CSCE 463/612
Networks and Distributed Processing
Spring 2025

Application Layer III

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February 6, 2025

Chapter 2: Roadmap

2.1 Principles of network applications

2.2 Web and HTTP

2.3 FTP

2.4 Electronic Mail

- SMTP, POP3, IMAP

2.5 DNS

2.6 P2P file sharing

2.7 Socket programming with TCP

2.8 Socket programming with UDP

2.9 Building a Web server

DNS: Domain Name System

- People: many identifiers
  - Name, SSN, passport #
- Internet hosts, routers:
  - IP address (32 bit) used for routing datagrams
  - Names (e.g., yahoo.com) used by humans

Q: how to map between IP addresses and names?

  - Original technique: global file hosts.txt with all known hosts; flat namespace

Domain Name System:

- Distributed database
  - Implemented in hierarchy of many *name servers*
- Application-layer protocol
  - Hosts communicate with name servers to *resolve* names/IPs
  - UDP port 53
  - Single-packet query
  - Single-packet response

DNS

Services

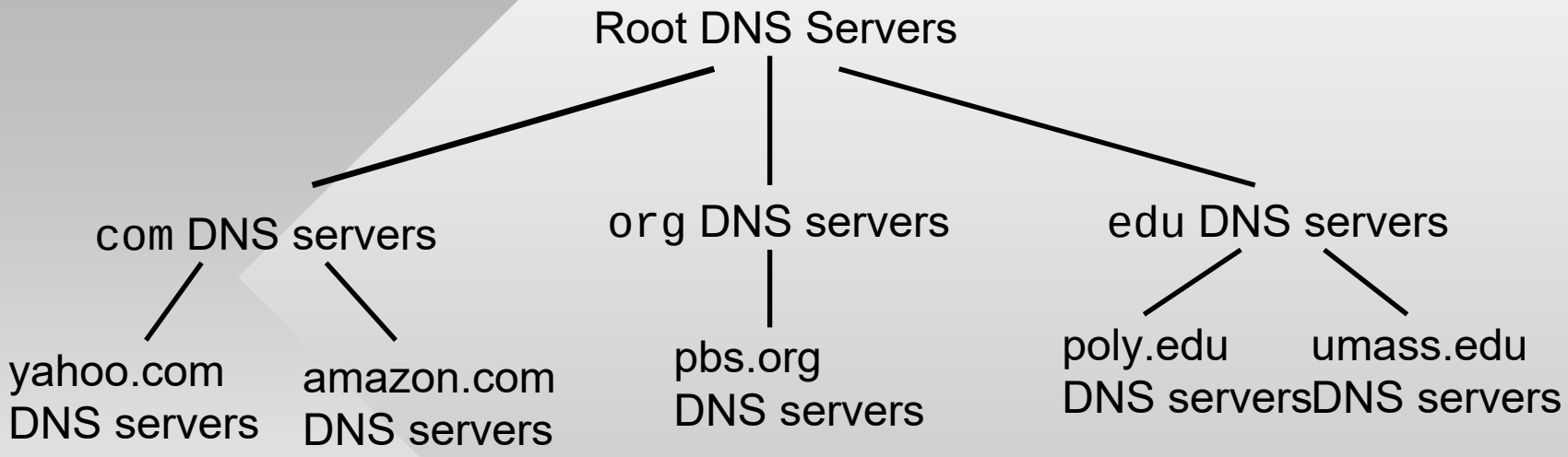
- Forward lookup
  - Hostname to IP translation
- Reverse lookup
  - IP to hostname
- Host aliasing
- Mail server lookup
- Load distribution
  - E.g., replicated web servers: set of IP addresses for one DNS name

Why not centralize DNS?

- Single point of failure
- Traffic volume (bandwidth, request rate)
- Lack of geographic proximity to user, hence high latency
- Inflexible (can't run code customized for domain)

Doesn't *scale!*

Distributed, Hierarchical Database



- Client wants IP for www.amazon.com:
  - Queries a root server to find the `com` DNS server
  - Queries the `com` server to get the `amazon.com` server
  - Queries the `amazon.com` DNS server to get IP address for `www.amazon.com`
- Who to ask about the location of root servers?
  - Nobody, their IPs are hardwired into OS

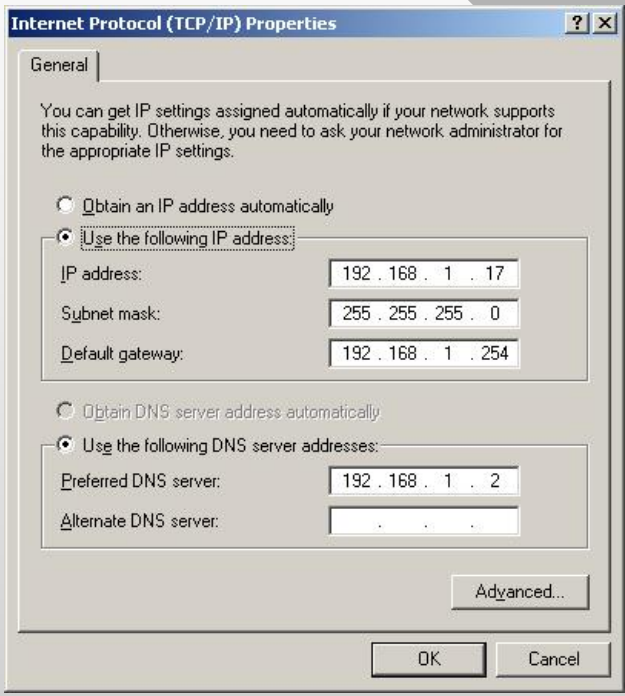
Types of DNS Servers

- There are 13 named root servers (called A-M), each with a fixed IP address
  - Some servers (e.g., A, C, F, I) are geographically distributed across multiple sites (1369 total in 2021)
  - More info: http://root-servers.org/

Types of DNS Servers

- Top-level domain (TLD) servers: responsible for generic TLDs (e.g., .com, .org, .net, .edu) and all country-code TLDs (e.g., .uk, .fr, .ca, .jp)
  - Around 1530 total gTLDs and cc-TLDs (2019)
  - Verisign runs .com , Educause .edu
- Authoritative servers: provide authoritative mappings for company servers (e.g., Web and mail)
  - Can be maintained by organization (e.g., amazon.com) or service provider (e.g., ISP or hosting company)
- Local name server: does not belong to the hierarchy
  - Any computer that accepts requests and then finds out the answer by traversing the DNS tree

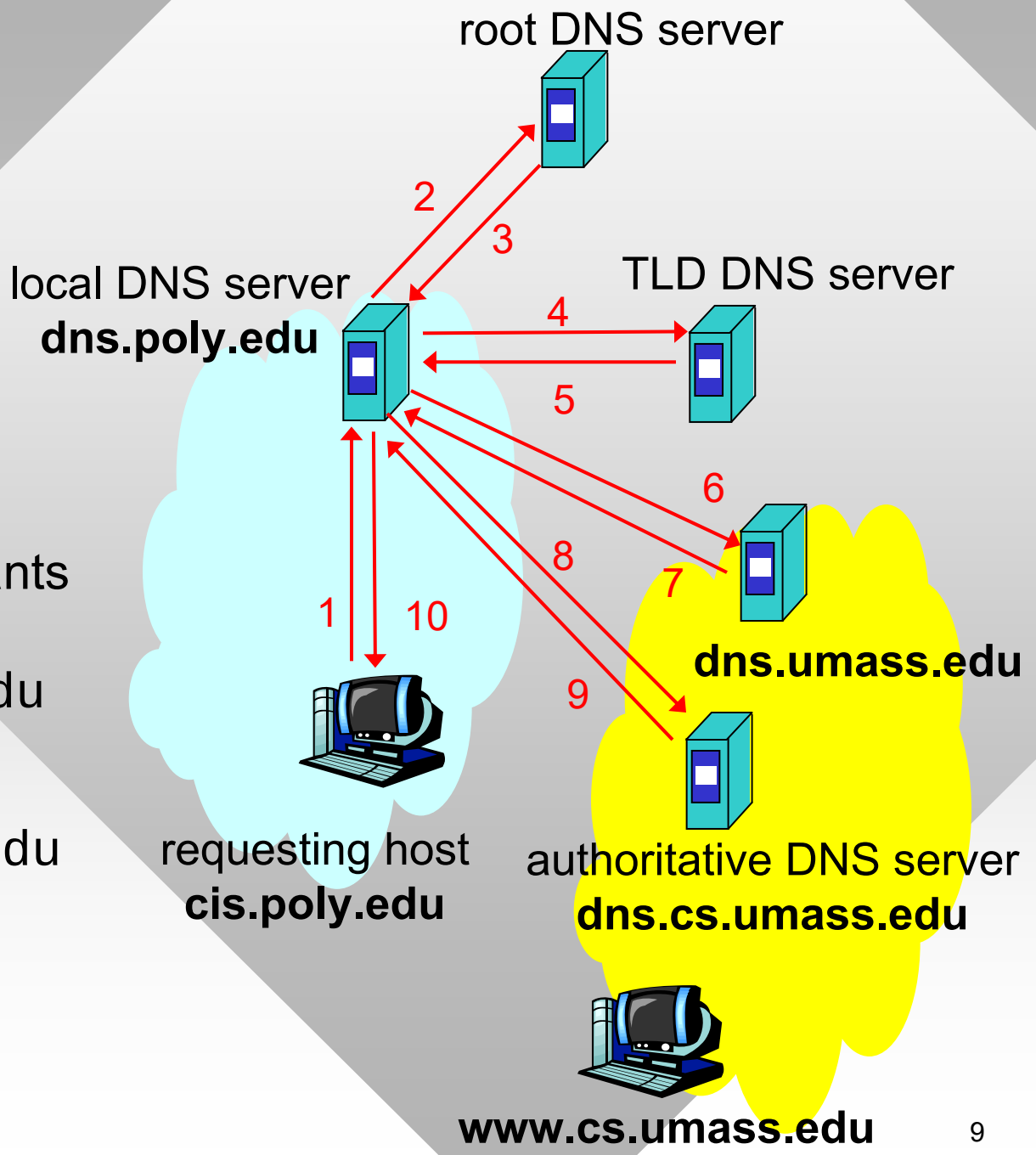
Local Name Servers



- Each network (ISP, company, university) has a few
  - Preferred DNS server in network options (alternate used for backup)
  - If you run BIND, set this to 127.0.0.1
  - Auto-configure via DHCP or set to 8.8.8.8 (Google DNS)
- When a host makes a DNS query (application calls gethostbyname), query is sent to local DNS server
  - Local server acts as a proxy (cache) and forwards query into hierarchy if it cannot answer it from cache
- Command-line tool for DNS queries is nslookup
  - Homework #2 implements essentially this

Example

- `cis.poly.edu` wants the IP address for `www.cs.umass.edu`
- Next request for `joe.cs.umass.edu` – What happens?



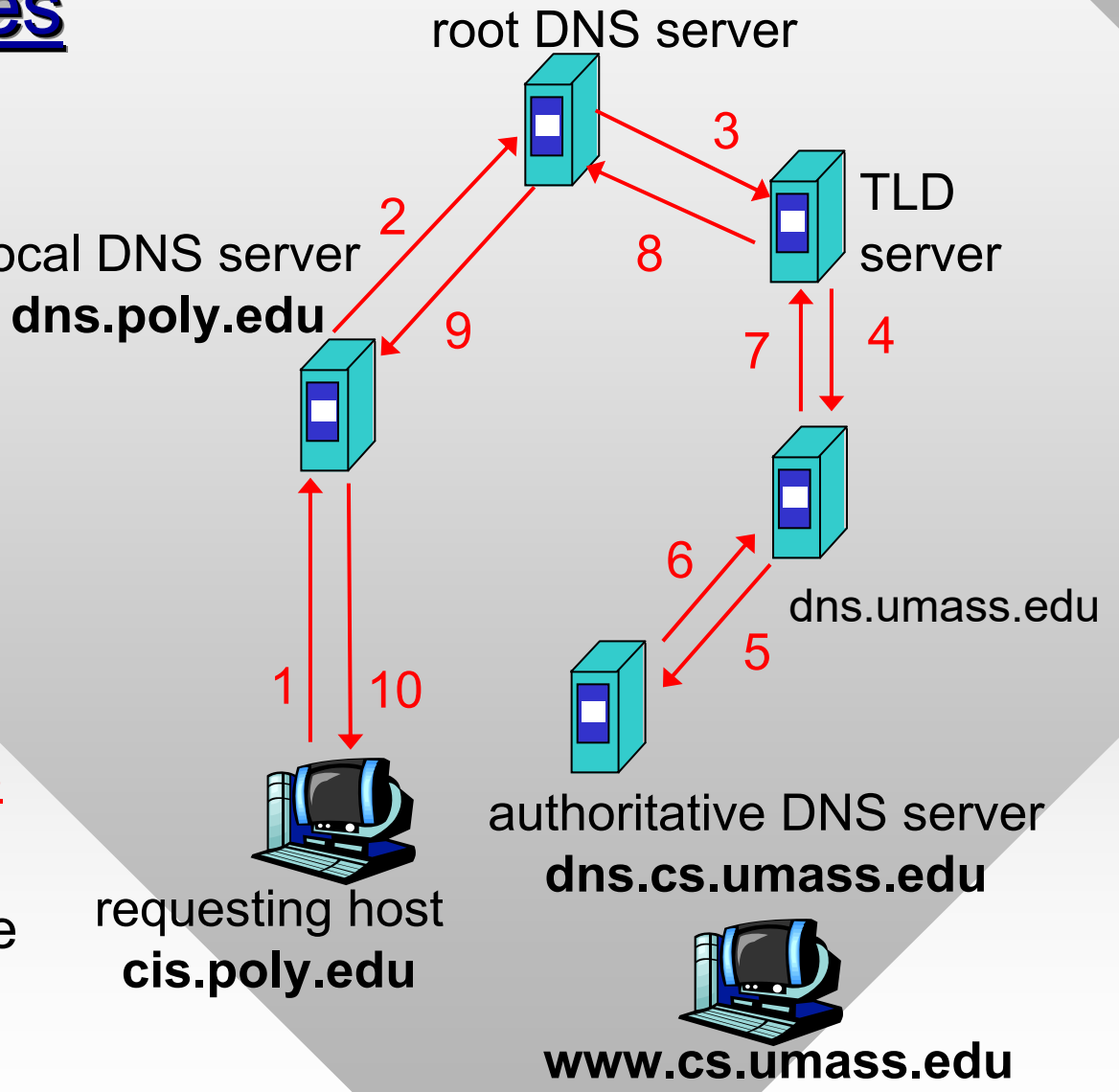
Recursive queries

Iterative query (previous page):

- Contacted server replies with name of server to contact
- "I don't know this name, but ask this other server"

Recursive query (this page):

- Puts burden of name resolution on contacted name server



DNS: Caching and Updating Records

- Once (any) name server learns a mapping, it *caches* the mapping
  - Cache entries time out (disappear) after some time (TTL)
  - Unexpired entries are served directly from cache, in which case they are called non-authoritative
  - If the DNS server of the target domain is contacted, the response is authoritative
- TLD servers are typically cached in local name servers
  - Thus root name servers not supposed to be visited often
- Study in 2007 showed load on individual root servers A-M was 6-16K queries/sec
  - During DDoS attacks in 2001 it was 38K/sec

DNS Records

Replace A with AAAA for IPv6

DNS: distributed database of resource records (RR)

(name, value, type, ttl)

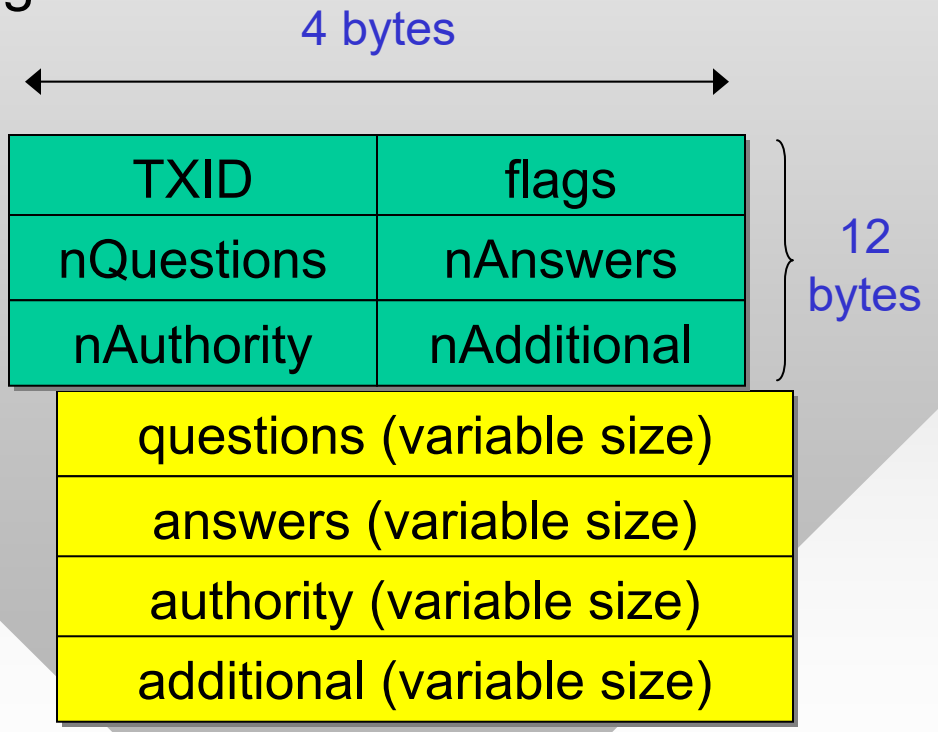
- Type A
  - name = host
  - value = IPv4 address (4 byte DWORD)
- Type NS
  - name = domain
  - value = hostname of authoritative name server for this domain
- Type CNAME
  - name = host
  - value = host it's aliased to
  - Reduces manual effort to change IPs and other records
- Type MX
  - name = domain
  - value = name of SMTP server associated with domain

Reverse Queries

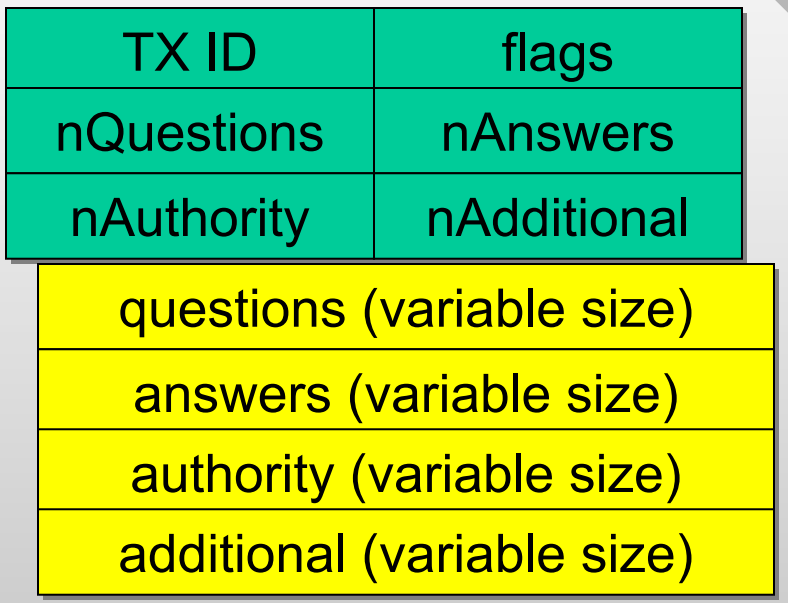
- Reverse DNS lookups are performed using a special construction of a fake DNS name
  - Reason: DNS resolves names from right to left with the semantics of going from the most general to the most specific
  - In IPs, the MSB is most general, LSB is most specific
- The IP address is reversed and is followed by "in-addr.arpa" (or "ip6.arpa" for IPv6)
  - Example: 128.194.135.65 is requested as 65.135.194.128.in-addr.arpa
  - The query type must be set to PTR
- RFC 1035 (1987) describes DNS headers/commands
  - Useful for hw2

DNS Protocol, Messages

- Query and reply messages use same format
  - Packet starts with a fixed DNS header (12 bytes)
  - Followed by a variable-length section
- Transaction ID (TXID)
  - 16-bit number assigned by client to each query
  - Echoed by server in response packet
- Flags specify the type of request being made and response status
- The other 4 fields provide a count of records in each variable-size section

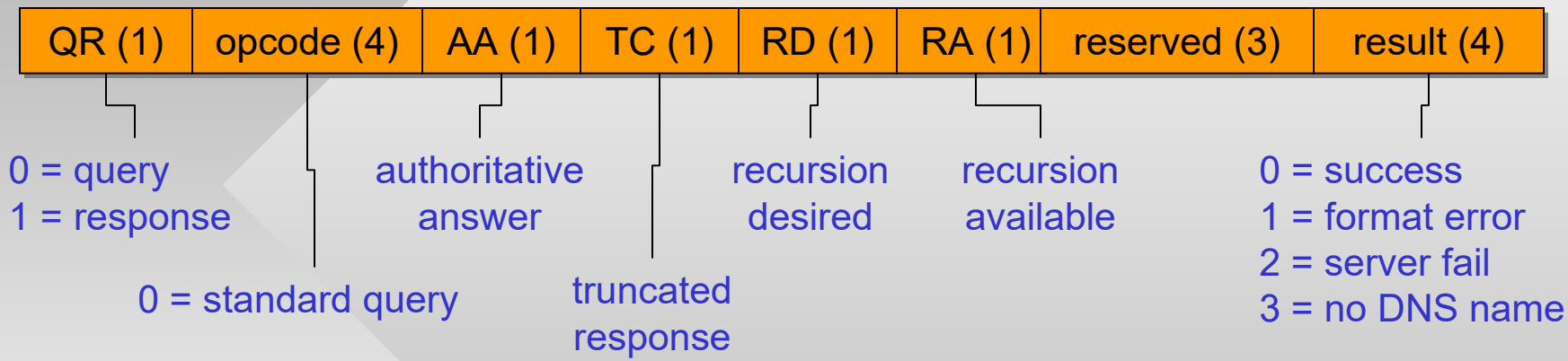


DNS Protocol, Messages



- Queries contain only the question section
  - Most servers expect one question per packet
- Response packets always repeat the question
  - Safety mechanism if TXID runs into collision at the client
- Authority section carries NS record(s)
  - Used during iterative lookups to specify the next DNS server to query (similar to HTTP redirects)
- All numbers are in network byte order
  - Use proper conversion (i.e., htons() in this case)

DNS Flags



- For binary fields, 1 = true and 0 = false
- For query packets:
  - Set RD = 1; all other fields are zero
  - Specify nQuestions = 1
  - Correctly create the actual question and append it to the header in the packet buffer

Nslookup Usage (Windows)

- nslookup -querytype=mx cs.tamu.edu

cached answers and additional records

```
Server:  gw.irl.cs.tamu.edu
Address:  128.194.135.72

Non-authoritative answer:
cs.tamu.edu MX preference = 100, mail exchanger = smtp-relay.tamu.edu
cs.tamu.edu MX preference = 10, mail exchanger = pine.cs.tamu.edu

smtp-relay.tamu.edu     internet address = 165.91.143.199
pine.cs.tamu.edu        internet address = 128.194.138.12
```

- nslookup -querytype=hinfo cs.tamu.edu

```
Server:  gw.irl.cs.tamu.edu
Address:  128.194.135.72

cs.tamu.edu
        primary name server = dns1.cs.tamu.edu
        responsible mail addr = root.cs.tamu.edu
        serial  = 2006090513
        refresh = 1800 (30 mins)
        retry   =  900 (15 mins)
        expire  = 1209600 (14 days)
        default TTL = 3600 (1 hour)
```

smaller preference value means higher priority

Nslookup Usage (Windows)

- nslookup -querytype=ptr 12.138.194.128.in-addr.arpa

```
Server:  gw.irl.cs.tamu.edu
Address:  128.194.135.72

Non-authoritative answer:
12.138.194.128.in-addr.arpa     name = mail.cs.tamu.edu
12.138.194.128.in-addr.arpa     name = pine.cs.tamu.edu
12.138.194.128.in-addr.arpa     name = pophost.cs.tamu.edu
12.138.194.128.in-addr.arpa     name = mailhost.cs.tamu.edu
12.138.194.128.in-addr.arpa     name = pop.cs.tamu.edu
12.138.194.128.in-addr.arpa     name = imap.cs.tamu.edu
```

nslookup performs string reversal transparently, but hw2 will need to do this explicitly

- nslookup -querytype=ptr 12.1.55.186

```
Server:  s18.irl.cs.tamu.edu
Address:  128.194.135.58

Non-authoritative answer:
186.55.1.12.in-addr.arpa        canonical name = 186.184/29.55.1.12.in-addr.arpa

186.184/29.55.1.12.in-addr.arpa name = outlook.milestonescientific.com
```

Using UDP

- DNS runs over UDP that has no connection phase
  - Each request and response is exactly 1 packet
  - Calls to recvfrom() and sendto() correspond to receiving/ sending 1 packet from/to a socket
  - No need to loop on receive
- General idea:

```
sock = socket (AF_INET, SOCK_DGRAM, 0);
// bind sock to port 0 – see the handout
len = CreateRequest(buf, hostname);
while (work to be done) {
  sendto (sock, buf, len, 0, &addressTo, ...);
  ...
  if (select (...) > 0) {
            recvfrom (sock, recvBuf, ..., 0, &addressFrom...);
            parseResponse (recvBuf);
  }
}
closesocket (sock);
```