Interdomain Routing

Reading: Sections P&D 4.3.{3,4}

EE122: Intro to Communication Networks

Fall 2006 (MW 4:00-5:30 in Donner 155)

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http://inst.eecs.berkeley.edu/~ee122/

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Outline

- Why does BGP exist?
  - What is interdomain routing and why do we need it?
  - Why does BGP look the way it does?
- How does BGP work?
  - Boring details
  - Yuck

pay more attention to the "why" than the "how"

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Routing

- Provides paths between networks
- Previous lecture presented two routing designs
  - link-state
  - distance vector
- Previous lecture assumed single domain
  - all routers have same routing metric (shortest path)
  - no privacy issues, no policy issues

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Internet is more complicated.....

- Internet not just unstructured collection of networks
- Internet is comprised of a set of "autonomous systems" (ASes)
  - independently run networks, some are commercial ISPs
  - currently around 20,000 ASes
- ASes are sometimes called "domains"
  - hence "interdomain routing"

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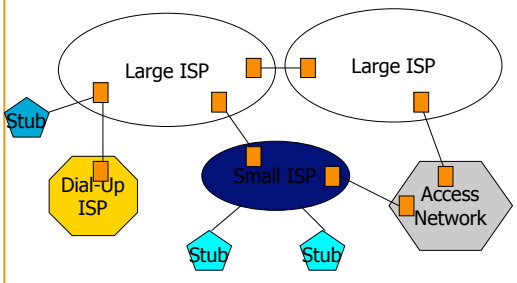
Internet: a large number of ASes



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This adds another level in hierarchy

- Three levels in logical routing hierarchy
  - networks: reaches individual hosts
  - intradomain: routes between networks
  - interdomain: routes between ASes
- Need a protocol to route between domains
  - BGP is current standard
- Different kinds of unification
  - IP unifies network technologies
  - BGP unifies network organizations

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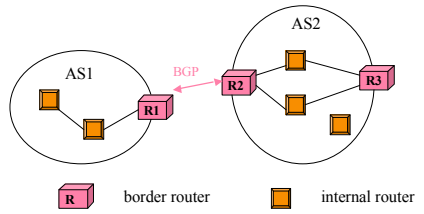
Who speaks BGP?



- Two types of routers
  - Border router (Edge), Internal router (Core)

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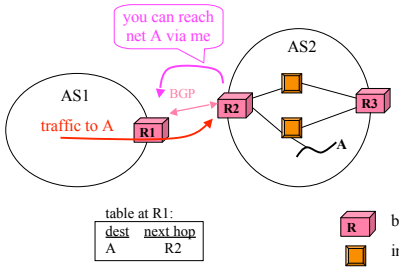
Purpose of BGP



Share connectivity information across ASes

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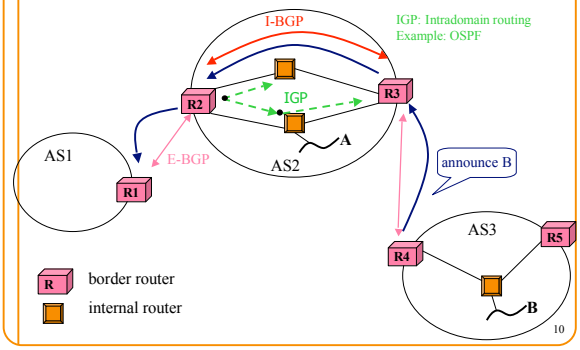
I-BGP and E-BGP



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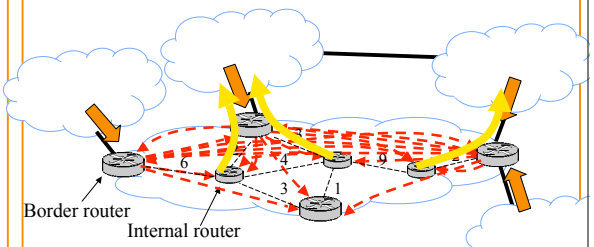
In more detail



1. Provide internal reachability (**IGP**) ------
2. Learn routes to external destinations (**eBGP**)
3. Distribute externally learned routes internally (**iBGP**)
4. Select closest egress (**IGP**) ------

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Rest of lecture...

- Motivate why BGP is the way it is
  - driven by two salient aspects of AS structure
- Discuss some problems with interdomain routing
- Discuss (briefly!) what a new BGP might look like
- Explain some of BGP's details
  - not fundamental, just series of specific design decisions

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#1 ASes are autonomous

- Want to choose their own internal routing protocol
  - different algorithms and metrics
- Want freedom to route based on policy
  - "my traffic can't be carried over my competitor's network"
  - "I don't want to carry transit traffic through my network"
  - not expressible as Internet-wide "shortest path"!
- Want to keep their connections and policies private
  - would reveal business relationships, network structure

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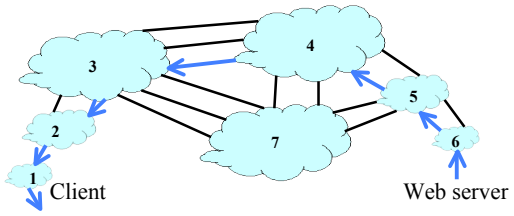
#2 ASes have business relationships

- Three kinds of relationships between ASes
  - AS A can be AS B's *customer*
  - AS A can be AS B's *provider*
  - AS A can be AS B's *peer*
- Business implications
  - customer pays provider
  - peers don't pay each other
- Policy implications
  - "When sending traffic, I prefer to route through customers over peers, and peers over providers"
  - "I don't carry traffic from one provider to another provider"

AS-level topology

- Destinations are IP prefixes (e.g., 12.0.0.0/8)
- Nodes are Autonomous Systems (ASes)
  - internals are hidden
- Links are connections & business relationships



What routing algorithm can we use?

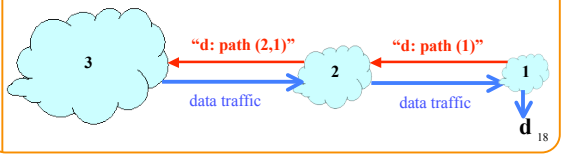
- Key issues are *policy* and *privacy*
- Can't use shortest path
  - domains don't have any shared metric
  - *policy choices might not be shortest path*
- Can't use link state
  - would have to flood policy preferences and topology
  - *would violate privacy*

What about distance vector?

- Does not reveal any connectivity information
- But is designed to compute shortest paths
- Extend distance vector to allow policy choices?

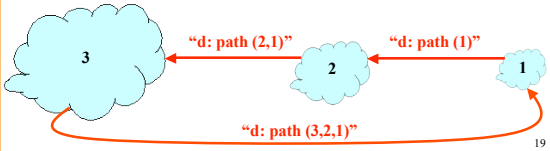
Path-Vector Routing

- Extension of distance-vector routing
  - Support flexible routing policies
  - Faster loop detection (no 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



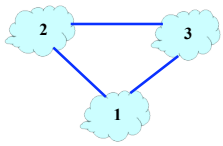
Faster Loop Detection

- Node can easily detect a loop
  - Look for its own node identifier in the path
  - E.g., node 1 sees itself in the path "3, 2, 1"
- Node can simply discard paths with loops
  - E.g., node 1 simply discards the advertisement



Flexible Policies

- Each node can apply local policies
  - Path selection: Which path to use?
  - Path export: Which paths to advertise?
- Examples
  - Node 2 may prefer the path "2, 3, 1" over "2, 1"
  - Node 1 may not let node 3 hear the path "1, 2"



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Selection vs Export

- Selection policies
  - determines which paths I want my traffic to take
- Export policies
  - determines whose traffic I am willing to carry
- Notes:
  - any traffic I carry will follow the same path my traffic takes, so there is a connection between the two
  - from a protocol perspective, decisions can be *arbitrary*
    - can depend on entire path (advantage of PV approach)

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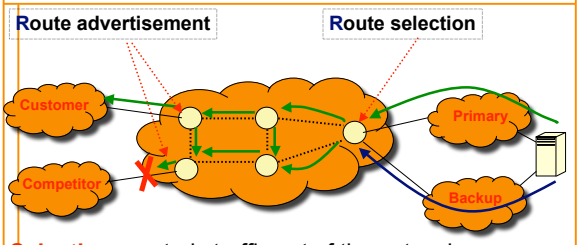
Illustration



Selection: controls traffic out of the network

Export: controls traffic into the network

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Examples of Standard Policies

- Transit network:
  - Selection: prefer customer to peer to provider
  - Export: only export customer's routes to peers
- Multihomed (nontransit) network:
  - Export: Don't export routes for other domains
  - Selection: pick primary over backup

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Any Questions?

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Issues with Path-Vector Policy Routing

- Reachability
- Security
- Performance
- Lack of isolation
- Policy oscillations

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Reachability

- In normal routing, if graph is connected then reachability is assured
- With policy routing, this does not always hold

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Security

- An AS can claim to serve a prefix that they actually don't have a route to (blackholing traffic)
  - problem not specific to policy or path vector
  - important because of AS autonomy
- Fixable: make ASes "prove" they have a path

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Performance

- BGP designed for policy not performance
- "Hot Potato" routing common but suboptimal
  - AS wants to hand off the packet as soon as possible
- 20% of paths inflated by at least 5 router hops
- Not clear this is a significant problem

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Lack of Isolation

- If there is a change in the path, the path must be re-advertised to every node upstream of the change
- Distance-vector provides more isolation

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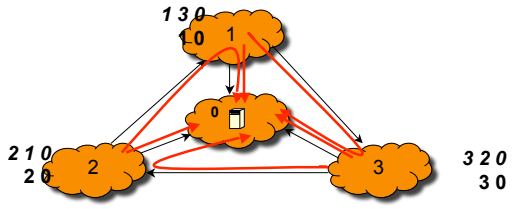
Persistent Oscillations due to Policies

Depends on the interactions of policies



We are back to where we started!

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Policy Oscillations (cont'd)

- Policy autonomy vs network stability
  - focus of much recent research
- If there is no global constraint, then any degree of autonomy can lead to oscillations
  - only "shortest path" is guaranteed to be stable
- However, if policies follow normal business practices, stability is guaranteed
  - lack of cycles in business graph a global constraint

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Redesigning BGP

- If we keep all the current constraints, not many alternative design options (at high-level)
  - Which constraints might we lift?
- Are most policies really private?
  - could use link-state for some of the routing
- Do ASes really need to see the entire path?
  - could hide some of the path, reducing updates
- Can AS structure be integrated into addressing?

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Any Questions?

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Rest of lecture....

- BGP details
- Stay awake as long as you can.....

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Border Gateway Protocol (BGP)

- Interdomain routing protocol for the Internet
  - Prefix-based path-vector protocol
  - Policy-based routing based on AS Paths
  - Evolved during the past 15 years

- **1989 : BGP-1 [RFC 1105]**
  - **Replacement for EGP (1984, RFC 904)**
- **1990 : BGP-2 [RFC 1163]**
- **1991 : BGP-3 [RFC 1267]**
- **1995 : BGP-4 [RFC 1771]**
  - **Support for Classless Interdomain Routing (CIDR)**

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BGP Routing Table

```
ner-routes>show ip bgp
BGP table version is 6128791, local router ID is 4.2.34.165
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete
   Network          Next Hop            Metric LocPrf Weight Path
* i3.0.0.0         4.0.6.142                1000     50      0 701 80 i
* i4.0.0.0         4.24.1.35                   0    100      0 i
* i12.3.21.0/23    192.205.32.153              0     50      0 7018 4264 6468 ?
* e128.32.0.0/16   192.205.32.153              0     50      0 7018 4264 6468 25 e
```

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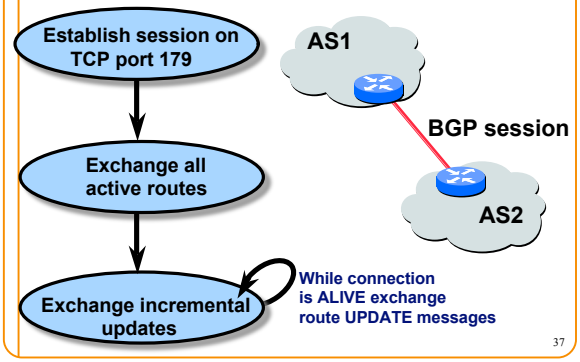
BGP Operations



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Incremental Protocol

- A node learns multiple paths to destination
  - Stores all of the routes in a routing table
  - 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

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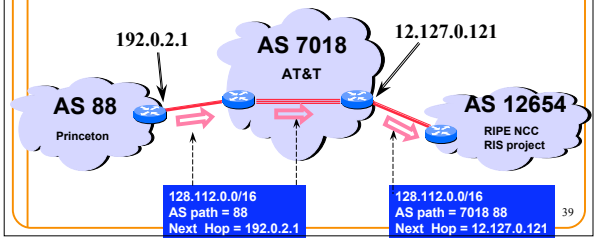
BGP Route

- Destination prefix (e.g,. 128.112.0.0/16)
- Routes have attributes, including
  - AS path (e.g., "7018 88")
  - Next-hop IP address (e.g., 12.127.0.121)



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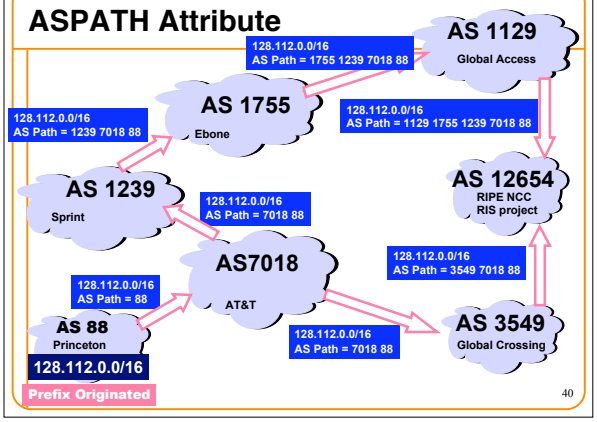
ASPATH Attribute



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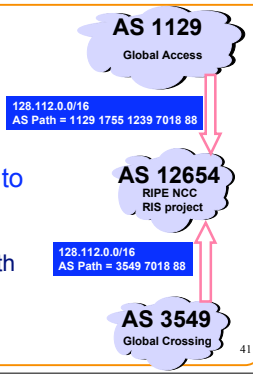
BGP Path Selection

- Simplest case
  - Shortest AS path
  - Arbitrary tie break
  - AS 12654 prefers path through Global Crossing
- But, BGP is not limited to shortest-path routing
  - Policy-based routing
  - Could choose longer path



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Other Routing Attributes

- Origin, MED, Local Preference,....
- Origin:
  - Who originated the announcement?
  - Where was a prefix *injected* into BGP?
  - IGP, BGP or Incomplete (often used for static routes)

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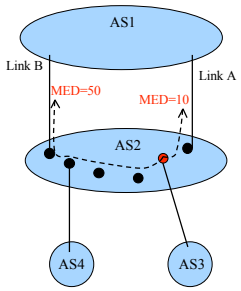
Multi-Exit Discriminator (MED)

- When ASes interconnected via 2 or more links
- AS announcing prefix sets MED (AS2 in picture)
- AS receiving prefix uses MED to select link
- A way to specify how close a prefix is to the link it is announced on



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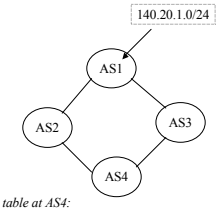
Local Preference

Policy choice between different AS paths

The higher the value the more preferred

Carried by IBGP, local to the AS.



BGP table at AS4:

Destination	AS Path	Local Pref
140.20.1.0/24	AS3 AS1	300
140.20.1.0/24	AS2 AS1	100

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Choosing Best Route (simplified)

- Choose AS path with highest LOCAL_PREF
  - Preference-based routing
  - Tie: select route with shortest hop-count
- Multiple egress choices for same neighboring AS:
  - choose path with min MED value
- Among IGP paths, choose one with lowest cost
  - Finally use router ID to break the tie.

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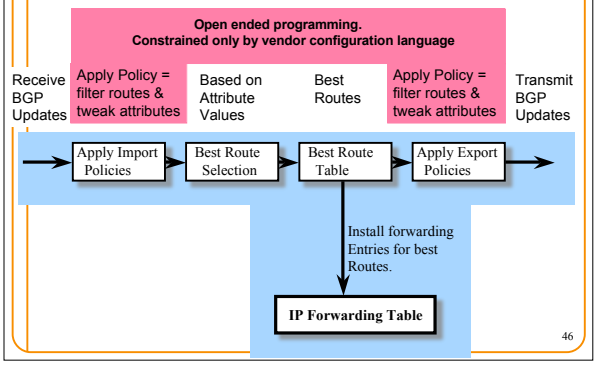
BGP Route Processing



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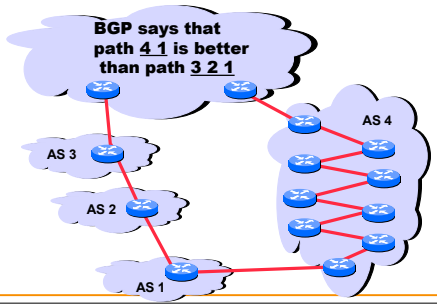
AS is Not a Single Node

- AS path length can be misleading
  - An AS may have many router-level hops



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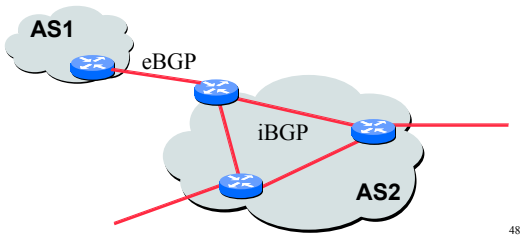
An AS is Not a Single Node

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



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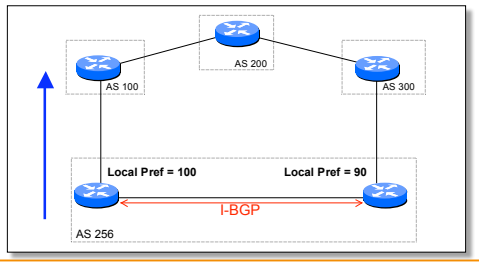
Internal BGP and Local Preference

- Example
  - Both routers prefer the path through AS 100 on the left
  - … even though the right router learns an external path



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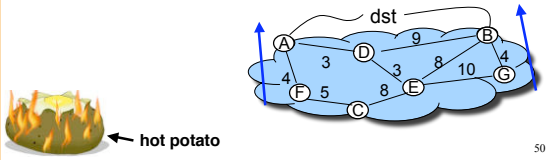
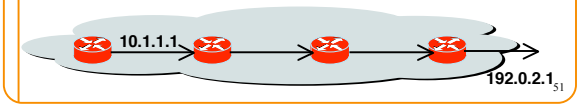
Hot-Potato (Early-Exit) Routing

- Hot-potato routing
  - Each router selects the closest egress point
  - … based on the path cost in intradomain protocol
- Somewhat in conflict with MED



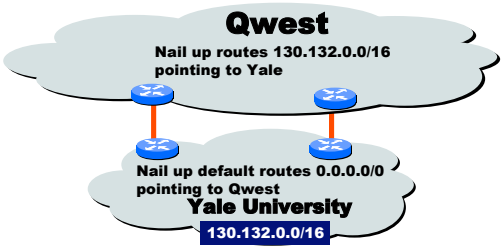
Joining BGP and IGP Information

- Border Gateway Protocol (BGP)
  - Announces reachability to external destinations
  - 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
    - 192.0.2.1 reached via 10.1.1.1



Some Routers Don't Need BGP

- Customer that connects to a single upstream ISP
  - The ISP can introduce the prefixes into BGP
  - … and the customer can simply default-route to the ISP



Summary

- BGP is essential to the Internet
  - ties different organizations together
- Poses fundamental challenges....
  - leads to use of path vector approach
- ...and myriad details