Announcement: Project 1 released!

- Released yesterday: spec is on the website (and Ed)
- Due Monday, Feb. 26 at 11:59PM
- More office hours next week for the project
- Can also ask questions on Ed
- Extensions can be granted for DSP students and extenuating circumstances. Form will be uploaded to Ed soon.

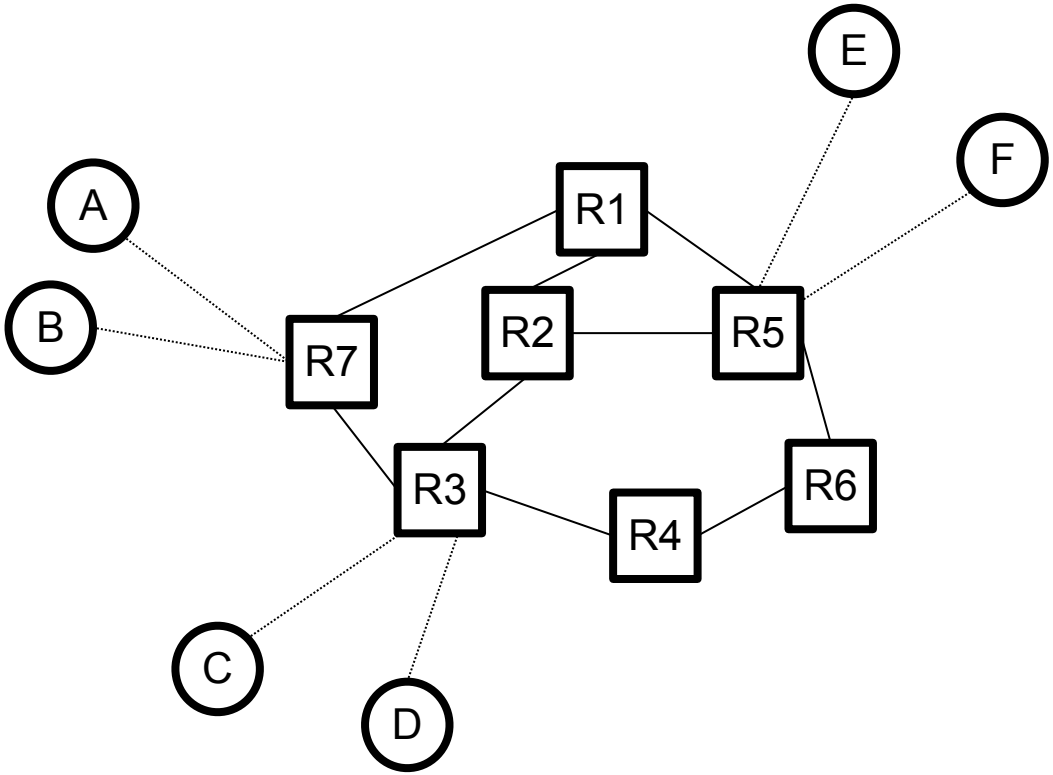
CS 168
Interdomain Routing

Spring 2024

Sylvia Ratnasamy

CS168.io

Routing, so far...



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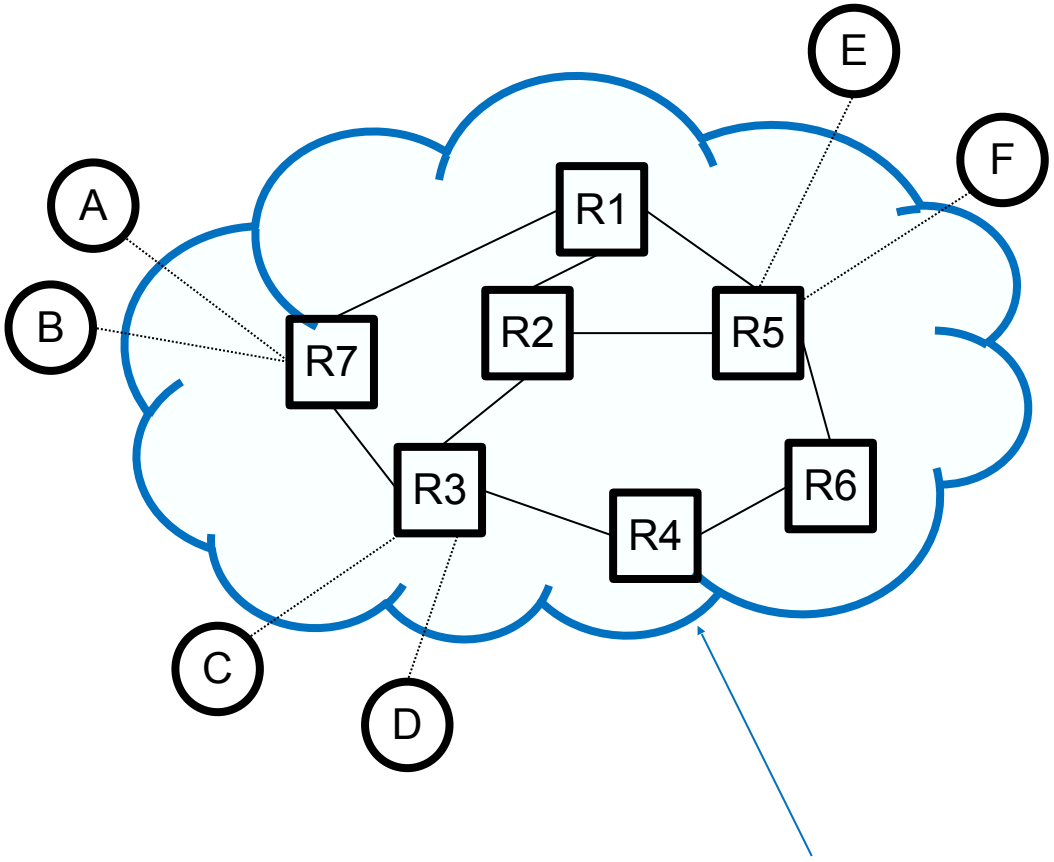
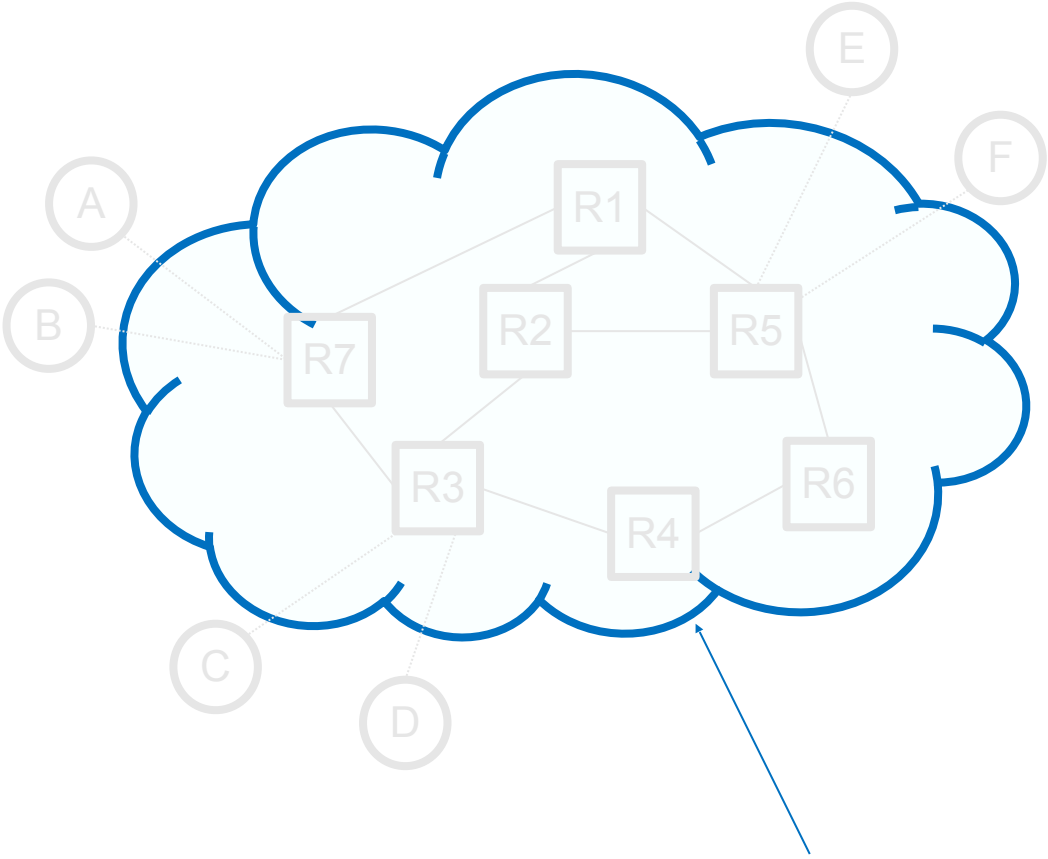


"Domain" or "Autonomous System (AS)"



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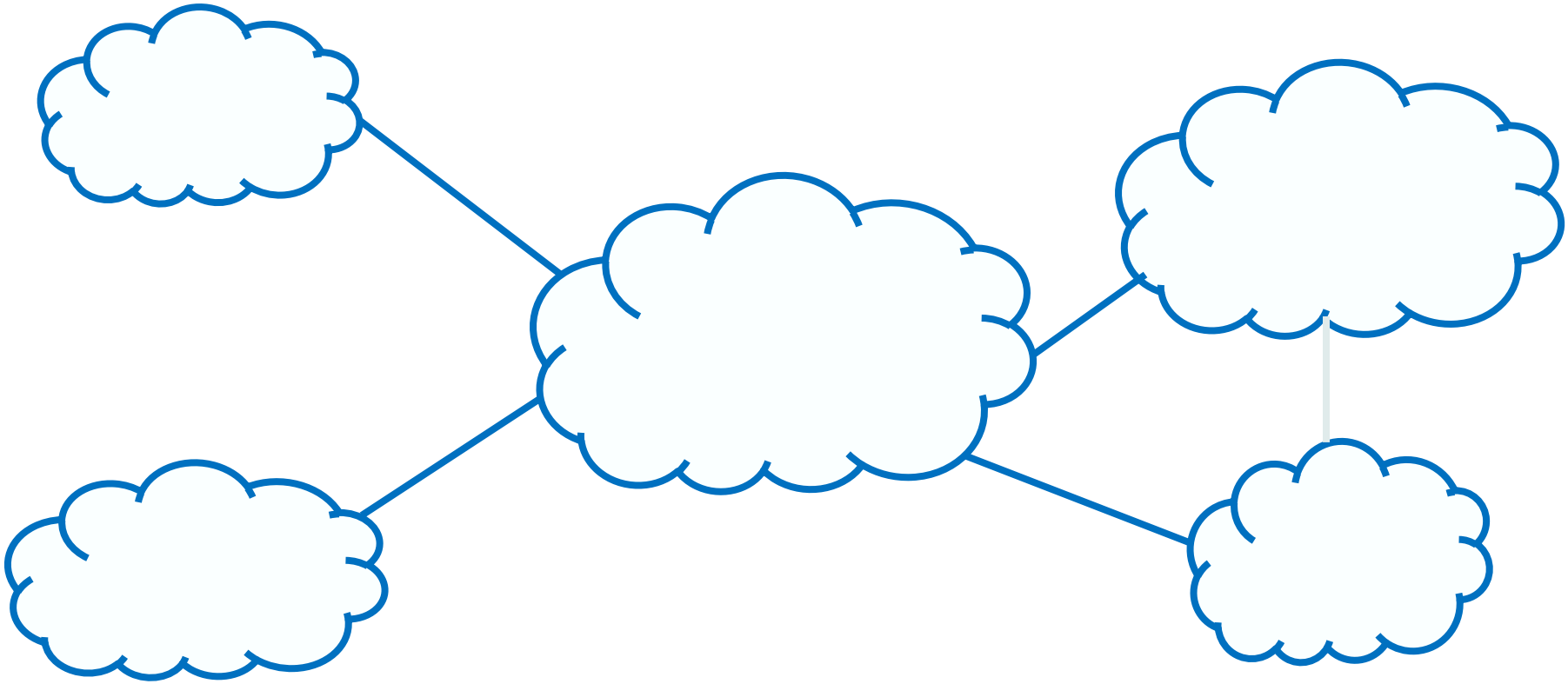

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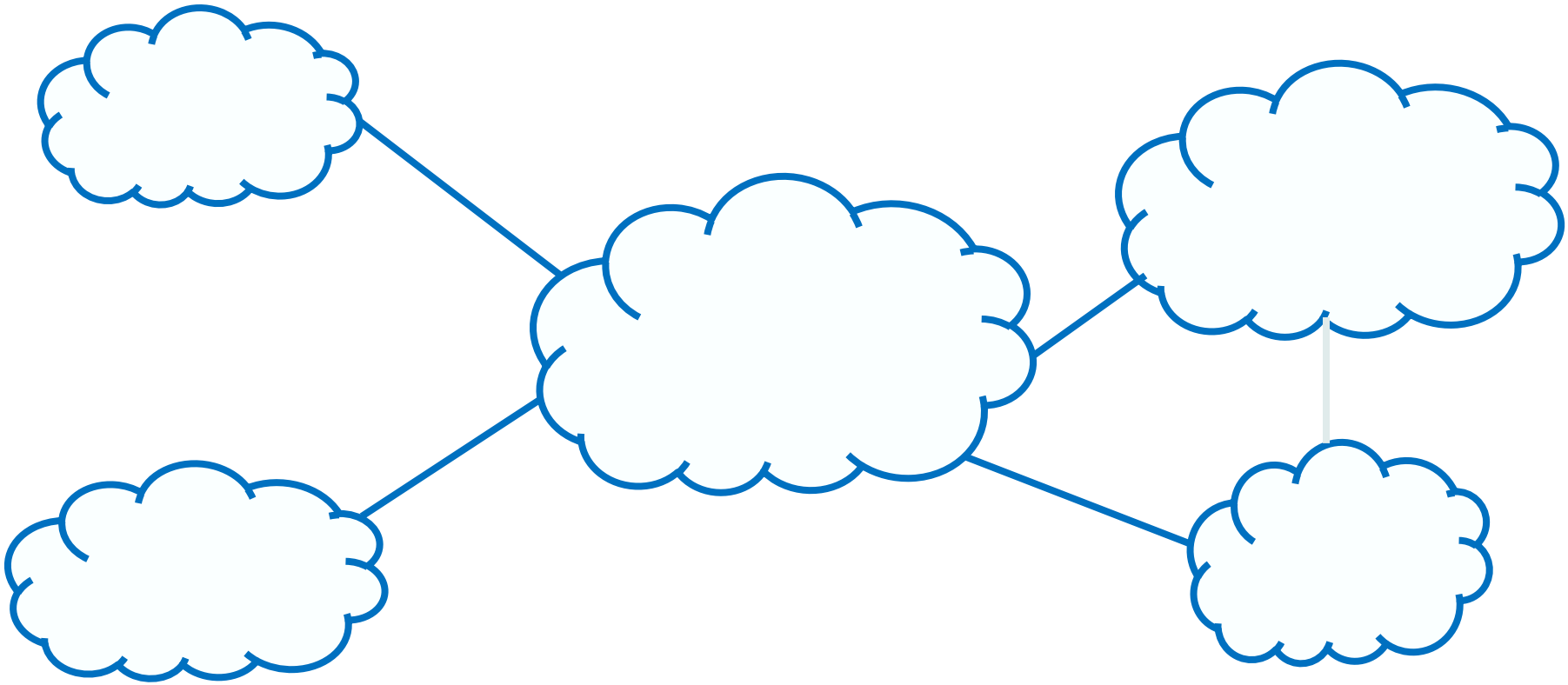

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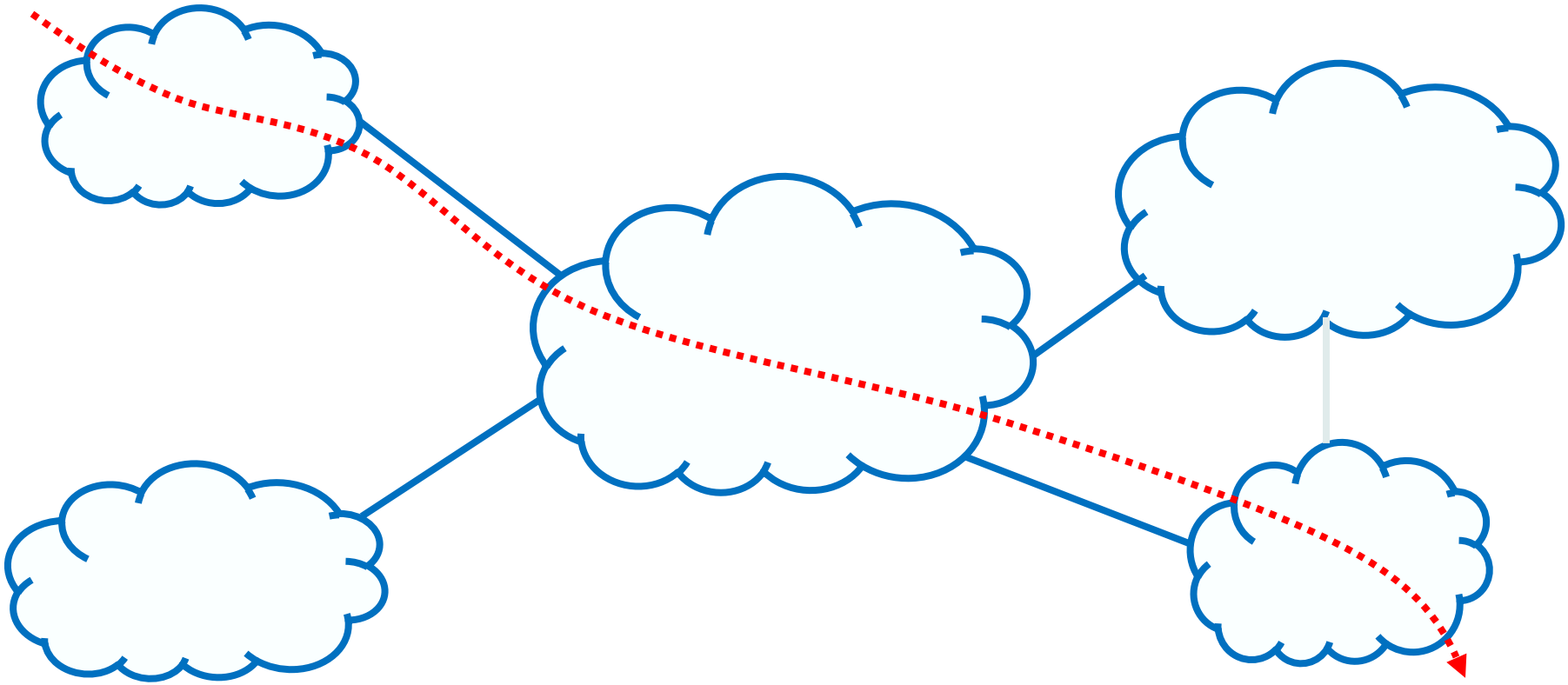

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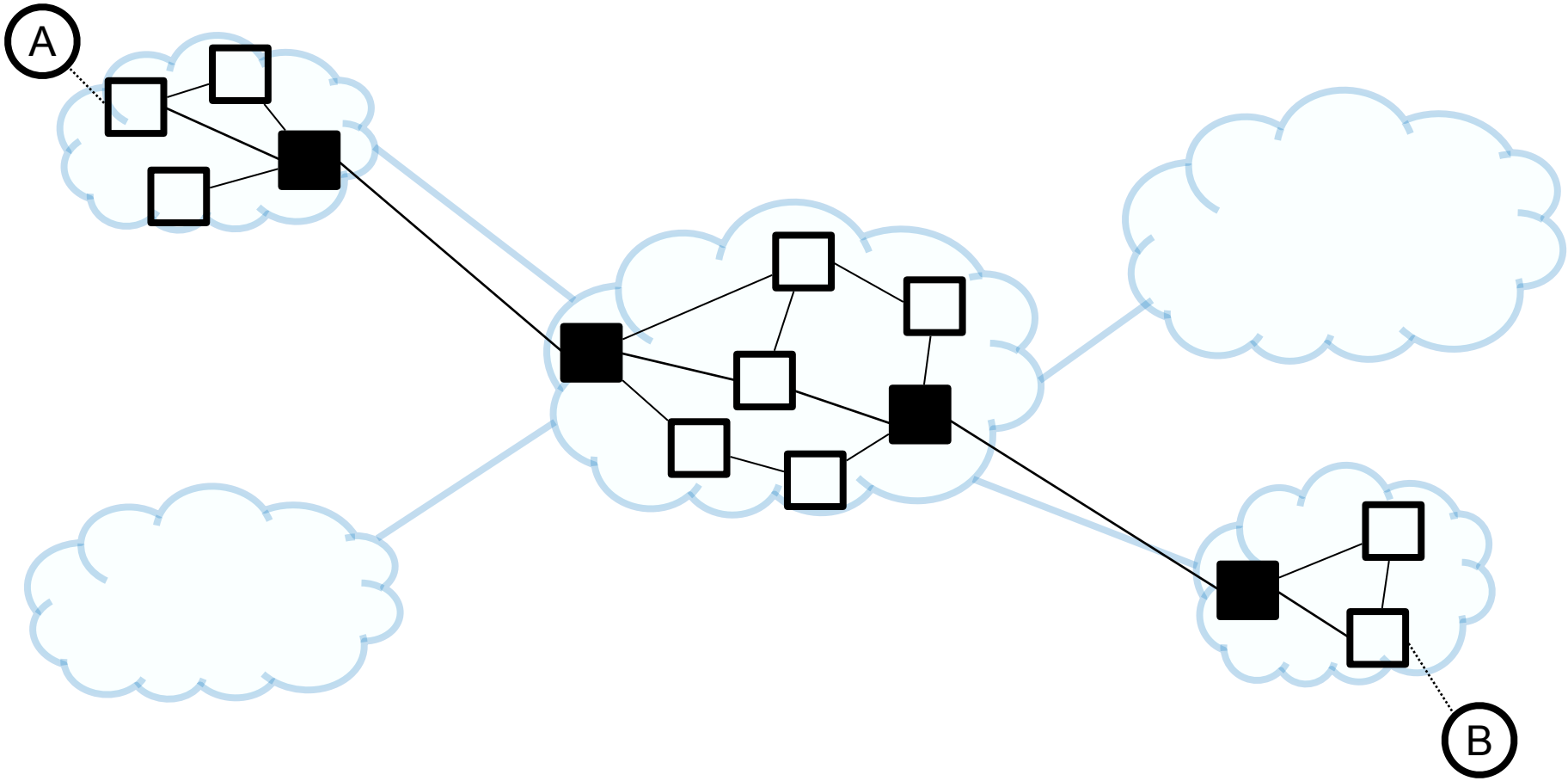

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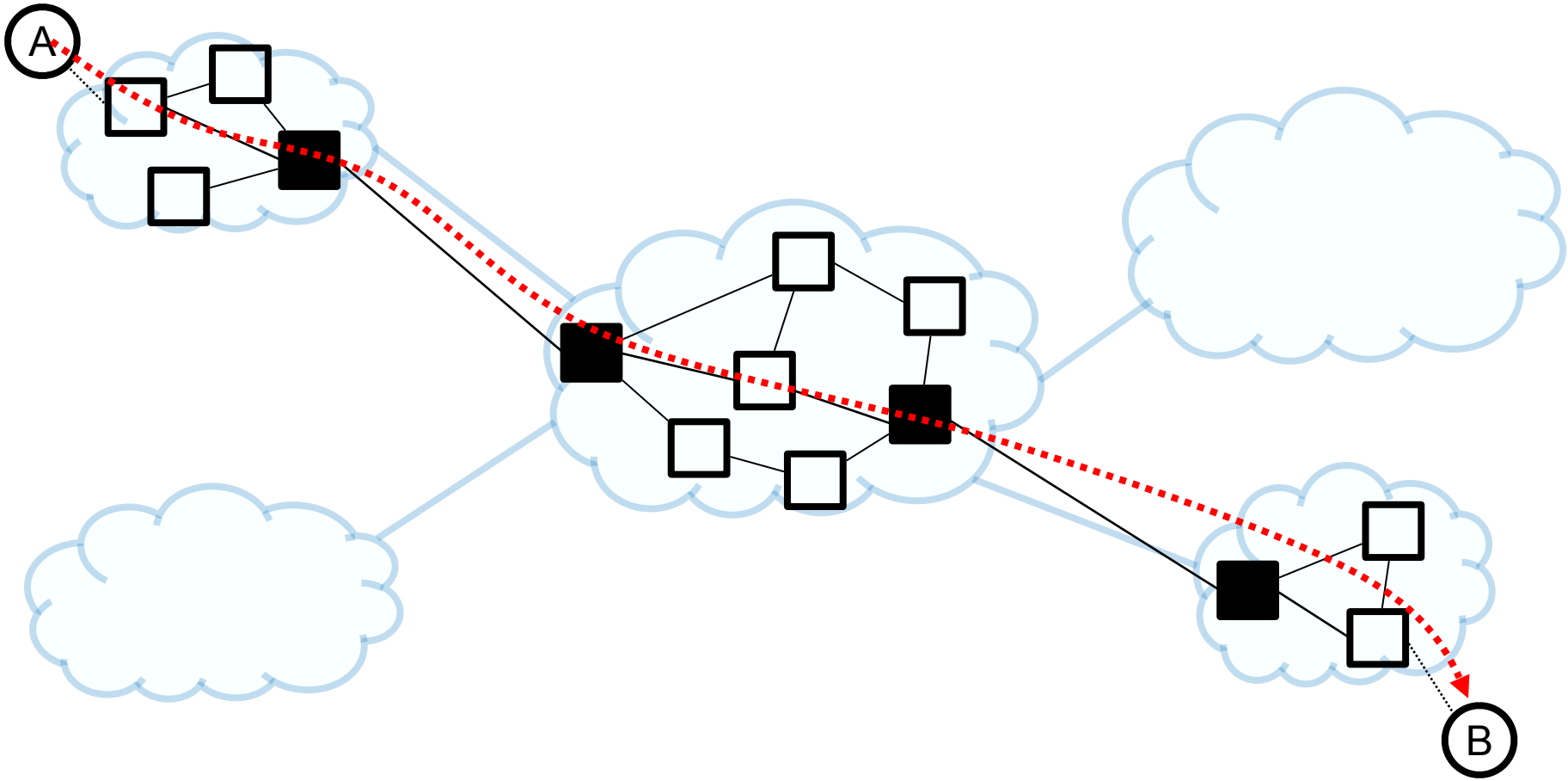

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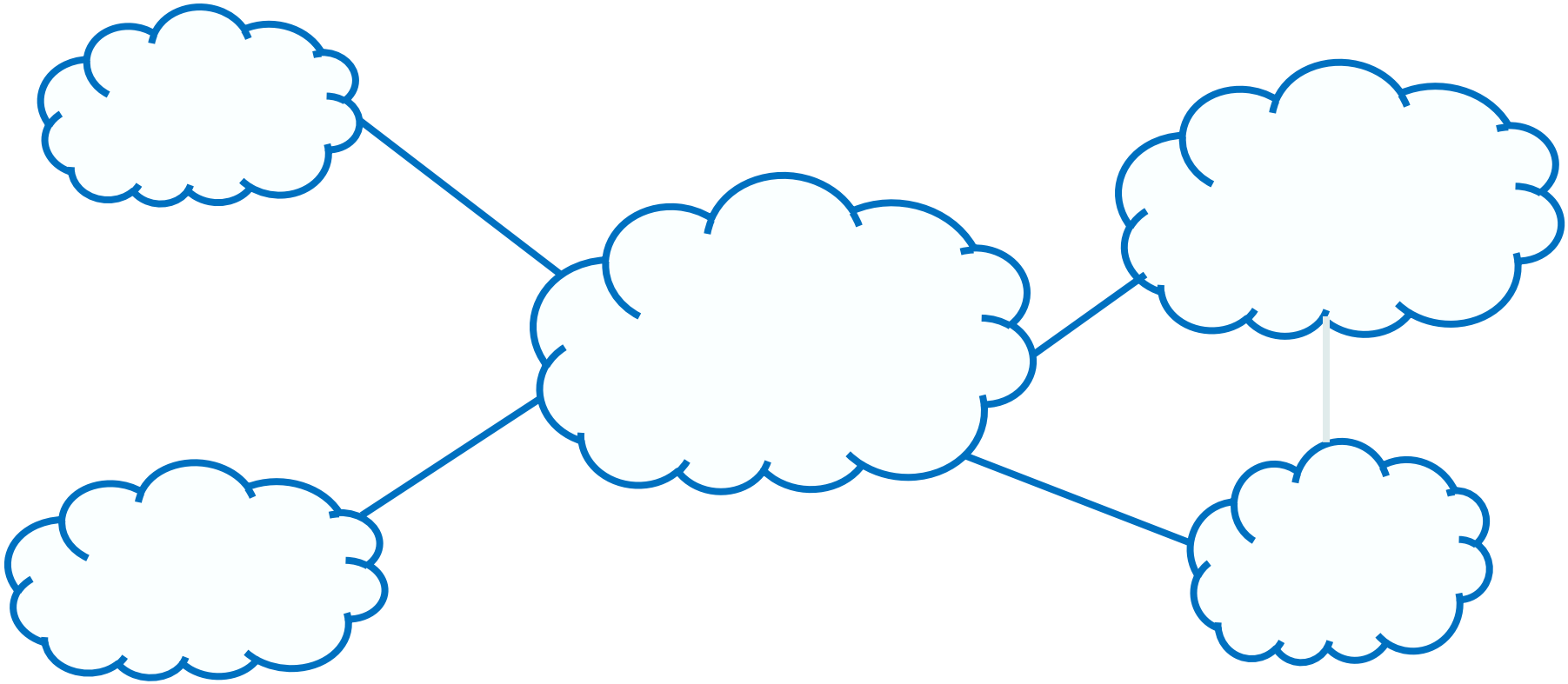

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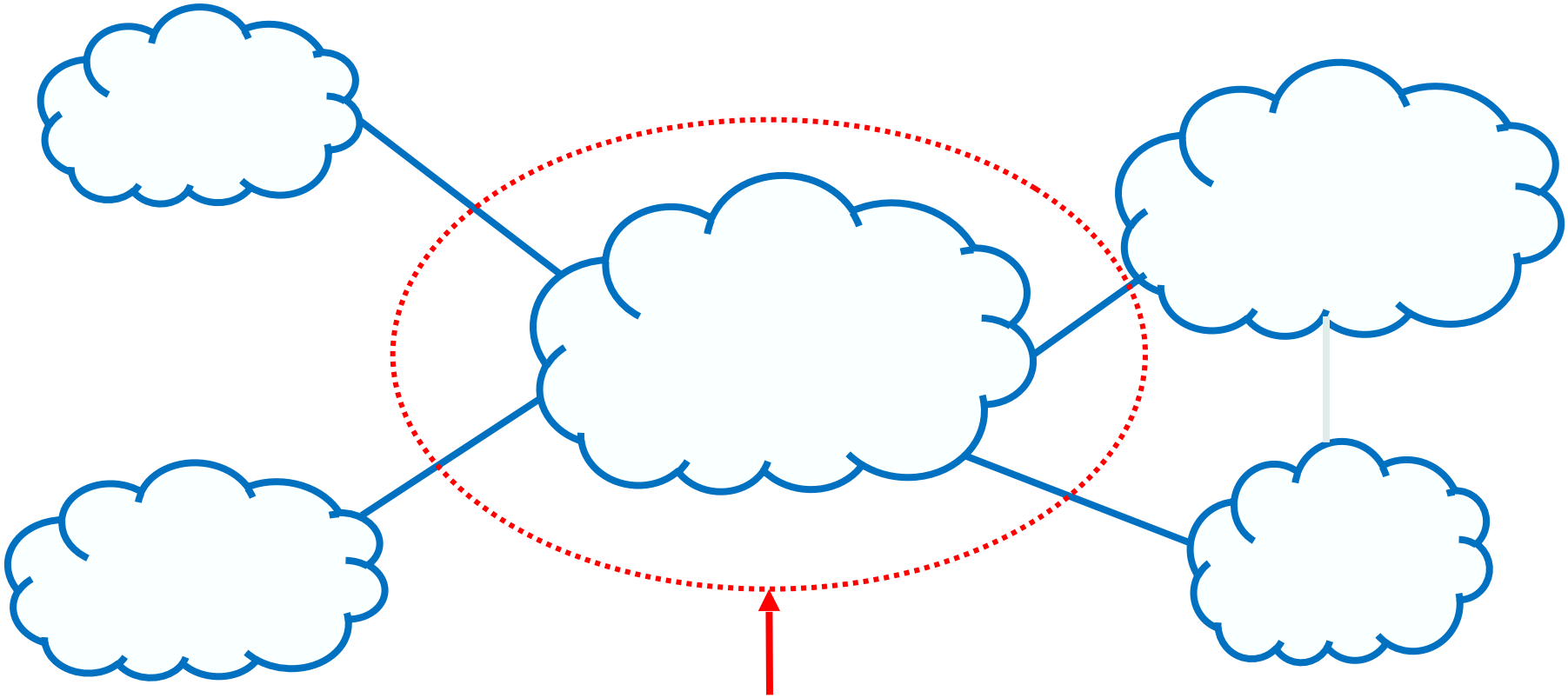

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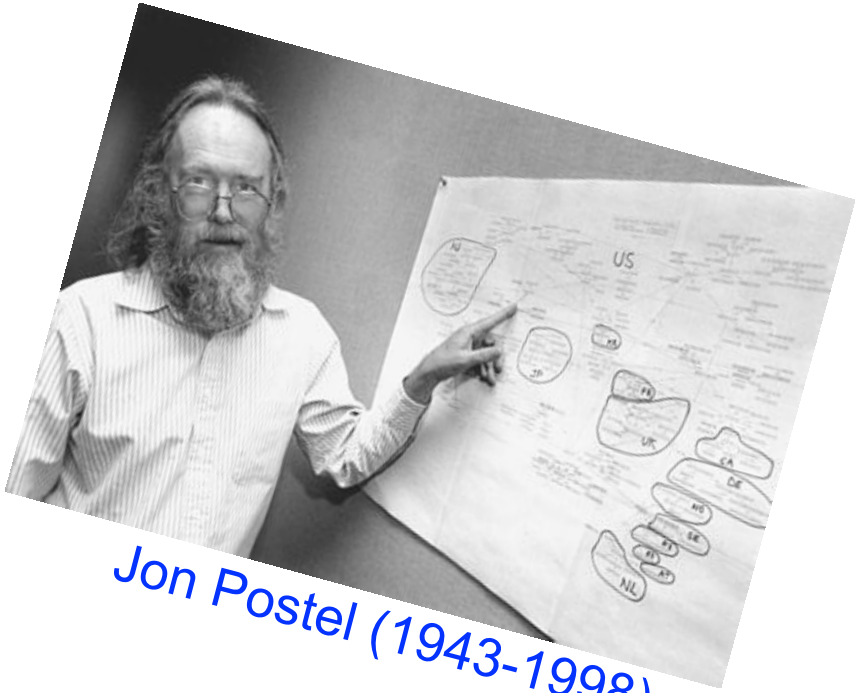

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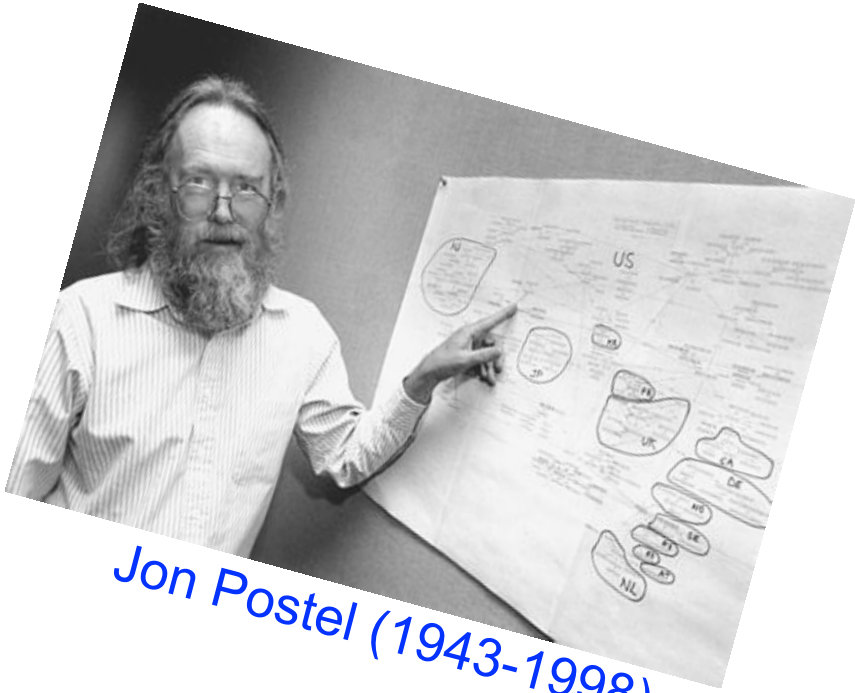

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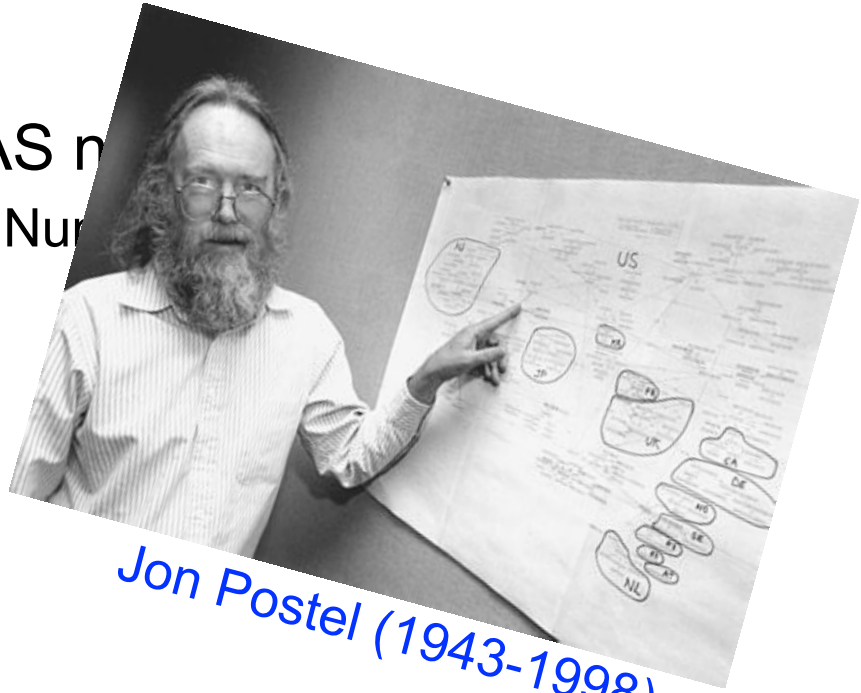
Autonomous Systems (AS)

- AS is a network under a single administrative control
  - Think AT&T, UCB, IBM, France Telecom *etc.*
- Often informally called “domains”
- Each AS is assigned a unique AS n
  - Assigned by the Internet Assigned Nu
  - E.g., ASN 25 is UCB



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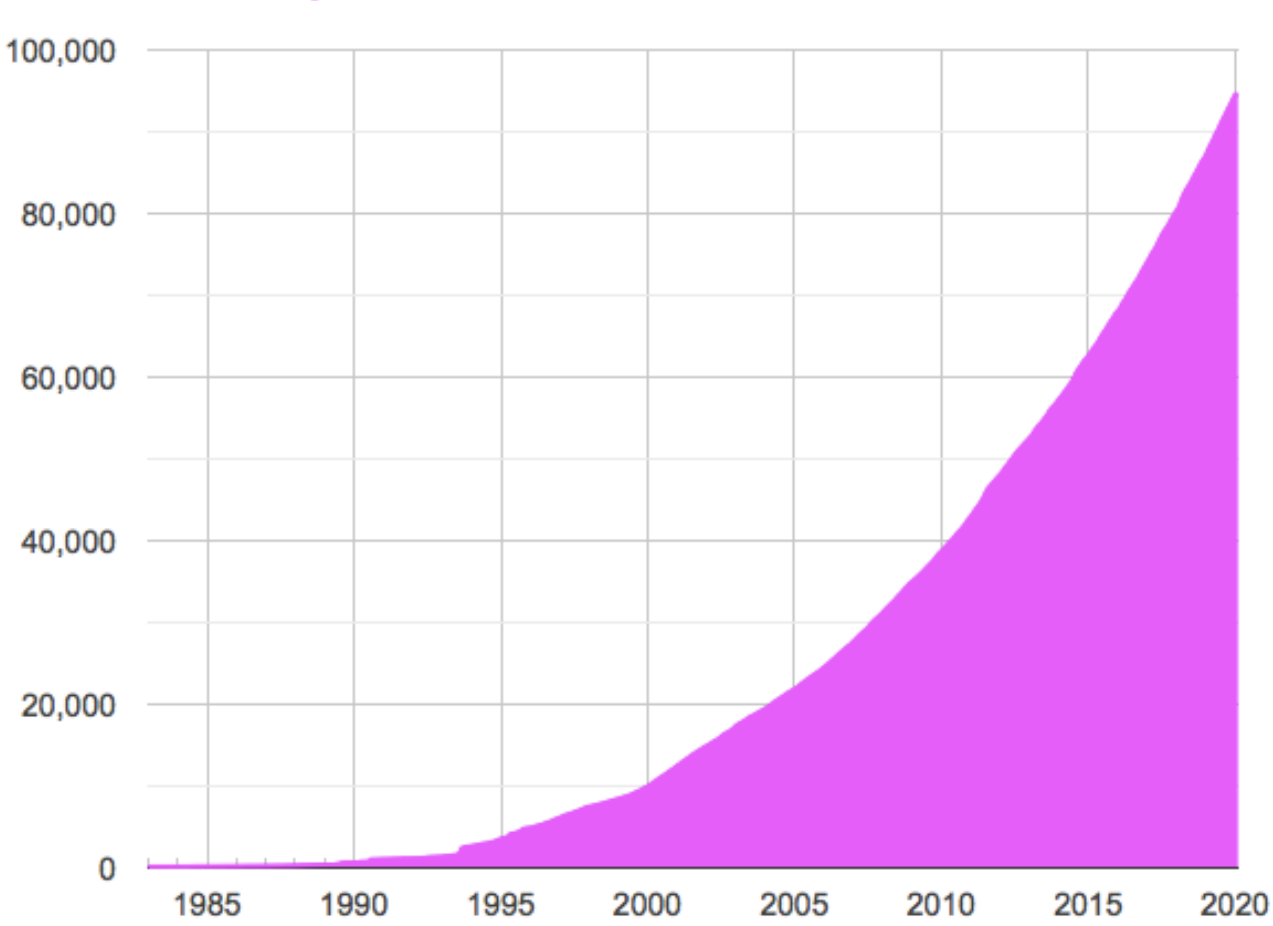

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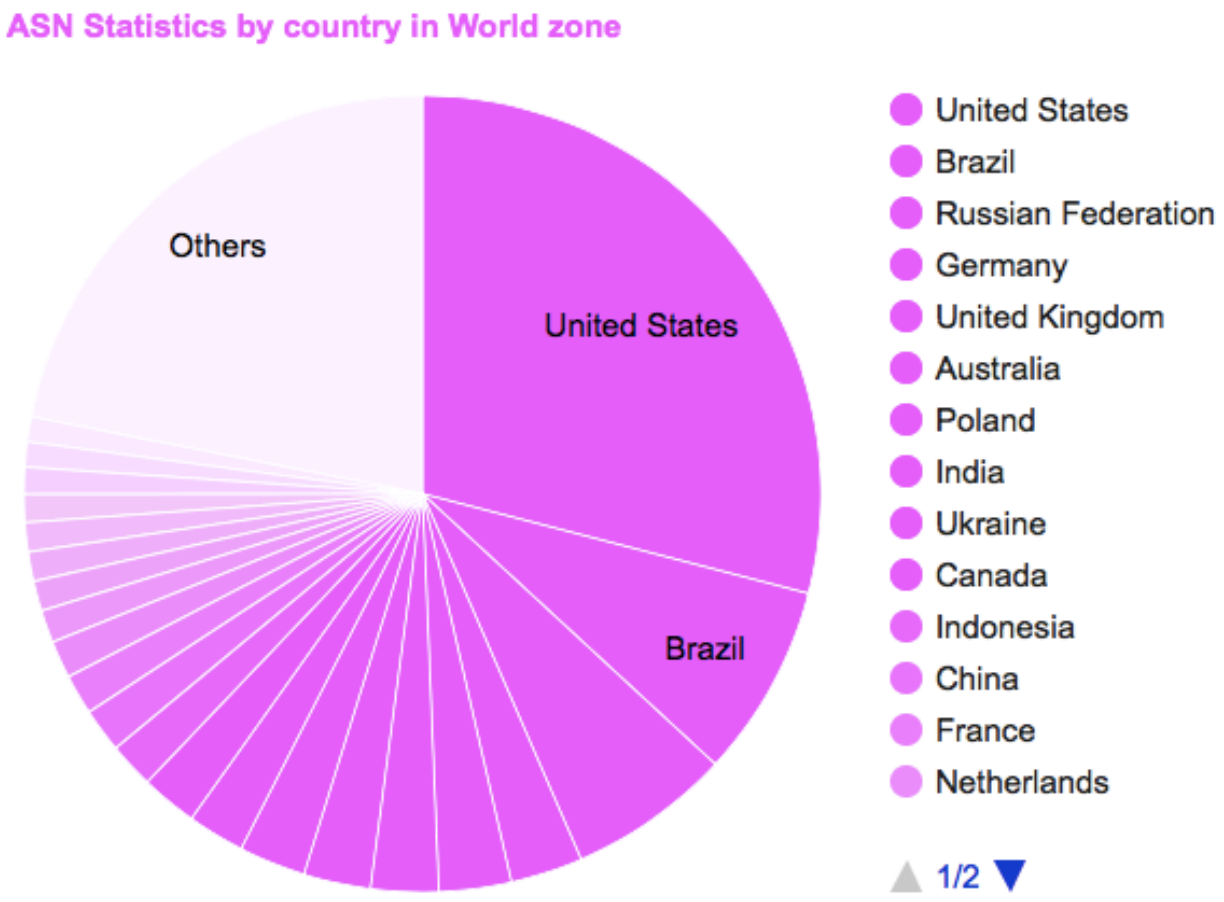

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  - Companies, universities, etc.
- **Transit**: carries packets on behalf of other *ASes*
  - Can vary greatly in scale (global, regional, etc.)

Interdomain topology is shaped by the business relationships between ASes

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- Three basic kinds of relationships between ASes
  - AS X can be AS Y's *customer*
  - AS X can be AS Y's *provider*
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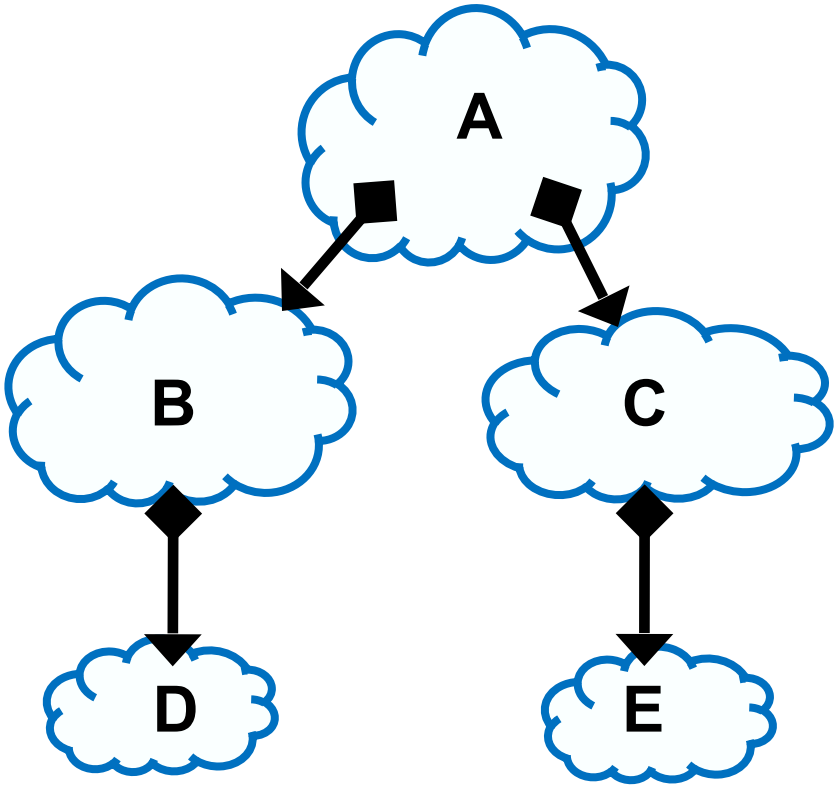
- Business implications
  - Customer pays provider
  - Peers don't pay each other
    - Assumed to exchange roughly equal traffic

AS graph w/ business relationships



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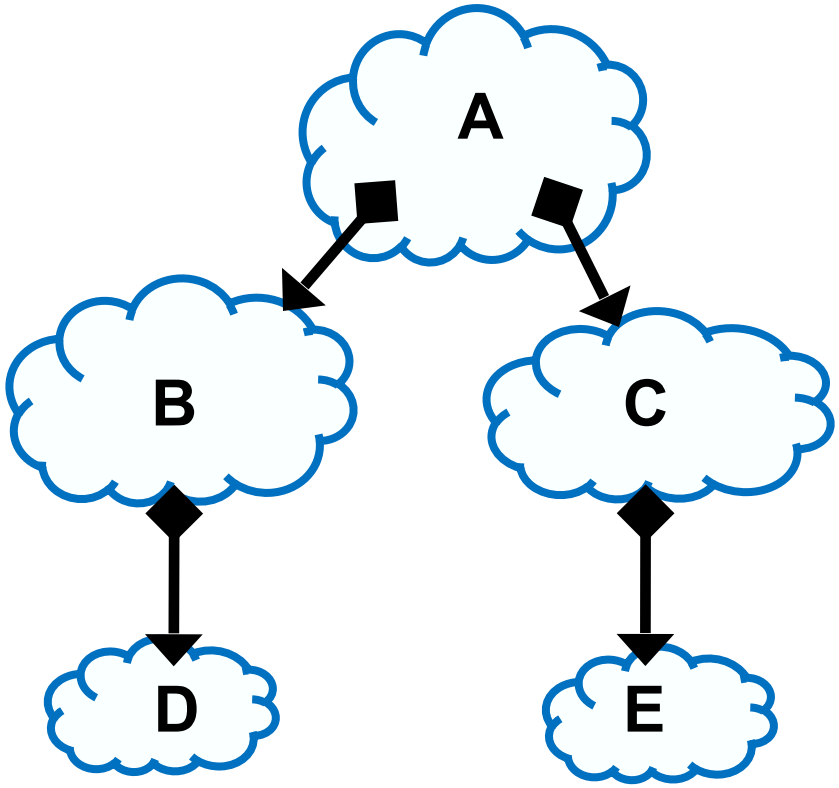

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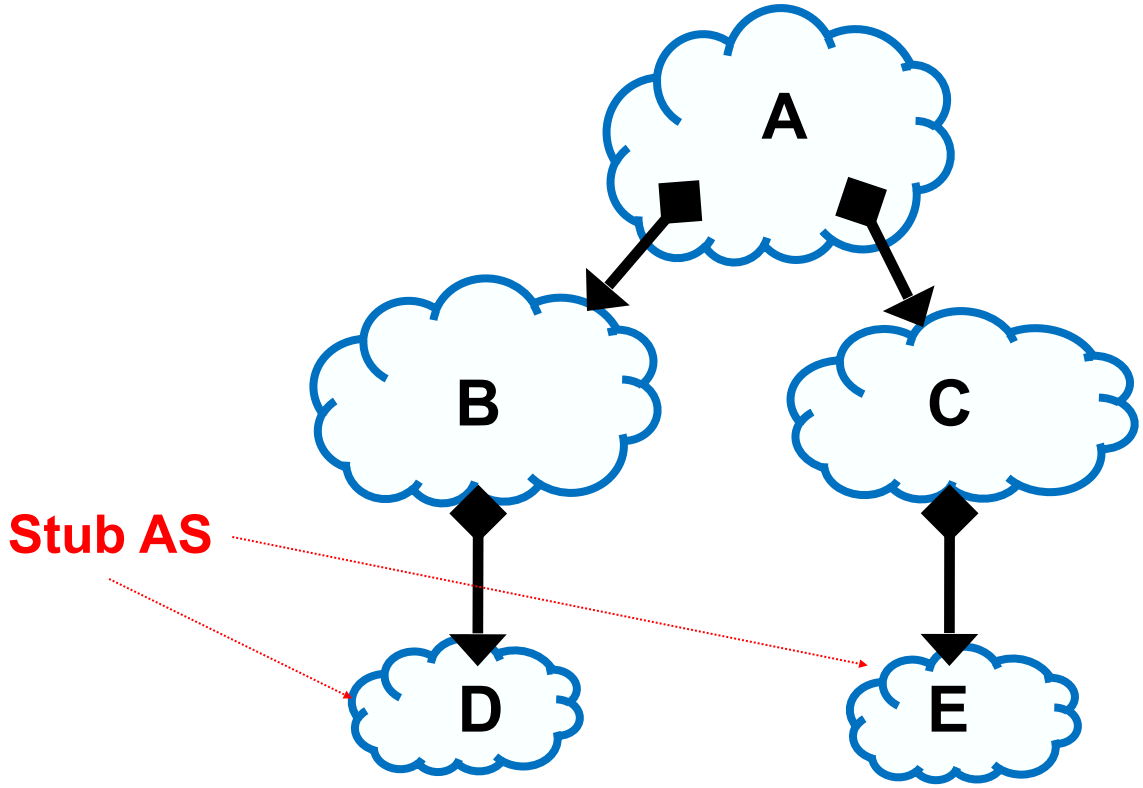

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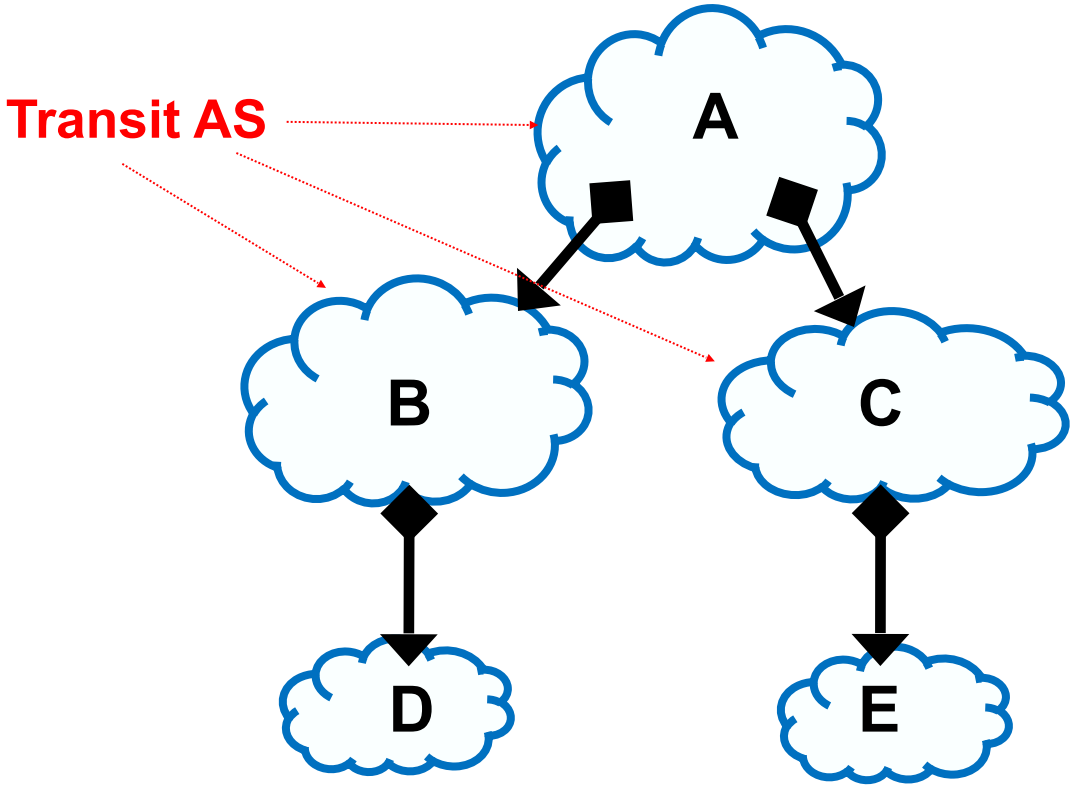

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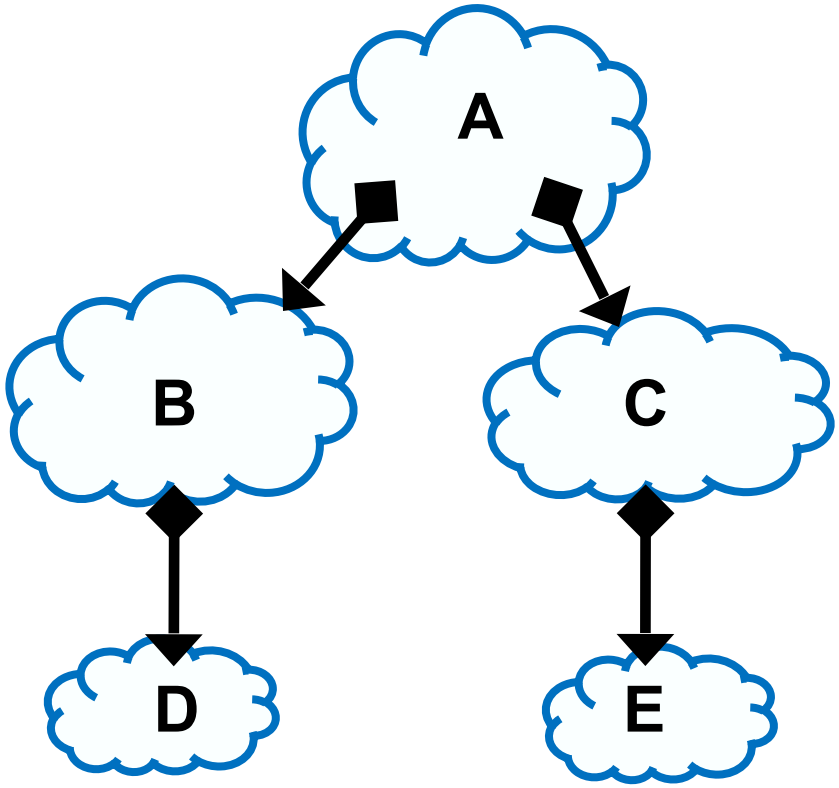

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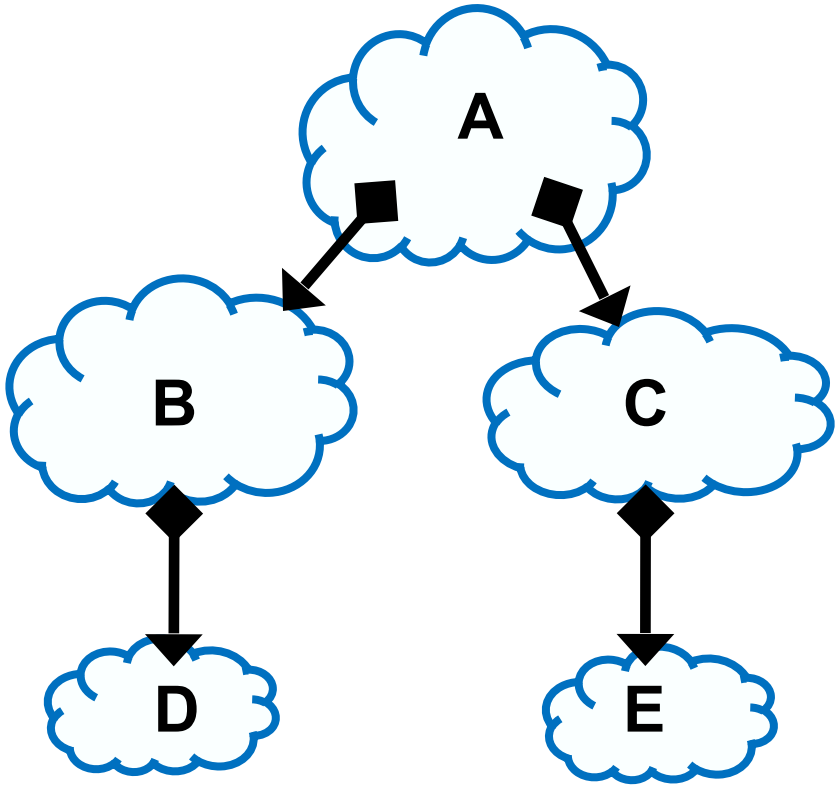

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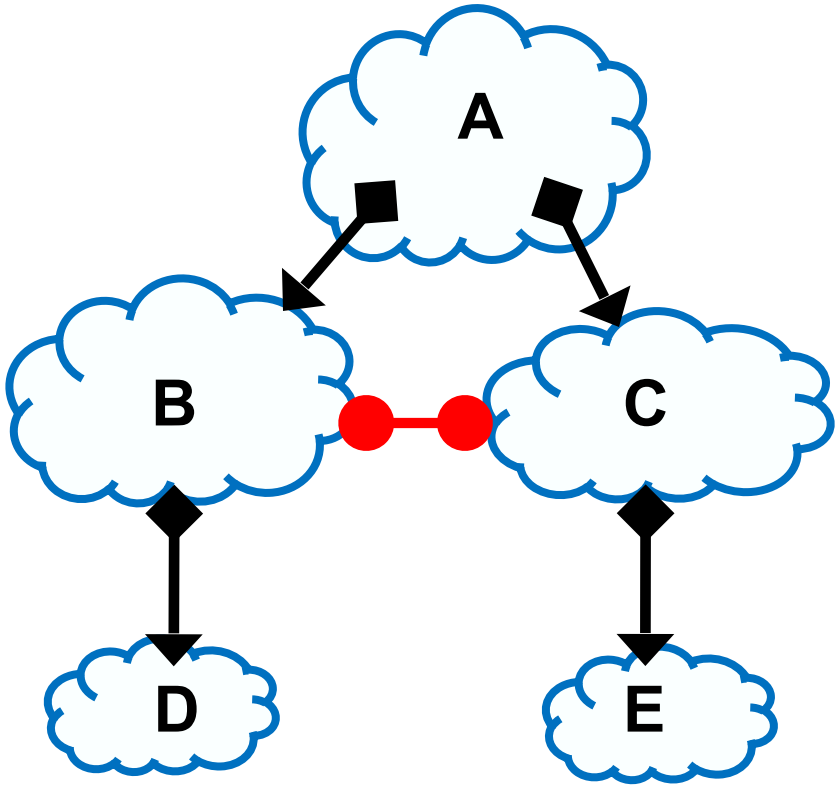

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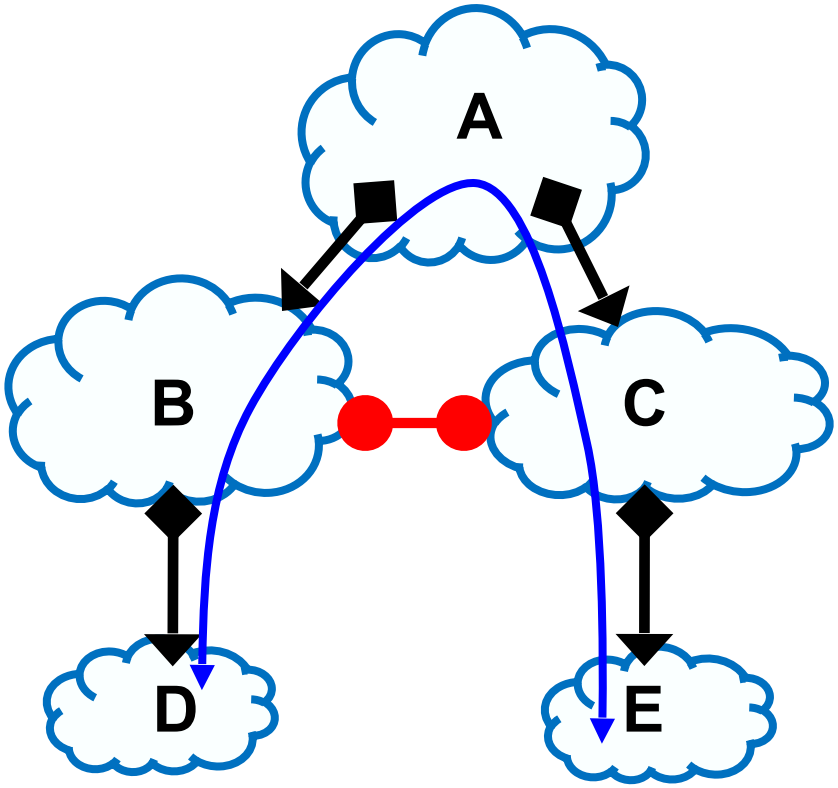

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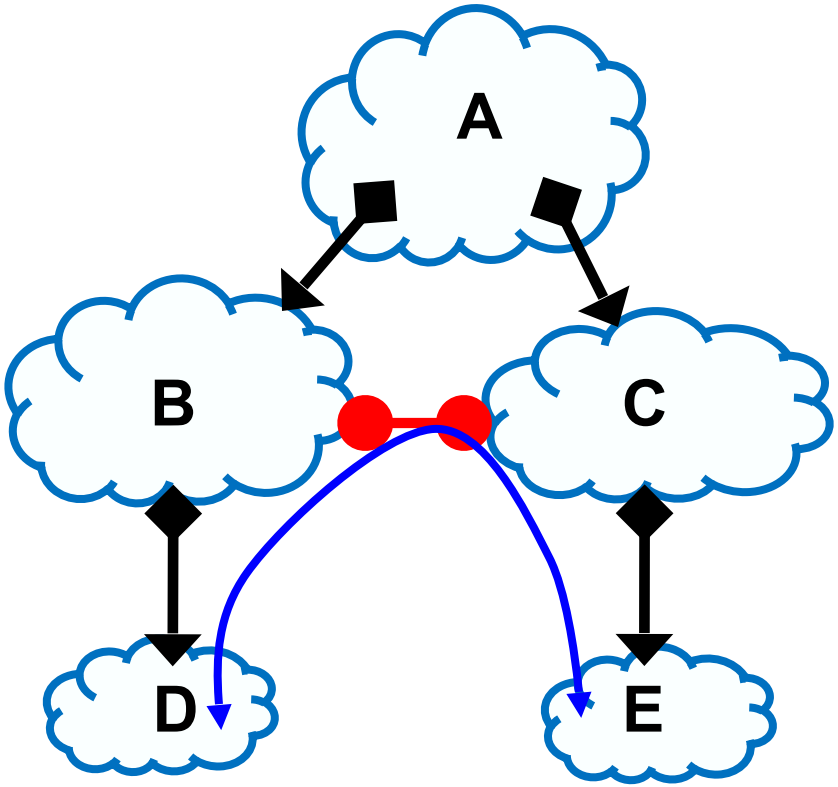

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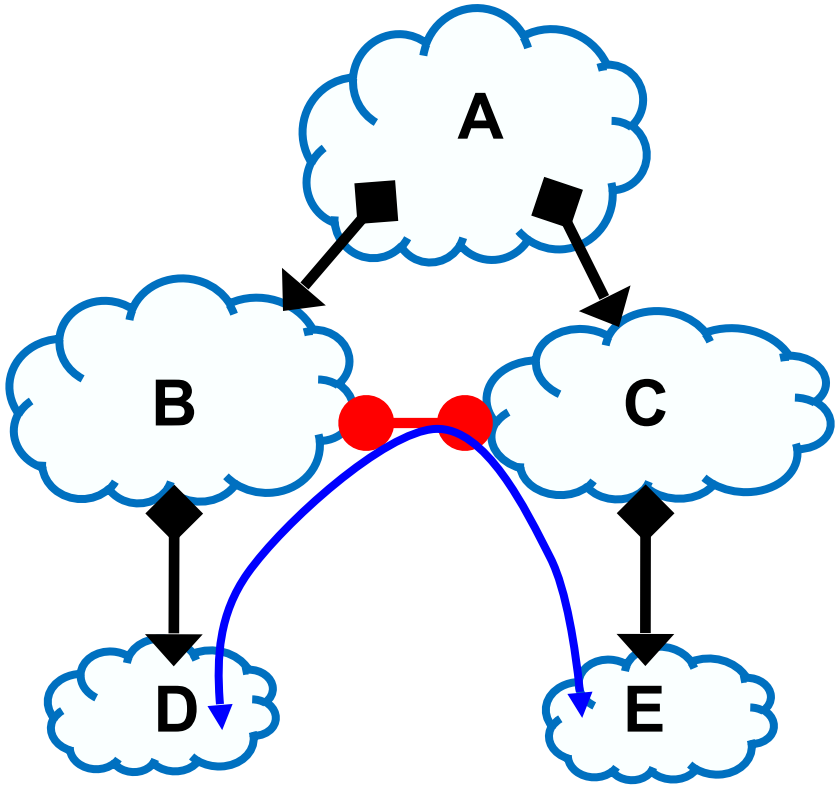

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Peering saves B ***and*** C money

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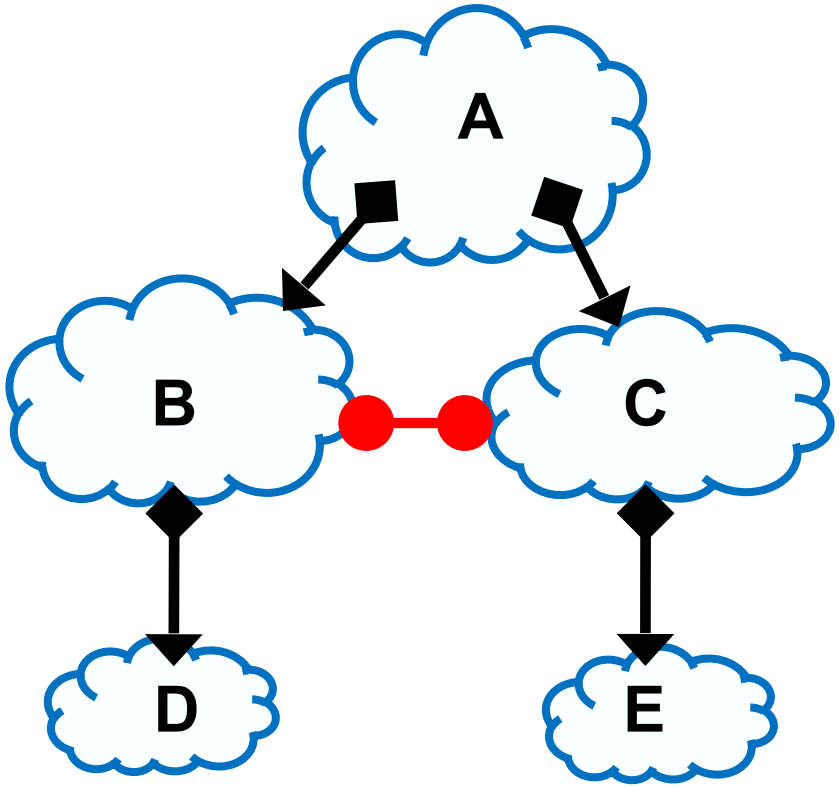

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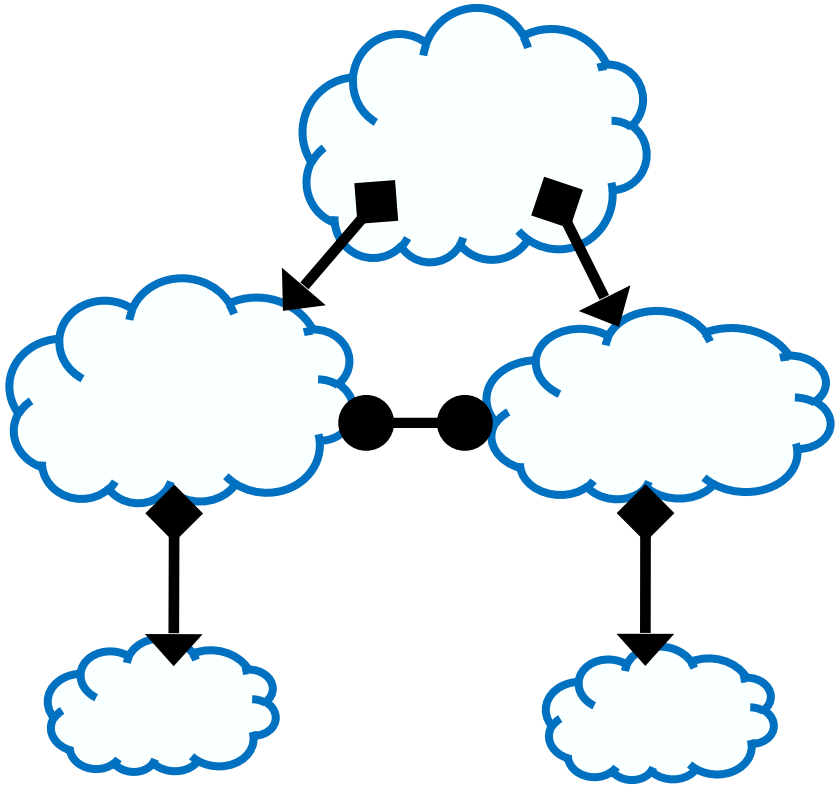

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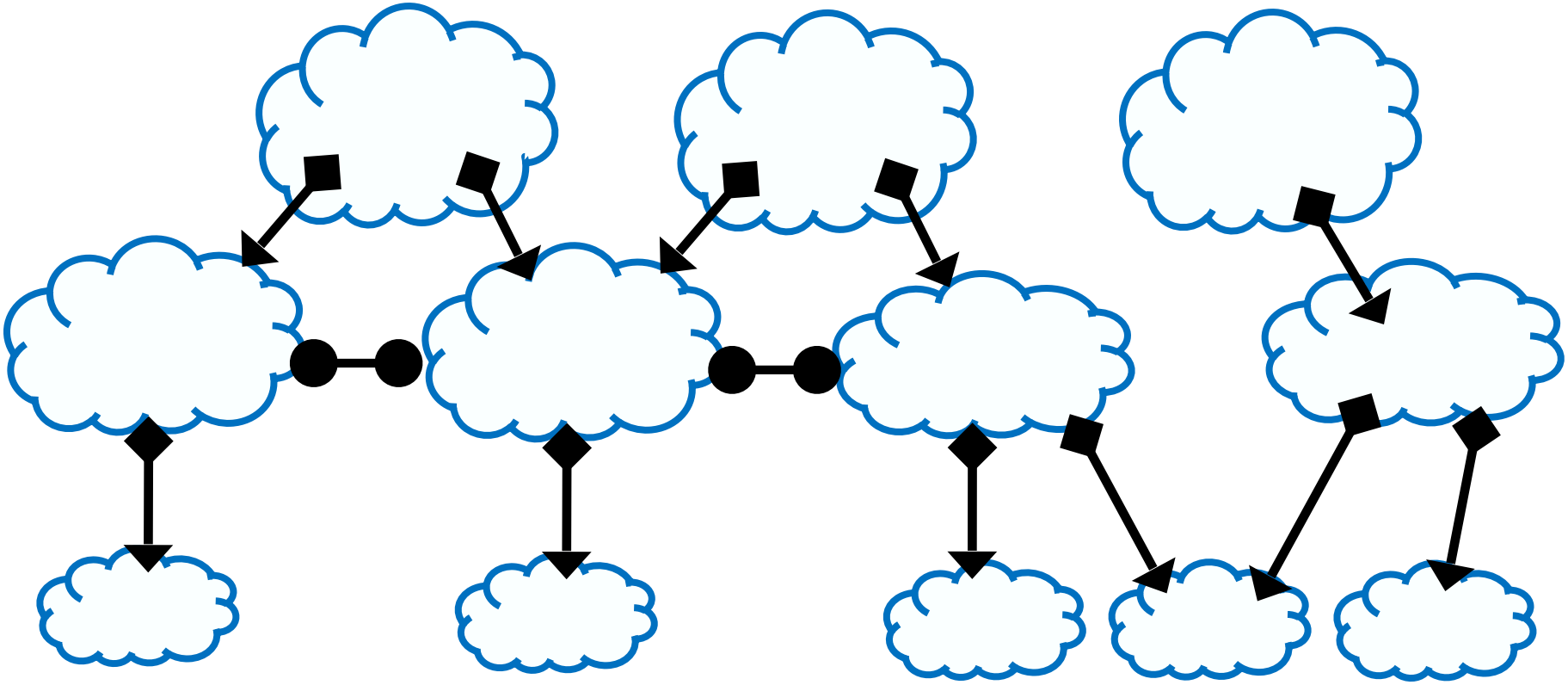

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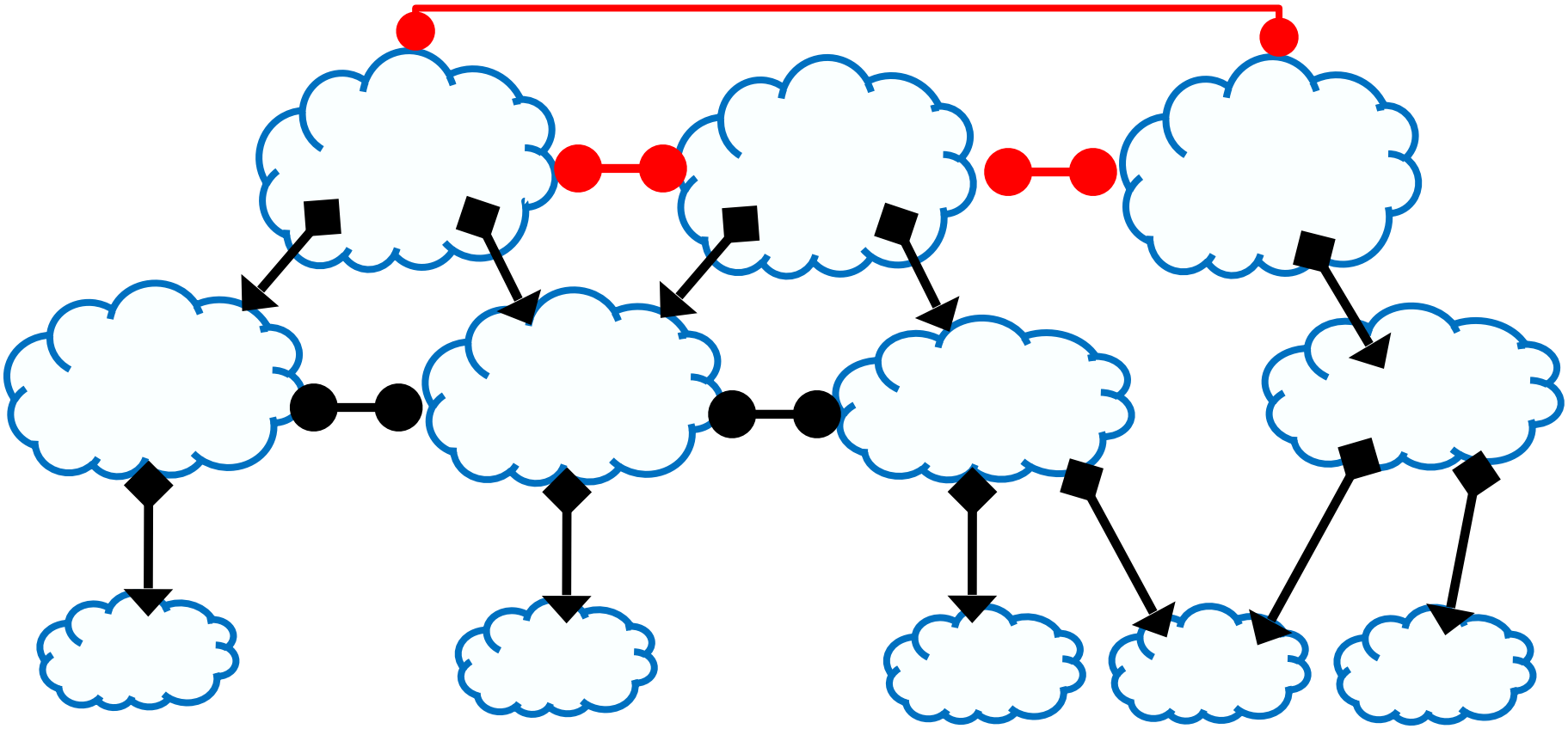

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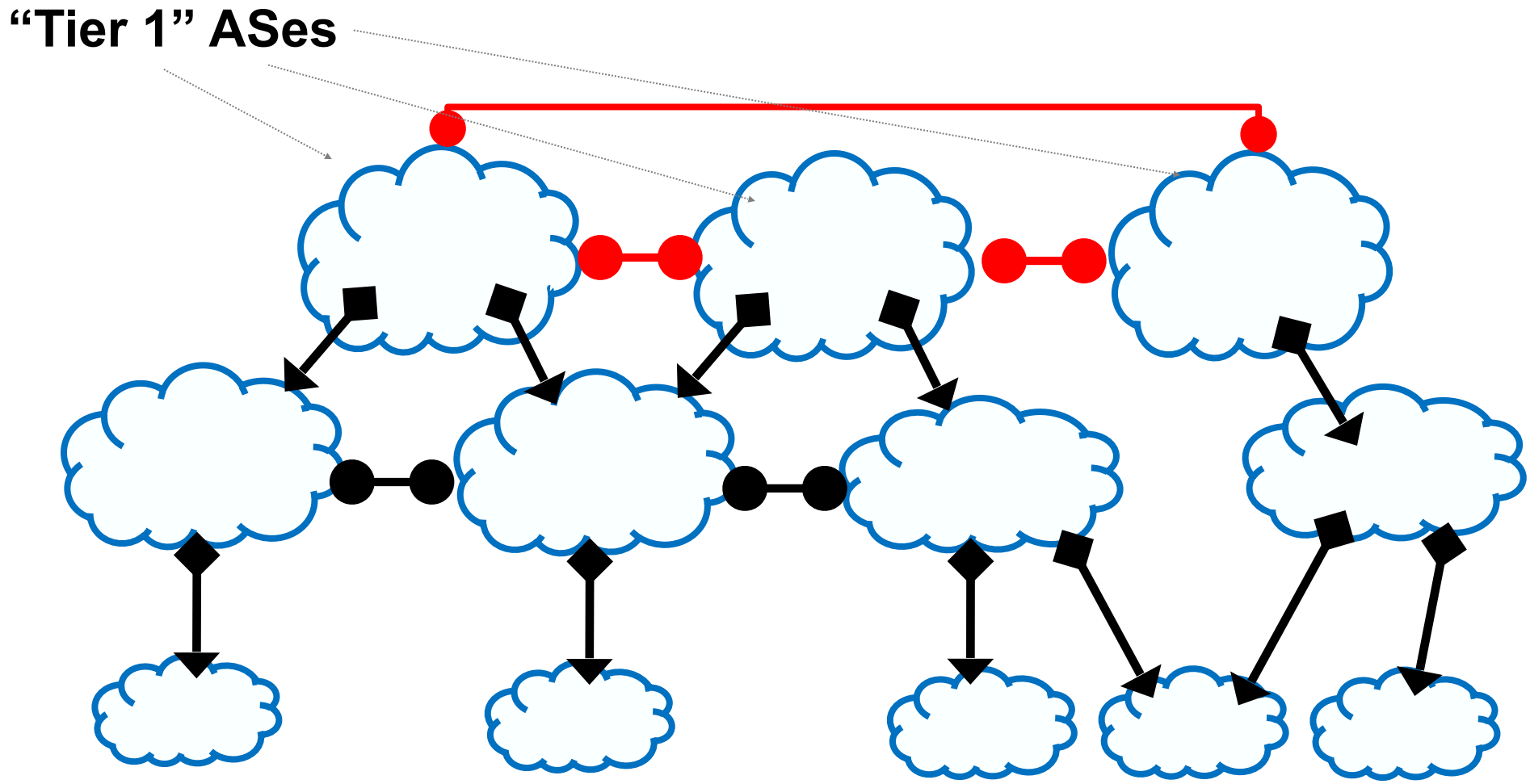

Outline

- Context
- Goals / Challenges
- Approach
- Detailed design
- Problems with BGP

Recall: goals for intradomain routing?

- Goals
  - Find valid routes → no loops, no deadends
  - Find “good” paths → least cost paths

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- Still want valid routes, *etc.*

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- Still want valid routes, *etc.*
- Plus two new goals:
  - Scalability: routing must scale to the entire Internet!
  - Policy compliance: routes must reflect business goals

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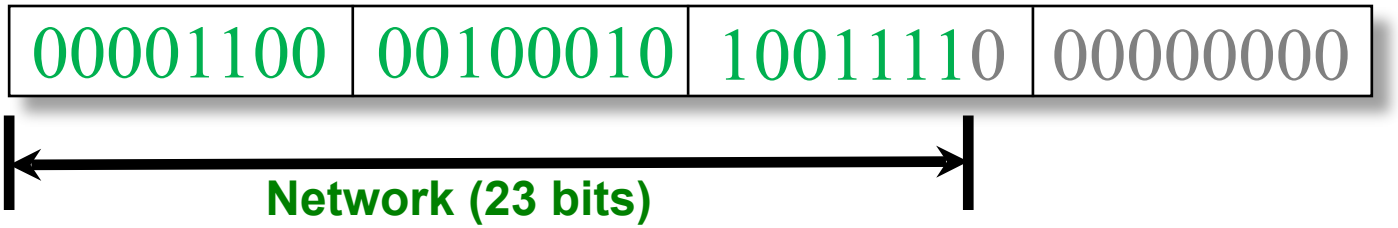
- Recall, last lecture: host addressing key to scaling!

Recall, IP addressing: Hierarchical

- Hierarchical address structure
- Hierarchical address allocation
- Hierarchical addresses and routing scalability

Recall, IP addresses

- IP address is 32 bits
- Partitioned into a network prefix and host suffix



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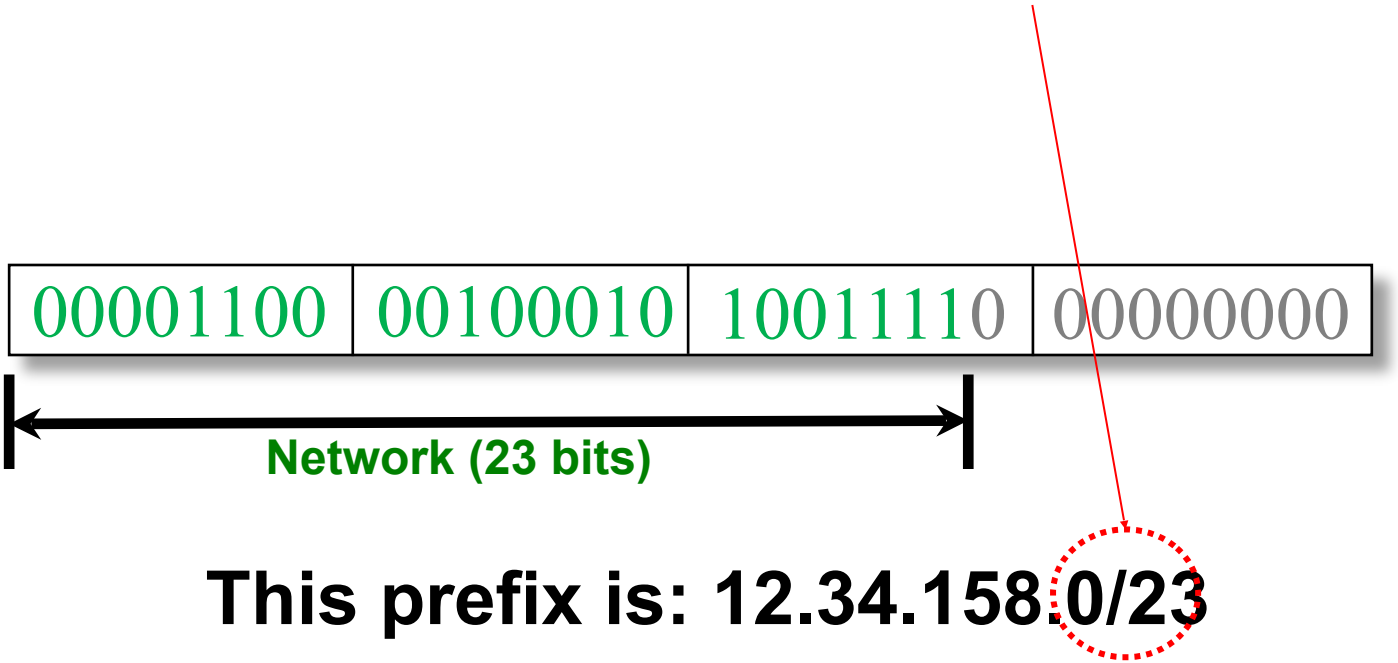

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- For convenience (in lecture): a.b.0.0/16

Destinations in interdomain routing are prefixes

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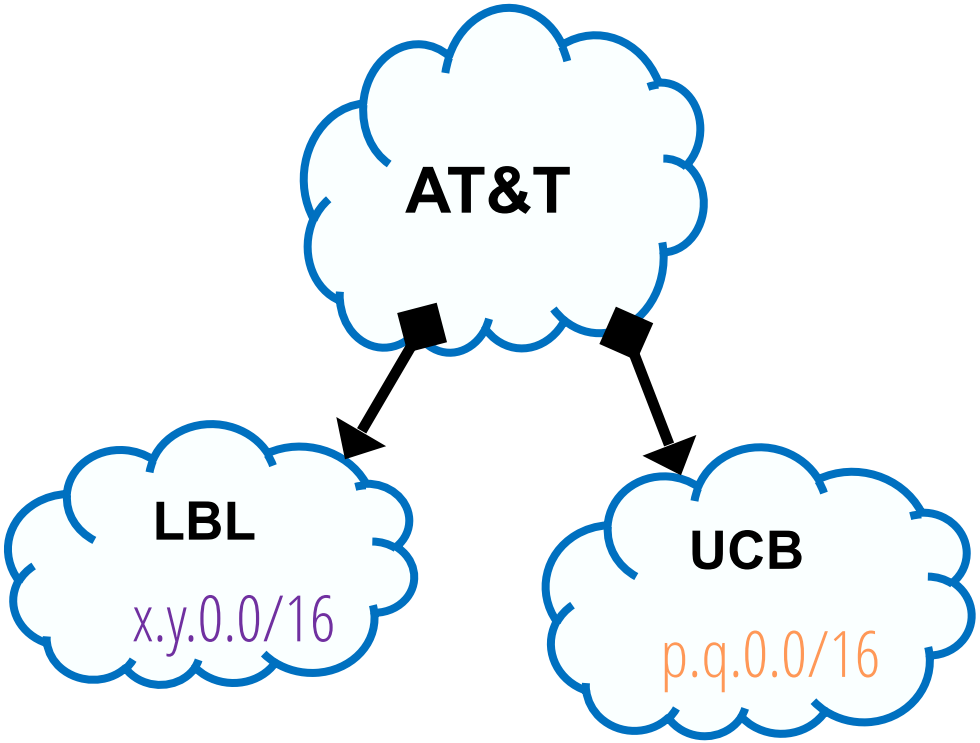

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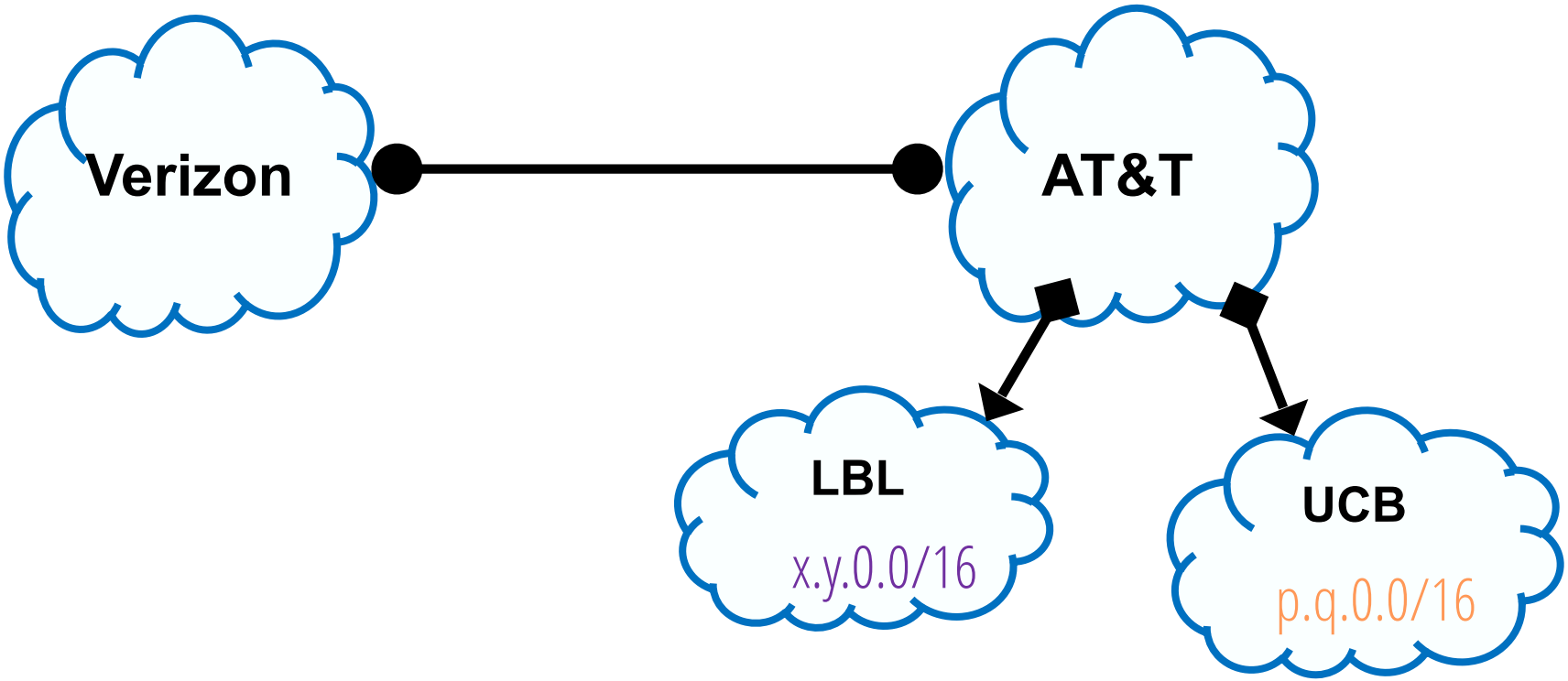

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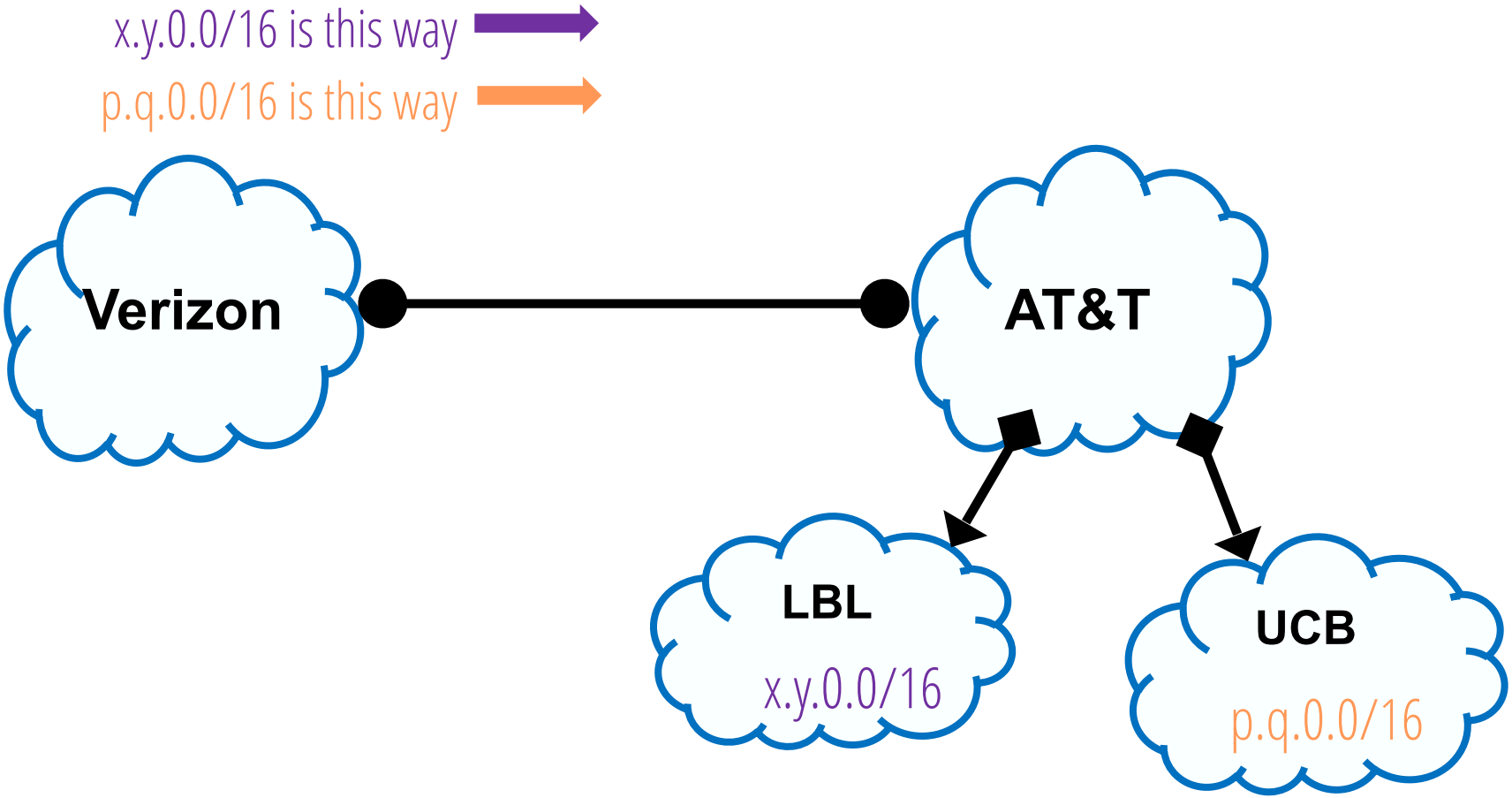

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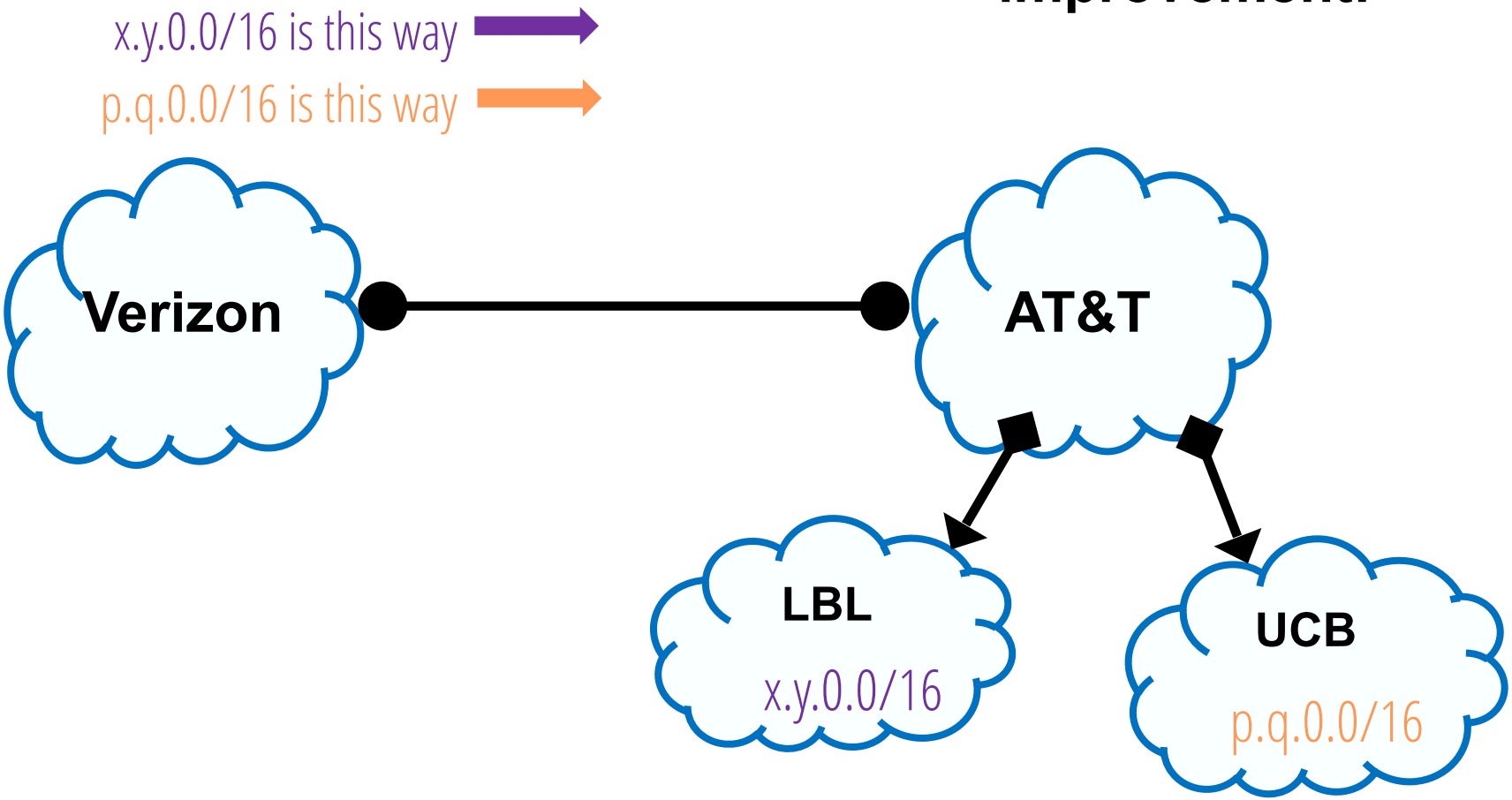
Already a huge improvement!



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Recall, last lecture... Hierarchical address assignment

- ICANN gives out large prefixes to ...
- RIRs (Regional Internet Registries) who give out sub-prefixes to ...
- Large organizations (e.g., AT&T) who give out sub-prefixes to ...
- Smaller organizations and individuals (e.g., UCB)

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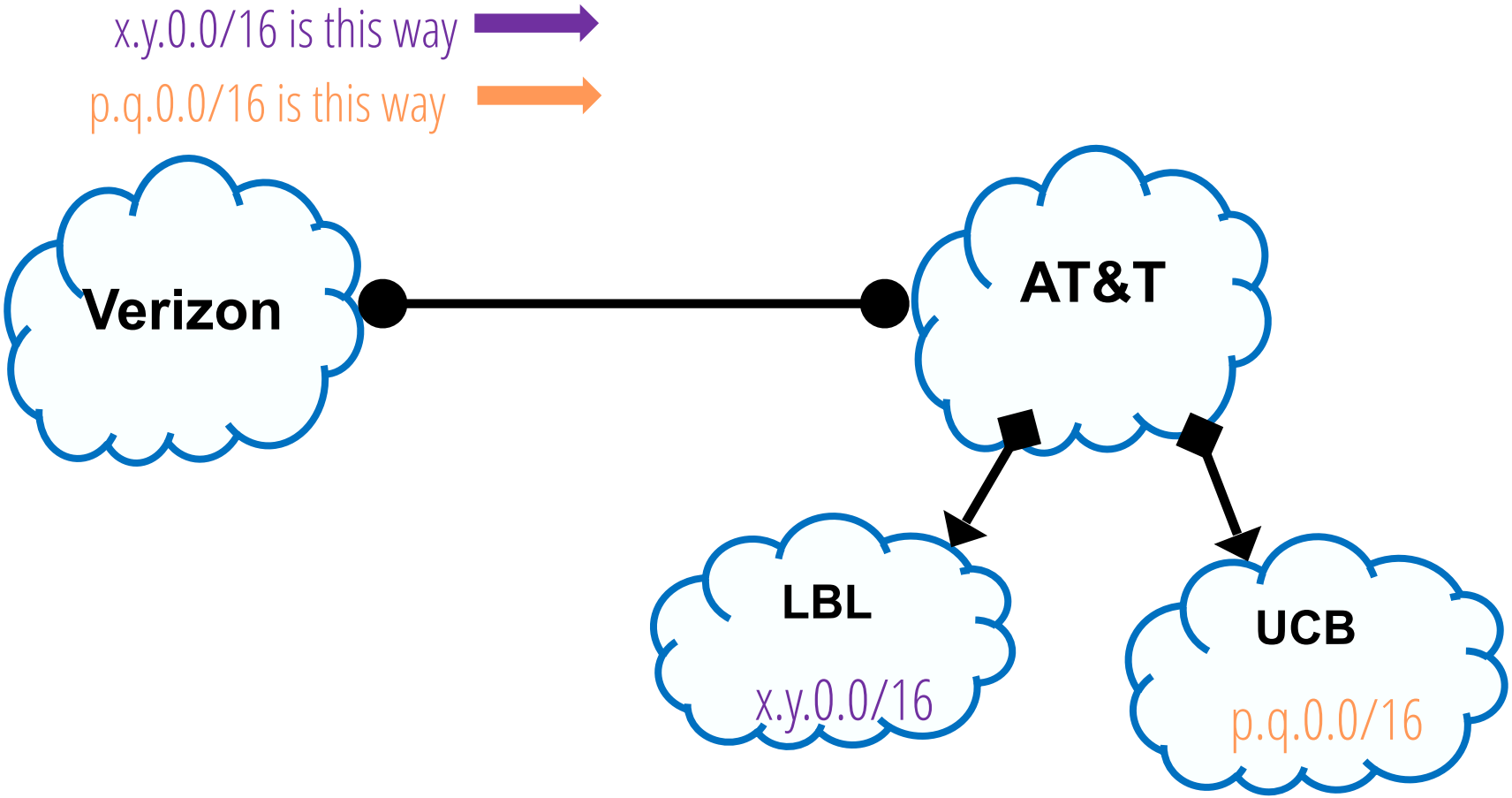

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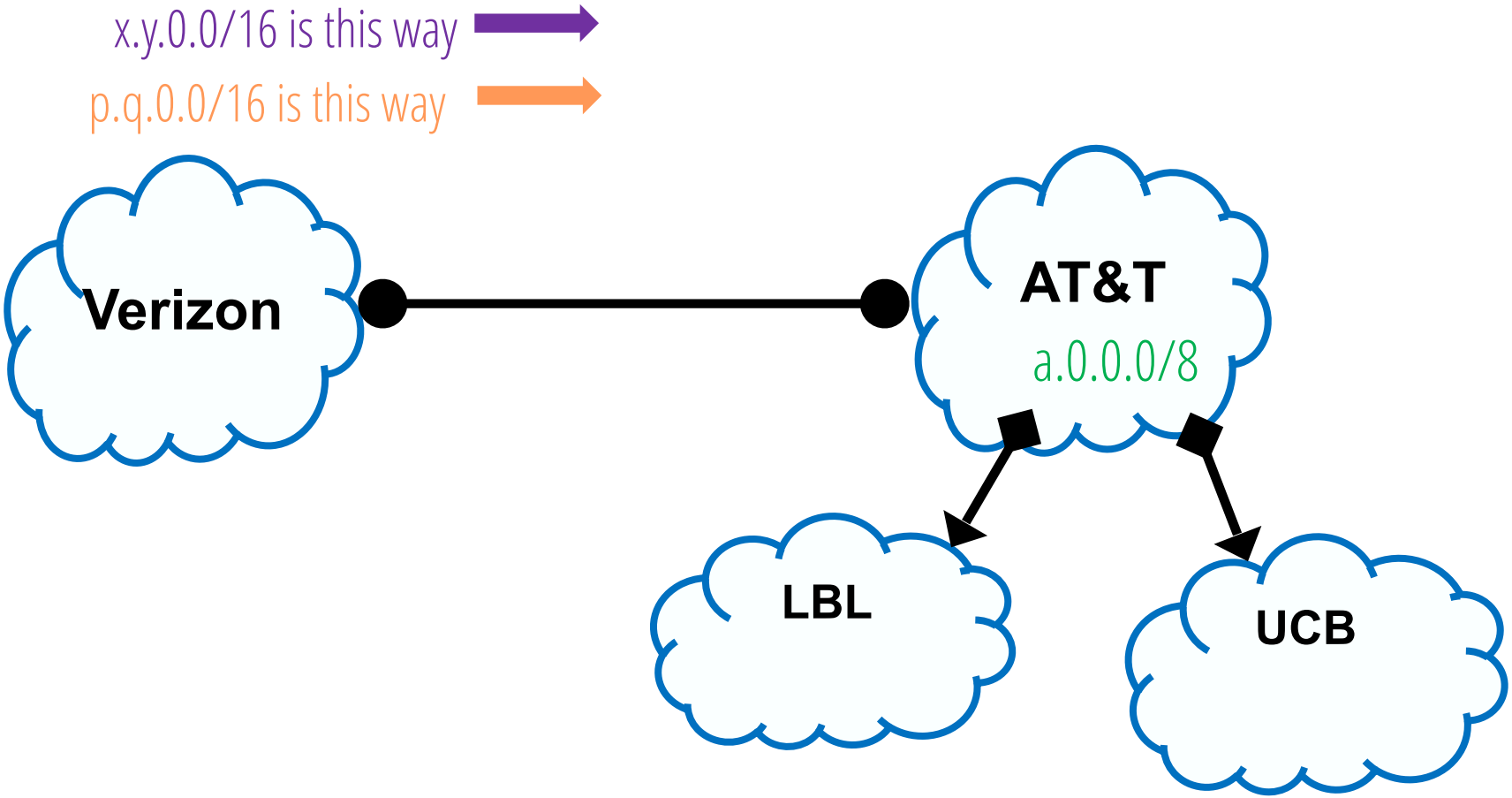

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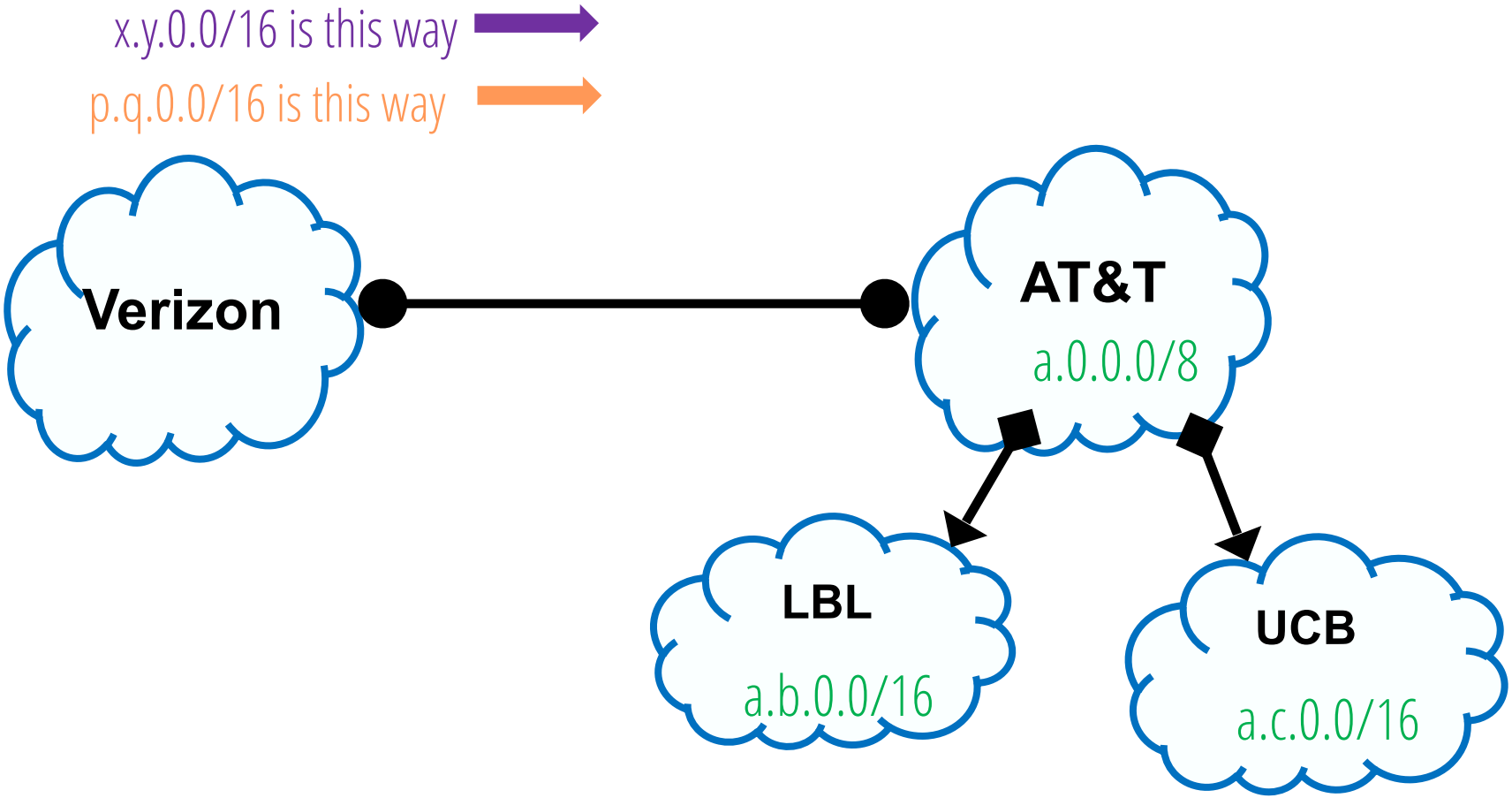

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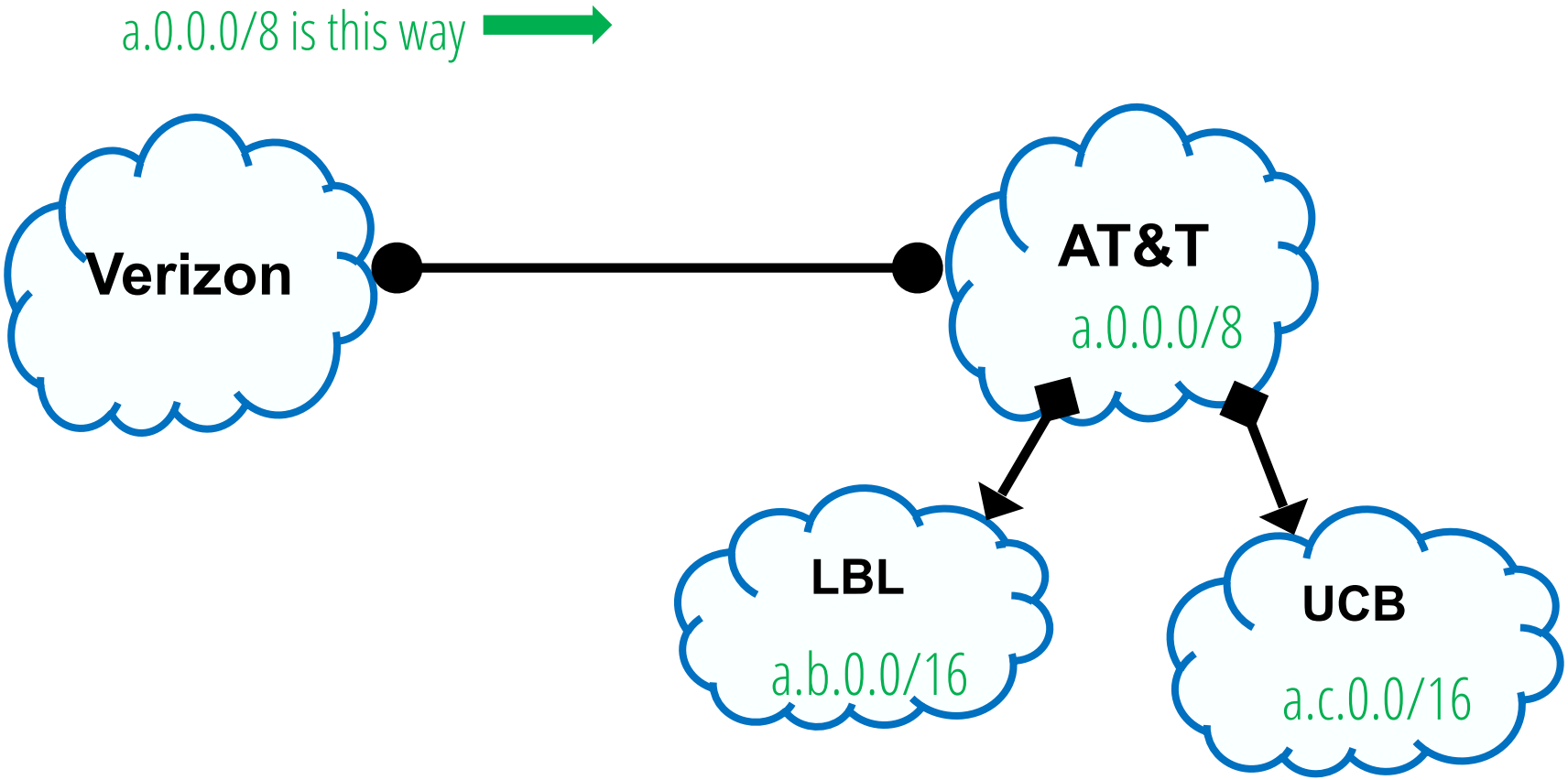

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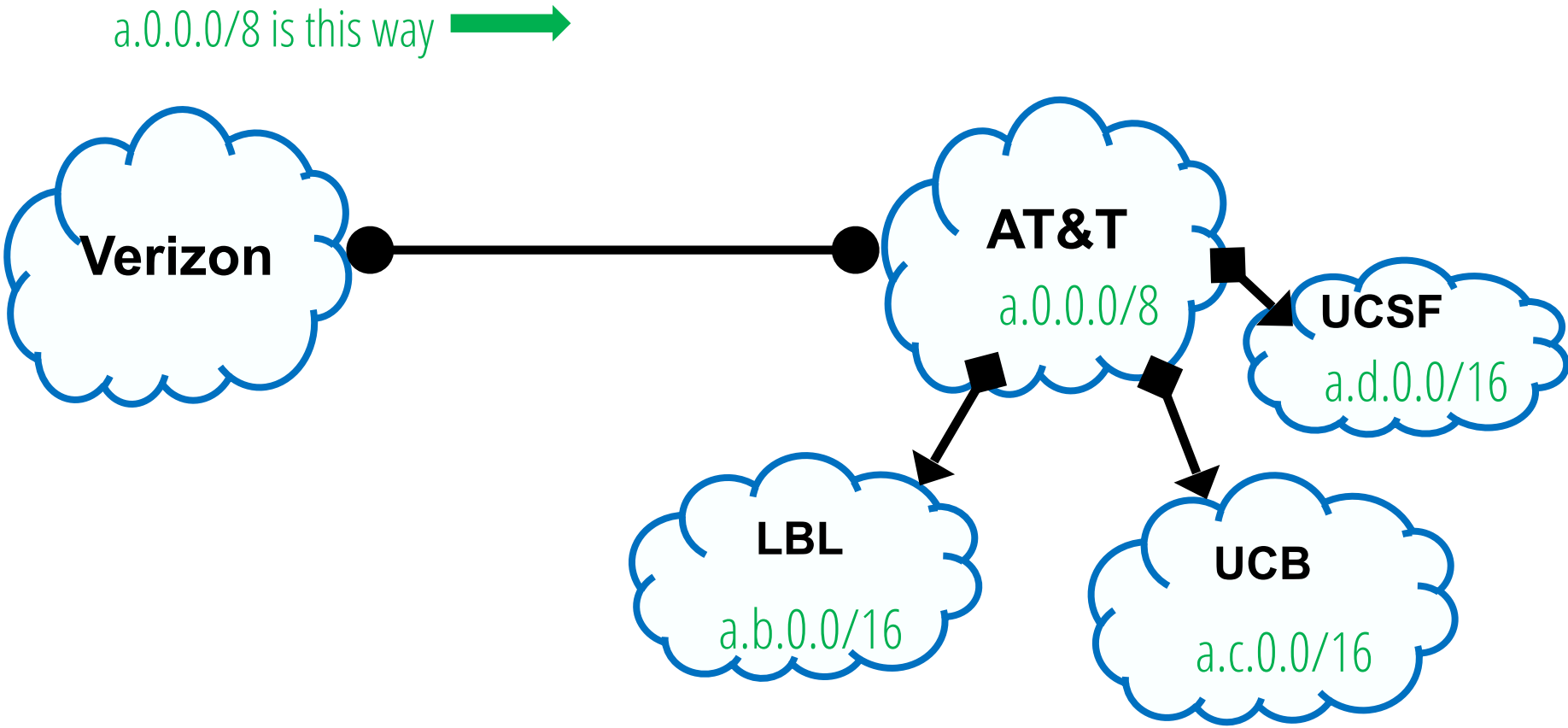
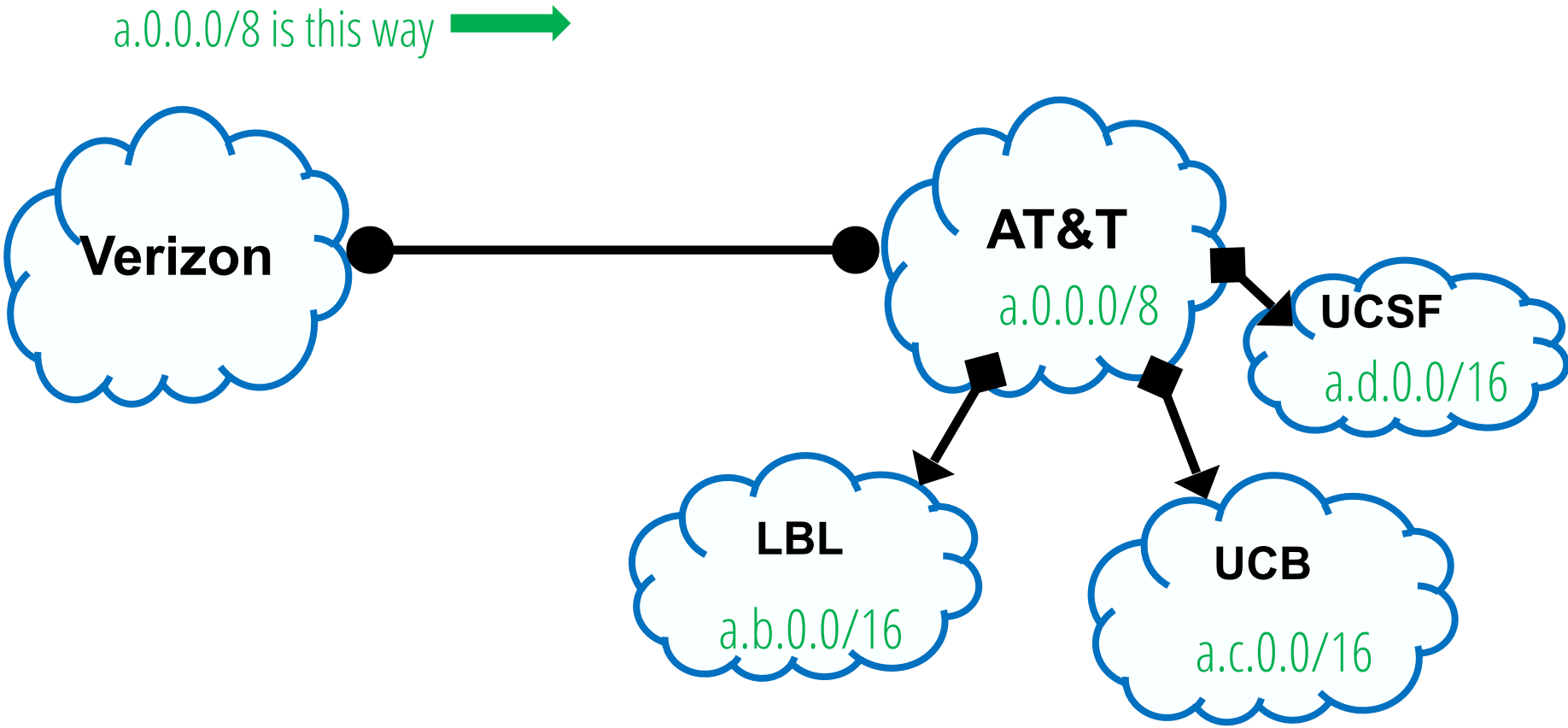


Back to our AS Graph ...

Hierarchical allocation enables aggregation!



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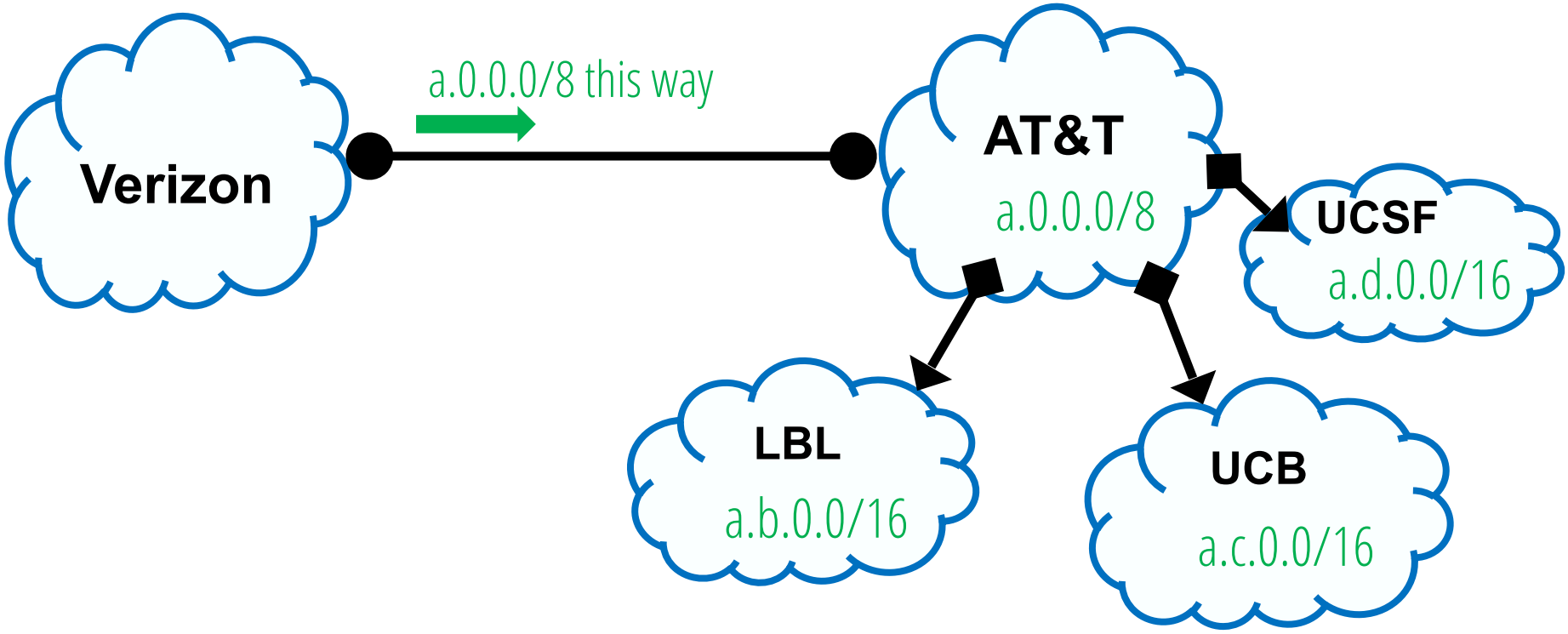

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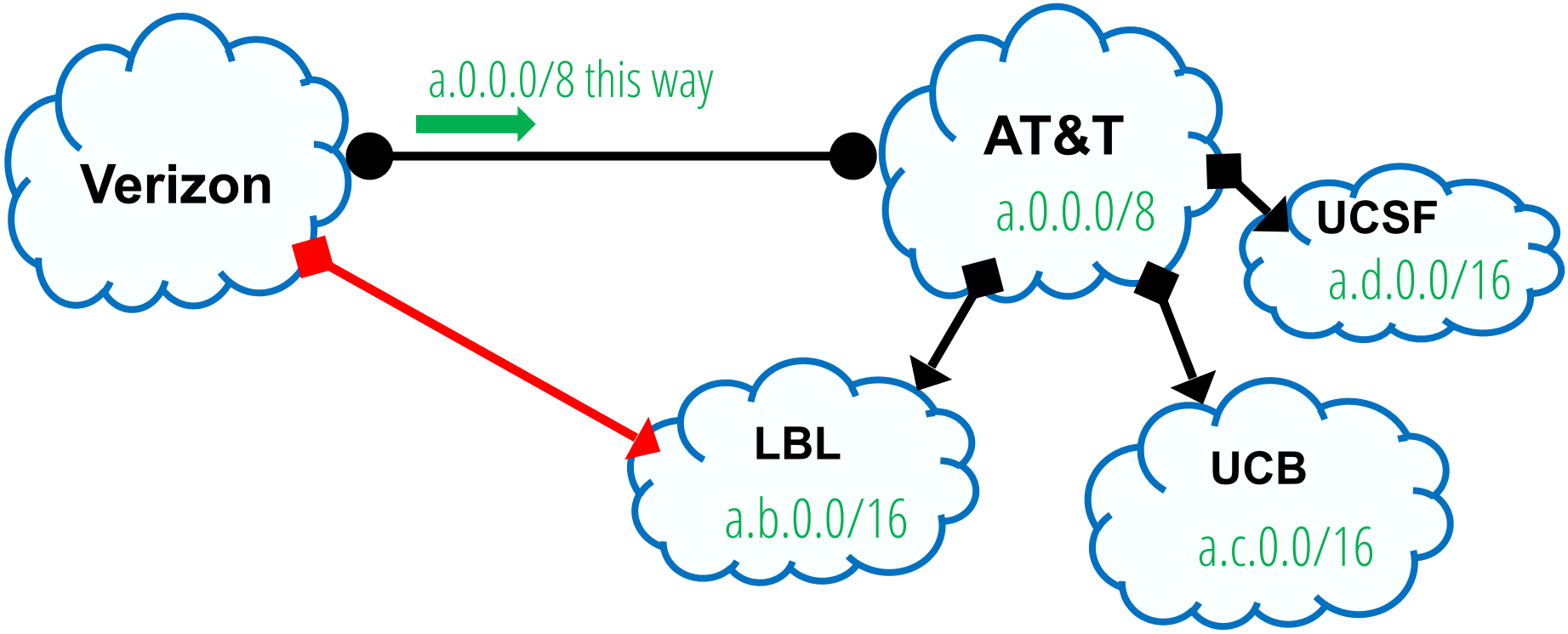

Now LBL wants to be “multi-homed”

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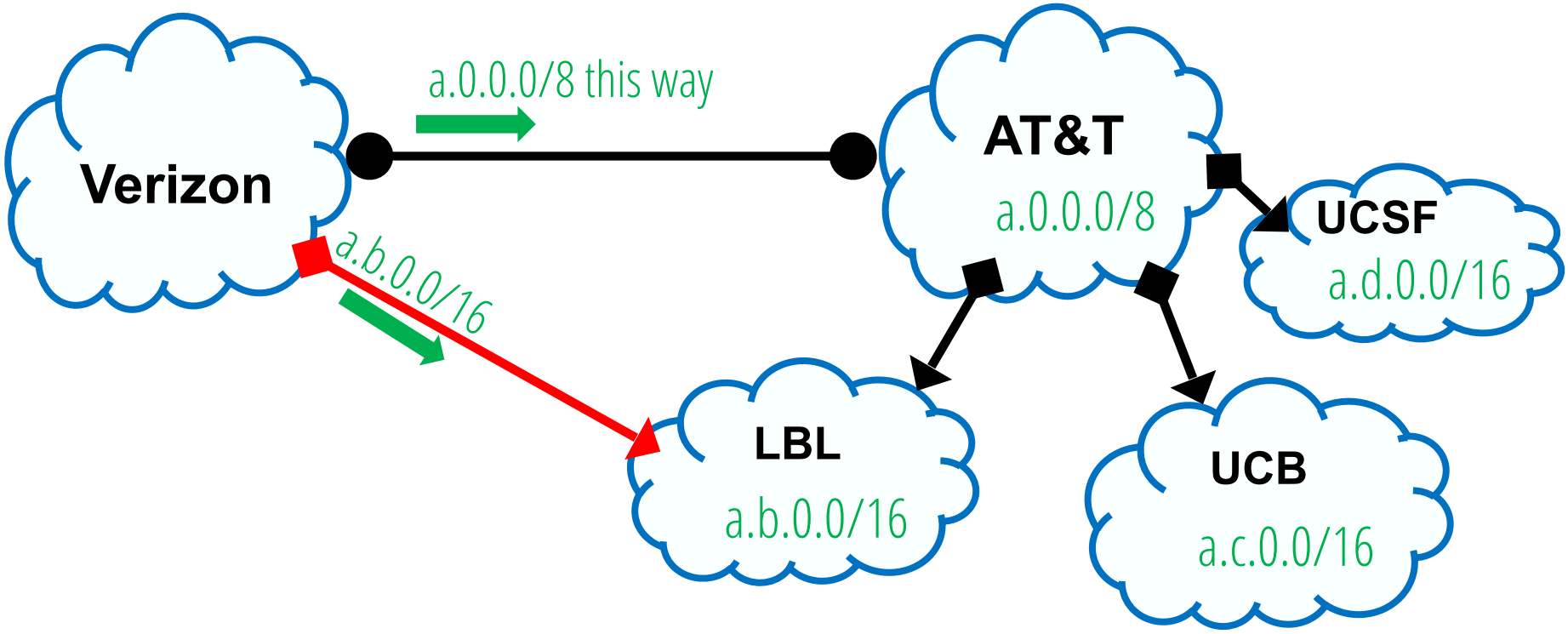
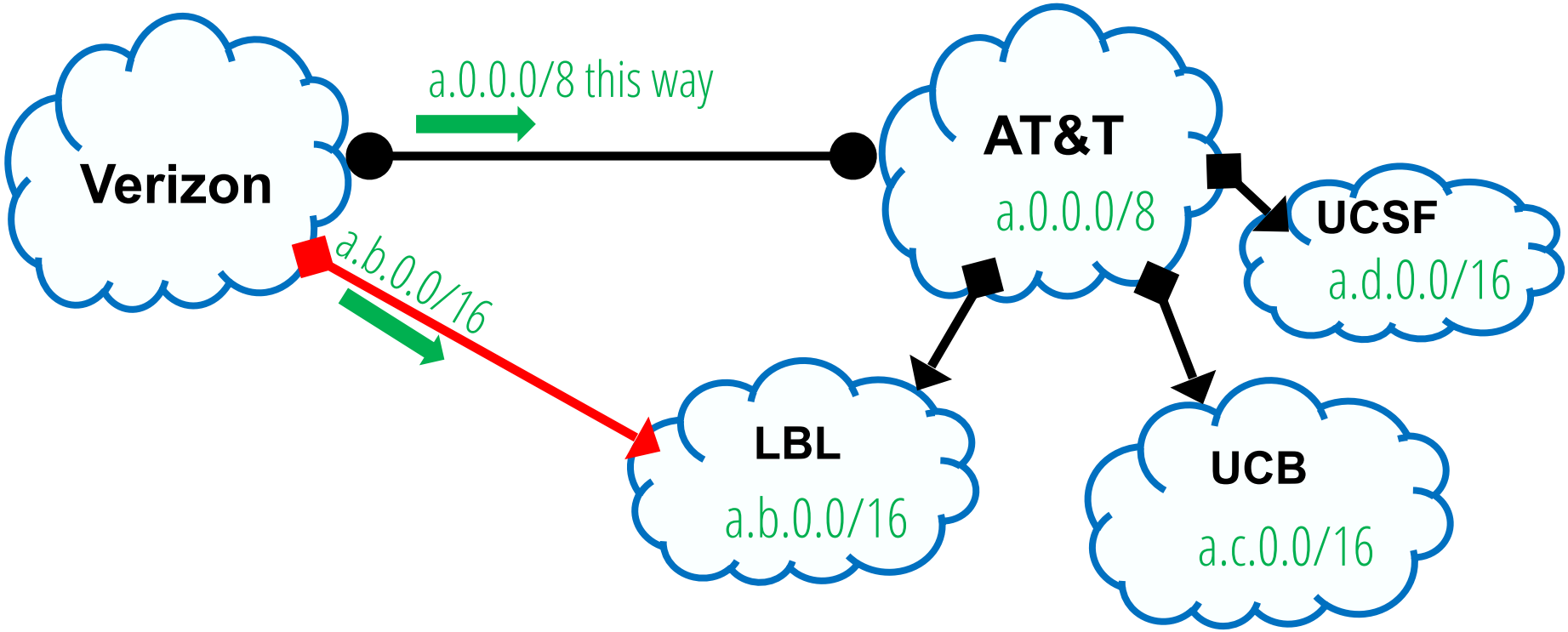


Verizon needs routing entries for both a.0.0.0/8 and a.b.0.0/16

Back to our AS Graph ...

Multi-homing limits aggregation!



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  - But can't do this if addresses are assigned randomly!
- Hierarchical addressing is key to scaling
  - Works best when allocation hierarchy matches topology

Goals for interdomain routing?

- Two new goals:
  - Scalability: routing must scale to the entire Internet!
  - Policy compliance: routes must reflect business goals

Administrative preferences shape interdomain routing

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- ASes want freedom to pick routes based on policy

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- Not expressible as Internet-wide “least cost”!

Two Principles For Typical Policies

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1) Don’t accept to carry traffic if you are not being paid!

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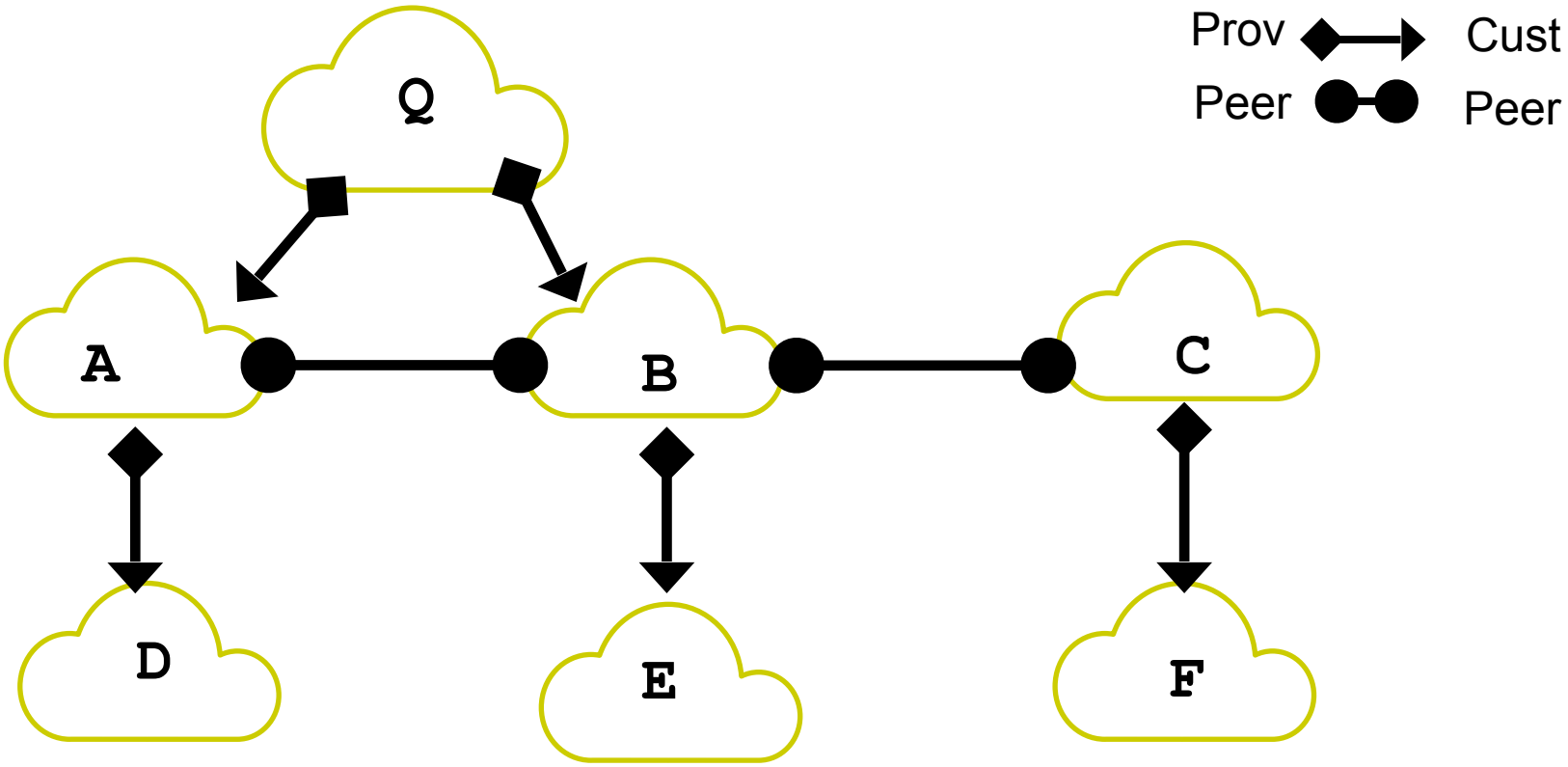
2) Make/save money when sending traffic

- Prefer sending traffic to customer
- If can’t do that, then a peer
- Only send via a provider if I have to
- This is about where I *send* traffic

Routing Follows the Money!



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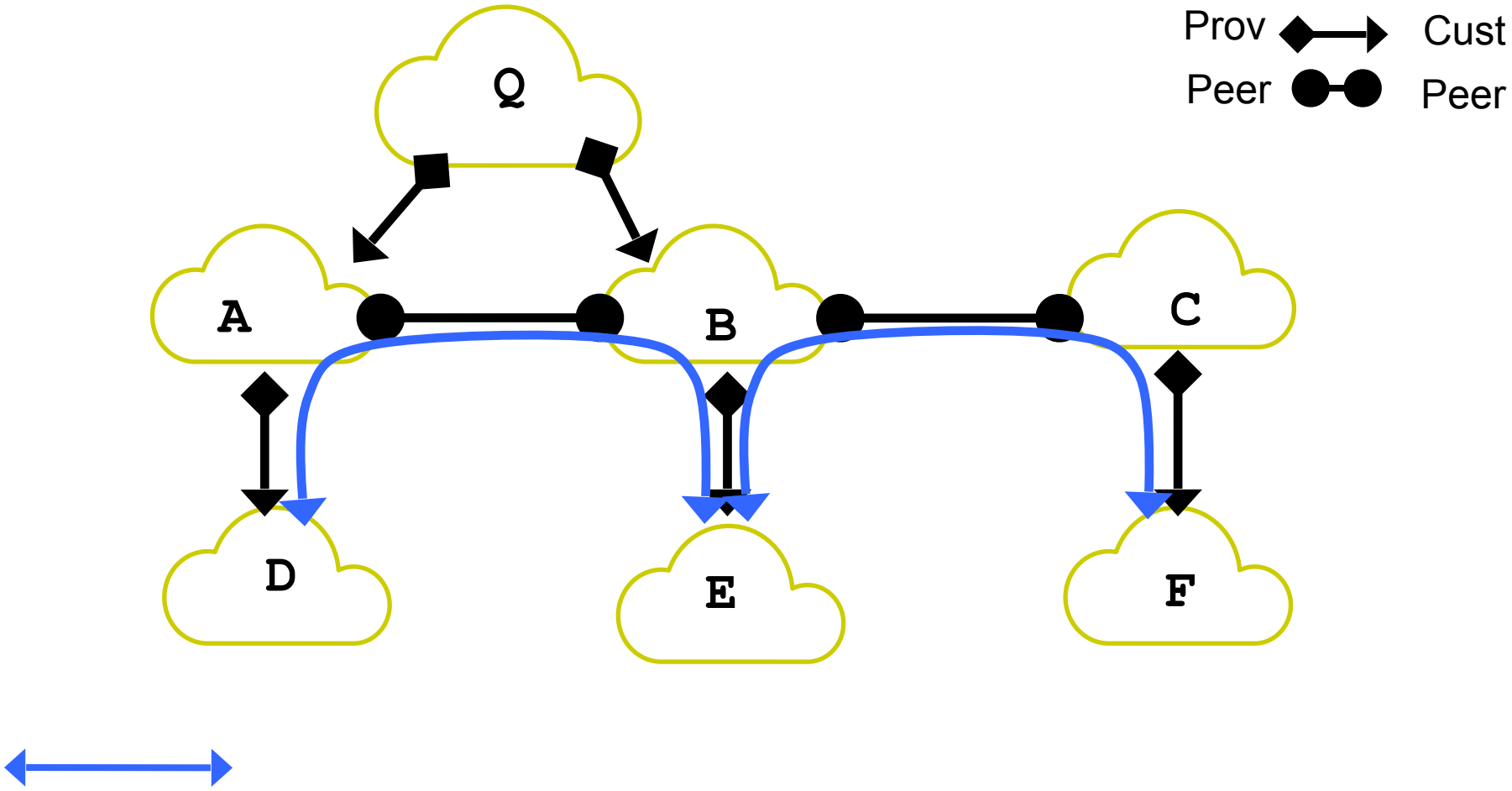

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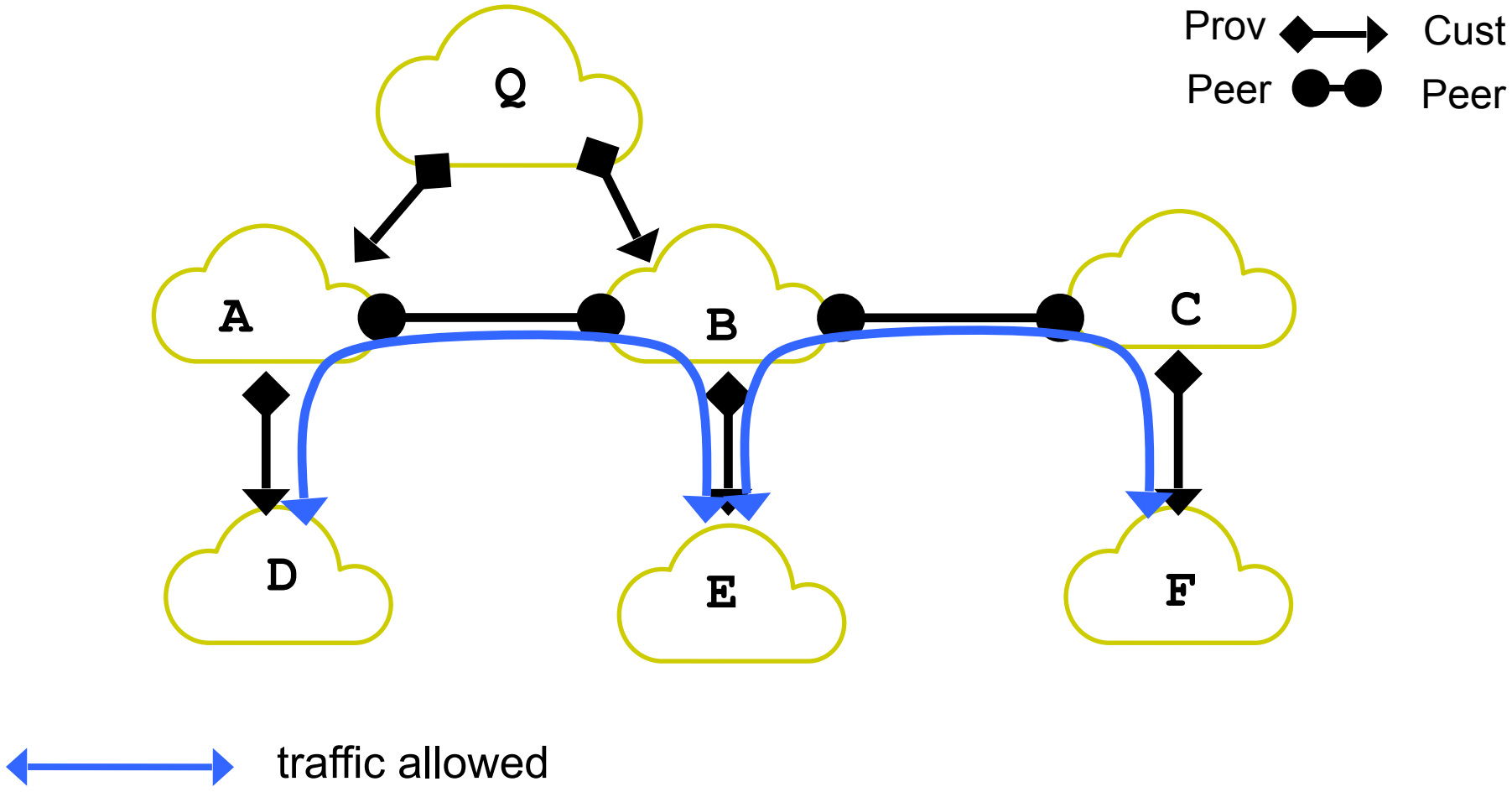

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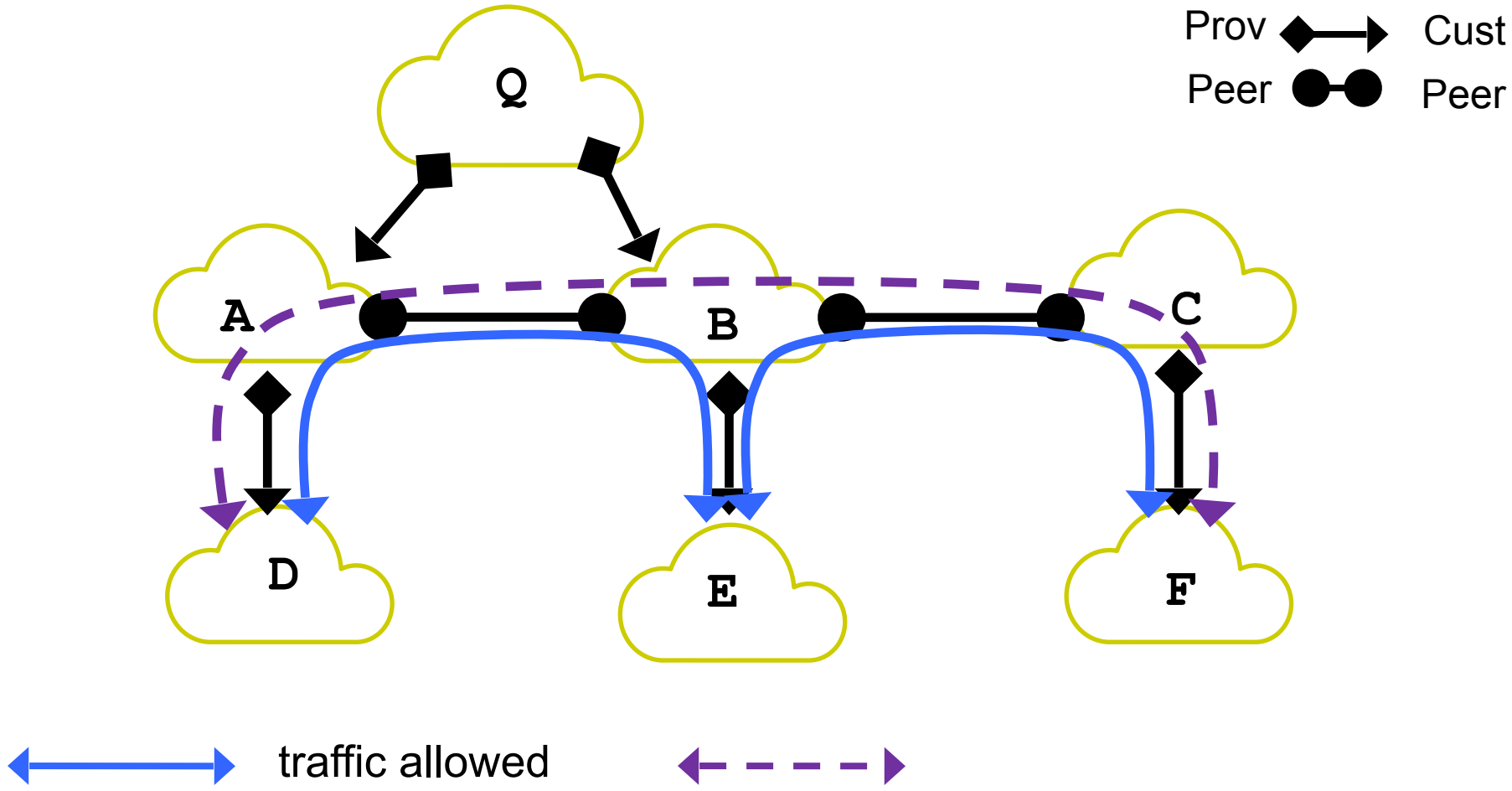

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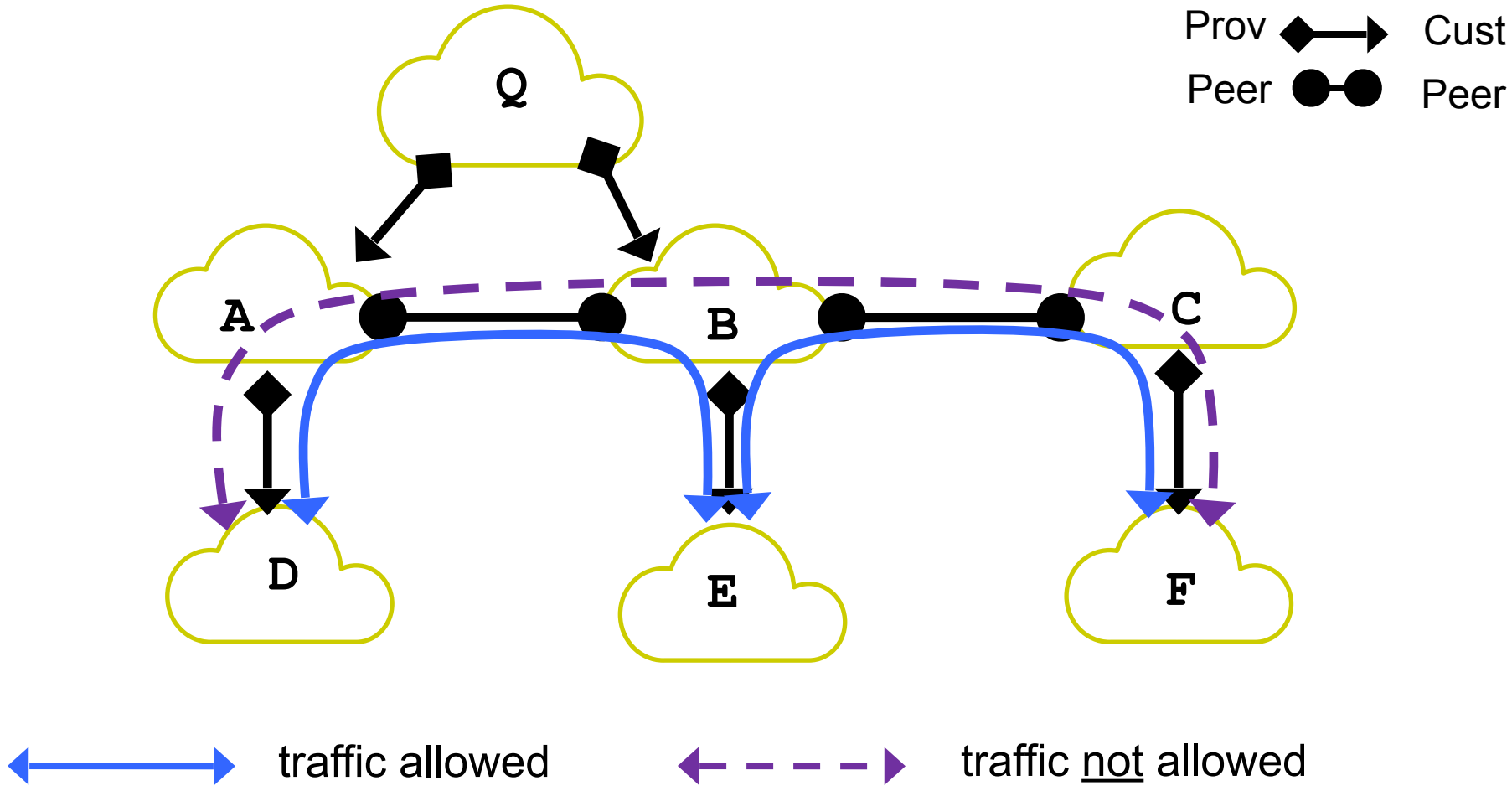

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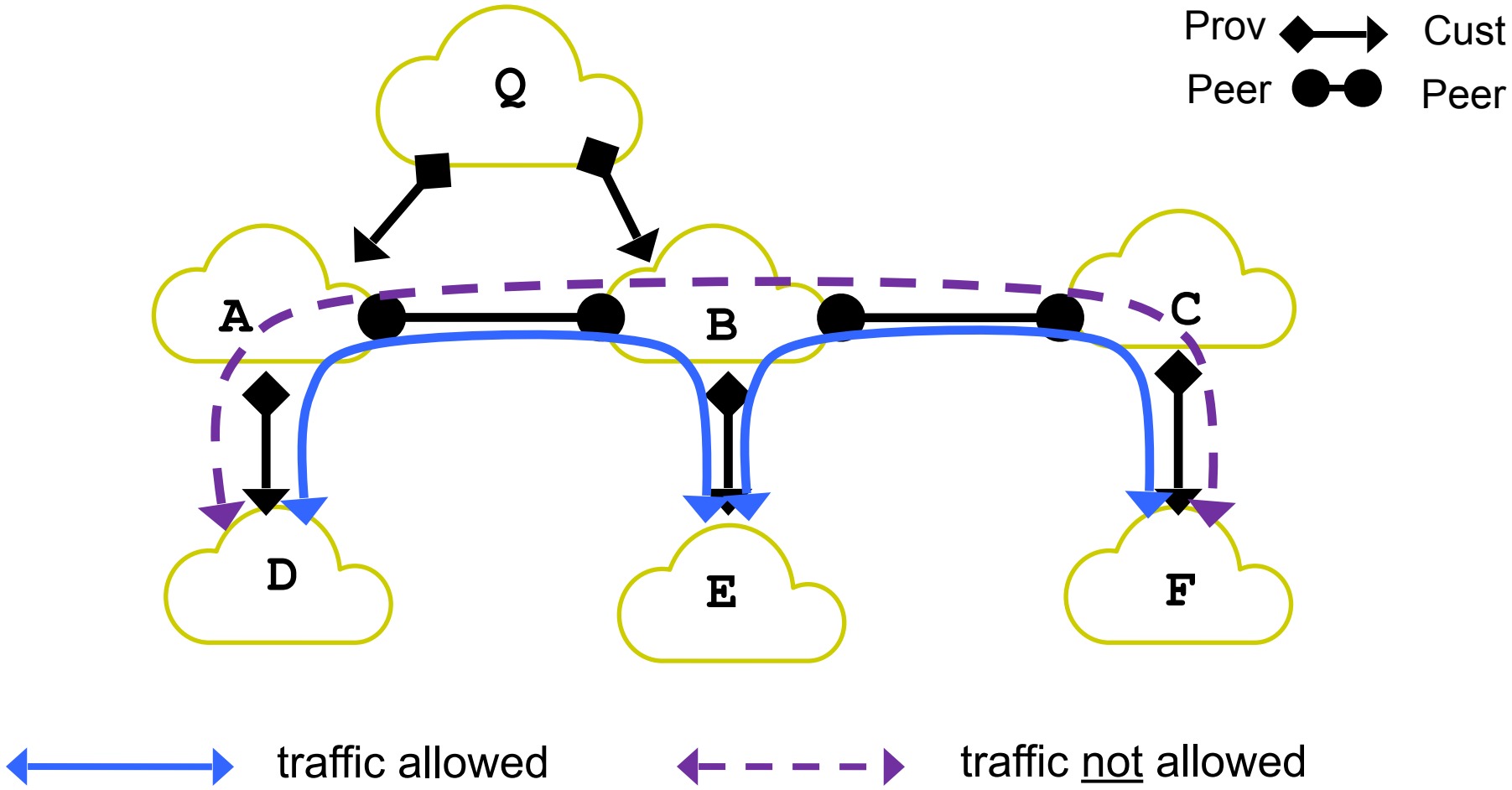

Peers do not provide transit between other peers

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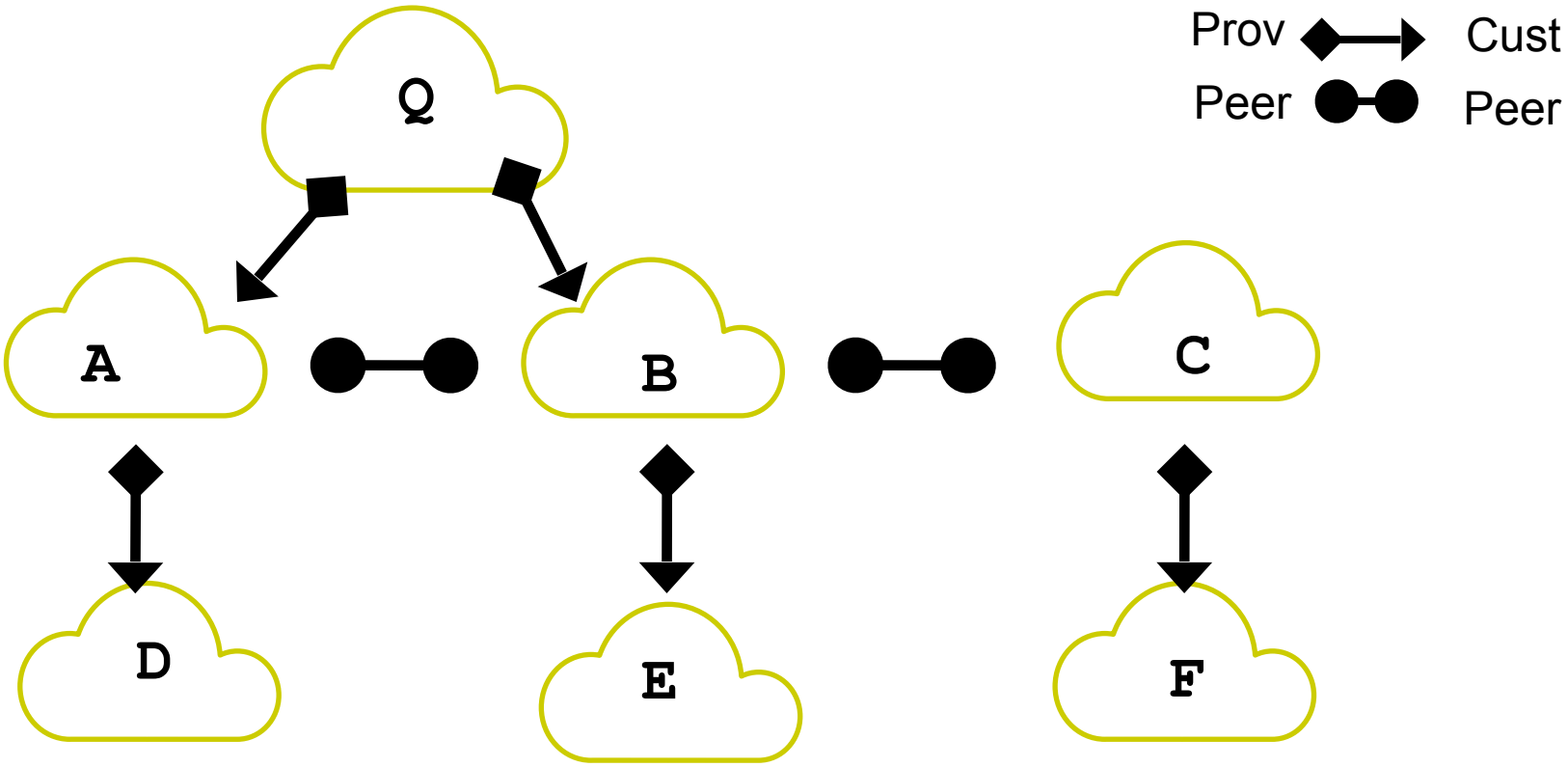

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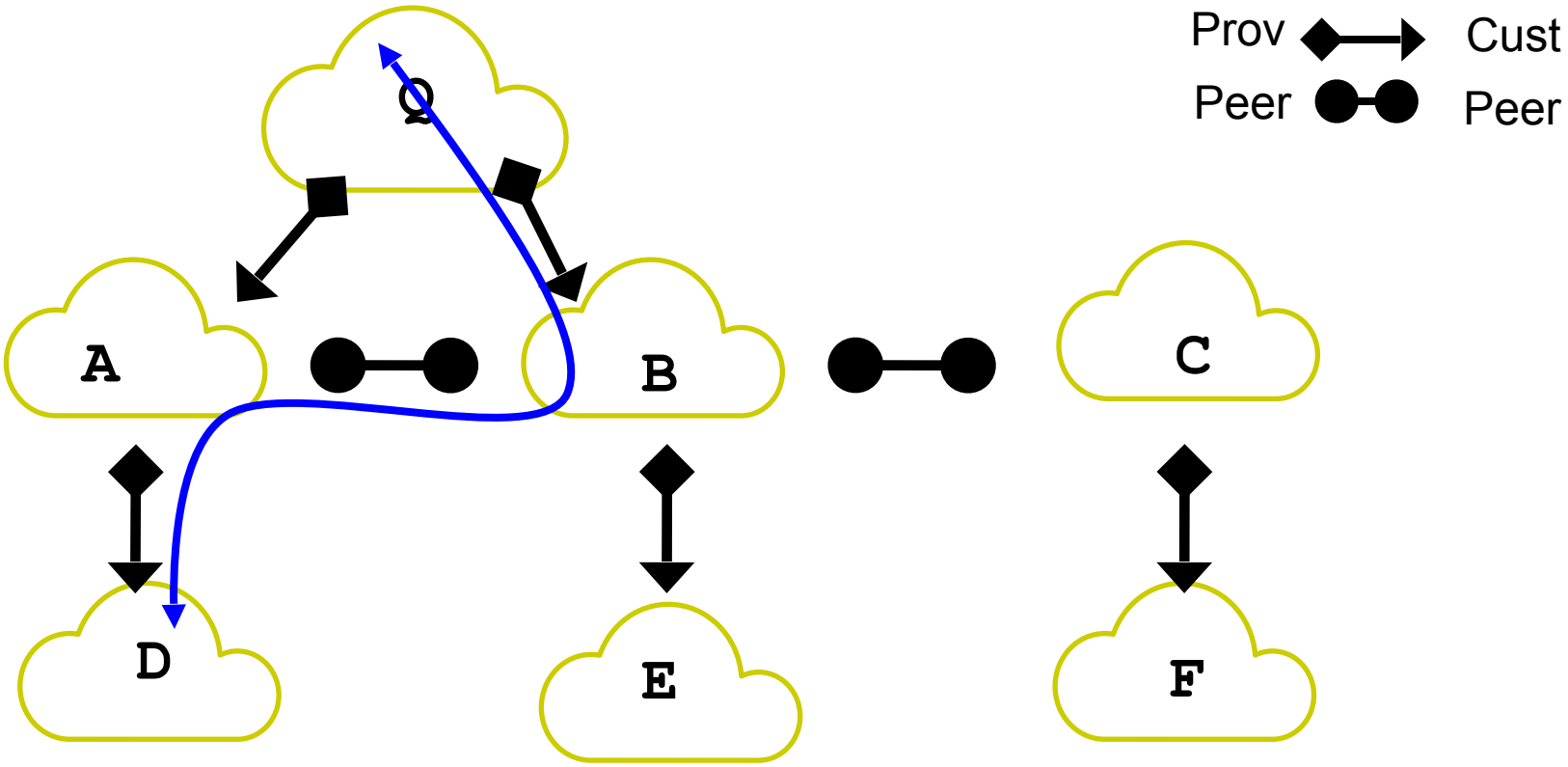

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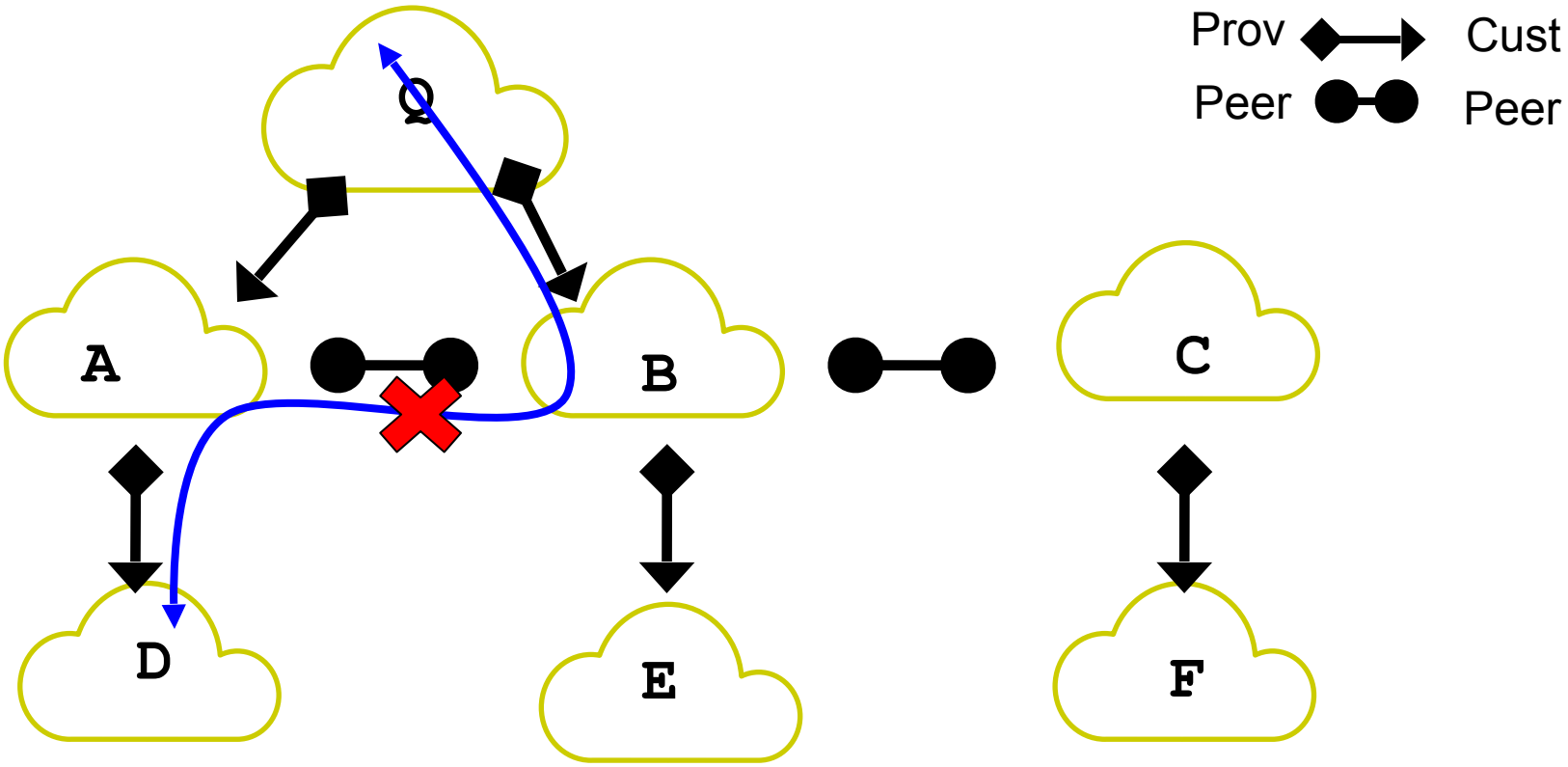

An AS only carries traffic to/from its own customers over a peering link

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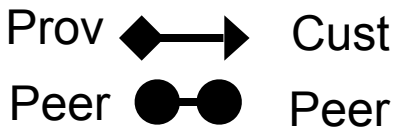

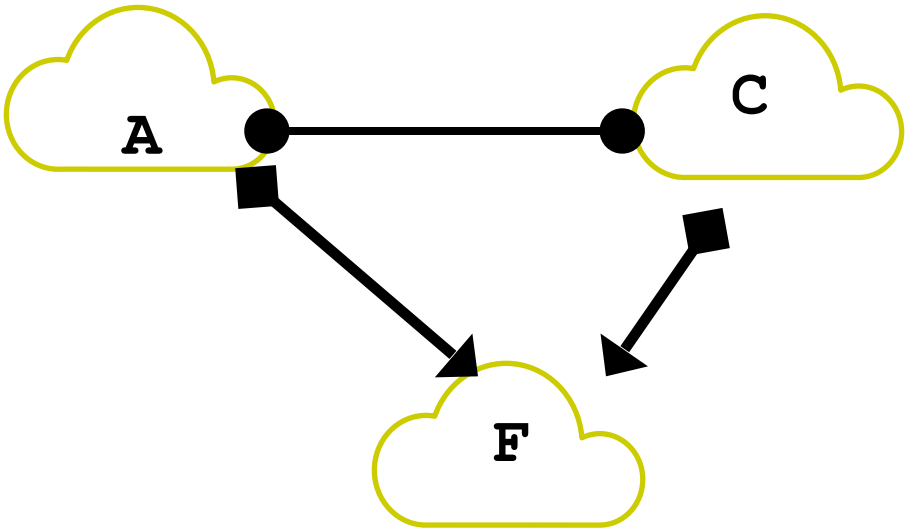

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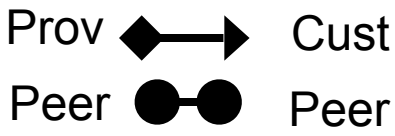

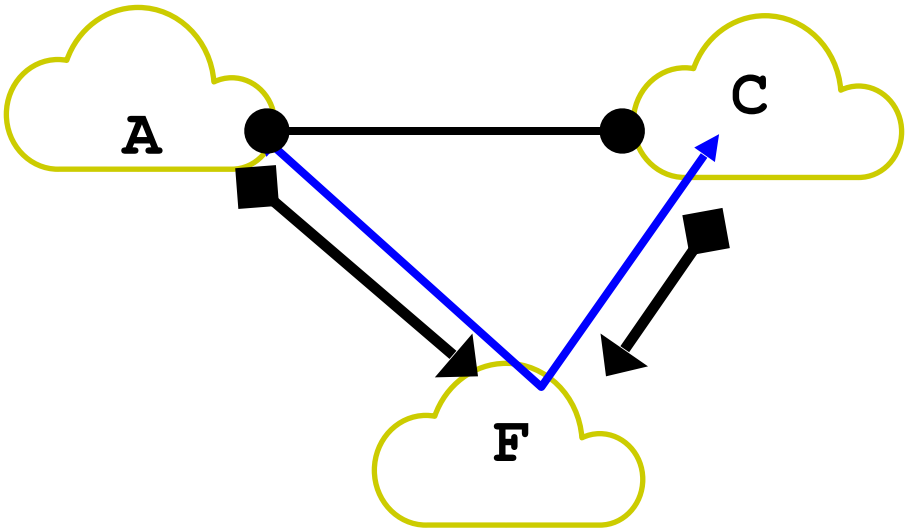

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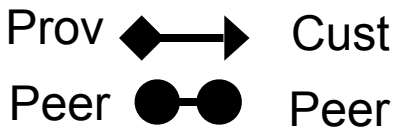

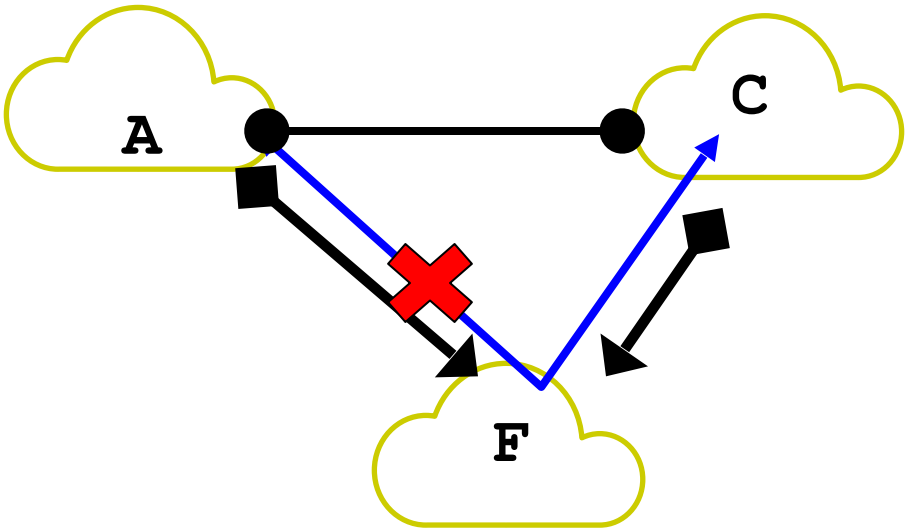

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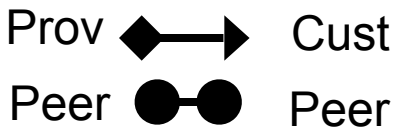

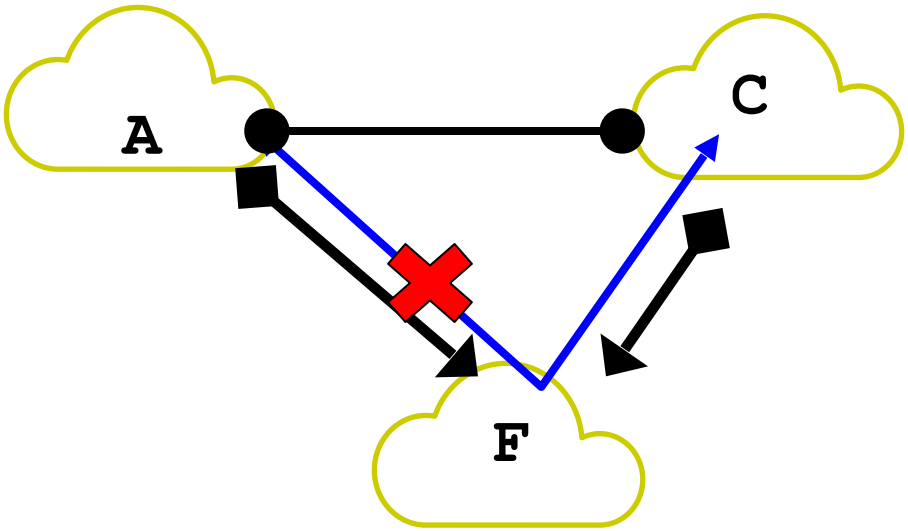

Routes are “valley free” (will return to this later)

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  - While preserving domains' **autonomy** and **privacy**
- Border Gateway Protocol (BGP) is current design

The Rise of a New Routing Paradigm

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  - Developed 1989-1995
- Has proven effective but with some serious warts

Outline

- Context
- Goals / Challenges
- Approach
- BGP: detailed design
- Limitations

Recap: Interdomain Setup

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- Route selection based on AS policy, while respecting AS autonomy and privacy

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BGP extends DV to accommodate policy

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- Approach
  - From DV to BGP
  - How policy is implemented (detail-free version)
- Detailed design
- Problems with BGP

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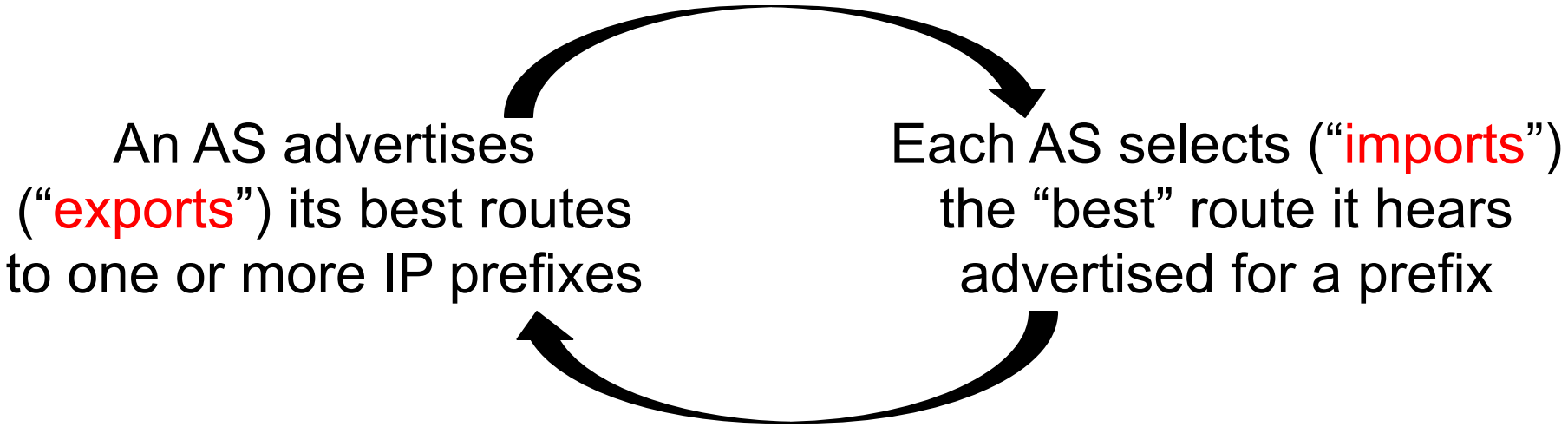
Each AS selects ("imports") the "best" route it hears advertised for a prefix

BGP: Basic Idea



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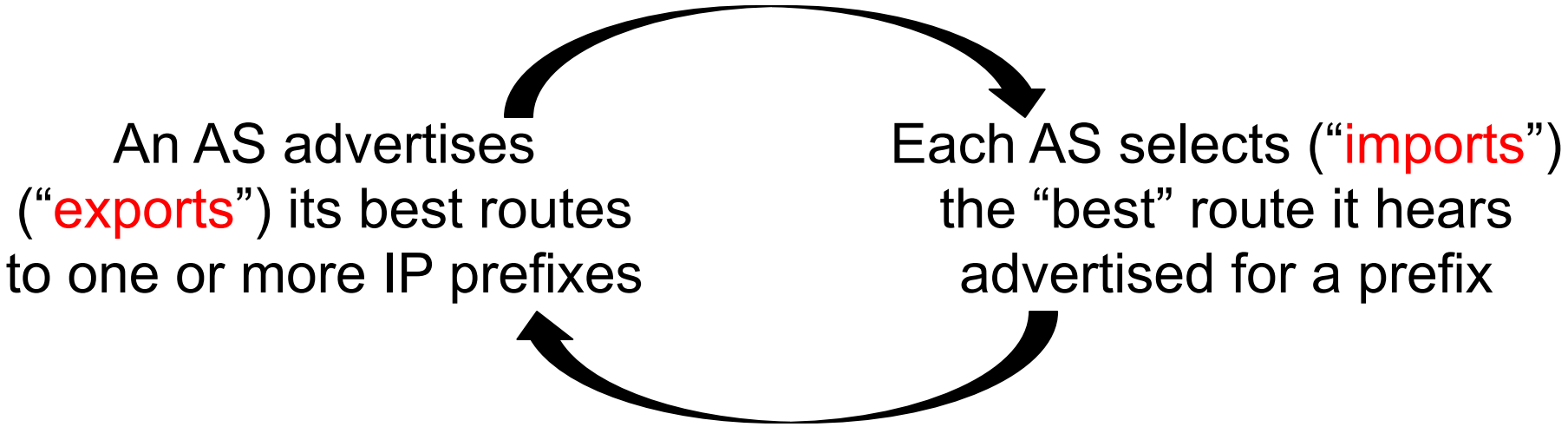

Policy will determine which route advertisements
are selected and which are advertised (more later)

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Differences between BGP and DV

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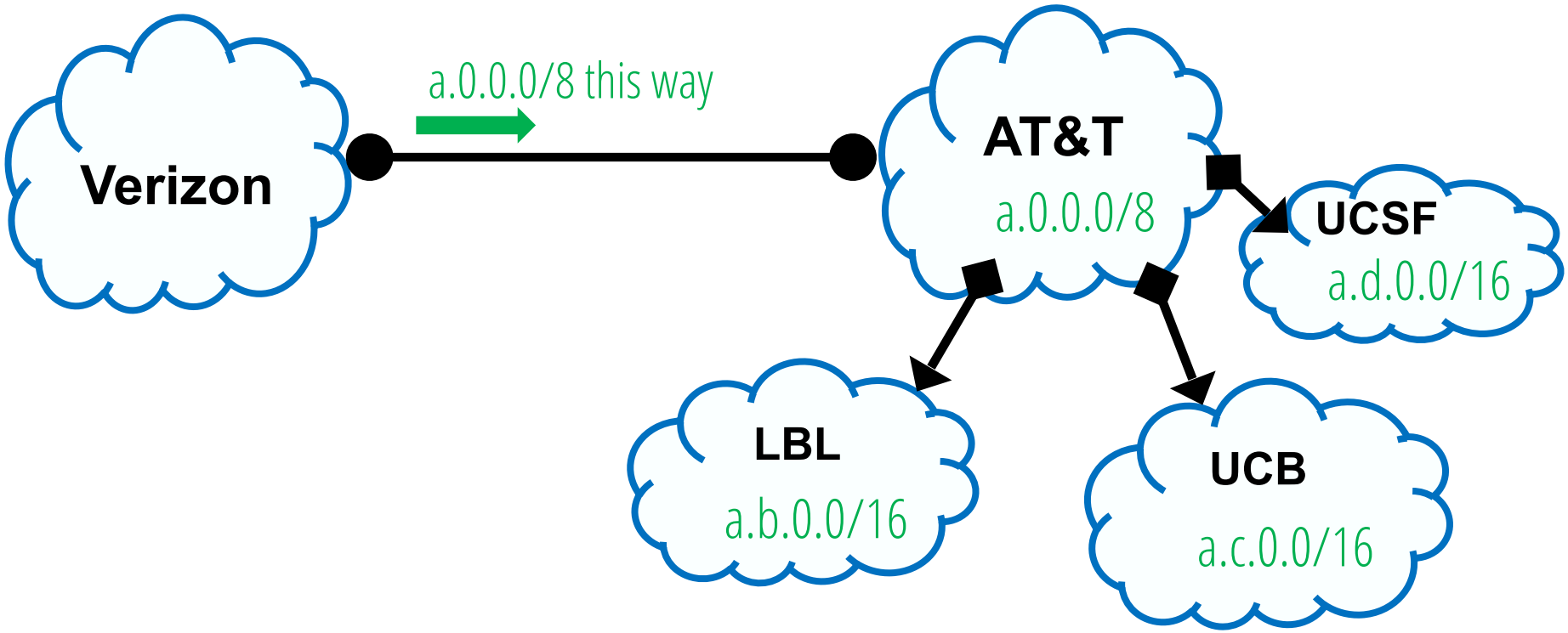

Differences between BGP and DV
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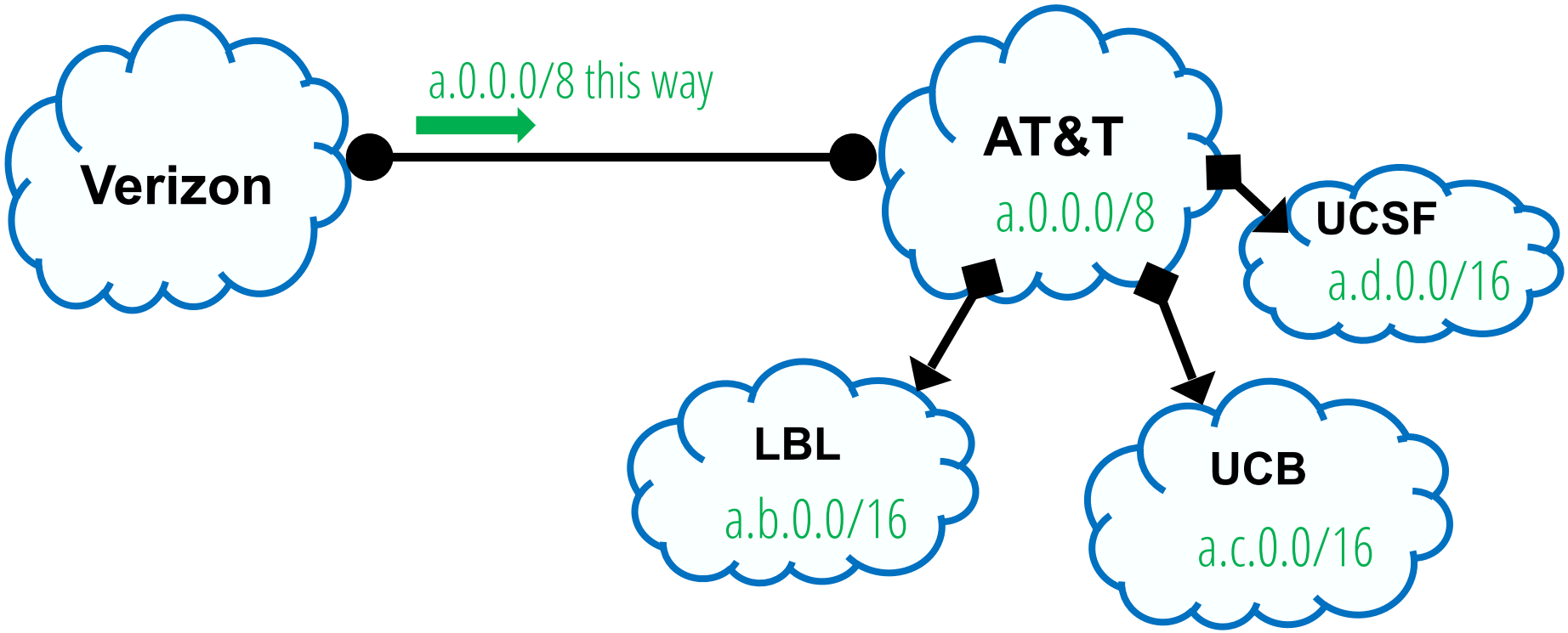
- For scalability, BGP may aggregate routes for different prefixes



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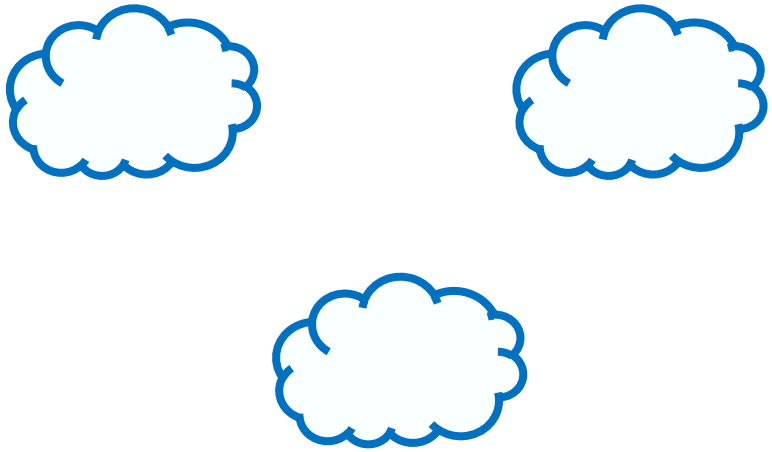

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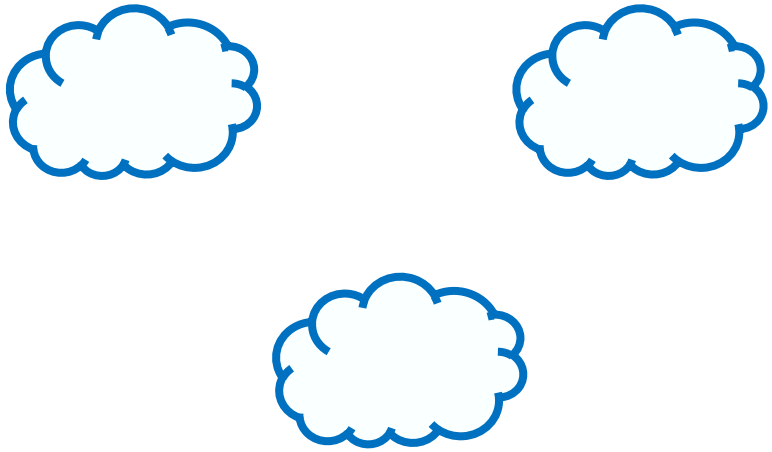

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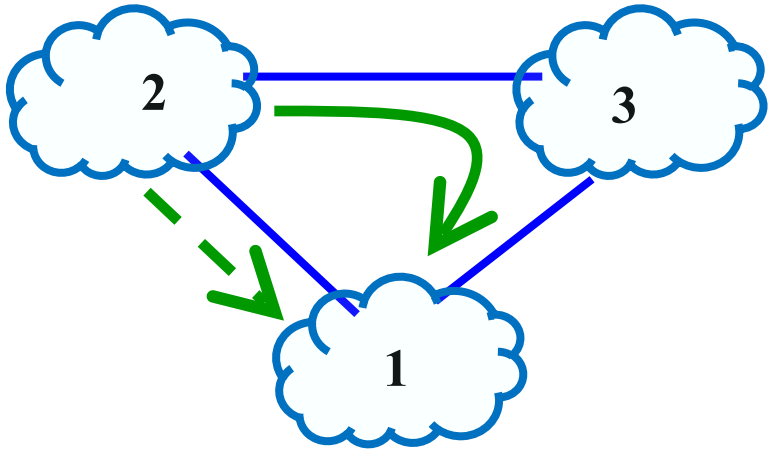

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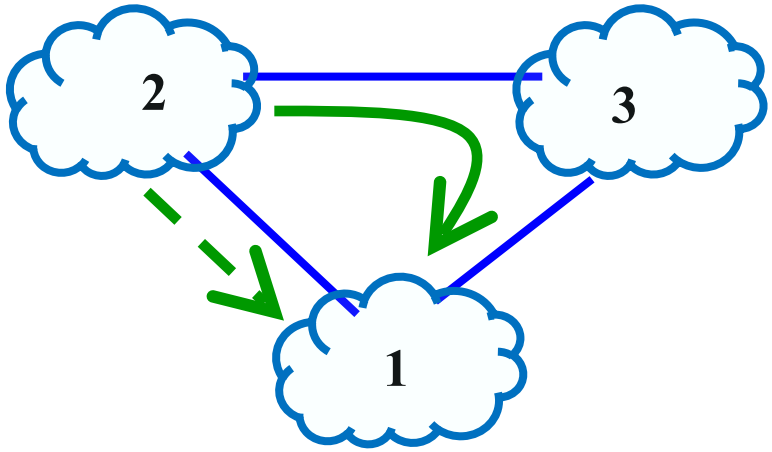

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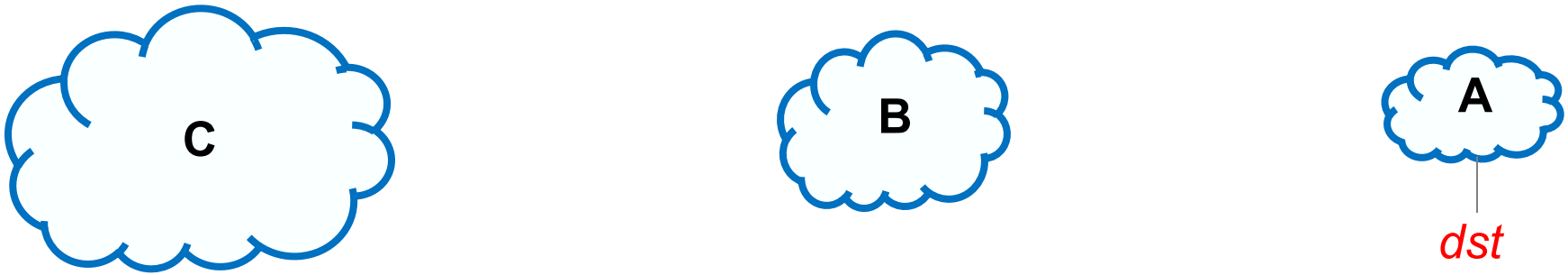
- How do we avoid loops?

Differences between BGP and DV

(3) distance-vector → path-vector



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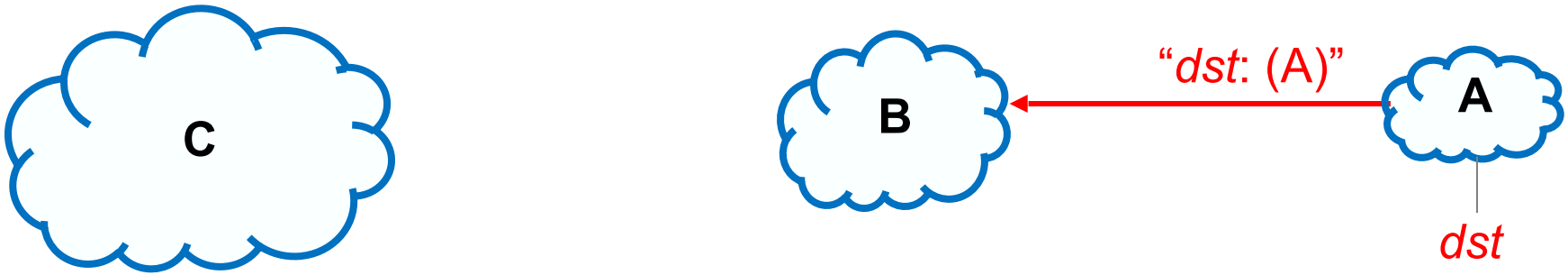

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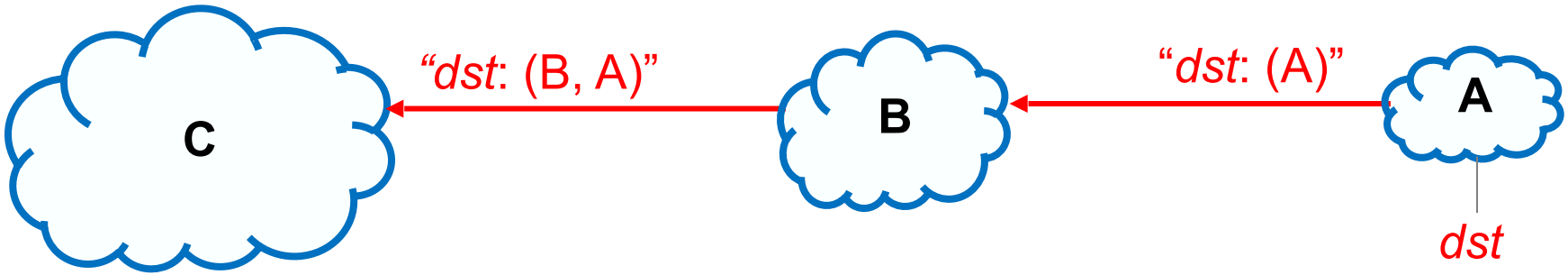

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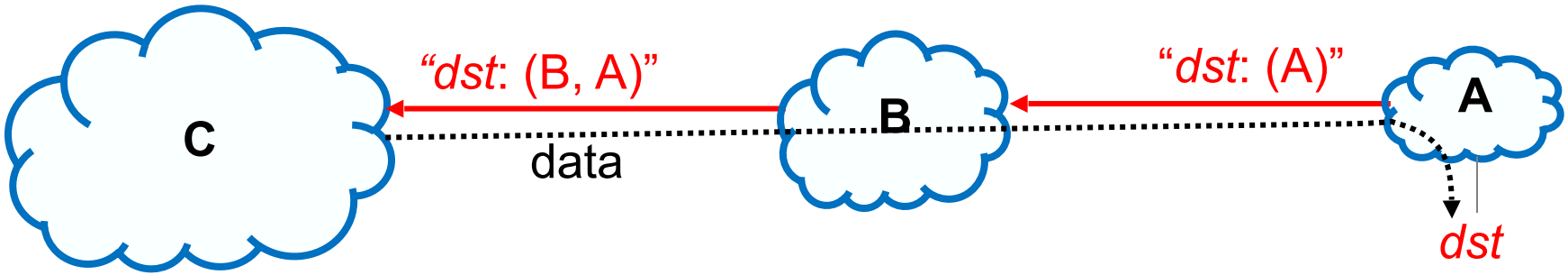

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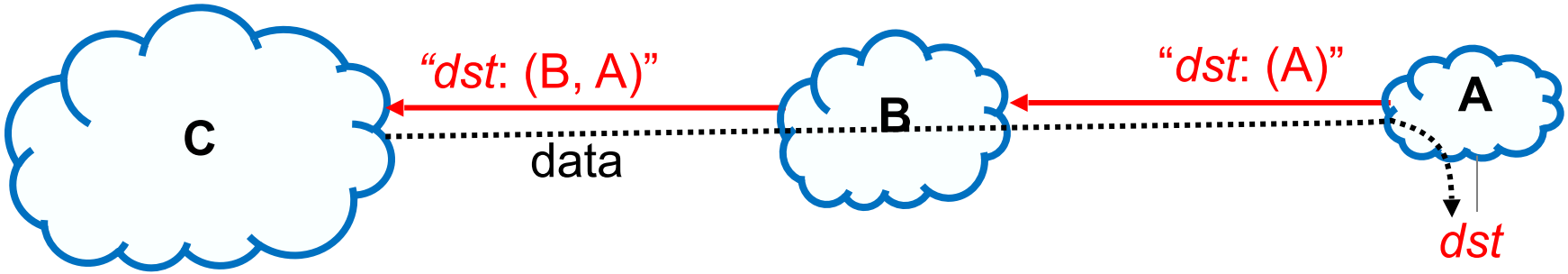
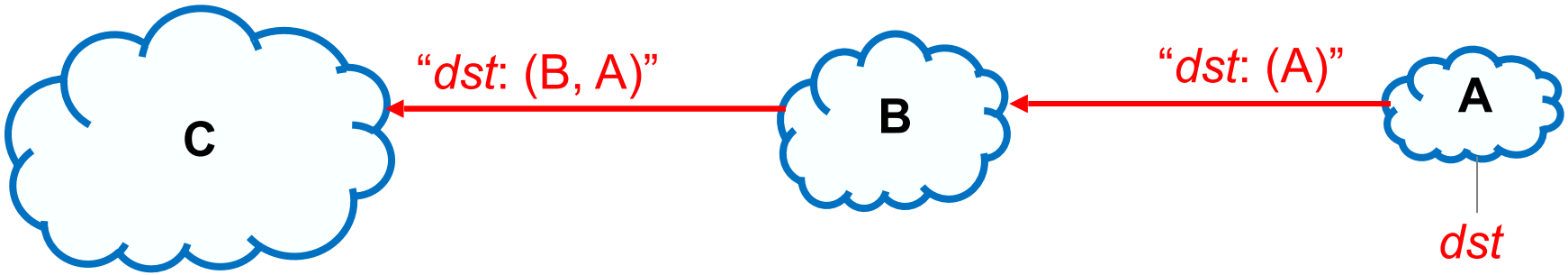
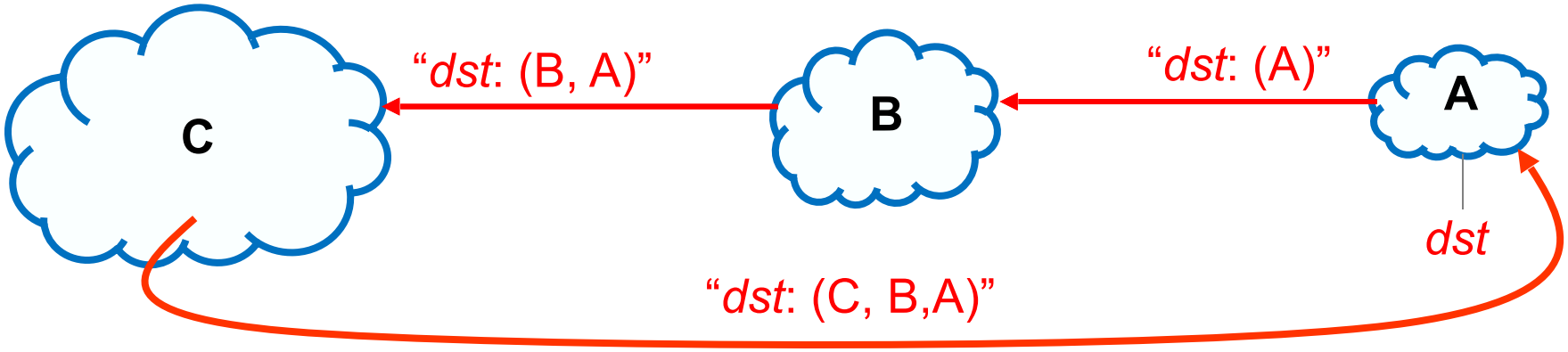


Loop Detection w/ Path Vector



Loop Detection w/ Path Vector

- AS can easily detect and discard paths w/ loops
  - E.g., A sees itself in the path “C, B, A”
  - E.g., A simply discards the advertisement



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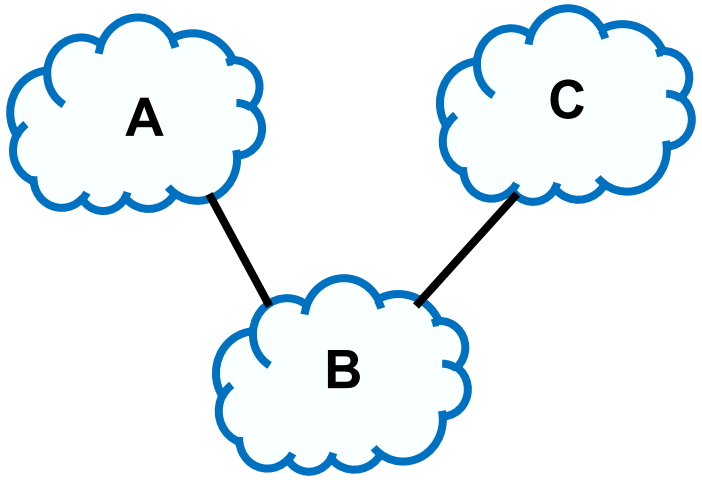
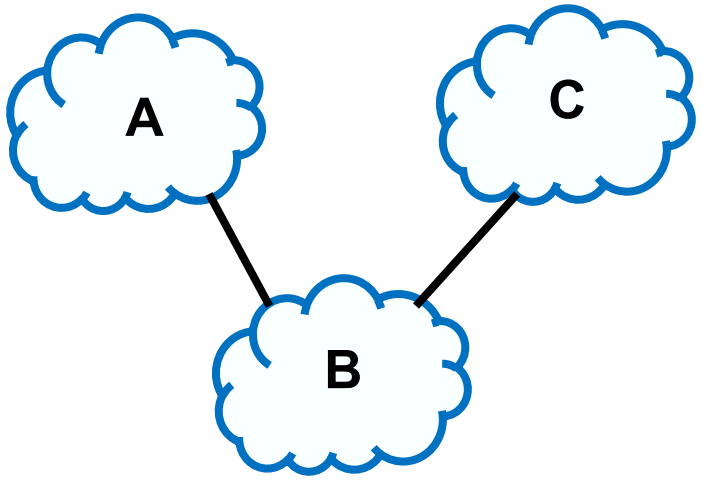


Example: B does not want to carry traffic between A and C

Differences between BGP and DV
(4) Selective route advertisement

- For policy reasons, an AS may choose not to advertise a route to a destination
- Hence, reachability is not guaranteed even if graph is connected



Example: B does not want to carry traffic between A and C

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(4) Selective route advertisement

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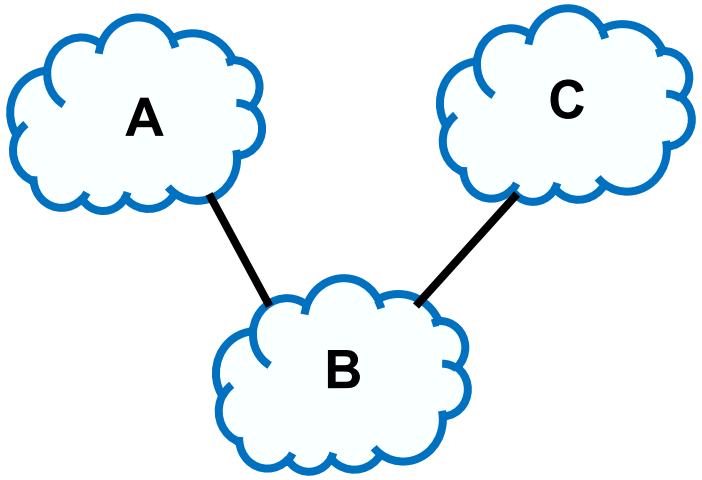

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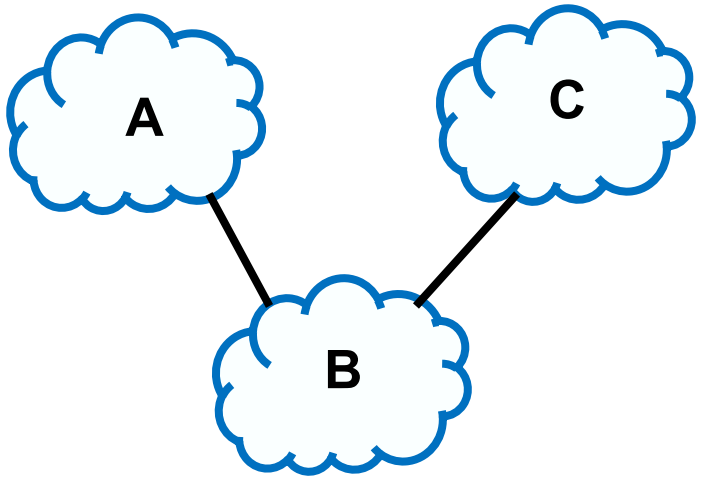

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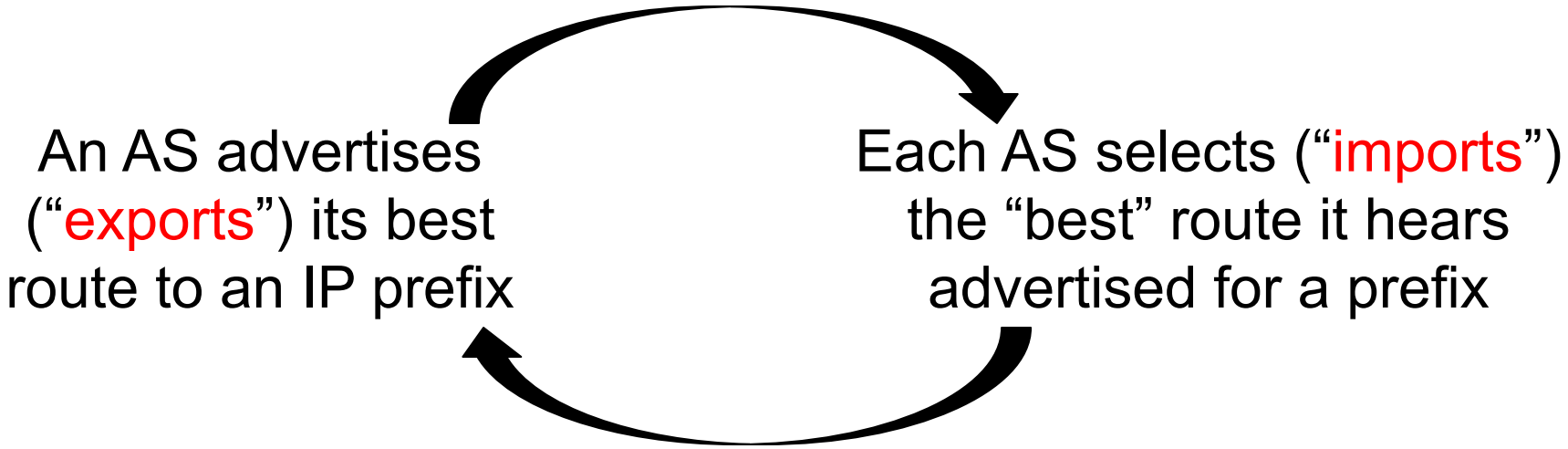
Recap: four differences

- BGP may aggregate destinations and routes
- Route selection not based on shortest path
- Advertise the entire path (path vector)
- Selective route advertisement

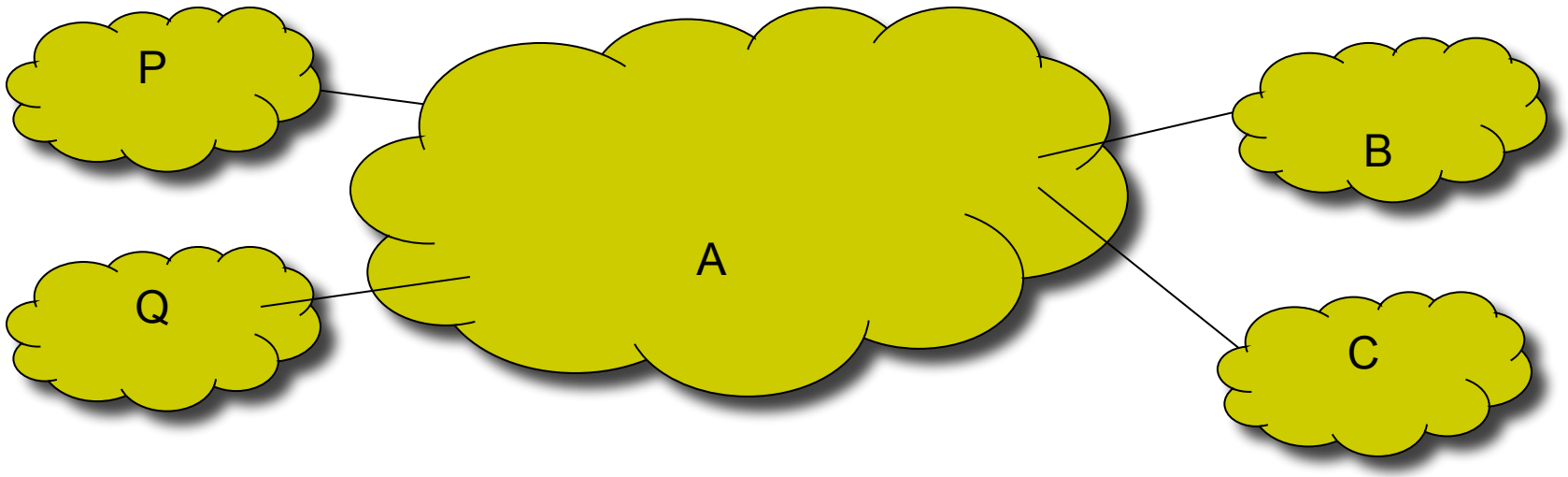
Outline

- Context
- Goals
- **Approach**:
  - BGP extends Distance-Vector
  - How policy is implemented (detail-free version)
- Detailed design
- Limitations

Recall:


An AS advertises ("exports") its best route to an IP prefix
Each AS selects ("imports") the "best" route it hears advertised for a prefix

Policy imposed in how routes are import and exported



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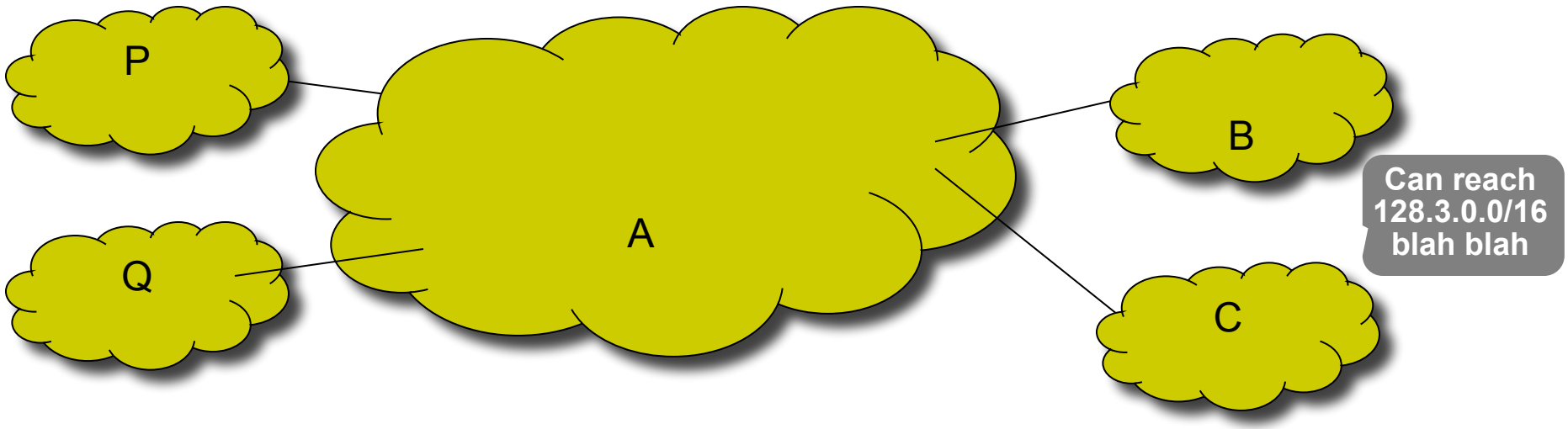

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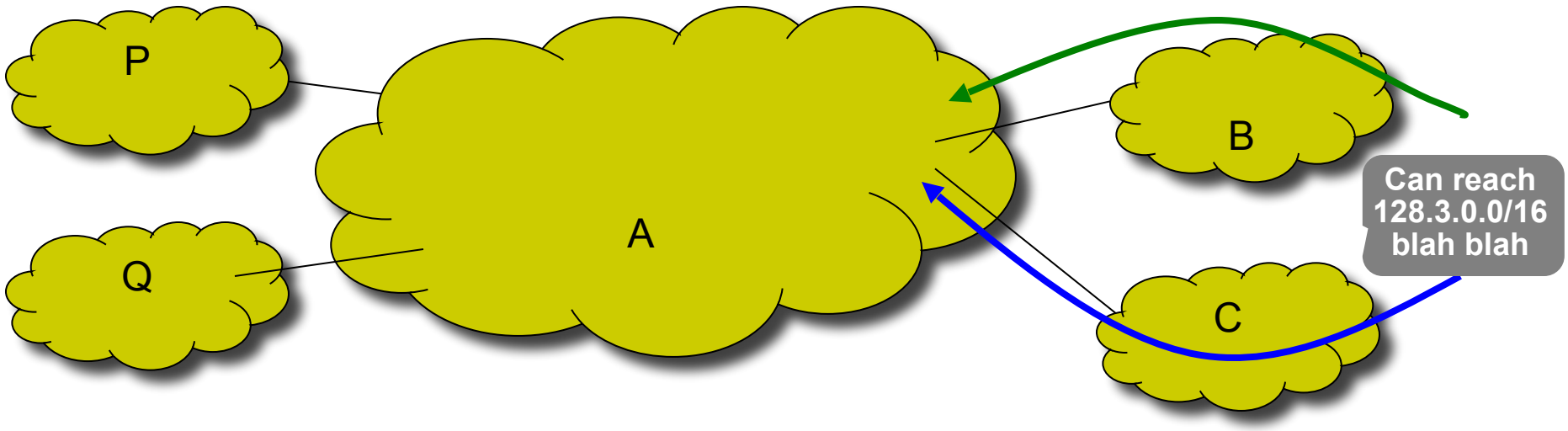

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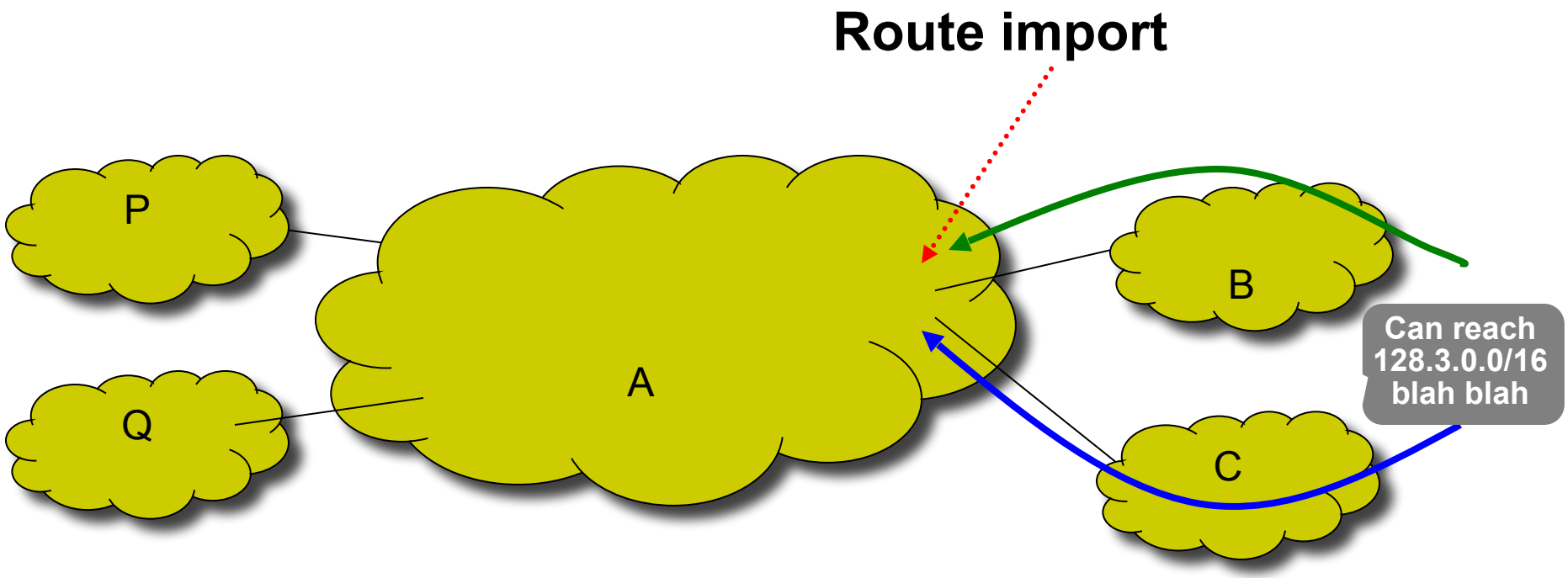

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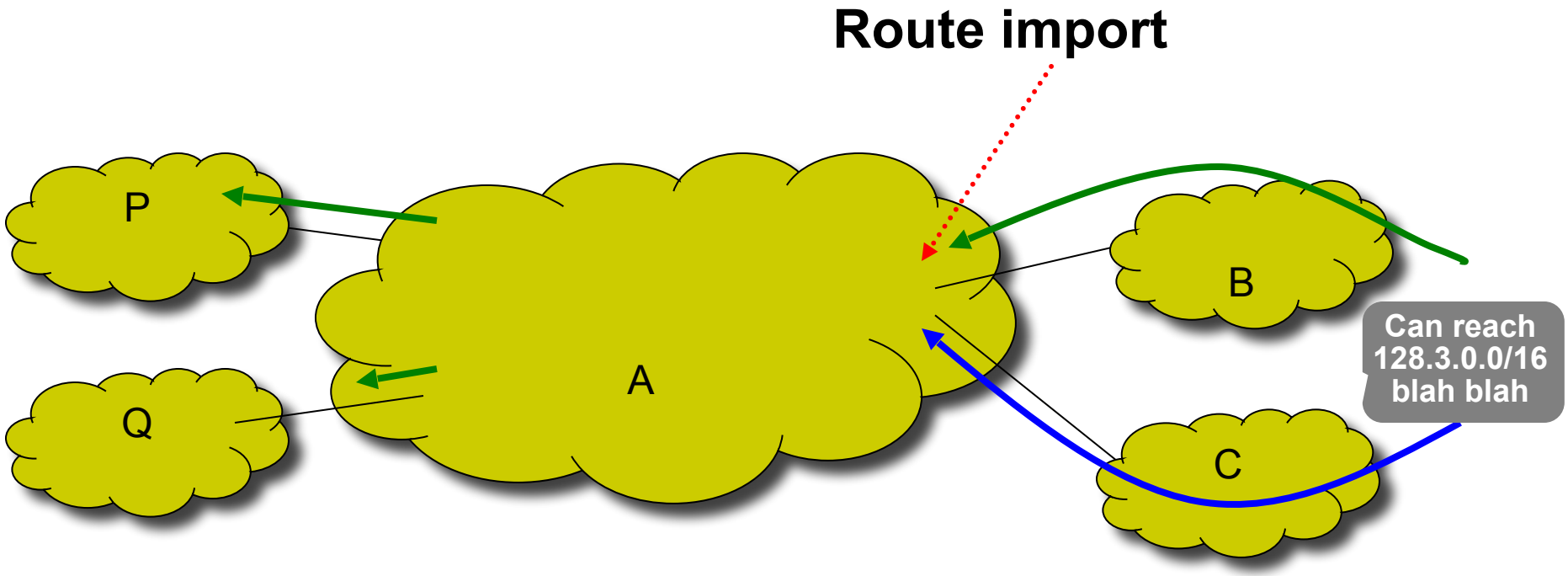

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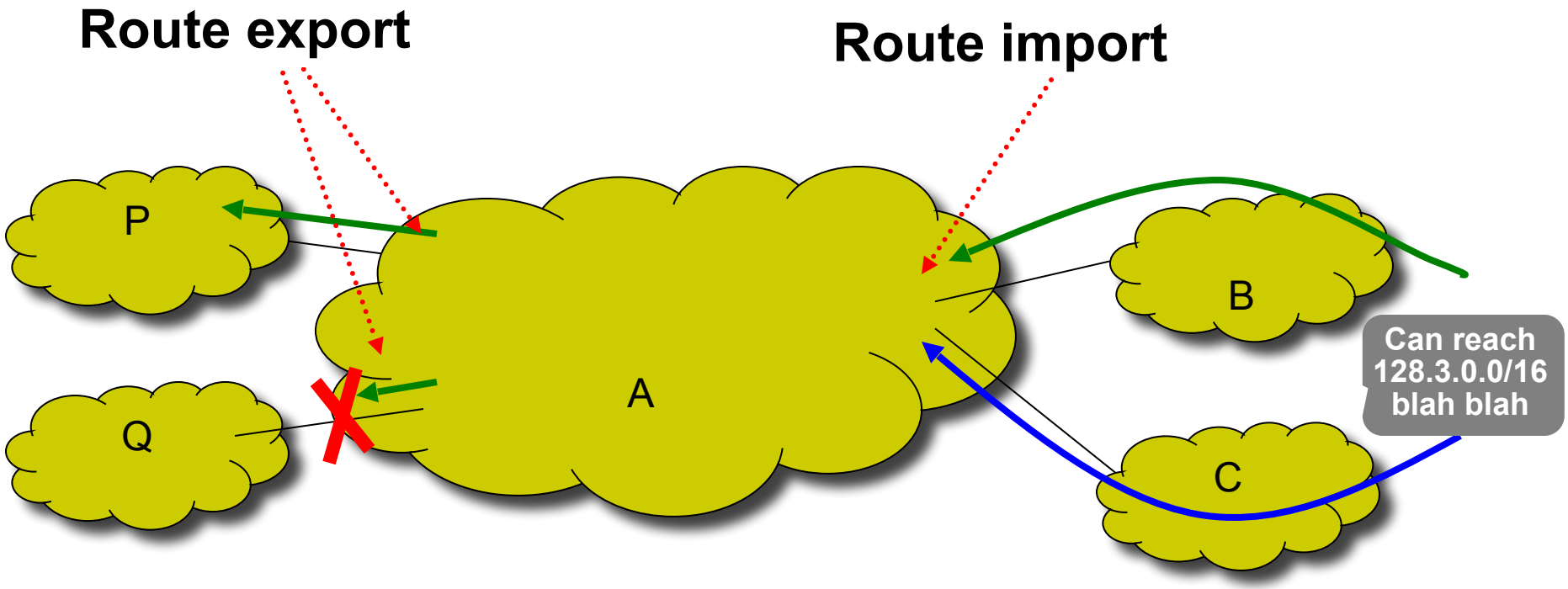

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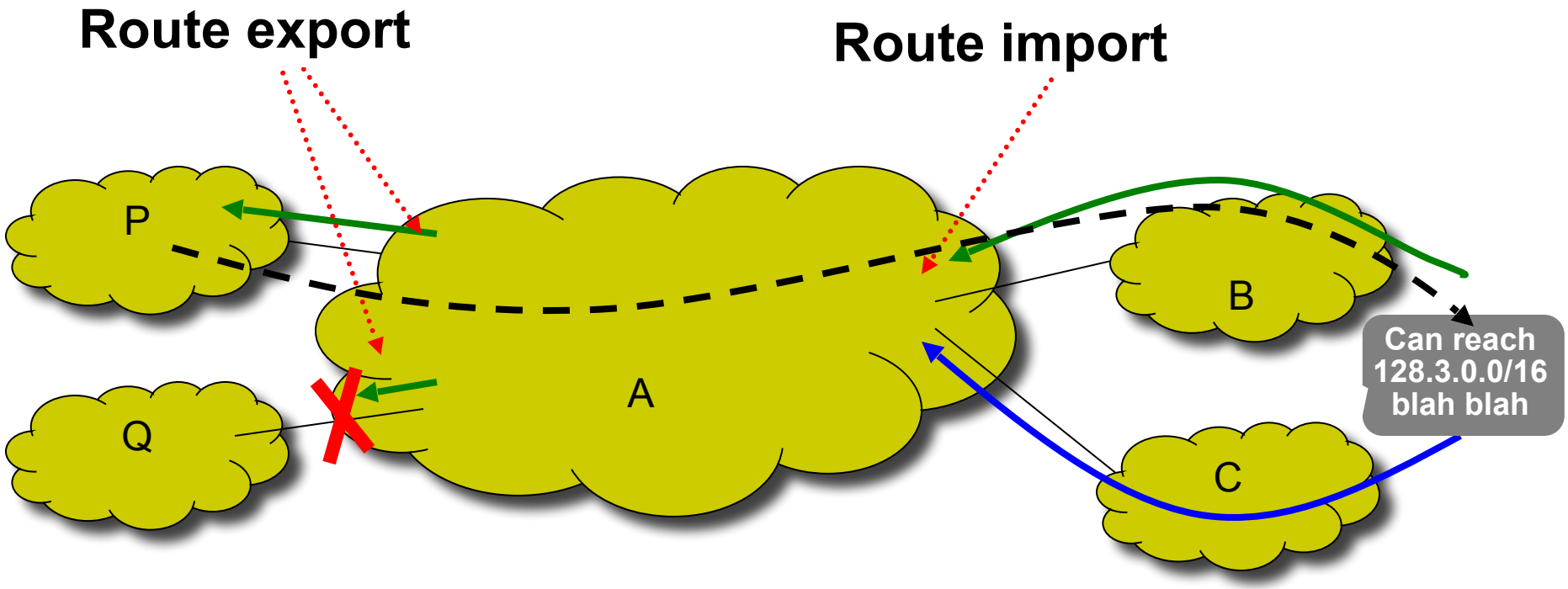

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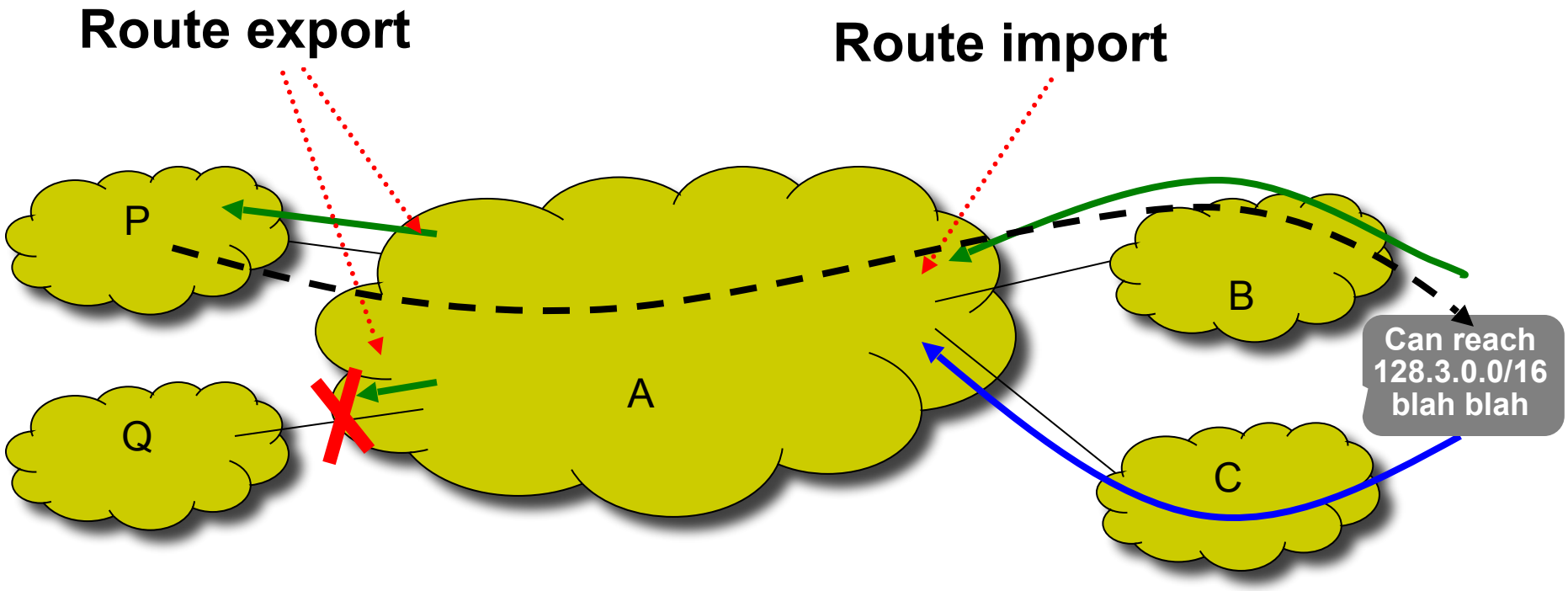

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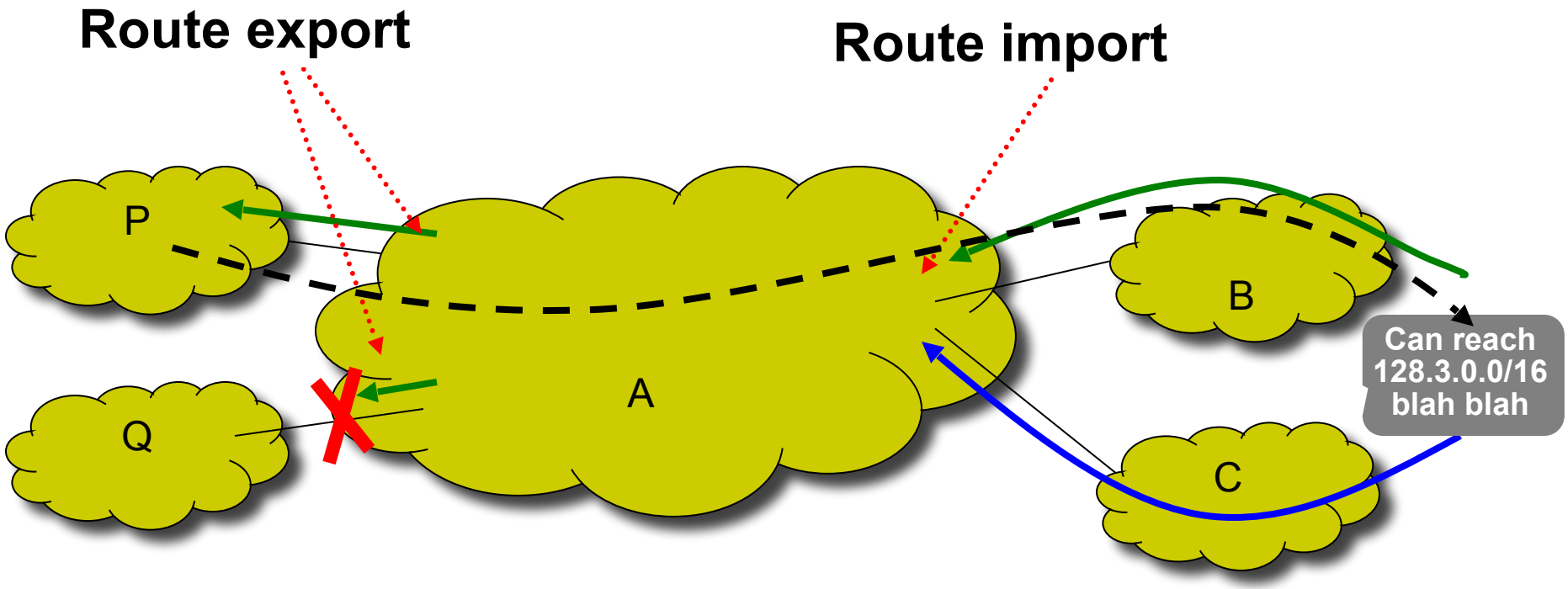

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- **Export**: Which path to advertise?
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Repeating Two Crucial Points

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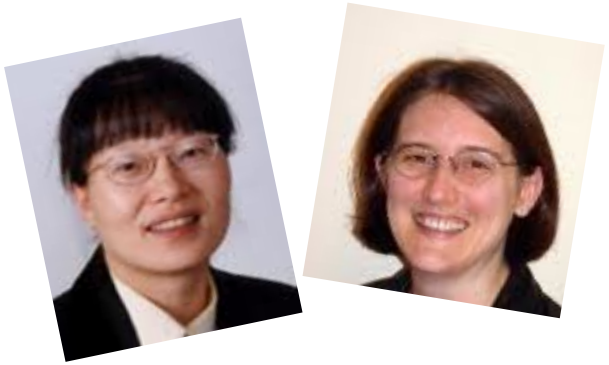
- Export: Which path to advertise?
  - Determines **which** traffic you ***carry***
  - Why? This determines who can send traffic to you

Gao-Rexford Rules



- Rules that describe common – not required! – practice in import/export policies
- Essential to understanding why the Internet works
  - Because it wouldn't if policies were completely general

Gao-Rexford Rule: Import policy

- When importing (selecting) a route to a destination, pick route advertised by customer > peer > provider

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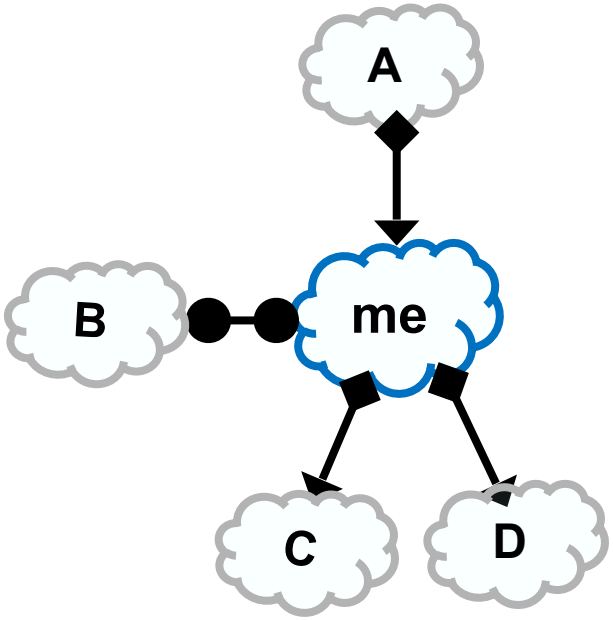
Provider	



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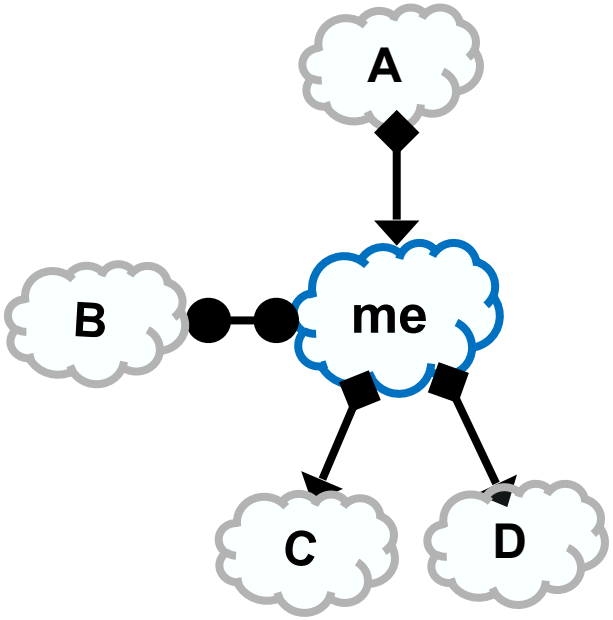

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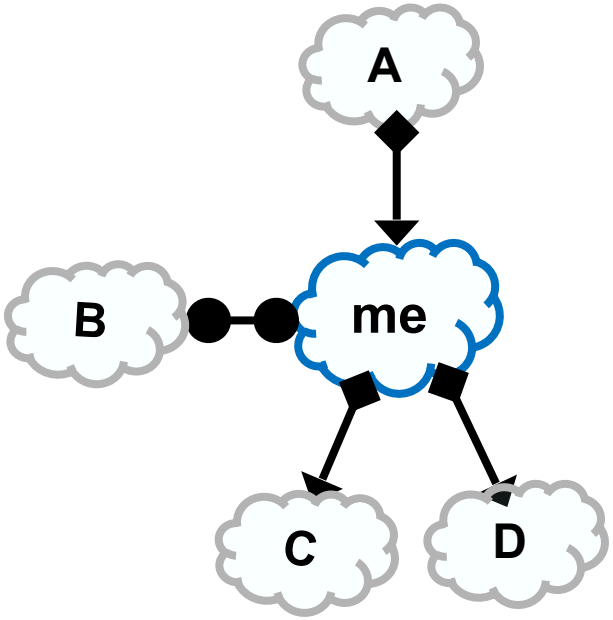

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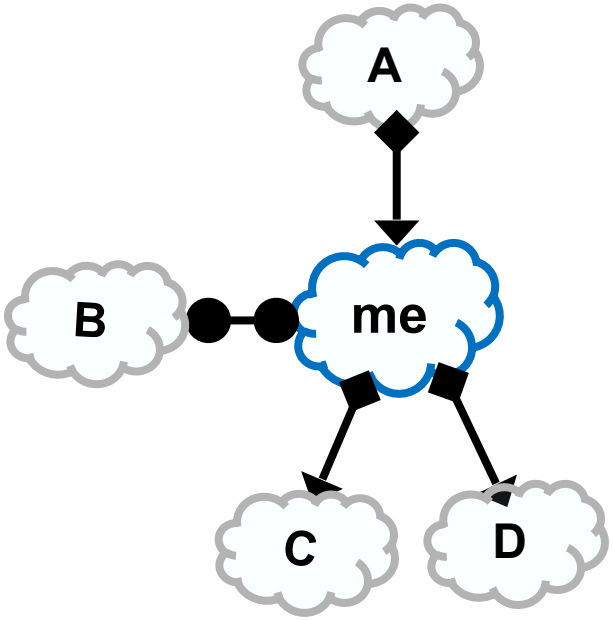
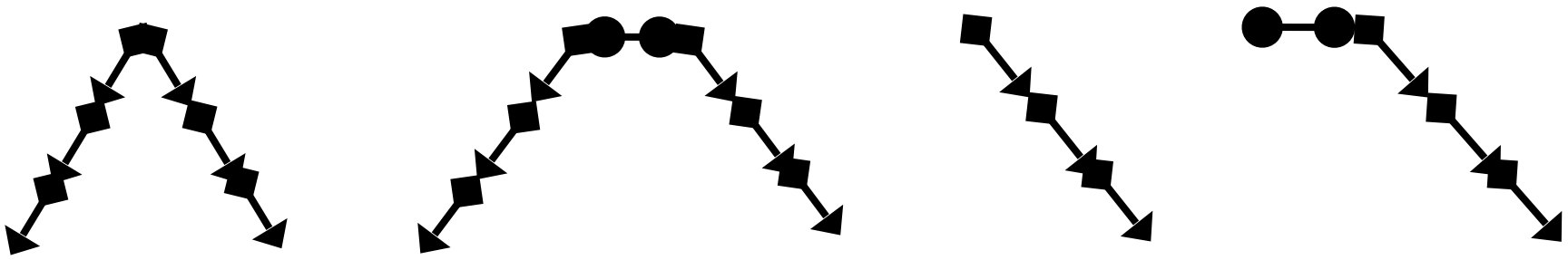


Gao-Rexford Rules: Property

If all ASes follow G-R, routes are "valley free"



"valley free" == "single peaked"

(proof sketch in discussion section)

Gao-Rexford Rules: Implication

- Under two assumptions about the AS graph (coming up), if all ASes follow Gao-Rexford, we can guarantee:
  - **Reachability**: any two ASes can communicate
  - **Convergence**: all routers agree on paths
- The above hold in steady state

Questions?