15-441 15-641 Computer Networking

Inter-Domain Routing

Border Gateway Protocol -BGP

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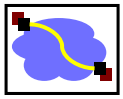
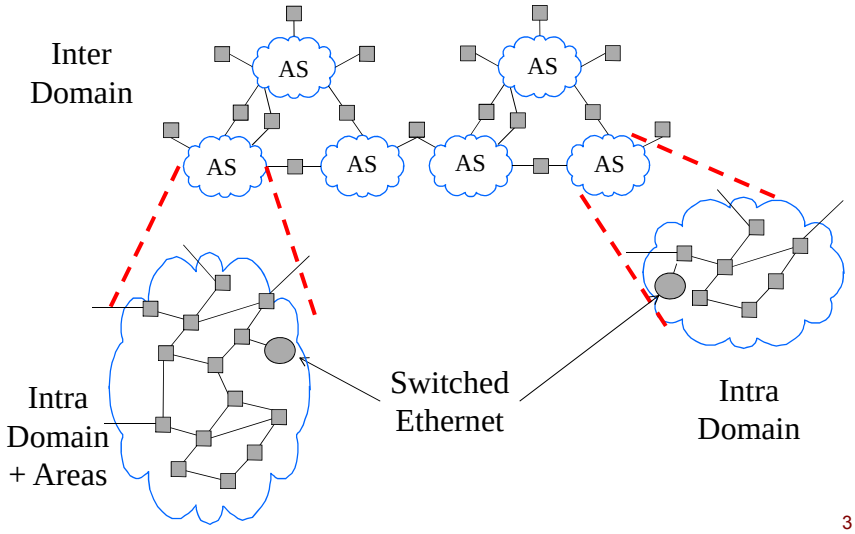
www.cs.cmu.edu/~prs/15-441-F15

Outline



- Routing hierarchy
- Internet structure
- External BGP (E-BGP)
- Internal BGP (I-BGP)

Inter and Intra-Domain Routing



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Internet's Area Hierarchy

- What is an Autonomous System (AS)?
  - A set of routers under a single technical administration, using an *interior gateway protocol (IGP)* and common metrics to route packets within the AS and using an *exterior gateway protocol (EGP)* to route packets to other AS's
- Each AS assigned unique ID
  - Only transit domains really need it
- ASes peer with other ASes at network exchanges
  - "Gateway routers" forward packets across ASes

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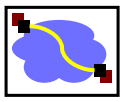
AS Numbers (ASNs)



ASNs are 16 bit values 64512 through 65535 are “private”

- Genuity: 1
- MIT: 3
- CMU: 9
- UC San Diego: 7377
- AT&T: 7018, 6341, 5074, …
- UUNET: 701, 702, 284, 12199, …
- Sprint: 1239, 1240, 6211, 6242, …
- …

ASNs represent units of routing policy

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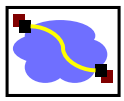
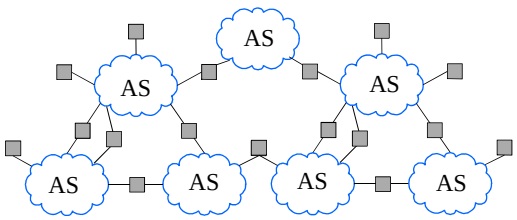
A Logical View of the Internet?





- Logical consequency of hierarchy: repeat the intra-domain connectivity at inter-net level
  - Based on IP and OSPF style routing protocols
- NOT TRUE!
  - Lots of problems with this picture

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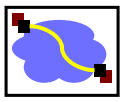
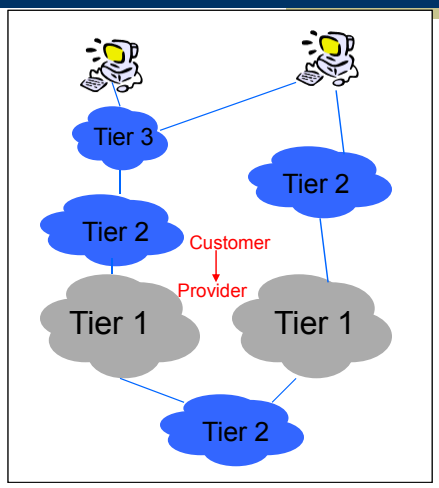
A Logical View of the Internet



- ASes play different roles in the Internet
- Tier 1 ISP: gobal, internet wide connectivity
- Tier 2 ISP: regional or country-wide
- Tier 3 ISP: local
- Emergent property:
  - Businesses specialize
  - Business relationships



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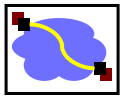
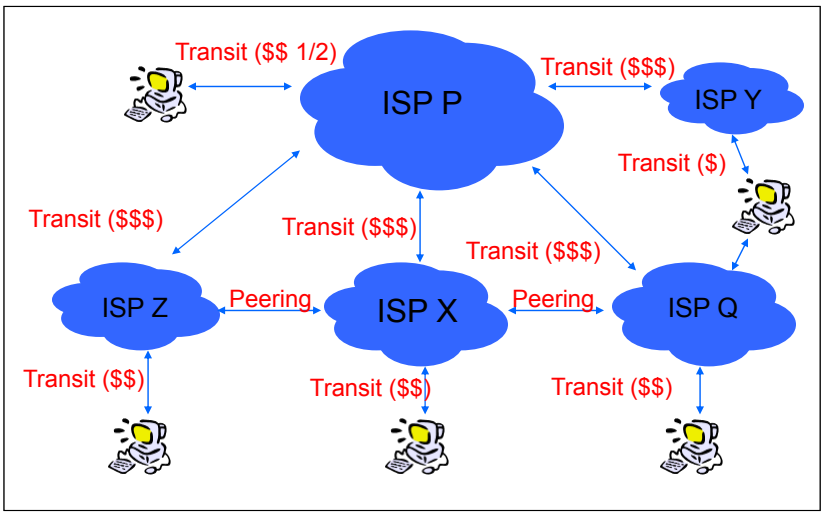
A More Interesting Example





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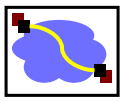
Policy Rules



- WHY?
  - Consider the economics of the Internet
  - Why does an ISP forward packets?
- Emergent property: “Valley-free” routing
  - Number links as (+1, 0, -1) for provider, peer and customer
  - In any path should only see sequence of +1, followed by at most one 0, followed by sequence of -1

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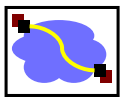
Outline



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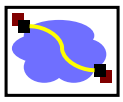
History



- Mid-80s: EGP
  - Reachability protocol (no shortest path)
  - Did not accommodate cycles (tree topology)
  - Evolved when all networks connected to NSF backbone
- Commercialization led to richer topologies – Result: BGP introduced as routing protocol
  - Latest version is BGP-4 - supports CIDR
  - Primary objective:
    - Connectivity not performance
    - Respect business relationships
    - Allow for local policies in each AS

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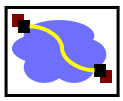
Choices



- Link state or distance vector?
  - Constraint: No universal metric – policy decisions
- Problems with distance-vector:
  - Bellman-Ford algorithm may converge slowly
  - Problems with “count to infinity”
- Problems with link state:
  - Metric used by routers not the same – loops
  - LS database too large – entire Internet
  - May expose policies to other AS’s

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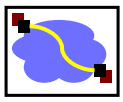
Solution: Distance Vector with Path



- Each routing update carries the entire path
- Loops are detected as follows:
  - When AS gets route, check if AS already in path
    - If yes, reject route
    - If no, add self and (possibly) advertise route further
- Advantage:
  - Metrics are local - AS chooses path, protocol ensures no loops

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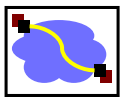
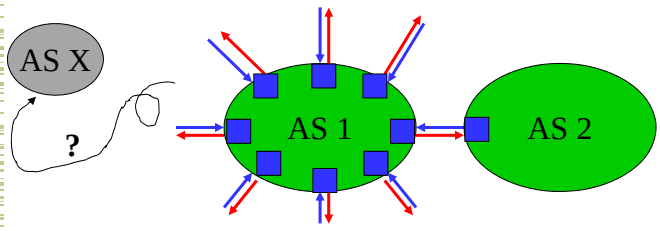
Policy-based Routing: AS 1 to X





1. Receive reachability destination for destination X
   - Select path to X based on local policies
2. Advertise your path to X selectively
   - Use local policies to decide who to advertise it to
- Colors are flipped for AS 2

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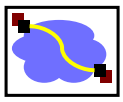
Interconnecting BGP Peers



- BGP uses TCP to connect peers
- Advantages:
  - Simplifies BGP
  - No need for periodic refresh - routes are valid until withdrawn, or the connection is lost
  - Incremental updates
- Disadvantages
  - Congestion control on a routing protocol?
  - Poor interaction with other traffic during high load

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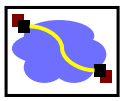
Hop-by-hop Model



- BGP only advertises routes that it uses to its neighbors
- Consistent with the hop-by-hop Internet paradigm
  - e.g., AS1 cannot tell AS2 to route to other AS's in a manner different than what AS2 has chosen
- BGP enforces policies by

1. choosing paths from multiple alternatives and
2. controlling advertisement to other AS's

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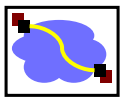
Examples of BGP Policies



- A multi-homed AS refuses to act as transit
  - Limit path advertisement
- A multi-homed AS can become transit for some AS's
  - Only advertise paths to some AS's
- An AS can favor or disfavor certain AS's for traffic transit from itself
  - By choosing those paths among the options

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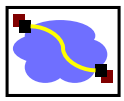
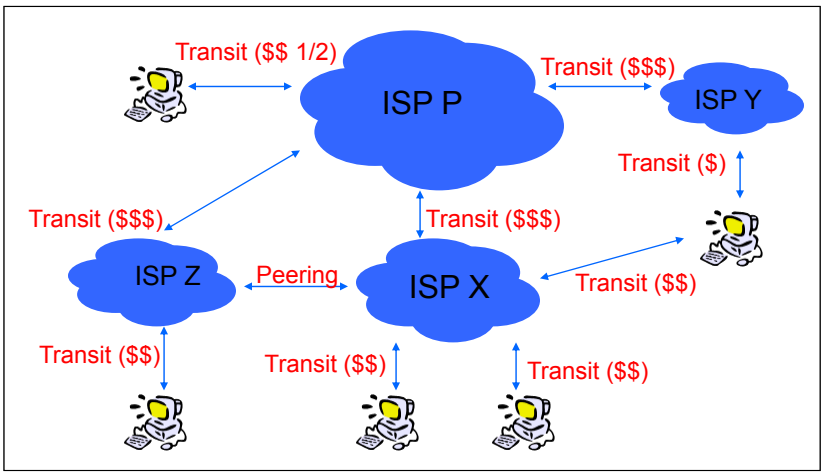
Some Examples





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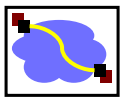
BGP Messages



- Open
  - Announces AS ID
  - Determines hold timer – interval between keep_alive or update messages, zero interval implies no keep_alive
- Keep_alive
  - Sent periodically (but before hold timer expires) to peers to ensure connectivity.
  - Sent in place of an UPDATE message
- Notification
  - Used for error notification
  - TCP connection is closed *immediately* after notification

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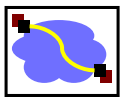
BGP UPDATE Message



- List of withdrawn routes
- Network layer reachability information
  - List of reachable prefixes
- Path attributes
  - Origin
  - Path
  - Metrics: used by policies for path selection
- All prefixes advertised in message have same path attributes

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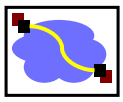
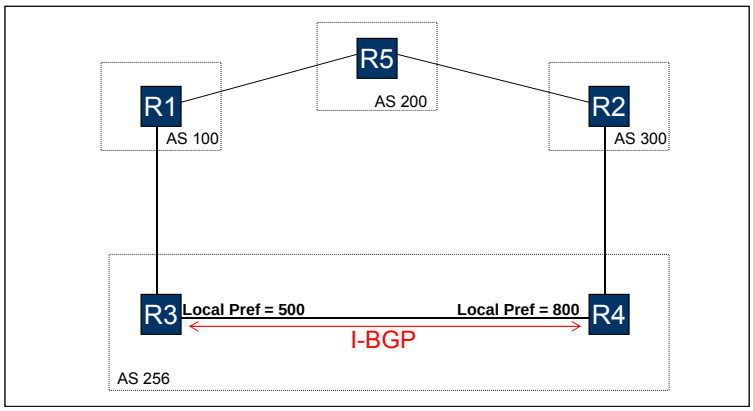
LOCAL PREF



- Local (within an AS) mechanism to provide relative priority among BGP routers (e.g. R3 over R4)



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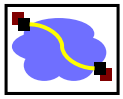
LOCAL PREF – Common Uses



- Routers have a default LOCAL PREF
  - Can be changed for specific ASes
- Peering vs. transit
  - Prefer to use peering connection, why?
- In general, customer > peer > provider
  - Use LOCAL PREF to ensure this

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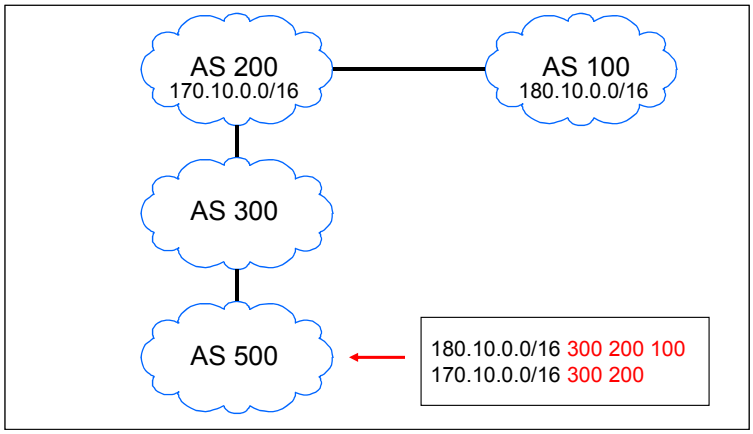
AS_PATH

- List of traversed AS's



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Multi-Exit Discriminator (MED)

- Hint to external neighbors about the preferred path into an AS
  - Non-transitive attribute
    - Different AS choose different scales
- Used when two AS's connect to each other in more than one place

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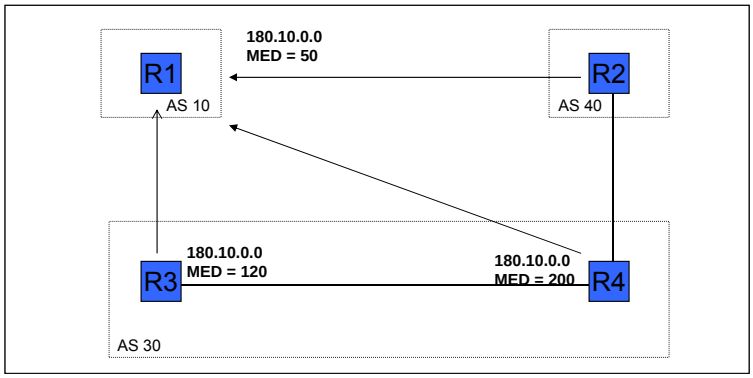
MED

- Hint to R1 to use R3 over R4 link
- Cannot compare AS40's values to AS30's



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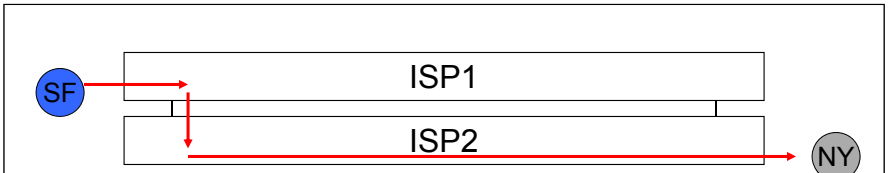
MED

- MED is typically used in provider/subscriber scenarios
- It can lead to unfairness if used between ISP because it may force one ISP to carry more traffic:



- ISP1 ignores MED from ISP2
- ISP2 obeys MED from ISP1
- ISP2 ends up carrying traffic most of the way

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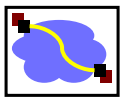
Path Selection Criteria



- Attributes + external (policy) information
- Rough ordering for path selection
  - Highest LOCAL-PREF
    - Captures business relationships and other factors
  - Shortest AS-PATH
  - Lowest origin type
  - Lowest MED (if routes learned from same neighbor)
  - eBGP over iBGP-learned
  - Lowest internal routing cost to border router
  - Tie breaker, e.g., lowest router ID

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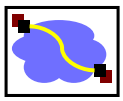
Outline



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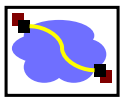
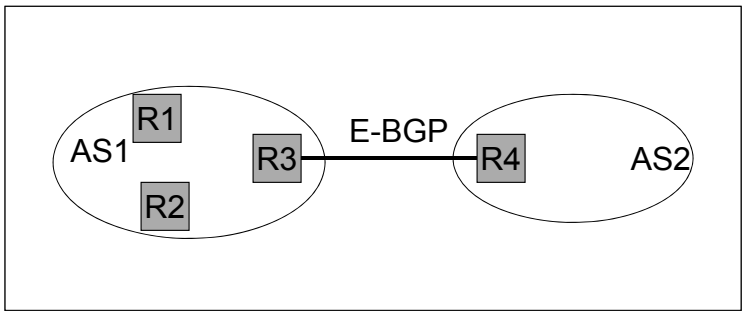
Internal vs. External BGP



- BGP can be used by R3 and R4 to learn routes
- How do R1 and R2 learn routes?
- Border gateways also need to run an internal routing protcol
  - Establish connectivity between routers inside AS
- I-BGP: uses same messages as E-BGP



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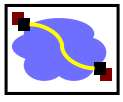
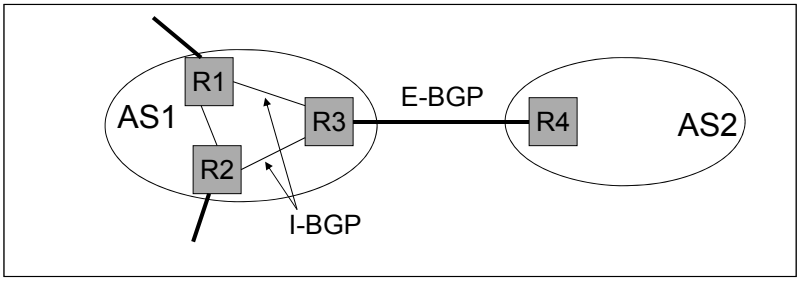
I-BGP Route Advertisements



- I-BGP uses different rules about re-advertising prefixes:
  - Prefix learned from E-BGP can be advertised to I-BGP neighbor and vice-versa, but
  - Prefix learned from I-BGP neighbors cannot be advertised to other I-BGP neighbors → direct connections (TCP) for I-BGP routers
  - Reason: AS PATH is the same AS and thus danger of looping.



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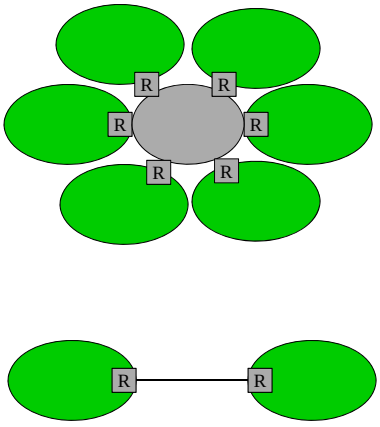
How Do ISPs Peer?



- Public peering: use network to connect large number of ISPs in Internet eXchange Point (IXP)
  - Managed by IXP operator
  - Layer 2 private network
  - Efficient: can have 100s of ISPs
  - Has led to increase in peering
- Private peering: directly connect ISP border router
  - Set up as private connection
  - Typically done in an Internet eXchange Point (IXP)

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Important Concepts

- Wide area Internet structure and routing driven by economic considerations
  - Customer, providers and peers
- BGP designed to:
  - Provide hierarchy that allows scalability
  - Allow enforcement of policies related to structure
- Mechanisms
  - Path vector – scalable, hides structure from neighbors, detects loops quickly

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