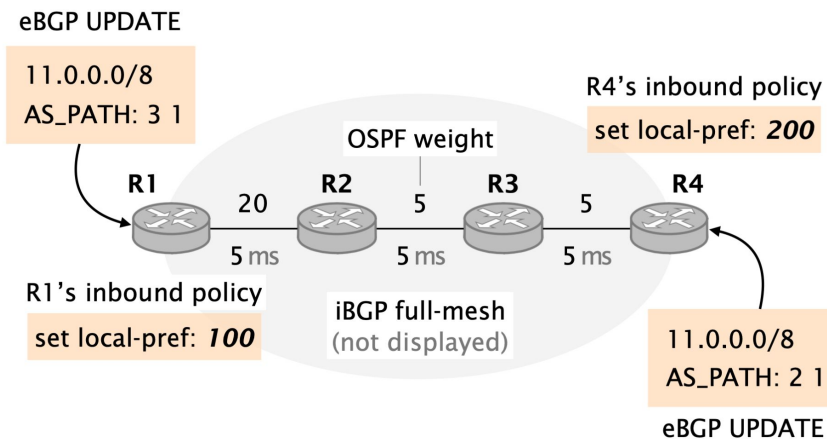


Question

Consider the BGP network composed of 4 routers depicted in Figure on the right. Two of these routers, R1 and R4 are egress routers and maintain eBGP sessions with external neighbors.

R1 is configured to associate a local-preference of 100 to externally-learned routes, while R4 is configured to associate a local-preference of 200 to externally-learned routes.

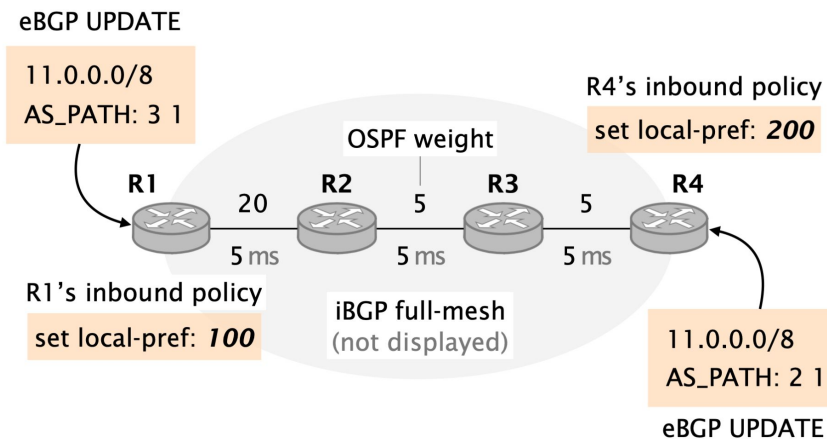
R2 and R3 are internal routers. All four routers are connected in an iBGP full-mesh. OSPF is used as intra-domain routing protocol. The link weights are indicated in the figure, e.g. the (R1, R2) link is configured with a weight of 20. The Figure also indicates the propagation delay for each link (e.g., it takes 5ms for a packet to propagate between R1 and R2).



A simple BGP network learning external routes via eBGP on R1 and R4.

Question

Considering the above configuration, indicate the next-hop used by each router in the steady state, i.e., once the network has fully converged. Use the keyword “external” to indicate that an edge router is forwarding outside of the domain. Note that we are not looking for the BGP next-hop but rather the next-hop a packet would take when being forwarded.



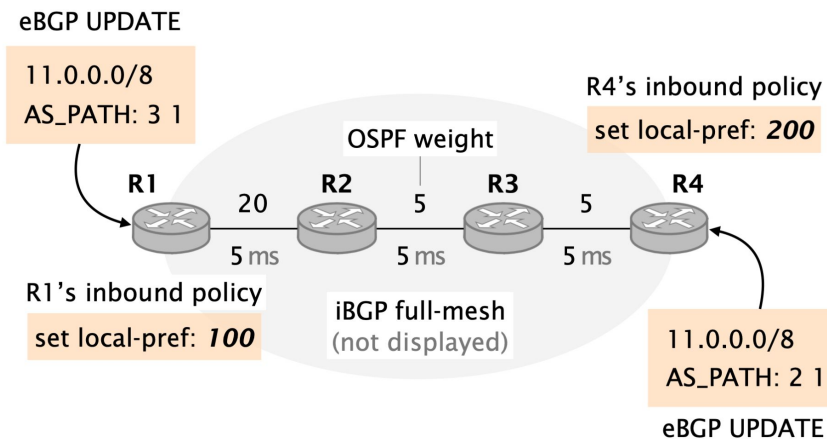
A simple BGP network learning external routes via eBGP on R1 and R4.

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Solution: Since the externally-learned route at R4 has a higher local-preference than the one at R1 (200 vs. 100), all routers select the route from R4. We get the following next-hops:

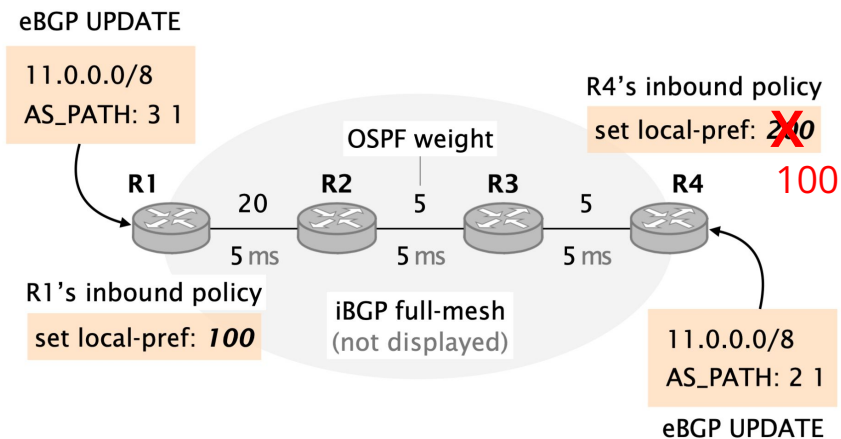
- R1: R2
- R2: R3
- R3: R4
- R4: <external>



A simple BGP network learning external routes via eBGP on R1 and R4.

Question

It turns out that the network operator changed her mind. This time, she configures R4 to associate a local-preference of 100 to externally-learned routes (i.e. the same local-preference value as on R1). Indicate the next-hop used by each router in the steady state (once the network has fully converged). Again use the keyword “external” to indicate that an egress router is forwarding outside of the domain.



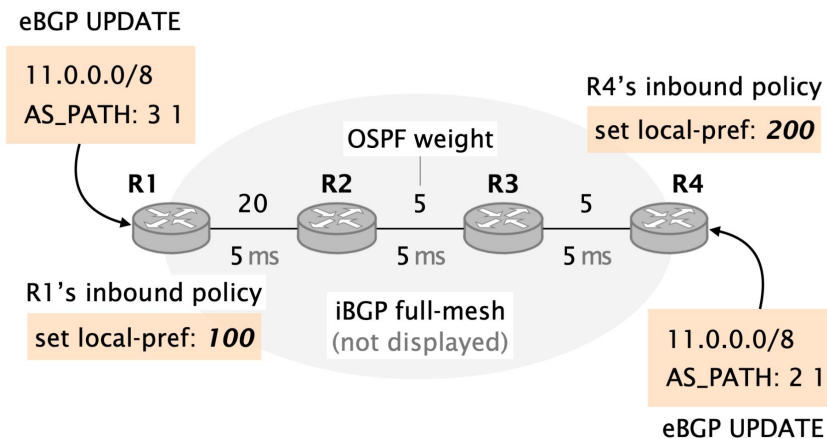
A simple BGP network learning external routes via eBGP on R1 and R4.

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Solution: Since both externally-learned routes are now equally preferred, the routers consider the next criteria in the decision process. Finally, they will select the route with the lower IGP metric to the BGP next-hop. We get the following next-hops:

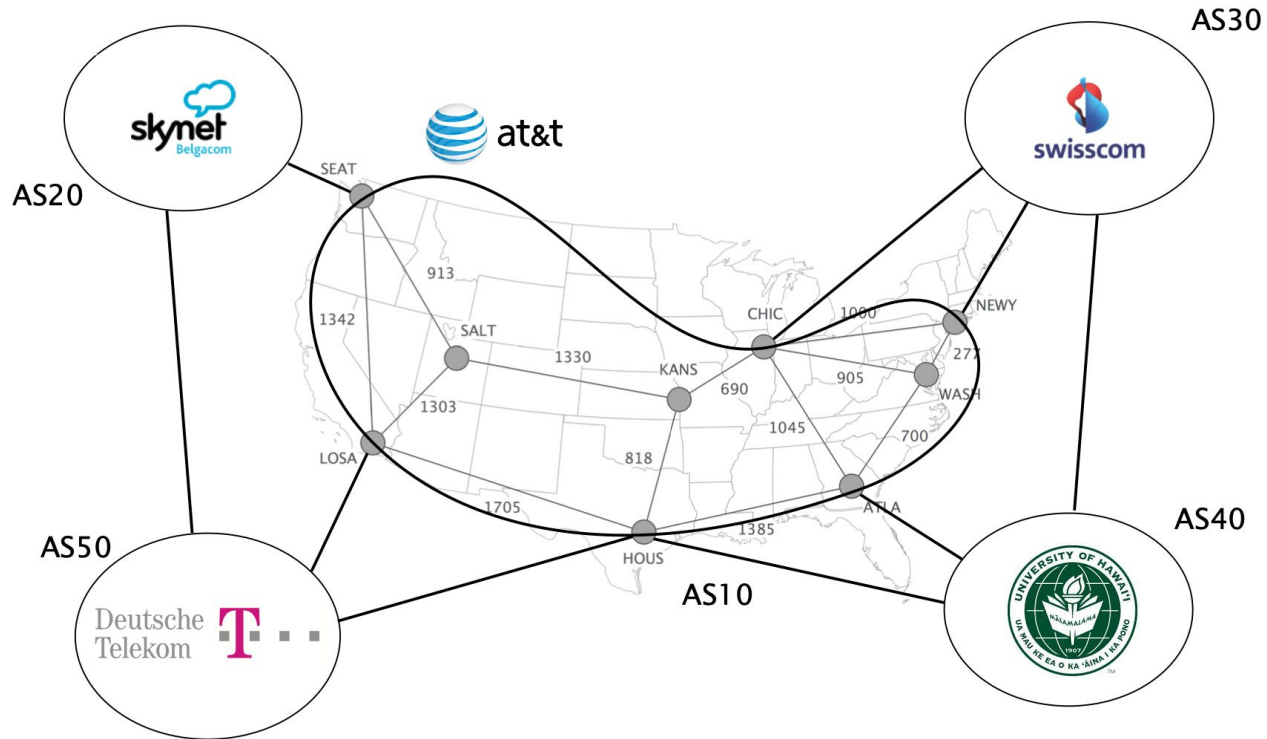
- R1: <external>
- R2: R3
- R3: R4
- R4: <external>



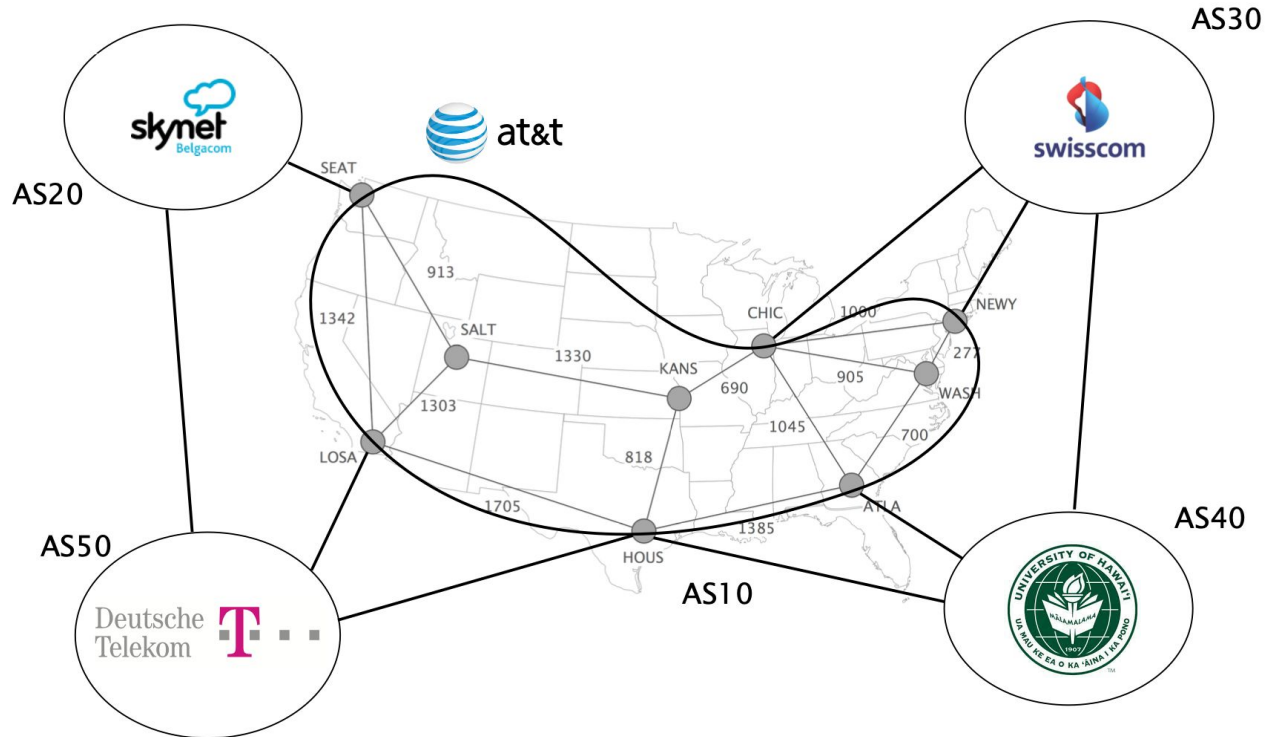
A simple BGP network learning external routes via eBGP on R1 and R4.

BGP Policies

The Internet topology is shaped according to **business relationships**



2 ASes **only** connect if they have a business relationship

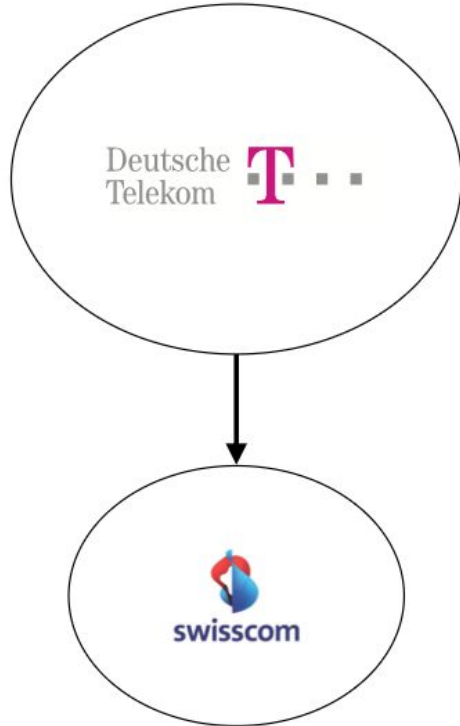


2 Main business relationships today

There are 2 main business relationships today:

- customer/provider
- peer/peer

Customers pay providers to get Internet connectivity

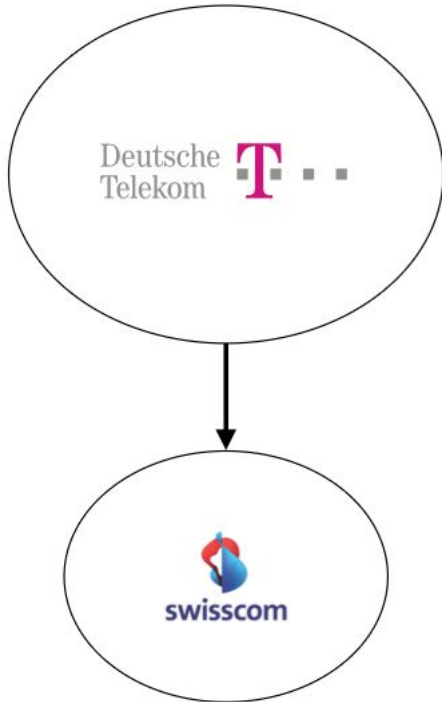


provider

\$\$\$

customer

The amount paid is based on peak usage, usually according to the 95th percentile rule



Every 5 minutes, DT records the # of bytes sent/received

At the end of the month, DT

- sorts all values in decreasing order
- removes the top 5% values
- bills wrt highest remaining value

Most ISPs discounts traffic unit price when pre-committing to certain volume

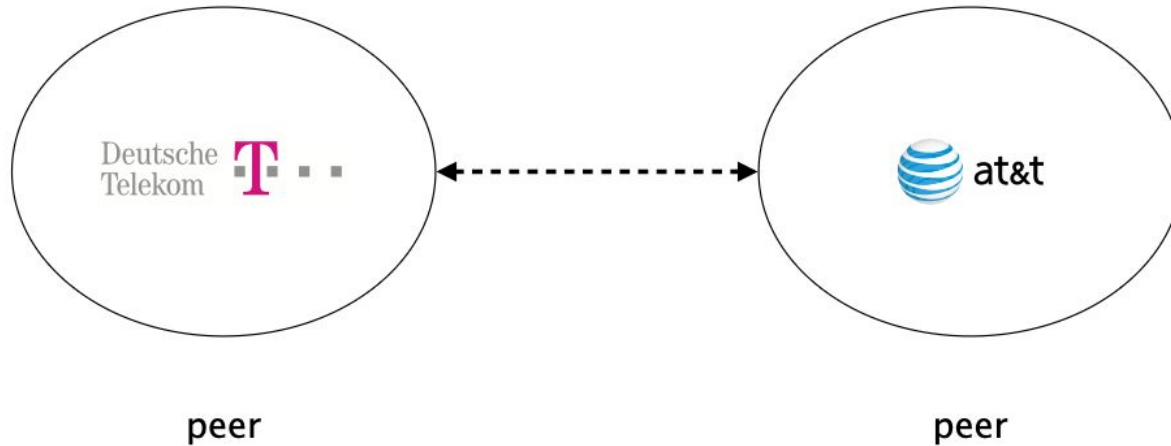
commit		unit price (\$)	Minimum monthly bill (\$/month)
10	Mbps	12	120
100	Mbps	5	500
1	Gbps	3.50	3,500
10	Gbps	1.20	12,000
100	Gbps	0.70	70,000

Examples taken from The 2014 Internet Peering Playbook

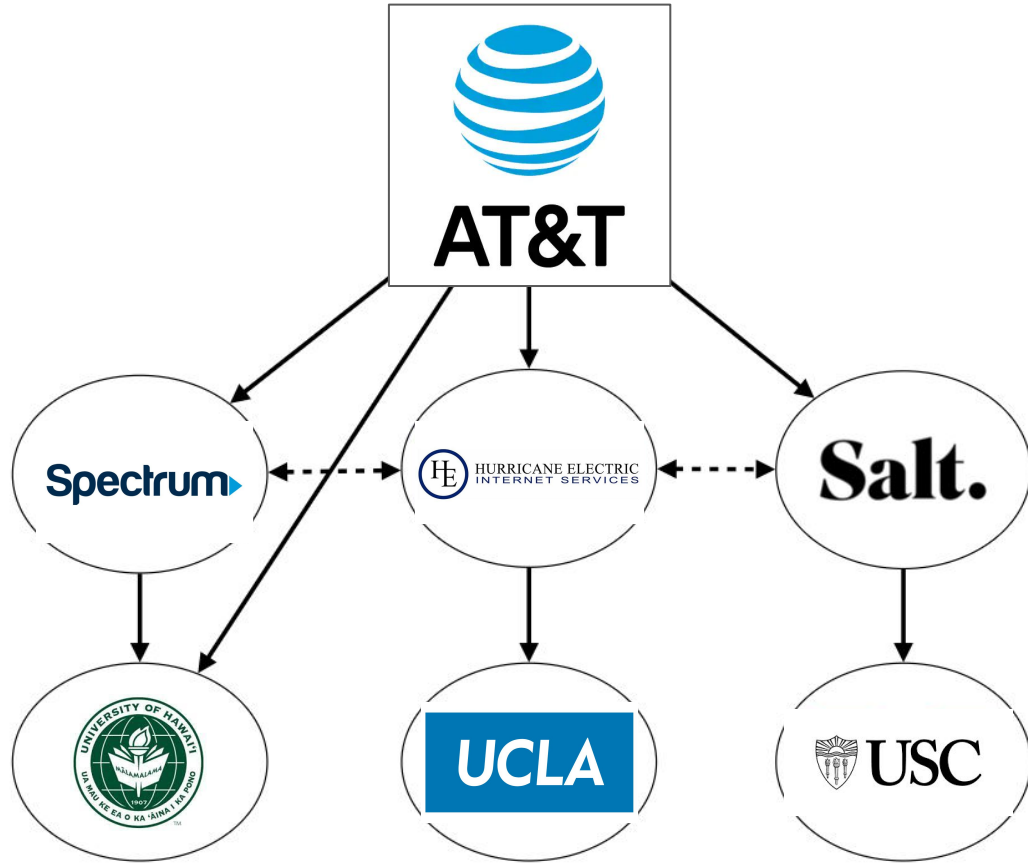
Internet Transit Prices have been continuously declining during the last 20 years

Internet Transit Pricing (1998-2015)			
Source: http://DrPeering.net			
Year	Internet Transit Price		% decline
1998	\$1,200.00	per Mbps	
1999	\$800.00	per Mbps	33%
2000	\$675.00	per Mbps	16%
2001	\$400.00	per Mbps	41%
2002	\$200.00	per Mbps	50%
2003	\$120.00	per Mbps	40%
2004	\$90.00	per Mbps	25%
2005	\$75.00	per Mbps	17%
2006	\$50.00	per Mbps	33%
2007	\$25.00	per Mbps	50%
2008	\$12.00	per Mbps	52%
2009	\$9.00	per Mbps	25%
2010	\$5.00	per Mbps	44%
2011	\$3.25	per Mbps	35%
2012	\$2.34	per Mbps	28%
2013	\$1.57	per Mbps	33%
2014	\$0.94	per Mbps	40%
2015	\$0.63	per Mbps	33%

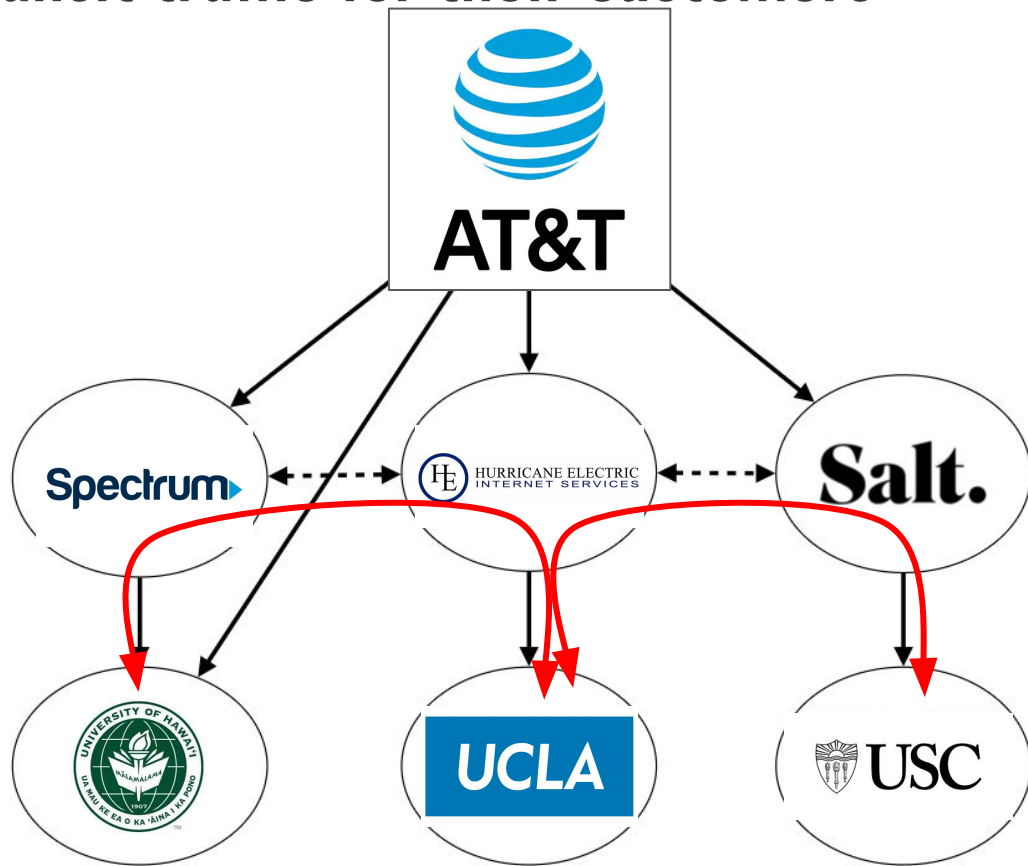
Peers don't pay each other for connectivity, they do it out of common interest



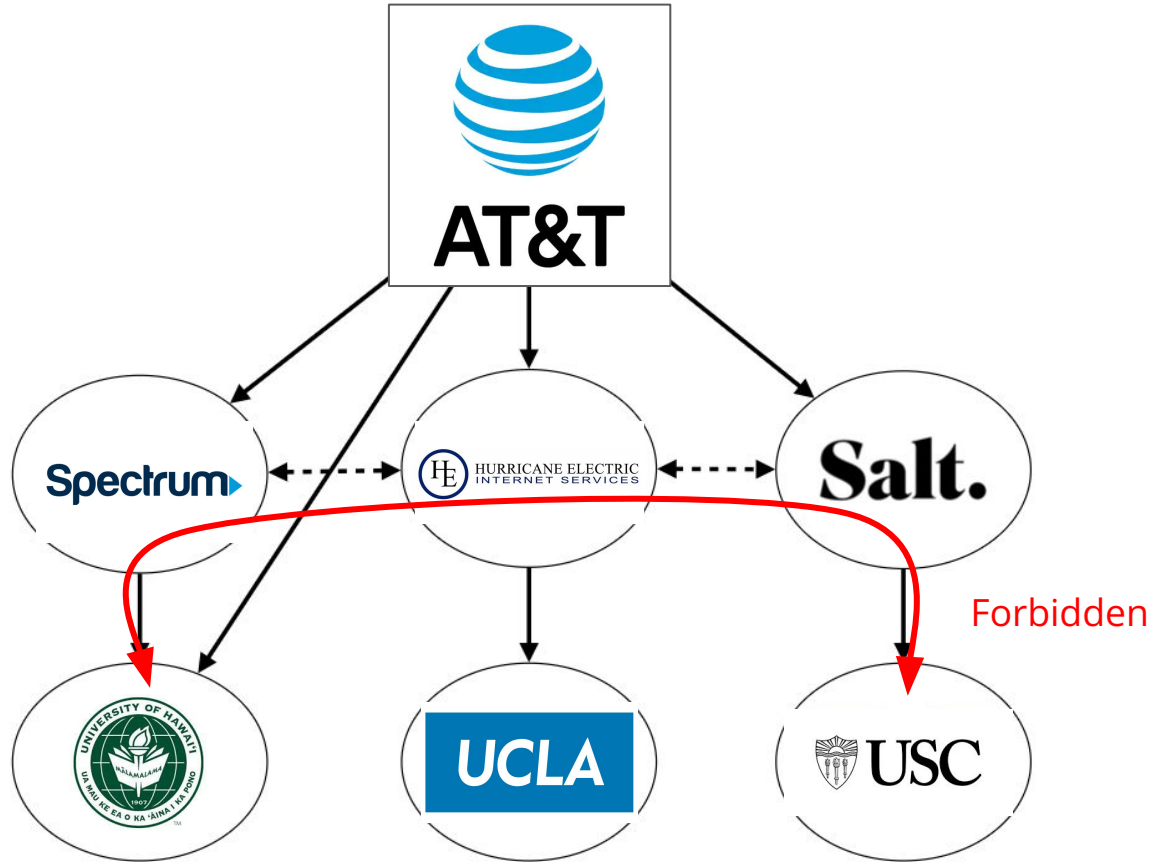
DT and ATT exchange *tons* of traffic.
they save money by directly connecting to each other



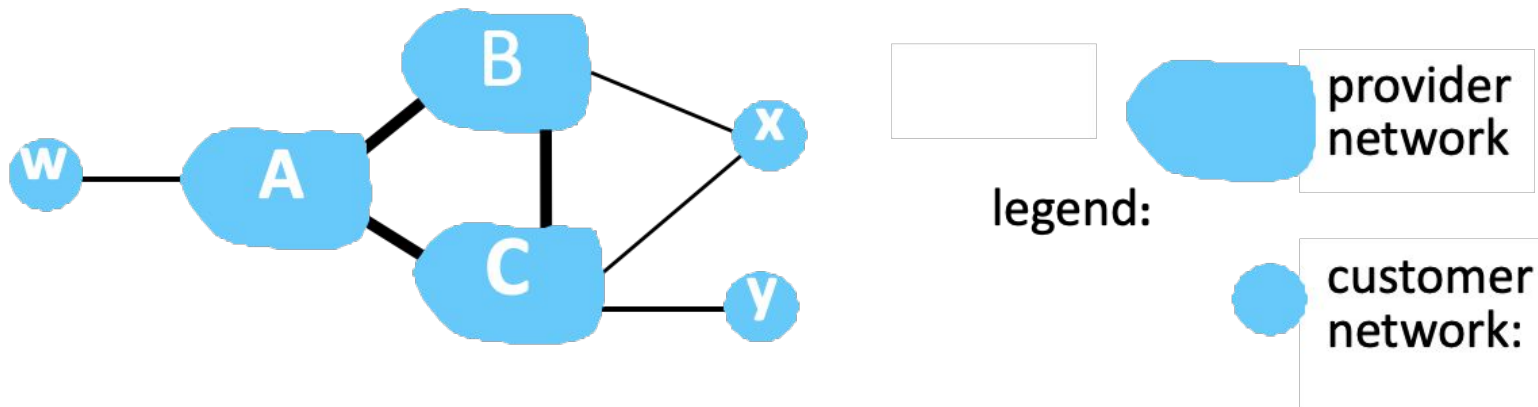
Providers transit traffic for their customers



Providers DO NOT transit traffic between each other

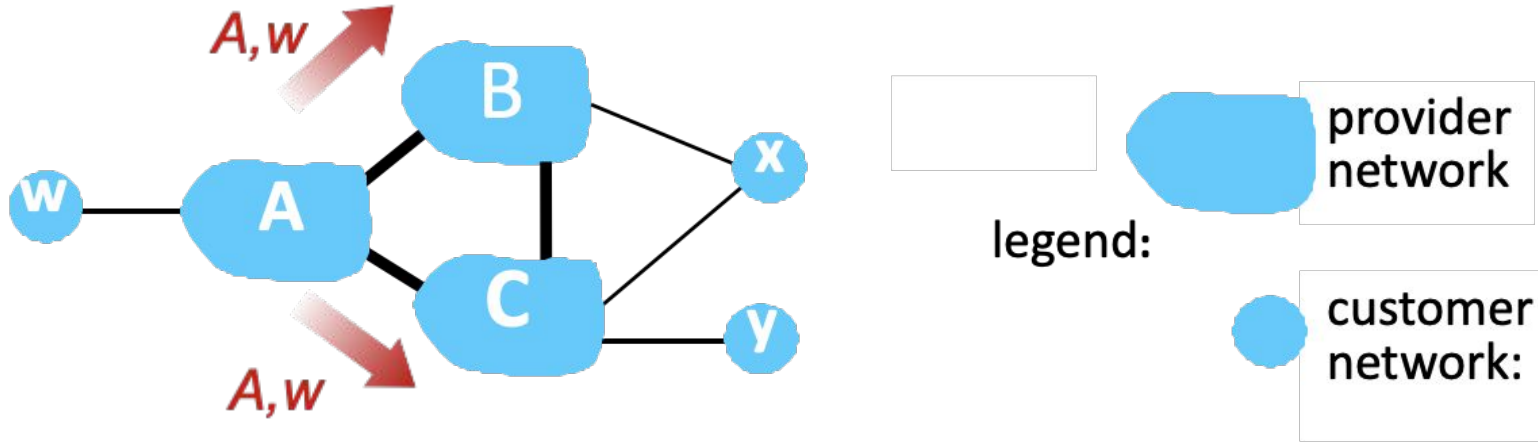


Providers DO NOT transit traffic between each other



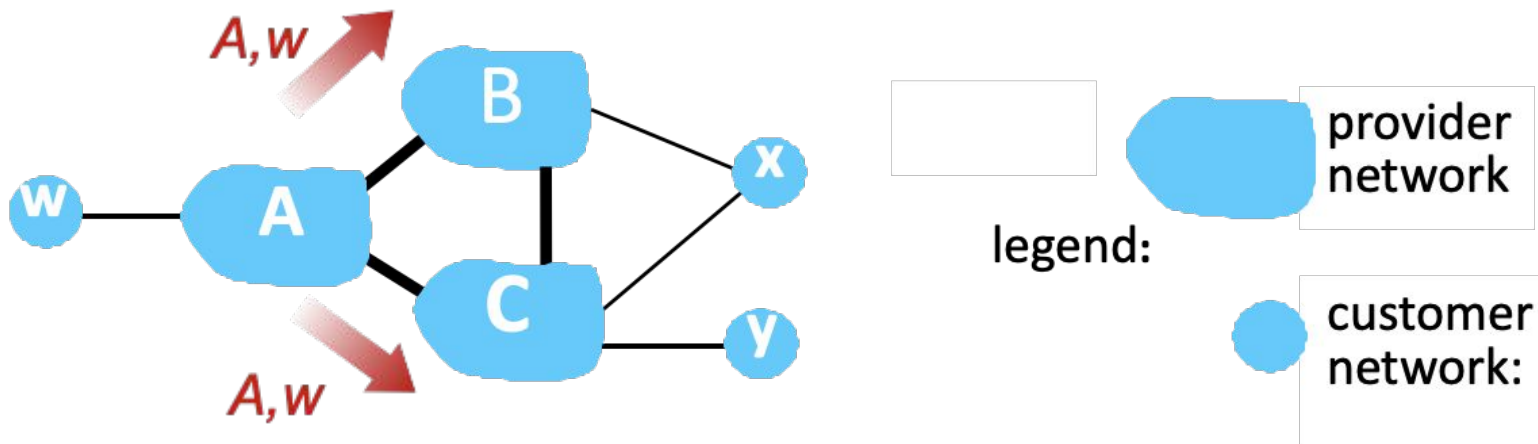
ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs – a typical “real world” policy)

Providers DO NOT transit traffic between each other



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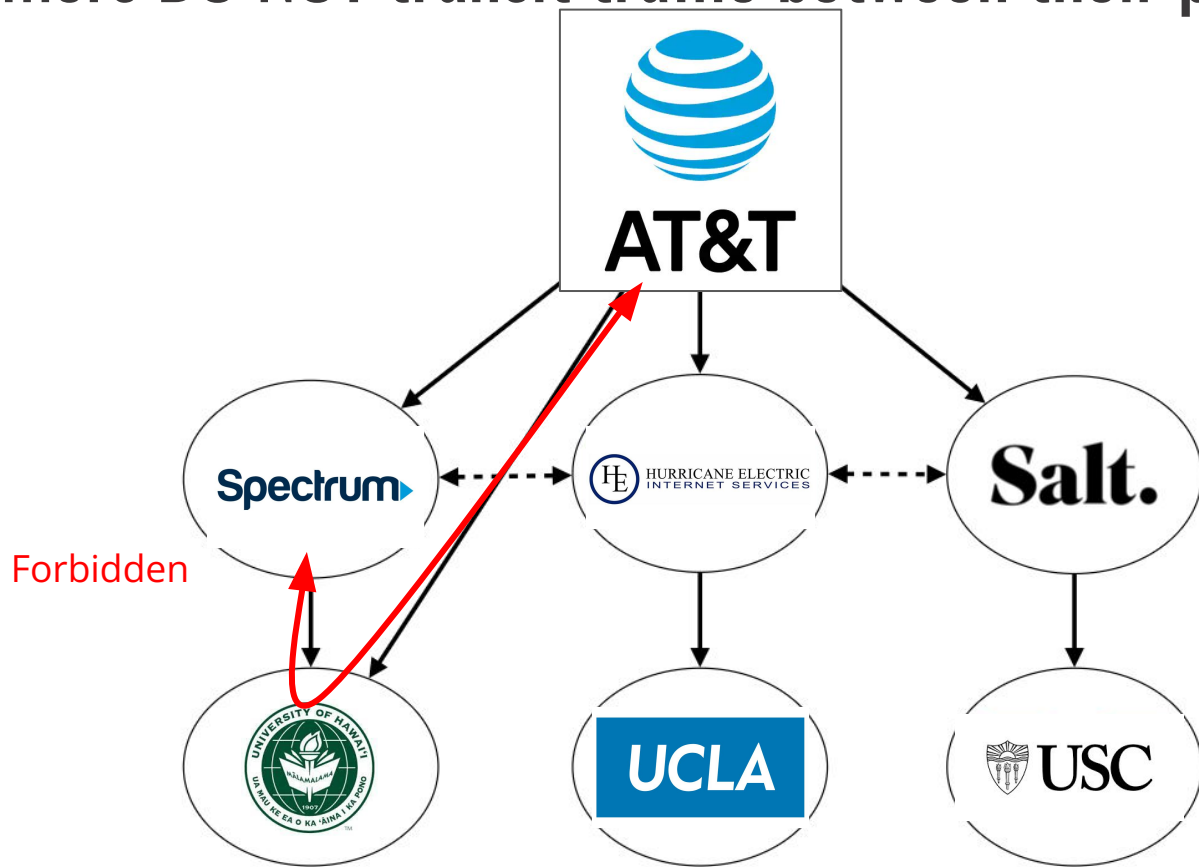
Providers DO NOT transit traffic between each other



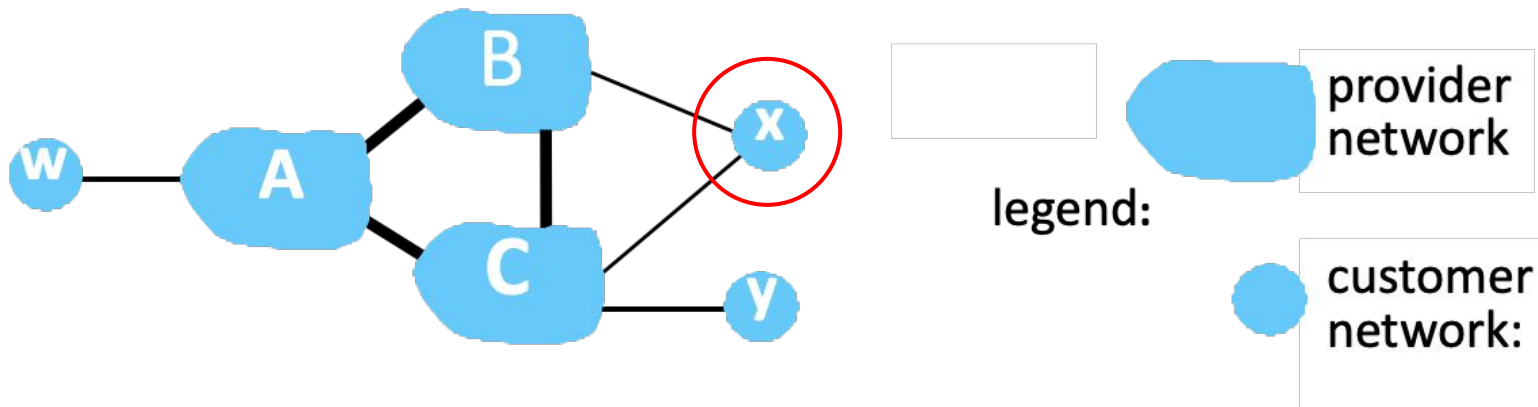
ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs – a typical “real world” policy)

- A advertises path Aw to B and to C
- B chooses not to advertise B-Aw to C!
 - B gets no “revenue” for routing C-B-Aw, since none of C, A, w are B’s customers
 - C does not learn about C-B-Aw path
- C will route C-Aw (not using B) to get to w

Customers DO NOT transit traffic between their providers



Customers DO NOT transit traffic between their providers



ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs – a typical “real world” policy)

- A,B,C are provider networks
- x,w,y are customers (of provider networks)
- x is **dual-homed**: attached to two networks
- policy to enforce: x does not want to route from B to C via x
 - .. so x will not advertise to B a route to C

Route policies are defined by constraining which BGP routes are selected and exported



Selection

which path to use?



Export

which path to advertise?

Route policies are defined by constraining which BGP routes are selected and exported



Selection

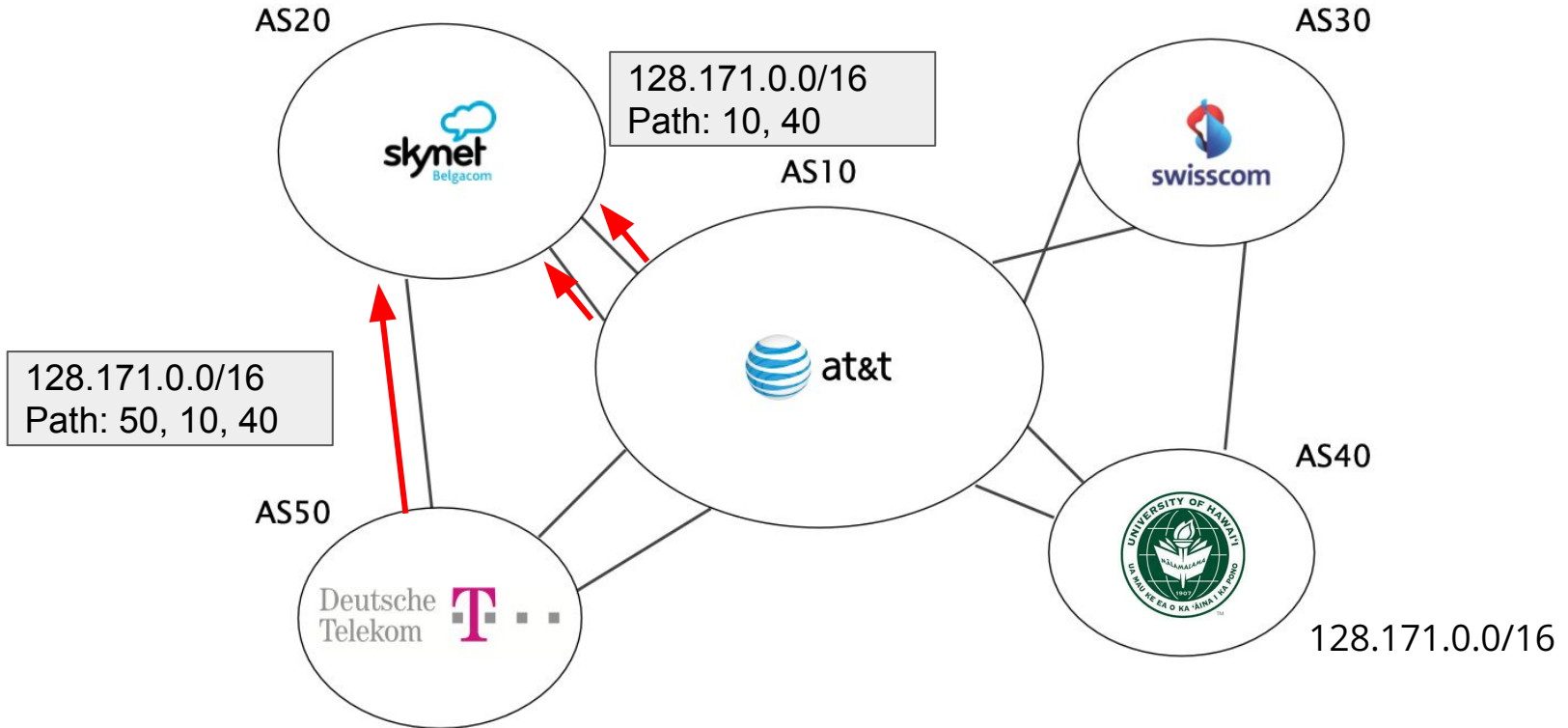
which path to use?

Control outbound traffic

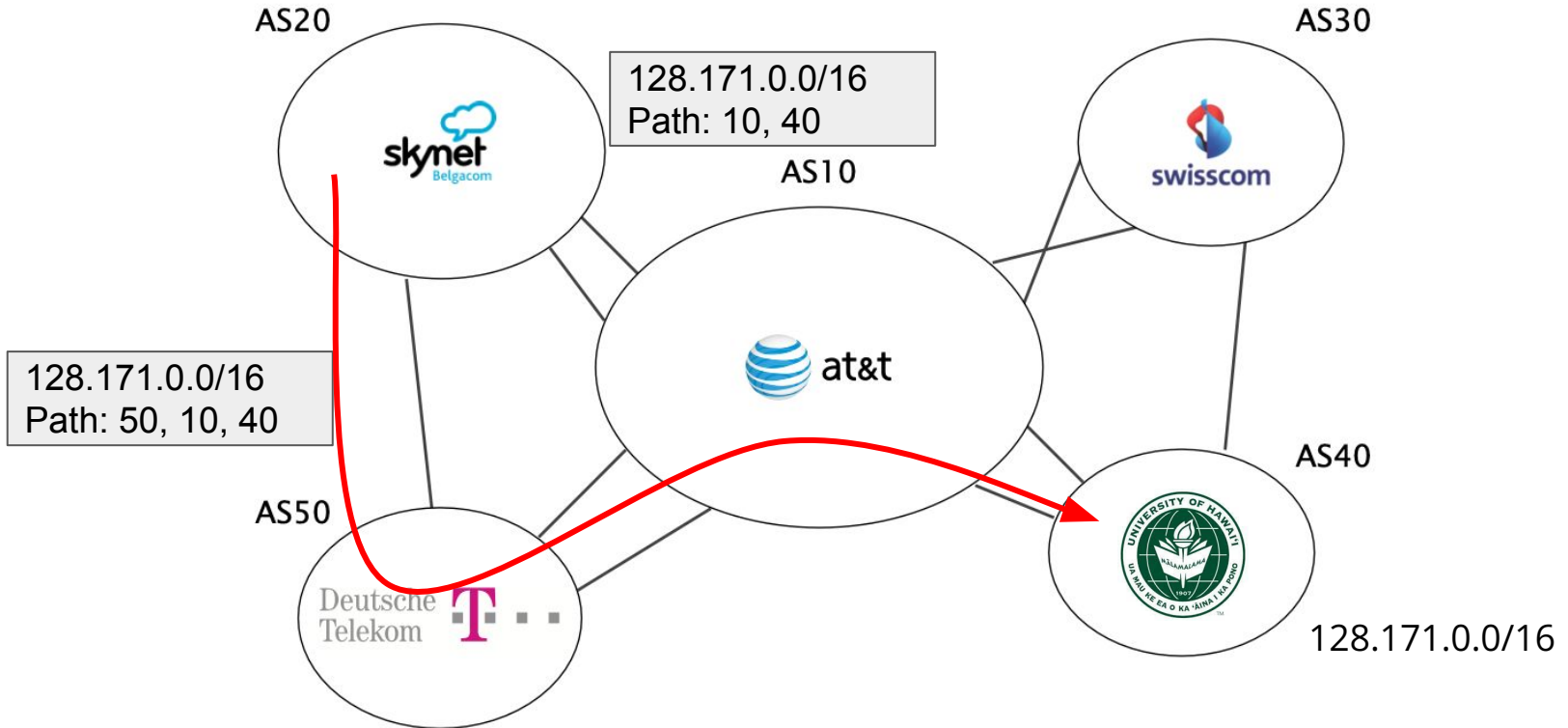
Export

which path to advertise?

Always prefer DT over AT&T



Always prefer DT over AT&T



Business relationships condition route selection

For a destination p , prefer routes coming from

- customers over
- peers over
- providers



route type

Route policies are defined by constraining which BGP routes are selected and exported



Selection

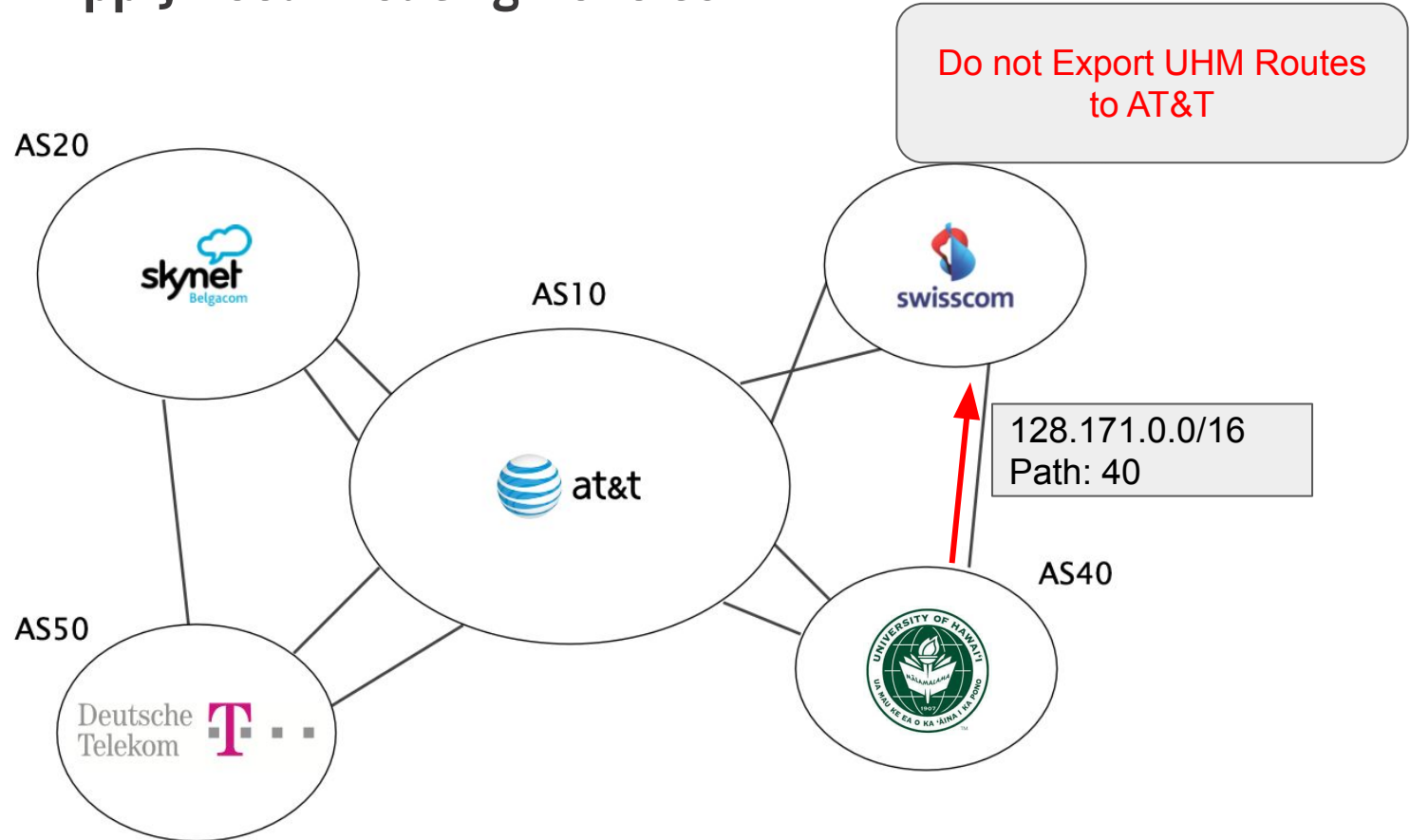
which path to use?

Export

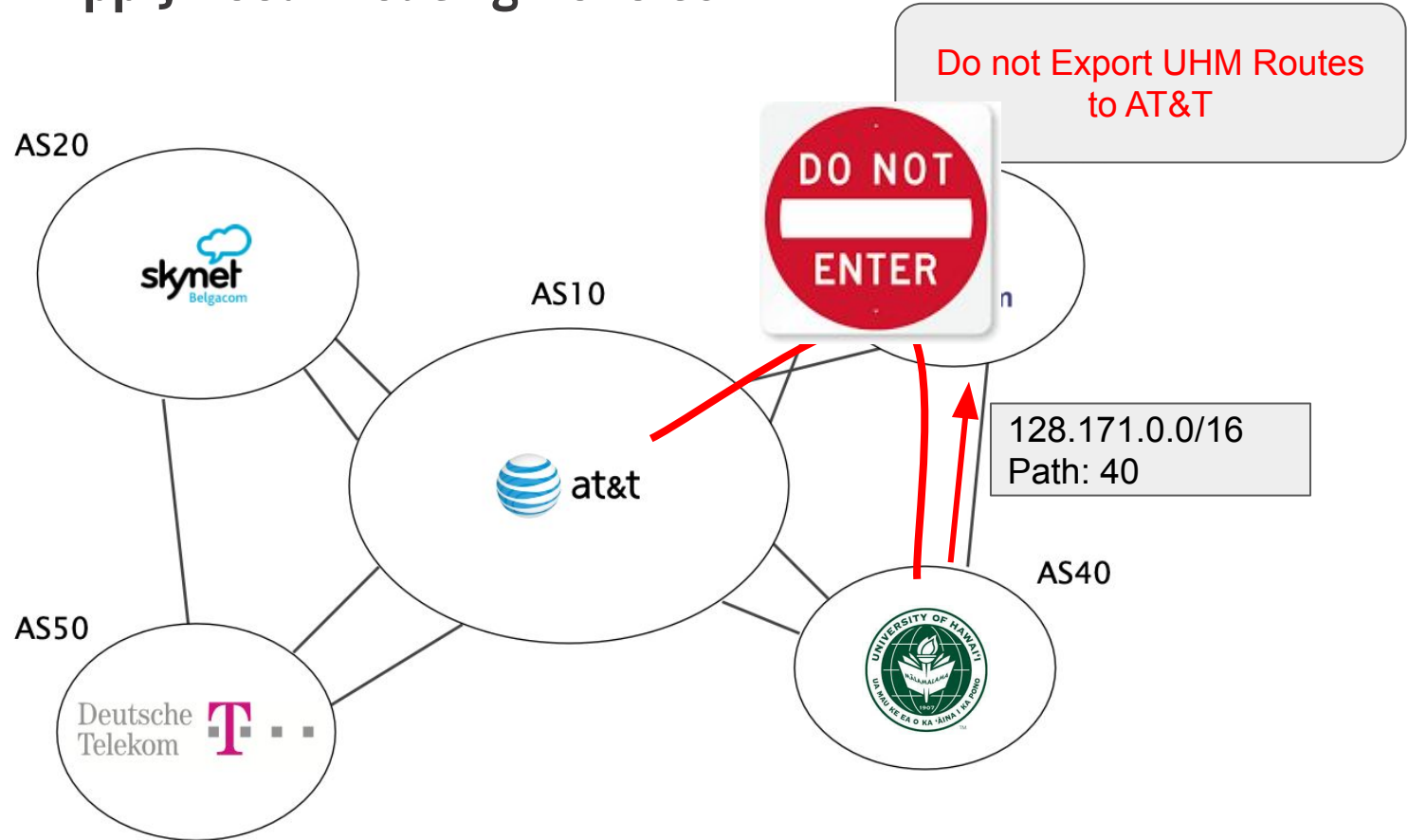
which path to advertise?

Control inbound traffic

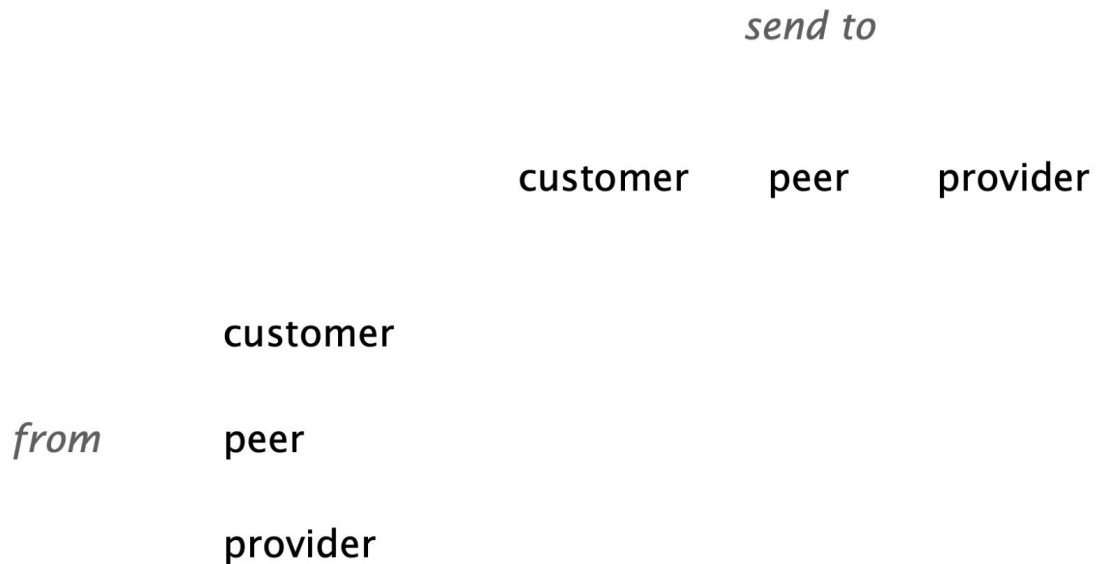
Each AS Can Apply Local Routing Policies






Each AS Can Apply Local Routing Policies



Business relationships constrain route exportation



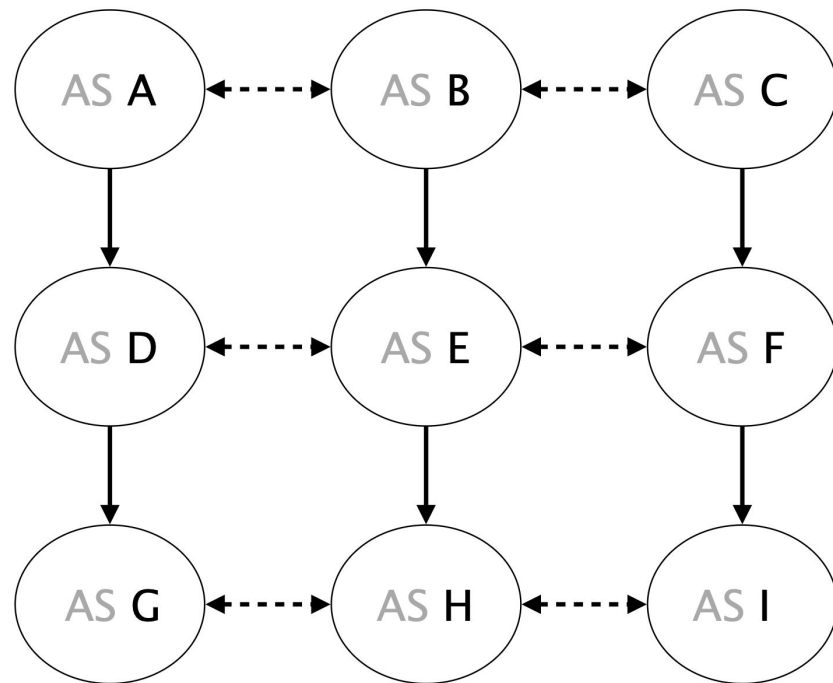
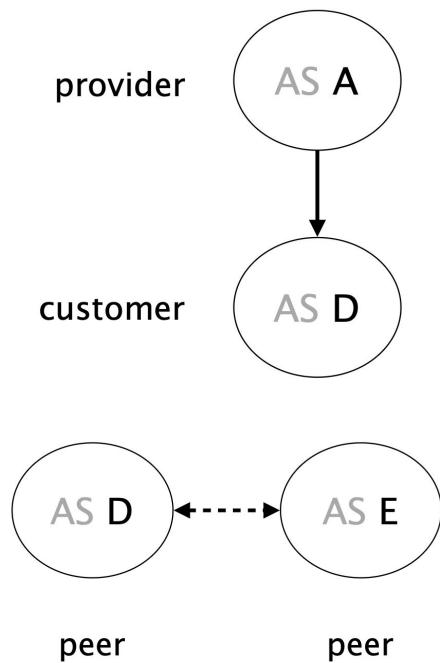
Routes from customers are propagated to everyone else

		<i>send to</i>		
		customer	peer	provider
<i>from</i>	customer			
	peer			
	provider			

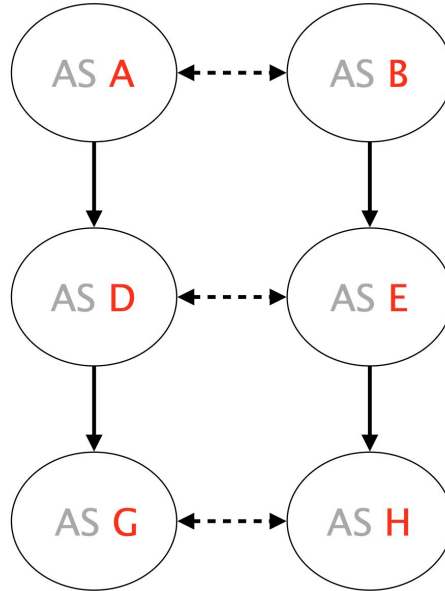
Routes from peers and providers are only propagated to customer

		<i>send to</i>		
		customer	peer	provider
<i>from</i>	customer			
	peer		-	-
	provider		-	-

Example

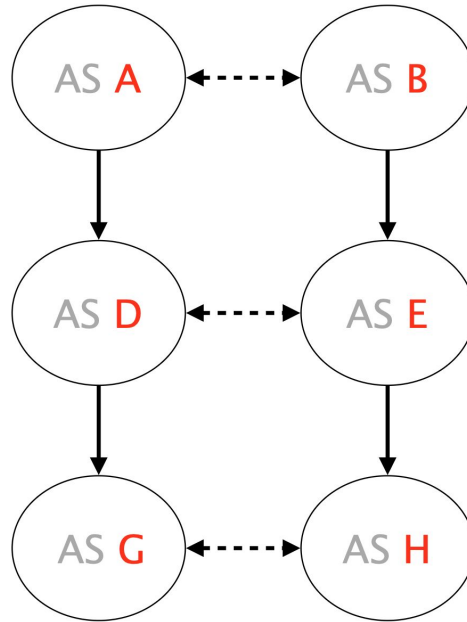


Example



Is (G,D,A,B,E,H) a valid path?

Example



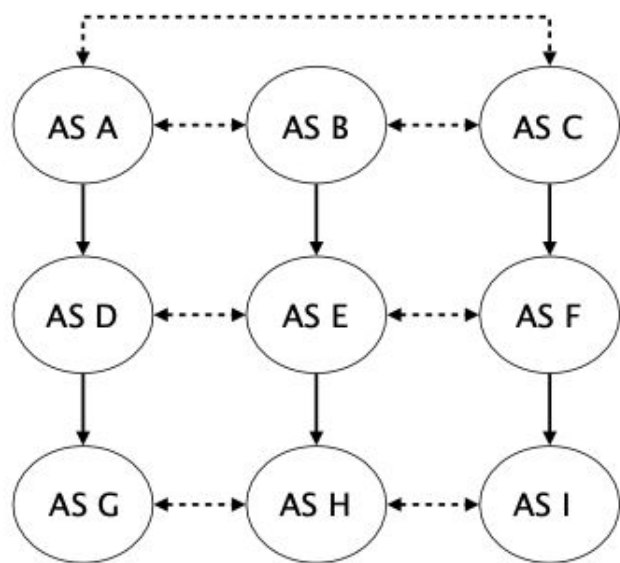
Will (G,D,A,B,E,H) actually see packets?

Questions

Consider now the network depicted on the right. Single-headed plain arrows point from providers to their customers (AS A is the provider of AS D), while double-headed dashed arrows connect peers (AS D and AS E are peers). Each AS in the network originates a unique prefix that it advertises to all its BGP neighbors. Each AS also applies the default selection and exportation BGP policies based on their customers, peers and providers.

What path (sequence of ASes) is followed when AS G sends packets destined to the prefix originated by AS E?

What path (sequence of ASes) is followed when AS F sends packets destined to the prefix originated by AS G?



A simple BGP network

Questions

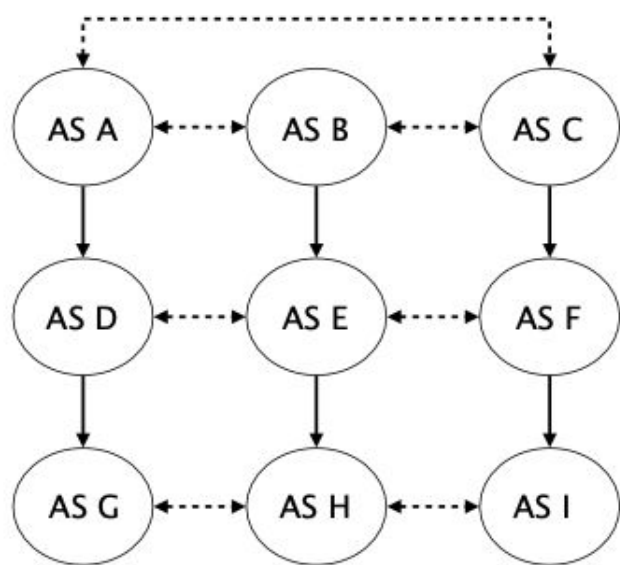
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Solution: [G, D, E]

What path (sequence of ASes) is followed when AS F sends packets destined to the prefix originated by AS G?

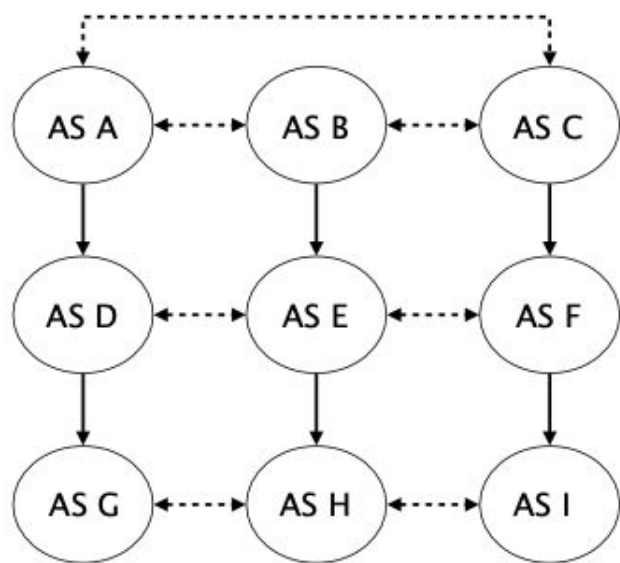
Solution: [F, C, A, D, G]



A simple BGP network

Questions

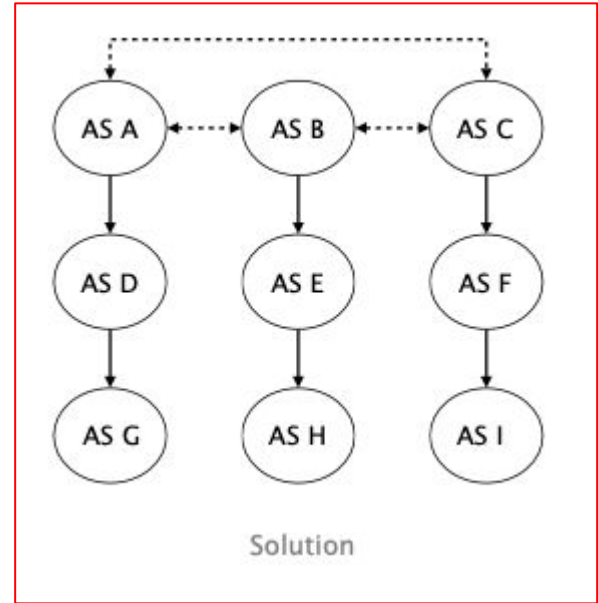
Suppose AS A and AS C give you a “dump” of all the BGP routes they learn for every destination. You then extract all links from the AS paths seen in those “dumps” and use them to construct a view of the AS-level topology. Draw the resulting AS-level topology.



A simple BGP network

Questions

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BGP Policy Wrapup

To implement their selection policy, operators define input filters which manipulates the LOCAL-PREF

For a destination p , prefer routes coming from

- customers over
 - peers over
 - providers
- 
- route type*

BGP Policy Wrapup

