Computer Networks

Jiaqi Zheng

Material with thanks Mosharaf Chowdhury, and many other colleagues.

Agenda

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

Recap: Improving HTTP performance

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

Replication

- 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)

- 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 caching and replication
  - Pull: Direct result of clients' requests (caching)
  - Push: Expectation of high access rate (replication)
- Can do some processing to handle dynamic webpage content

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:
  - CDNs
  - Web hosting companies
  - Cloud infrastructure

CDN example – Akamai

- Akamai creates new domain names for each client
  - e.g., a128.g.akamai.net for 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

How to direct clients to particular replicas?

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

DNS: DOMAIN NAME SYSTEM

Internet names & addresses

- 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?

- Convenience
  - Easier to remember www.google.com than 216.58.216.100

- Provides a level of indirection!
  - Decoupled names from addresses
  - Many uses beyond just naming a specific host

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

DNS: History (cont'd)

- 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

Goals

- 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

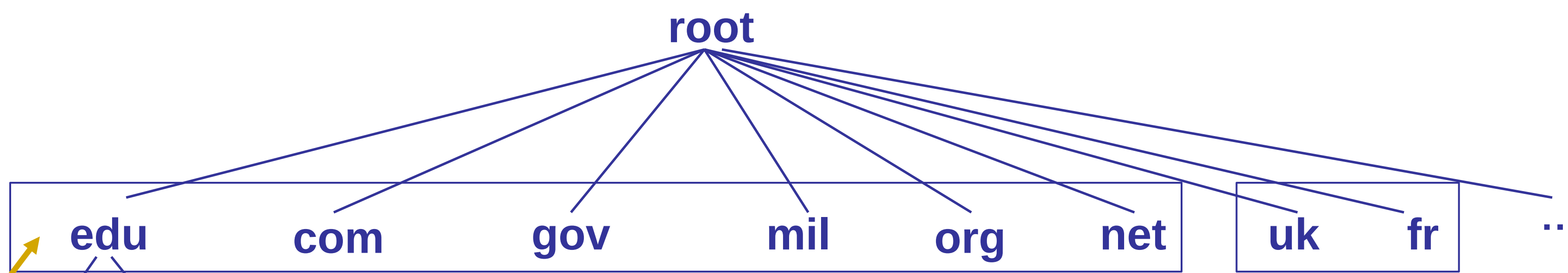
How?

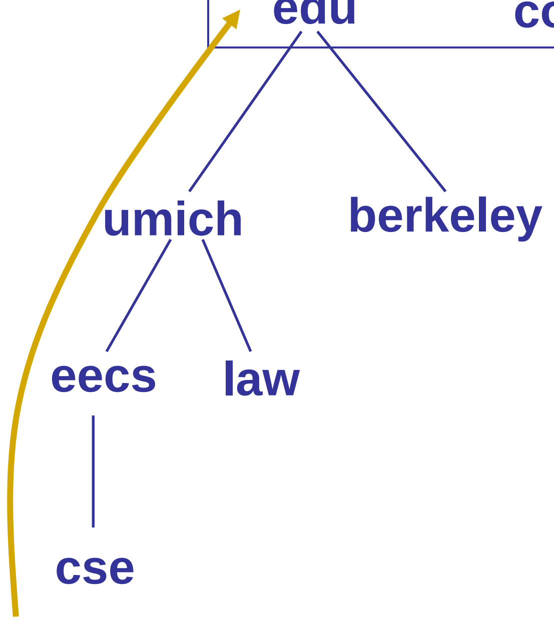
- Partition the namespace
- Distribute administration of each partition
  - Autonomy to update my own (machines’) names
  - Don’t have to track everybody’s updates
- Distribute name resolution for each partition
- How should we partition things?

Key idea: Hierarchy

- 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

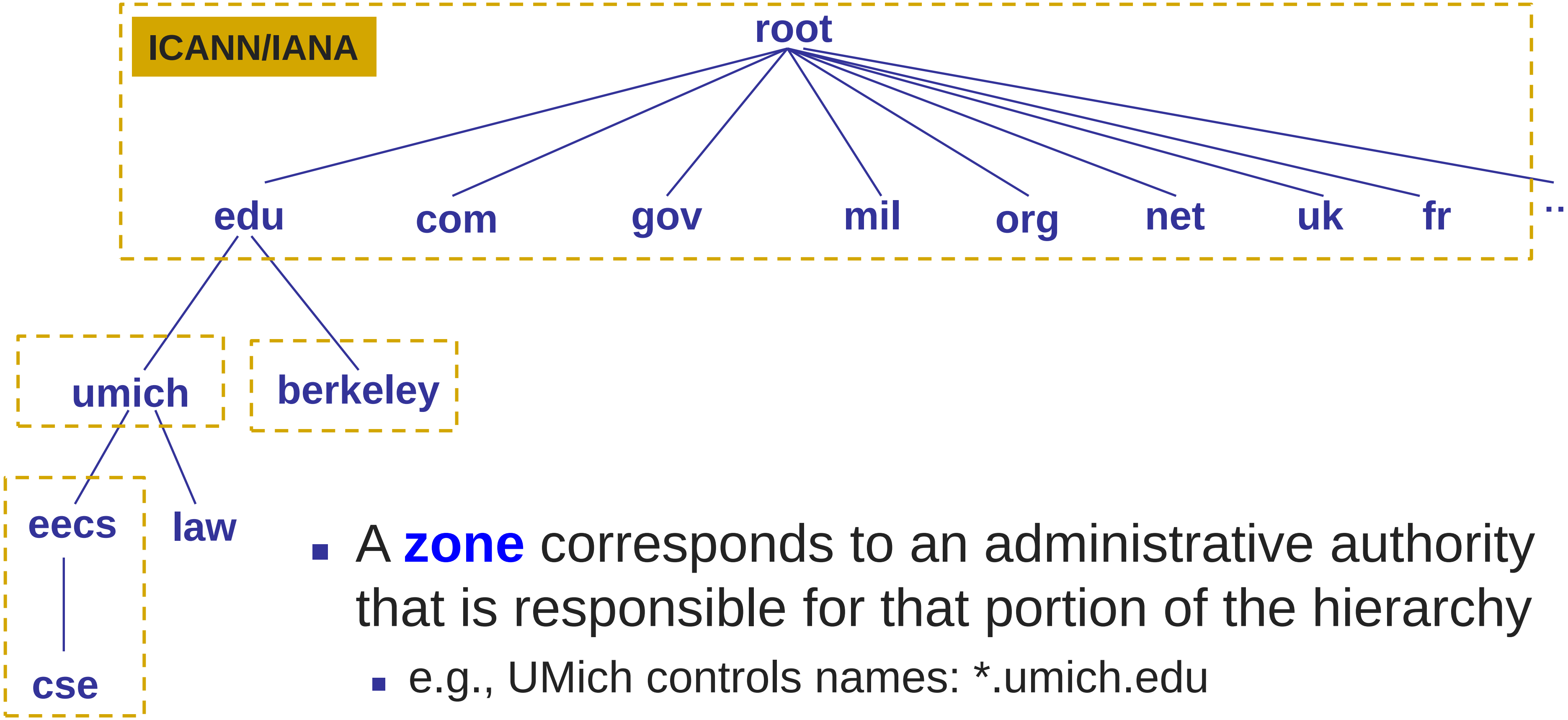
Hierarchical namespace





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

Server hierarchy

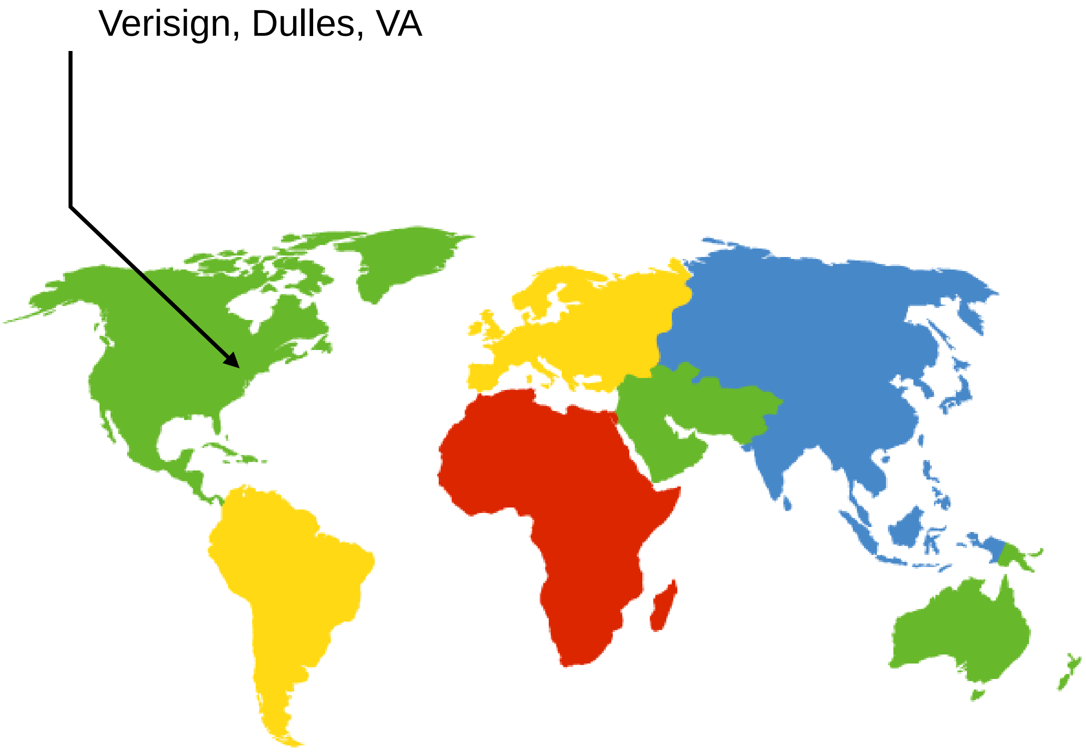
- Top of hierarchy: Root servers
  - Location hardwired into other servers
- Next Level: Top-level domain (TLD) servers
  - .com, .edu, etc.
  - Managed professionally
- Bottom Level: Authoritative DNS servers
  - Actually store the name-to-address mapping
  - Maintained by the corresponding administrative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

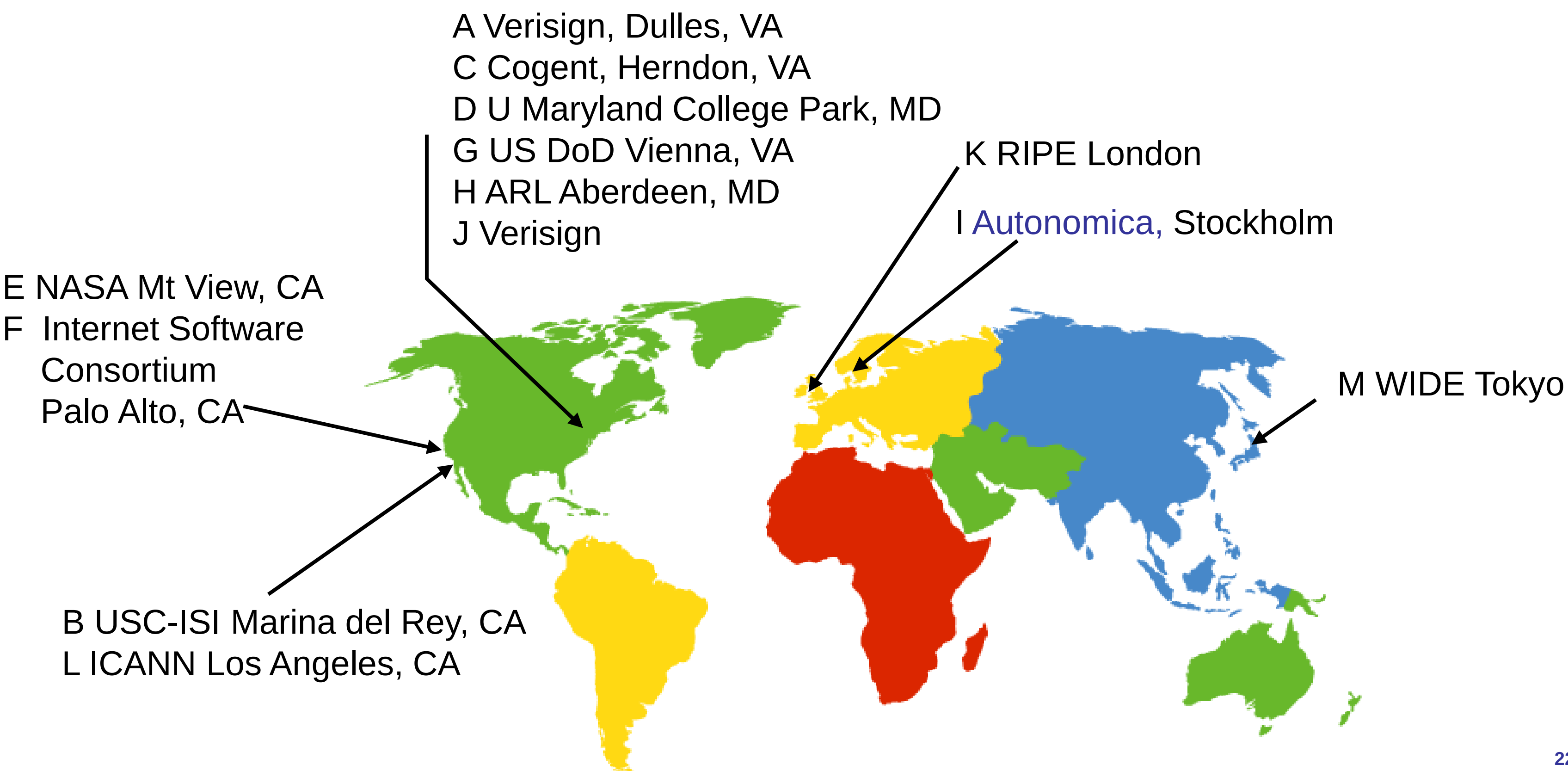
DNS root

- 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 replicated via anycast

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
- Characteristics
  - Very robust
  - Requires no modification to routing algorithms

DNS records

- 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 (cont'd)

- 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)

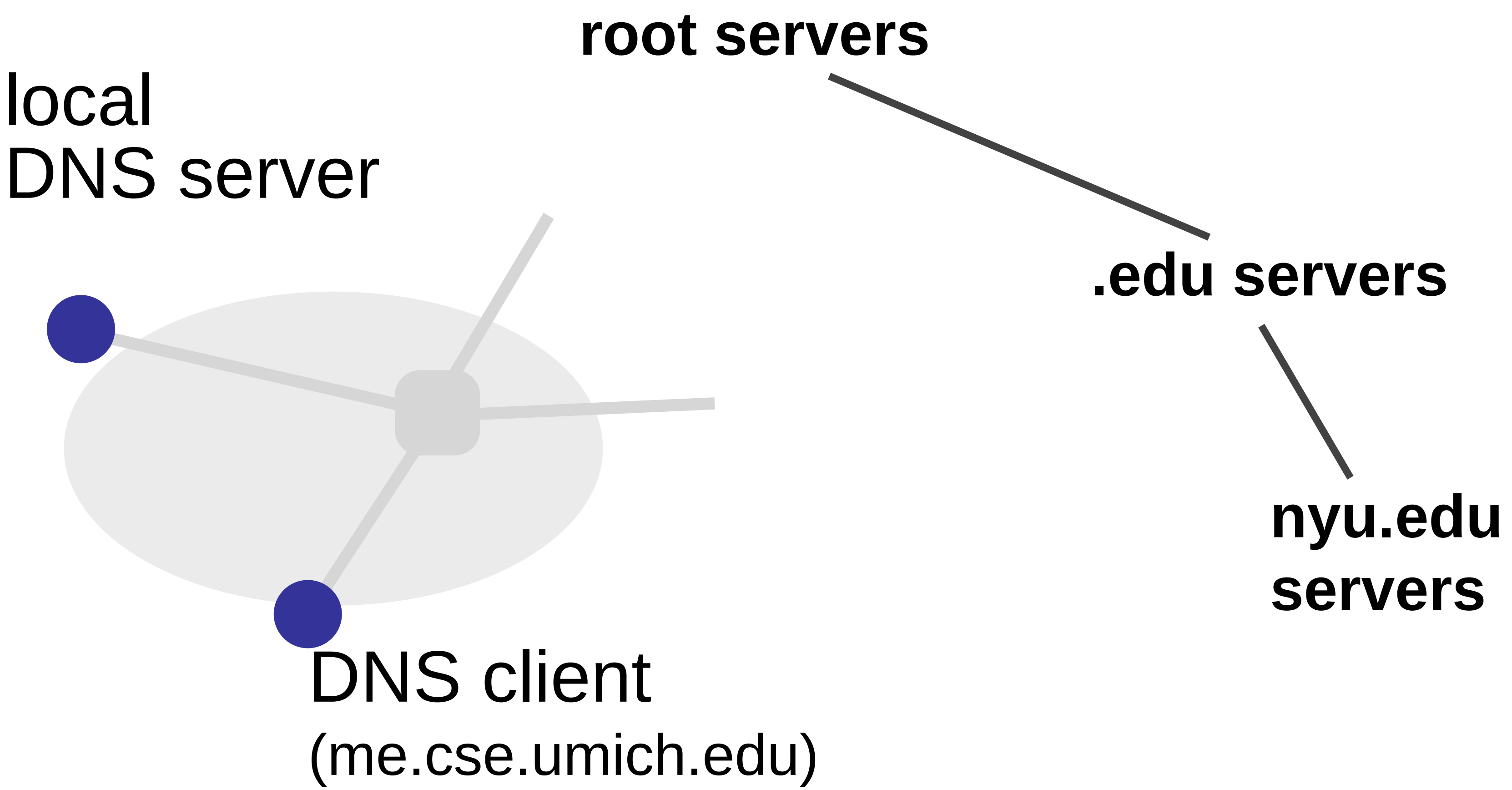
Inserting Resource Records into DNS

- Register foobar.com at registrar (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

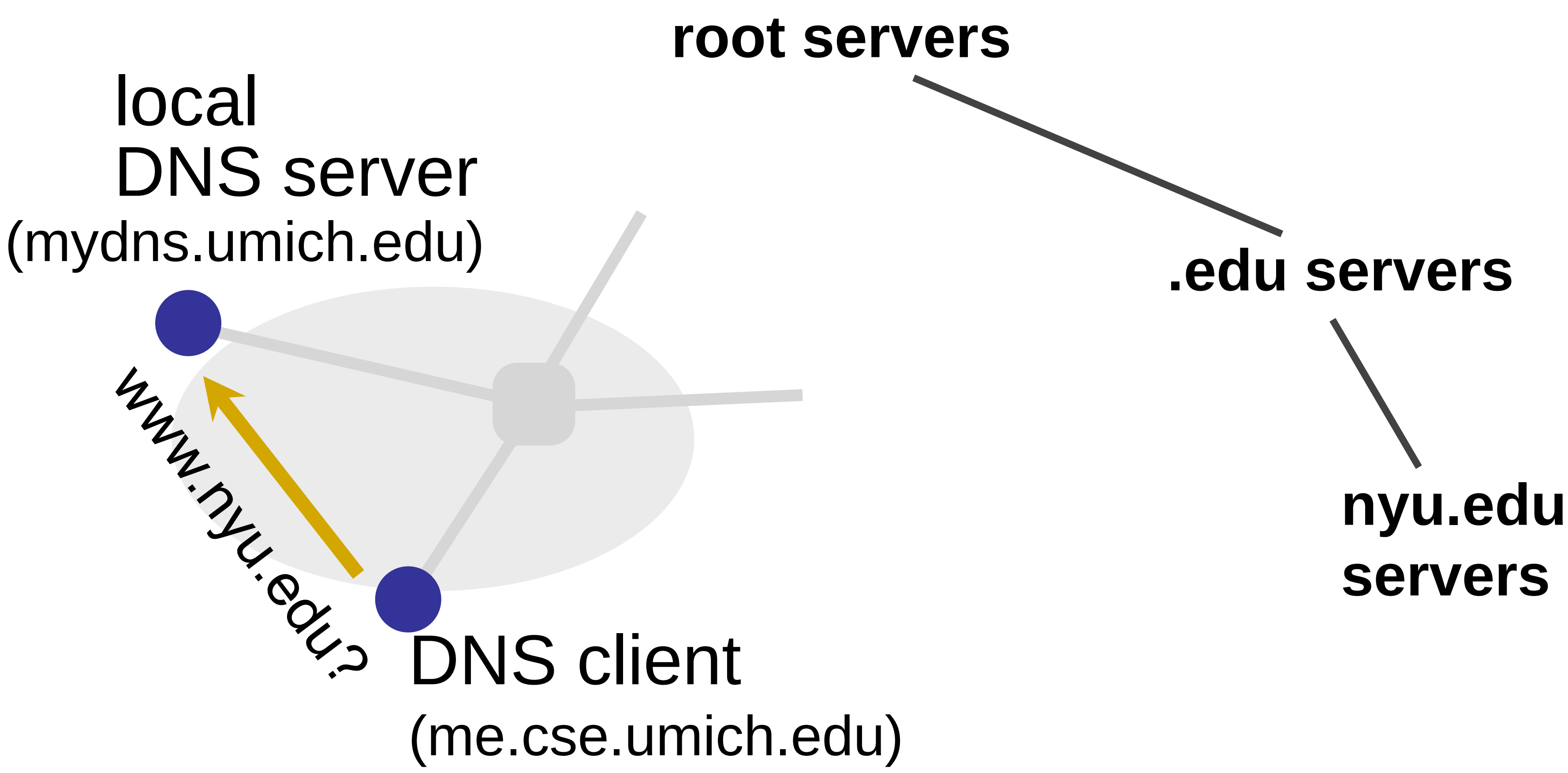
Using DNS (Client/App View)

- 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 `gethostbyname()` to trigger DNS request to its local DNS server

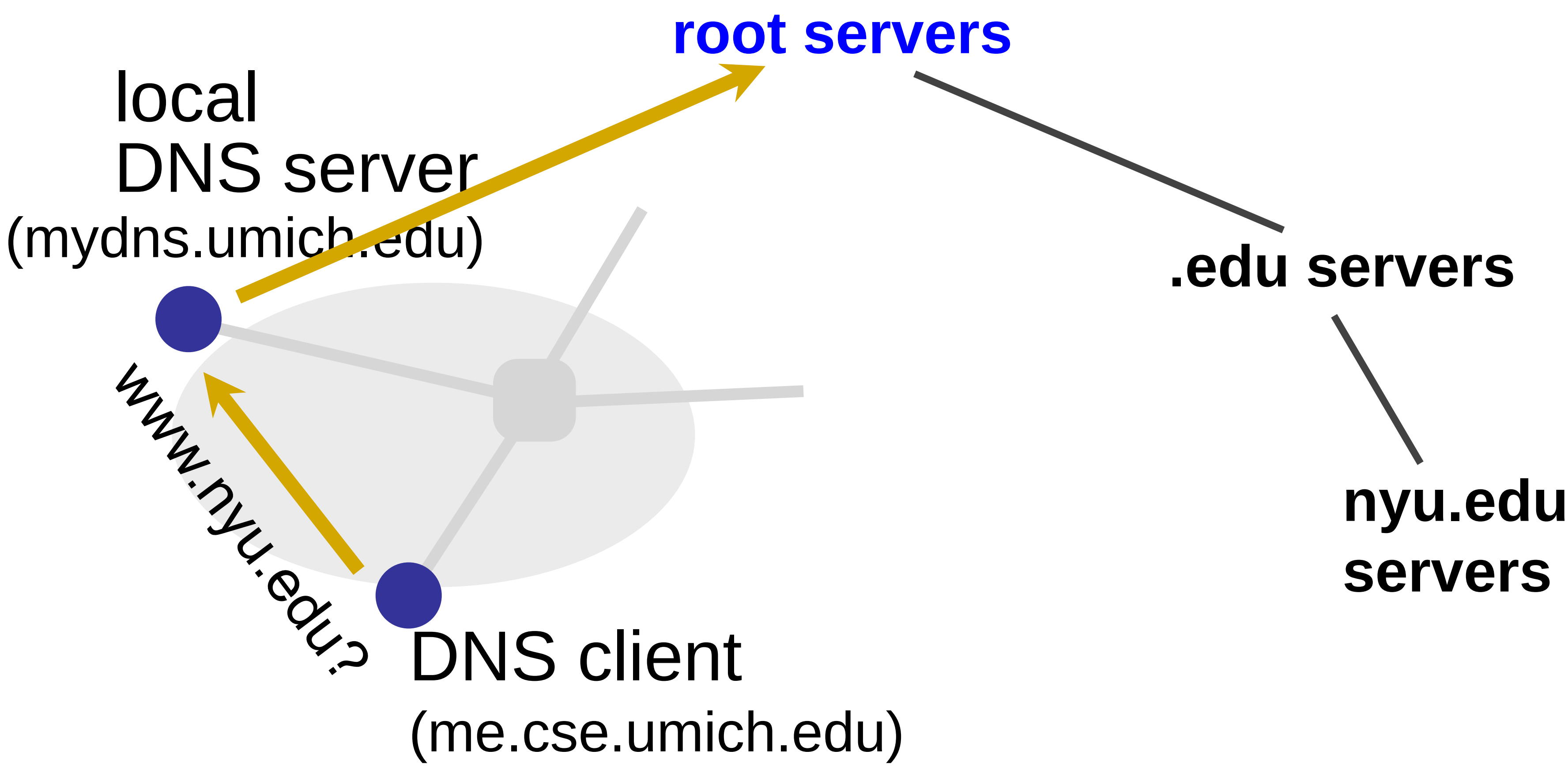
Name resolution



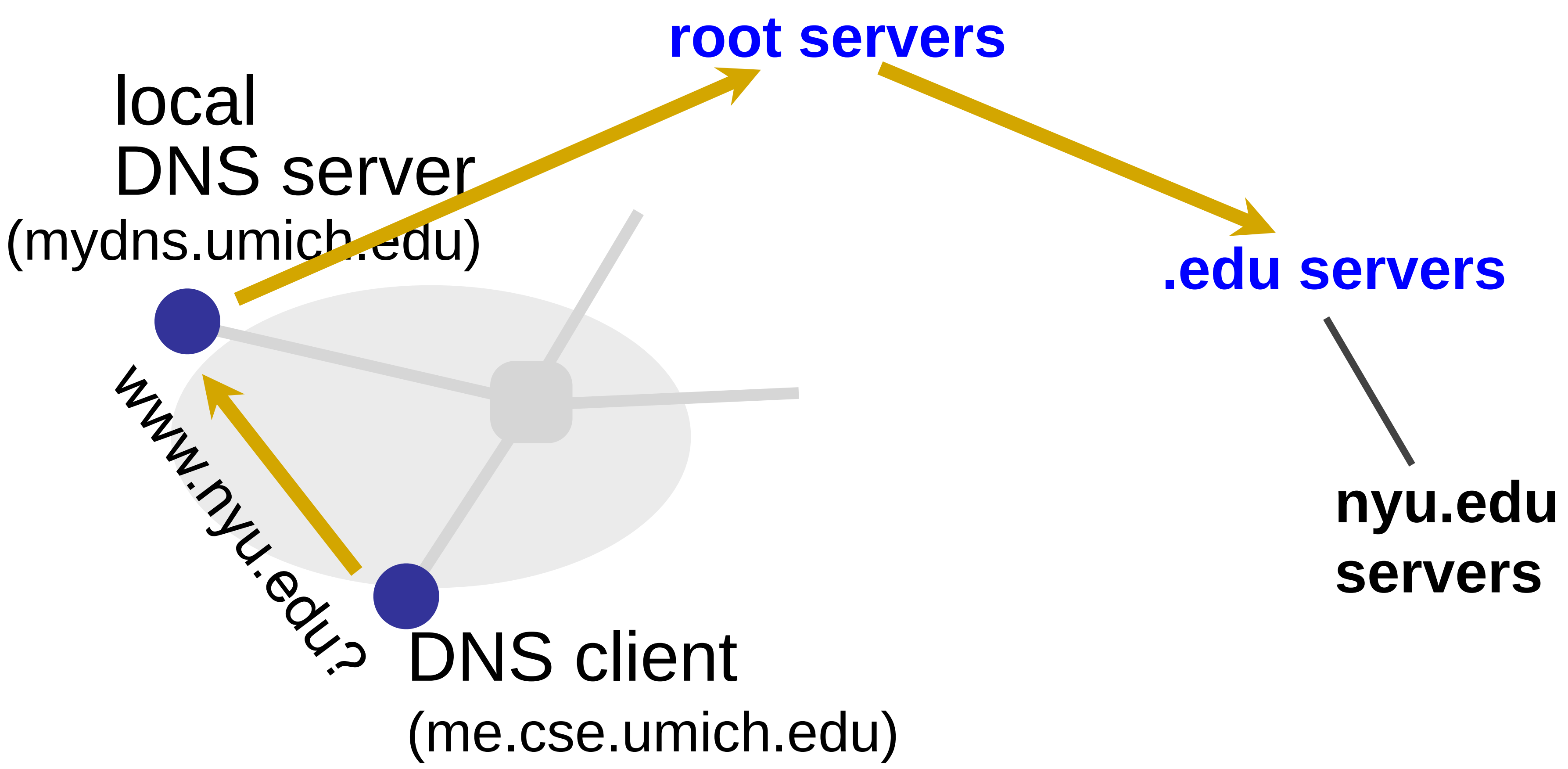
Name resolution



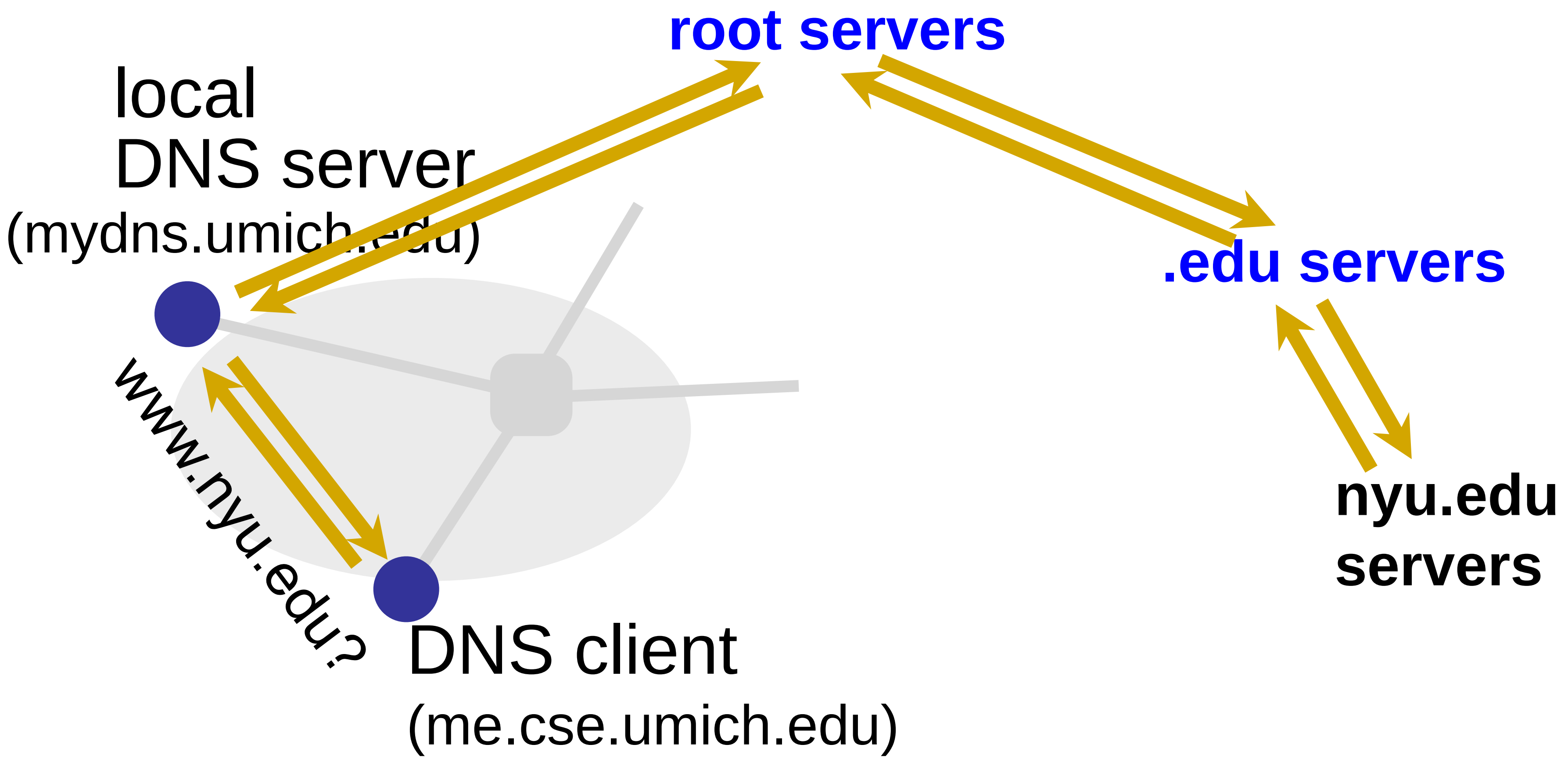
Name resolution



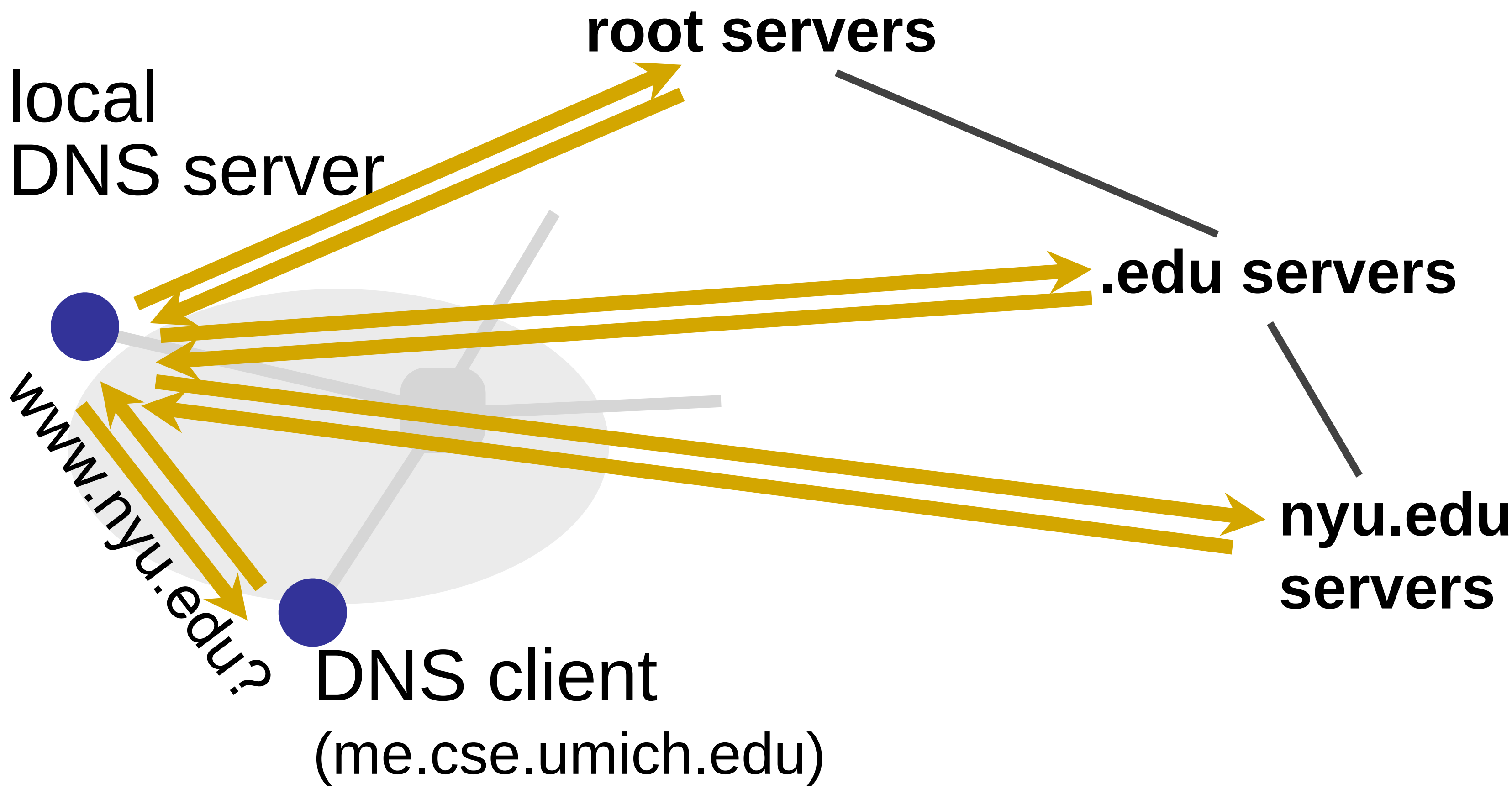
Name resolution



Name resolution: Recursive



Name resolution: Iterative



Two ways to resolve a name

- 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

- 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: Are we there yet?

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

Reliability

- 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?

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

DNS caching

- 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.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
- Negative caching is optional
  - Not widely implemented

Important properties of DNS

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

DNS provides indirection

- 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)
- 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
- This flexibility applies only within domain!

Summary

- 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