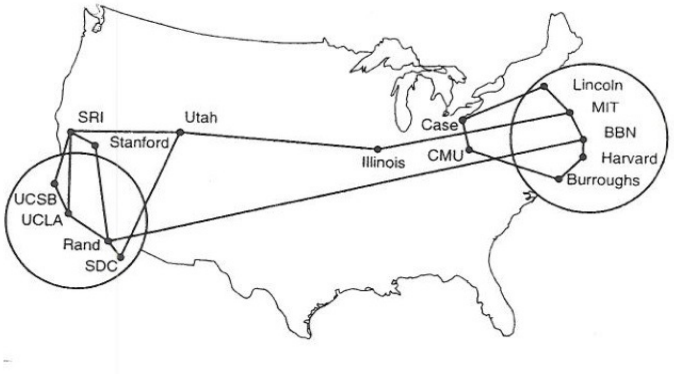


Internet Addresses

Reading: Chapter 4

Internet Addresses

Outline/Goals

IP addresses RFC 950, STD 05

- Dotted-quad notation
- IP prefixes for aggregation

- Address allocation
  - Classful addresses
  - Classless InterDomain Routing (CIDR) - RFC 4632, BDP 122, RFC 1817
  - Growth in the number of prefixes over time
- Packet forwarding
  - Forwarding tables
  - Longest-prefix match forwarding
  - Where forwarding tables come from
- Chapter 4!!!!

Internet Addresses

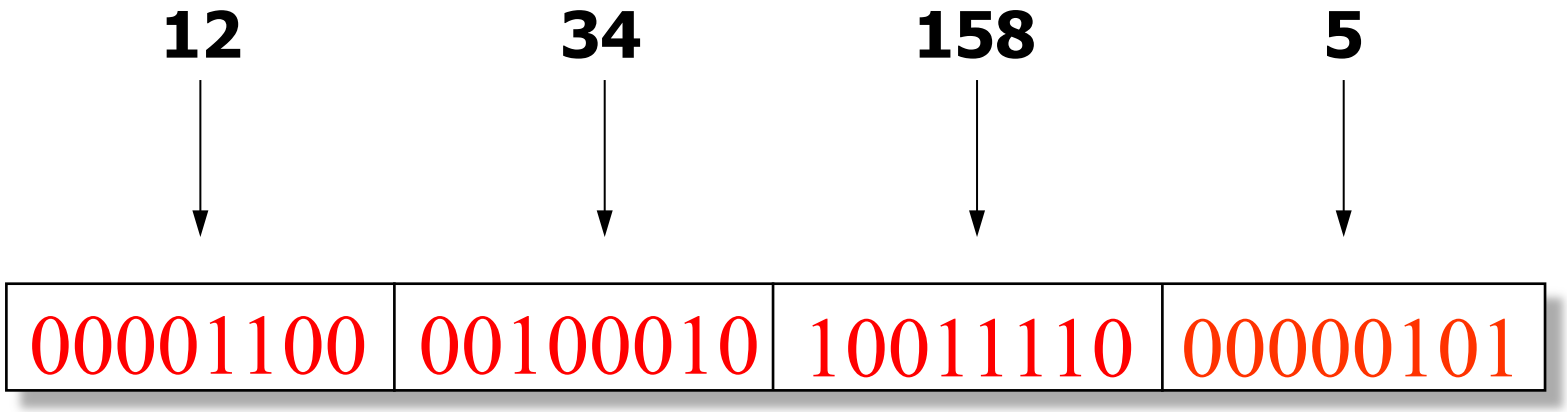
- Hide Physical Network
- Make Internet appear as a single, uniform entity
- Help in routing
- Universal Communications Service
  - Allow any host to communicate with any other host, don't care about actual location.

Host Identifiers

- Name - what an object is
- Address - where it is—logically vs physical (MAC)
- Route - how to get there

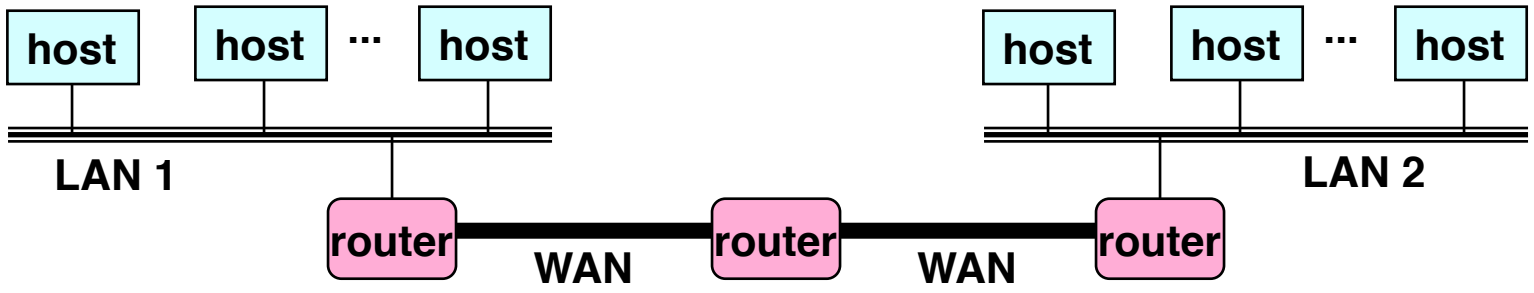
IP Address (IPv4)

- A unique 32-bit number
- Identifies an interface (on a host, on a router, …)
- Represented in dotted-quad notation



Grouping Related Hosts

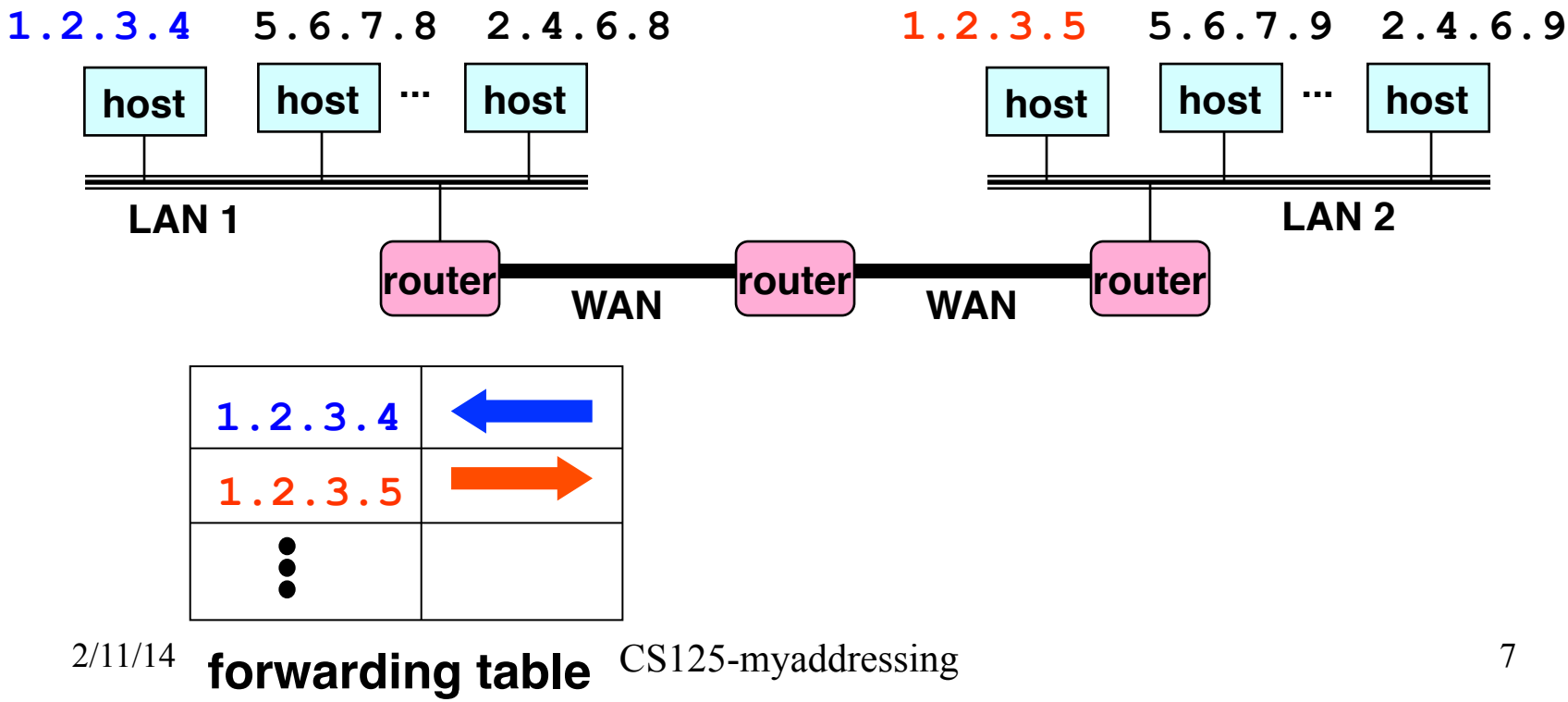
- The Internet is an "inter-network"
  - Used to connect *networks* together, not *hosts*
  - Needs a way to address a network (i.e., group of hosts)



LAN = Local Area Network – interconnected hosts
WAN = Wide Area Network – interconnected networks

Scalability Challenge

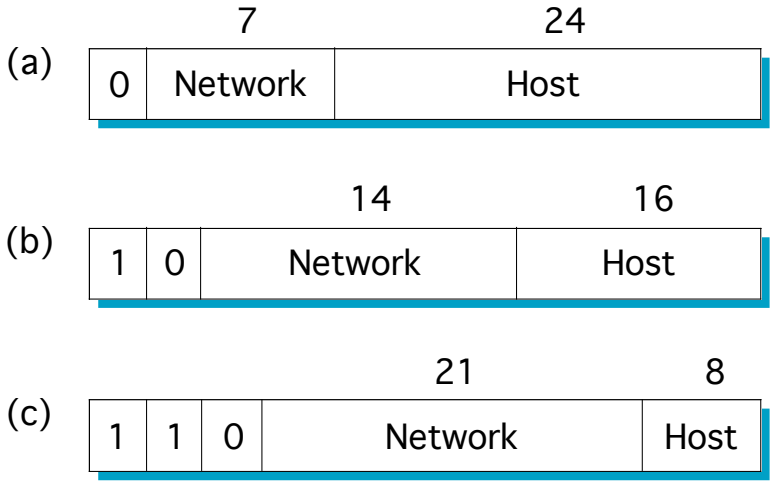
- Suppose hosts had arbitrary addresses
  - Then every router would need a lot of information
  - …to know how to direct packets toward the host



Internet Address (Global) Structure

- Properties
  - globally unique
  - hierarchical: network + host

- Dot Notation
  - 10.3.2.4
  - 128.96.33.81
  - 192.12.69.77



Complete Internet Address Allocations

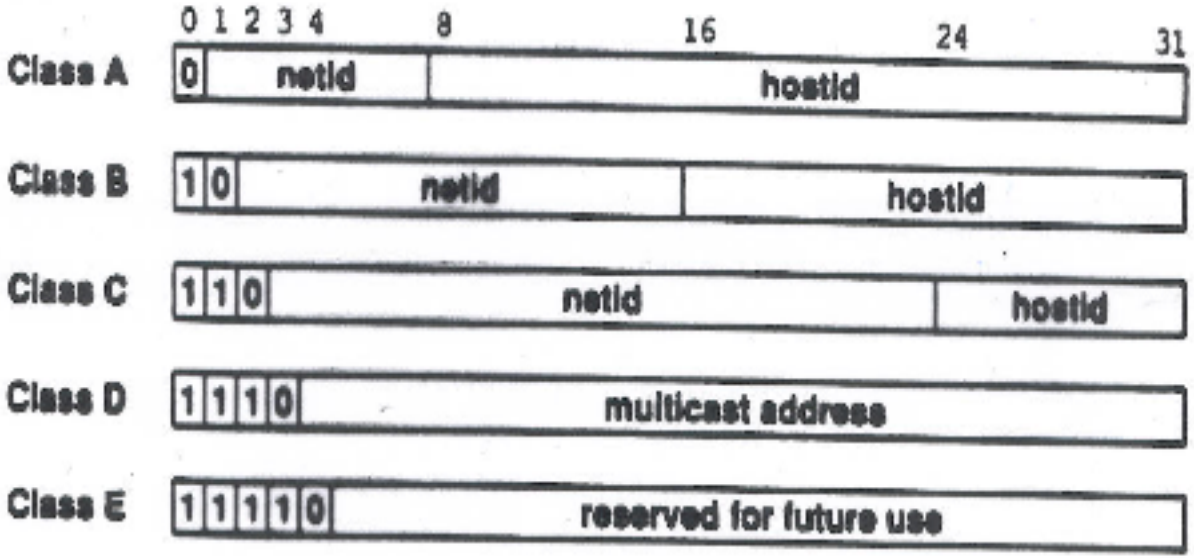
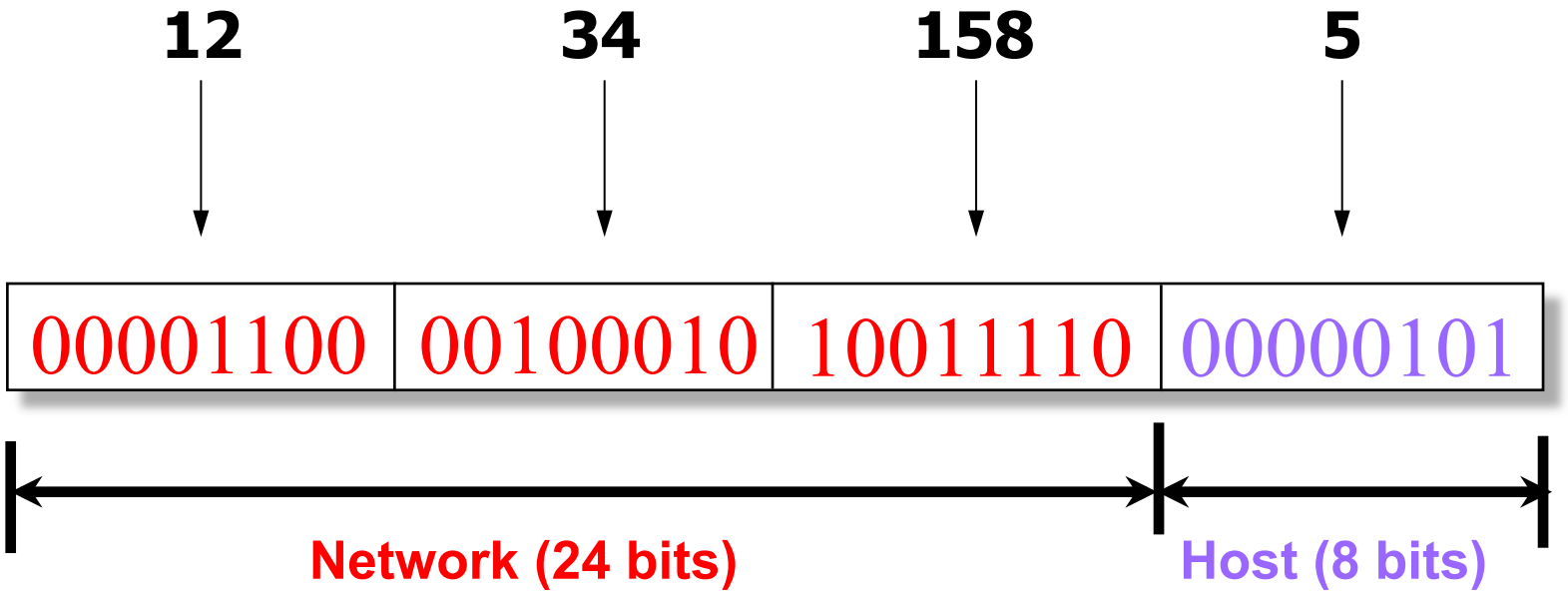


Figure 4.1 The five forms of Internet (IP) addresses. The three primary forms, Classes *A*, *B* and *C*, can be distinguished by the first two bits.

Hierarchical Addressing: IP Prefixes

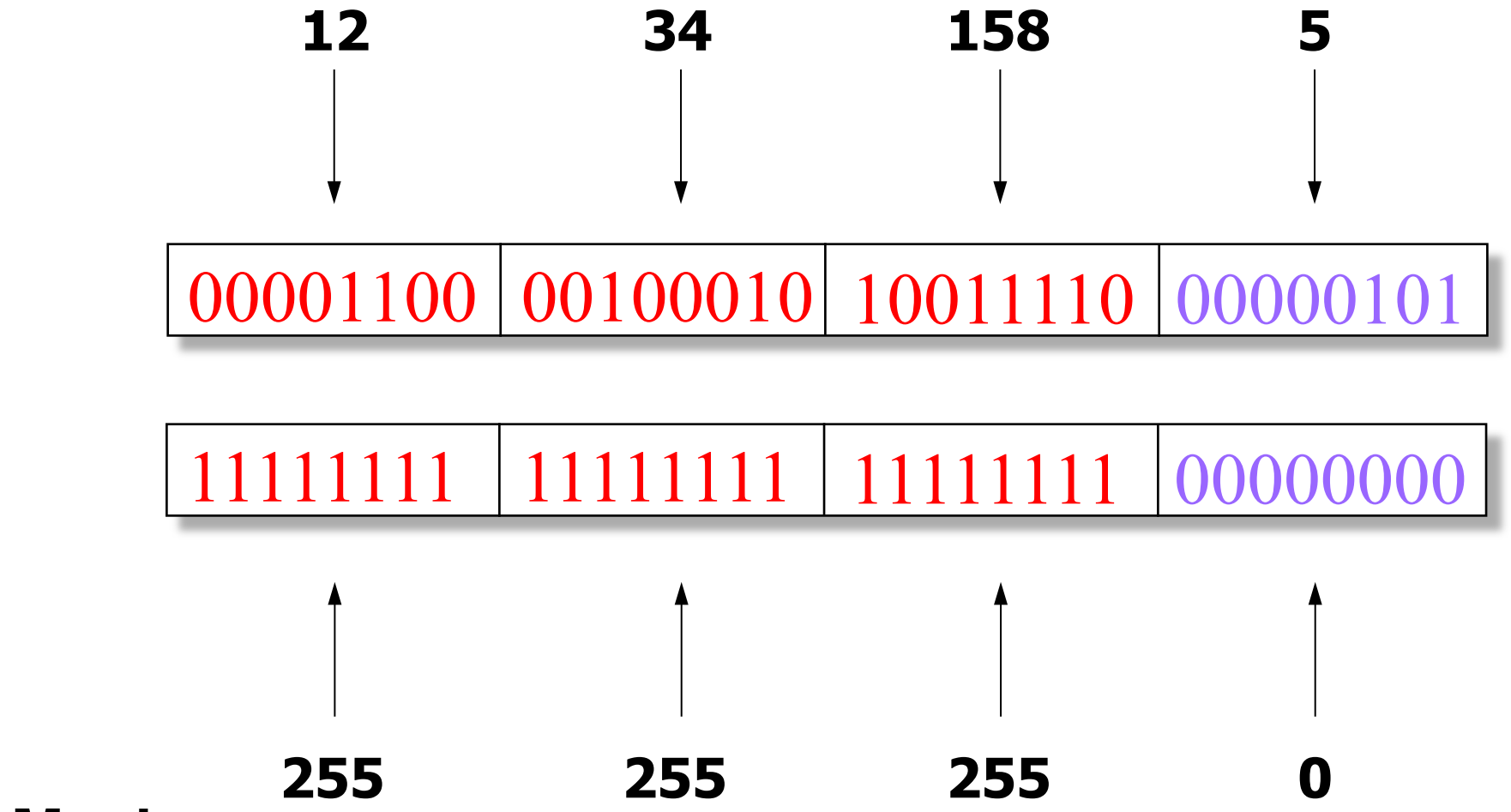
- Divided into network & host portions (left and right)
- 12.34.158.0/24 is a 24-bit prefix with 2^8 addresses



Internet Address Range

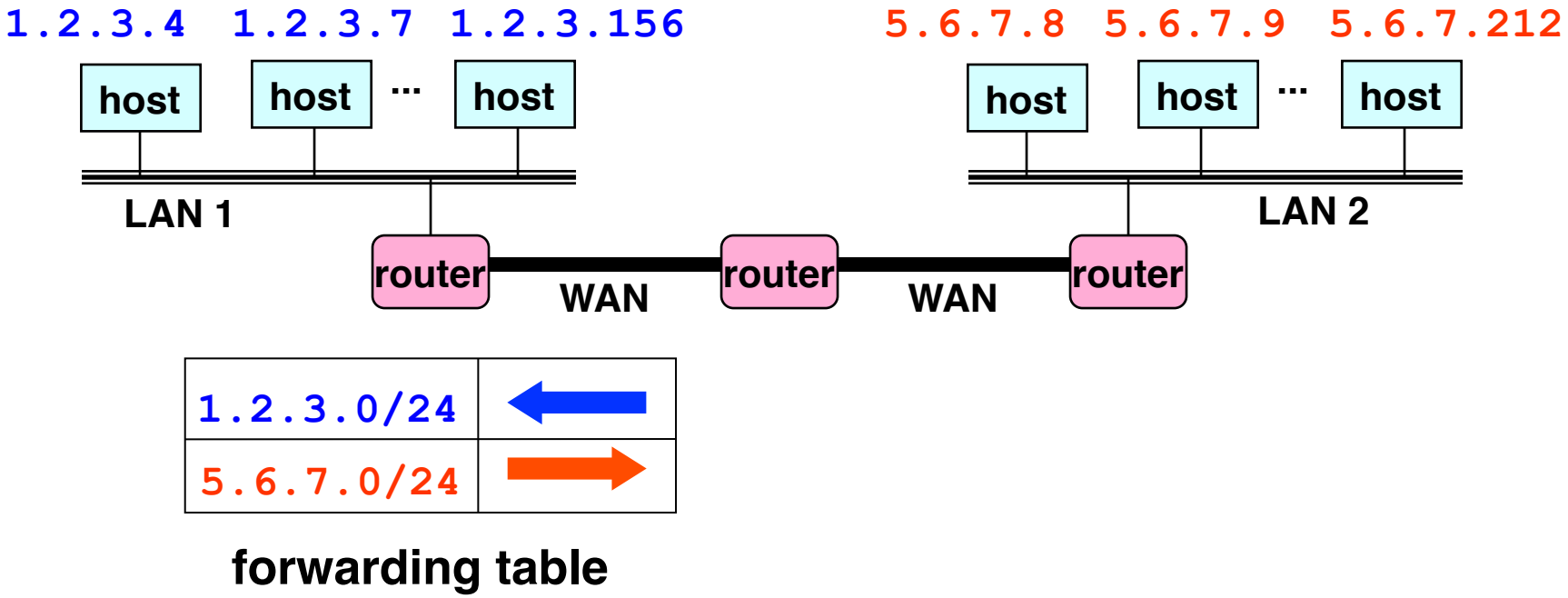
- Class A: 0.0.0.0 - 127.255.255.255
- Class B: 128.0.0.0 - 191.255.255.255
- Class C: 192.0.0.0 - 223.255.255.255
- Class D: 224.0.0.0 - 239.255.255.255
- Class E: 240.0.0.0 - 247.255.255.255

IP Address and a 24-bit Subnet Mask



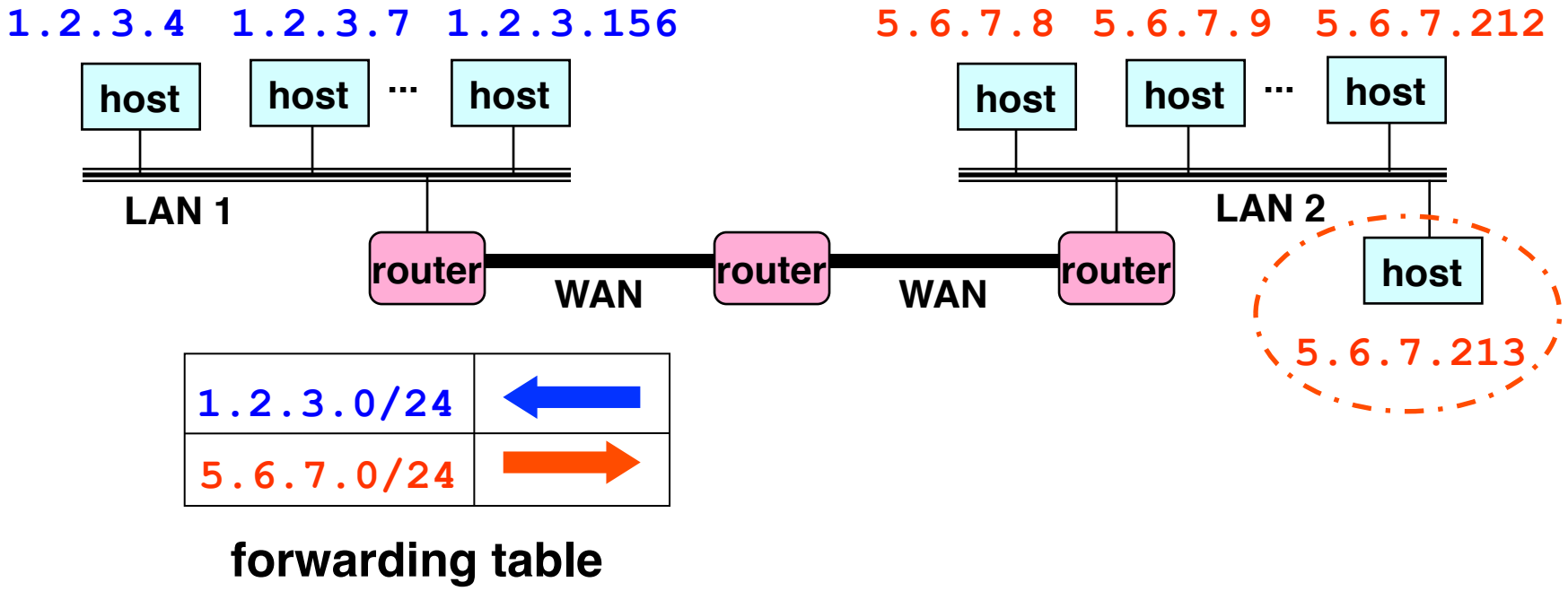
Scalability Improved

- Number related hosts from a common subnet
  - 1.2.3.0/24 on the left LAN
  - 5.6.7.0/24 on the right LAN



Easy to Add New Hosts

- No need to update the routers
  - E.g., adding a new host 5.6.7.213 on the right
  - Doesn't require adding a new forwarding entry



Weaknesses in IP Addressing

- When host moves, its IP address must change
- Change in network size, e.g., class C moves to class B
- Routing is based on Network Address, multiple interfaces have multiple unrelated addresses
- Not enough addresses

Address Allocation

Classful Addressing

- In the olden days, only fixed allocation sizes
  - Class A: 0*
    - Very large /8 blocks (e.g., MIT has 18.0.0.0/8)
  - Class B: 10*
    - Large /16 blocks (e.g,. Princeton has 128.112.0.0/16)
  - Class C: 110*
    - Small /24 blocks (e.g., AT&T Labs has 192.20.225.0/24)
  - Class D: 1110*
    - Multicast groups
  - Class E: 11110*
    - Reserved for future use
- This is why folks use dotted-quad notation!

Classless Inter-Domain Routing (CIDR)

Use two 32-bit numbers to represent a network.
Network number = IP address + Mask

IP Address : 12.4.0.0 IP Mask: 255.254.0.0

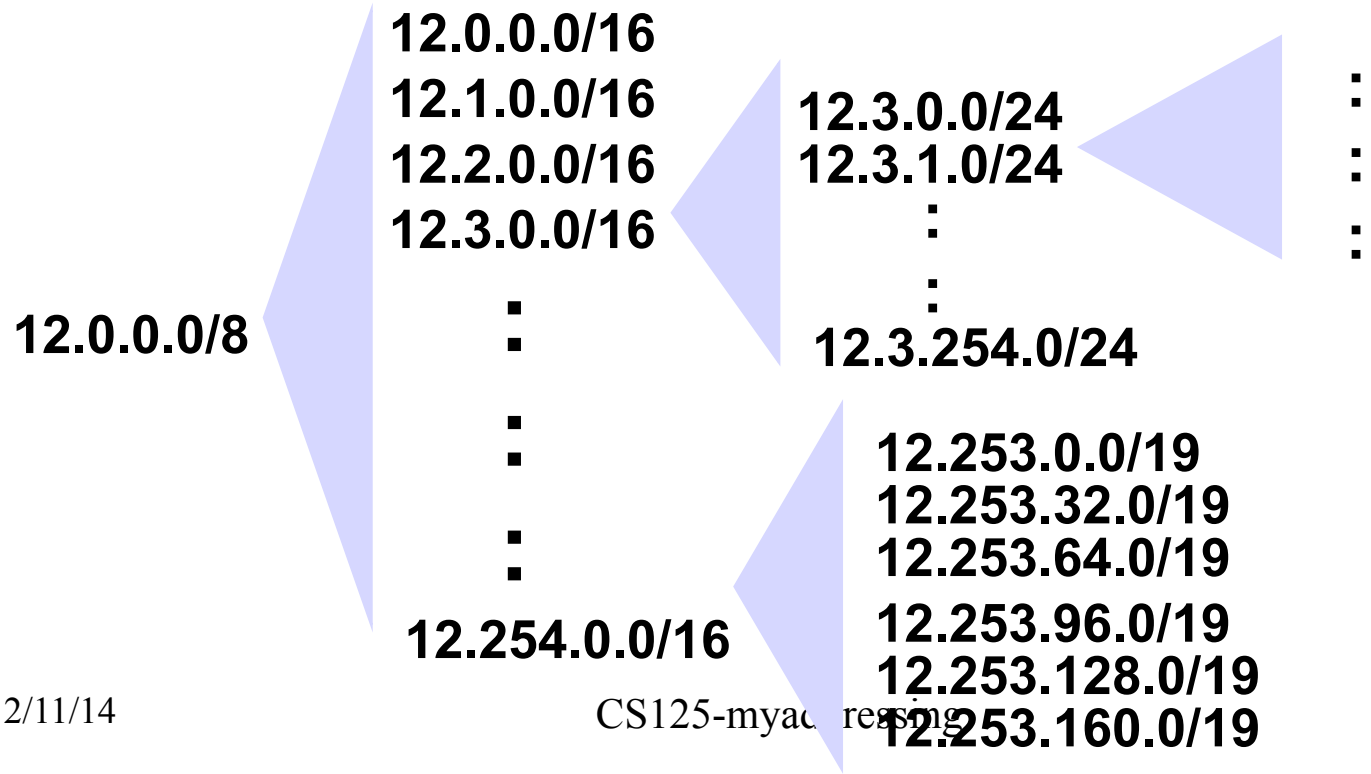
Address	00001100	00000100	00000000	00000000
Mask	11111111	11111110	00000000	00000000

Network Prefix | **for hosts**

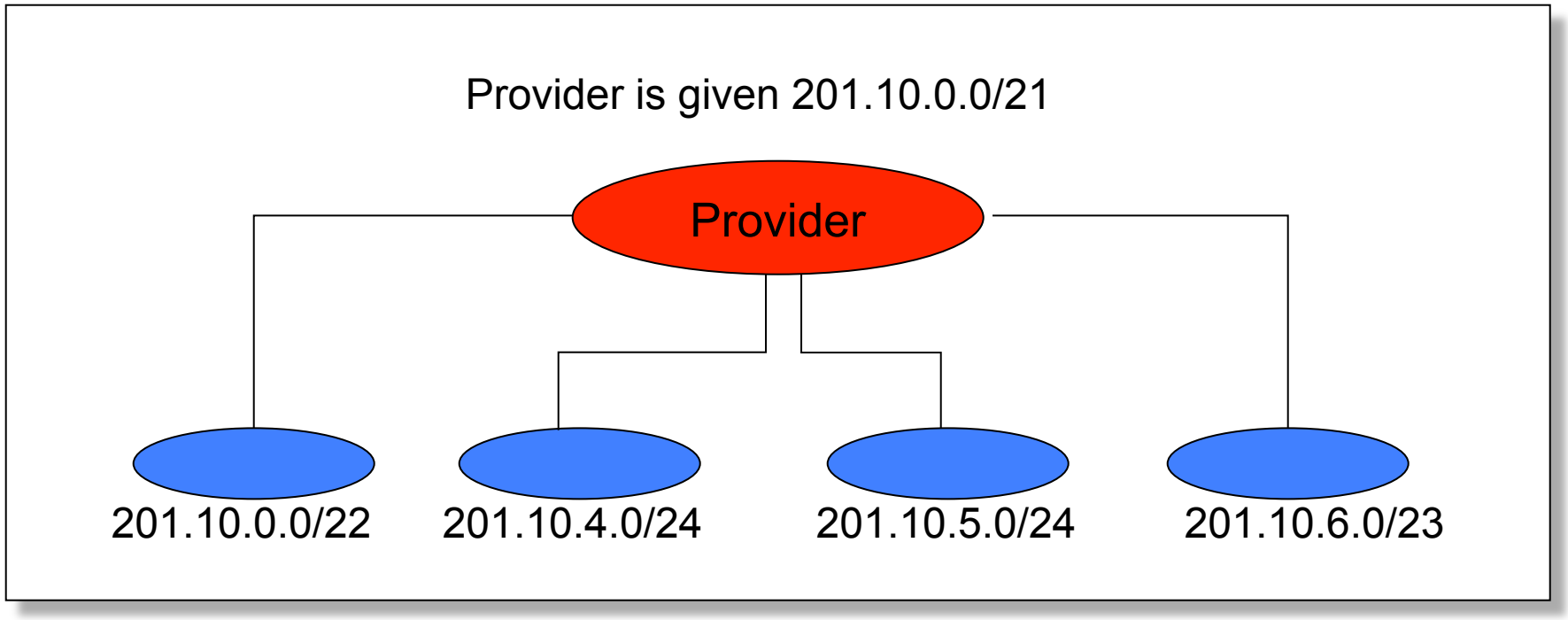
Written as 12.4.0.0/15

CIDR: Hierarchal Address Allocation

- Prefixes are key to Internet scalability
  - Address allocated in contiguous chunks (prefixes)
  - Routing protocols and packet forwarding based on prefixes
  - Today, routing tables contain ~150,000-200,000 prefixes

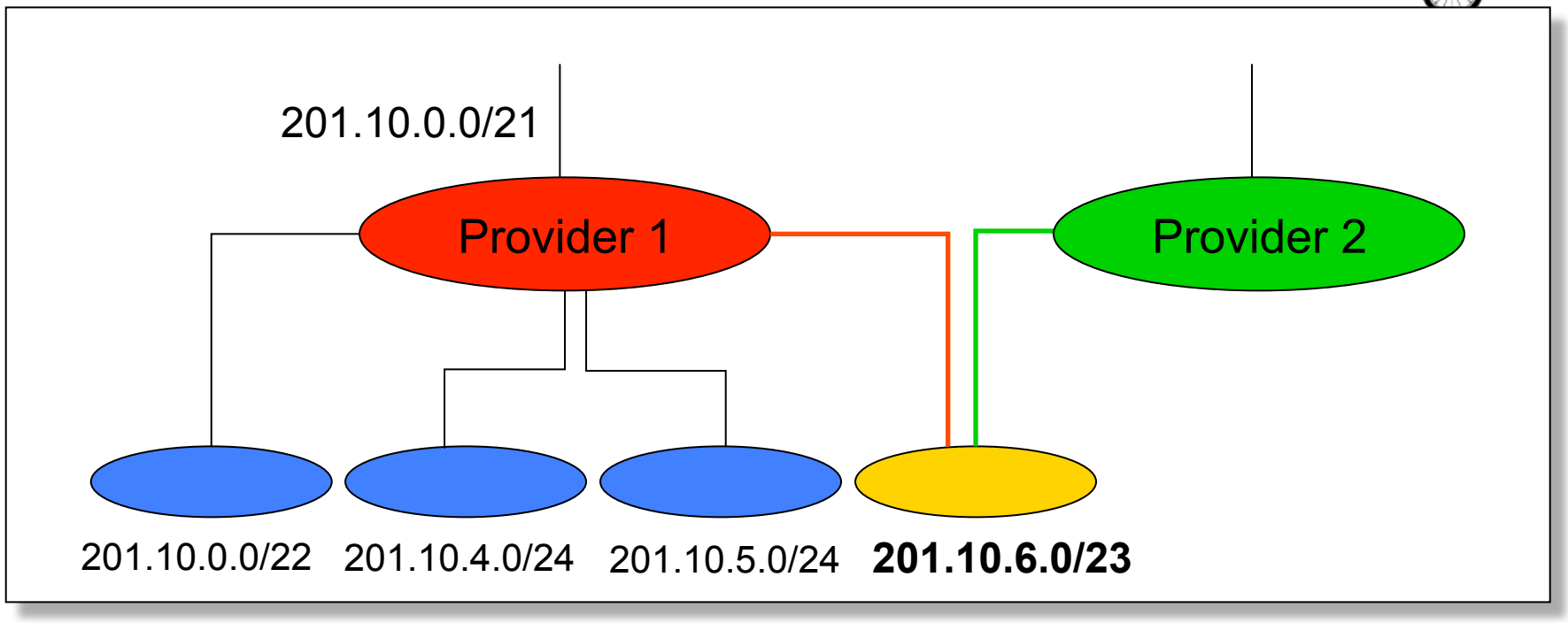


Scalability: Address Aggregation



Routers in the rest of the Internet just need to know how to reach 201.10.0.0/21. The provider can direct the IP packets to the appropriate customer.

But, Aggregation Not Always Possible

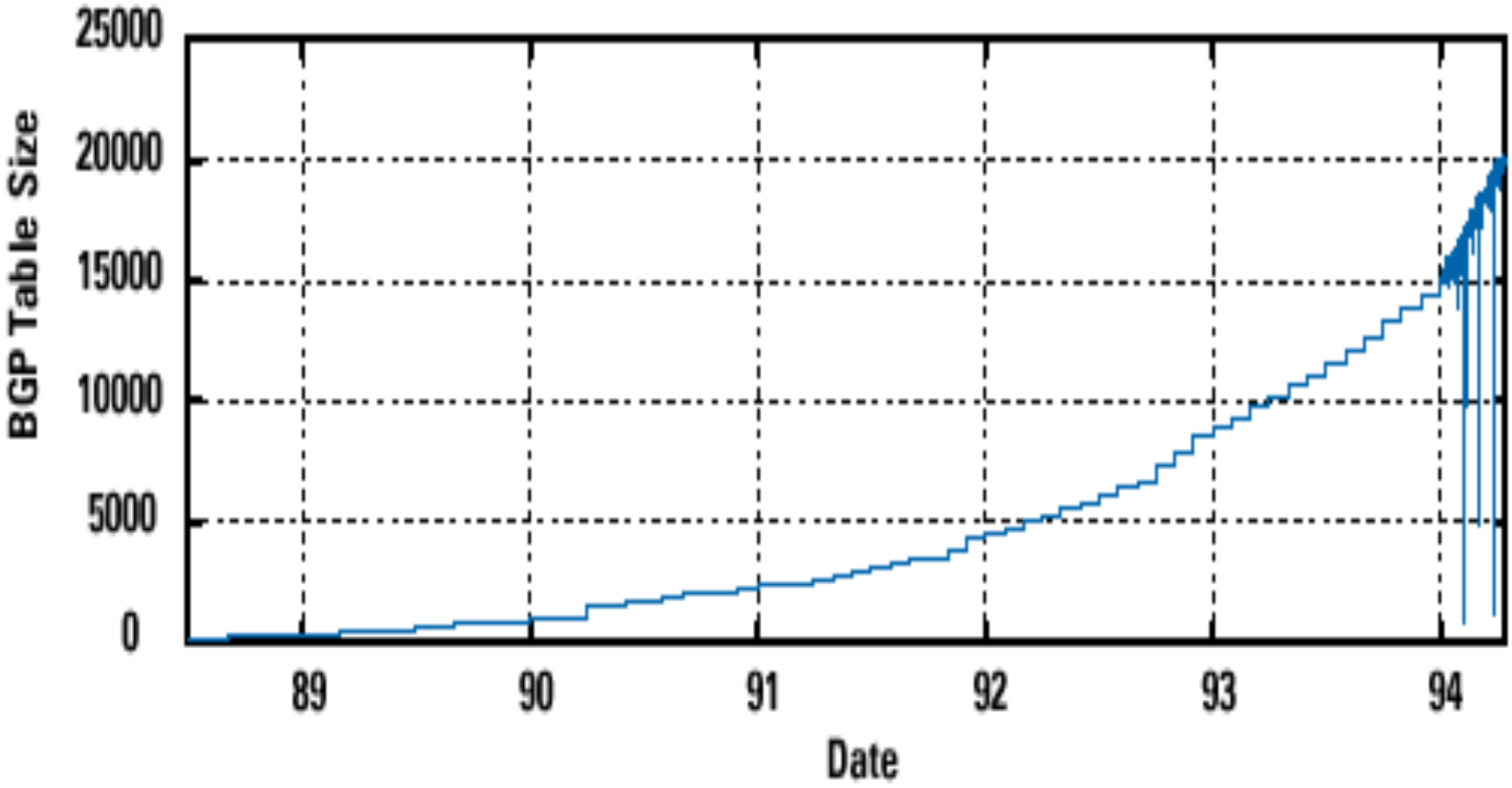


Multi-homed **customer with 201.10.6.0/23 has two providers. Other parts of the Internet need to know how to reach these destinations through *both* providers.**

Scalability Through Hierarchy

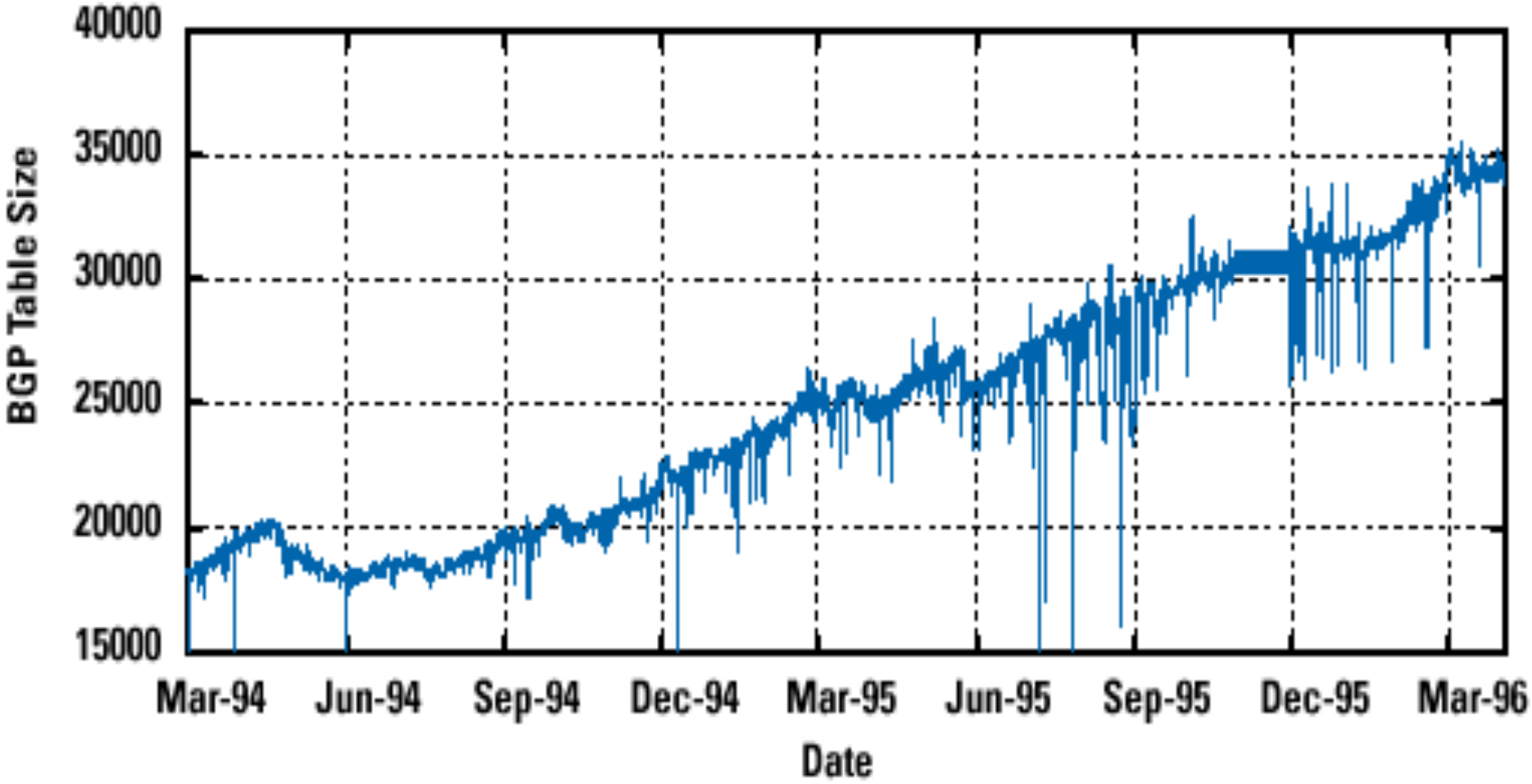
- Hierarchical addressing
  - Critical for scalable system
  - Don't require everyone to know everyone else
  - Reduces amount of updating when something changes
- Non-uniform hierarchy
  - Useful for heterogeneous networks of different sizes
  - Initial class-based addressing was far too coarse
  - Classless InterDomain Routing (CIDR) helps
- Next few slides
  - History of the number of globally-visible prefixes
  - Plots are # of prefixes vs. time

Pre-CIDR (1988-1994): Steep Growth



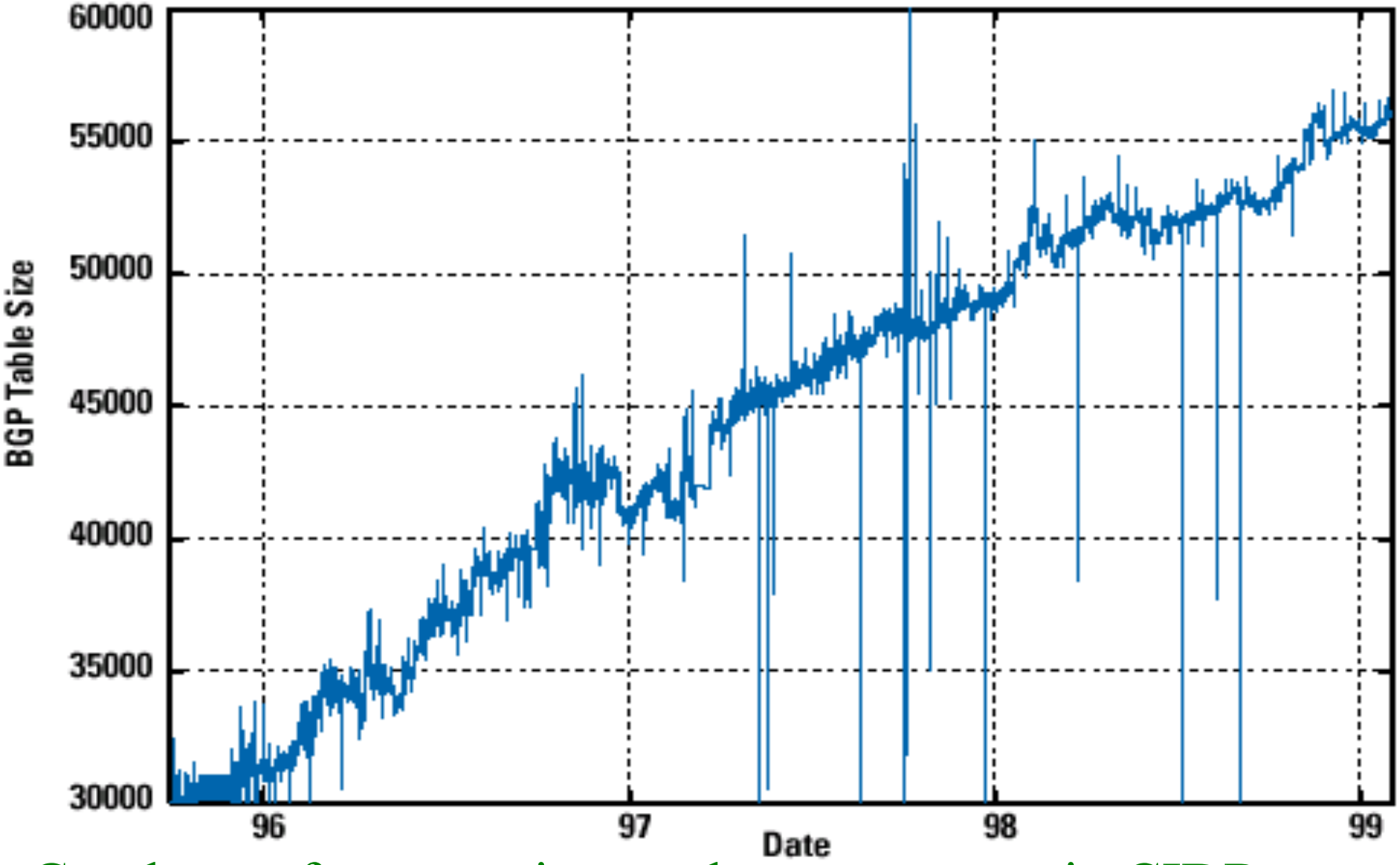
Growth faster than improvements in equipment capability

CIDR Deployed (1994-1996): Much Flatter?



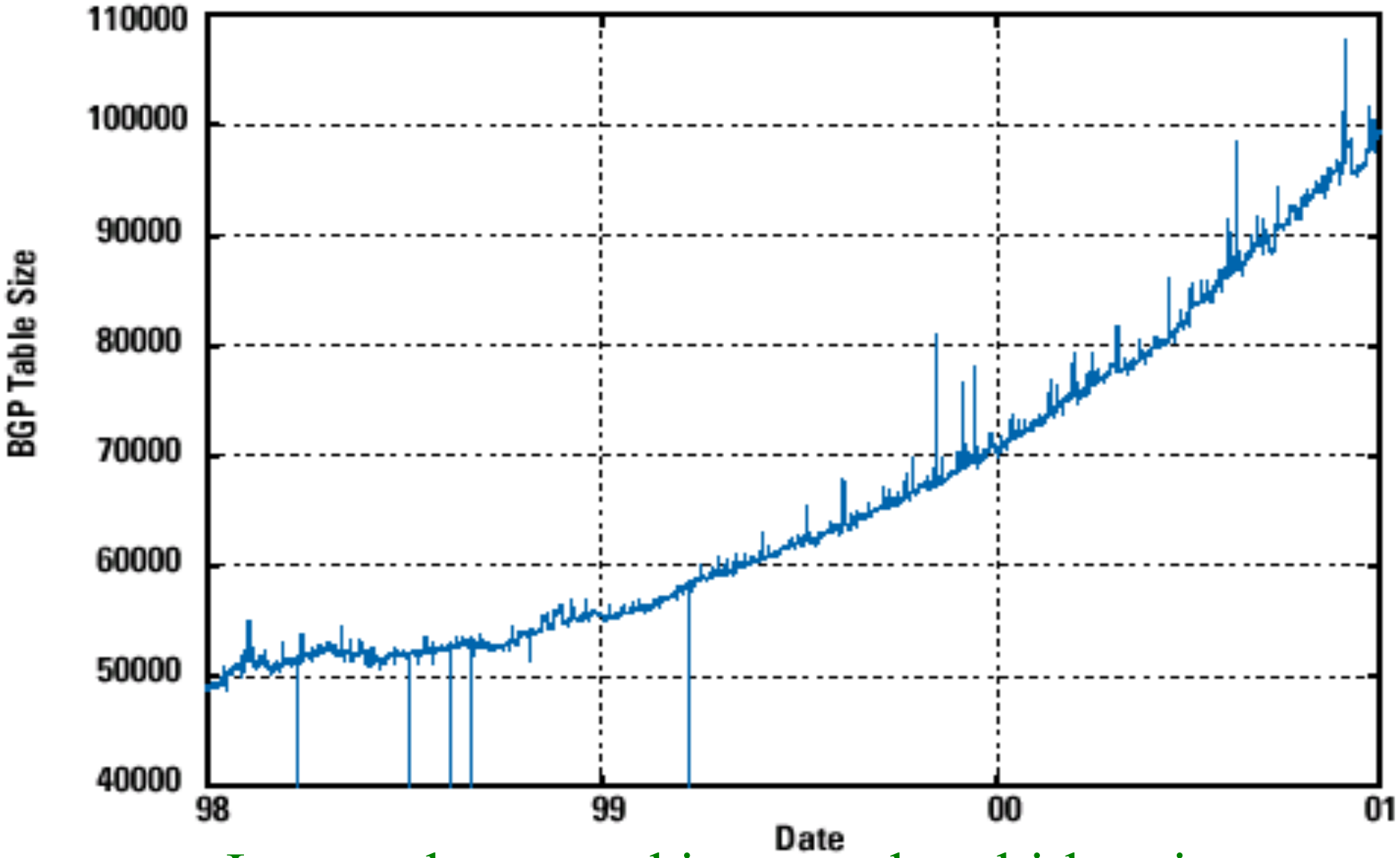
Efforts to aggregate (even decreases after IETF meetings!)

CIDR Growth (1996-1998): Roughly Linear



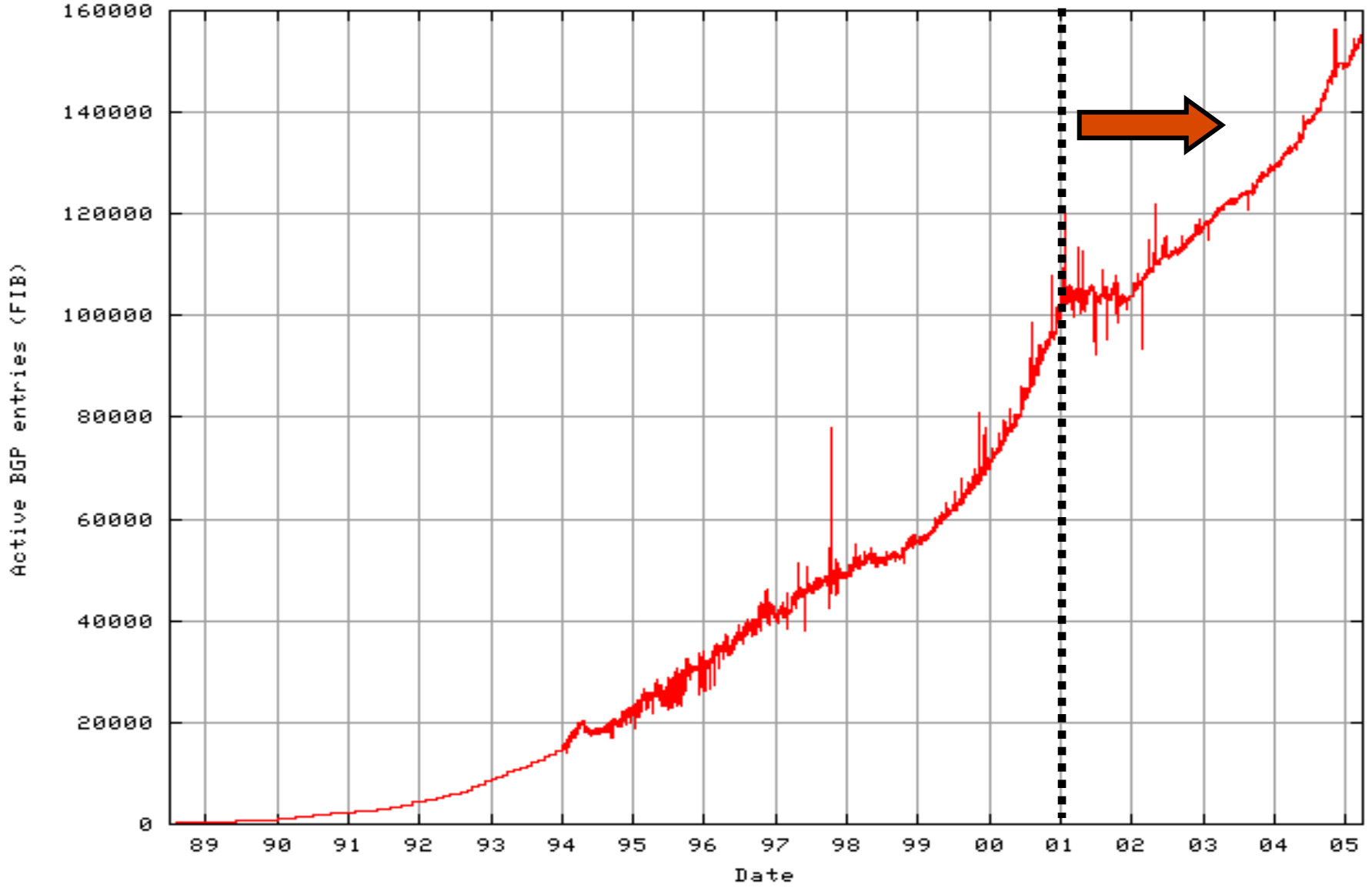
Good use of aggregation, and peer pressure in CIDR report

Boom Period (1998-2001): Steep Growth

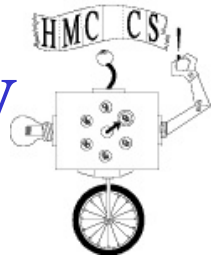


Internet boom and increased multi-homing

Long-Term View (1989-2005): Post-Boom



Obtaining a Block of Addresses Now



- Separation of control
  - Prefix: assigned *to* an institution
  - Addresses: assigned *by* the institution to their nodes
- Who assigns prefixes?
  - Internet Corporation for Assigned Names and Numbers
    - Allocates large address blocks to Regional Internet Registries
  - Regional Internet Registries (RIRs)
    - E.g., ARIN (American Registry for Internet Numbers)
    - Allocates address blocks within their regions
    - Allocated to Internet Service Providers and large institutions
  - Internet Service Providers (ISPs)
    - Allocate address blocks to their customers
    - Who may, in turn, allocate to their customers…

Figuring Out Who Owns an Address

- Address registries
  - Public record of address allocations
  - Internet Service Providers (ISPs) should update when giving addresses to customers
  - However, records are notoriously out-of-date
- Ways to query
  - UNIX: "whois –h whois.arin.net 128.112.136.35"
  - http://www.arin.net/whois/
  - http://www.geektools.com/whois.php
  - …

Example Output for 128.112.136.35

OrgName: Princeton University
OrgID: PRNU
Address: Office of Information Technology
Address: 87 Prospect Avenue
City: Princeton
StateProv: NJ
PostalCode: 08544-2007
Country: US
NetRange: 128.112.0.0 - 128.112.255.255
CIDR: 128.112.0.0/16
NetName: PRINCETON
NetHandle: NET-128-112-0-0-1
Parent: NET-128-0-0-0-0
NetType: Direct Allocation
RegDate: 1986-02-24

Are 32-bit Addresses Enough?

- Not all that many unique addresses
  - $2^{32} = 4{,}294{,}967{,}296$ (just over four billion)
  - Plus, some are reserved for special purposes
  - And, addresses are allocated in larger blocks
- And, many devices need IP addresses
  - Computers, PDAs, routers, tanks, toasters, …
- Long-term solution: a larger address space
  - IPv6 has 128-bit addresses ($2^{128} = 3.403 \times 10^{38}$)
- Short-term solutions: limping along with IPv4
  - Private addresses
  - Network address translation (NAT)
  - Dynamically-assigned addresses (DHCP)

Hard Policy Questions

- How much address space per geographic region?
  - Equal amount per country?
  - Proportional to the population?
  - What about addresses already allocated?
- Address space portability?
  - Keep your address block when you change providers?
  - Pro: avoid having to renumber your equipment
  - Con: reduces the effectiveness of address aggregation
- Keeping the address registries up to date?
  - What about mergers and acquisitions?
  - Delegation of address blocks to customers?
  - As a result, the registries are horribly out of date

Conclusions

- IP address
  - A 32-bit number
  - Allocated in prefixes
  - Non-uniform hierarchy for scalability and flexibility
  - Too small....