Discovery

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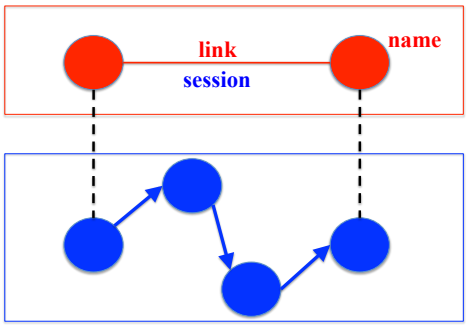
COS 461: Computer Networks

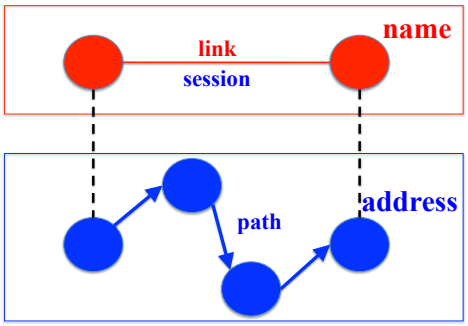
Lectures: MW 10-10:50am in Architecture N101

http://www.cs.princeton.edu/courses/archive/spr12/cos461/

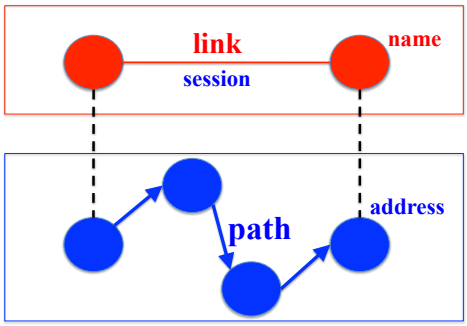
Relationship Between Layers



Discovery: Mapping Name to Address



Routing: Mapping Link to Path



Naming

What's in a Name?

- Human readable?
  - If users interact with the names
- Fixed length?
  - If equipment processes at high speed
- Large name space?
  - If many nodes need unique names
- Hierarchical names?
  - If the system is very large and/or federated
- Self-certifying?
  - If preventing "spoofing" is important

Different Kinds of Names

- **Host name** (e.g., www.cs.princeton.edu)
  - Mnemonic, variable-length, appreciated *by humans*
  - Hierarchical, based on organizations
- **IP address** (e.g., 128.112.7.156)
  - Numerical 32-bit address appreciated *by routers*
  - Hierarchical, based on organizations and topology
- **MAC address** (e.g., 00-15-C5-49-04-A9)
  - Numerical 48-bit address appreciated *by adapters*
  - Non-hierarchical, unrelated to network topology

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Hierarchical Assignment Processes

- **Host name:** www.cs.princeton.edu
  - Domain: registrar for each top-level domain (e.g., .edu)
  - Host name: local administrator assigns to each host
- **IP addresses:** 128.112.7.156
  - Prefixes: ICANN, regional Internet registries, and ISPs
  - Hosts: static configuration, or dynamic using DHCP
- **MAC addresses:** 00-15-C5-49-04-A9
  - Blocks: assigned to vendors by the IEEE
  - Adapters: assigned by the vendor from its block

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Host Names vs. IP Addresses

- Names are easier (for us!) to remember
  - www.cnn.com vs. 64.236.16.20
- IP addresses can change underneath
  - E.g., renumbering when changing providers
- Name could map to multiple IP addresses
  - www.cnn.com to multiple replicas of the Web site
- Map to different addresses in different places
  - E.g., to reduce latency, or return different content
- Multiple names for the same address
  - E.g., aliases like ee.mit.edu and cs.mit.edu

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IP vs. MAC Addresses

- LANs designed for arbitrary network protocols
  - Not just for IP (e.g., IPX, Appletalk, X.25, …)
  - Different LANs may have different addressing schemes
- A host may move to a new location
  - So, cannot simply assign a static IP address
  - Instead, must reconfigure the adapter
- Must identify the adapter during bootstrap
  - Need to talk to the adapter to assign it an IP address

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Discovery

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Directories

- A key-value store
  - Key: name, value: address(es)
  - Answer queries: given name, return address(es)
- Caching the response
  - Reuse the response, for a period of time
  - Better performance and lower overhead
- Allow entries to change
  - Updating the address(es) associated with a name
  - Invalidating or expiring cached responses

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Directory Design: Three Extremes

- Flood the query (e.g., ARP)
  - The named node responds with its address
  - But, high overhead in large networks
- Push data to all clients (/etc/hosts)
  - All nodes store a full copy of the directory
  - But, high overhead for many names and updates
- Central directory server
  - All data and queries handled by one machine
  - But, poor performance, scalability, and reliability

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Directory Design: Distributed Solutions

- Hierarchical directory (e.g., DNS)
  - Follow the hierarchy in the name space
  - Distribute the directory, distribute the queries
  - Enable decentralized updates to the directory
- Distributed Hash Table (e.g. P2P applications)
  - Directory as a hash table with flat names
  - Each directory node handles range of hash outputs
  - Use hash to direct query to the directory node

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Domain Name System (DNS) Hierarchy

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Domain Name System (DNS)

- Properties of DNS
  - Hierarchical name space divided into zones
  - Distributed over a collection of DNS servers
- Hierarchy of DNS servers
  - Root servers
  - Top-level domain (TLD) servers
  - Authoritative DNS servers
- Performing the translations
  - Local DNS servers and client resolvers

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DNS Root Servers

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

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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, ca, jp)
  - Managed professionally (e.g., Educause for "edu")
- Authoritative DNS servers
  - Provide public records for hosts at an organization
  - For the organization's servers (e.g., Web and mail)
  - Can be maintained locally or by a service provider

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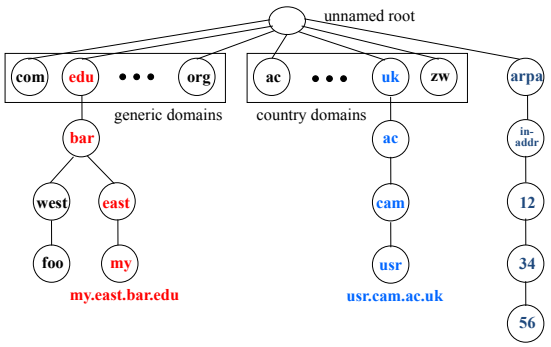
Distributed Hierarchical Database



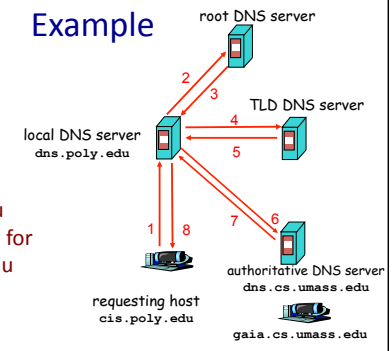
DNS Queries

Using DNS

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

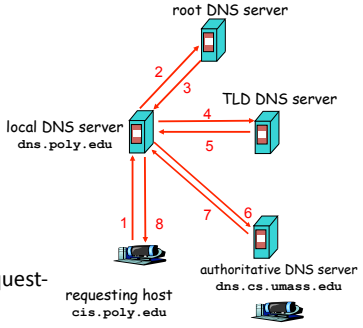
Example

Host at cis.poly.edu wants IP address for gaia.cs.umass.edu



Recursive vs. Iterative Queries

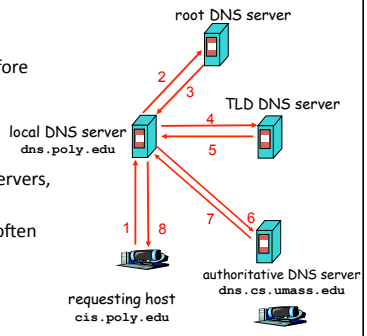
- Recursive query
  - Ask server to get answer for you
  - E.g., request 1 and response 8
- Iterative query
  - Ask server who to ask next
  - E.g., all other request-response pairs



DNS Caching

DNS Caching

- DNS query latency
  - E.g., 1 sec latency before starting a download
- Caching to reduce overhead and delay
  - Small # of top-level servers, that change rarely
  - Popular sites visited often
- Where to cache?
  - Local DNS server
  - Browser



DNS Cache Consistency

- Cache consistency
  - Ensuring cached data is up to date
- DNS design considerations
  - Cached data is "read only"
  - Explicit invalidation would be expensive
- Avoiding stale information
  - Responses include a "time to live" (TTL) field
  - Delete the cached entry after TTL expires

Setting the Time To Live (TTL)

- TTL trade-offs
  - Small TTL: fast response to change
  - Large TTL: higher cache hit rate
- Following the hierarchy
  - Top of the hierarchy: days or weeks
  - Bottom of the hierarchy: seconds to hours
- Tension in practice
  - CDNs set low TTLs for load balancing and failover
  - Browsers cache for 15-60 seconds

Negative Caching

- Broken domain names are slow to resolve
  - Misspellings like www.cnn.comm and www.cnnn.com
  - These can take a long time to fail the first time
- Remember things that *don't* work
  - Good to remember that they don't work
  - … so the failure takes less time in the future
- But don't remember for *too* long
  - Use a time-to-live to expire

DNS Protocol

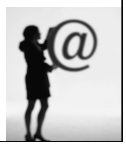
Database of Resource Records (RRs)

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 = CNAME
  - name is alias name for some "canonical" (the real) name www.ibm.com is really servereast.backup2.ibm.com
  - value is canonical name
- Type = MX
  - value is name of mail server associated with name

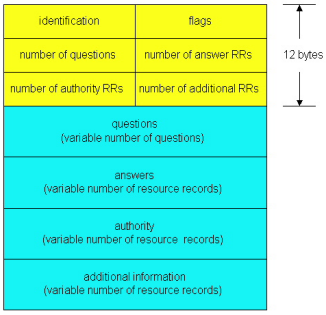
Inserting Resource Records into DNS

- Register foobar.com at Network Solutions
  - Provide registrar with names and IP addresses of your authoritative name server (primary & secondary)
  - Registrar inserts two RRs 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



DNS Protocol

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



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DNS Reliability

- DNS servers are replicated
  - Name service available if at least one replica is up
  - Queries can be load balanced between replicas
- UDP used for queries
  - Need reliability: must implement this on top of UDP
- 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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Learning Your Local DNS Server

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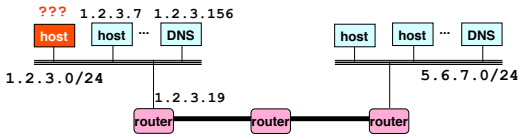
How To Bootstrap an End Host?

- What local DNS server to use?
- What IP address the host should use?
- How to send packets to remote destinations?



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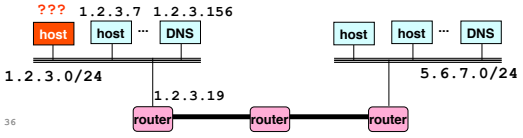
Avoiding Manual Configuration

- Dynamic Host Configuration Protocol (DHCP)
  - End host learns how to send packets
  - Learn IP address, DNS servers, and gateway
- Address Resolution Protocol (ARP)
  - Others learn how to send packets to the end host
  - Learn mapping between IP & interface addresses



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Key Ideas in Both Protocols

- **Broadcasting**: when in doubt, shout!
  - Broadcast query to all hosts in local-area-network
- **Caching**: remember the past for a while
  - Store the information you learn to reduce overhead
  - Remember your address & other host's addresses
- **Soft state**: … but eventually forget the past
  - Associate a time-to-live field with the information
  - … and either refresh or discard the information

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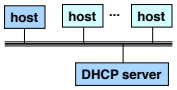
Bootstrapping Problem

- Host doesn't have an IP address yet
  - So, host doesn't know what source to use
- Host doesn't know who to ask for an IP address
  - So, host doesn't know what destination to use
- Solution: discover a server who can help
  - Broadcast a DHCP server-discovery message
  - Server sends a DHCP "offer" offering an address



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Response from the DHCP Server

- DHCP "offer message" from the server
  - Configuration parameters (proposed IP address, mask, gateway router, DNS server, ...)
  - Lease time (the time the information remains valid)
- Multiple servers may respond with an offer
  - The client decides which offer to accept
    - Client sends a DHCP request echoing the parameters
  - The DHCP server responds with an ACK to confirm
    - And the other servers see they were not chosen

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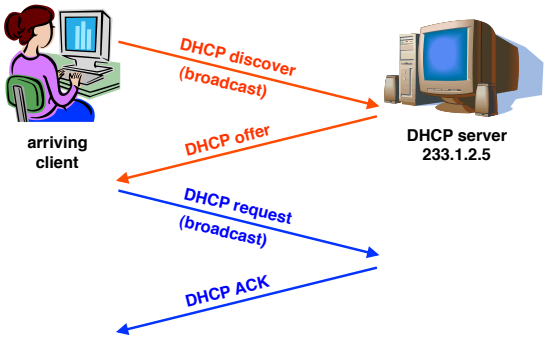
Dynamic Host Configuration Protocol



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Deciding What IP Address to Offer

- Static allocation
  - All parameters are statically configured in the server
  - E.g., a dedicated IP address for each MAC address
  - Makes it easy to track a host over time
- Dynamic allocation
  - Server maintains a pool of available addresses
  - … and assigns them to hosts on demand
  - Enables more efficient use of the pool of addresses

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Soft State: Refresh or Forget

- Why is a lease time necessary?
  - Client can release the IP address (DHCP RELEASE)
    - E.g., "ipconfig /release" at the command line
    - E.g., clean shutdown of the computer
  - But, the host might not release the address
    - E.g., the host crashes (blue screen of death!), buggy client
  - Don't want the address to be allocated forever
- Performance trade-offs
  - Short lease: returns inactive addresses quickly
  - Long lease: avoids overhead of frequent renewals

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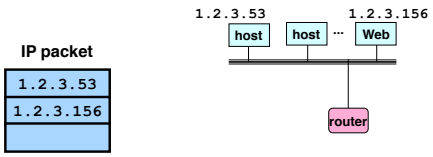
So, Now the Host Knows Things

- IP address
- Mask
- Gateway router
- DNS server

- And can send packets to other IP addresses
  - How to learn the MAC address of the destination?

Sending Packets Over a Link



- Adapters only understand MAC addresses
  - Translate the destination IP address to MAC address
  - Encapsulate the IP packet inside a link-level frame

Address Resolution Protocol Table

- Every node maintains an ARP table
  - (IP address, MAC address) pair
- Consult the table when sending a packet
  - Map destination IP to destination MAC address
  - Encapsulate and transmit the data packet
- But, what if the IP address is not in the table?
  - Sender broadcasts: "Who has IP address 1.2.3.156?"
  - Receiver responds: "MAC address 58-23-D7-FA-20-B0"
  - Sender caches the result in its ARP table

Conclusion

- Discovery
  - Mapping a name at the upper layer
  - … to an address at the lower layer
- Domain Name System (DNS)
  - Hierarchical names, hierarchical directory
  - Query-response protocol with caching
  - Time-To-Live to expire stale cached responses
- Next time: routing