# CSCI-1680
# Network Layer:
# Inter-domain Routing – Policy and Security

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Based partly on lecture notes by Jennifer Rexford, Rob Sherwood, David Mazières, Phil Levis, John Jannotti

# Administrivia

- **Homework 2 is out**
- **Rodrigo's office hours:**
  - Wednesday 1-3 (or by appointment)

# Today

- **BGP Continued**
  - Policy routing, instability, vulnerabilities

# Route Selection

- More specific prefix
- Next-hop reachable?
- Prefer highest weight
  - Computed using some AS-specific local policy
- Prefer highest local-pref
- Prefer locally originated routes
- Prefer routes with shortest AS path length
- Prefer eBGP over iBGP
- Prefer routes with lowest cost to egress point
  - Hot-potato routing
- Tie-breaking rules
  - E.g., oldest route, lowest router-id

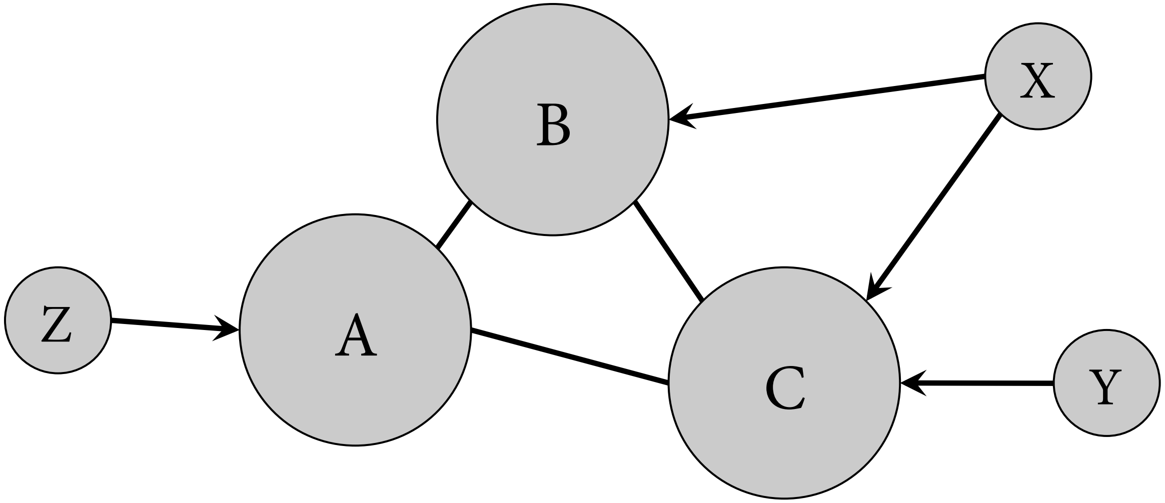
# Customer/Provider AS relationships

- **Customer pays for connectivity**
  - E.g. Brown contracts with OSHEAN
  - Customer is stub, provider is a transit
- **Many customers are multi-homed**
  - E.g., OSHEAN connects to Level3, Cogent
- **Typical policies:**
  - Provider tells all neighbors how to reach customer
  - Provider prefers routes from customers ($$)
  - Customer does not provide transit service

# Peer Relationships

- **ASs agree to exchange traffic for free**
  - Penalties/Renegotiate if imbalance
- **Tier 1 ISPs have no default route: all peer with each other**
- **You are Tier *i* + 1 if you have a default route to a Tier *I***
- **Typical policies**
  - AS only exports customer routes to peer
  - AS exports a peer's routes only to its customers
  - Goal: avoid being transit when no gain

# AS Relationships



- **How to prevent X from forwarding transit between B and C?**
- **How to avoid transit between CBA ?**
  - B: BAZ -> X
  - B: BAZ -> C ? (=> Y: CBAZ and Y:CAZ)

Example from Kurose and Ross, 5th Ed

# Gao-Rexford Model

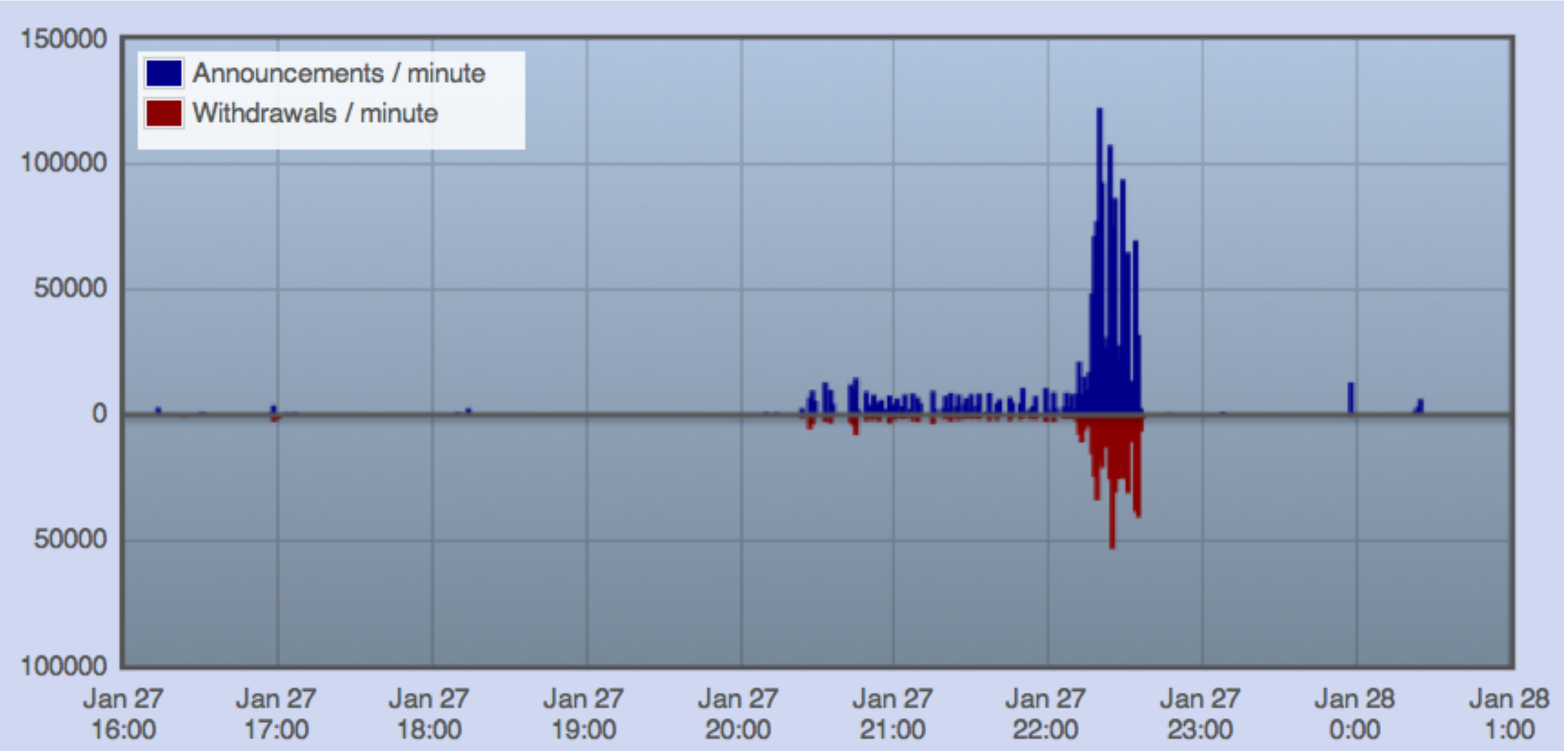
- **(simplified) Two types of relationships: peers and customer/provider**
- **Export rules:**
  - Customer route may be exported to all neighbors
  - Peer or provider route is only exported to customers
- **Preference rules:**
  - Prefer routes through customer ($$)
- **If all ASes follow this, shown to lead to stable network**

# Peering Drama

- Cogent vs. Level3 were peers
- In 2003, Level3 decided to start charging Cogent
- Cogent said no
- Internet partition: Cogent's customers couldn't get to Level3's customers and vice-versa
  - Other ISPs were affected as well
- Took 3 weeks to reach an undisclosed agreement

# “Shutting off” the Internet

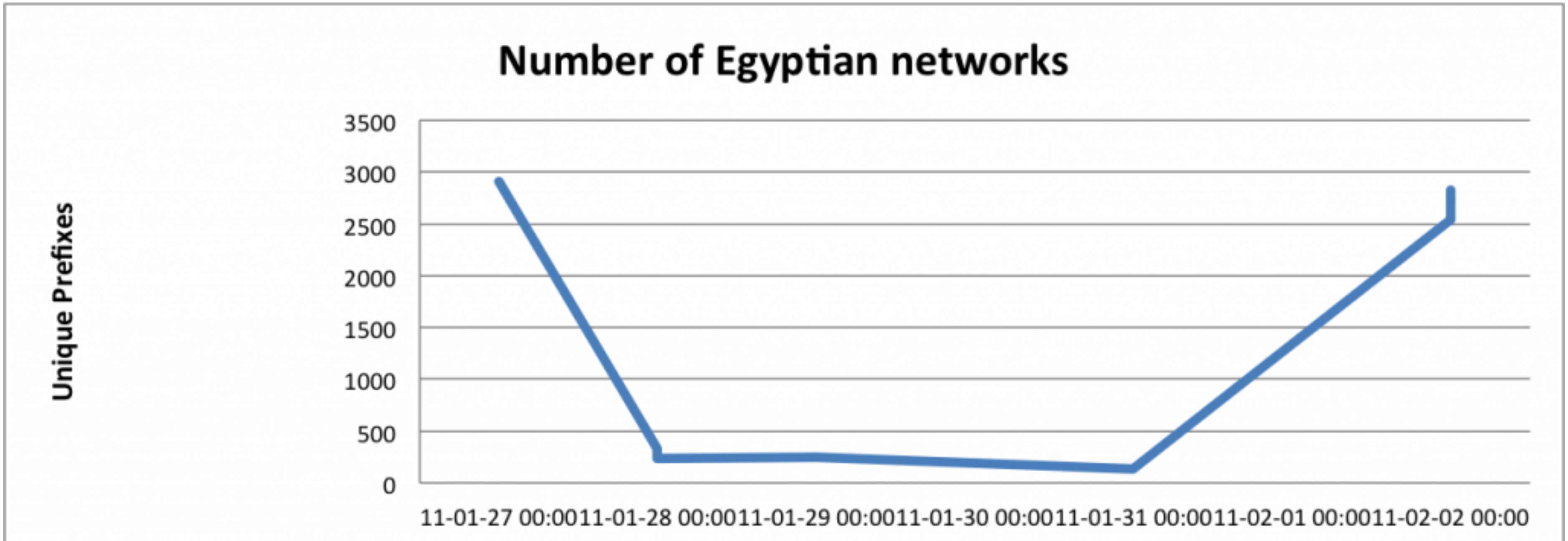
- **Starting from Jan 27th, 2011, Egypt was disconnected from the Internet**
  - 2769/2903 networks withdrawn from BGP (95%)!



Static view on BGP activity for prefixes originating from Egyptian organisations between 27 Jan 16:00 UTC and 28 Jan 01:00 UTC

Source: RIPEStat - http://stat.ripe.net/egypt/

# Egypt Incident



| | 11-01-27 00:00 | 11-01-28 02:00 | 11-01-28 16:00 | 11-01-28 20:00 | 11-01-29 00:00 | 11-01-29 18:00 | 11-01-31 22:00 | 11-02-02 10:00 | 11-02-02 12:00 |
|---|---|---|---|---|---|---|---|---|---|
| ▬ Number of Egyptian networks | 2903 | 327 | 239 | 241 | 242 | 243 | 134 | 2539 | 2825 |

Source: BGPMon (http://bgpmon.net/blog/?p=480)

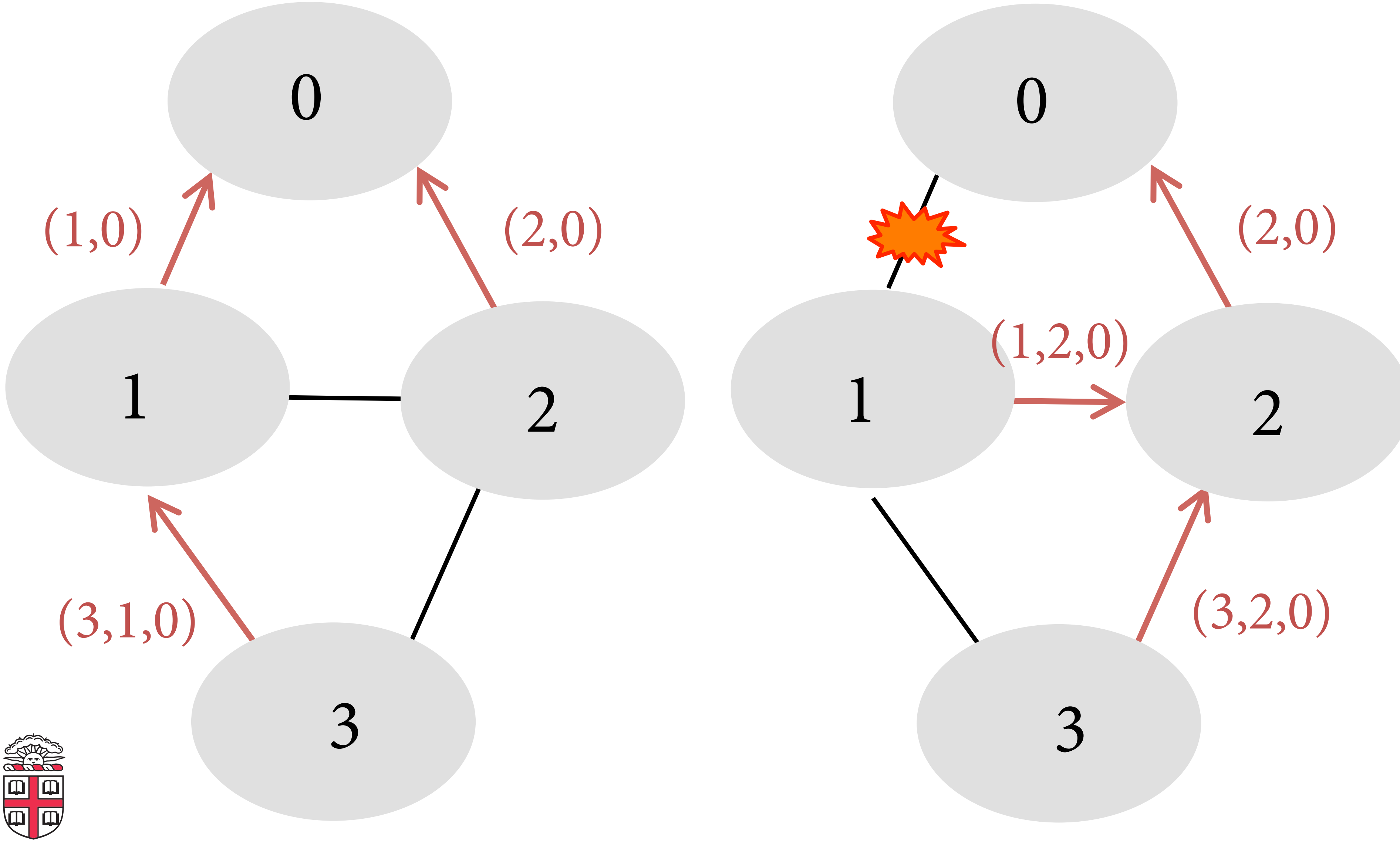
# Some BGP Challenges

- **Convergence**
- **Traffic engineering**
  - How to assure certain routes are selected
- **Scaling (route reflectors)**
- **Security**

# Convergence

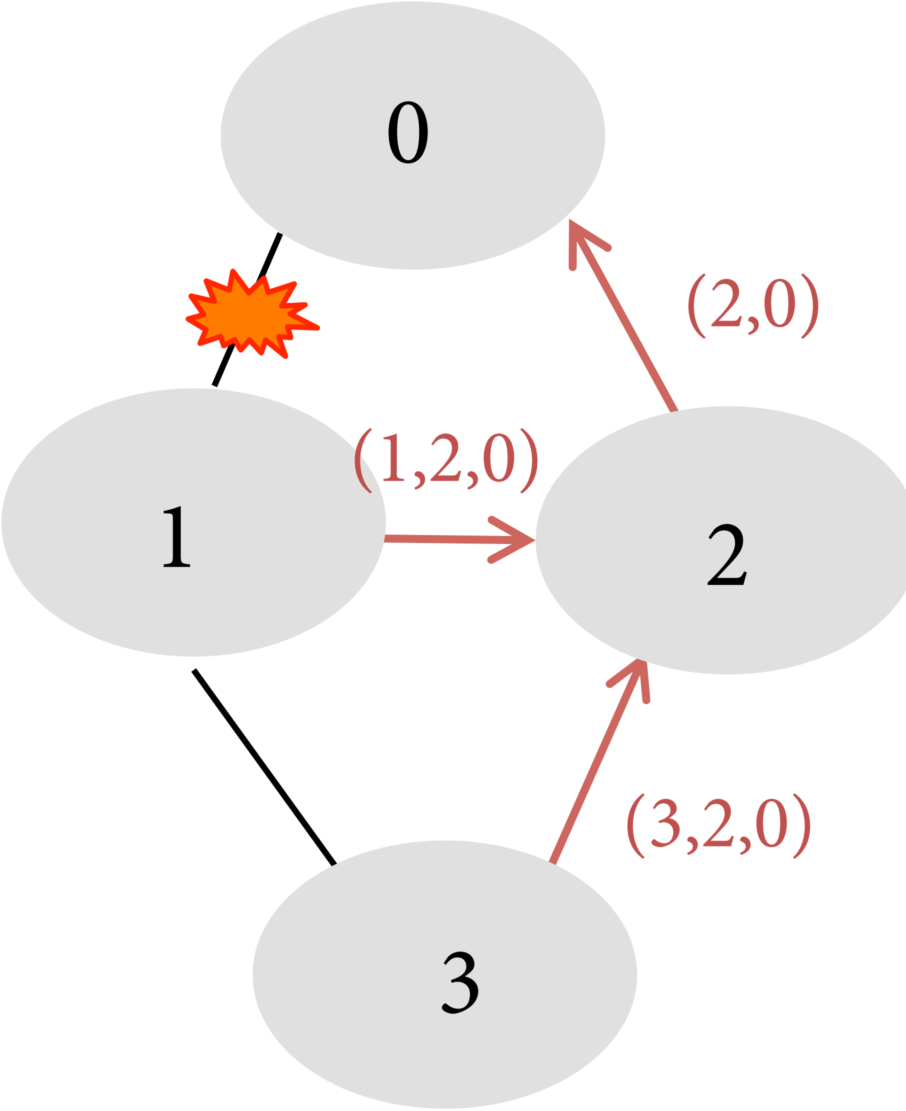
- **Given a change, how long until the network re-stabilizes?**
  - Depends on change: sometimes never
  - Open research problem: "tweak and pray"
  - Distributed setting is challenging
- **Some reasons for change**
  - Topology changes
  - BGP session failures
  - Changes in policy
  - Conflicts between policies can cause oscillation

# Routing Change: Before and After



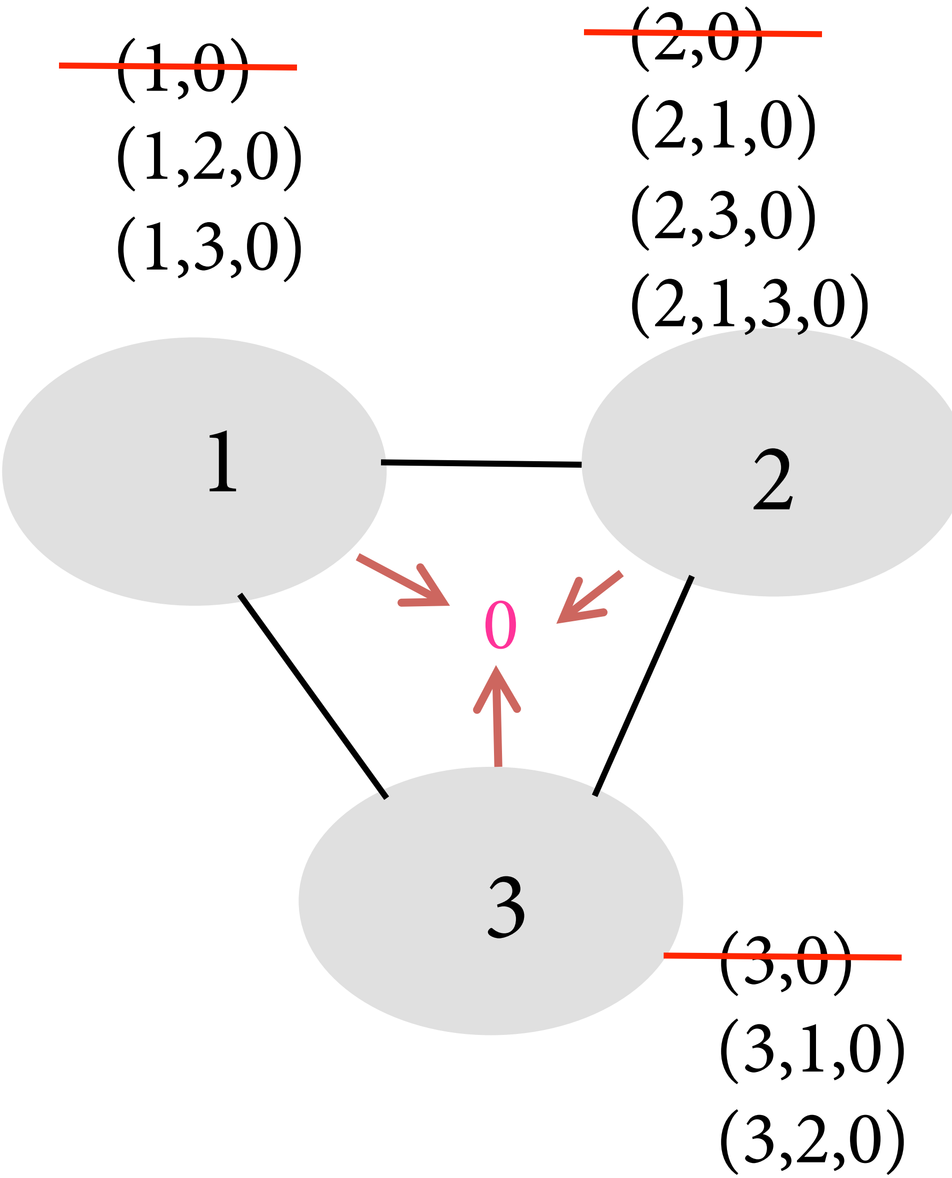
# Routing Change: Path Exploration

- **AS 1**
  - Delete the route (1,0)
  - Switch to next route (1,2,0)
  - Send route (1,2,0) to AS 3
- **AS 3**
  - Sees (1,2,0) replace (1,0)
  - Compares to route (2,0)
  - Switches to using AS 2



# Routing Change: Path Exploration

- **Initial situation**
  - Destination 0 is alive
  - All ASes use direct path
- **When destination dies**
  - All ASes lose direct path
  - All switch to longer paths
  - Eventually withdrawn
- **E.g., AS 2**
  - (2,0) → (2,1,0)
  - (2,1,0) → (2,3,0)
  - (2,3,0) → (2,1,3,0)
  - (2,1,3,0) → null
- **Convergence may be slow!**



~~(1,0)~~
(1,2,0)
(1,3,0)

~~(2,0)~~
(2,1,0)
(2,3,0)
(2,1,3,0)

~~(3,0)~~
(3,1,0)
(3,2,0)

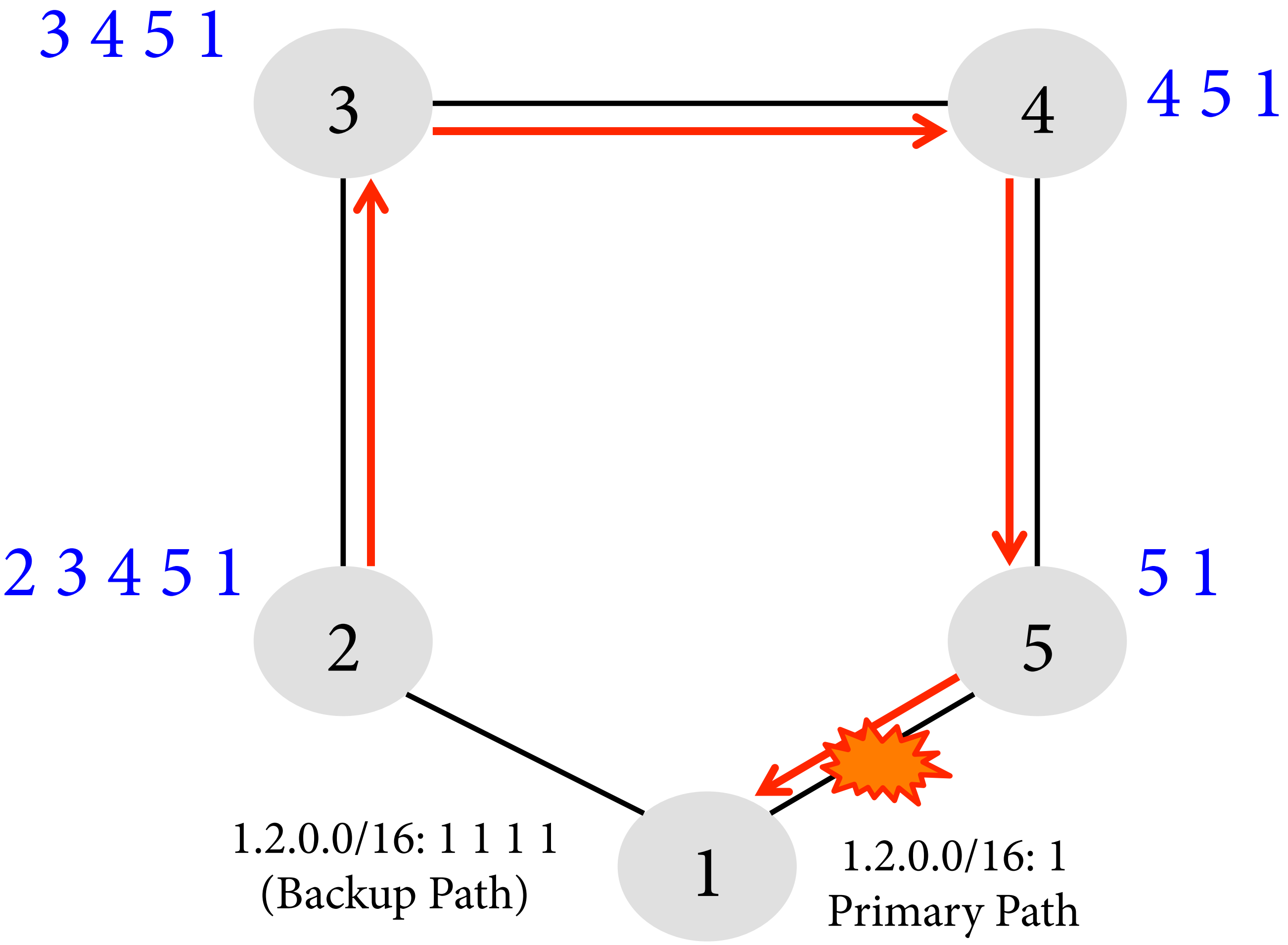
# Route Engineering

- Route filtering
- Setting weights
- More specific routes: longest prefix
- AS prepending: “477 477 477 477”
- More of an art than science

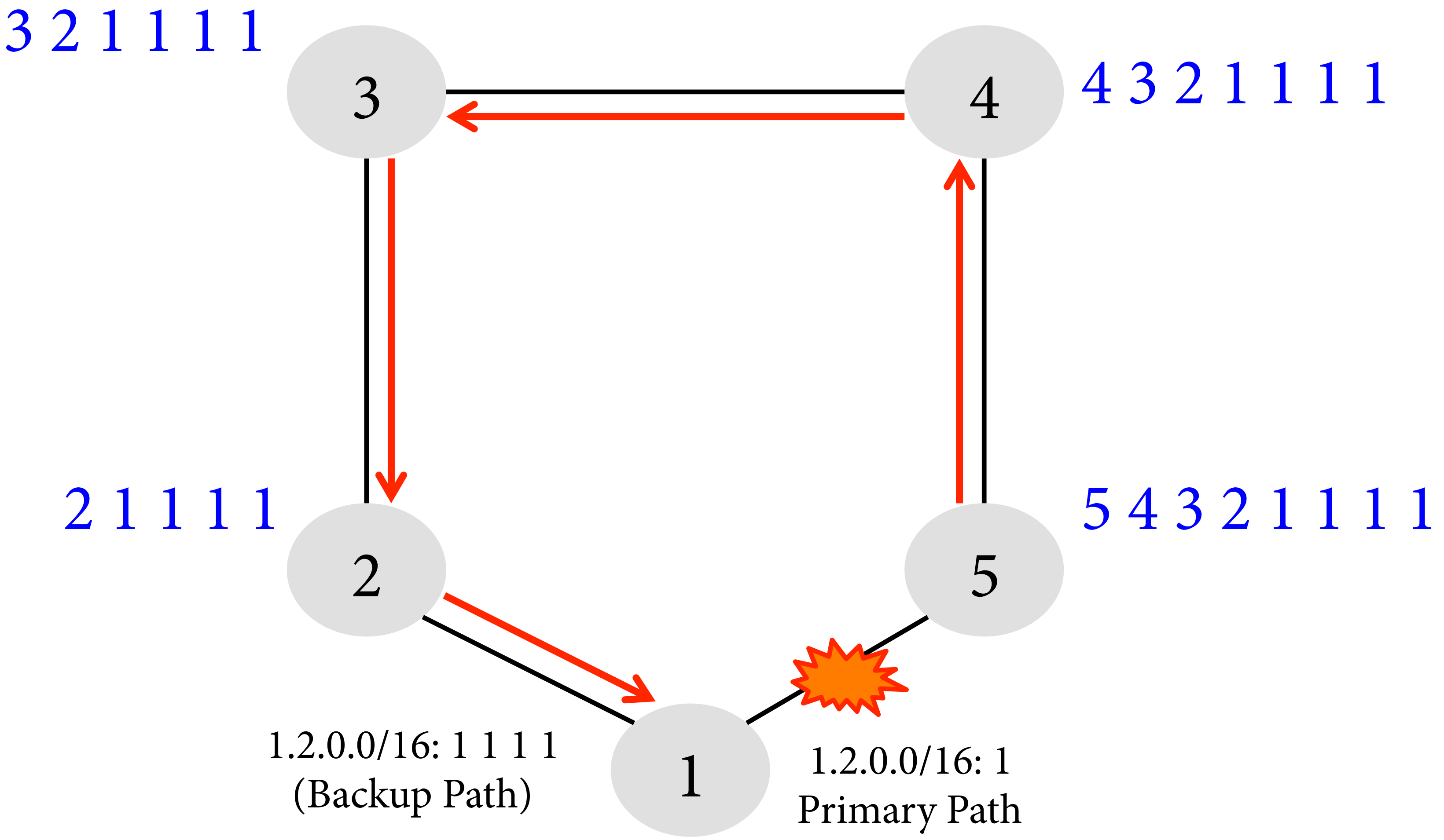
# Multiple Stable Configurations
# BGP Wedgies [RFC 4264]

- **Typical policy:**
  - Prefer routes from customers
  - Then prefer shortest paths

# BGP Wedgies

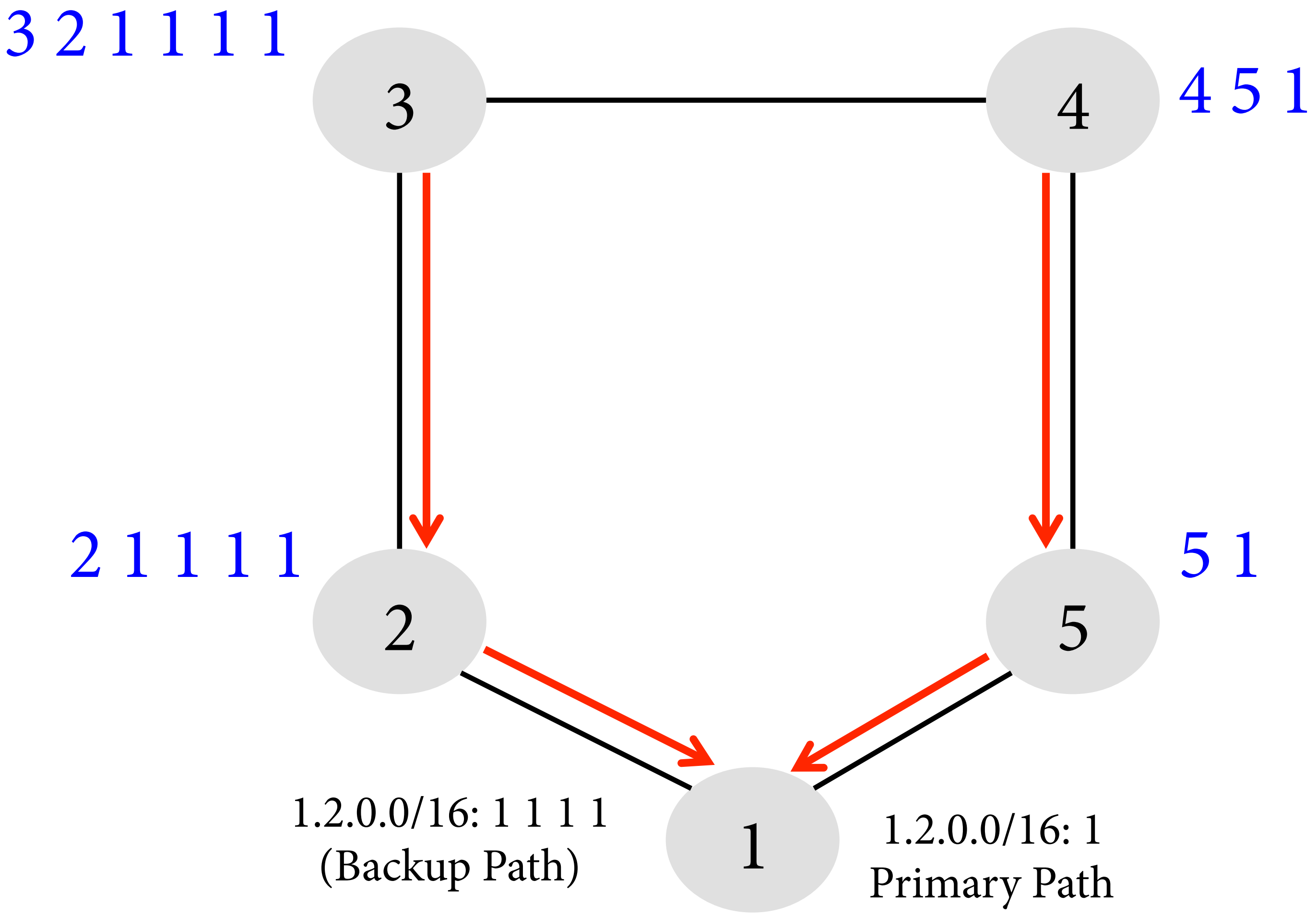

3 4 5 1
3
4
4 5 1
2 3 4 5 1
2
5
5 1
1
1.2.0.0/16: 1 1 1 1
(Backup Path)
1.2.0.0/16: 1
Primary Path

# BGP Wedgies


3 2 1 1 1 1
3
4
4 3 2 1 1 1 1
2 1 1 1 1
2
5
5 4 3 2 1 1 1 1
1
1.2.0.0/16: 1 1 1 1
(Backup Path)
1.2.0.0/16: 1
Primary Path

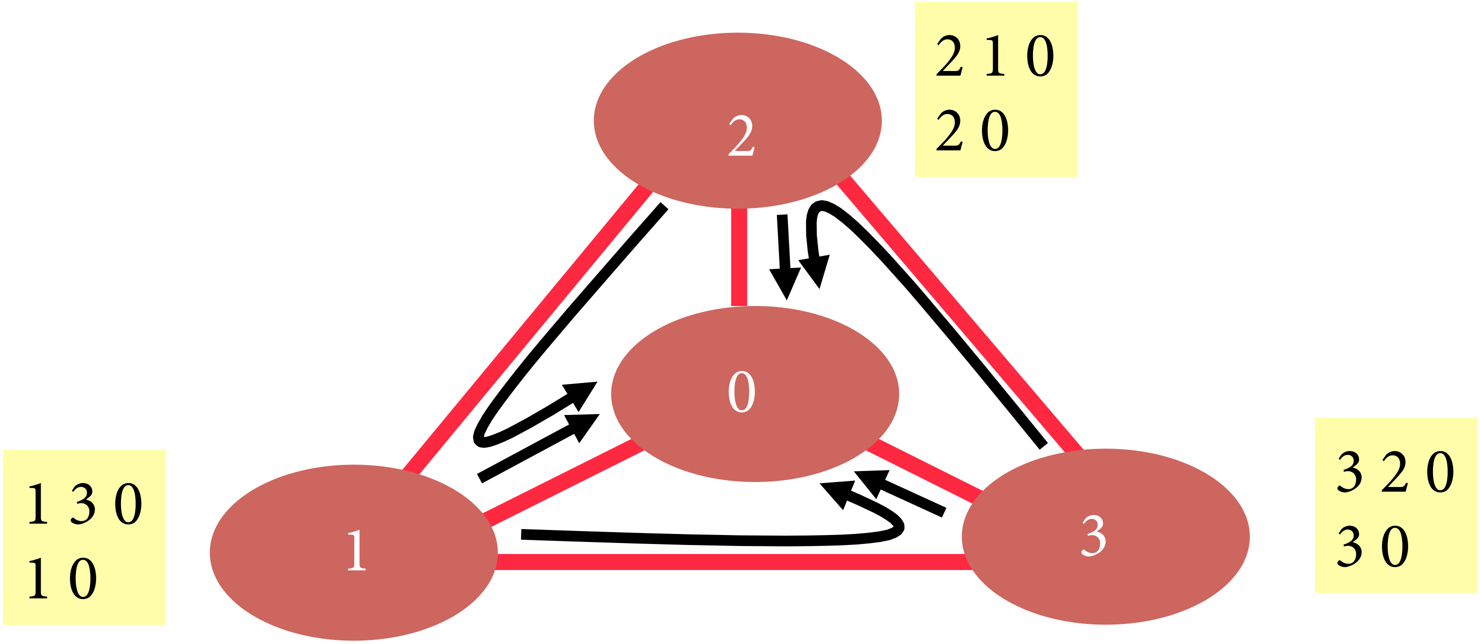
# BGP Wedgies

3 prefers customer route: stable configuration!



# Unstable Configurations

- **Due to policy conflicts (Dispute Wheel)**



2 1 0
2 0

1 3 0
1 0

3 2 0
3 0

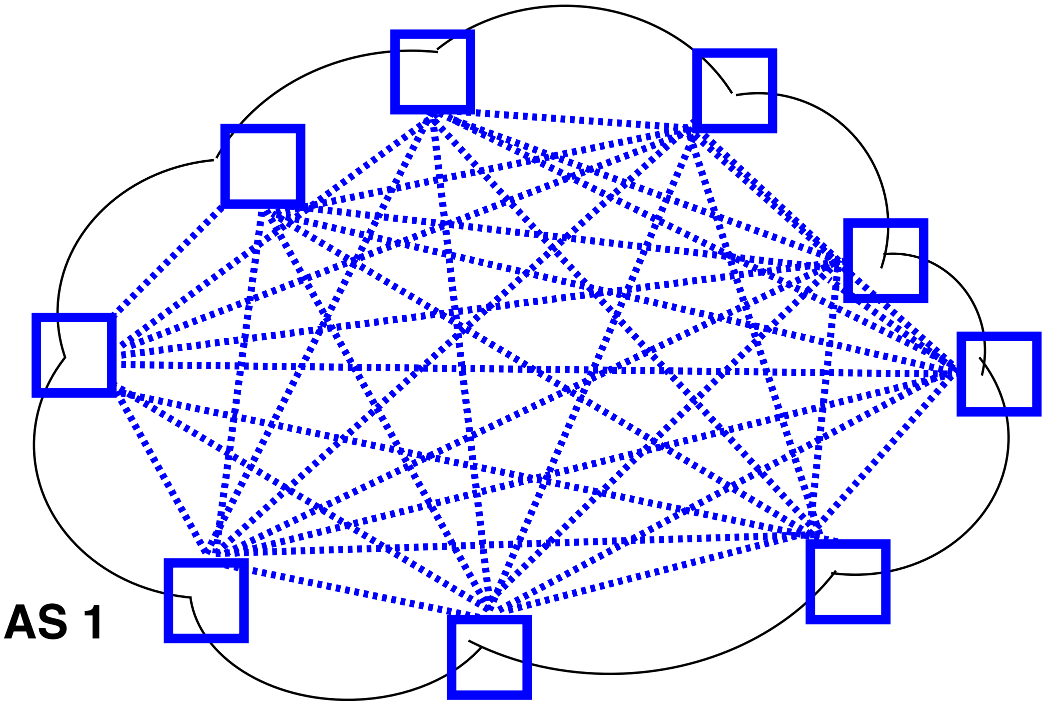
# Avoiding BGP Instabilities

- **Detecting conflicting policies**
  - Centralized: NP-Complete problem!
  - Distributed: open research problem
  - Requires too much cooperation
- **Detecting oscillations**
  - Monitoring for repetitive BGP messages
- **Restricted routing policies and topologies**
  - Some topologies / policies proven to be safe*

* Gao & Rexford, "Stable Internet Routing without Global Coordination", IEEE/ACM ToN, 2001

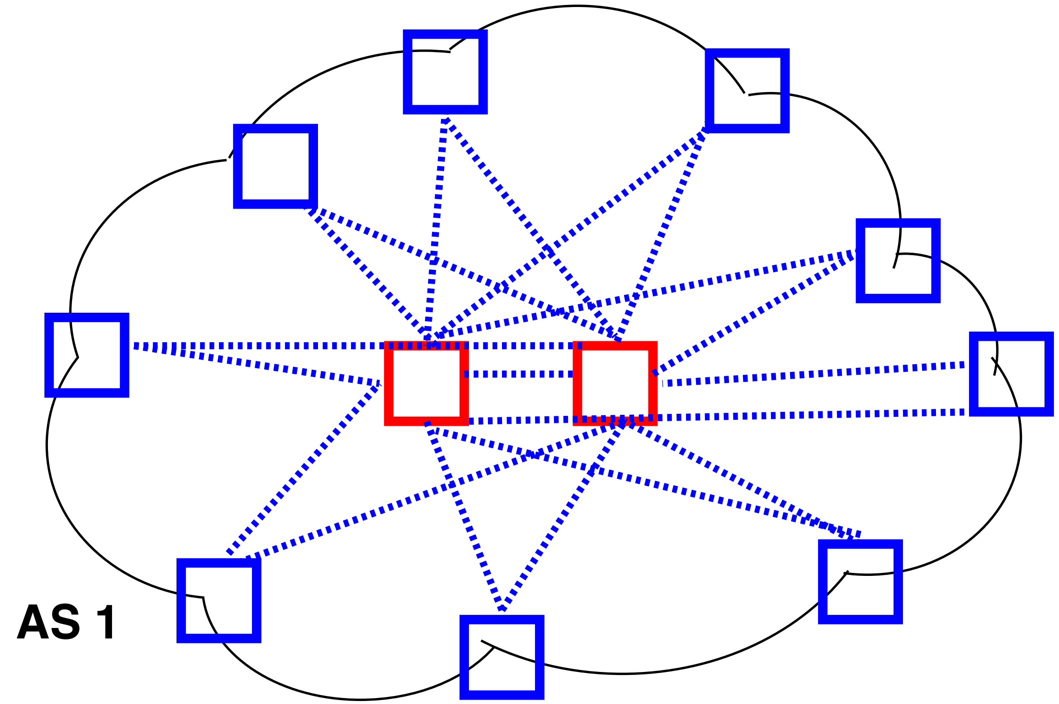
# Scaling iBGP: route reflectors

iBGP Mesh == O(n^2) mess



# Scaling iBGP: route reflectors

Solution: Route Reflectors
O(n*k)



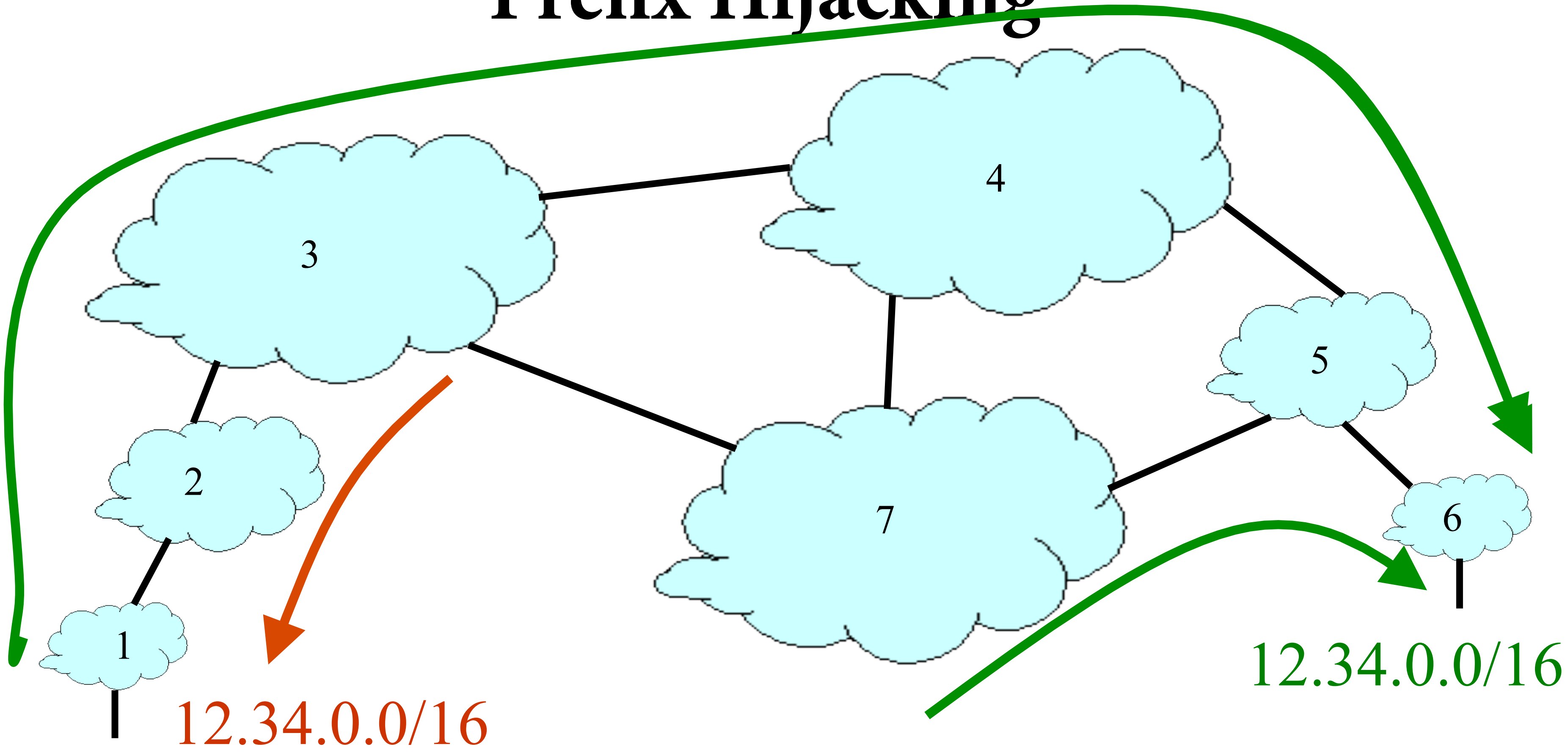
# BGP Security Goals

- Confidential message exchange between neighbors
- Validity of routing information
  - Origin, Path, Policy
- Correspondence to the data path

# Origin: IP Address Ownership and Hijacking

- **IP address block assignment**
  - Regional Internet Registries (ARIN, RIPE, APNIC)
  - Internet Service Providers
- **Proper origination of a prefix into BGP**
  - By the AS who owns the prefix
  - … or, by its upstream provider(s) in its behalf
- **However, what's to stop someone else?**
  - Prefix hijacking: another AS originates the prefix
  - BGP does not verify that the AS is authorized
  - Registries of prefix ownership are inaccurate

# Prefix Hijacking

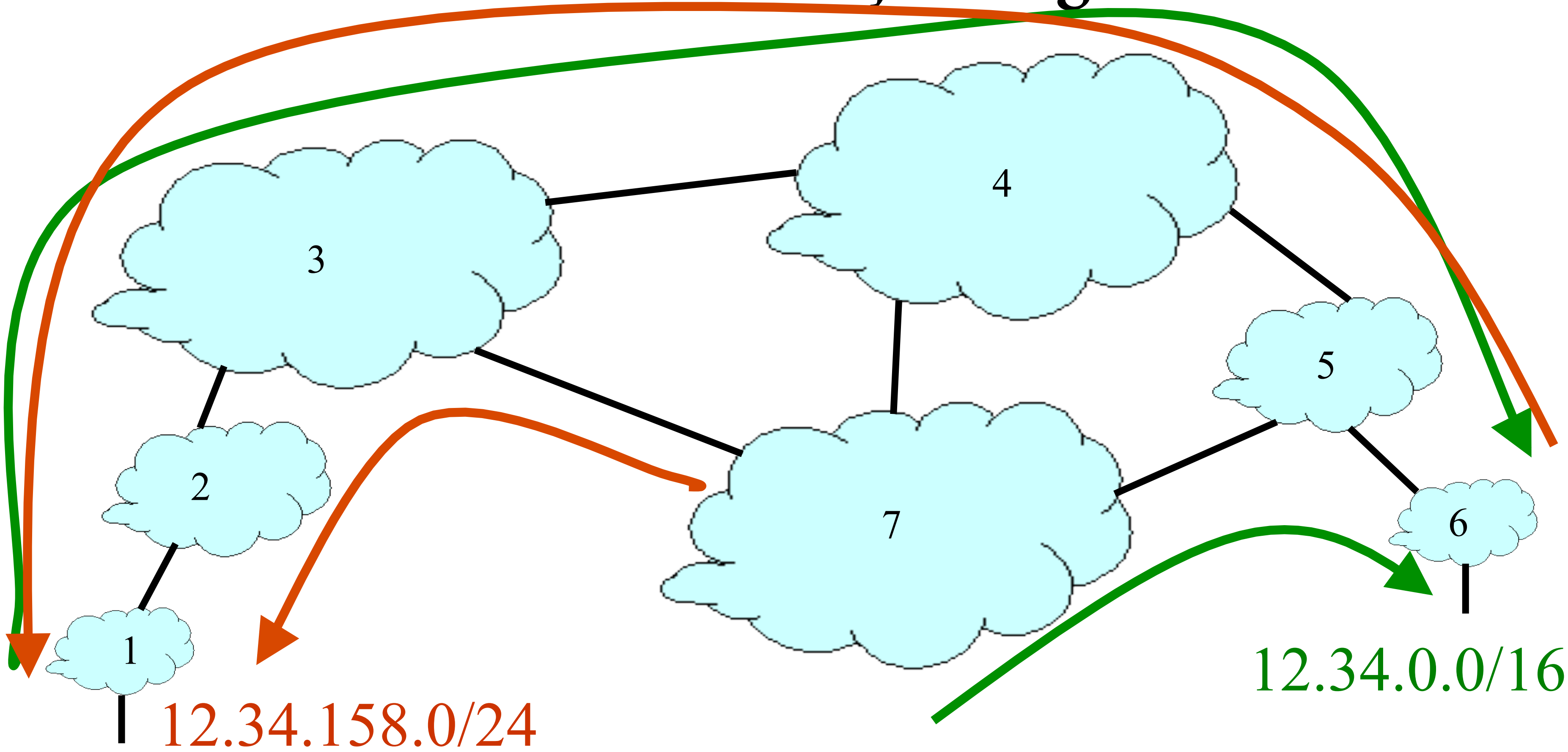


- **Consequences for the affected ASes**
  - Blackhole: data traffic is discarded
  - Snooping: data traffic is inspected, and then redirected
  - Impersonation: data traffic is sent to bogus destinations

# Hijacking is Hard to Debug

- **Real origin AS doesn't see the problem**
  - Picks its own route
  - Might not even learn the bogus route
- **May not cause loss of connectivity**
  - E.g., if the bogus AS snoops and redirects
  - … may only cause performance degradation
- **Or, loss of connectivity is isolated**
  - E.g., only for sources in parts of the Internet
- **Diagnosing prefix hijacking**
  - Analyzing updates from many vantage points
  - Launching traceroute from many vantage points

# Sub-Prefix Hijacking



- **Originating a more-specific prefix**
  - Every AS picks the bogus route for that prefix
  - Traffic follows the longest matching prefix

# How to Hijack a Prefix

- **The hijacking AS has**
  - Router with eBGP session(s)
  - Configured to originate the prefix
- **Getting access to the router**
  - Network operator makes configuration mistake
  - Disgruntled operator launches an attack
  - Outsider breaks in to the router and reconfigures
- **Getting other ASes to believe bogus route**
  - Neighbor ASes not filtering the routes
  - … e.g., by allowing only expected prefixes
  - But, specifying filters on *peering* links is hard

# Pakistan Youtube incident

- Youtube's has prefix 208.65.152.0/22
- Pakistan's government order Youtube blocked
- Pakistan Telecom (AS 17557) announces 208.65.153.0/24 in the wrong direction (outwards!)
- Longest prefix match caused worldwide outage
- http://www.youtube.com/watch?v=IzLPKuAOe50

# Many other incidents

- **Spammers steal unused IP space to hide**
  - Announce very short prefixes (e.g., /8). Why?
  - For a short amount of time
- **China incident, April 8th 2010**
  - China Telecom's AS23724 generally announces 40 prefixes
  - On April 8th, announced ~37,000 prefixes
  - About 10% leaked outside of China
  - Suddenly, going to [www.dell.com](http://www.dell.com) might have you routing through AS23724!

# Attacks on BGP Paths

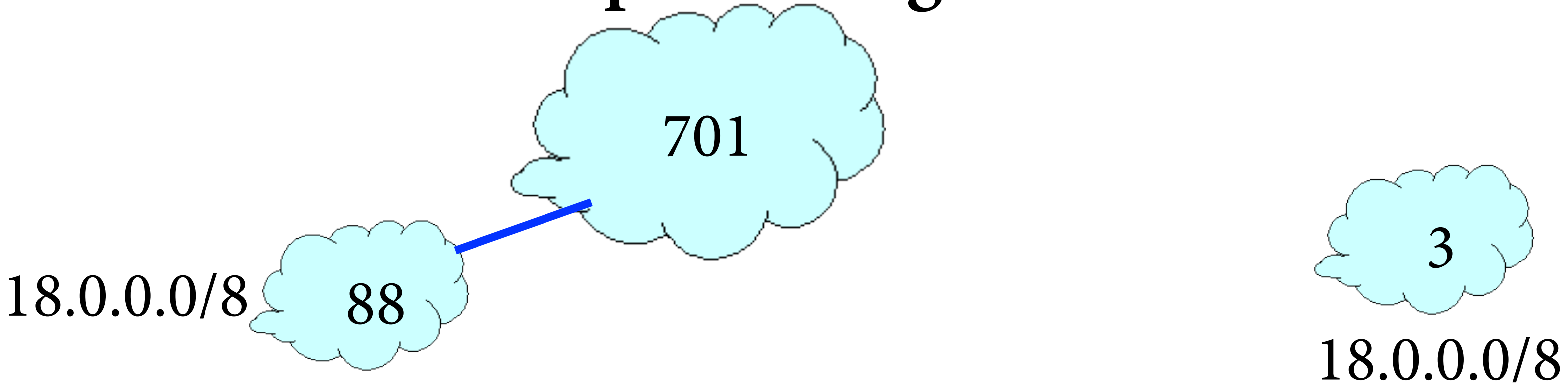
- **Remove an AS from the path**
  - E.g., 701 3715 88 -> 701 88
- **Why?**
  - Attract sources that would normally avoid AS 3715
  - Make path through you look more attractive
  - Make AS 88 look like it is closer to the core
  - Can fool loop detection!
- **May be hard to tell whether this is a lie**
  - 88 could indeed connect directly to 701!

# Attacks on BGP Paths

- **Adding ASes to the path**
  - E.g., 701 88 -> 701 3715 88
- **Why?**
  - Trigger loop detection in AS 3715
    - This would block unwanted traffic from AS 3715!
  - Make your AS look more connected
- **Who can tell this is a lie?**
  - AS 3715 could, if it could see the route
  - AS 88 could, but would it really care?

# Attacks on BGP Paths

- **Adding ASes at the end of the path**
  - E.g., 701 88 into 701 88 3
- **Why?**
  - Evade detection for a bogus route (if added AS is legitimate owner of a prefix)
- **Hard to tell that the path is bogus!**



# Proposed Solution: S-BGP

- **Based on a public key infrastructure**
- **Address attestations**
  - Claims the right to originate a prefix
  - Signed and distributed out of band
  - Checked through delegation chain from ICANN
- **Route attestations**
  - Attribute in BGP update message
  - Signed by each AS as route along path
- **S-BGP can avoid**
  - Prefix hijacking
  - Addition, removal, or reordering of intermediate ASes

# S-BGP Deployment

- **Very challenging**
  - PKI (RPKI)
  - Accurate address registries
  - Need to perform cryptographic operations on all path operations
  - Flag day almost impossible
  - Incremental deployment offers little incentive
- **But there is hope! [Goldberg et al, 2011]**
  - Road to incremental deployment
  - Change rules to break ties for secure paths
  - If a few top Tier-1 ISPs
  - Plus their respective stub clients deploy simplified version (just sign, not validate)
  - Gains in traffic => $ => adoption!

# Data Plane Attacks

- **Routers/ASes can advertise one route, but not necessarily follow it!**
- **May drop packets**
  - Or a fraction of packets
  - What if you just slow down some traffic?
- **Can send packets in a different direction**
  - Impersonation attack
  - Snooping attack
- **How to detect?**
  - Congestion or an attack?
  - Can let ping/traceroute packets go through
  - End-to-end checks?
- **Harder to pull off, as you need control of a router**

# BGP Recap

- Key protocol that holds Internet routing together
- Path Vector Protocol among Autonomous Systems
- Policy, feasibility first; non-optimal routes
- Important security problems

# Next Class

- **Network layer wrap up**