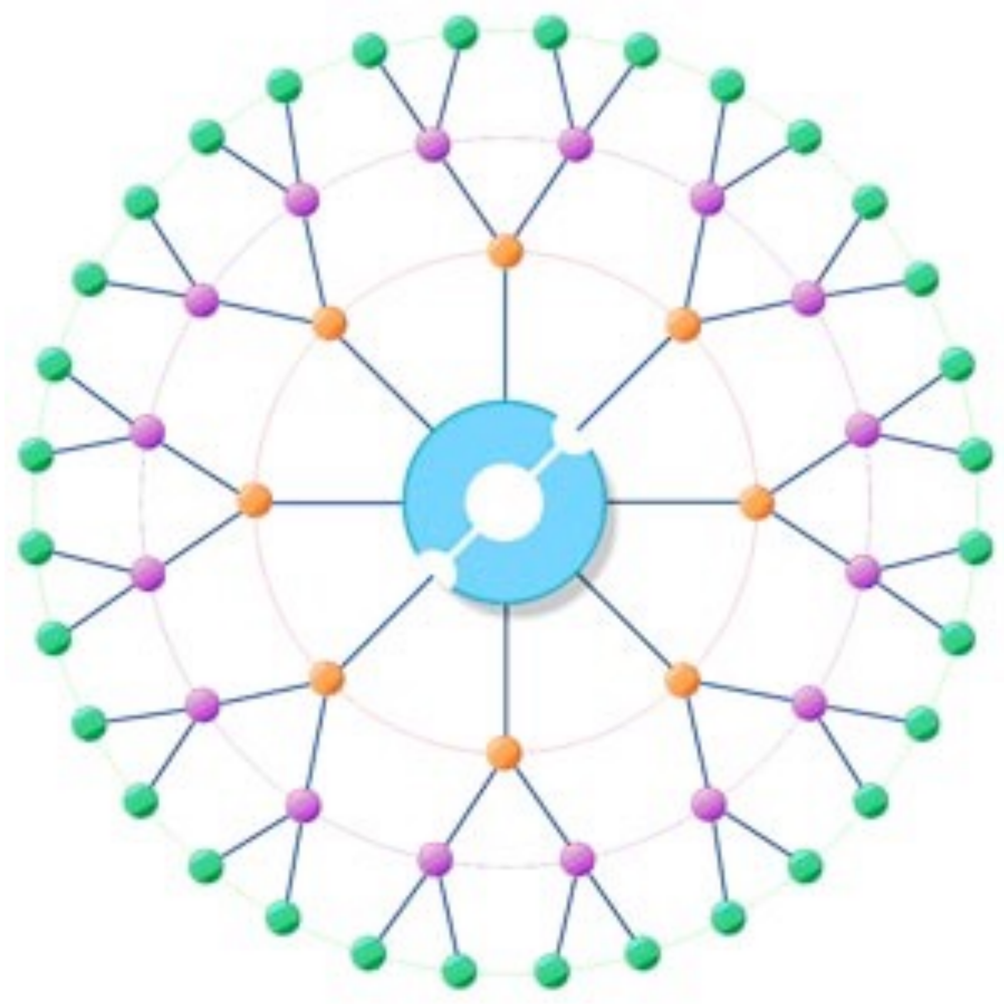
PennState

CSE 543: Computer Security
Module: Network Security

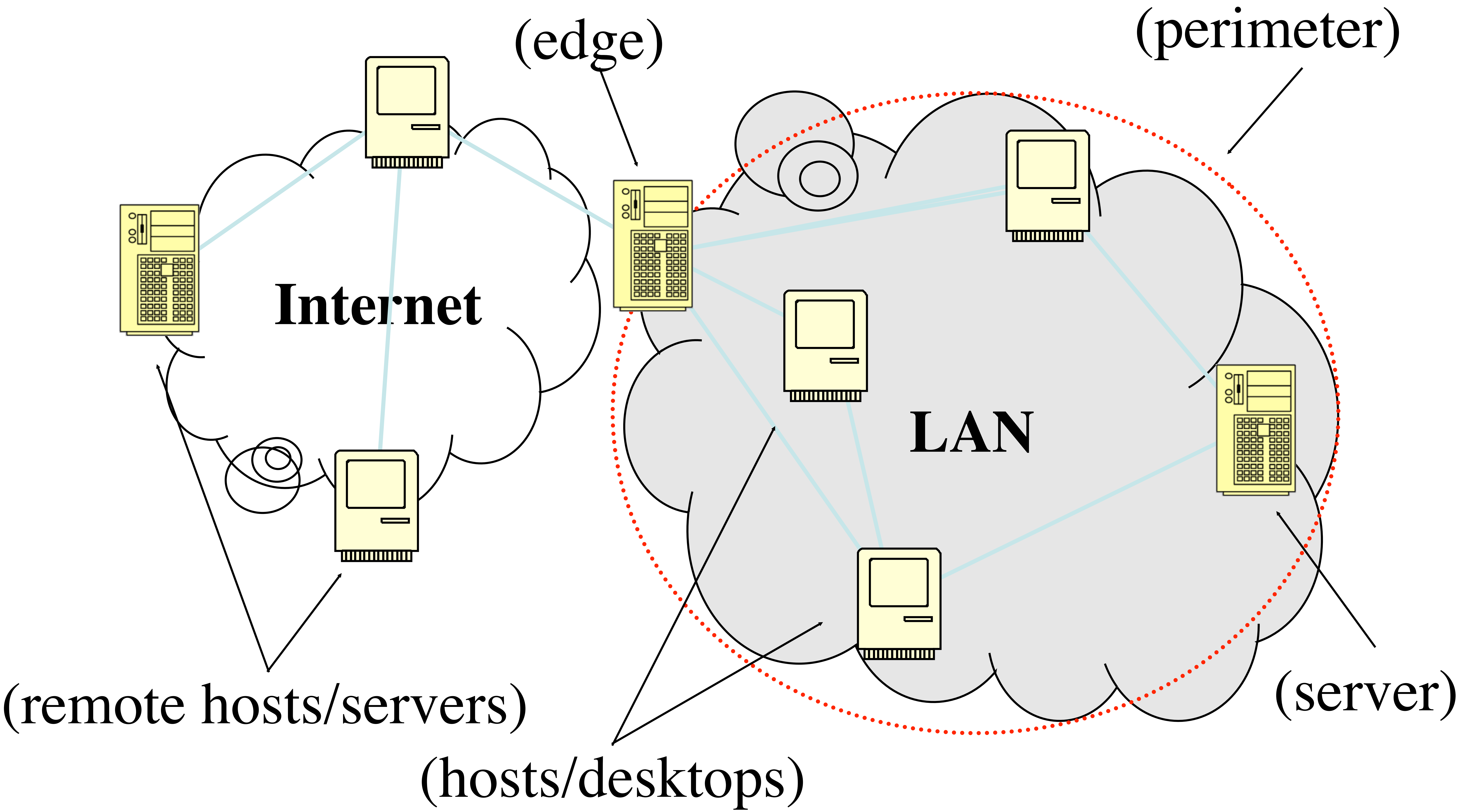
Prof. Syed Rafiul Hussain
Department of Computer Science and Engineering
The Pennsylvania State University

Networking…

- Fundamentally about transmitting information between two devices
- Direct communication is now possible between any two devices anywhere (just about)
  - Lots of abstraction involved
  - Lots of network components
  - Standard protocols
  - Wired and wireless
  - Works in *protection* environment
- What about ensuring *security*?

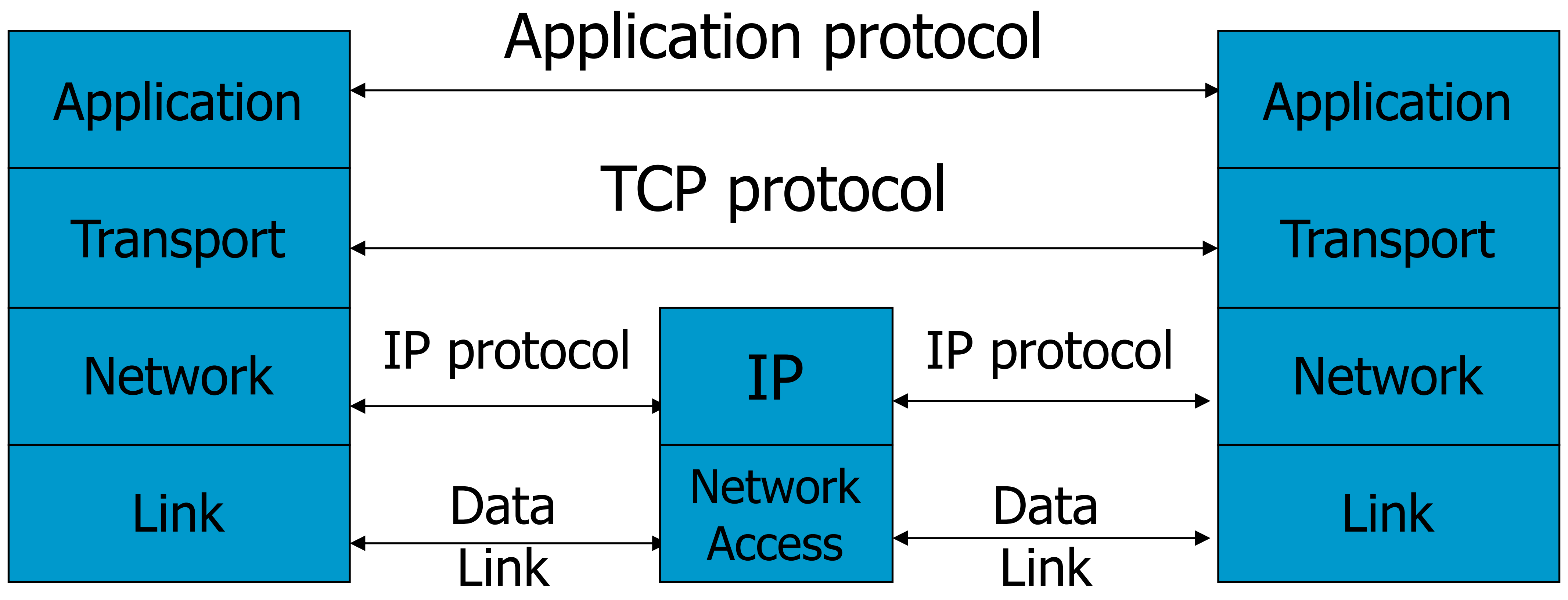


Network


(edge)
(perimeter)
Internet
LAN
(remote hosts/servers)
(hosts/desktops)
(server)

TCP/IP Protocol Stack

- Internet Protocol (IP)
  - Really refers to a whole collection of protocols making up the vast majority of the Internet
- Routing
  - How these packets move from place to place
- Network management
  - Administrators have to maintain the services and infrastructure supporting everyone's daily activities



Network security: the high bits

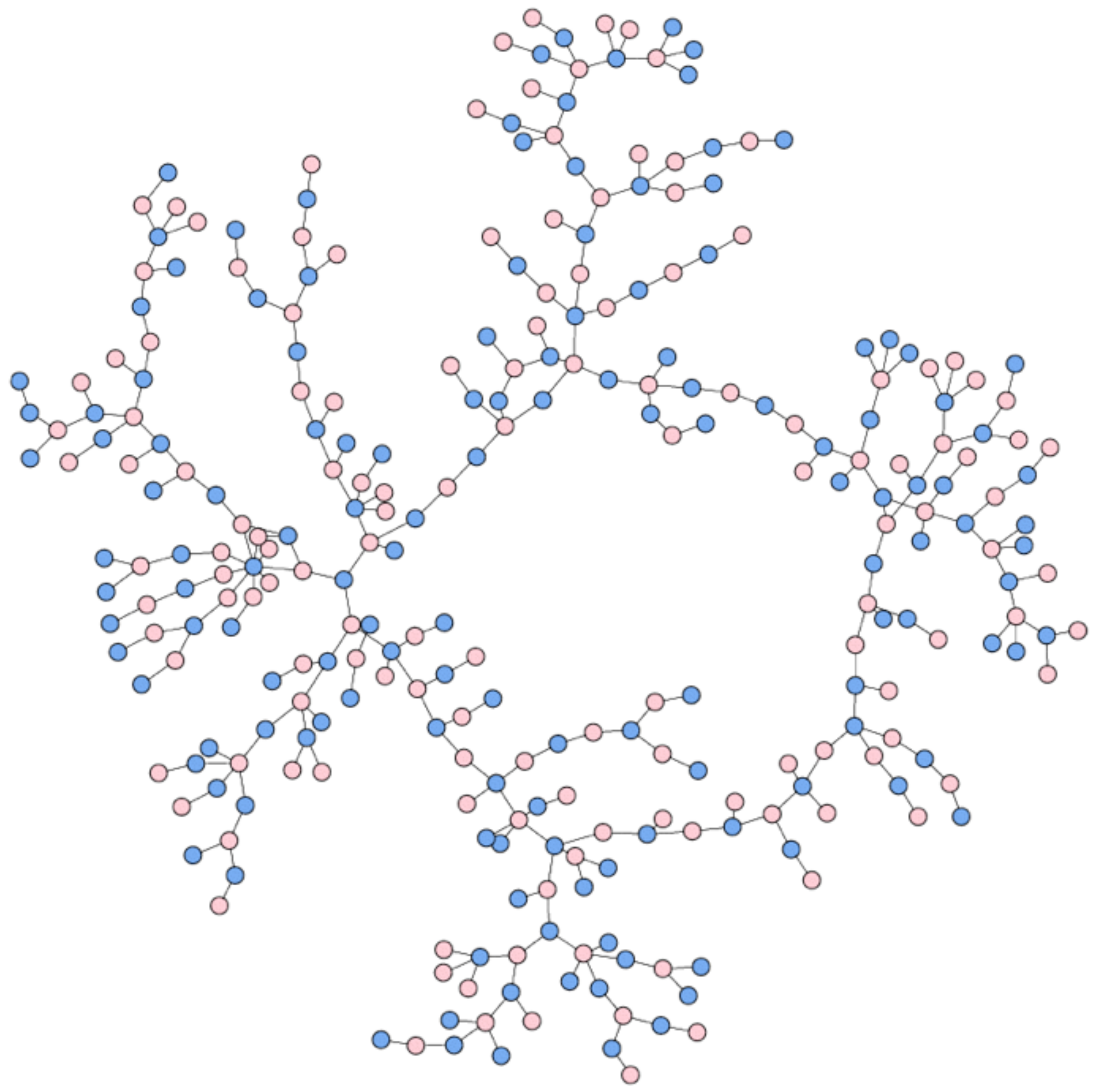
PennState

- The network is …
  - … a collection of interconnected computers
  - … with resources that must be protected
  - … from unwanted inspection or modification
  - … while maintaining adequate quality of service.
- Another way of seeing network security is ...
  - ... securing the networked computers such that the integrity, confidentiality, and availability of the resources is maintained.

?

Exploiting the network ...

- The Internet is extremely vulnerable to attack
  - it is a huge open system ...
  - which adheres to the *end-to-end* principle
    - smart end-points, dumb network



- Can you think of any *large-scale attacks* that would be enabled by this setup?

Types of Addresses in Internet

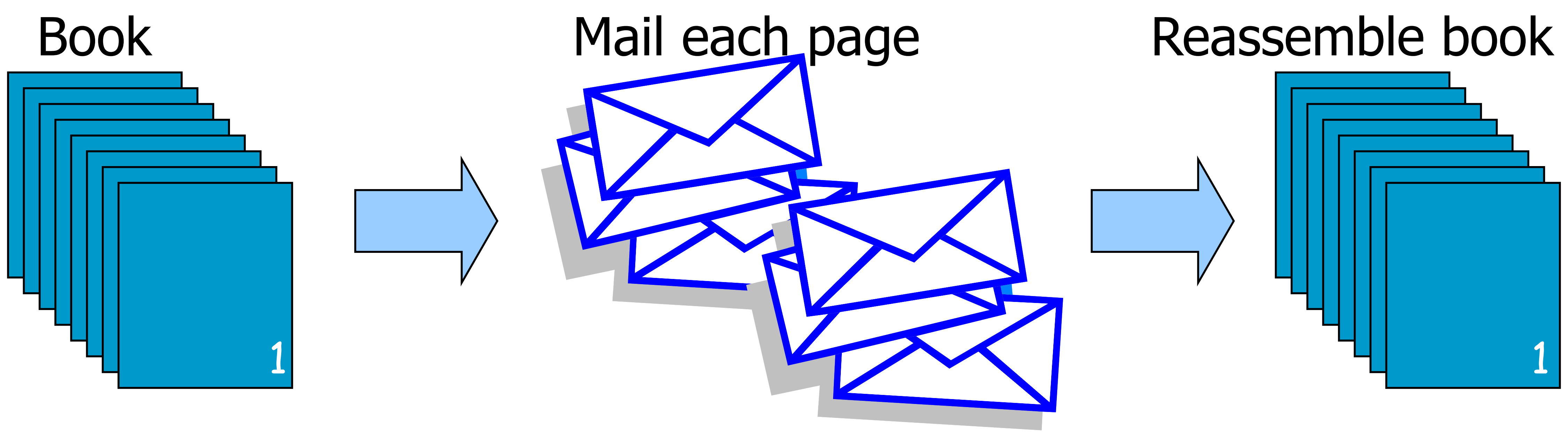
- Media Access Control (MAC) addresses in the network access layer
  - Associated w/ network interface card (NIC)
  - 48 bits or 64 bits
- IP addresses for the network layer
  - 32 bits for IPv4, and 128 bits for IPv6
  - E.g., 128.3.23.3
- IP addresses + ports for the transport layer
  - E.g., 128.3.23.3:80
- Domain names for the application/human layer
  - E.g., www.psu.edu

Routing and Translation of Addresses

- Translation between IP addresses and MAC addresses
  - Address Resolution Protocol (ARP) for IPv4
  - Neighbor Discovery Protocol (NDP) for IPv6
- Routing with IP addresses
  - TCP, UDP, IP for routing packets, connections
  - Border Gateway Protocol for routing table updates
- Translation between IP addresses and domain names
  - Domain Name System (DNS)

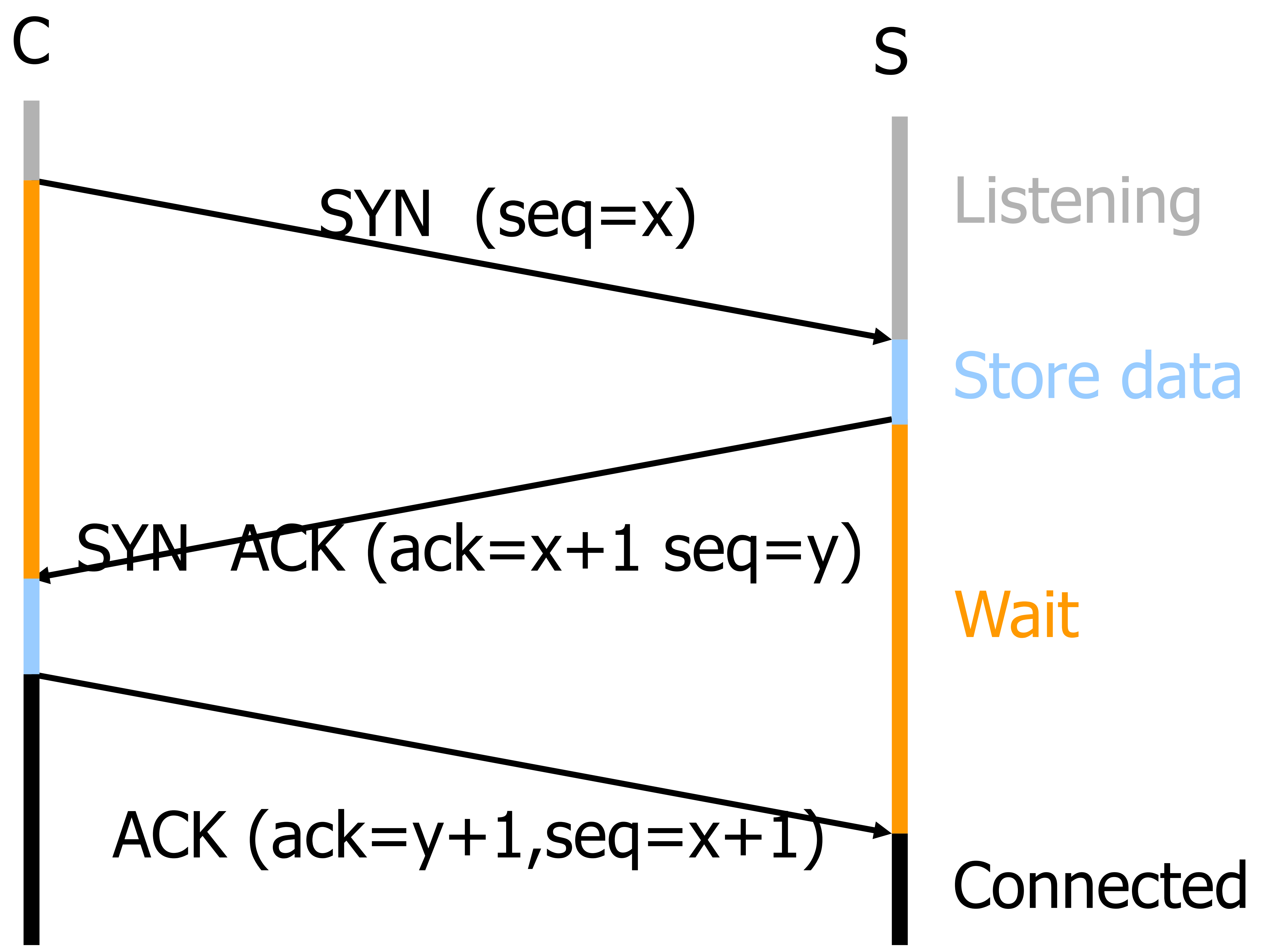
Transmission Control Protocol

- Connection-oriented, preserves order
  - Sender
    - Break data into packets
    - Attach sequence numbers
- Receiver
  - Acknowledge receipt; lost packets are resent
  - Reassemble packets in correct order



-

TCP Handshake

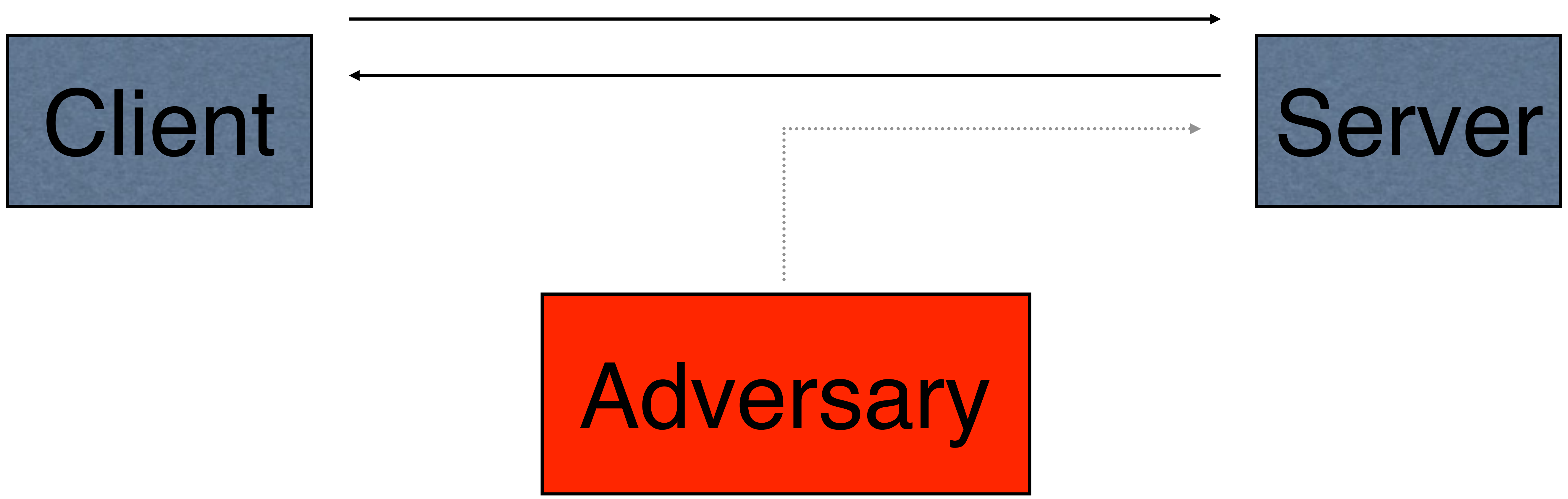


Sequence number prediction

- TCP/IP uses a *three-way handshake* to establish a connection

1. Client -> Server: Q_C
2. Server -> Client: $Q_{S,}$ ack(Q_C) where sequence number Q_S is nonce
3. C -> S: ack(Q_S) … then send data

2. However assume the bad guy does not hear msg 2, if he can guess Q_S, then he can get S to accept whatever data it wants (useful if doing IP authentication, e.g., "rsh")



DoS Vulnerability Caused by Session Hijacking

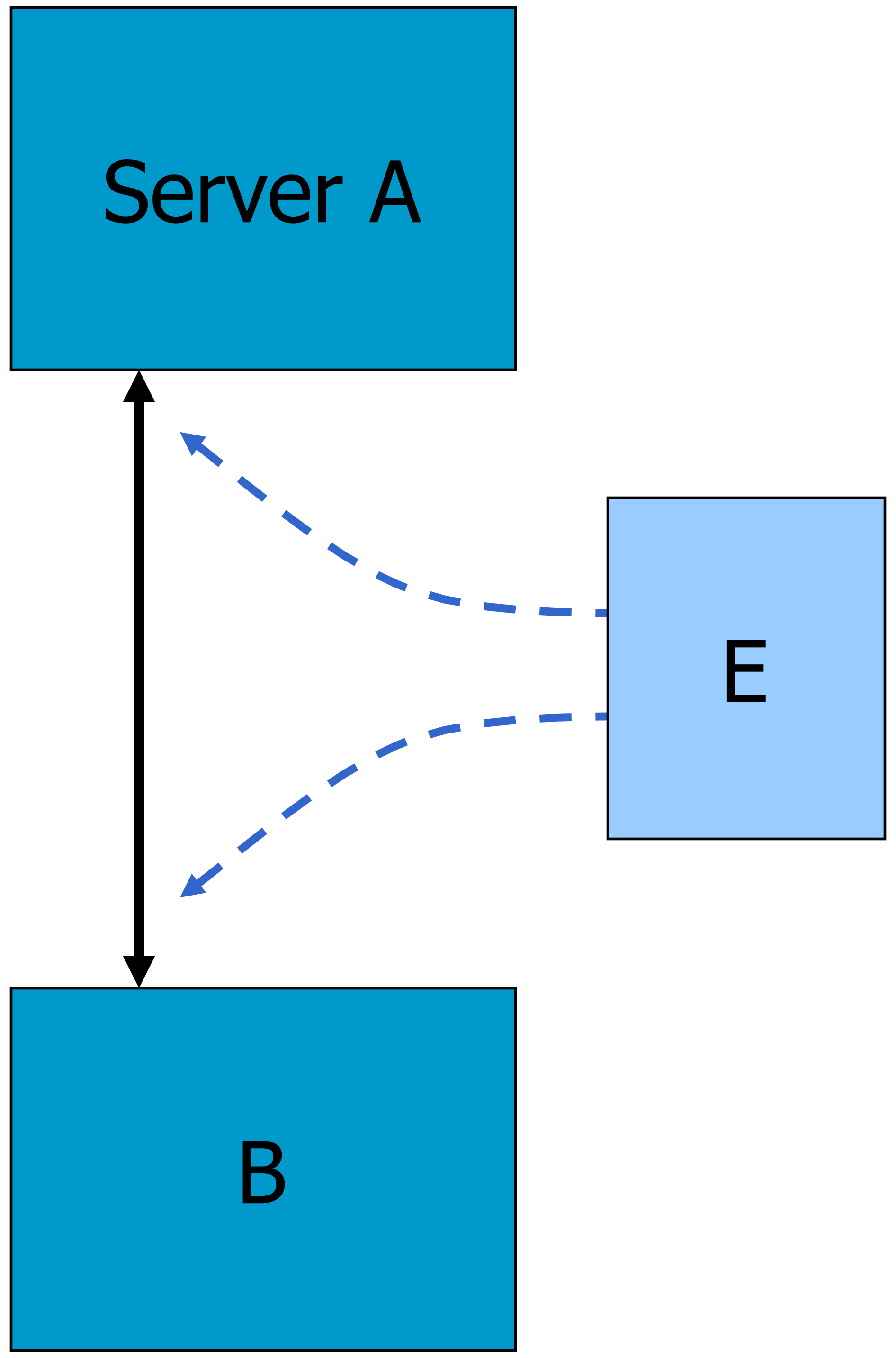
- Suppose attacker can guess seq. number for an existing connection:
  - Attacker can send Reset packet to close connection.
    - Results in DoS.
  - Naively, success prob. is 1/2^32 (32-bit seq. #'s).
  - Most systems allow for a large window of acceptable seq. #'s
    - Much higher success probability.
- Attack is most effective against long lived connections, e.g. BGP.

TCP Seq Prediction Attack

- Predict the sequence number used to identify the packets in a TCP connection, and then counterfeit packets.
- Adversary: do not have full control over the network, but can inject packets with fake source IP addresses
  - E.g., control a computer on the local network
- TCP sequence numbers are used for authenticating packets
- Initial seq# needs high degree of unpredictability
  - If attacker knows initial seq # and amount of traffic sent, can estimate likely current values
  - Some implementations are vulnerable

Blind TCP Session Hijacking

- A, B trusted connection
  - Send packets with predictable seq numbers
- E impersonates B to A
  - Opens connection to A to get initial seq number
  - DoS B's queue
  - Sends packets to A that resemble B's transmission
  - E cannot receive, but may execute commands on A

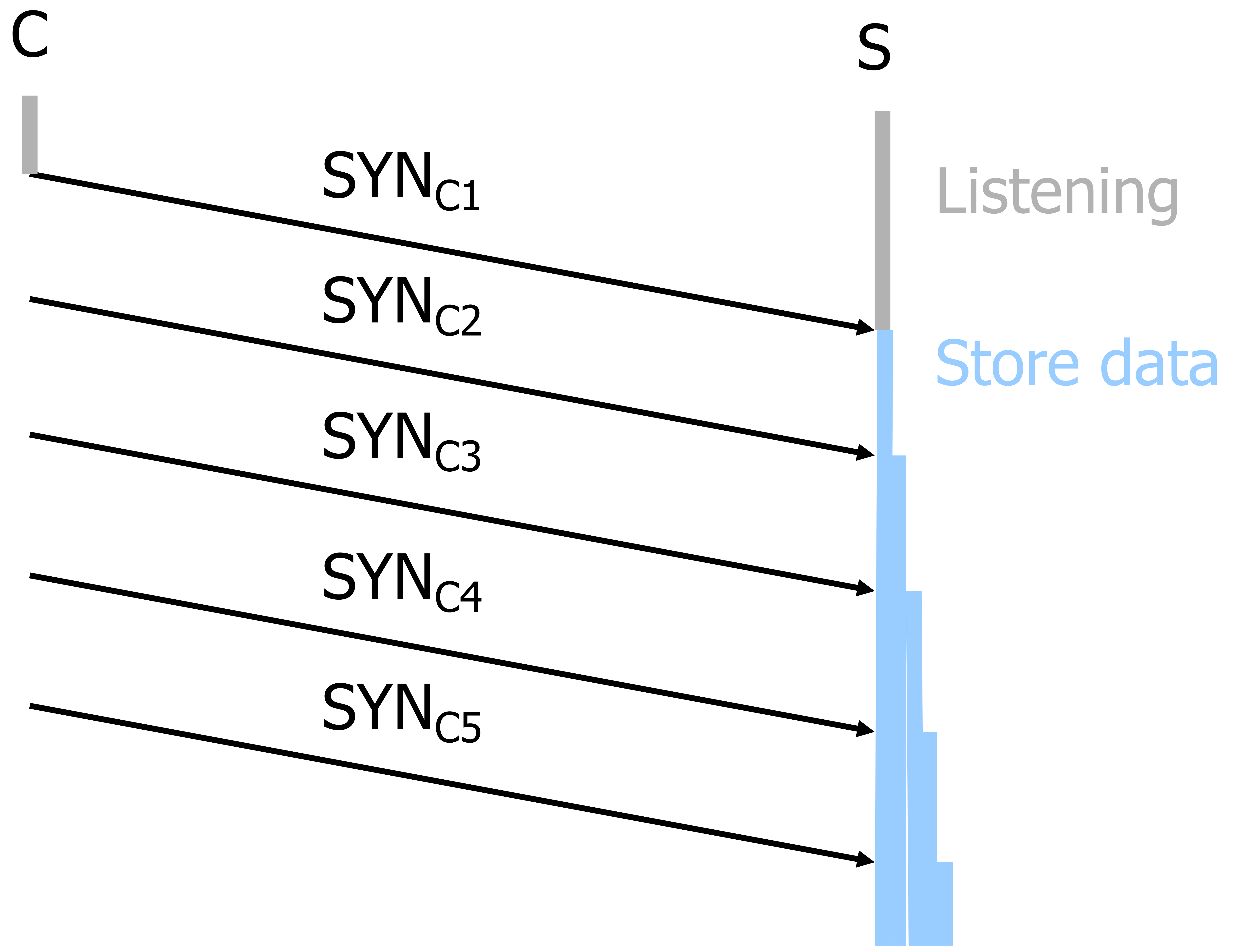


Attack can be blocked if E is outside firewall.

Risks from Session Hijacking

- Inject data into an unencrypted server-to-server traffic, such as an e-mail exchange, DNS zone transfers, etc.
- Inject data into an unencrypted client-to-server traffic, such as ftp file downloads, http responses.
- Spoof IP addresses, which are often used for preliminary checks on firewalls or at the service level.
- Carry out MITM attacks on weak cryptographic protocols.
  - often result in warnings to users that get ignored
- Denial of service attacks, such as resetting the connection.

SYN Flooding



SYN Flooding

- Attacker sends many connection requests
  - Spoofed source addresses
- Victim allocates resources for each request
  - Connection requests exist until timeout
  - Old implementations have a small and fixed bound on half-open connections
- Resources exhausted => requests rejected
- No more effective than other channel capacity-based attack today
-

Sequence Number Prediction (fixes)

- The only way you really fix this problem to stop making the sequence numbers predictable:
  - Randomize them -- you can use DES or some other mechanism to generate them randomly
  - There is an entire sub-field devoted to the creation and management of randomness in OSes
- Also, you could look for inconsistencies in timing information
  - Assumption: the adversary has different timing
  - OK, may be helpful, but far from definitive

What's Changed?

- Collaborative TCP Sequence Number Inference Attack -- How to Crack Sequence Number Under A Second
  Zhiyun Qian, Z. Morley Mao, Yinglian Xie
  In Proceedings of ACM Conference on Computer and Communications Security (CCS) 2012, Raleigh, NC.

- Off-Path TCP Sequence Number Inference Attack -- How Firewall Middleboxes Reduce Security Zhiyun Qian, Z. Morley Mao
  In Proceedings of IEEE Security and Privacy (Oakland) 2012, San Francisco, CA.

- Still have TCP sequence number attacks

Internet Control Message Protocol (ICMP)

PennState

- ICMP is used as a control plane for IP messages
  - Ping (connectivity probe)
    - Destination Unreachable (error notification)
    - Time-to-live exceeded (error notification)
- These are largely indispensable tools for network management and control
  - Error notification codes can be used to reset connections without any authentication
- Solution: verify/sanity check sources and content
  - ICMP "returned packets"
- Real solution: filter most of ICMP, ignore it

The "ping of death" …

- In 1996, someone discovered that many operating systems, routers, etc. could be crashed/rebooted by sending a single malformed packet
  - It turns out that you can send a IP packet larger than 65,535 (2^{16}), it would crash the system
  - The real reason lies in the way fragmentation works
    - It allows somebody to send a packet bigger than IP allows which blows up most fixed buffer size implementations
    - … and dumps core, blue screen of death, etc.
  - Note: this is not really ICMP specific, but easy (try it)

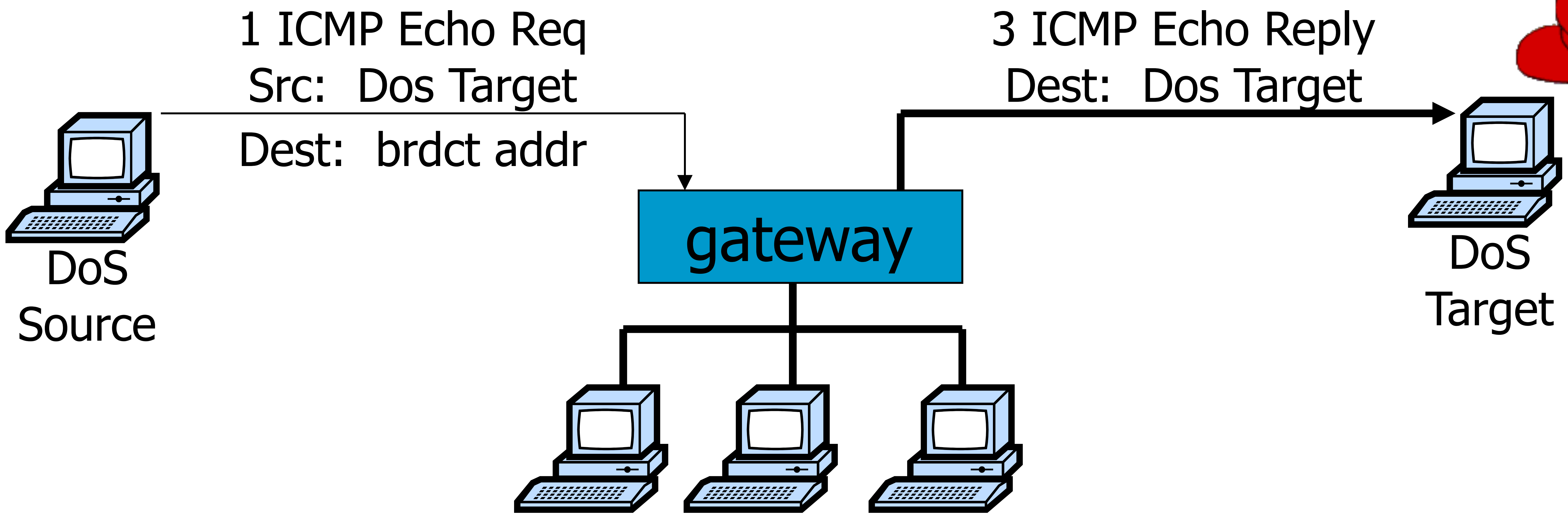
```
% ping -l 65555 your.host.ip.address
```

- This was a popular pastime of early hackers

Smurf DoS Attack

PennState

- Send ping request to broadcast addr (ICMP Echo Req)
- Lots of responses:
- Every host on target network generates a ping reply (ICMP Echo Reply) to victim
- Ping reply stream can overload victim
-



Prevention: reject external packets to broadcast address

Address Resolution Protocol (ARP)

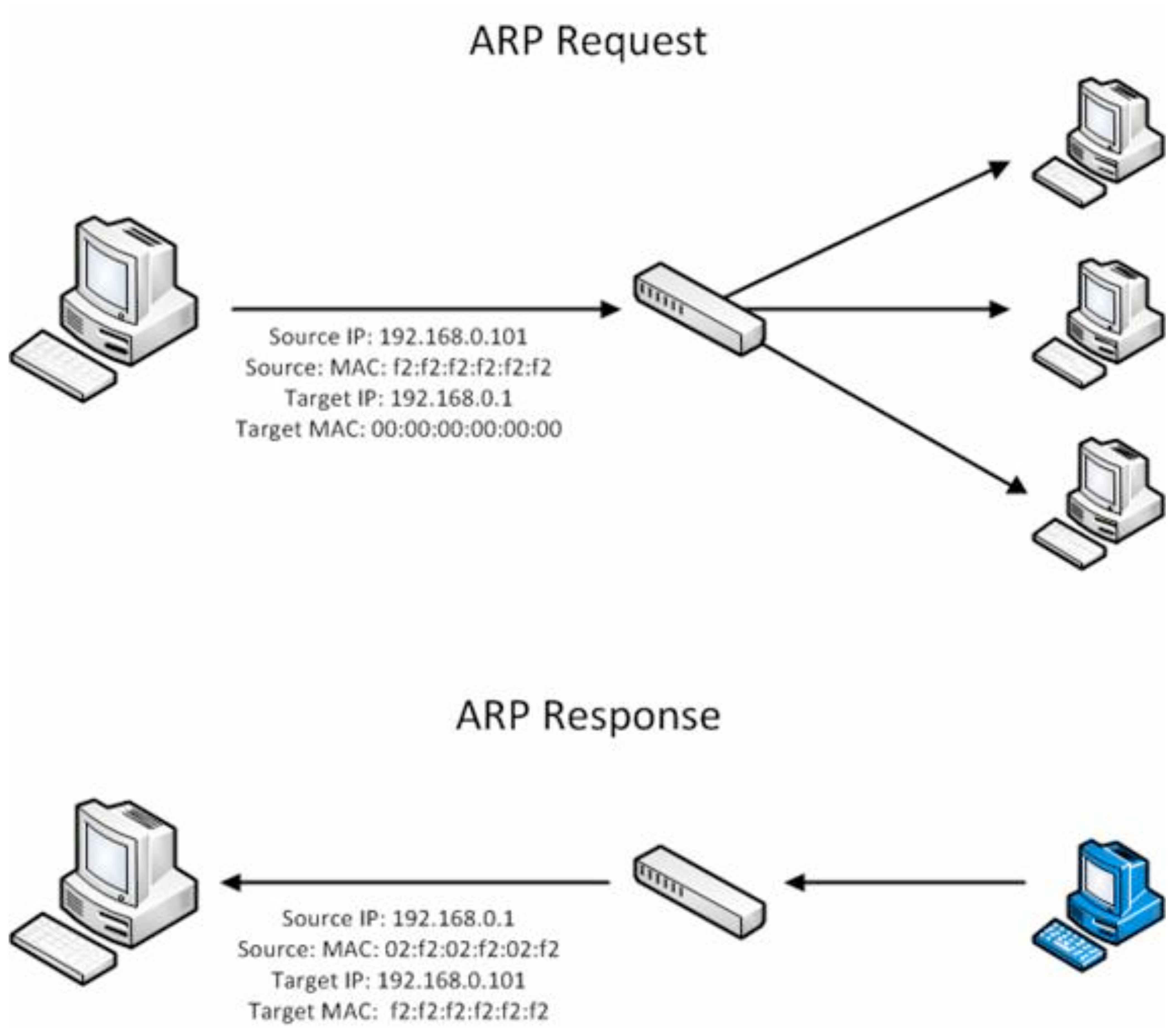
- Protocol used to map IP address onto the physical layer addresses (MAC)

  1) ARP request: who has x.x.x.x?

  2) ARP response: me!

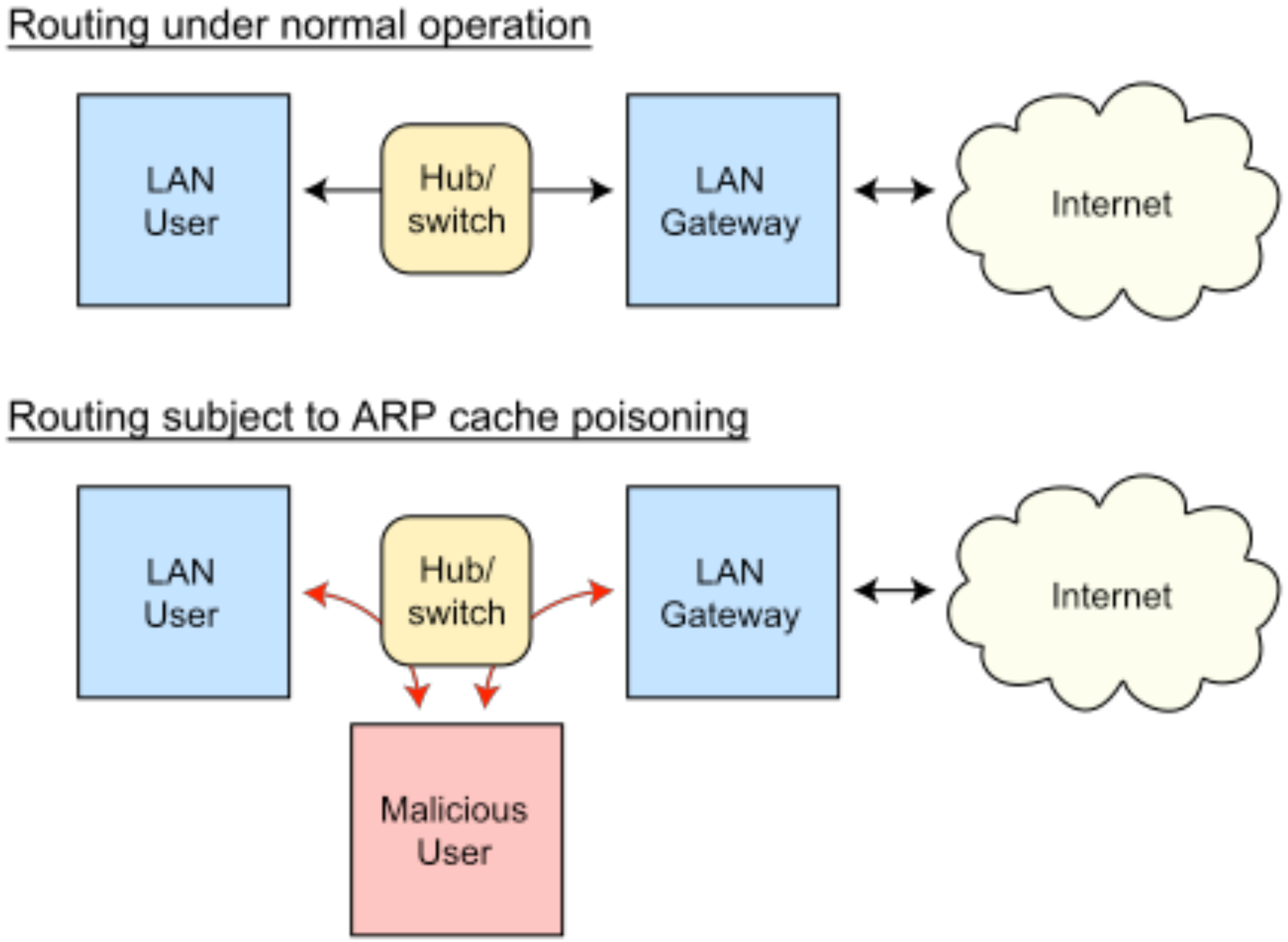
- Policy: last response in wins
- Used to forward packets on the appropriate interfaces by network devices
  - Also used for IP over other LAN technologies, e.g. IEEE 802.11
  - Each host maintains a table of IP to MAC addresses

    Q: Why would you want to spoof an IP address?



ARP Spoofing (Poisoning)

- Send fake or 'spoofed' ARP messages to an Ethernet LAN.
- To have other machines associate IP addresses with the attacker's MAC



- Defenses
  - static ARP table
  - DHCP Certification (use access control to ensure that hosts only use the IP addresses assigned to them, and that only authorized DHCP servers are accessible).
  - Detection: Arpwatch (sending email when updates occur),

ARP poisoning

- Attack: replace good entries with your own
- Leads to
  - Session hijacking
  - Man-in-the-middle attacks
  - Denial of service, etc.

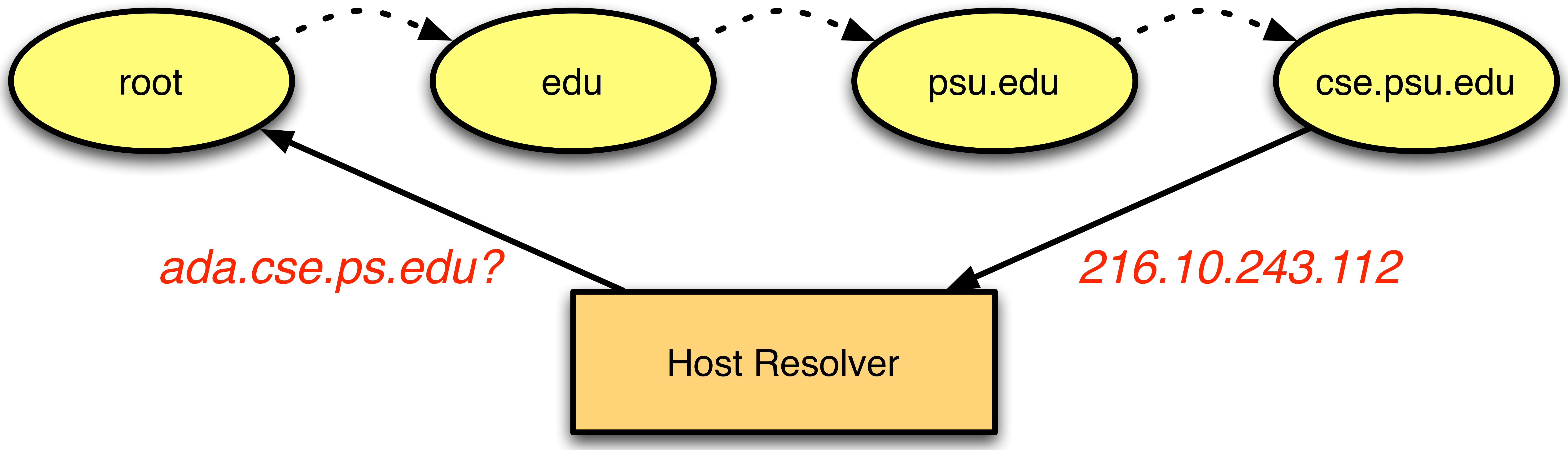
- Lots of other ways to abuse ARP.
- Nobody has really come up with a good solution
  - Except smart switches, routers that keep track of MACs
- However, some not worried
  - If adversary is in your perimeter, you are in big trouble
  - You should validate the source of each packet independently (e.g., via IPsec)

POP/SMTP/FTP

- Post office protocol - mail retrieval
  - Passwords passed in the clear (duh)
  - Solution: SSL, SSH, Kerberos
- Simple mail transport protocol (SMTP) - email
  - Nothing authenticated: SPAM
  - Nothing hidden: eavesdropping
  - Solution: SMTP AUTH
- File Transfer protocol - file retrieval
  - Passwords passed in the clear (duh)
  - Solution: SSL, SSH, Kerberos

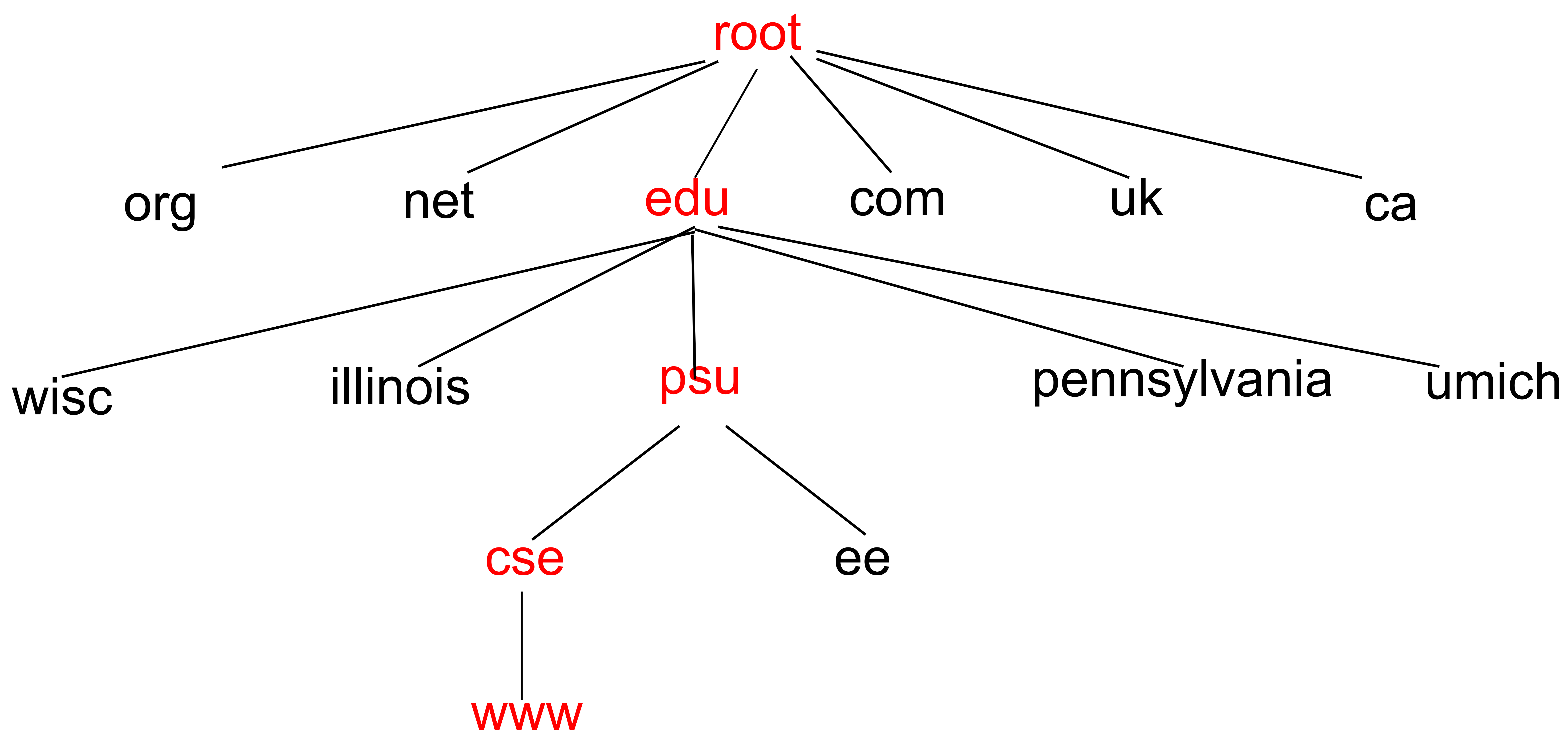
DNS - The domain name system

- DNS maps between IP address (12.1.1.3) and domain and host names (ada.cse.psu.edu)
  - How it works: the "root" servers redirect you to the top level domains (TLD) DNS servers, which redirect you to the appropriate sub-domain, and recursively ….
  - Note: there are 13 "root" servers that contain the TLDs for .org, .edu, and country specific registries (.fr, .ch)



Domain Name System

Hierarchical Name Space



- Each host stores mapping between hostnames and IP addresses
- Local hosts file (e.g. /etc/hosts):

127.0.0.1 localhost

152.14.93.88 cse.psu.edu

158.130.69.163 www.cis.upenn.edu

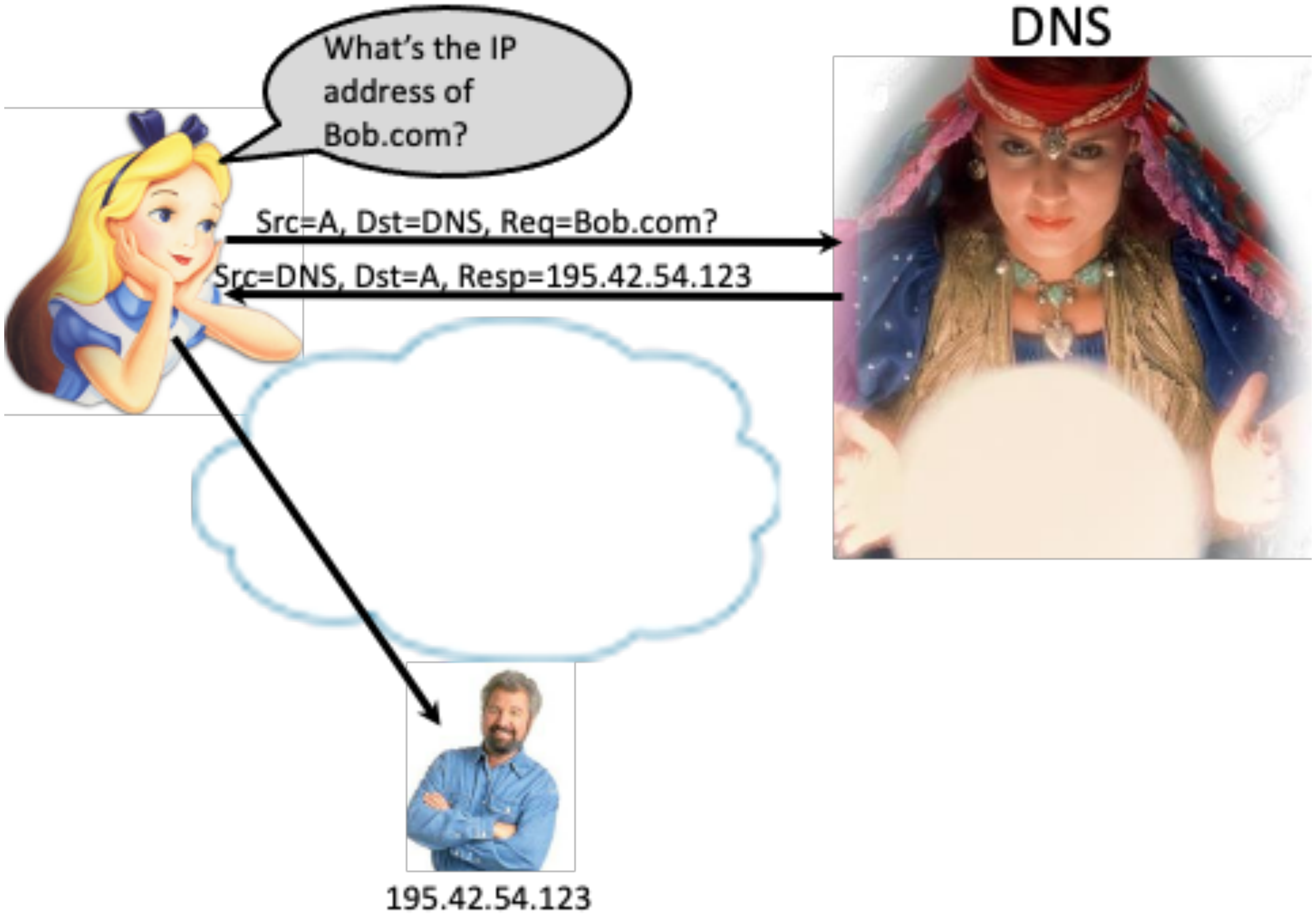
18.9.22.169 www.mit.edu

- Q: Does this scale?

Domain Name System (DNS)

- Created in 1983
- Distributed translation service between hostnames and IP addresses
- http://cse.psu.edu → http://152.14.93.88

Domain Name System



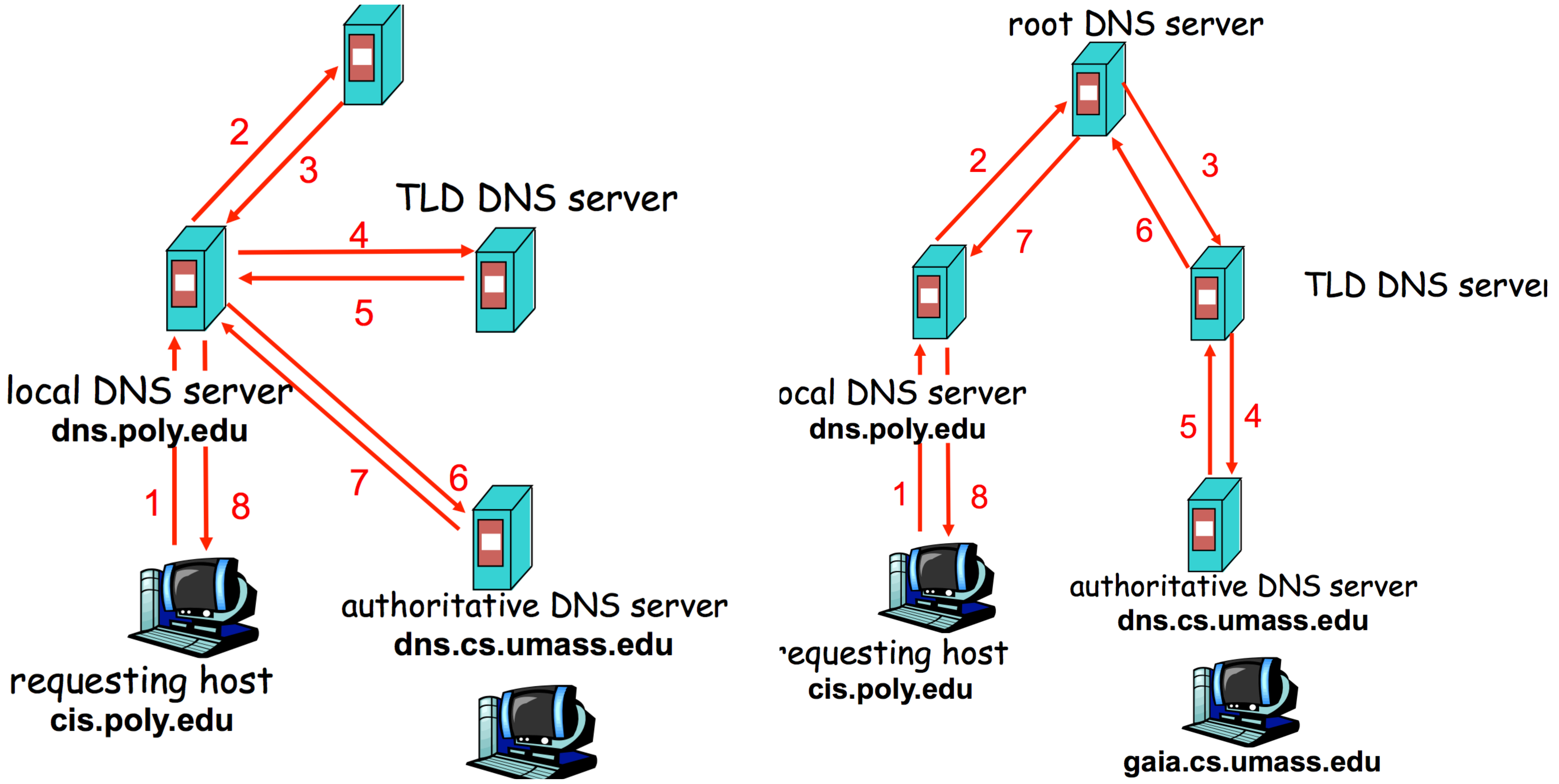
Domain Name Servers

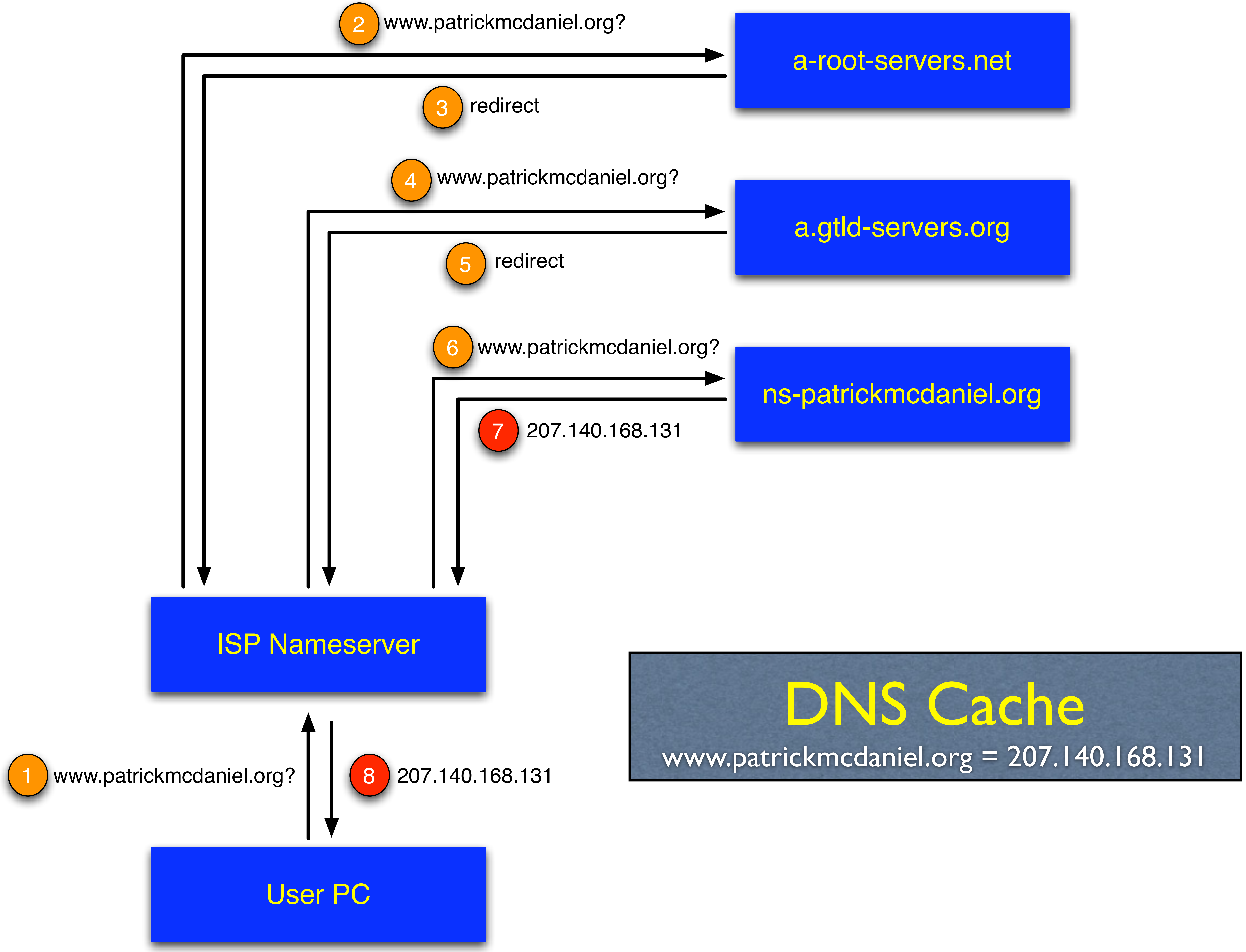
- Top-level domain (TLD) servers:
  - responsible for com, org, net, edu, etc, and all top-level country domains, e.g. uk, fr, ca, jp.
  - Network Solutions maintains servers for ".com"
- Authoritative DNS servers:
  - organization's DNS servers, providing authoritative hostname to IP mappings for organization's servers.
  - gives authoritative results for hostnames that have been configured via zone records
  - can be maintained by organization or service provider
- Local Name Server
  - does not strictly belong to hierarchy
  - each ISP (residential ISP, company, university) has one.

DNS Resolving

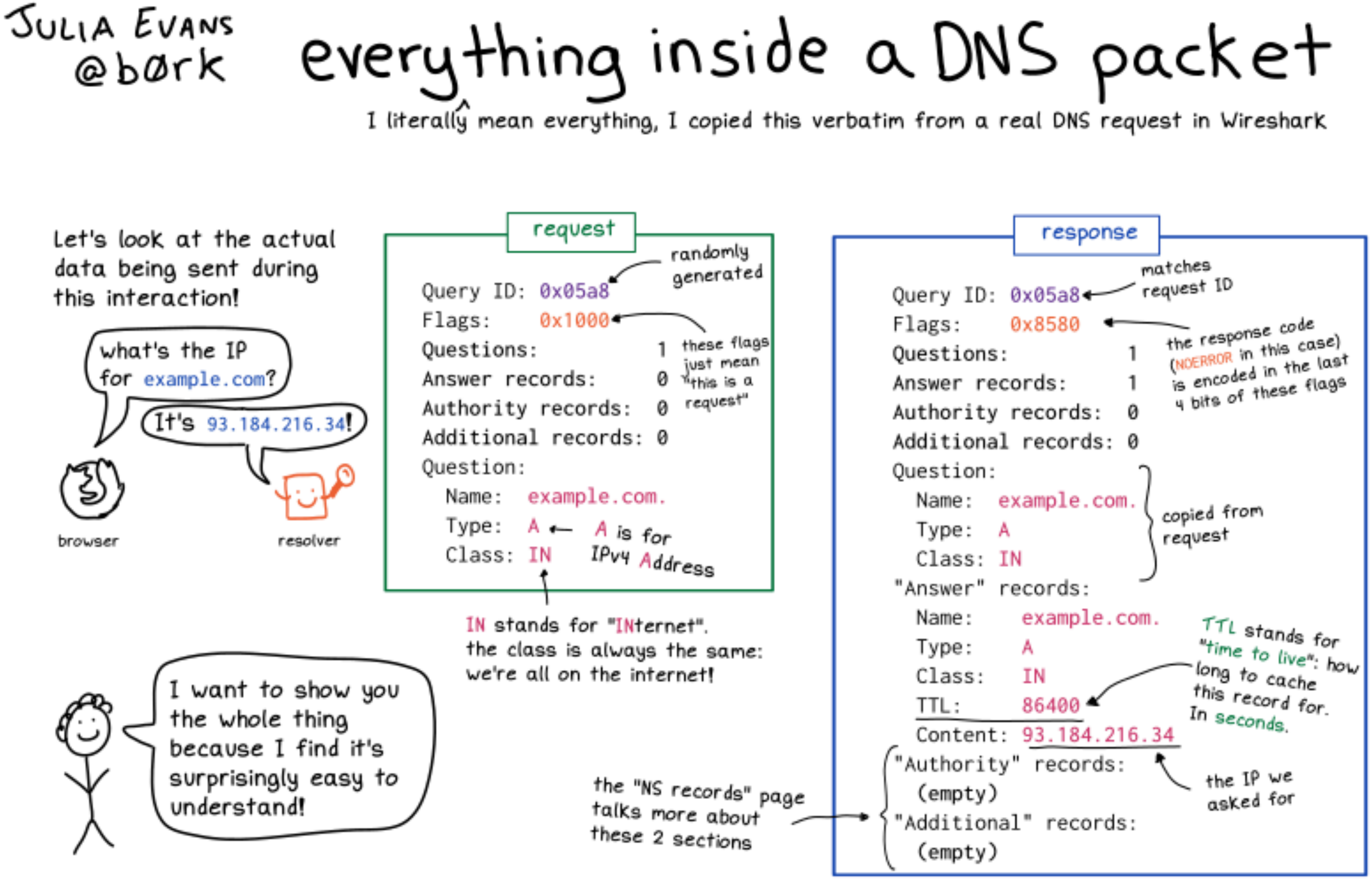
- When host makes DNS query, query is sent to its local DNS server.
  - acts as proxy, forwards query into hierarchy.

- Two resolving schemes:
  - Iterative, and
  - Recursive.




2 www.patrickmcdaniel.org?
a-root-servers.net
3 redirect
4 www.patrickmcdaniel.org?
a.gtld-servers.org
5 redirect
6 www.patrickmcdaniel.org?
ns-patrickmcdaniel.org
7 207.140.168.131
ISP Nameserver
DNS Cache
www.patrickmcdaniel.org = 207.140.168.131
1 www.patrickmcdaniel.org?
8 207.140.168.131
User PC

Everything Inside a DNS Packet



"Glue" information

- Suppose you ask a name server for a record and it redirects you to another name server (NS record)
  - e.g., if you ask a root for a NS (name server) record for NET, it returns NS records for the authoritative servers for .net
    - An NS record (or nameserver record) is a DNS record that contains the name of the authoritative name server within a domain or DNS zone
- It will also give you the A (resource) record for the authoritative servers you were directed to
  - avoid looking them up
  - This is known as the "glue" records

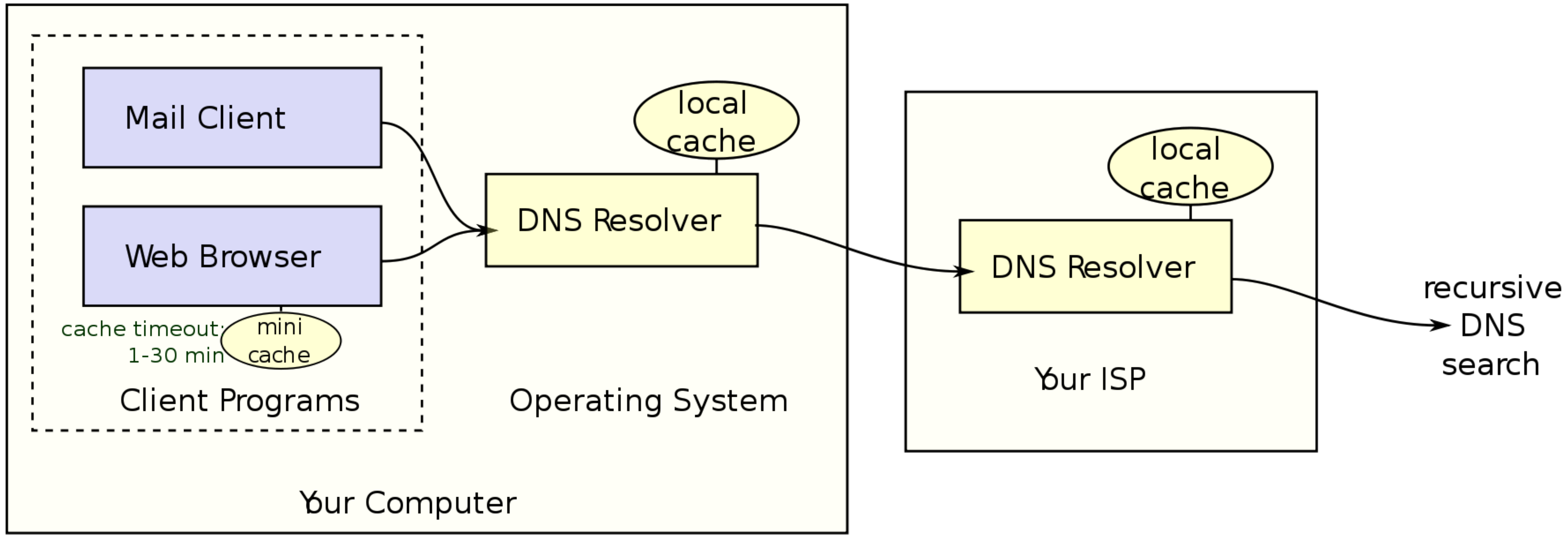
.NET referrals

```
/* Authority section */
NET.                    IN   NS A.GTLD-SERVERS.NET.
                        IN   NS B.GTLD-SERVERS.NET.
                        IN   NS C.GTLD-SERVERS.NET.
                        ...
                        IN   NS M.GTLD-SERVERS.NET.

/* Additional section - "glue" records */
A.GTLD-SERVERS.net.     IN   A  192.5.6.30
B.GTLD-SERVERS.net.     IN   A  192.33.14.30
C.GTLD-SERVERS.net.     IN   A  192.26.92.30
...
M.GTLD-SERVERS.net.     IN   A  192.55.83.30
```

Caching

- DNS responses are cached
  - Quick response for repeated translations
- Negative results are also cached
  - Save time for nonexistent sites, e.g. misspelling
- Cached data periodically times out
  - Each record has a TTL field



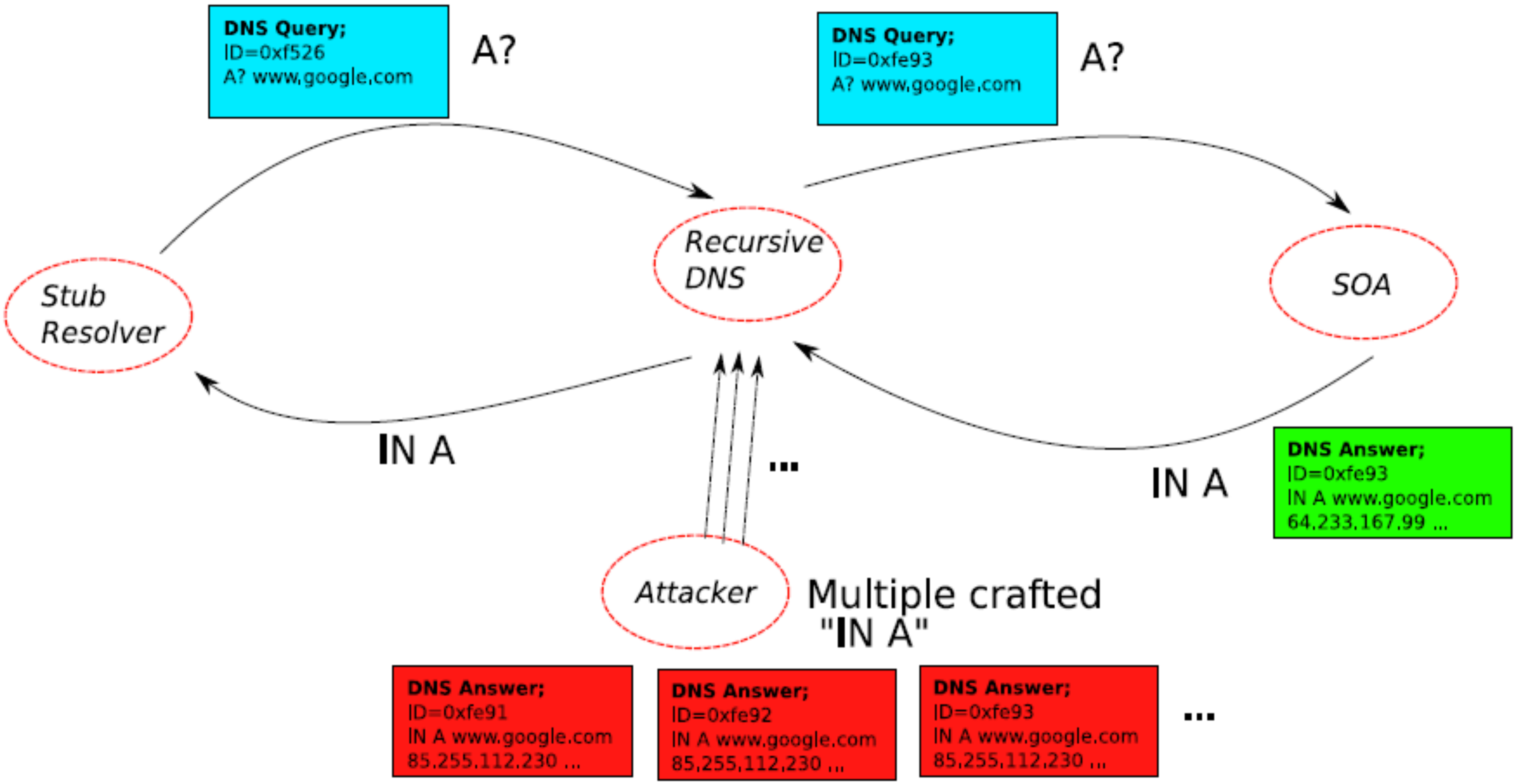
DNS Vulnerabilities

- Nothing is authenticated, so really the game is over
  - You cannot really trust what you hear …
  - But, many applications are doing just that.
  - Spoofing of DNS is really dangerous
- Moreover, DNS is a catalog of resources
  - Zone-transfers allow bulk acquisition of DNS data
  - … and hence provide a map for attacking the network
- Lots of opportunity to abuse the system
  - Relies heavily on caching for efficiency -- cache pollution
  - Once something is wrong, it can remain that way in caches for a long time (e.g., it takes a long time flush)
  - Data may be corrupted before it gets to authoritative server

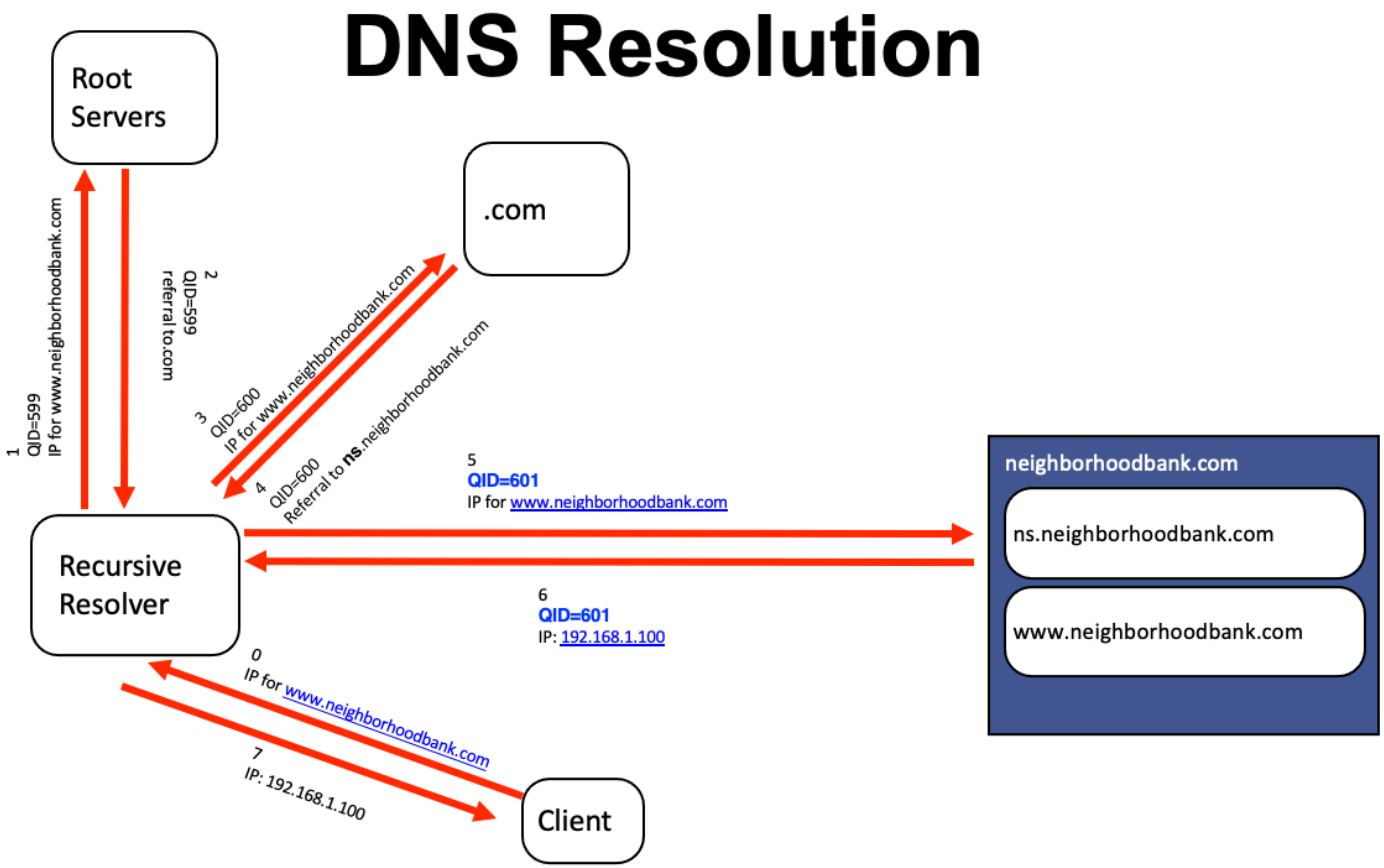
A Cache Poisoning Attack

- All requests have a unique query ID
- The nameserver/resolver uses this information to match up requests and responses
- If an adversary can guess the query ID, then it can forge the responses and pollute the DNS cache
  - 16-bit query IDs (not hard)
  - Some servers increment IDs (or use other bad algo.)
  - First one in wins!!!
- Note: If you can observe the traffic going to a name server, you can pretty much arbitrarily own the Internet for the clients it serves.

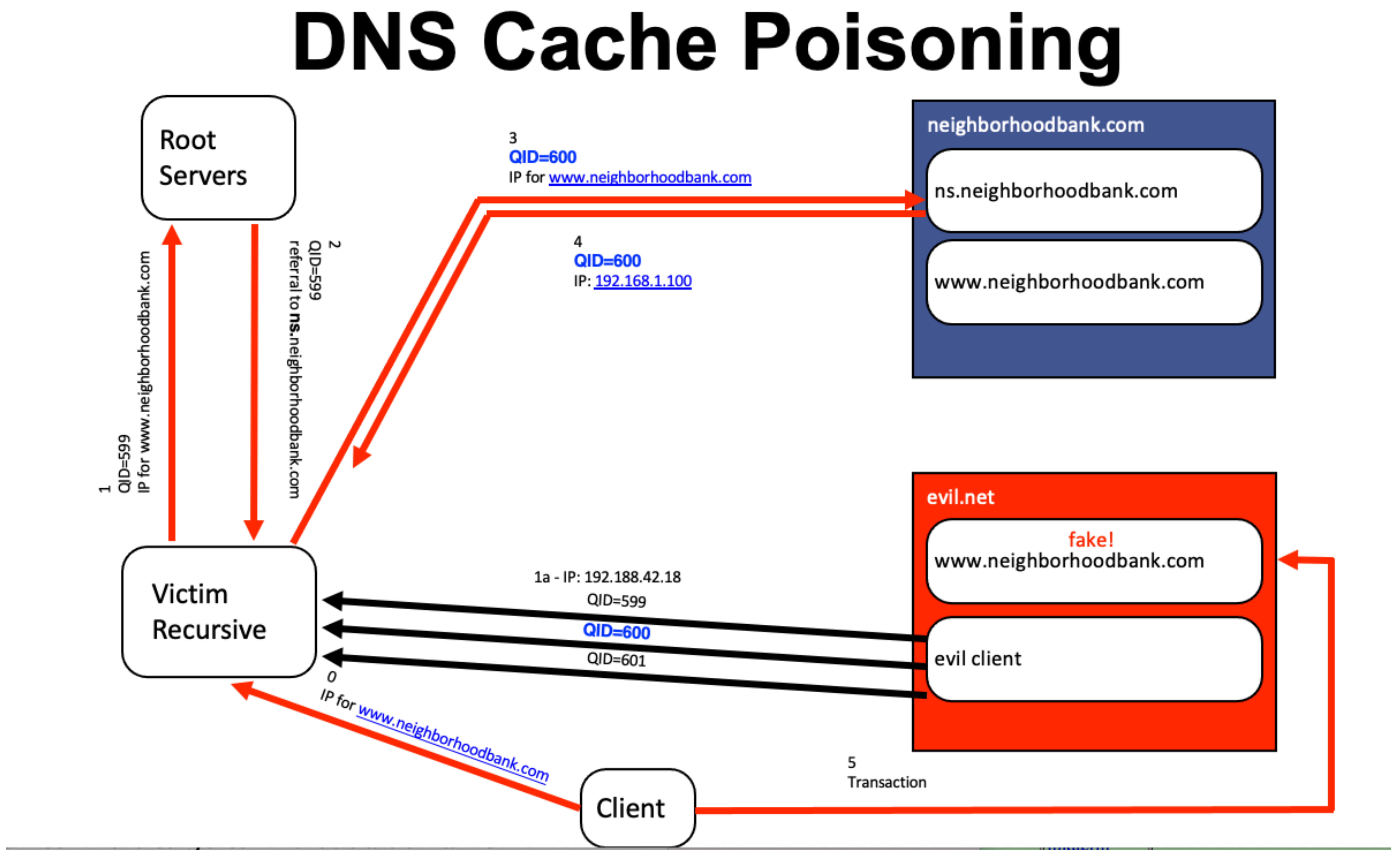
DNS Cache Poisoning: Racing to Respond First



DNS Resolution



DNS Cache Poisoning: Racing to



User Side Attack - Pharming

- Exploit DNS poisoning attack
  - Change IP addresses to redirect URLs to fraudulent sites
  - Potentially more dangerous than phishing attacks
    - Why?

- DNS poisoning attacks have occurred:
  - January 2005, the domain name for a large New York ISP, Panix, was hijacked to a site in Australia.
  - In November 2004, Google and Amazon users were sent to Med Network Inc., an online pharmacy

DNS Cache Poisoning

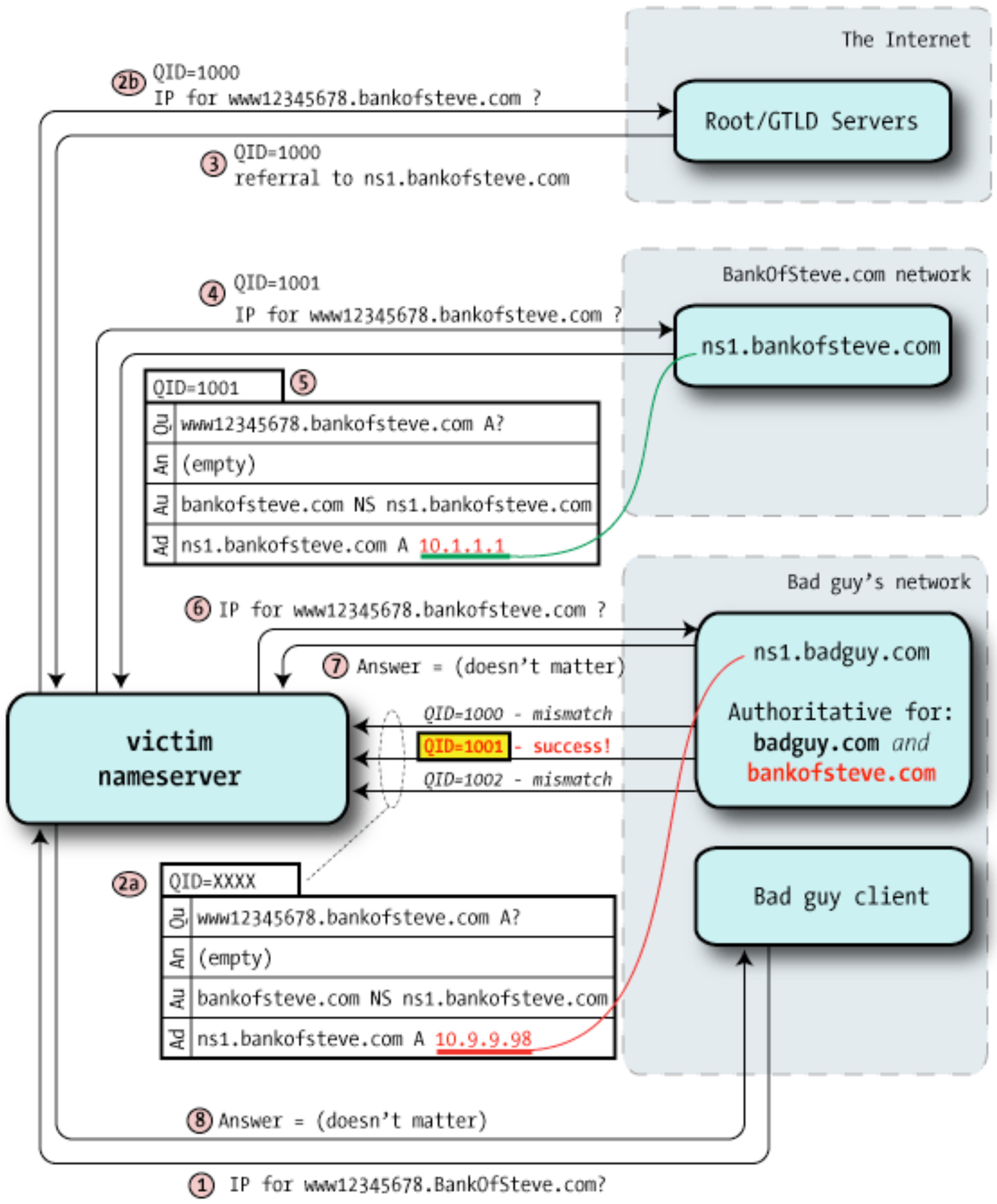
- Attacker wants his IP address returned for a DNS query
- When the resolver asks ns1.google.com for www.google.com, the attacker could reply first, with his own IP
- What is supposed to prevent this?
  - Transaction ID
    - 16-bit random number
    - The real server knows the number, because it was contained in the query
    - The attacker has to guess
-

DNS Cache Poisoning

- Responding before the real nameserver
  - An attacker can guess when a DNS cache entry times out and a query has been sent, and provide a fake response.
  - The fake response will be accepted only when its 16-bit transaction ID matches the query
  - CERT reported in 1997 that BIND uses sequential transaction ID and is easily predicted
  - fixed by using random transaction IDs

Kaminsky DNS Vulnerability

1. Query a random host in a victim zone, e.g., 1234.cse.psu.edu
2. Spoof responses* as before, but *delegate authority* to some server which you own.
   1. The glue records you give make you authoritative
3. You now own the domain.
4. unixwiz.net/techtips/lguide-kaminsky-dns-vuln.html



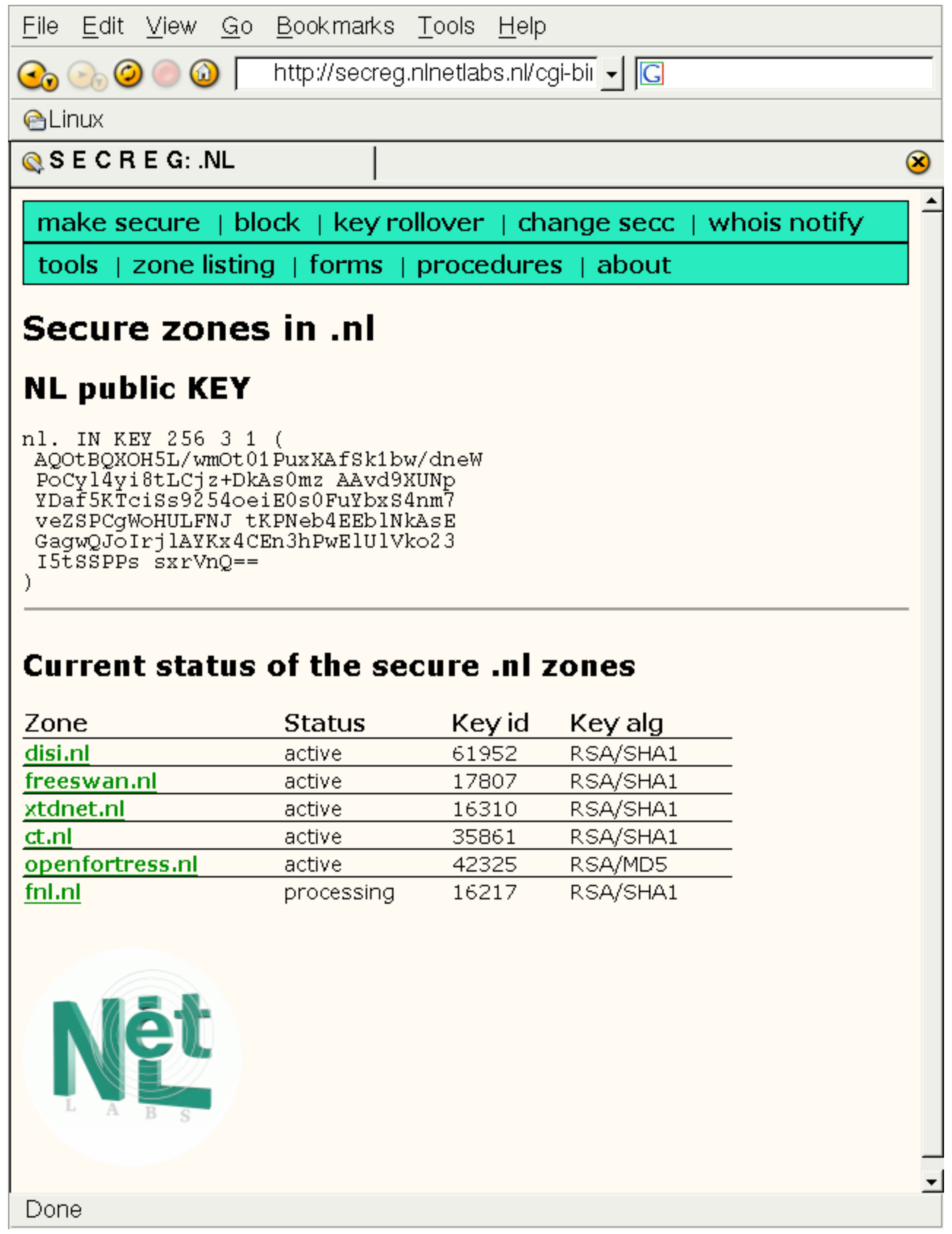
*the original attack exploited poor ID selection

Kaminski Fixes

- Make the ID harder to guess (randomized ports)
  - Amplified ID space from 2^{16} to 2^{27}
- Prevent foreign requests from being processed
  - E.g., filter requests from outside domain
- Observe and filter conflicting requests
  - E.g., if you see a lot of bogus looking requests, be careful
- All of this treats the symptoms, not the disease.
  - Lack of authenticated values
  - Thus, if you can observe request traffic, prevent legitimate responses, or are just plain patient, you can mount these attacks.

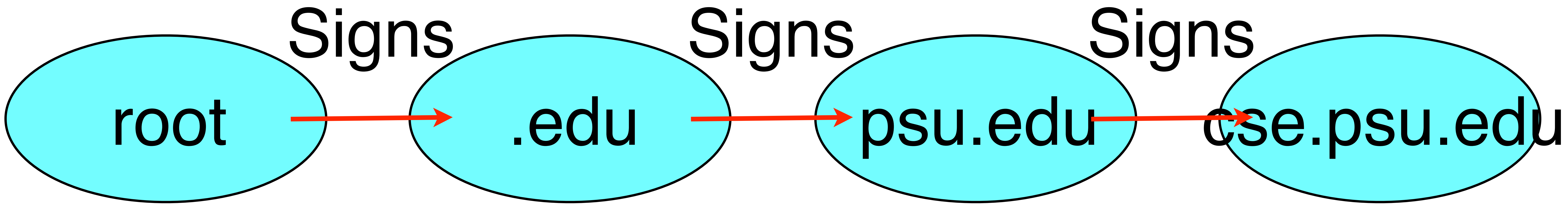
DNSSEC

- A standard-based (IETF) solution to security in DNS
  - Prevents data spoofing and corruption
  - Public key based solution to verifying DNS data
  - Authenticates
    - Communication between servers
    - DNS data
      - content
      - existence
      - non-existence
    - Public keys (a bootstrap for PKI?)



DNSSEC Mechanisms

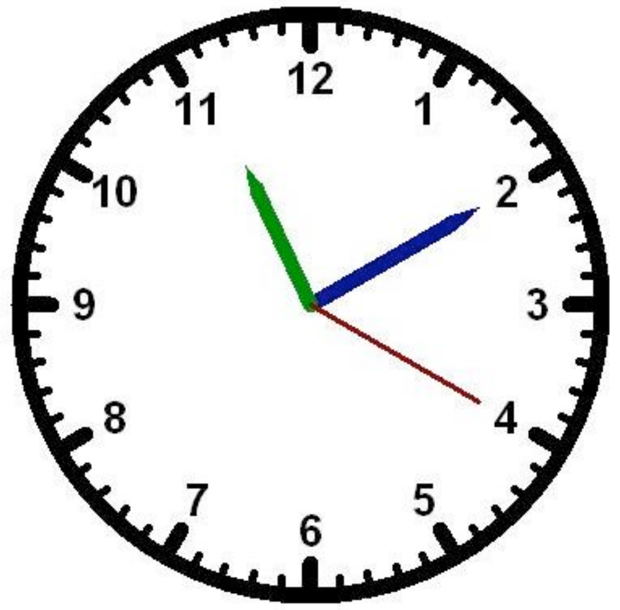
- Securing the DNS records
  - Each domain signs their "zone" with a private key
  - Public keys published via DNS
  - *Indirectly* signed by parent zones
  - Ideally, you only need a self-signed root, and follow keys down the hierarchy



DNSSEC Mechanisms

PennState

- TSIG : transaction signatures protect DNS operations
  - Zone loads, some server to server requests (master -> slave), etc.
  - Time-stamped signed responses for dynamic requests
  - A misnomer -- it currently uses shared secrets for TSIG (HMAC) or do real signatures using public key cryptography
- SIG0: a public key equivalent of TSIG
  - Works similarly, but with public keys
  - Not as popular as TSIG



- Note: these mechanisms assume clock sync. (NTP)