Distributed Route Aggregation on the GlObal Network (DRAGON)

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Last year in the news (August 2014)

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TECHNOLOGY

Echoes of Y2K: Engineers Buzz That Internet Is Outgrowing Its Gear

Routers That Send Data Online Could Become Overloaded as Number of Internet Routes Hits '512K'

By DREW FITZGERALD CONNECT

Updated Aug. 13, 2014 7:38 p.m. ET

BBC | News | Sp

NEWS TECHNOLOGY

14 August 2014 Last updated at 12:05 GMT

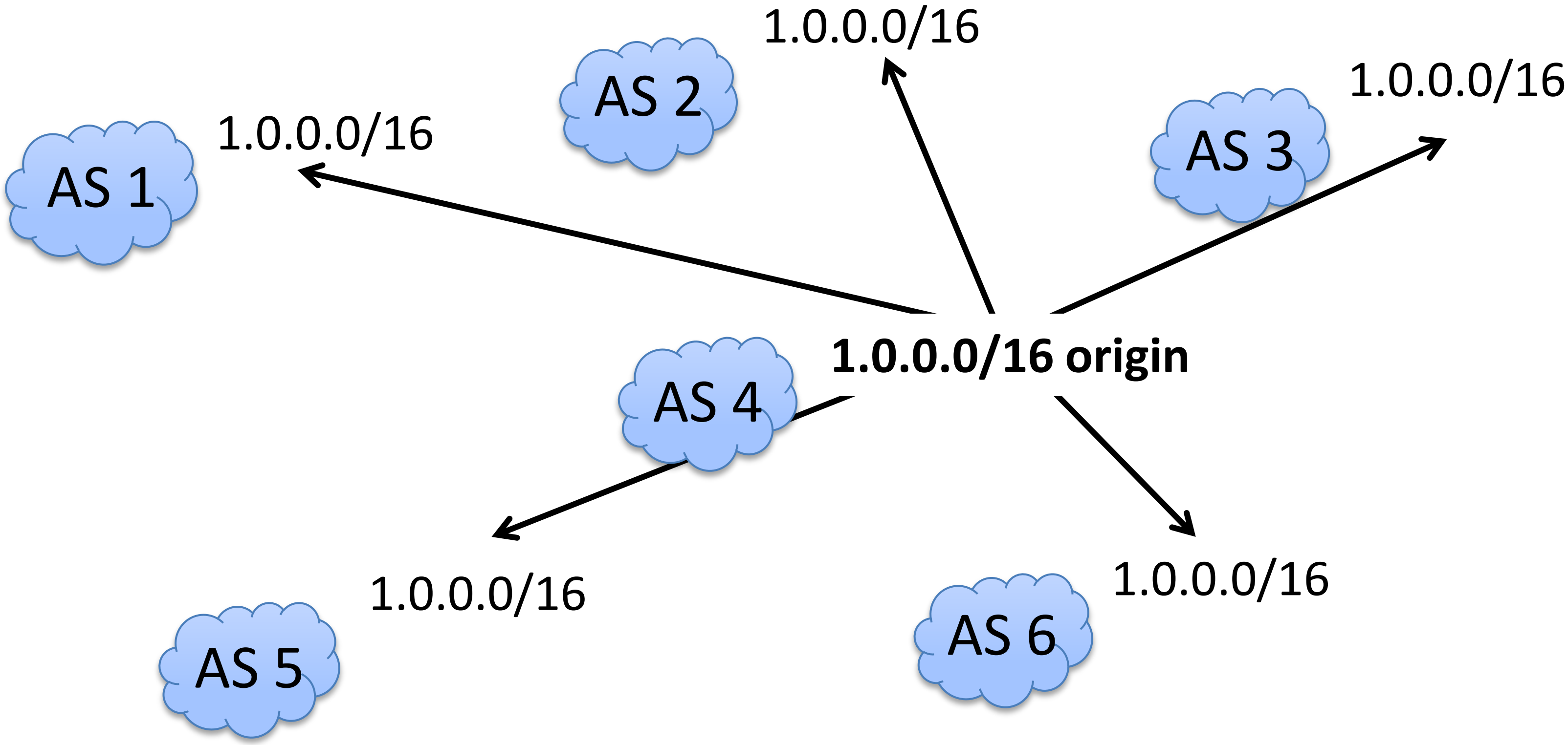
Browsing speeds may slow as net hardware bug bites

By Mark Ward

Technology correspondent, BBC News

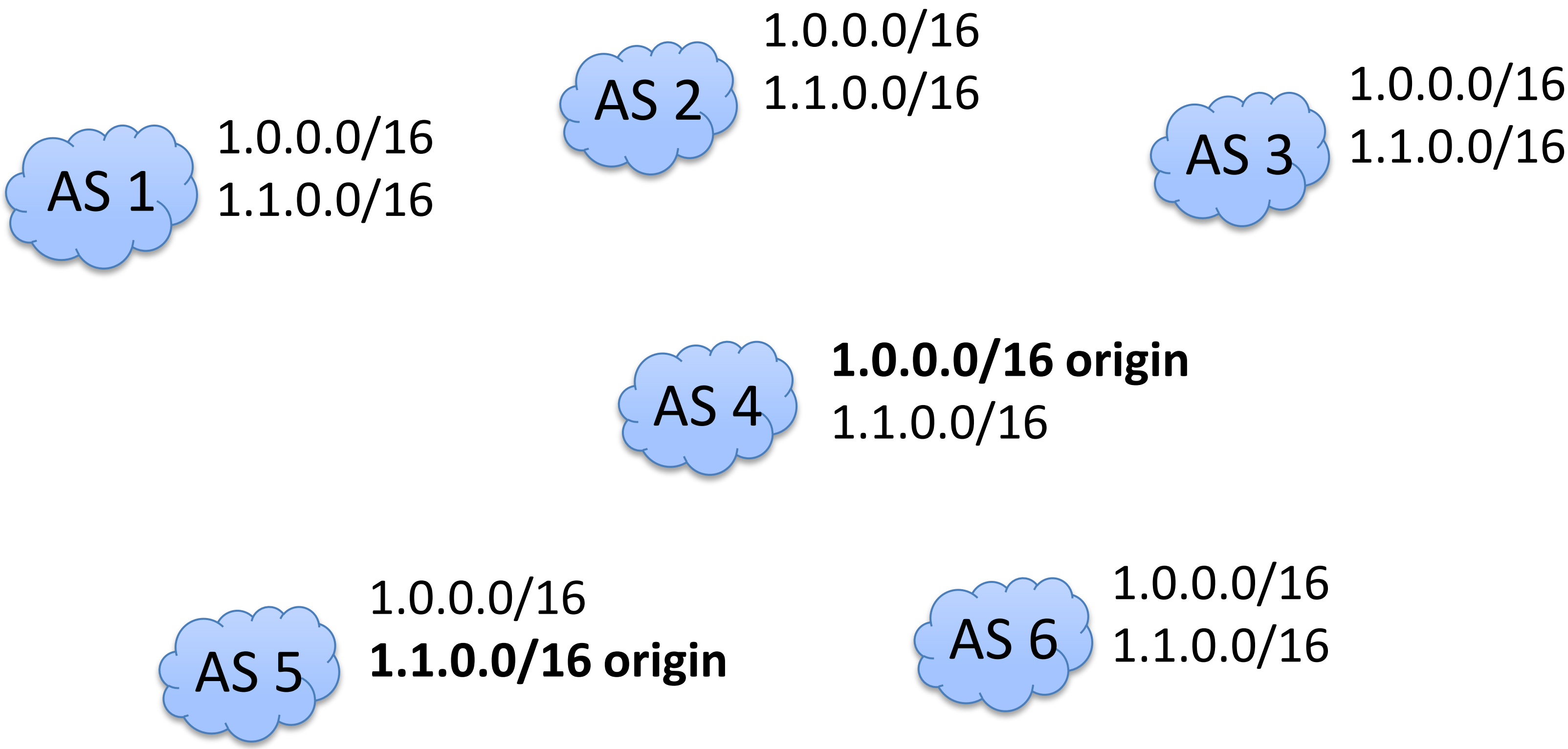
Some routers could not process the +512 K IPv4 prefixes they were learning about

Not a scalable routing system



Most of the originated prefixes are routed globally (by BGP)

Not a scalable routing system



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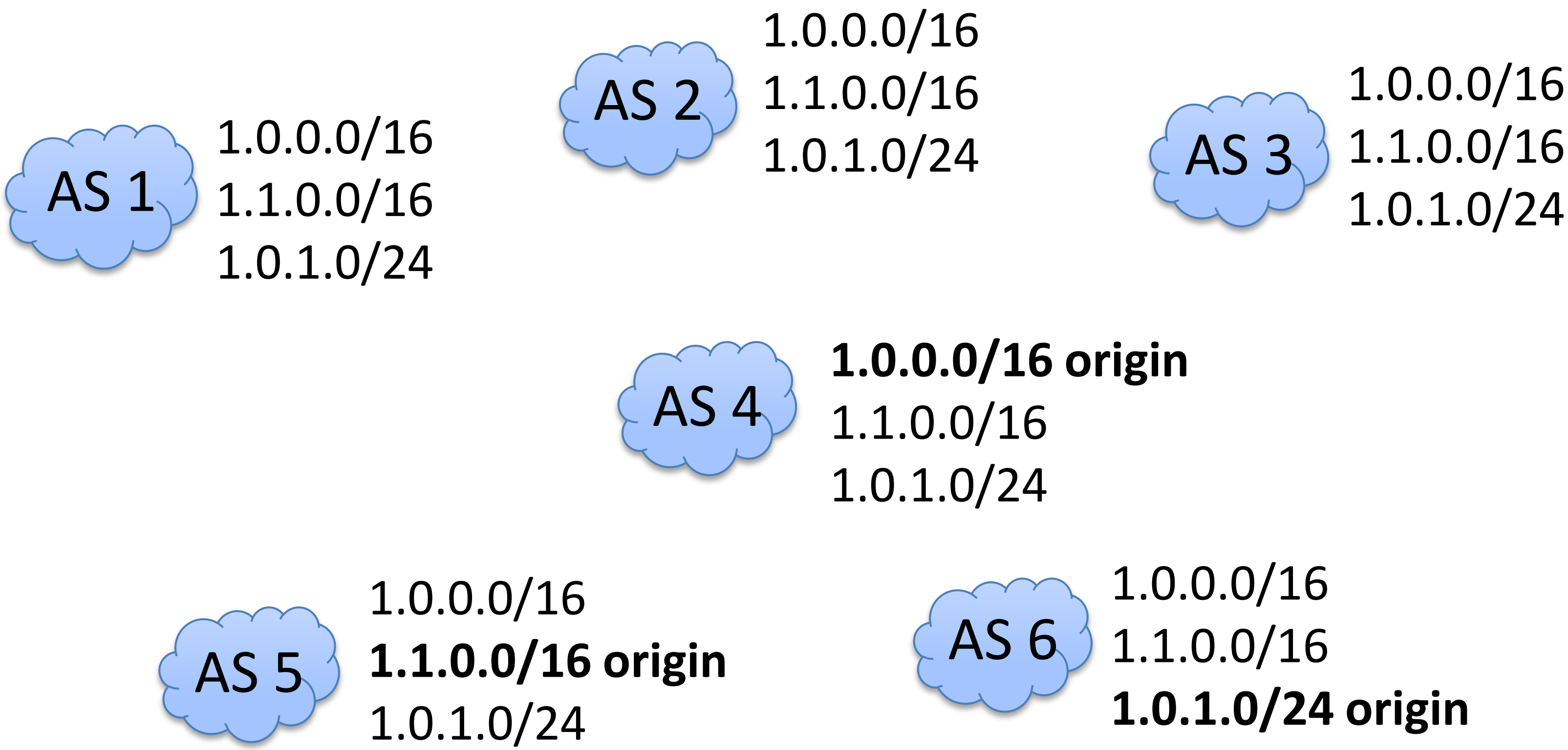

Most of the originated prefixes are routed globally (by BGP)

No scalability: poor performance

- Forwarding tables (FIBs) growth & address look-up time increase
- Routing tables (RIBs) growth
- BGP session set-up time increase
- Churn & convergence time increase

Further scalability concerns

- IPv6 prefixes can be formed in potentially larger numbers than IPv4 prefixes
- Secure BGP adds computational overhead to routing processes

DRAGON

Distributed solution to scale the Internet routing system

Basic DRAGON: **49%** savings on routing state

Full DRAGON: **79%** savings on routing state

No changes to the BGP protocol
No changes to the forwarding plane
Readily implemented with updated router software

Outline

- Scalability: global view
- DRAGON: filtering strategy
- DRAGON: aggregation strategy
- DRAGON: performance evaluation
- Conclusions

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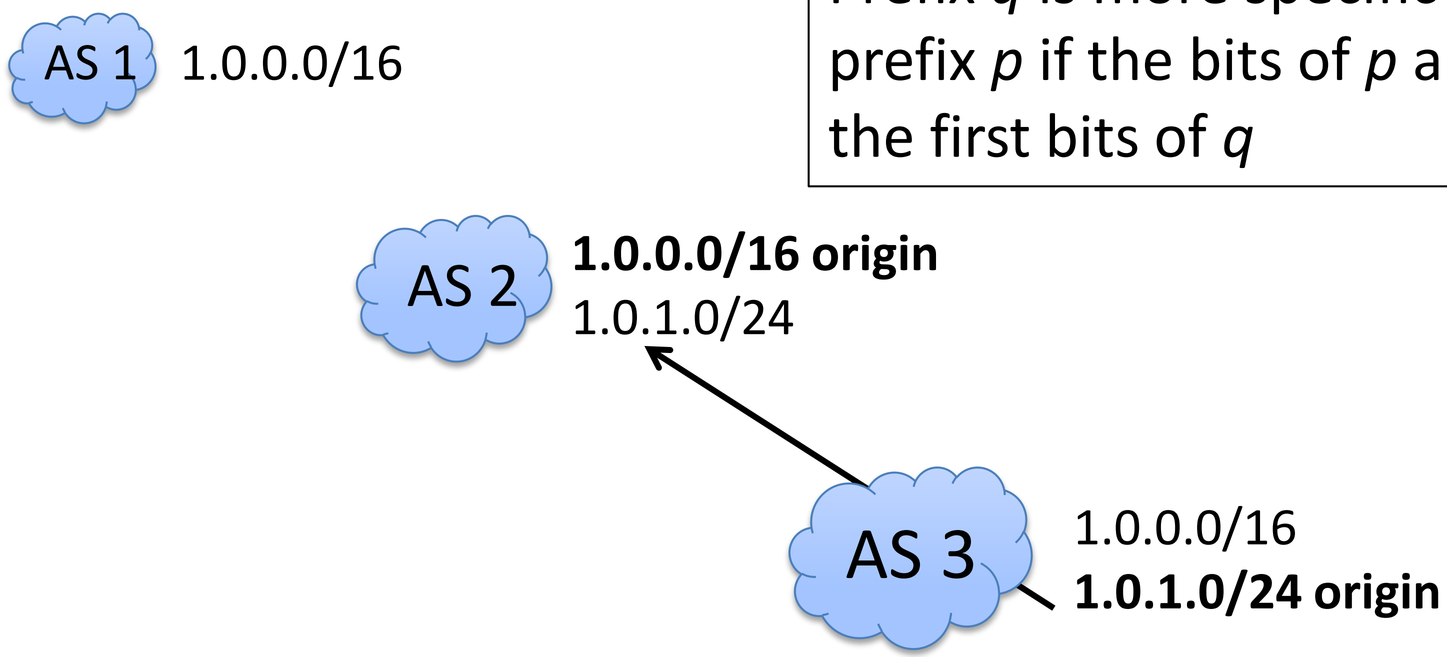
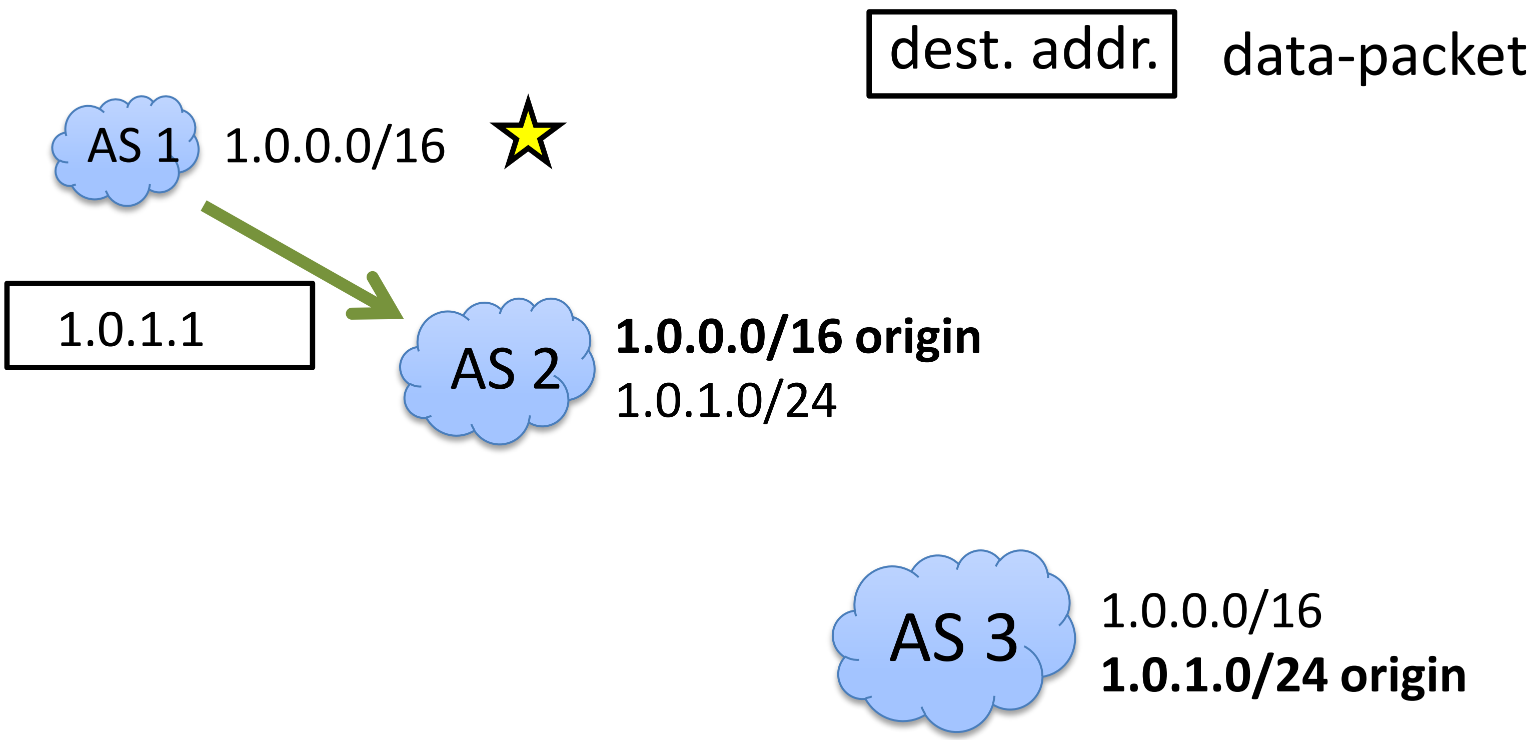
Scalability: global view (routing)

Specificity
Prefix *q* is more specific than prefix *p* if the bits of *p* are the first bits of *q*



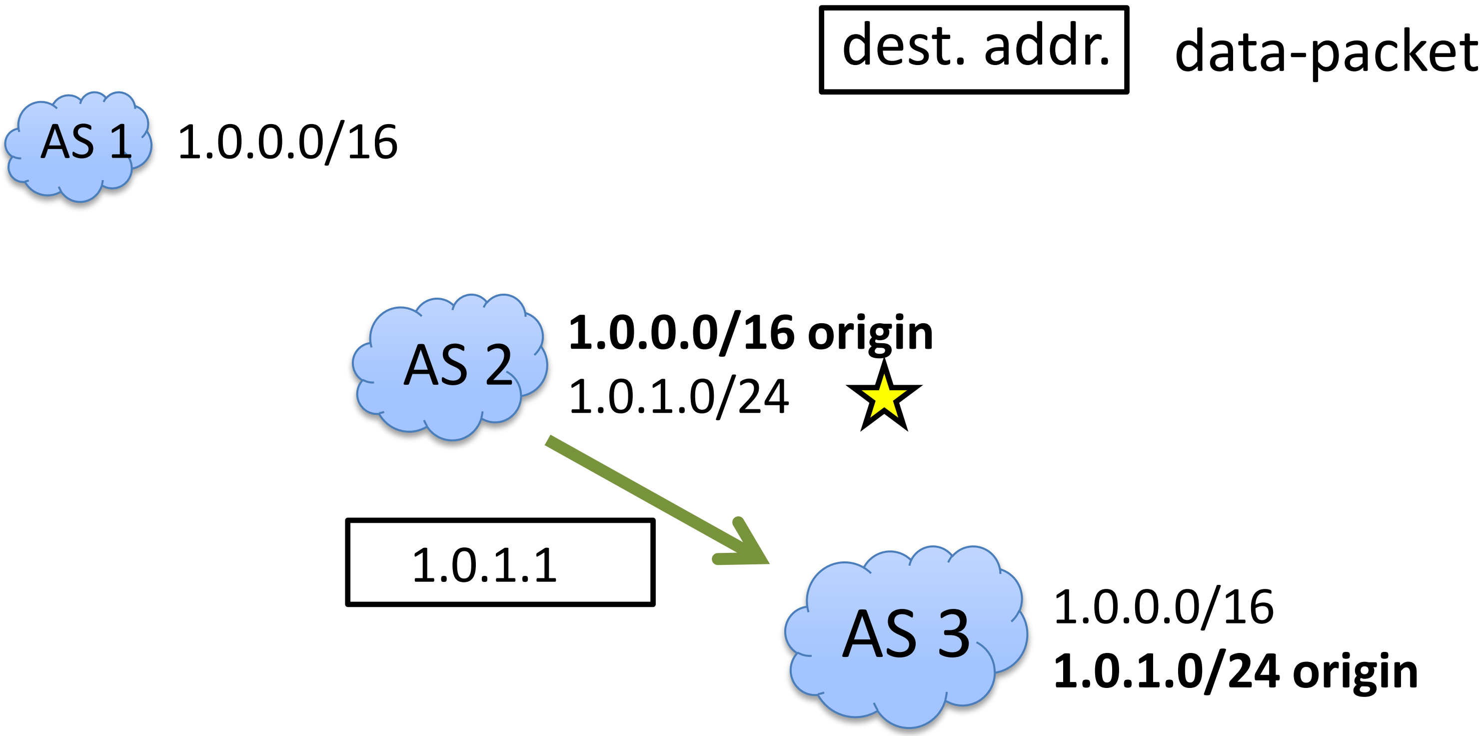
Propagation of more specific prefixes only in a small vicinity of their origin ASs

Scalability: global view (forwarding)

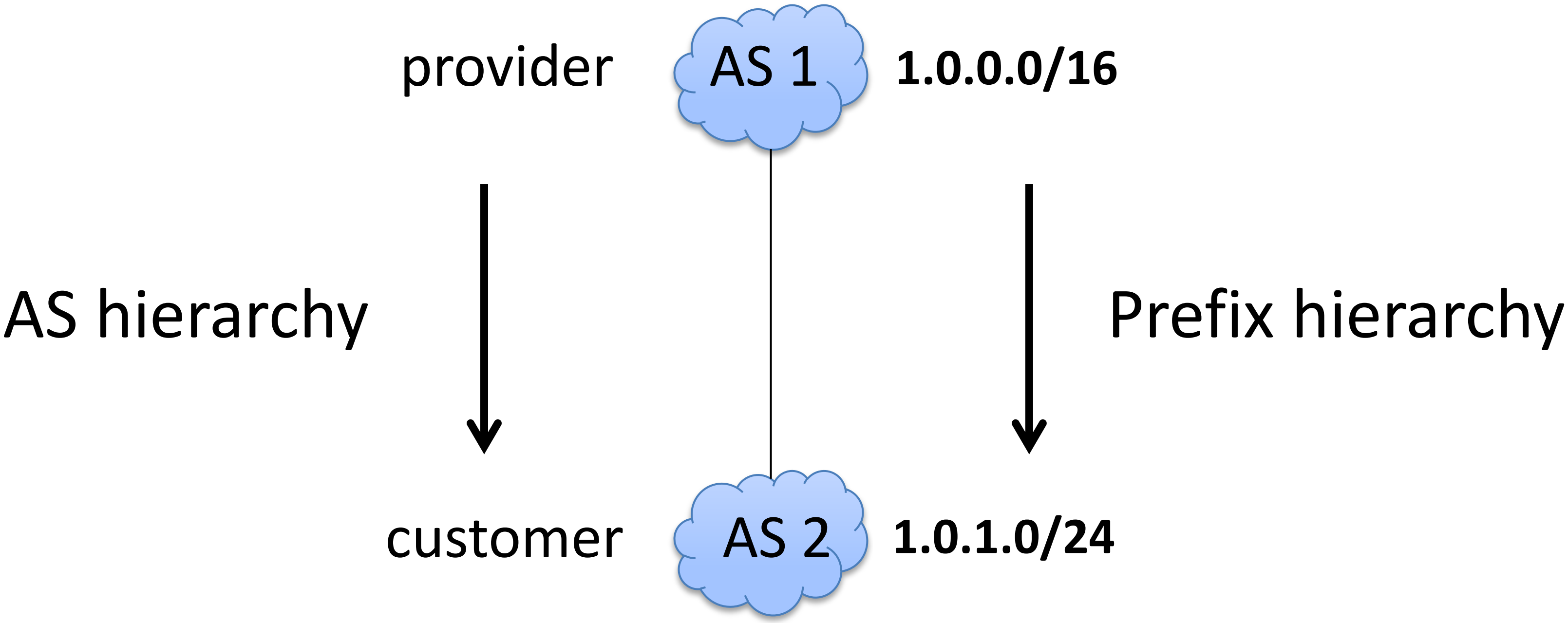


Most ASs forward data-packets on the (aggregated) less specific prefixes

Scalability: global view (forwarding)

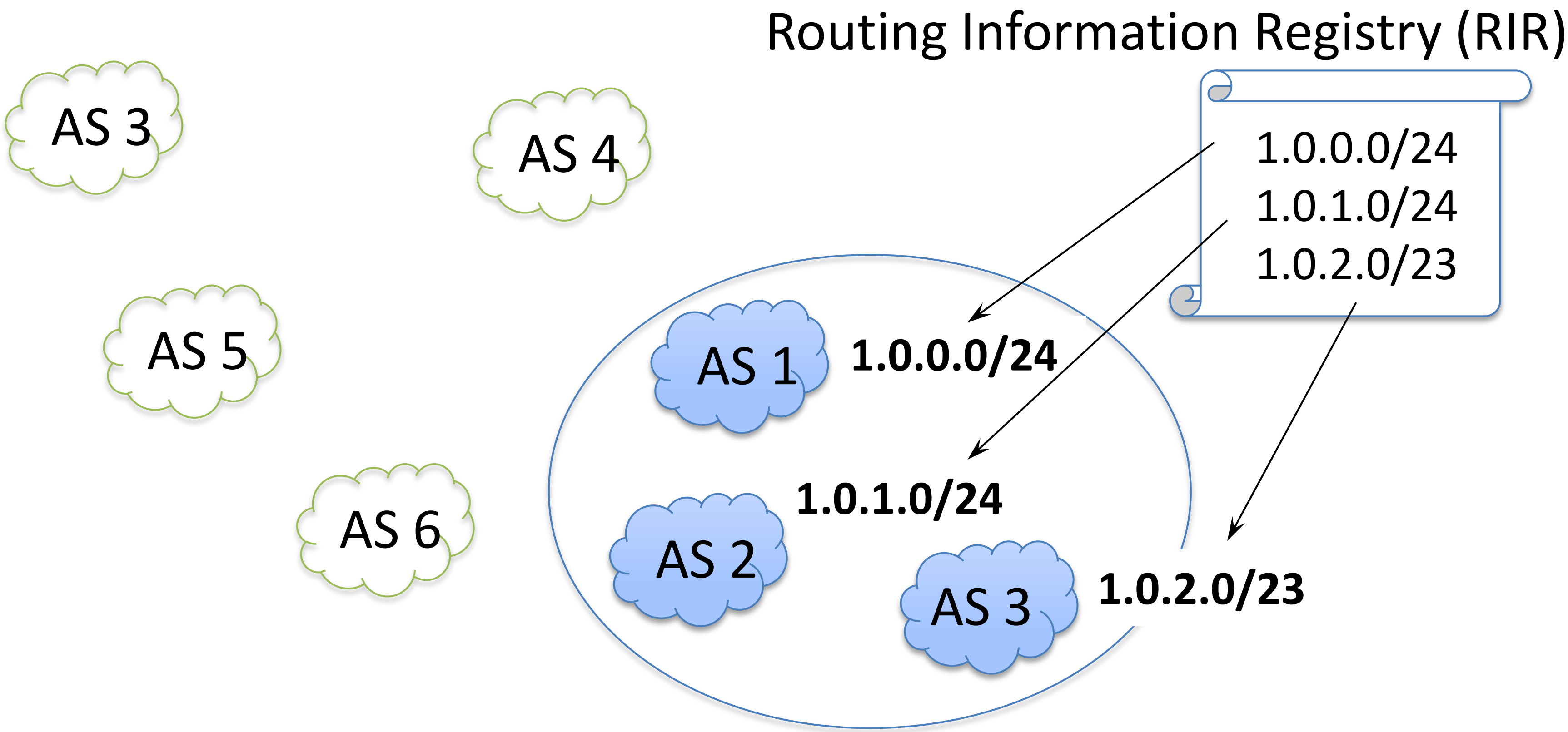


Hope for scalability? Hierarchies



AS-hierarchy aligned with prefix hierarchy

Hope for scalability? Clustering



1.0.0.0/24 + 1.0.1.0/24 + 1.0.2.0/23 = 1.0.0.0/22

Geography *roughly* clusters together ASs with aggregatable address space

Challenge: global vs. local

How to realize the global view through automated local routing decisions?

especially, given that the Internet routing system is as decentralized as it can be:

- each AS decides where to connect
- each AS decides where to acquire address space
- each AS sets its own routing policies

Outline

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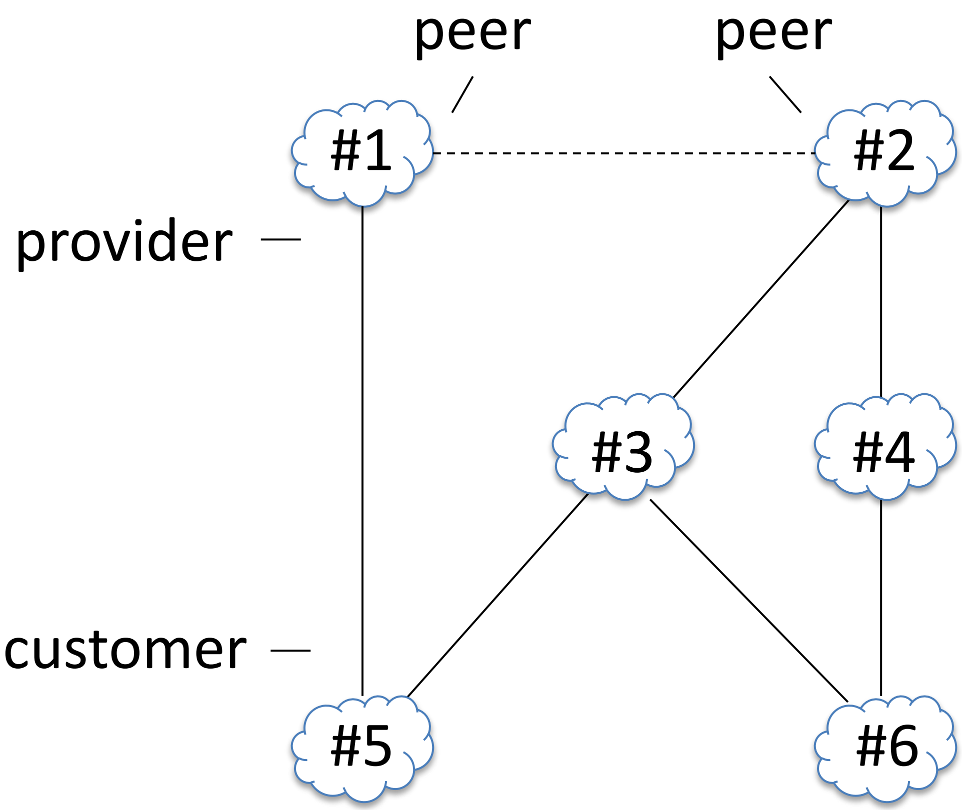
- DRAGON: filtering strategy
- DRAGON: aggregation strategy
- DRAGON: performance evaluation
- Conclusions

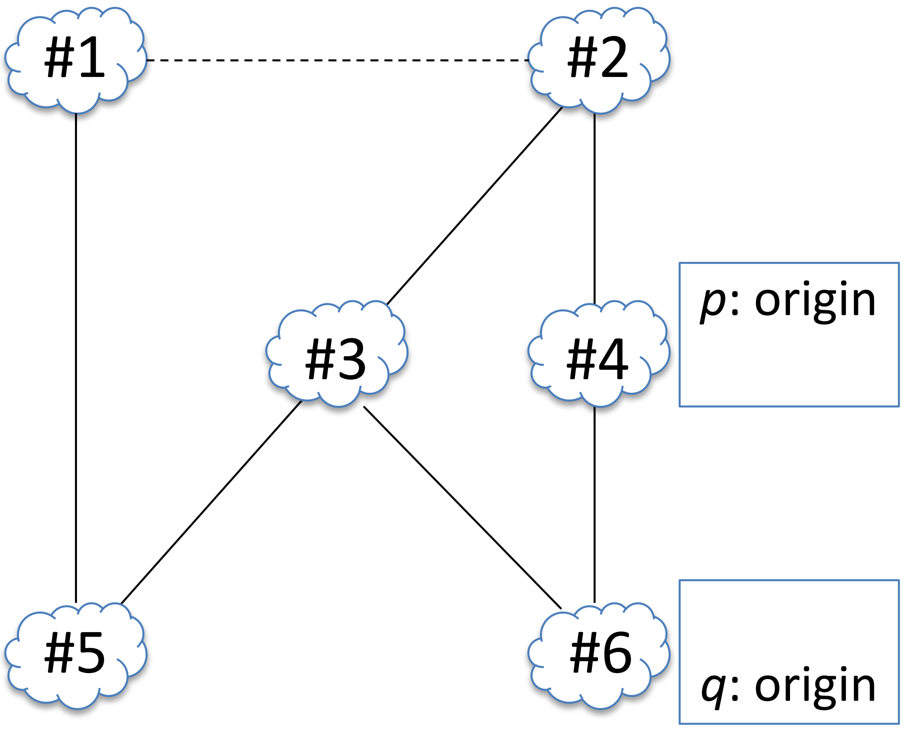
Filtering strategy

- Locally filter the more specific prefixes when possible
  - no black holes
  - respect routing policies
- Use built-in incentives to filter locally
  - save on forwarding state
  - forward along best route (dictated by routing policies)
- *Exchange routing information with standard BGP*

Providers, customers, and peers



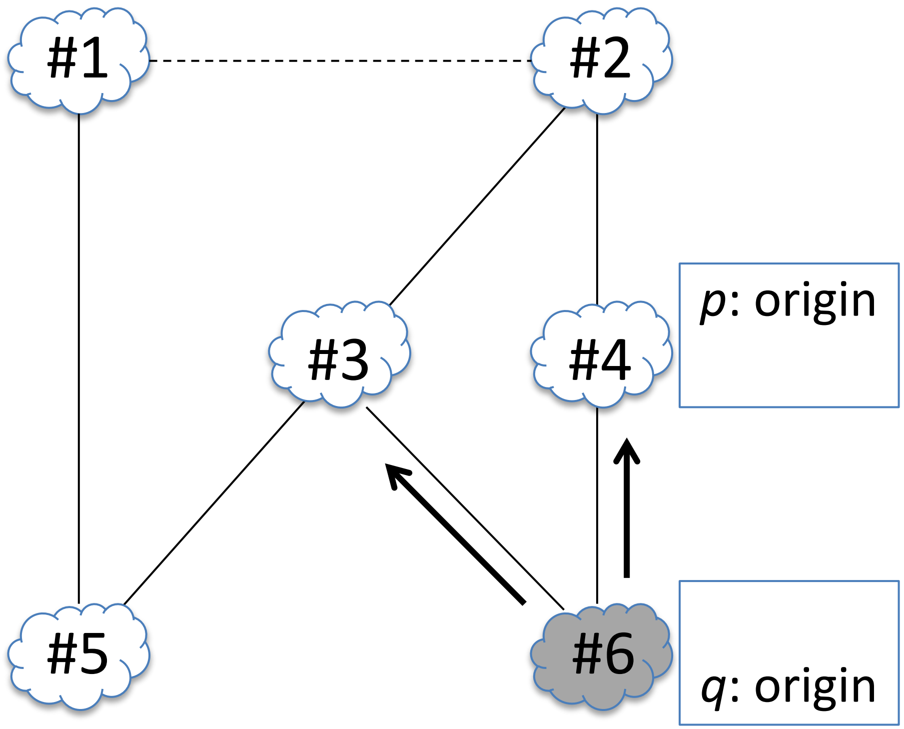
Prefixes



#6 originates *q* (1.0.0.0/24); #4 originates *p* (1.0.0.0/16)

q* more specific than *p

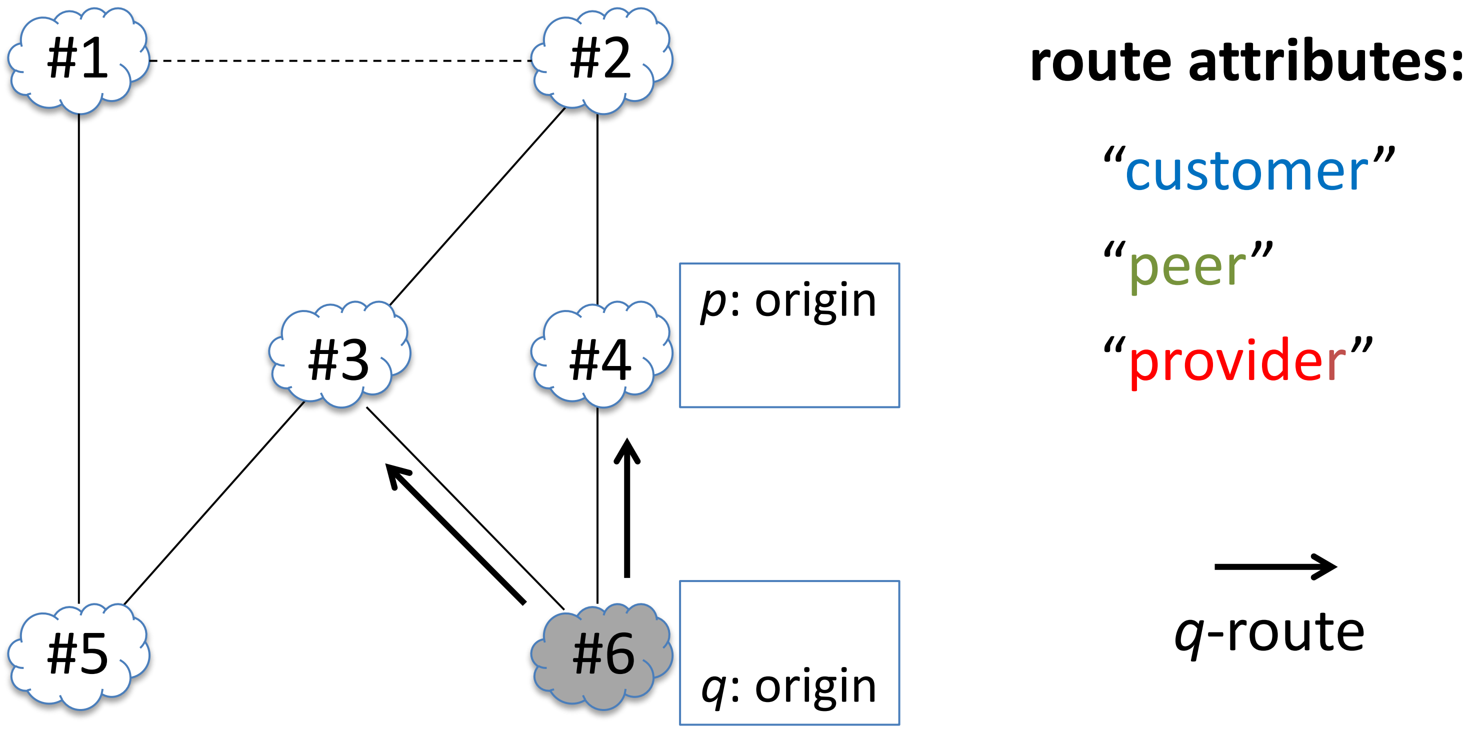
Routes



Route
Association between a prefix and an attribute, from a totally ordered set of attributes

q-route
(route pertaining to *q*)

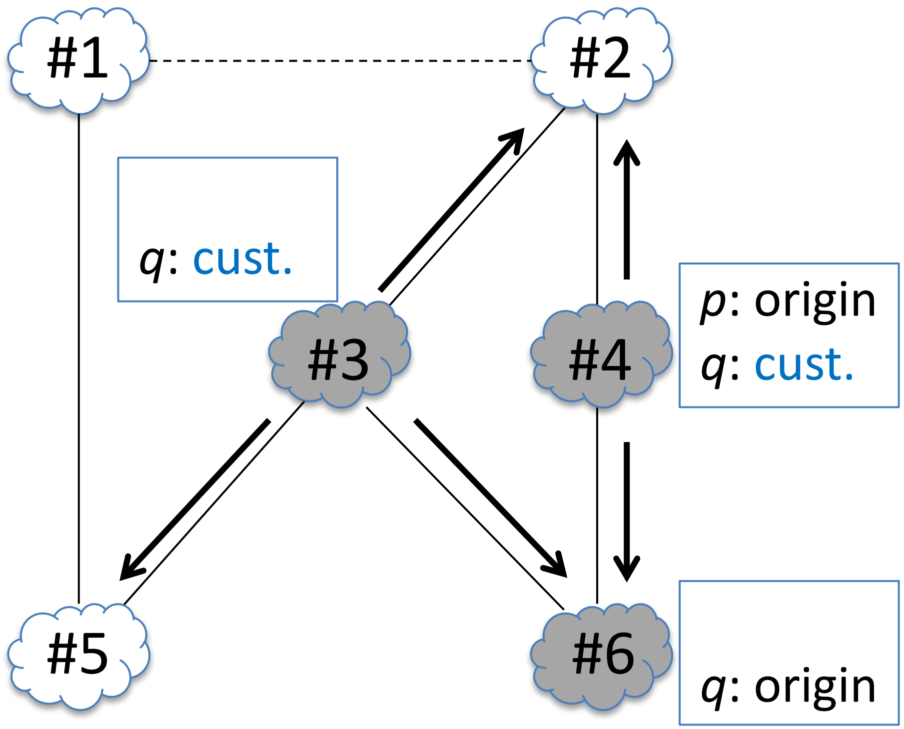
Gao-Rexford routing policies



preferences: customer then peer then provider

exportations: all routes from customers; all routes to customers

Gao-Rexford routing policies



route attributes:

"customer"

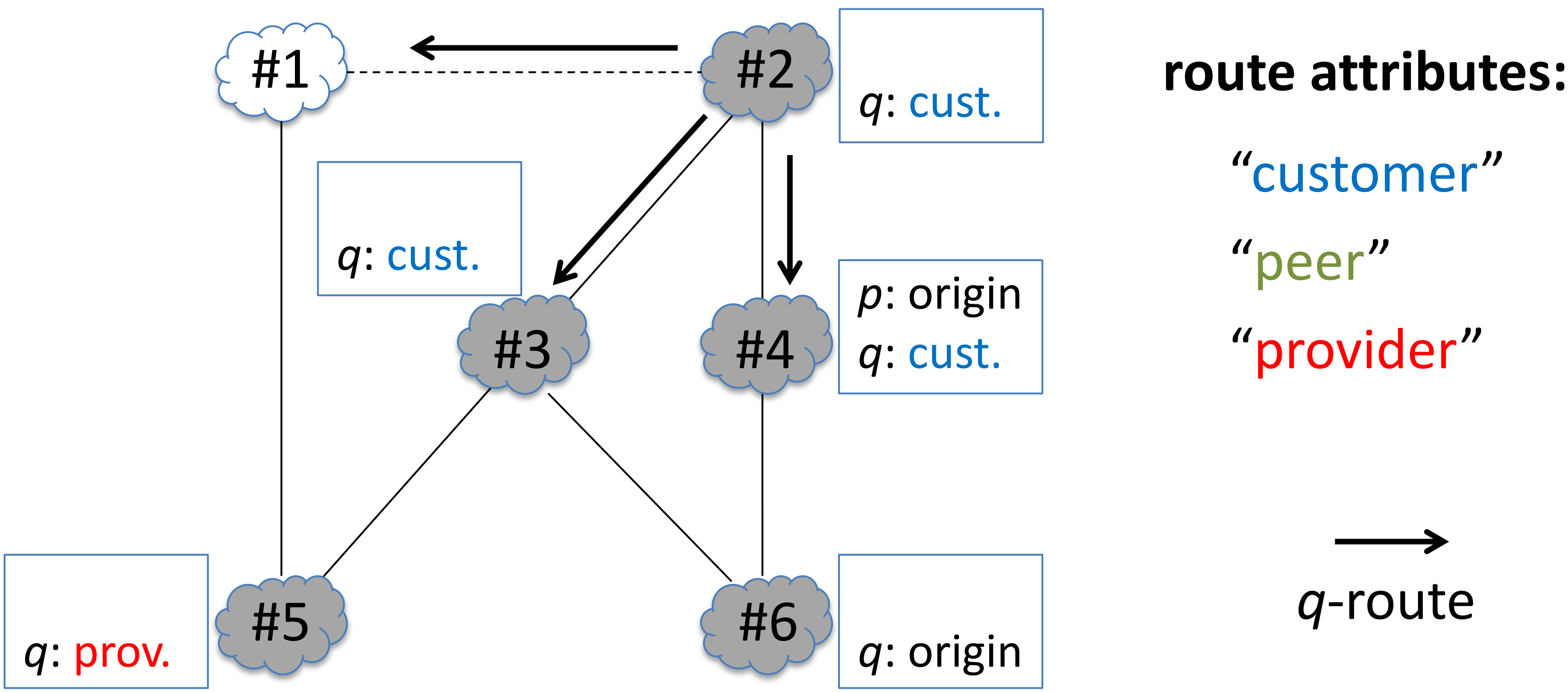
"peer"

"provider"

preferences: customer then peer then provider

exportations: all routes from customers; all routes to customers

Gao-Rexford routing policies



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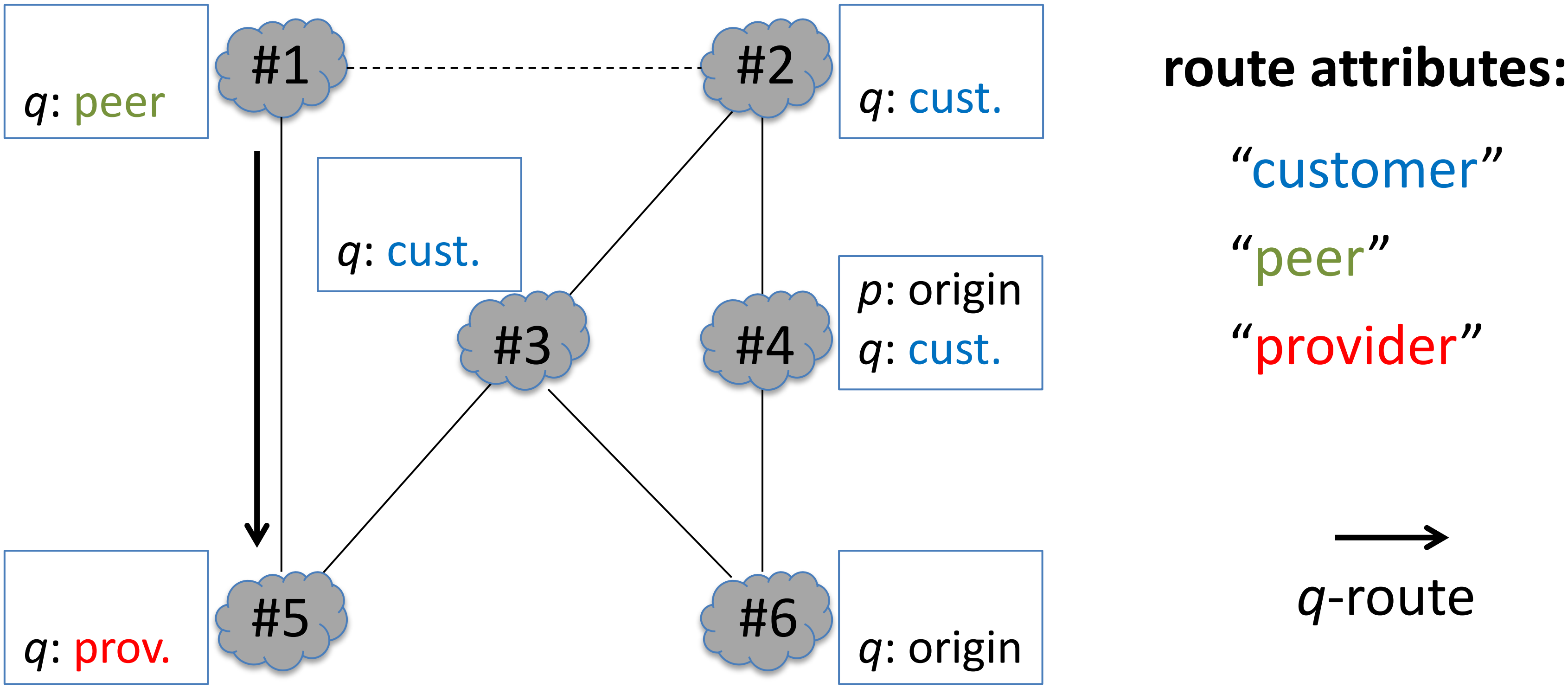
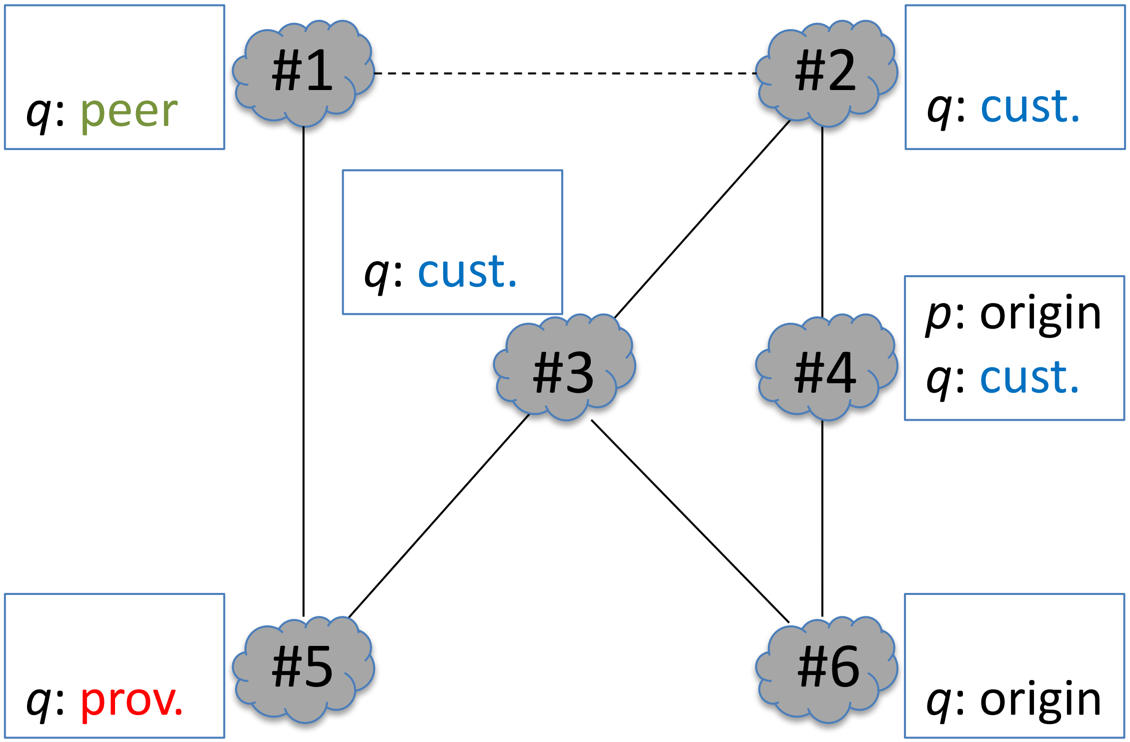
Gao-Rexford routing policies



preferences: customer then peer then provider

exportations: all routes from customers; all routes to customers

Final state for prefix *q*



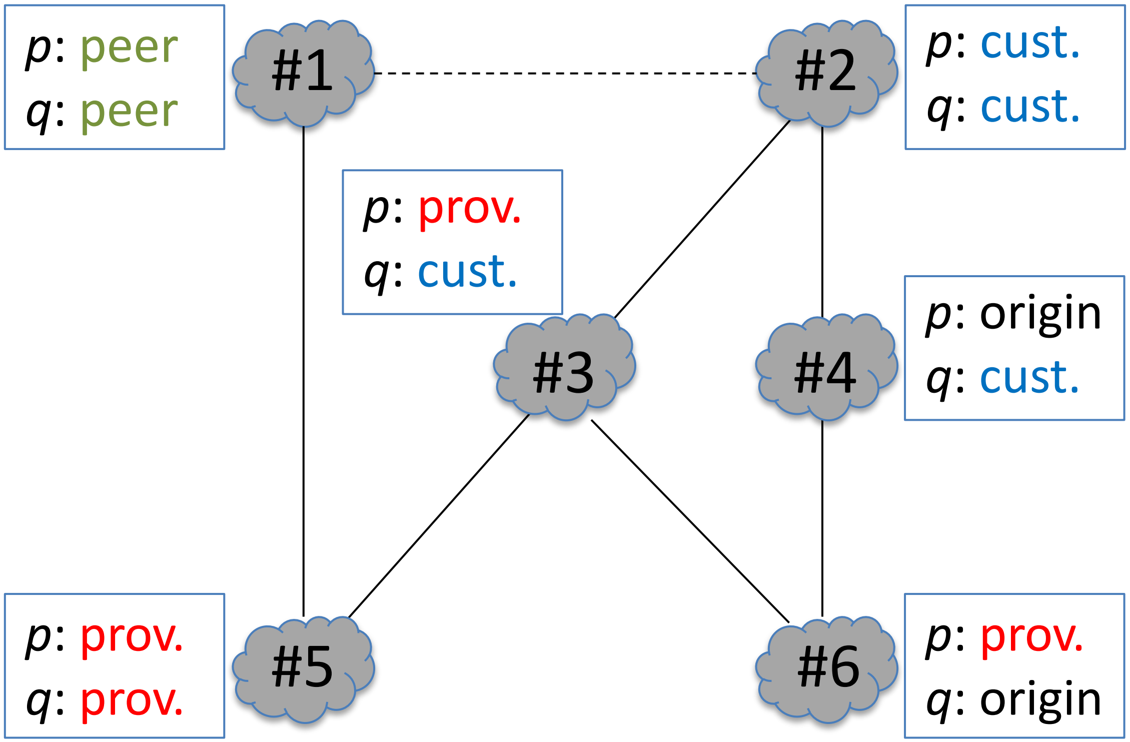
route attributes:

"customer"

"peer"

"provider"

Final state for prefixes *q* and *p*



route attributes:

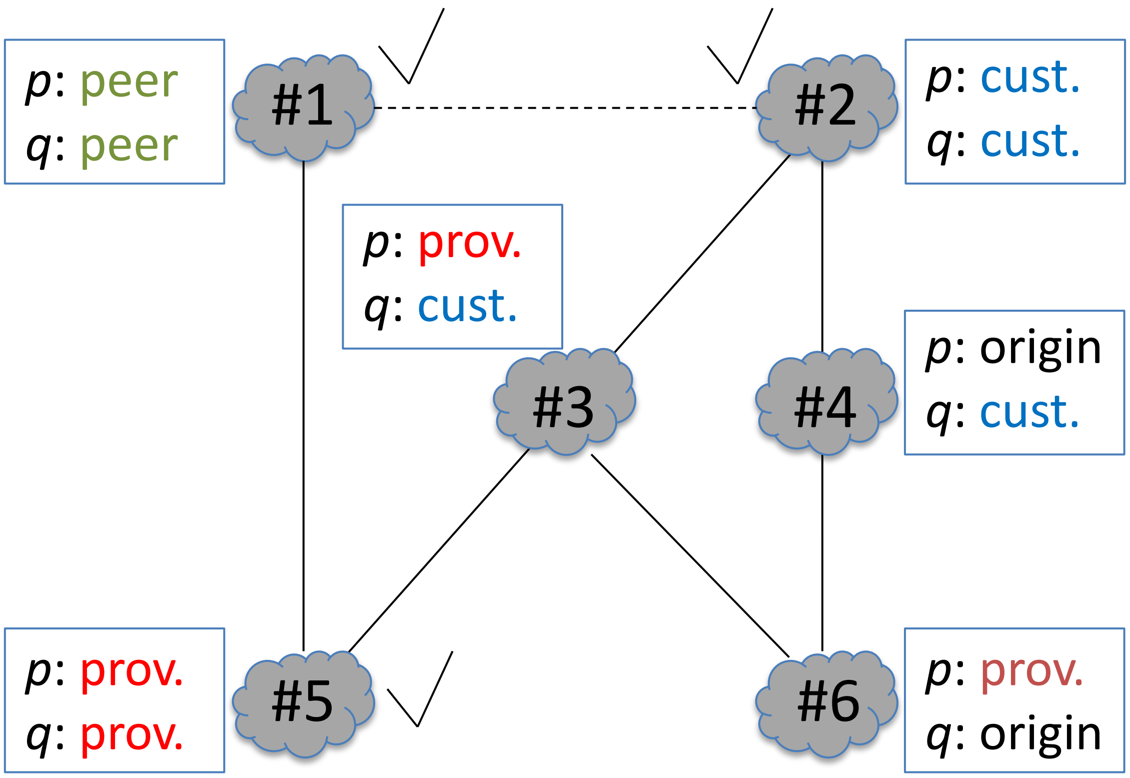
"customer"

"peer"

"provider"

forwarding: longest prefix match rule

Filtering code (FC)



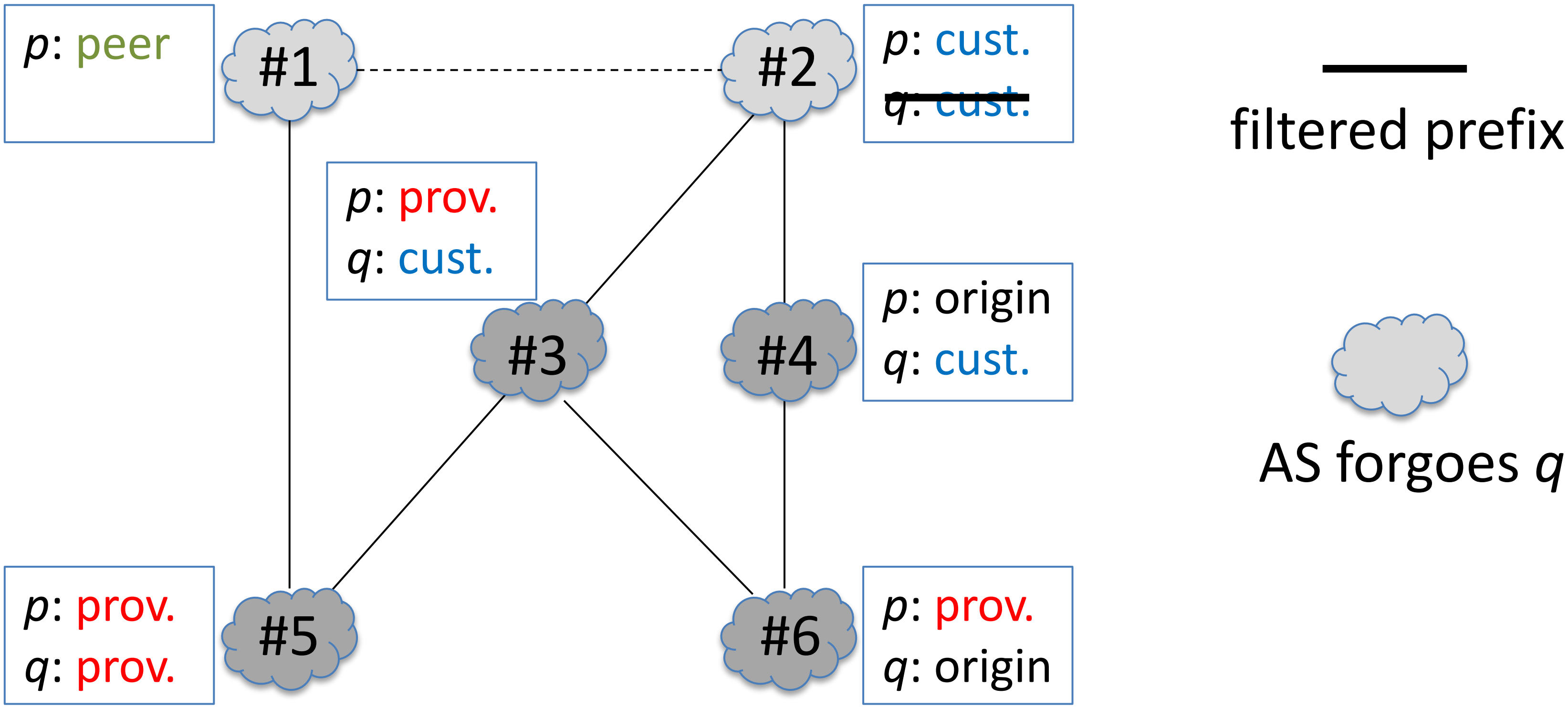
Filtering Code (FC)

Other than origin of *p*, in the presence of *p*, filter *q* if only if:

attribute of *p*-route
same or preferred to
attribute of *q*-route

√ ASs that filter *q* upon execution of FC

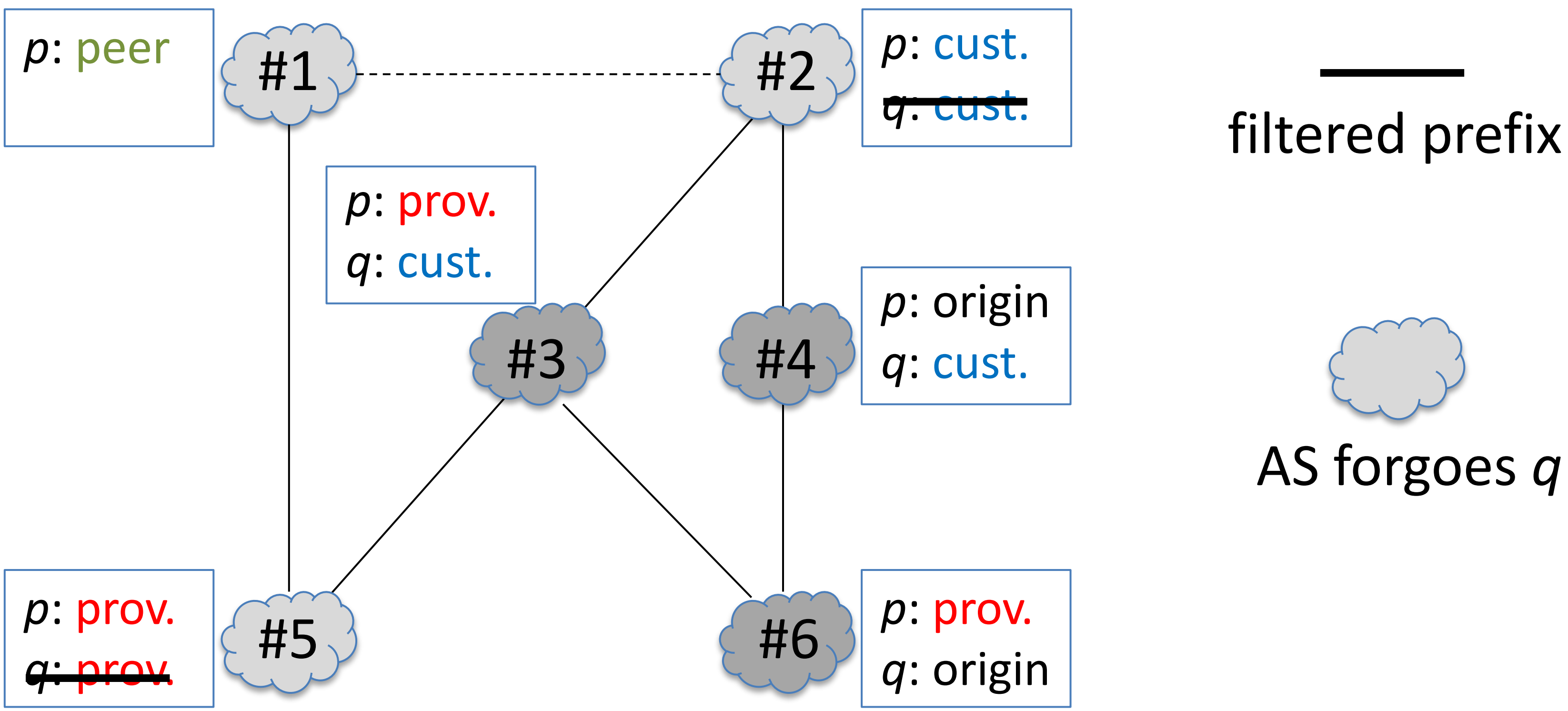
AS 2 applies FC



AS 2 filters *q* ➡

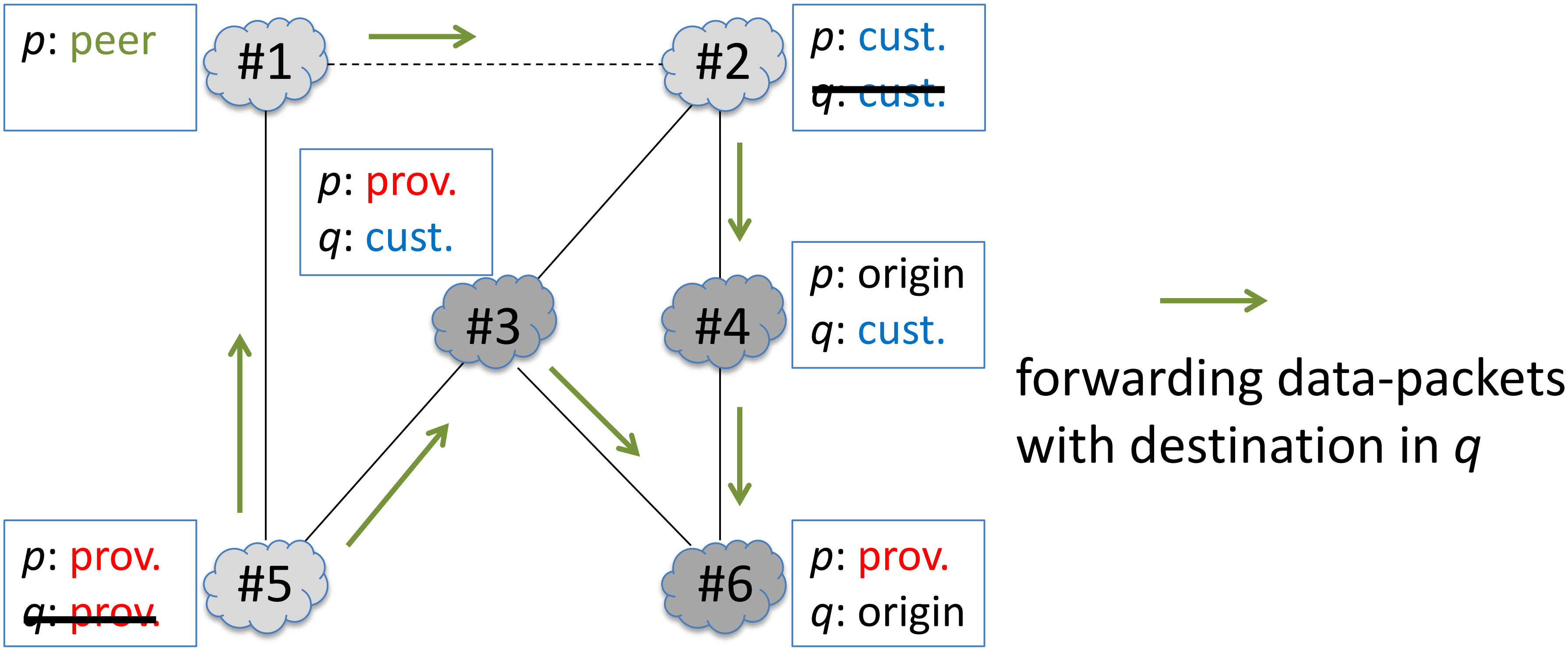
- AS 2 saves on forwarding state
- AS 1 is oblivious of *q*; it saves on forwarding and routing state

All ASs apply FC



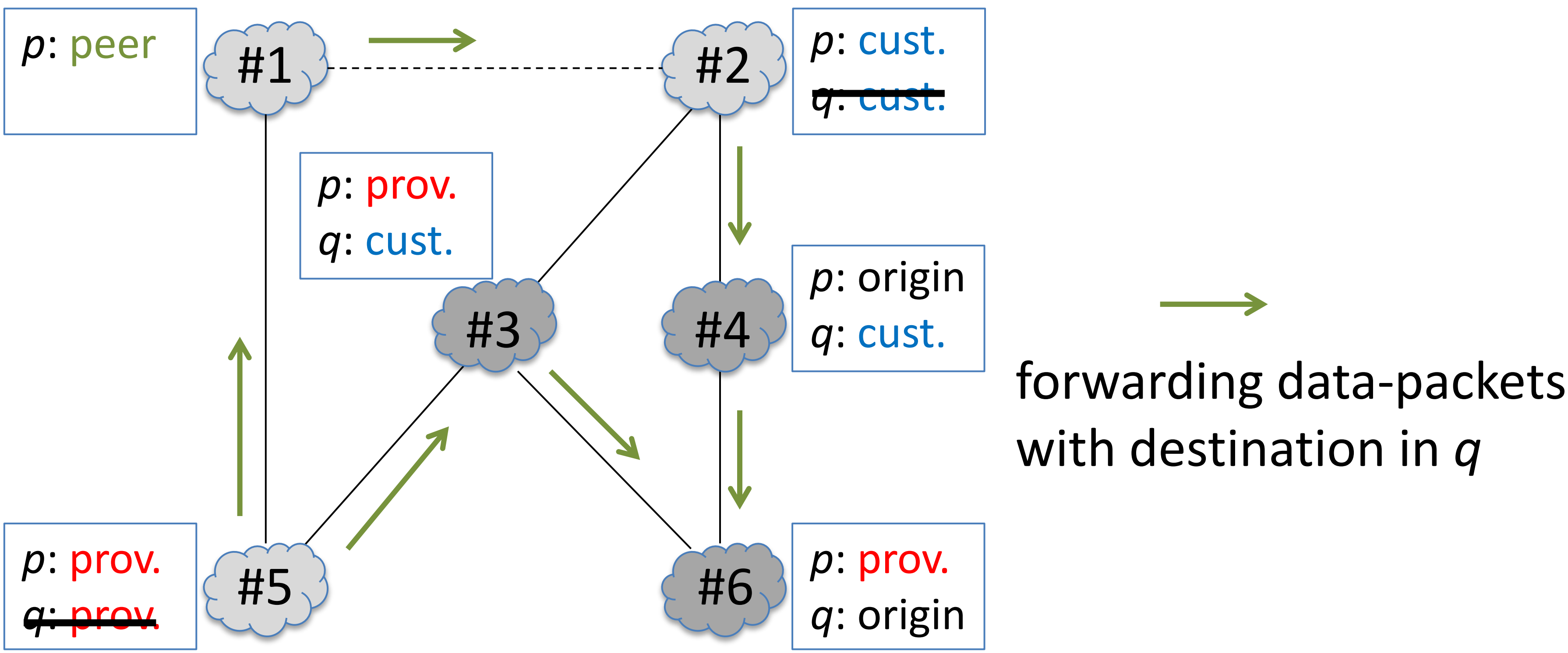
AS 1, AS 2, and AS 3 forgo *q* ➡ forwarding to *q* using less specific *p*

Global property: correctness



Correctness: no routing anomalies (no black holes)

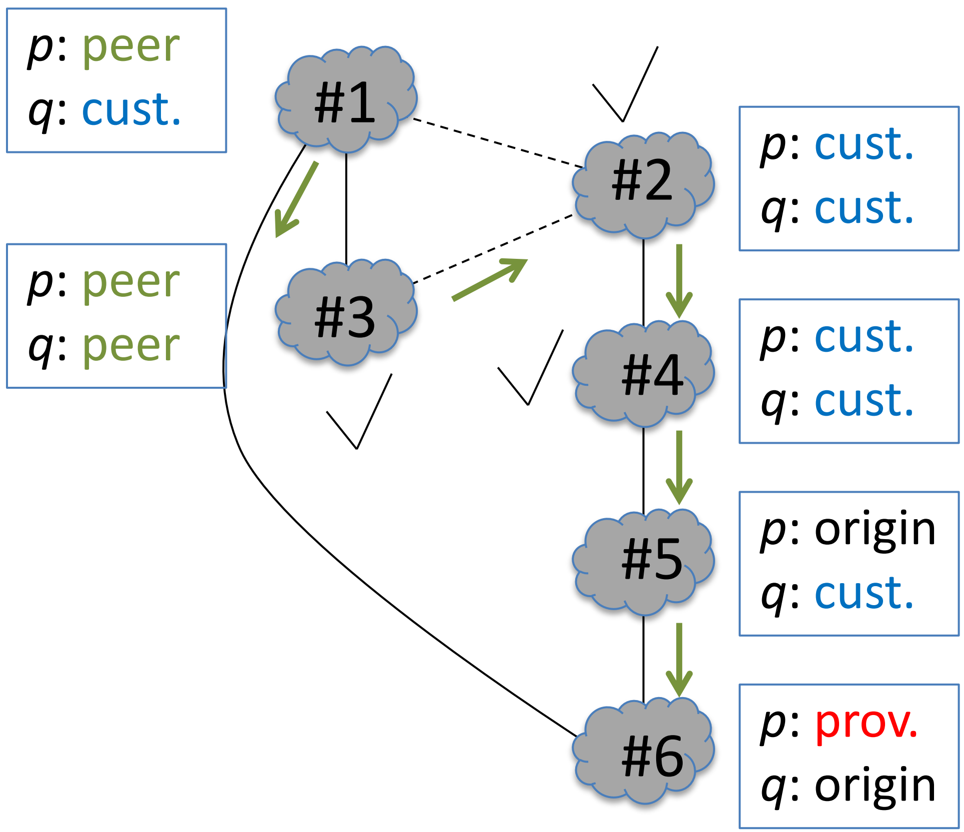
Global property: route consistency



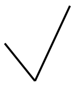
Route consistency: attribute of route used to forward data-packets is preserved

Optimal route consistency: set of ASs that forgo *q* is maximal

Partial deployment

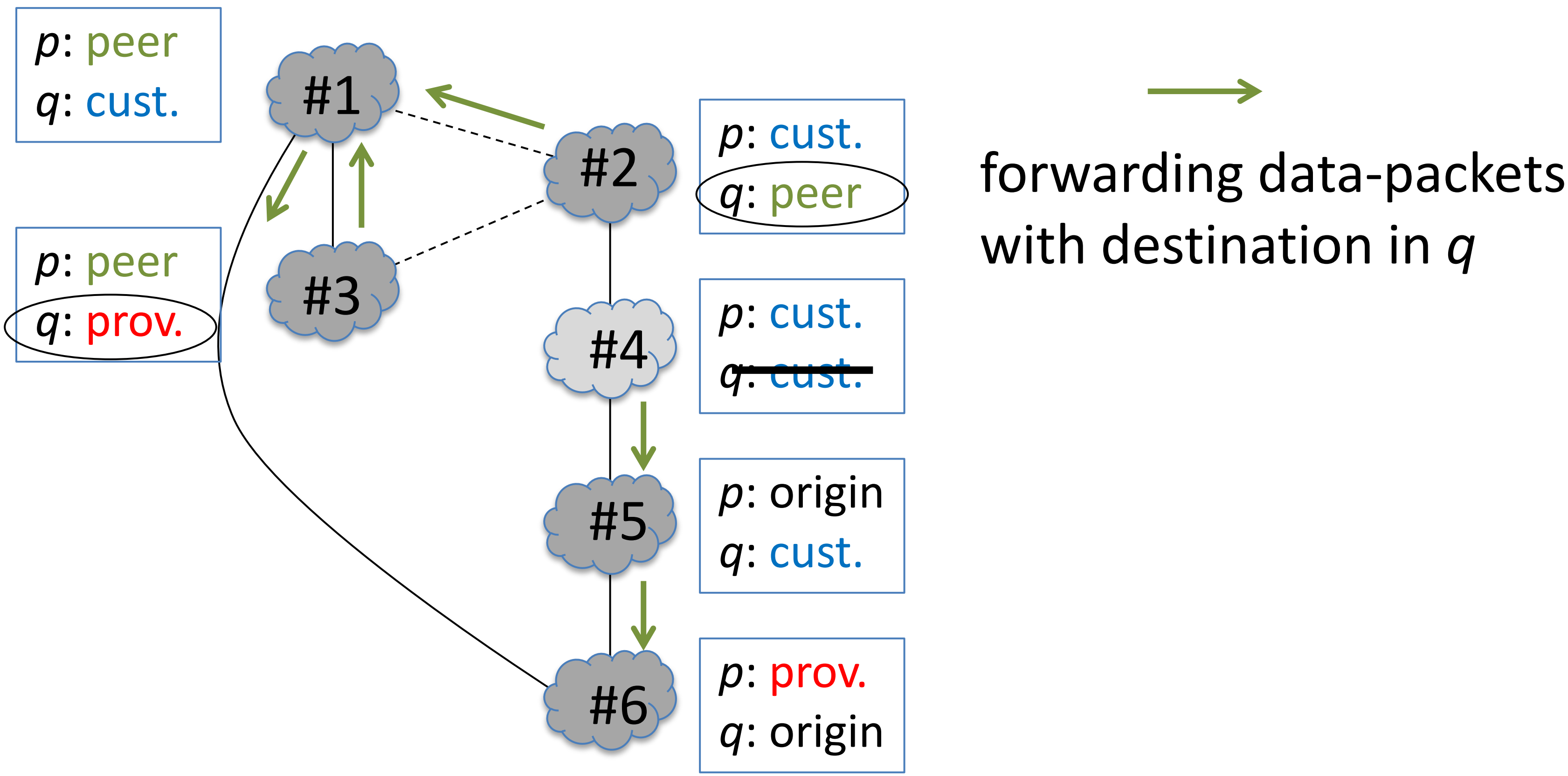


forwarding data-packets with destination in *q*



ASs that filter *q* upon execution of FC

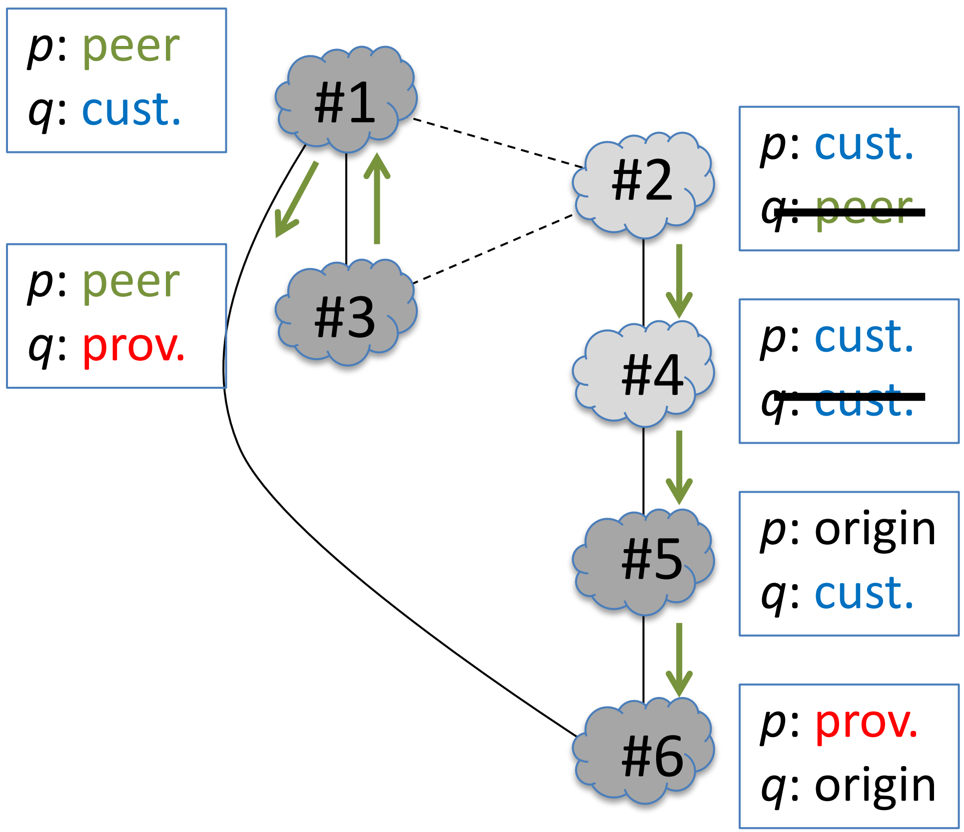
Partial deployment: incentives



AS 2 (and AS 3) has a double incentive to apply the FC:

- saves on forwarding state
- improves attribute of route used to forward data-packets

Partial deployment: incentives



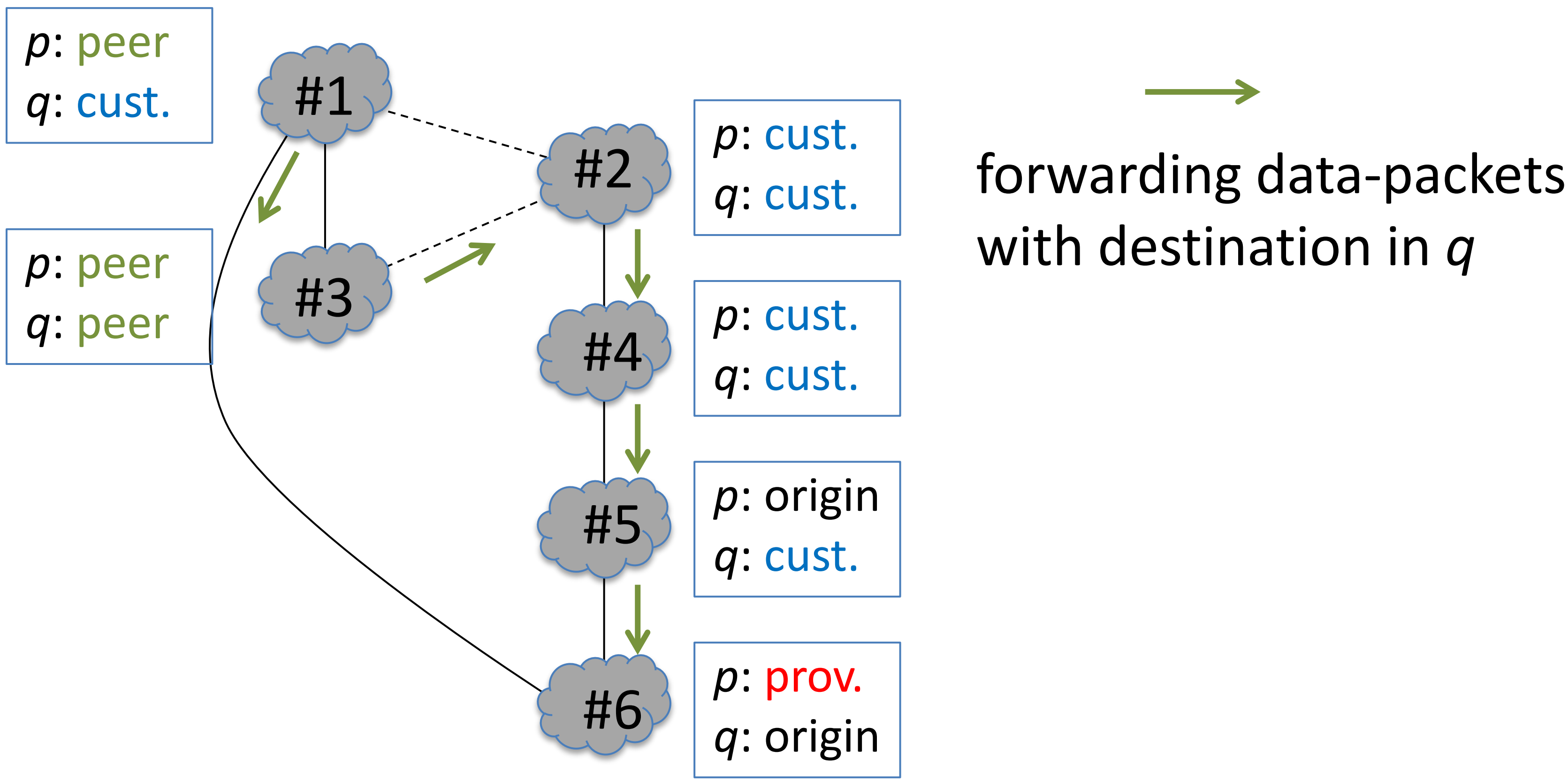
⟶ forwarding data-packets with destination in *q*

AS 2 applies FC

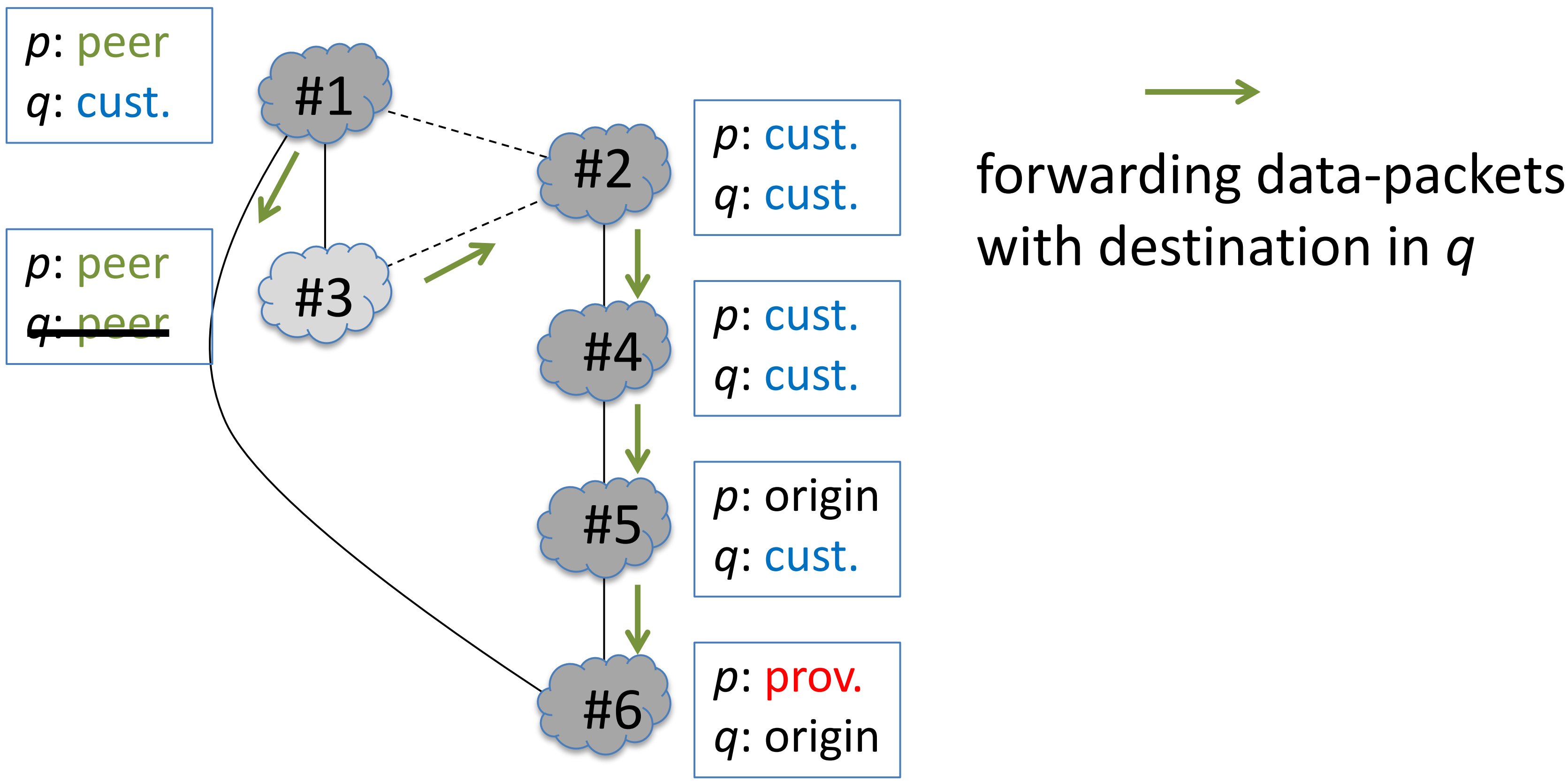
➡

AS 2 reverts to forwarding data-packets with address in *q* to AS 4

Partial deployment: route consistency

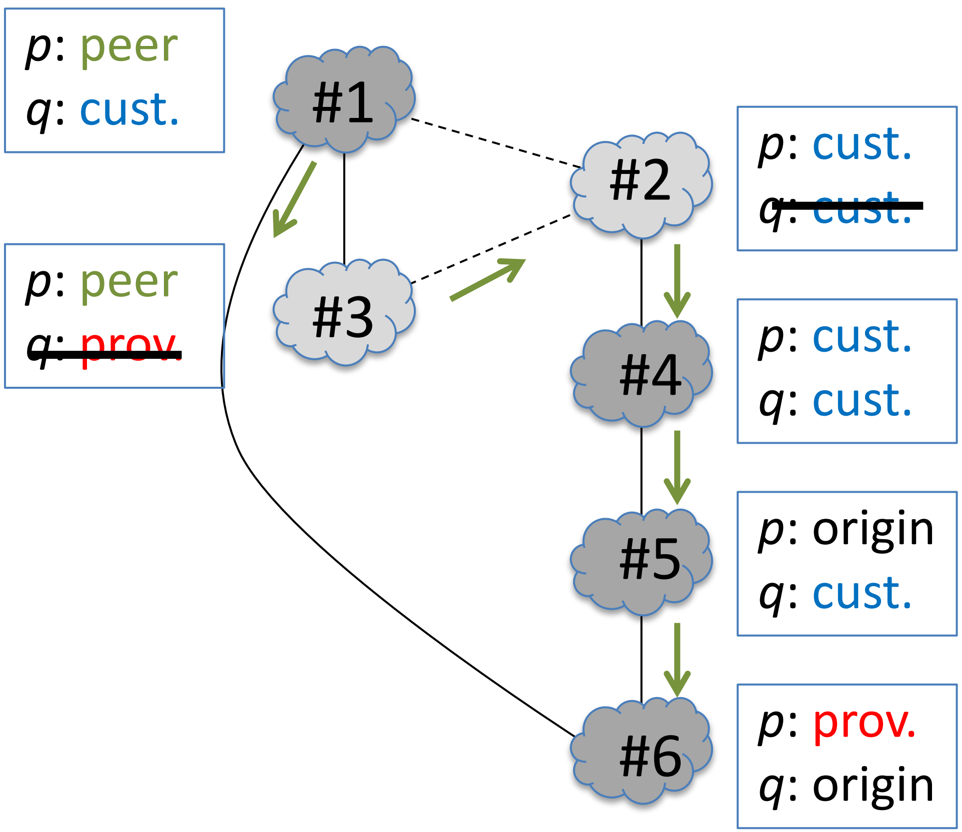


Partial deployment: route consistency



First to apply FC are ASs that elect a peer or provider *q*-route

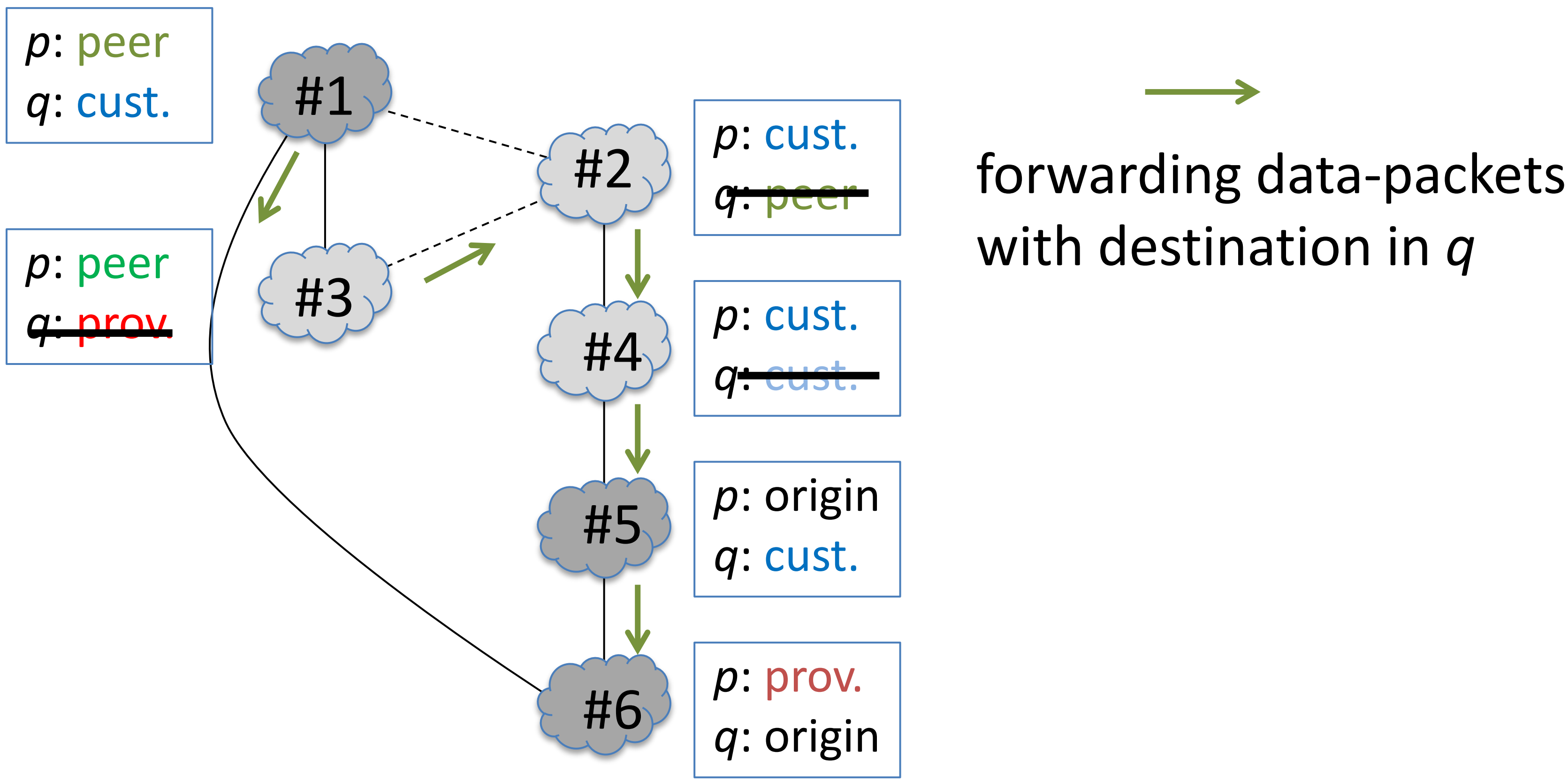
Partial deployment: route consistency



forwarding data-packets with destination in *q*

Next to apply FC are ASs for which providers have already applied FC

Partial deployment: route consistency



Next to apply FC are ASs for which providers have already applied FC

Filtering strategy: general case

- Trees of prefixes learned from BGP
  – FC for a prefix in relation to the parent prefix
- Correctness
  – for the routing policies for which BGP is correct
- Route consistency (optimal and through partial deployment)
  – for *isotone* routing policies (includes Gao-Rexford)

Optimal route consistency is not synonymous with *efficiency* (think shortest paths)

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- Scalability: global view
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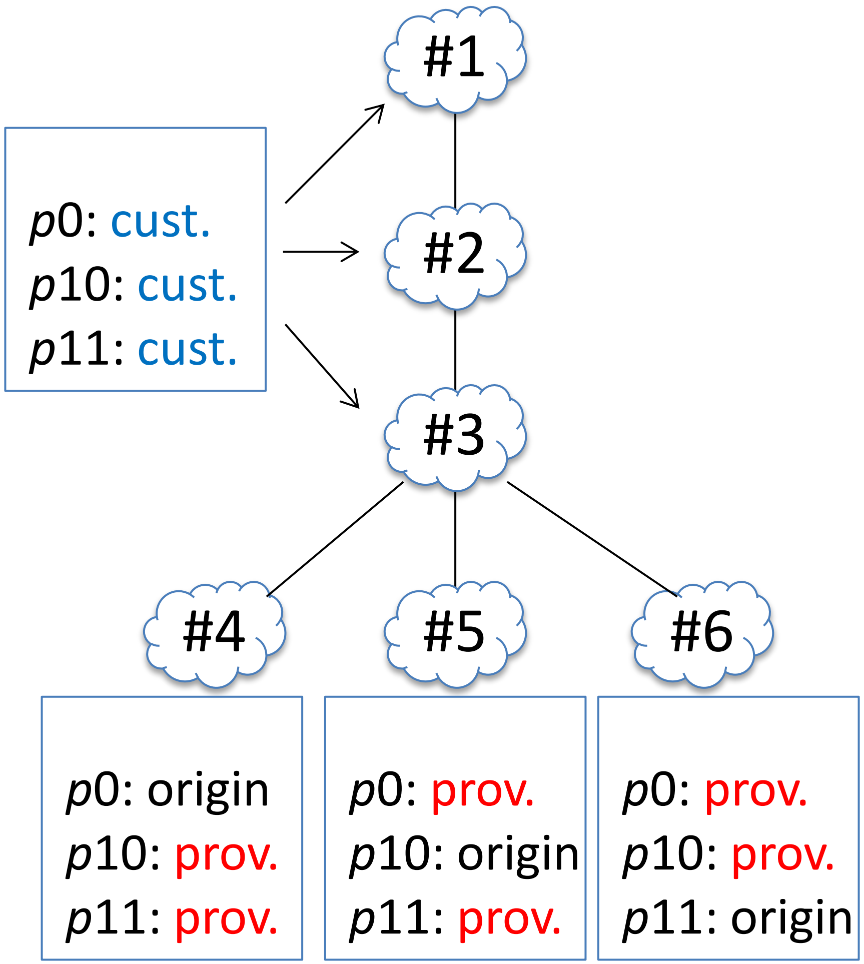
Aggregation strategy

- Locally originate aggregation prefixes when beneficial
  - new address space is *not* created
  - allow filtering of provider-independent prefixes
  - self-organization when more than one AS originates the same aggregation prefix
- *Again, exchange routing information with standard BGP*

Aggregation prefix

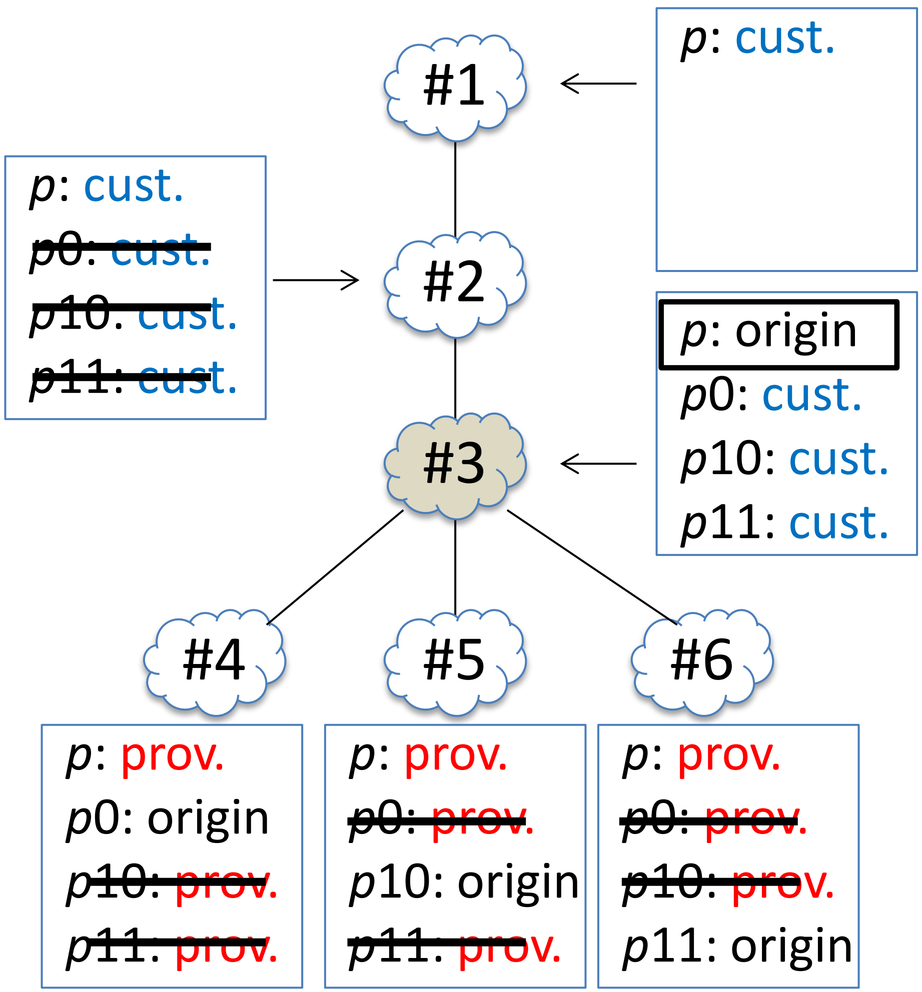


Aggregation prefix

1. no routable address space is created
2. at least two covered prefixes
3. customer route is elected for each of the covered prefixes

p0 + *p*10 + *p*11= *p*; *p* is an aggregation prefix at AS 3

AS 3 originates *p*



AS 1 is oblivious of *p*0, *p*10, and *p*11

AS 2 filters *p*0, *p*10, and *p*11

AS 4 filters *p*10 and *p*11

AS 5 filters *p*0 and *p*11

AS 6 filters *p*0 and *p*10

Aggregation strategy: general case

- Trees of prefixes learned from BGP
  - aggregation prefixes cover parentless prefixes
- Self-organization
  - for the routing policies for which BGP is correct
- Optimal origins
  - for *isotone* routing policies (includes Gao-Rexford)

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Data-sets

- Annotated topology (CAIDA, Feb. 2015)
  - ~50K ASs; ~42K stub ASs
  - ~94K provider links; ~94K customer links; 180K peer links
- IPv4-prefixes-to-ASs mapping (CAIDA, Feb. 2015)
  - ~530K prefixes
  - ~270K parentless prefixes
  - ~210K prefixes have same origin AS as parent

FIB filtering efficiency: definition

Normalized amount of reduction brought by DRAGON to the forwarding tables of an AS

$$\textbf{FilterEff} = \frac{\#\,(\text{FIB entries BGP}) - \#\,(\text{FIB entries DRAGON})}{\#\,(\text{FIB entries BGP})}$$

FIB filtering efficiency: results

	Basic DRAGON filtering	**Full DRAGON** filtering & aggregation
Min. FilterEff	**47%**	
% of ASs with at least Min. FilterEff	**100%**	
Max. FilterEff	**49%**	
% of ASs attaining Max. FilterEff	**87%**	

FIB filtering efficiency: results

	Basic DRAGON filtering	**Full DRAGON** filtering & aggregation
Min. FilterEff	**47%**	**69%**
% of ASs with at least Min. FilterEff	**100%**	**100%**
Max. FilterEff	**49%**	**79%**
% of ASs attaining Max. FilterEff	**87%**	**87%**

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Conclusions

- DRAGON is a BGP add-on to scale the Internet routing system
- DRAGON can be deployed incrementally
- DRAGON reduces the amount of forwarding state by approximately 80%
- DRAGON is – more fundamentally – a solid framework to reason about route aggregation

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Thank you!