CS 3700
Networks and Distributed Systems

Lecture 11: DNS + NAT

Revised 3/10/14

Outline

- DNS
- NAT
- Other middleboxes

Layer 8 (The Carbon-based nodes)

- If you want to…
  - Call someone, you need to ask for their phone number
    - You can’t just dial “P R O F M I S L O V E”
  - Mail someone, you need to get their address first

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  - Mail someone, you need to get their address first
- What about the Internet?
  - If you need to reach Google, you need their IP
  - Does anyone know Google's IP?
- Problem:
  - People can't remember IP addresses
  - Need human readable names that map to IPs

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- Names, e.g. www.northeastern.edu
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- How do you map from one to the other?
  - Domain Name System (DNS)

History

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  - */etc/hosts* on Linux
  - C:*Windows**System32**drivers**etc**hosts* on Windows

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- Centralized, manual system
  - Changes were submitted to SRI via email
  - Machines periodically FTP new copies of *hosts.txt*
  - Administrators could pick names at their discretion
  - Any name was allowed
    - alans_server_at_neu_pwns_joo_lol_kthxbye

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- Thus, DNS was born

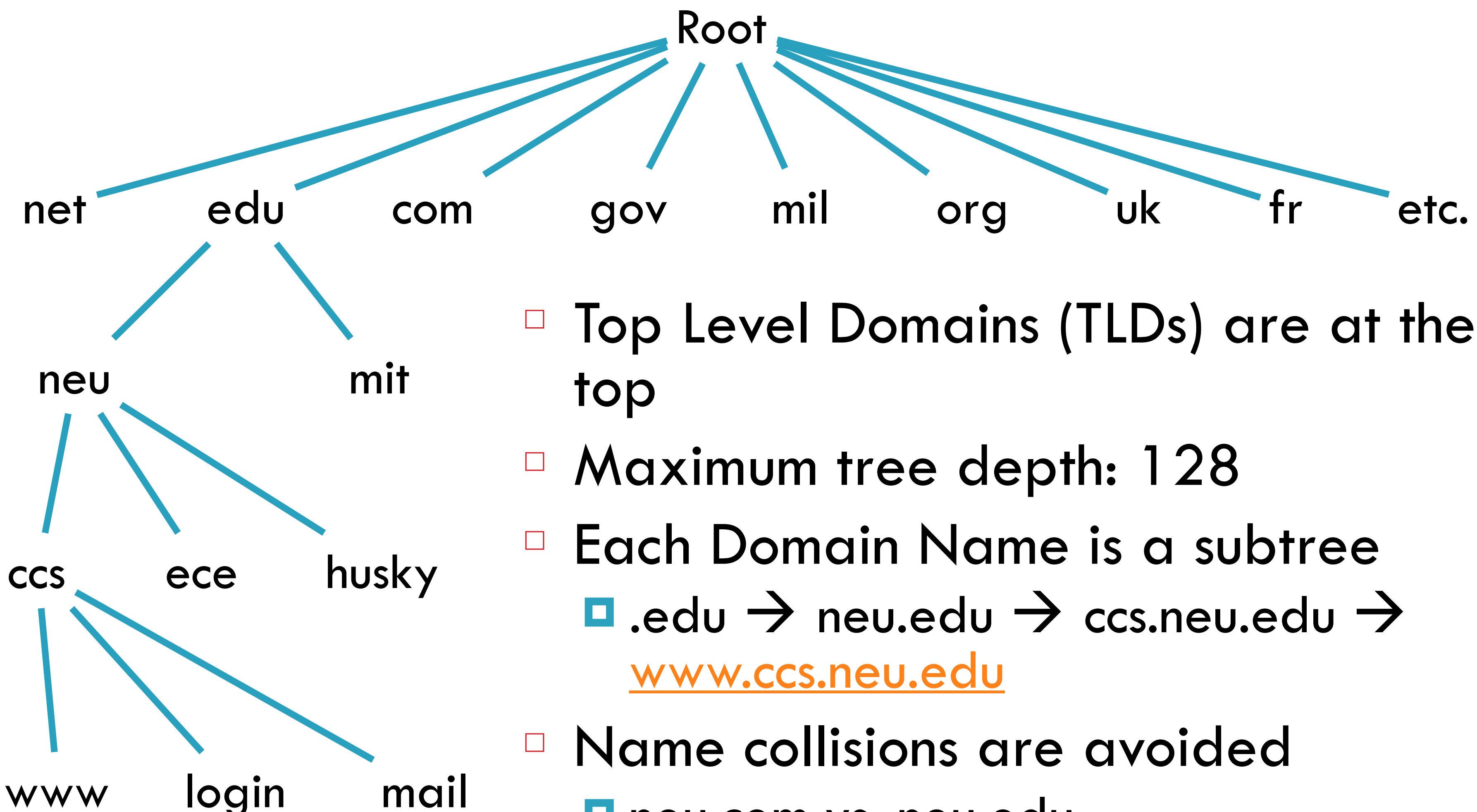
Outline

- DNS Basics
- DNS Security

DNS at a High-Level

- Domain Name System
- Distributed database
  - No centralization
- Simple client/server architecture
  - UDP port 53, some implementations also use TCP
  - Why?
- Hierarchical namespace
  - As opposed to original, flat namespace
  - e.g. .com → google.com → mail.google.com

Naming Hierarchy



- Top Level Domains (TLDs) are at the top
- Maximum tree depth: 128
- Each Domain Name is a subtree
  - .edu → neu.edu → ccs.neu.edu → www.ccs.neu.edu
- Name collisions are avoided
  - neu.com vs. neu.edu

Naming Hierarchy

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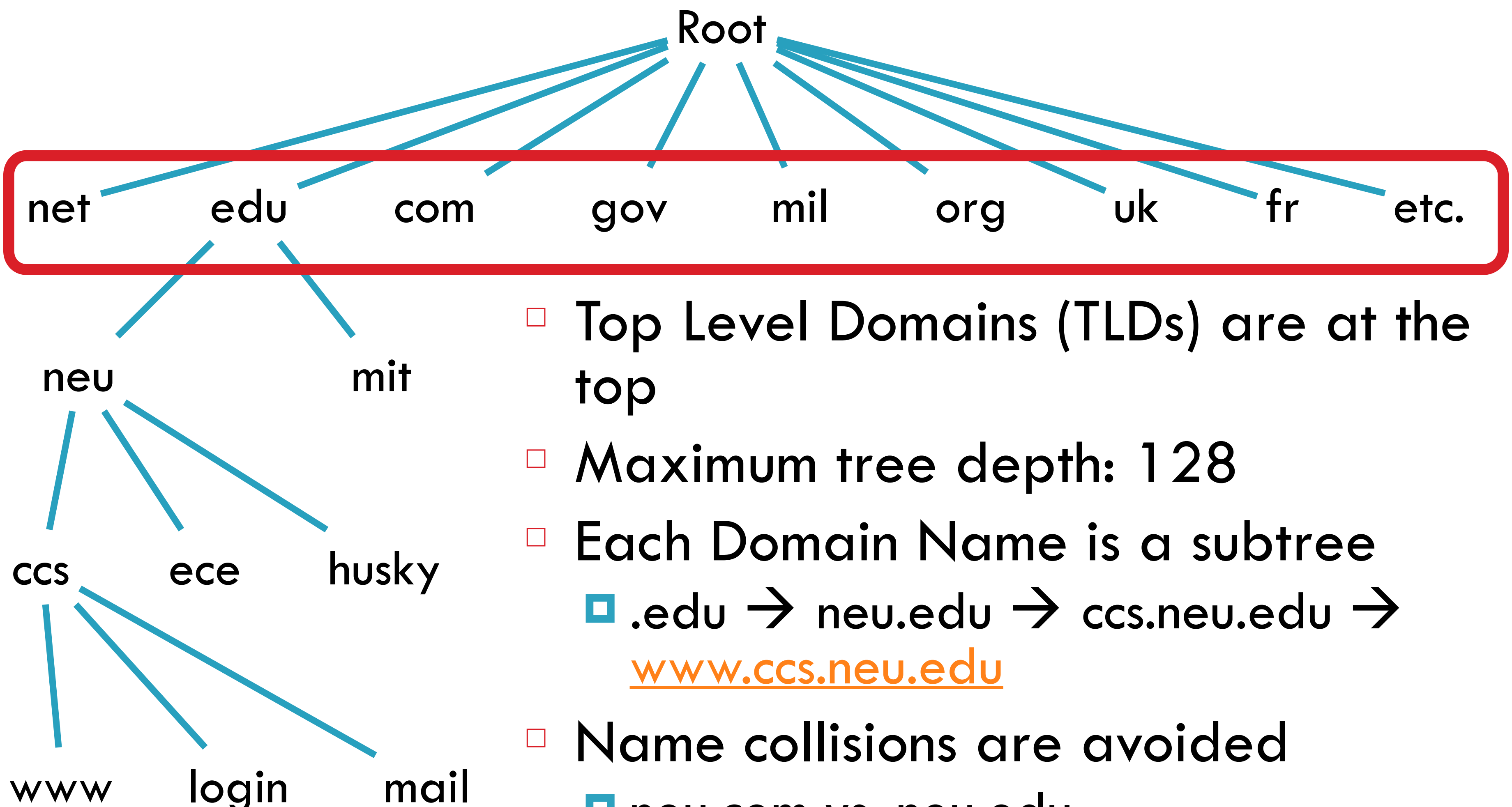

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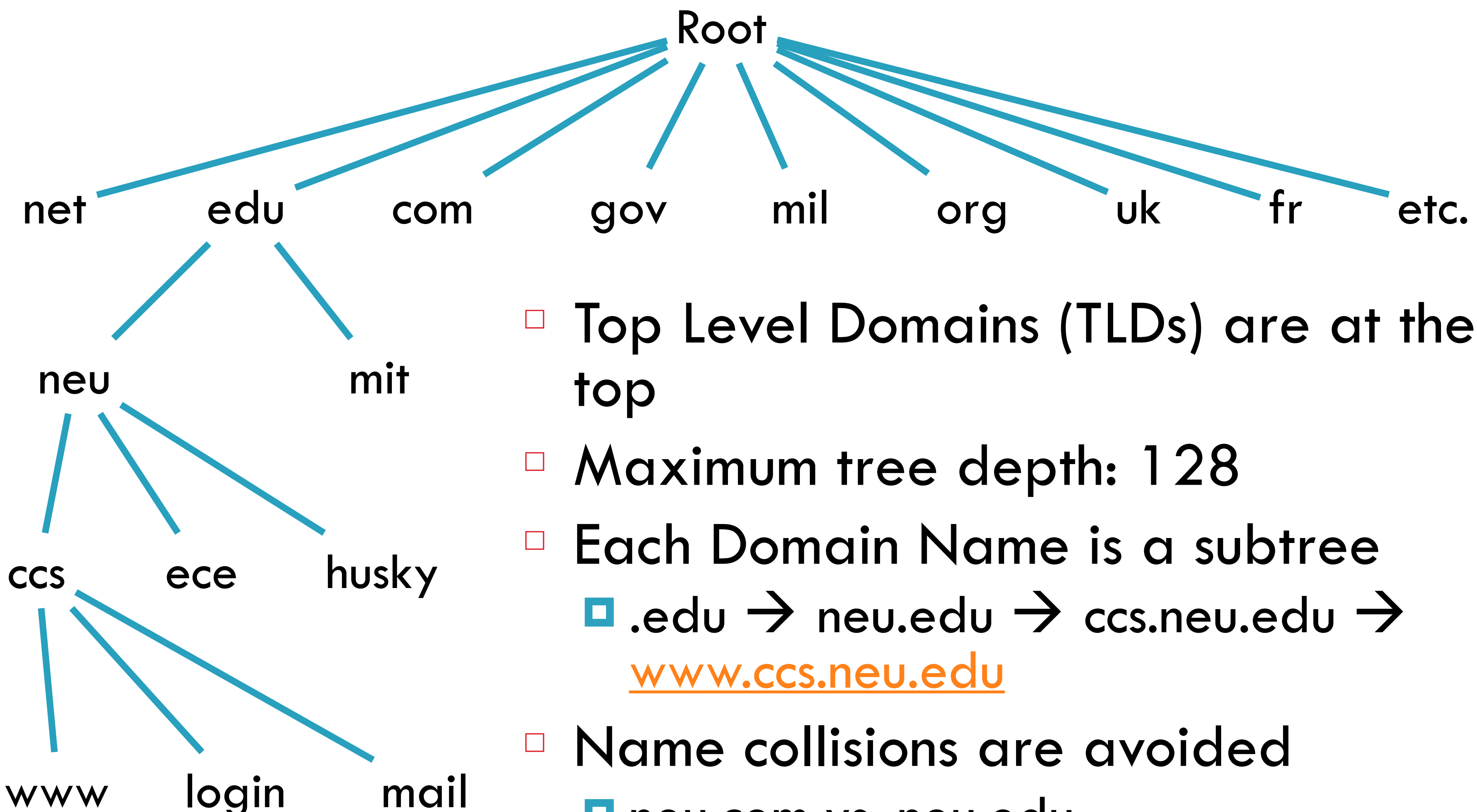

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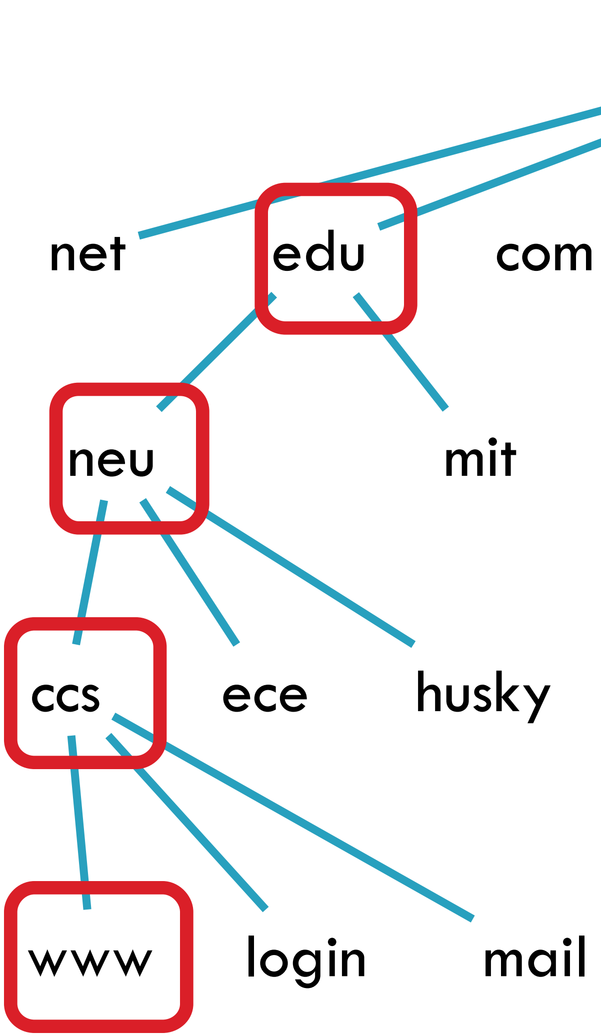

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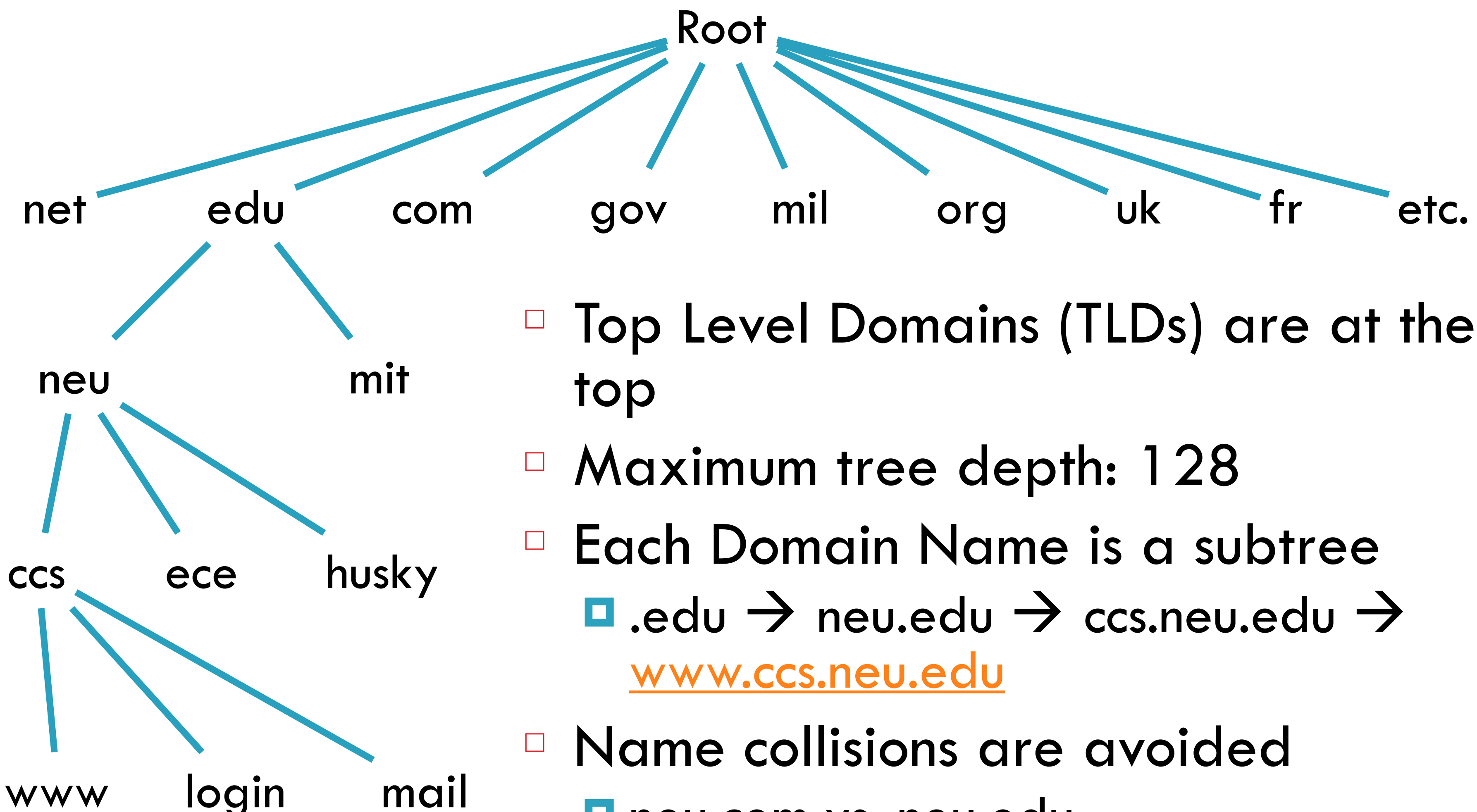

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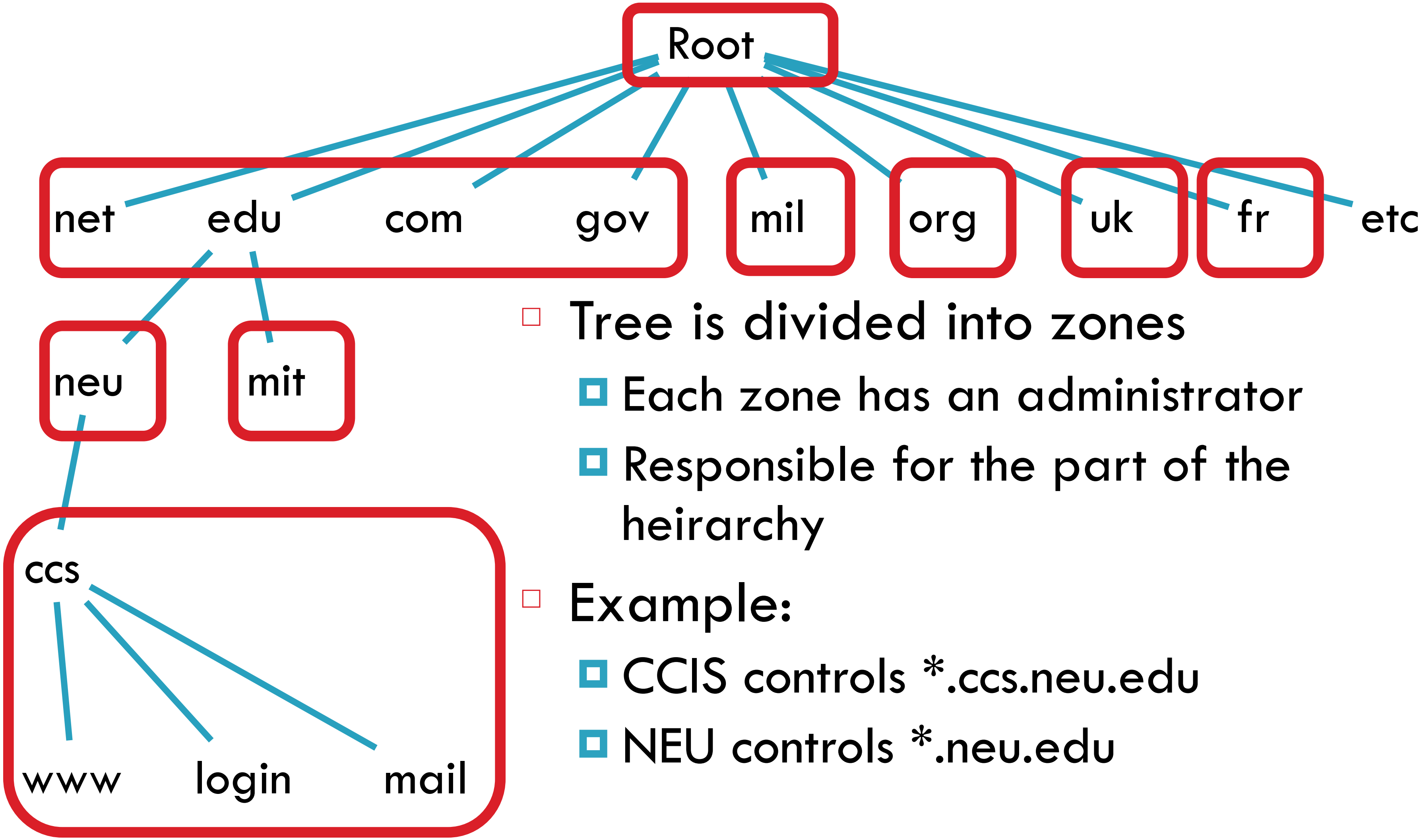
Hierarchical Administration



- Tree is divided into zones
  - Each zone has an administrator
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- Example:
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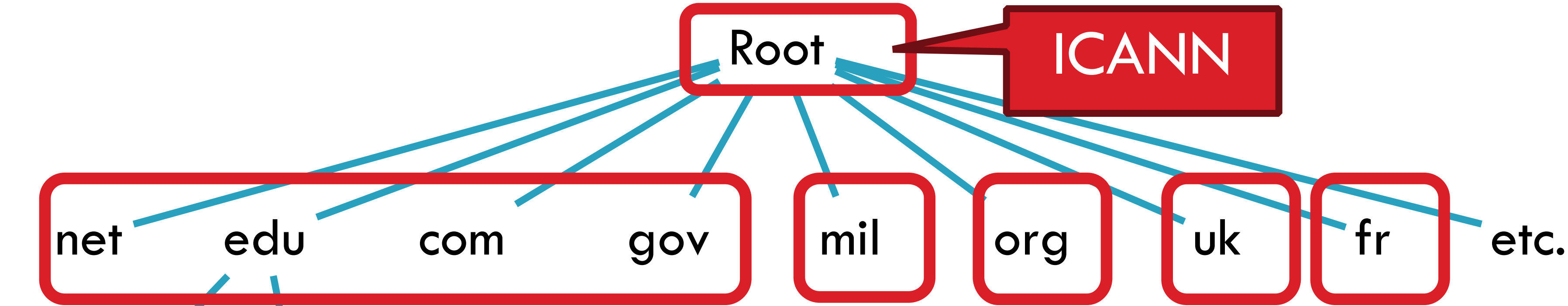

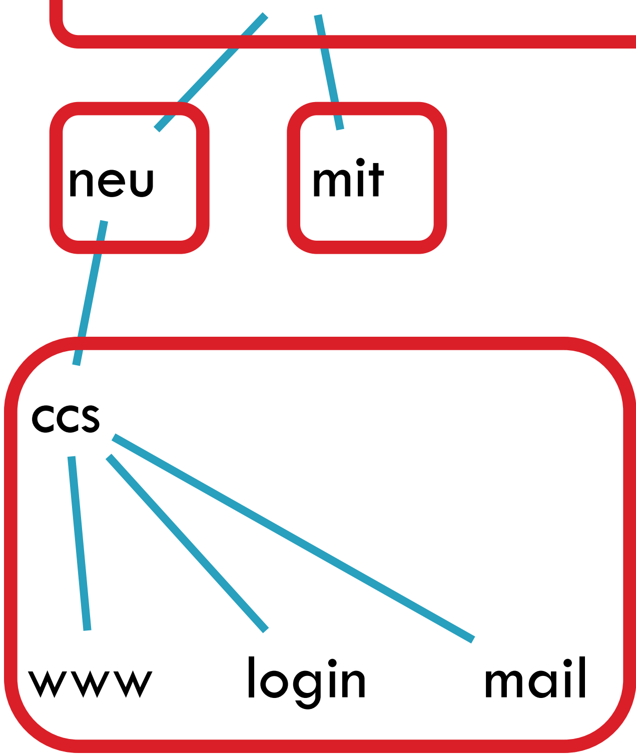

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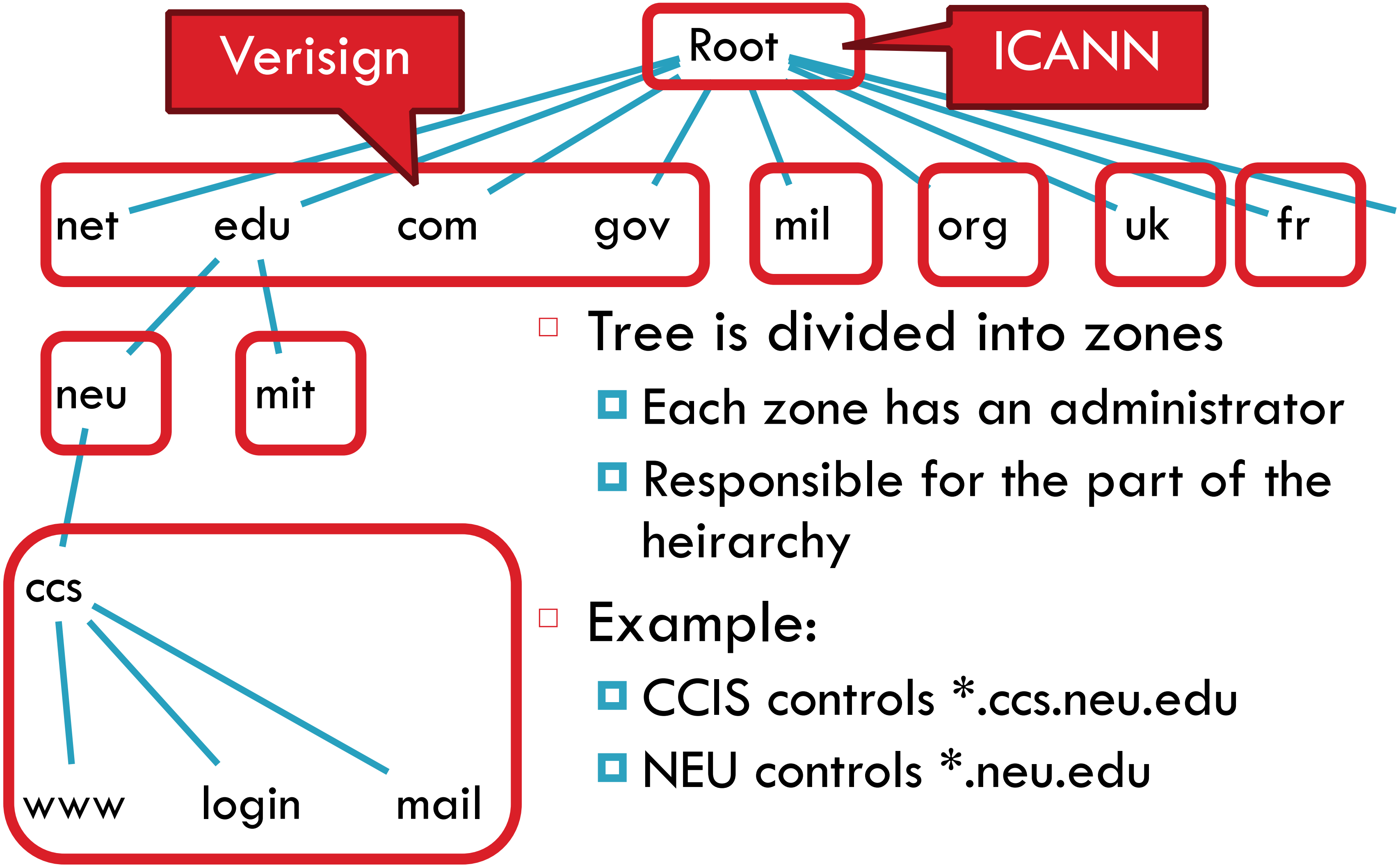

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- Functions of each DNS server:
  - Authority over a portion of the hierarchy
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    - May be replicated for robustness
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    - Resolve queries for unknown names
- Root servers know about all TLDs
  - The buck stops at the root servers

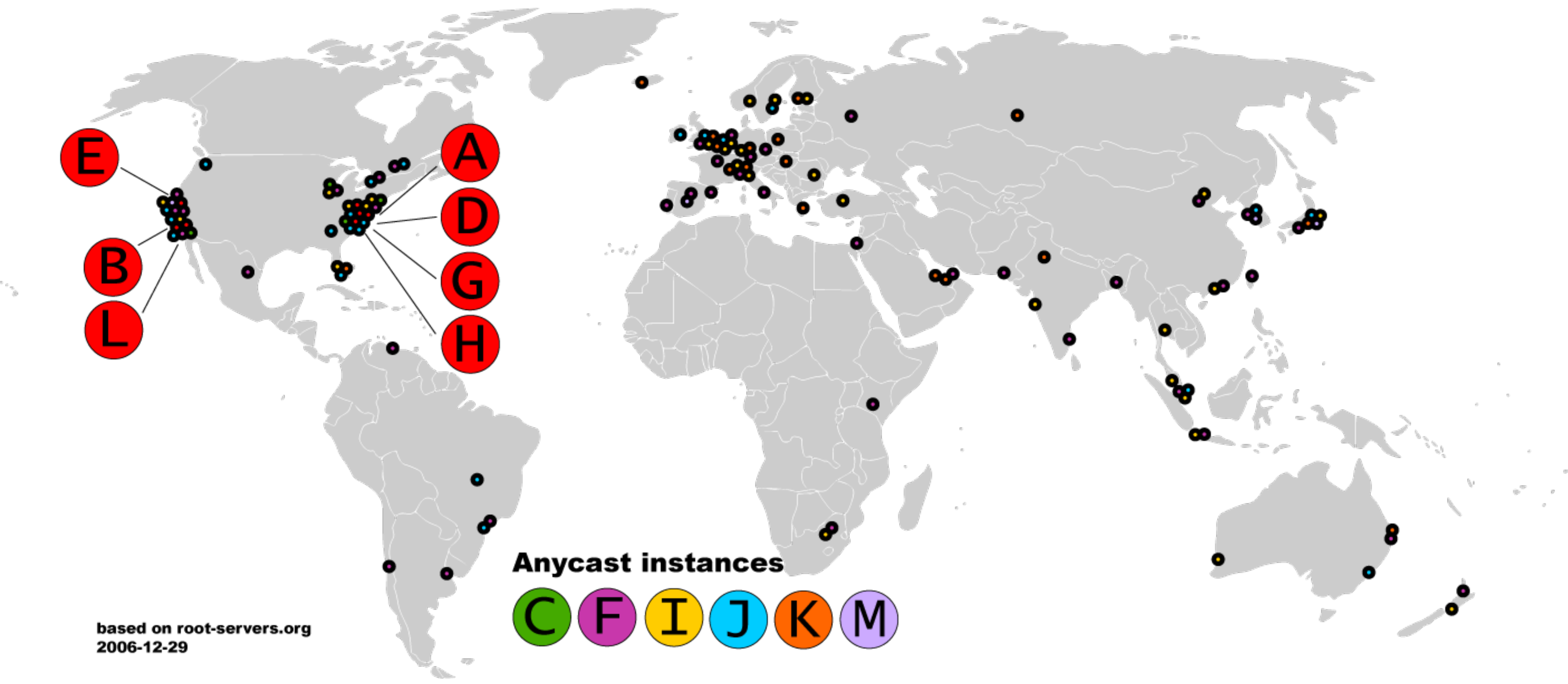
Root Name Servers

- Responsible for the Root Zone File
  - Lists the TLDs and who controls them
  - ~272KB in size

com.	172800	IN	NS	a.gtld-servers.net.
com.	172800	IN	NS	b.gtld-servers.net.
com.	172800	IN	NS	c.gtld-servers.net.

- Administered by ICANN
  - 13 root servers, labeled A→M
  - 6 are anycasted, i.e. they are globally replicated
- Contacted when names cannot be resolved
  - In practice, most systems cache this information

Map of the Roots



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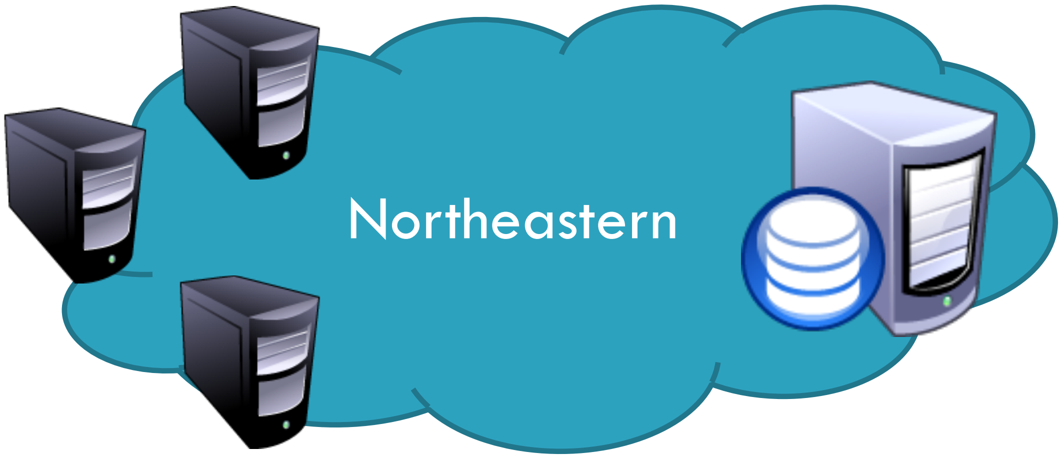

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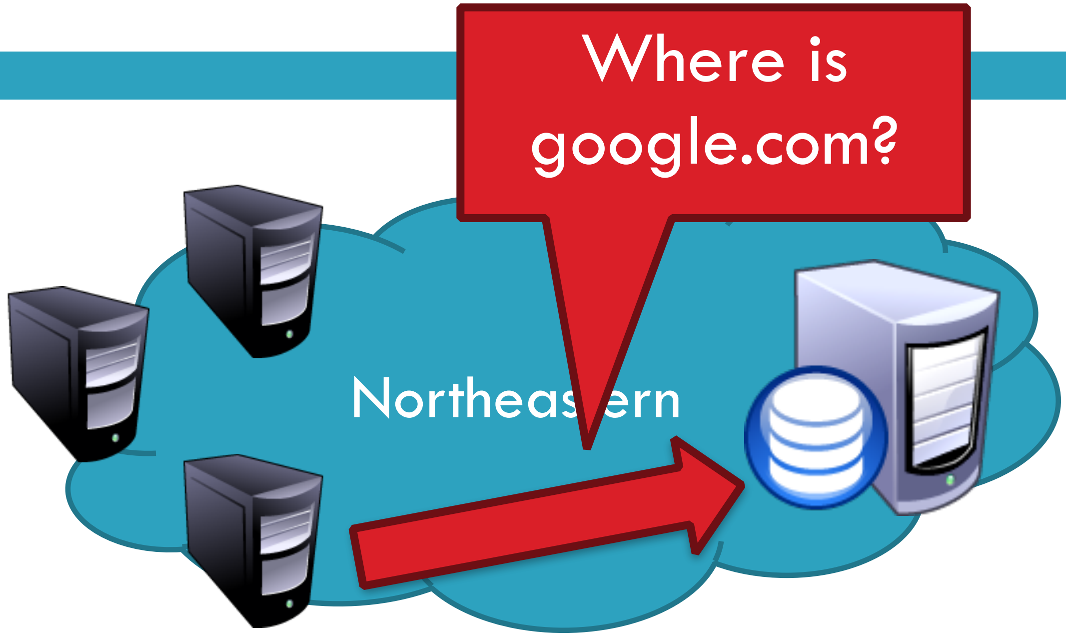

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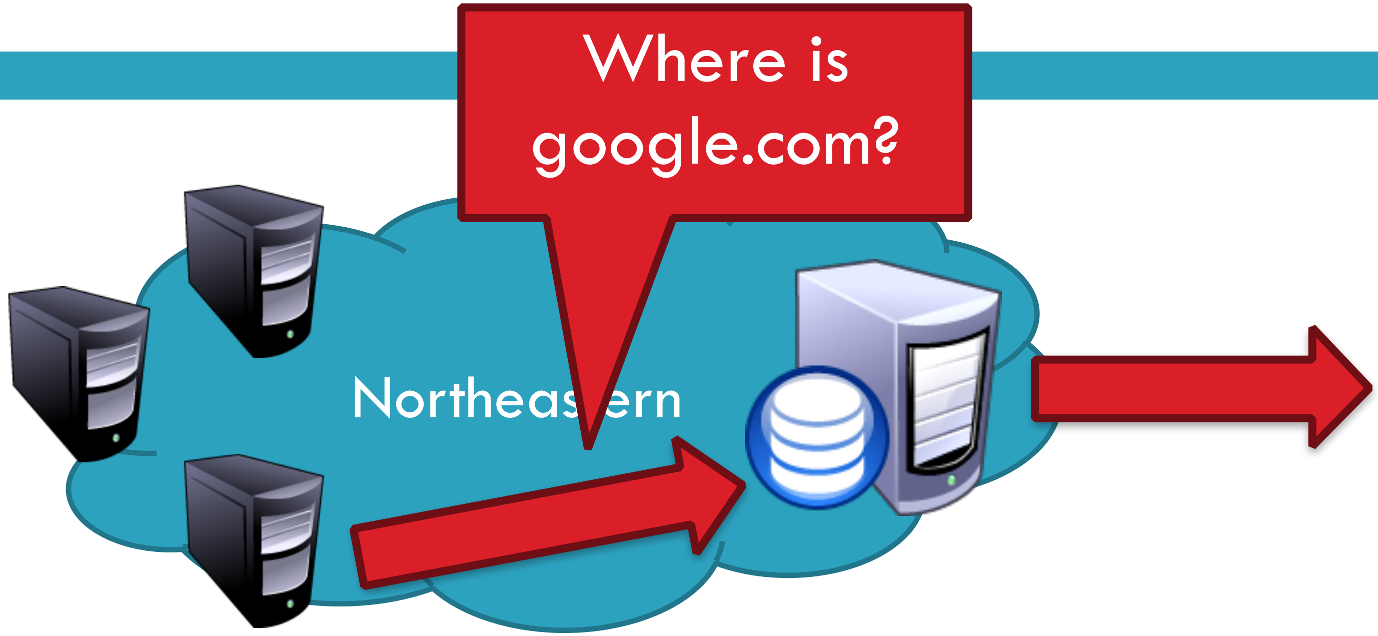

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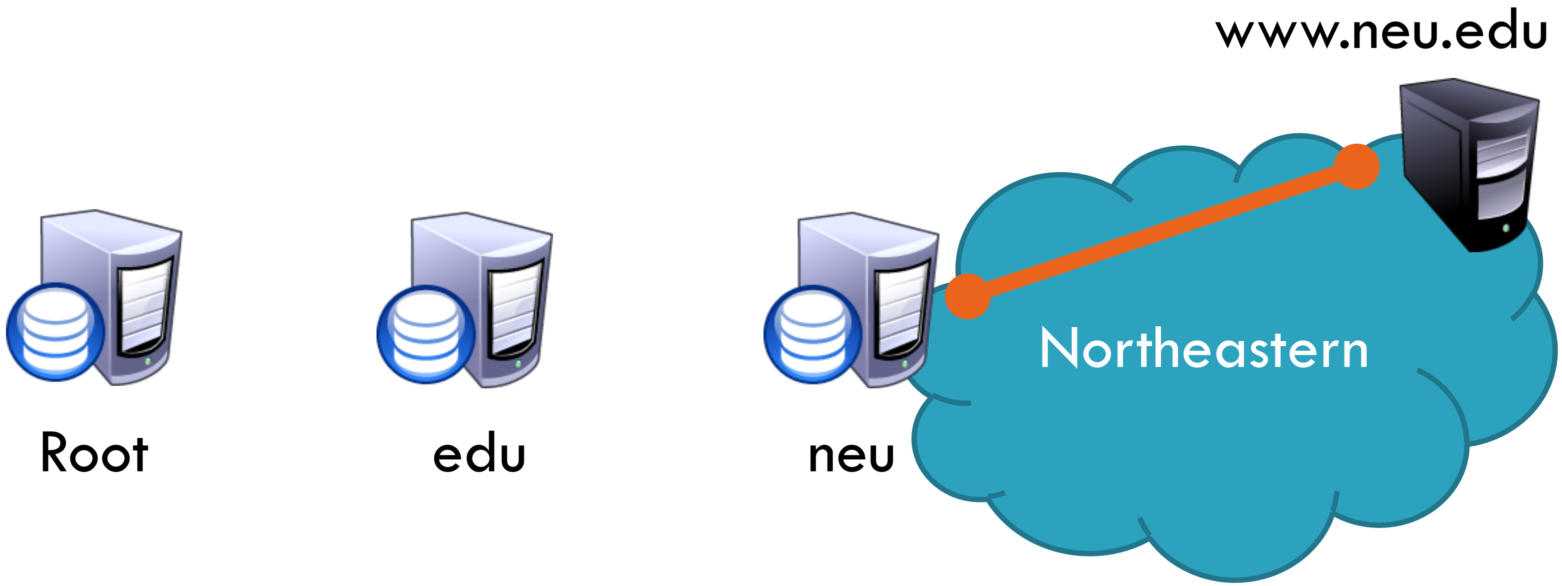

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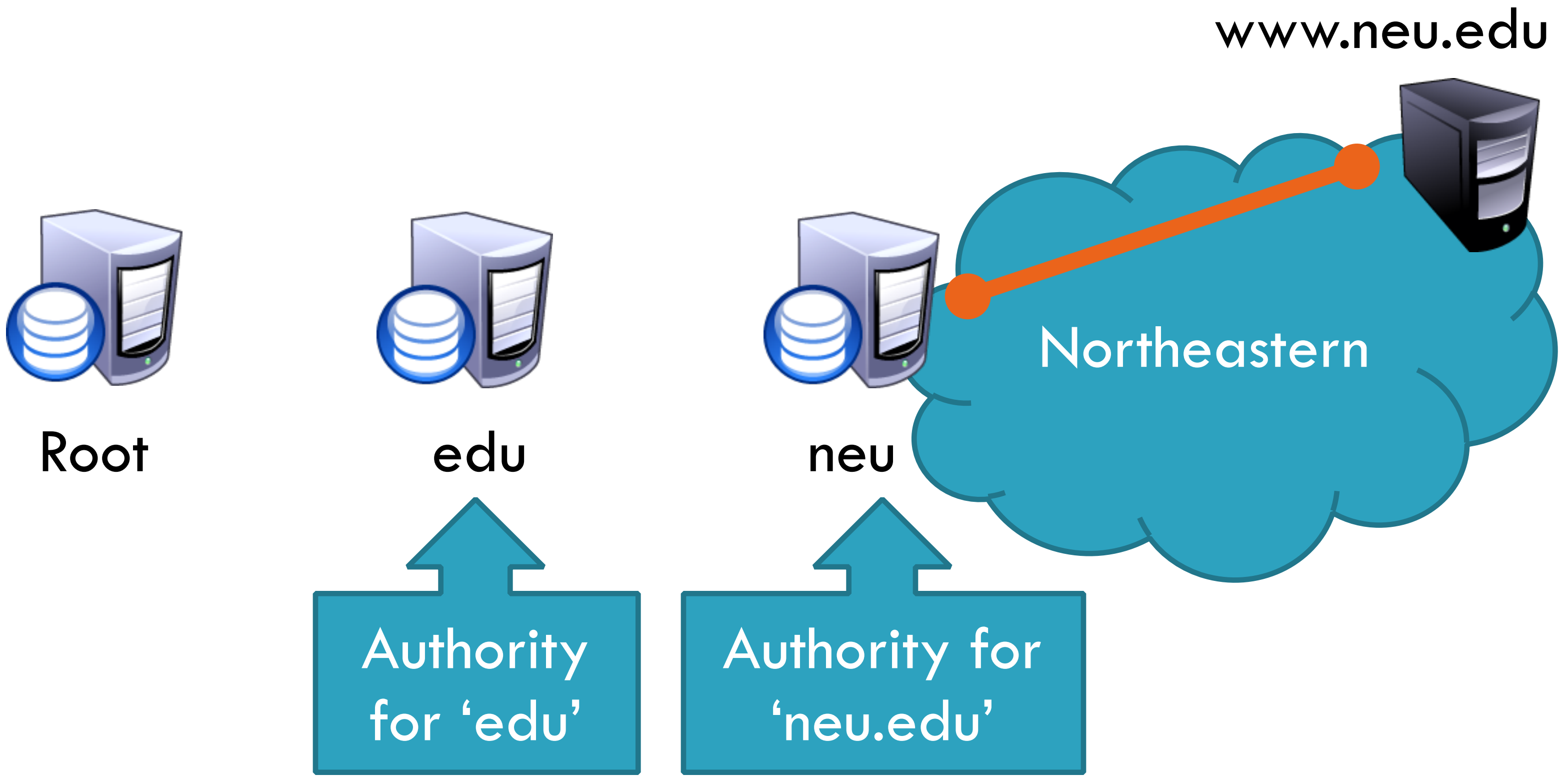

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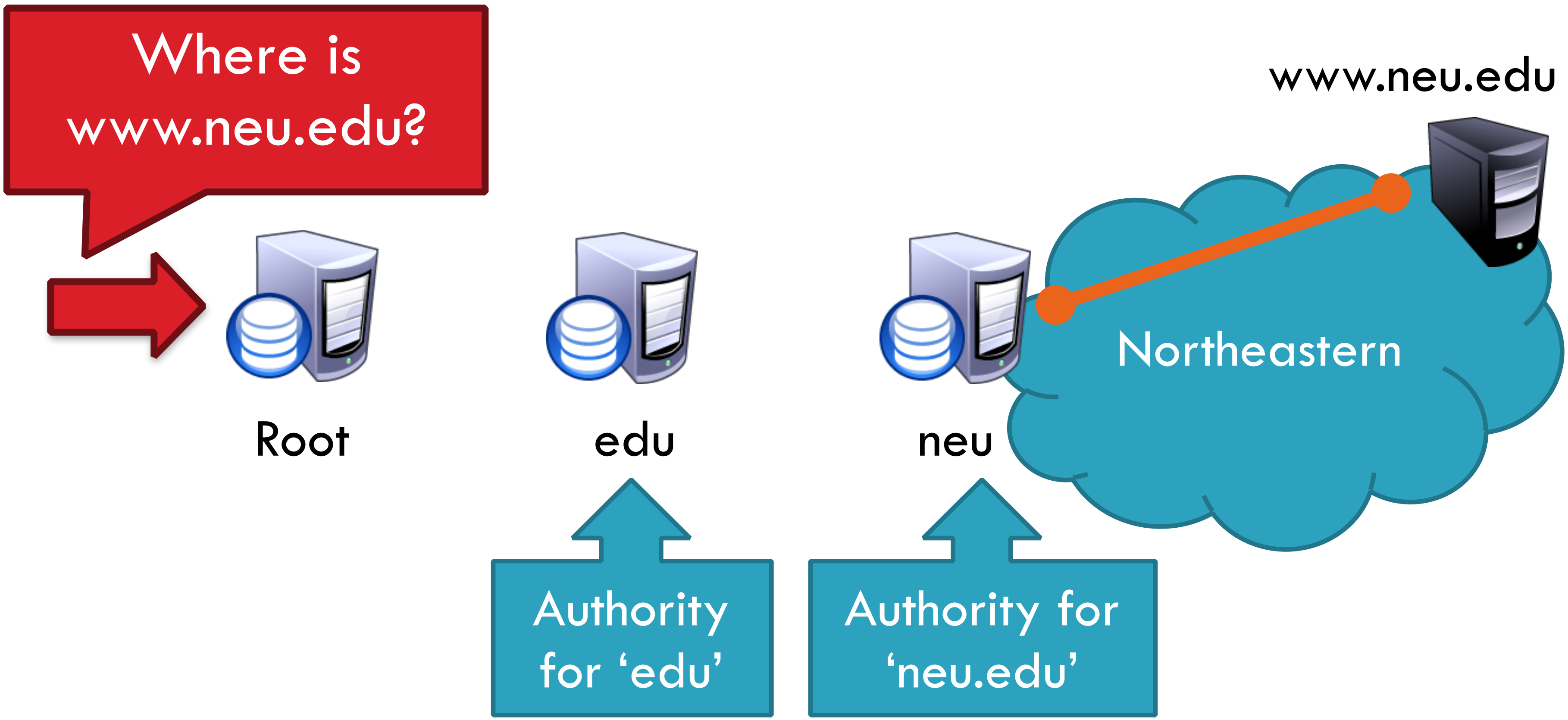

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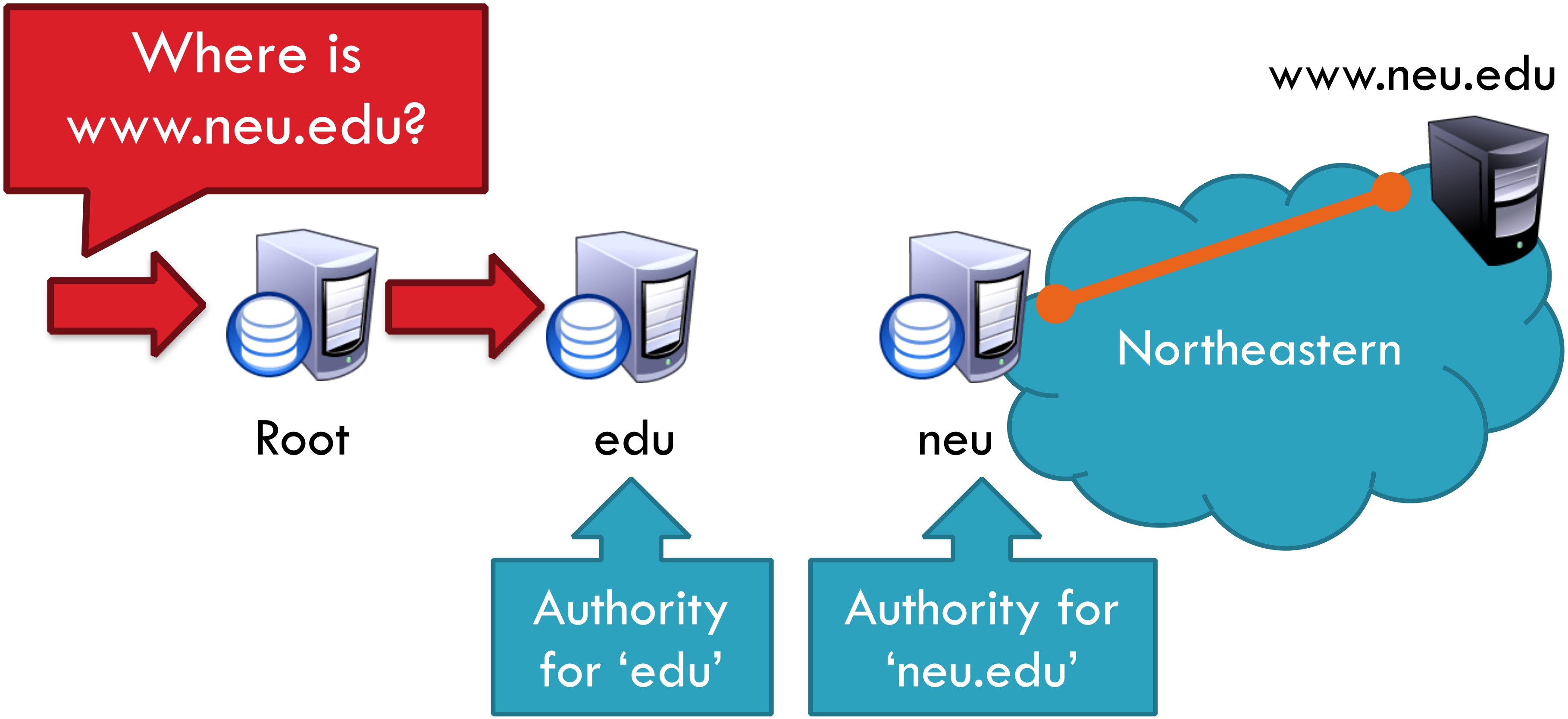

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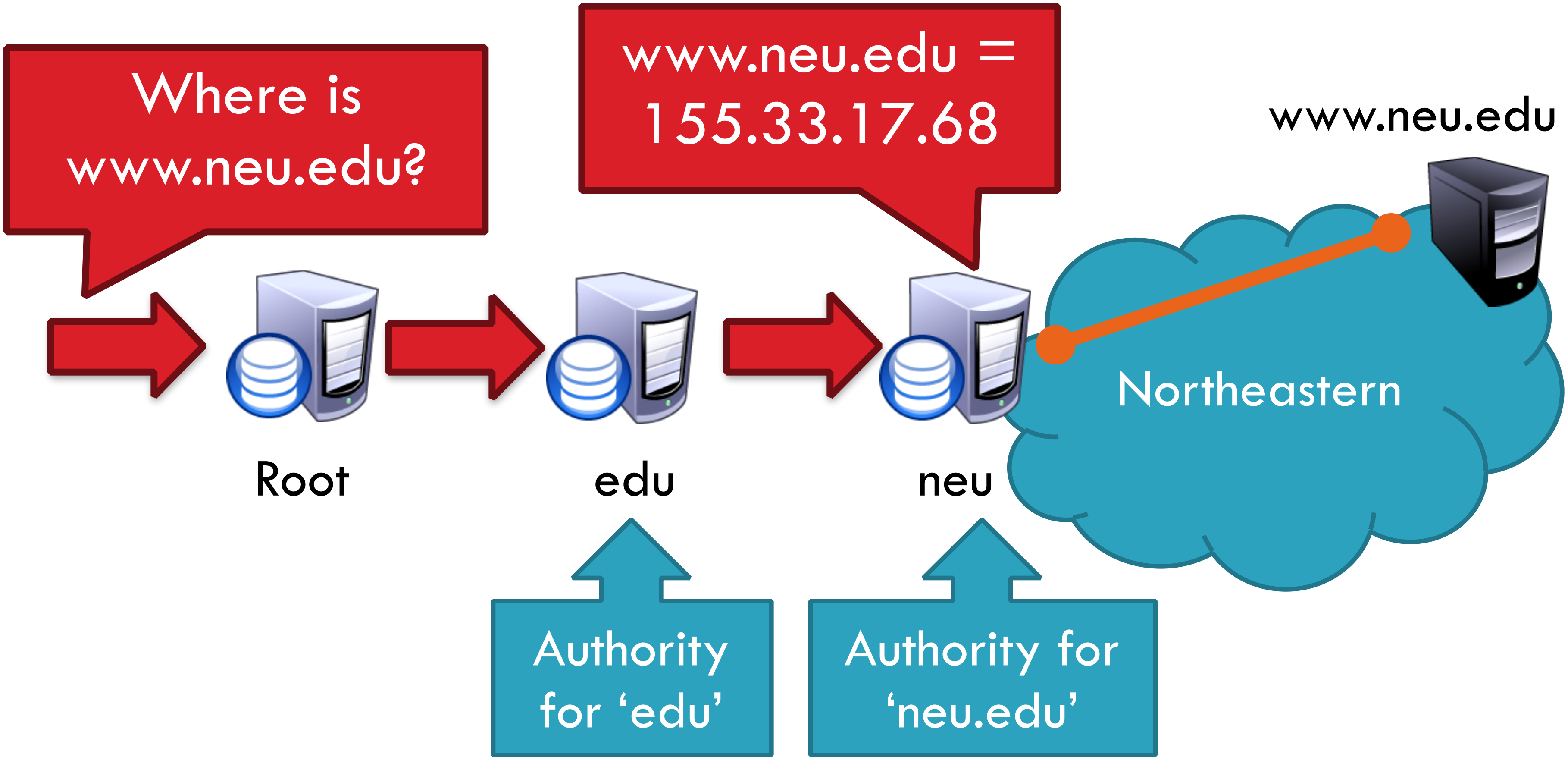

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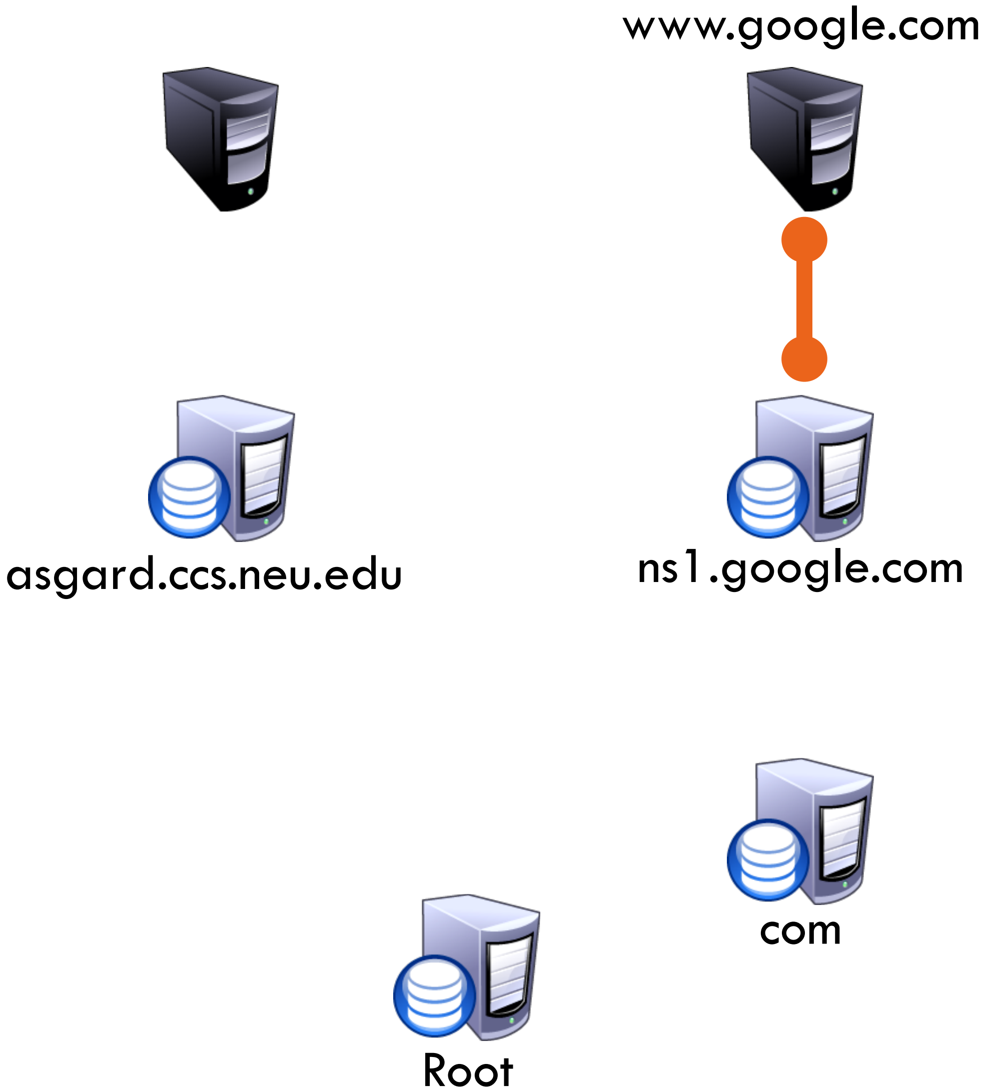
- Otherwise, go down the hierarchy and search for the authoritative name server
  - Every local DNS server knows the root servers
  - Use cache to skip steps if possible
    - e.g. skip the root and go directly to .edu if the root file is cached

Recursive DNS Query



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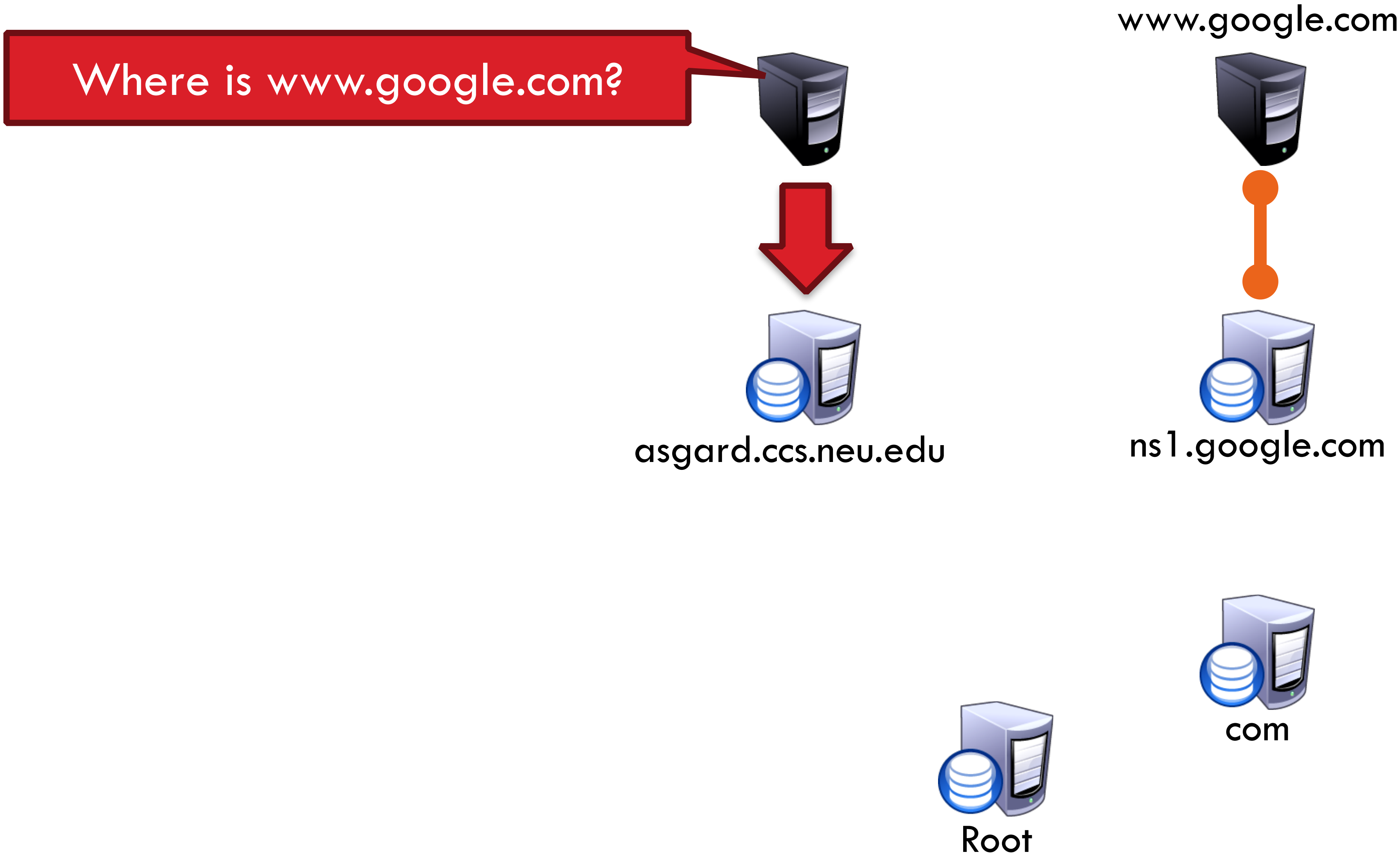

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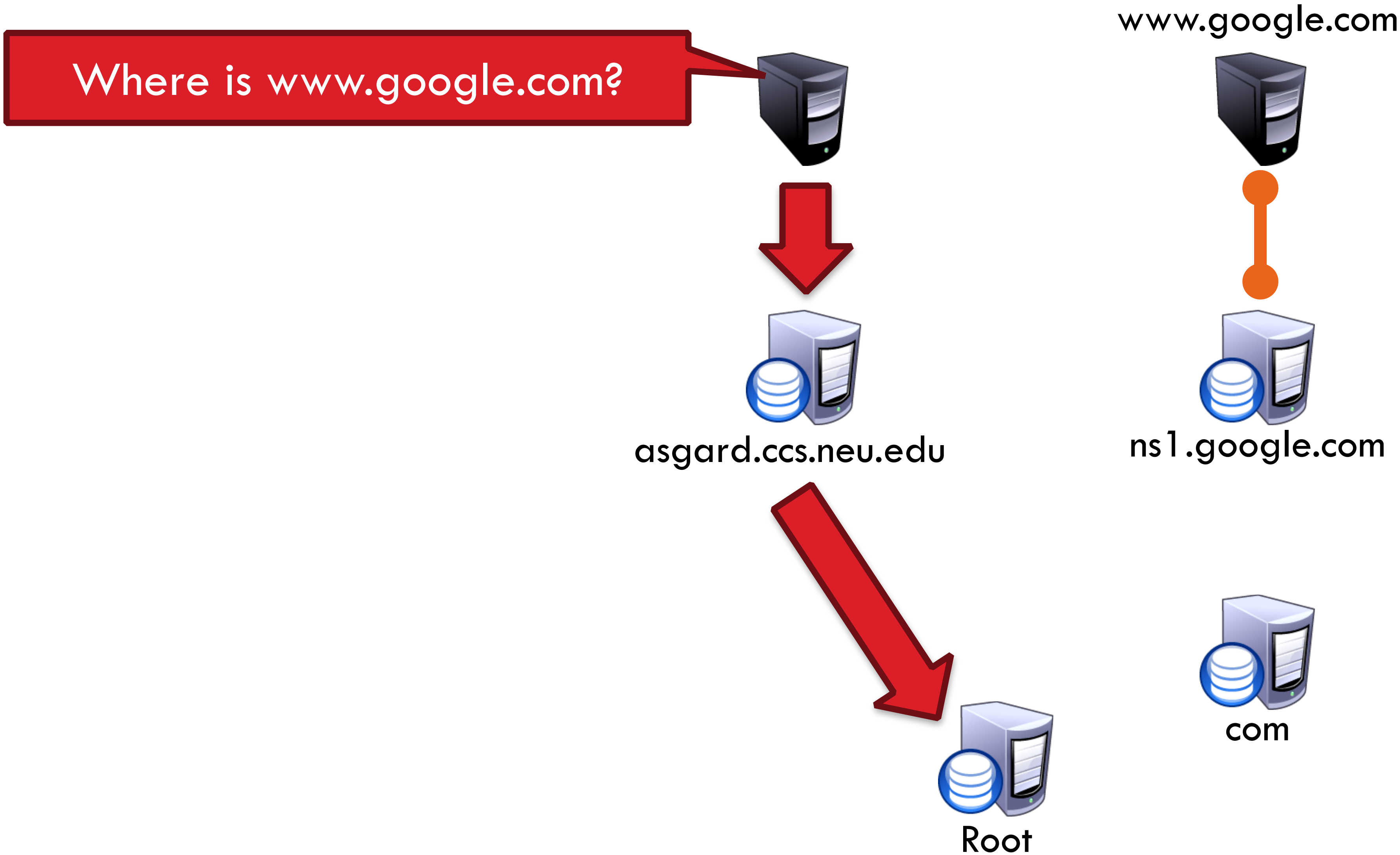

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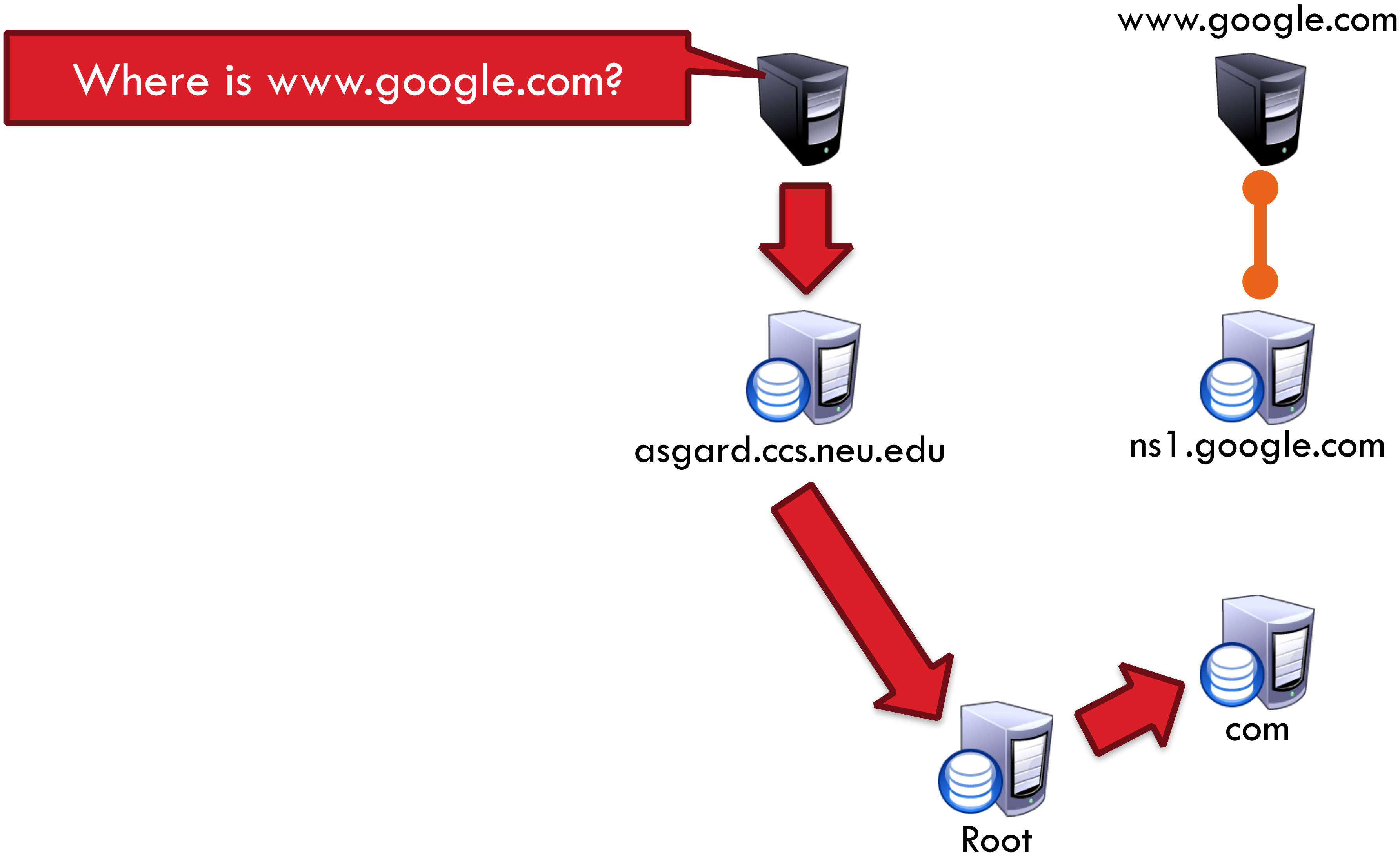

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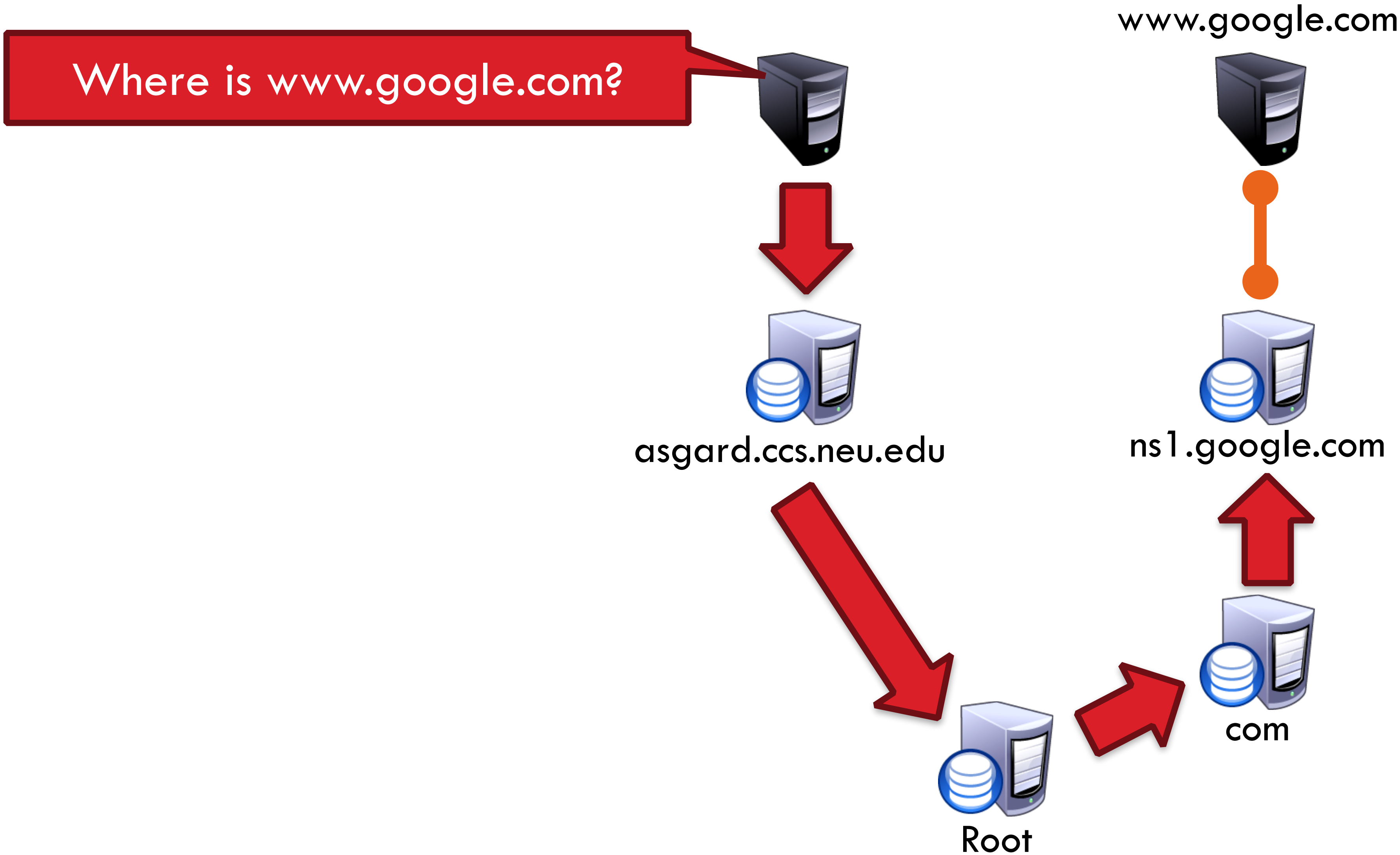

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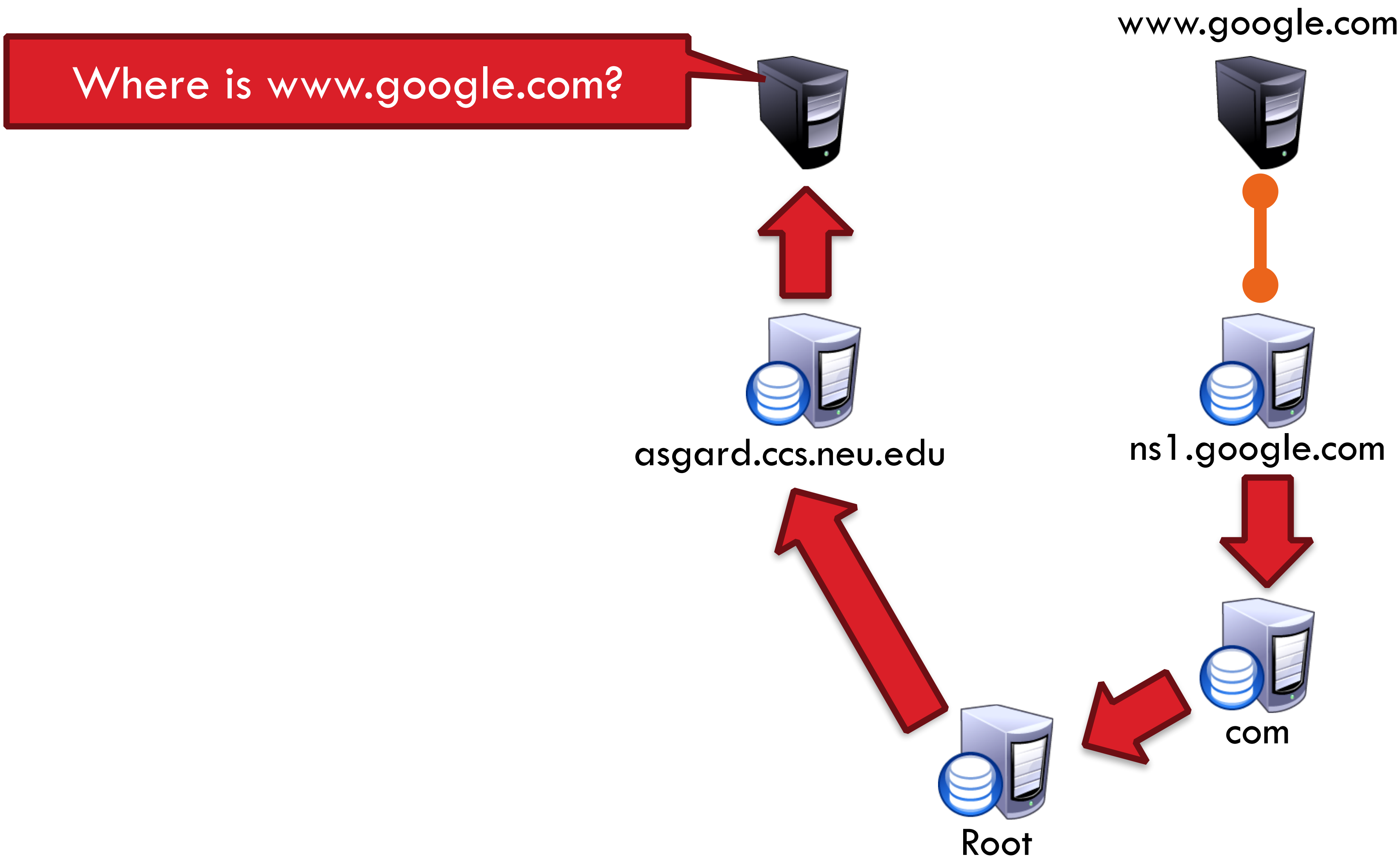

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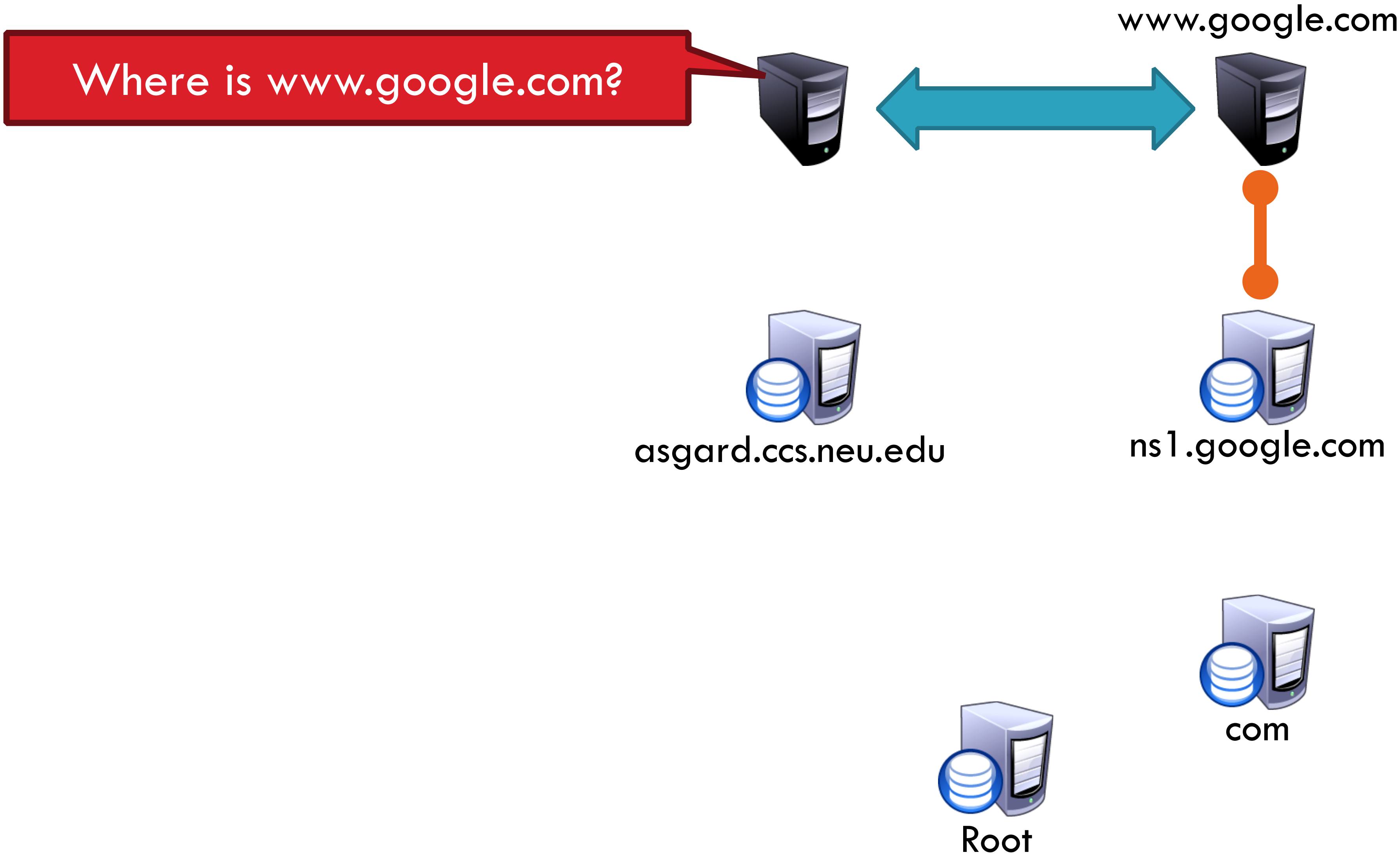

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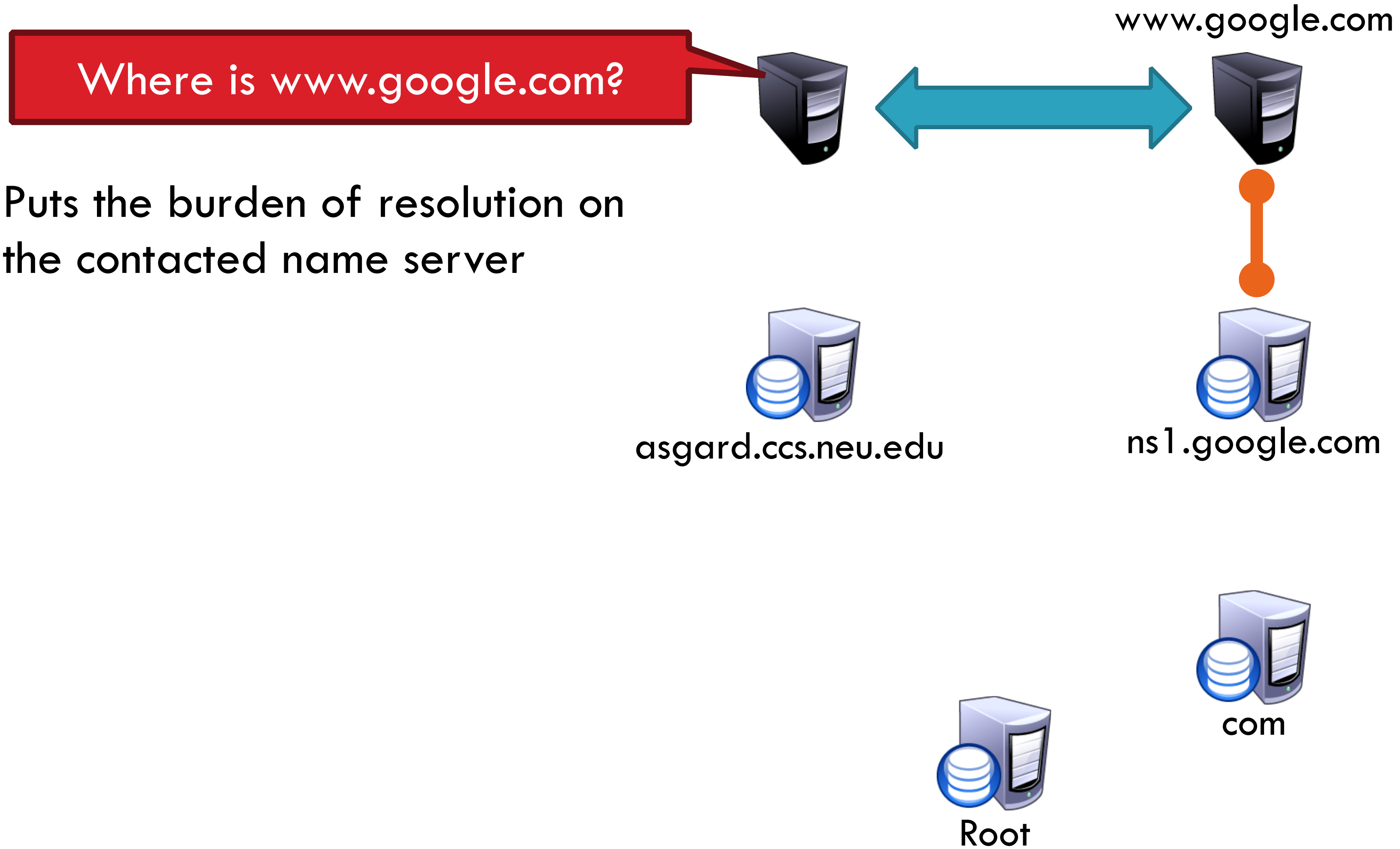
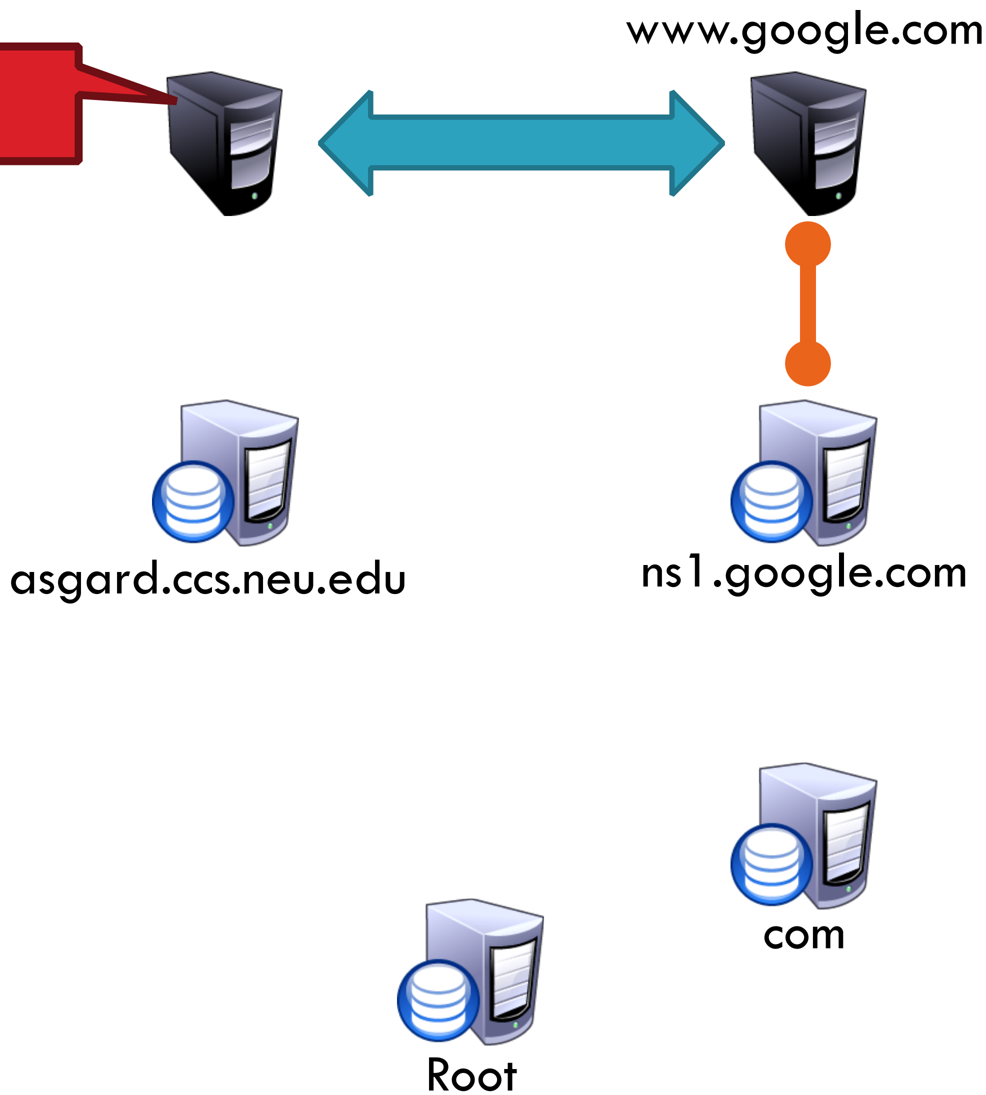


Recursive DNS Query

Where is www.google.com?

- Puts the burden of resolution on the contacted name server
- How does asgard know who to forward responses too?
  - Random IDs embedded in DNS queries



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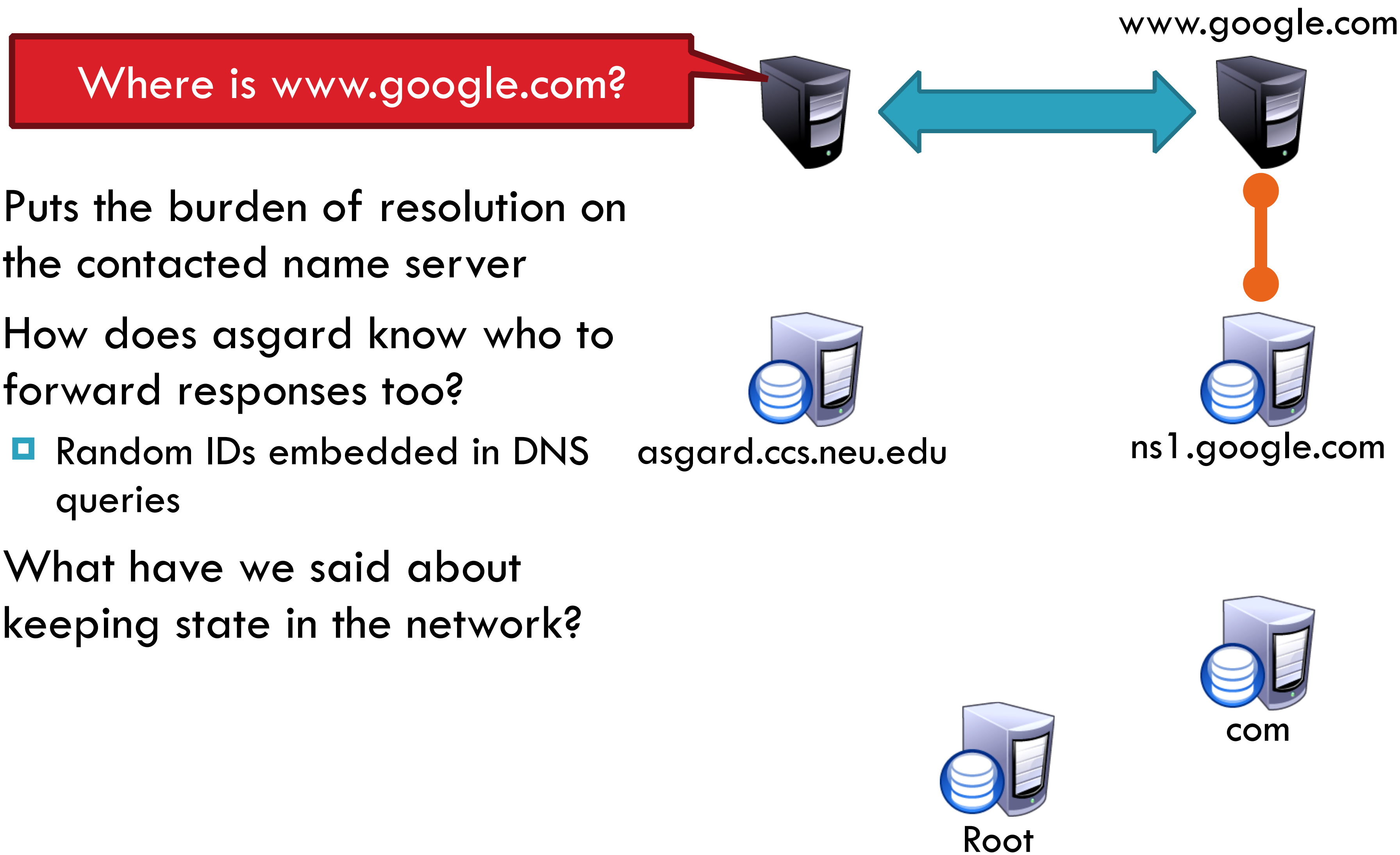

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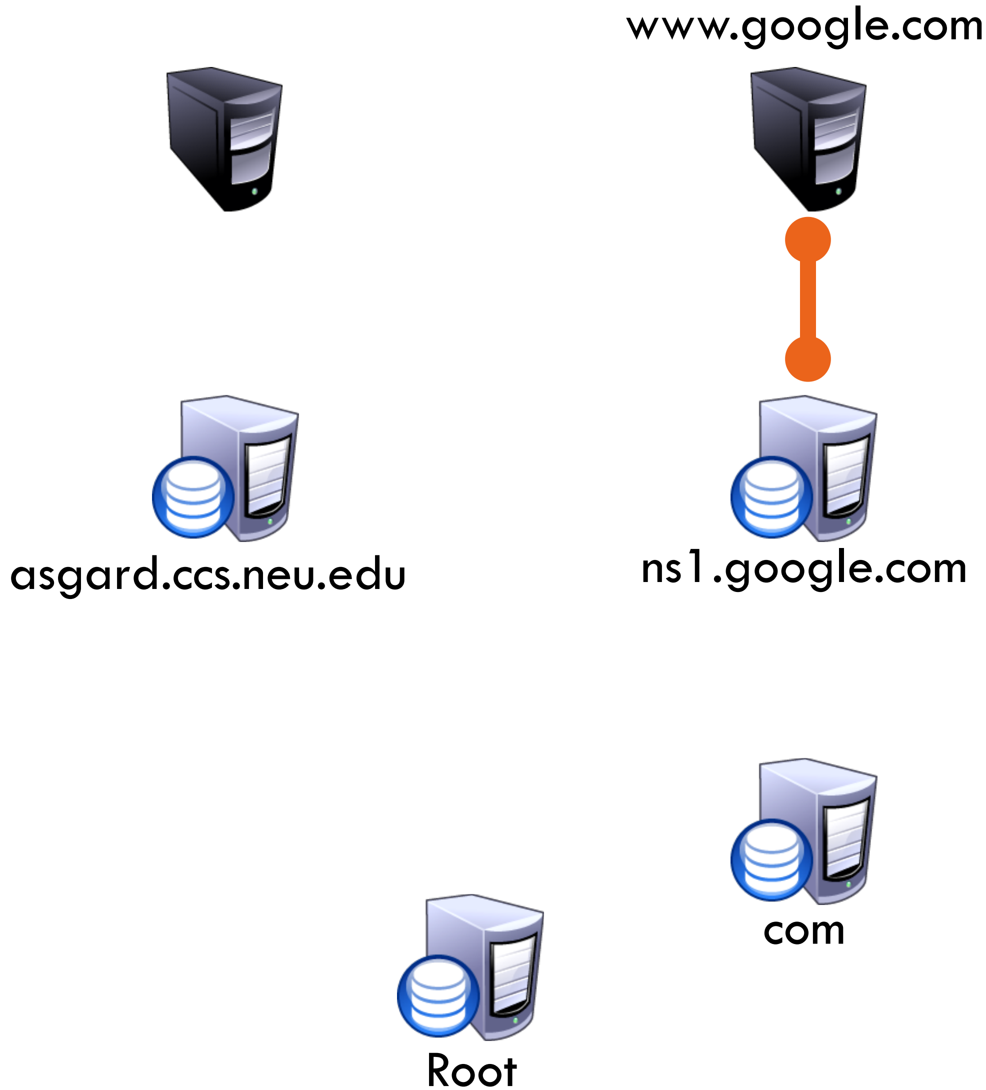
- What have we said about keeping state in the network?

Iterated DNS query



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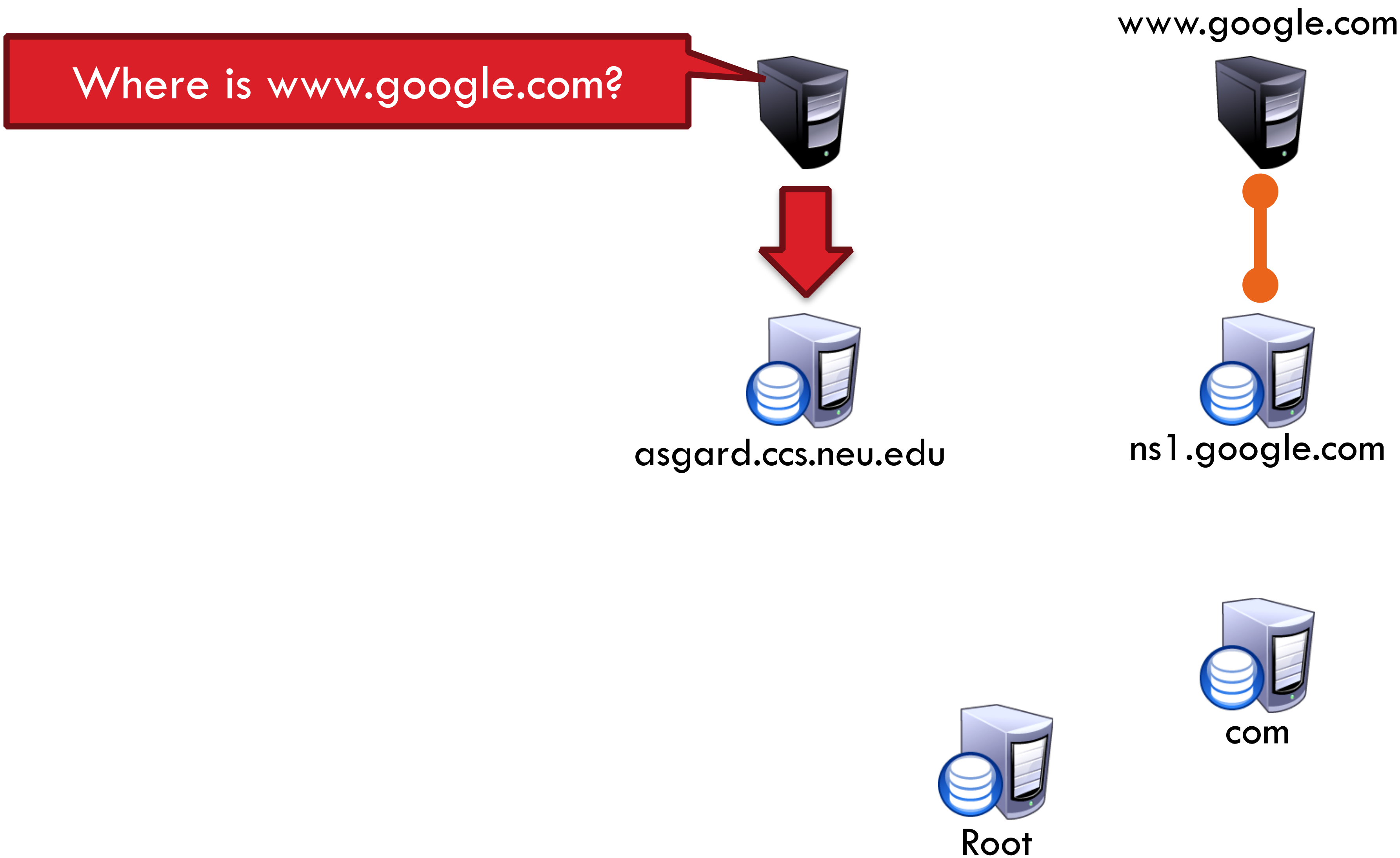

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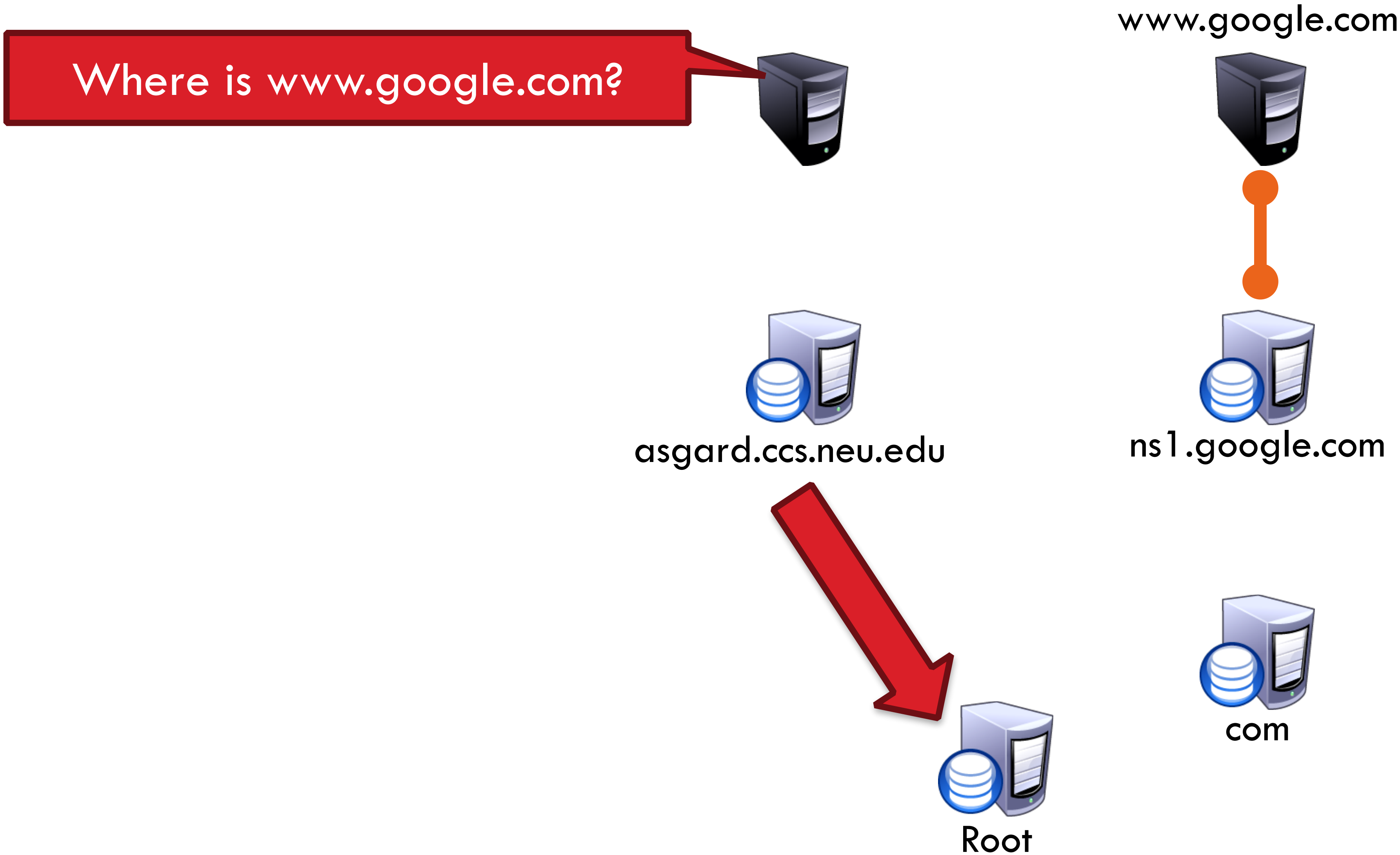

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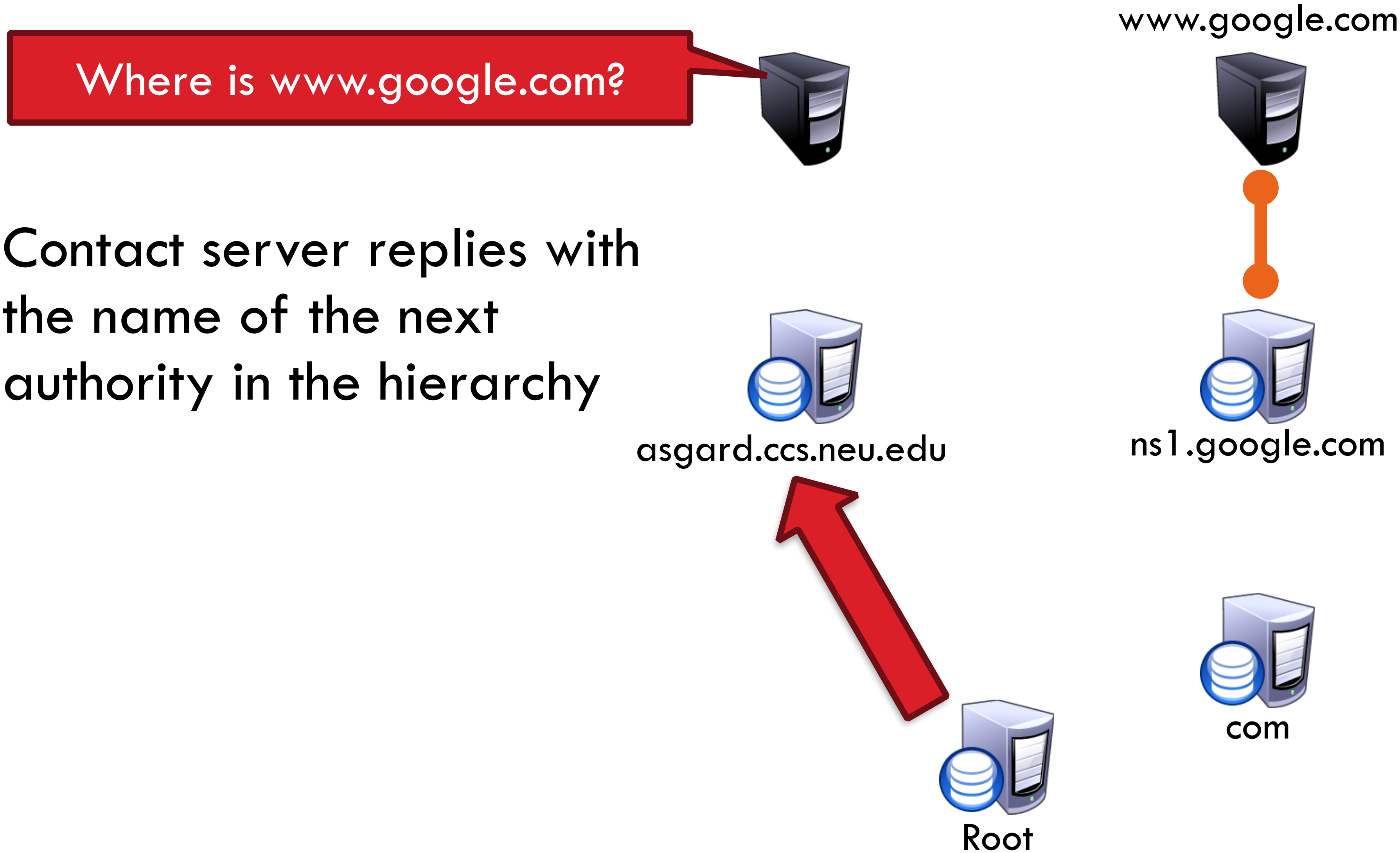

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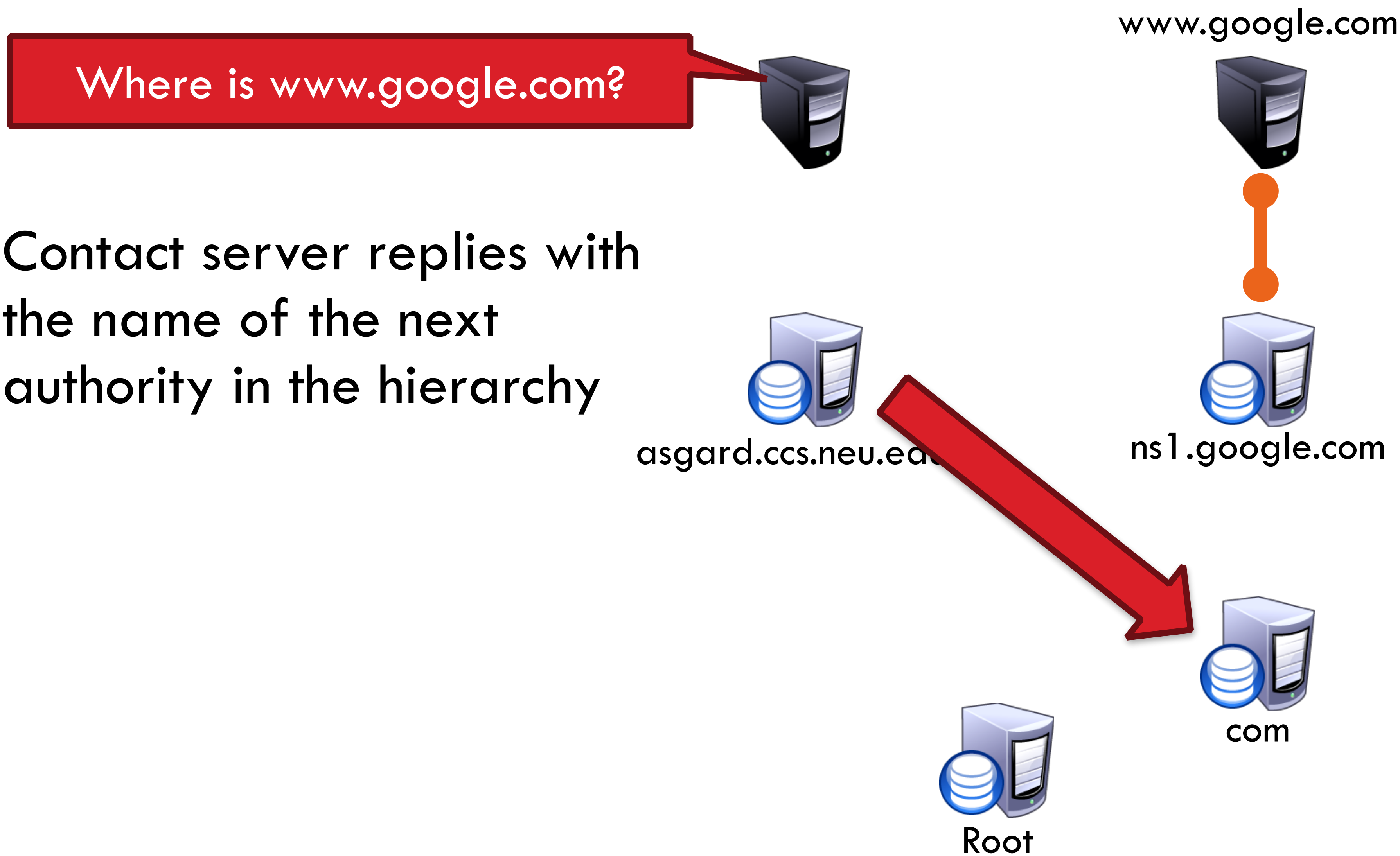

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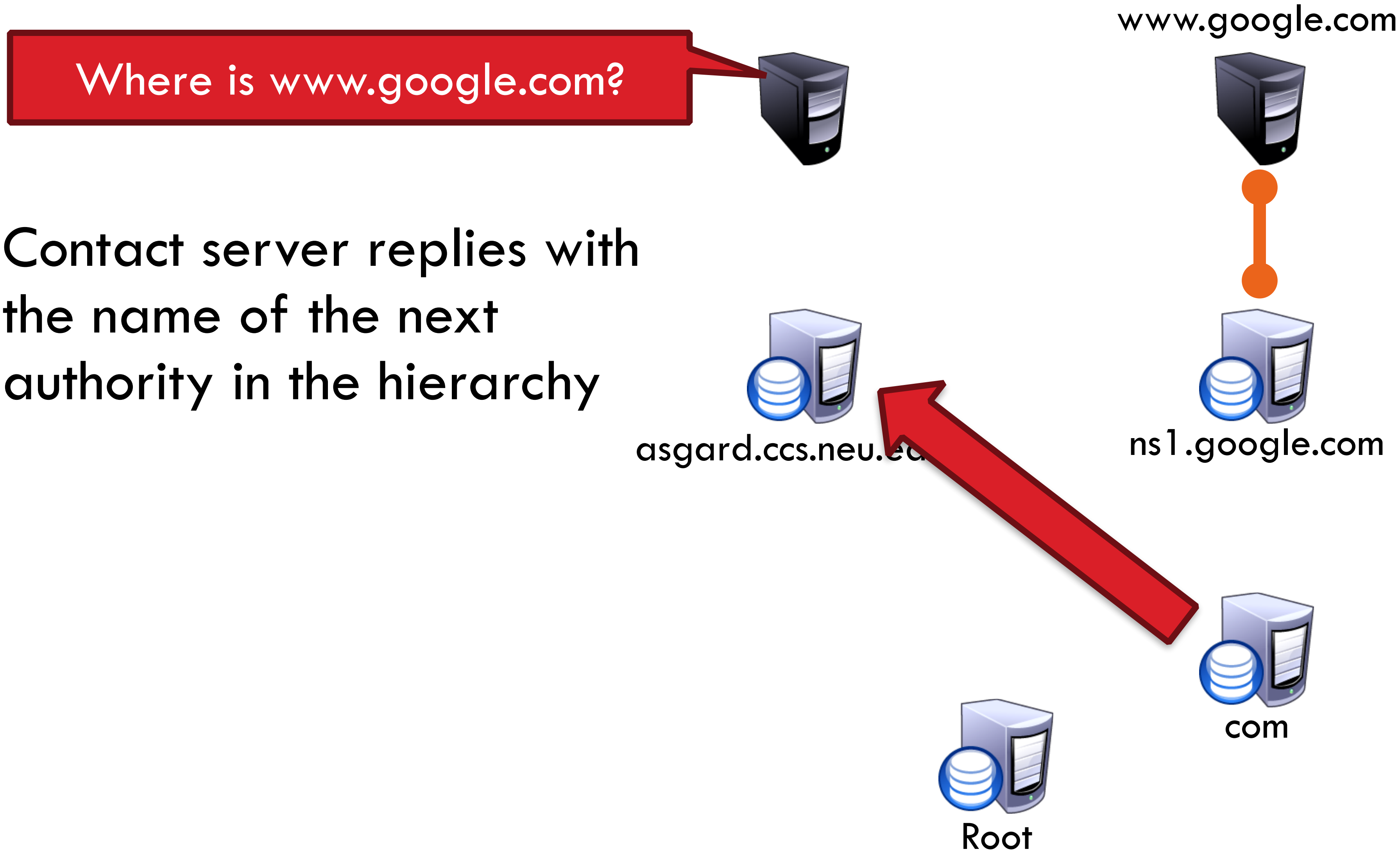

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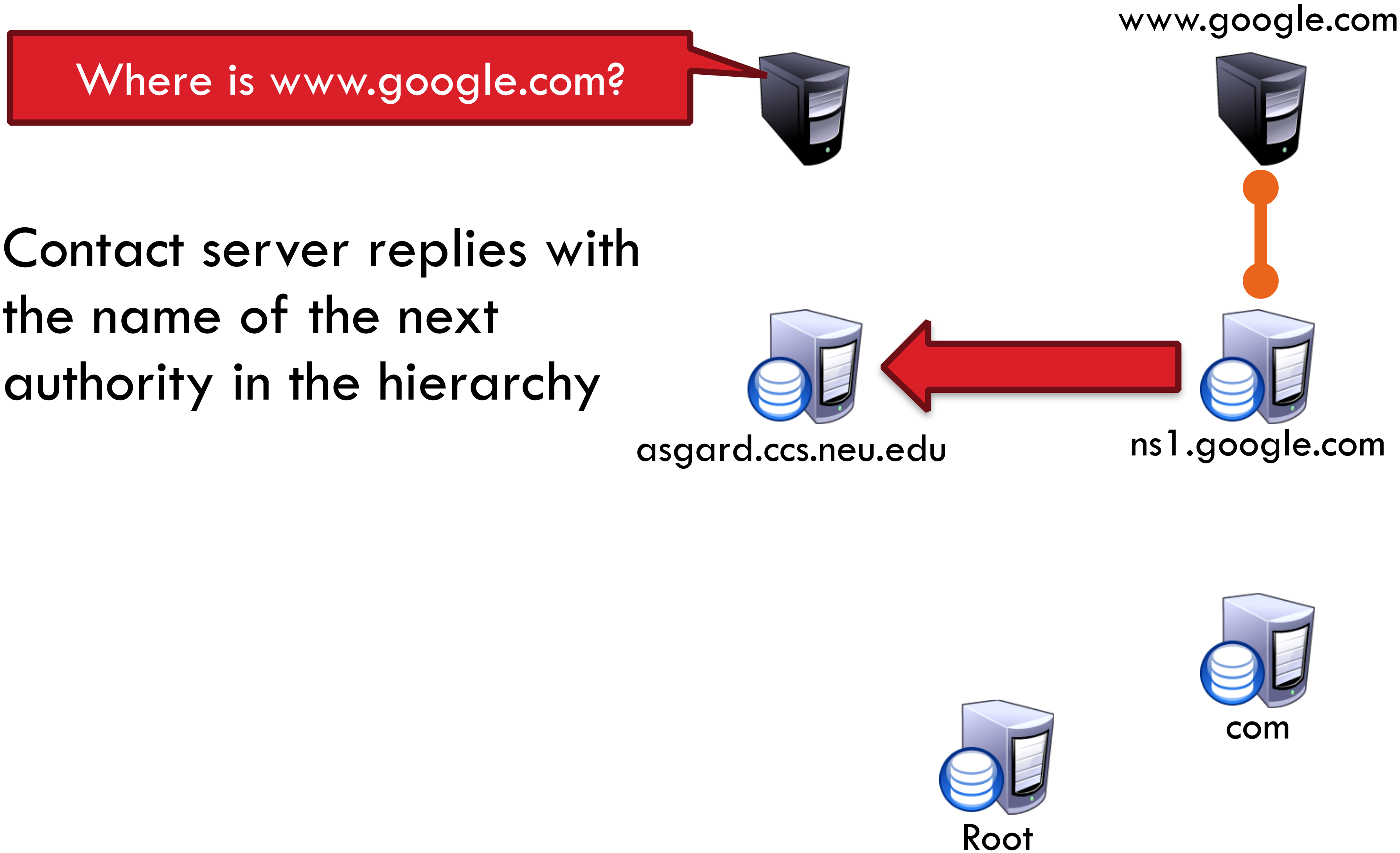

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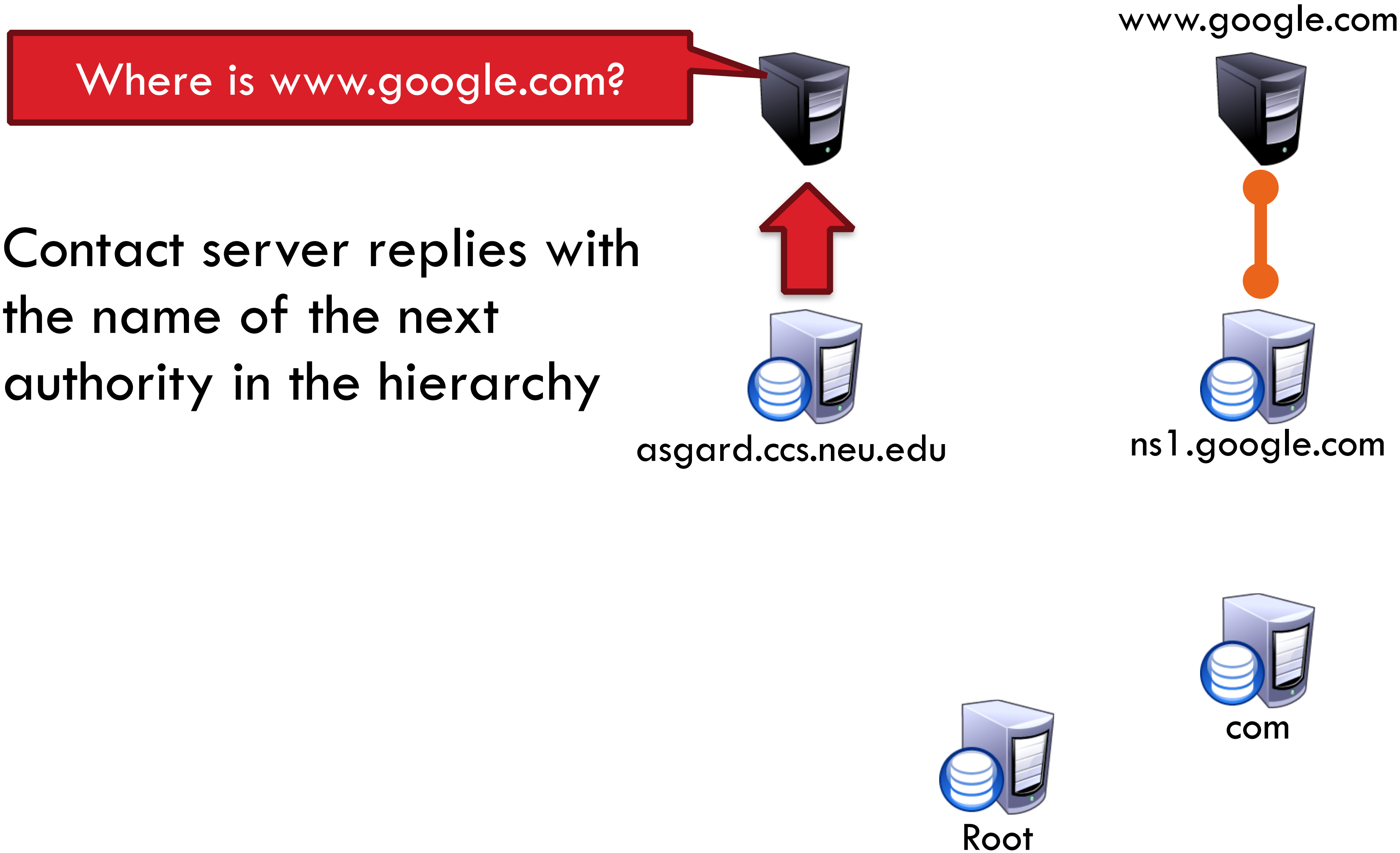

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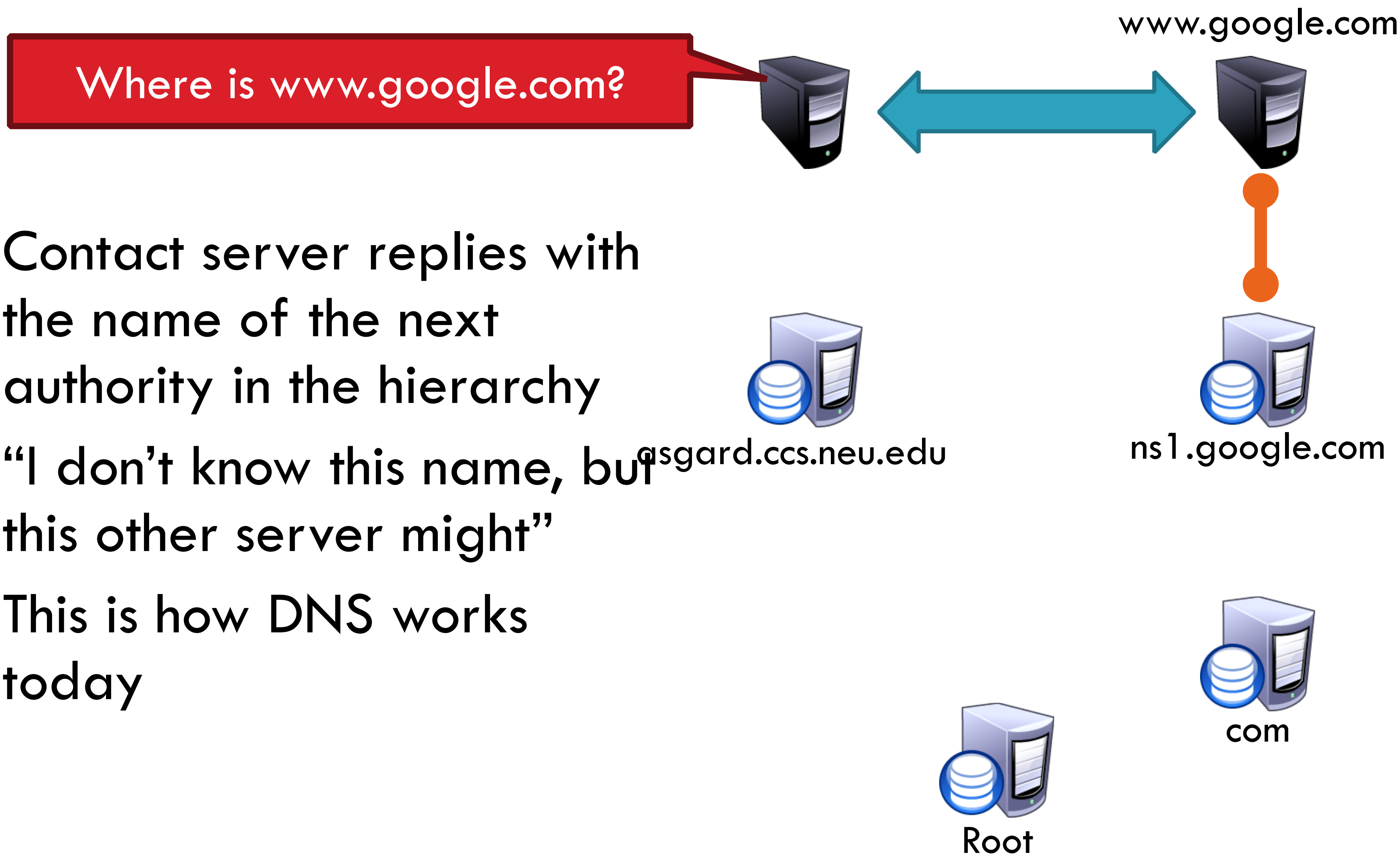
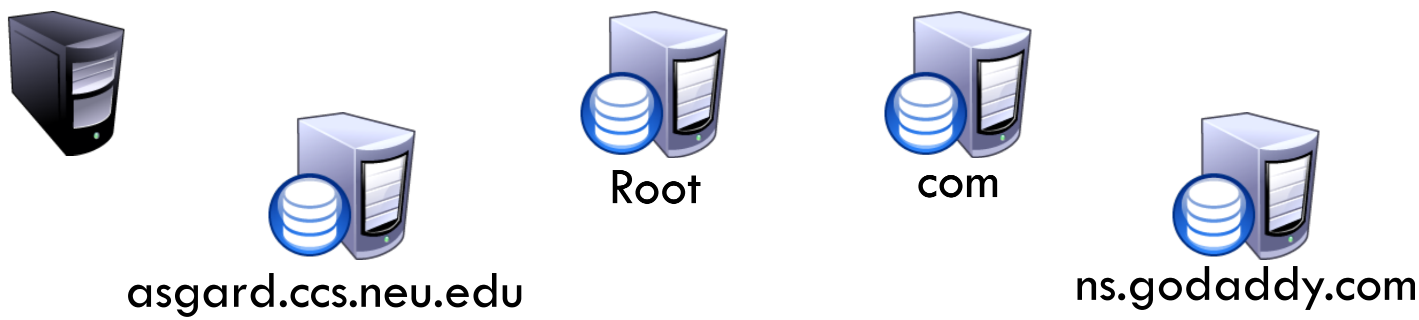


- Contact server replies with the name of the next authority in the hierarchy
- "I don't know this name, but this other server might"
- This is how DNS works today

DNS Propagation

- How many of you have purchased a domain name?
  - Did you notice that it took ~72 hours for your name to become accessible?
  - This delay is called DNS Propagation



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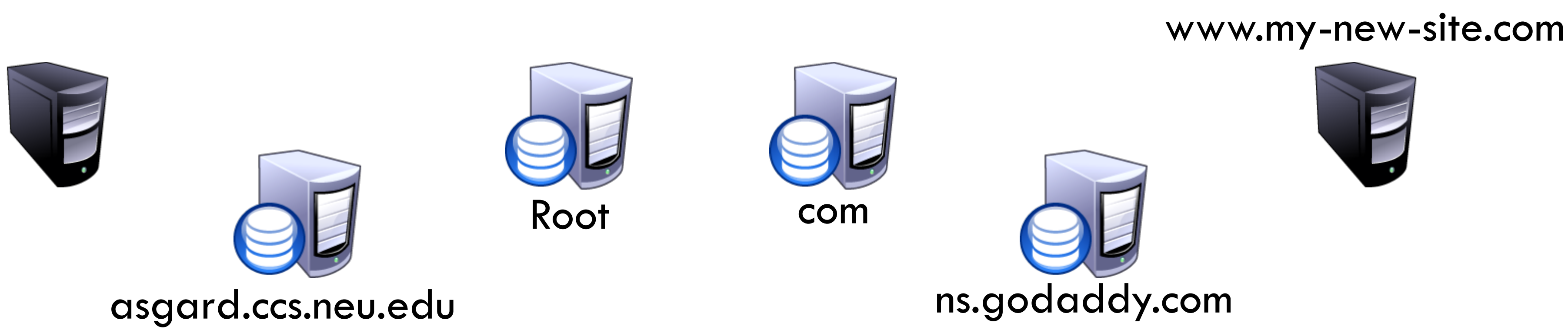

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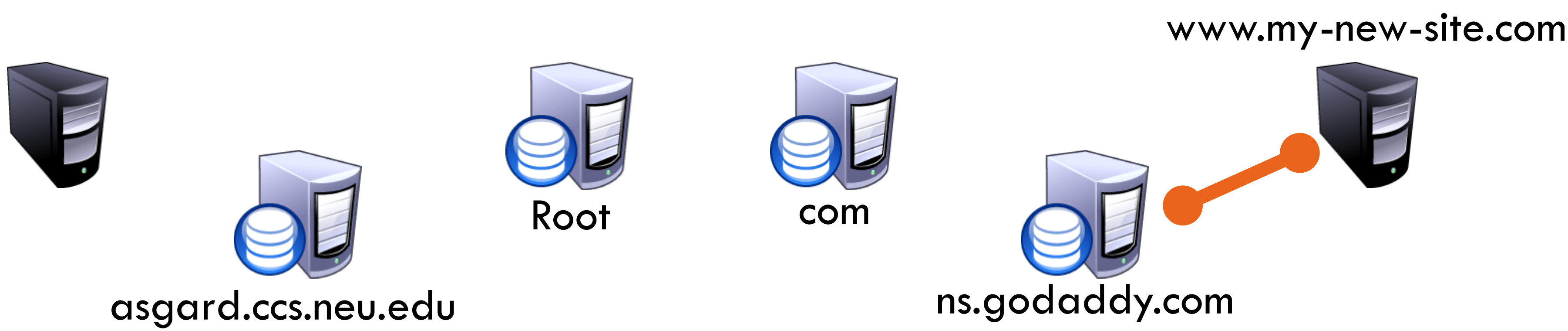

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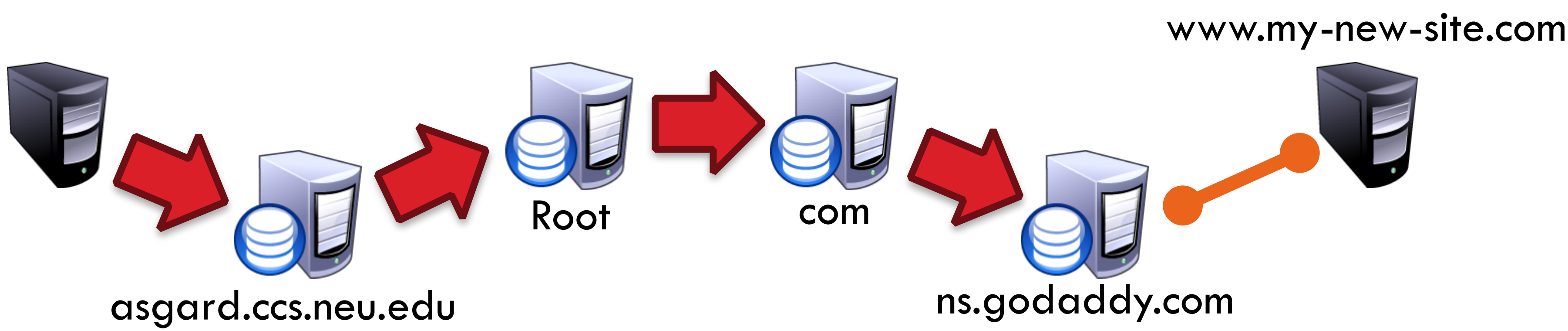

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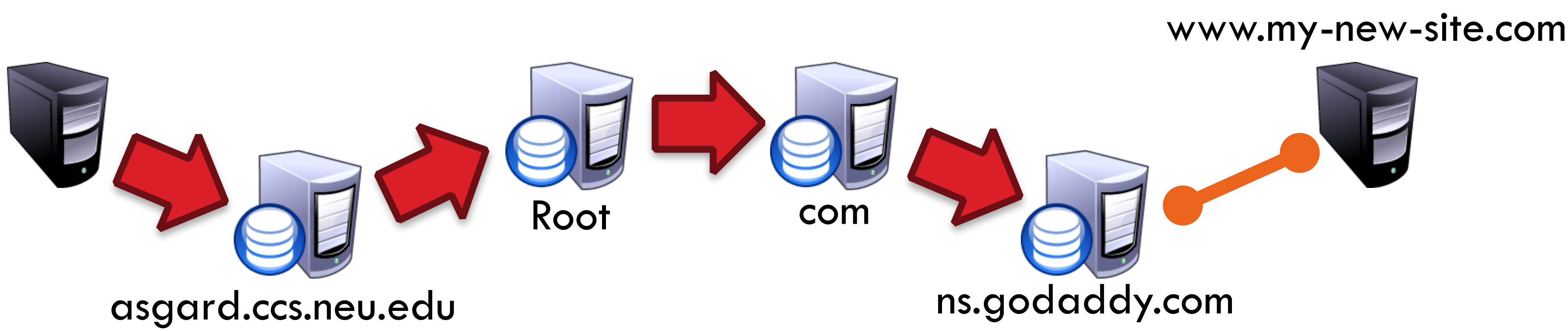

- Why would this process fail for a new DNS name?

Caching vs. Freshness

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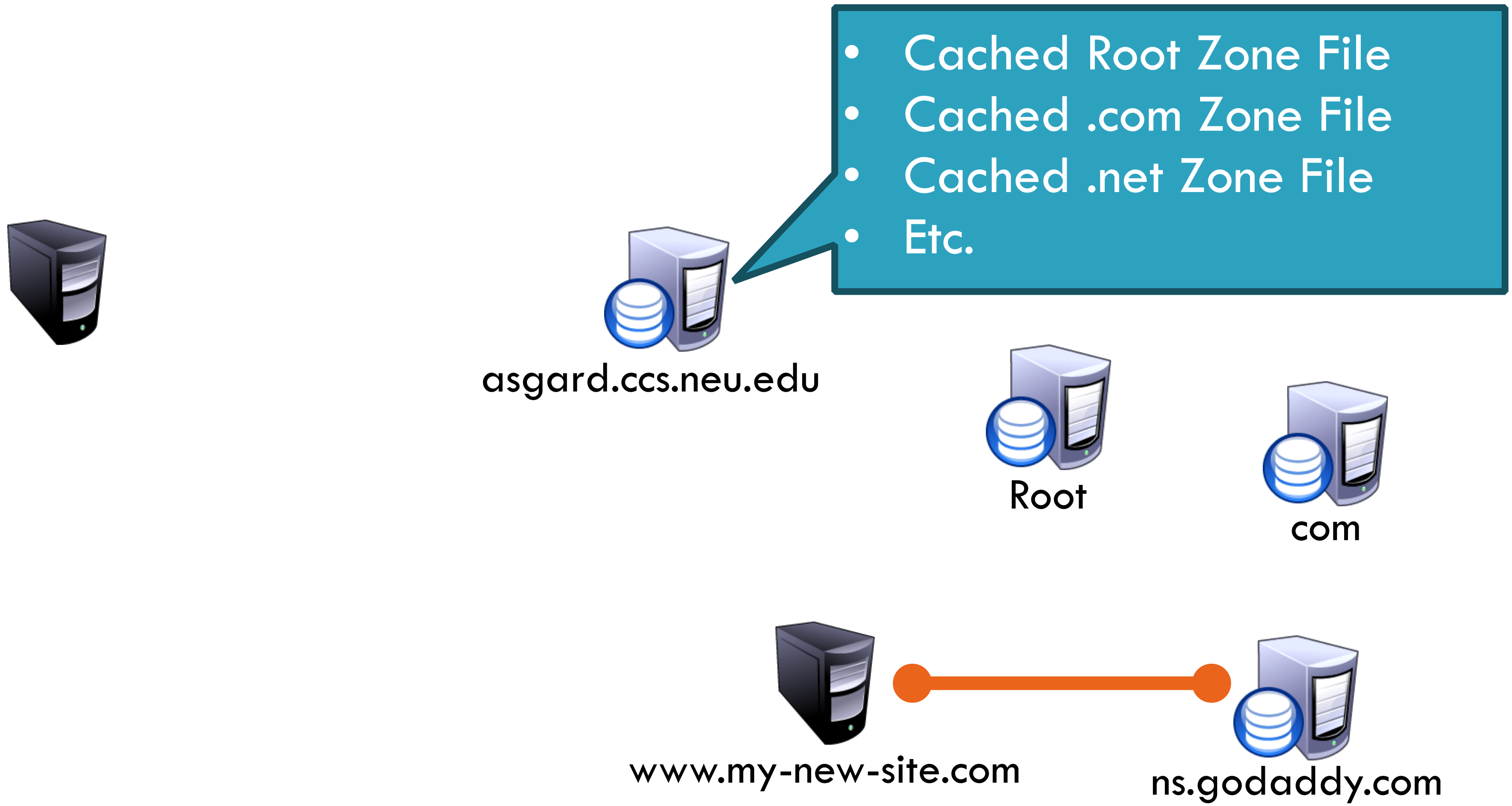

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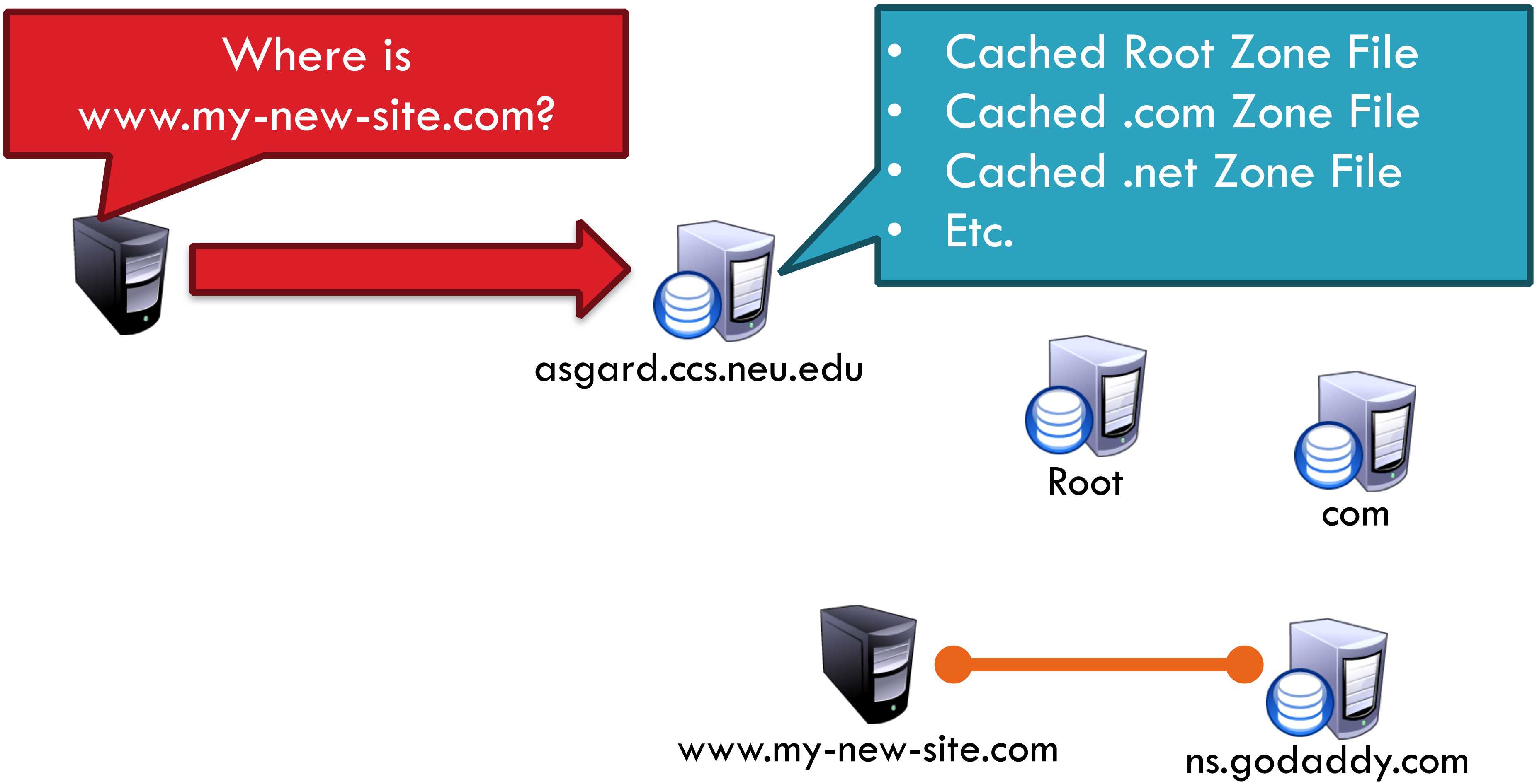

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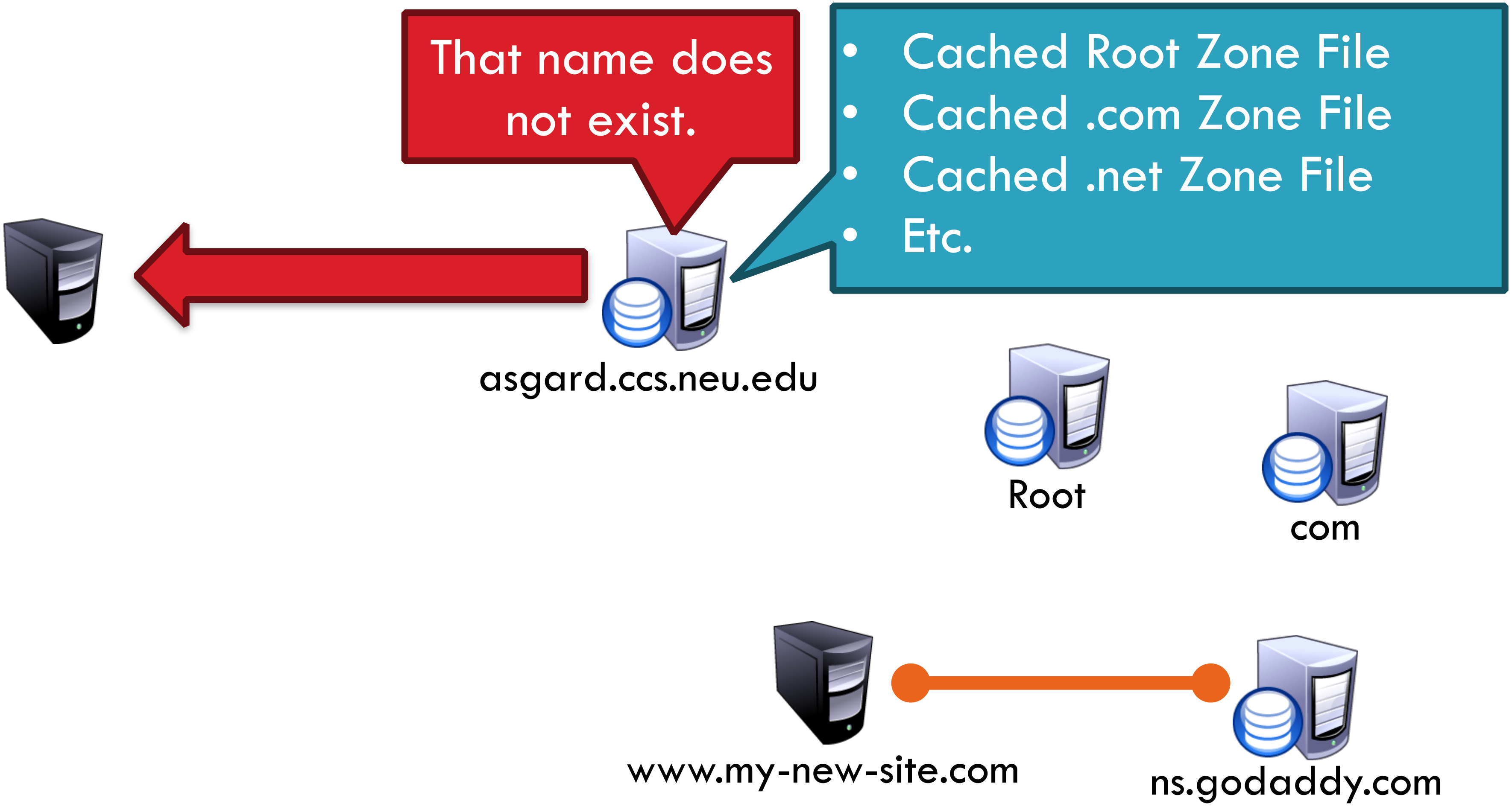

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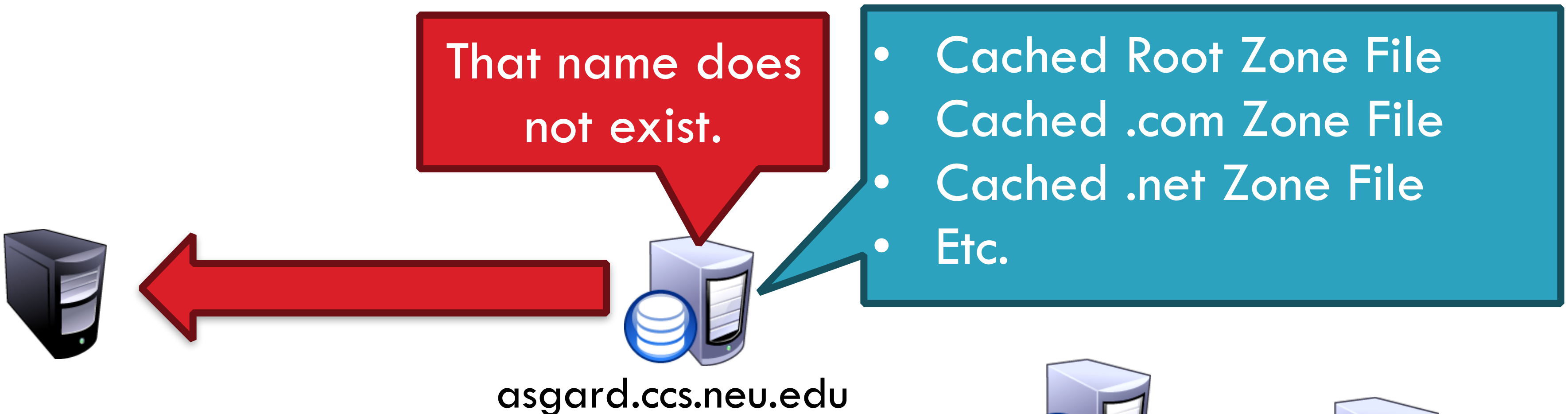

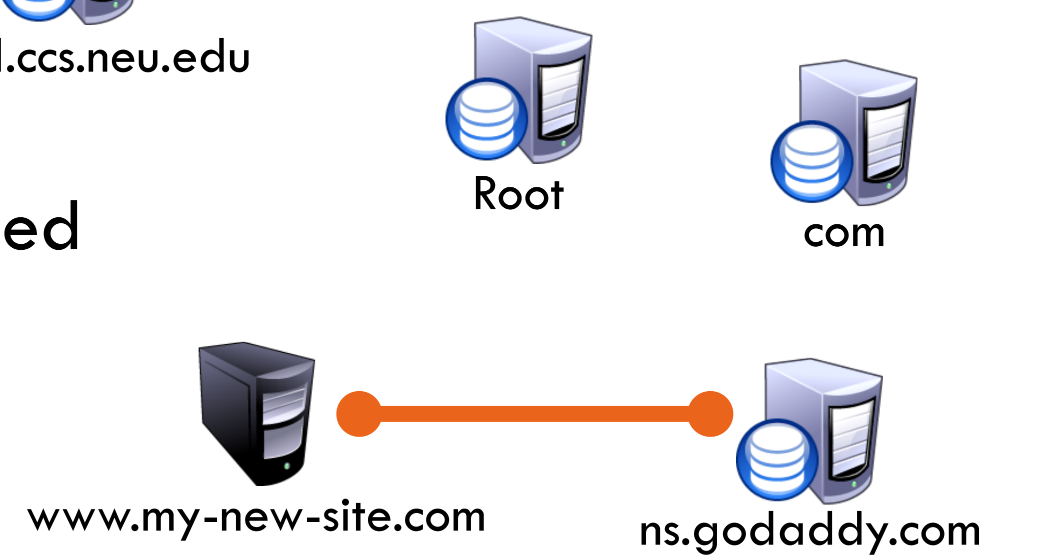

- Zone files may be cached for 1-72 hours

DNS Resource Records

- DNS queries have two fields: name and type
- Resource record is the response to a query
  - Four fields: (name, value, type, TTL)
  - There may be multiple records returned for one query

DNS Resource Records

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- What are do the name and value mean?
  - Depends on the type of query and response

DNS Types

- Type = A / AAAA
  - Name = domain name
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Query

Name: www.ccs.neu.edu
Type: A

DNS Types

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Query

Name: www.ccs.neu.edu
Type: A

Resp.

Name: www.ccs.neu.edu
Value: 129.10.116.81

DNS Types

- Type = A / AAAA
  - Name = domain name
  - Value = IP address
  - A is IPv4, AAAA is IPv6

Query	Name: www.ccs.neu.edu Type: A
Resp.	Name: www.ccs.neu.edu Value: 129.10.116.81

- Type = NS
  - Name = partial domain
  - Value = name of DNS server for this domain
  - "Go send your query to this other server"

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Query
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Query
Name: ccs.neu.edu
Type: NS

Resp.
Name: ccs.neu.edu
Value: 129.10.116.51

DNS Types, Continued

- Type = CNAME
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  - CDNs use this

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DNS Types, Continued

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Query

Name: foo.mysite.com
Type: CNAME

Resp.

Name: foo.mysite.com
Value: bar.mysite.com

DNS Types, Continued

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Query

Name: foo.mysite.com
Type: CNAME

Resp.

Name: foo.mysite.com
Value: bar.mysite.com

- Type = MX
  - Name = domain in email address
  - Value = canonical name of mail server

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Type: MX

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Query
Name: foo.mysite.com
Type: CNAME

Resp.
Name: foo.mysite.com
Value: bar.mysite.com

- Type = MX
  - Name = domain in email address
  - Value = canonical name of mail server

Query
Name: ccs.neu.edu
Type: MX

Resp.
Name: ccs.neu.edu
Value: amber.ccs.neu.edu

Reverse Lookups

- What about the IP→name mapping?
- Separate server hierarchy stores reverse mappings
  - Rooted at in-addr.arpa and ip6.arpa
- Additional DNS record type: PTR
  - Name = IP address
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- Not guaranteed to exist
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DNS as Indirection Service

- DNS gives us very powerful capabilities
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DNS as Indirection Service

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- Changing the IPs of machines becomes trivial
  - e.g. you want to move your web server to a new host
  - Just change the DNS record!

Aliasing and Load Balancing

- One machine can have many aliases

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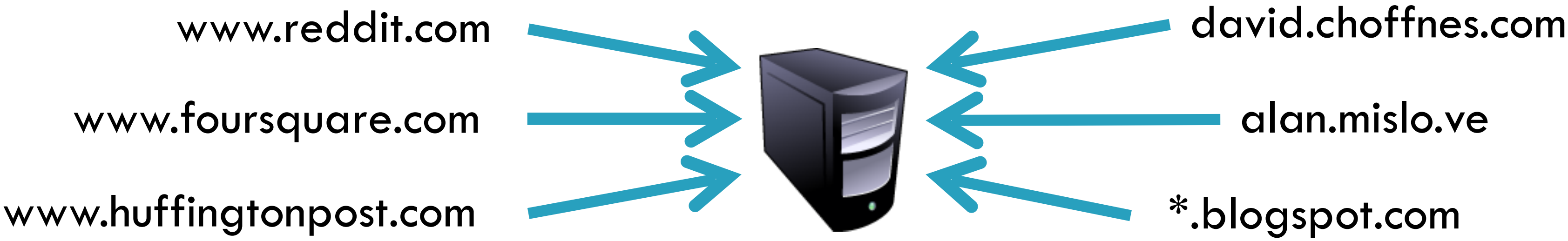
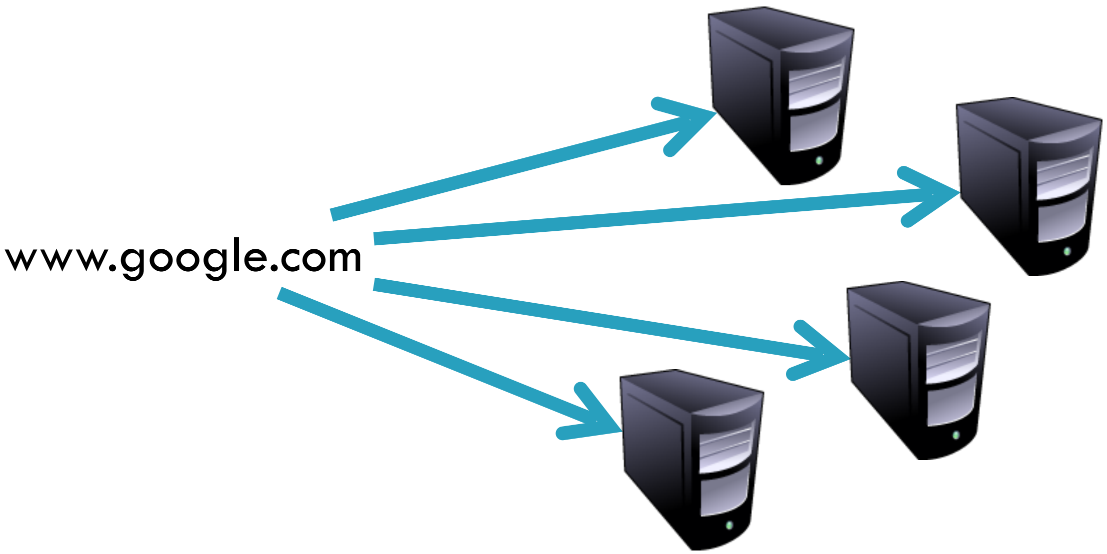
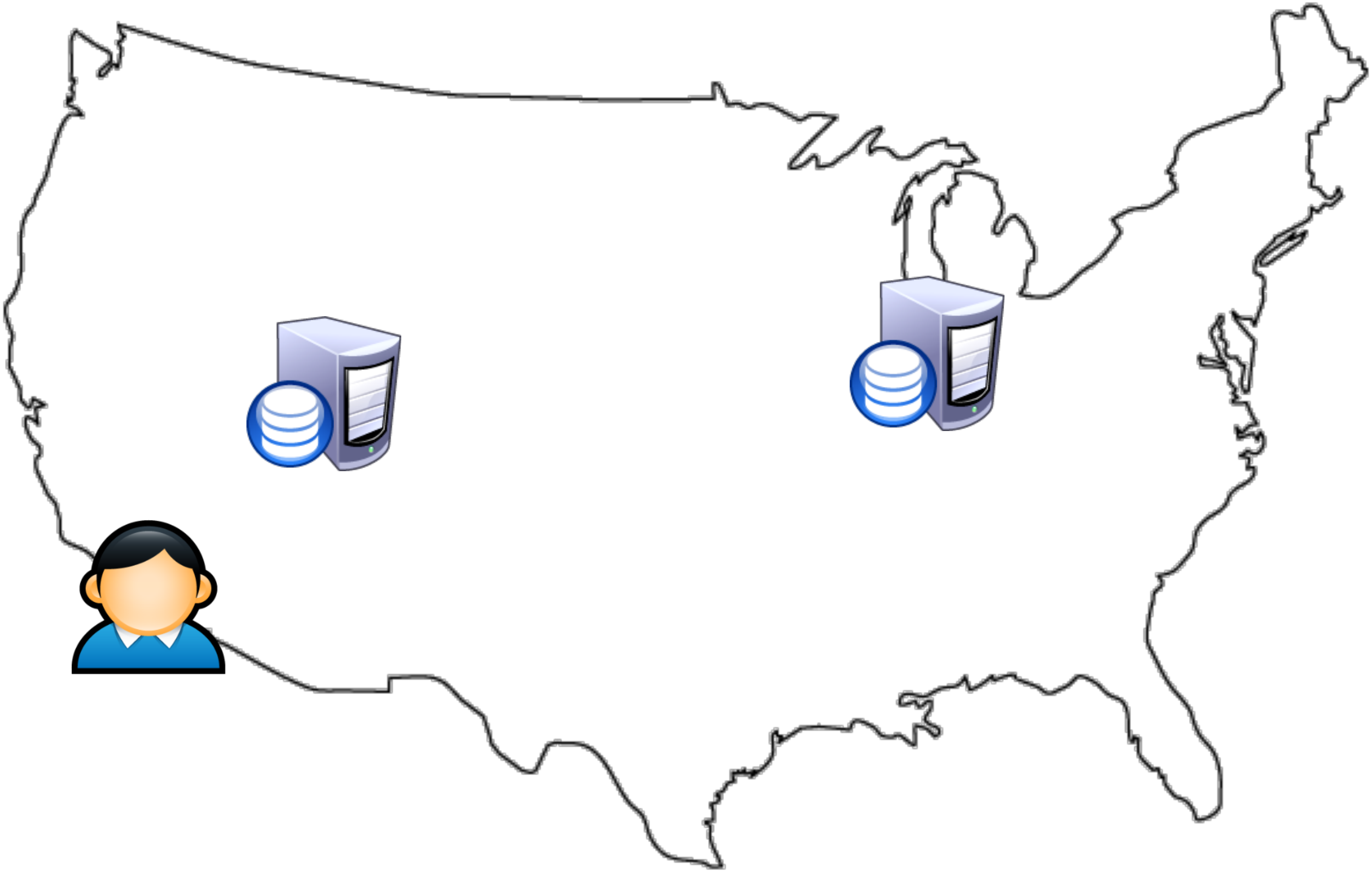


- One domain can map to multiple machines



Content Delivery Networks



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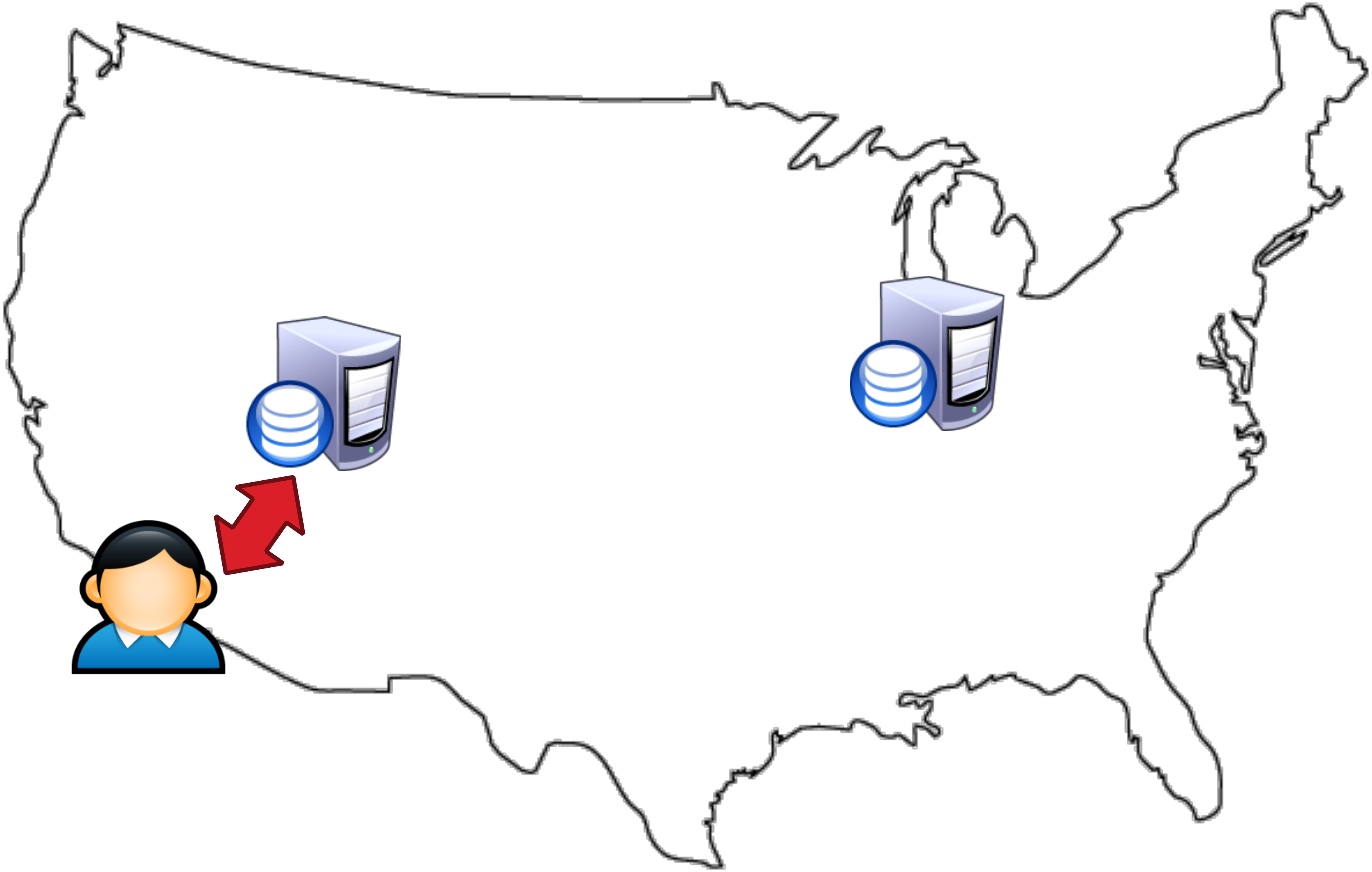

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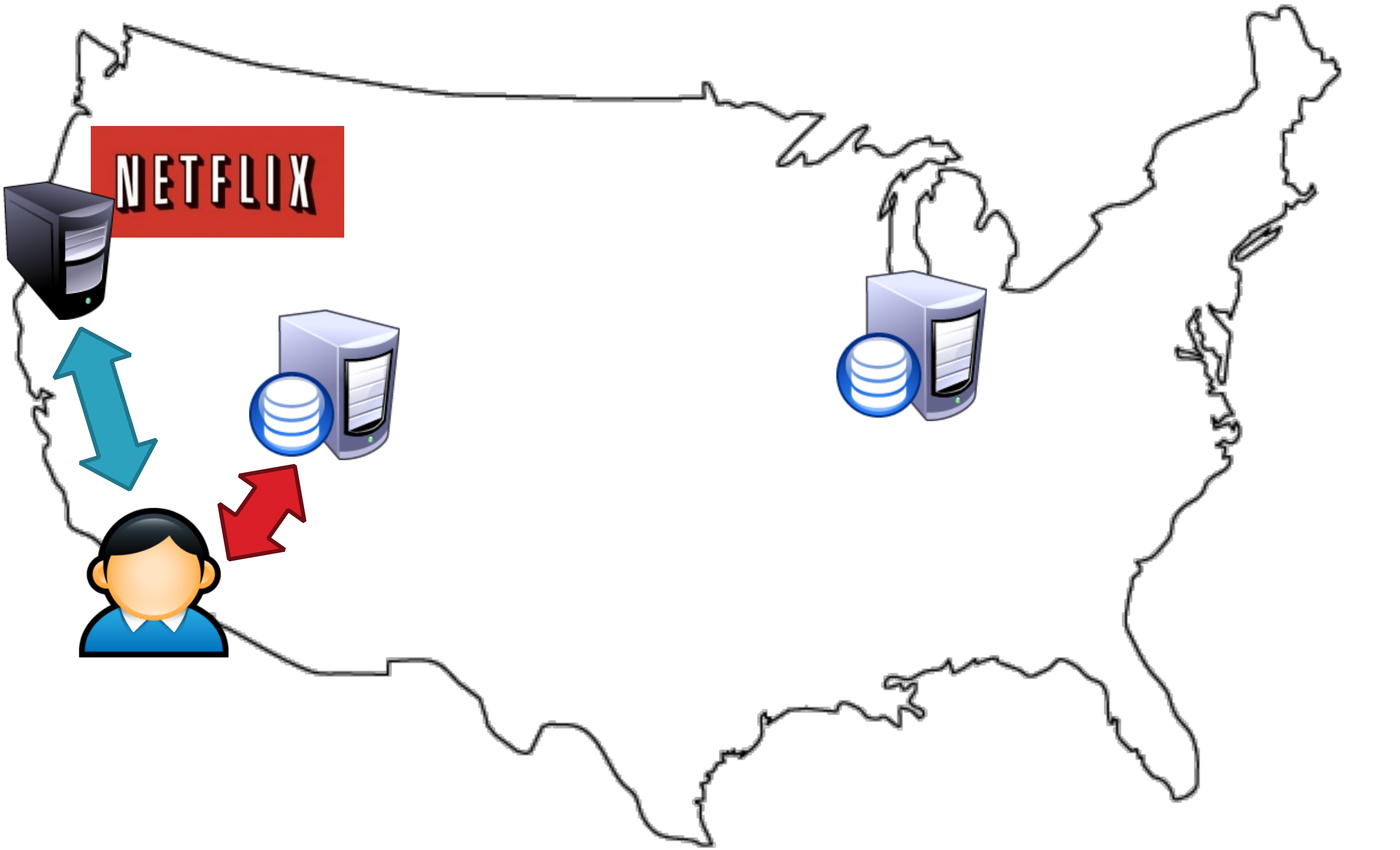

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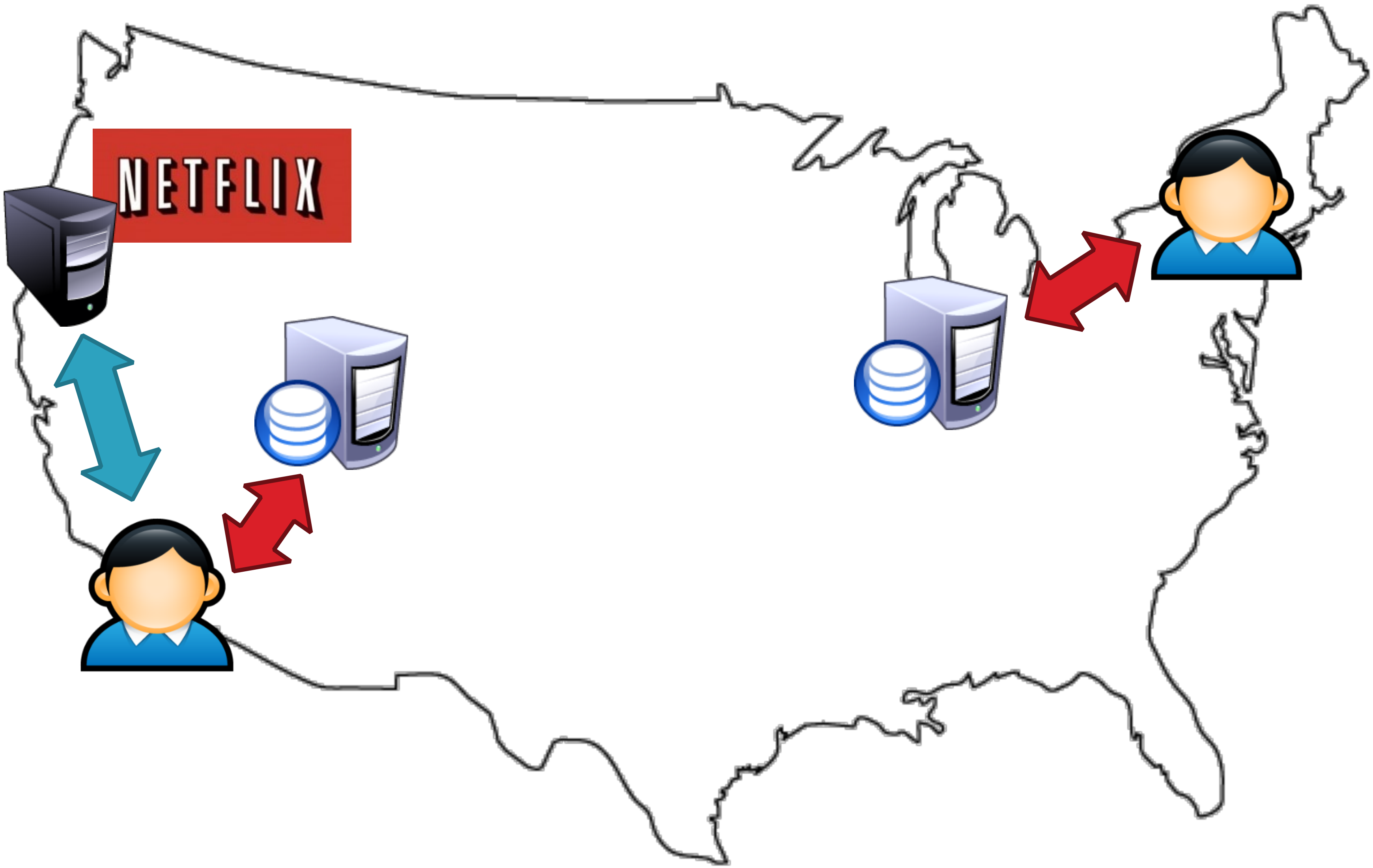

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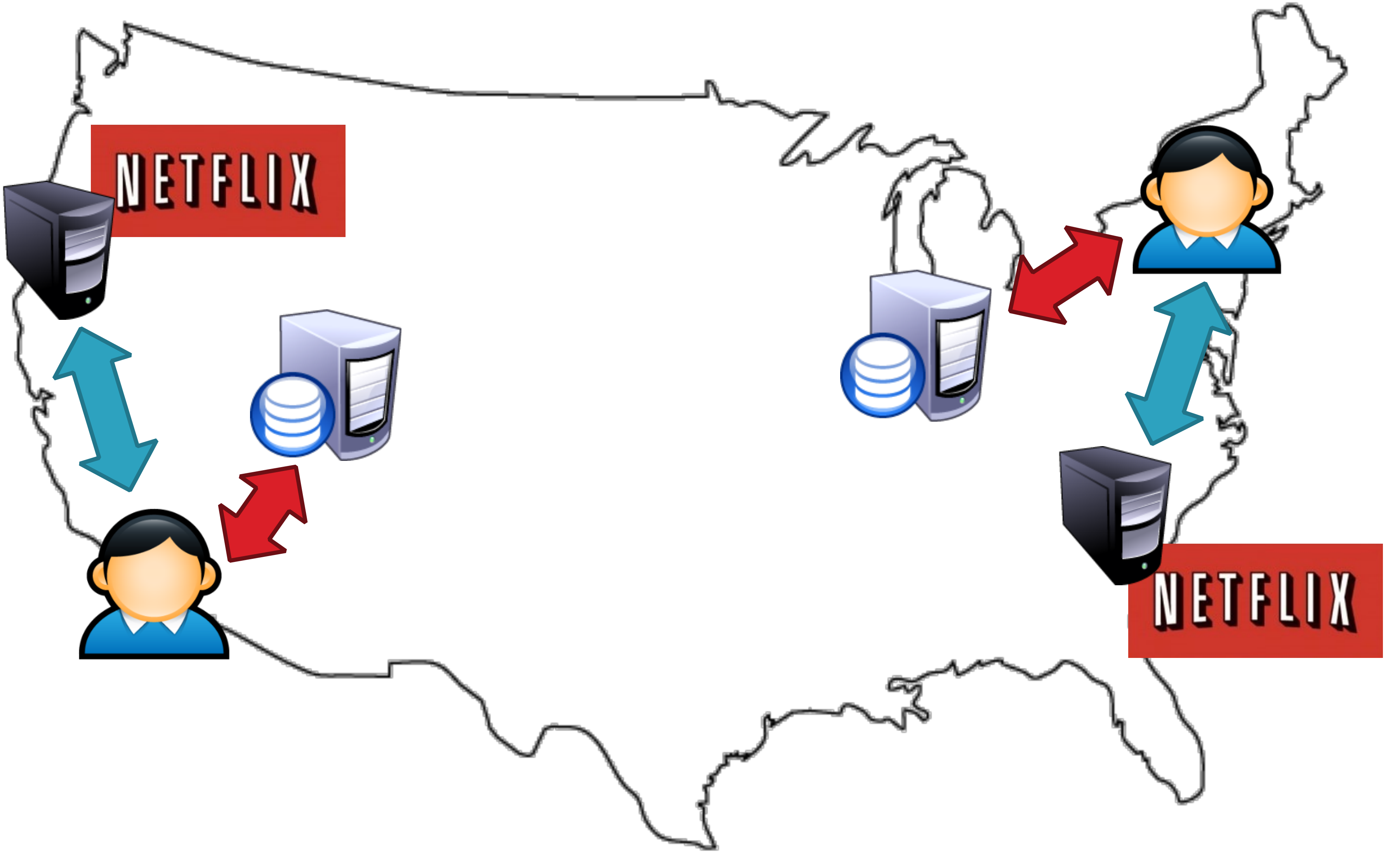

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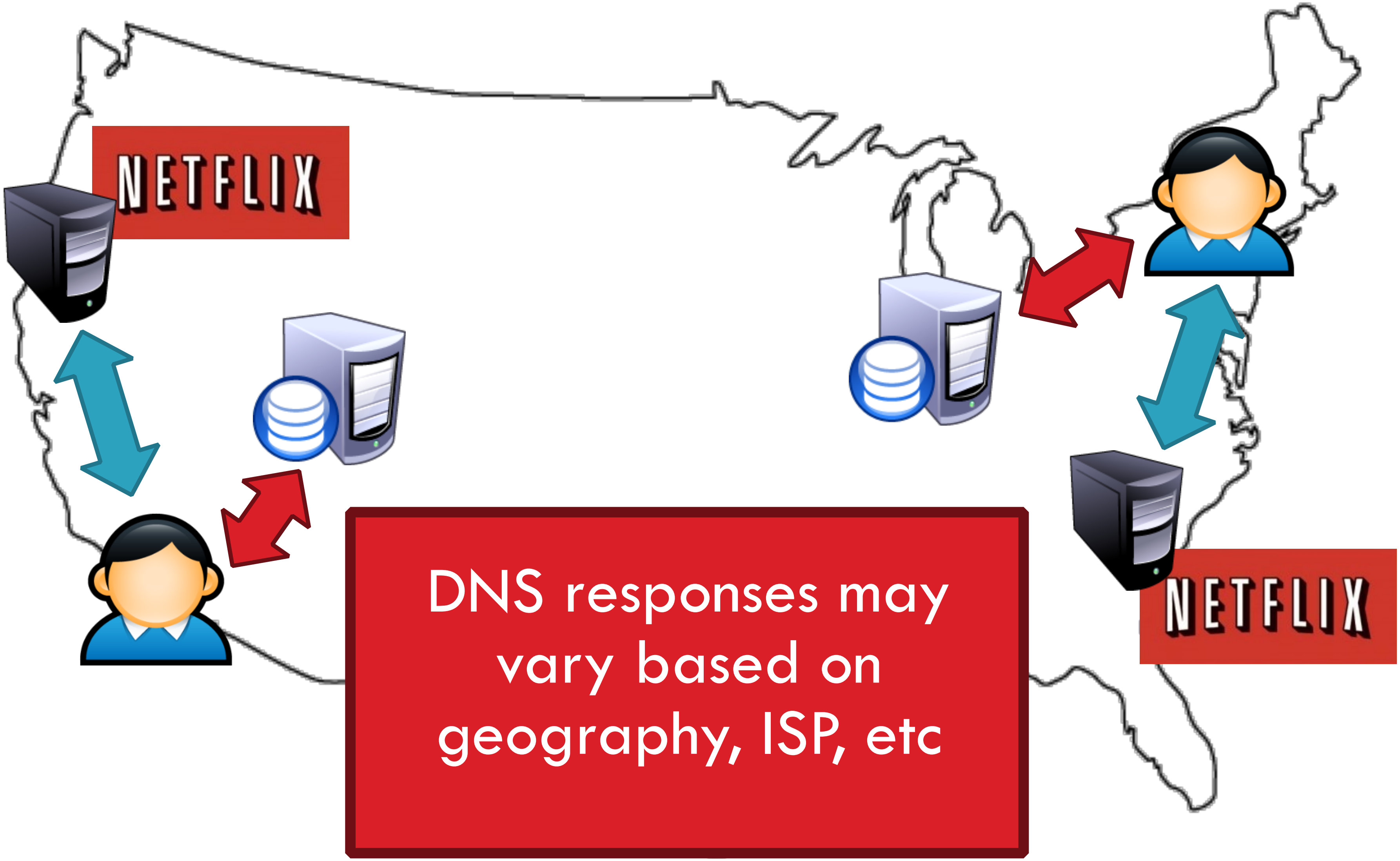

Outline

- DNS Basics
- DNS Security

The Importance of DNS

- Without DNS…
  - How could you get to any websites?

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The Importance of DNS

- Without DNS…
  - How could you get to any websites?
- You are your mailserver
  - When you sign up for websites, you use your email address
  - What if someone hijacks the DNS for your mail server?
- DNS is the root of trust for the web
  - When a user types www.bankofamerica.com, they expect to be taken to their bank's website
  - What if the DNS record is compromised?

Denial Of Service

- Flood DNS servers with requests until they fail
- October 2002: massive DDoS against the root name servers
  - What was the effect?

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- October 2002: massive DDoS against the root name servers
  - What was the effect?
  - … users didn't even notice
  - Root zone file is cached almost everywhere
- More targeted attacks can be effective
  - Local DNS server → cannot access DNS
  - Authoritative server → cannot access domain

DNS Hijacking

- Infect their OS or browser with a virus/trojan
  - e.g. Many trojans change entries in /etc/hosts
  - *.bankofamerica.com → evilbank.com
- Man-in-the-middle

- Response Spoofing
  - Eavesdrop on requests
  - Outrace the servers response

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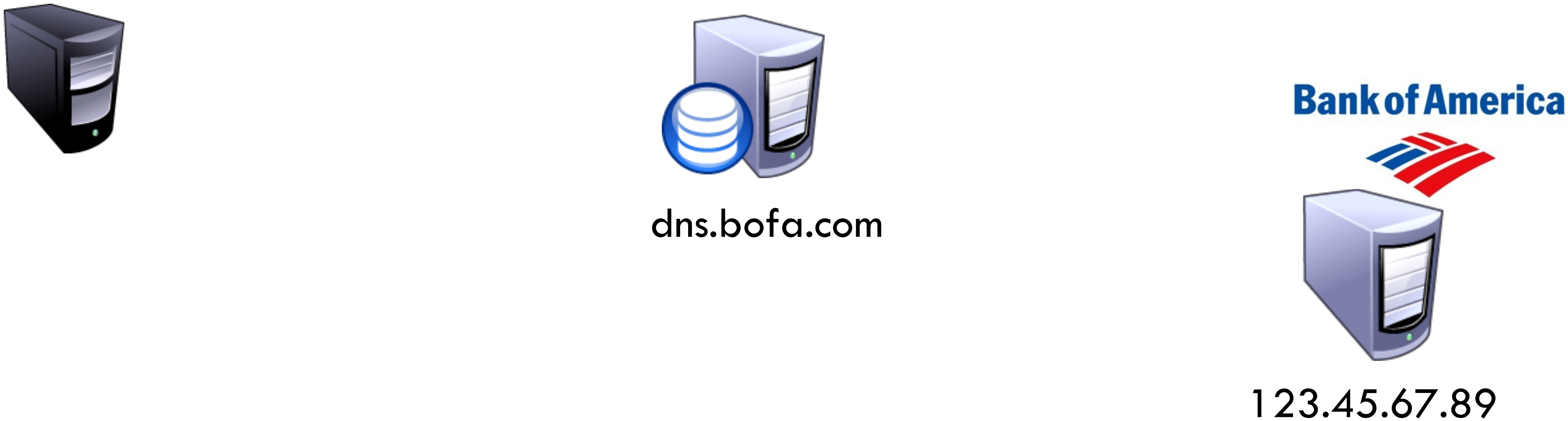
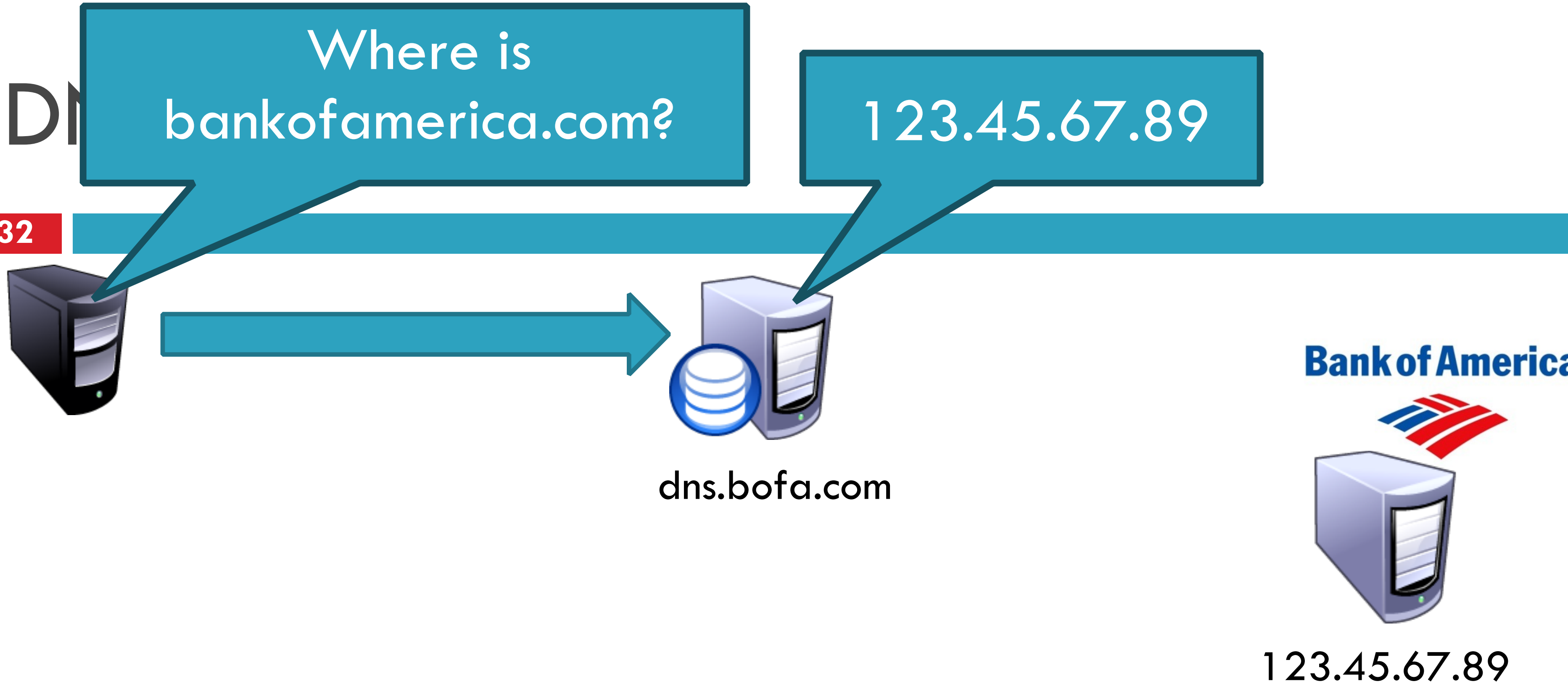


DN


Where is bankofamerica.com?
123.45.67.89
dns.bofa.com
Bank of America
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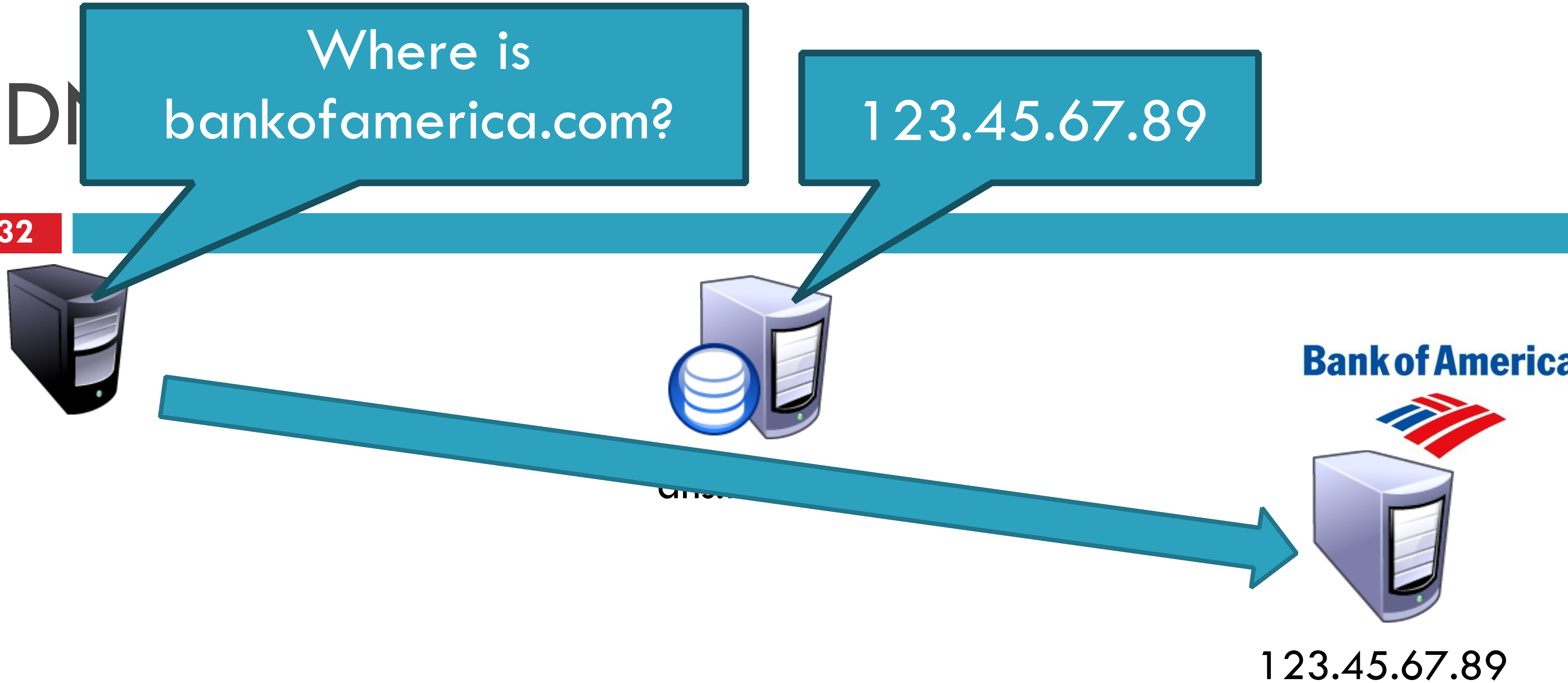
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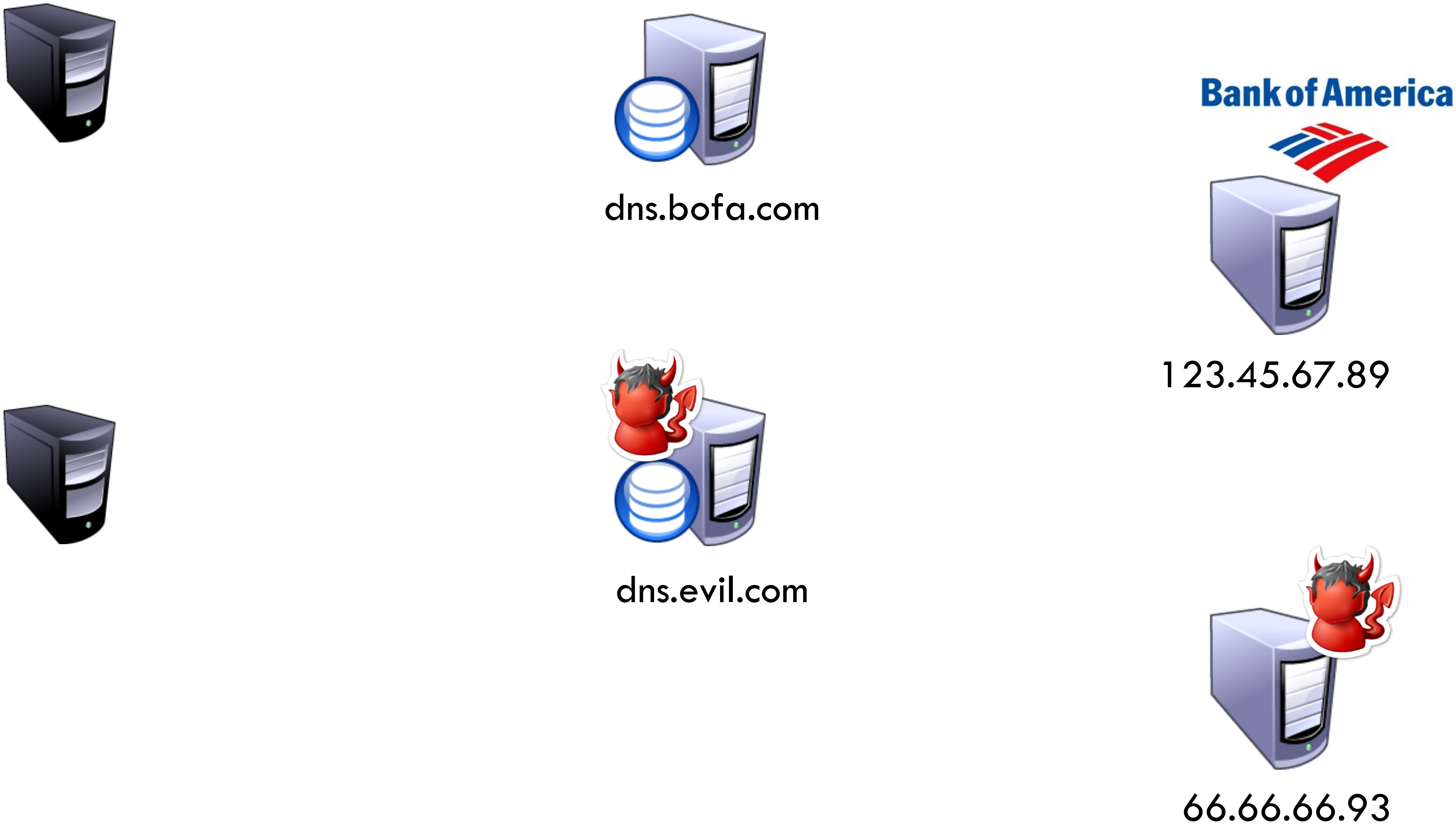

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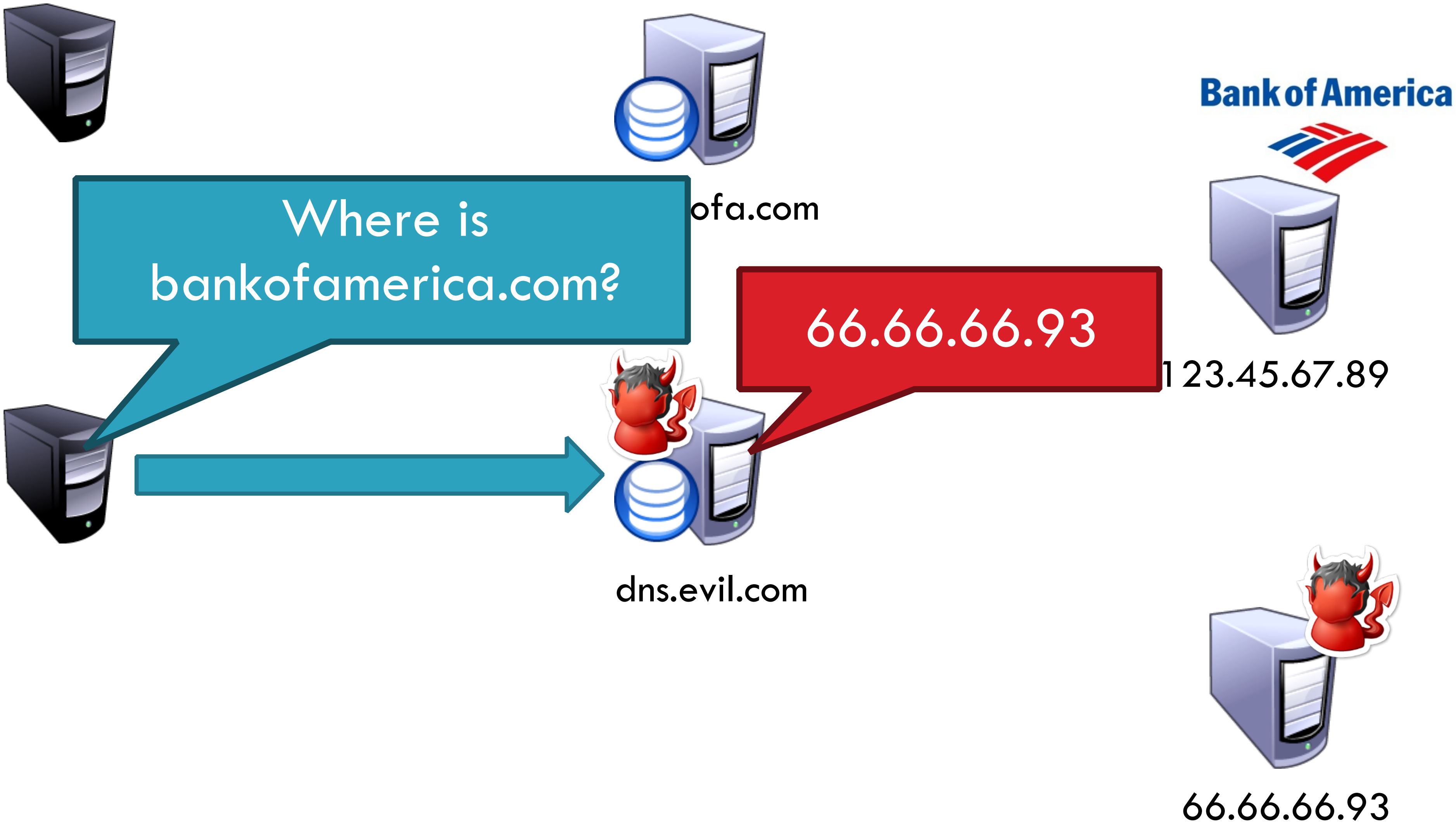

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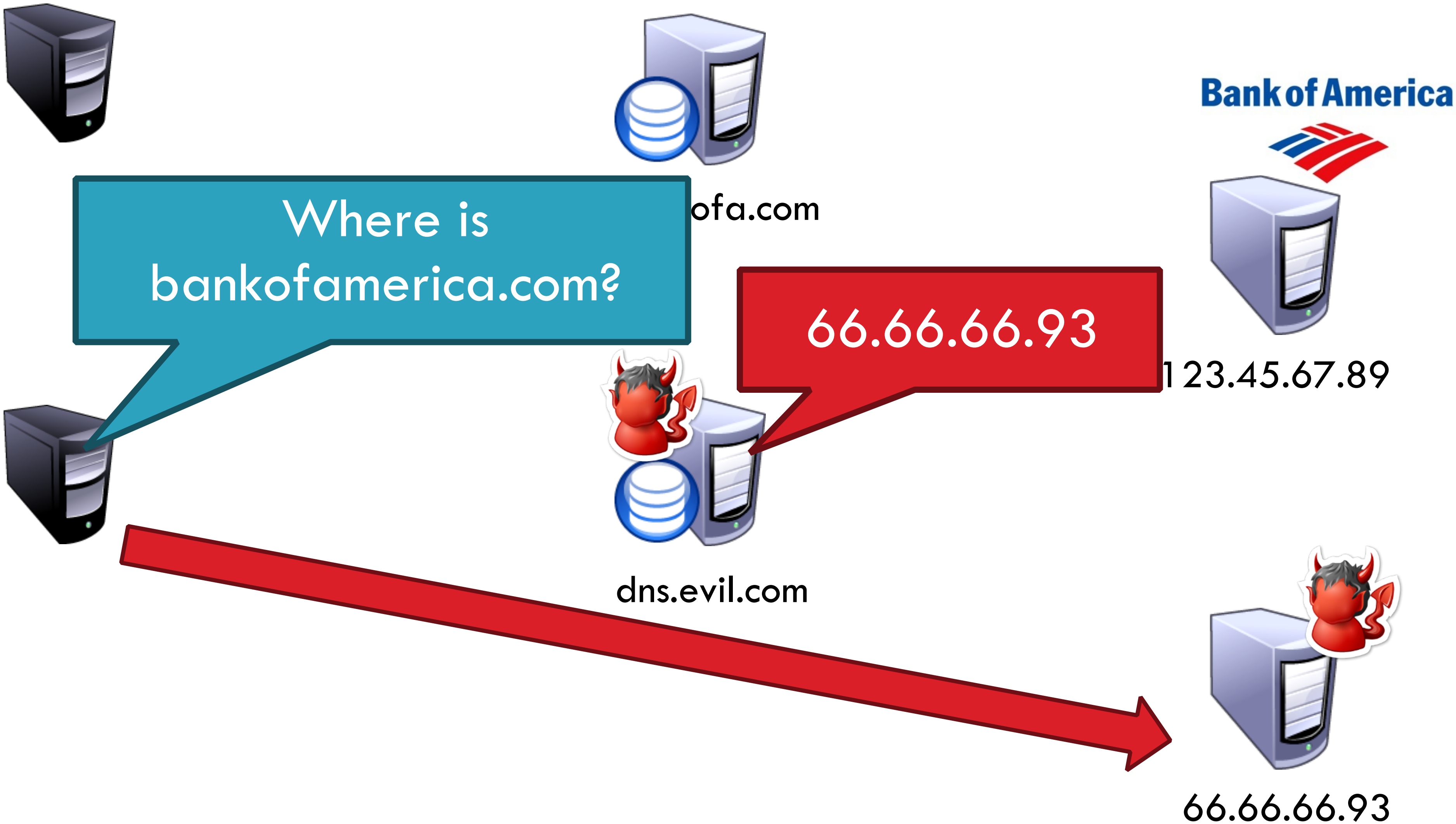

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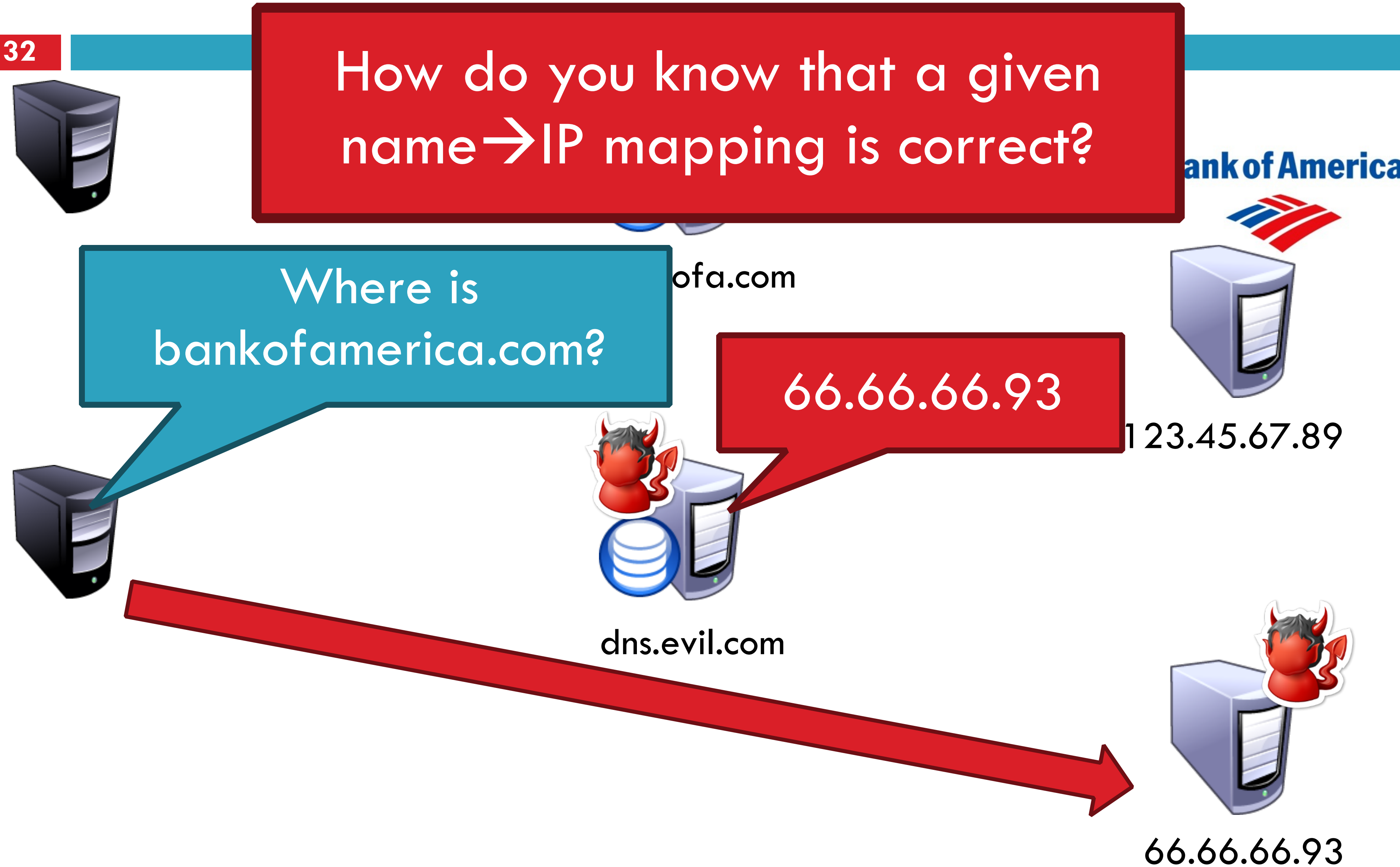

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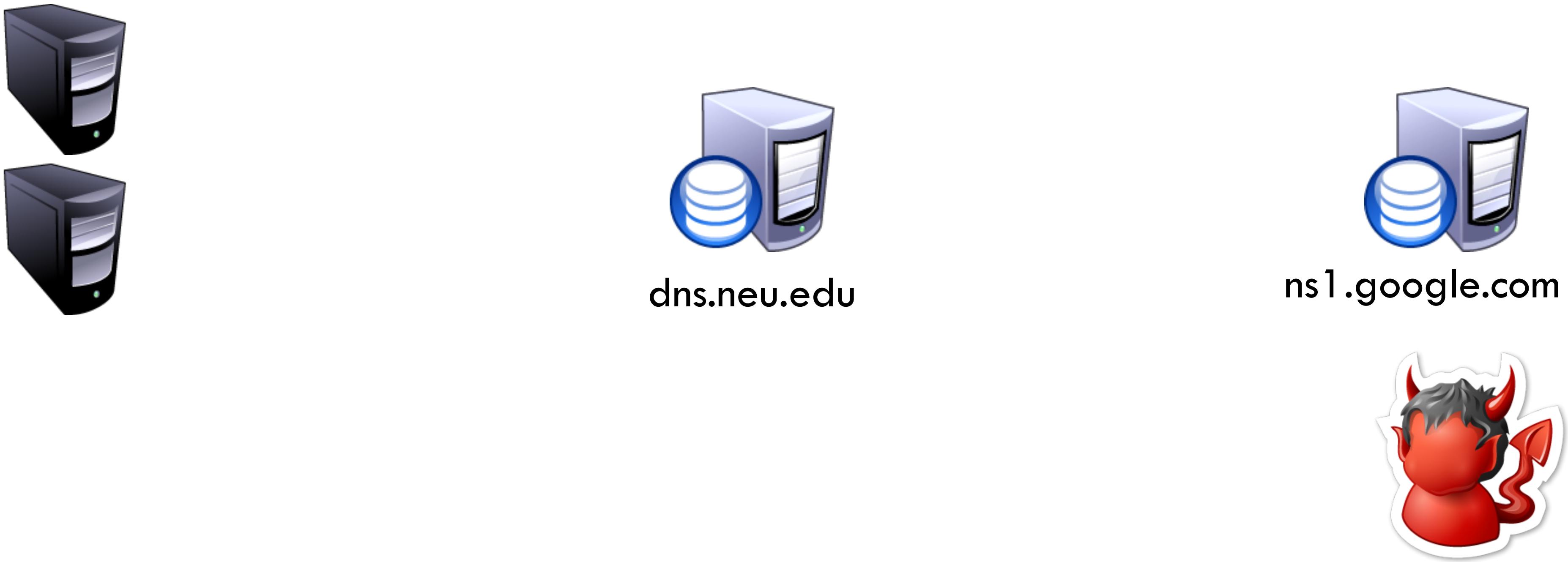

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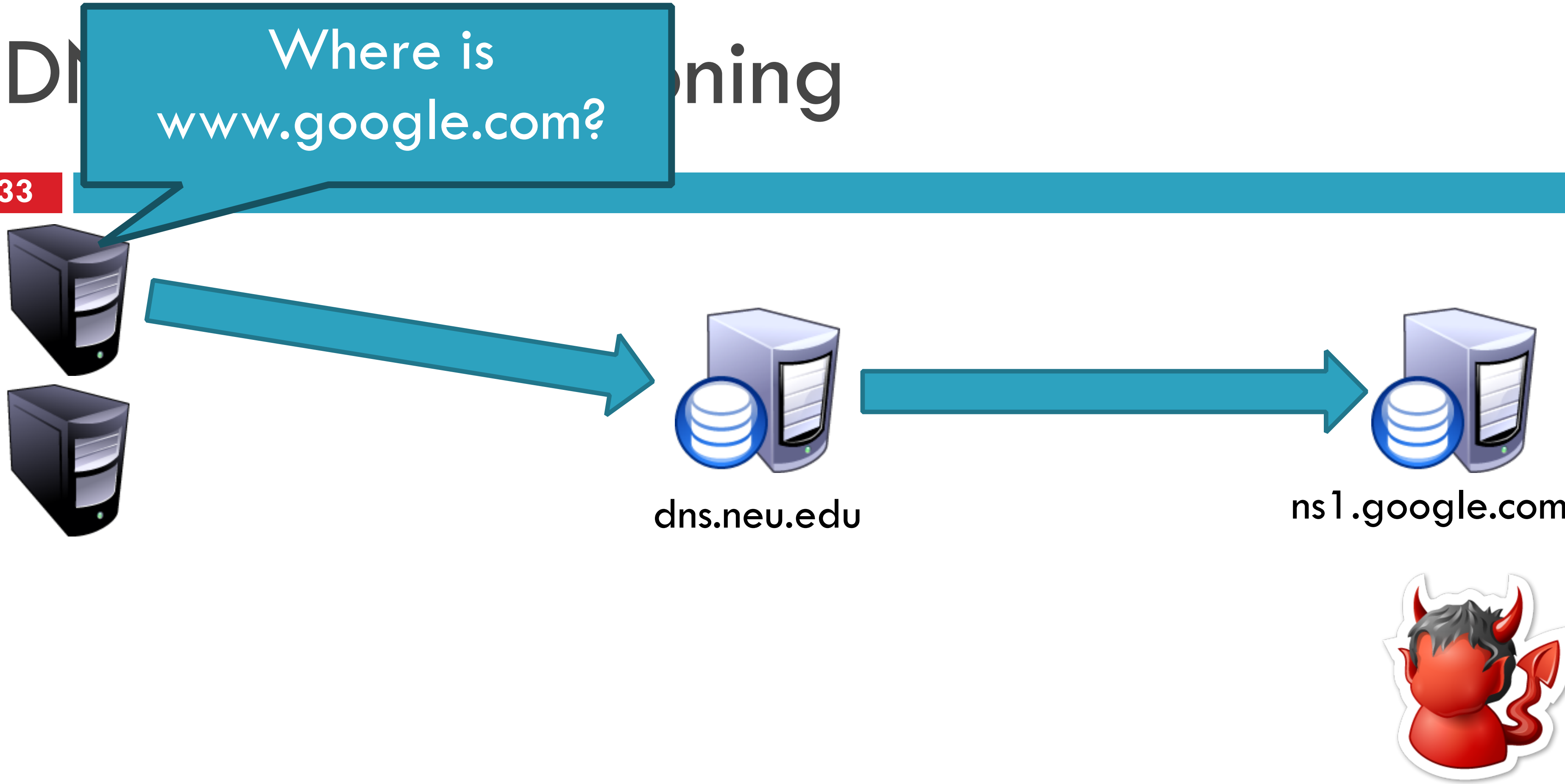

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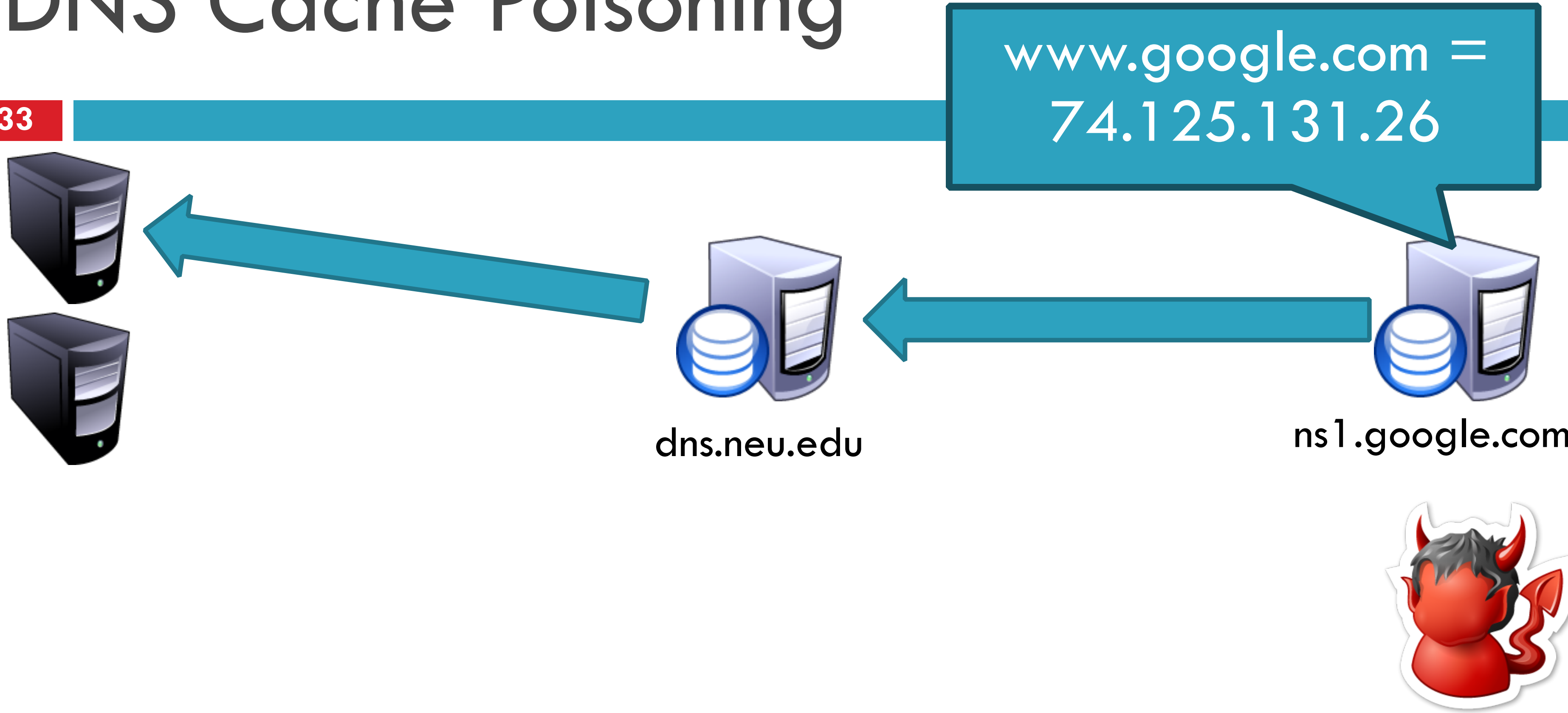

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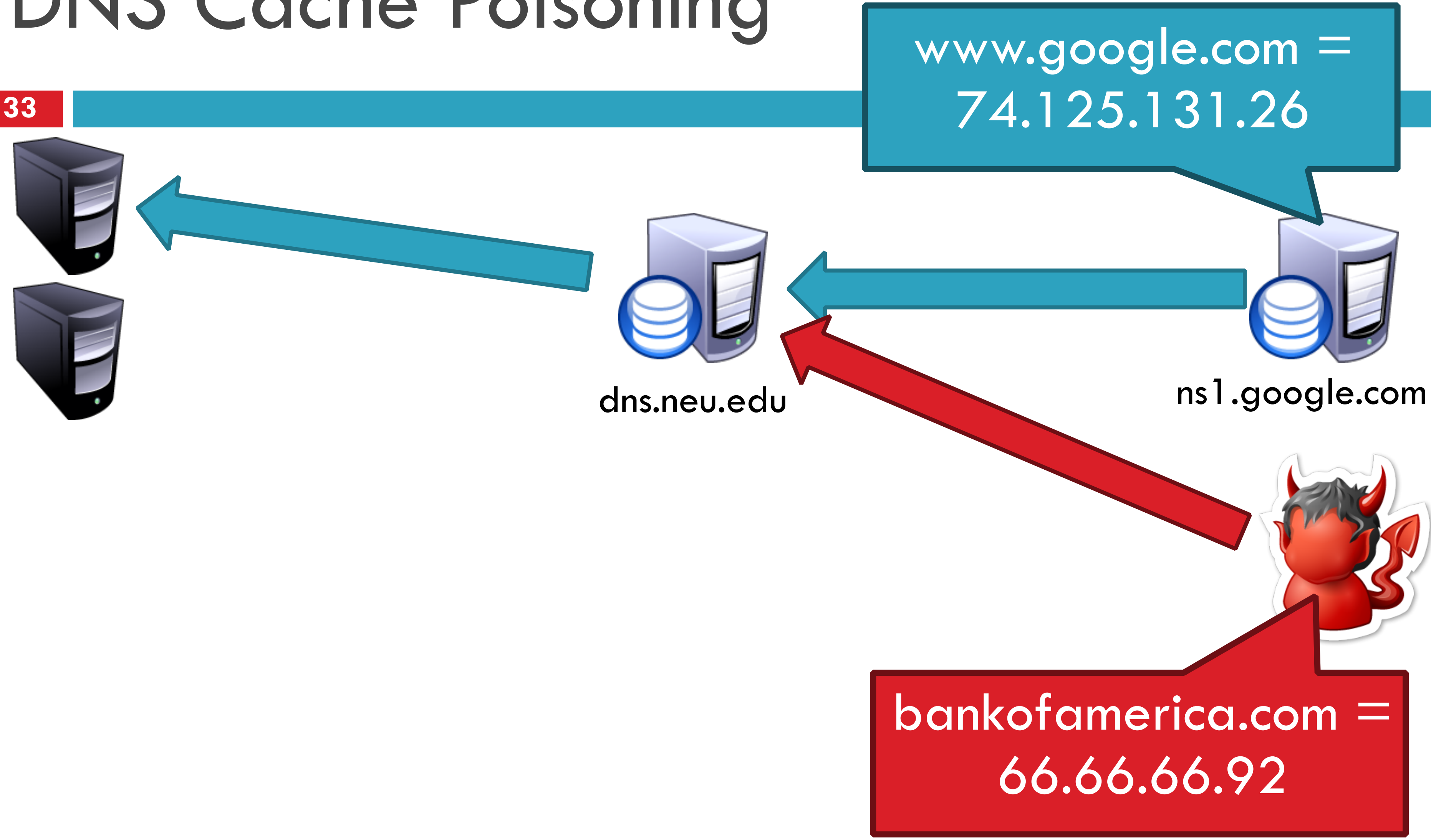

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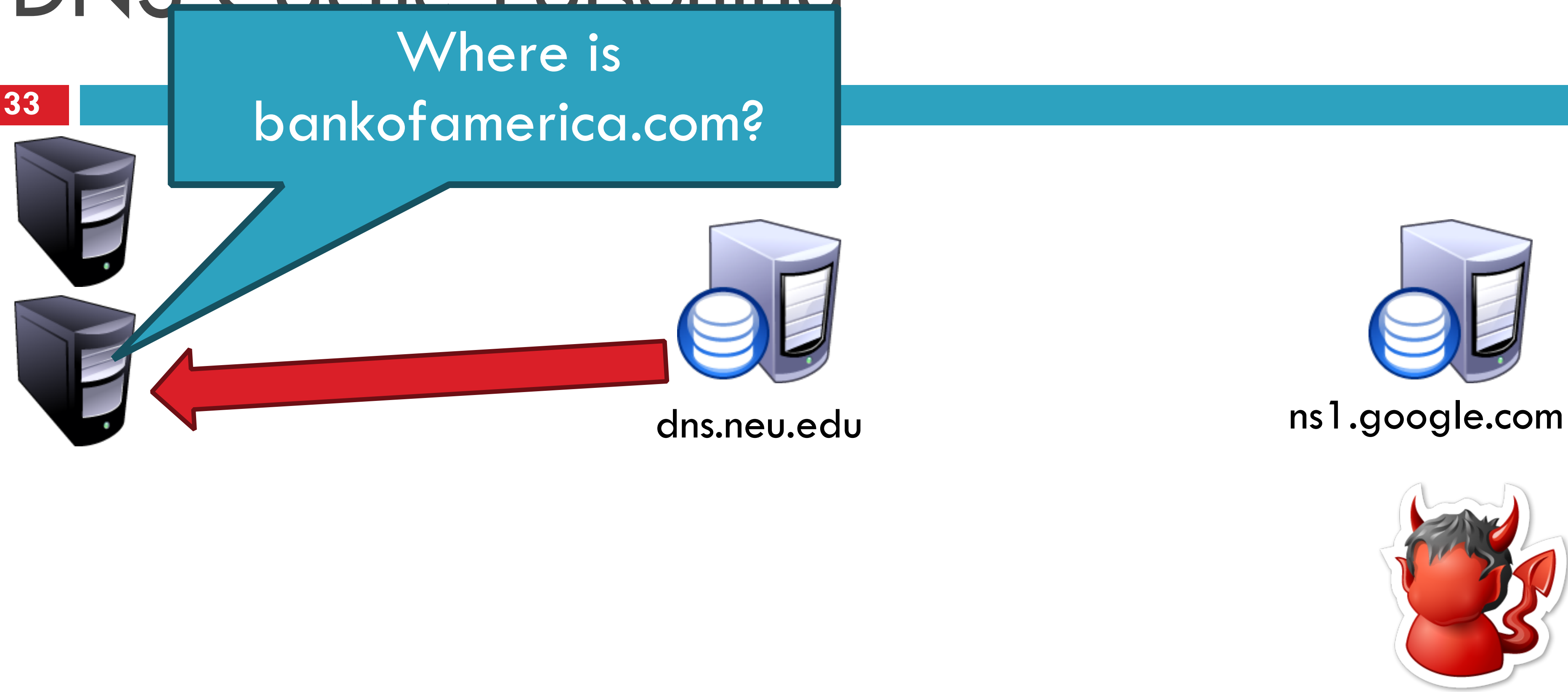

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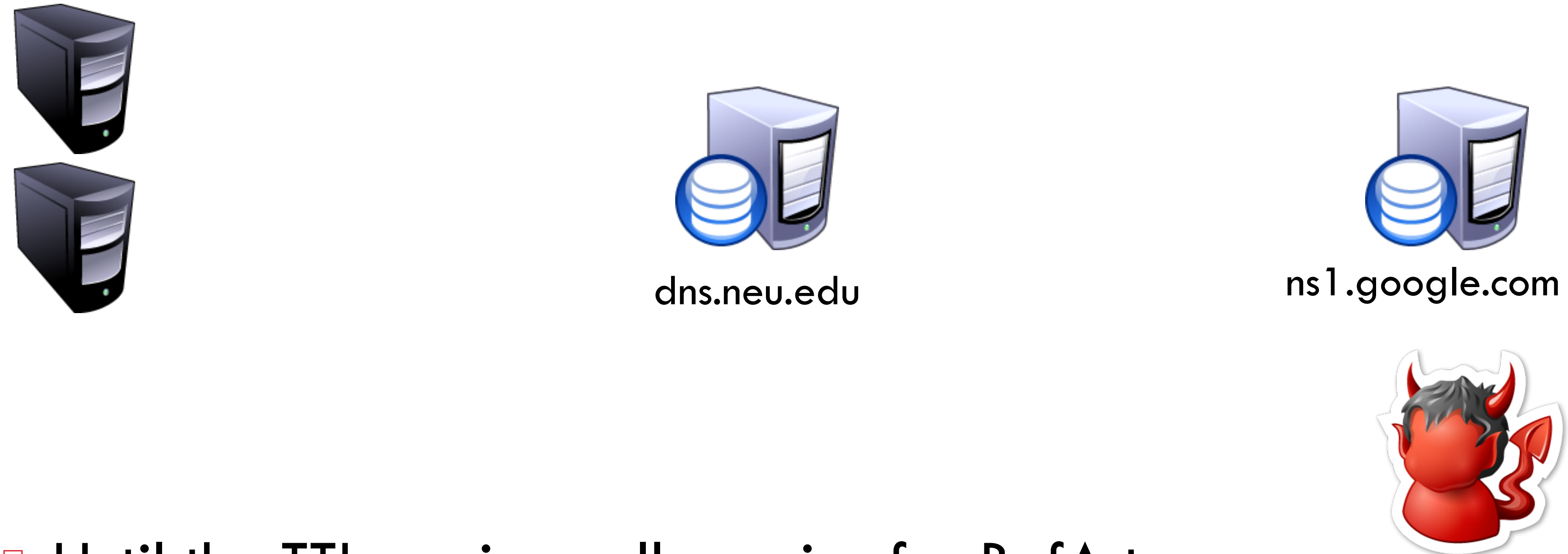

- Until the TTL expires, all queries for BofA to dns.neu.edu will return poisoned result
- Much worse than spoofing/man-in-the-middle
  - Whole ISPs can be impacted!

Solution: DNSSEC

- Cryptographically sign critical resource records
  - Resolver can verify the cryptographic signature
- Two new resource types
  - Type = DNSKEY
    - Name = Zone domain name
    - Value = Public key for the zone
  - Type = RRSIG
    - Name = (type, name) tuple, i.e. the query itself
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Creates a hierarchy of trust within each zone

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Prevents hijacking and spoofing

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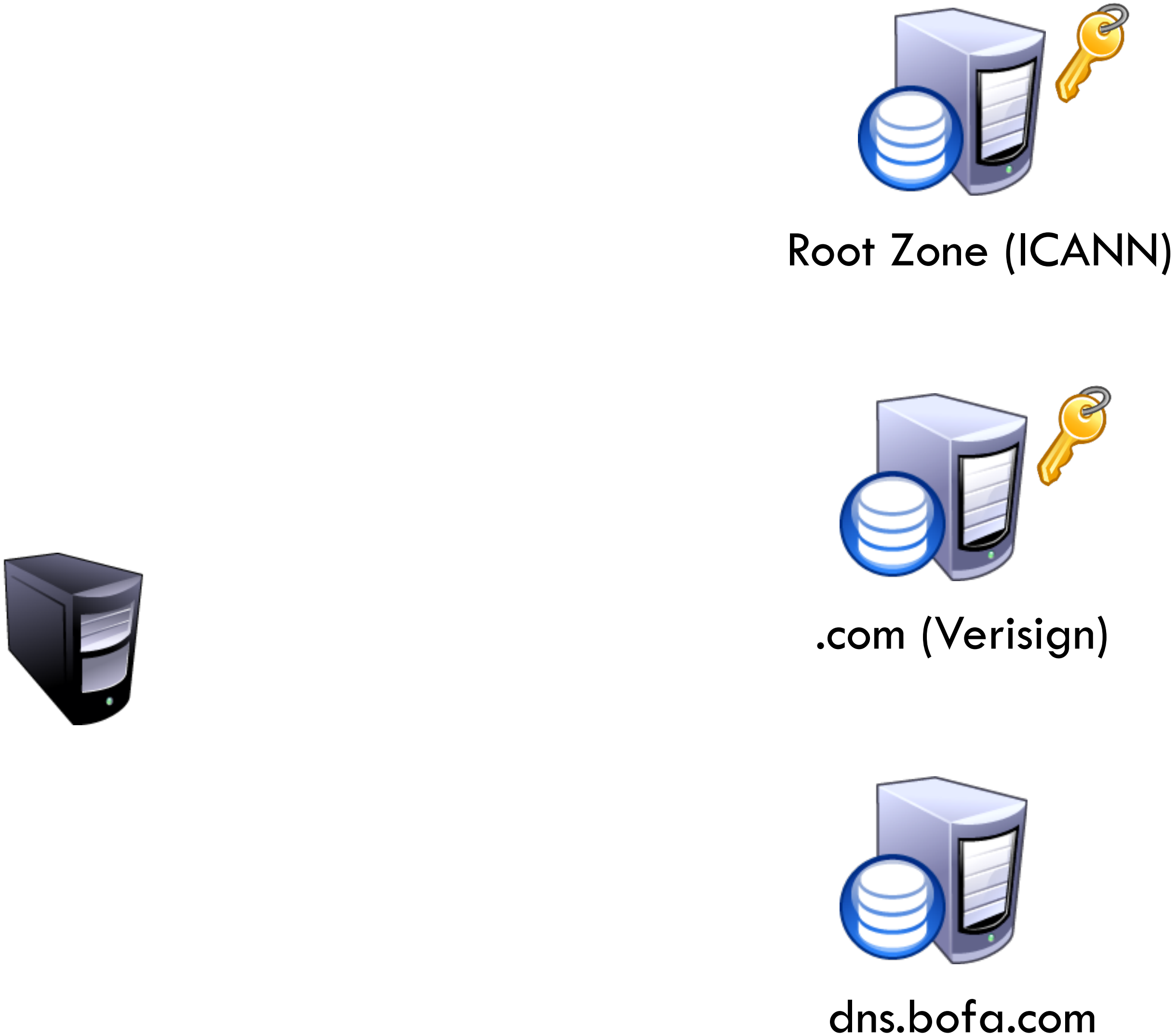
- Deployment
  - On the roots since July 2010
  - Verisign enabled it on .com and .net in January 2011
  - Comcast is the first major ISP to support it (January 2012)

DNSSEC Hierarchy of Trust



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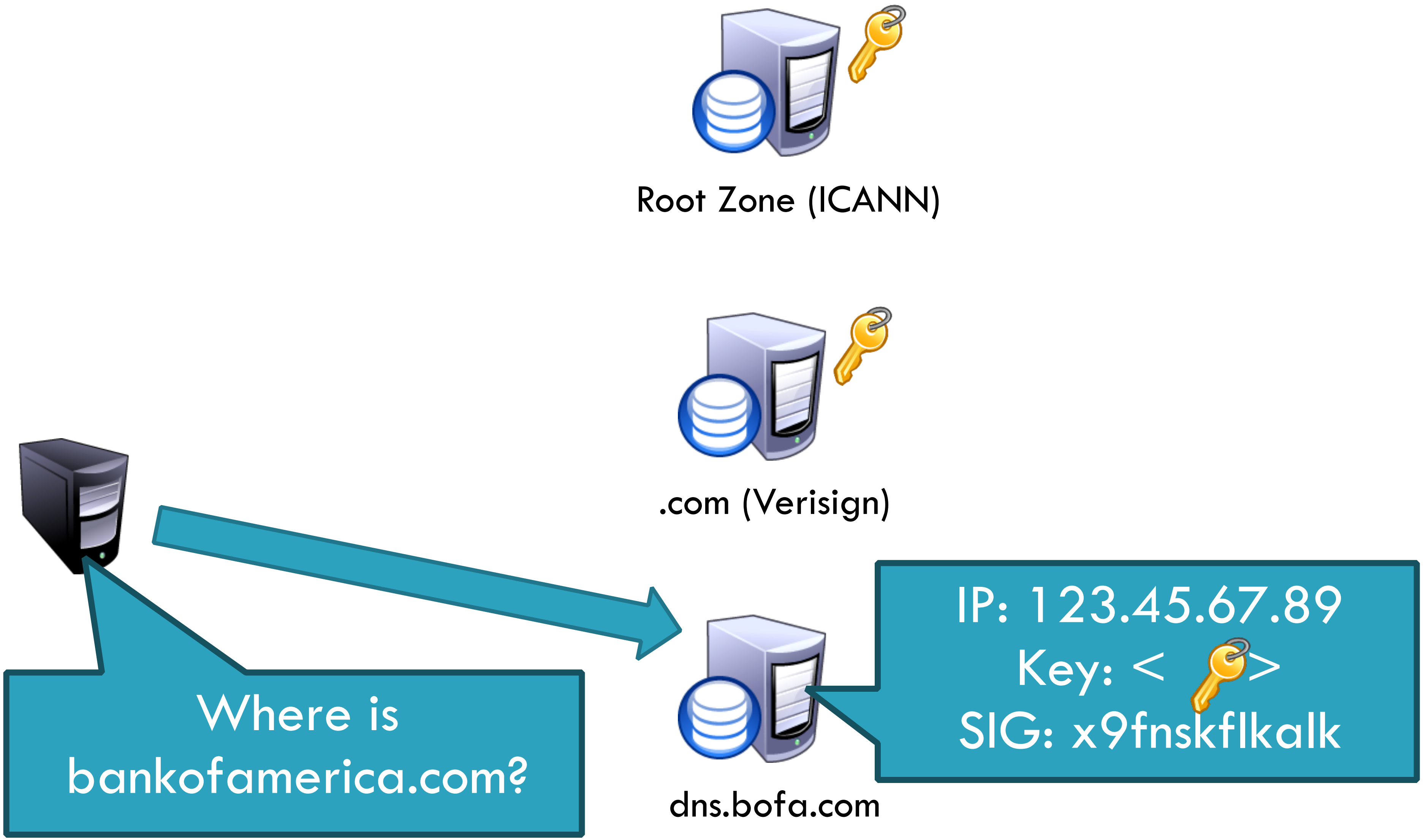

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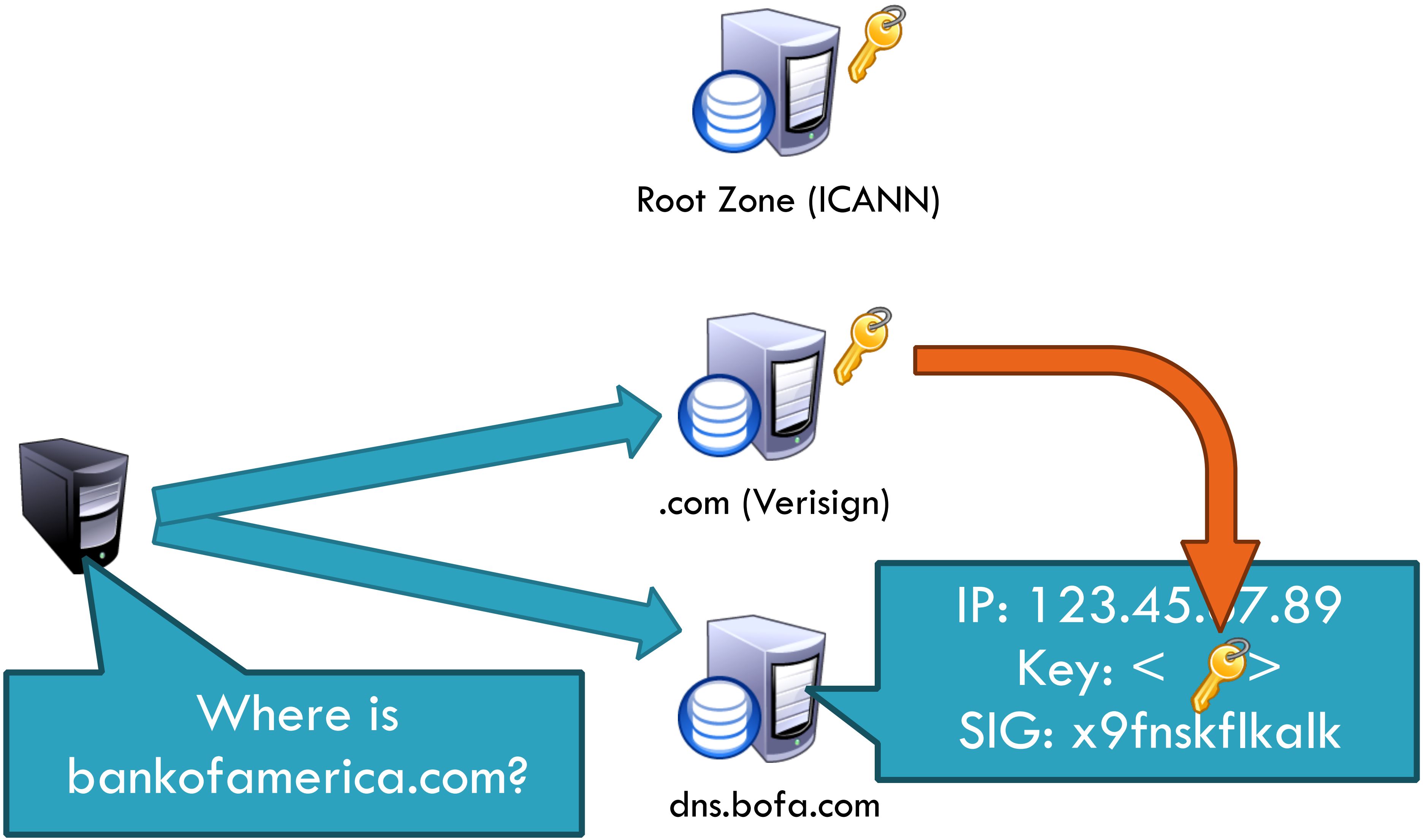

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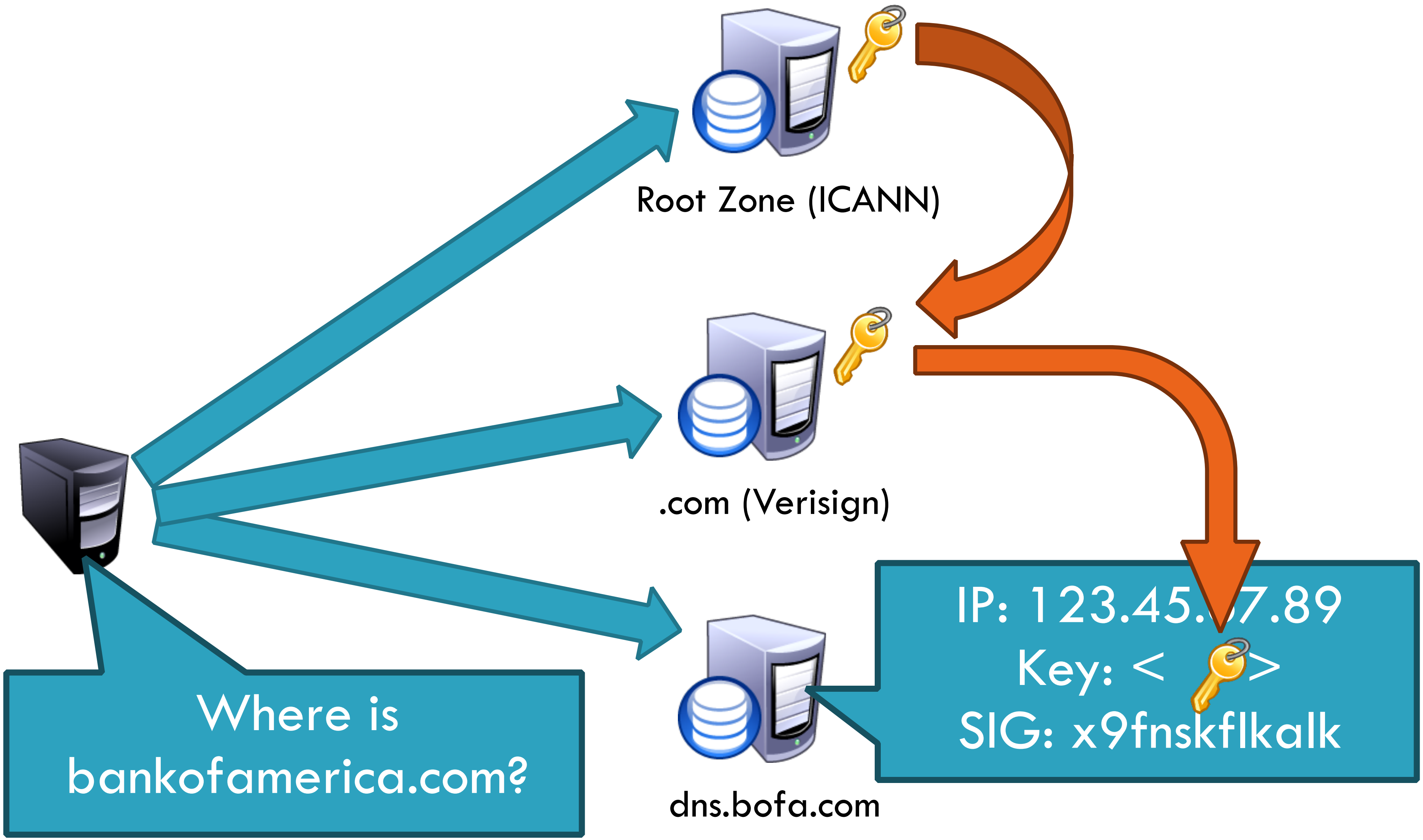

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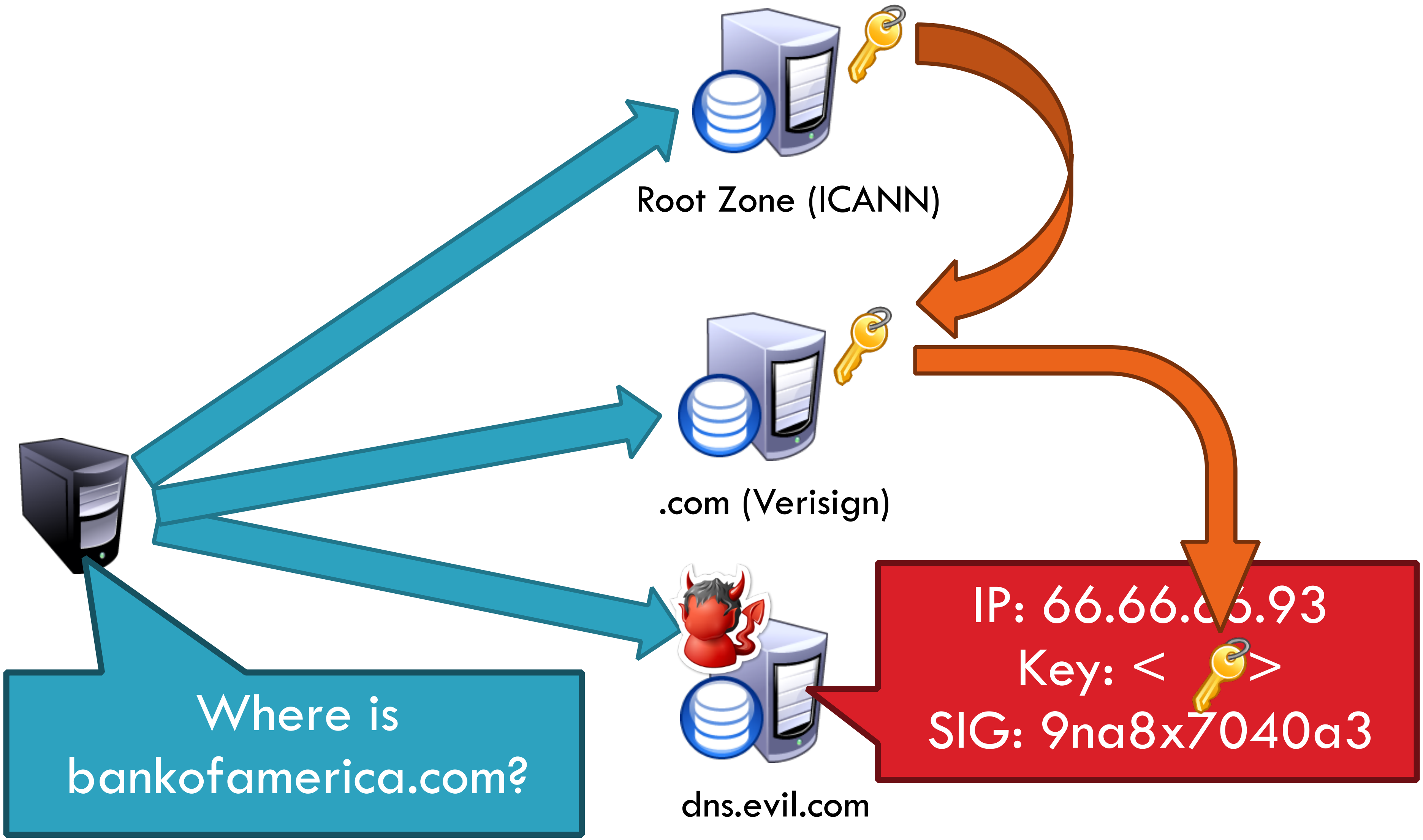

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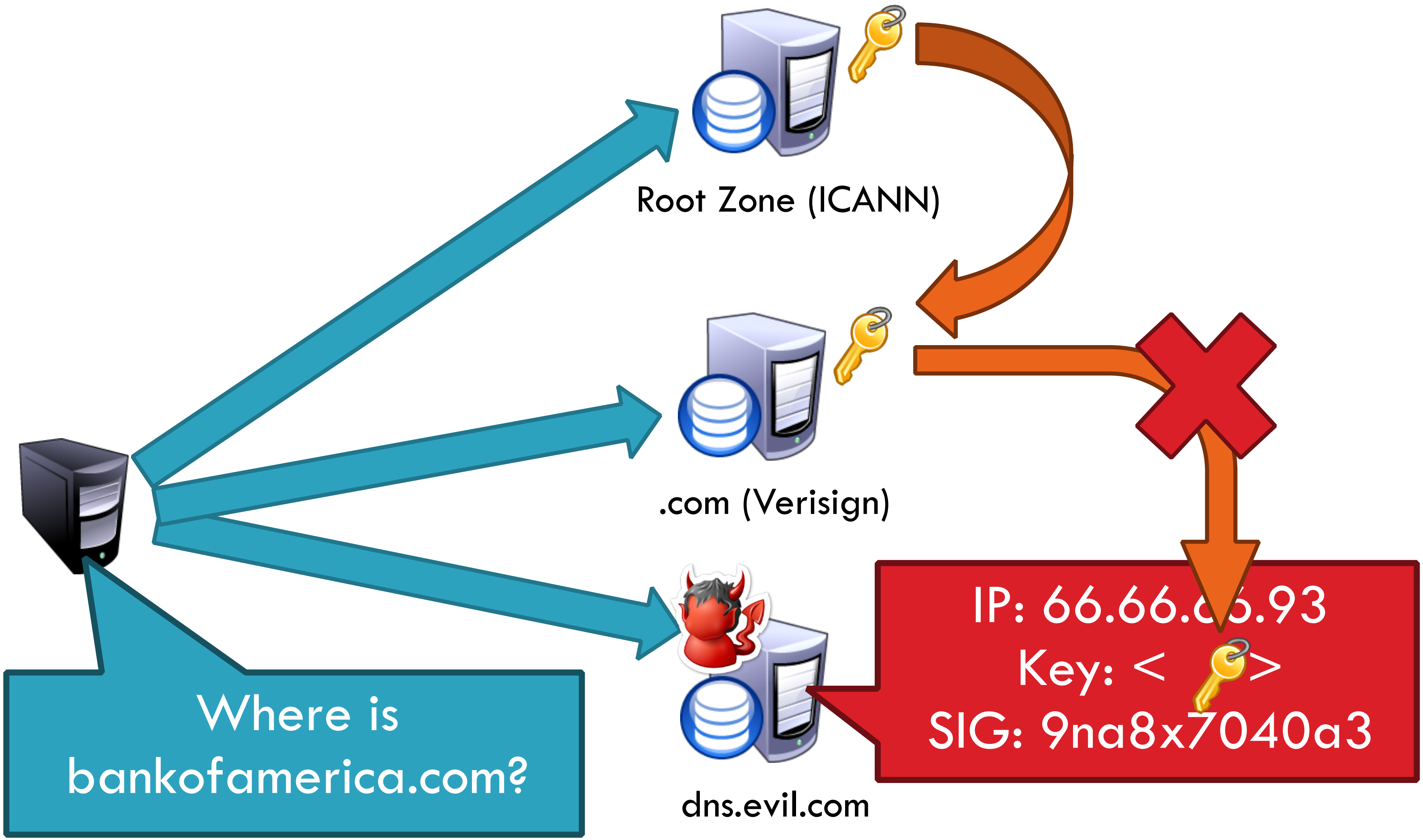

Site Finder

- September 2003: Verisign created DNS wildcards for *.com and *.net
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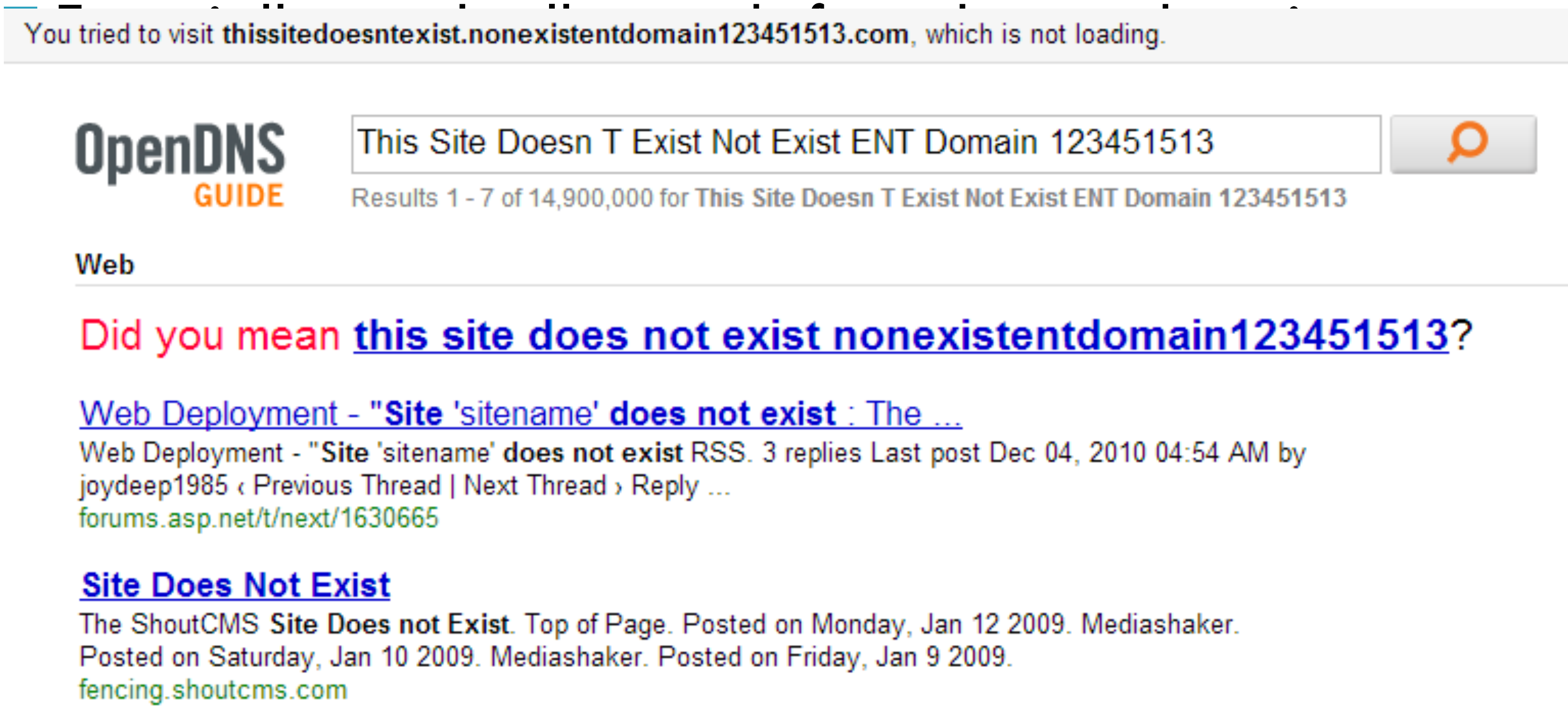

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  - Essentially, catch-all records for unknown domains
  - Pointed to a search website run by Verisign
  - Search website was full of advertisements
- Extremely controversial move
  - Is this DNS hijacking?
  - Definitely abuse of trust by Verisign
  - Site Finder was quickly shut down, lawsuits ensued

Much More to DNS

- Caching: when, where, how much, etc.

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- DNS and botnets
- Politics and growth of the DNS system
  - Governance
  - New TLDs (.xxx, .biz), eliminating TLDs altogether
  - Copyright, arbitration, squatting, typo-squatting

Outline

- DNS
- NAT
- Other middleboxes

The IPv4 Shortage

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  - Additional IPs cost extra
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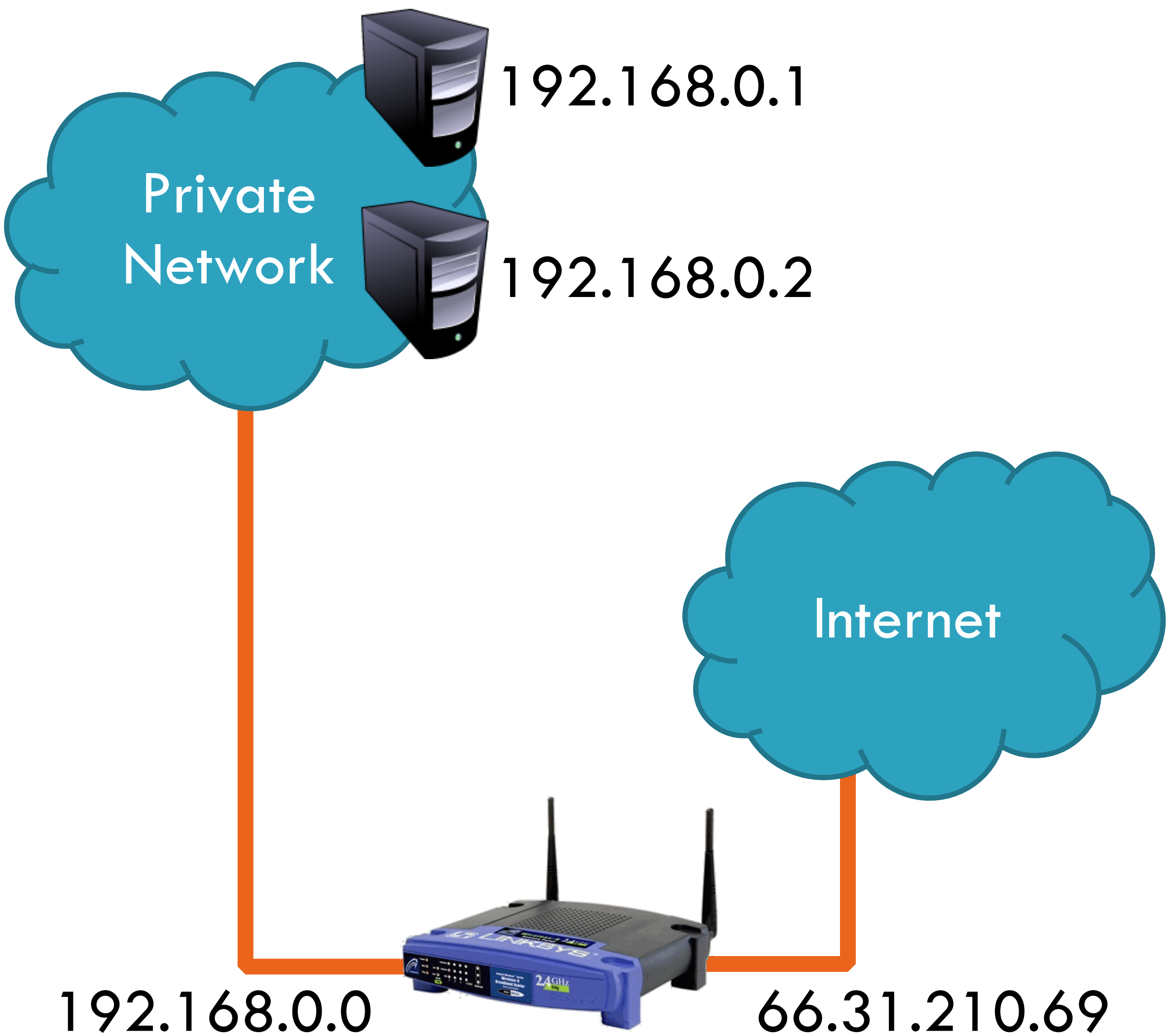
  - Laptops and desktops
  - TV, bluray players, game consoles
  - Tablets, smartphones, eReaders
- How to get all these devices online?

Private IP Networks

- Idea: create a range of private IPs that are separate from the rest of the network
  - Use the private IPs for internal routing
  - Use a special router to bridge the LAN and the WAN
- Properties of private IPs
  - Not globally unique
  - Usually taken from non-routable IP ranges (why?)
- Typical private IP ranges
  - 10.0.0.0 – 10.255.255.255
  - 172.16.0.0 – 172.31.255.255
  - 192.168.0.0 – 192.168.255.255

Private Networks



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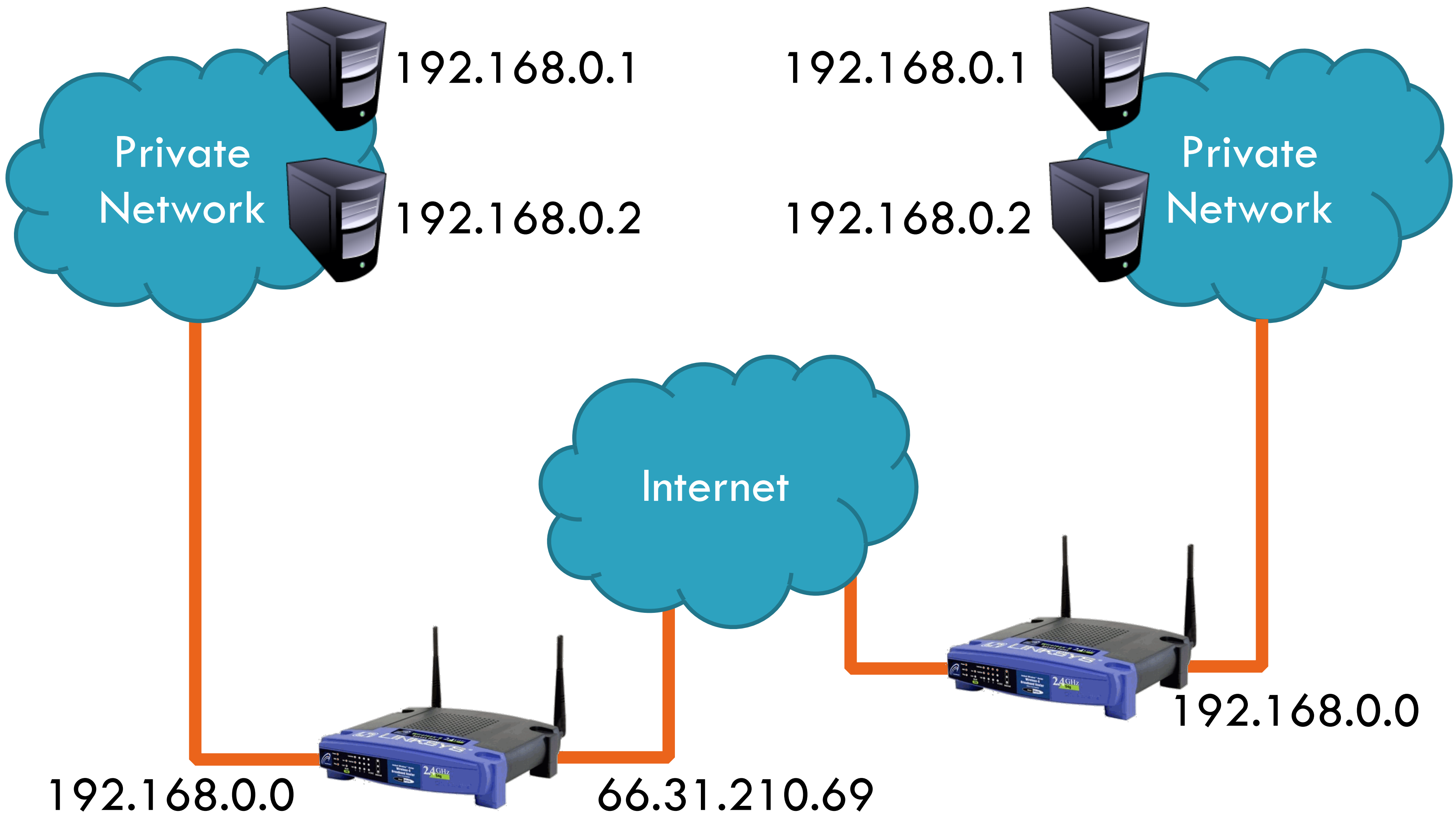

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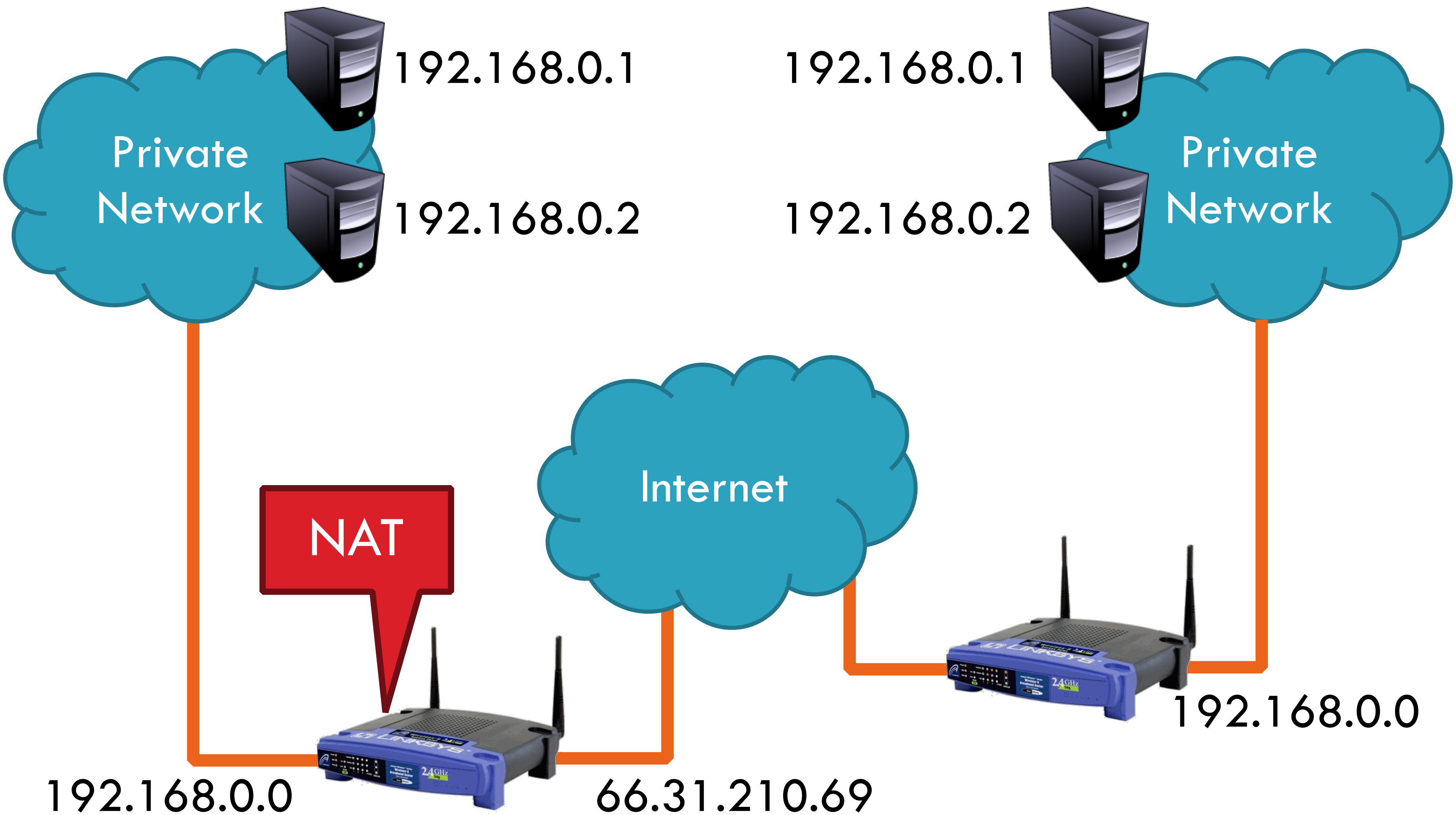
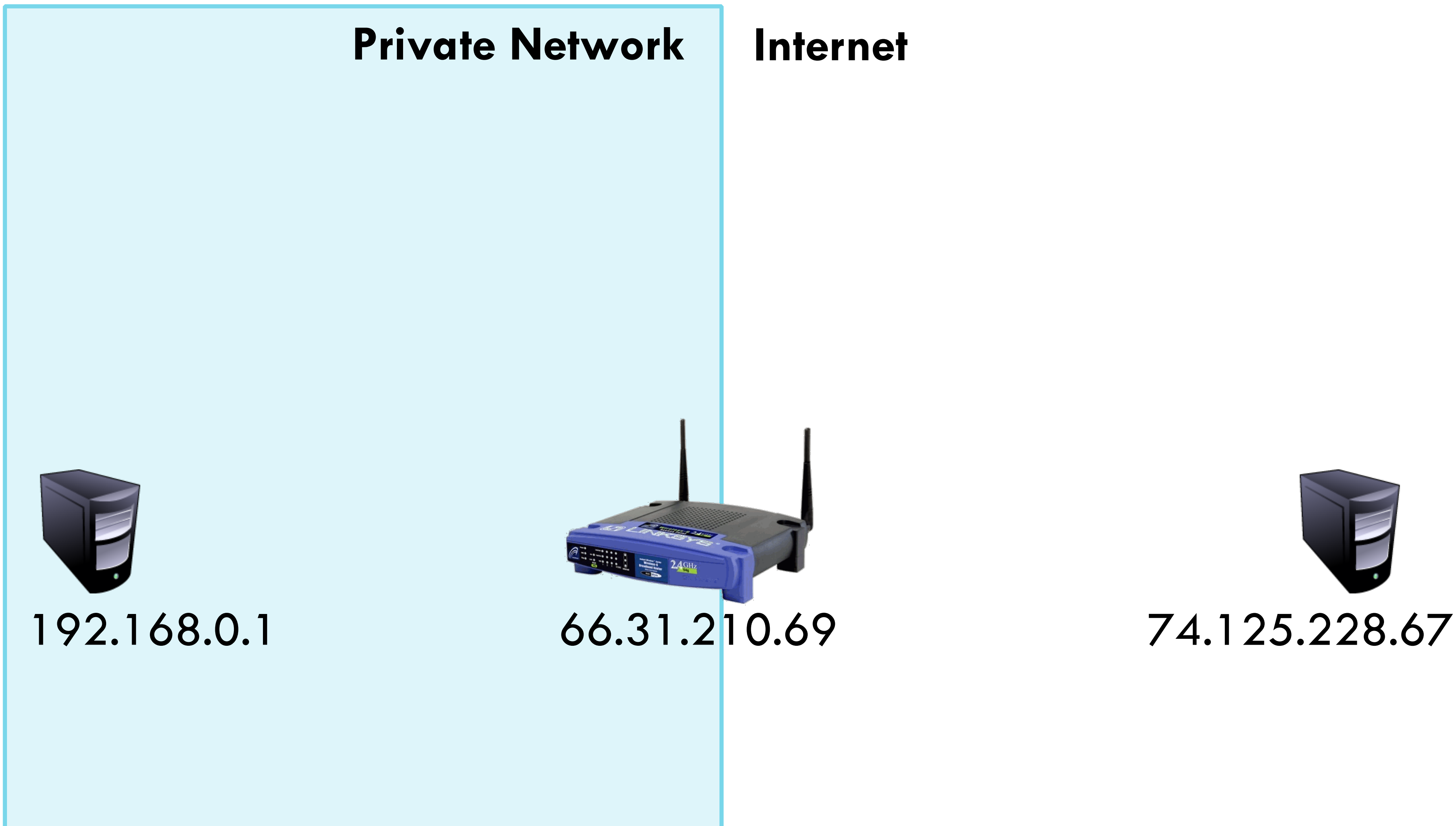


Network Address Translation (NAT)

- NAT allows hosts on a private network to communicate with the Internet
  - Warning: connectivity is not seamless
- Special router at the boundary of a private network
  - Replaces internal IPs with external IP
    - This is "Network Address Translation"
  - May also replace TCP/UDP port numbers
- Maintains a table of active flows
  - Outgoing packets initialize a table entry
  - Incoming packets are rewritten based on the table

Basic NAT Operation



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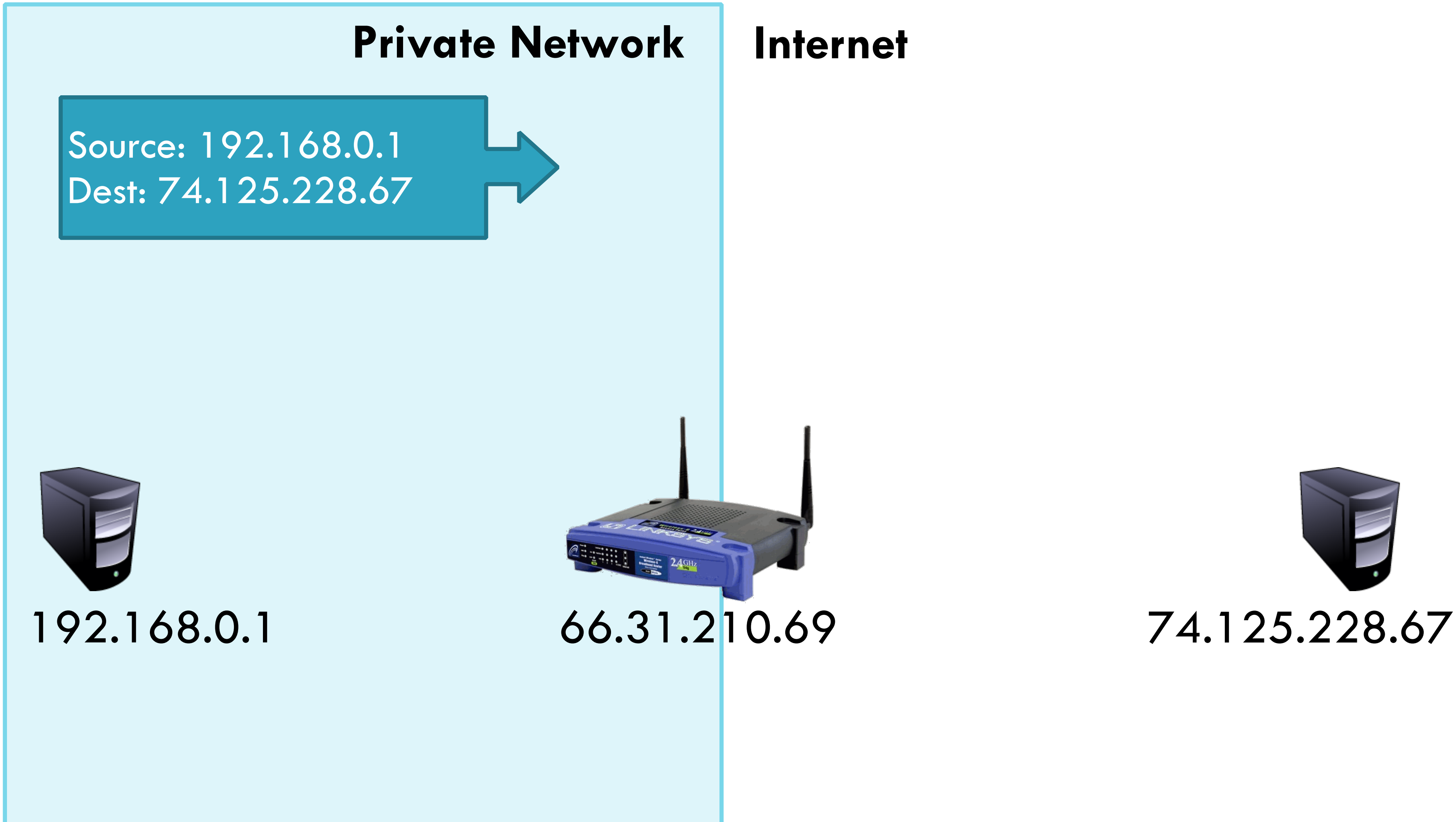

Basic NAT Operation

Private Network **Internet**

Source: 192.168.0.1
Dest: 74.125.228.67

Private Address	**Public Address**
192.168.0.1:2345	***74.125.228.67:80***

192.168.0.1

66.31.210.69

74.125.228.67

Basic NAT Operation

Private Network

Internet

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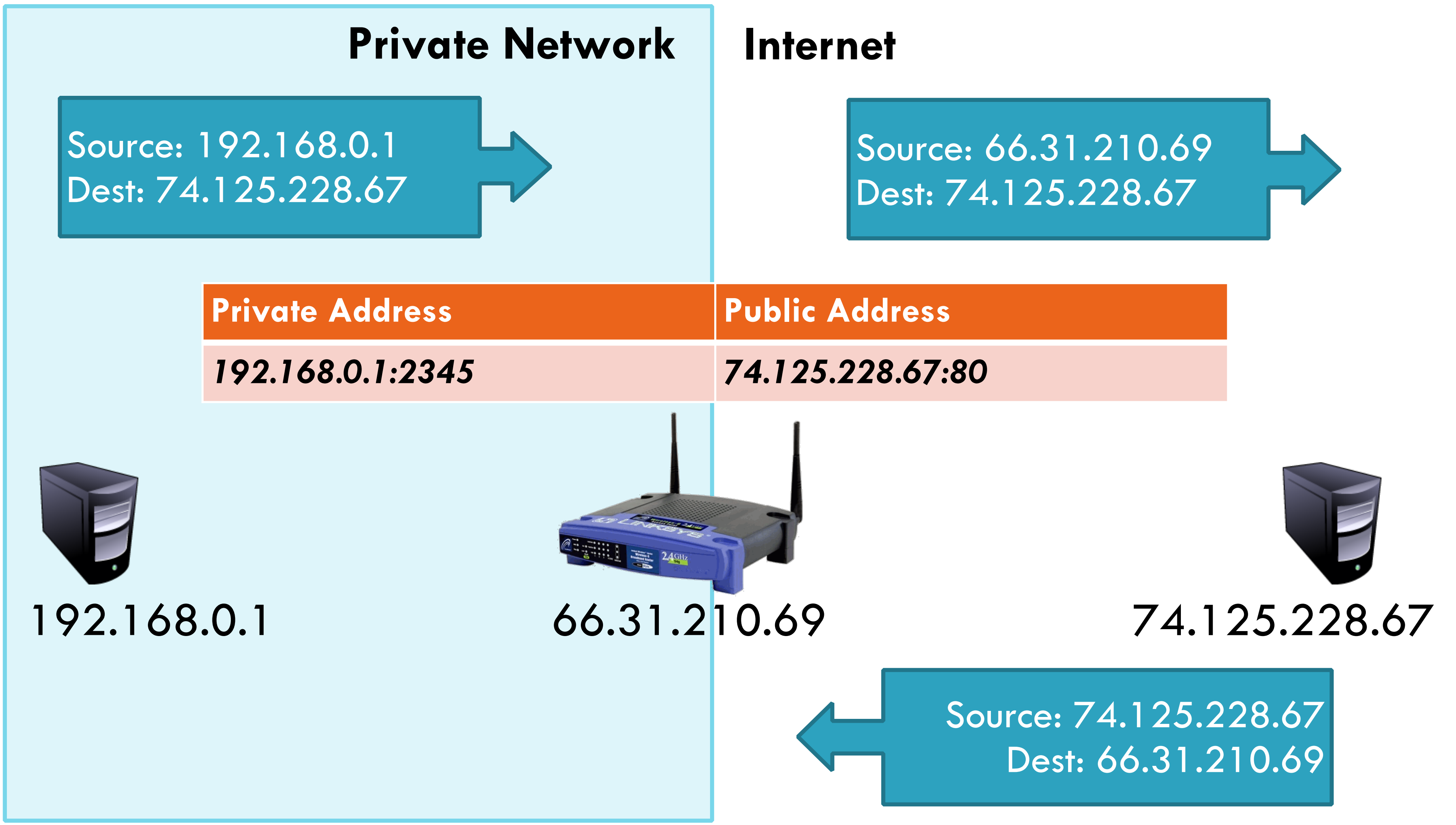

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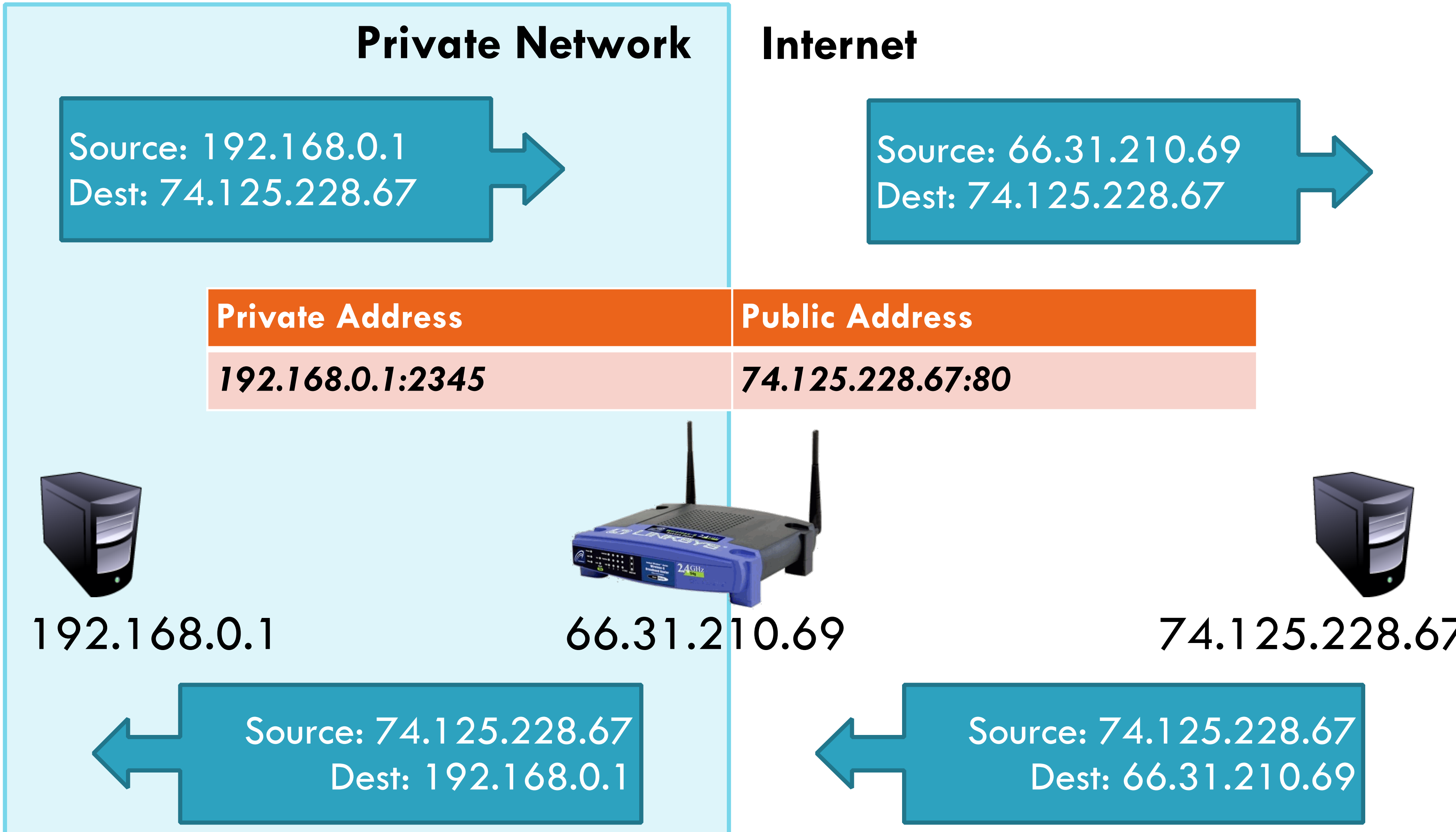

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Advantages of NATs

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- Allow migration between ISPs
  - Even if the public IP address changes, you don't need to reconfigure the machines on the LAN
- Load balancing
  - Forward traffic from a single public IP to multiple private hosts

Natural Firewall

Private Network **Internet**

Private Address	Public Address

192.168.0.1

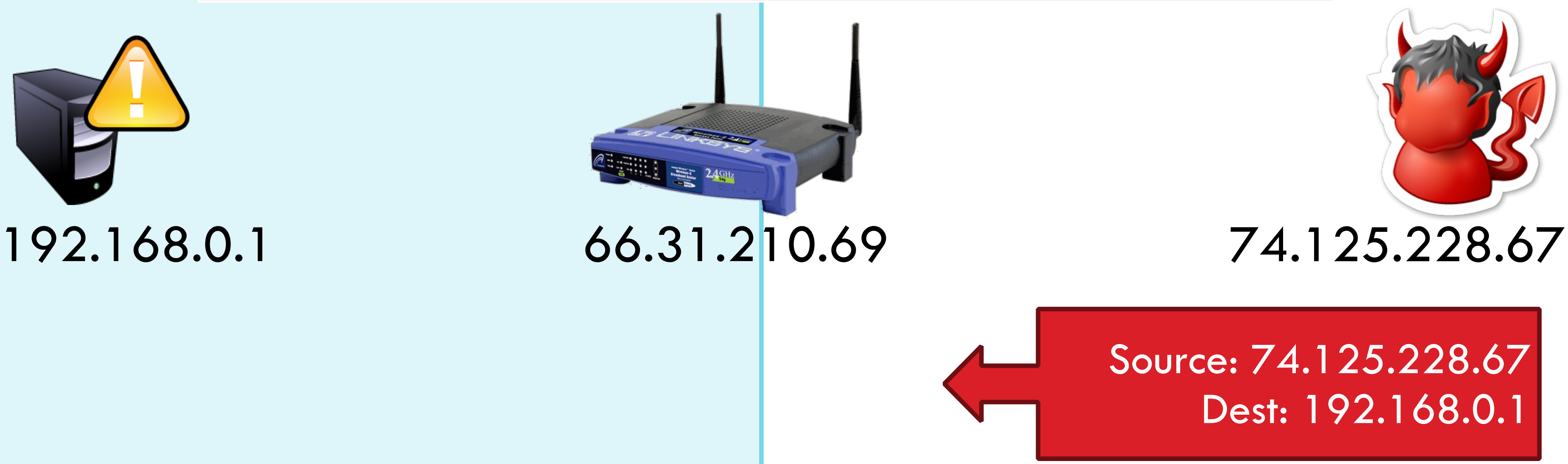
66.31.210.69

74.125.228.67

Natural Firewall

Private Network **Internet**

Private Address	Public Address



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- What about IPs embedded in data payloads?

Port Forwarding

Private Network **Internet**

Private Address	Public Address
192.168.0.1:7000	*.*.*.*:*

192.168.0.1

66.31.210.69

74.125.228.67

Port Forwarding

Private Network **Internet**

Private Address	Public Address
192.168.0.1:7000	*.*.*.*:*

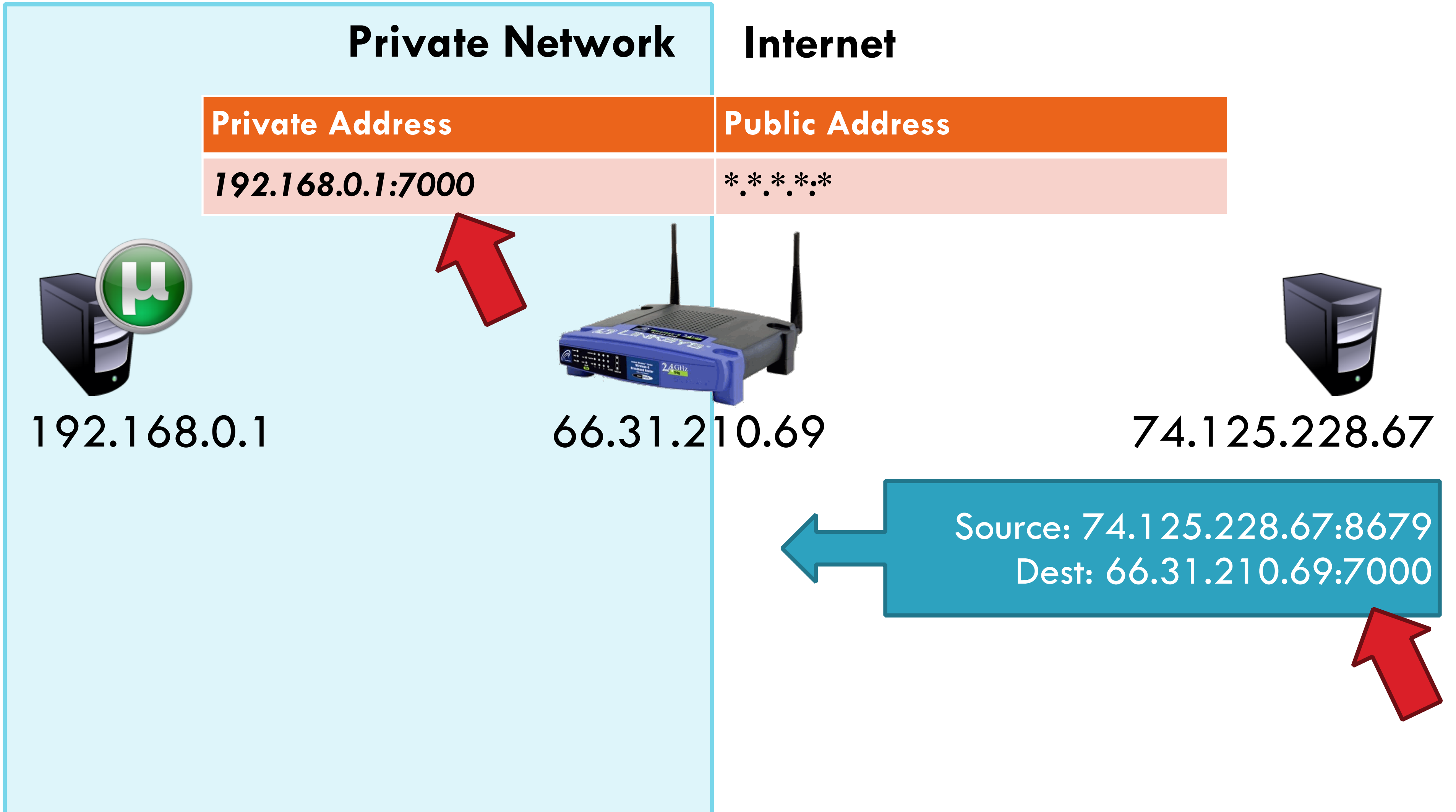
192.168.0.1

66.31.210.69

74.125.228.67

Source: 74.125.228.67:8679
Dest: 66.31.210.69:7000

Port Forwarding



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Port Forwarding

Private Network **Internet**

Private Address	Public Address
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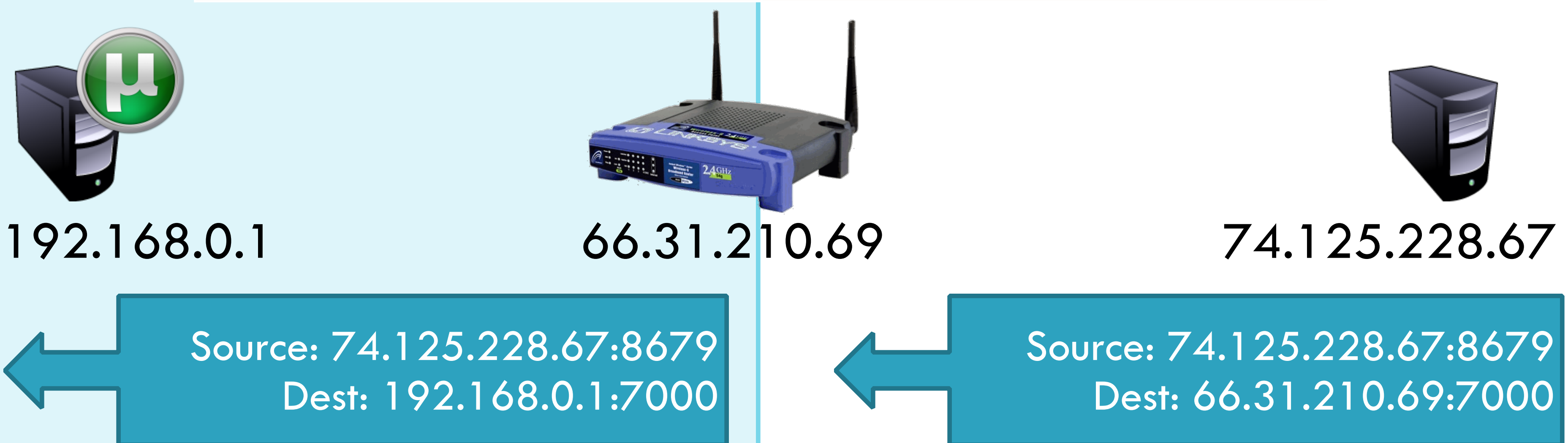

Hole Punching

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- Problem: How to enable connectivity through NATs?

- Two application-level protocols for hole punching
  - STUN
  - TURN

STUN

- **S**ession **T**raversal **U**tilities for **N**AT
  - Use a third-party to echo your global IP address
  - Also used to probe for symmetric NATs/firewalls
    - i.e. are external ports open or closed?

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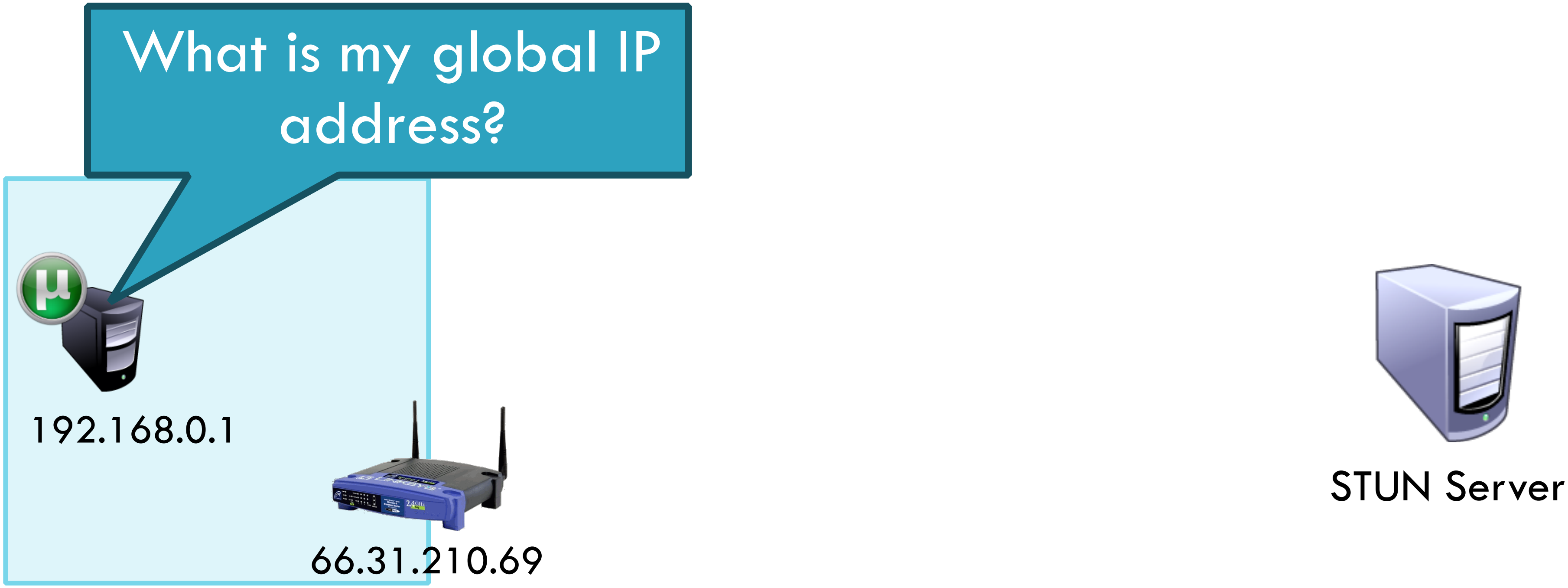

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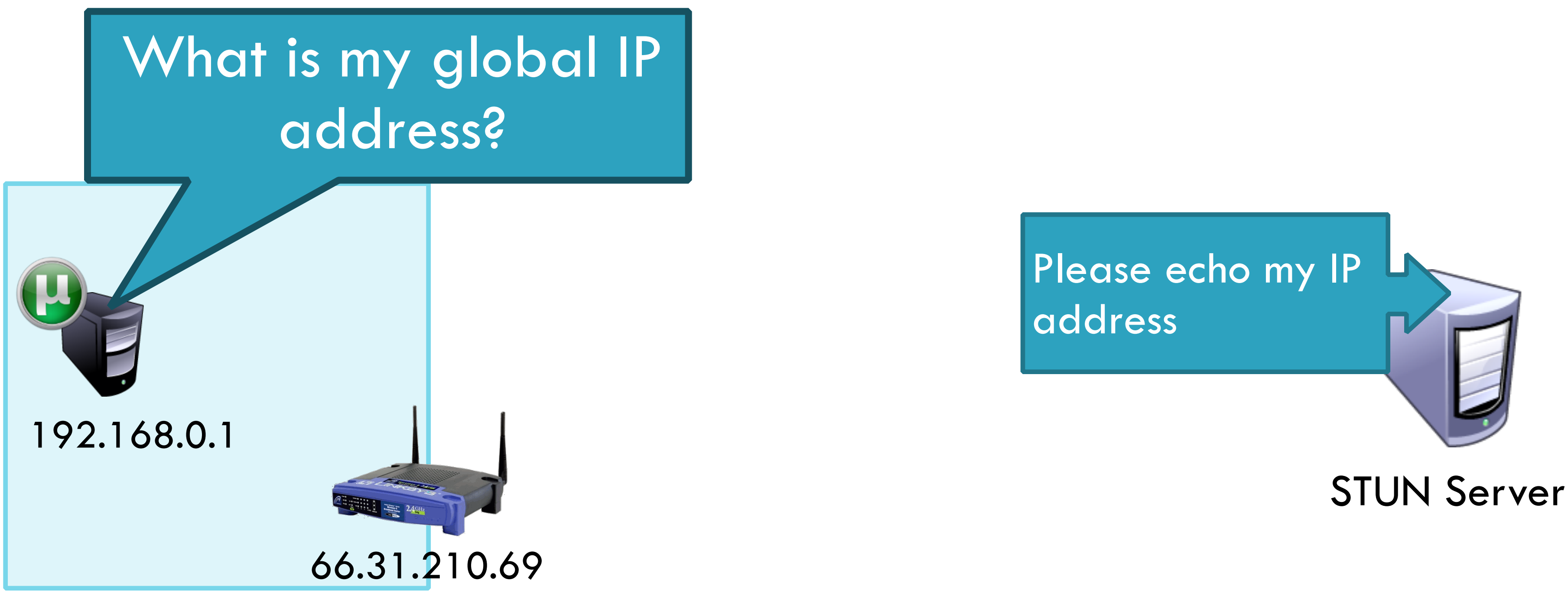

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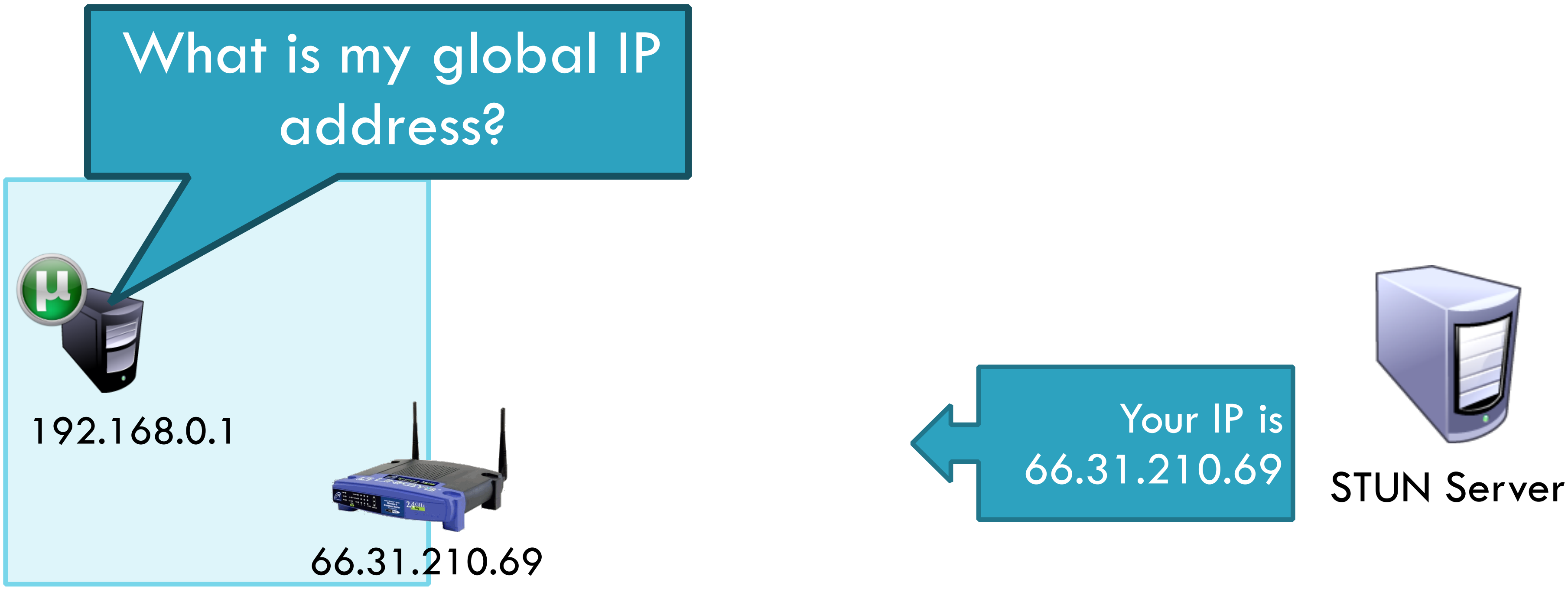

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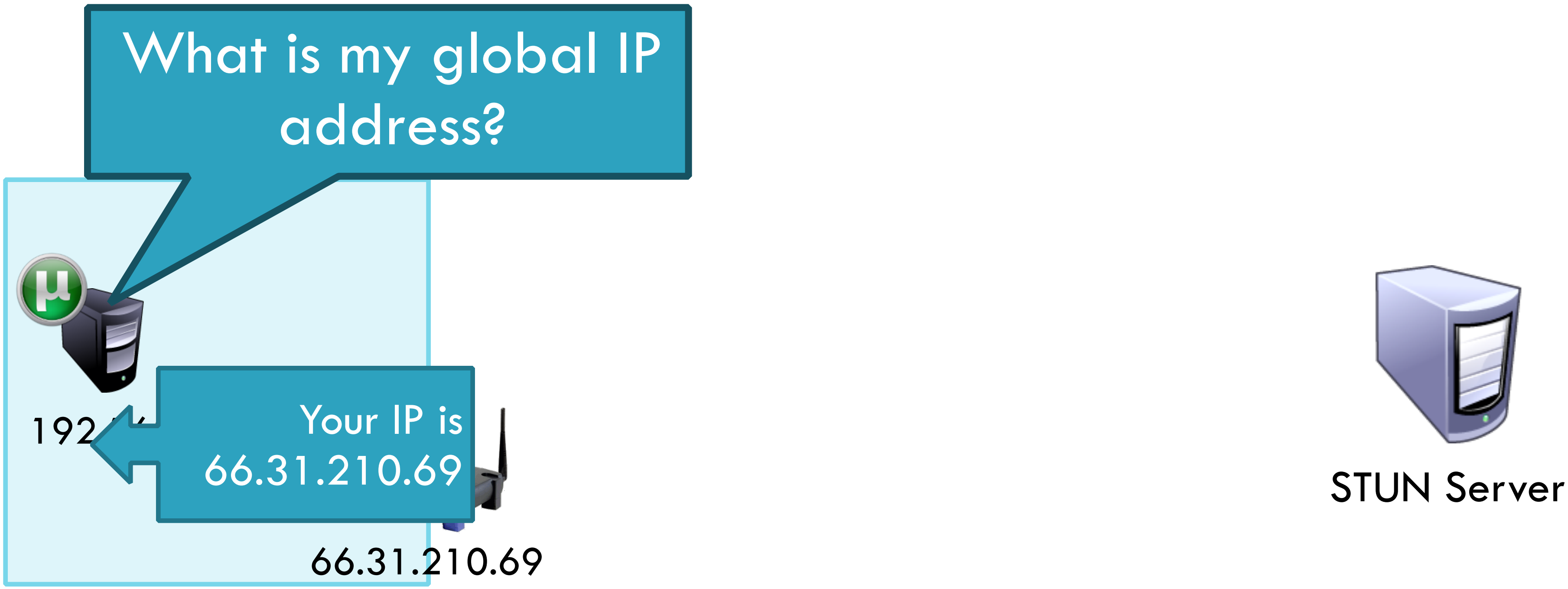
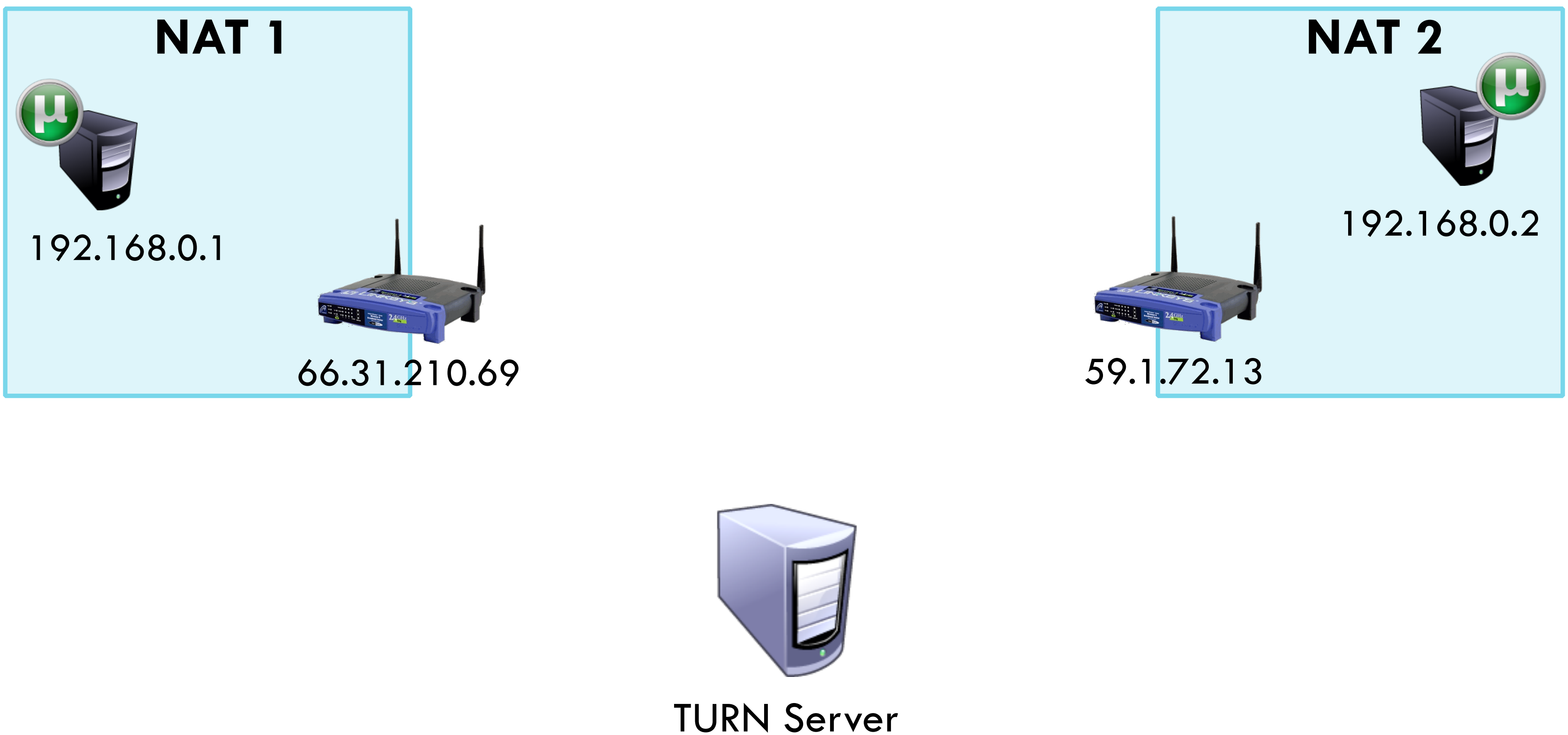


Problems With STUN

- Only useful in certain situations
  - One peer is behind a symmetric NAT
  - Both peers are behind partial NATs
- Not useful when both peers are fully behind full NATs

TURN

- Traversal Using Relays around NAT



TURN

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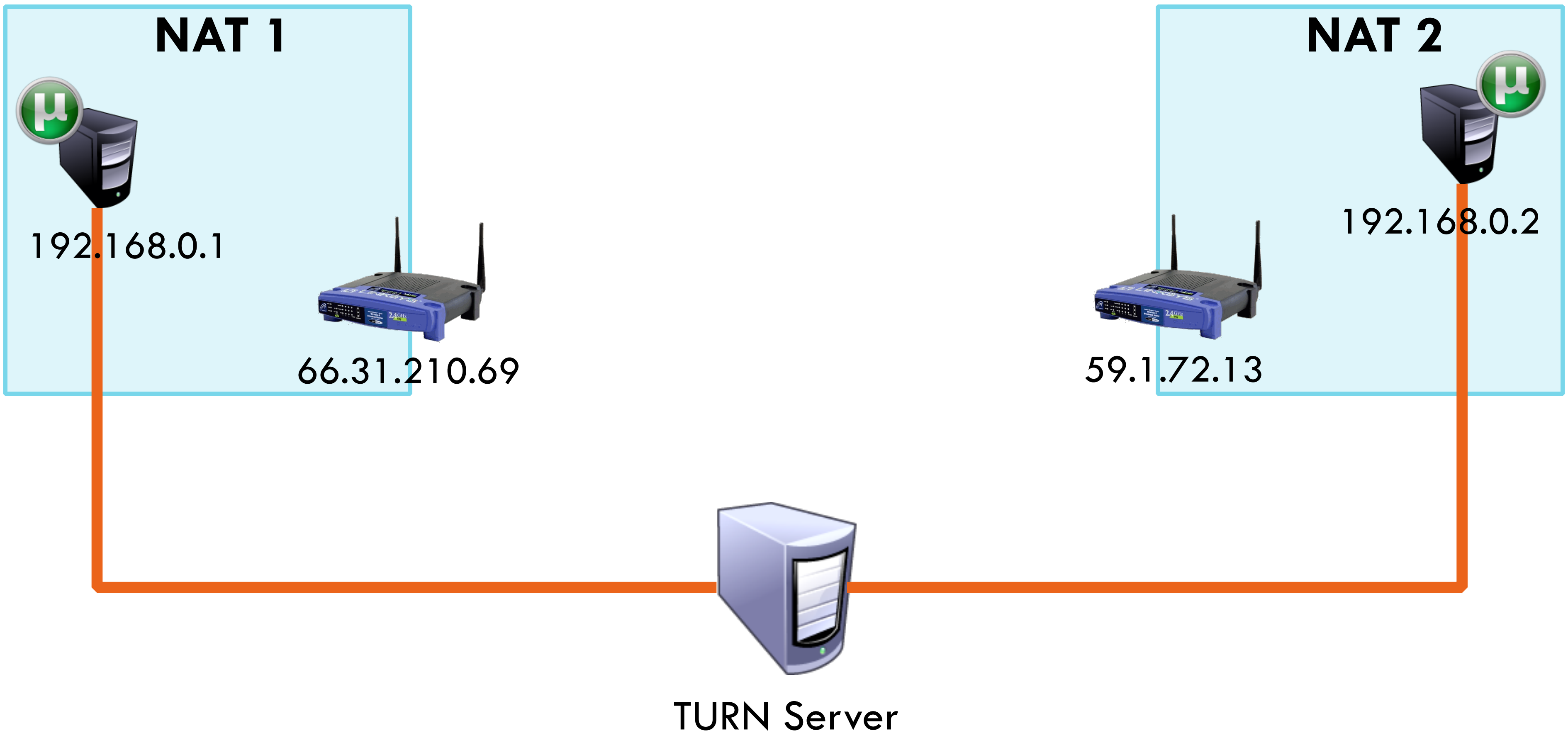

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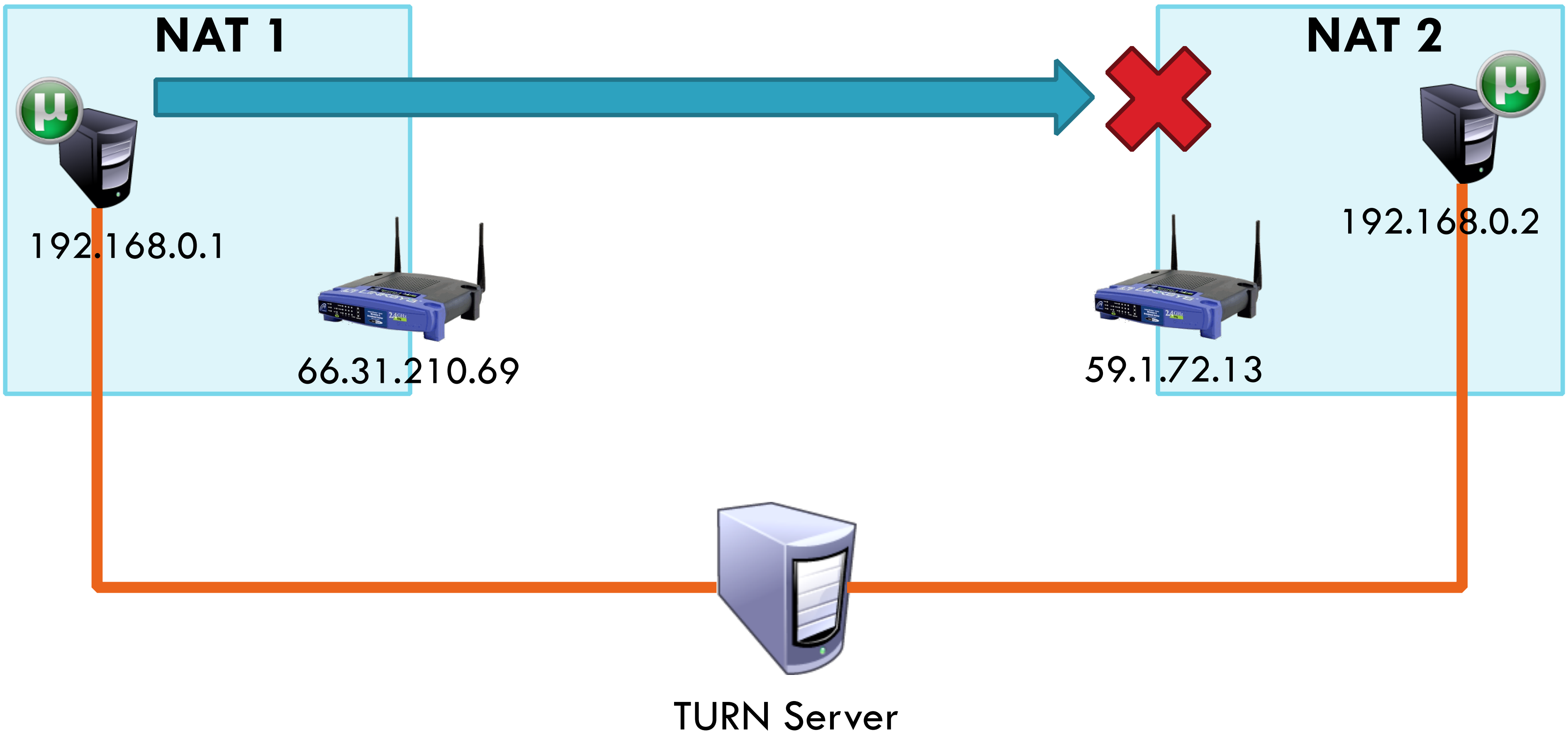

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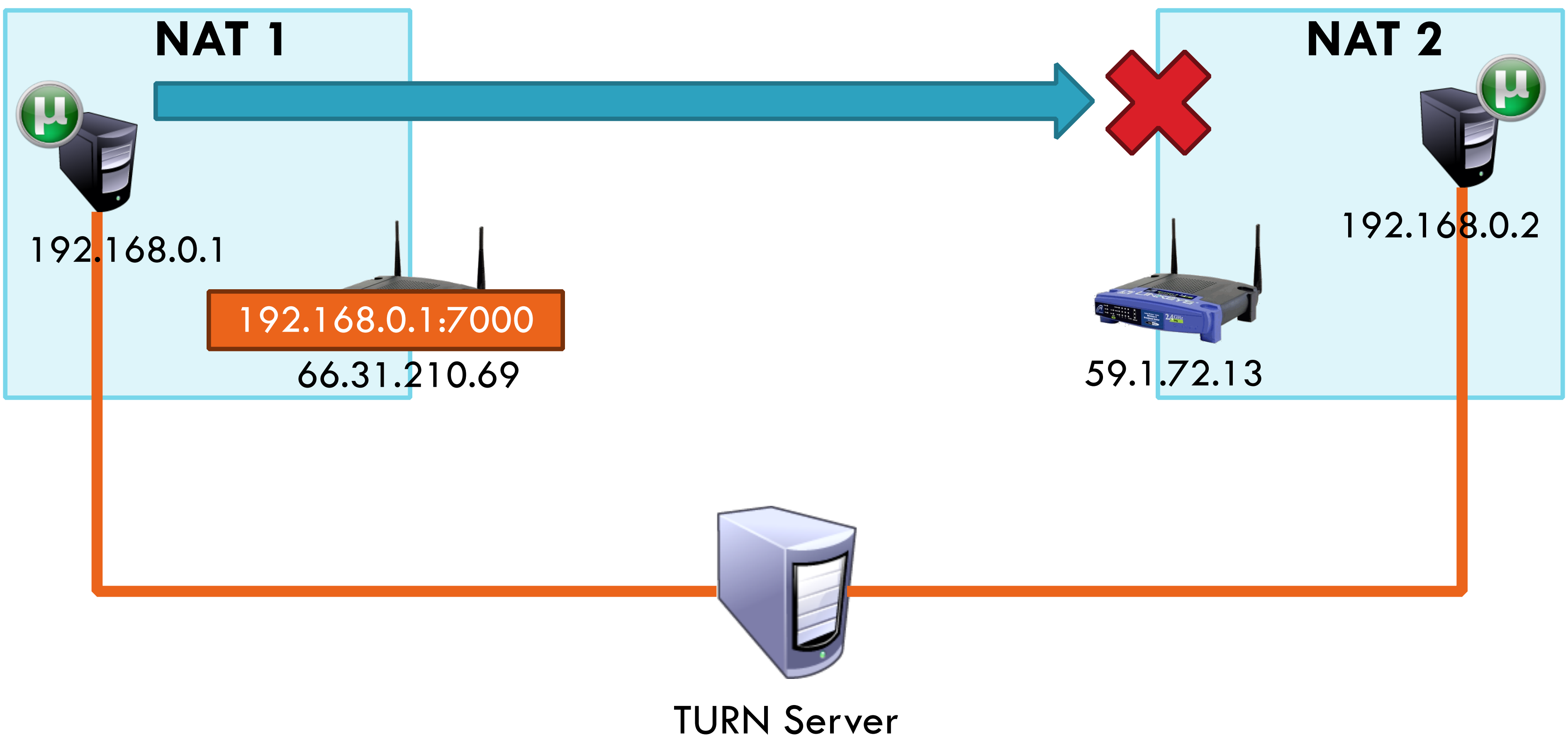

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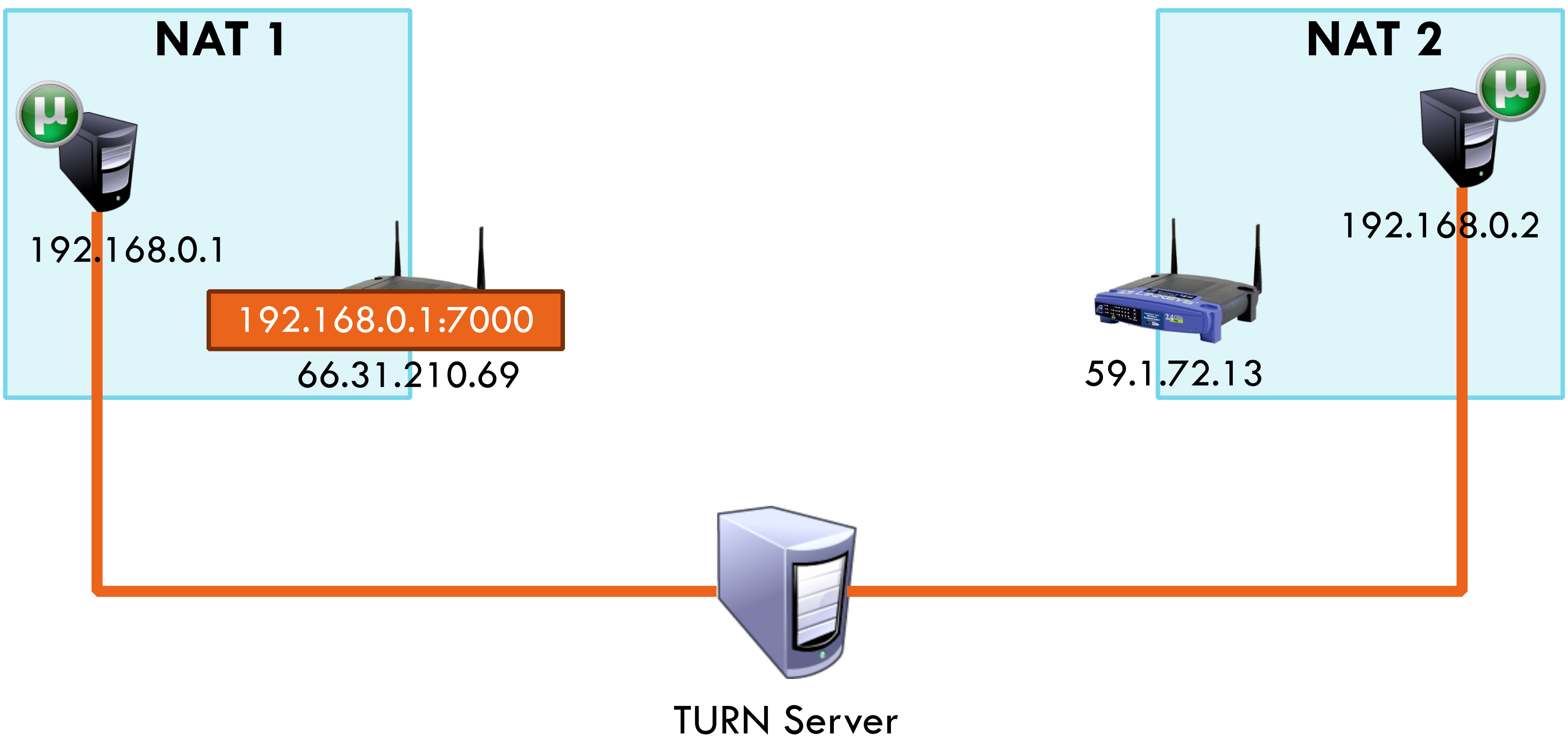
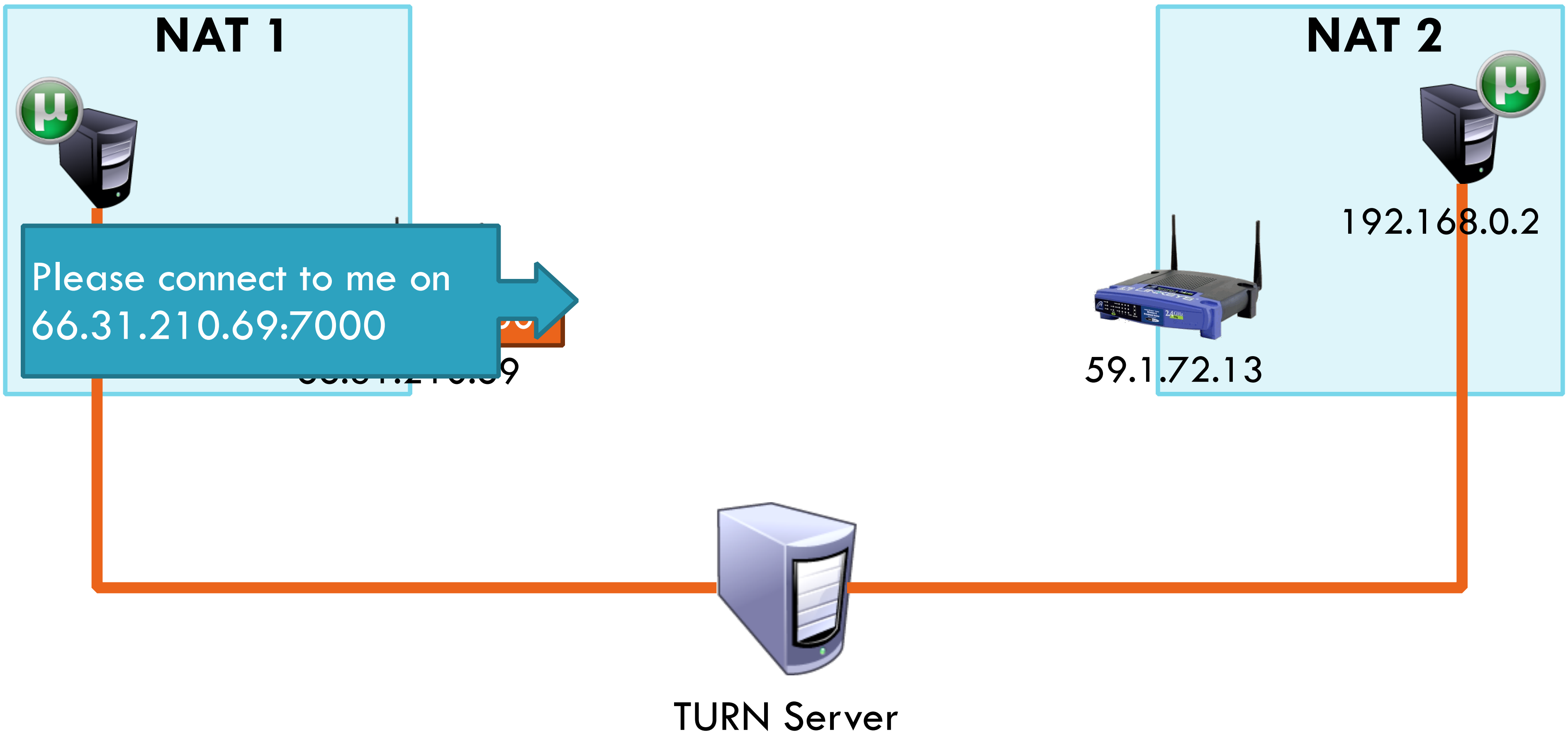


TURN

- Traversal **U**sing **R**elays around **NAT**



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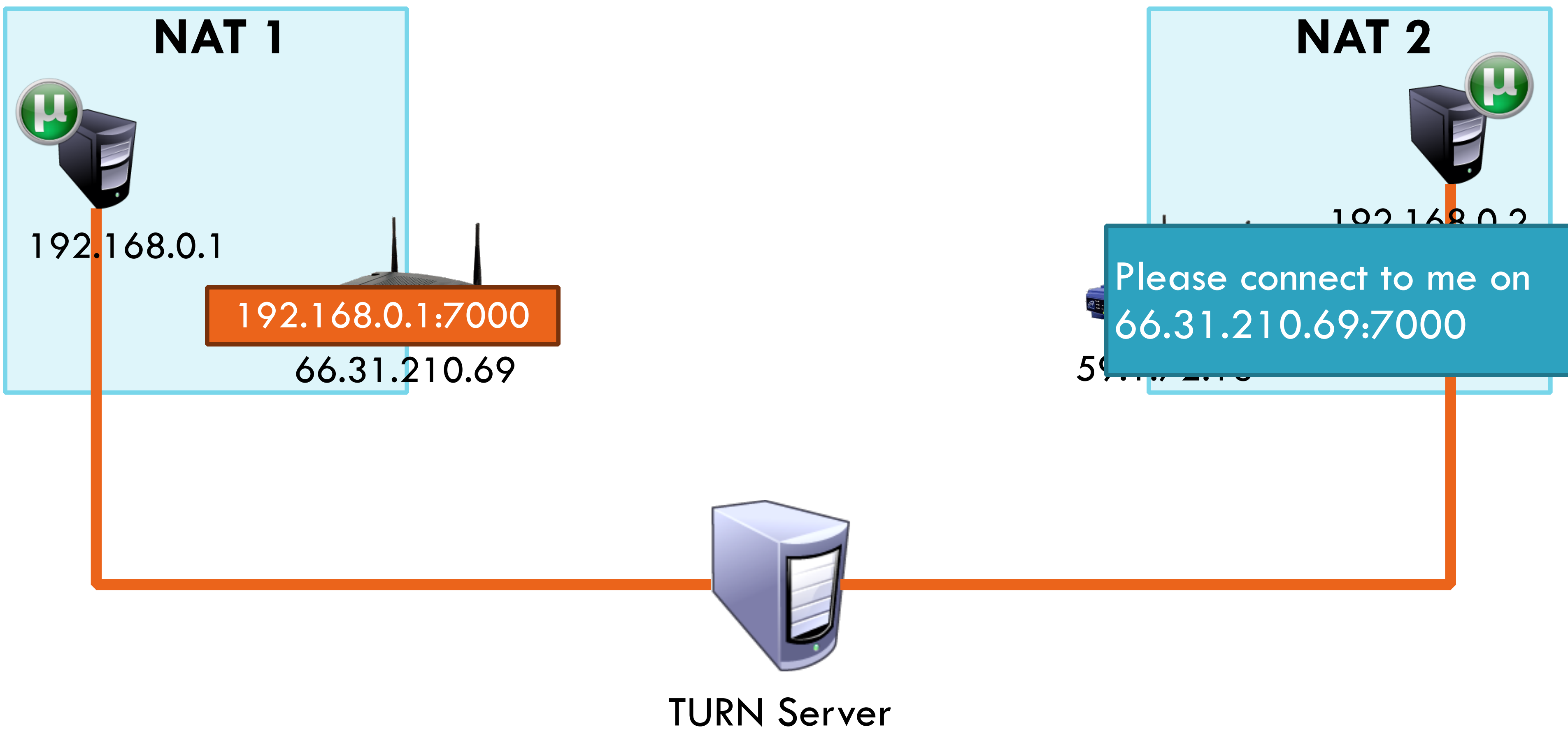

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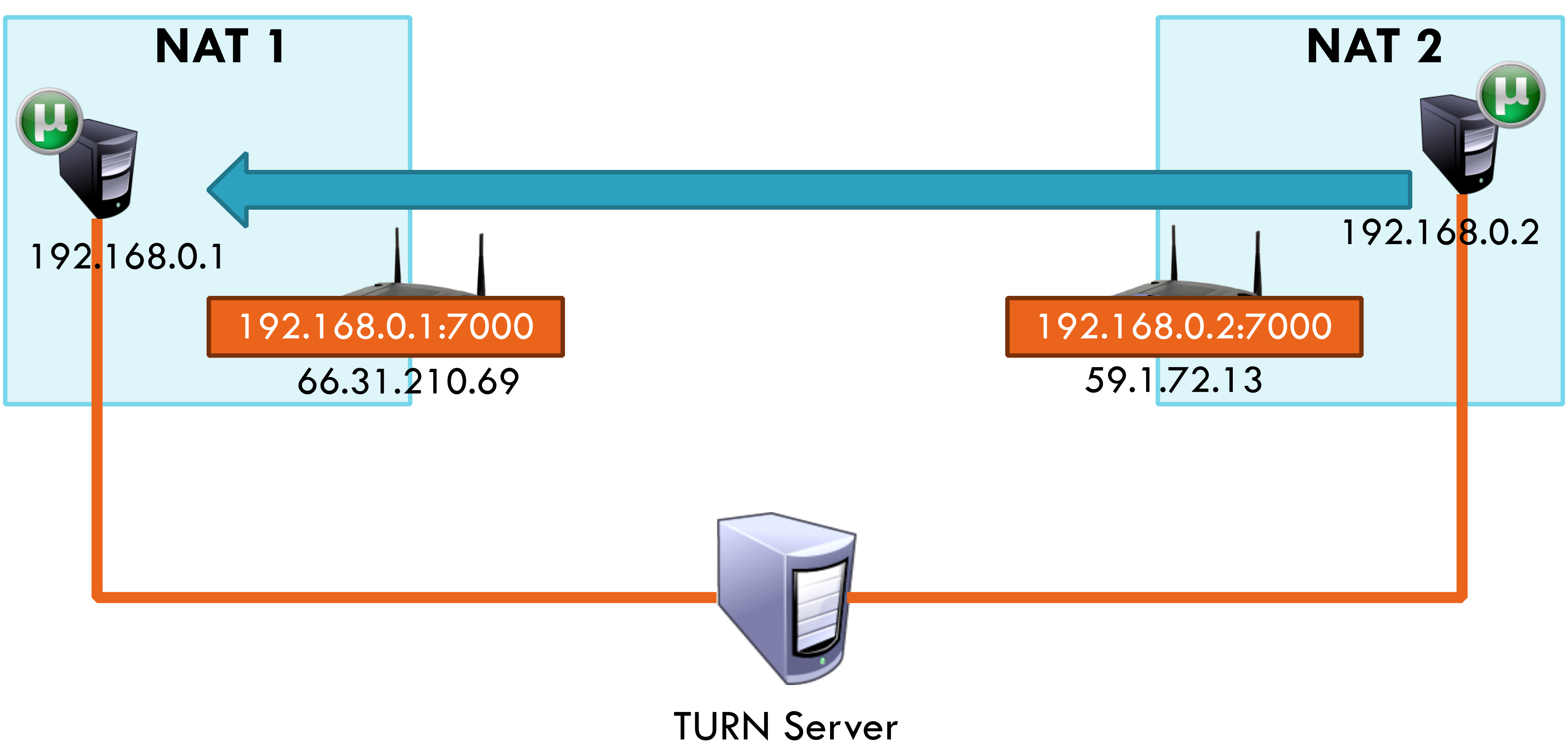

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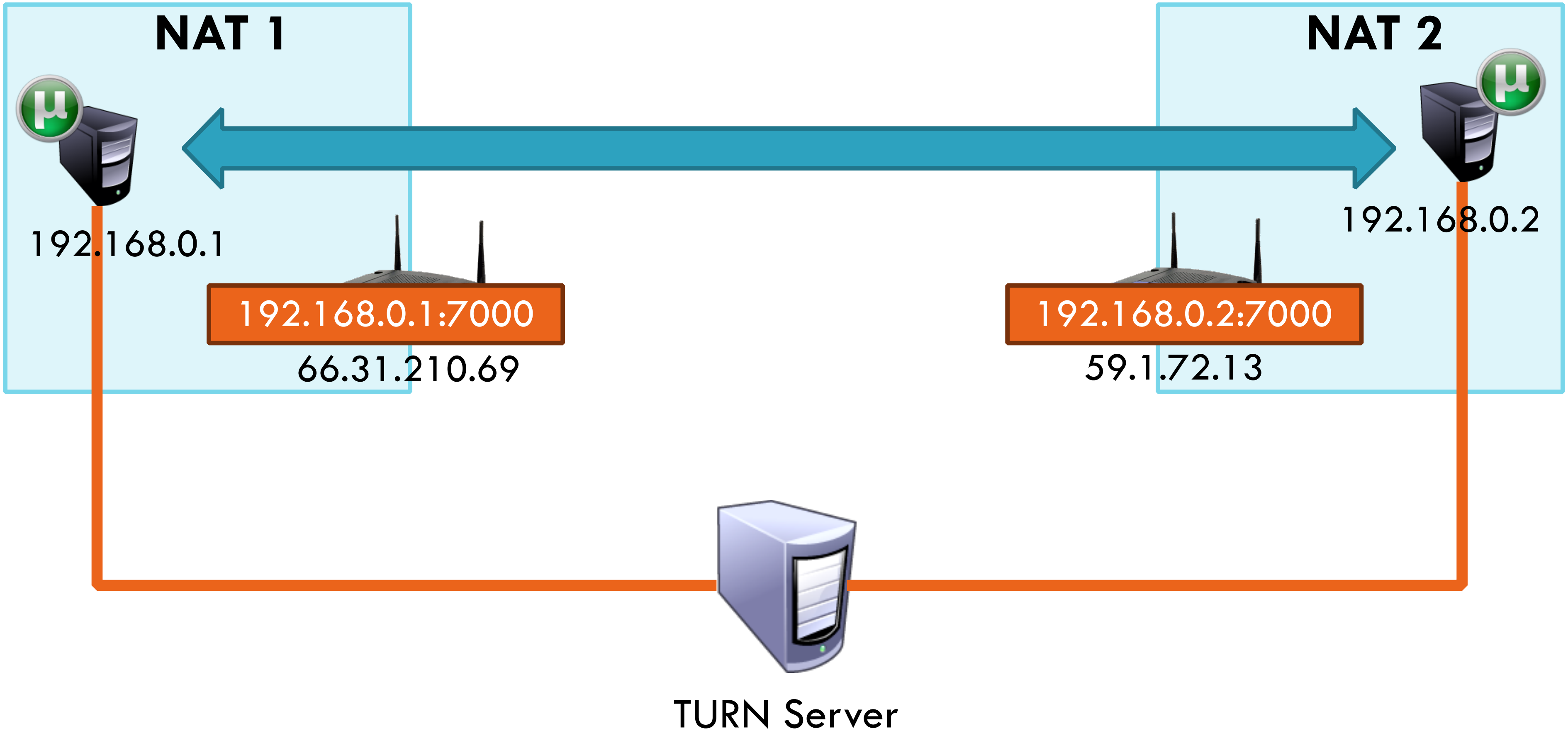

Outline

- DNS
- NAT
- Other middleboxes

Firewall

- A device that blocks traffic according to a set of rules
  - Why?
  - Services with vulnerabilities turned on by default
  - ISP policy forbidding certain traffic due to ToS
- Typically specified using a 5-tuple
  - E.g., block outbound SMTP; block inbound SQL server reqs
- GFC (Great Firewall of China)
  - Known to block based on IP, filter DNS requests, etc

Web caching

- ISP installs cache near network edge that caches copies of Web pages
  - Why?
  - **Performance:** Content is closer to clients, TCP will perform better with lower RTTs
  - **Cost:** "free" for the ISP to serve from inside the network
- Limitations
  - Much of today's content is not static (why does this matter?)
  - Content ownership
  - Potential privacy issues
  - Long tail of content popularity

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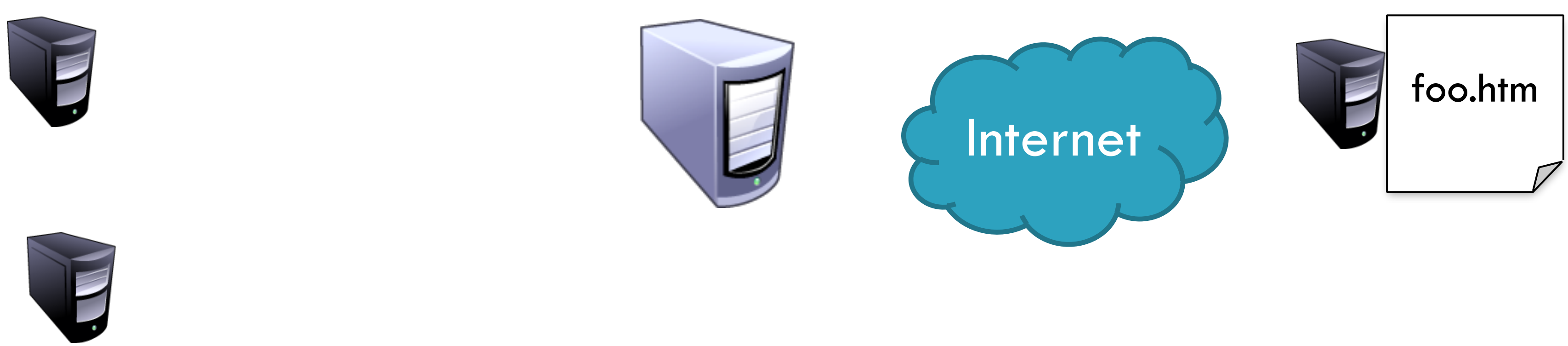

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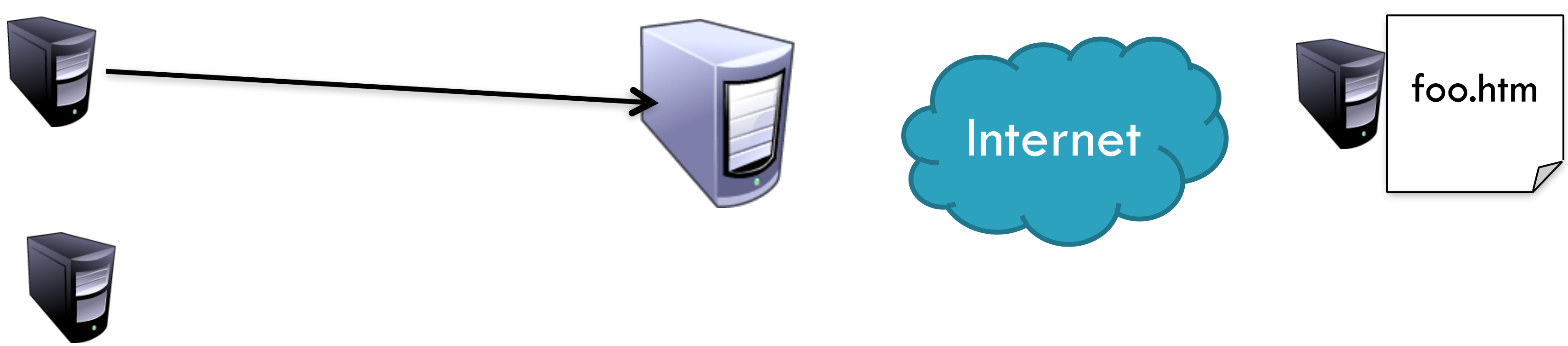

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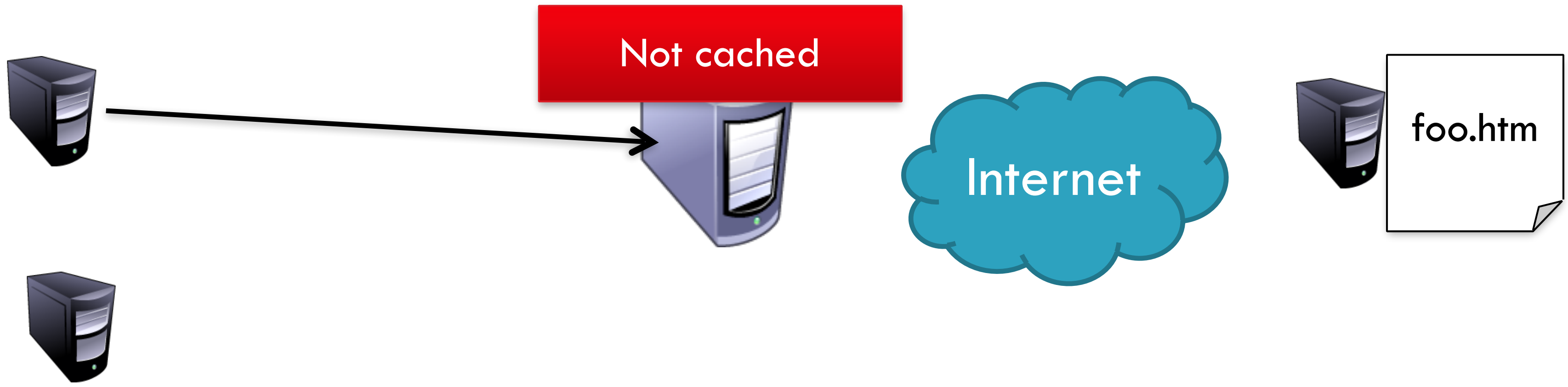

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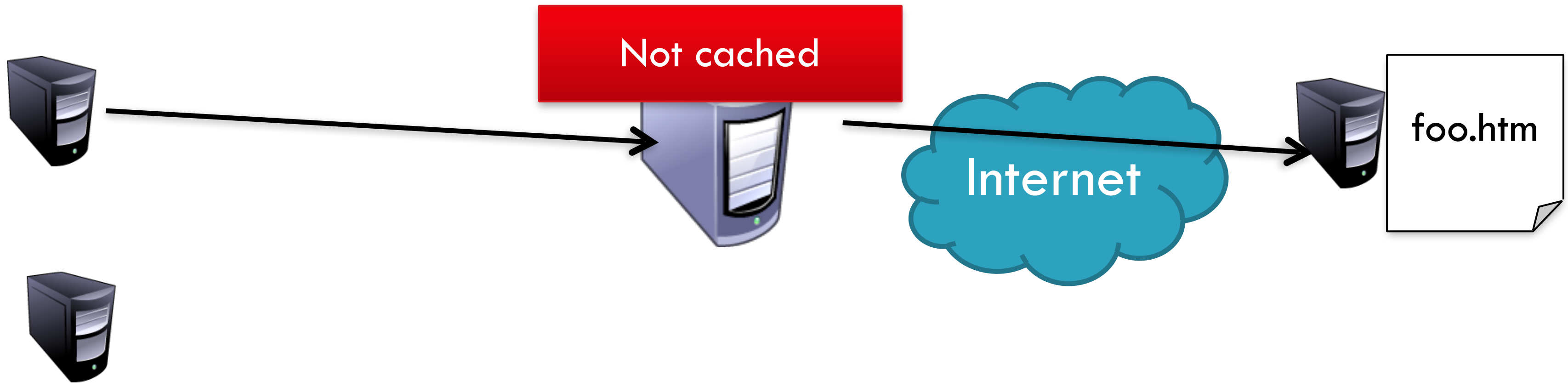

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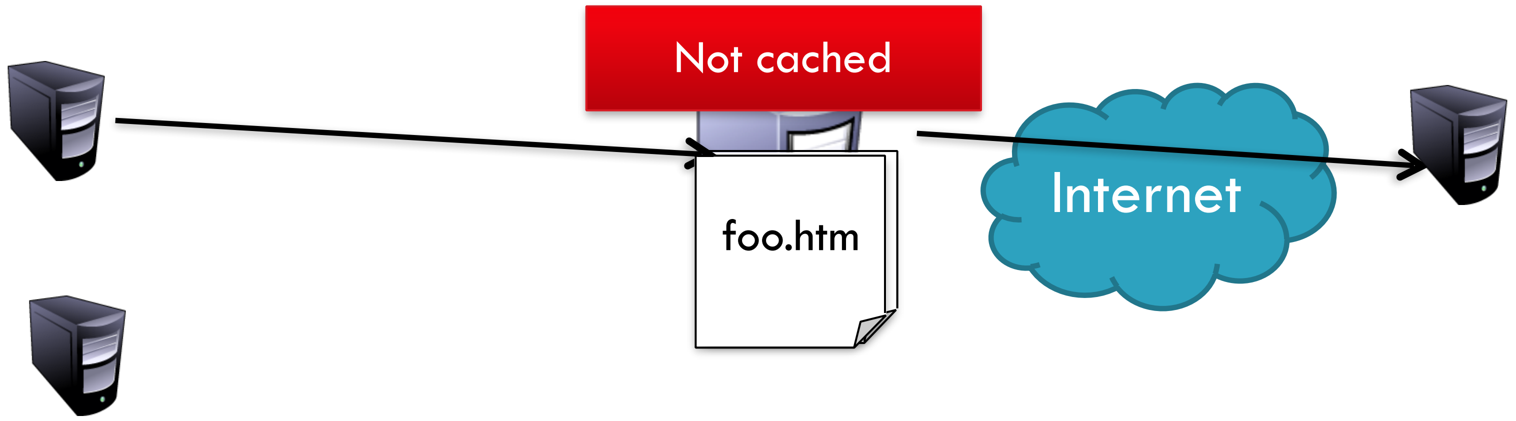

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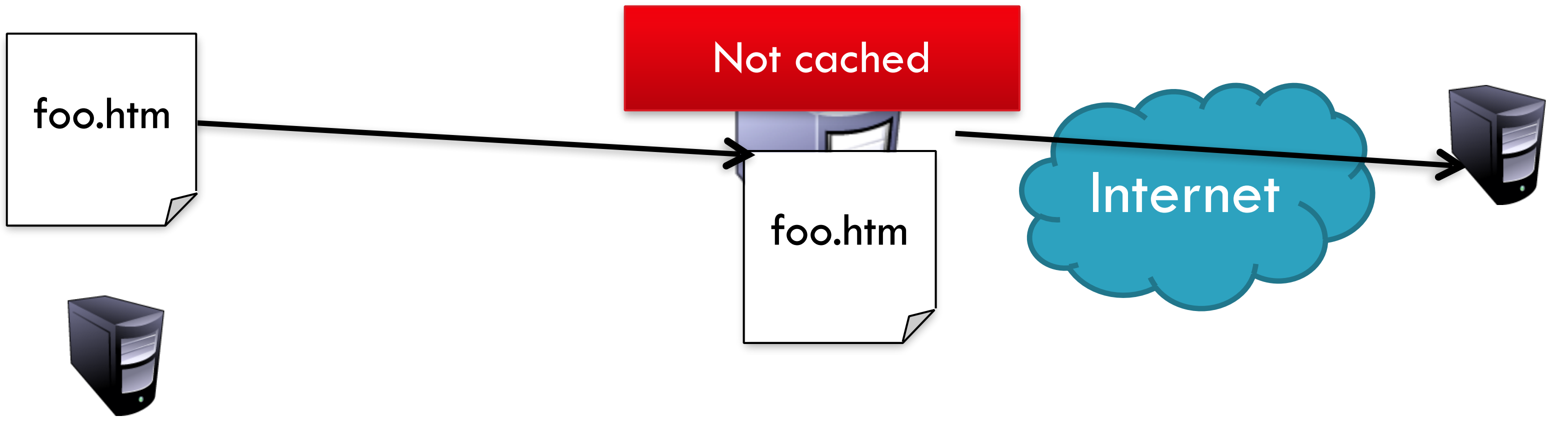

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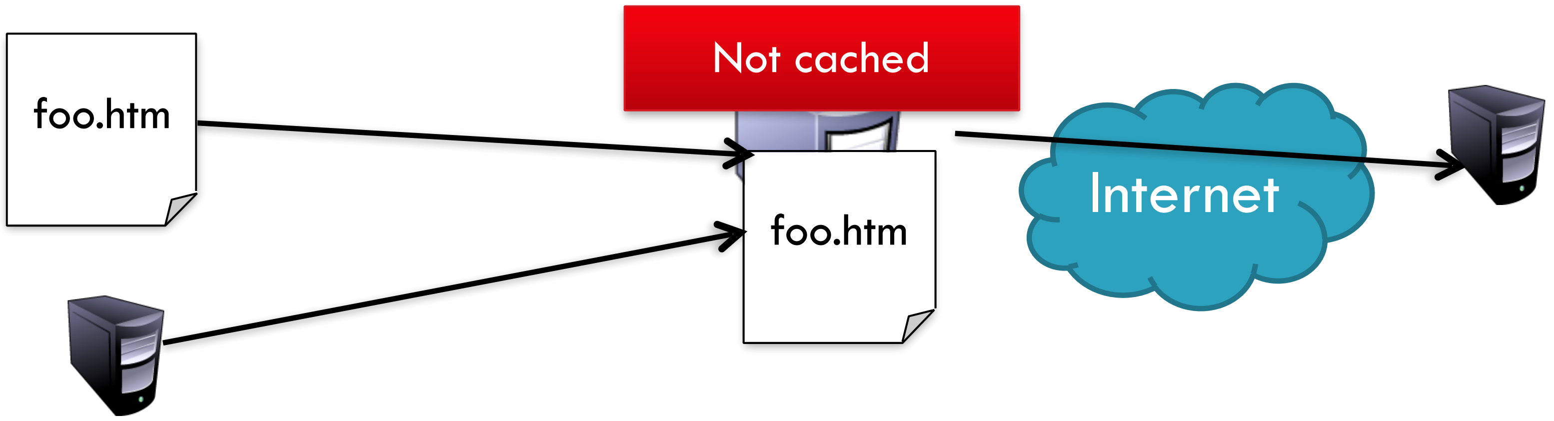

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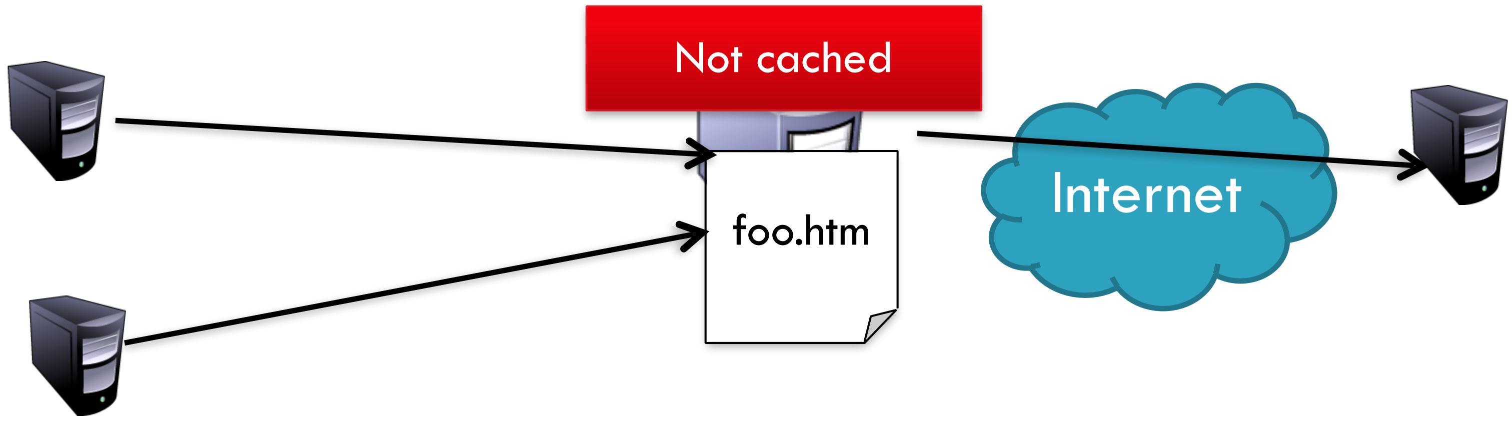
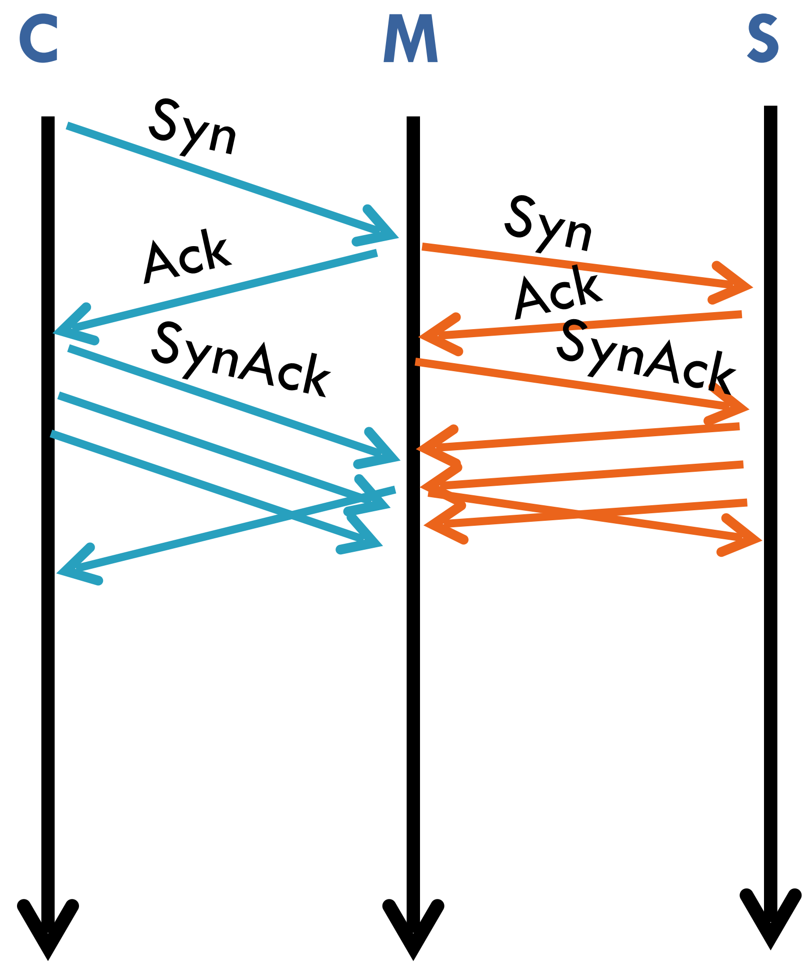


Proxying

- Non-split connections
  - Like NAT, but IP address is no longer the one assigned to you
- Split connections
  - Middlebox maintains two flows: C-M and M-S
  - Can be done transparently
    - How?



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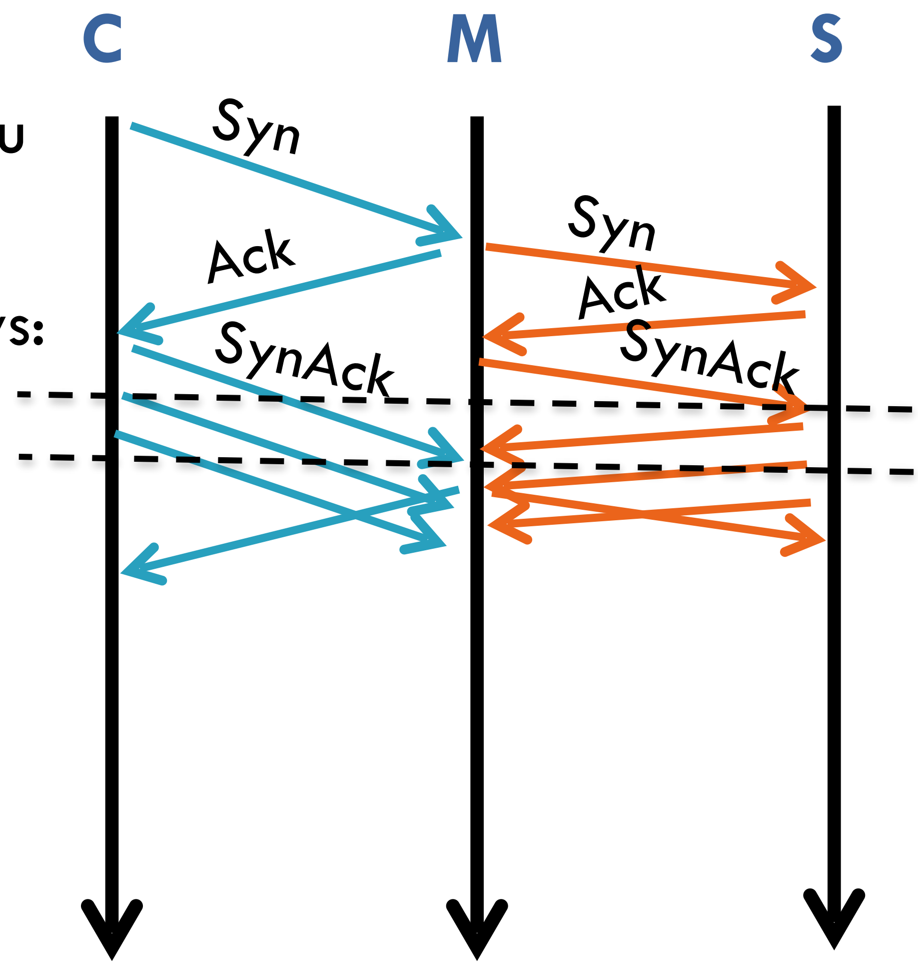
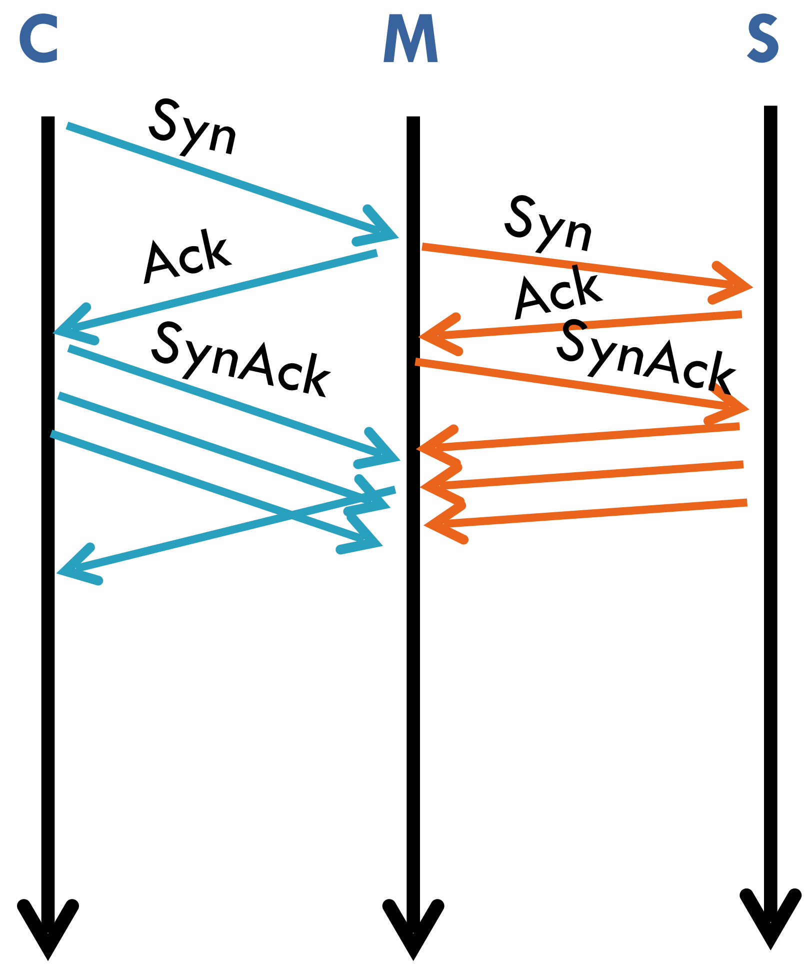


Proxying

- Advantages
  - RTT is lower on each end
  - Can use different MTUs
  - Particularly useful in cell ntwks
- Disadvantages
  - Extra delay can be bad for small flows
  - Buffering/state makes it potentially costly



Shaping

- ISPs are often charged according to 95% model
  - Internet usage is very "peaky", e.g., at 5pm, or when House of Cards season 2 is released

- To control costs, ISPs such as Rogers **shape** client traffic
  - Time-of day
  - Traffic type
- Common implementations
  - Token Bucket (see next deck)
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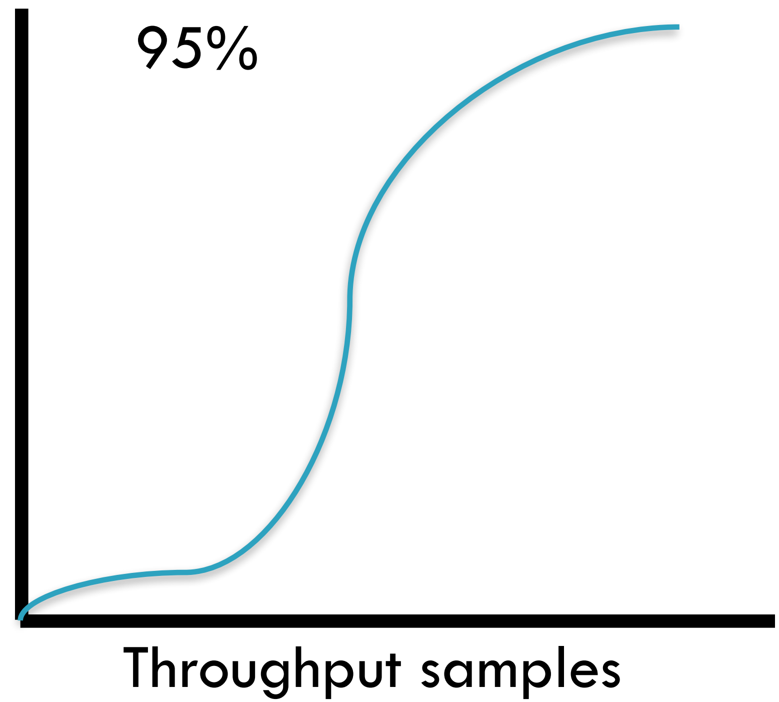

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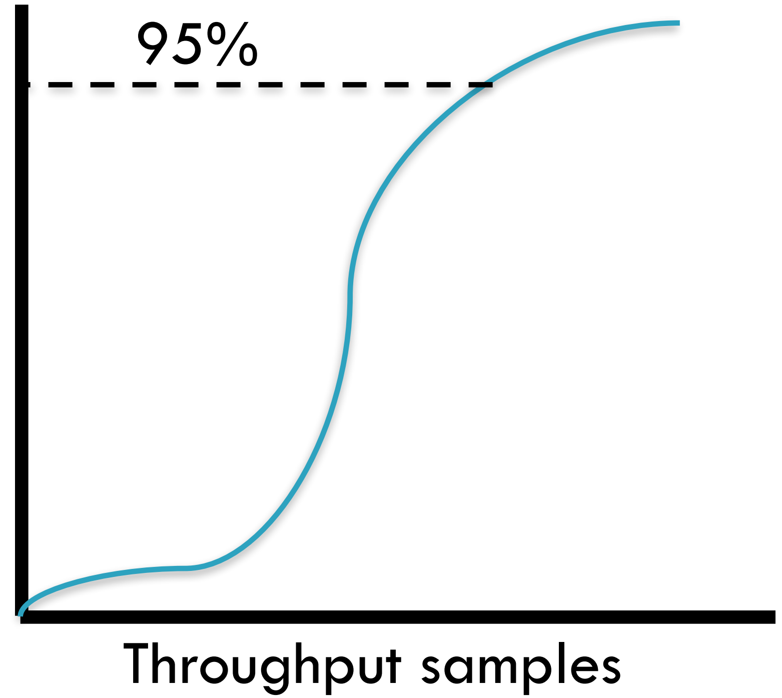

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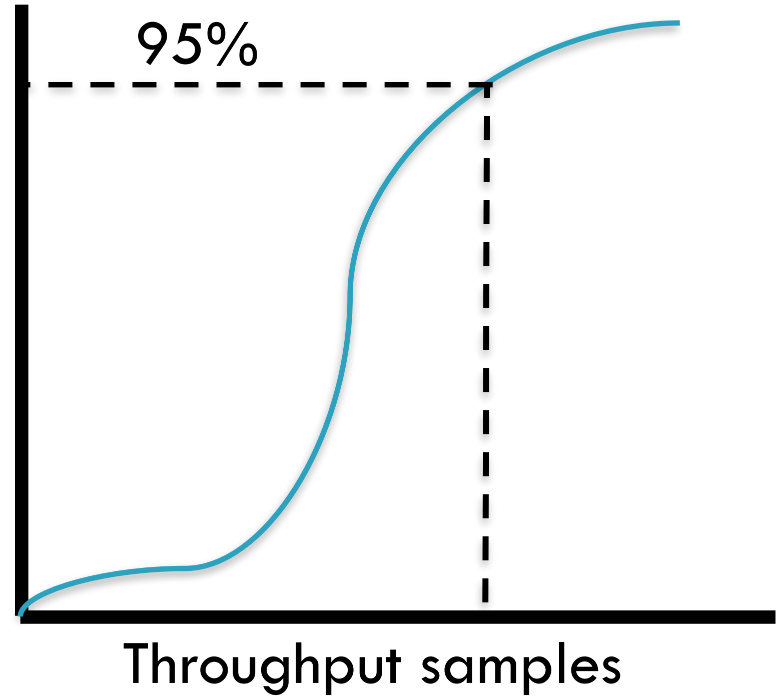

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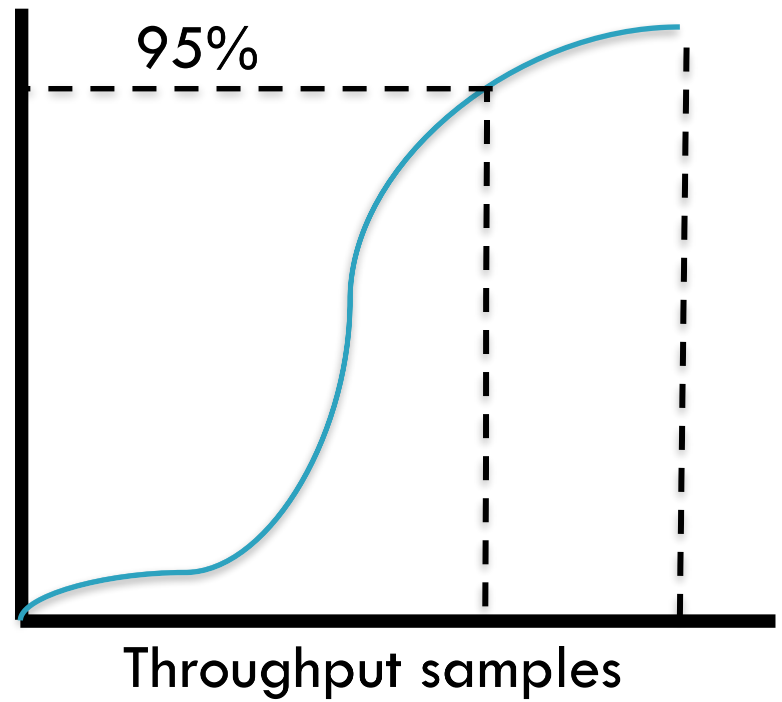

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