# Transport Protocols & DNS

**EE 122: Intro to Communication Networks**

Fall 2006 (MW 4-5:30 in Donner 155)

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http://inst.eecs.berkeley.edu/~ee122/

Materials with thanks to Jennifer Rexford, Ion Stoica, and colleagues at Princeton and UC Berkeley



## Announcements

- We're soliciting feedback
  - What's not working? What's working well?
- Send via email …
- … or if you want to be anonymous, put a note in my box in Soda, 3rd floor (near dept. admins)



## Goals for Today's Lecture, Part 1

- Principles underlying transport-layer services
  - (De)multiplexing via port numbers
  - Reliable delivery
  - Performance issues:
    - Stop-and-Wait vs. Sliding Window
    - Flow control
- Service models of Internet transport protocols
  - User Datagram Protocol (UDP)
  - Transmission Control Protocol (TCP)
- Not a goal for today: details of TCP's operation



## Goals of Today's Lecture, Part 2

- Concepts & principles underlying Domain Name System (DNS)
  - Indirection: names in place of addresses
  - Hierarchy: in names, addresses, and servers
  - Caching: of mappings from names to/from addresses
- Inner workings of DNS
  - DNS resolvers and servers
  - Iterative and recursive queries
  - TTL-based caching
  - Use of the `dig` utility



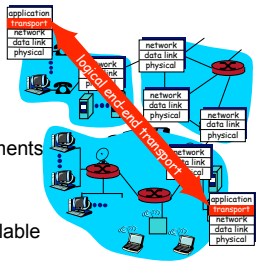
## Role of Transport Layer

- Application layer
  - Communication for specific applications
  - E.g., HyperText Transfer Protocol (HTTP), File Transfer Protocol (FTP), Network News Transfer Protocol (NNTP)
- Transport layer
  - Communication between processes (e.g., socket)
  - Relies on network layer; serves the application layer
  - E.g., TCP and UDP
- Network layer
  - Logical communication between nodes
  - Hides details of the link technology
  - E.g., IP



## Transport Protocols

- Provide *logical communication* between application processes running on different hosts
- Run on end hosts
  - Sender: breaks application messages into segments, and passes to network layer
  - Receiver: reassembles segments into messages, passes to application layer
- Multiple transport protocol available to applications
  - Internet: TCP and UDP (mainly)



## Internet Transport Protocols

- Datagram messaging service (UDP)
  - No-frills extension of "best-effort" IP
- Reliable, in-order delivery (TCP)
  - Connection set-up
  - Discarding of corrupted packets
  - Retransmission of lost packets
  - Flow control
  - Congestion control
- Services not available
  - Delay guarantees
  - Bandwidth guarantees
  - Sessions that survive change-of-IP-address

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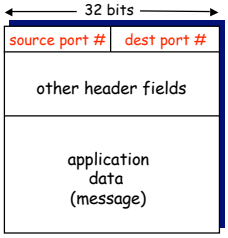
## Multiplexing and Demultiplexing

- Host receives IP datagrams
  - Each datagram has source and destination IP address,
  - Each datagram carries one transport-layer segment
  - Each segment has source and destination port number
- Host uses IP addresses and port numbers to direct the segment to appropriate socket




TCP/UDP segment format

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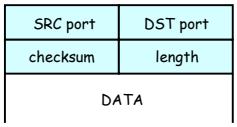
## Unreliable Message Delivery Service

- Lightweight communication between processes
  - Avoid overhead and delays of ordered, reliable delivery
  - Send messages to and receive them from a socket
- User Datagram Protocol (UDP; RFC 768 - 1980!)
  - IP plus port numbers to support (de)multiplexing
  - Optional error checking on the packet contents
    - (checksum field = 0 means "don't verify checksum")

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## Why Would Anyone Use UDP?

- Finer control over what data is sent and when
  - As soon as an application process writes into the socket
  - … UDP will package the data and send the packet
- No delay for connection establishment
  - UDP just blasts away without any formal preliminaries
  - … which avoids introducing any unnecessary delays
- No connection state
  - No allocation of buffers, sequence #s, timers …
  - … making it easier to handle many active clients at once
- Small packet header overhead
  - UDP header is only 8 bytes

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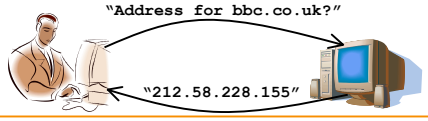
## Popular Applications That Use UDP

- Multimedia streaming
  - Retransmitting lost/corrupted packets often pointless - by the time the packet is retransmitted, it's too late
  - E.g., telephone calls, video conferencing, gaming
- Simple query protocols like Domain Name System
  - Connection establishment overhead would double cost
  - Easier to have application retransmit if needed

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## Transmission Control Protocol (TCP)

- Connection oriented
  - Explicit set-up and tear-down of TCP session
- Stream-of-bytes service
  - Sends and receives a stream of bytes, not messages
- Congestion control
  - Dynamic adaptation to network path's capacity
- Reliable, in-order delivery
  - TCP tries very hard to ensure byte stream (eventually) arrives intact
    - In the presence of corruption and loss
- Flow control
  - Ensure that sender doesn't overwhelm receiver

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## Reliable Delivery

- How do we design for reliable delivery?
  - One possible model: how does it work talking on your cell phone?
- Positive acknowledgment ("Ack")
  - Explicit confirmation by receiver
  - TCP acknowledgments are cumulative ("I've received everything up through sequence #N")
    - With an option for acknowledging individual segments ("SACK")
- Negative acknowledgment ("Nack")
  - "I'm missing the following: …"
  - How might the receiver tell something's missing? Can they always do this?
  - (Only used by TCP in implicit fashion - "fast retransmit")

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## Reliable Delivery, con't

- Timeout
  - If haven't heard anything from receiver, send again
  - Problem: for how long do you wait?
    - TCP uses function of estimated RTT
  - Problem: what if no Ack for retransmission?
    - TCP (and other schemes) employs exponential backoff
    - Double timer up to maximum - tapers off load during congestion
- A very different approach to reliability: send redundant data
  - Cell phone analogy: "Meet me at 3PM - repeat 3PM"
  - Forward error correction
  - Recovers from lost data nearly immediately!
  - But: only can cope with a limited degree of loss
  - And: adds load to the network

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## TCP Support for Reliable Delivery

- Sequence numbers
  - Used to detect missing data
  - ... and for putting the data back in order
- Checksum
  - Used to detect corrupted data at the receiver
  - …leading the receiver to drop the packet
  - No error signal sent - recovery via normal retransmission
- Retransmission
  - Sender retransmits lost or corrupted data
  - Timeout based on estimates of round-trip time (RTT)
  - Fast retransmit algorithm for rapid retransmission

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## Efficient Transport Reliability

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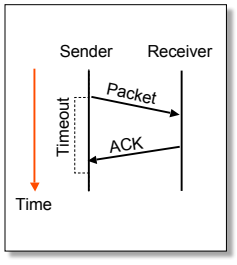
## Automatic Repeat reQuest (ARQ)

- Automatic Repeat Request
  - Receiver sends acknowledgment (ACK) when it receives packet
  - Sender waits for ACK and times out if does not arrive within some time period
- Simplest ARQ protocol
  - **Stop and Wait**
  - Send a packet, stop and wait until ACK arrives

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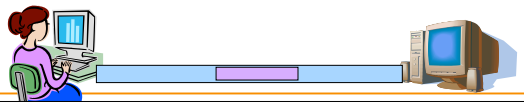
## How Fast Can Stop-and-Wait Go?

- Suppose we're sending from UCB to New York:
  - Bandwidth = 1 Mbps (megabits/sec)
  - RTT = 100 msec
  - Maximum Transmission Unit (MTU) = 1500 B = 12,000 b
  - No other load on the path and no packet loss
- What (approximately) is the fastest we can transmit using Stop-and-Wait?
- How about if Bandwidth = 1 Gbps?



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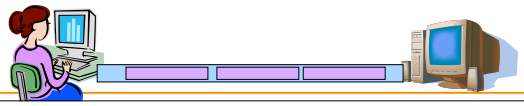
## Allowing Multiple Packets in Flight

- "In Flight" = "Unacknowledged"
- Sender-side issue: how many packets (bytes)?
- Receiver-side issue: how much buffer for data that's "above a sequence hole"?
  - I.e., data that can't be delivered since previous data is missing
  - Assumes service model is in-order delivery (like TCP)



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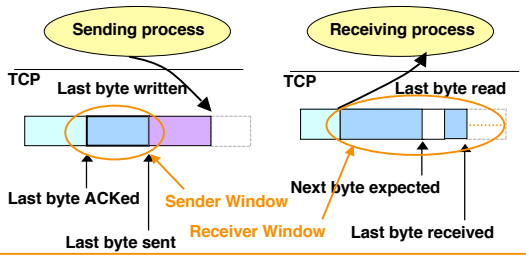
## *Sliding Window*

- Allow a larger amount of data "in flight"
  - Allow sender to get ahead of the receiver
  - … though not *too far* ahead

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## *Sliding Window*, con't

- Both sender & receiver maintain a **window** that governs amount of data in flight (sender) or not-yet-delivered (receiver)
- Left edge of window:
  - Sender: beginning of unacknowledged data
  - Receiver: beginning of undelivered data
- Right edge of window: left edge + size
  - Sender: size = maximum amount of data in flight
    - Determines rate
    - Sender must have at least this much buffer (maybe more)
  - Receiver: size = maximum amount of undelivered data
    - Receiver has this much buffer

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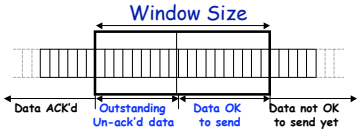
## *Sliding Window*, con't

- Sender: window advances when new data ack'd
- Receiver: window advances as receiving process consumes data
- What happens if Send Window Size (SWS) exceeds Receive Window Size (RWS)?
- Receiver advertises RWS to the sender
  - Sender agrees not to exceed this amount
  - Given this, when can SWS ≠ RWS?

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## Performance with Sliding Window

- Given previous UCB ↔ New York 1 Mbps path
  - Sender window = 100 Kb = 12.5 KB
- How fast can we transmit?
- What about with 12.5 KB window & 1 Gbps path?
- Window required to fully utilize path:
  - **Bandwidth-delay product** (or "delay-bandwidth product")
  - 1 Gbps * 100 msec = 100 Mb = 12.5 MB
  - Can picture as path's storage capacity
  - Note: large window = many packets in flight

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## 5 Minute Break

Questions Before We Proceed?

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## Domain Name System (DNS)



## Host Names vs. IP addresses

- Host names
  - Mnemonic name appreciated by humans
  - Variable length, full alphabet of characters
  - Provide little (if any) information about location
  - Examples: www.cnn.com and bbc.co.uk
- IP addresses
  - Numerical address appreciated by routers
  - Fixed length, binary number
  - Hierarchical, related to host location
  - Examples: 64.236.16.20 and 212.58.228.155



## Separating Naming and Addressing

- Names are easier to remember
  - www.cnn.com vs. 64.236.16.20
- Addresses can change underneath
  - Move www.cnn.com to 64.236.16.20
  - E.g., renumbering when changing providers
- Name could map to multiple IP addresses
  - www.cnn.com to multiple (8) replicas of the Web site
- Map to different addresses* in different places
  - Address of a nearby copy of the Web site
  - E.g., to reduce latency, or return different content
- Multiple names for the same address
  - E.g., aliases like www.cnn.com and cnn.com



## Scalable (Name ↔ Address) Mappings

- Originally: per-host file
  - Flat namespace
  - `/etc/hosts` (what is this on your computer today?)
  - SRI kept master copy
  - Downloaded regularly
- Single server doesn't scale
  - Traffic implosion (lookups & updates)
  - Single point of failure
  - Amazing politics

**Need a distributed, hierarchical collection of servers**

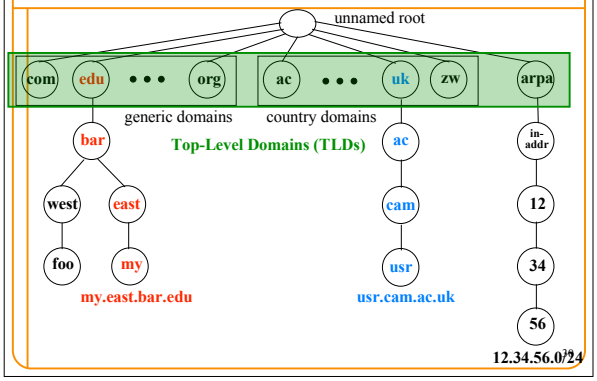


## Domain Name System (DNS)

- Properties of DNS
  - Hierarchical name space divided into zones
  - Zones distributed over collection of DNS servers
- Hierarchy of DNS servers
  - Root (hardwired into other servers)
  - Top-level domain (TLD) servers
  - Authoritative DNS servers
- Performing the translations
  - Local DNS servers
  - Resolver software

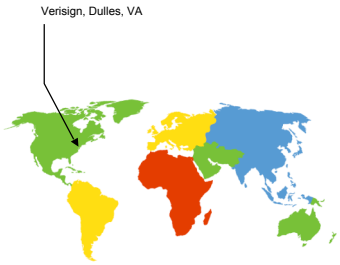


## Distributed Hierarchical Database



## DNS Root

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

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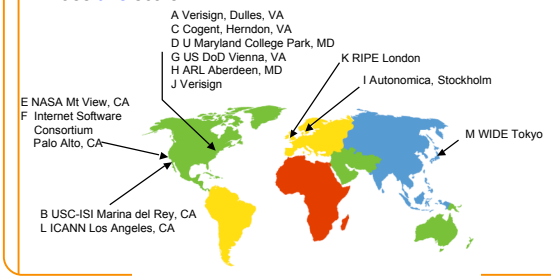
## DNS Root Servers

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

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## DNS Root Servers

- 13 root servers (see http://www.root-servers.org/)
  - Labeled A through M
- Replication via any-casting (localized routing for addresses)


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## TLD and Authoritative DNS Servers

- Top-level domain (TLD) servers
  - Generic domains (e.g., com, org, edu)
  - Country domains (e.g., uk, fr, cn, jp)
  - Special domains (e.g., arpa)
  - Typically managed professionally
    - Network Solutions maintains servers for "**com**"
    - Educause maintains servers for "**edu**"
- Authoritative DNS servers
  - Provide public records for hosts at an organization
    - Private records may differ, though not part of original design's intent
  - For the organization's servers (e.g., Web and mail)
  - Can be maintained locally or by a service provider

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## Using DNS

- Local DNS server ("default name server")
  - Usually near the endhosts that use it
  - Local hosts configured with local server (e.g., `/etc/resolv.conf`) or learn server via DHCP
- Client application
  - Extract server name (e.g., from the URL)
  - Do *gethostbyname()* to trigger resolver code
- Server application
  - Extract client IP address from socket
  - Optional *gethostbyaddr()* to translate into name

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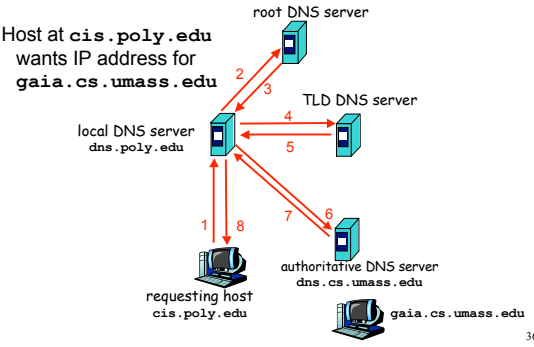
## Example

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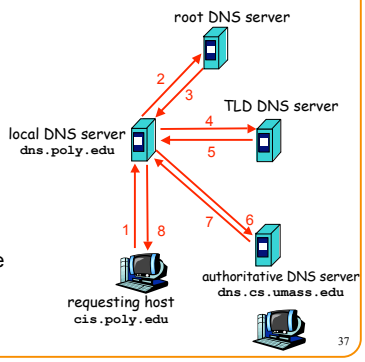
## Recursive vs. Iterative Queries

- 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



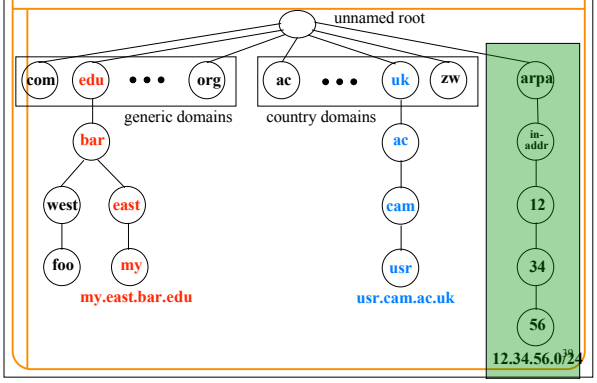



## Reverse Mapping (Address → Host)

- How do we go the other direction, from an IP address to the corresponding hostname?
- Addresses already have natural "quad" hierarchy:
  - 12.34.56.78
- But: quad notation has most-sig. hierarchy element on left, while www.cnn.com has it on the right
- Idea: reverse the quads = 78.56.34.12 …
  - … and look that up in the DNS
- Under what TLD?
  - Convention: **in-addr.arpa**
  - So lookup is for `78.56.34.12.in-addr.arpa`



## Distributed Hierarchical Database






## 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



## DNS Resource Records

DNS: distributed DB storing resource records (RR)

RR format: `(name, value, type, ttl)`

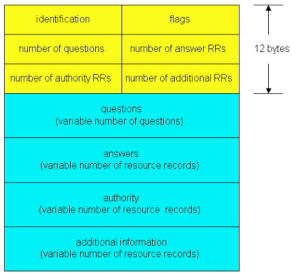
- Type=A
  - **`name`** is hostname
  - **`value`** is IP address
- Type=NS
  - **`name`** is domain (e.g. foo.com)
  - **`value`** is hostname of authoritative name server for this domain
- Type=PTR
  - **`name`** is reversed IP quads
    - E.g. 78.56.34.12.in-addr.arpa
  - **`value`** is corresponding hostname
- Type=CNAME
  - **`name`** is alias name for some "canonical" name
    E.g., **`www.cs.mit.edu`** is really **`eecsweb.mit.edu`**
  - **`value`** is canonical name
- Type=MX
  - **`value`** is name of mailserver associated with **`name`**
  - Also includes a weight/preference

## DNS Protocol

**DNS protocol**: *query* and *reply* messages, both with same *message format*

Message header

- Identification: 16 bit # for query, reply to query uses same #
- Flags:
  - Query or reply
  - Recursion desired
  - Recursion available
  - Reply is authoritative






## Interactive DNS lookups using `dig`

- `dig` program on Unix
  - Allows querying of DNS system
  - Dumps each field in DNS responses
  - By default, executes recursive queries
    - Disable via `+norecurse` so that operates one step at a time



```
unix> dig +norecurse @a.root-servers.net www.cnn.com

; <<>> DiG 9.2.2 <<>> +norecurse @a.root-servers.net www.cnn.com
;; global options:  printcmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 21041
;; flags: qr; QUERY: 1, ANSWER: 0, AUTHORITY: 13, ADDITIONAL: 14

;; QUESTION SECTION:
;www.cnn.com.                   IN      A

;; AUTHORITY SECTION:
com.                    172800  IN      NS      A.GTLD-SERVERS.NET.
com.                    172800  IN      NS      G.GTLD-SERVERS.NET.
com.                    172800  IN      NS      H.GTLD-SERVERS.NET.
com.                    172800  IN      NS      C.GTLD-SERVERS.NET.
com.                    172800  IN      NS      I.GTLD-SERVERS.NET.
com.                    172800  IN      NS      B.GTLD-SERVERS.NET.
com.                    172800  IN      NS      D.GTLD-SERVERS.NET.
com.                    172800  IN      NS      L.GTLD-SERVERS.NET.
com.                    172800  IN      NS      F.GTLD-SERVERS.NET.
com.                    172800  IN      NS      J.GTLD-SERVERS.NET.
com.                    172800  IN      NS      K.GTLD-SERVERS.NET.
com.                    172800  IN      NS      E.GTLD-SERVERS.NET.
com.                    172800  IN      NS      M.GTLD-SERVERS.NET.
```

Note, no "**ANSWER**" section

```
;; ADDITIONAL SECTION:
A.GTLD-SERVERS.NET.     172800  IN      AAAA    2001:503:a83e::2:30
A.GTLD-SERVERS.NET.     172800  IN      A       192.5.6.30
G.GTLD-SERVERS.NET.     172800  IN      A       192.42.93.30
H.GTLD-SERVERS.NET.     172800  IN      A       192.54.112.30
C.GTLD-SERVERS.NET.     172800  IN      A       192.26.92.30
I.GTLD-SERVERS.NET.     172800  IN      A       192.43.172.30
B.GTLD-SERVERS.NET.     172800  IN      AAAA    2001:503:231d::2:30
B.GTLD-SERVERS.NET.     172800  IN      A       192.33.14.30
D.GTLD-SERVERS.NET.     172800  IN      A       192.31.80.30
L.GTLD-SERVERS.NET.     172800  IN      A       192.41.162.30
F.GTLD-SERVERS.NET.     172800  IN      A       192.35.51.30
J.GTLD-SERVERS.NET.     172800  IN      A       192.48.79.30
K.GTLD-SERVERS.NET.     172800  IN      A       192.52.178.30
E.GTLD-SERVERS.NET.     172800  IN      A       192.12.94.30

;; Query time: 117 msec
;; SERVER: 198.41.0.4#53(a.root-servers.net)
;; WHEN: Mon Sep 25 11:13:15 2006
;; MSG SIZE  rcvd: 501
```

```
dig +norecurse @g.gtld-servers.net www.cnn.com

; <<>> DiG 9.2.4 <<>> +norecurse @g.gtld-servers.net www.cnn.com
;; global options:  printcmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 74
;; flags: qr; QUERY: 1, ANSWER: 0, AUTHORITY: 4, ADDITIONAL: 4

;; QUESTION SECTION:
;www.cnn.com.                   IN      A

;; AUTHORITY SECTION:
cnn.com.                172800  IN      NS      twdns-01.ns.aol.com.
cnn.com.                172800  IN      NS      twdns-02.ns.aol.com.
cnn.com.                172800  IN      NS      twdns-03.ns.aol.com.
cnn.com.                172800  IN      NS      twdns-04.ns.aol.com.

;; ADDITIONAL SECTION:
twdns-01.ns.aol.com.    172800  IN      A       149.174.213.151
twdns-02.ns.aol.com.    172800  IN      A       152.163.239.216
twdns-03.ns.aol.com.    172800  IN      A       207.200.73.85
twdns-04.ns.aol.com.    172800  IN      A       64.12.147.120
```

```
dig +norecurse @twdns-01.ns.aol.com www.cnn.com
…
;; QUESTION SECTION:
;www.cnn.com.                   IN      A

;; ANSWER SECTION:
www.cnn.com.            300     IN      CNAME   cnn.com.
cnn.com.                300     IN      A       64.236.24.12
cnn.com.                300     IN      A       64.236.24.20
cnn.com.                300     IN      A       64.236.24.28
cnn.com.                300     IN      A       64.236.29.120
cnn.com.                300     IN      A       64.236.16.20
cnn.com.                300     IN      A       64.236.16.52
cnn.com.                300     IN      A       64.236.16.84
cnn.com.                300     IN      A       64.236.16.116

;; AUTHORITY SECTION:
cnn.com.                600     IN      NS      twdns-02.ns.aol.com.
cnn.com.                600     IN      NS      twdns-03.ns.aol.com.
cnn.com.                600     IN      NS      twdns-04.ns.aol.com.
cnn.com.                600     IN      NS      twdns-01.ns.aol.com.
```

## Reliability

- DNS servers are replicated
  - 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
  - Spec supports TCP too, but not always implemented
- Try alternate servers on timeout
  - Exponential backoff when retrying same server
- Same identifier for all queries
  - Don't care which server responds

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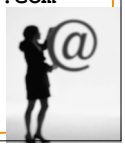
## Inserting Resource Records into DNS

- Example: just created startup "FooBar"
- Register `foobar.com` at Network Solutions (say)
  - Provide registrar with names and IP addresses of your authoritative name server (primary and secondary)
  - Registrar inserts two RR pairs into the `com` TLD server:
    - (`foobar.com`, `dns1.foobar.com`, `NS`)
    - (`dns1.foobar.com`, `212.212.212.1`, `A`)
- Put in authoritative server `dns1.foobar.com`
  - Type A record for `www.foobar.com`
  - Type MX record for `foobar.com`




## Summary

- Transport protocols
  - Multiplexing and demultiplexing via port numbers
  - UDP gives simple datagram service
  - TCP gives reliable byte-stream service
  - Reliability immediately raises performance issues
    - Stop-and-Wait vs. Sliding Window
- Domain Name System (DNS)
  - Distributed, hierarchical database
  - Distributed collection of servers
  - Caching to improve performance
  - Examine using `dig` utility

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## Next Week

- Security analysis of DNS
- Application protocols:
  - File transfer: FTP
  - Email: SMTP
- Reading:
  - Sections 9.2.1 and skim RFC 959
- Project #1 due this Thursday by 11PM PDT
- Reminder: feedback solicited

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