

# Inferring Autonomous System Relationships in the Internet

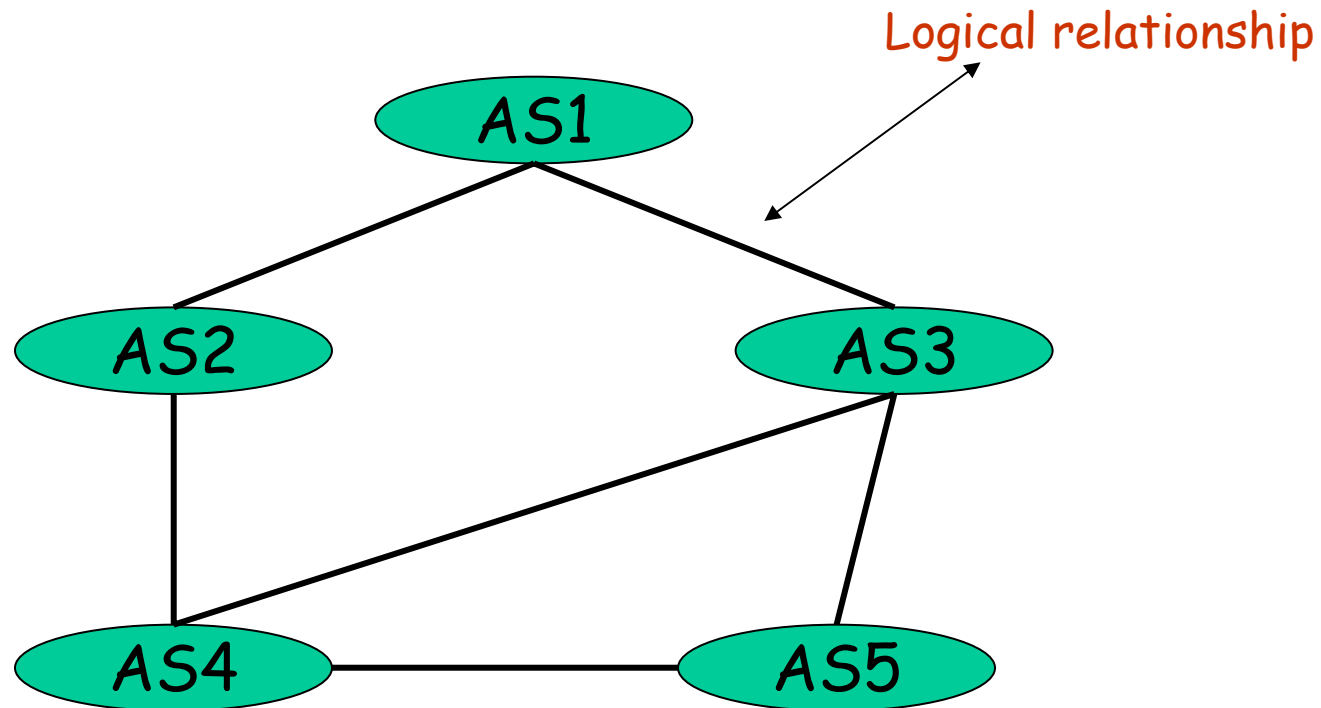
Lixin Gao

# Motivation

- Routing policies are constrained by the contractual commercial agreements between administrative domains
- *For example:* AS sets policy so that it does not provide transit services between its providers
- Therefore connectivity does not imply reachability
- Policies not just connectivity influence the structural properties of the Internet

# Background

Connectivity between ASes can be modeled using an AS graph  $G = (V, E)$

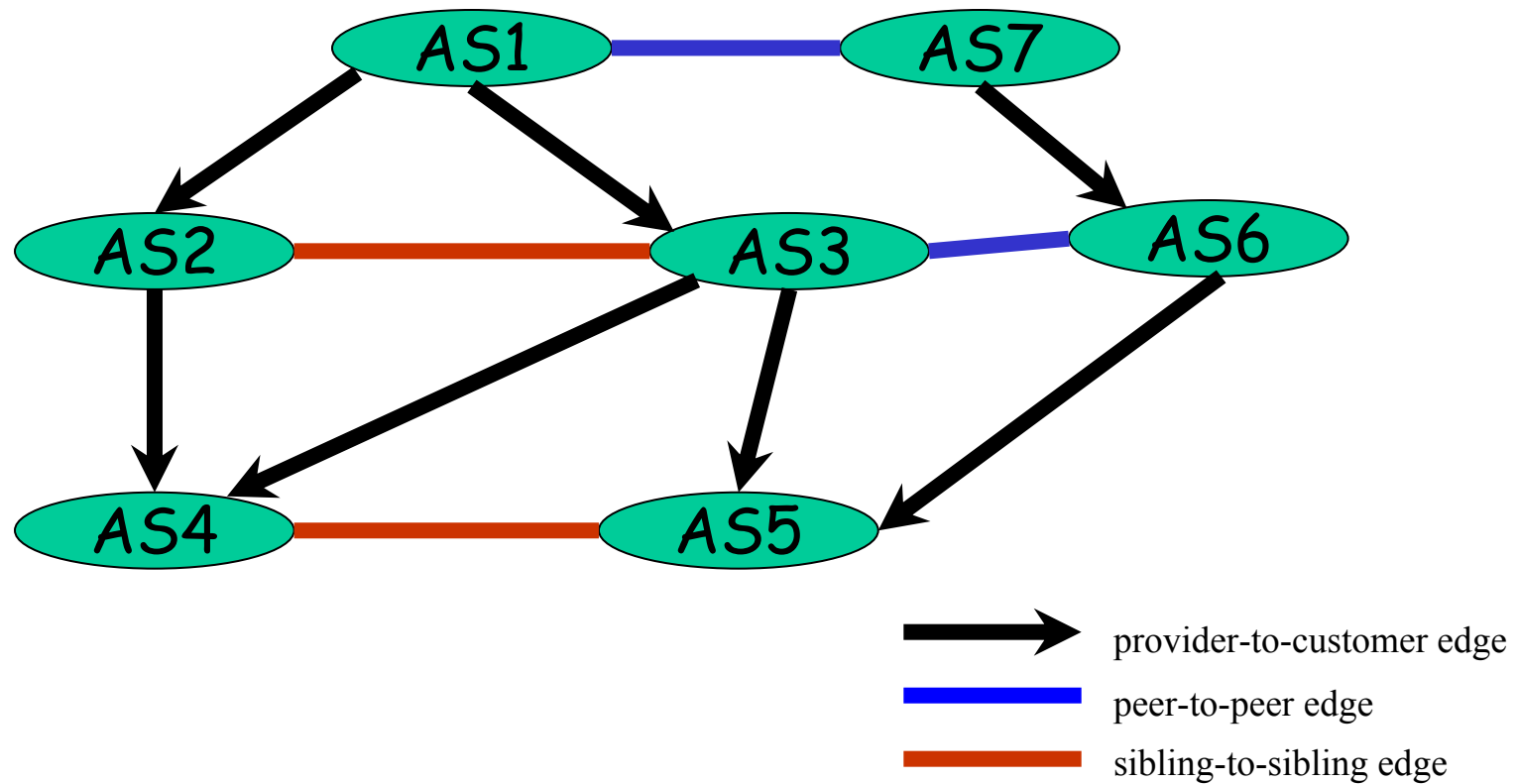


# AS Relationships

- The commercial agreements between pairs of **administrative domains** can be classified into:
  - customer-provider relationship
  - peering relationship
  - mutual-transit relationship
- Classification for relationship of pairs of **Autonomous Systems**:
  - customer-to-provider relationship
  - provider-to-customer relationship
  - peer-to-peer relationship
  - sibling-to-sibling relationship

# Annotated AS graph

Partially directed graph labeled with relationship

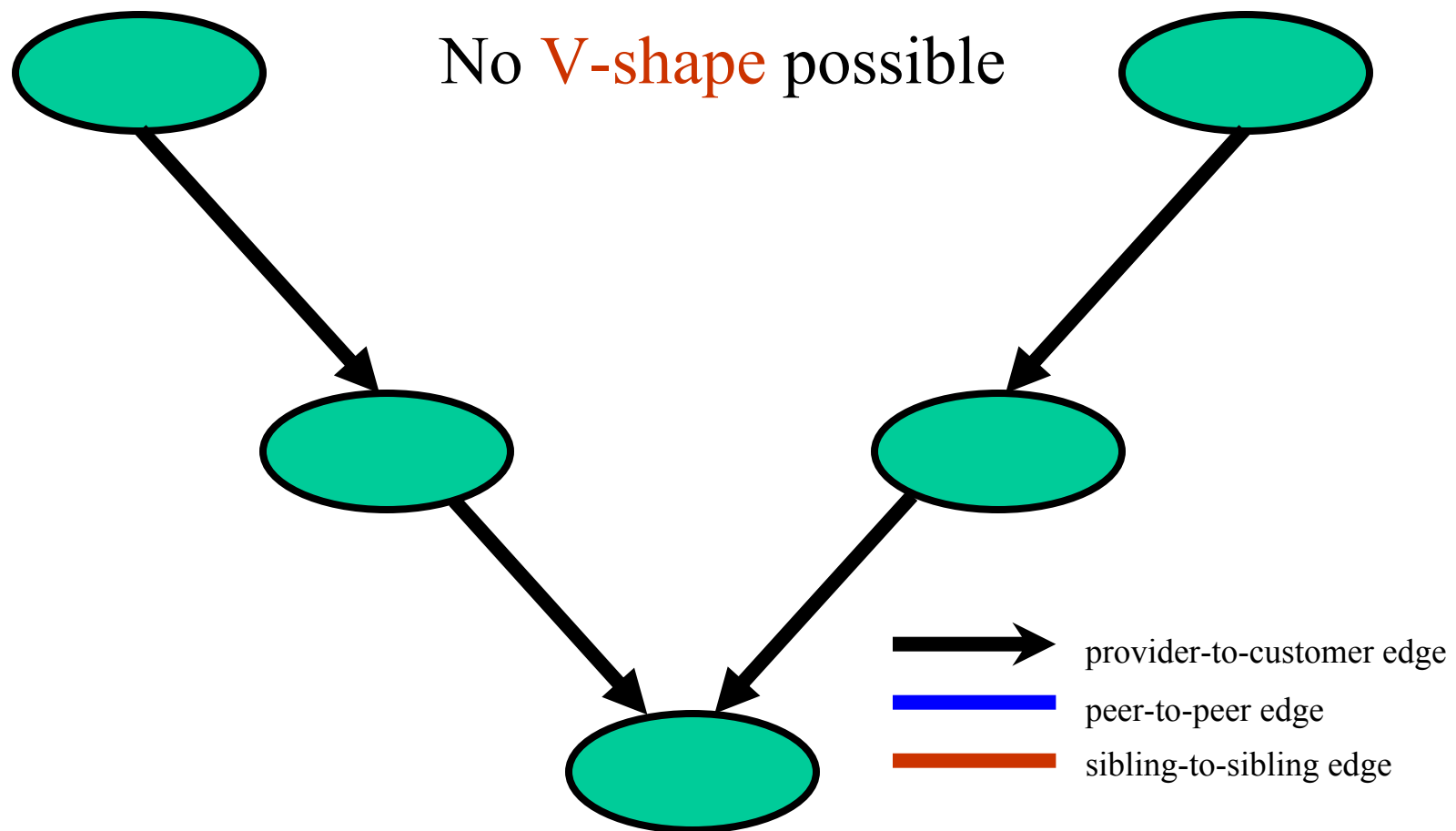


# Rules governing BGP export policy

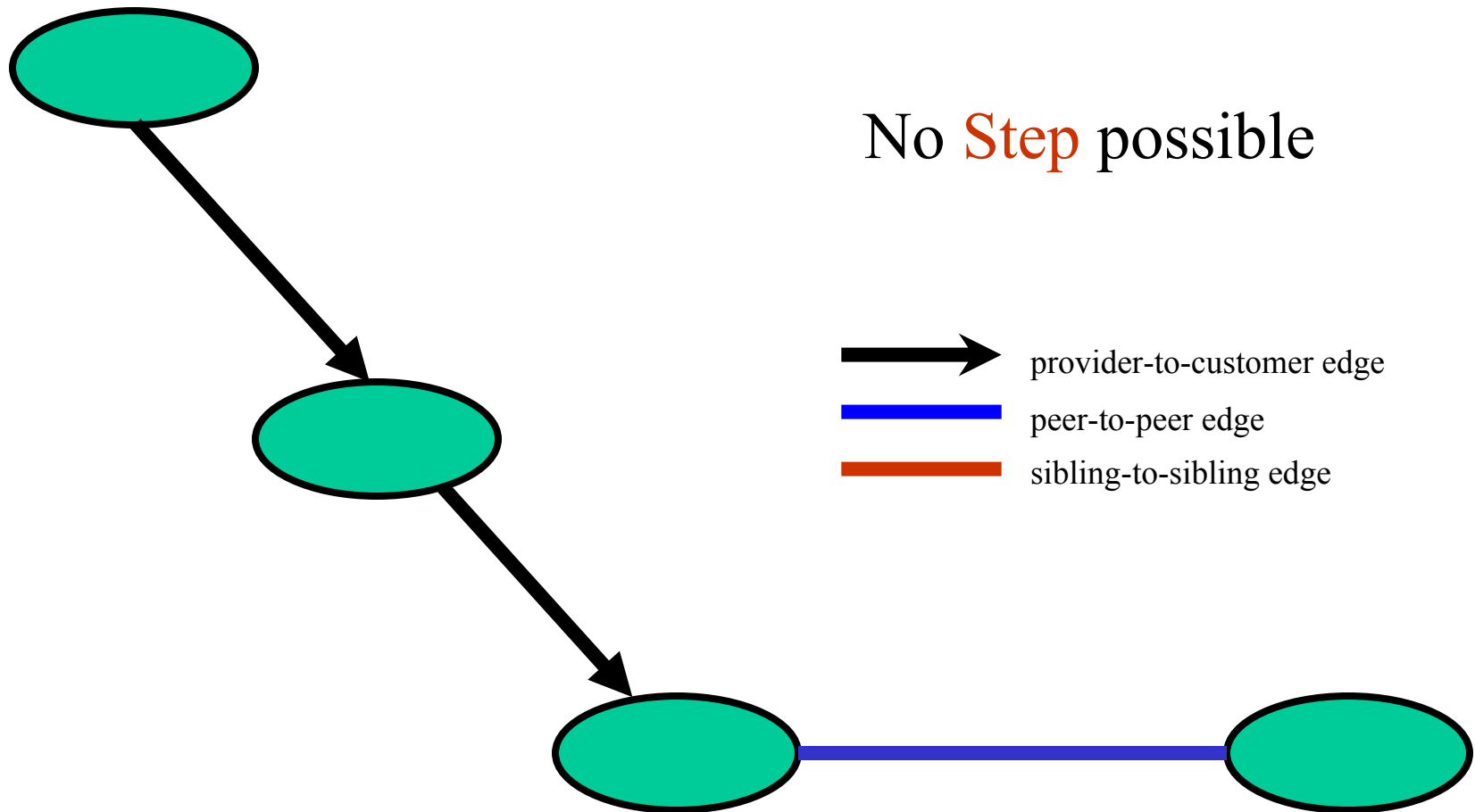
	Own Routes	Customer's Routes	Sibling's Route	Provider's Route	Peer's Route
Exporting to a Provider	×	×	×		
Exporting to a Customer	×	×	×	×	×
Exporting to a Peer	×	×	×		
Exporting to a Sibling	×	×	×	×	×

Selective export rules indicate that a BGP routing table entry should have a certain pattern

# Valley-free property



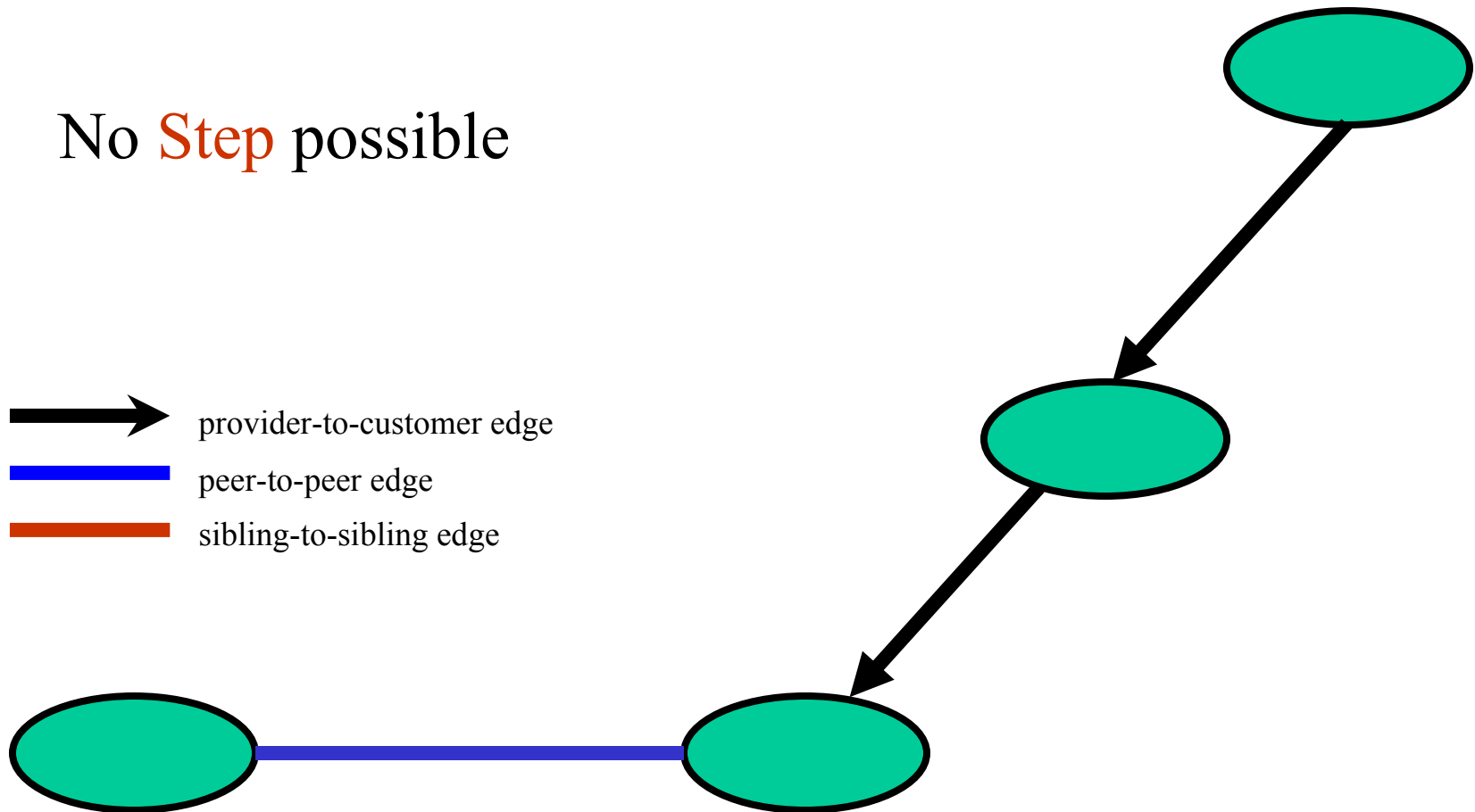
# Valley-free property



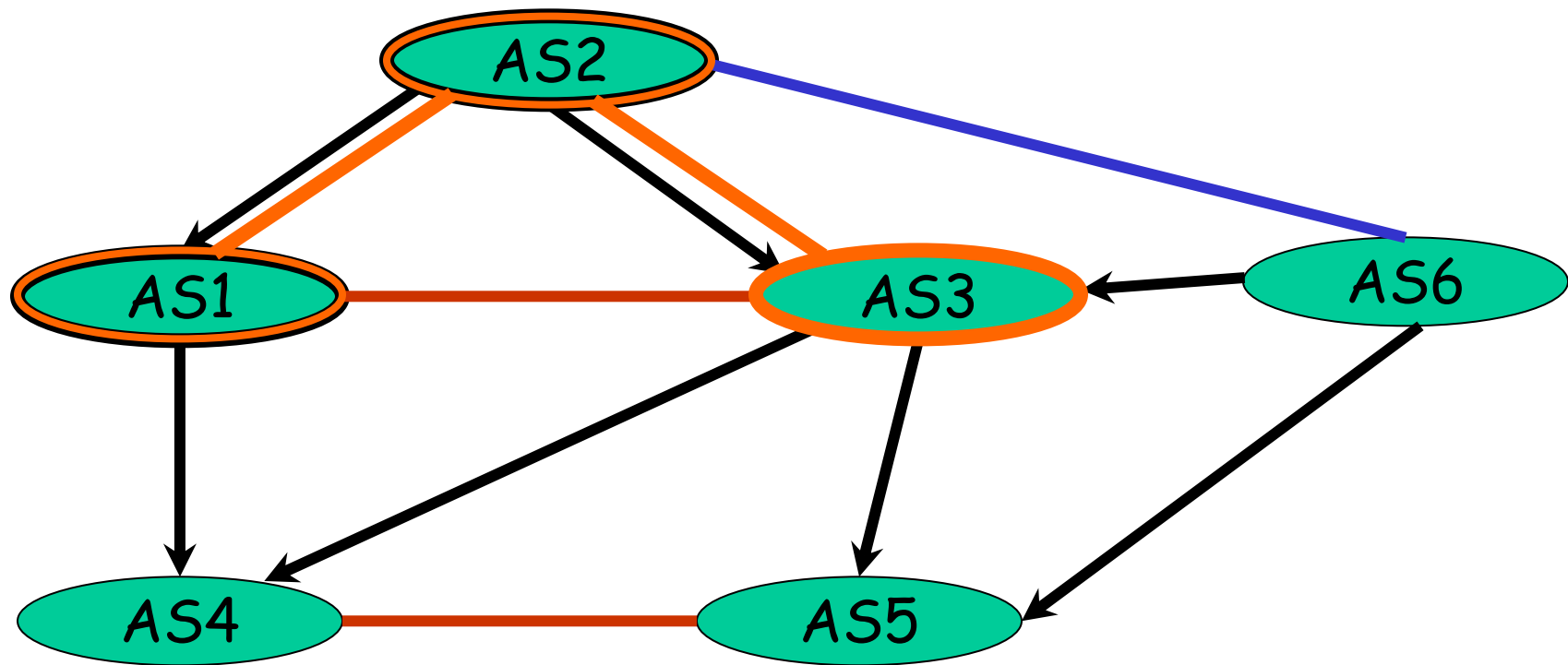


# Valley-free property

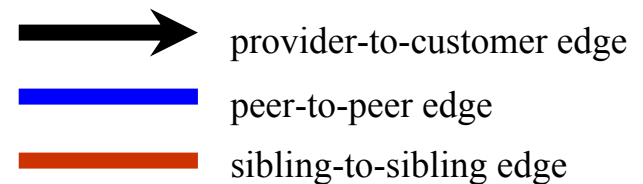
No **Step** possible



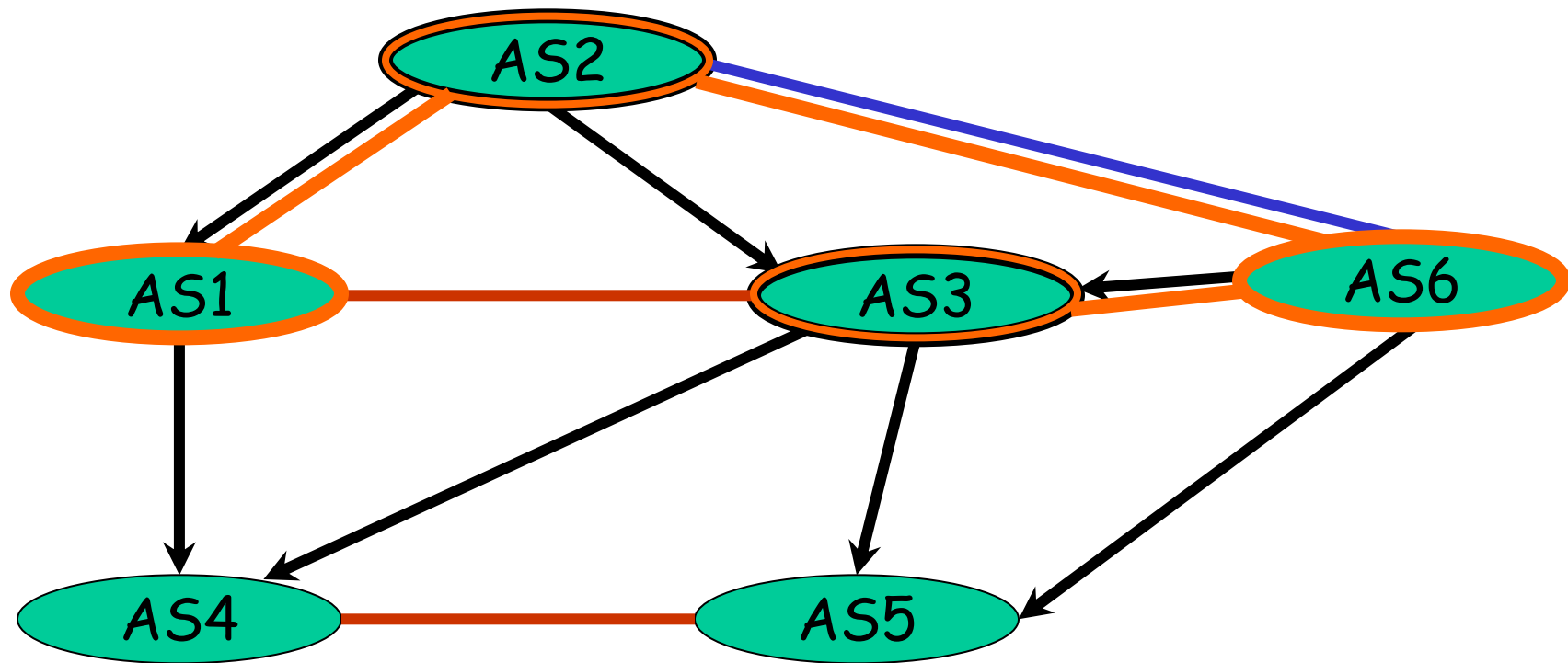
# Valley-free property






**AS path (1,2,3) is valley-free**



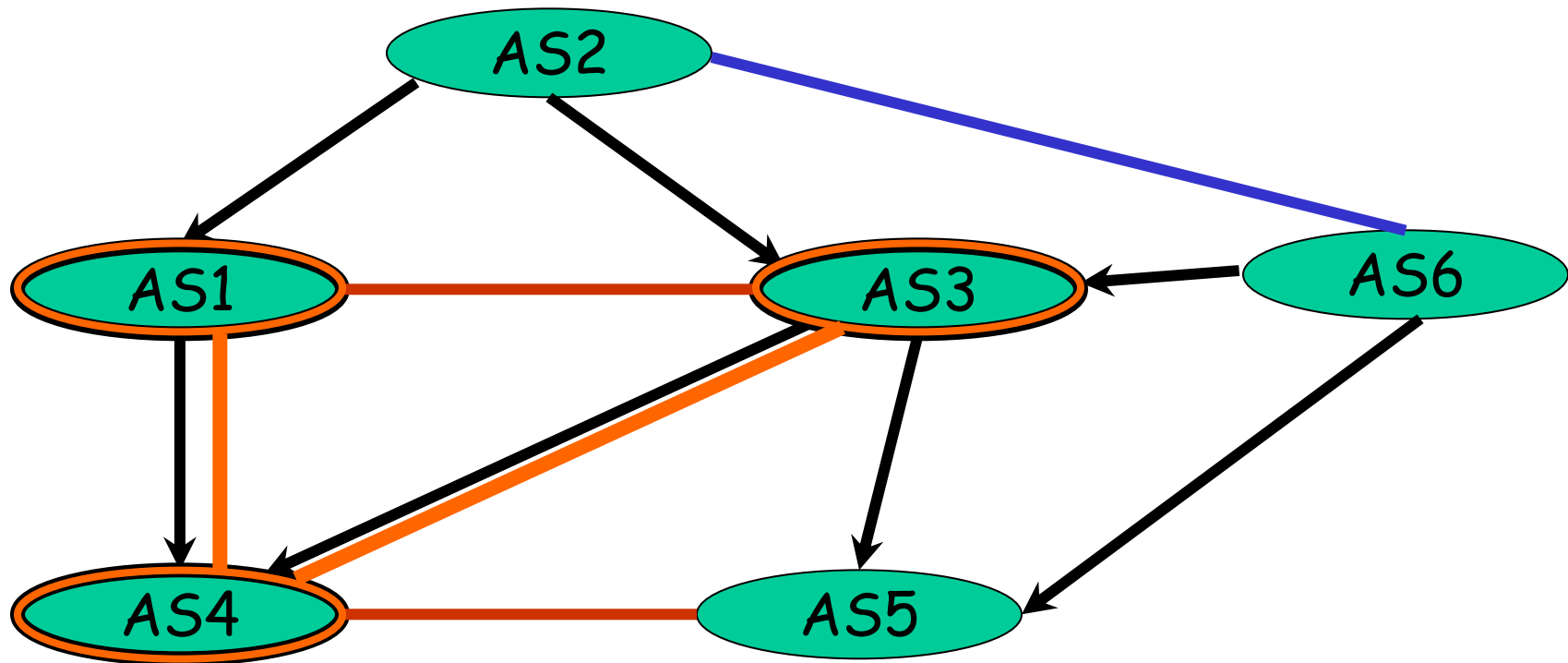
# Valley-free property



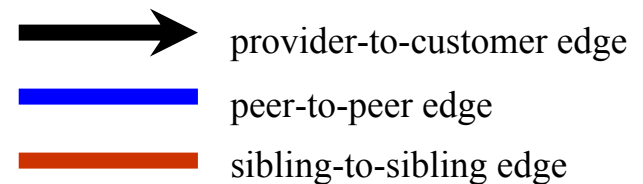
**AS path (1,2,6,3) is valley-free**

-  provider-to-customer edge
-  peer-to-peer edge
-  sibling-to-sibling edge

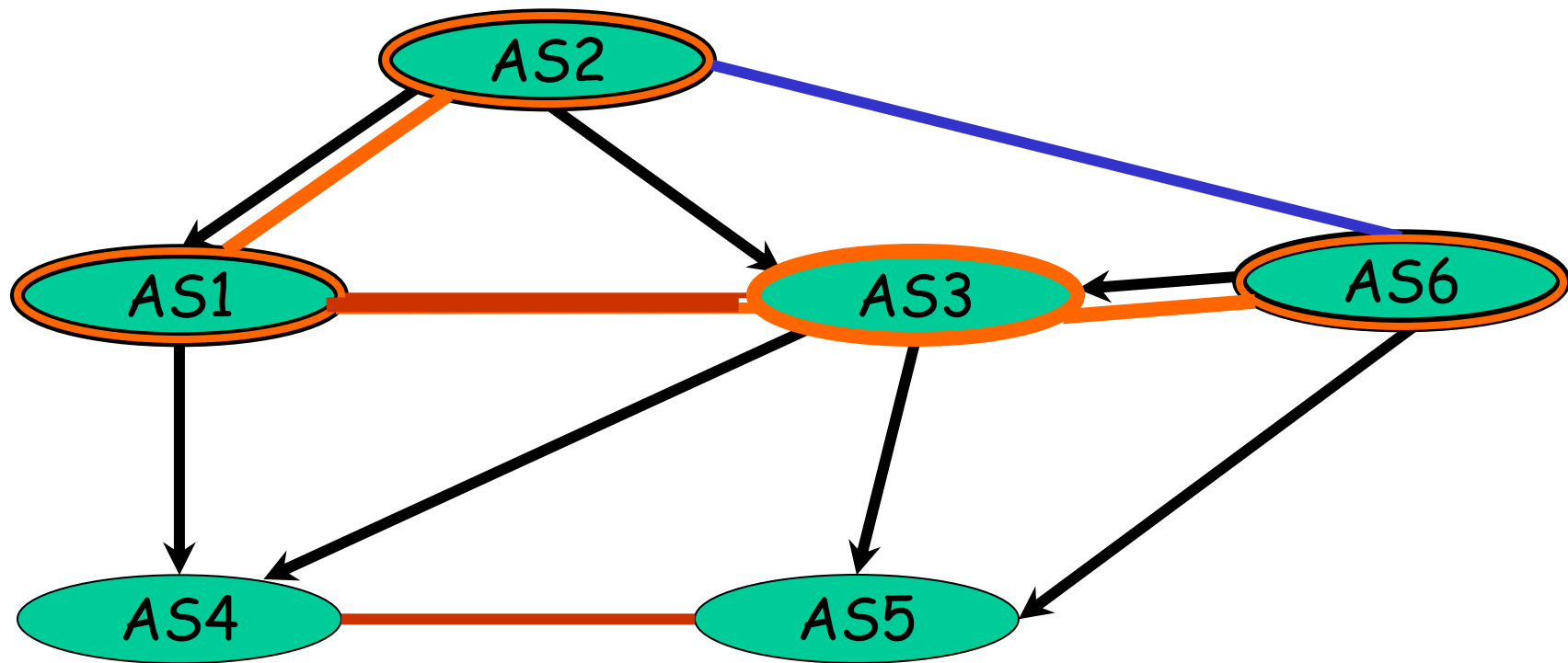
# Valley-free property



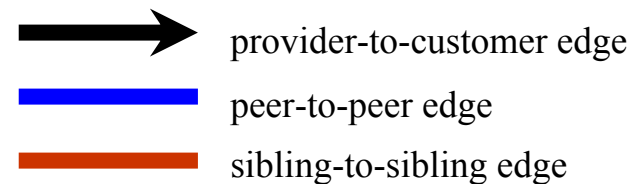
AS path (1,4,3) is **not** valley-free



# Valley-free property



AS path (2,1,3,6) is **not** valley-free



# Valley-free property

- After traversing a provider-to-customer or peer-to-peer edge, the AS path **can not** traverse a customer-to-provider or peer-to-peer edge.

# Routing Table Entry Patterns

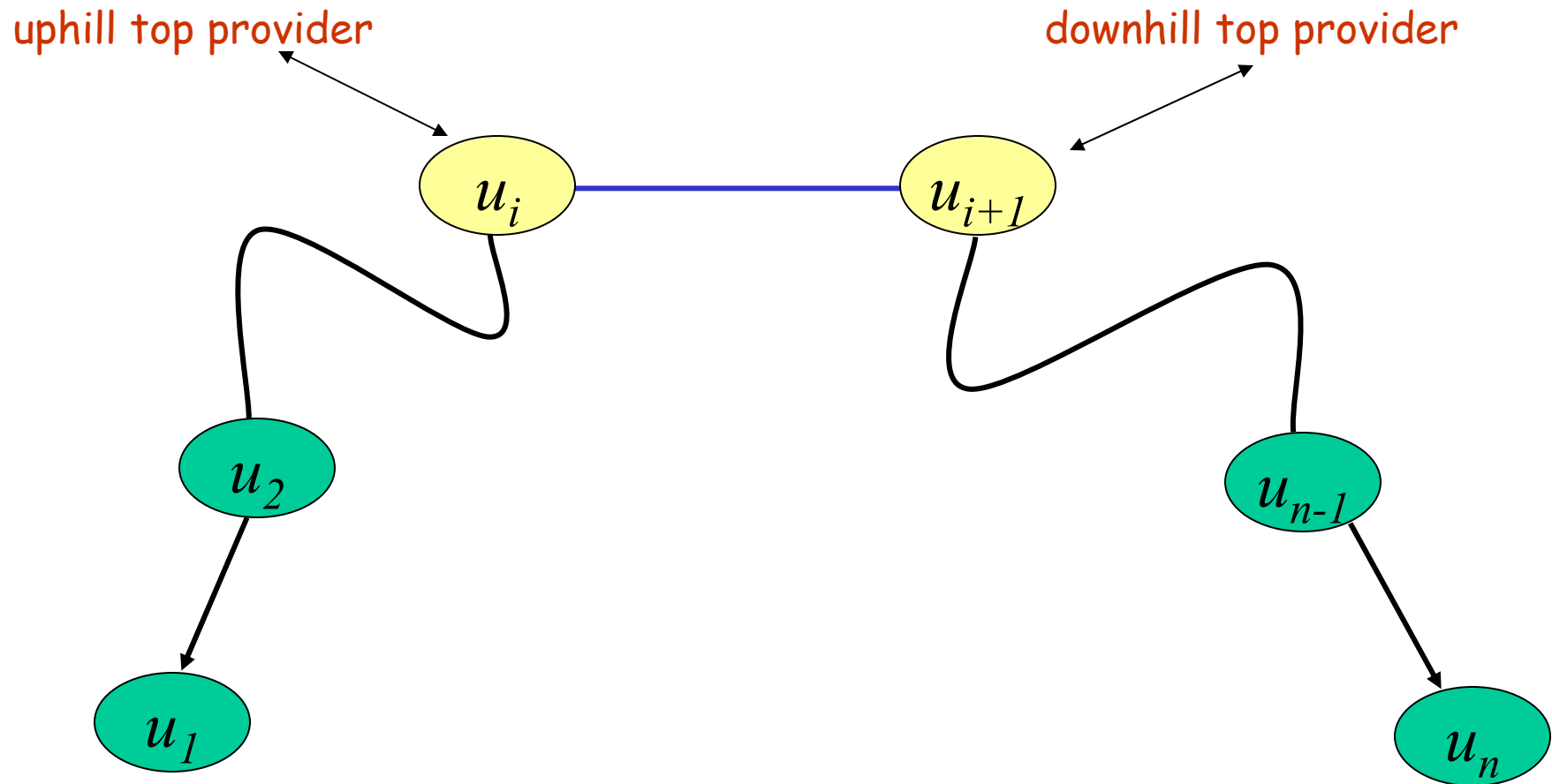
- **Downhill Path:** a sequence of edges that are either provider-to-customer or sibling-to-sibling
- **Uphill Path:** a sequence of edges that are either customer-to-provider or sibling-to-sibling

# Routing Table Entry Patterns

- An AS path of a BGP routing table entry has one of the following patterns:
  - an uphill path followed by a peer-to-peer edge followed by a downhill path
  - an uphill path
  - a downhill path
  - an uphill path followed by a downhill path
  - an uphill path followed by a peer-to-peer edge
  - a peer-to-peer edge followed by a downhill path



# Routing Table Entry Patterns



# Heuristic Algorithms

- The Algorithm for inferring AS relationships is based on the fact that ASes set up their export policies according to the relationships and on the resulting patterns on BGP routing table entries
- It is also based on the intuition that a provider typically has a larger size than its customer and the size of an AS is typically proportional to its degree in the AS graph

# Heuristic Algorithms

- top provider of an AS path is the AS that has the highest degree among all ASes in the path
- we can infer that consecutive AS pairs on the left of the top provider are customer-to-provider or sibling-to-sibling edges and on the right are provider-to-customer or sibling-to-sibling edges

# Inference Results

	TOTAL ROUTING ENTRIES	TOTAL EDGES	SIBLING-TO-SIBLING EDGES INFERRED BY BASIC (PERCENT AGE)	SIBLING-TO-SIBLING EDGES INFERRED BY REFINED (IGNORED ENTRIES)	PEER-TO-PEER EDGES INFERRED BY FINAL [R=60] (PERCENT AGE)	PEER-TO-PEER EDGES INFERRED BY FINAL [R=60] (PERCENT AGE)
1999/9/27	968674	11288	149 (1.3%)	124 (25)	884 (7.8%)	733 (6.5%)
2000/1/2	936058	12571	186 (1.47%)	135 (51)	838 (6.7%)	668 (5.3%)
2000/3/9	1227596	13800	203 (1.47%)	157 (46)	857 (6.2%)	713 (5.7%)

# Verification of Inferred Relationships by AT&T

OUR INFERENCE	AT&T INFORMATION	PERCENTAGE OF AS
Customer	Customer	99.8%
	Peer	0.2%
Peer	Peer	76.5%
	Customer	23.5%
Sibling	Sibling	20%
	Peer	60%
	Customer	20%
Nonexistent	Customer	95.6%
	Peer	4.4%

Comparing inference results from Basic and Final( $R=\infty$ ) with AT&T internal information

# Verification of Inferred Relationships by AT&T

OUR INFERENCE	AT&T INFORMATION	PERCENTAGE OF AS
Customer	Customer	99.5%
	Peer	0.5%
Peer	Peer	76.5%
	Customer	23.5%
Sibling	Sibling	25%
	Peer	50%
	Customer	25%
Nonexistent	Customer	95.6%
	Peer	4.4%

Comparing inference results from Refined and Final( $R=\infty$ ) with AT&T internal information

# Verification of Inferred Relationships by AT&T

OUR INFERENCE	AT&T INFORMATION	PERCENTAGE OF AS
Customer	Customer	99.8%
	Peer	0.2%
Peer	Peer	100%
Sibling	Sibling	20%
	Peer	60%
	Customer	20%
Nonexistent	Customer	95.6%
	Peer	4.4%

Comparing inference results from Basic and Final(R=60) with AT&T internal information