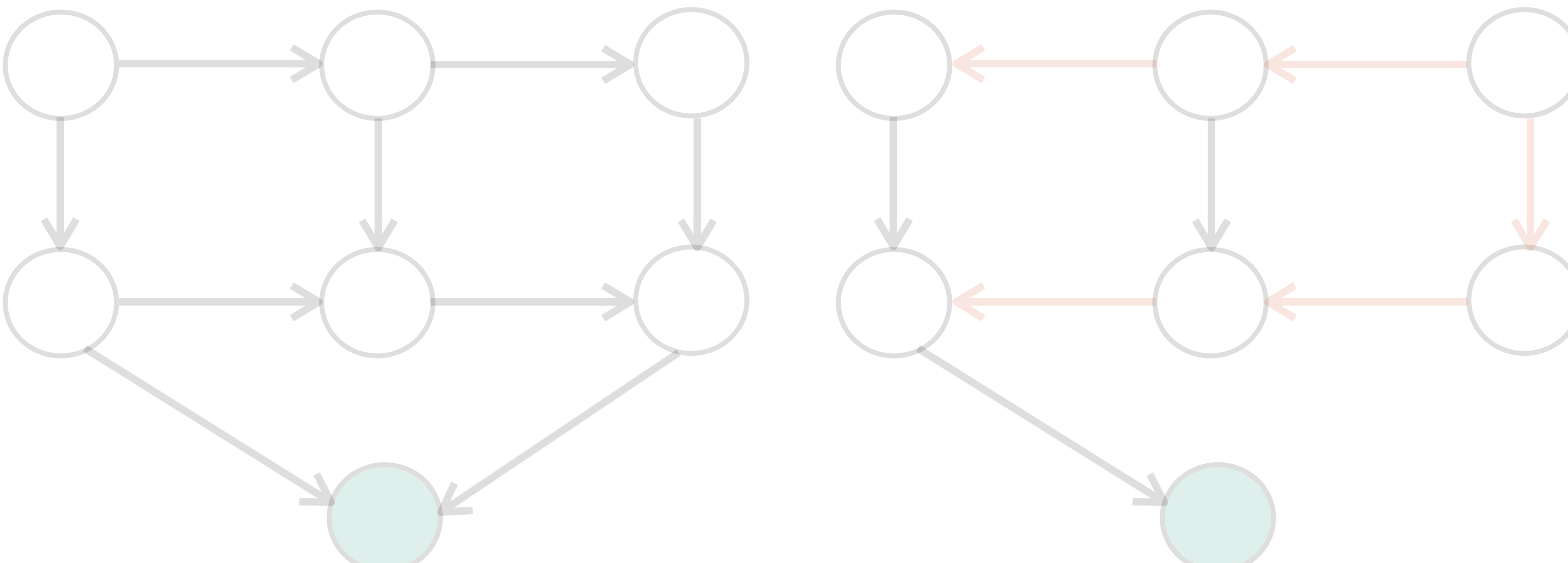
1. Take advantage of available redundancy.

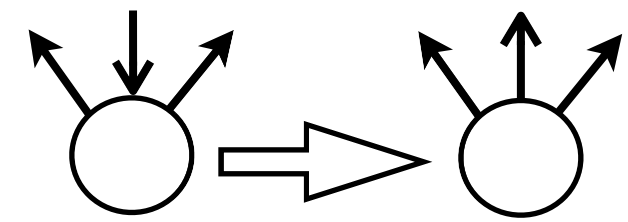
Guaranteeing Connectivity



1. Take advantage of available redundancy.
2. Restore connectivity at data speeds.

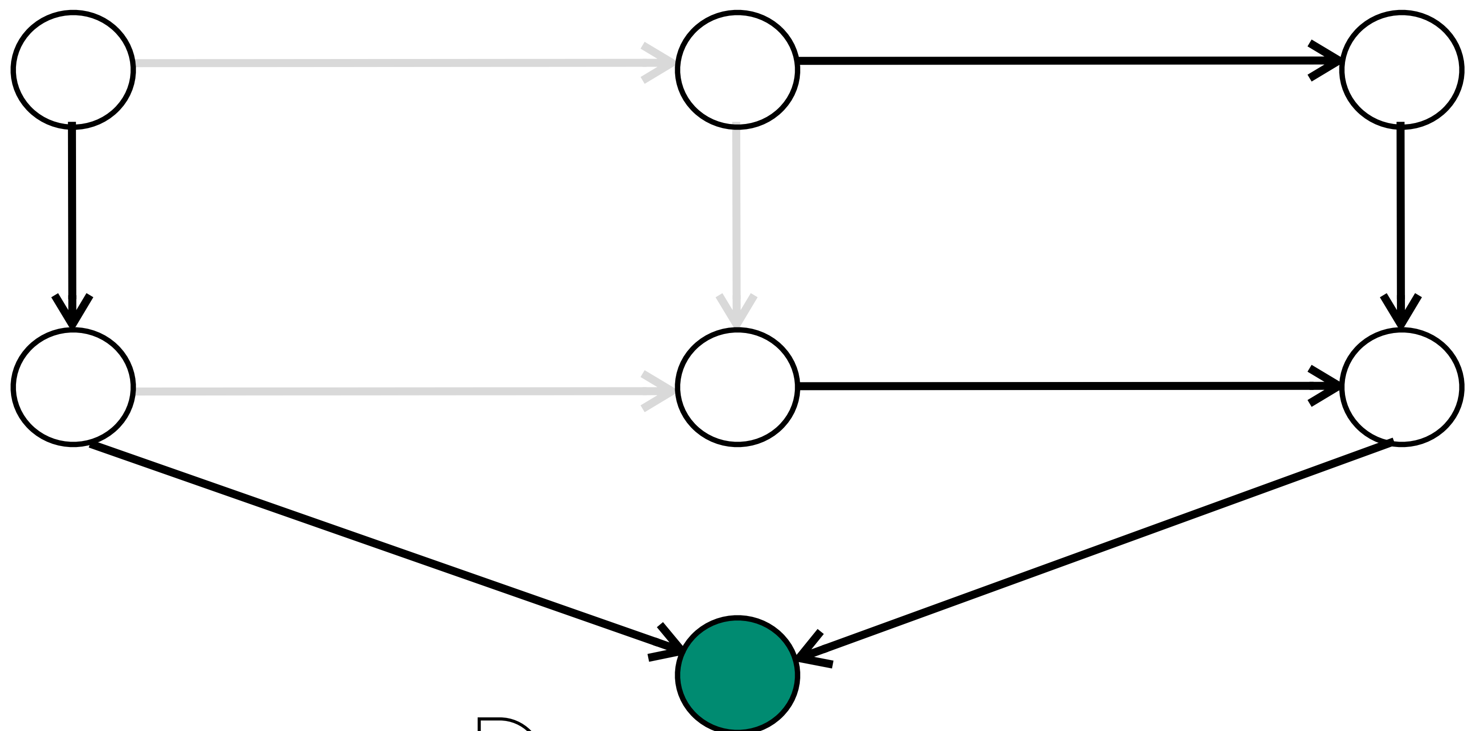
Guaranteeing Connectivity



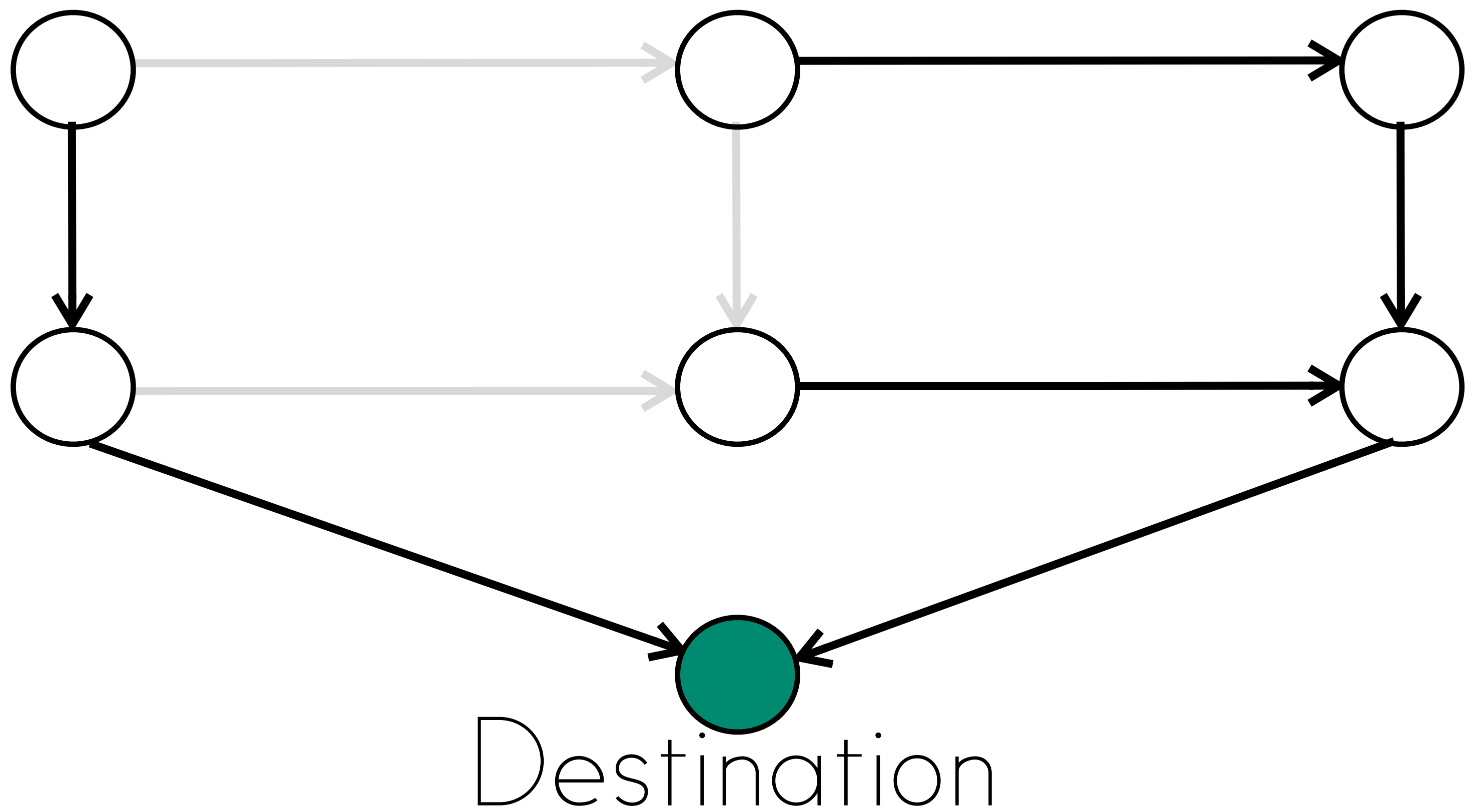


1. Take advantage of available redundancy.
2. Restore connectivity at data speeds.
3. Achieve optimality at control speeds.

Using Redundancy: DAGs

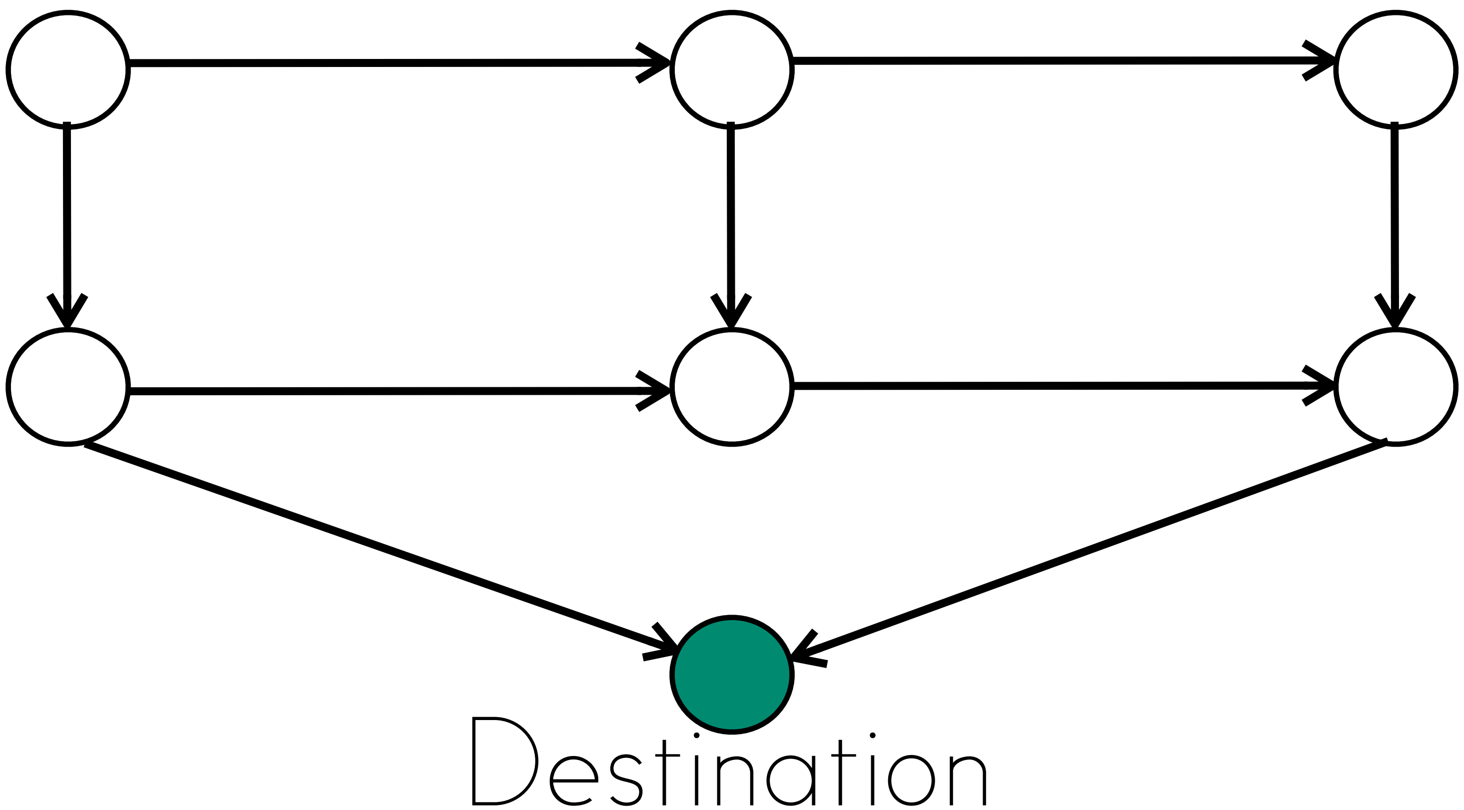


Using Redundancy: DAGs



- Current paths to a destination do not use all links

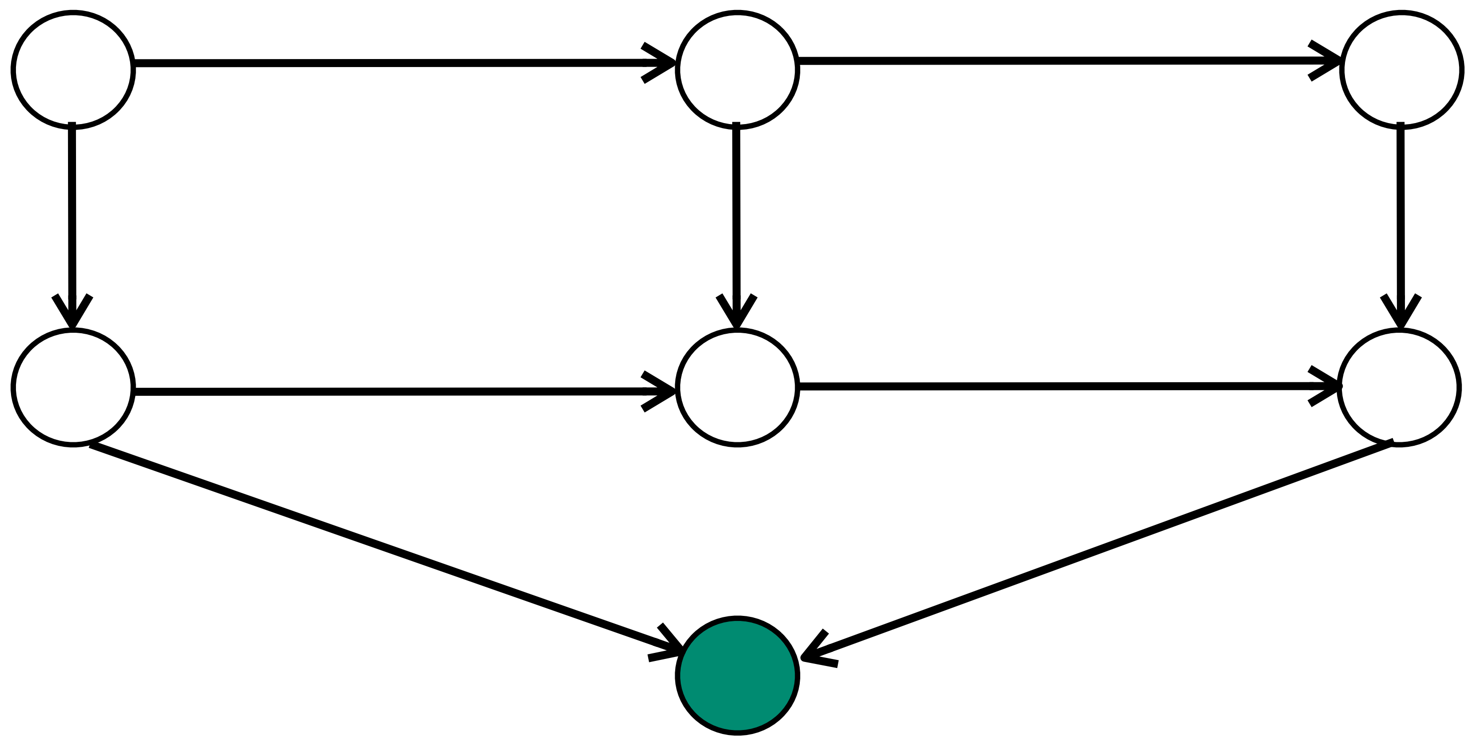
Using Redundancy: DAGs



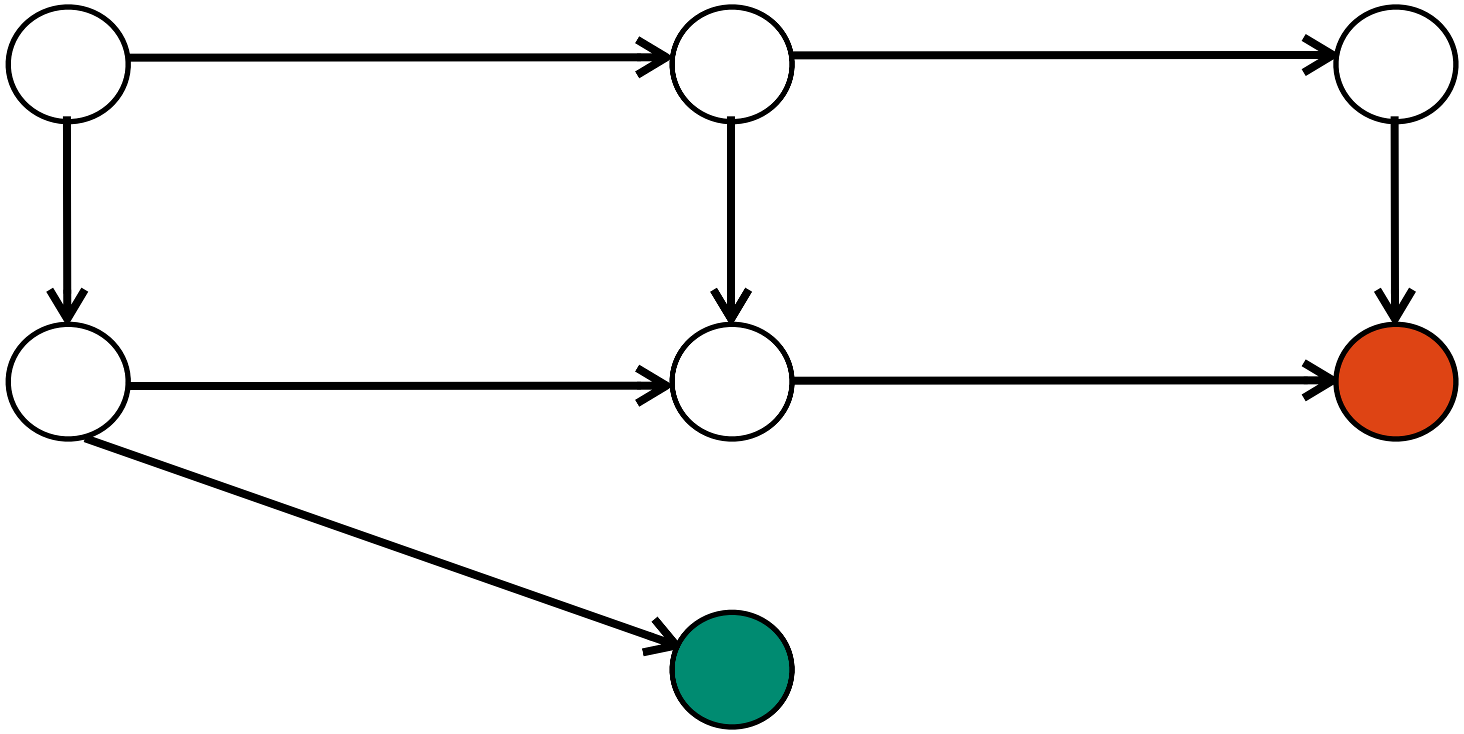
- Current paths to a destination do not use all links
- Extend routing tables to increase redundancy.

Restoring Connectivity

Reverse to Reconnect

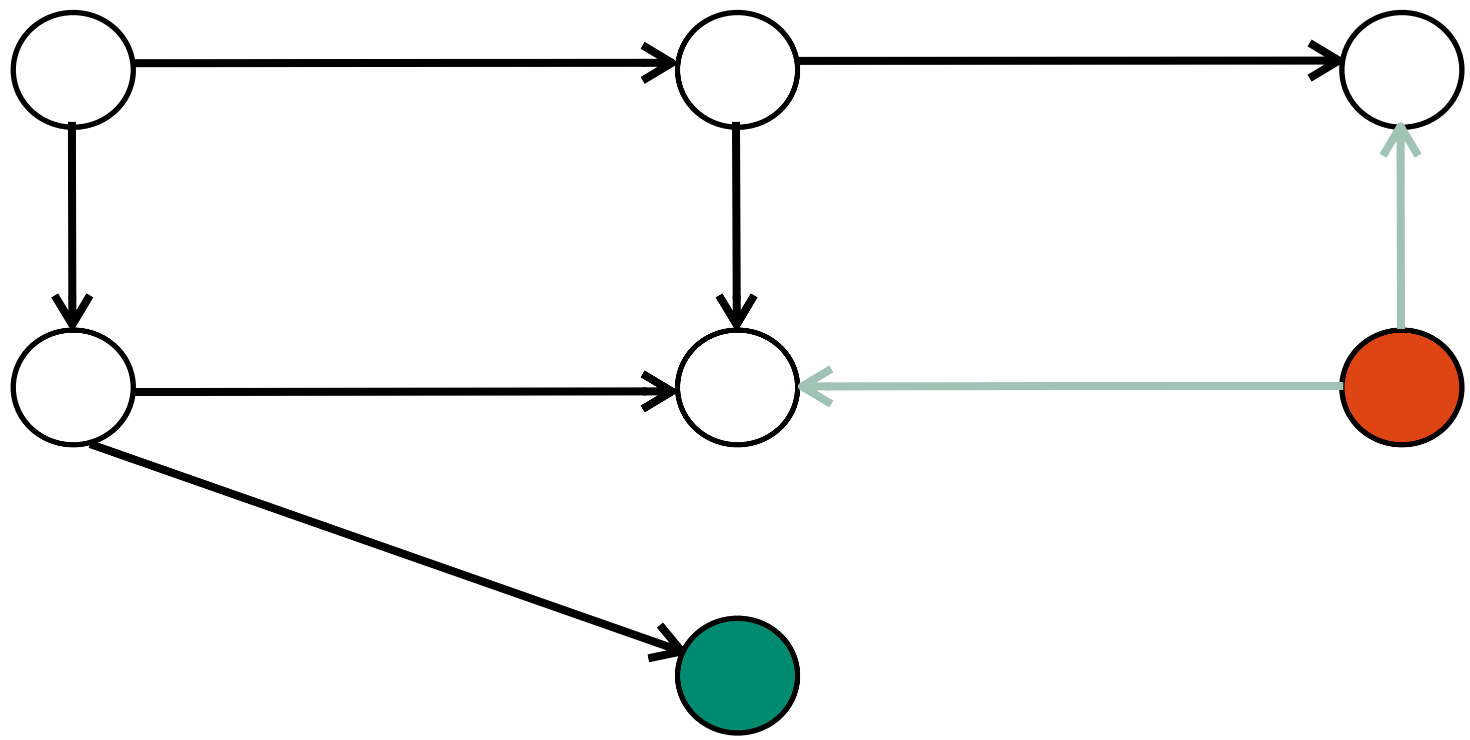


Reverse to Reconnect



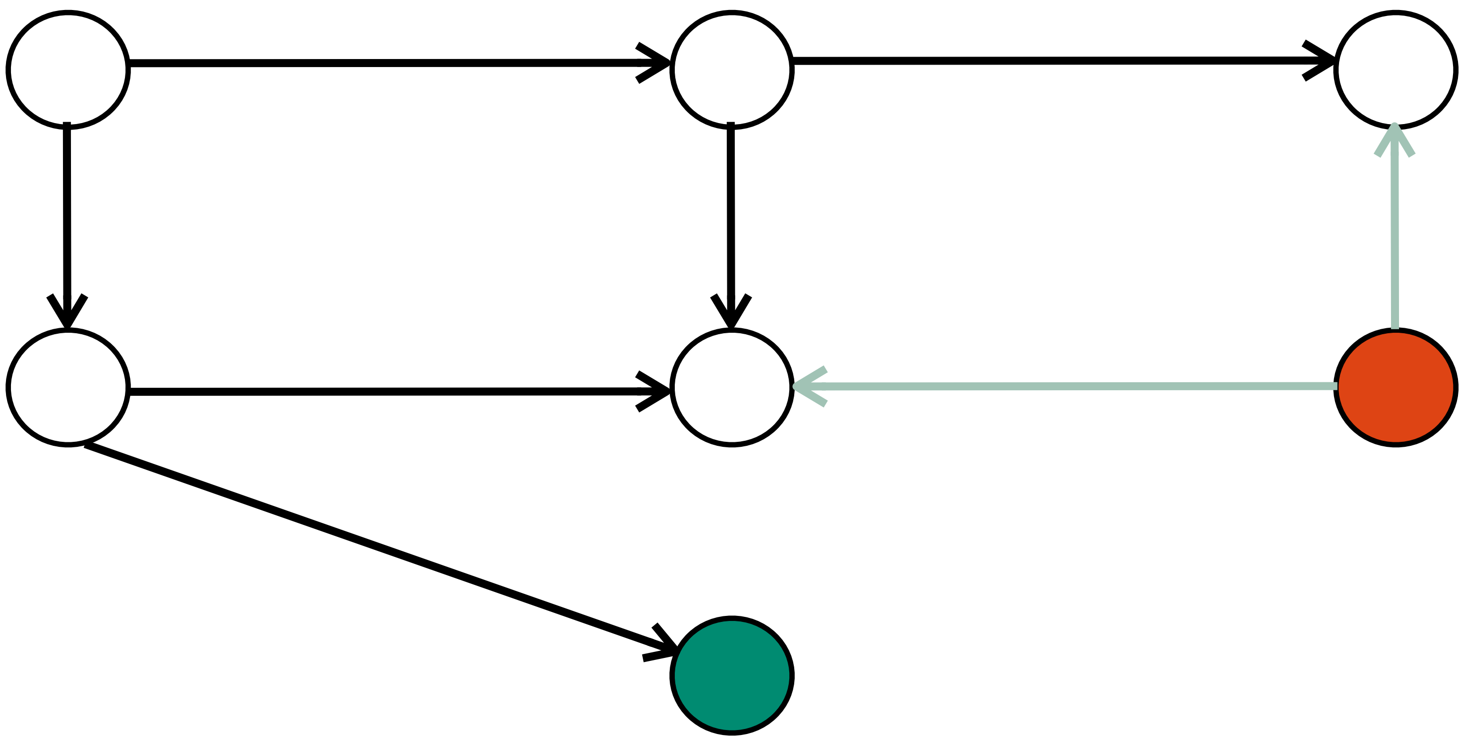
- Link failure can disconnect a DAG.

Reverse to Reconnect



- Link failure can disconnect a DAG.
- Disconnected node reverses all links to point out.

Reverse to Reconnect



- Link failure can disconnect a DAG.
- Disconnected node reverses all links to point out.
- Finite set of reversals reconnect DAG.

Reversals in Data Plane

- Two challenges must be addressed

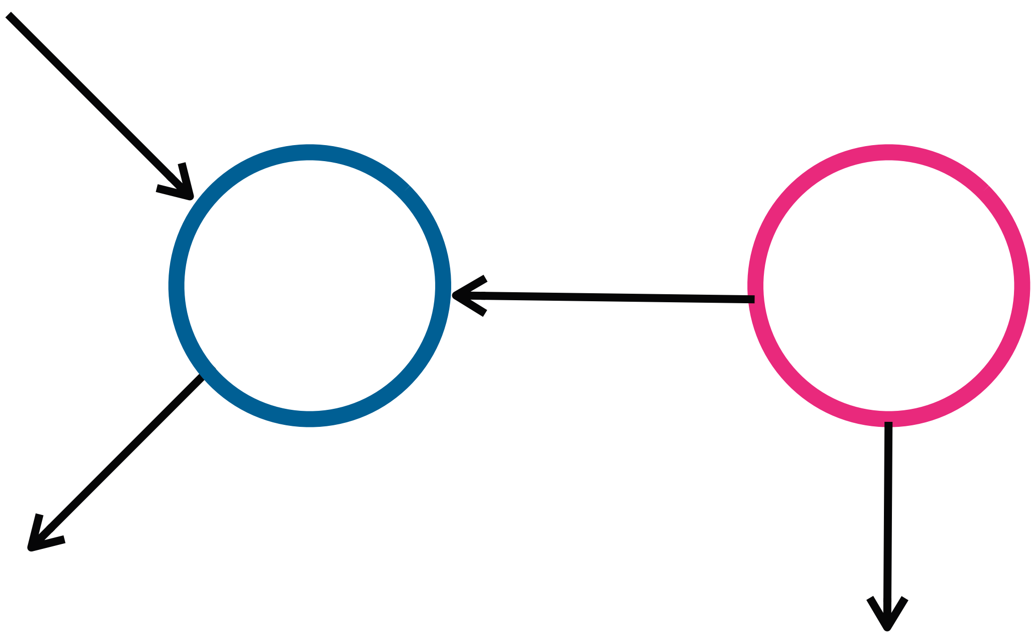
Reversals in Data Plane

- Two challenges must be addressed
  - Notifications can be lost.

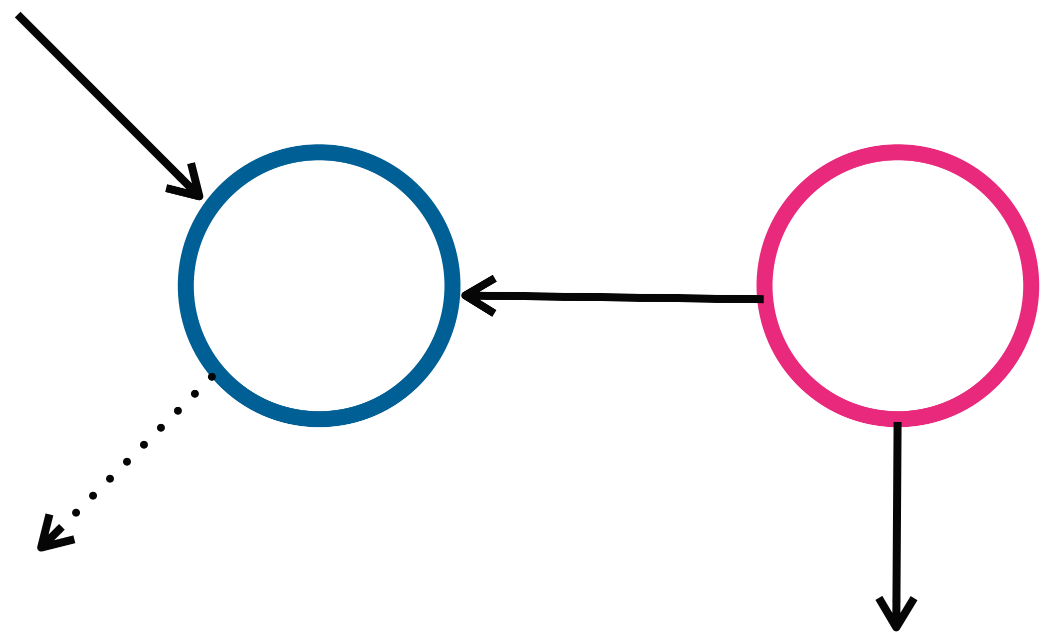
Reversals in Data Plane

- Two challenges must be addressed
  - Notifications can be lost.
  - Notifications can be delayed.

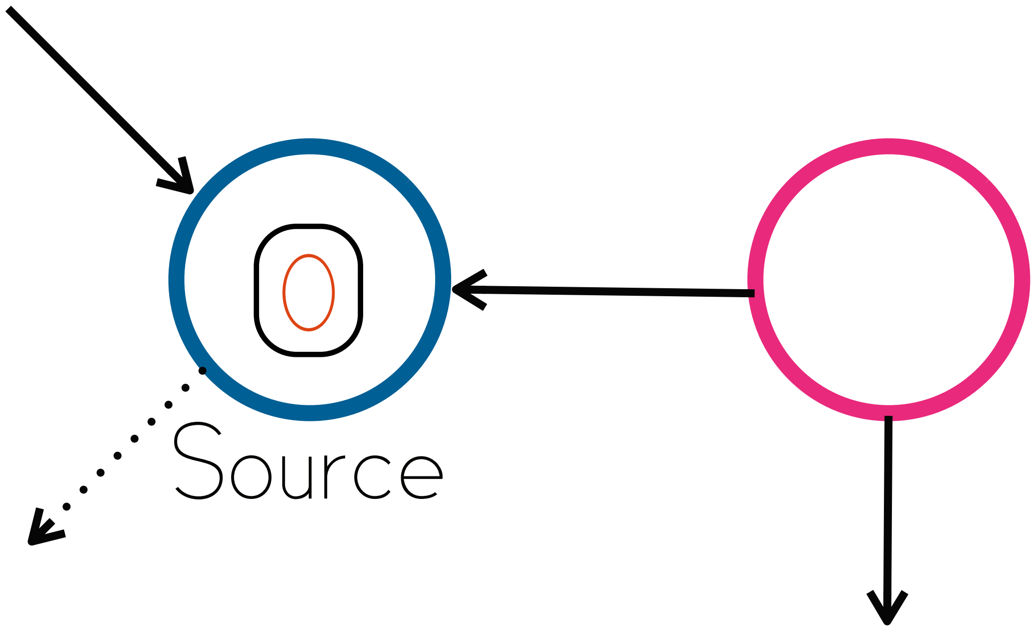
Walk Through



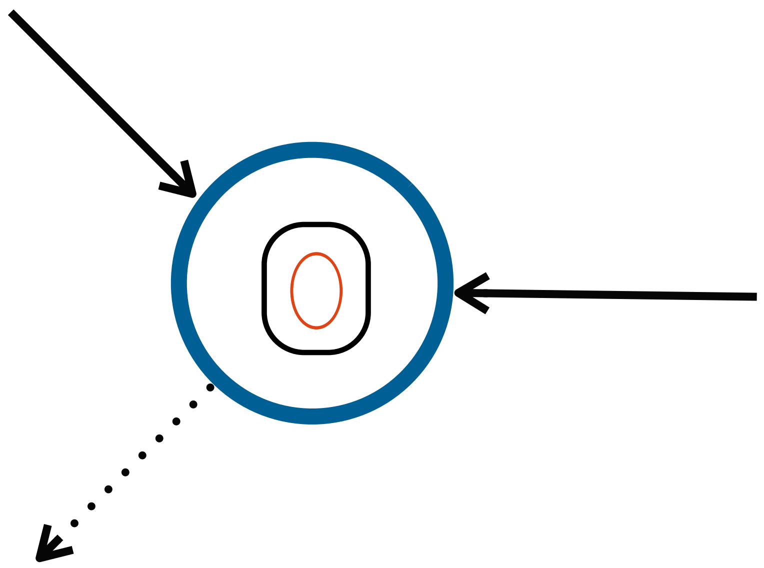
Walk Through



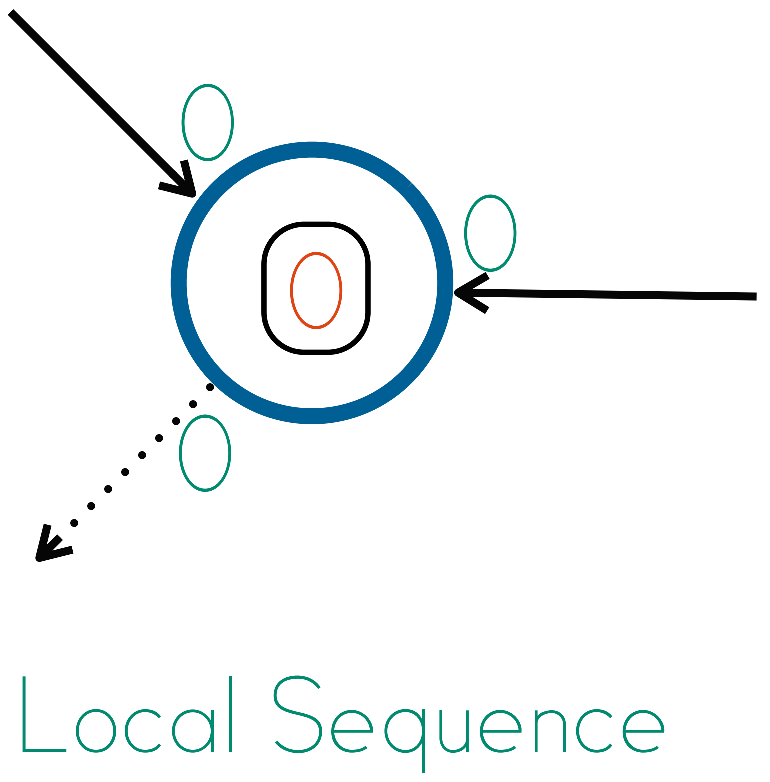
Walk Through



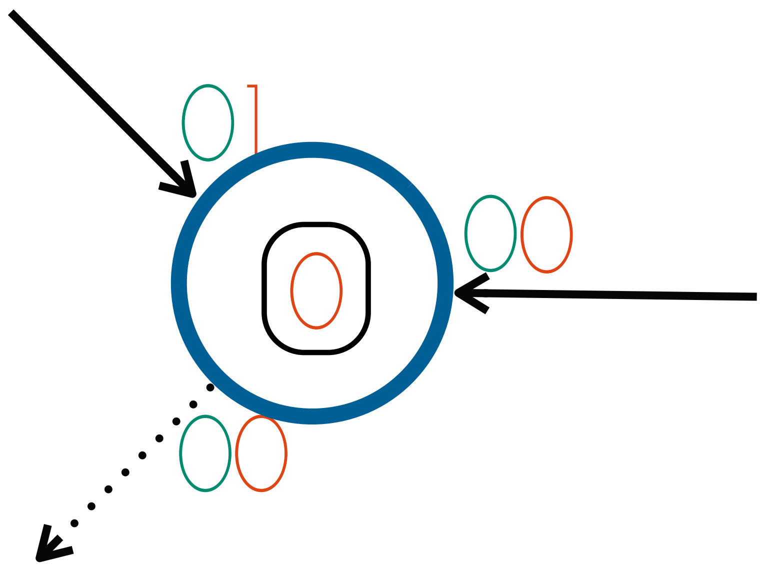
Create an OUT Link



Create an OUT Link

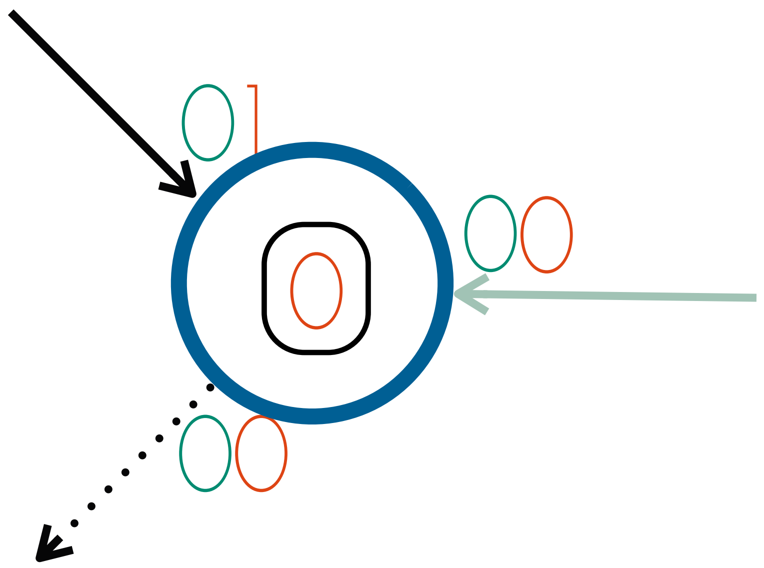


Create an OUT Link



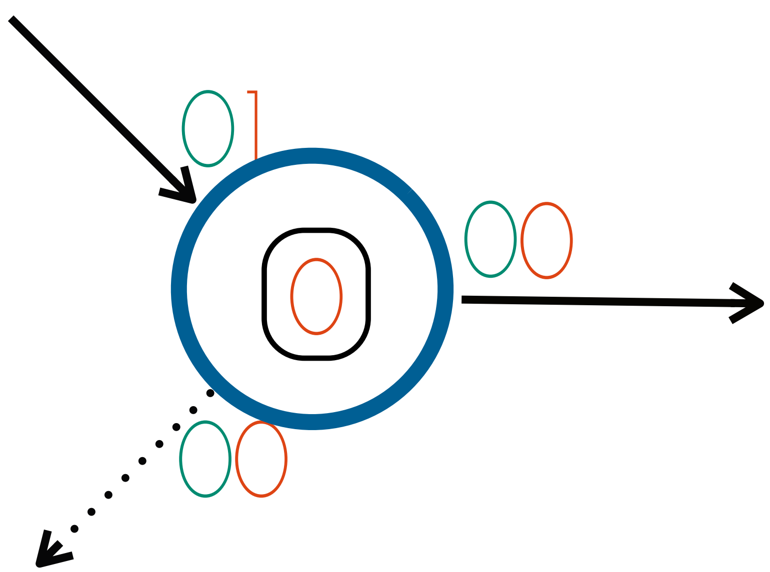
Local Sequence
Remote Sequence

Create an OUT Link



Local Sequence
Remote Sequence
→ Reversible

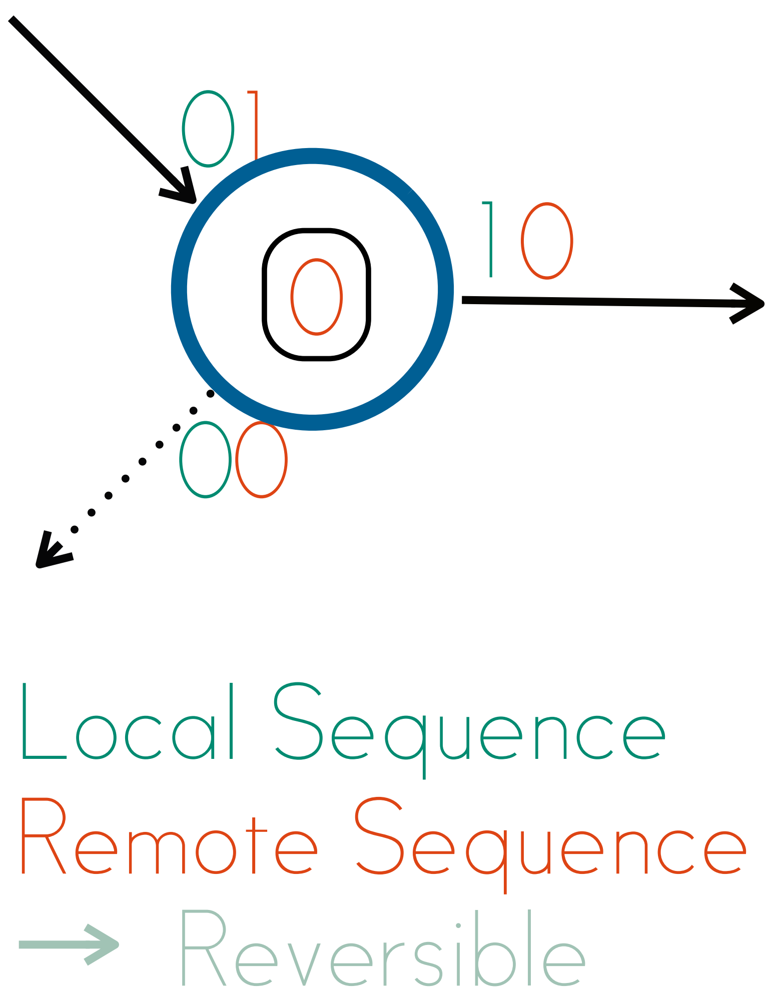
Create an OUT Link



- Reverse link direction

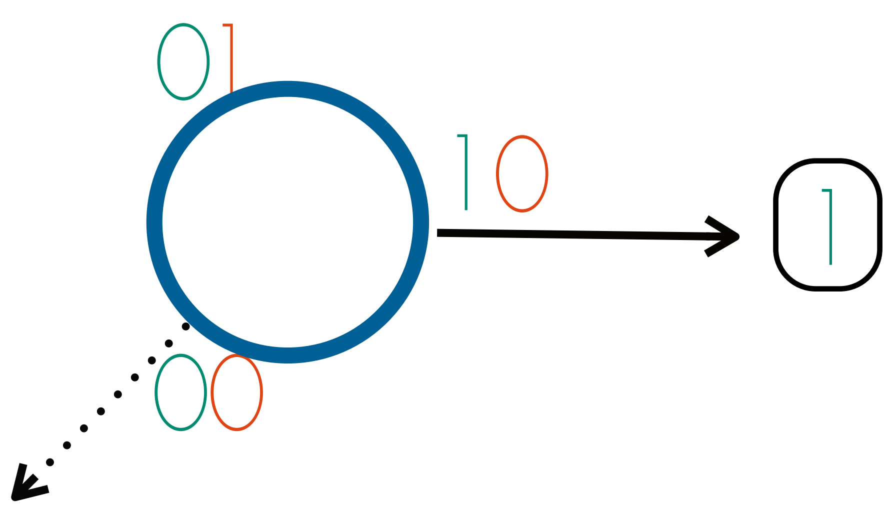
Local Sequence
Remote Sequence
→ Reversible

Create an OUT Link



- Reverse link direction
- Increment Local Sequence

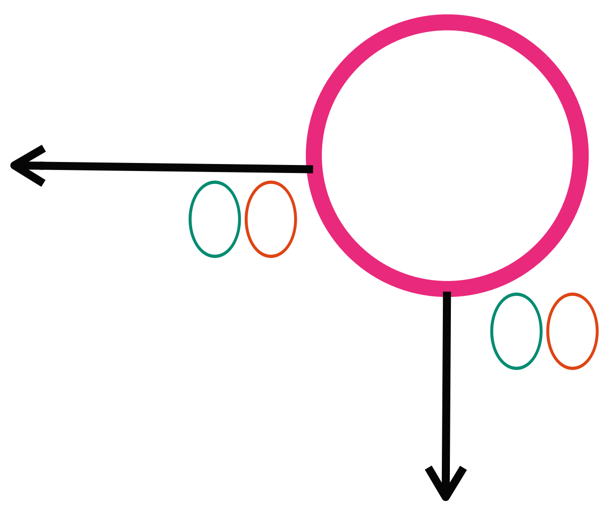
Create an OUT Link



- Reverse link direction
- Increment Local Sequence
- Forward packet

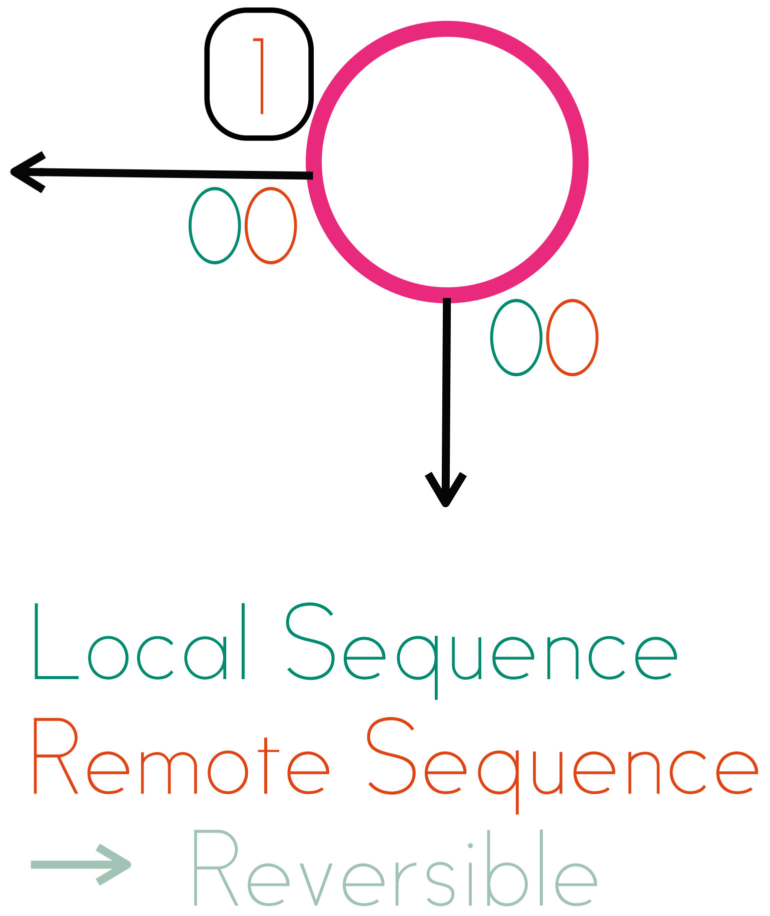
Local Sequence
Remote Sequence
→ Reversible

Dealing with Notifications



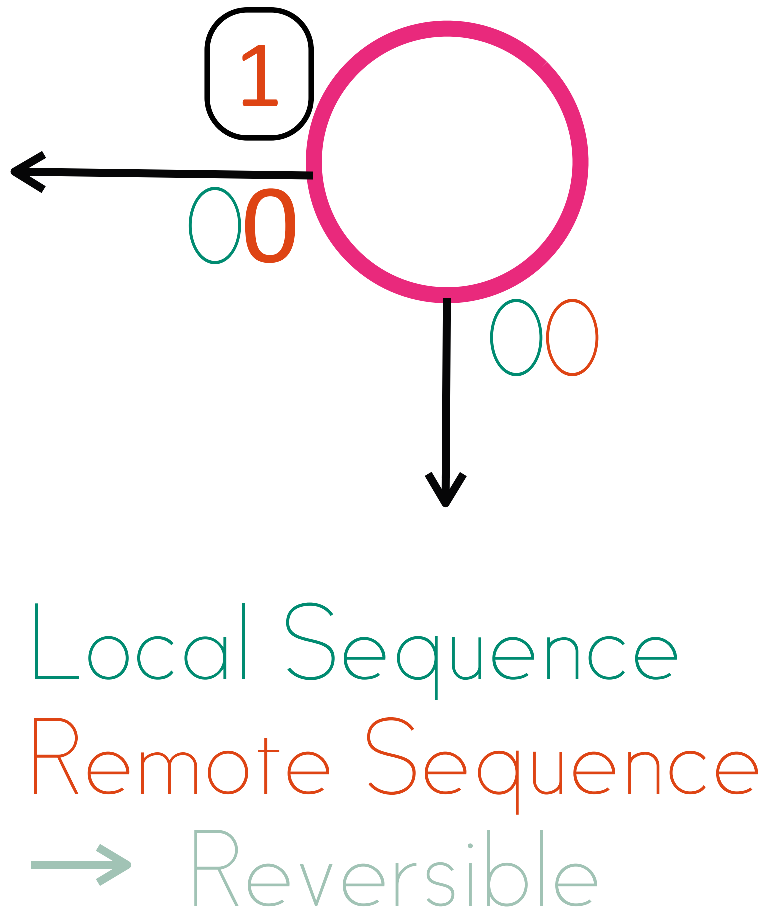
Local Sequence
Remote Sequence
→ Reversible

Dealing with Notifications



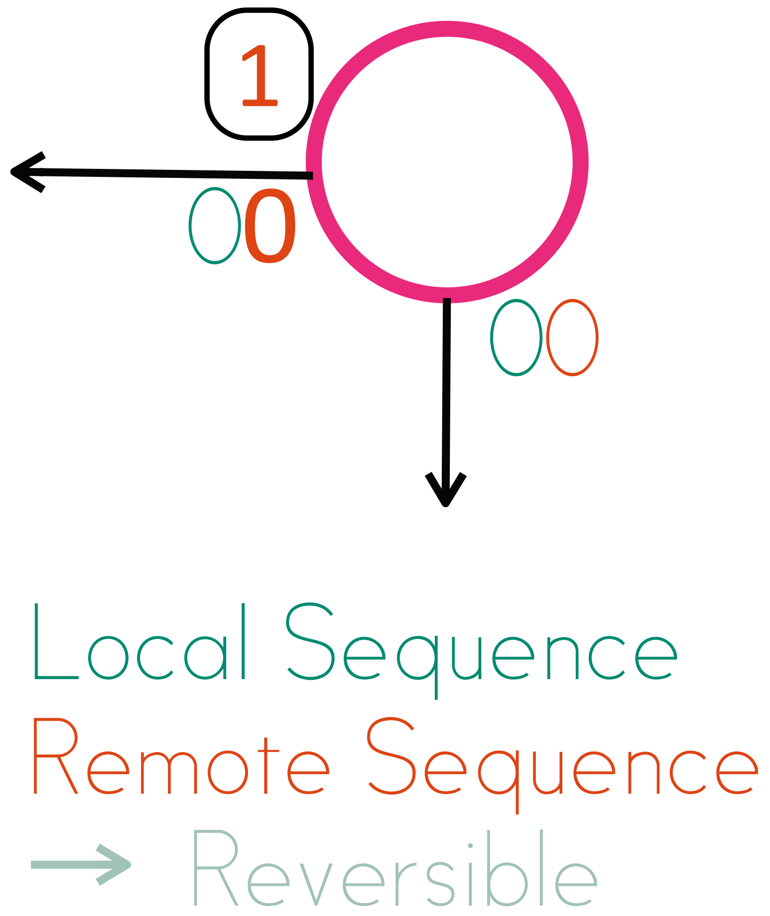
- Receive on link pointing OUT

Dealing with Notifications



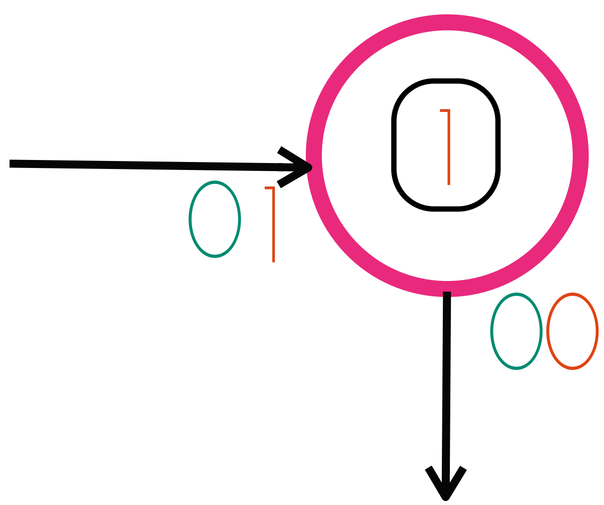
- Receive on link pointing OUT
- Compare sequence numbers

Dealing with Notifications



- Receive on link pointing OUT
- Compare sequence numbers
  - See if anything changed

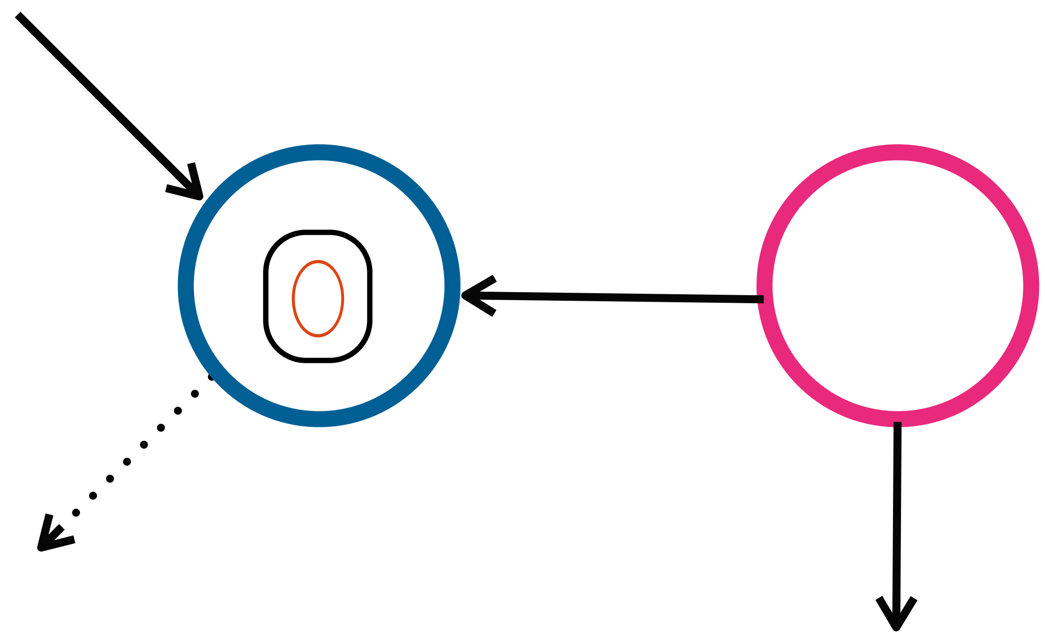
Dealing with Notifications



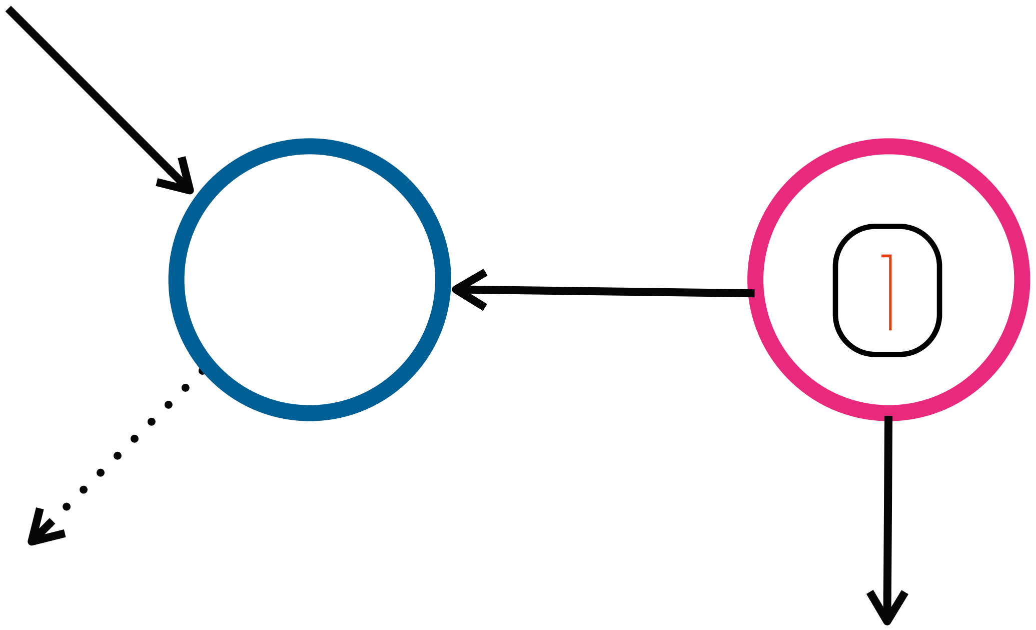
Local Sequence
Remote Sequence
→ Reversible

- Receive on link pointing OUT
- Compare sequence numbers
  - See if anything changed
- Reverse link

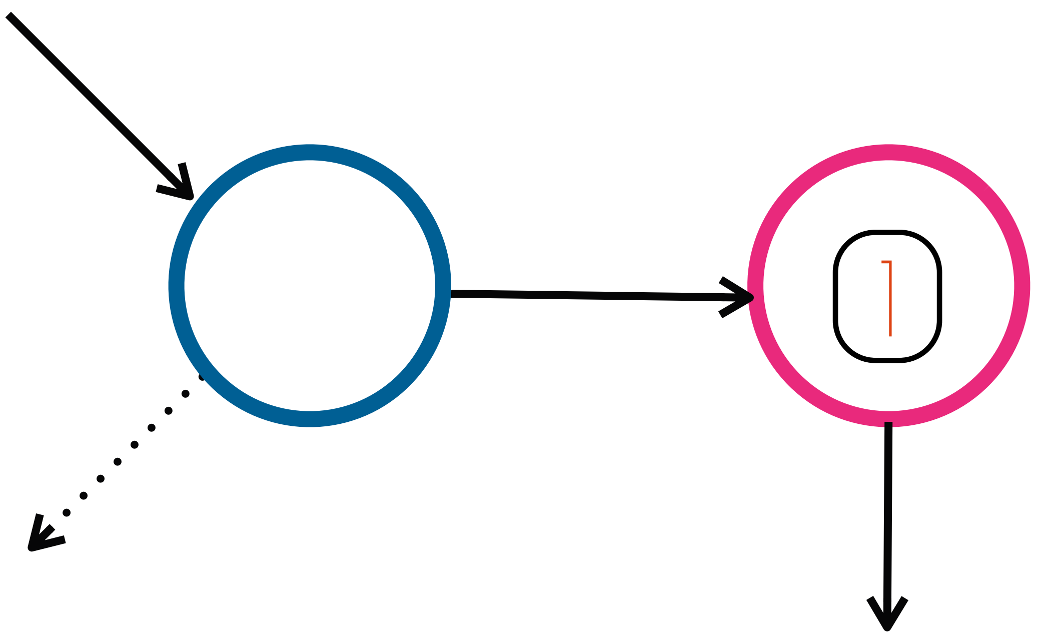
Zooming Out



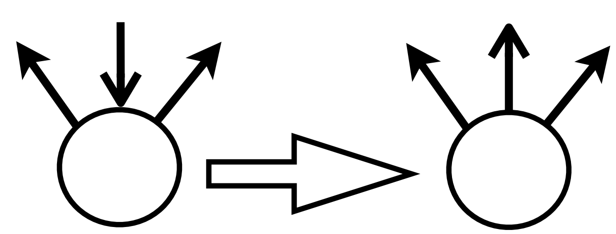
Zooming Out



Zooming Out



What about Optimality?



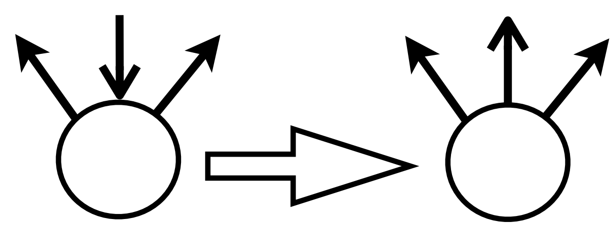
Safe Control Plane

- Cannot interfere with data plane.

Safe Control Plane

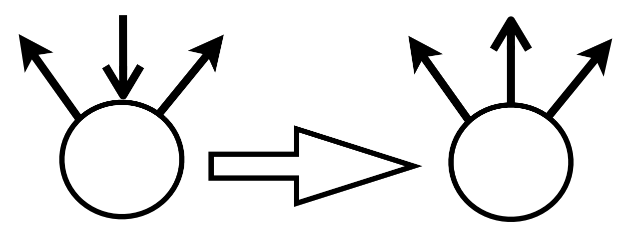
- Cannot interfere with data plane.
- Build a safe primitive

Safe Control Plane



- Cannot interfere with data plane.
- Build a safe primitive
  - Set all edges of a node to point out

Safe Control Plane



- Cannot interfere with data plane.
- Build a safe primitive
  - Set all edges of a node to point out
- Described in paper

Evaluation

Evaluation Overview

- Test on WAN and datacenter topologies
  - Stretch, Throughput, Latency
- Effect of FIB update delays
  - On latency and throughput
- End-to-end benefits of using DDC.

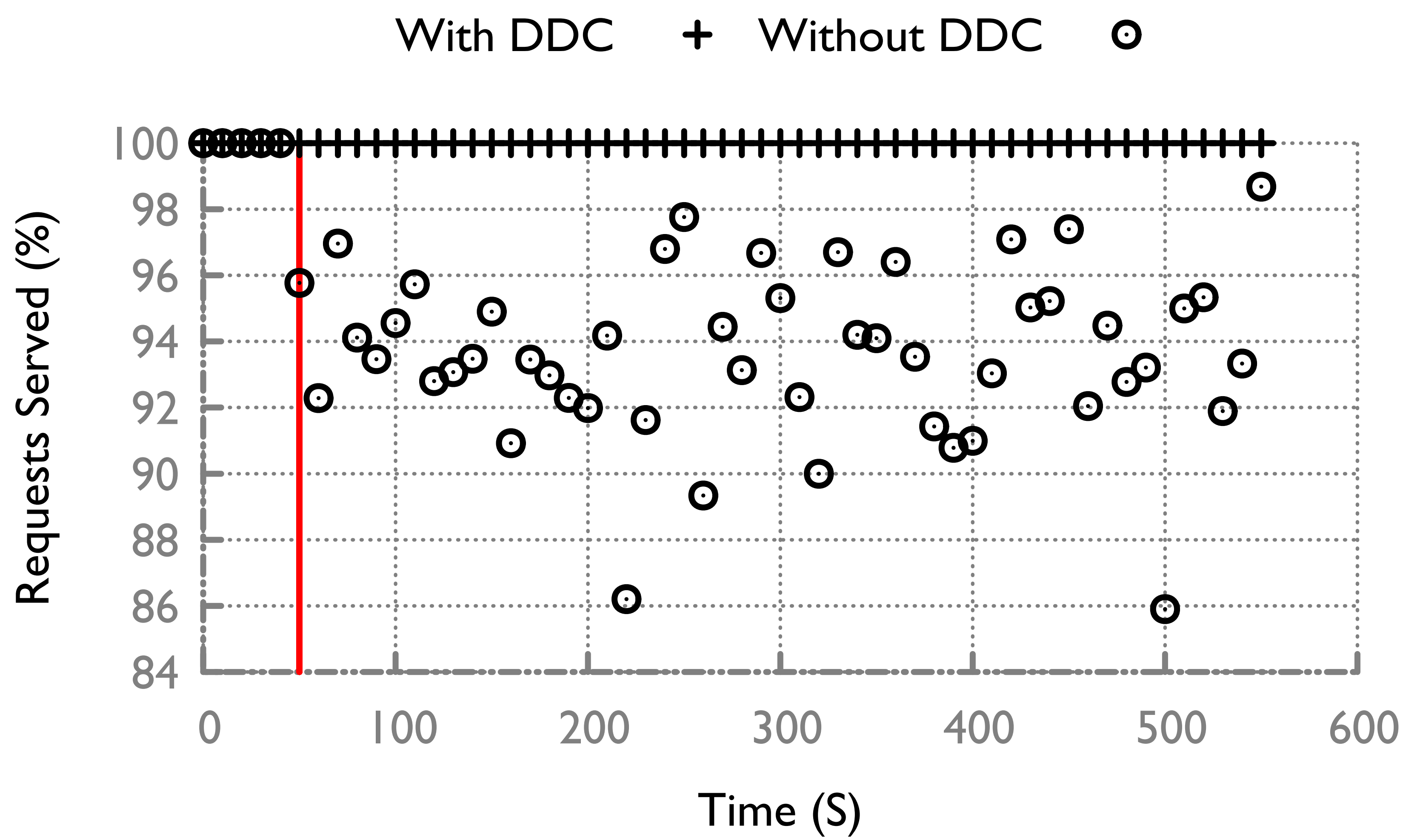
Evaluation Overview

- Test on WAN and datacenter topologies
  - Stretch, Throughput, Latency
- Effect of FIB update delays
  - On latency and throughput
- End-to-end benefits of using DDC.

End-to-End Test

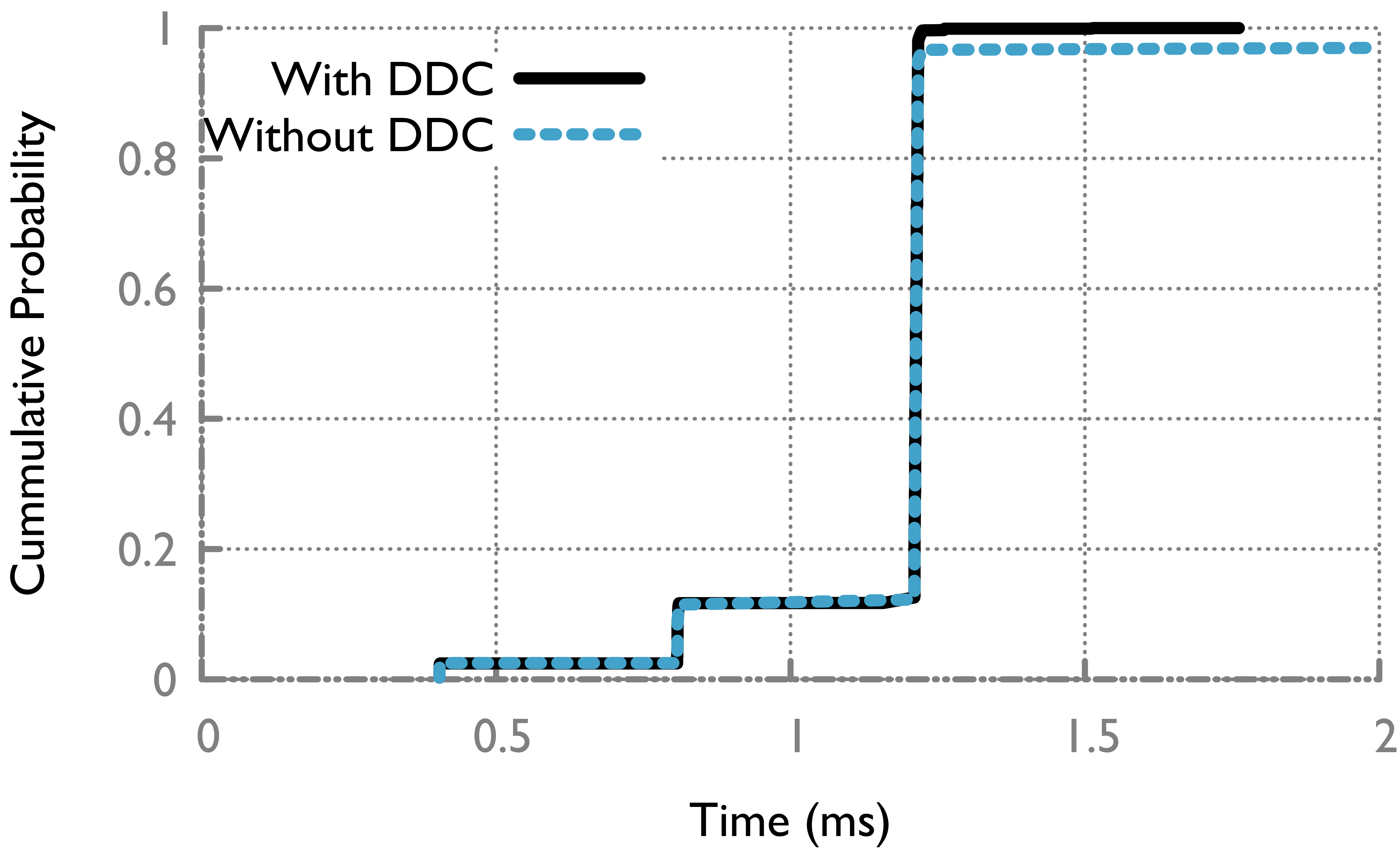
- 8 Pod FatTree
- Partition aggregate workload
- 5 link failures
- Simulated effect for 550 seconds

Requests Fulfilled



- Bucketed 10 second intervals.
- Percentage requests satisfied.

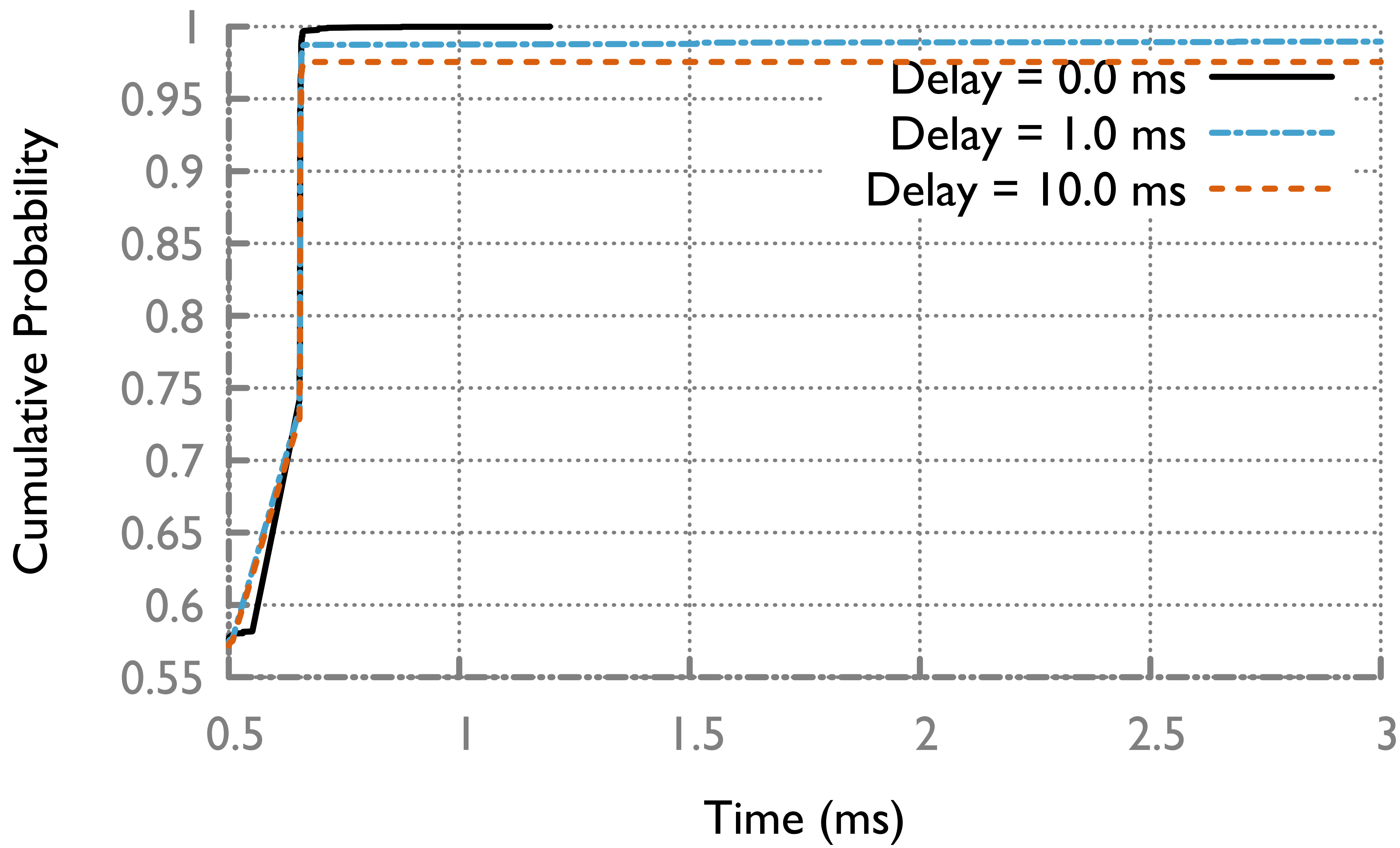
Request Latency



FIB Update Delay

- What is the impact of delayed FIB changes
  - On packet latency?
  - Three link failure: all traffic in test affected.
  - Focus on behavior before convergence.

FIB Update Delay



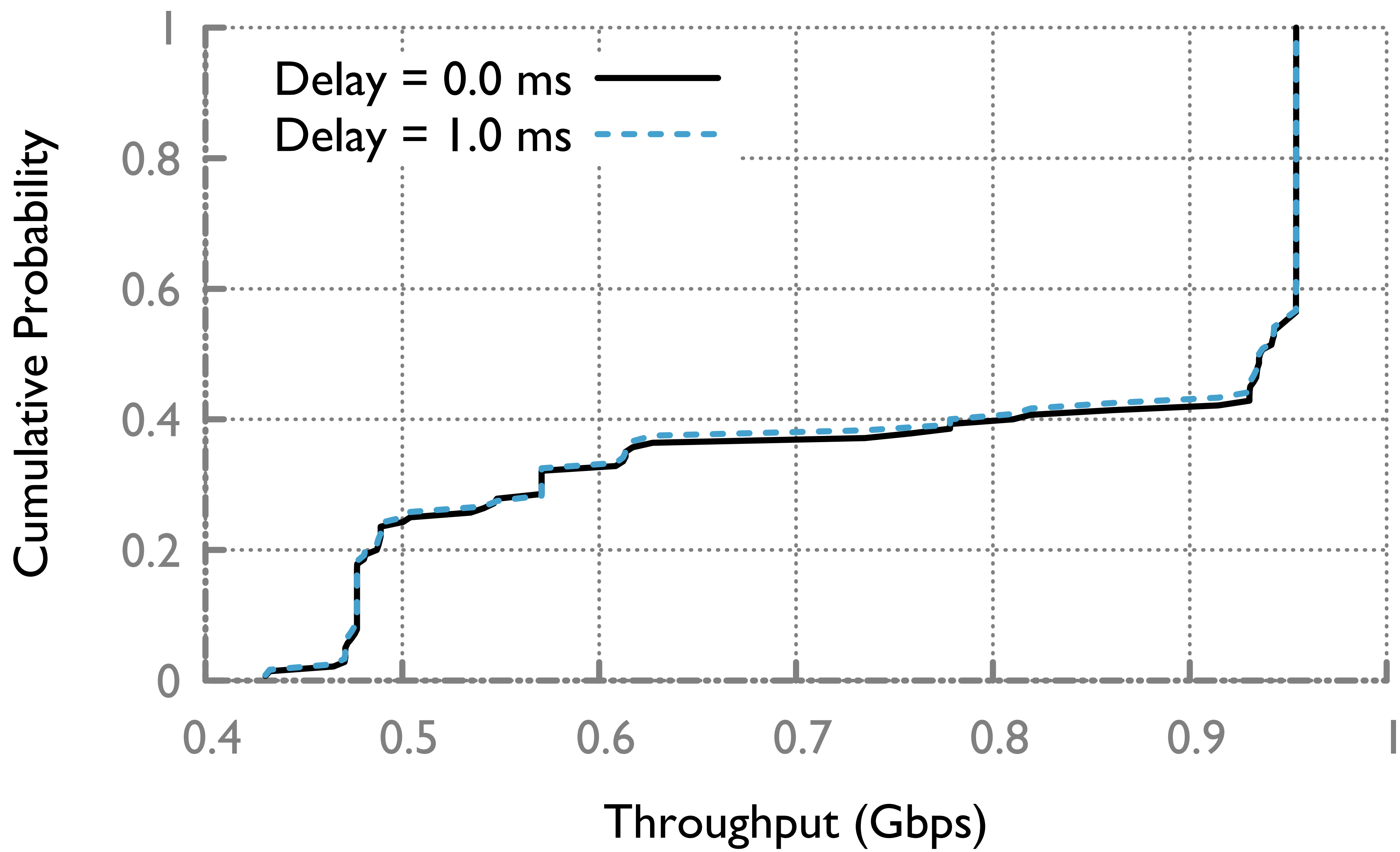
Overall ~99% of packets in under 3 ms.

No packets get dropped, just long tail.

FIB Update Delay

- What is the impact of delayed FIB changes
  - On TCP throughput?
  - Use a WAN topology (AS 2914)
  - 1 Gbps links
  - 5 link failures

FIB Update Delay



In the Same Vein…

- FCP (SIGCOMM '07)
  - Unbounded bits in header
  - Extensive FIB changes on failure packet
- Packet Re-Cycling (HotNets '10)
  - First solve an NP-Complete problem.
  - log(network diameter) bits in header.
  - DDC is simpler.

Potential Impact

- ASICs implement DDC
  - Connectivity guaranteed by the data plane.
  - Control Plane focuses on optimality/functionality.

Questions?