Cycle 4: Cloud Networking and Services

CS 436: Spring 2018

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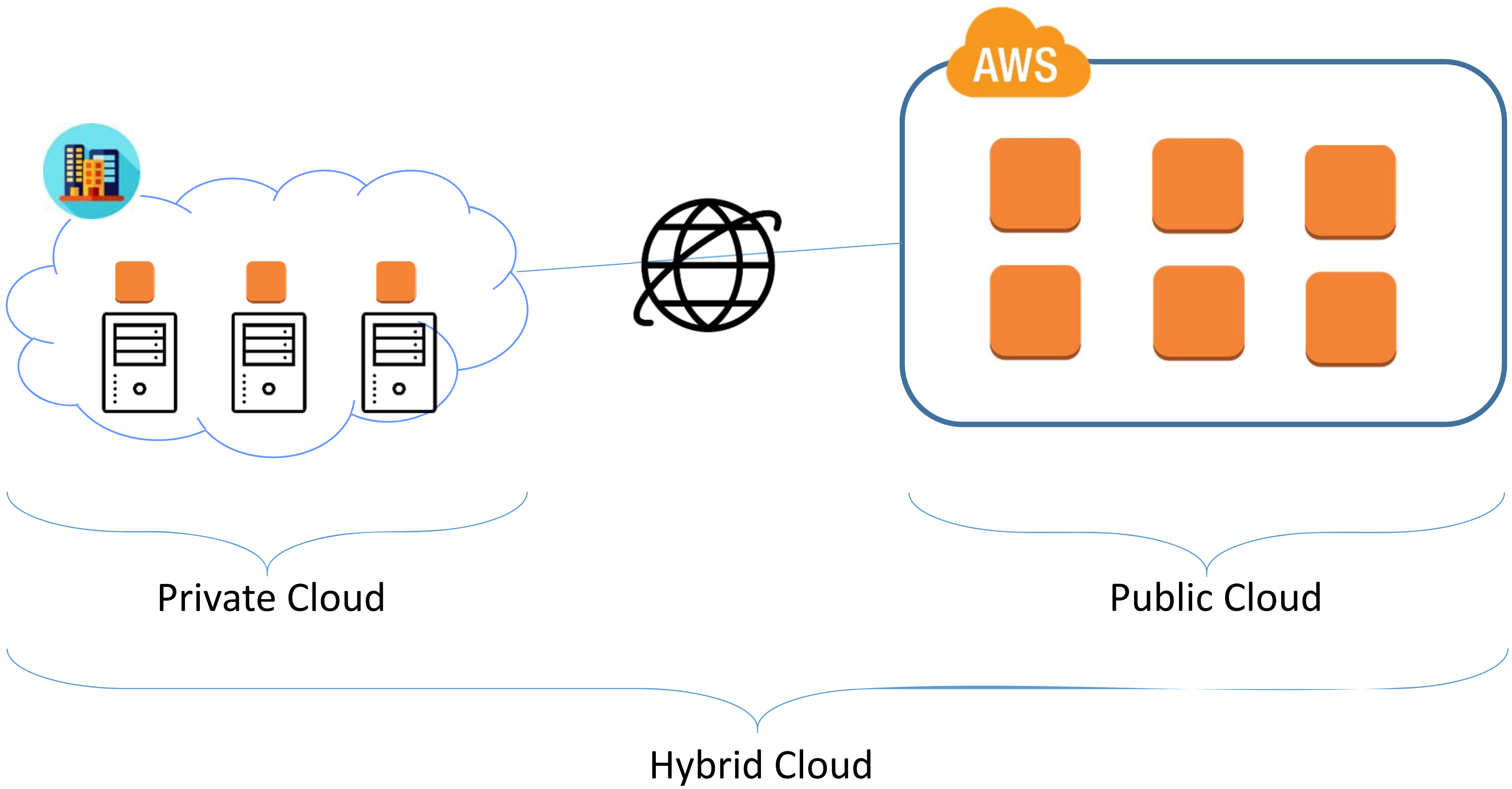
What is a cloud?

- IT model enabling shared, ubiquitous access to compute resources

- Cloud networking: access of networking resources in the cloud

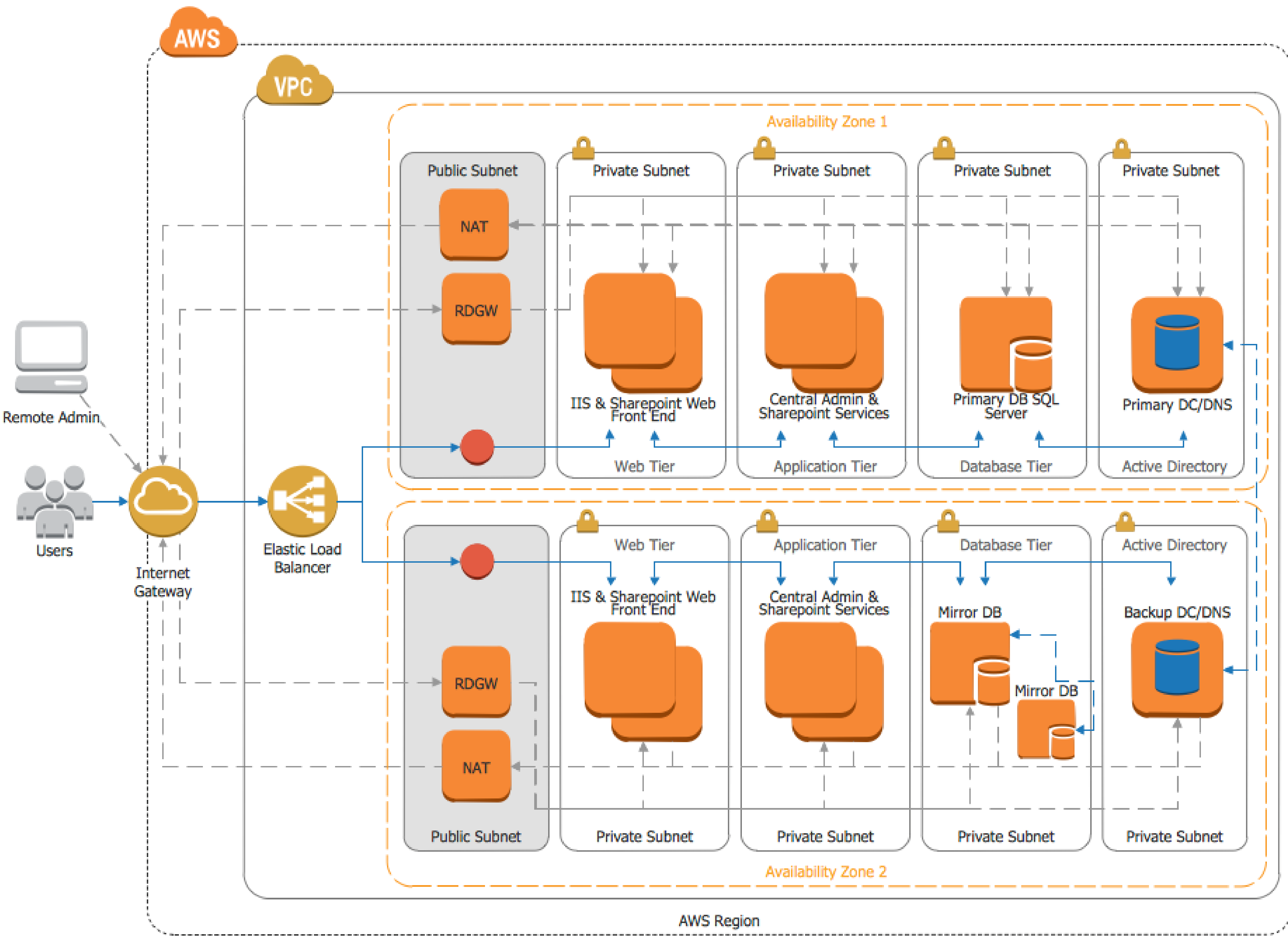
- Examples:
  - Cloud-hosted networking (AWS, Azure)
  - Cloud-hosted management (Meraki, Aerohive)

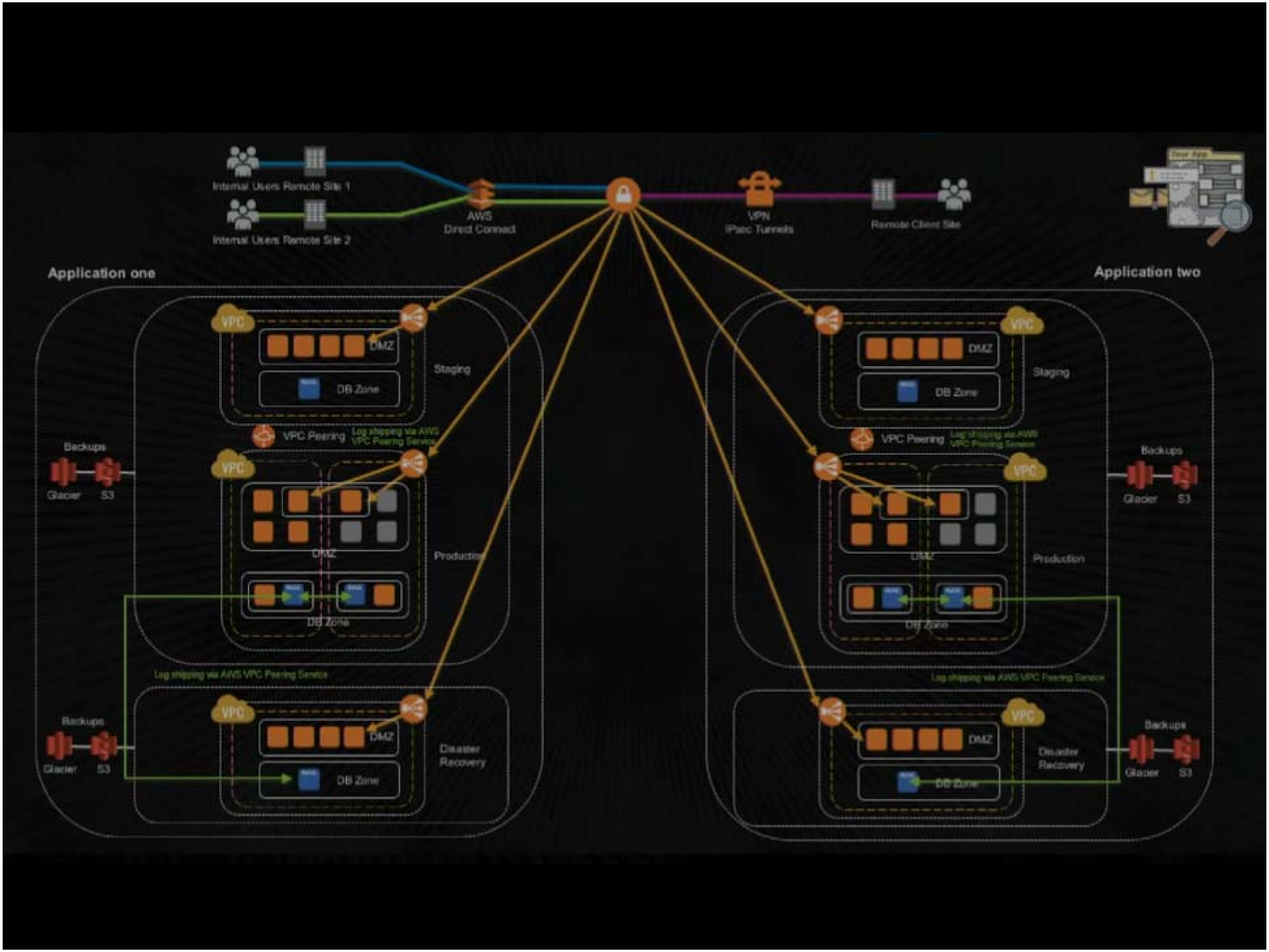
Types of clouds



Types of clouds

- Software as a Service (SaaS)
  - Provider provides software, which is centrally hosted
  - Examples: Google Apps, Salesforce, Cisco WebEx
- Infrastructure as a Service (IaaS)
  - Customers lease virtual machines they configure themselves
  - Examples: AWS, Azure, IBM SmartCloud
- Platform as a Service (PaaS)
  - Customers work with services created/maintained by provider
  - Examples: AWS, Azure, RedHat OpenShift
- Function as a Service (FaaS)
  - Customer provides code, Provider provides functions and event triggers
  - Examples: Google Cloud Functions, AWS Lambda, MS Azure Functions


AWS
VPC
Availability Zone 1
Public Subnet
NAT
RDGW
Private Subnet
IIS & Sharepoint Web Front End
Web Tier
Private Subnet
Central Admin & Sharepoint Services
Application Tier
Private Subnet
Primary DB SQL Server
Database Tier
Private Subnet
Primary DC/DNS
Active Directory
Remote Admin
Users
Internet Gateway
Elastic Load Balancer
Web Tier
IIS & Sharepoint Web Front End
Application Tier
Central Admin & Sharepoint Services
Database Tier
Mirror DB
Mirror DB
Active Directory
Backup DC/DNS
RDGW
NAT
Public Subnet
Private Subnet
Private Subnet
Private Subnet
Private Subnet
Availability Zone 2
AWS Region


Internal Users Remote Site 1
Internal Users Remote Site 2
AWS
Direct Connect
VPN
IPsec Tunnels
Remote Client Site
Application one
VPC
DMZ
DB Zone
Staging
VPC Peering
Log shipping via AWS VPC Peering Service
Backups
Glacier
S3
VPC
DMZ
Production
DB Zone
Log shipping via AWS VPC Peering Service
Backups
Glacier
S3
VPC
DMZ
DB Zone
Disaster Recovery
Application two
VPC
DMZ
DB Zone
Staging
VPC Peering
Log shipping via AWS VPC Peering Service
VPC
DMZ
Production
DB Zone
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Log shipping via AWS VPC Peering Service
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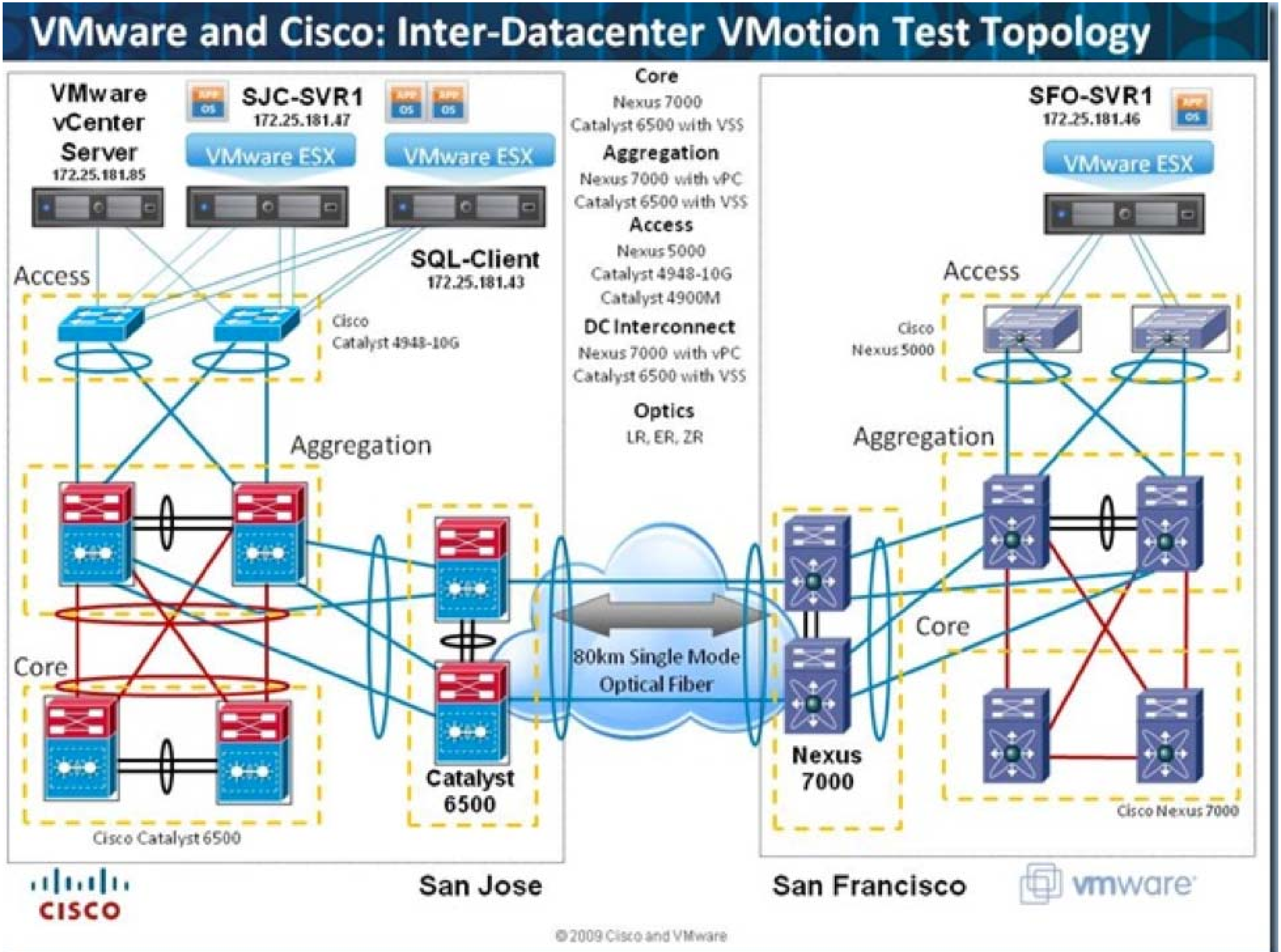
DMZ
DB Zone
Disaster Recovery
Backups
Glacier
S3


VMware and Cisco: Inter-Datacenter VMotion Test Topology
VMware vCenter Server
172.25.181.85
SJC-SVR1
172.25.181.47
VMware ESX
VMware ESX
SQL-Client
172.25.181.43
Access
Cisco Catalyst 4948-10G
Aggregation
Core
Cisco Catalyst 6500
Catalyst 6500
Core
Nexus 7000
Catalyst 6500 with VSS
Aggregation
Nexus 7000 with vPC
Catalyst 6500 with VSS
Access
Nexus 5000
Catalyst 4948-10G
Catalyst 4900M
DC Interconnect
Nexus 7000 with vPC
Catalyst 6500 with VSS
Optics
LR, ER, ZR
80km Single Mode Optical Fiber
SFO-SVR1
172.25.181.46
VMware ESX
Access
Cisco Nexus 5000
Aggregation
Core
Nexus 7000
Cisco Nexus 7000
San Jose
San Francisco
CISCO
vmware
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Public Services

Directing Traffic to Services

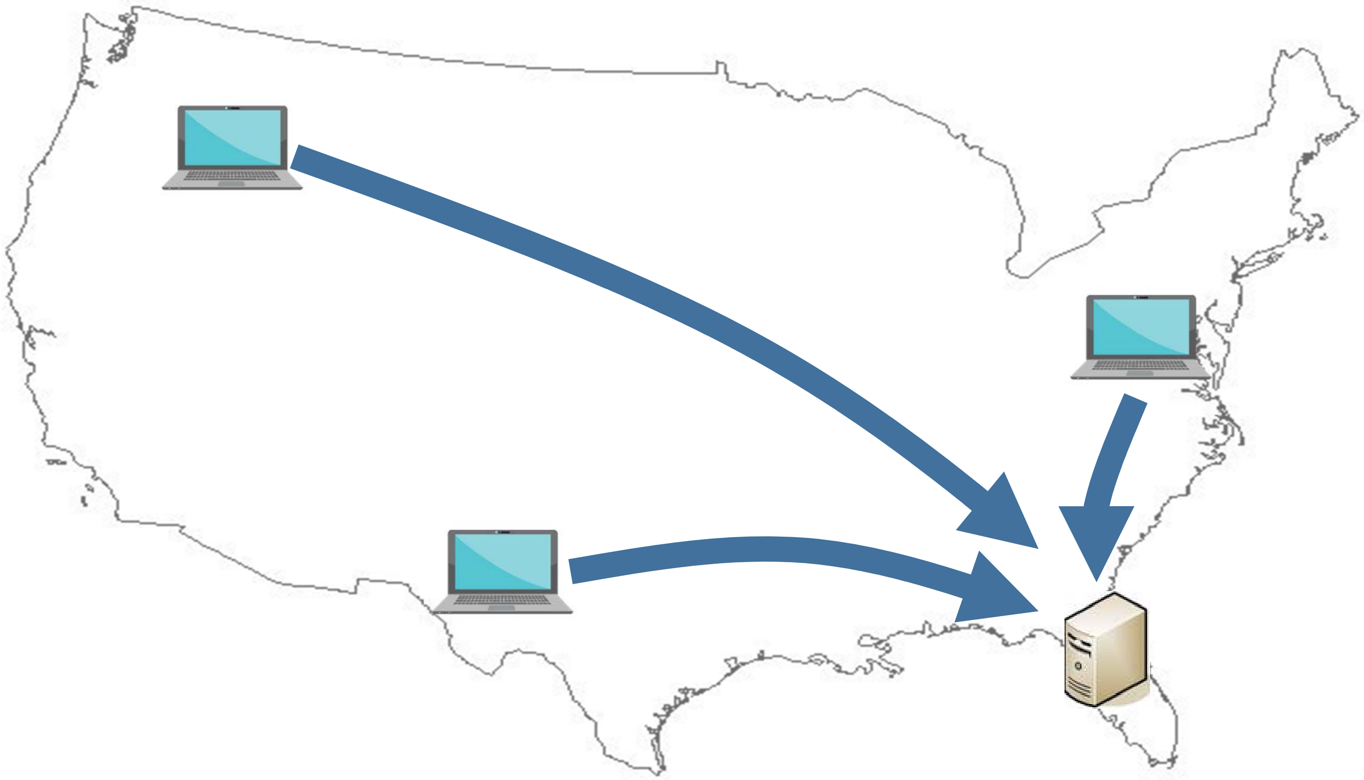
- Need to provide services to public users (or internal users)

- Challenges: redundancy, low latency, etc
- Concepts:
  - Anycast/Load Balancing
  - NAT

Anycast and Load Balancing

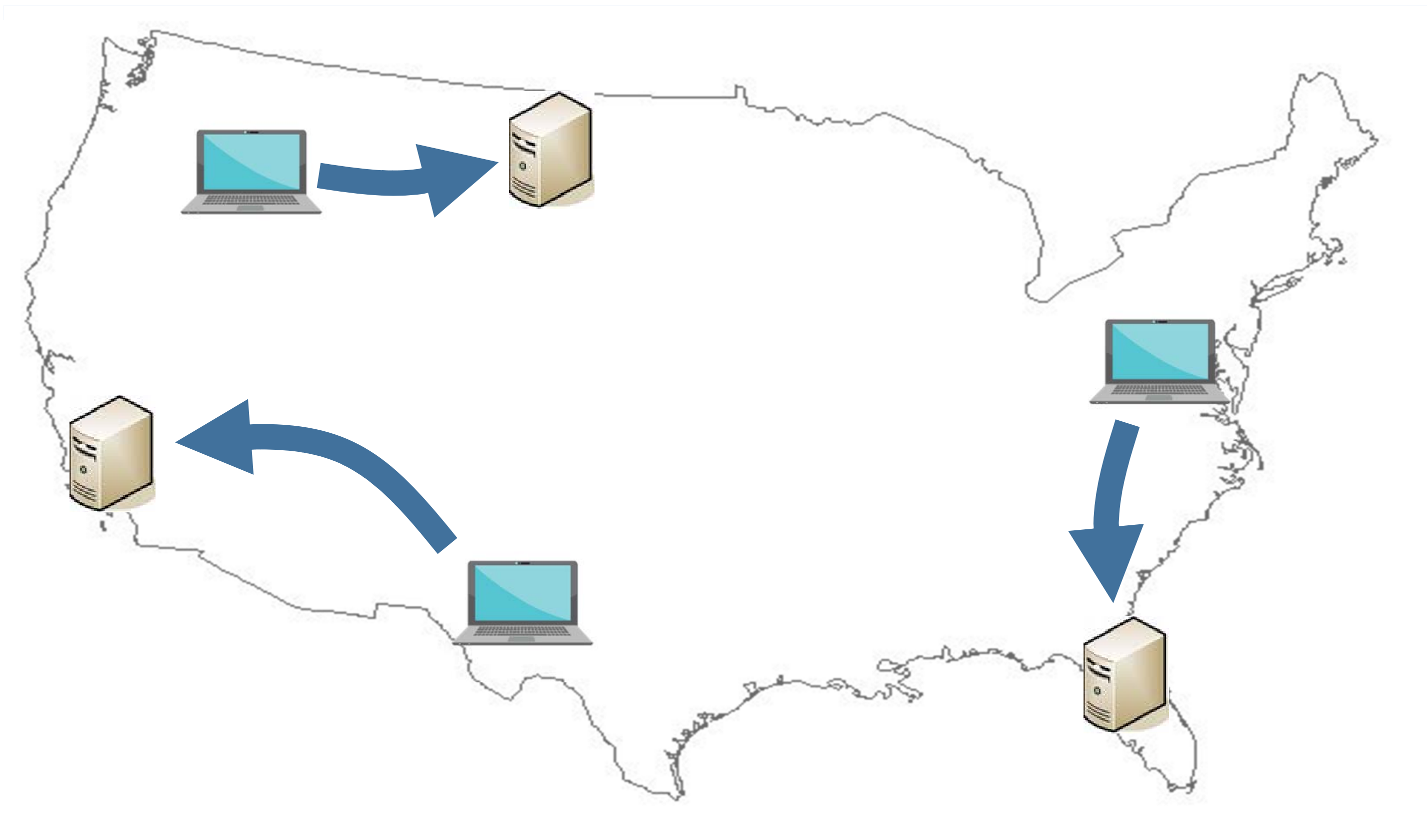
- Direct users to servers
- Done for various reasons
  - For resiliency
  - To balance load
  - To give differential QOS, to target advertisements, to censor…
- Key approaches
  - Wide-area: DNS anycast
  - Wide- and local-area: IP anycast
  - Local-area: load balancing appliance

How to deploy a big Internet svc



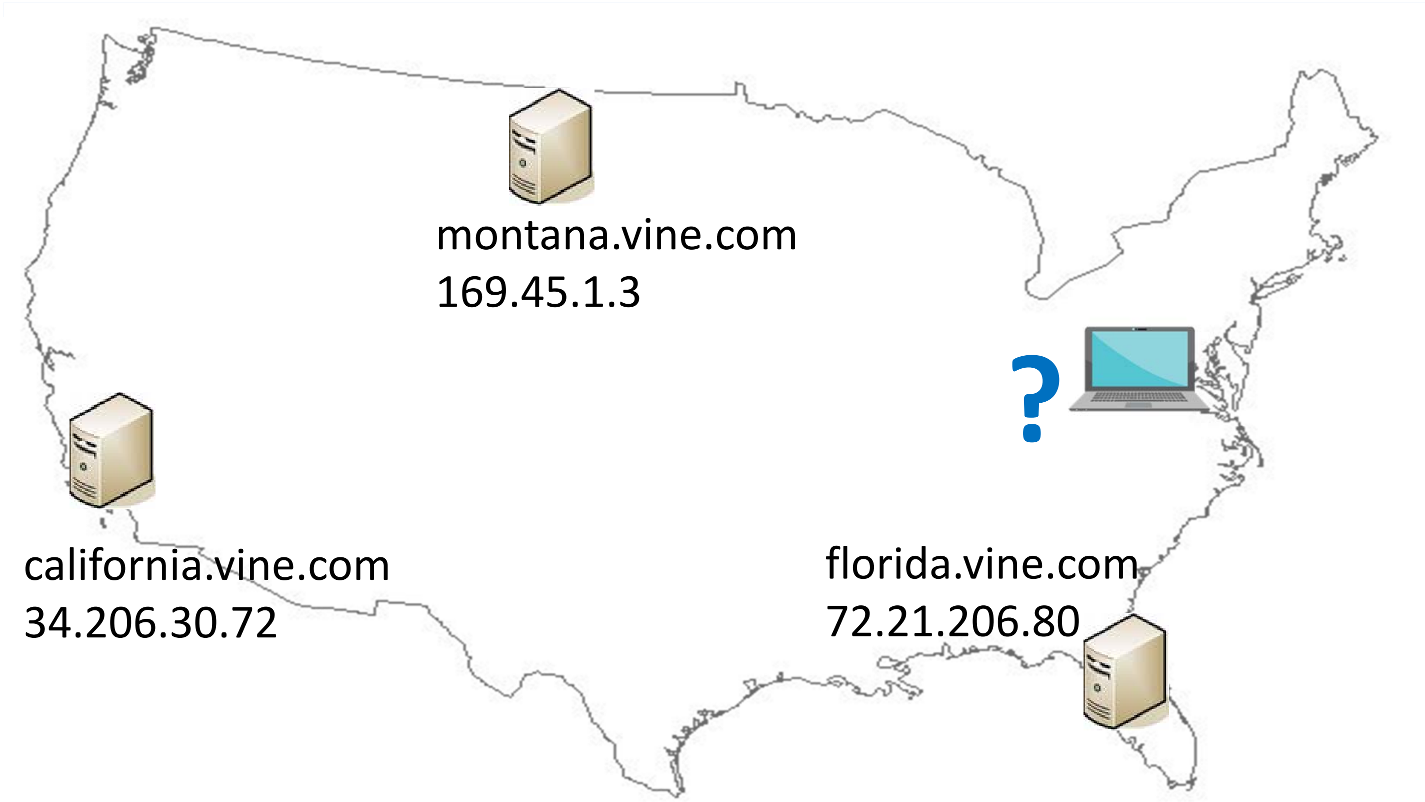
- Solution: Put down a server somewhere
- Problems: Too much load, Far away from some clients, Single point of failure, Easy to DoS

Better: Deploy multiple servers



- Solution: Put down several servers
- Benefits: Improve scaling, resilience, proximity
- Question: How to actually implement this

How about: Tell users where to go



- Solution: Tell users which servers to go to
- Problem: How are you going to enforce that
  - Could filter users who don't listen
  - How to know where users are located?

Better idea: Transparent direction

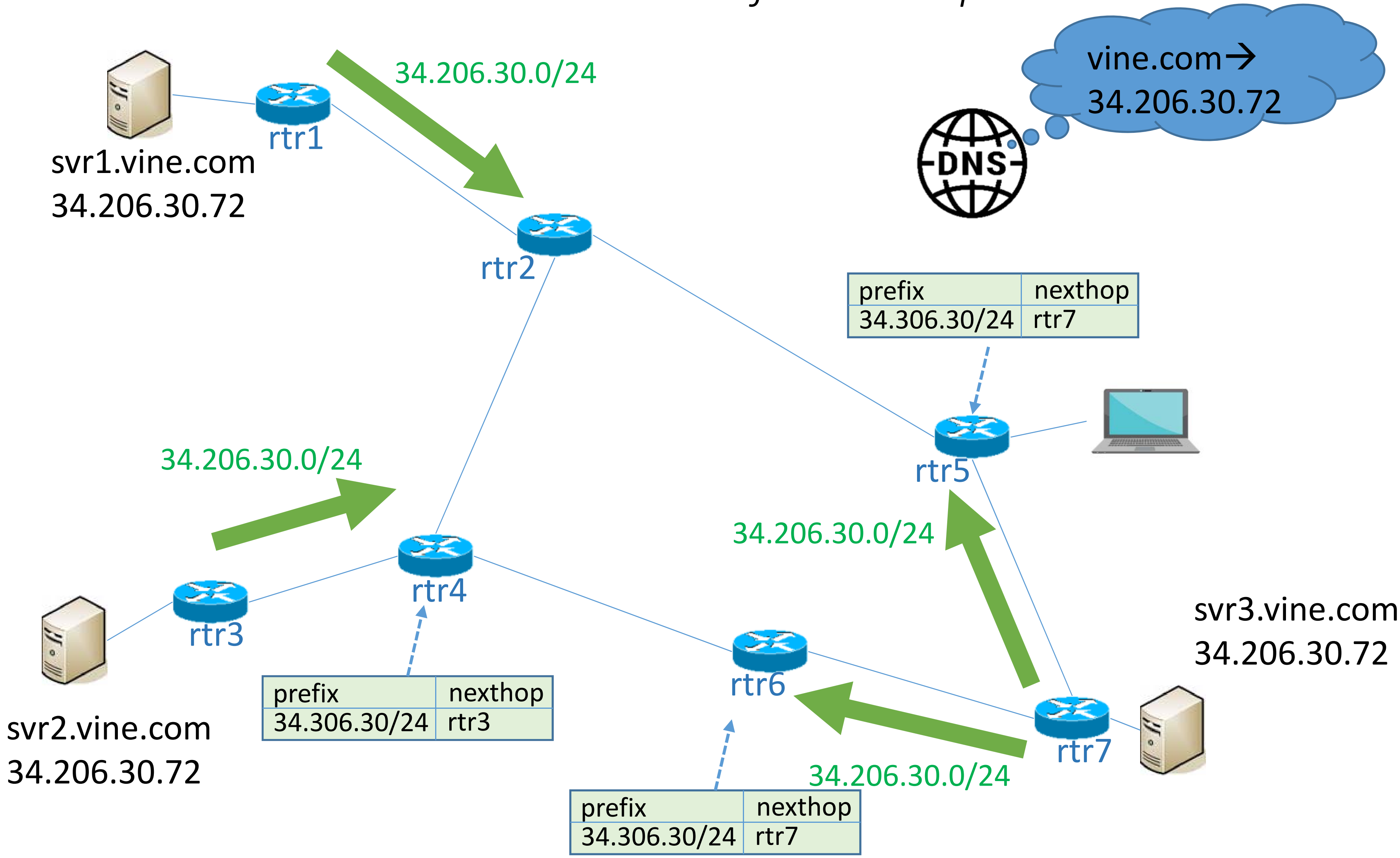
- Give the illusion of single server
- Benefits:
  - Don’t have to coordinate with humans
  - Can force users to servers in desirable ways
- Approach: Anycast
  - DNS Anycast (typically wide-area)
  - IP Anycast (typically wide- and regional-area)
  - Load balancers (typically local-area)

Approach 1: IP Anycast

- Idea: advertise same server address from multiple locations
  - Configure upstream routers to advertise same/overlapping prefix
- Routers in between choose shortest path
  - Directs traffic towards “closest” server
    - Closest in terms of # of hops

Approach 1: IP Anycast

Idea: advertise same server address from multiple locations



IP Anycast: Pros and Cons

- IP Anycast has several nice properties
- Fully transparent to higher layers
- ISPs and network can control
- Fast failover for network failures
  - Networks on server events leads to churn

- Cons:
  - Imprecise control (can't always control how advertisements flow)

Approach 2: DNS Anycast

- DNS is a huge distributed service
  - But you control the name→address mapping for your domain
- Idea: modify Authoritative DNS to return different mappings for different clients
  - Goal: map clients to “nearby” servers
- Inputs to mapping function
  - Mapping of Internet topology
    - Useful for estimating latency between hosts
  - Server loads
  - Etc

How are users assigned to PoPs

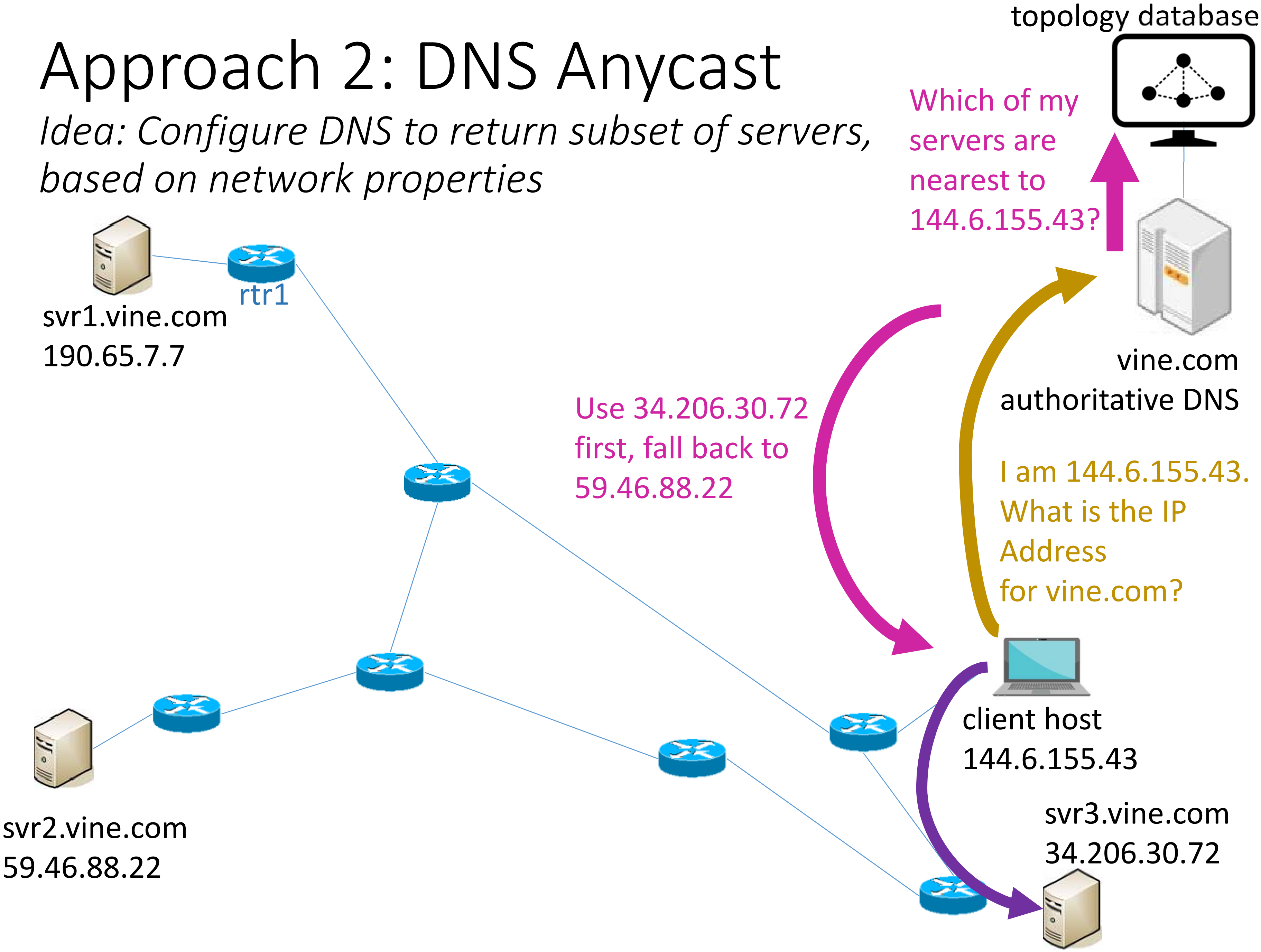
- Through DNS
  - Resolving server can hand back an IP address “close” to requesting user

```
# Chicago
$ dig +short www.linkedin.com
216.52.242.80
```

```
# Spain
$ dig @109.69.8.51 +short www.linkedin.com
91.225.248.80
```

Approach 2: DNS Anycast

Idea: Configure DNS to return subset of servers, based on network properties



Approach 2: DNS Anycast

Config DNS to return subset of servers, based on network properties

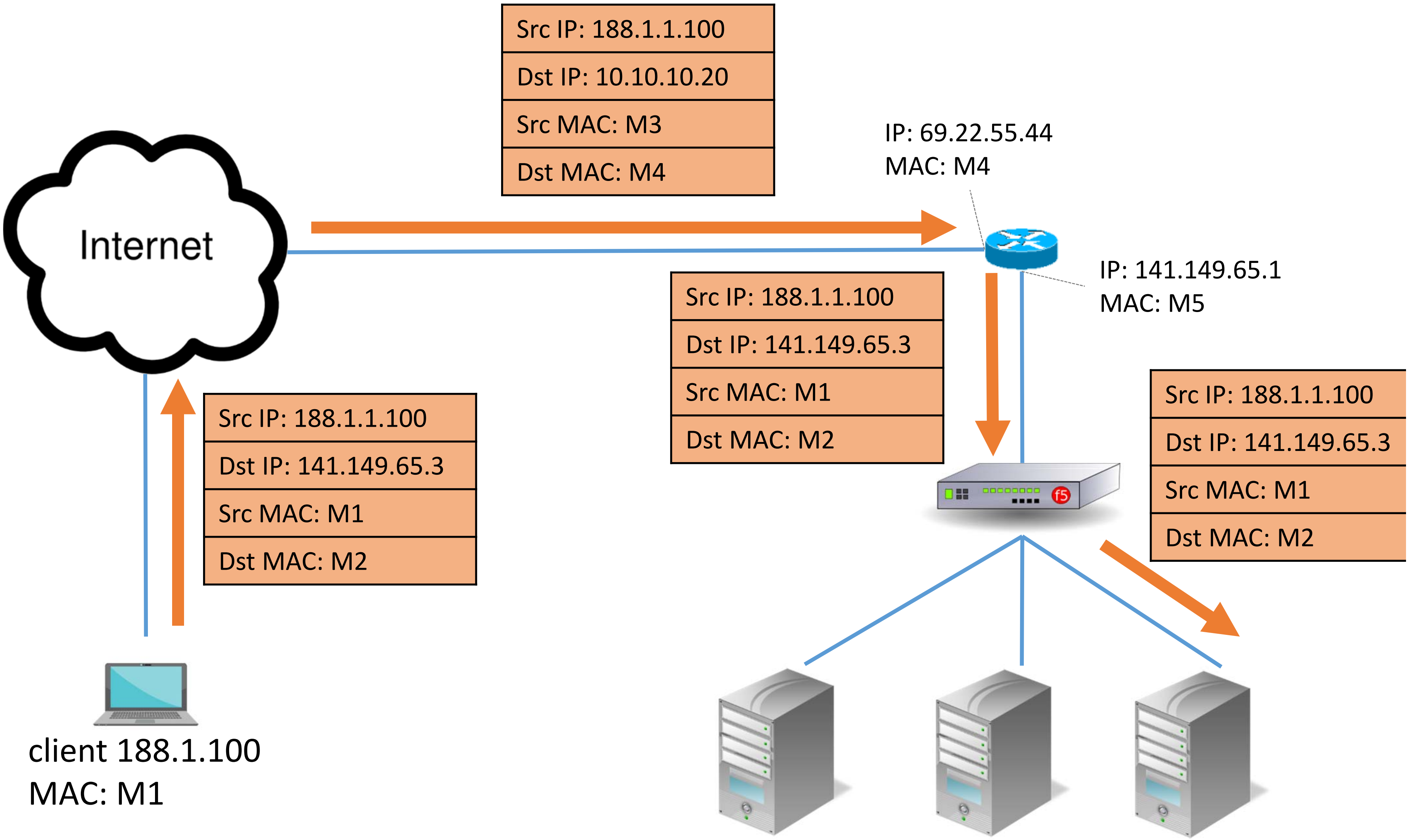
- Benefits
  - Tighter control over host-server mappings than IP anycast
    - Can map based on latency, server load
  - No need to coordinate with network operator
    - Need to convince providers to advertise prefix

- Cons
  - Harder for ISPs to control traffic
  - May require additional infrastructure to probe/survey network
  - Need to coordinate with DNS provider
  - Clients may be far from their local DNS (where request actually comes from)
  - Some local DNS servers don’t conform to specifications

Approach 3: Load-Balancing Devices

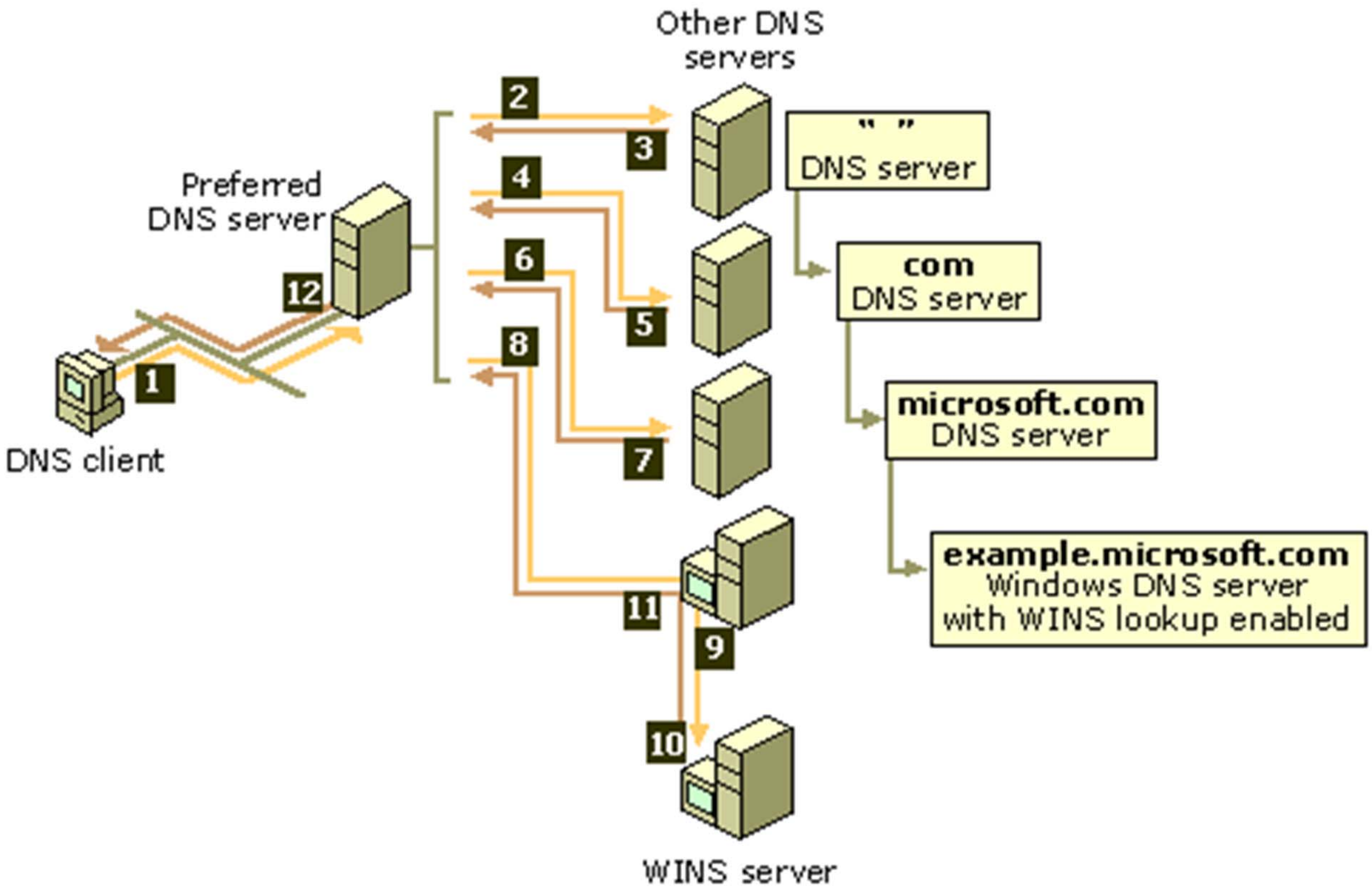
- In the local area, we have tighter control over forwarding
  - Can force ingress/egress path to be symmetric
  - Forwarding speeds low enough to deeply inspect packets
  - Network latency less of an issue
- Approach: install load-balancing hardware into the network
  - Device monitors servers, uses load balancing algorithm to distribute traffic

Approach 3: Load-Balancing Devices



DNS

DNS Lookup Process (Background)



Internet Names & Addresses

- Machine addresses: *e.g., 192.17.90.136*
  - router-usable labels for machines
  - conforms to network structure (the “where”)
- Machine names: *e.g., instr.engr.illinois.edu*
  - human-usable labels for machines
  - conforms to organizational structure (the “who”)
- The Domain Name System (DNS) is how we map from one to the other

DNS: History

- Initially all host-address mappings were in a hosts.txt file (in /etc/hosts):
  - Maintained by the Stanford Research Institute (SRI)
  - Changes were submitted to SRI by email
  - New versions of hosts.txt periodically FTP’d from SRI
  - An administrator could pick names at their discretion

- As the Internet grew this system broke down:
  - SRI couldn’t handle the load; names were not unique; hosts had inaccurate copies of hosts.txt

- The Domain Name System (DNS) was invented to fix this
  - First name server implementation done by 4 students

Goals

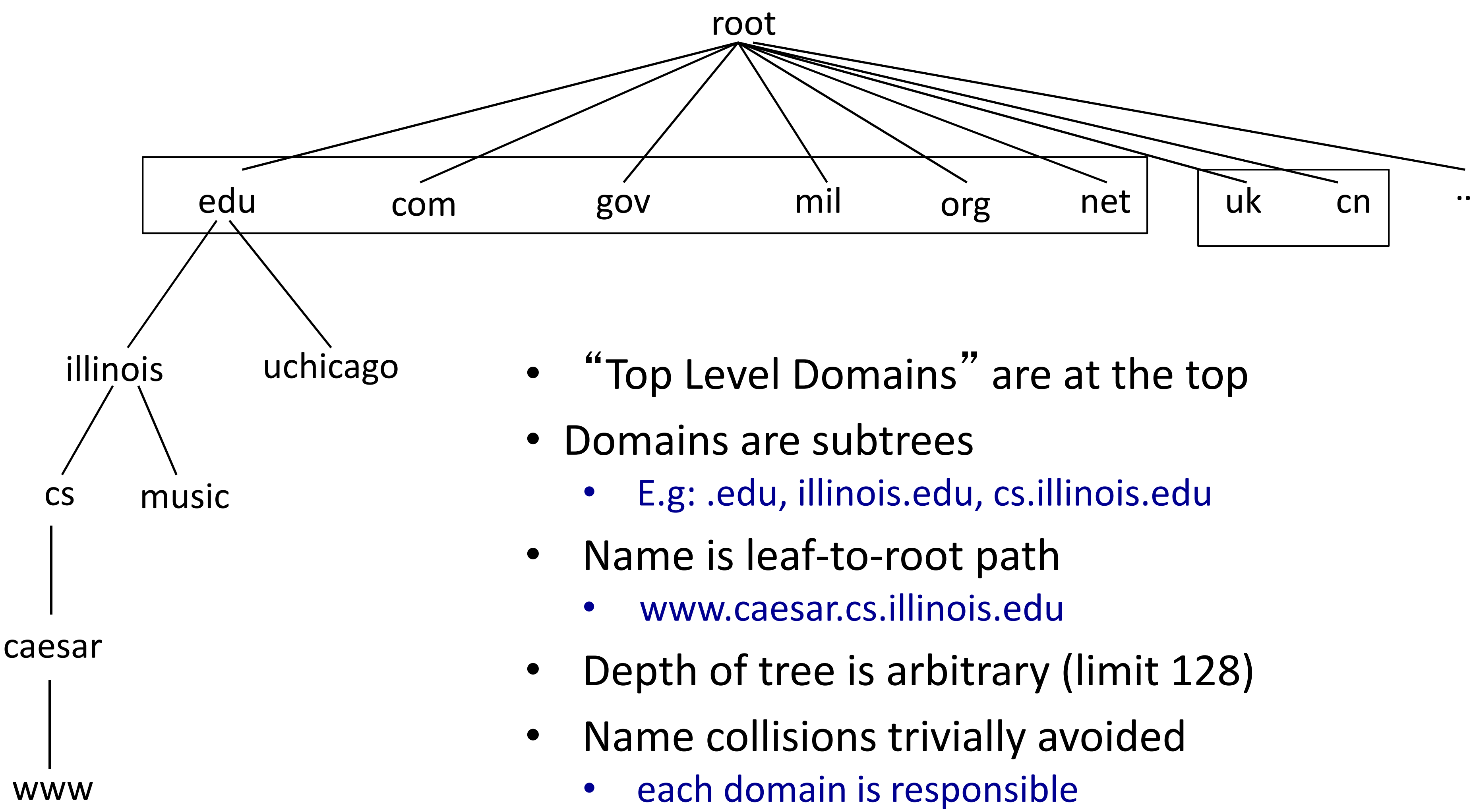
- No naming conflicts (uniqueness)
- Scalable
  - many names
  - (secondary) frequent updates
- Distributed, autonomous administration
  - Ability to update my own (machines') names
  - Don't have to track everybody's updates
- Highly available
- Lookups are fast
- Non-goal?: perfect consistency

Key idea: Hierarchy

Three intertwined hierarchies

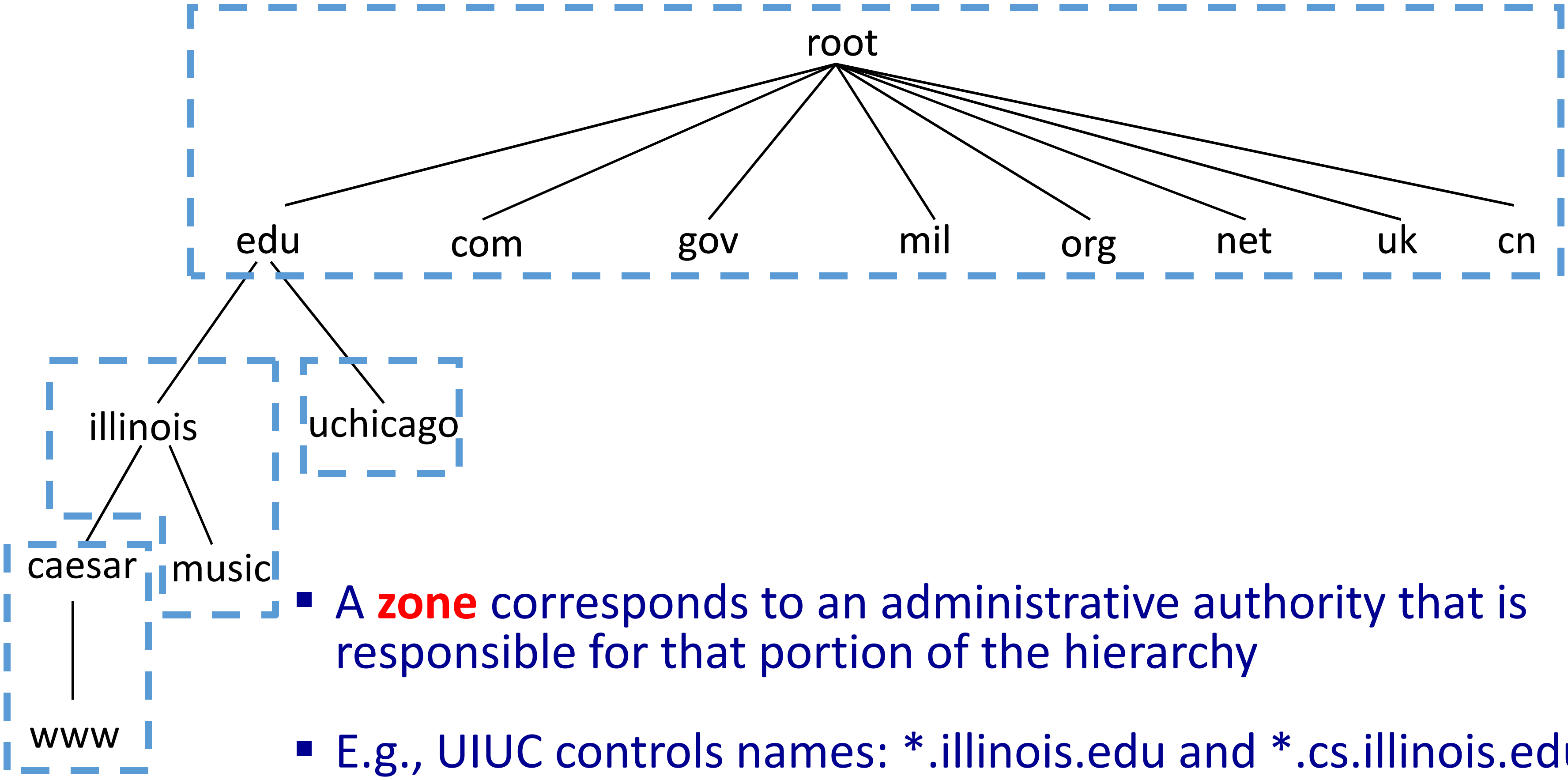
- Hierarchical namespace
  - As opposed to original flat namespace
- Hierarchically administered
  - As opposed to centralized
- (Distributed) hierarchy of servers
  - As opposed to centralized storage

Hierarchical Namespace



- "Top Level Domains" are at the top
- Domains are subtrees
  - E.g: .edu, illinois.edu, cs.illinois.edu
- Name is leaf-to-root path
  - www.caesar.cs.illinois.edu
- Depth of tree is arbitrary (limit 128)
- Name collisions trivially avoided
  - each domain is responsible

Hierarchical Administration



- A **zone** corresponds to an administrative authority that is responsible for that portion of the hierarchy
- E.g., UIUC controls names: *.illinois.edu and *.cs.illinois.edu

- E.g., CS controls names: *.cs.illinois.edu

Server Hierarchy

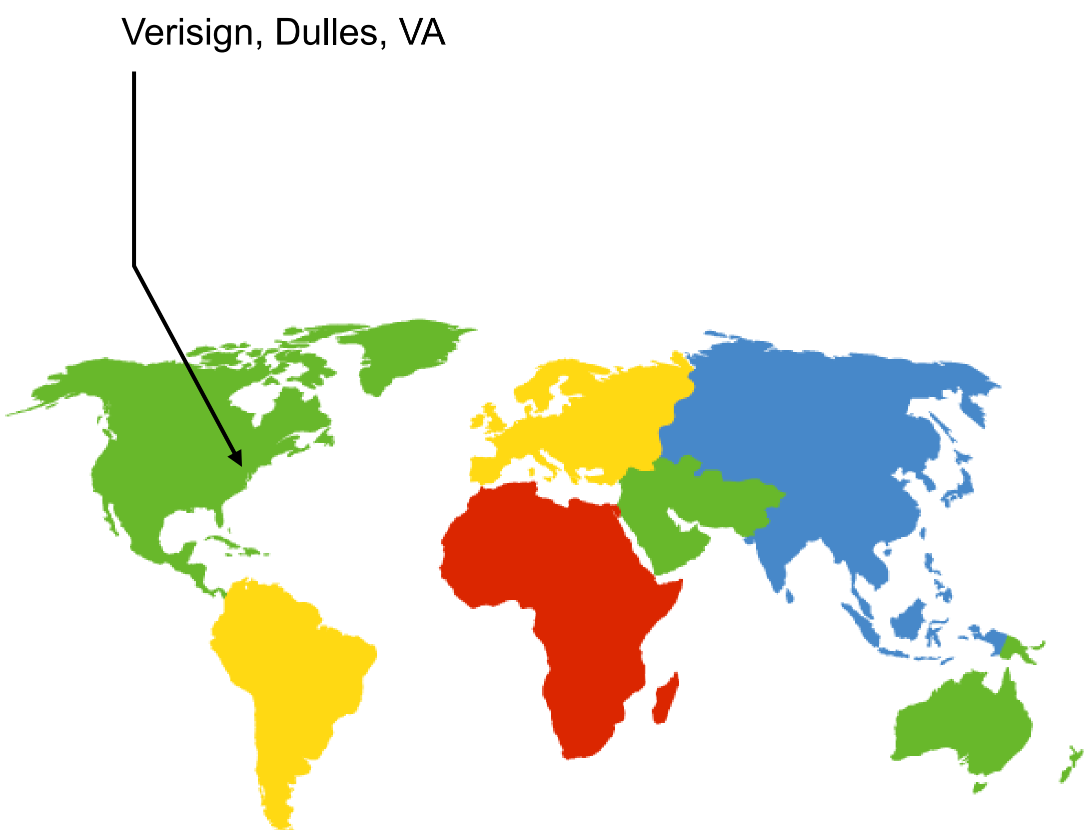
- Top of hierarchy: Root servers
  - Location hardwired into other servers
- Next Level: Top-level domain (TLD) servers
  - .com, .edu, etc.
  - Managed professionally
- Bottom Level: Authoritative DNS servers
  - Actually store the name-to-address mapping
  - Maintained by the corresponding administrative authority

Server Hierarchy

- Each server stores a (small!) subset of the total DNS database
- An authoritative DNS server stores “resource records” for all DNS names in the domain that it has authority for
- Each server needs to know other servers that are responsible for the other portions of the hierarchy
  - Every server knows the root
  - Root server knows about all top-level domains

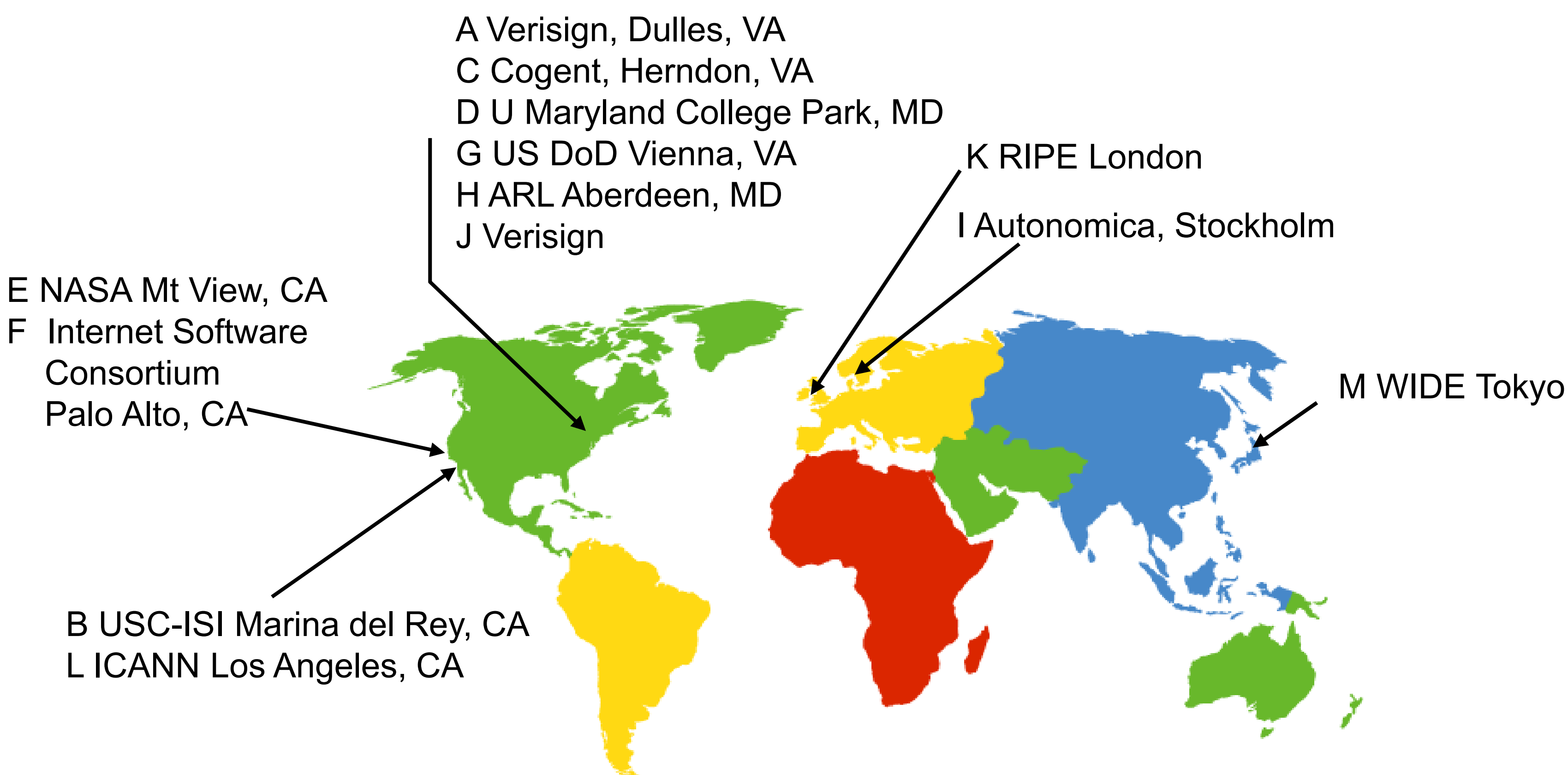
DNS Root

- Located in Virginia, USA
- How do we make the root scale?



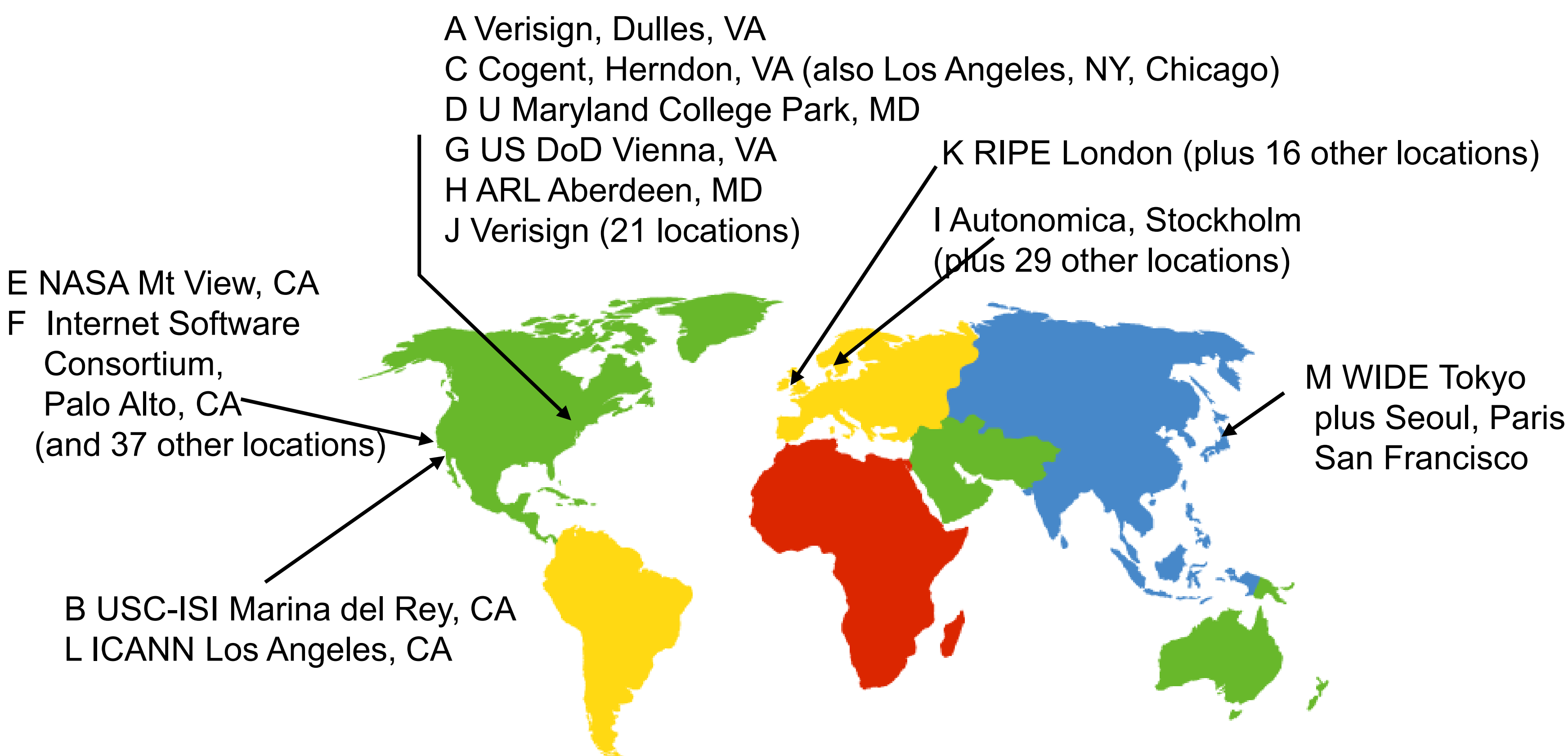
DNS Root Servers

- 13 root servers (labeled A-M; see http://www.root-servers.org/)



DNS Root Servers

- 13 root servers (labeled A-M; see http://www.root-servers.org/)
- Replicated via any-casting



Anycast in a nutshell

- Routing finds shortest paths to destination
- If several locations are given the same address, then the network will deliver the packet to the closest location with that address
- This is called “anycast”
  - Very robust
  - Requires no modification to routing algorithms

Using DNS (Client/App View)

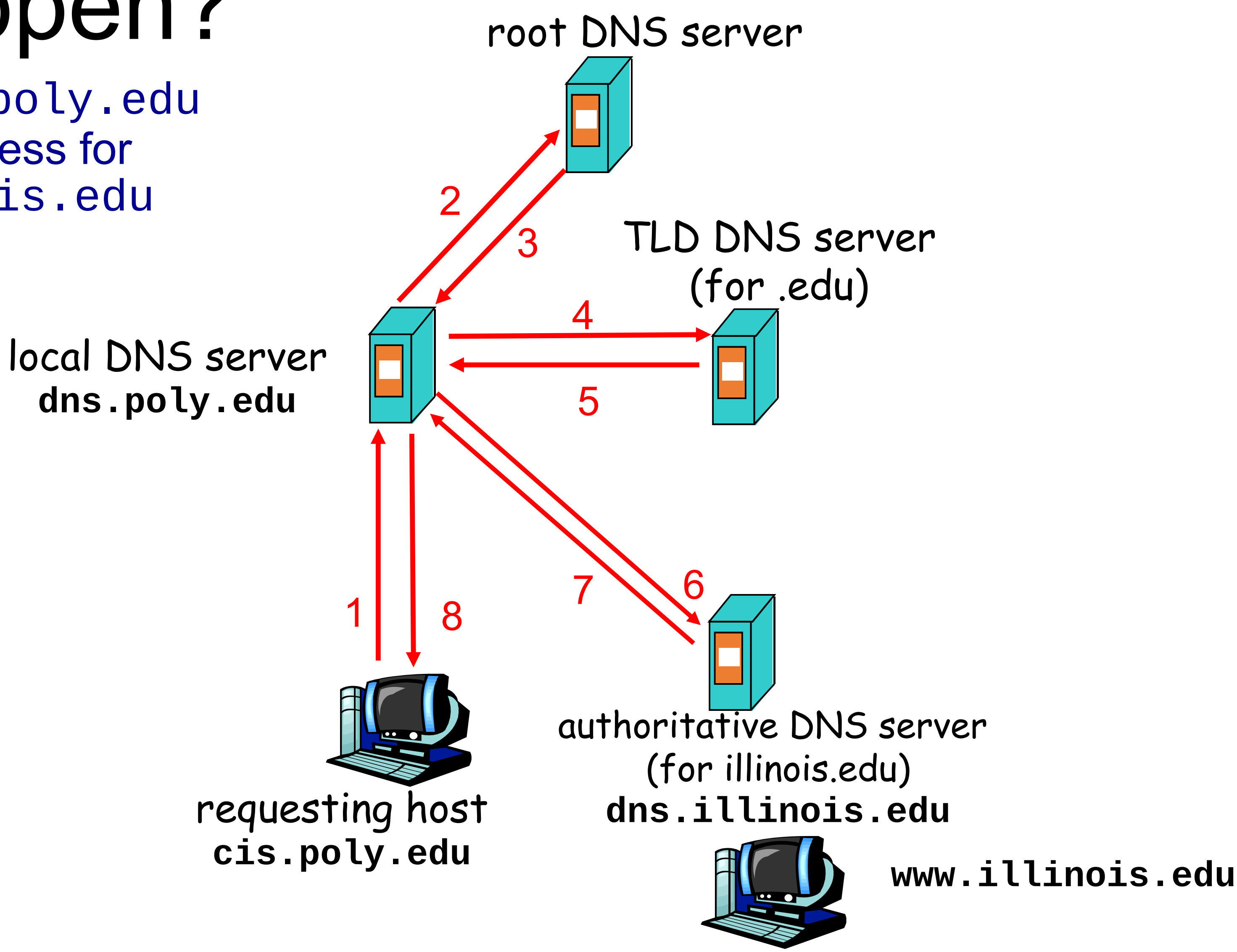
- Two components
  - Local DNS servers
  - Resolver software on hosts

- Local DNS server (“default name server”)
  - Usually near the endhosts that use it
  - Hosts configured with local server address (e.g., /etc/resolv.conf) or learn server via a host configuration protocol (e.g., DHCP)

- Client application
  - Obtain DNS name (e.g., from URL)
  - Do **gethostbyname()** to trigger DNS request to its local DNS server

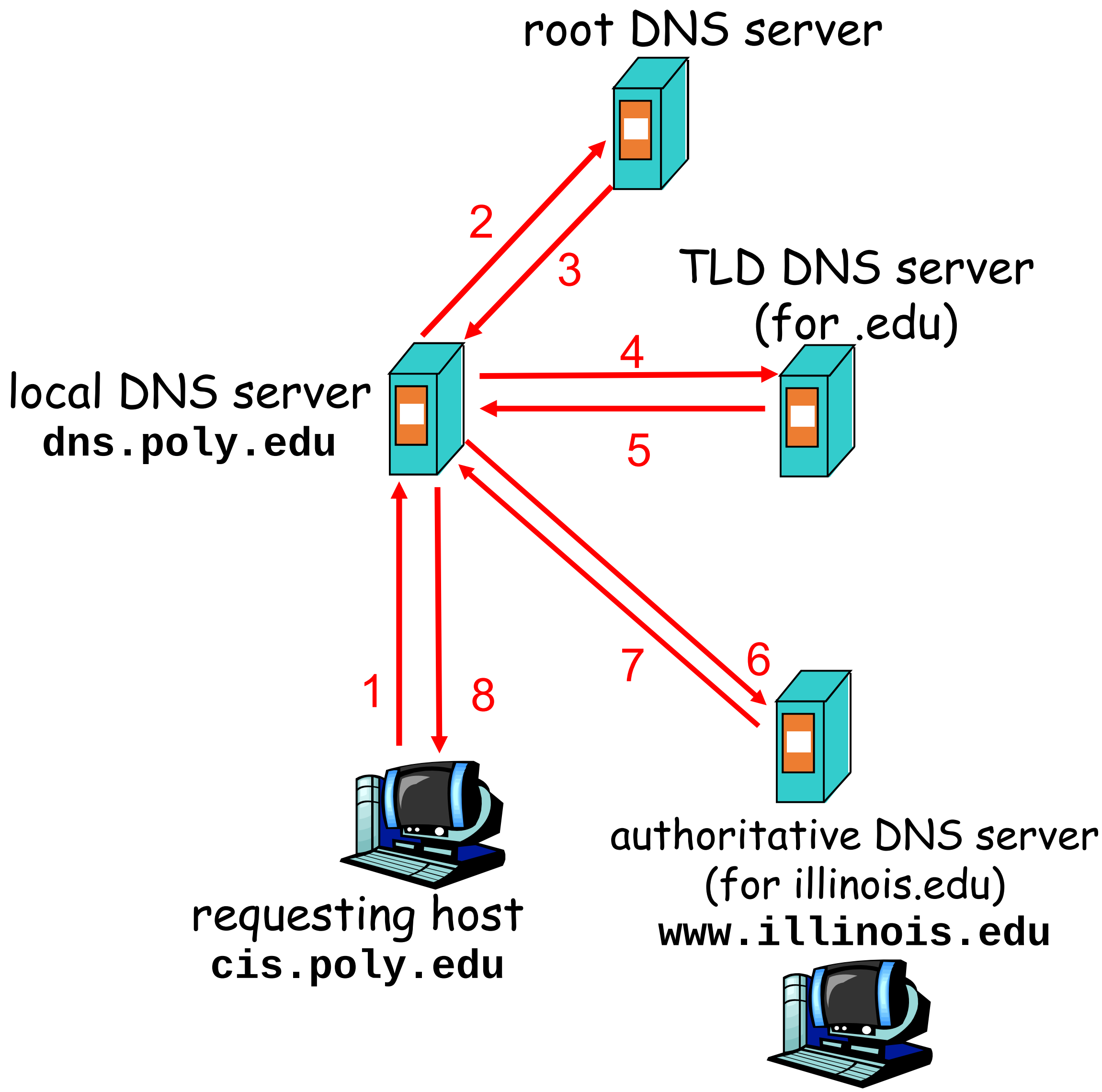
How Does Resolution Happen?

Host at `cis.poly.edu` wants IP address for `www.illinois.edu`



Recursive vs. Iterative Queries

- Recursive query
  - Ask server to get answer for you
  - E.g., request 1 and response 8
- Iterative query
  - Ask server who to ask next
  - E.g., all other request-response pairs
- Usually recursive is disabled (subject to DoS attacks)



DNS Records

- DNS info. stored as resource records (RRs)
  - RR is (name, value, type, TTL)

- Type = A: *(→ Address)*
  - name = hostname
  - value = IP address

- Type = NS: *(→ Name Server)*
  - name = domain
  - value = name of dns server for domain

DNS Records (cont'd)

- Type = CNAME: *(→ Canonical NAME)*
  - name = hostname
  - value = canonical name
- Type = MX: *(→ Mail eXchanger)*
  - name = domain in email address
  - value = canonical name(s) of mail server(s)
- Example:

```
NAME                      TYPE   VALUE
--------------------------------------------------
bar.example.com.          CNAME  foo.example.com.
foo.example.com.          A      192.0.2.23
```

Inserting Resource Records into DNS

- Example: just created company “FooBar”
- Get a block of address space from ISP
  - Say 212.44.9.128/25
- Register **`foobar.com`** at registrar (e.g., Network Solutions)
  - Provide registrar with names and IP addresses of your authoritative name server (primary and secondary)
  - Registrar inserts RR pairs into the **`.com`** TLD server:
    - (**`foobar.com`**, **`dns1.foobar.com`**, **`NS`**)
    - (**`dns1.foobar.com`**, **`212.44.9.129`**, **`A`**)
- You store appropriate records in your server **`dns1.foobar.com:`**
  - e.g., type A record for **`www.foobar.com`**
  - e.g., type MX record for **`foobar.com`**

DNS Protocol

- Query and Reply messages; both with the same message format
  - header: identifier, flags, *etc.*
  - plus resource records
  - *see text/section for details*

- Client--server interaction on UDP Port 53
  - Spec supports TCP too, but not always implemented

Goals -- how are we doing?

- No naming conflicts (uniqueness)
- Scalable
- Distributed, autonomous administration
- Highly available
- Fast lookups

DNS Caching

- Performing all these queries takes time
  - And all this before actual communication takes place
  - E.g., 1-second latency before starting Web download
- Caching can greatly reduce overhead
  - The top-level servers very rarely change
  - Popular sites (e.g., www.cnn.com) visited often
  - Local DNS server often has the information cached
- How DNS caching works
  - DNS servers cache responses to queries
  - Responses include a "time to live" (TTL) field
  - Server deletes cached entry after TTL expires

Negative Caching

- Remember things that don’ t work
  - Misspellings like *www.cnn.comm* and *www.cnnn.com*
  - These can take a long time to fail the first time
  - Good to remember that they don’t work
  - … so the failure takes less time the next time around
- But: negative caching is optional
  - And not widely implemented

Reliability

- DNS servers are replicated (primary/secondary)
  - Name service available if at least one replica is up
  - Queries can be load-balanced between replicas
- Usually, UDP used for queries
  - Need reliability: must implement this on top of UDP
- Try alternate servers on timeout
  - Exponential backoff when retrying same server
- Same identifier for all queries
  - Don’t care which server responds

Important Properties of DNS

Administrative delegation and hierarchy results in:

- Easy unique naming
- “Fate sharing” for network failures
- Reasonable trust model
- Caching lends scalability, performance

DNS provides Indirection

- Addresses can change underneath
  - Move www.cnn.com to 4.125.91.21
  - Humans/Apps should be unaffected
- Name could map to multiple IP addresses
  - Enables
    - Load-balancing
    - Reducing latency by picking nearby servers
- Multiple names for the same address
  - E.g., many services (mail, www, ftp) on same machine
  - E.g., aliases like www.cnn.com and cnn.com
- But, this flexibility applies only within domain!

DNSSEC

- What if a DNS server gets compromised/intercepted?
  - Can redirect users to other sites
  - E.g., fake bank site that learns your password
  - "Cache poisoning" – filling DNS caches with bad information
- Solution: DNSSEC
  - Digitally sign IP-to-name mappings
    - Signature is cryptographic hash of DNS data
  - If signatures can't be verified, error to user
  - Doesn't mitigate DoS or provide data confidentiality

DNSSEC Lookup

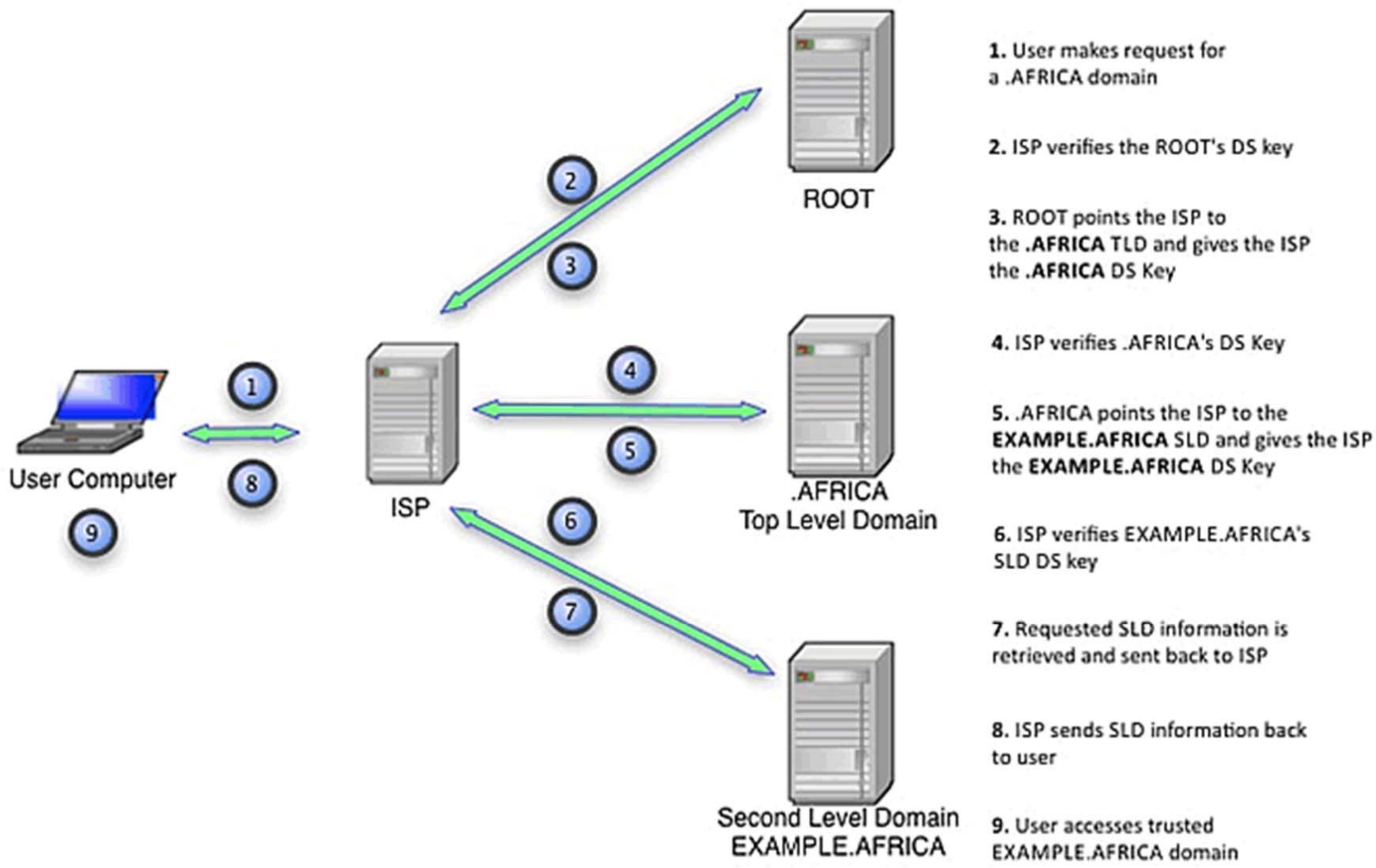
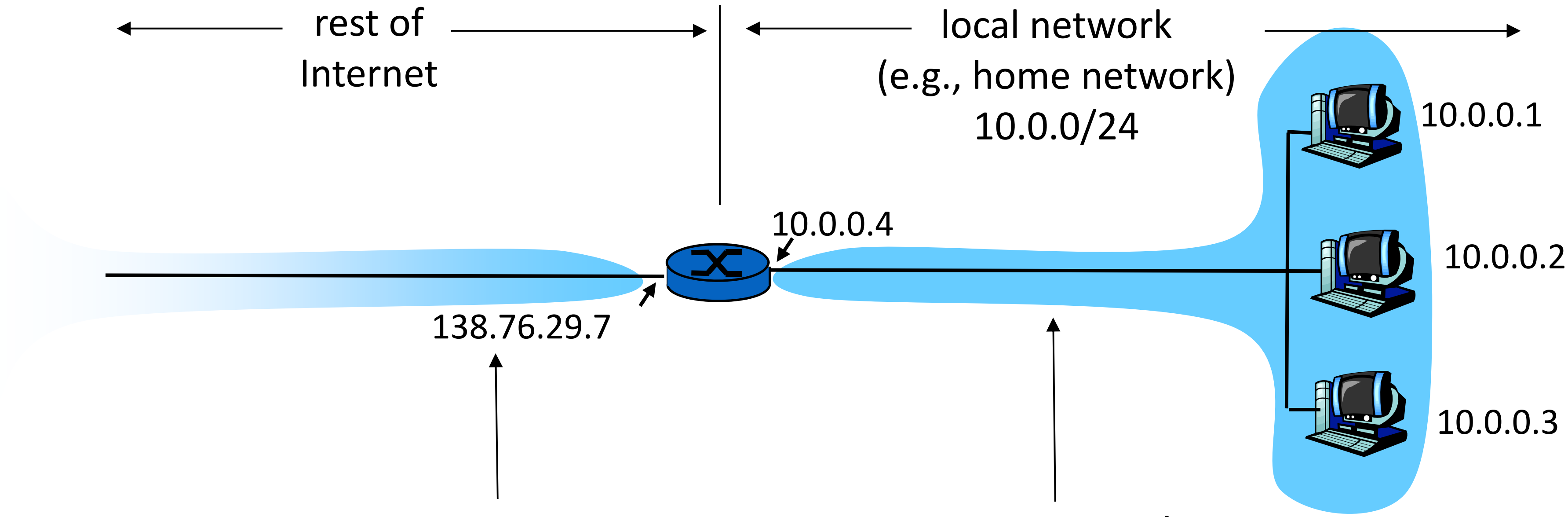


Figure 1: Example of Trust Chain Using DNSSEC

NAT

NAT: Network Address Translation



All datagrams *leaving* local network have same single source NAT IP address: 138.76.29.7, different source port numbers

Datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

NAT: Network Address Translation

- Motivation: local network uses just one IP address as far as outside word is concerned:
  - no need to be allocated range of addresses from ISP: - just one IP address is used for all devices
  - can change addresses of devices in local network without notifying outside world
  - can change ISP without changing addresses of devices in local network
  - devices inside local net not explicitly addressable, visible by outside world (a security plus).

NAT: Network Address Translation

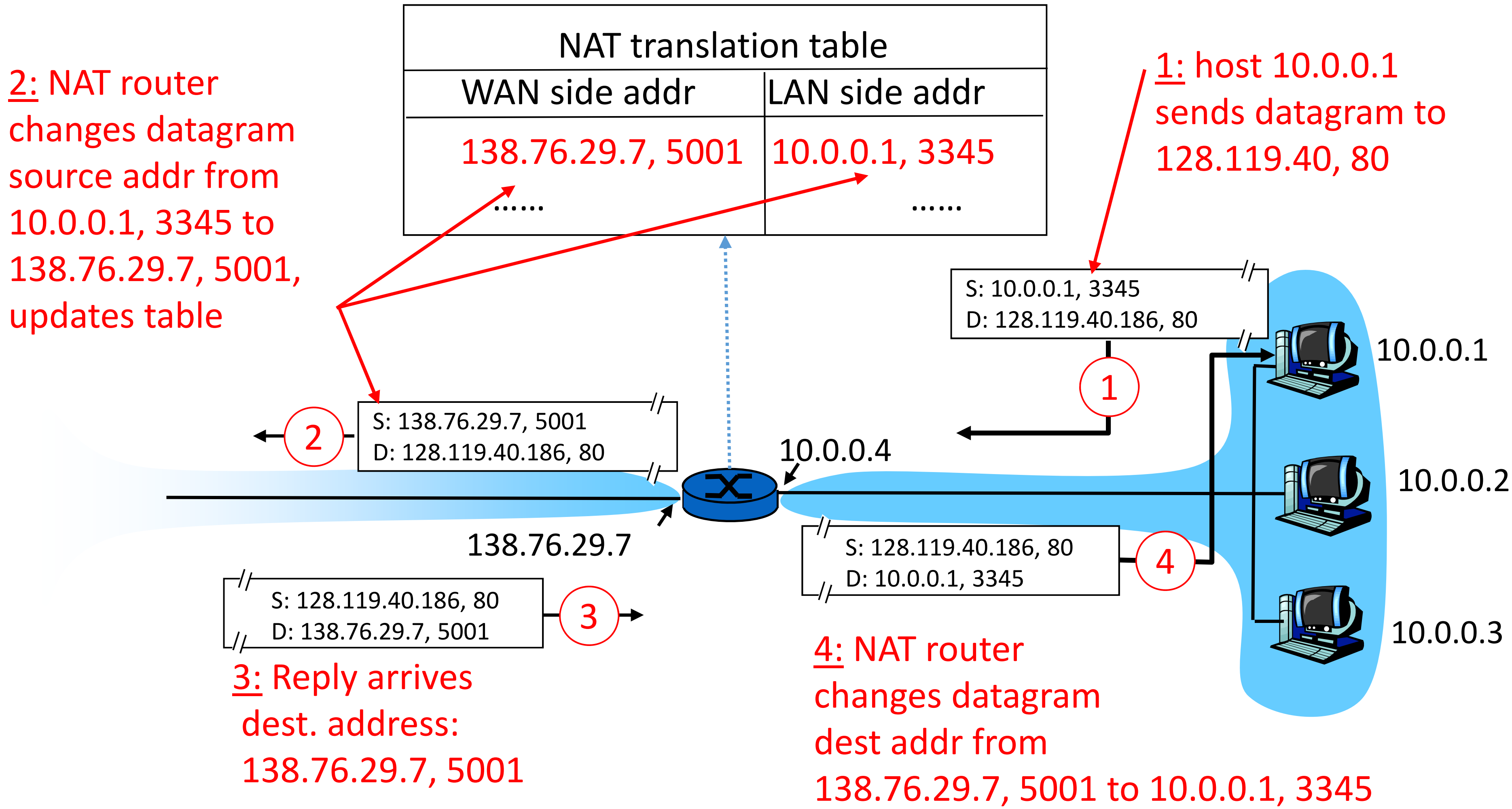
Implementation: NAT router must:

- *outgoing datagrams: replace* (source IP address, port #) of every outgoing datagram to (NAT IP address, new port #)
  . . . remote clients/servers will respond using (NAT IP address, new port #) as destination addr.

- *remember (in NAT translation table)* every (source IP address, port #) to (NAT IP address, new port #) translation pair

- *incoming datagrams: replace* (NAT IP address, new port #) in dest fields of every incoming datagram with corresponding (source IP address, port #) stored in NAT table

NAT: Network Address Translation



NAT: Network Address Translation

- 16-bit port-number field:
  - 60,000 simultaneous connections with a single LAN-side address!
- NAT is (was?) controversial:
  - routers should only process up to layer 3
  - violates end-to-end argument
    - NAT possibility must be taken into account by app designers, eg, P2P applications
  - address shortage should instead be solved by IPv6

Types of NAT

- PAT: Port-Address Translation
  - Uses port field in addition to address field
- Restricted NAT
  - An external host H_e can only contact an internal host H_i if H_i has previously sent packets to H_e
  - See also "hole-punching" source sends packet to create association, informs association to peer (may have to guess port assignment alg)
- Port forwarding
  - Install static mapping in NAT, to make services on internal network publicly reachable
  - E.g., port 80 on NAT address gets mapped to machine X, port 8080
- Carrier-grade NAT
  - NAT run by an ISP, as opposed to an enterprise/end-user
  - NAT444: cust private nw → provider private nw → public nw