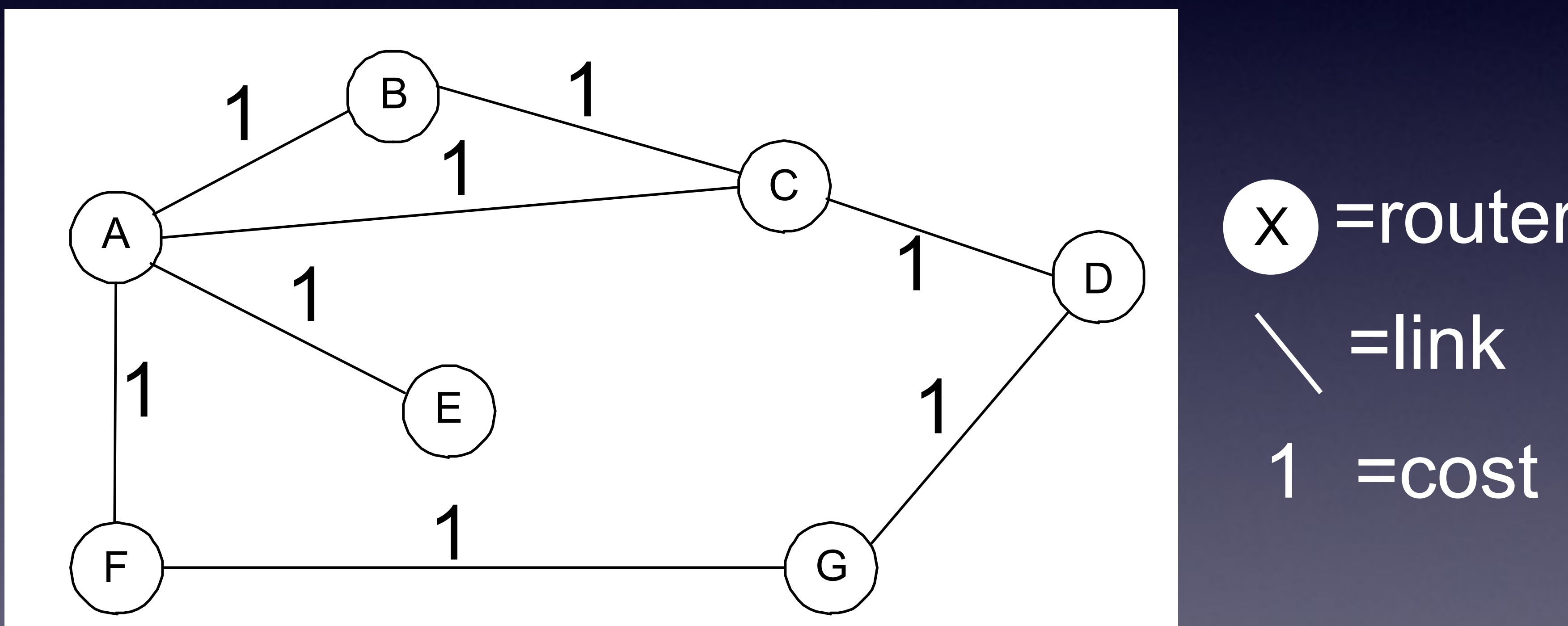
Inter-domain Routing

Setting

- Start with simpler goal of intra-domain routing
- Routing is the process that all routers go through to calculate the routing tables
  - each router knows how to get to every destination in the network

Network as a Graph

- Routing is essentially a problem in graph theory



Two Approaches

- Link state routing:
  - every node collects a representation of the entire graph and computes shortest paths
  - forwards packets along shortest paths to destination
- Distance vector routing:
  - each node knows only about its next hop links
  - each node maintains a vector of costs to all dests
  - periodically exchange with neighbors its routing table

- What are the issues that we have to take into account as we generalize this to a routing protocol for the Internet?

    - What should be the goals of an ideal routing protocol for the Internet?

Setting

- BGP is the "inter-domain" routing protocol
  - Each "domain" is a separately administered entity
  - Also referred to as "autonomous systems" (ASes)
  - Each AS might have multiple prefixes (a contiguous set of addresses, e.g., MIT has 18.*.*.* and UW is 128.208.*.*)
- Routers route packets based on "longest prefix match"
  - Routing table contains the next hop based on a prefix basis
  - Find the best prefix match and route using it
  - What are the implications of using "longest prefix matching"?

Business Relationships

- Neighboring ASes have business contracts
  - How much traffic to carry
  - Which destinations to reach
  - How much money to pay
- Common business relationships
  - Customer-provider
  - Peer-peer
  - Sibling

Customer-Provider Relationship

- Customer needs to be reachable from everyone
  - Provider ensures all neighbors can reach the customer
- Customer needs to reach everyone
- Payments in both directions
- Typically “95th percentile billing”

Peer-Peer relationship

- Peers exchange traffic between customers
  - AS lets its peer reach (only) its customers
  - Often the relationship is settlement-free (i.e., no $$$)

AS Structure

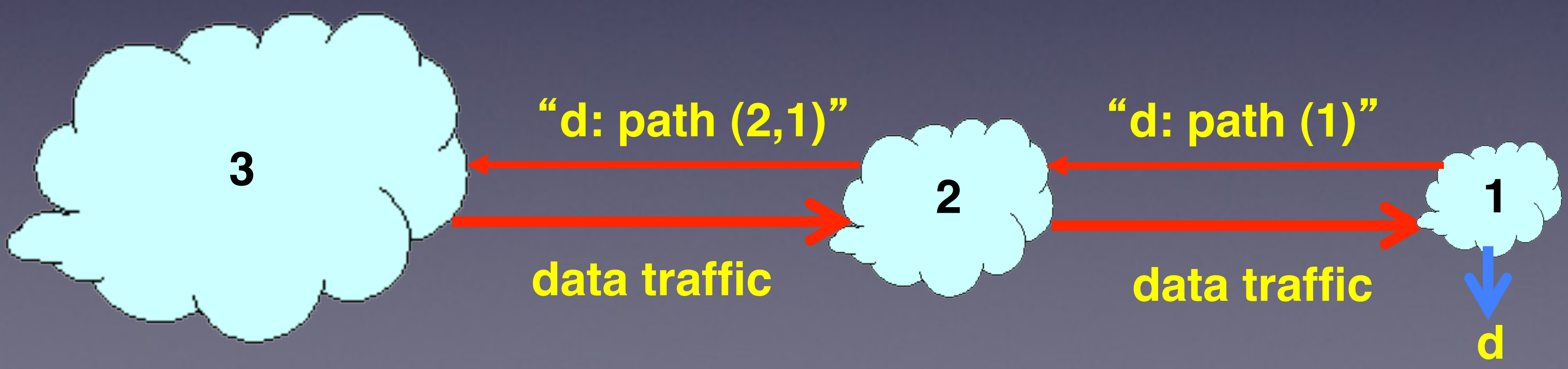
- Top of the Internet hierarchy
  - Has no upstream provider of its own
  - Typically has a large (inter)national backbone
  - Around 10-12 ASes: AT&T, Sprint, Level 3, …
- Lower-layer providers (tier-2, …)
  - Provide transit service to downstream customers
  - But need at least one provider of their own
- Stub ASes
  - Do not provide transit service
  - Connect to upstream provider(s)

What is BGP?

- Policy-based path vector routing
  - Path vector: a path of ASes
  - Respect the policies (customer-provider, peer-to-peer, etc.)
    - mechanism for filtering and selecting paths
    - at import and export time

Path-Vector Routing

- Extension of distance-vector routing
  - Support flexible routing policies
  - Faster convergence (avoid count-to-infinity)
- Key idea: advertise the entire path
  - Distance vector: send distance metric per dest d
  - Path vector: send the entire path for each dest d



- How powerful is the framework? How would you use import/export policies to influence routing?
  - how to implement provider-customer relationships?
  - how to implement peering relationships?

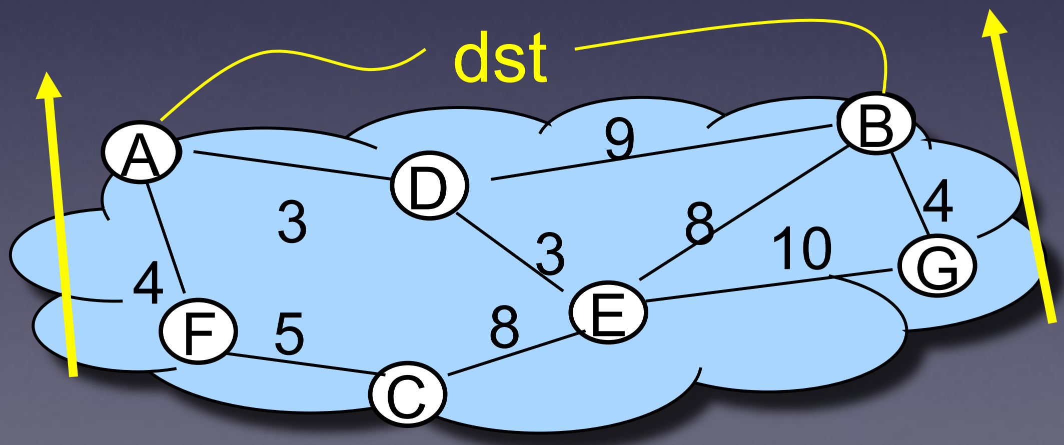
- What are the implications of BGP policy-based routing?

BGP Route Preferences

Priority	Rule	Remarks
1	LOCAL PREF	Highest LOCAL PREF (§4.2.3). *E.g.*, Prefer transit customer routes over peer and provider routes.
2	ASPATH	Shortest ASPATH length (§4.3.5) *Not* shortest number of Internet hops or delay.
3	MED	Lowest MED preferred (§4.3.5). May be ignored, esp. if no financial incentive involved.
4	eBGP > iBGP	Did AS learn route via eBGP (preferred) or iBGP?
5	IGP path	Lowest IGP path cost to next hop (egress router). If all else equal so far, pick shortest internal path.
6	Router ID	Smallest router ID (IP address). A random (but unchanging) choice; some implementations use a different tie-break such as the oldest route.

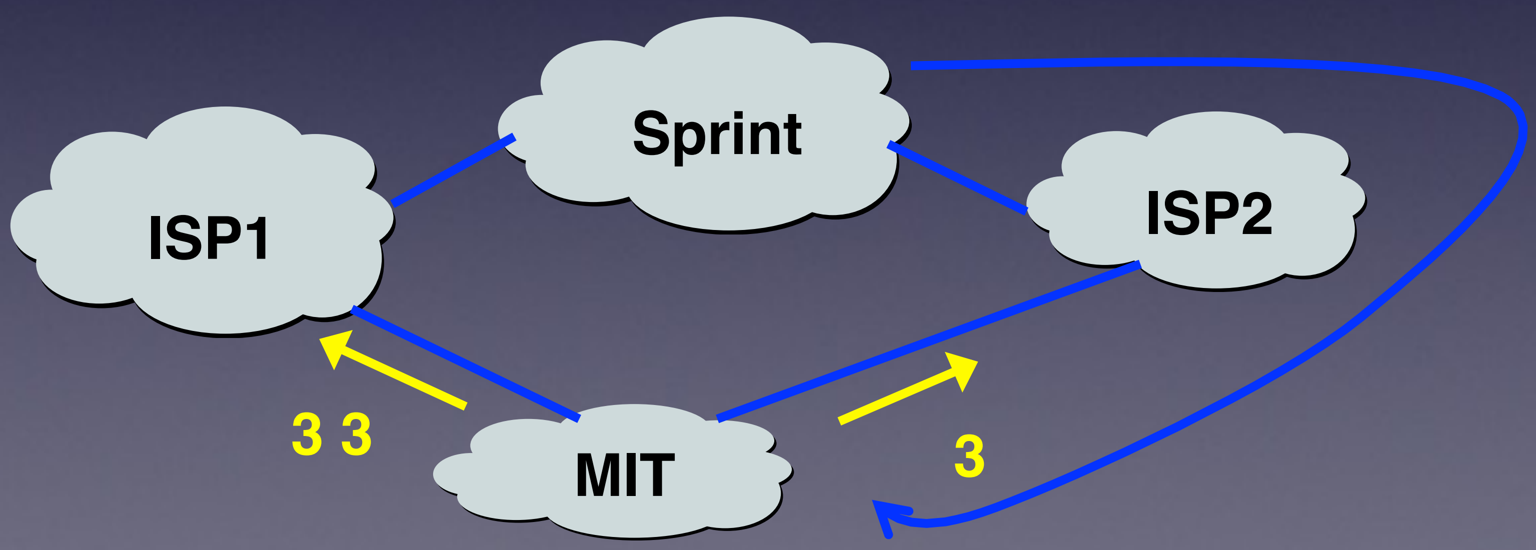
Hot-Potato (Early-Exit) Routing

- Hot-potato routing
  - Each router selects the closest egress point
  - … based on the path cost in intradomain protocol
- BGP decision process
  - Highest local preference
  - Shortest AS path
  - Closest egress point
  - Arbitrary tie break

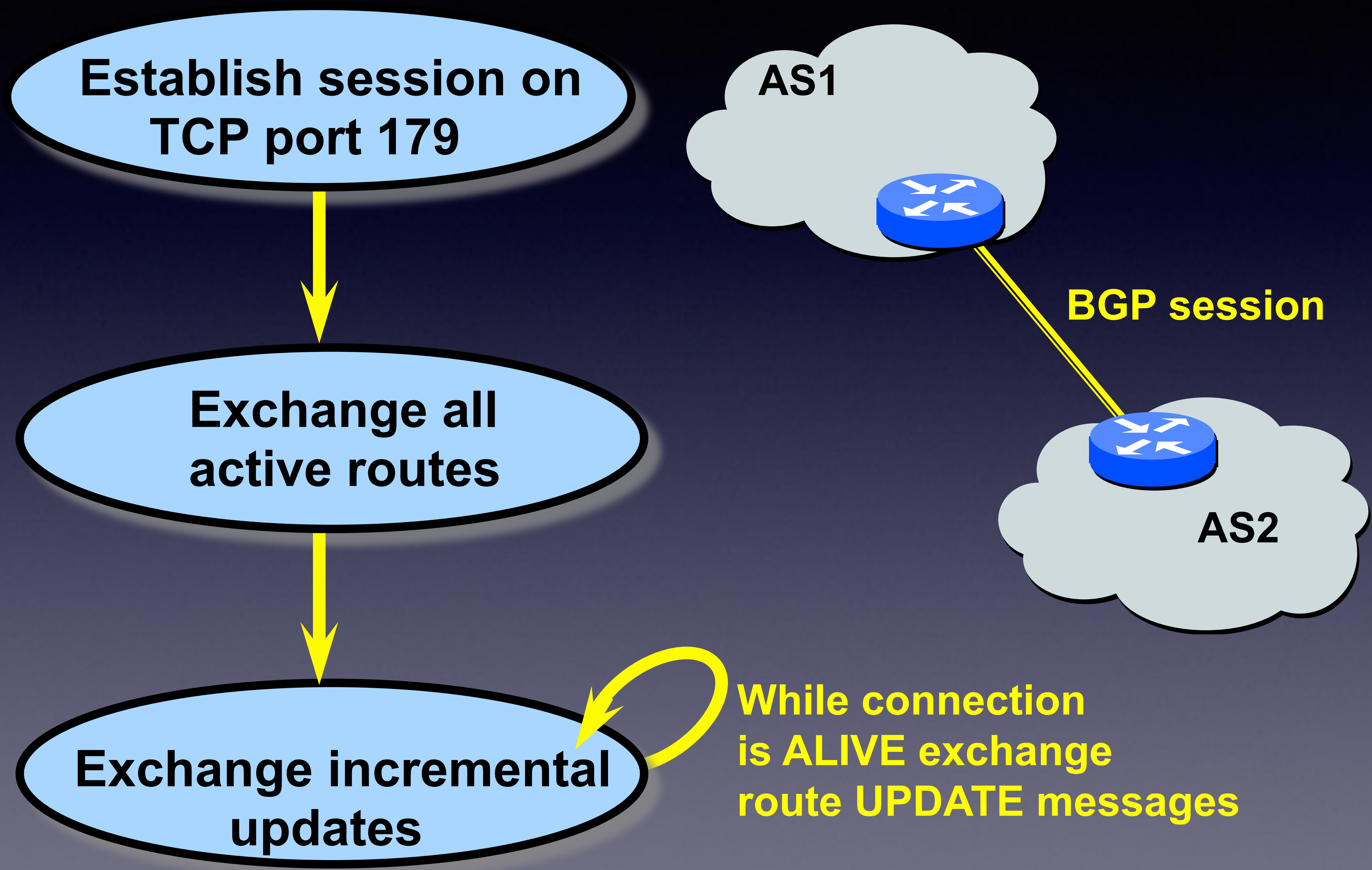


Export Policy

- Modify attributes of the active route
  - To influence the way other ASes behave
  - Example: AS prepending
- Artificially inflate AS path length seen by others
  - Convince some ASes to send traffic another way



BGP Protocol



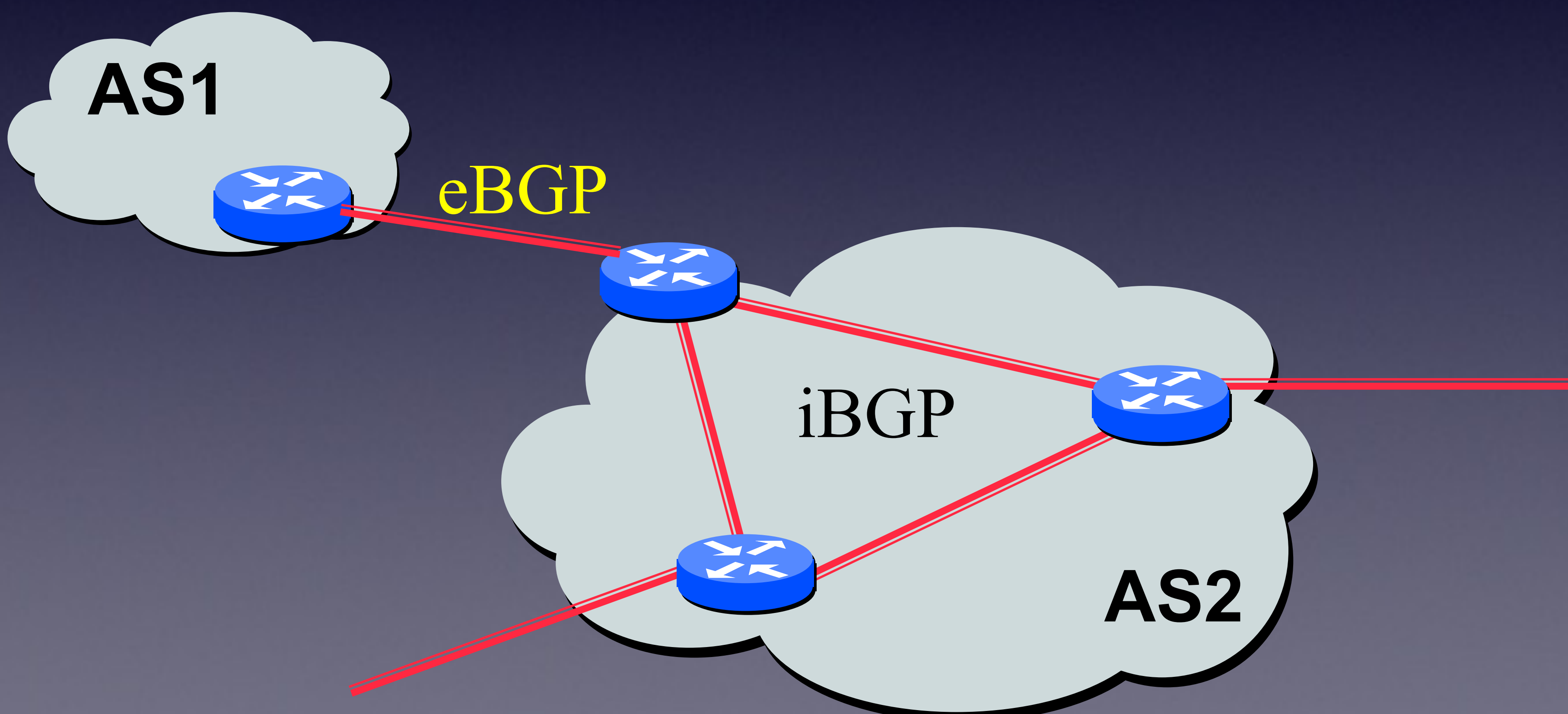
Incremental Protocol

- A node learns multiple paths to destination
  - Applies policy to select a single active route
  - … and may advertise the route to its neighbors
- Incremental updates
  - Announcement
    - Upon selecting a new active route, add node id to path
    - … and (optionally) advertise to each neighbor
  - Withdrawal
    - If the active route is no longer available
    - … send a withdrawal message to the neighbors

- BGP inside an AS
  - Need to propagate BGP paths through the AS
  - Need to interface with intra-domain protocol

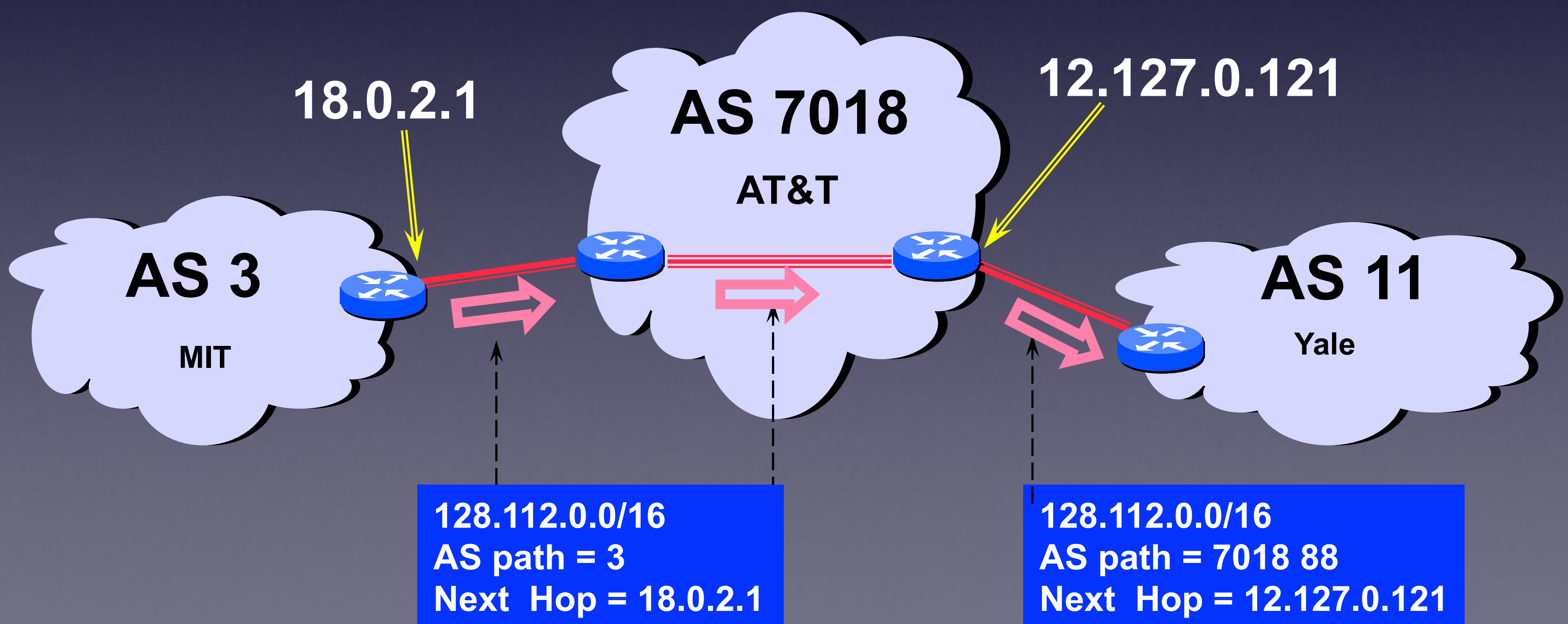
AS is not a single node

- Multiple routers in an AS
  - Need to distribute BGP information within the AS
  - Internal BGP (iBGP) sessions between routers



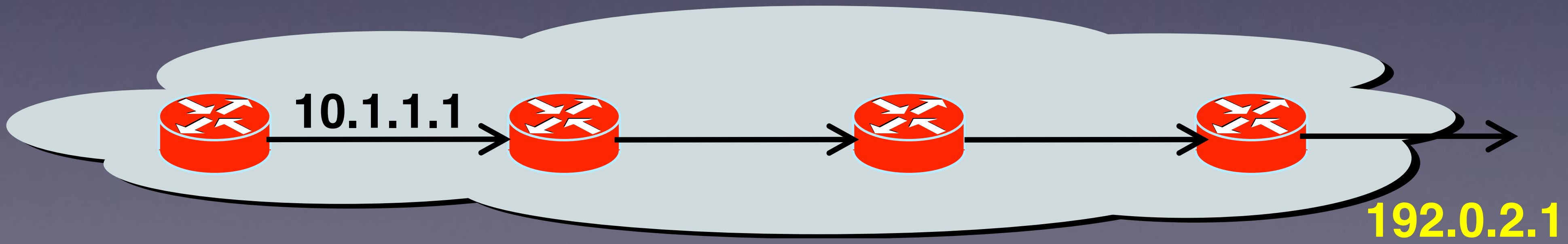
BGP Route

- Destination prefix (e.g., 128.112.0.0/16)
- Route attributes, including
  - AS path (e.g., “7018 88”)
  - Next-hop IP address (e.g., 12.127.0.121)



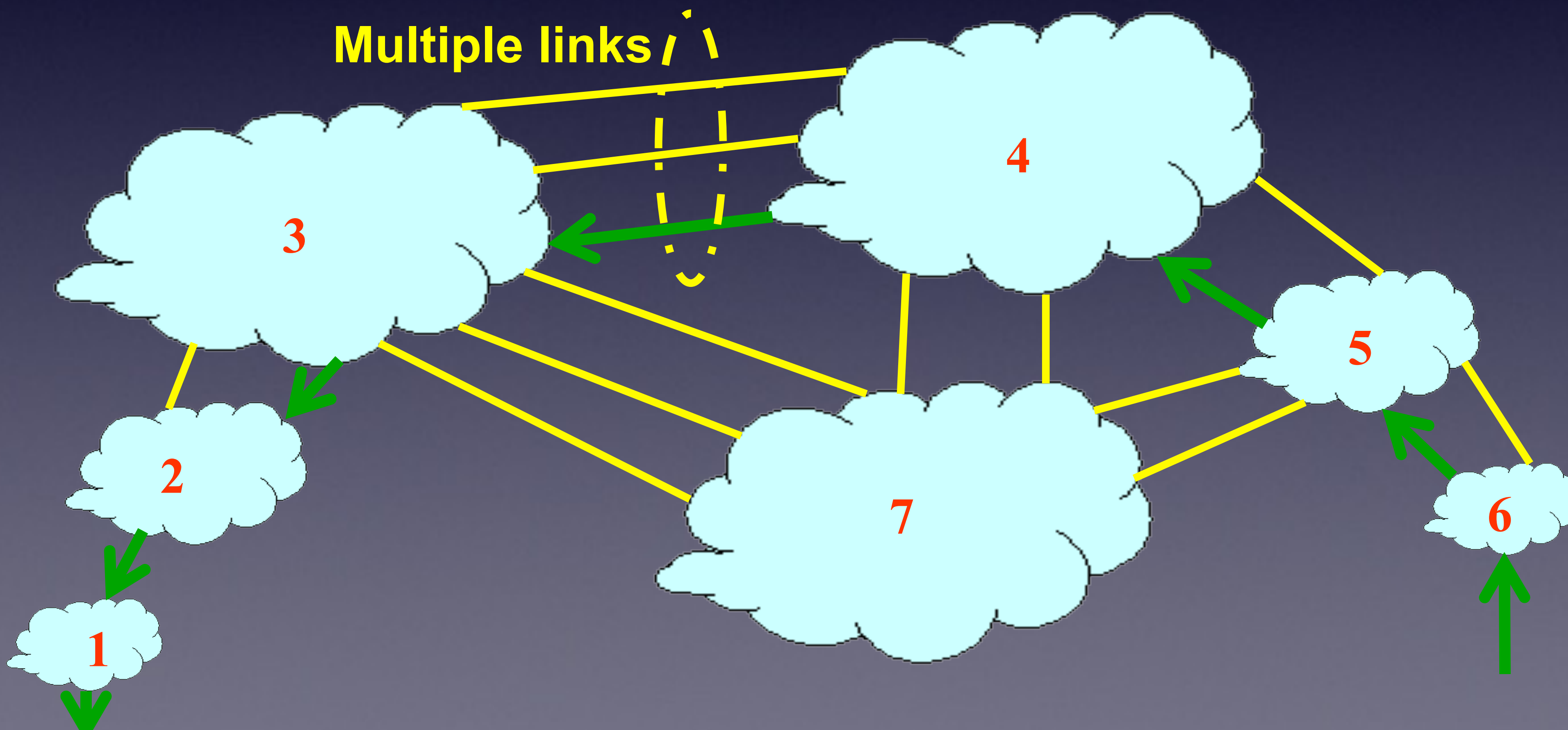
Joining BGP and IGP

- Border Gateway Protocol (BGP)
  - Maps a destination prefix to an egress point
  - 128.112.0.0/16 reached via 192.0.2.1
- Interior Gateway Protocol (IGP)
  - Used to compute paths within the AS
  - Maps an egress point to an outgoing link

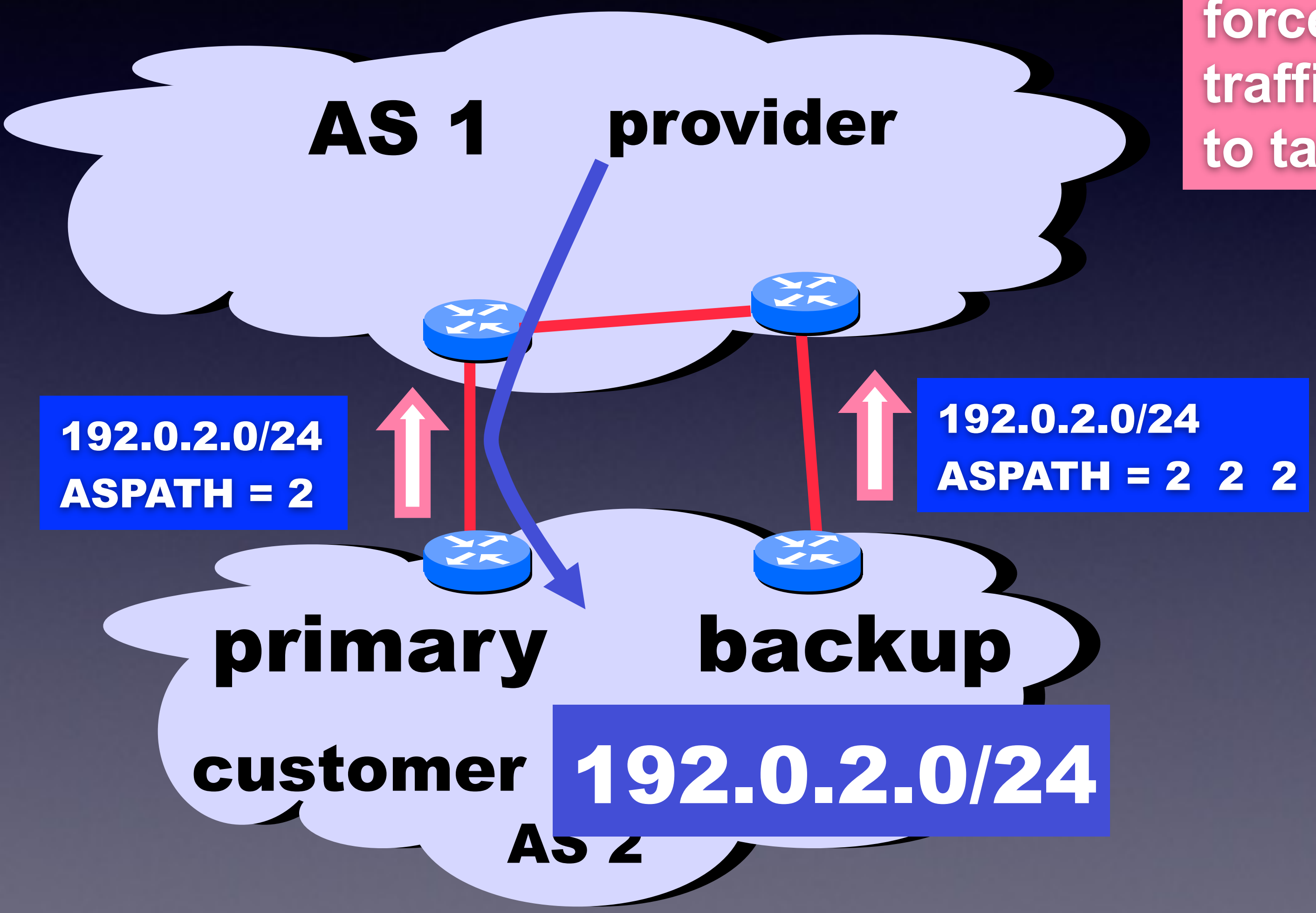


An AS may learn many routes

- Multiple connections to neighboring ASes
  - Multiple border routers may learn good routes
  - … with the same local-pref and AS path length

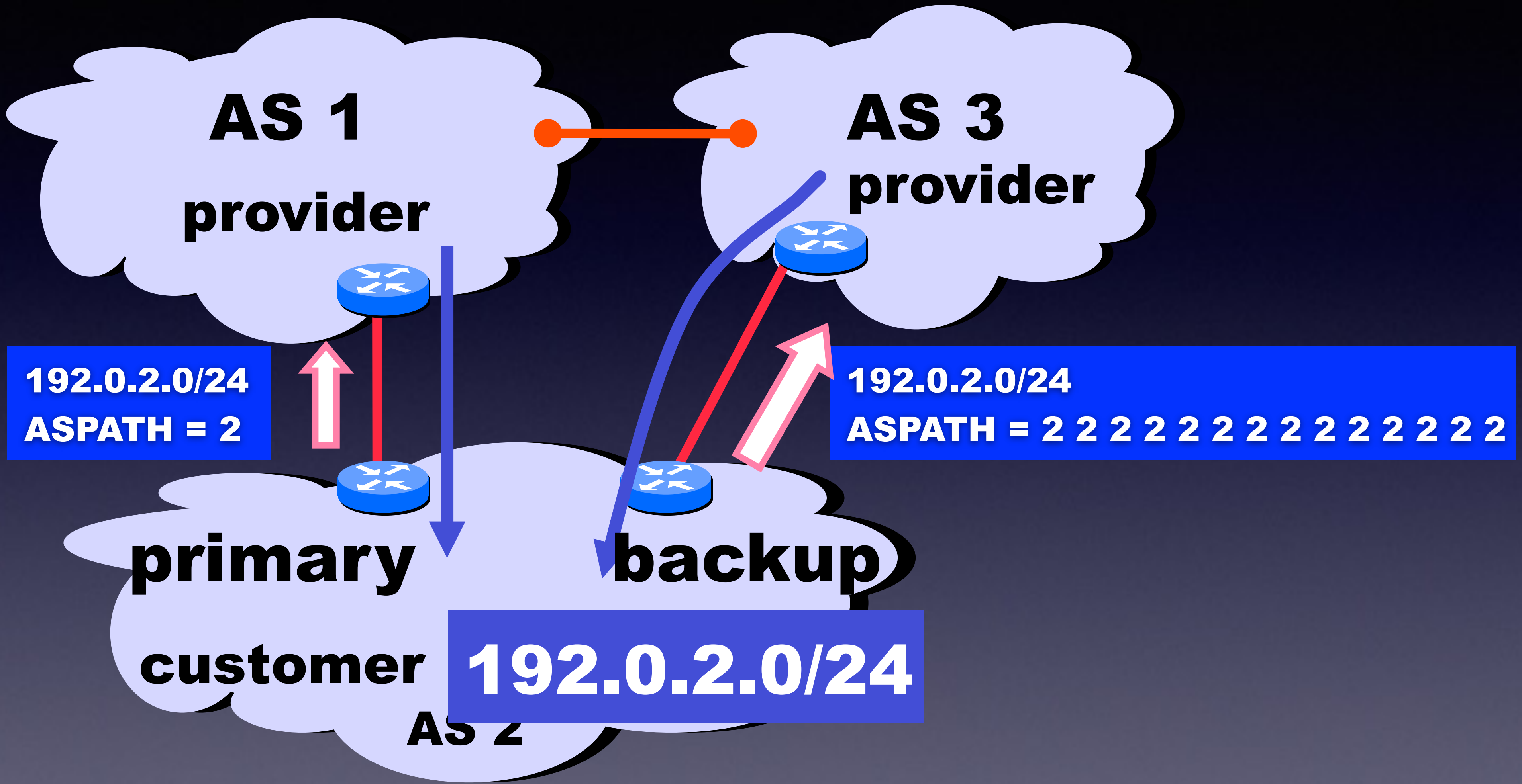


Primary-Backup Paths

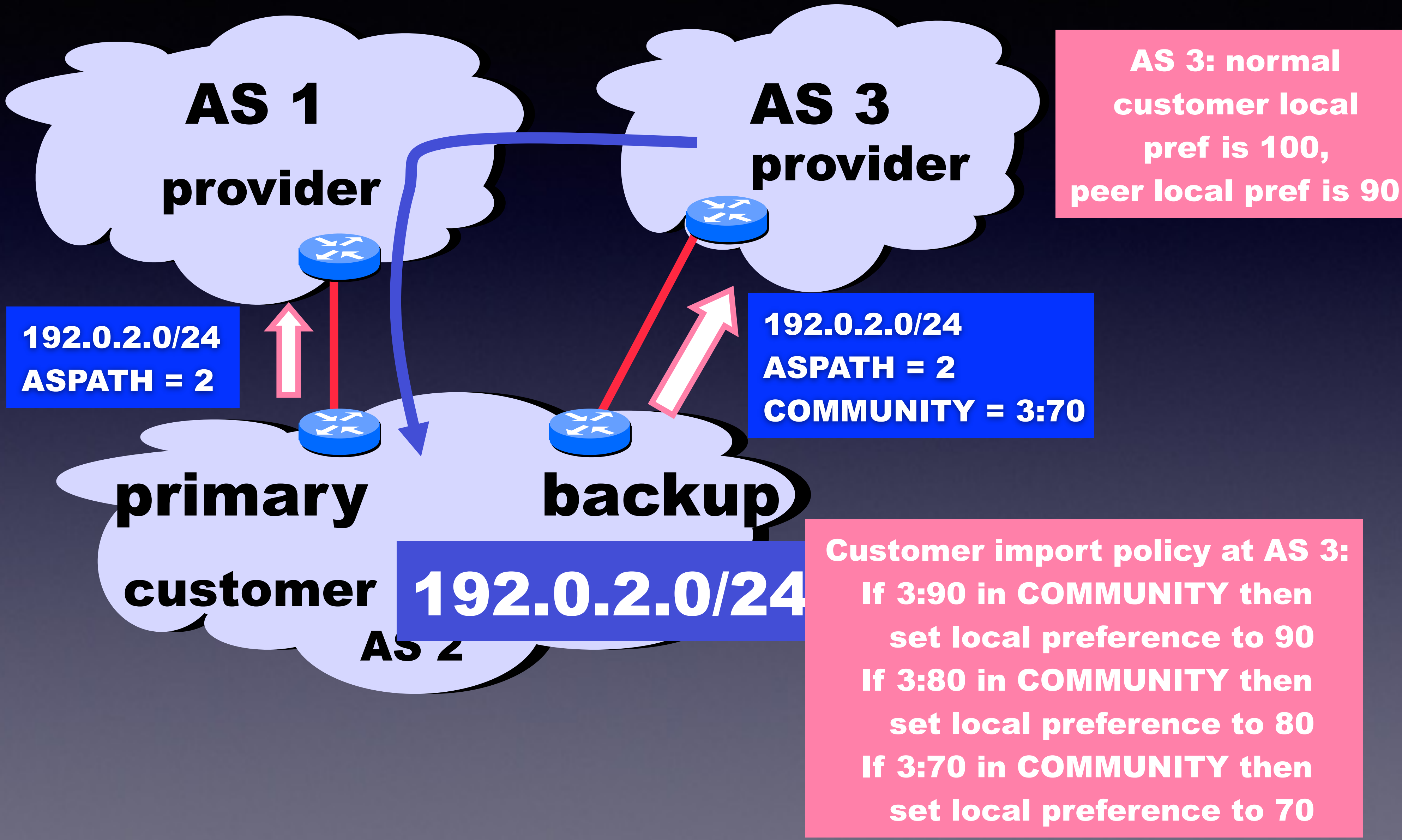


Prepending will (usually) force inbound traffic from AS 1 to take primary link

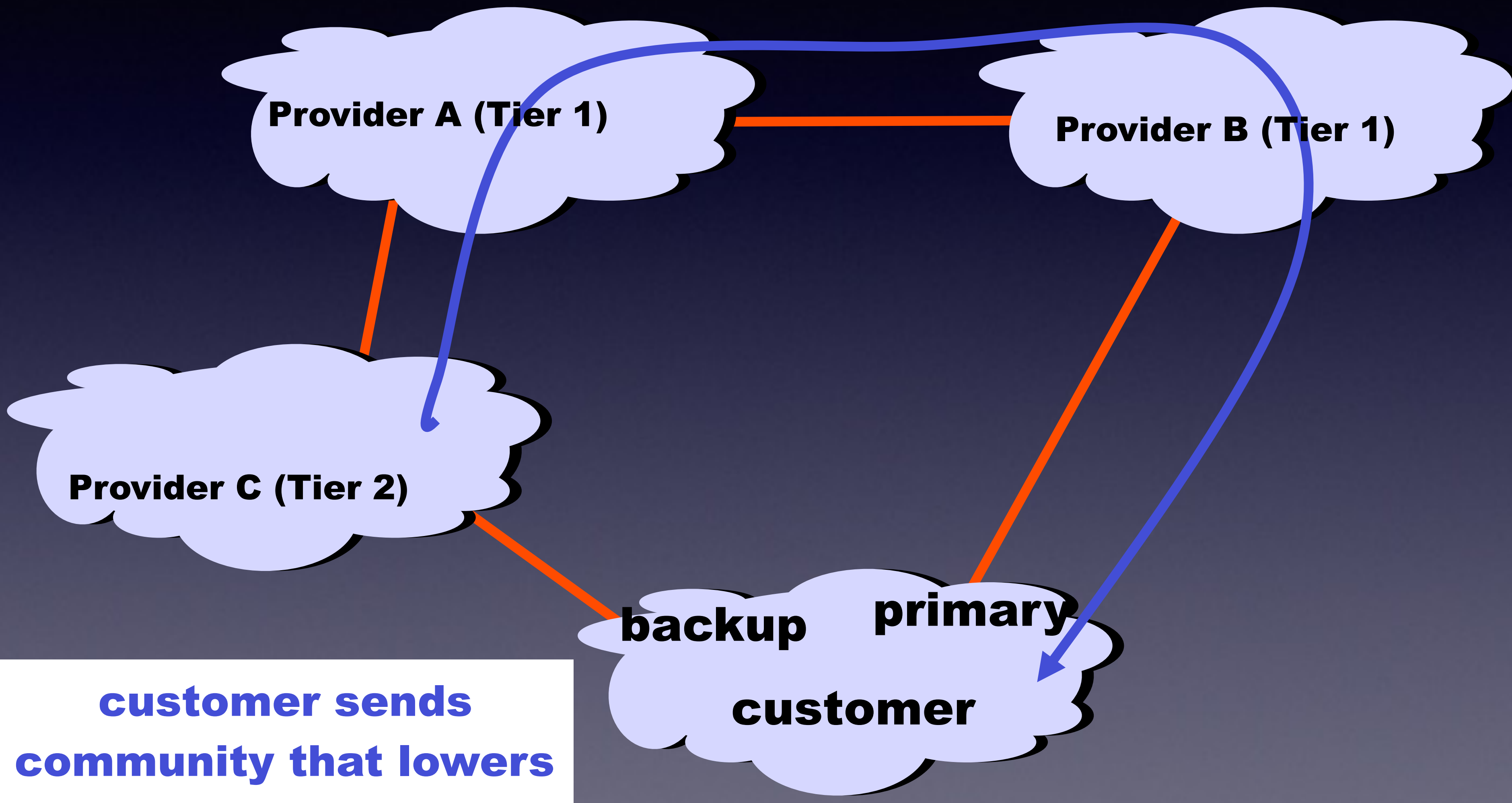
Prepending Doesn't Always Work



BGP Communities

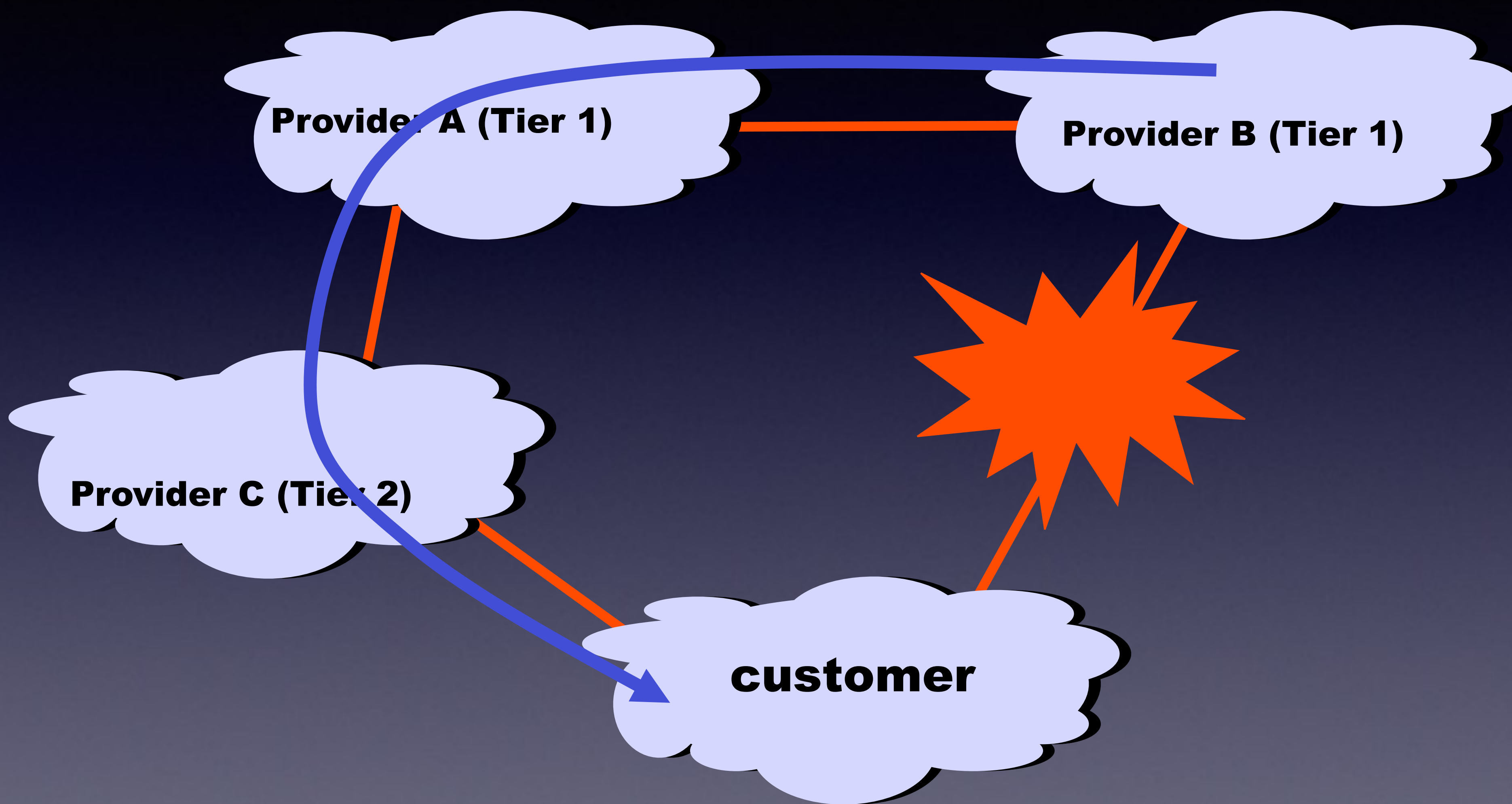


Customer Installs Backup



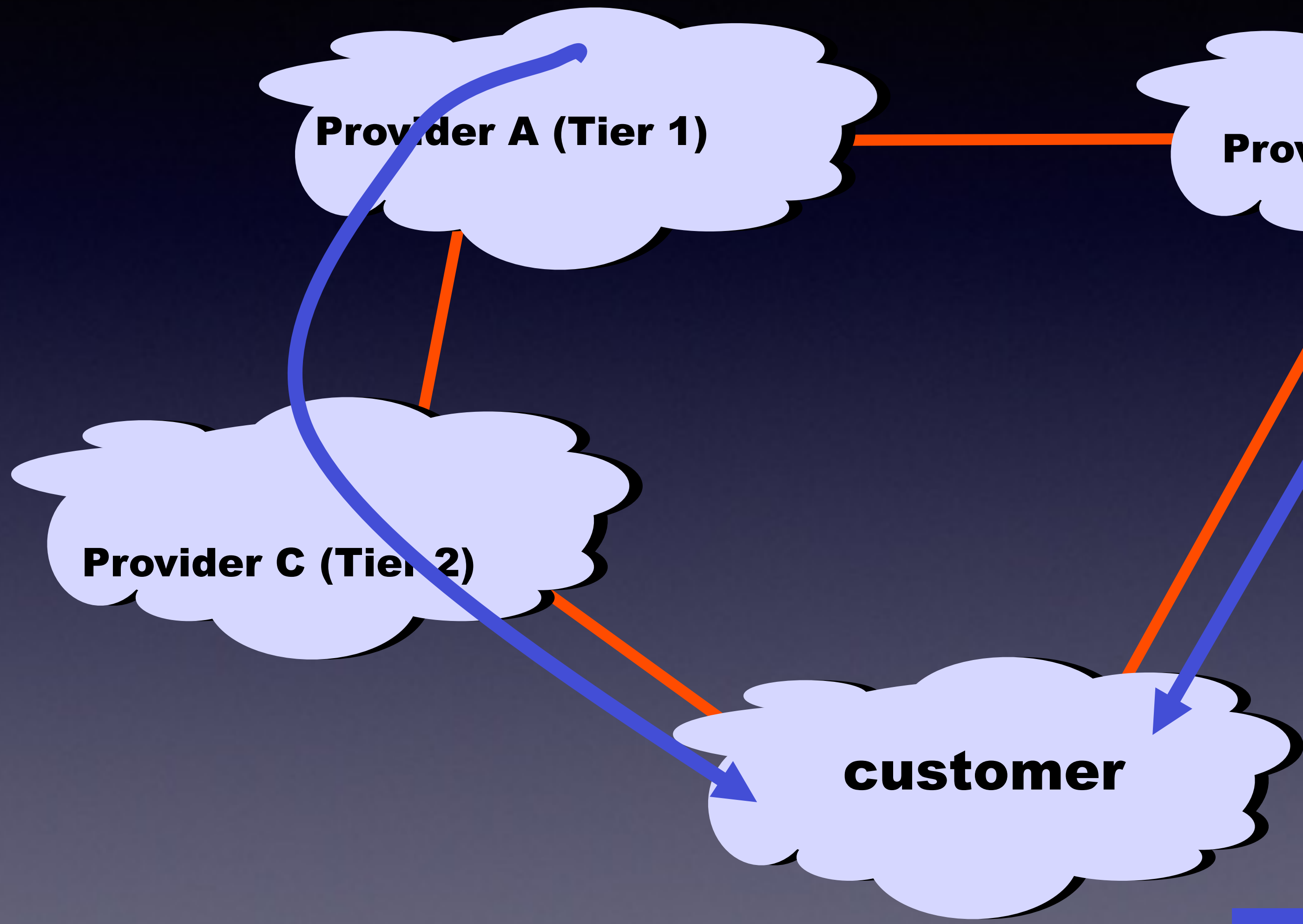
customer sends community that lowers local preference below a provider's

Failure Happens!



customer is happy that backup was installed …

Primary is Repaired...



This is a stable BGP routing!

One "solution" --- reset BGP session on backup link!

- Is BGP secure?
- Is BGP high performant?

Observations

- There is no guarantee that a BGP configuration has a unique routing solution.
  - When multiple solutions exist, the (unpredictable) order of updates will determine which one wins.
- There is no guarantee that a BGP configuration has any solution
- Complex policies (weights, communities setting preferences, and so on) increase chances of routing anomalies.