

# **EECS 489**

# **Computer Networks**

**Winter 2023**

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*Material with thanks to Aditya Akella, Sugih Jamin, Philip Levis, Sylvia Ratnasamy, Peter Steenkiste, and many other colleagues.*

# Agenda

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- CDN: Content Distribution Network
- DNS: Domain Name System

# Recap:

# Improving HTTP performance

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- Optimizing connections using three “P”s
  - Persistent (latency)
  - Parallel/concurrent (bandwidth and latency)
  - Pipelined over the same connection (latency)
- Caching
  - Forward proxy: close to clients
  - Reverse proxy: close to servers
- Replication

# Replication

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

# Content Distribution Networks (CDN)

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- Caching and replication as a service
- Large-scale distributed storage infrastructure (usually) administered by one entity
  - e.g., Akamai is in 130 countries and 1700 networks
- Combination of caching and replication
  - **Pull**: Direct result of clients' requests (caching)
  - **Push**: Expectation of high access rate (replication)

# Cost-effective content delivery

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- 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:
  - CDNs
  - Web hosting companies
  - Cloud infrastructure

# CDN example – Akamai

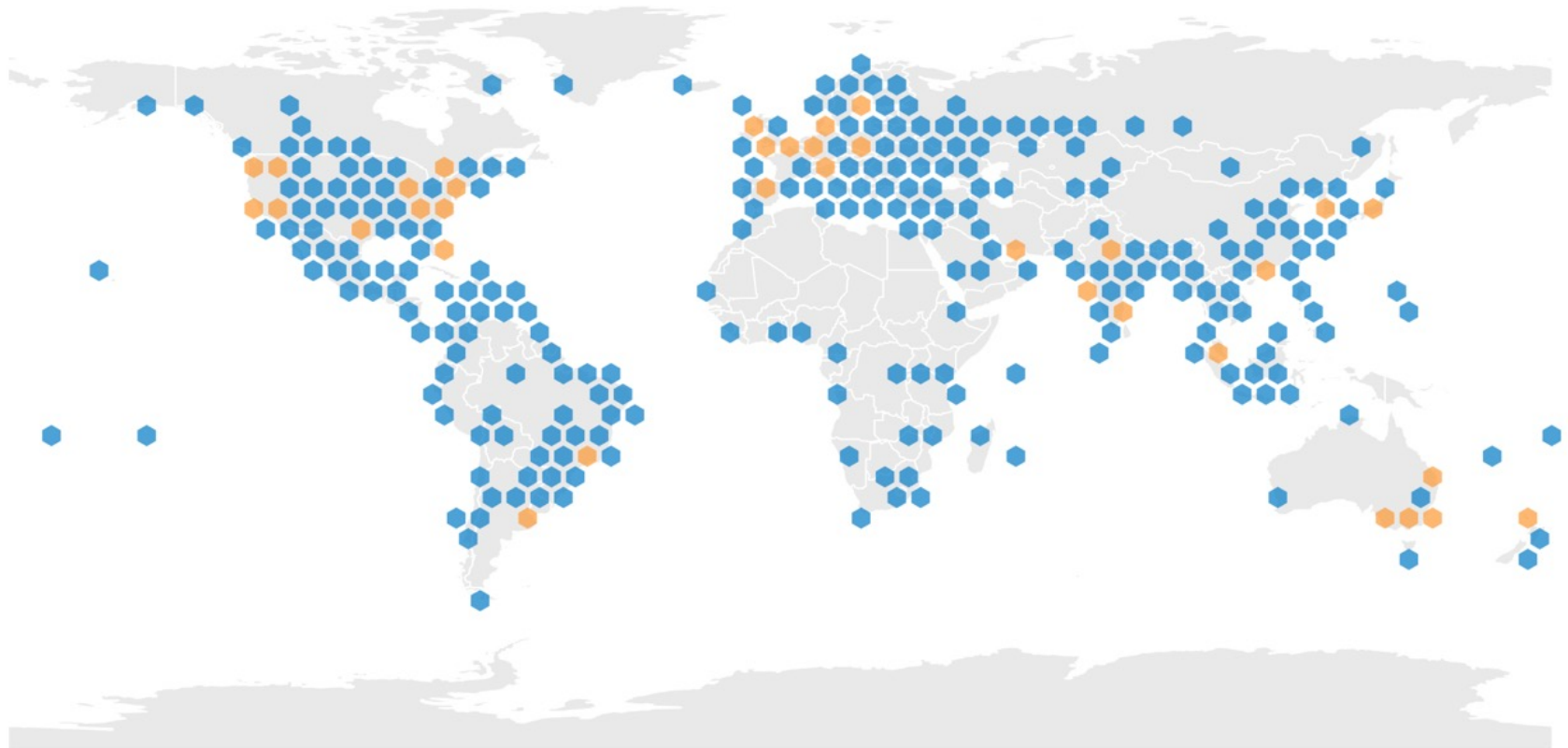
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- Akamai creates new domain names for each client
  - e.g., [a128.g.akamai.net](http://a128.g.akamai.net) for [cnn.com](http://cnn.com)
- The client content provider modifies content so that embedded URLs reference new domains
  - “Akamaize” content
  - 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

# CDN example – Akamai

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■ Akamai Media Delivery Network   ■ Akamai Media Delivery + Storage



Retrieved on Sep 10, 2021 from <https://www.akamai.com/visualizations/media-delivery-network-map>



# Why direct clients to particular replicas?

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- Balancing load across server replicas
- Pairing clients with nearby servers to decrease latency and overall bandwidth usage

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# **DNS: DOMAIN NAME SYSTEM**

# Internet names & addresses

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- Machine addresses: e.g., 141.212.113.143
  - Router-usable labels for machines
  - Conforms to network structure (the “where”)
- Machine names: e.g., cse.umich.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
  - A **directory** service

# Why?

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- Convenience
  - Easier to remember
- Provides a **level of indirection!**
  - Decoupled names from addresses
  - Many uses beyond just naming a specific host

# DNS: History

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- Initially all host-address mappings were in a `hosts.txt` file (in `/etc/hosts`):
  - Maintained by the Stanford Research Institute (SRI)
  - Changes were submitted by email and updates downloaded periodically from SRI
- As the Internet grew SRI could not handle load
  - Names were not unique anymore
  - Hosts had inaccurate copies of `hosts.txt`

# DNS: History

- In 1983, the first stable operational DNS implementation included
  - The associated query protocol;
  - A server implementation; and
  - Initial root servers.
- Since inception, DNS scaled from 1000s of queries/day to 10s of billions queries/day



## AWARDS & RECOGNITION

### Mockapetris Honored for Developing Domain Name System

ACM named [Paul Mockapetris](#) recipient of the 2019 ACM Software System Award for developing the Domain Name System (DNS), which provides the worldwide distributed directory service that is an essential component of the functionality of the global internet. In 1983, Mockapetris designed and built the DNS, creating the associated query protocol, a server implementation, and initial root servers. Taken together, these components provided the first stable operational DNS system.

# Goals

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- Uniqueness: no naming conflicts
- Scalable
  - Many names and frequent updates (secondary)
- Distributed, autonomous administration
  - Ability to update my own (machines') names
  - Don't have to track everybody's updates
- Highly available
- Lookups are fast
- Perfect consistency is a non-goal

# How?

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- Partition the namespace
- Distribute administration of each partition
  - Autonomy to update my own (machines') names
  - Don't have to track everybody's updates
- Distribute name resolution for each partition
- How should we partition things?

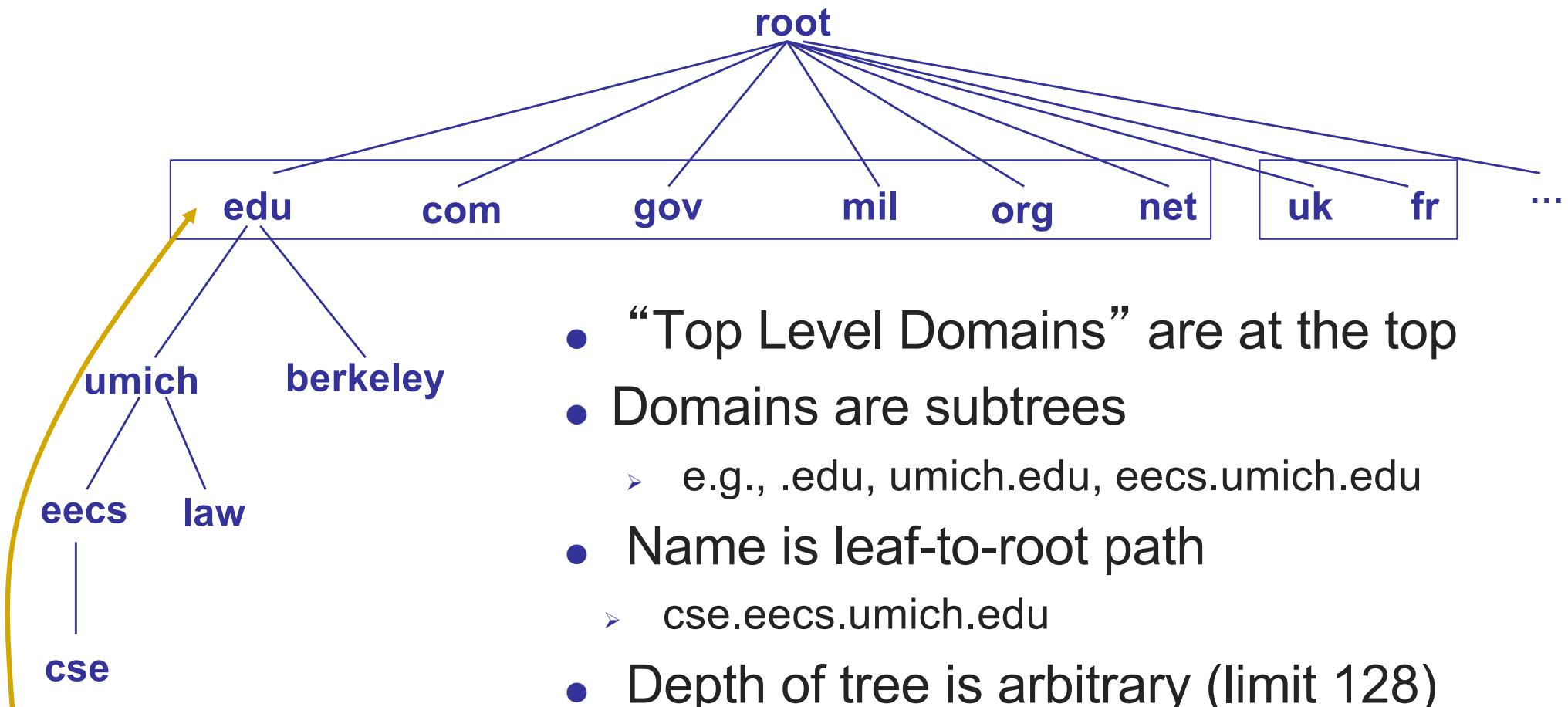


# Key idea: Hierarchy

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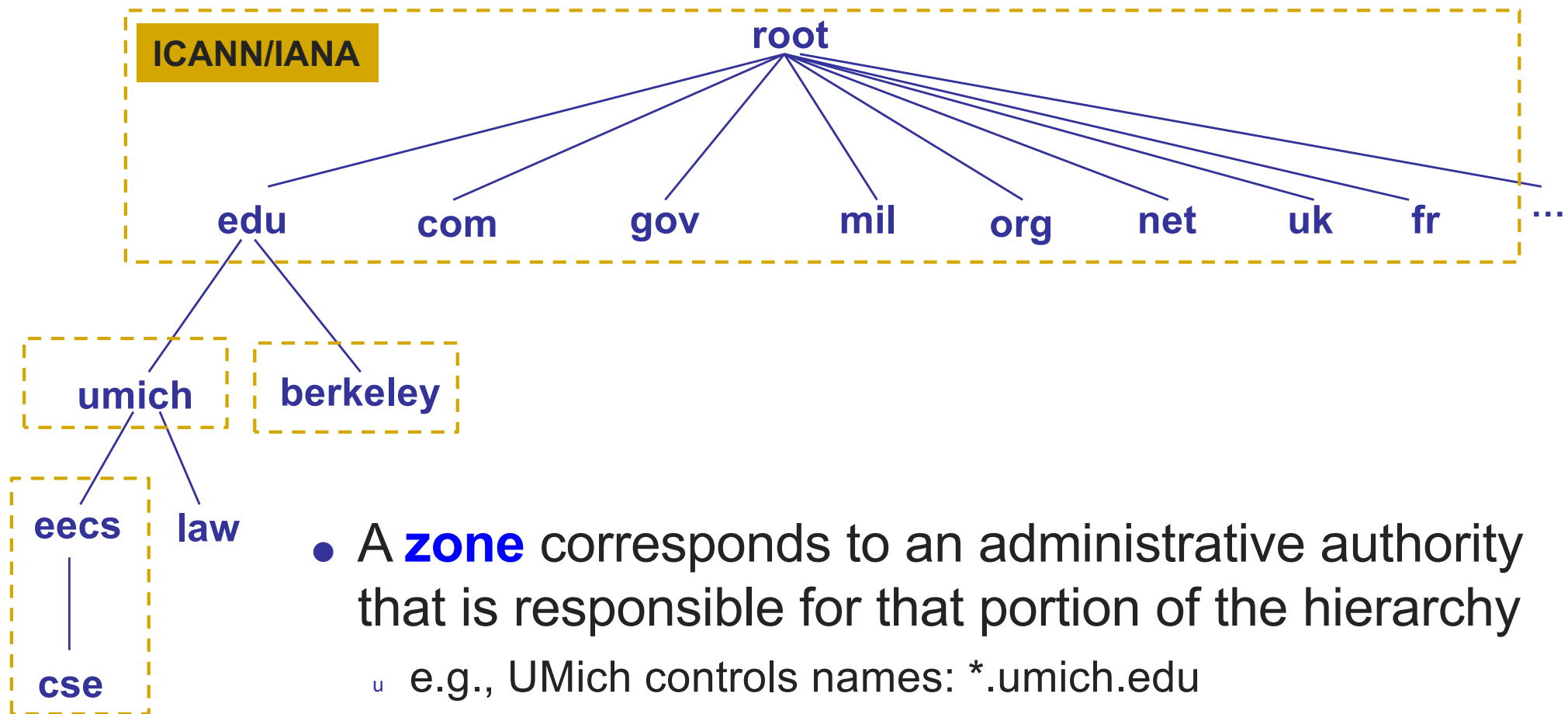
- Three intertwined hierarchies
  - Hierarchical namespace
    - » As opposed to original flat namespace
  - Hierarchically administered
    - » As opposed to centralized
  - (Distributed) hierarchy of servers
    - » As opposed to centralized storage

# Hierarchical namespace



- “Top Level Domains” are at the top
- Domains are subtrees
  - e.g., .edu, umich.edu, eeecs.umich.edu
- Name is leaf-to-root path
  - cse.eeecs.umich.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
  - u e.g., UMich controls names: \*.umich.edu
  - u e.g., EECS controls names: \*.eeecs.umich.edu

# Server hierarchy

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- 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

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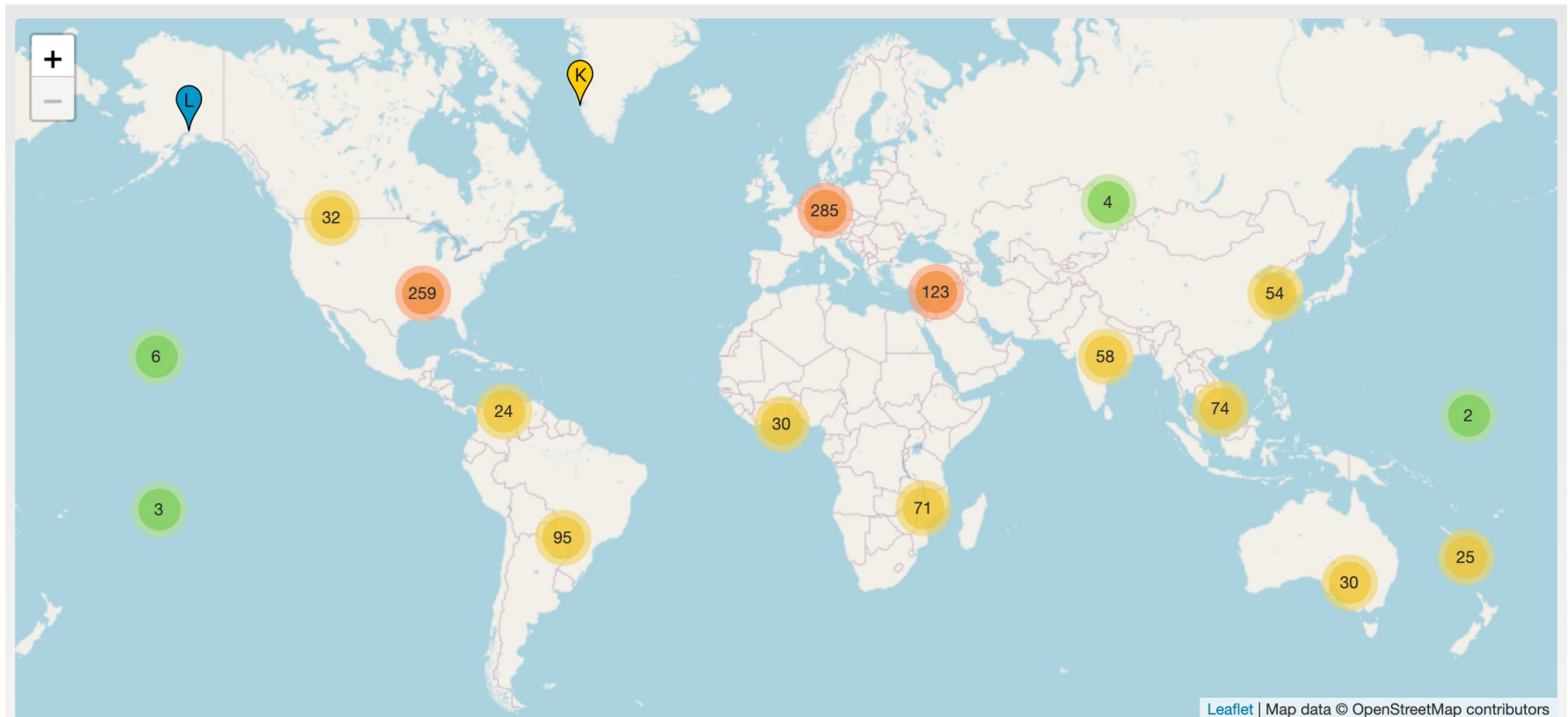
- Each server stores a (small!) subset of the total DNS database
- An authoritative DNS server stores “**resource records**” for all DNS names in the domain that it has authority for
- Each server needs to know other servers responsible for other portions of the hierarchy
  - Every server knows the root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

# DNS root

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

# 13 DNS root servers



As of 09/15/2021 4:28 p.m., the root server system consists of 1402 instances operated by the 12 independent root server operators.

<https://root-servers.org/>

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**5-MINUTE BREAK!**



# Announcements

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- Midterm Wed Feb 22 2023
  - 9AM
- Assignment 1 due Fri Jan 27, 2023, 11:59 PM.

# DNS records

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- DNS servers store **resource records (RRs)**
  - RR is (name, value, type, TTL)
- Type = A: (→ **A**ddress)
  - name = hostname
  - value = IP address
- Type = NS: (→ **N**ame **S**erver)
  - name = domain
  - value = name of DNS server for domain

# DNS records (cont'd)

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- Type = CNAME: (→ Canonical Name)
  - name = alias name for some “canonical” (real) name
    - » e.g., cse.umich.edu is really cse.eecs.umich.edu
  - value = canonical name
- Type = MX: (→ Mail eXchanger)
  - name = domain in email address
  - value = name(s) of mail server(s)

# Inserting Resource Records into DNS

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- Register foobar.com at registrar
  - 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

# Using DNS (Client/App View)

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- Two components
  - Local DNS servers
  - Resolver software on hosts
- Local DNS server (“default name server”)
  - Clients configured with default server’s address OR learn it via a host configuration protocol (e.g., DHCP)
- Client application
  - Obtain DNS name (e.g., from URL)
  - Do `getnameinfo()` to trigger DNS request to its local DNS server

# dig

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dig nyu.edu

```
; <<>> DiG 9.10.6 <<>> nyu.edu
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 47443
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 1

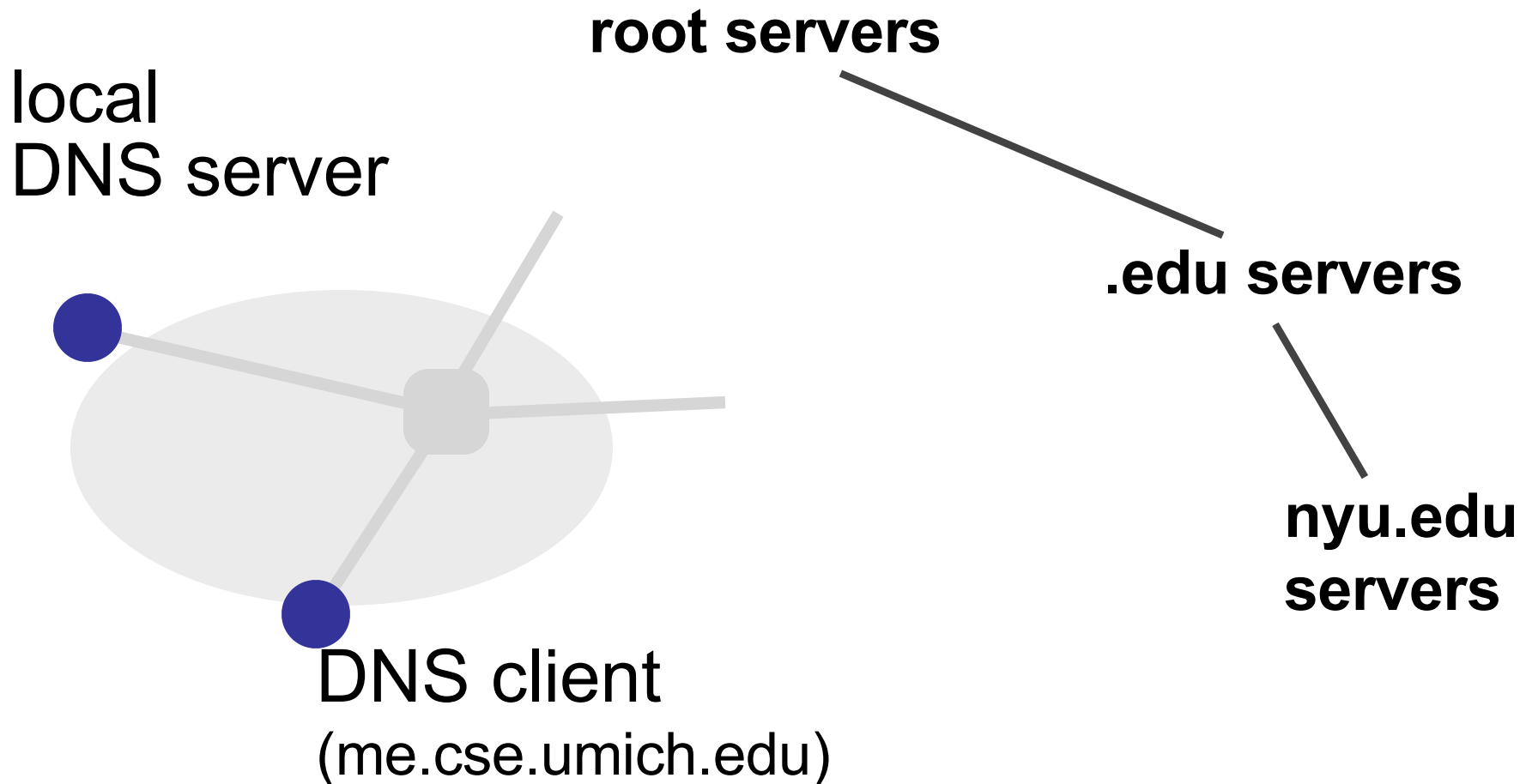
;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 512
;; QUESTION SECTION:
;nyu.edu.                IN      A

;; ANSWER SECTION:
nyu.edu.                 60      IN      A      216.165.47.10

;; Query time: 39 msec
;; SERVER: 192.168.1.1#53(192.168.1.1)
;; WHEN: Fri Sep 10 08:21:43 EDT 2021
;; MSG SIZE  rcvd: 52
```

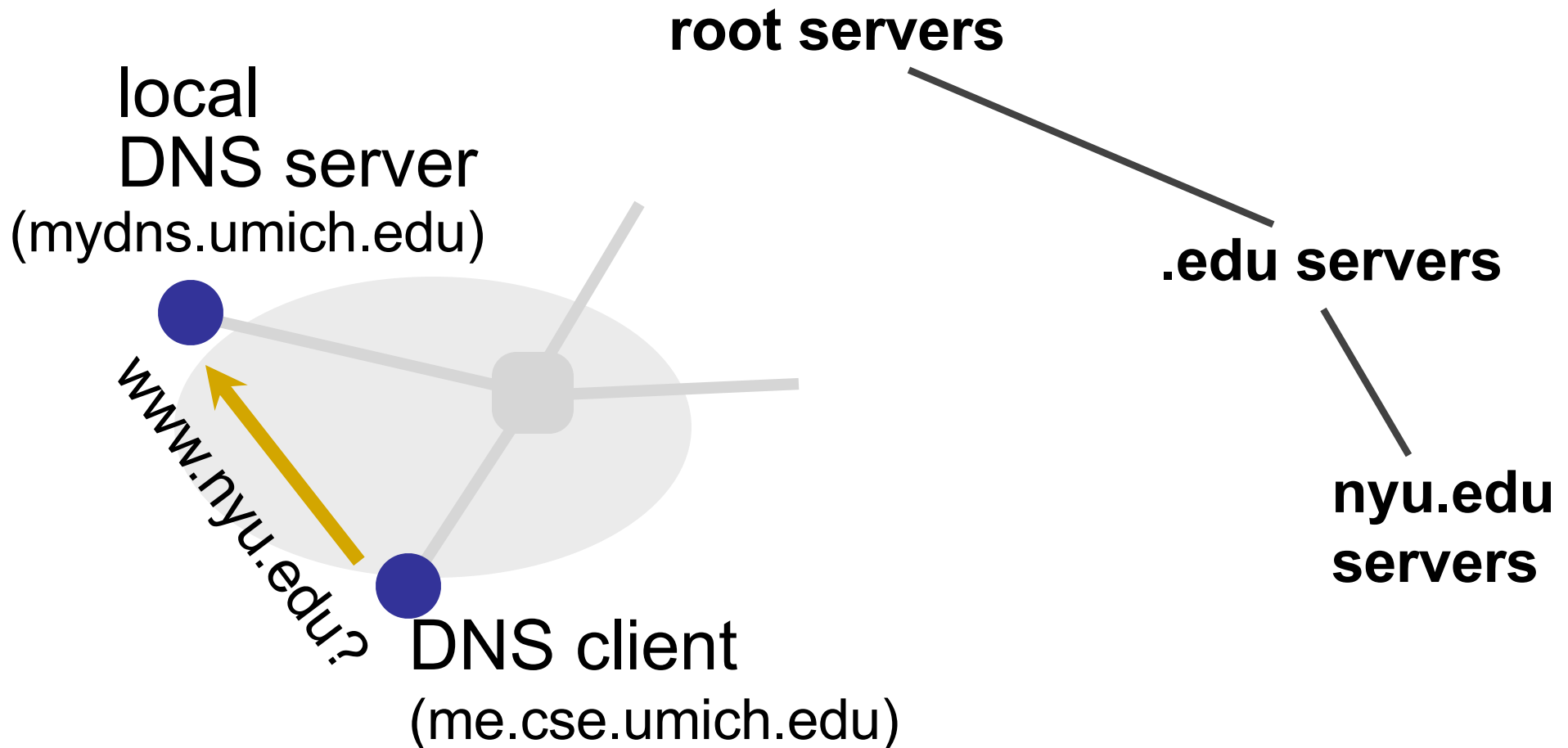
# Name resolution

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# Name resolution

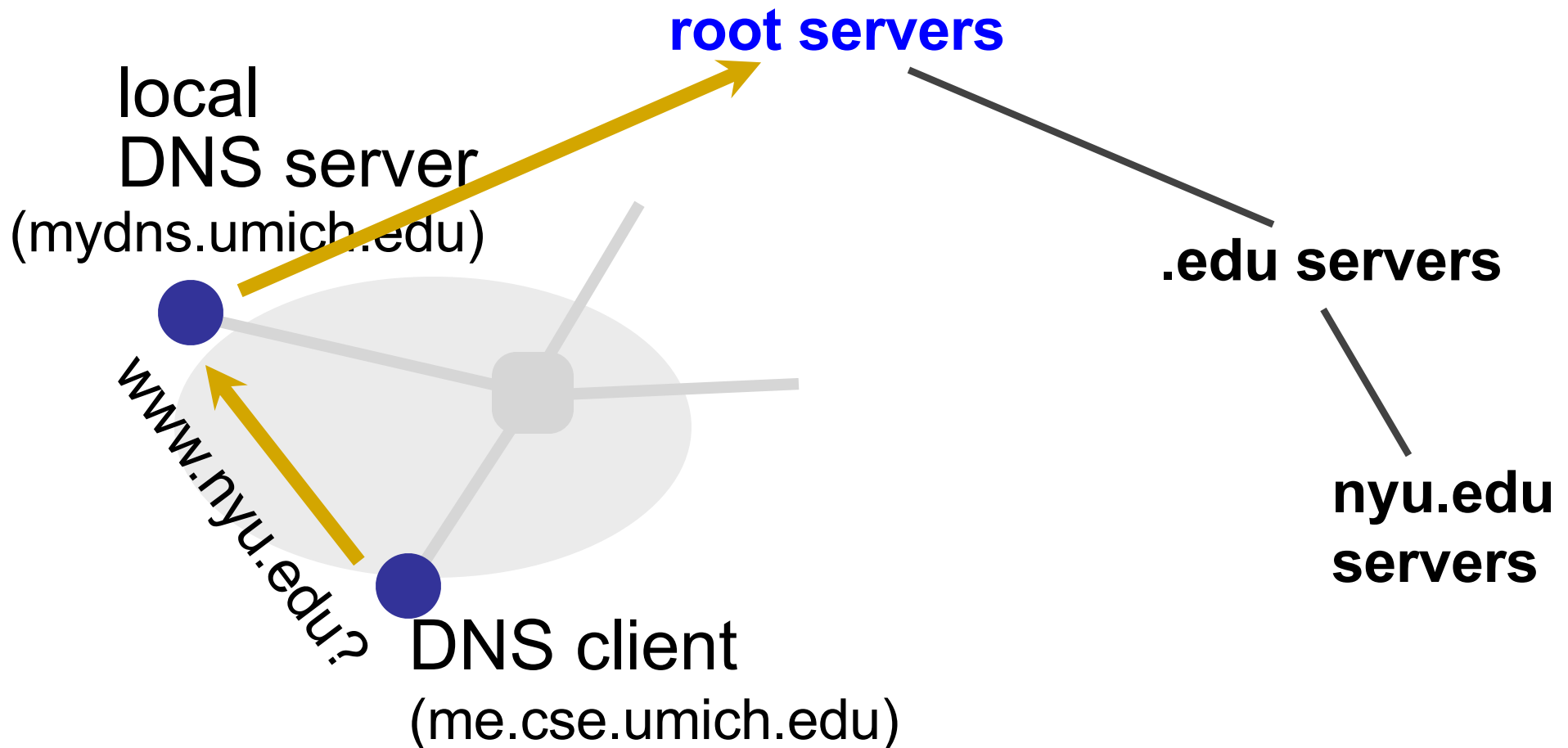
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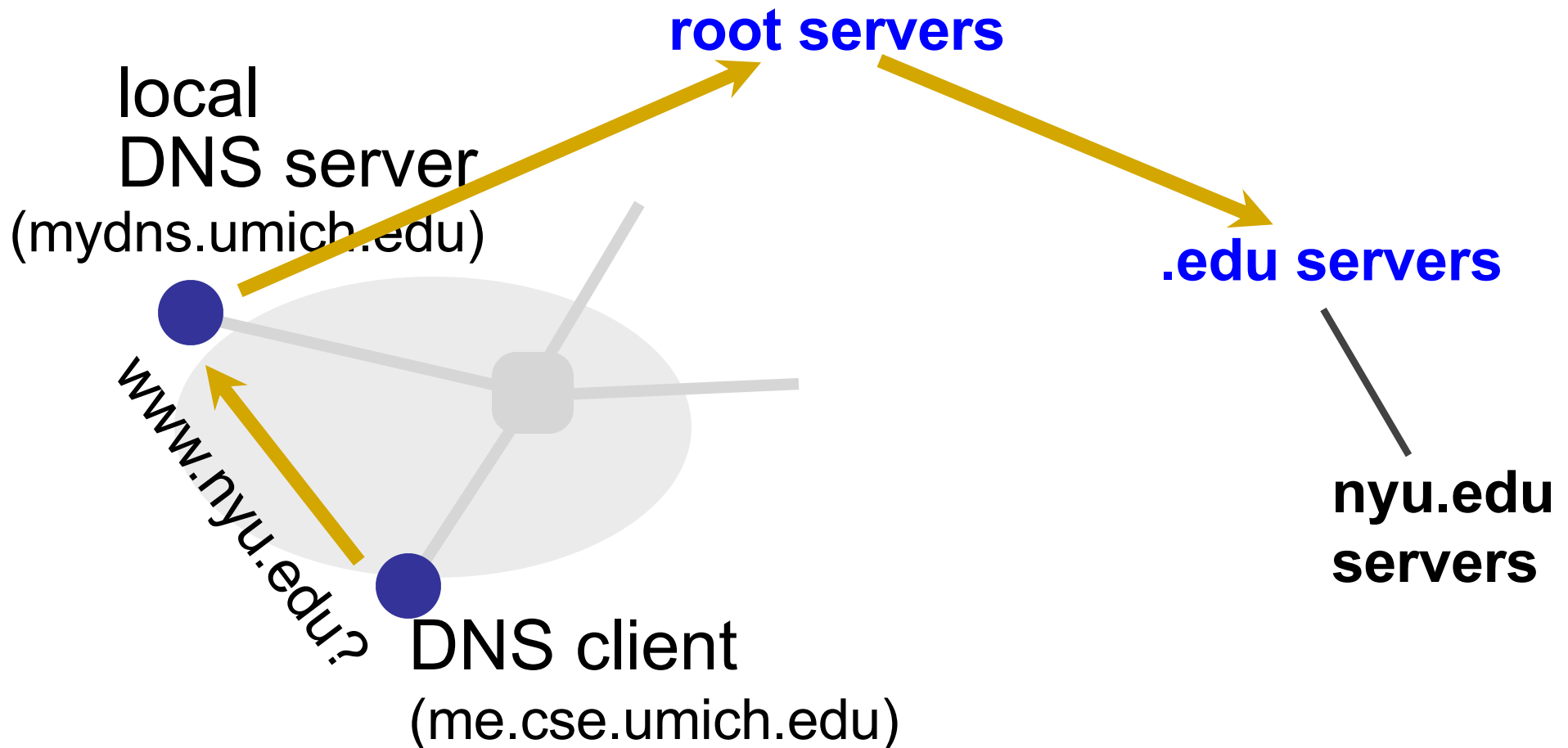
# Name resolution

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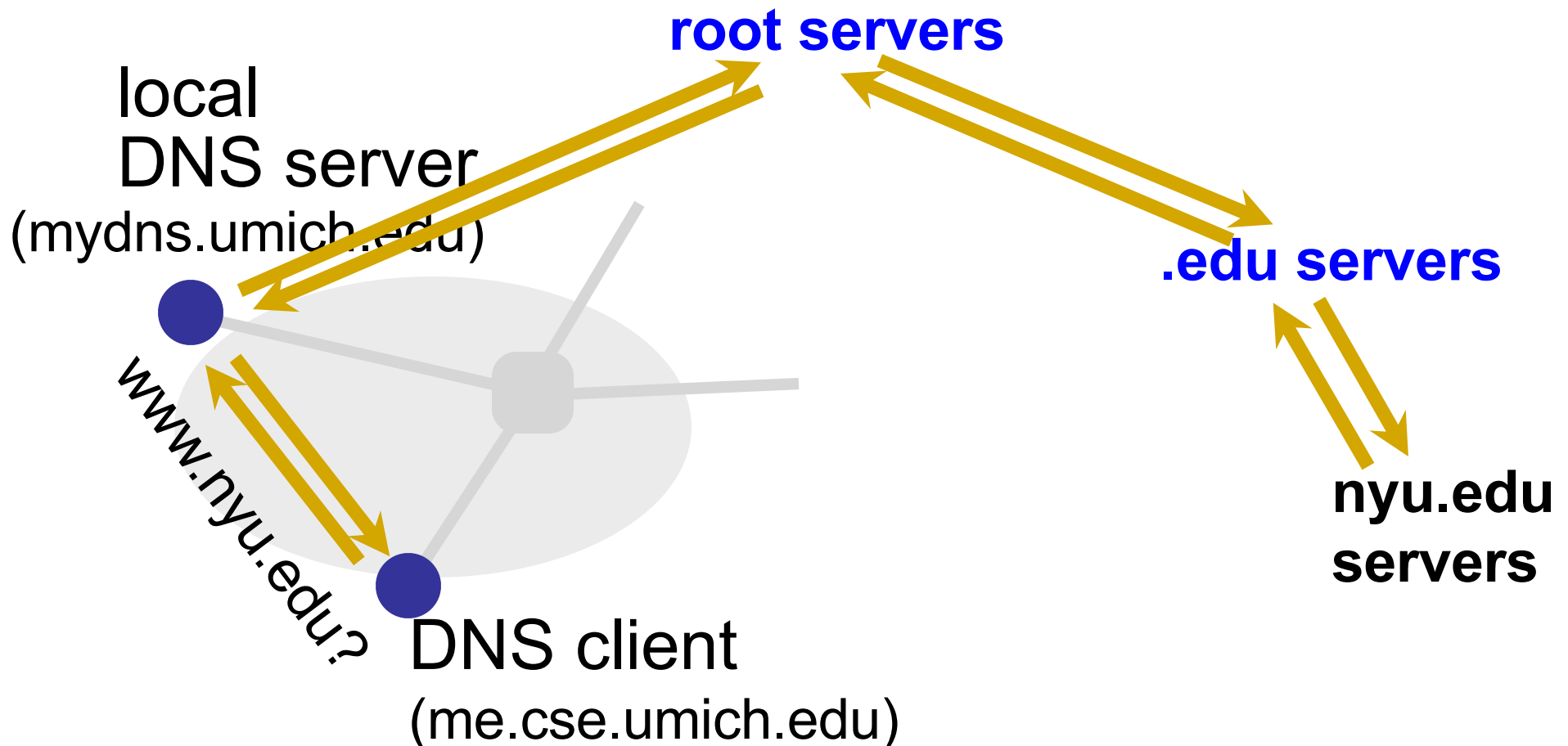


# Name resolution

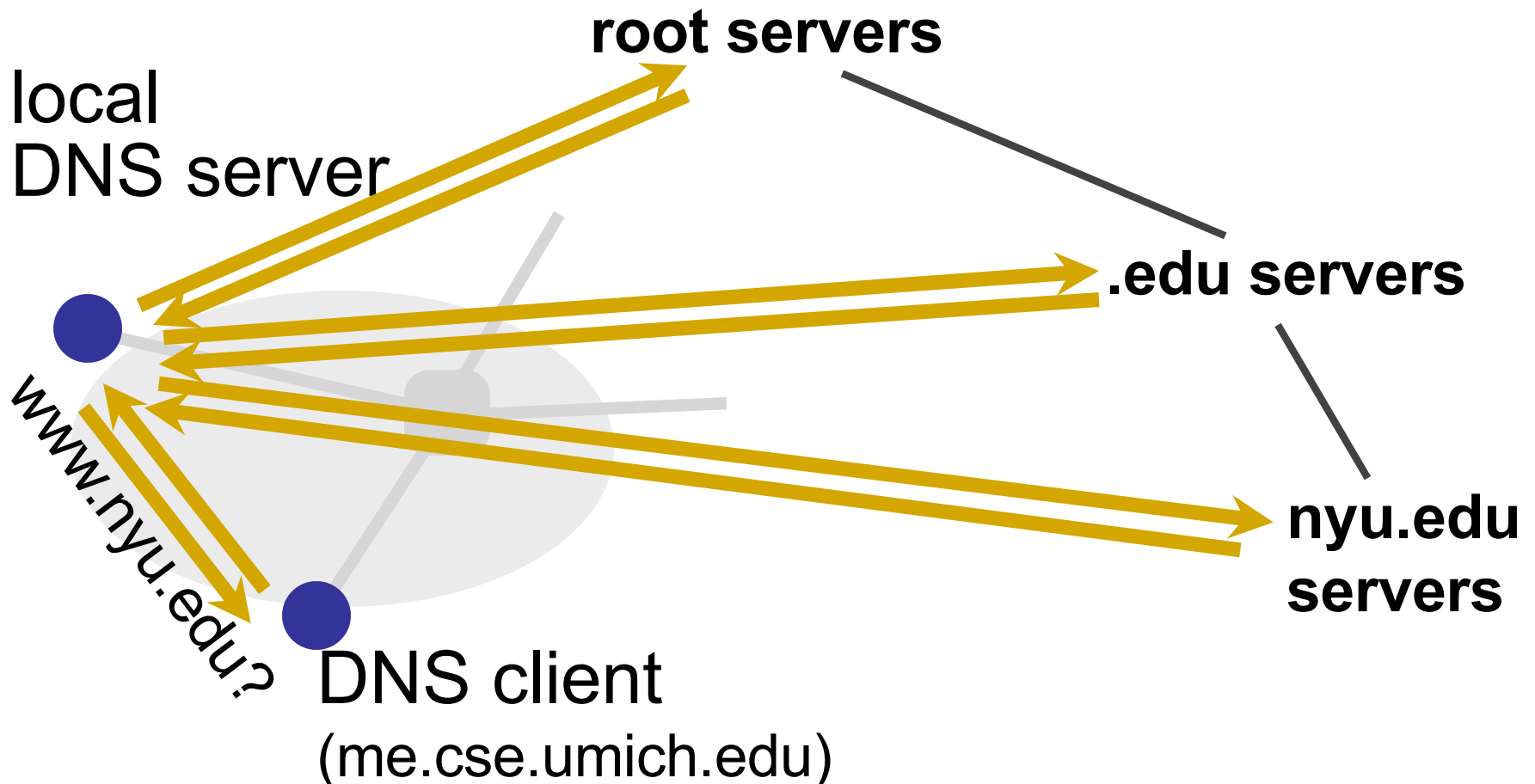
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# Name resolution: Recursive



# Name resolution: Iterative



# Two ways to resolve a name

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- Recursive name resolution
  - Ask server to do it for you
- Iterative name resolution
  - Ask server who to ask next
- The iterative example we saw is a mix of both!

# DNS protocol

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- Query and Reply messages; both with the same message format
  - Header: identifier, flags, etc.
  - Plus resource records
- Client–server interaction on UDP Port 53
  - Spec supports TCP too, but not always implemented

# Goals: Are we there yet?

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- Uniqueness: No naming conflicts
- Scalable
- Distributed, autonomous administration
- Highly available?

# Reliability

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- **Replicated** DNS servers (primary/secondary)
  - Name service available if at least one replica is up
  - Queries can be load-balanced between replicas
- Usually, UDP used for queries
  - Reliability, if needed, must be implemented on UDP
- Try alternate servers on timeout
  - **Exponential backoff** when retrying same server
- Same identifier for all queries
  - Don't care which server responds



# Goals: Are we there yet?

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- Uniqueness: No naming conflicts
- Scalable
- Distributed, autonomous administration
- Highly available
- Fast lookups?

# DNS caching

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- Performing all these queries takes time
  - Up to 1-second latency before starting download
- Caching can greatly reduce overhead
  - The top-level servers very rarely change
  - Popular sites (e.g., [www.google.com](http://www.google.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

# TTL in dig output

dig nyu.edu

```
; <<>> DiG 9.10.6 <<>> nyu.edu
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 47443
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 1

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 512
;; QUESTION SECTION:
;nyu.edu.                                IN      A

;; ANSWER SECTION:
nyu.edu.                                TTL
    60                                  IN      A      216.165.47.10

;; Query time: 39 msec
;; SERVER: 192.168.1.1#53(192.168.1.1)
;; WHEN: Fri Sep 10 08:21:43 EDT 2021
;; MSG SIZE rcvd: 52
```

# Negative caching

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- Remember things that do not work
  - Misspellings like `www.google.comm`
  - These can take a long time to fail the first time
  - Good to remember that they do not work so the failure takes less time the next time around
- Negative caching is optional
  - Not widely implemented

# Important properties of DNS

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- Administrative delegation and hierarchy enables:
  - Easy unique naming
  - “Fate sharing” for network failures
  - Reasonable trust model
  - Caching increases scalability and performance

# DNS provides indirection

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- Addresses can change underneath
  - Move `www.cnn.com` to `4.125.91.21`
- Name could map to multiple IP addresses
  - Load-balancing (CDN)
  - Reducing latency by picking nearby servers (CDN)
  - Try out: `dig google.com` a few times
- Multiple names for the same address
  - E.g., many services (mail, www) on same machine
  - E.g., aliases like `www.cnn.com` and `cnn.com`

# Summary

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- CDNs improve web performance
  - Via replication and caching
  - Good server selection
- DNS allows us to go to webpages without having to memorize IP addresses
  - Allows a level of indirection that enables many functionalities including CDN server selection