CS4450

Computer Networks:
Architecture and Protocols

Lecture 23
DNS and HTTP

What is DNS?

- **User has name of entity she/he wants to access**
  - E.g., www.cnn.com
  - Content, host, etc.
- However, **Internet routes and forwards requests based on IP addresses**
  - Need to convert name (e.g., www.cnn.com) to an IP address
- **Domain Name System (DNS)**
  - **Provides the mapping from name to IP address**
  - User asks DNS: what is the IP address for www.cnn.com
  - DNS responds: 157.166.255.18

Correctness Requirements

- **Addresses can change underneath**
  - Move www.cnn.com to 4.125.91.21
  - Humans/Applications should be unaffected

- **Name could map to multiple IP addresses**
  - www.cnn.com to multiple replicas to the Web site
  - To enable “load balancing” or reduced latency
    - Replicas may see different load (eg, due to geographic location)
    - Some replicas may be closer to the user

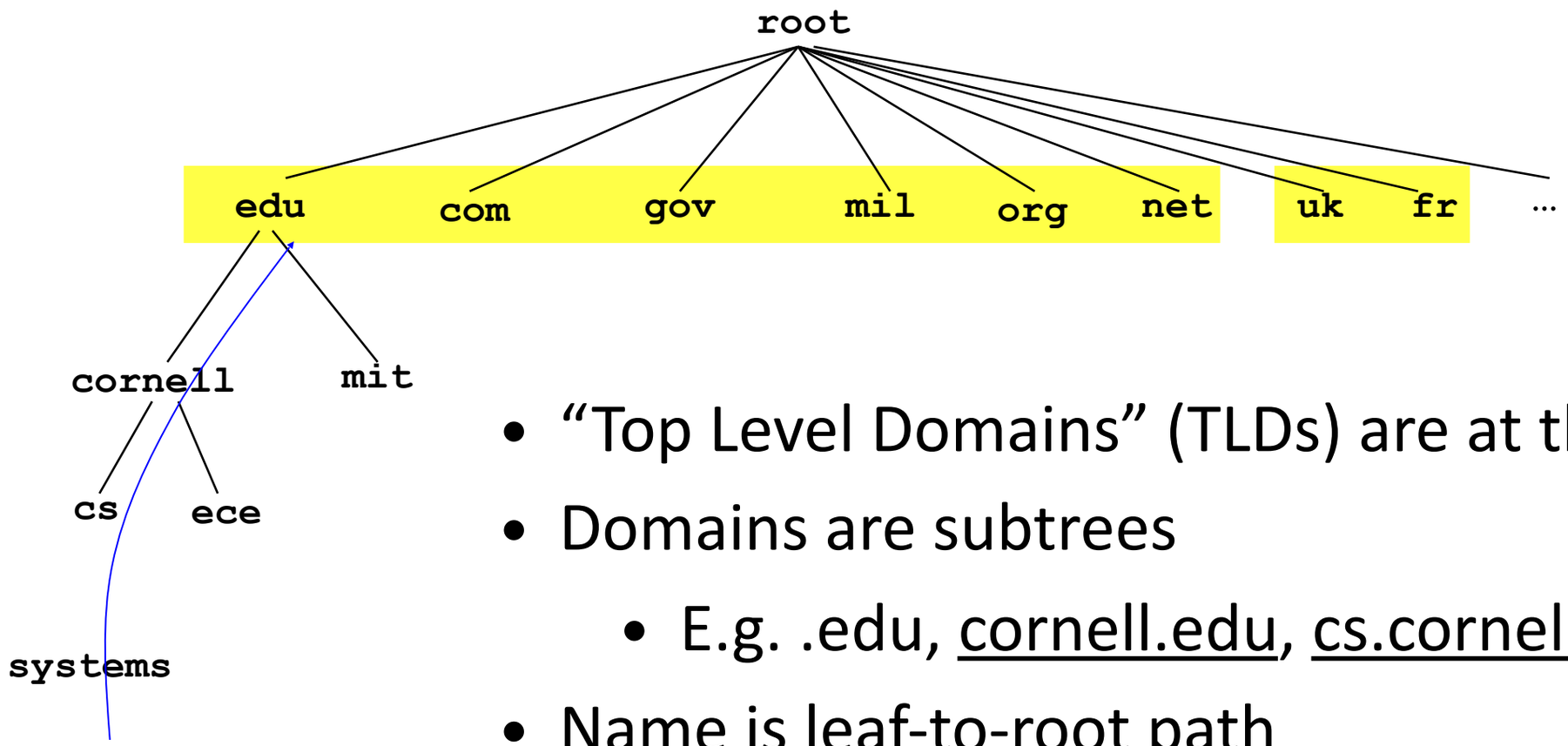
- **Multiple names for the same address**
  - E.g., www.cnn.com and cnn.com should map to same IP addresses

Goals and Approach

- **Goals**
    - Correctness (from previous slide)
    - Scaling (names, users, updates, etc.)
    - Ease of management (uniqueness of names, etc.)
    - Availability and consistency
    - Fast lookups

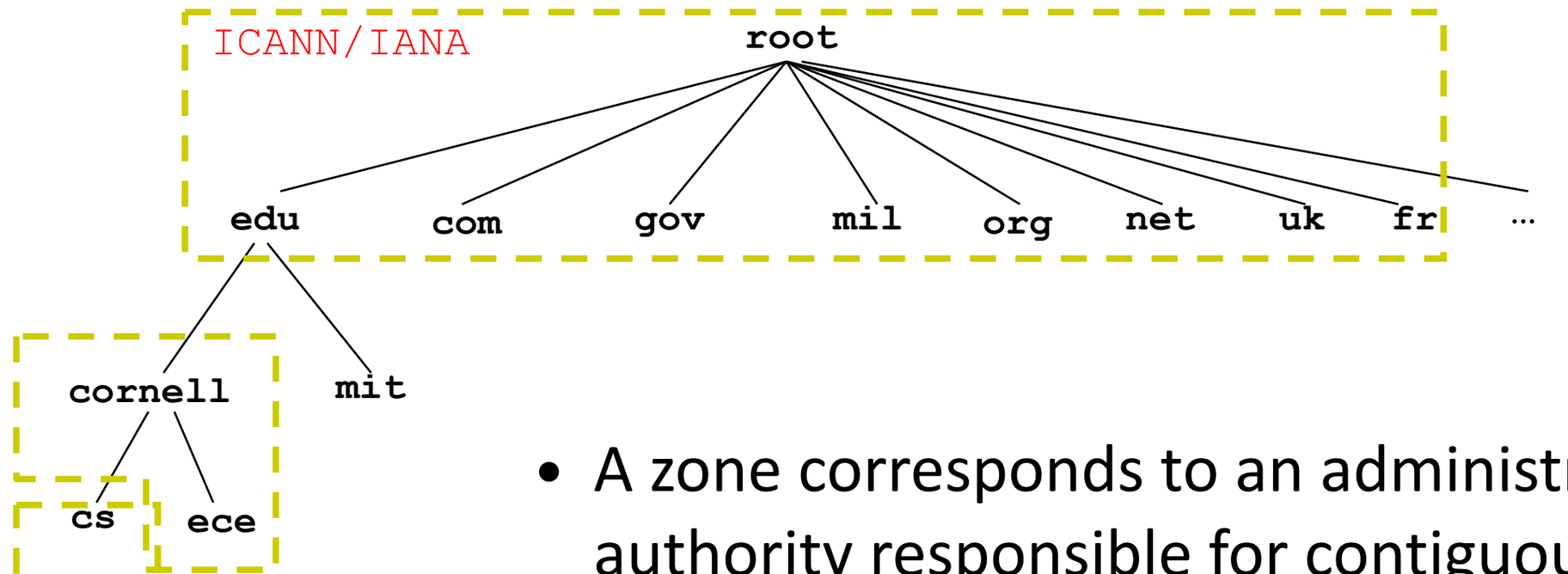
- **Approach: Three intertwined hierarchies**
    - Hierarchical Namespace: exploit structure in names
    - Hierarchical Administration: hierarchy of authority over names
    - Hierarchical Infrastructure: hierarchy of DNS servers

Hierarchical Namespace



- "Top Level Domains" (TLDs) are at the top
- Domains are subtrees
  - E.g. .edu, cornell.edu, cs.cornell.edu
- Name is leaf-to-root path
  - systems.cs.cornell.edu

Hierarchical Administration



- A zone corresponds to an administrative authority responsible for contiguous portion of hierarchy
  - Cornell controls *.cornell.edu
  - CS controls *.cs.cornell.edu
- Name collisions trivially avoided
  - Each domain can ensure this locally

Hierarchical Infrastructure

- Top of hierarchy: root
  - Location hardwired into other servers
- Next level: Top Level Domain (TLD) servers
  - .com, .edu, etc.
- Bottom level: Authoritative DNS servers
  - Actually do the mapping
  - Can be maintained locally or by a service provider

Per Domain Availability

- DNS Servers are **replicated**
  - Primary and secondary name servers are required
  - Name service available if at least one replica is up
  - Queries can be load-balanced among replicas

- Try alternate servers on timeout
  - **Exponential backoff** when retrying the same server

Who Knows What?

- Every server knows address of root name server
- Root servers know the address of all TLD servers
- Every node knows the address of all children
- An ***authoritative*** DNS server stores name-to-address mappings ("resource records") for all DNS names in the domain that it has authority for
- Therefore, each server:
  - Stores only a subset of the total DNS database (scalable!)
  - Can discover server(s) for any portion of the hierarchy

Benefits of This Approach

- Scalable in names, updates, lookups, users
- Highly available: domains replicate independently
- Extensible: can add TLDs just by changing root db
- Autonomous administration:
    - Each domain manages own names and servers
    - And can further delegate
    - Easily ensures uniqueness of names
    - And consistency of databases

DNS Records (details)

- DNS servers store 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 (details continued)

- Type = MXL (-> Main eXchanger)
  - name = domain in email address
  - value = name(s) of main server(s)

- Type = CNAME: (-> Canonical NAME)
  - Name = alias
  - Value is “canonical” name

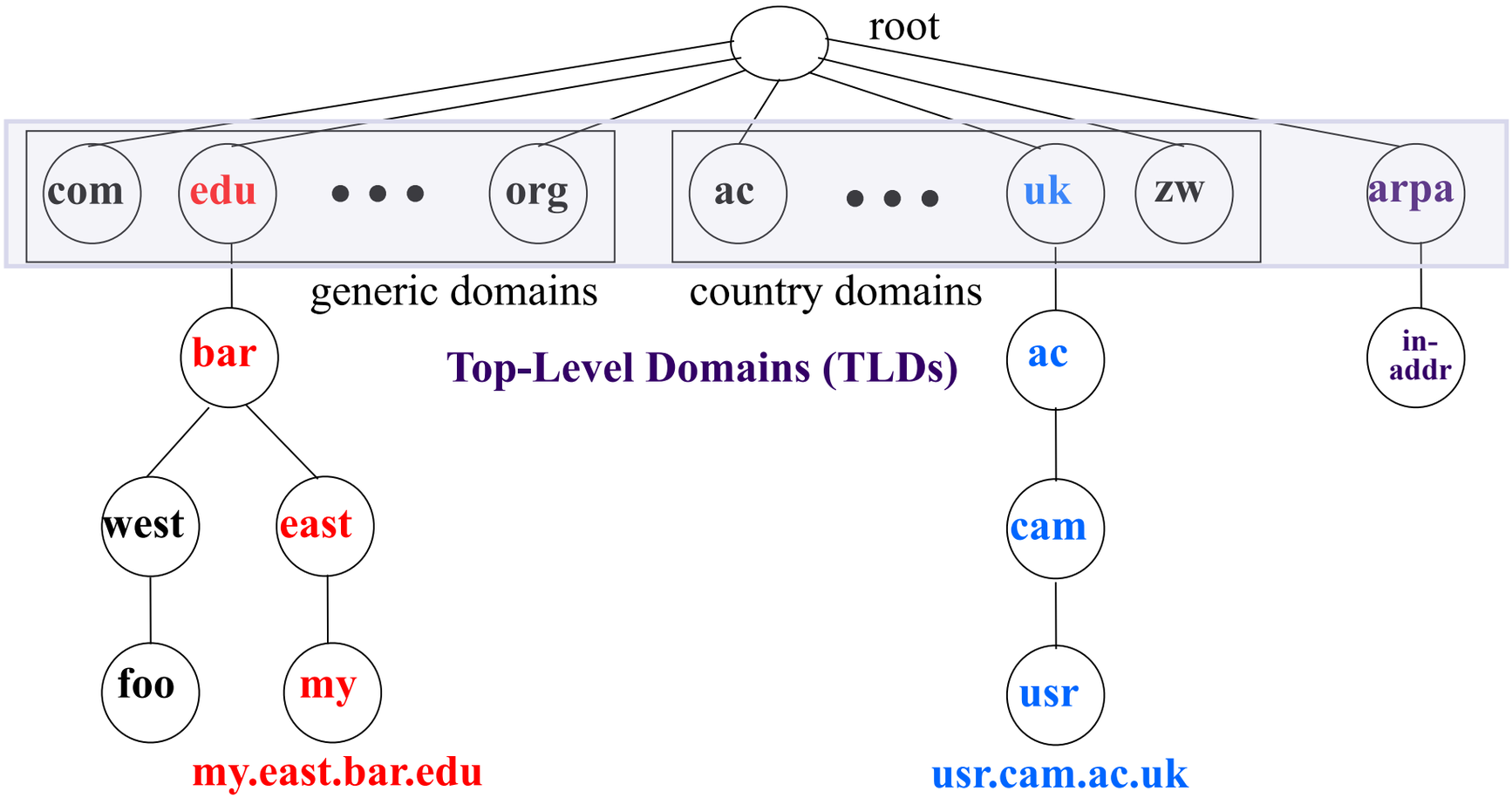
- Type = PTR: (-> Pointer)
  - name is reversed IP
  - value is corresponding hostname

Inserting Resource Records into DNS

- Example: you just created company “FooBar”
- You get a block of IP addresses from your ISP
  - E.g., 212.44.9.128/25
- Register foobar.com at registrar (e.g., GoDaddy)
  - Provide registrar with names and IP addresses of your authoritative name server(s)
    - Registrar inserts RR pairs into the .com TLD server:
      - (foobar.com, dns1.foobar.com, NS)
      - (dns1.foobar.com, 212.44.9.129, A)
- Store resource records in your server dns1.foobar.com
  - e.g., type A record for www.foobar.com
  - e.g., type MX record for foobar.com

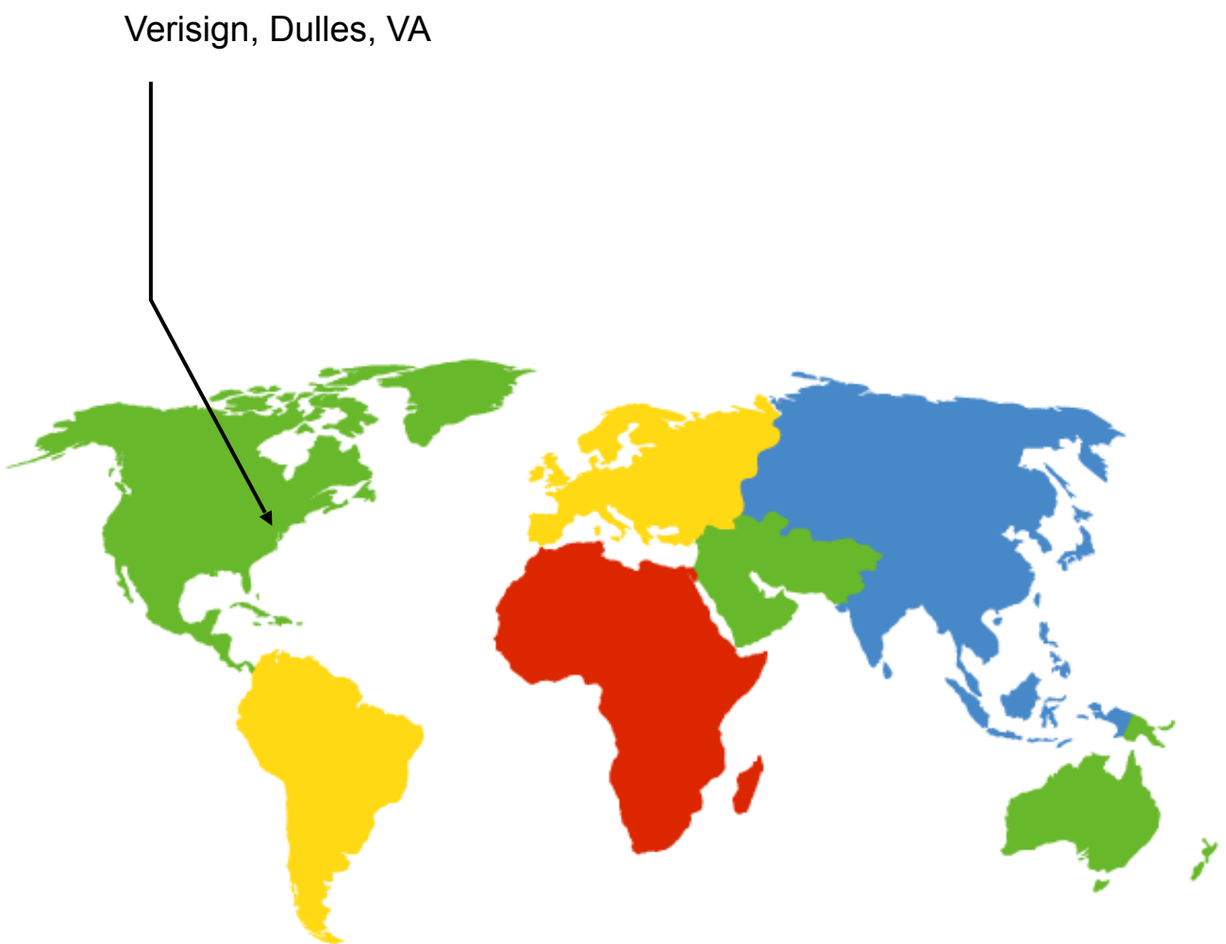
Distributed Hierarchical Database

Everything scales but the root!



DNS Root

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



DNS Root Servers

- 13 root servers (see http://www.root-servers.org/)
  - Labeled A through M
- How can we seamlessly scale this further?

Anycast

- Routing finds shortest paths to destination
- If several locations are given the same address:
  - Network will deliver the packet to closest location with that address
- This is called "**anycast**"
  - No modification of routing is needed for this….
- Allows for seamless replication of resources
  - Any problems with this approach?

DNS Root Servers

- 13 root servers (see http://www.root-servers.org/)
  - Labeled A through M

- Replication via any-casting (localized routing for addresses)

Using DNS

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

- Local DNS server (“default name server”)
  - Usually near the end hosts that use it
  - Local hosts configured with local server (e.g, /etc/resolv.conf) or learn server via DHCP

- Client application
  - Obtain DNS name (e.g., from the URL)
  - Do **gethostbyname()** to trigger resolver code
  - Which then sends request to local DNS server

root servers

Local DNS server

(mydns.cornell.edu)

.edu servers

nyu.edu servers

DNS client

(me.cs.cornell.edu)

root servers

Local DNS server

(mydns.cornell.edu)

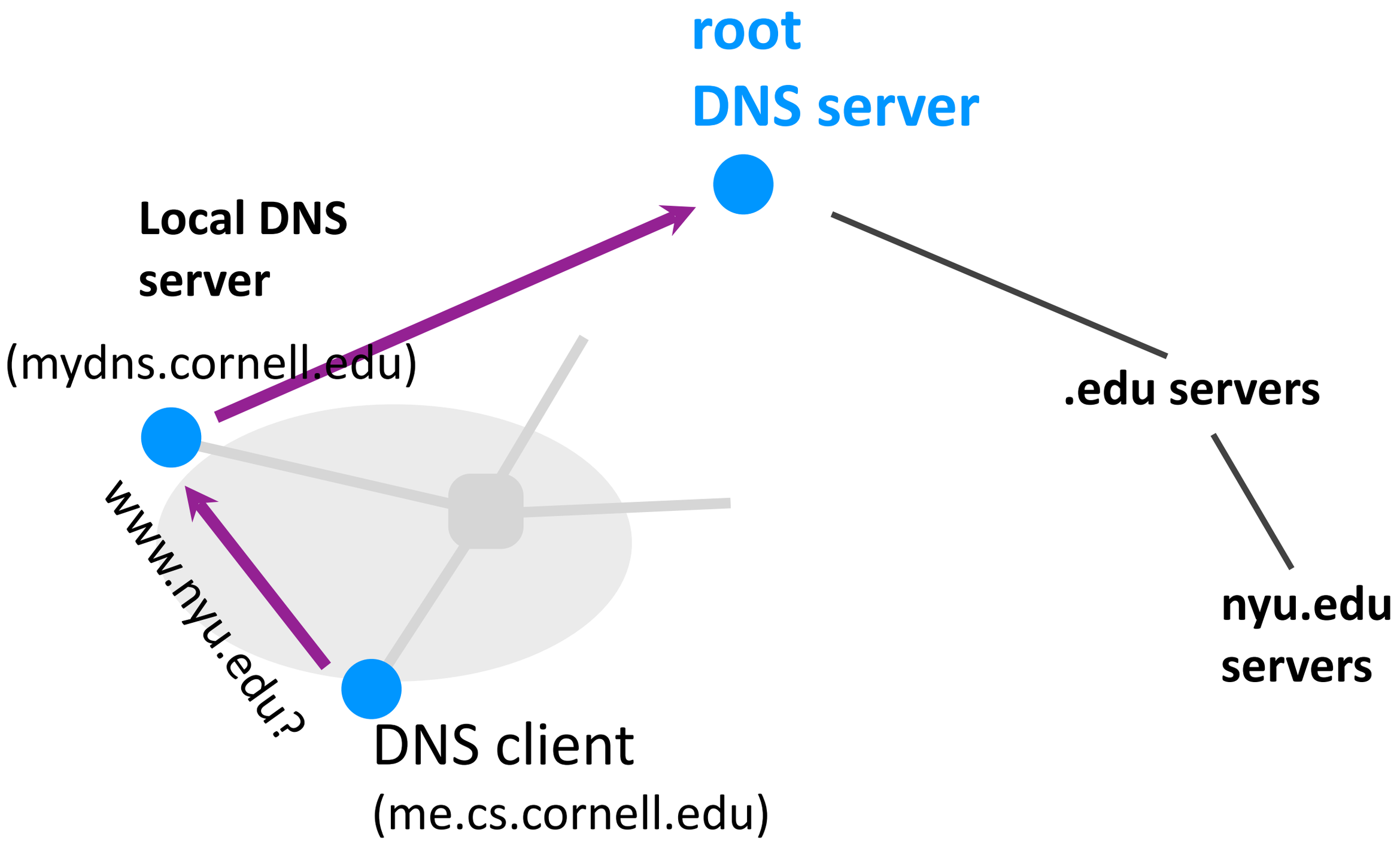
.edu servers

nyu.edu servers

www.nyu.edu?

DNS client

(me.cs.cornell.edu)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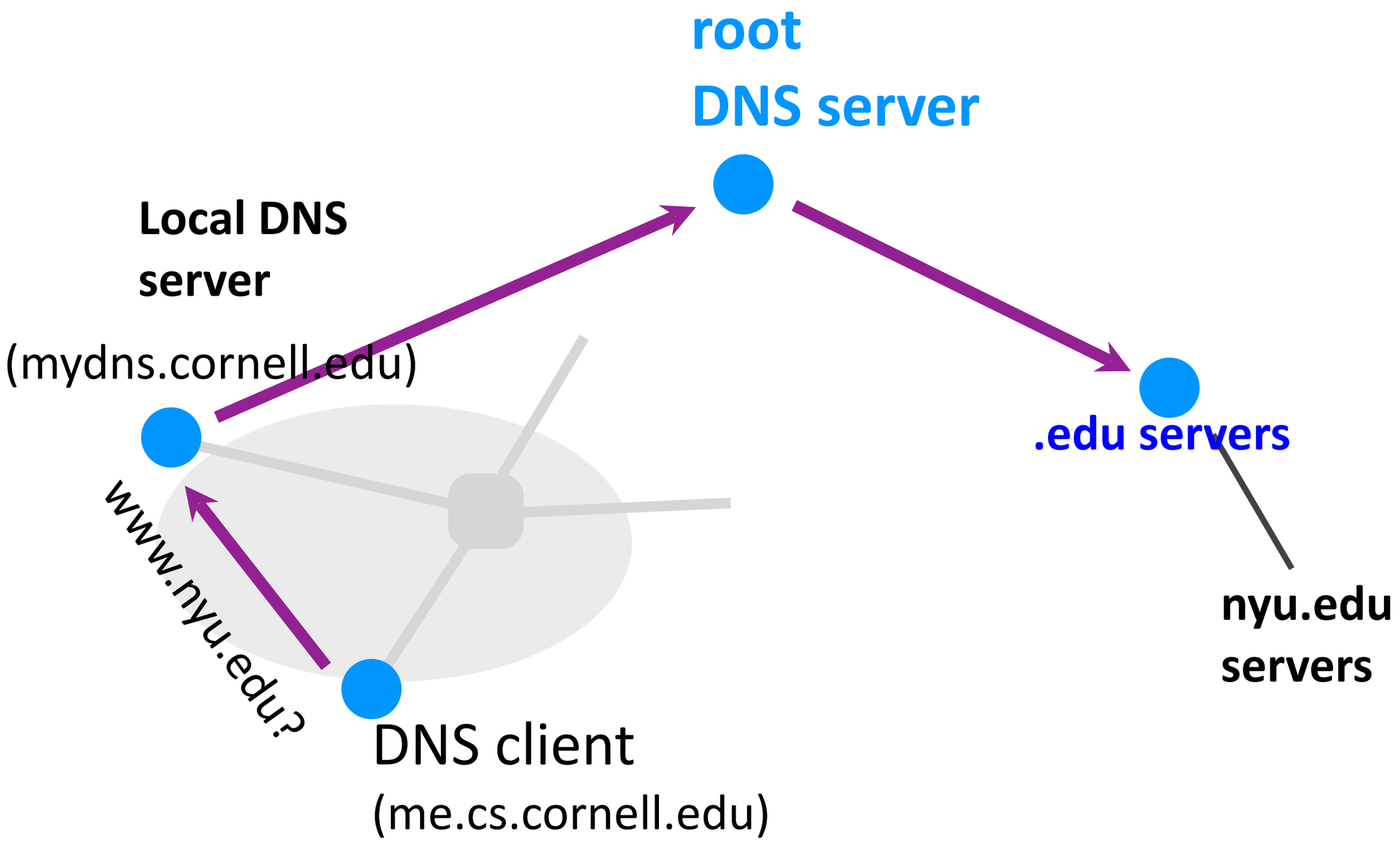
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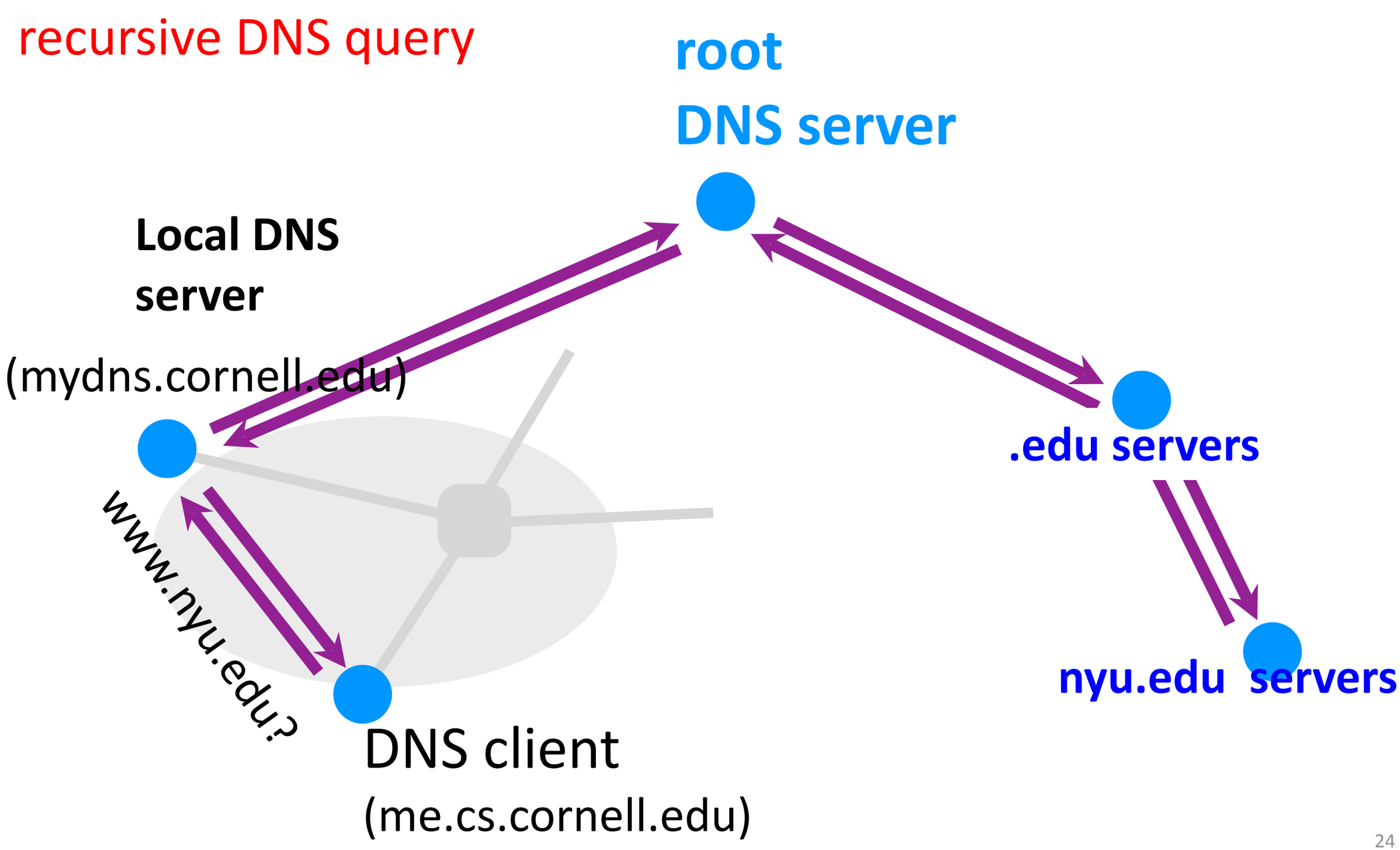
recursive DNS query



root
DNS server

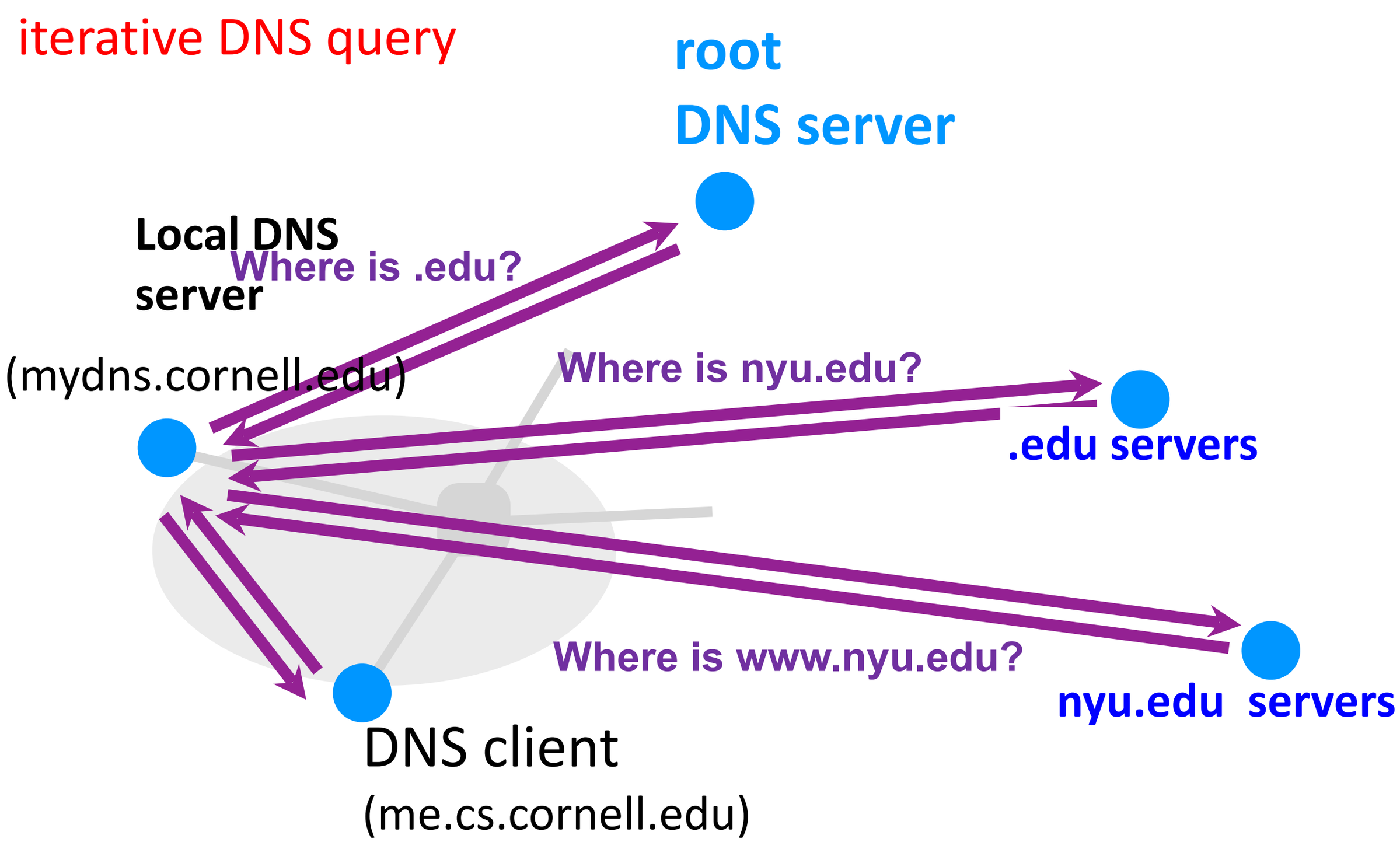
Local DNS
server
(mydns.cornell.edu)

.edu servers

nyu.edu servers

DNS client
(me.cs.cornell.edu)

iterative DNS query



DNS Protocol

- Query and Reply messages
  - Both with the same message format
  - *see text for details*

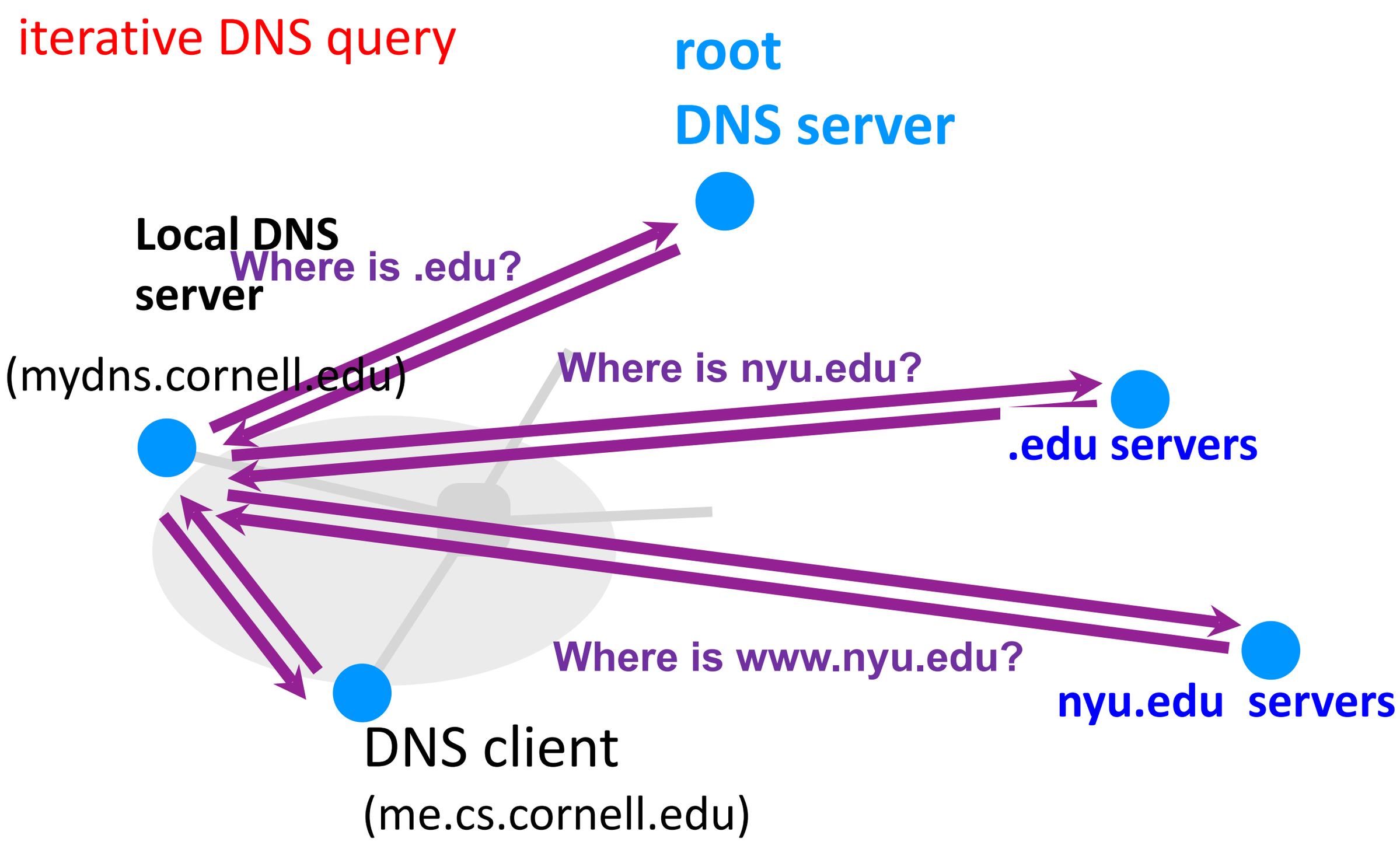
- Client-Server interaction on UDP Port 53
  - Spec supports TCP too, but not always implemented
  - Reliability via repeating requests on timeout

- Resolution is almost always “iterative”

Goals

- Scaling (names, users, updates, etc.)
  - Yes
- Ease of management (uniqueness of names, etc.)
  - Yes
- Availability and consistency
  - Yes
- Fast lookups
  - ??

iterative DNS query



DNS Caching

- 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

- Why caching is effective
  - The top-level servers very rarely change
  - Popular sites visited often -> local DNS server often has the information cached

Questions?

The Web

The Web – Precursor

- 1967, Ted Nelson, Xanadu:
  - A world-wide publishing network that would allow information to be stored not as separate files but as connected literature
  - Owners of documents would be automatically paid via electronic means for the virtual copying of their documents

- Coined the term “Hypertext”
- Influenced research community
  - Who then missed the web…..

Ted Nelson

The Web – Precursor

- Physicist trying to solve real problem
    - Distributed access to data

- World Wide Web (WWW): a distributed database of “pages” linked through **Hypertext Transport Protocol** (HTTP)
    - First HTTP implementation - 1990
        - Tim Berners-Lee at CERN
    - HTTP/0.9 – 1991
        - Simple GET command for the Web
    - HTTP/1.0 –1992
        - Client/Server information, simple caching
    - HTTP/1.1 - 1996

Tim Berners-Lee

Web Components

- Infrastructure:
  - Clients
  - Servers
  - Proxies
- Content:
  - Individual objects (files, etc.)
  - Web sites (coherent collection of objects)
- Implementation
  - URL: naming content
  - HTTP: protocol for exchanging content

URL Syntax

protocol://hostname[:port]/directorypath/resource

protocol	http, ftp, https, smtp, rtsp, *etc*.
hostname	DNS name, IP address
port	Defaults to protocol's standard port *e.g.* http: 80 https: 443
directory path	Hierarchical, reflecting file system
resource	Identifies the desired resource Can also extend to program executions: `http://us.f413.mail.yahoo.com/ym/ShowLetter?box=%40B%40Bulk&MsgId=2604_1744106_29699_1123_1261_0_28917_3552_1289957100&Search=&Nhead=f&YY=31454&order=down&sort=date&pos=0&view=a&head=b`

Web and DNS

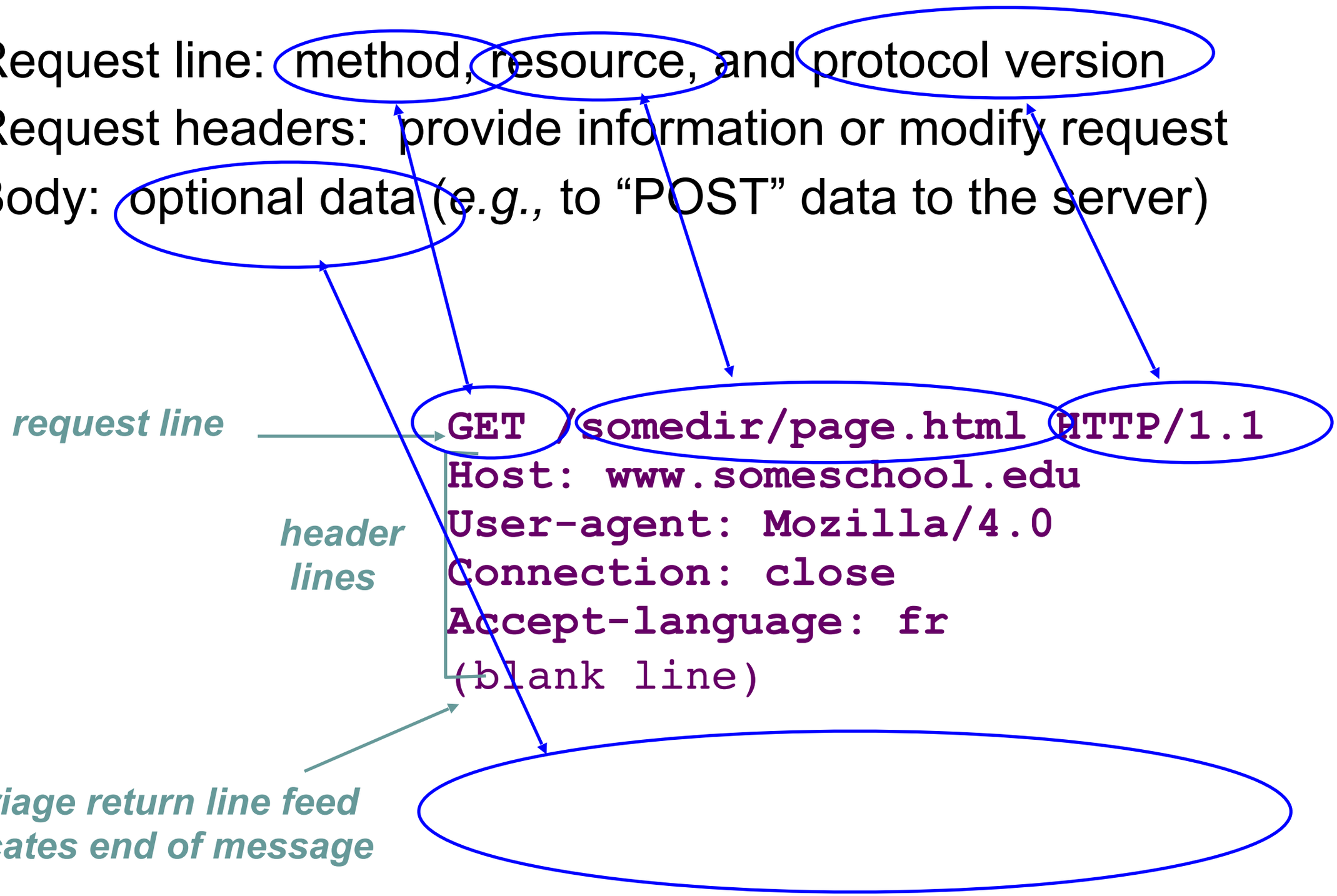
- URLs use hostnames
- Thus, content names are tied to specific hosts
- Why is this a problem?
- Makes persistence of names problematic…

Hyper Text Transfer Protocol (HTTP)

- Client-server architecture
  - Server is “always on” and “well known”
  - Clients initiate contact to server
- Synchronous request/reply protocol
  - Runs on top of transport layer, Port 80
- Stateless
- ASCII format

HTTP request message

- Request line: method, resource, and protocol version
- Request headers: provide information or modify request
- Body: optional data (*e.g.,* to “POST” data to the server)



HTTP response message

- Status line: protocol version, status code, status phrase
- Response headers: provide information
- Body: optional data

status line
(protocol, status code, status phrase)

header lines

data
e.g., requested HTML file

```
HTTP/1.1 200 OK
Connection close
Date: Thu, 06 Aug 2006 12:00:15 GMT
Server: Apache/1.3.0 (Unix)
Last-Modified: Mon, 22 Jun 2006 ...
Content-Length: 6821
Content-Type: text/html
(blank line)
data data data data data ...
```

HTTP is Stateless

- Each request-response treated independently
  - Servers not required to retain state for HTTP
    - The application may have lots of state, but not HTTP

- **Good**: Improves scalability on the server-side
  - Failure handling is easier
  - Can handle higher rate of requests
  - Order of requests doesn't matter (to HTTP)

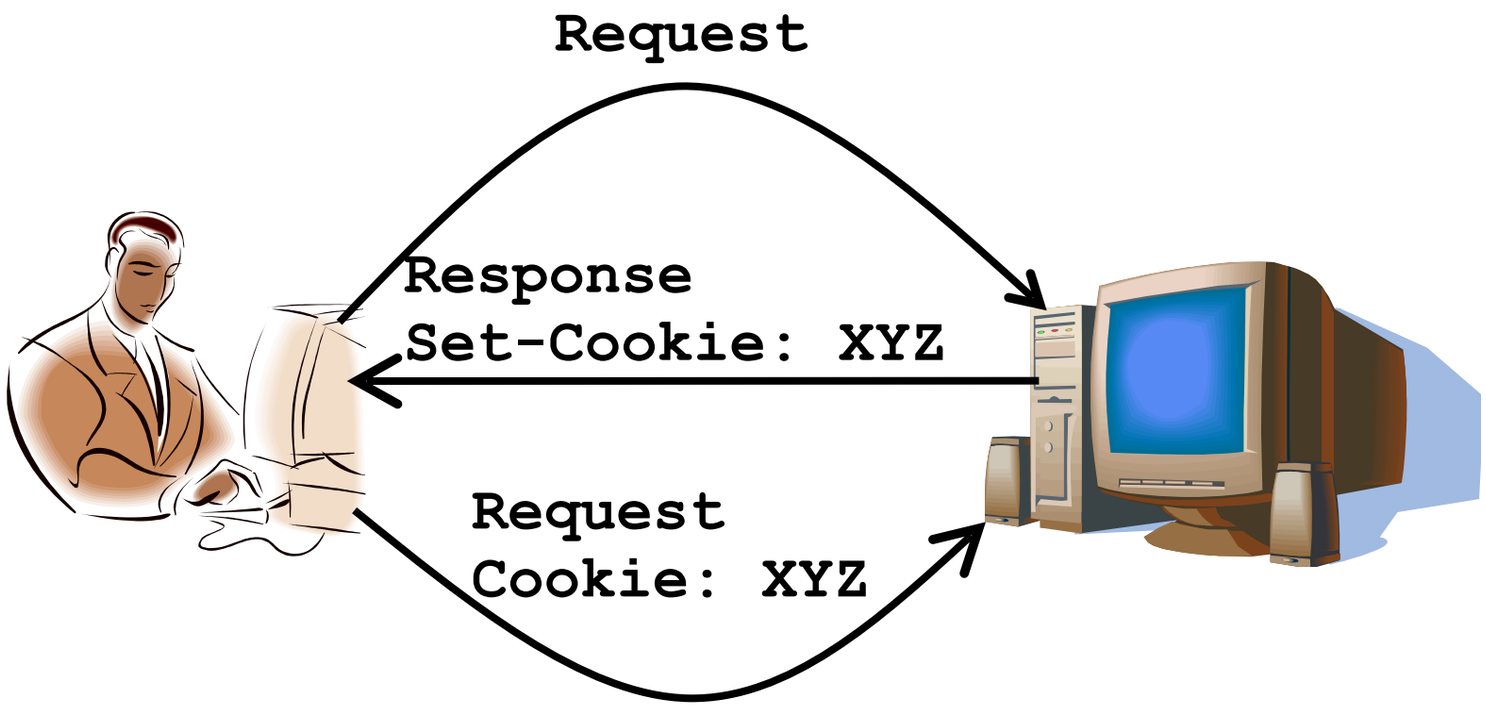
- **Bad**: Some applications need persistent state
  - Need to uniquely identify user or store temporary info
  - e.g., Shopping cart, user profiles, usage tracking, …

Question

- How does a stateless protocol keep state?

State in a Stateless Protocol: Cookies

- Client-side state maintenance
  - Client stores small state on behalf of server
  - Client sends state in future requests to the server
- Can provide authentication



HTTP Performance Issues

Performance Goals

- User
  - Fast downloads
  - High availability
- Content provider
  - Happy users (hence, above)
  - Cost-effective infrastructure
- Network (secondary)
  - Avoid overload

Caching and replication resolve most of these issues

HTTP Performance

- Most Web pages have multiple objects
  - e.g., HTML file and a bunch of embedded images
- How do you retrieve those objects (naively)?
  - One item at a time
- New connection per (small) object!
- Requires 2RTTs worth of latency per object

Improving HTTP Performance

- **Persistent Connections**

- Maintain connection across multiple requests
  - Including transfers subsequent to current page
  - Client or server can tear down connection

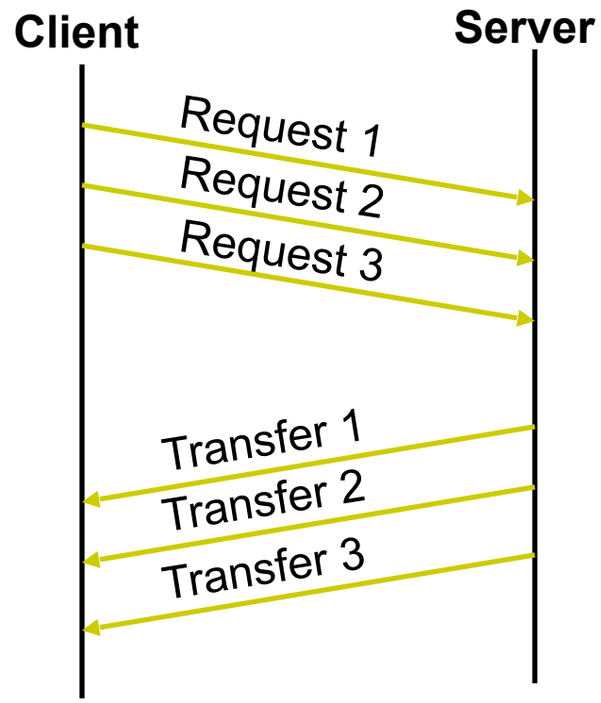
- Performance advantages:
  - Avoid overhead of connection set-up and tear-down

- Default in HTTP/1.1

Improving HTTP Performance

- **Pipelined Requests and Responses**

- Batch requests and responses to reduce the number of packets



Questions?

Improving HTTP Performance: Caching

- Why does caching work?
    - Exploits locality of reference
- How well does caching work?
    - Very well, up to a limit
- File popularity has high peak but long tail
    - Large overlap in highly popular content
    - But many unique requests
- A universal story!
    - Hit rate of cache grows logarithmically with size

Improving HTTP Performance: Caching - How?

- Modifier to GET requests:
  - If-modified-since — returns “not modified” if resource not modified since specified time
- Client specifies “if-modified-since” time in request
- Server compares this against “last modified” time of resource
- Server returns “Not Modified” if resource has not changed
- …. or a “OK” with the latest version otherwise

Improving HTTP Performance: Caching - How?

- Modifier to GET requests:
  - If-modified-since — returns “not modified” if resource not modified since specified time

- Response header:
  - Expires — TTL: how long it’s safe to cache the resource
  - No-cache — ignore all caches; always het resource directly from server

Typical Caching Interaction

- Client issues request for object

- If it is in local client cache:
  - If within TTL, respond to client
  - If not within TTL, send if-modified-since to server
    - If server has updated copy, it sends it
    - If not, server responds saying that it doesn't

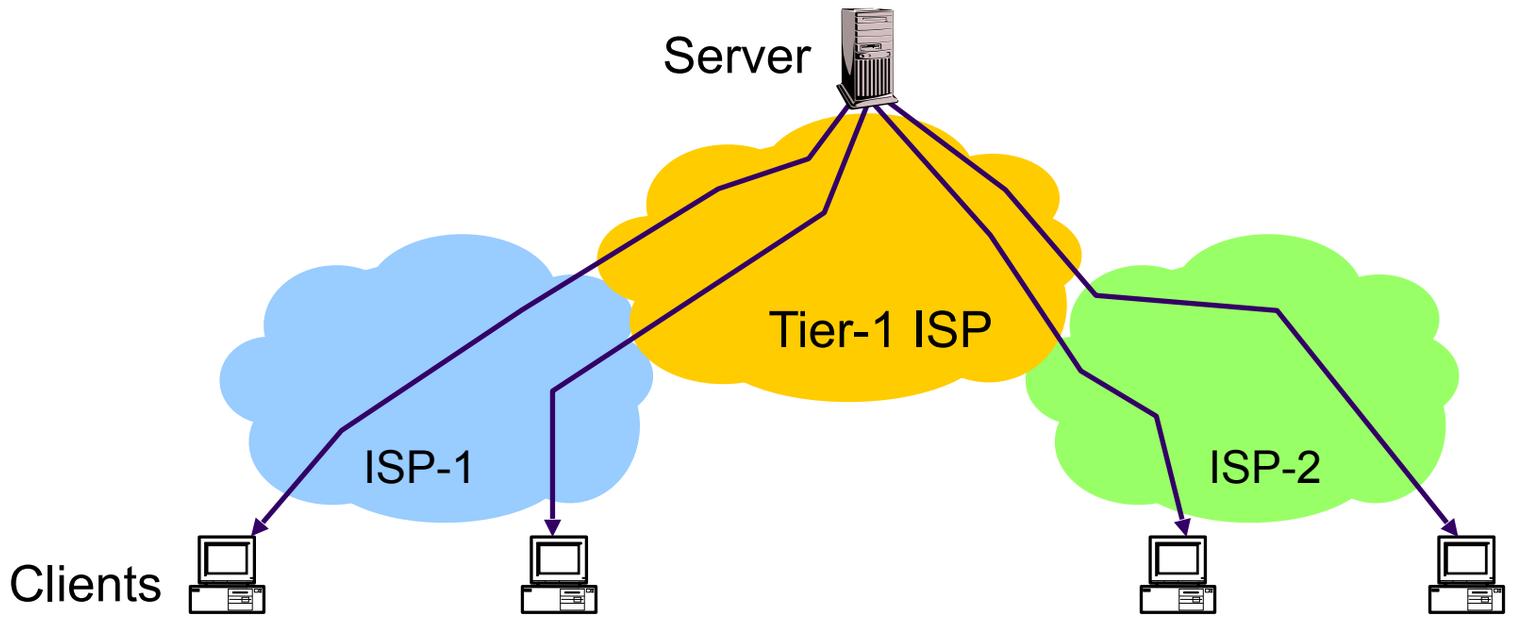
- If not in local client cache:
  - Send request to server
  - This request may pass through other caches, which use a similar algorithm

Improving HTTP Performance: Caching - Where?

- Options
  - Client
  - Forward proxies
  - Reverse proxies
  - Content Distribution Network

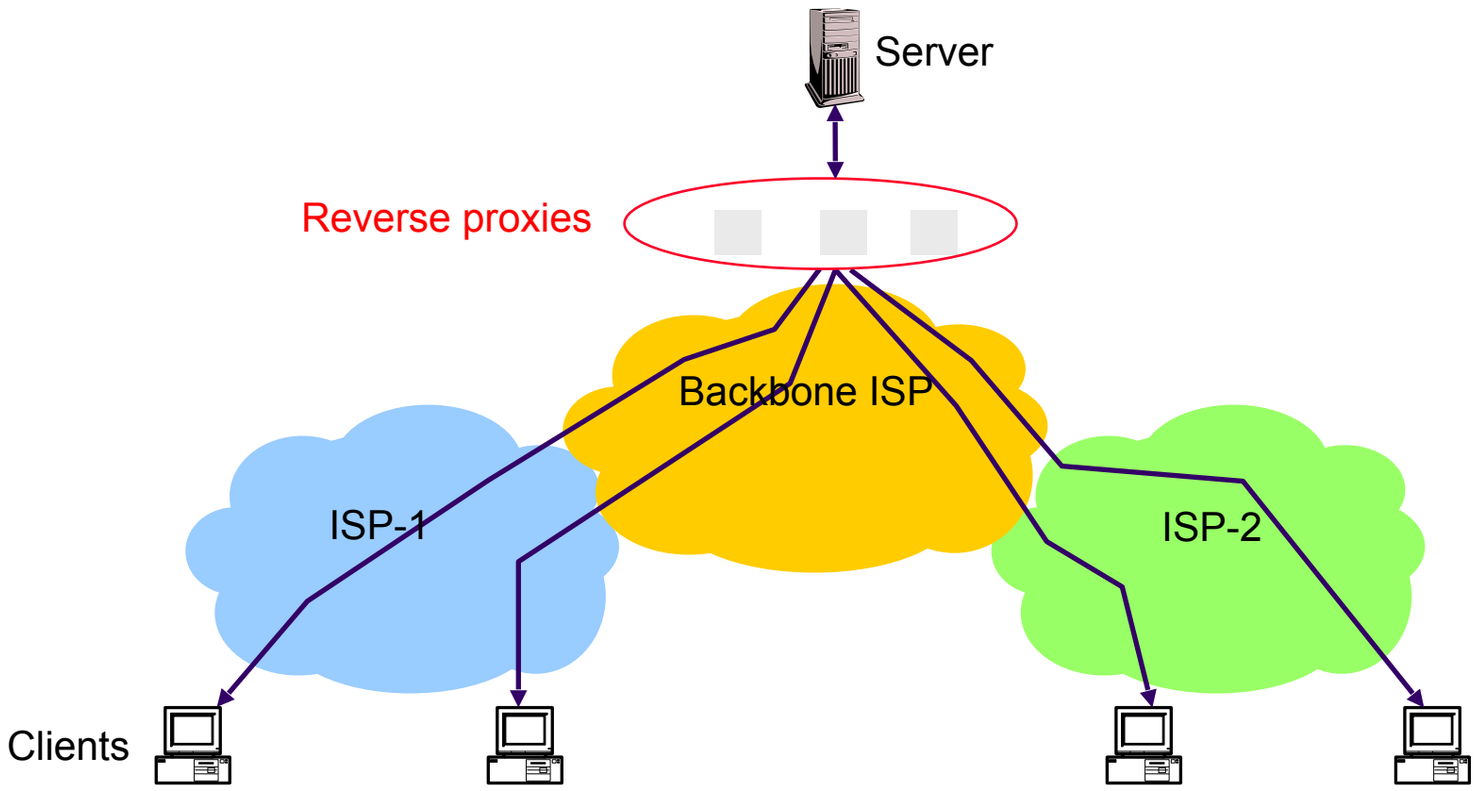
Improving HTTP Performance: Caching - Where?

- Baseline: Many clients transfer same information
  - Generate unnecessary server and network load
  - Clients experience unnecessary latency



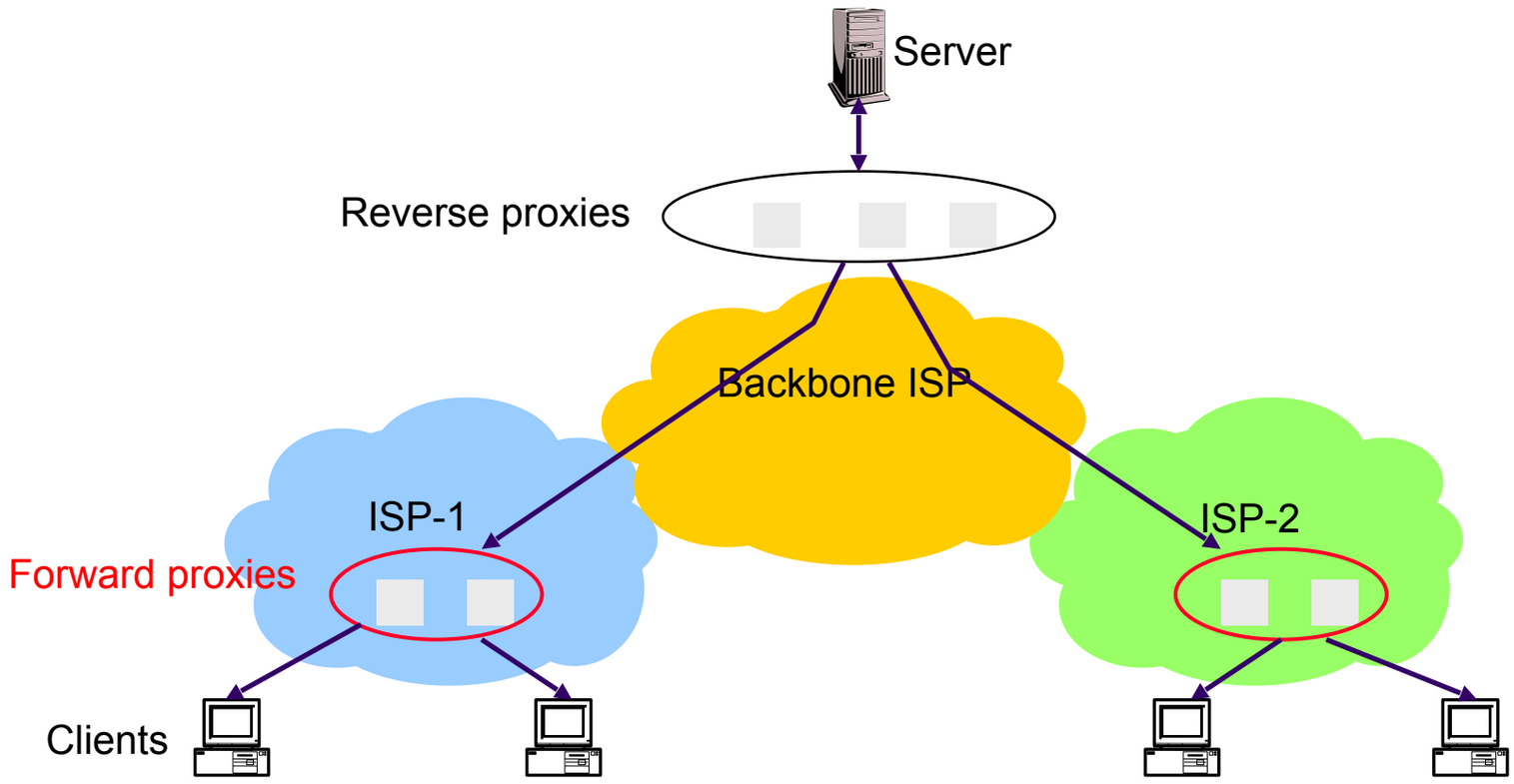
Caching with Reverse Proxies

- Cache documents close to server
  - Decrease server load
- Typically done by content provider



Caching with Forward Proxies

- Cache documents close to clients
  - Reduce network traffic and decrease latency
- Typically done by ISPs or enterprises



Improving HTTP Performance: Replication

- Replicate popular Web site across many machines
  - Spreads load on servers
  - Places content closer to clients
  - Helps when content isn't cacheable

- Problem: Want to direct client to particular replica
  - Balance load across server replicas
  - Pair clients with nearby servers

- Common solution:
  - DNS returns different addresses based on client's geo location, server load, etc.

Content Distribution Networks

- **Caching and replication as a service**

- Large-scale distributed storage infrastructure (usually) administered by one entity
    - e.g., Akamai has servers in 20,000+ locations

- Combination of (pull) caching and (push) replication
    - **Pull**: Direct result of clients' requests
    - **Push**: Expectation of high access rate

- Also do some processing
    - Handle dynamic web pages
    - Transcoding

CDN Example — Akamai

- Akamai creates new domain names for each client
  - e.g., a128.g.akamai.net for cnn.com
- The CDN's DNS servers are authoritative for the new domains
- The client content provider modifies its content so that embedded URLs reference the new domains.
  - "Akamaize" content
    - e.g.: http://www.cnn.com/image-of-the-day.gif becomes http://a128.g.akamai.net/image-of-the-day.gif
- Requests now sent to CDN's infrastructure…

Cost-Effective Content Delivery

- General theme: multiple sites hosted on shared physical infrastructure
  - efficiency of statistical multiplexing
  - economies of scale (volume pricing, etc.)
  - amortization of human operator costs

- Examples:
  - Web hosting companies
  - CDNs
  - Cloud infrastructure

Questions?

Backup slide: History of DNS

- Originally: per-host file hosts.txt in /etc/hosts
    - SRI (Menlo Park) kept master copy
    - Downloaded regularly
    - Flat namespaces

- As the Internet grew this system broke down
    - SRI couldn’t handle the load
    - Conflicts in selecting names
    - Hosts had inaccurate copies of hosts.txt

- Domain Name System (DNS) invented to fix this
    - First server implementation done by 4 UCB students!

DNS Measurements (MIT data from 2000)

- What is being looked up?
  - ~60% requests for A records
  - ~25% for PTR records
  - ~5% for MX records
  - ~6% for ANY (wildcard) records
- How long does it take?
  - Median ~100msec (but 90th percentile ~500msec)
  - 80% have no referrals; 99.9% have fewer than four
- Query packets per lookup: ~2.4
  - But this is misleading….

DNS Measurements (MIT data from 2000)

- Does DNS give answers?
  - ~23% of lookups fail to elicit an answer!
  - ~13% of lookups result in NXDOMAIN (or similar)
    - Mostly reverse lookups
  - Only ~64% of queries are successful!
    - How come the web seems to work so well?

- ~ 63% of DNS packets in unanswered queries!
  - Failing queries are frequently retransmitted
  - 99.9% successful queries have ≤2 requests

Moral of the Story

- The Internet was designed to be highly resilient.
  - No matter what goes wrong, it tries to recover
- **In a highly resilient system, many things can be going wrong without you noticing it!**

DNS Measurements (MIT data from 2000)

- Top 10% of names accounted for ~70% of lookups
  - Caching should really help!
- 9% of lookups are unique
  - Cache hit rate can never exceed 91%
- Cache hit rates ~ 75%
  - But caching for more than 10 hosts doesn't add much

A Common Pattern…..

- Distributions of various metrics (file lengths, access patterns, etc.) often have two properties:
  - Large fraction of total metric in the top 10%
  - Sizable fraction (~10%) of total fraction in low values
- In an exponential distribution
  - Large fraction is in top 10%
  - But low values have very little of overall total
- Lesson: in networking, have to pay attention to both ends of distribution (high peak and long tail)
  - Here, caching helps, but not a panacea

Why not name content directly?

- How do you know where to send the request?
- How do you scale?
- How do you trust the response?
  - Requesting host
  - Network
- How would you design it?

Scorecard: Getting n Small Objects

- **Time dominated by latency**
- One at a time: ~2n RTT
- M concurrent: ~2[n/m] RTT
- Persistent: ~(n+1) RTT
- Pipelined: ~2 RTT

- Pipelined/Persistent: ~2RTT first time, RTT later

Scorecard: Getting n Large Objects

- **Time dominated by bandwidth**
- One at a time: ~nF/B
- M concurrent: it depends
  - If more flows get no additional bandwidth: ~nF/B
  - If shared with large population of users: ~[n/m] F/B
    - Where each TCP connection gets the same bandwidth
- Pipelined and/or Persistent: ~nF/B
  - The only thing that helps is getting more bandwidth