ELEC / COMP 177 – Fall 2012

Computer Networking → Recap

Some slides from Kurose and Ross, *Computer Networking*, 5th Edition

Schedule

- No class next week
- **Homework #5 –** Due Tuesday, Nov 13th
- **Homework #6 - Presentation on security/ privacy**
  - **Topic selection** – Due Tuesday, Nov 20th
  - **Slides** – Due Monday, Nov 26th
  - **Present!** – Tuesday, Nov 27th (and Thursday)
- **Project #3** – Due Tuesday, Dec 4th

Homework #6

- *Looking for a change of pace…*
- **In-class oral presentations**
  - Pick a single topic related to network privacy or security
    - Attacks? Defenses? Revolutionary new network designs?
  - Read about it and understand it
  - Present topic to *your peers* in this class
  - **4-6 slides, 8-9 minutes talking, 1 minute questions**

Homework #6 Requirements

- **Topic must be <u>approved</u>** by instructor
  - Prevents overlap in topics
  - A quick email is fine
  - Due Tuesday, Nov 20th
- **Slides must be uploaded to Sakai**
  - I'll assemble them into a single file on my laptop
  - Due Monday, Nov 26th by midnight
  - PowerPoint or PDF please…
- **Present!** – Tuesday, Nov 27th (and Thursday)

Project #3: Web Proxy

- **Due:** Tuesday, December 4th by 11:59pm
- What is a web proxy?
  - Makes HTTP requests on behalf of a client
- Why proxy?
  - Performance (from caching)
  - Content Filtering and Transformation
    - Block pages? (security)
    - Reformat pages? (for mobile devices)
  - Privacy – harder to link HTTP request to a specific individual

Project #3 – Web Proxy

- Client (web browser) must be modified!
  - IP and port of proxy
  - Capabilities? HTTP/1.1, no pipelining
- Client sends out *slightly* different HTTP request
  - Without proxy:
    - ```
      GET /about HTTP/1.1
      Host: www.google.com
      ```
  - With proxy:
    - ```
      GET http://www.google.com/about HTTP/1.1
      Host: www.google.com
      ```
    - Now the proxy (redundantly) knows the destination server!

Project #3 – Web Proxy

1. Proxy is running on server and listening on a port
2. User enters URL in browser and hits enter
3. Client connects and sends *modified* HTTP request to **proxy**, not to destination server
4. Proxy decodes URL
5. Proxy opens connection to destination server
6. Proxy sends *normal* HTTP request for object
7. Proxy receives response from destination server
8. Proxy forwards full response to client (Headers and data!)
9. Proxy closes connection to destination server and client

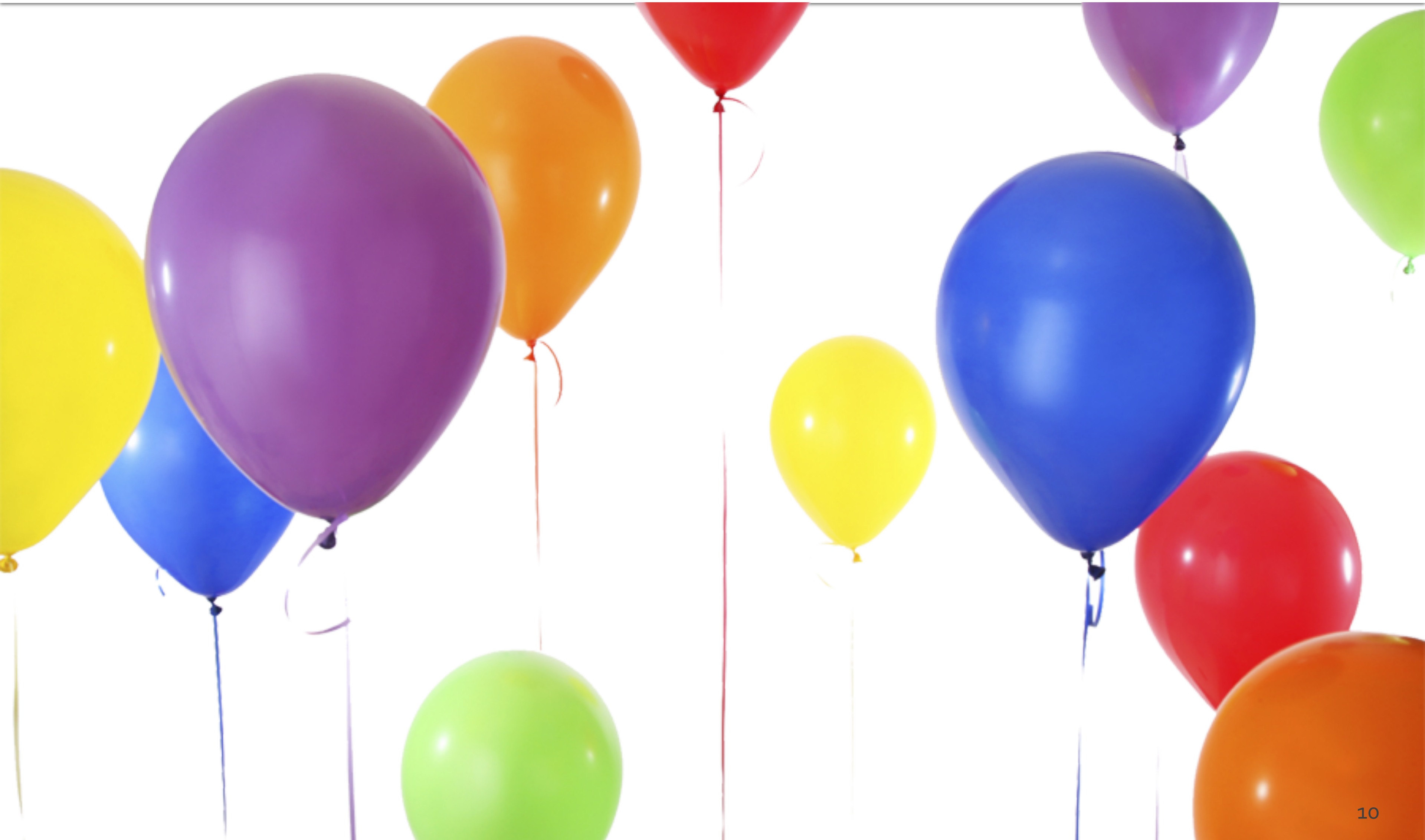
Project #3 – Web Proxy

- Tip – Use netcat when debugging to listen on a port and see what your client is sending

```
jshafer:~> netcat -l -p 4567 -v
listening on [any] 4567 ...
connect to [127.0.0.1] from localhost [127.0.0.1] 49711
GET http://www.opensuse.org/ HTTP/1.1
Host: www.opensuse.org
User-Agent: Mozilla/5.0 (X11; U; Linux x86_64; en-US; rv:
1.9.2.10) Gecko/20100914 SUSE/3.6.10-0.3.1 Firefox/3.6.10
Accept: text/html,application/xhtml+xml,application/
xml;q=0.9,*/*;q=0.8
Accept-Language: en-us,en;q=0.5
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Connection: close
Proxy-Connection: close
```

Recap
(Putting Things Together)

Congratulations!



Milestone

- Reached an important milestone in the last class
- **Successfully sent a single IP packet across the global Internet**
  - Now know all of the key protocols and standards necessary to accomplish that task
  - Let's review the semester to date…

Recap – Ethernet Frame

7	1	6	6	2	0-1500	0-46	4	
Preamble	SFD	**DA**	**SA**	**Type**	**Data**	Pad	CRC	*Gap...*

- Destination MAC address
- Source MAC address
- Type (of encapsulated data)
- The data!
- **Who assigns the source address?**
  - **Does it contain information on network location?**
- **If I just have an Ethernet frame, where can I send data to?**

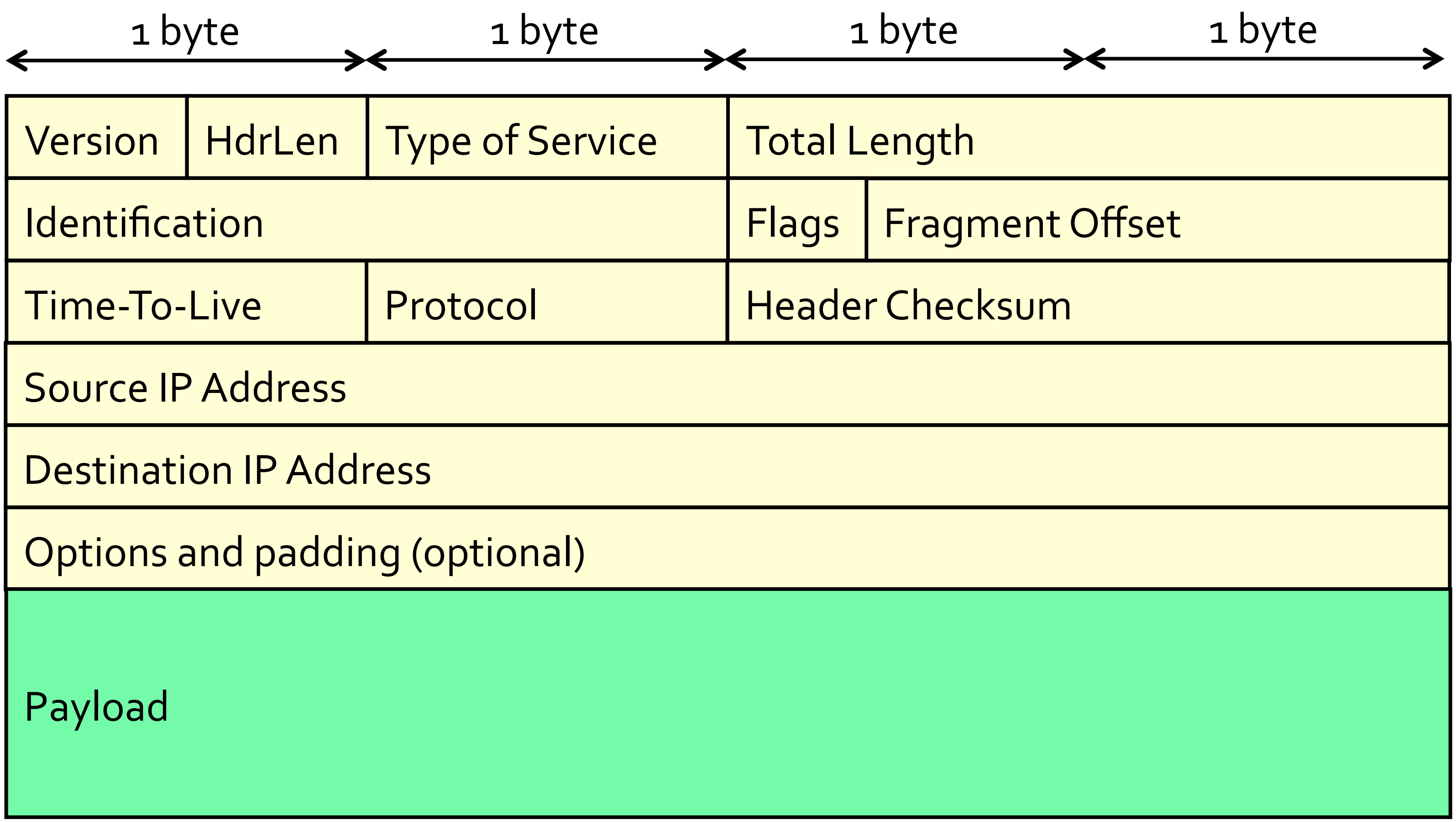
Recap – Ethernet Switch

- **How does a switch learn the location of computers on the network? (what *field*)**
- **What is stored in the forwarding table?**
  - MAC address, output port
- **What happens if a switch has no match in its forwarding table?**

Recap – Ethernet

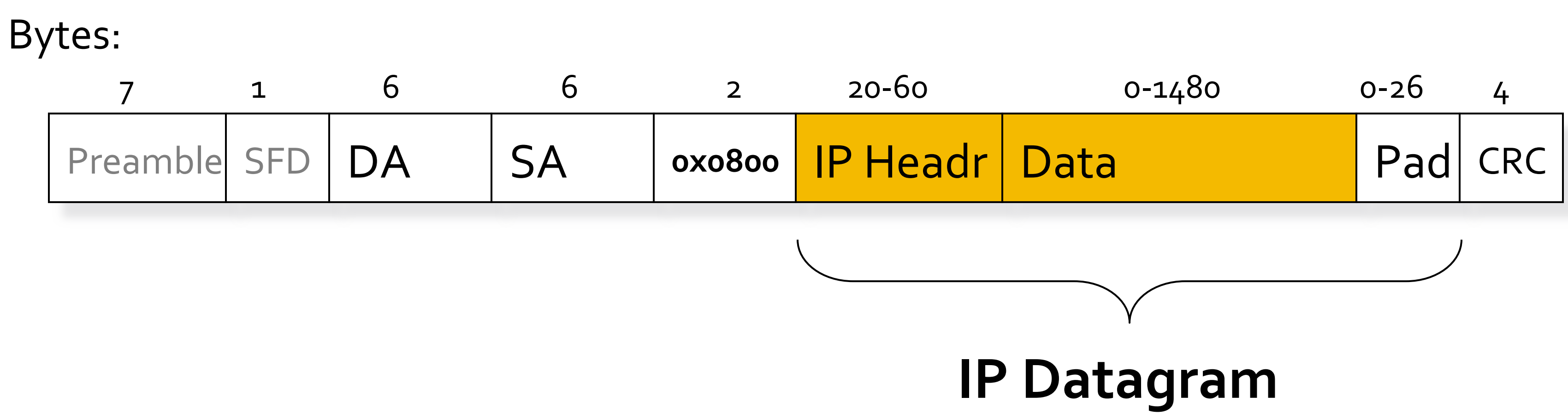
- **Why can't we use Ethernet for global communication?**
  - Broadcasts to find location of computers – too much bandwidth to do worldwide
  - Loops – Ethernet uses spanning tree to prevent loops
    - Can't have a single "root" of the Internet!
  - **Address contains no information about location on network**
    - Would need to have a forwarding table with one entry for every PC on the Internet we want to communicate with
    - i.e. a single worldwide "phonebook" with no shortcuts!

Recap – IP Datagram



Recap – IP Datagram

- Are IP packets separate from Ethernet frames?



- Time-to-live field: what's it used for?

Recap – IP encapsulated in Ethernet

<table>
<tr><td colspan="5">Destination MAC Address</td></tr>
<tr><td colspan="2">Destination MAC Address</td><td colspan="3">Source MAC Address</td></tr>
<tr><td colspan="5">Source MAC Address</td></tr>
<tr><td colspan="2">Type (0x0800)</td><td>Version</td><td>HdrLen</td><td>Type of Service</td></tr>
<tr><td colspan="2">Total Length</td><td colspan="3">Identification</td></tr>
<tr><td>Flags</td><td>Fragment Offset</td><td colspan="2">Time-To-Live</td><td>Protocol</td></tr>
<tr><td colspan="2">Header Checksum</td><td colspan="3">Source IP Address</td></tr>
<tr><td colspan="2">Source IP Address</td><td colspan="3">Destination IP Address</td></tr>
<tr><td colspan="2">Destination IP Address</td><td colspan="3">Options and Padding</td></tr>
<tr><td colspan="2">Options and Padding</td><td colspan="3">Payload</td></tr>
<tr><td colspan="5">Payload</td></tr>
<tr><td colspan="5">Ethernet CRC</td></tr>
</table>

Recap – IP Datagram

- **Where does the source IP address come from?**
  - DHCP (possibly running on the router)
- **Where does the destination IP address come from?**
  - DNS can be used to translate a host name from the *user* (e.g. www.pacific.edu) into an IP address (e.g. `138.9.110.12`)

Recap – IP Routers

- Ethernet switches forward packets based on destination MAC address
- **What do routers forward packets based on?**
  - Destination IP address
- **What is in the router's forwarding table?**
  - Prefixes, e.g. `138.16.9/24`
  - Next hop IP + exit port
- **What happens if more than one prefix matches the destination IP address?**
  - Longest prefix match determines winner

Recap – Forwarding versus Routing

FORWARDING

- Move packets from router's input to appropriate router output
- *Longest prefix match* (LPM)

ROUTING

- Determine path (route) taken by packets from source to destination
- Routing algorithms such as RIP and OSPF

Example

- Send a single IP packet from Pacific to the main Moscow State University web server
- My IP:
  - 138.9.253.252
- MSU's IP:
  - 93.180.0.18

Traceroute

How does this actually **work**?

```
dhcp-10-6-162-134:~ shafer$ traceroute -q 1 www.msu.ru
traceroute to www.msu.ru (93.180.0.18), 64 hops max, 52 byte packets
 1  10.6.163.254 (10.6.163.254)  1.677 ms
 2  10.0.0.141 (10.0.0.141)  1.116 ms
 3  10.0.0.90 (10.0.0.90)  1.053 ms
 4  138.9.253.252 (138.9.253.252)  5.200 ms
 5  74.202.6.5 (74.202.6.5)  8.137 ms
 6  pao1-pr1-xe-1-2-0-0.us.twtelecom.net (66.192.242.70)  13.241 ms
 7  te-9-4.car1.sanjose2.level3.net (4.59.0.229)  92.772 ms
 8  vlan70.csw2.sanjose1.level3.net (4.69.152.126)  8.440 ms
 9  ae-71-71.ebr1.sanjose1.level3.net (4.69.153.5)  11.130 ms
10  ae-2-2.ebr2.newyork1.level3.net (4.69.135.186)  80.992 ms
11  ae-82-82.csw3.newyork1.level3.net (4.69.148.42)  77.316 ms
12  ae-61-61.ebr1.newyork1.level3.net (4.69.134.65)  74.584 ms
13  ae-41-41.ebr2.london1.level3.net (4.69.137.65)  147.127 ms
14  ae-48-48.ebr2.amsterdam1.level3.net (4.69.143.81)  151.779 ms
15  ae-1-100.ebr1.amsterdam1.level3.net (4.69.141.169)  152.848 ms
16  ae-48-48.ebr2.dusseldorf1.level3.net (4.69.143.210)  156.349 ms
17  4.69.200.174 (4.69.200.174)  168.386 ms
18  ae-1-100.ebr1.berlin1.level3.net (4.69.148.205)  167.652 ms
19  ae-4-9.bar1.stockholm1.level3.net (4.69.200.253)  192.668 ms
20  213.242.110.198 (213.242.110.198)  176.501 ms
21  b57-1-gw.spb.runnet.ru (194.85.40.129)  198.827 ms
22  m9-1-gw.msk.runnet.ru (194.85.40.133)  204.276 ms
23  msu.msk.runnet.ru (194.190.254.118)  202.454 ms
24  93.180.0.158 (93.180.0.158)  201.358 ms
25  93.180.0.170 (93.180.0.170)  200.257 ms
26  www.msu.ru (93.180.0.18)  204.045 ms !Z
```

Companies Handling Our Packet

Number	Name
1)	University of the Pacific
2)	Time Warner Telecom
3)	Level 3 Communications
4)	Runnet - State Institute of Information Technologies & Telecommunications (SIIT&T "Informika")
5)	Moscow State University

Assumptions

- Assume that I know
  - My own MAC address (hardwired on the NIC)
  - My own IP address (assigned via DHCP to be within my local subnet)
  - The subnet mask for my local network
  - The IP address of my gateway router leading "outside"
  - The IP address of MSU that I want to send a message to

Step 1

- **What happens first?**
  - Compare destination IP with my IP and subnet mask
    - My IP: `138.9.110.104`
    - My subnet mask: `255.255.255.0`
    - Thus, my subnet is `138.9.110/24`
  - Destination IP of `93.180.0.18` is (way!) outside my LAN

Step 2

- **The destination is outside of my LAN. What happens next?**
  - Need to send packet to gateway router
- **What does the Ethernet/IP packet look like?**
  - Destination MAC: ???
  - Source MAC: My MAC
  - Destination IP: MSU's IP
  - Source IP: My IP
  - TTL: 64 (a reasonable default)

Step 3

- **How do I get the MAC address of the router port attached to my LAN?**
  - I know my gateway router's IP address
  - Use ARP (Address Resolution Protocol)
- **Who receives my ARP request?**
  - Everyone – broadcast to all hosts on LAN
  - *"Who has 138.16.110.1? Tell 138.9.110.104"*
- **Who replies to my ARP request?**
  - Only the host (if any) with the requested IP address. This should be the router

Step 4

- Assume there is an Ethernet switch between you and the router
- **What happens if the switch has seen the MAC address of the router before?**
  - Packet is sent out only the port that faces the router
- **What happens if the switch has *not* seen the MAC address before?**
  - Packet is broadcast out all ports
- Switch **always** learns (or re-learns) from each packet

Step 5

- The packet reaches your gateway router (first router between here and MSU)
- **What does the router do?**
  - Verify checksums
  - Longest prefix match on destination IP address
- **What information is returned from router's forwarding table?**
  - Next hop IP address
    - (of subsequent router, or final host)
  - Output port

Step 6

- Assume the next hop is also connected to this router via Ethernet
- **What do we need to know to send a message to this router?**
  - Its MAC address
- **How do we find this?**
  - Router does ARP (just like hosts do ARP)

Step 7

- **How does the router modify the packet when retransmitting?**
  - Destination MAC = change to be MAC of next hop
  - Source MAC = change to be MAC of this router
  - Destination IP = unchanged
  - Source IP = unchanged
  - TTL = decrement by 1
  - Checksum = recalculated

Step 8

- This process of re-transmitting a packet repeats for many routers across the network
  - *26 in this example*
- Eventually, however, the "next hop" in the forwarding table is the actual destination computer
  - Packet has arrived!
- **Is that all the complexity in the Internet?**
  - **No – forwarding tables in the router aren't created by magic!**

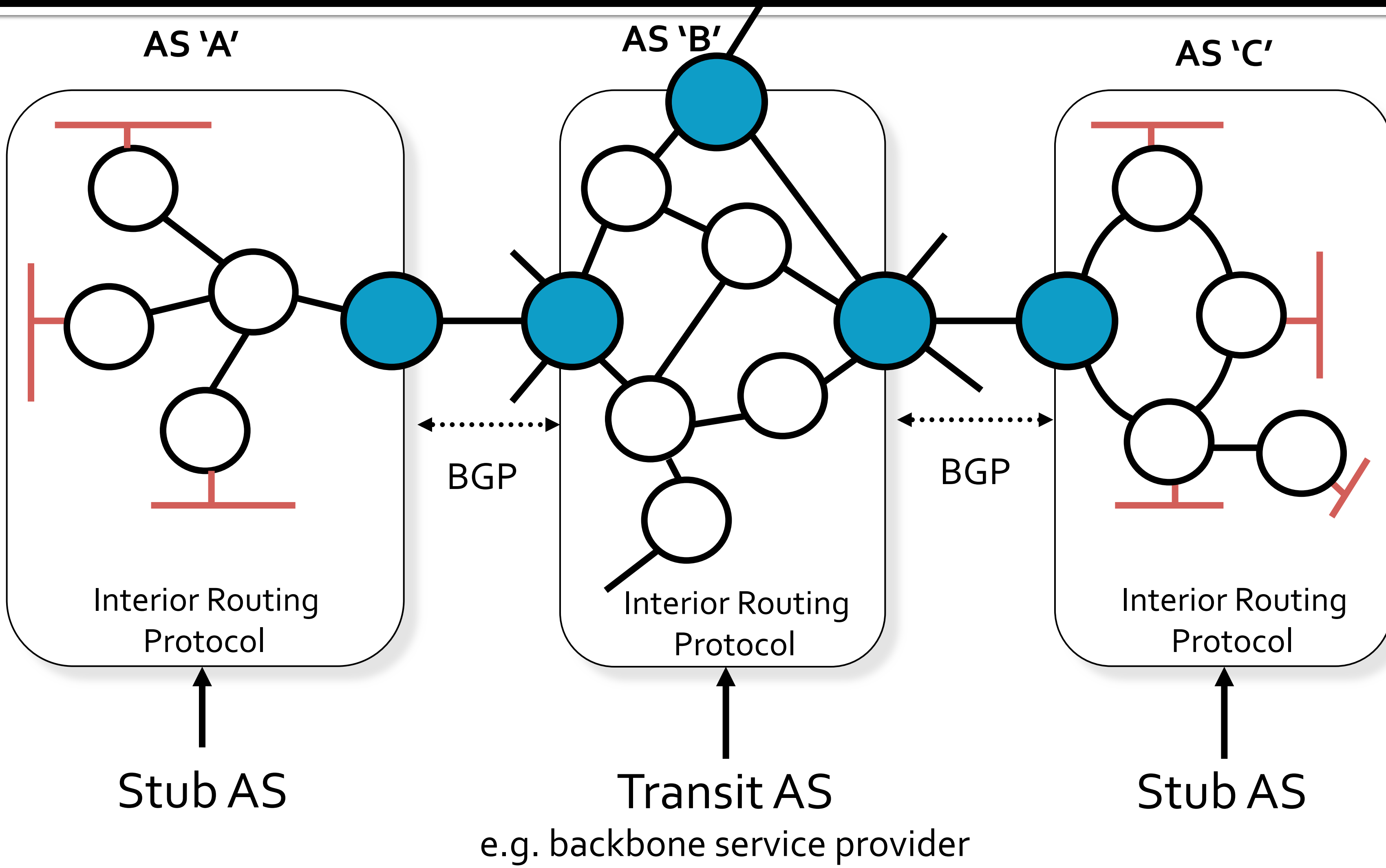
Routing

- In addition to forwarding packets, routers are busy (*asynchronously*) calculating **least-cost** routes to destinations
  - Goal: Have the forwarding table ready by the time your packet arrives with a specific destination
- **What happens if the forwarding table isn't ready, and there is no entry for your destination?**
  - Packet is dropped – you lose

Autonomous Systems

- **What is an autonomous system?**
  - Grouping of routers owned/administered by a single entity
- **Can a company only have a single autonomous system?**
  - No, can have multiple AS's
- **Why might I have more than one?**
  - Better routing for geography (i.e. North America versus Europe versus Asia)
  - Other reasons…

Autonomous Systems



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 5  [AS0] 74.202.6.5 (74.202.6.5)  8.137 ms
 6  [AS4323] pao1-pr1-xe-1-2-0-0.us.twtelecom.net (66.192.242.70)  13.241 ms
 7  [AS3356] te-9-4.car1.sanjose2.level3.net (4.59.0.229)  92.772 ms
 8  [AS3356] vlan70.csw2.sanjose1.level3.net (4.69.152.126)  8.440 ms
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26  [AS2848] www.msu.ru (93.180.0.18)  204.045 ms !Z
```

AS Numbers in Traceroute

AS	Name
0	Reserved (local use)
18663	University of the Pacific *(Traceroute didn't resolve this due to missing information in address registry…)*
4323	Time Warner Telecom
3356	Level 3 Communications
3267	Runnet - State Institute of Information Technologies & Telecommunications (SIIT&T "Informika")
2848	Moscow State University

First AS

- First AS is Pacific's (AS18663)
- Do a lookup on the AS
  - http://www.ripe.net/data-tools/stats/ris/routing-information-service
  - https://www.dan.me.uk/bgplookup
  - http://www.peeringdb.com/
    - Among other places…
- Pacific's gateway(s) to the Internet advertise a BGP prefix (aka subnet)
  - **`138.9.0.0/16`**

First AS

- An advertisement is a *promise:*
  - If you give me packets destined for IP addresses in this range, I will move them closer to their destination.
  - In this case, we *are* the destination!
  - This advertisement *originates* from our AS

Second AS

- Pacific buys Internet service from Time Warner (AS4323) , which has border routers that speak BGP
  - Pacific's routers talk to their routers, and they learn of our advertisement for 138.9.0.0/16
  - Now, Time Warner knows how to reach Pacific's IPs
  - We also learn of their advertisements!
    - Both for prefixes *originating* at those ISPs, and prefixes *reachable* through those ISPs

Announcements

- **When Time Warner give our routers their BGP announcements, do we get lots of tiny entries like 138.9.0.0/16?**
  - Maybe
  - But, routes can be aggregated together and expressed with smaller prefixes, e.g. `138.0.0.0/8`
    - Reduces communication time plus router CPU and memory requirements

Second AS (continued)

- Pacific had only 1 announcement
- Time Warner *originates* ~159 announcements (as of Nov 2012)
  - Some are large, e.g. `173.226.0.0/15`
  - Some are small, e.g. `159.157.233.0/24`
- Time Warner also provides transit to their *downstream* customers' prefixes, including Pacific's prefix
  - Total of ~6395 announcements (as of Nov 2012)
  - We get this full list, as does ever other (BGP-speaking) AS connected to Time Warner

Third AS

- Time Warner (AS4323) can move this packet to San Jose, where it enters the Equinix Internet Exchange (See https://www.peeringdb.com)
  - Private location to peer ("exchange traffic") with dozens of other companies
  - Akamai, Apple, Amazon, Facebook, Google, Microsoft, many ISPs, etc…
- Time Warner connects with Level 3 (AS3356)
  - *Do they pay, or is this free?*
  - Same sharing of BGP announcements occurs here

Last AS

- The same thing is happening over in Eurasia
- Last AS of our path is Moscow State University (AS2848)
- MSU's gateway(s) to the Internet advertise a BGP prefix for `93.180.0.0/18` (along with 3 others that *originate* in this AS)
  - That encompasses the destination IP of `93.180.0.18`

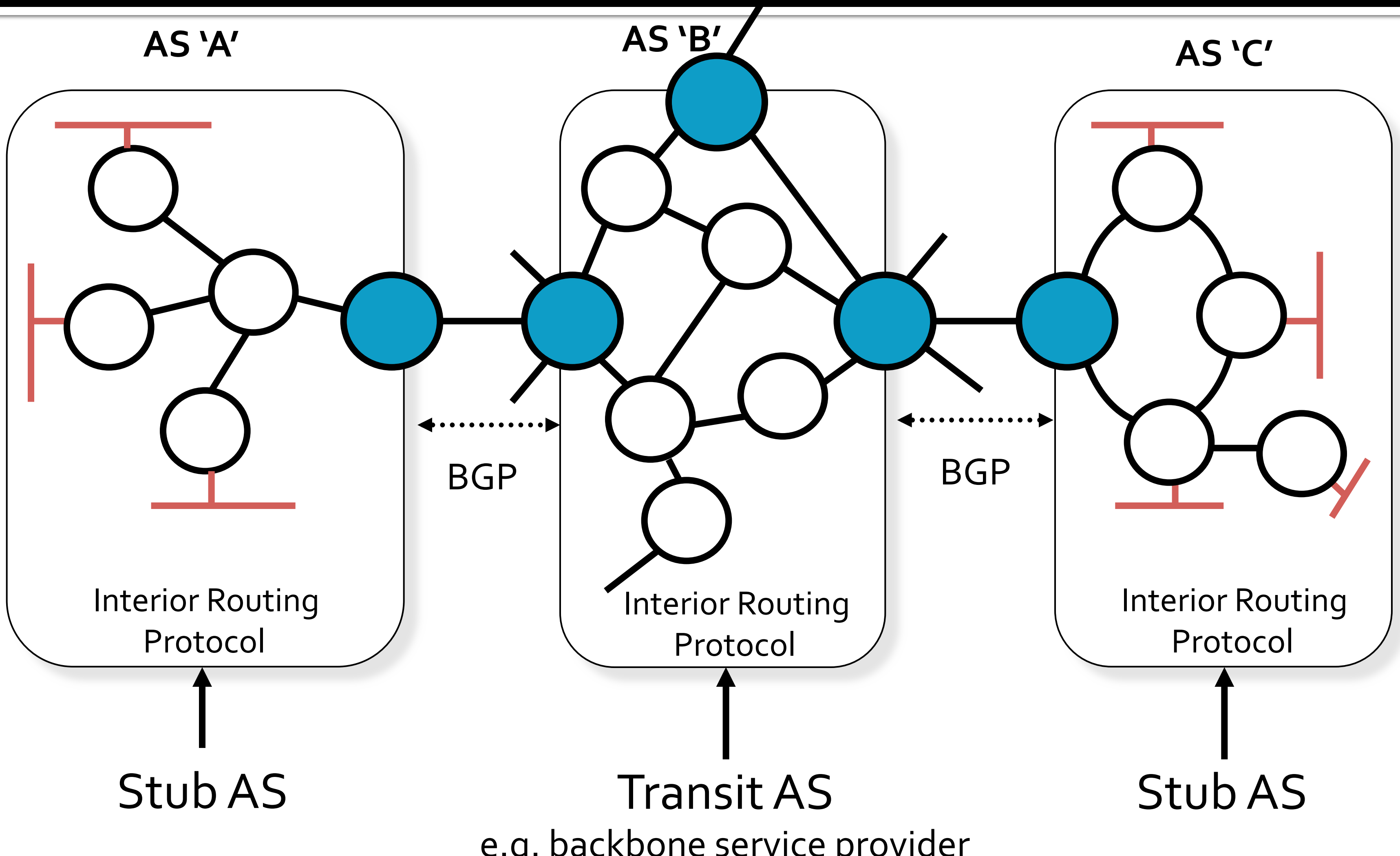
Next-to-last AS

- Moscow State University connects to Runnet (AS3267)
  - Runnet announces prefix `93.180.0.0/18` (along with 291 others reachable *downstream*, and 13 that *originate* in this AS)
  - Runnet now knows how to reach IPs that belong to MSU
- Runnet obtains transit through Level3, so our link is complete!

What's Missing?

- The forwarding table!
  - We keep forgetting to generate the forwarding table!
- Need more information
  - BGP tells us links between autonomous systems
  - Other protocols (RIP, OSPF) tell us paths within autonomous systems

Autonomous Systems



Interior Routing Protocol

- Let’s say (hypothetically) that Time Warner runs RIP, a distance-vector protocol
- **Does each router have a complete view of the network inside the AS?**
  - No
- **What algorithm is used to develop routes?**
  - Bellman-Ford (using distance vectors)

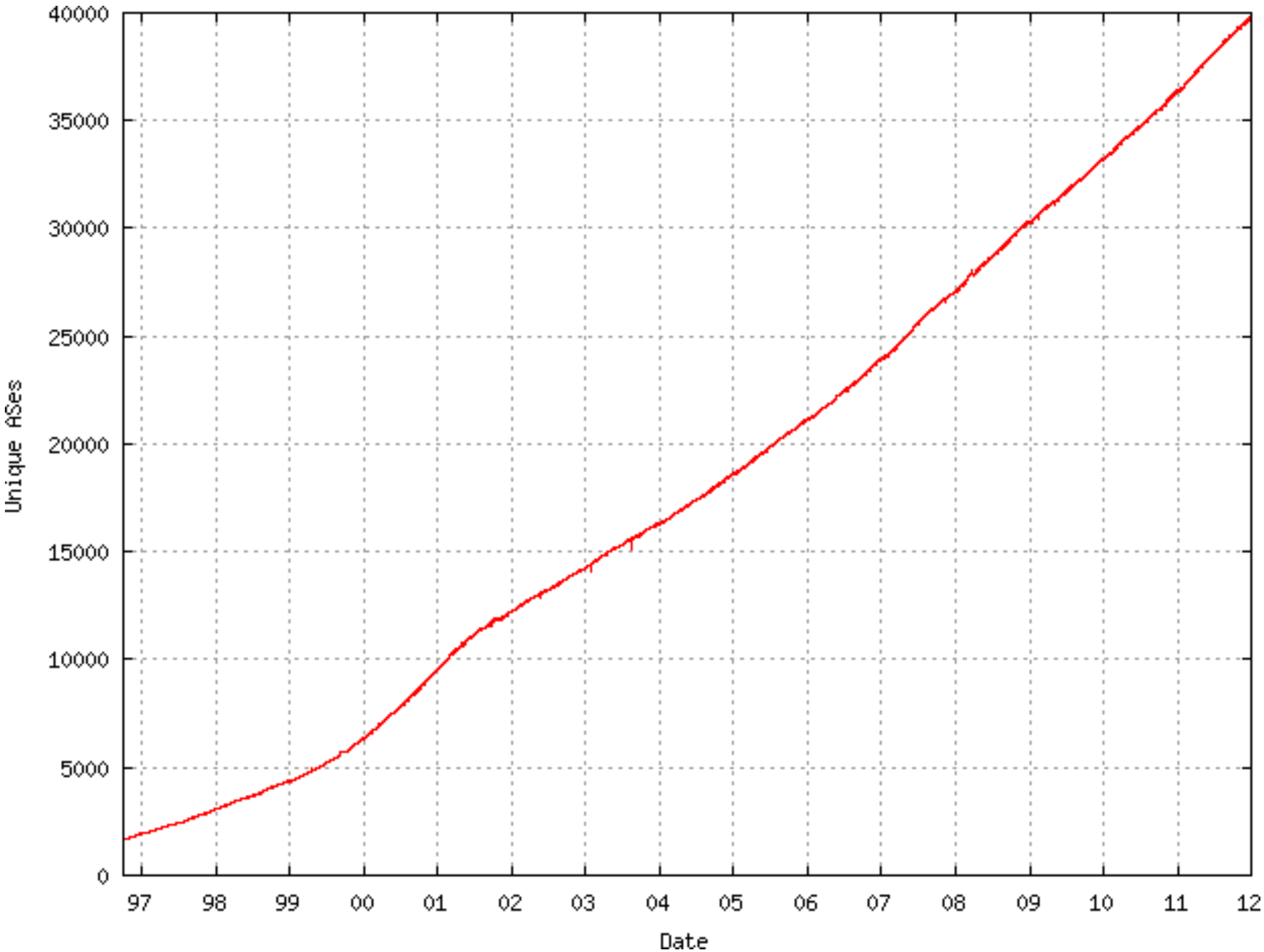
Interior Routing Protocol

- Let's say (hypothetically) that Time Warner runs OSPF, a link-state protocol
- **Does each router have a complete view of the network inside the AS?**
  - Yes
- **What algorithm is used to develop routes?**
  - Dijkstra's

End Result is the Same

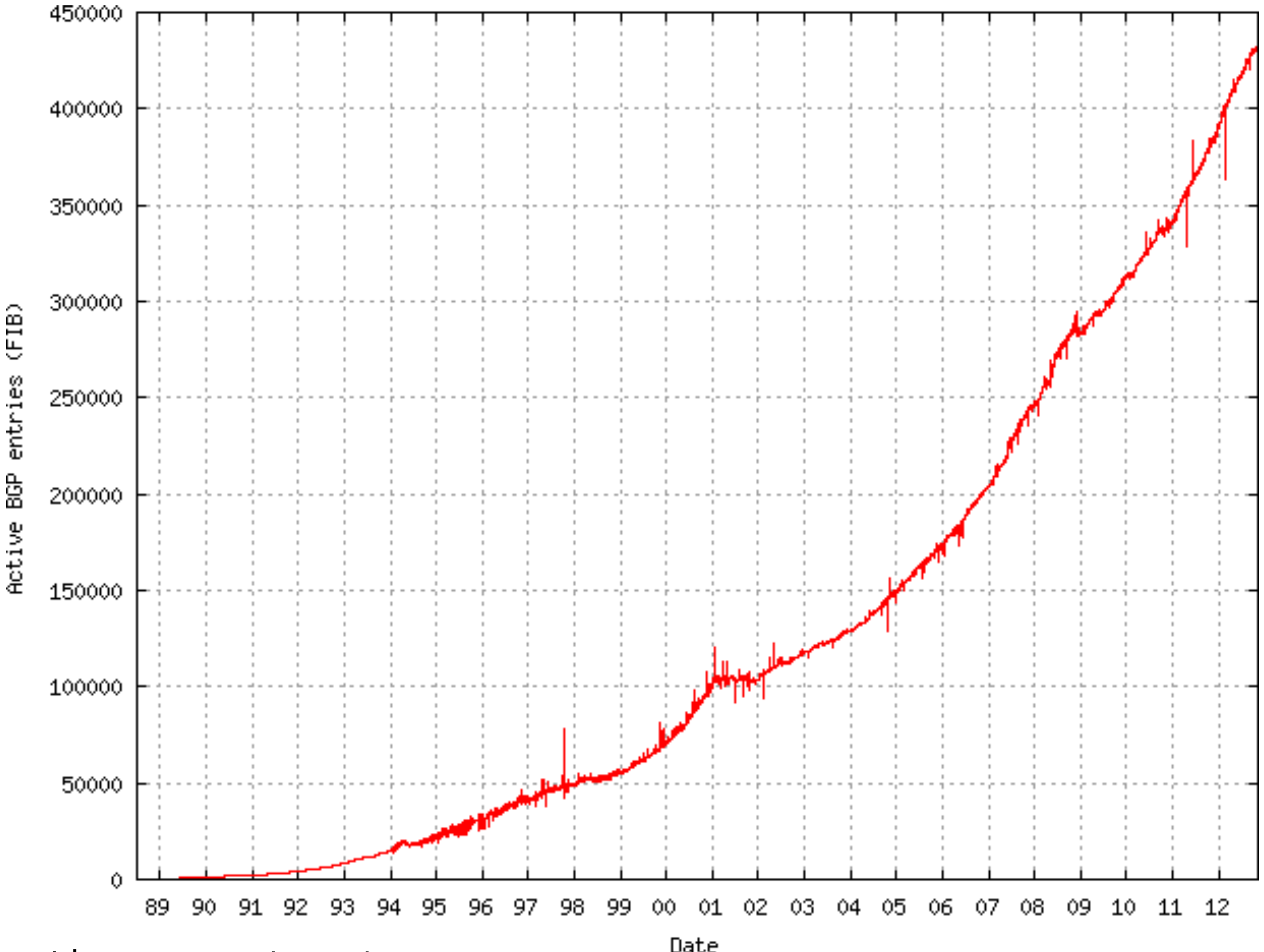
- Each router inside the AS updates its own forwarding table to direct BGP prefixes to the appropriate gateway router to the next AS
  - Rules might be very simple, i.e. just forward everything not destined to this AS to the same gateway router
  - Or rules might be complicated…
- **End result is a forwarding table for the router**
  - Prefix (for LPM)
  - Next-hop IP
  - Exit port

Growth of Internet – AS's



http://www.cidr-report.org/as2.0/

Growth of Internet – BGP Entries (prefixes)



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Growth

- **What does this growth mean for routers on the BGP-speaking Internet?**
  - They need to grow too! (more memory, faster CPUs, etc…)

What Does *My* Computer Do?

- **Does *my* computer speak BGP?**
  - No – your ISP's external gateway router does
- **Does *my* computer speak RIP or OSPF?**
  - No – your ISP's internal routers do
- **Does *my* computer speak ARP?**
  - Yes
- **Does *my* computer speak IP?**
  - Yes
- **Does *my* computer speak Ethernet?**
  - Yes

Milestone

- **Successfully sent a single IP packet across the global Internet**
  - Now know all of the key protocols and standards necessary to accomplish that task
- **Now can I waste time watching LOLcats?**

Milestone

- Not quite. One IP packet by itself is not enough to transmit an entire image
- **What else do we need?**
  - Method to **link multiple IP packets together** and deliver them to the **correct process** on the receiver
    - **Transport layer**: UDP, TCP (TCP also provides **reliability!**)
  - **Applications** need to be written to use this reliable network communication, and they need protocols of their own!
    - Web = HTTP, Email = POP / IMAP / SMTP, …