

INFO/CS 4302

Web Information Systems

FT 2012

Week 2: Internet History & Architecture
(Part 2)

Theresa Velden

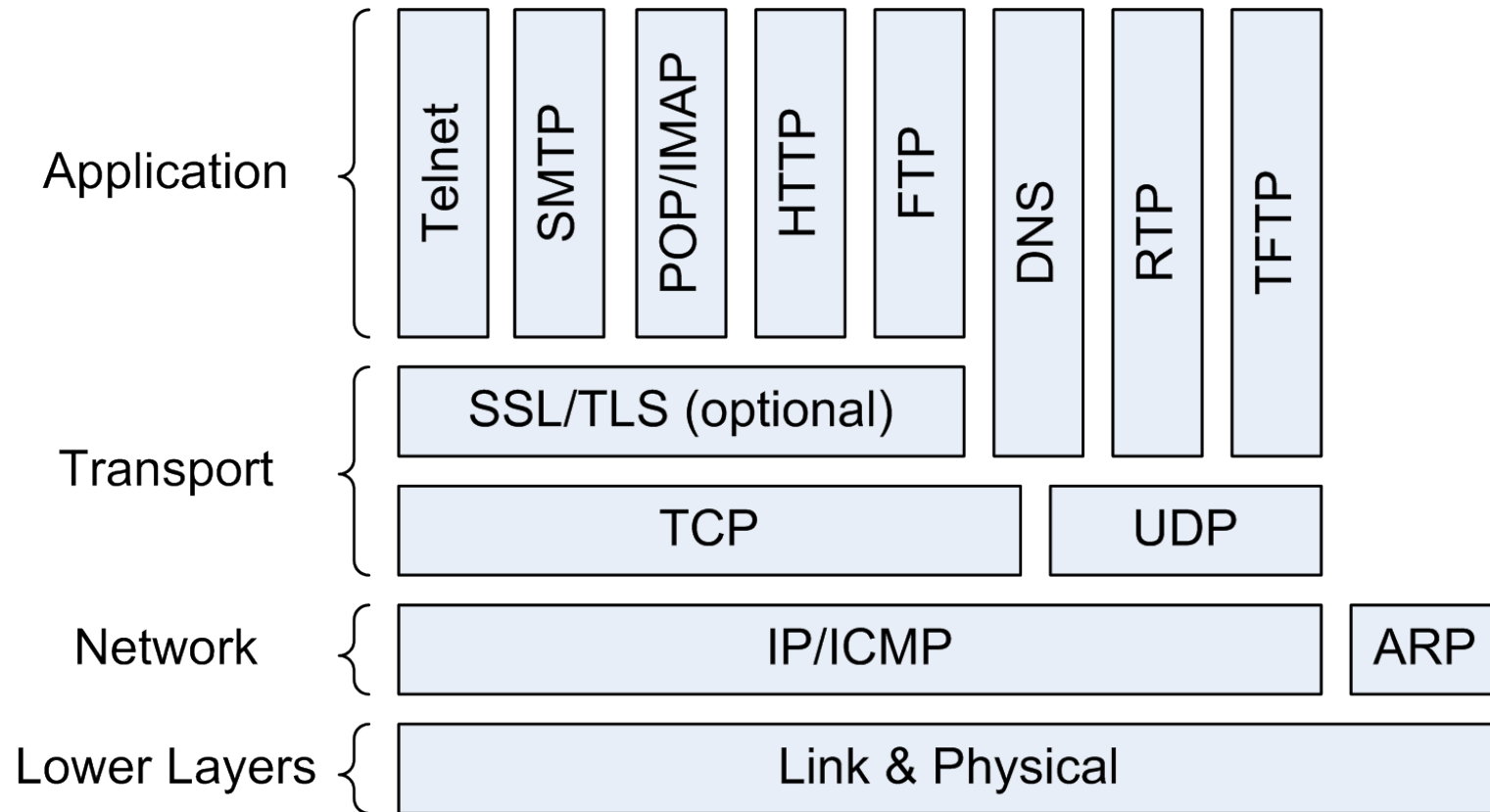
RECAP: INTERNET ARCHITECTURE

Internet Essentials

- IP: common interoperability foundation (addressing and routing)
- Packet switching: flexible, store & forward; difficult to trace
- Architecture layered and modularized
- End-to-end principle: intelligence at the end points
- Domain Name System: two-layer virtual address space
 - IP address (32 bit, 128 bit)
 - Domain name: www.cornell.edu
- Governance by a combo of engineers (IETF), non-governmental agencies, companies and governments

[source: Carl Lagoze, lecture slides INFO4302 Fall 2011]

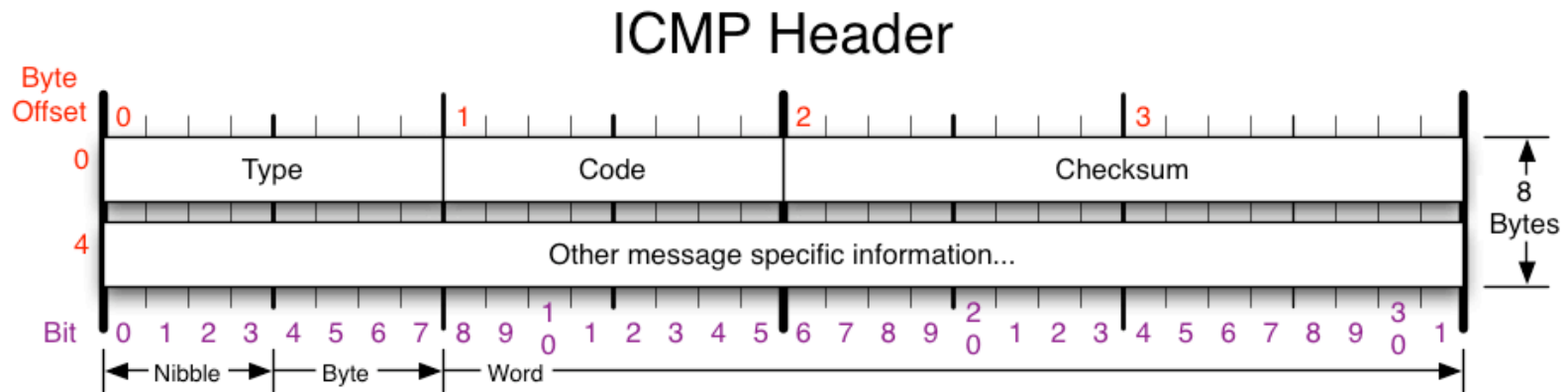
TCP/IP Protocol Suite



Well-Known Application Layer Protocols

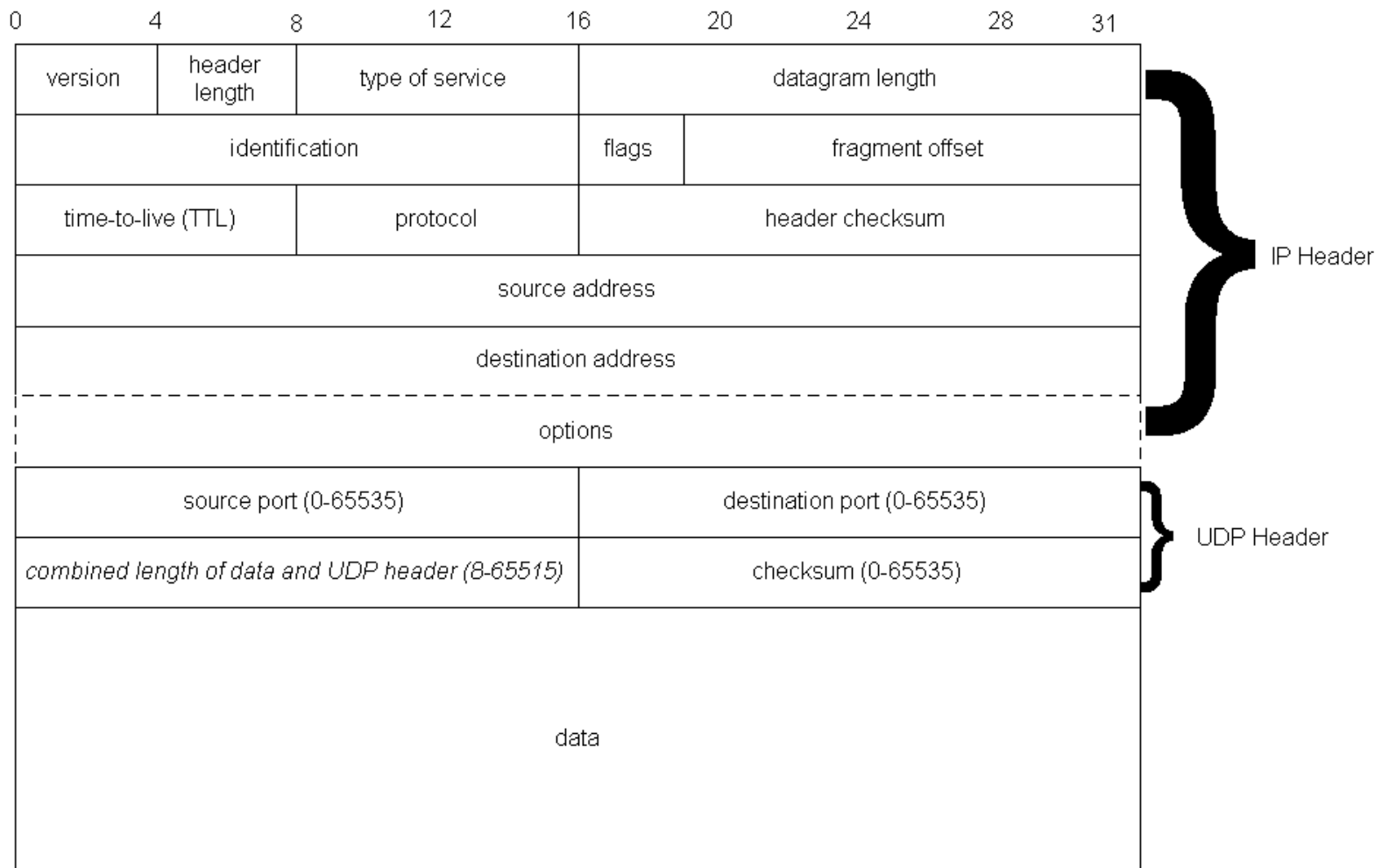
- Telnet – external terminal interface, RFC 854 (1983)
- FTP – file transfer, RFC 959 (1985)
- SMTP – mail transport, RFC 821 (1982)
- HTTP – distributed, collaborative hypermedia systems, RFC 1945 (1.0 1996), RFC 2616 (1.1 1999)

Network Layer: ICMP (Internet Control Message Protocol)



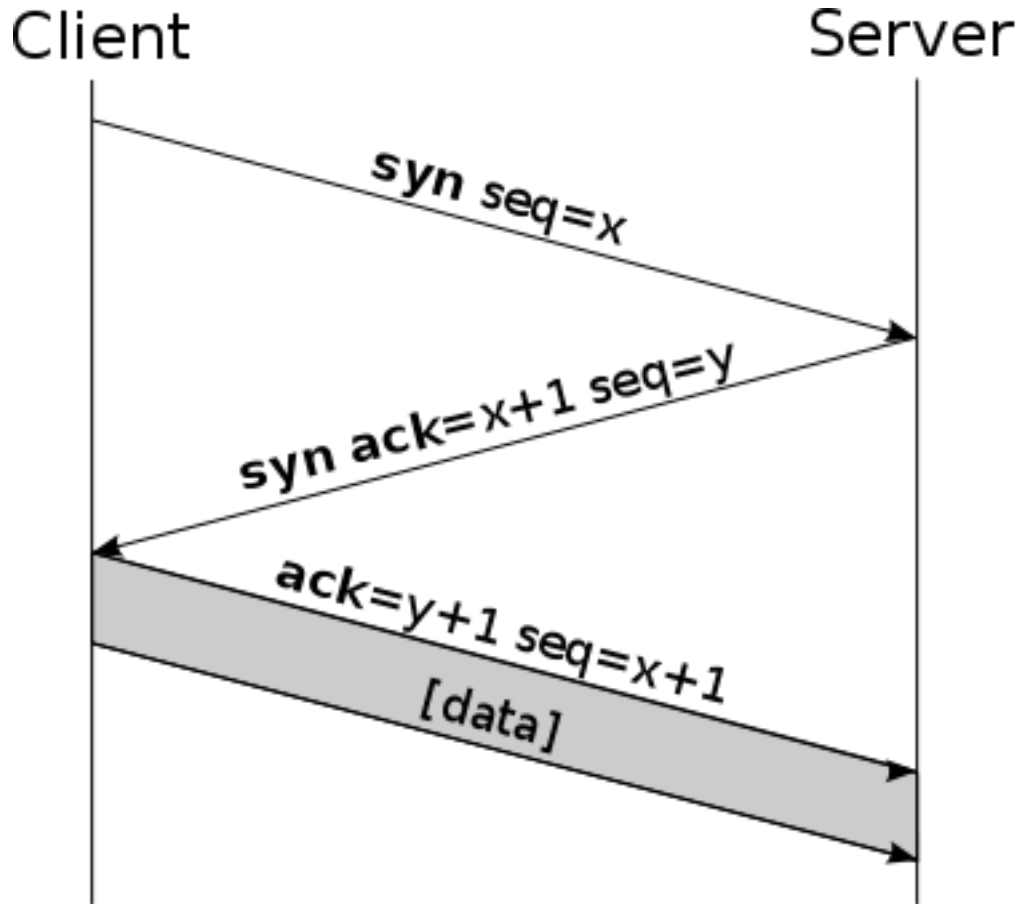
ICMP Message Types			Checksum																																																																																																																																	
<table border="0"> <tr><td>Type</td><td>Code/Name</td><td></td></tr> <tr><td>0</td><td>Echo Reply</td><td></td></tr> <tr><td>3</td><td>Destination Unreachable</td><td></td></tr> <tr><td> 0</td><td>Net Unreachable</td><td></td></tr> <tr><td> 1</td><td>Host Unreachable</td><td></td></tr> <tr><td> 2</td><td>Protocol Unreachable</td><td></td></tr> <tr><td> 3</td><td>Port Unreachable</td><td></td></tr> <tr><td> 4</td><td>Fragmentation required, and DF set</td><td></td></tr> <tr><td> 5</td><td>Source Route Failed</td><td></td></tr> <tr><td> 6</td><td>Destination Network Unknown</td><td></td></tr> <tr><td> 7</td><td>Destination Host Unknown</td><td></td></tr> <tr><td> 8</td><td>Source Host Isolated</td><td></td></tr> <tr><td> 9</td><td>Network Administratively Prohibited</td><td></td></tr> <tr><td> 10</td><td>Host Administratively Prohibited</td><td></td></tr> <tr><td> 11</td><td>Network Unreachable for TOS</td><td></td></tr> </table>	Type	Code/Name		0	Echo Reply		3	Destination Unreachable		0	Net Unreachable		1	Host Unreachable		2	Protocol Unreachable		3	Port Unreachable		4	Fragmentation required, and DF set		5	Source Route Failed		6	Destination Network Unknown		7	Destination Host Unknown		8	Source Host Isolated		9	Network Administratively Prohibited		10	Host Administratively Prohibited		11	Network Unreachable for TOS		<table border="0"> <tr><td>Type</td><td>Code/Name</td><td></td></tr> <tr><td>3</td><td>Destination Unreachable (continued)</td><td></td></tr> <tr><td> 12</td><td>Host Unreachable for TOS</td><td></td></tr> <tr><td> 13</td><td>Communication Administratively Prohibited</td><td></td></tr> <tr><td>4</td><td>Source Quench</td><td></td></tr> <tr><td>5</td><td>Redirect</td><td></td></tr> <tr><td> 0</td><td>Redirect Datagram for the Network</td><td></td></tr> <tr><td> 1</td><td>Redirect Datagram for the Host</td><td></td></tr> <tr><td> 2</td><td>Redirect Datagram for the TOS & Network</td><td></td></tr> <tr><td> 3</td><td>Redirect Datagram for the TOS & Host</td><td></td></tr> <tr><td>8</td><td>Echo</td><td></td></tr> <tr><td>9</td><td>Router Advertisement</td><td></td></tr> <tr><td>10</td><td>Router Selection</td><td></td></tr> </table>	Type	Code/Name		3	Destination Unreachable (continued)		12	Host Unreachable for TOS		13	Communication Administratively Prohibited		4	Source Quench		5	Redirect		0	Redirect Datagram for the Network		1	Redirect Datagram for the Host		2	Redirect Datagram for the TOS & Network		3	Redirect Datagram for the TOS & Host		8	Echo		9	Router Advertisement		10	Router Selection		<table border="0"> <tr><td>Type</td><td>Code/Name</td><td></td></tr> <tr><td>11</td><td>Time Exceeded</td><td></td></tr> <tr><td> 0</td><td>TTL Exceeded</td><td></td></tr> <tr><td> 1</td><td>Fragment Reassembly Time Exceeded</td><td></td></tr> <tr><td>12</td><td>Parameter Problem</td><td></td></tr> <tr><td> 0</td><td>Pointer Problem</td><td></td></tr> <tr><td> 1</td><td>Missing a Required Operand</td><td></td></tr> <tr><td> 2</td><td>Bad Length</td><td></td></tr> <tr><td>13</td><td>Timestamp</td><td></td></tr> <tr><td>14</td><td>Timestamp Reply</td><td></td></tr> <tr><td>15</td><td>Information Request</td><td></td></tr> <tr><td>16</td><td>Information Reply</td><td></td></tr> <tr><td>17</td><td>Address Mask Request</td><td></td></tr> <tr><td>18</td><td>Address Mask Reply</td><td></td></tr> <tr><td>30</td><td>Traceroute</td><td></td></tr> </table>	Type	Code/Name		11	Time Exceeded		0	TTL Exceeded		1	Fragment Reassembly Time Exceeded		12	Parameter Problem		0	Pointer Problem		1	Missing a Required Operand		2	Bad Length		13	Timestamp		14	Timestamp Reply		15	Information Request		16	Information Reply		17	Address Mask Request		18	Address Mask Reply		30	Traceroute		<p>Checksum of ICMP header</p> <p style="text-align: center;">RFC 792</p> <p>Please refer to RFC 792 for the Internet Control Message protocol (ICMP) specification.</p>
Type	Code/Name																																																																																																																																			
0	Echo Reply																																																																																																																																			
3	Destination Unreachable																																																																																																																																			
0	Net Unreachable																																																																																																																																			
1	Host Unreachable																																																																																																																																			
2	Protocol Unreachable																																																																																																																																			
3	Port Unreachable																																																																																																																																			
4	Fragmentation required, and DF set																																																																																																																																			
5	Source Route Failed																																																																																																																																			
6	Destination Network Unknown																																																																																																																																			
7	Destination Host Unknown																																																																																																																																			
8	Source Host Isolated																																																																																																																																			
9	Network Administratively Prohibited																																																																																																																																			
10	Host Administratively Prohibited																																																																																																																																			
11	Network Unreachable for TOS																																																																																																																																			
Type	Code/Name																																																																																																																																			
3	Destination Unreachable (continued)																																																																																																																																			
12	Host Unreachable for TOS																																																																																																																																			
13	Communication Administratively Prohibited																																																																																																																																			
4	Source Quench																																																																																																																																			
5	Redirect																																																																																																																																			
0	Redirect Datagram for the Network																																																																																																																																			
1	Redirect Datagram for the Host																																																																																																																																			
2	Redirect Datagram for the TOS & Network																																																																																																																																			
3	Redirect Datagram for the TOS & Host																																																																																																																																			
8	Echo																																																																																																																																			
9	Router Advertisement																																																																																																																																			
10	Router Selection																																																																																																																																			
Type	Code/Name																																																																																																																																			
11	Time Exceeded																																																																																																																																			
0	TTL Exceeded																																																																																																																																			
1	Fragment Reassembly Time Exceeded																																																																																																																																			
12	Parameter Problem																																																																																																																																			
0	Pointer Problem																																																																																																																																			
1	Missing a Required Operand																																																																																																																																			
2	Bad Length																																																																																																																																			
13	Timestamp																																																																																																																																			
14	Timestamp Reply																																																																																																																																			
15	Information Request																																																																																																																																			
16	Information Reply																																																																																																																																			
17	Address Mask Request																																																																																																																																			
18	Address Mask Reply																																																																																																																																			
30	Traceroute																																																																																																																																			

Transport Layer: User Datagram Protocol



Stateless, unreliable; preferred for streaming

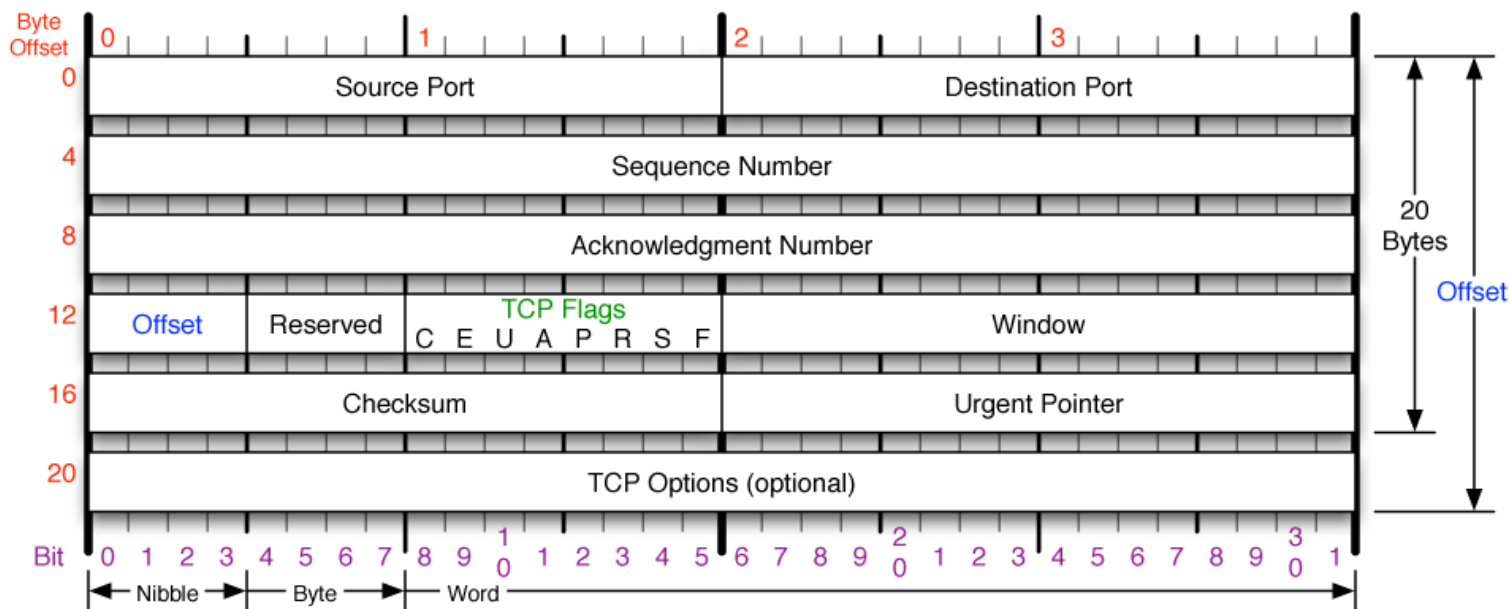
Transport Layer: TCP Three Way Handshake



virtual connection, reliable; used for http

Transfer Control Protocol

TCP Header



TCP Flags

C E U A P R S F

Congestion Window

- C 0x80 Reduced (CWR)
- E 0x40 ECN Echo (ECE)
- U 0x20 Urgent
- A 0x10 Ack
- P 0x08 Push
- R 0x04 Reset
- S 0x02 Syn
- F 0x01 Fin

Congestion Notification

ECN (Explicit Congestion Notification). See RFC 3168 for full details, valid states below.

Packet State	DSB	ECN bits
Syn	0 0	1 1
Syn-Ack	0 0	0 1
Ack	0 1	0 0
No Congestion	0 1	0 0
No Congestion	1 0	0 0
Congestion	1 1	0 0
Receiver Response	1 1	0 1
Sender Response	1 1	1 1

TCP Options

- 0 End of Options List
- 1 No Operation (NOP, Pad)
- 2 Maximum segment size
- 3 Window Scale
- 4 Selective ACK ok
- 8 Timestamp

Checksum

Checksum of entire TCP segment and pseudo header (parts of IP header)

Offset

Number of 32-bit words in TCP header, minimum value of 5. Multiply by 4 to get byte count.

RFC 793

Please refer to RFC 793 for the complete Transmission Control Protocol (TCP) Specification.

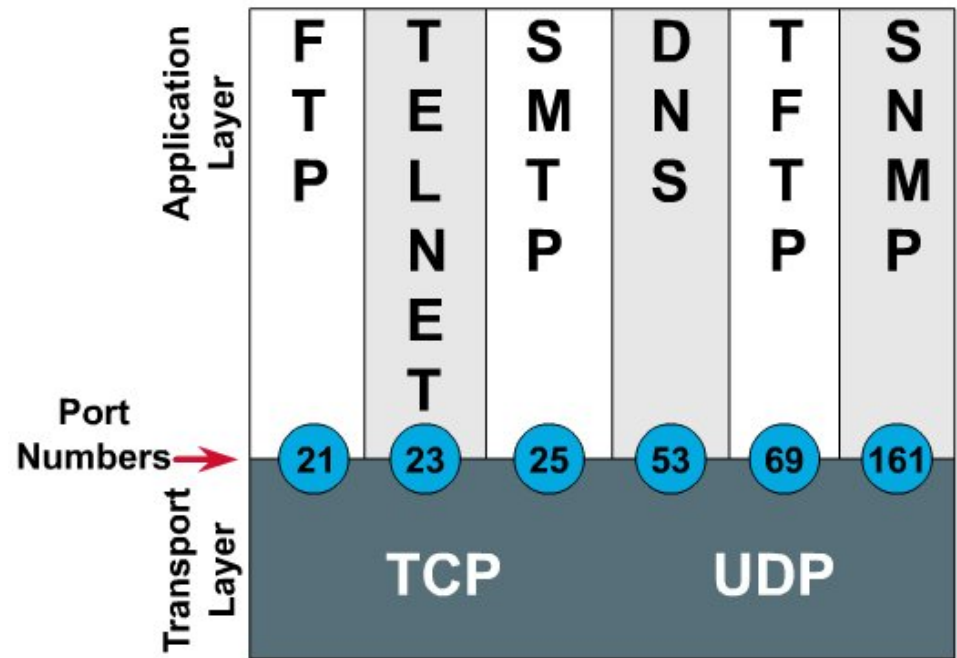
TCP/UDP Sockets (“Virtual Ports”)

- IANA maintains a Service Name and Transport Protocol Port Number Registry:

“Service names and port numbers are used to distinguish between different services that run over transport protocols such as TCP, UDP, DCCP, and SCTP”.

- Services such as: ftp, smtp, whois...
- Needed for binding to applications (IP address/port number, using a protocol such as TCP or UDP)

Port Numbers



Port Number Listings:

<http://www.ietf.org/assignments/service-names-port-numbers/service-names-port-numbers.txt>

http://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers

INTERNET PROTOCOLS IN ACTION

Which domain name server is my computer using?

```
dhcp103-45:info4302-website theresavelden$ cat /etc/resolv.conf
#
# Mac OS X Notice
#
# This file is not used by the host name and address resolution
# or the DNS query routing mechanisms used by most processes on
# this Mac OS X system.
#
# This file is automatically generated.
#
domain cs.cornell.edu
nameserver 128.84.96.11
nameserver 128.84.86.41
nameserver 128.84.96.10
nameserver 128.84.86.40
```

whois

- **RFC 3912** <http://tools.ietf.org/html/rfc3912>
- TCP-based transaction-oriented query/response protocol
- Originally: information about registered domain names
- Port Number (IANA):

Service name	Port number	Transport Protocol	Reference
– nicname	43	tcp	Who Is
– nicname	43	udp	Who Is

```
dhcp103-45:info4302-website theresavelden$ whois "n 128.84.86.40"
```

```
#  
# The following results may also be obtained via:  
# http://whois.arin.net/rest/nets;q=128.84.86.40?  
showDetails=true&showARIN=false&ext=netref2  
#
```

```
NetRange:      128.84.0.0 - 128.84.255.255  
CIDR:          128.84.0.0/16  
OriginAS:       
NetName:      CORNELL-NET  
NetHandle:    NET-128-84-0-0-1  
Parent:       NET-128-0-0-0-0  
NetType:      Direct Assignment  
RegDate:      1985-05-29  
Updated:      2011-10-07  
Ref:          http://whois.arin.net/rest/net/NET-128-84-0-0-1
```

```
OrgName:      Cornell University  
OrgId:        CORNEL  
Address:      Cornell Information Technologies  
Address:      757 Rhodes Hall  
City:         Ithaca  
StateProv:    NY  
PostalCode:   14853  
Country:      US  
RegDate:      1984-08-10  
Updated:      2011-10-07  
Ref:          http://whois.arin.net/rest/org/CORNEL
```

```
OrgTechHandle: DEC12-ARIN  
OrgTechName:  Eckstrom, Daniel  
OrgTechPhone: +1-607-255-5902  
OrgTechEmail: de10@cornell.edu  
OrgTechRef:   http://whois.arin.net/rest/poc/DEC12-ARIN
```

whois 128.84.86.40?

```
dhcp103-45:info4302-website theresavelden$ whois "n 128.84.86.40"
```

```
#  
# The following results may also be obtained via:  
# http://whois.arin.net/rest/nets;q=128.84.86.40?  
showDetails=true&showARIN=false&ext=netref2  
#
```

```
NetRange:      128.84.0.0 - 128.84.255.255
```

```
CIDR:          128.84.0.0/16
```

```
OriginAS:
```

```
NetName:       CORNELL-NET
```

```
NetHandle:     NET-128-84-0-0-1
```

```
Parent:        NET-128-0-0-0-0
```

```
NetType:       Direct Assignment
```

```
RegDate:       1985-05-29
```

```
Updated:       2011-10-07
```

```
Ref:           http://whois.arin.net
```

```
OrgName:       Cornell University
```

```
OrgId:         CORNEL
```

```
Address:       Cornell Information
```

```
Address:       757 Rhodes Hall
```

```
City:          Ithaca
```

```
StateProv:     NY
```

```
PostalCode:    14853
```

```
Country:       US
```

```
RegDate:       1984-08-10
```

```
Updated:       2011-10-07
```

```
Ref:           http://whois.arin.net
```

```
OrgTechHandle: DEC12-ARIN
```

```
OrgTechName:   Eckstrom, Daniel
```

```
OrgTechPhone:  +1-607-255-5902
```

```
OrgTechEmail:  de10@cornell.edu
```

```
OrgTechRef:    http://whois.arin.net/rest/poc/DEC12-ARIN
```



Cornell University

VIVO

Research & Expertise
Across Cornell

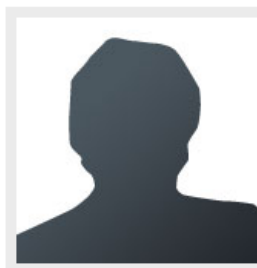
[Home](#)

[People](#)

[Organizations](#)

[Research](#)

[Events](#)



Eckstrom, Daniel

Positions

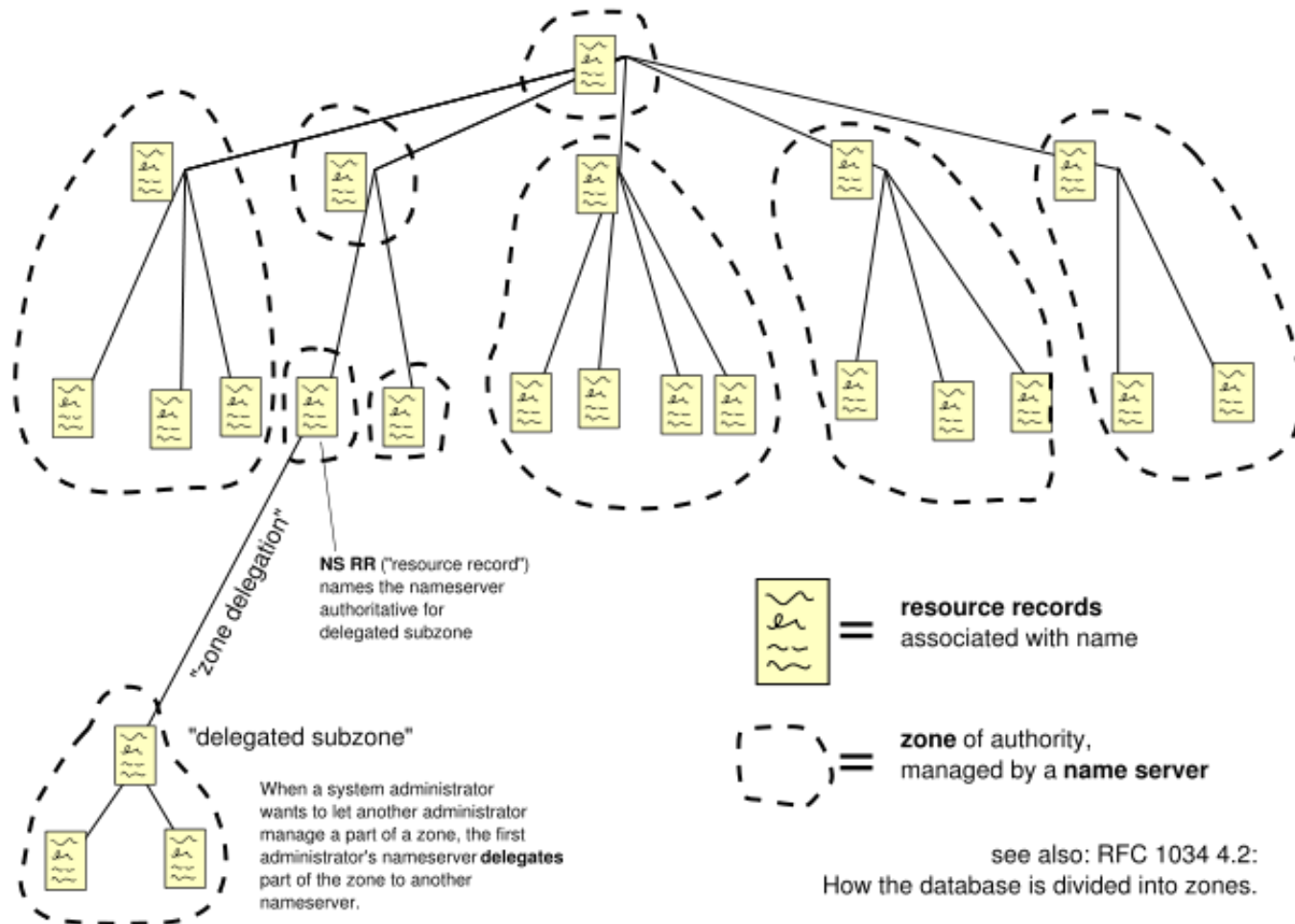
► Network Engineer Lead, [CIT INFRASTRUCTURE](#)

[Contact information](#)



Does Cornell have to have a domain name server?

Domain Name Space



How is my DNS lookup routed?

- Choose domain name server to send request to
- Public domain name server IP address = **8.8.8.8** (provided courtesy of google)
- Domain name I want to resolve:
cs.cornell.edu
- DNS lookup utility: “dig”

Tracing Domain Name Resolution (1)

`dig +trace @8.8.8.8 cs.cornell.edu`  **domain name**
 **public name server by google**

```
dhcp103-45:info4302-website theresavelden$ dig +trace @8.8.8.8 cs.cornell.edu
```

```
; <<>> DiG 9.6-ESV-R4-P3 <<>> +trace @8.8.8.8 cs.cornell.edu
```

```
; (1 server found)
```

```
;; global options: +cmd
```

```
.          11187      IN      NS      h.root-servers.net.
.          11187      IN      NS      g.root-servers.net.
.          11187      IN      NS      a.root-servers.net.
.          11187      IN      NS      k.root-servers.net.
.          11187      IN      NS      m.root-servers.net.
.          11187      IN      NS      e.root-servers.net.
.          11187      IN      NS      d.root-servers.net.
.          11187      IN      NS      j.root-servers.net.
.          11187      IN      NS      f.root-servers.net.
.          11187      IN      NS      l.root-servers.net.
.          11187      IN      NS      i.root-servers.net.
.          11187      IN      NS      b.root-servers.net.
.          11187      IN      NS      c.root-servers.net.
```

**from public name
server**

```
;; Received 228 bytes from 8.8.8.8#53(8.8.8.8) in 20 ms
```

Tracing Domain Name Resolution (2)

```
edu.          172800   IN   NS   g.edu-servers.net.
edu.          172800   IN   NS   c.edu-servers.net.
edu.          172800   IN   NS   l.edu-servers.net.
edu.          172800   IN   NS   f.edu-servers.net.
edu.          172800   IN   NS   d.edu-servers.net.
edu.          172800   IN   NS   a.edu-servers.net.
```

from root server

```
;; Received 267 bytes from 192.36.148.17#53 (i.root-servers.net) in
113 ms
```

```
cornell.edu.  172800   IN   NS   bigred.cit.cornell.edu.
cornell.edu.  172800   IN   NS   dns.cit.cornell.edu.
cornell.edu.  172800   IN   NS   drdns.cit.cornell.edu.
```

from top level
domain server

```
;; Received 143 bytes from 192.31.80.30#53 (d.edu-servers.net) in 25
ms
```

```
cs.cornell.edu.  86400   IN   A    128.84.96.11
cs.cornell.edu.  86400   IN   A    128.84.96.12
cs.cornell.edu.  86400   IN   A    128.84.96.13
cs.cornell.edu.  86400   IN   A    128.84.96.10
cs.cornell.edu.  432000  IN   NS   bigred.cit.cornell.edu.
cs.cornell.edu.  432000  IN   NS   dns.cit.cornell.edu.
cs.cornell.edu.  432000  IN   NS   drdns.cit.cornell.edu.
cs.cornell.edu.  432000  IN   NS   cudns.cit.cornell.edu.
```

```
;; Received 243 bytes from 192.35.82.53#53(dns.cit.cornell.edu) in 1 ms
```

Tracing Domain Name Resolution (2)

```
edu.          172800   IN   NS   g.edu-servers.net.
edu.          172800   IN   NS   c.edu-servers.net.
edu.          172800   IN   NS   l.edu-servers.net.
edu.          172800   IN   NS   f.edu-servers.net.
edu.          172800   IN   NS   d.edu-servers.net.
edu.          172800   IN   NS   a.edu-servers.net.
;; Received 267 bytes from 192.36.148.17#53(i.root-servers.net) in
113 ms
```

```
cornell.edu.  172800   IN   NS   bigred.cit.cornell.edu.
cornell.edu.  172800   IN   NS   dns.cit.cornell.edu.
cornell.edu.  172800   IN   NS   drdns.cit.cornell.edu.
;; Received 143 bytes from 192.31.80.30#53(d.edu-servers.net) in 25
ms
```

```
cs.cornell.edu.  86400   IN   A    128.84.96.11
cs.cornell.edu.  86400   IN   A    128.84.96.12
cs.cornell.edu.  86400   IN   A    128.84.96.13
cs.cornell.edu.  86400   IN   A    128.84.96.10
cs.cornell.edu.  432000  IN   NS   bigred.cit.cornell.edu.
cs.cornell.edu.  432000  IN   NS   dns.cit.cornell.edu.
cs.cornell.edu.  432000  IN   NS   drdns.cit.cornell.edu.
cs.cornell.edu.  432000  IN   NS   cudns.cit.cornell.edu.
;; Received 243 bytes from 192.35.82.53#53(dns.cit.cornell.edu) in 1 ms
```

#53 ???



TCP/UDP Sockets (“Virtual Ports”)

19	TCP	UDP	Character Generator Protocol (CHARGEN)
20	TCP		FTP—data transfer
21	TCP		FTP—control (command)
22	TCP		Secure Shell (SSH)—used for secure logins, file transfers (<i>scp</i> , <i>sftp</i>) and port forwarding
23	TCP		Telnet protocol—unencrypted text communications
24	TCP	UDP	Priv-mail : any private mail system.
25	TCP		Simple Mail Transfer Protocol (SMTP)—used for e-mail routing between mail servers
26	TCP	UDP	Unassigned
27	TCP	UDP	NSW User System FE
29	TCP	UDP	MSG ICP
33	TCP	UDP	Display Support Protocol
35	TCP	UDP	Any private printer server protocol
37	TCP	UDP	TIME protocol
39	TCP	UDP	Resource Location Protocol ^[7] (RLP)—used for determining the location of higher level services
40	TCP	UDP	Unassigned
42	TCP	UDP	ARPA Host Name Server Protocol
42	TCP	UDP	Windows Internet Name Service
43	TCP		WHOIS protocol
47	TCP	UDP	NI FTP ^[7]
49	TCP	UDP	TACACS Login Host protocol
50	TCP	UDP	Remote Mail Checking Protocol ^[8]
51	TCP	UDP	IMP Logical Address Maintenance
52	TCP	UDP	XNS (Xerox Network Systems) Time Protocol
53	TCP	UDP	Domain Name System (DNS)
54	TCP	UDP	XNS (Xerox Network Systems) Clearinghouse

http://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers

What is the Internet route from cornell.edu to destinations abroad?

Examples:

- Max-Planck-Society (Germany)
- Chinese Academy of Sciences? (China)

How traceroute works:

- Sequence of packets send to a destination server
 - Windows: ICMP(Internet Control Message Protocol) echo requests
 - UNIX/LINUX: UDP + (unlikely) port number
- Count down of TTL (time-to-live) with each hop (port number in UNIX/LINUX case)
- When TTL=0, ICMP error message 'TTL exceeded in transit' is returned
- Traceroute determines IP of last hop from source field of error message, and time stamp for round trip
- Set of successive packets, each with TTL+1
- Latency:
 - Per round trip (return may differ from outgoing path and speed)
 - Physical distance matter! light through fiber = $\sim 200,000\text{km/sec}$, \rightarrow 200km (or 125 miles) per millisecond

traceroute

```
dhcp103-45:info4302-website theresavelden$ traceroute -I mpg.de
traceroute to mpg.de (134.76.31.209), 64 hops max, 52 byte packets
 1  csgate8 (128.84.103.2)  1.842 ms  1.600 ms  1.536 ms
 2  aerberus-rt (128.84.103.146)  0.883 ms  0.697 ms  0.753 ms
 3  rhodes1-6500-vl339.net.cornell.edu (128.84.154.1)  1.037 ms  0.918 ms
 4  core1-6500-te3-3.net.cornell.edu (128.253.222.161)  1.095 ms  1.256 ms
 5  nyc1-6500-vl11.net.cornell.edu (128.253.222.14)  9.065 ms  8.945 ms  9
 6  newy-nlr-vl4000.nelr.net (192.35.82.129)  8.998 ms  8.901 ms  8.835 ms
 7  216.24.184.86 (216.24.184.86)  83.941 ms  84.049 ms  84.031 ms
 8  so-2-0-0.rtl.fra.de.geant2.net (62.40.112.9)  90.824 ms  90.959 ms  10
 9  dfn-gw.rtl.fra.de.geant.net (62.40.124.34)  91.677 ms  92.054 ms  91.6
10  zr-han1-te0-0-0-1.x-win.dfn.de (188.1.145.214)  103.041 ms  103.042 ms
11  xr-goel-te1-1.x-win.dfn.de (188.1.144.70)  104.882 ms  104.831 ms  10
12  kr-gwdg.x-win.dfn.de (188.1.231.126)  104.841 ms  104.817 ms  104.901
13  gr-gwdg1-fvrf-int.gwdg.de (134.76.249.185)  104.849 ms  104.913 ms  1
14  public.web.mpg.de (134.76.31.209)  117.142 ms  116.965 ms  117.271 ms
```


traceroute

```
dhcp103-45:info4302-website theresavelden$ traceroute -I mpg.de
traceroute to mpg.de (134.76.31.209), 64 hops max, 52 byte packets
```

```
***** CORNELL LAN *****
```

```
1  csgate8 (128.84.103.2)  1.842 ms  1.600 ms  1.536 ms
2  aerberus-rt (128.84.103.146)  0.883 ms  0.697 ms  0.753 ms
3  rhodes1-6500-vl339.net.cornell.edu (128.84.154.1)  1.037 ms  0.918 ms
4  core1-6500-te3-3.net.cornell.edu (128.253.222.161)  1.095 ms  1.256 ms
5  nyc1-6500-vl11.net.cornell.edu (128.253.222.14)  9.065 ms  8.945 ms  9
```

```
***** CORNELL DMZ *****
```

```
6  newy-nlr-vl4000.nelr.net (192.35.82.129)  8.998 ms  8.901 ms  8.835 ms
```

```
***** National LambdaRail *****
```

```
7  216.24.184.86 (216.24.184.86)  83.941 ms  84.049 ms  84.031 ms
```

```
***** GEANT European Backbone *****
```

```
8  so-2-0-0.rtl.fra.de.geant2.net (62.40.112.9)  90.824 ms  90.959 ms  10
```

```
9  dfn-gw.rtl.fra.de.geant.net (62.40.124.34)  91.677 ms  92.054 ms  91.6
```

```
***** German Research Network X-Win *****
```

```
10  zr-han1-te0-0-0-1.x-win.dfn.de (188.1.145.214)  103.041 ms  103.042 ms
```

```
11  xr-goel-te1-1.x-win.dfn.de (188.1.144.70)  104.882 ms  104.831 ms  10
```

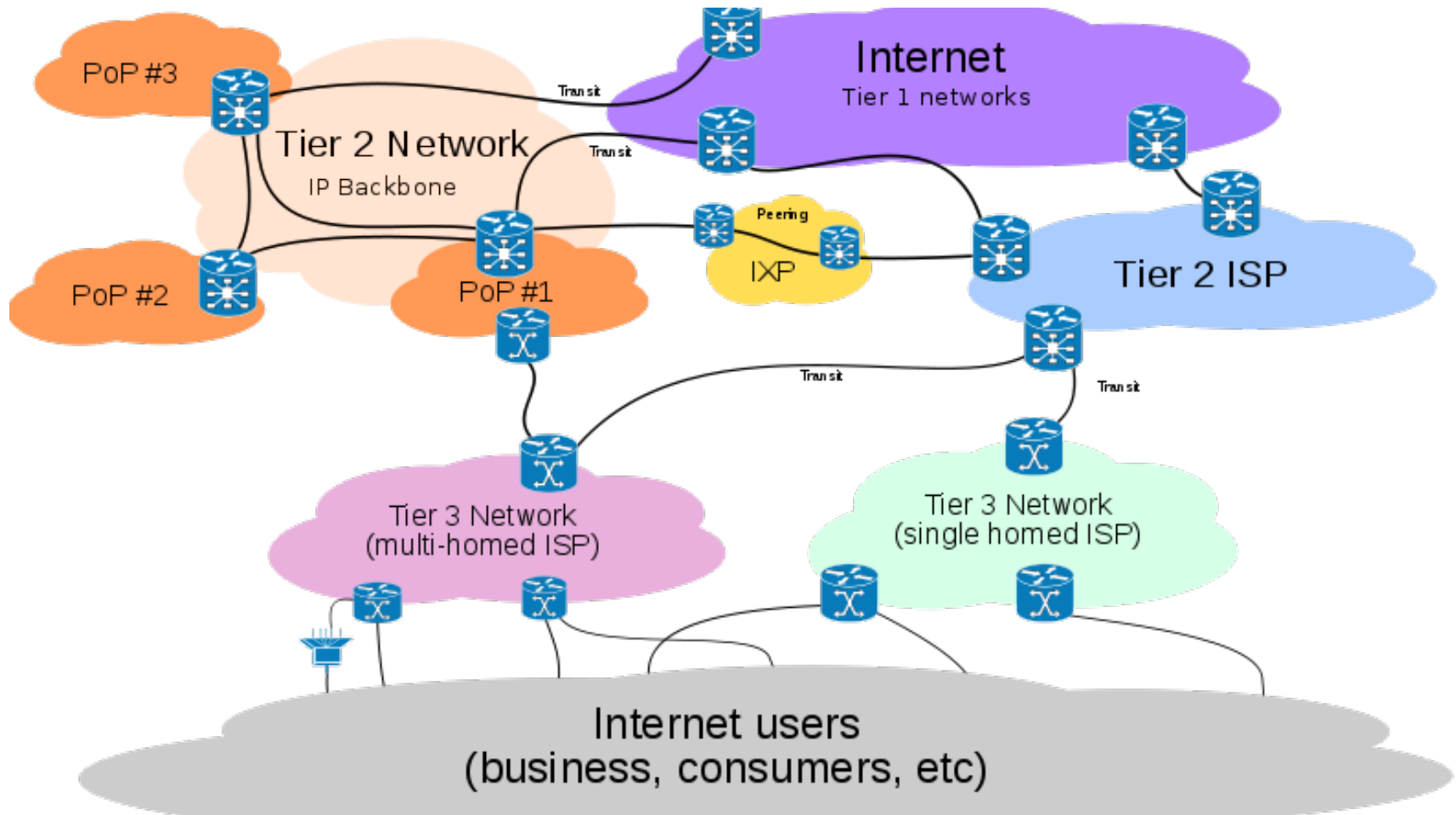
```
12  kr-gwdg.x-win.dfn.de (188.1.231.126)  104.841 ms  104.817 ms  104.901
```

```
***** Max Planck Computing Center *****
```

```
13  gr-gwdg1-fvrf-int.gwdg.de (134.76.249.185)  104.849 ms  104.913 ms  1
```

```
14  public.web.mpg.de (134.76.31.209)  117.142 ms  116.965 ms  117.271 ms
```

Internet Routing Architecture

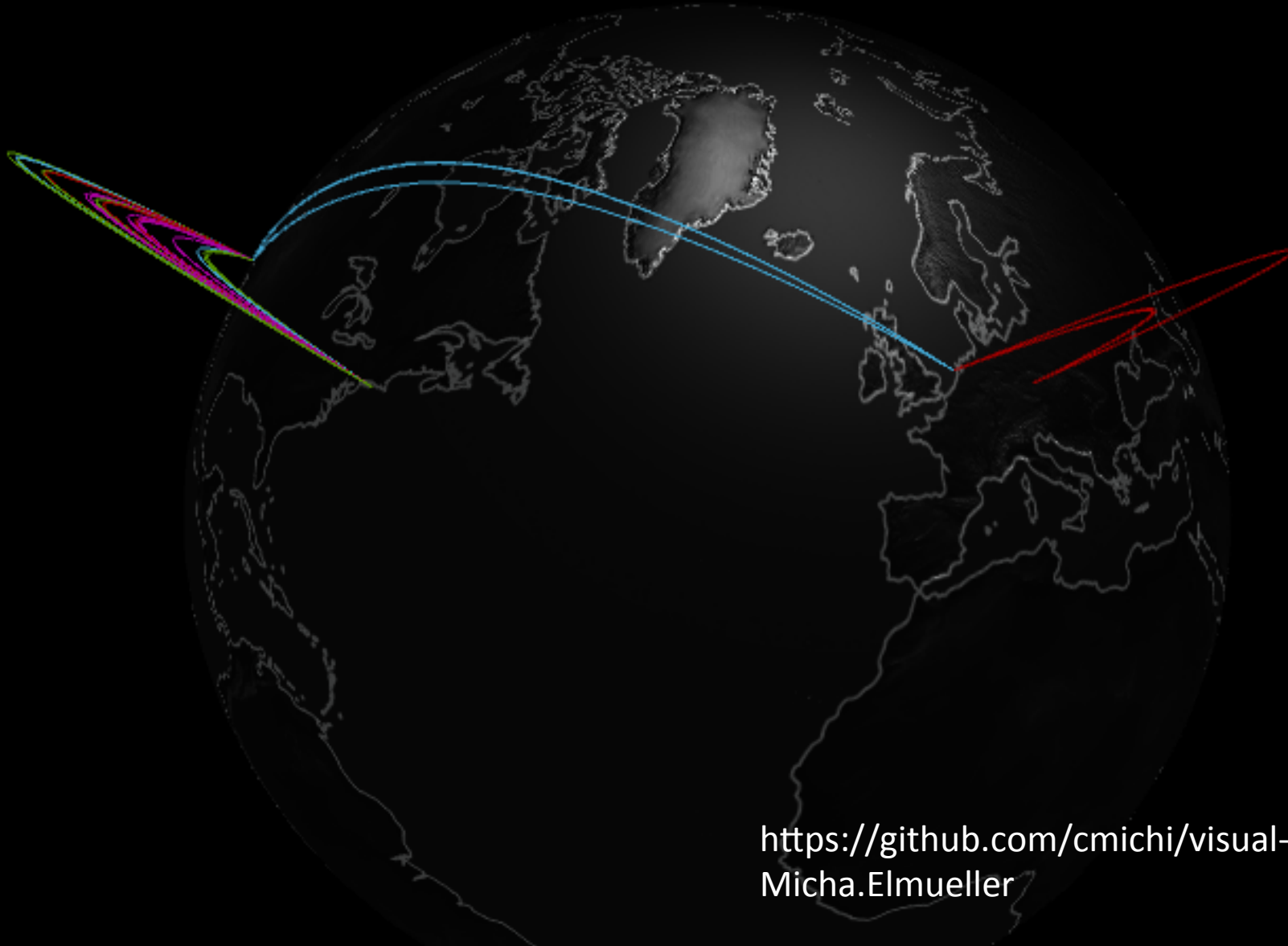


Source & further reading: http://en.wikipedia.org/wiki/Tier_1_network

traceroute Visualization

Traceroute visualization

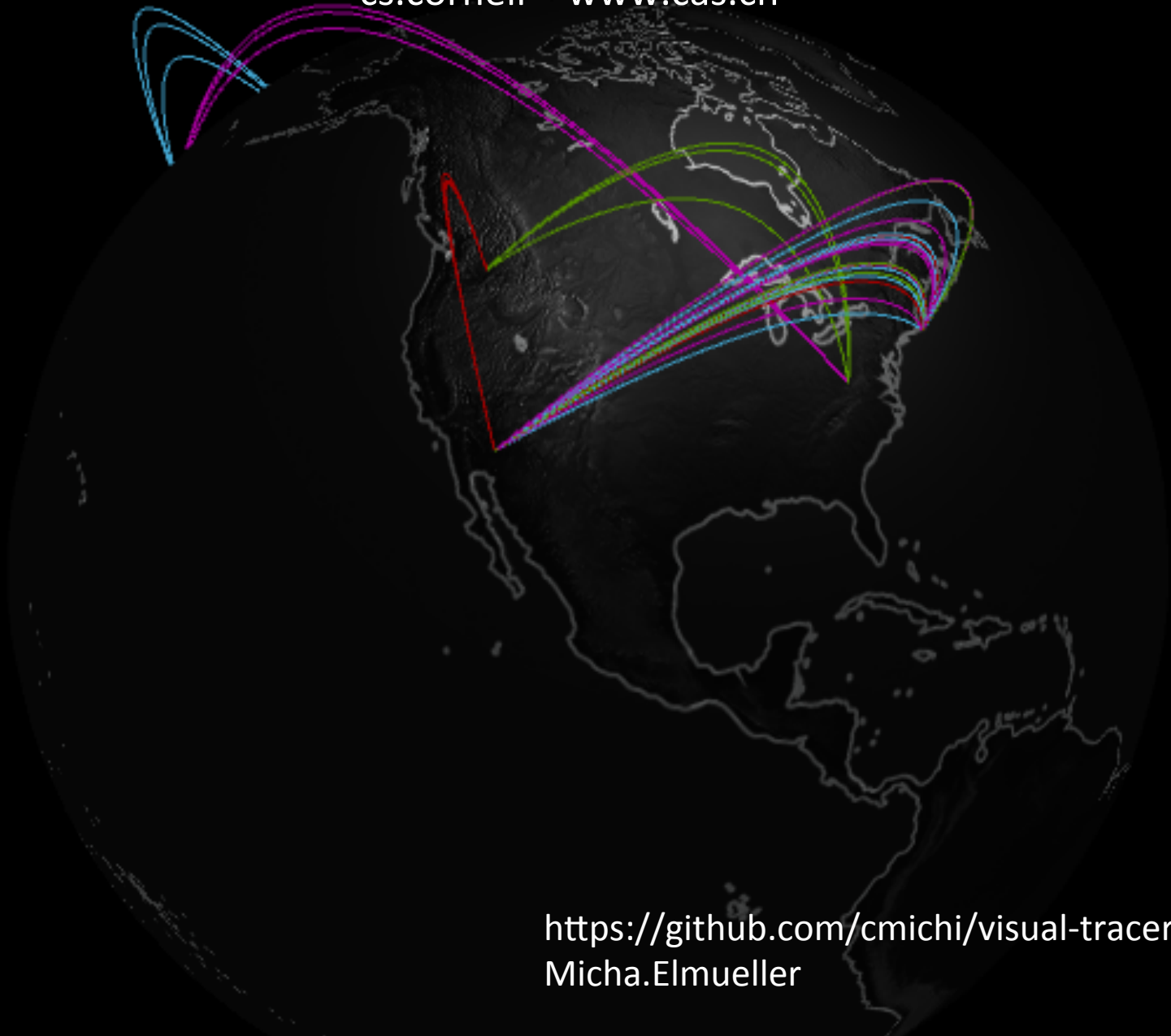
cs.cornell – www.mpg.de



<https://github.com/cmichi/visual-traceroute>
Micha.Elmüller

Traceroute visualization

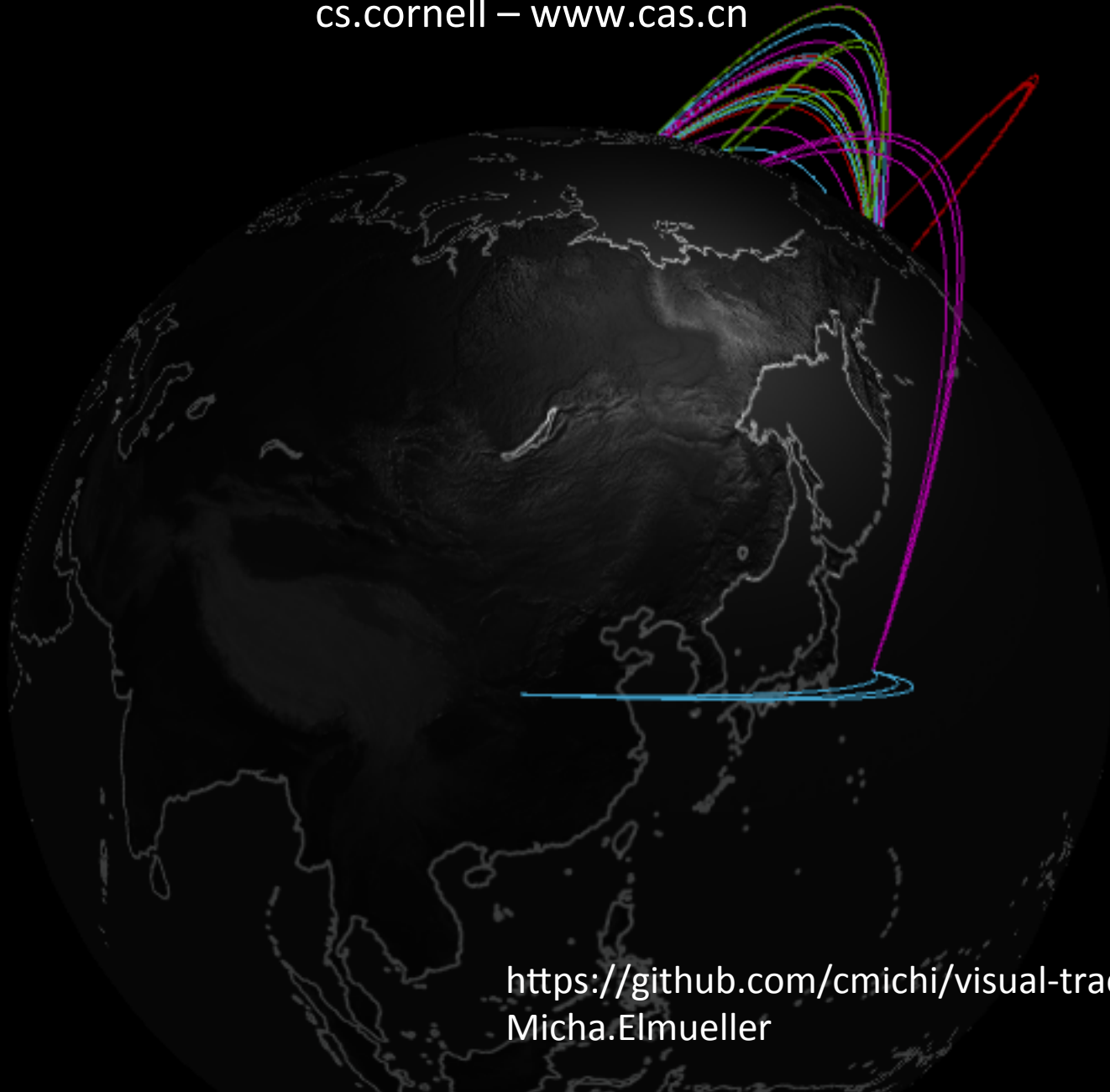
cs.cornell – www.cas.cn



<https://github.com/cmichi/visual-traceroute>
Micha.Elmüller

Traceroute visualization

cs.cornell – www.cas.cn



<https://github.com/cmichi/visual-traceroute>
Micha.Elmüller

MEASURING THE GROWTH OF THE INTERNET

The Growth of The Internet

- 4 billion IPv4 addresses depleted....

2-Layer Internet Routing Architecture

- Interdomain routing: Border Gateway Protocol (EBGP)
RFC4271 (Jan 2006)
- Internal routing (Interior Gateway Protocol, IBGP)
 - Domain specific routing policies
 - Domains = Autonomous Systems
 - Not every domain network has a ASN (ASNs express distinct interdomain routing policies)

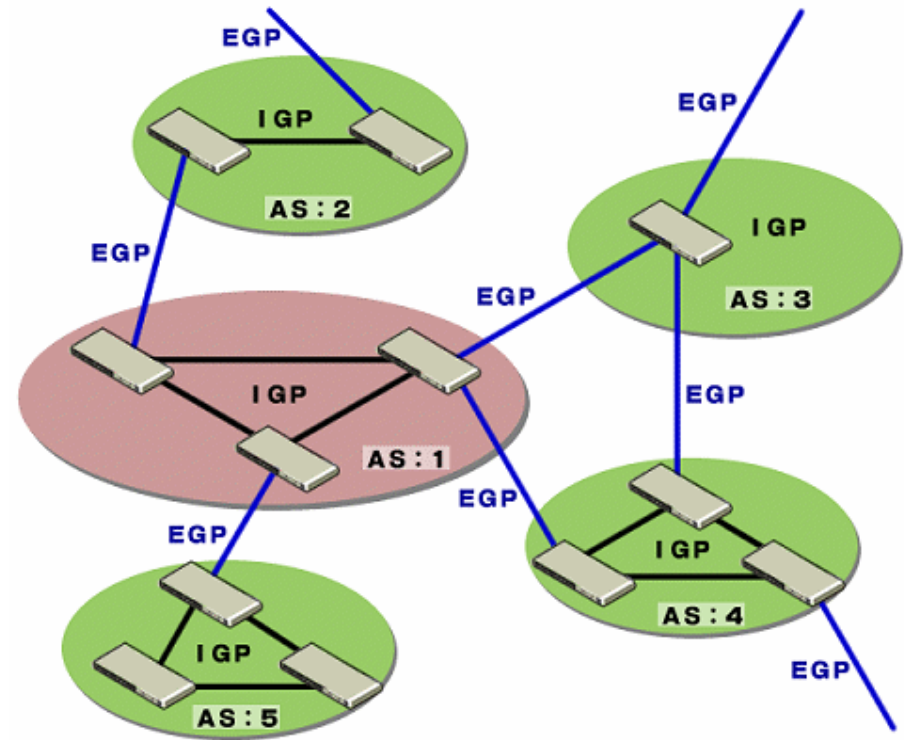


Image source: <http://www.atmarkit.co.jp/fnetwork/rensai/iprt01/iprt01.html>

Autonomous Systems (AS)

“The classic definition of an Autonomous System is a **set of routers under a single technical administration, using an interior gateway protocol (IGP) and common metrics to determine how to route packets within the AS, and using an inter-AS routing protocol to determine how to route packets to other ASes.** Since this classic definition was developed, it has become common for a single AS to use several IGPs and, sometimes, several sets of metrics within an AS.” [source: RFC 4271 (BGP-4, January 2006) Autonomous System (AS)]

AS Number:

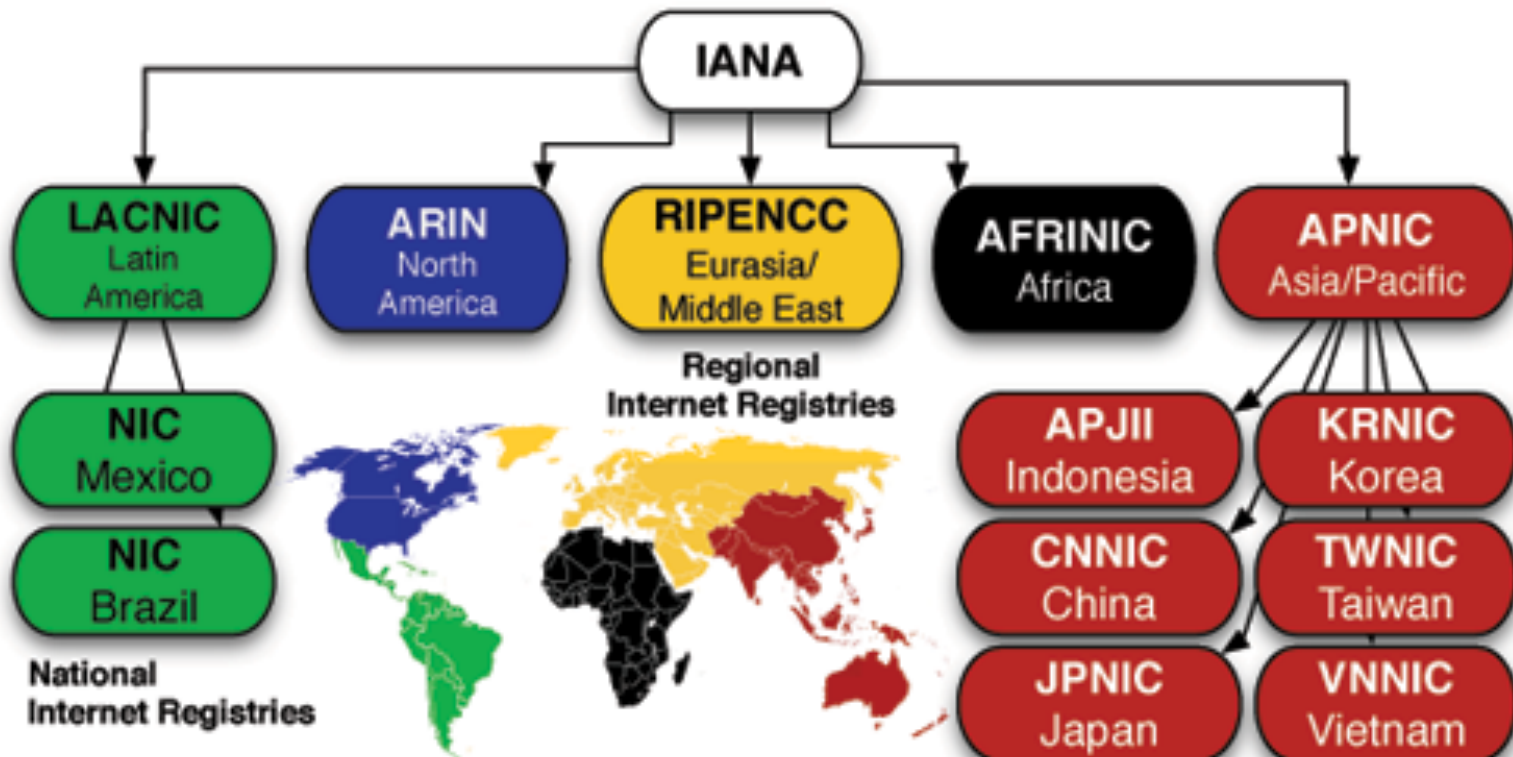
Historical: 16 bit number (65,536 values) [expected to be exhausted by 5 Jul 2014, see <http://www.potaroo.net/tools/asns/>]

Since January 2007: 32 bit number (4,294,967,296 values)

[source:

http://www.cisco.com/web/about/ac123/ac147/archived_issues/ipj_9-1/autonomous_system_numbers.html, Geoff Huston, APNIC]

Internet Registries



16 bit AS numbers (status as of 2012)

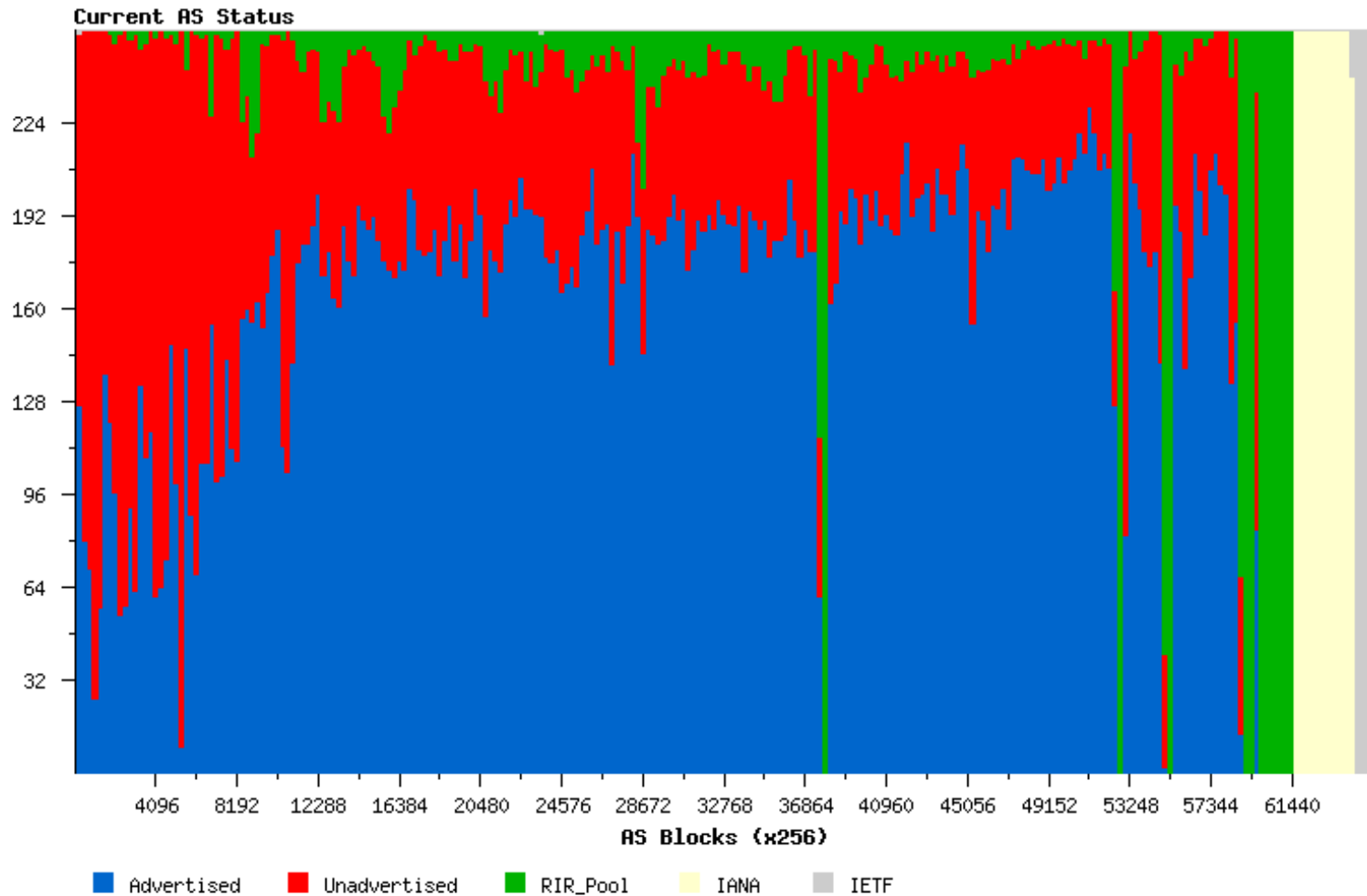


Figure 5 - AS Number Status

16 bit AS numbers (evolution)

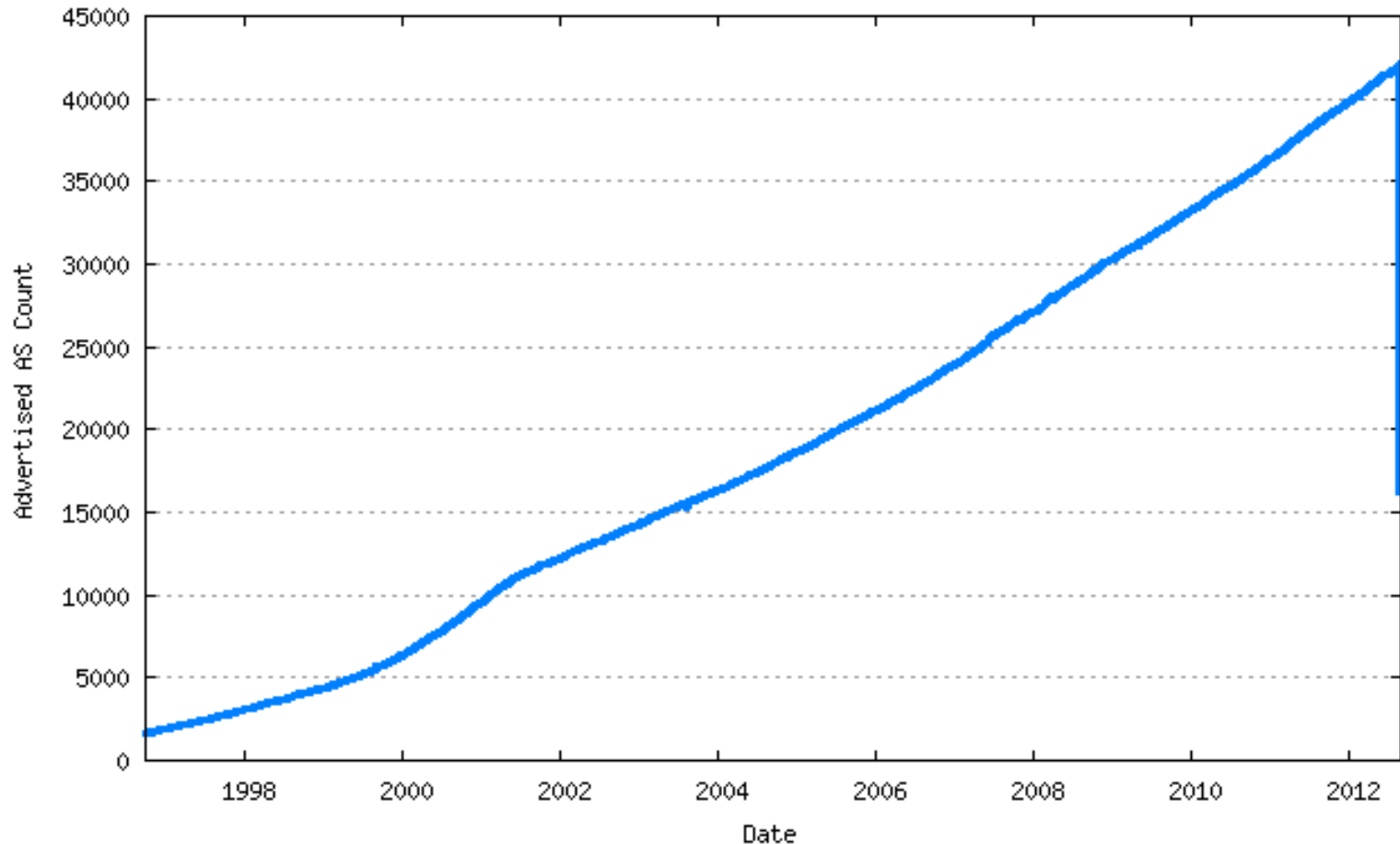


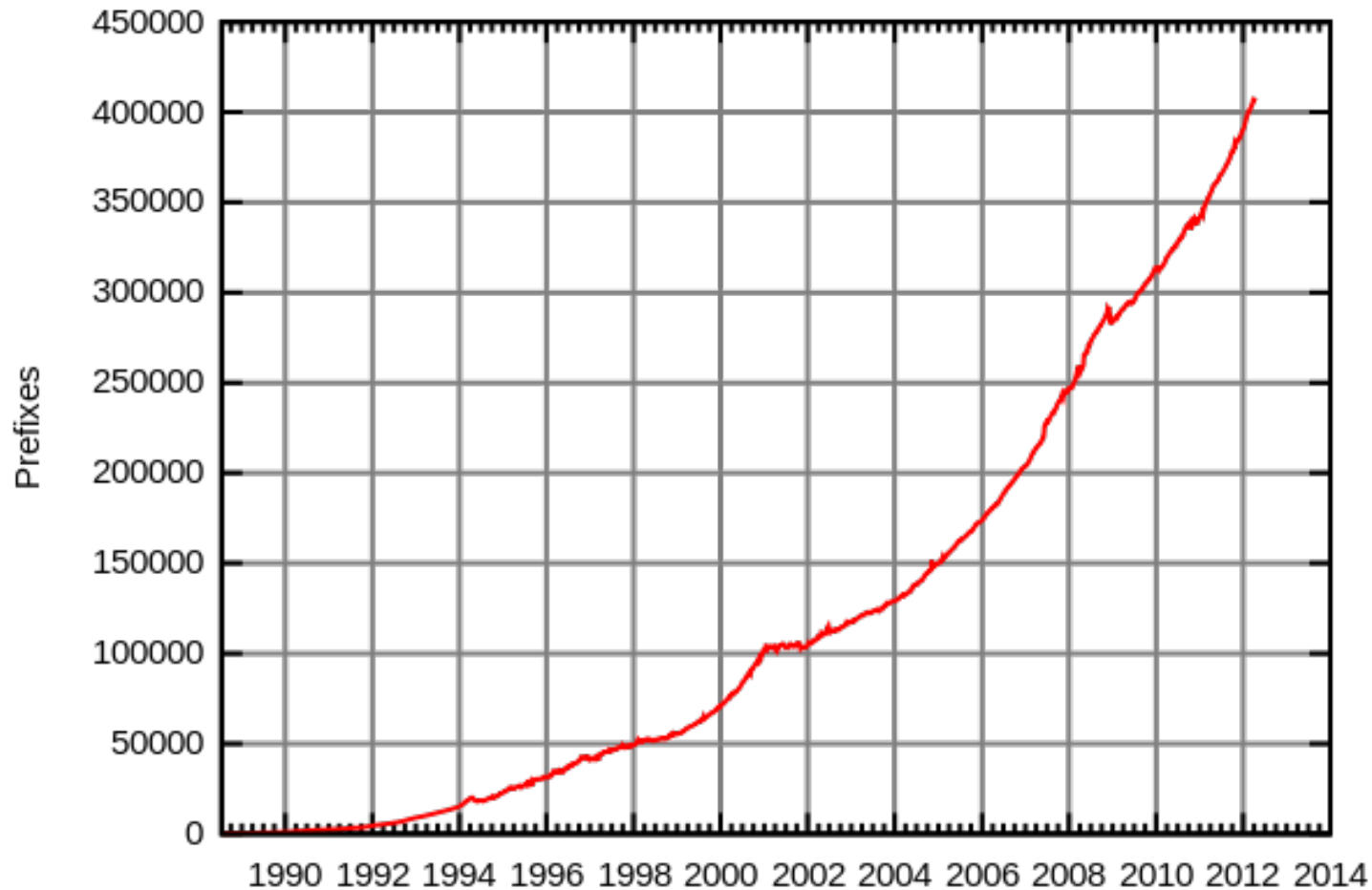
Figure 11 - Advertised AS Count

Border Gateway Protocol Routing Tables

- Essential to the decentralized nature of the Internet
- Uses Transfer Control Protocol (TCP), port 179
- Manually configured connections to peer (neighbors)
- Peers exchange routing information
- BGP Routing tables:
 - Paths (AS numbers) to destinations (only one per destination in forwarding table)
 - Broadcast 'update' to neighbors, add own AS number as prefix
 - Updates from neighbors stored in Routing Information Base (RIB)
 - Routers import no loops

Routing Table Growth 1990-2014

Prefixes announced
on the Internet

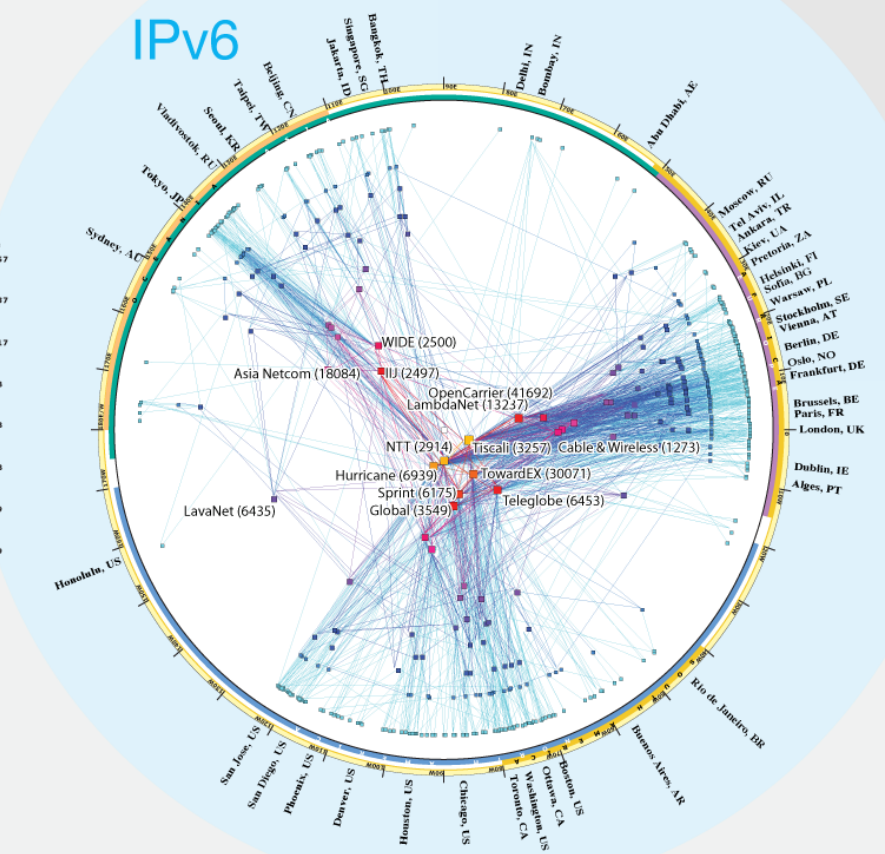
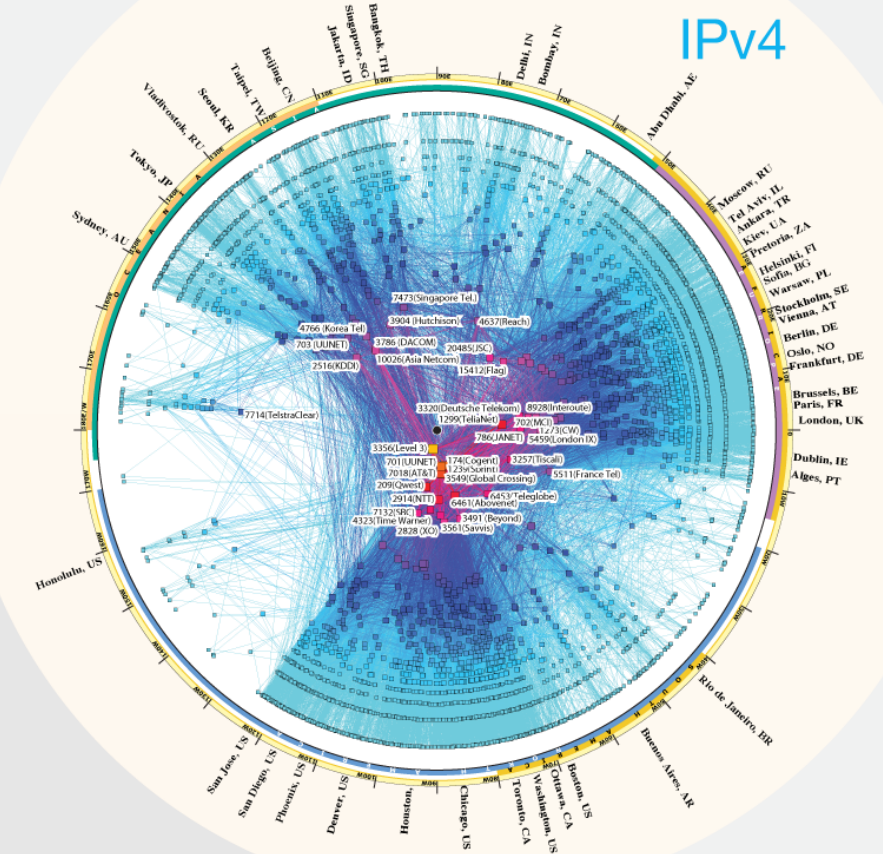


Source: wikipedia at http://en.wikipedia.org/wiki/File:Routing_Table_growth.svg; Based on the data from the CIDR report by T. Bates and al. See also <http://bgp.potaroo.net/>

AS Network Visualization

CAIDA's IPv4 & IPv6 AS Core
AS-level INTERNET GRAPH

Archipelago & Community Collected January 2008



Dates	Number of IP address	Number of IP links	Number of ASes	Number of ASlinks
IPv4 Jan. 2nd-17th, 2008	4,853,991	5,682,419	17,791	50,333
IPv6 Jan. 1st-8th, 2008	4,752	17,036	489	1,904

This visualization represents macroscopic snapshots of the IPv4 and IPv6 Internet topologies observed during the first week of January 2008. It simultaneously illustrates the peering richness of each topology and the worldwide distribution of nodes in each routing system.

The IPv4 data was collected between January 2nd and 17th 2008 by 13 CAIDA archipelago monitors located in 13 different cities, 11 countries and 3 continents: The monitors probed paths toward 48M IPv4 networks spread across 95% of the prefixes seen in Route Views Border Gateway Protocol (BGP) routing tables on 1 January 2008.

The IPv6 data was collected between January 1st and 8th 2008 by volunteers responding to a request sent to the North American Network Operators' Group (IANOG) mailing list. The volunteers scanned 63 different IPv6 destinations.

3 continents. They used the scamper command-line tool to probe 2.358 IPv6 destinations spread across 822 prefixes or 81% of the prefixes seen by RIPE NCC on 1 January 2008.

We aggregated these network views to construct IPv4 and IPv6 Internet graphs at the Autonomous System (AS) level. Each AS approximately corresponds to an Internet Service Provider (ISP). We map each IP address to the AS responsible for routing traffic to it, i.e., to the origin (end-of-path) AS for the IP prefix representing the best match of this address in BGP routing tables. For the IPv4 graph we used the BGP IPv4 routing table collected by Route Views. For the IPv6 graph we used the IPv6 routing table collected by RIPE NCC.

The position of each AS node is plotted in polar coordinates, position (radius, angle) calculated using the following

$$\text{radius} = 1 - \log \left(\frac{\text{outdegree}(\text{AS}) + 1}{\text{maximum outdegree} + 1} \right)$$

$$\text{angle} = \left(\frac{\text{longitude of the AS's BGP prefixes in netica}}{\text{longitude of the AS's BGP prefixes in netica}} \right)$$

The outdegree of an AS node is the number of next-hop ASes that were observed accepting our probe traffic from this AS. The link color reflects outdegree, from lowest (blue) to highest (yellow). Toward the center of the graph we have manually labeled some of the higher degree ASes with their associated ISPs.

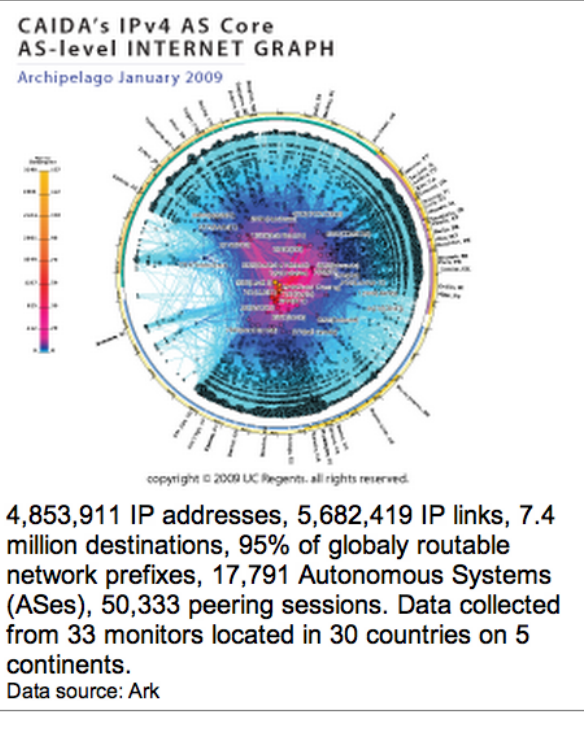
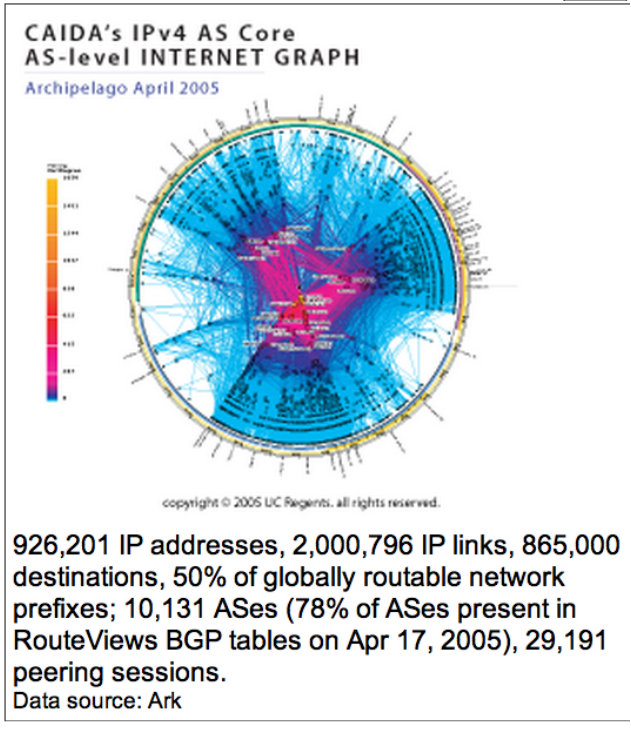
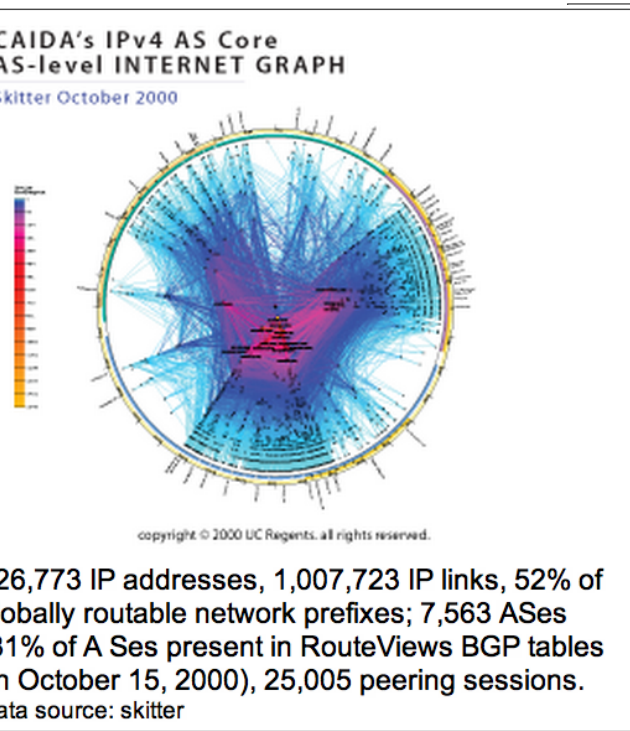
To determine the longitude of ASes, we used the IPv4 BGP table from Route Views and mapped each AS to its set of announced IPv4 prefixes. IPv4 tables are currently much larger, facilitating more accurate inference of geographic coverage of an AS. We

Envoy's Netacuity (R) mapped to a single geographic location in January 2008. We calculated the AS angle coordinate from the weighted average (by number of IP addresses in each mapped prefix) of the longitude coordinates of these prefixes.

The IPv6 graph with 486 ASes remains much smaller than the IPv4 graph with 18,753 ASes. While the IPv4 graph's central core is still dominated by American ASes, the IPv6 graph center is more balanced between American and Europe. A European ISP Tiscali (3257) has replaced the previously highest ranking AS NTT (2914), since our last IPv6 Internet AS core graph in 2005. Although NTT is a Japanese telecommunication company, the address space it uses for AS 2914 comes from the American company Verio, which NTT purchased in 2000. The fact that the largest AS in the IPv6 graph is European and that the other European ASes are comparable in degree to the American ASes

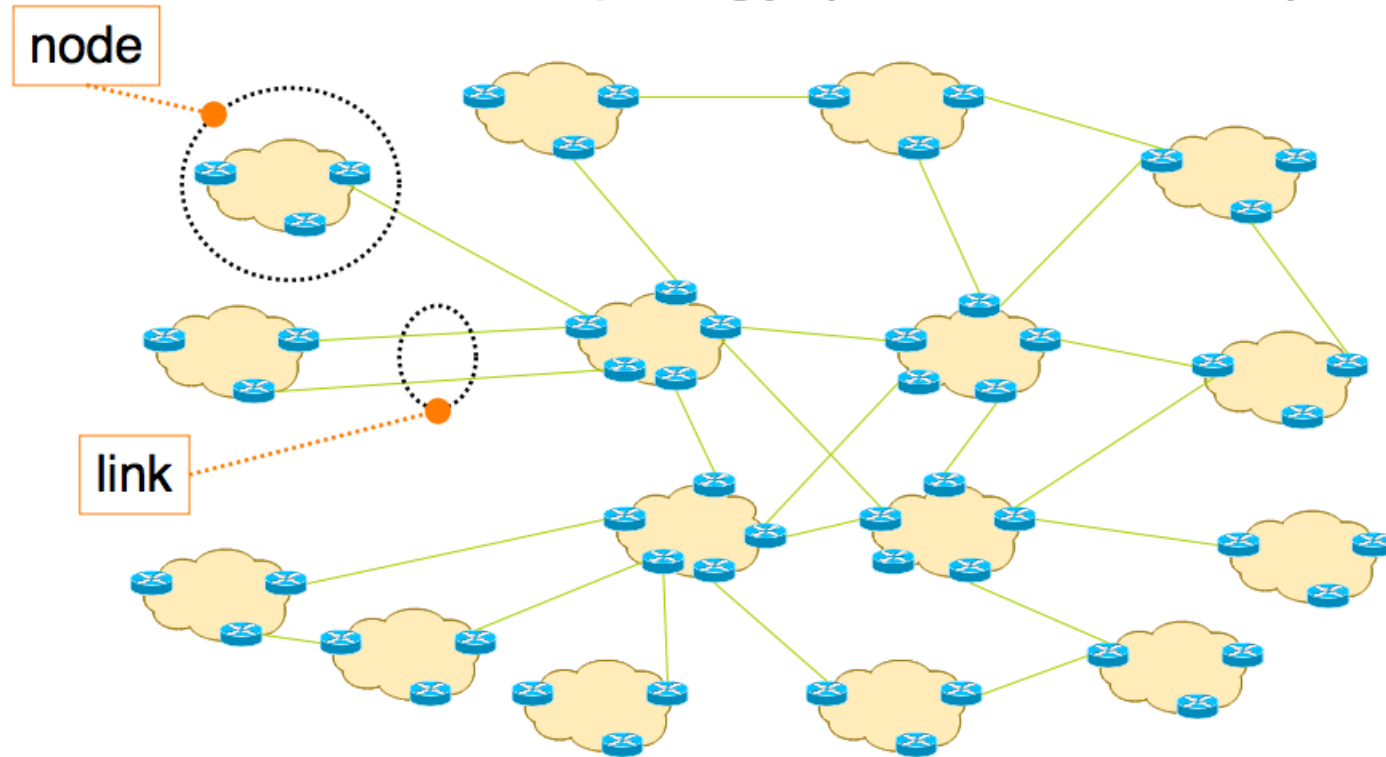
ANALYSIS TEAM: Bradley Huffaker, Kc Claffly, SOF FOWLER DEVELOPMENT: Young Hyun, Matthew Luckie, ROSTER DESIGN: Jennifer Hsu
COOPERATIVE ASSOCIATION FOR INTERNET DATA ANALYSIS: San Diego Supercomputer Center, University of California, San Diego, 350 Gilman Drive, #0601, La Jolla, CA 92093-0601, 858-534-5000, <http://www.caida.org/>
RIPE ROUTES: ARNET, ARPA, ARIX, ASTI Institute, CANET, CNIC, CNIS, ELINET, FomConer, HEANet (Iowa State University), KRIOnet2, Purdue University, BNP, FXK, Universitat Leipzig, Universitat Politècnica, University of Cambridge, University of Hawaii, University of Walsate
ACKNOWLEDGMENTS FOR IPv4: APNIC, AfriNIC, Alexander Gali, Anders Johansson, Antonio Prado, Antonio Querubin, ARIN, Axel Fernandez Alcantara, Bernhard Schmidt, Brad Dreibach, Brian Fitzgerald, CADA, Chris Morrow, Derek Mann, Gabriel Kerpen, Geoff Huston, Gen Steenberg, IFC, Jitichan Watt, Benjamin, Jean-Philippe Pica, John Kriestoff, John Dirmov, Sergio Cho, Kurt Jaeger, LACNIC, Martin Milekic, Mathias Arnold, RIPE NCC, Nuno Vieira, Olivier Robert, Sebastian Abt, Shane Kerr
Copyright (c) 2008 UC Regents http://www.caida.org/research/topology/as_core_network/
All rights reserved.

Historical AS Network Evolution



Issues with measuring Internet Topology

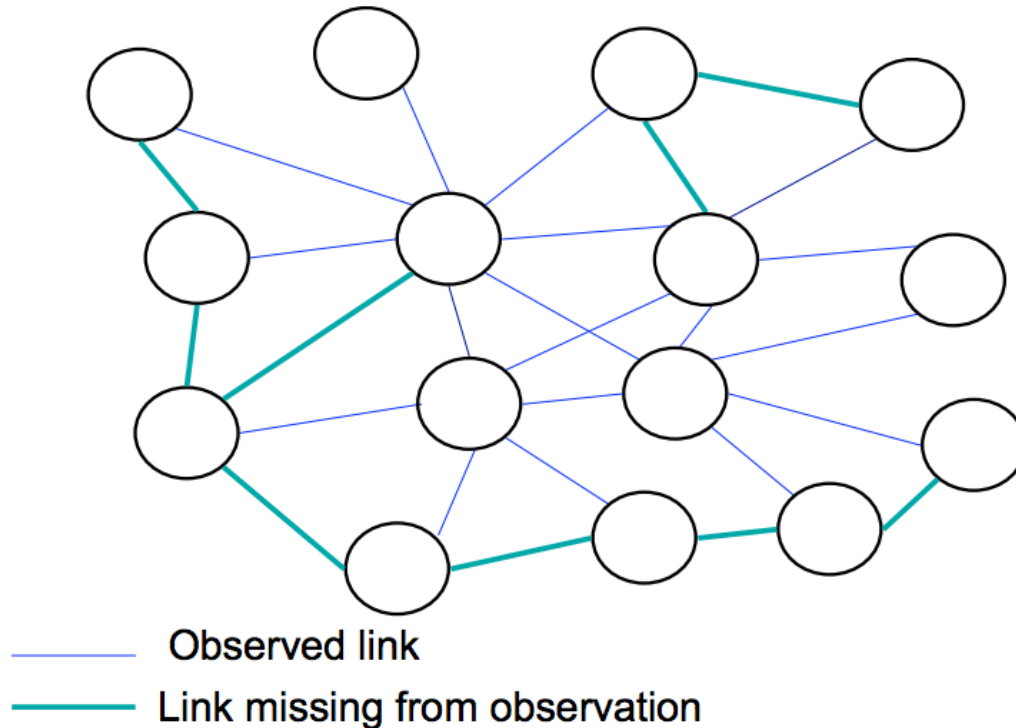
Internet AS topology (the abstraction)



Source: Ricardo Oliveira, Dan Pei, Walter Willinger, Beichuan Zhang, Lixia Zhang, "In Search of the Elusive Ground Truth: The Internet's AS-level Connectivity Structure", ACM SIGMETRICS, Annapolis, Maryland, June 2008.

Issues with measuring Internet Topology

Completeness of the AS graph



4

Source: Ricardo Oliveira, Dan Pei, Walter Willinger, Beichuan Zhang, Lixia Zhang, "In Search of the Elusive Ground Truth: The Internet's AS-level Connectivity Structure", ACM SIGMETRICS, Annapolis, Maryland, June 2008.

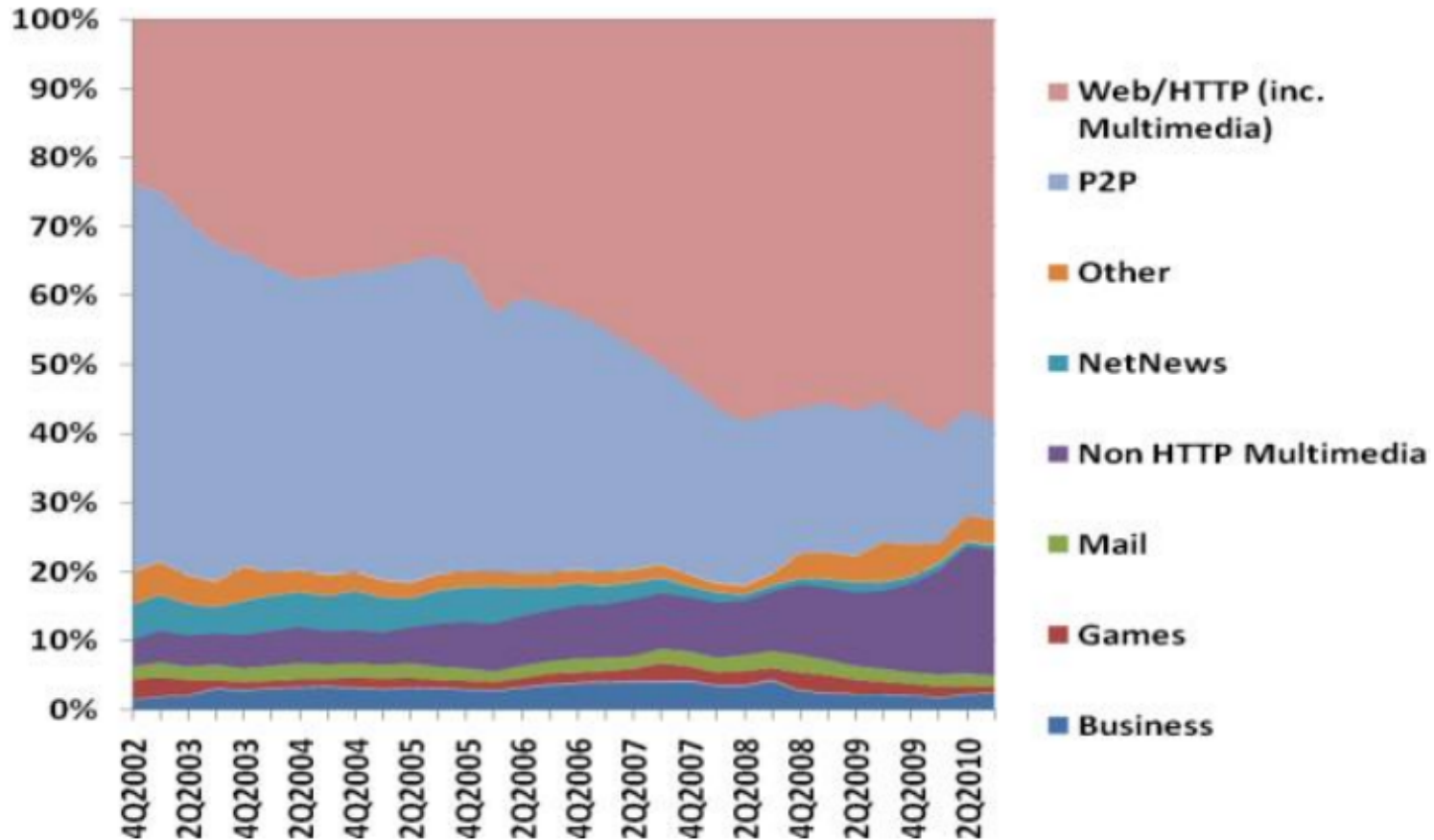
Words of caution about measuring Internet topology via BGP tables or using traceroute

M. Roughan, W. Willinger, O. Maennel, D. Perouli, and R. Bush, 10 Lessons from 10 Years of Measuring and Modeling the Internet's Autonomous Systems, IEEE Journal on Selected Areas in Communications, Vol. 29, No. 9, pp. 1-12, Oct. 2011.

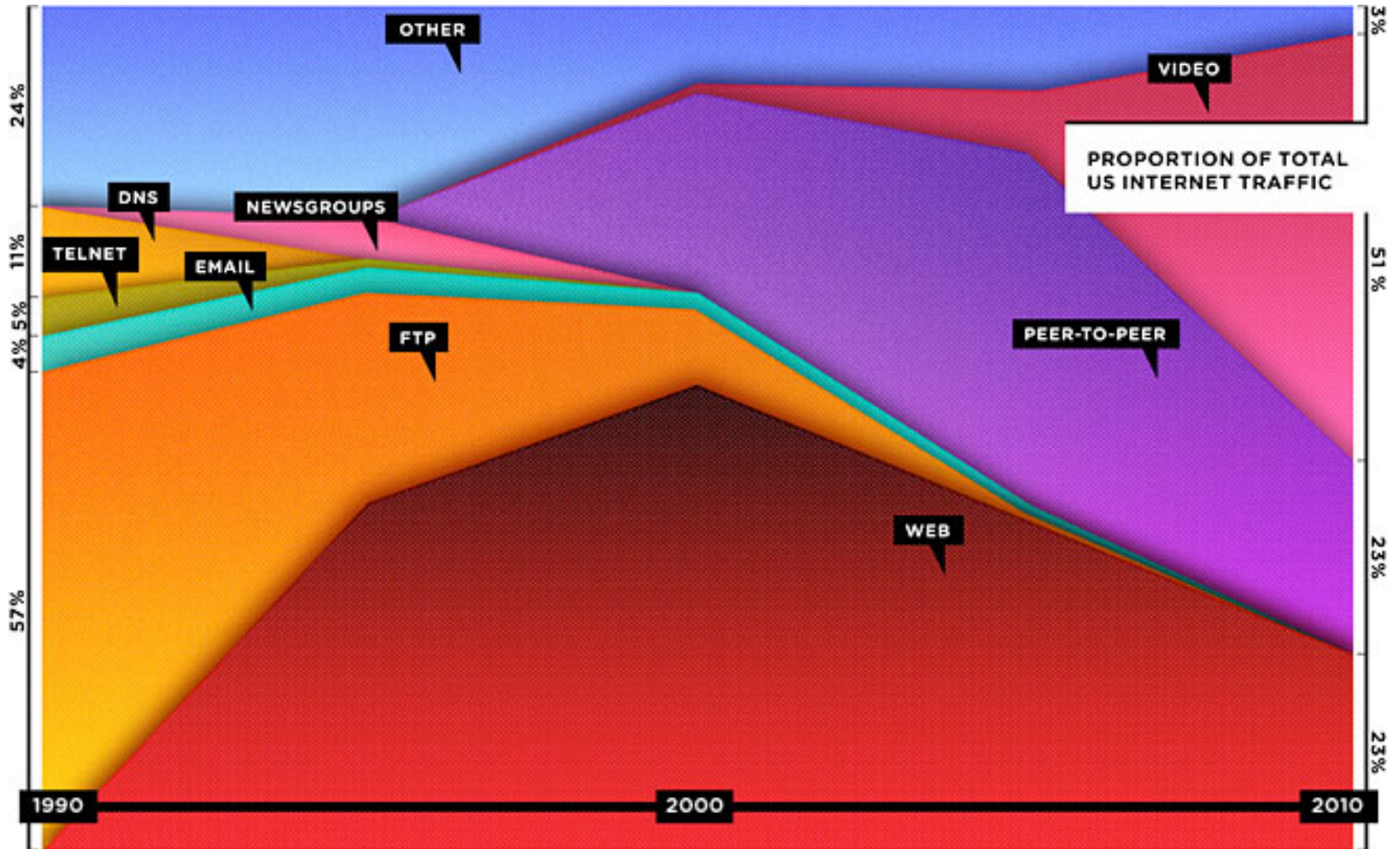
Ricardo Oliveira, Dan Pei , Walter Willinger, Beichuan Zhang, Lixia Zhang, "The (in)Completeness of the Observed Internet AS-level Structure", IEEE/ACM Transactions on Networking, February 2010.

Types of Internet Traffic

- http://www.research.att.com/techdocs/TD_100193.pdf



Types of Internet Traffic



[Source: Wired Magazin 2011]

OUTLOOK:

WEEK 6 (CROSS CUTTING ISSUE)

Net Neutrality & Openness



Tim Berners Lee

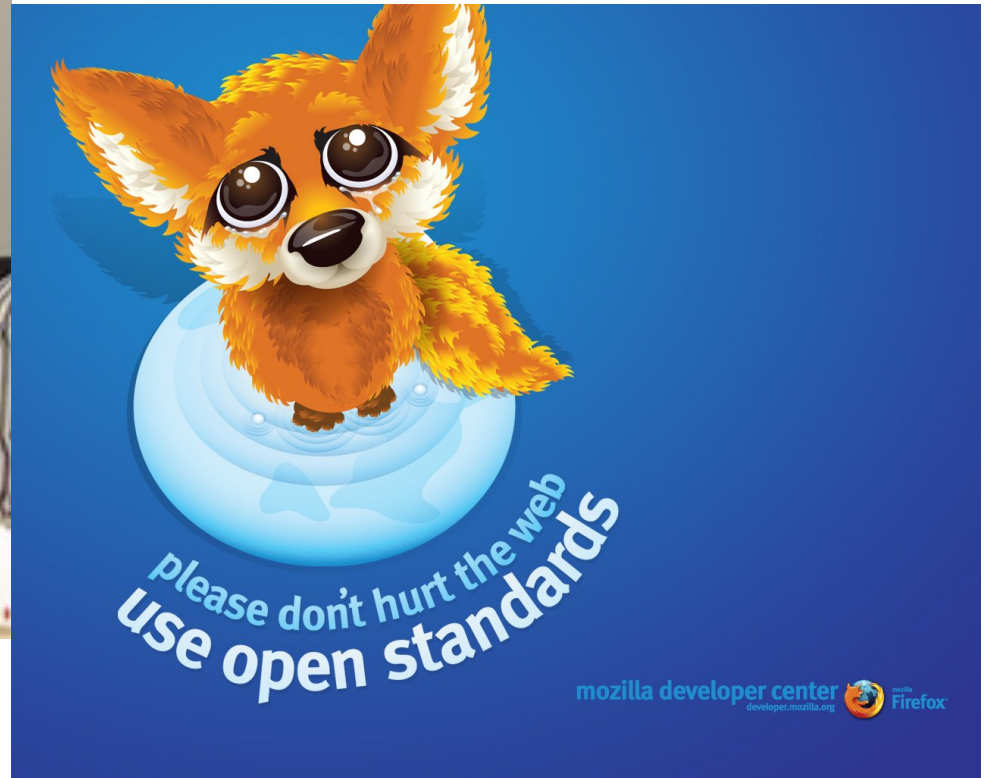
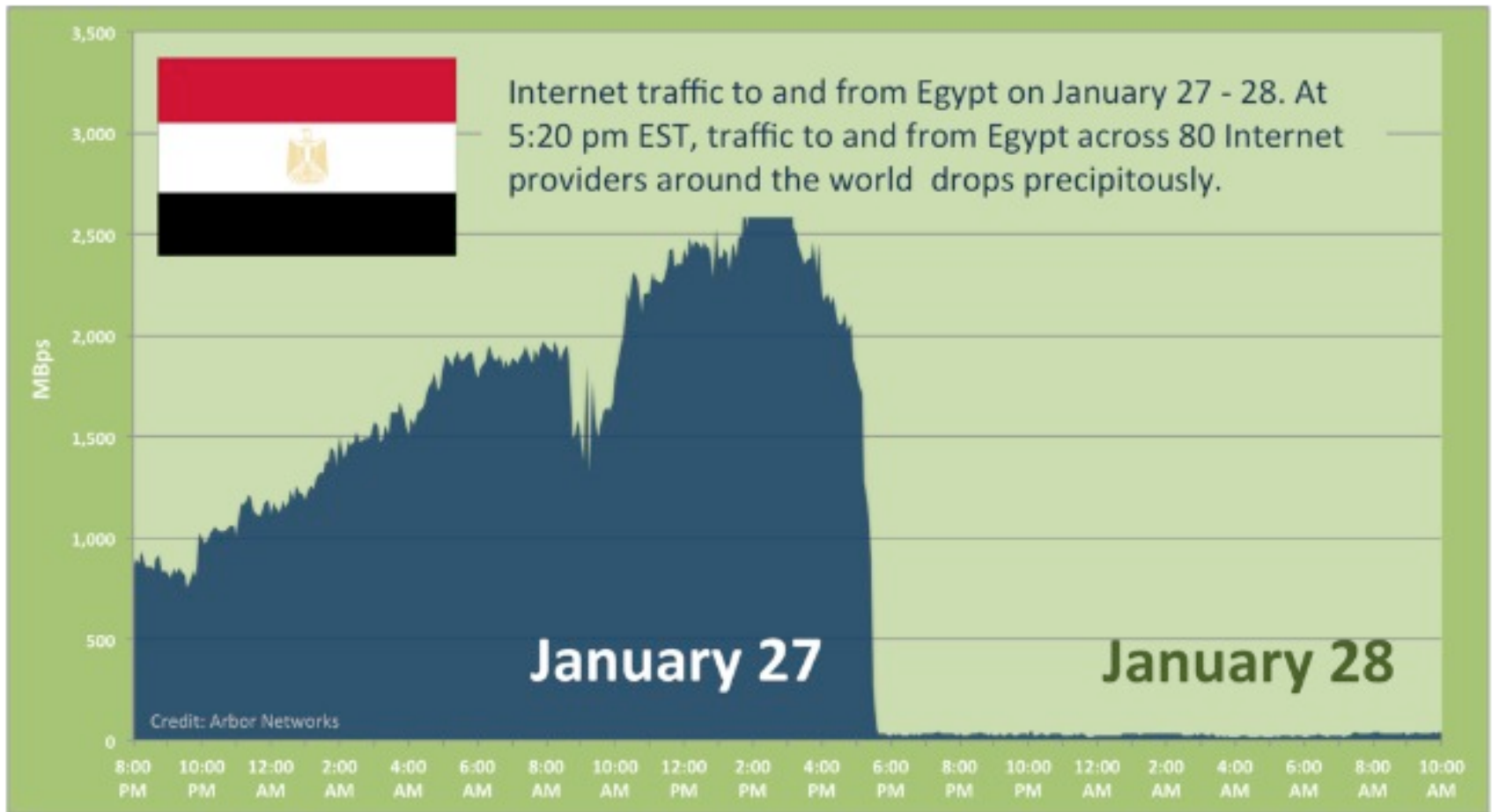


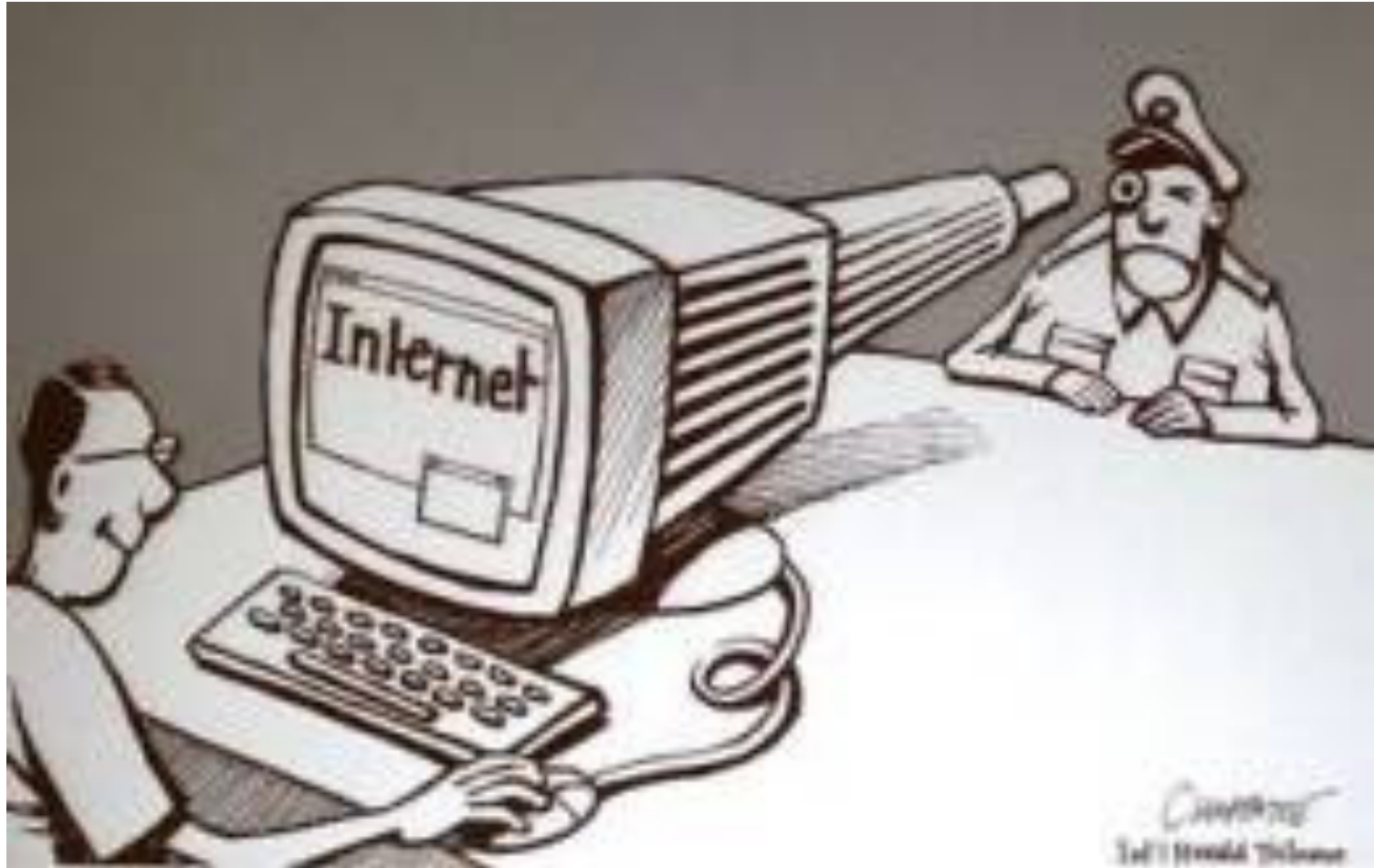
Photo of Tim Berners-Lee by Jim Grisanzio, released under a Creative Commons license

Internet Censorship



Source: arbor networks <http://ddos.arbornetworks.com/2011/01/egypt-loses-the-internet/>

Internet Surveillance



Cartoon by: Patrick Chappatte (International Herald Tribune)

Cast your vote on piazza:

Cross Cutting Issue for Week 6:

1. Net Neutrality
2. Internet Censorship
3. Internet Surveillance

Next Week:

- Week 3: History and Architecture of The World Wide Web
- Reminders:
 - Online course communication exclusively through piazza
 - Homework 1 due on Sunday via CMS (check whether you are on CMS otherwise email me on tav6)
 - Course website at <http://www.infosci.cornell.edu/Courses/info4302/2012fa/>