
# Translating Addresses

**Reading: Section 4.1 and 9.1**

CS 375: Computer Networks
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## Goals of Today's Lecture

- Three different kinds of addresses
  - Host names (e.g., www.cnn.com)
  - IP addresses (e.g., 64.236.16.20)
  - MAC addresses (e.g., 00-15-C5-49-04-A9)
- Protocols for translating between addresses
  - Domain Name System (DNS)
  - Dynamic Host Configuration Protocol (DHCP)
  - Address Resolution Protocol (ARP)
- Two main topics
  - Decentralized management of the name space
  - Boot-strapping an end host that attaches to the 'net

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## Separating Names and IP Addresses

- Names are easier (for us!) to remember
  - www.cnn.com vs. 64.236.16.20
- IP addresses can change underneath
  - Move www.cnn.com to 173.15.201.39
  - 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
  - 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 ee.mit.edu and cs.mit.edu

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## Separating IP and MAC Addresses

- LANs are designed for arbitrary network protocols
  - Not just for IP (e.g., IPX, Appletalk, X.25, …)
    - Though now IP is the main game in town
  - Different LANs may have different addressing schemes
    - Though now Ethernet address is the main game in town
- A host may move to a new location
  - So, cannot simply assign a static IP address
    - Since IP addresses depend on host's position in topology
  - Instead, must reconfigure the adapter
    - To assign it an IP address based on its current location
- Must identify the adapter during bootstrap process
  - Need to talk to the adapter to assign it an IP address



## Three Kinds of Identifiers

- **Host name** (e.g., www.cnn.com)
  - Mnemonic name appreciated *by humans*
  - Provides little (if any) information about location
  - Hierarchical, variable # of alpha-numeric characters
- **IP address** (e.g., 64.236.16.20)
  - Numerical address appreciated *by routers*
  - Related to host's current location in the topology
  - Hierarchical name space of 32 bits
- **MAC address** (e.g., 00-15-C5-49-04-A9)
  - Numerical address appreciated *within local area network*
  - Unique, hard-coded in the adapter when it is built
  - Flat name space of 48 bits



## Three Hierarchical Assignment Processes

- **Host name:** 219a.mathsci.denison.edu
  - Domain: registrar for each top-level domain (e.g., .edu)
  - Host name: local administrator assigns to each host
- **IP addresses:** 140.141.132.105
  - 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

## Mapping Between Identifiers

- Domain Name System (DNS)
  - Given a host name, provide the IP address
  - Given an IP address, provide the host name
- Dynamic Host Configuration Protocol (DHCP)
  - Given a MAC address, assign a unique IP address
  - … and tell host other stuff about the Local Area Network
  - To automate the boot-strapping process
- Address Resolution Protocol (ARP)
  - Given an IP address, provide the MAC address
  - To enable communication within the Local Area Network



## Outline: Domain Name System

- Computer science concepts underlying DNS
  - Indirection: names in place of addresses
  - Hierarchy: in names, addresses, and servers
  - Caching: of mappings from names to/from addresses
- DNS software components
  - DNS resolvers
  - DNS servers
- DNS queries
  - Iterative queries
  - Recursive queries
- DNS caching based on time-to-live (TTL)



## Strawman Solution #1: Local File

- Original name to address mapping
  - Flat namespace
  - /etc/hosts
  - SRI kept main copy
  - Downloaded regularly
- Count of hosts was increasing: moving from a machine per domain to machine per user
  - Many more downloads
  - Many more updates

## Strawman Solution #2: Central Server

- Central server
  - One place where all mappings are stored
  - All queries go to the central server
- Many practical problems
  - Single point of failure
  - High traffic volume
  - Distant centralized database
  - Single point of update
  - Does not scale

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



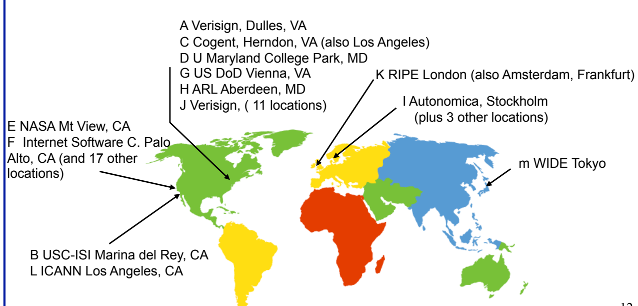
## Domain Name System (DNS)

- 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
  - Resolver software



## DNS Root Servers

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

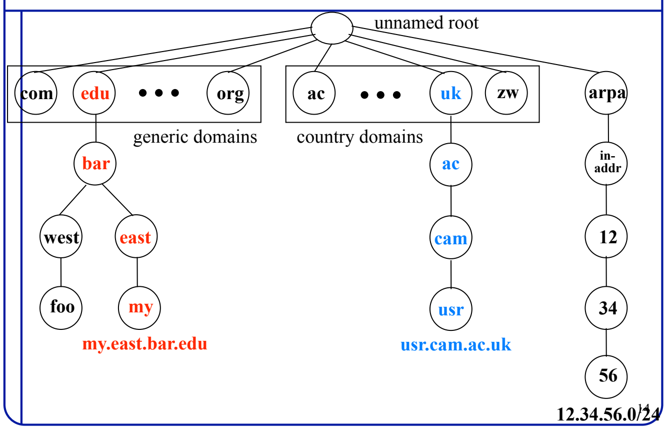


## TLD and Authoritative DNS Servers

- Top-level domain (TLD) servers
  - Generic domains (e.g., com, org, edu)
  - Country domains (e.g., uk, fr, ca, jp)
  - 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
  - For the organization’s servers (e.g., Web and mail)
  - Can be maintained locally or by a service provider



## Distributed Hierarchical Database



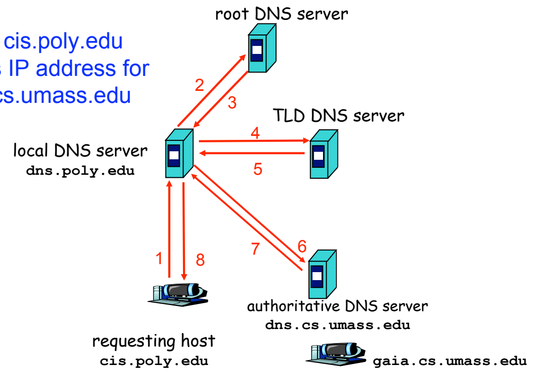



## Using DNS

- 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 trigger resolver code
- Server application
  - Extract client IP address from socket
  - Optional *gethostbyaddr()* to translate into name

## Example

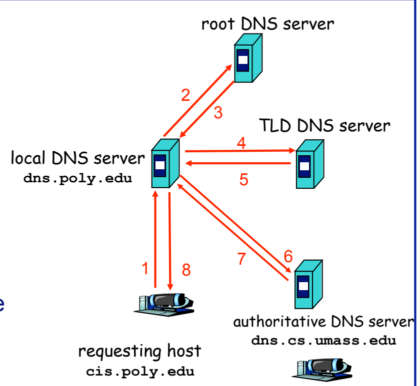
Host at cis.poly.edu wants IP address for gaia.cs.umass.edu






## 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

- Performing all these queries take time
  - And all this before the actual communication takes place
  - E.g., 1-second latency before starting Web download
- Caching can substantially 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 the 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



## 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=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 mailserver associated with **`name`**

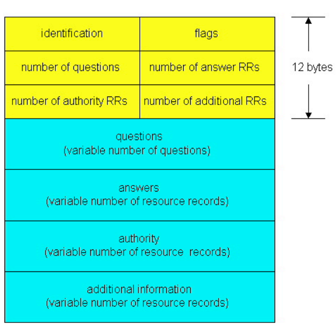


## DNS Protocol

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



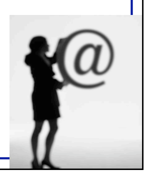
## Reliability

- 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



## Inserting Resource Records into DNS

- Example: just created startup “FooBar”
- Register foobar.com at Network Solutions
  - Provide registrar with names and IP addresses of your authoritative name server (primary and 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
- Play with “dig” on UNIX

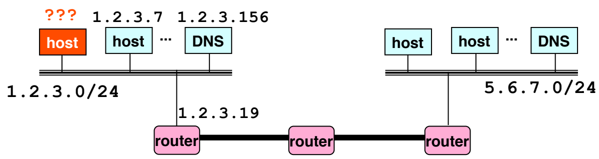



# Boot-Strapping an End Host

DHCP and ARP

## How To Bootstrap an End Host?

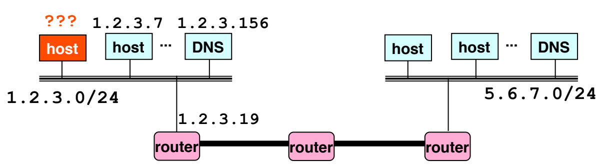
- What local Domain Name System server to use?
- What IP address the host should use?
- How to send packets to remote destinations?
- How to ensure incoming packets arrive?






## 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 address & interface address

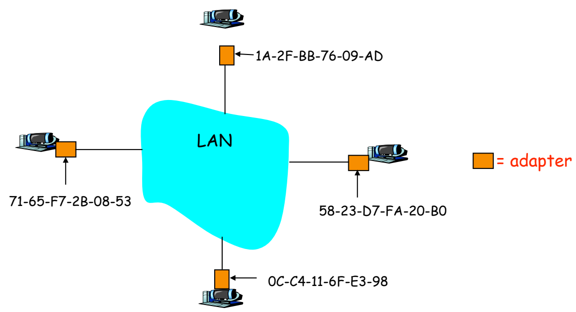





## Key Ideas in Both Protocols

- **Broadcasting:** when in doubt, shout!
  - Broadcast query to all hosts in the local-area-network
  - … when you don’t know how to identify the right one
- **Caching:** remember the past for a while
  - Store the information you learn to reduce overhead
  - Remember your own 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
  - Key for robustness in the face of unpredictable change

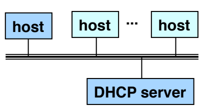
## Media Access Control (MAC) Addresses






## Bootstrapping Problem

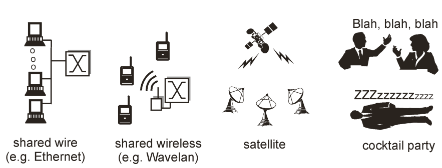
- Host doesn't have an IP address yet
  - So, host doesn't know what source address to use
- Host doesn't know who to ask for an IP address
  - So, host doesn't know what destination address to use
- Solution: shout to discover a server who can help
  - Broadcast a DHCP server-discovery message
  - Server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






## Broadcasting

- Broadcasting: sending to everyone
  - Special destination address: FF-FF-FF-FF-FF-FF
  - All adapters on the LAN receive the packet
- Delivering a broadcast packet
  - Easy on a "shared media"
  - Like shouting in a room – everyone can hear you

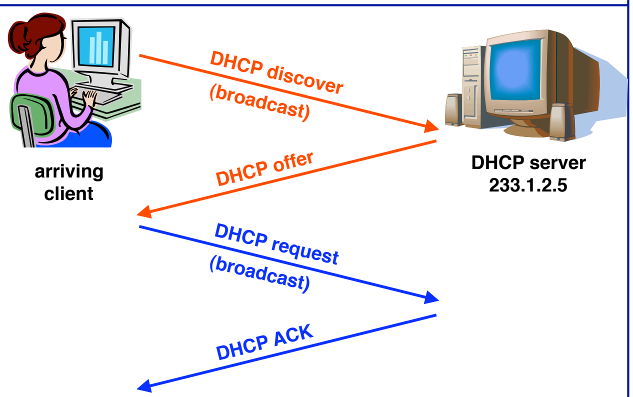


## Response from the DHCP Server

- 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
  - Multiple servers on the same broadcast media
  - Each may respond with an offer
  - The client can decide which offer to accept
- Accepting one of the offers
  - 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



## Dynamic Host Configuration Protocol






## Deciding What IP Address to Offer

- Server as centralized configuration database
  - All parameters are statically configured in the server
  - E.g., a dedicated IP address for each MAC address
  - Avoids complexity of configuring hosts directly
  - … while still having a permanent IP address per host
- Or, dynamic assignment of IP addresses
  - Server maintains a pool of available addresses
  - … and assigns them to hosts on demand
  - Leads to less configuration complexity
  - … and more efficient use of the pool of addresses
  - Though, it is harder to track the same host over time

## 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 DOS prompt
    - E.g., clean shutdown of the computer
  - But, the host might not release the address
    - E.g., the host crashes (blue screen of death!)
    - E.g., buggy client software
  - And you don’t want the address to be allocated forever
- Performance trade-offs
  - Short lease time: returns inactive addresses quickly
  - Long lease time: avoids overhead of frequent renewals

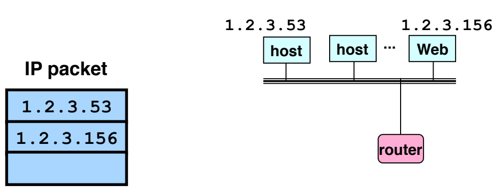


## So, Now the Host Knows Things

- IP address
- Mask
- Gateway router
- DNS server
- …
- And can send packets to other IP addresses
  - But, 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

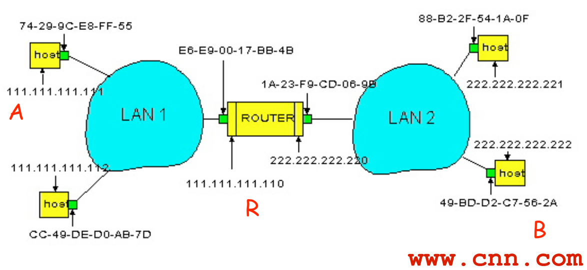
## Address Resolution Protocol Table

- Every node maintains an ARP table
  - (IP address, MAC address) pair
- Consult the table when sending a packet
  - Map destination IP address 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
- No need for network administrator to get involved



## Example: A Sending a Packet to B

How does host A send an IP packet to B (www.cnn.com)?

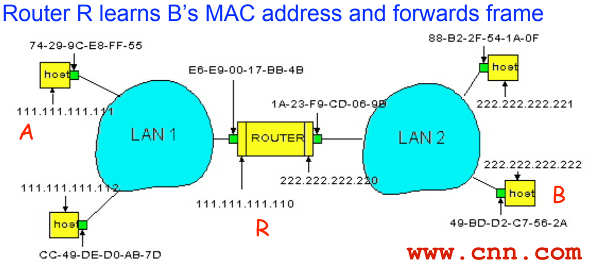



**A sends packet to R, and R sends packet to B.**



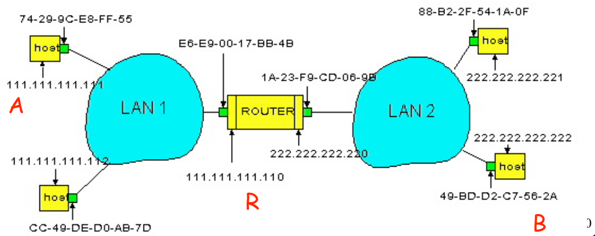
## Basic Steps

- Host A must learn the IP address of B via DNS
- Host A uses gateway R to reach external hosts
- Host A sends the frame to R's MAC address
- Router R forwards IP packet to outgoing interface
- Router R learns B's MAC address and forwards frame



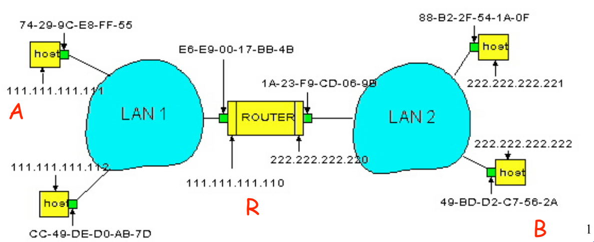
## Host A Learns the IP Address of B

- Host A does a DNS query to learn B's address
  - Suppose gethostbyname() returns 222.222.222.222
- Host A constructs an IP packet to send to B
  - Source 111.111.111.111, destination 222.222.222.222



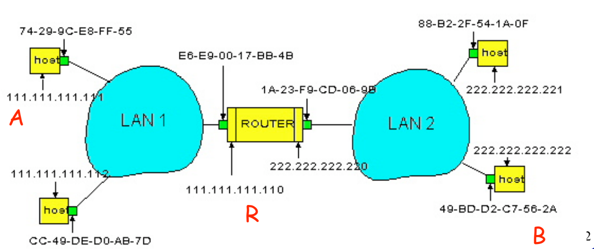

## Host A Learns the IP Address of B

- IP header
  - From A: 111.111.111.111
  - To B: 222.222.222.222
- Ethernet frame
  - From A: 74-29-9C-E8-FF-55
  - To gateway: ????



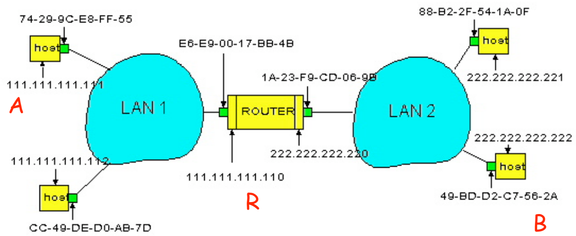

## Host A Decides to Send Through R

- Host A has a gateway router R
  - Used to reach destinations outside of 111.111.111.0/24
  - Address 111.111.111.110 for R learned via DHCP
- But, what is the MAC address of the gateway?



## Host A Sends Packet Through R

- Host A learns the MAC address of R's interface
  - ARP request: broadcast request for 111.111.111.110
  - ARP response: R responds with E6-E9-00-17-BB-4B
- Host A encapsulates the packet and sends to R



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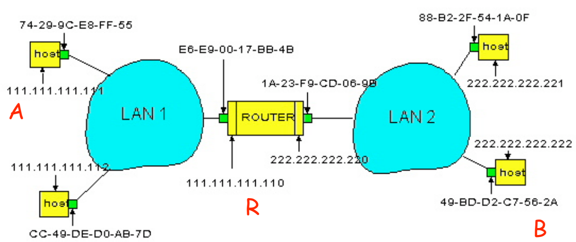
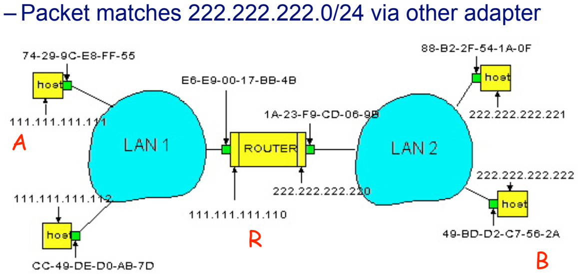




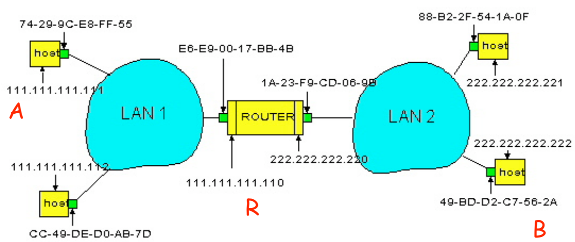

## R Decides how to Forward Packet

- Router R's adapter receives the packet
  - R extracts the IP packet from the Ethernet frame
  - R sees the IP packet is destined to 222.222.222.222
- Router R consults its forwarding table
  - Packet matches 222.222.222.0/24 via other adapter



## Router R Wants to Forward Packet

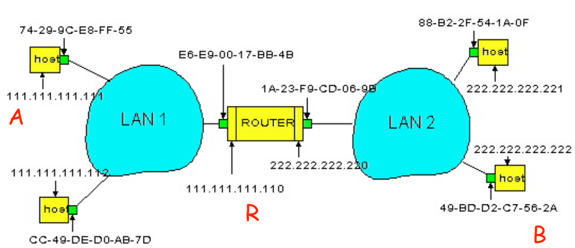
- IP header
  - From A: 111.111.111.111
  - To B: 222.222.222.222
- Ethernet frame
  - From R: 1A-23-F9-CD-06-9B
  - To B: ???






## R Sends Packet to B

- Router R's learns the MAC address of host B
  - ARP request: broadcast request for 222.222.222.222
  - ARP response: B responds with 49-BD-D2-C7-56-2A
- Router R encapsulates the packet and sends to B



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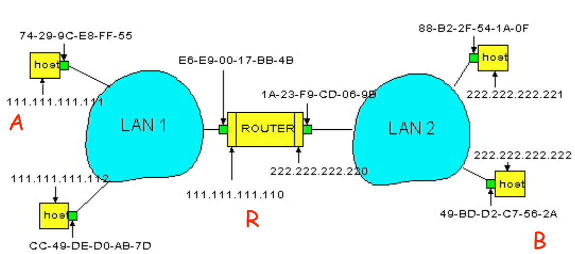

## Conclusion

- Domain Name System
  - Distributed, hierarchical database
  - Distributed collection of servers
  - Caching to improve performance
- Bootstrapping an end host
  - Dynamic Host Configuration Protocol (DHCP)
  - Address Resolution Protocol (ARP)
- Next class: middleboxes
  - Reading: Section 8.4 (for Monday) and Ch. 2
  - Network Address Translator (NAT)
  - Firewalls