CS 5435

# DNS Security

Vitaly Shmatikov

# Turkey (2014)

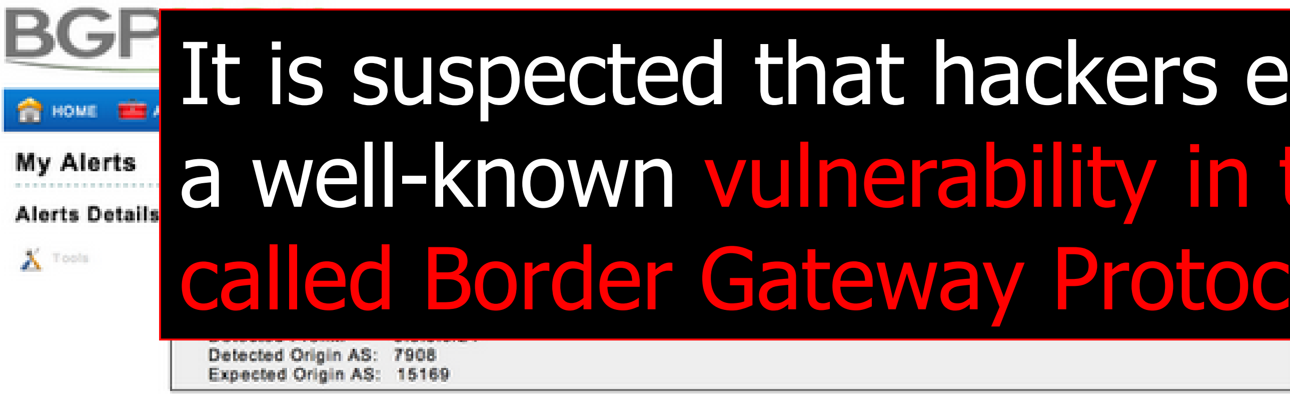

Engin Onder
Follow
#twitter blocked in #turkey tonight. folks are painting #google dns numbers onto the posters of the governing party.
pic.twitter.com/9vQ7NTgotO
DNS
8.8.8.8


DNS: 8.8.8.8 kuşun Ötsün
Alternatif: 8.8.4.4

Google DNS 8.8.8.8/32 was hijacked for ~22min yesterday, affecting networks in Brazil & Venezuela #bgp #hijack #dns pic.twitter.com/wlBuui8dwO

March 16, 2014

Reply Retweet Favorite More




It is suspected that hackers exploited a well-known vulnerability in the so-called Border Gateway Protocol (BGP)

RETWEETS 805
FAVORITES 156

# Turkish net hijack hits big name websites

**Visitors to the websites of Vodafone, the Daily Telegraph, UPS and four others were re-directed to a site set up by Turkish hackers on Sunda**

The hacking group, called Turkguvenligi, targeted the net's Domain Name System (DNS)


The di
on cor

Real U
into the IP address of the hackers' site.

This page greeted many visitors to the sites of
ers

No data from
compromised

Turkguvenligi revealed that it got access to the files using a well-established attack method known as SQL injection

ted Stories

The hacking
System (DNS

's developer

# DNS Hostname vs. IP Address

DNS hostname (e.g., www.cs.cornell.edu)

- Mnemonic name understood by humans
- Variable length, full alphabet of characters
- Provides little (if any) information about location

IP address (e.g., 128.84.202.53)

- Numerical address understood by routers
- Fixed length, decimal number
- Hierarchical address space, related to host location

# Uses of DNS

Hostname to IP address translation

- Reverse lookup: IP address to hostname translation

Host name aliasing: other DNS names for a host

- Alias hostnames point to canonical hostname

Email: look up domain’s mail server by domain name

# Different DNS Mappings

1-1 mapping between domain name and IP addr

- www.cs.cornell.edu maps to 132.236.207.20

Multiple domain names maps to the same IP addr

- eecs.mit.edu and cs.mit.edu both map to 18.62.1.6

Single domain name maps to multiple IP addrs

- aol.com and www.aol.com map to multiple IP addrs.

Some valid domain names don't map to any IP addr

- cmcl.cs.cmu.edu

# Goals of DNS

A wide-area distributed database

- Possibly biggest such database in the world!

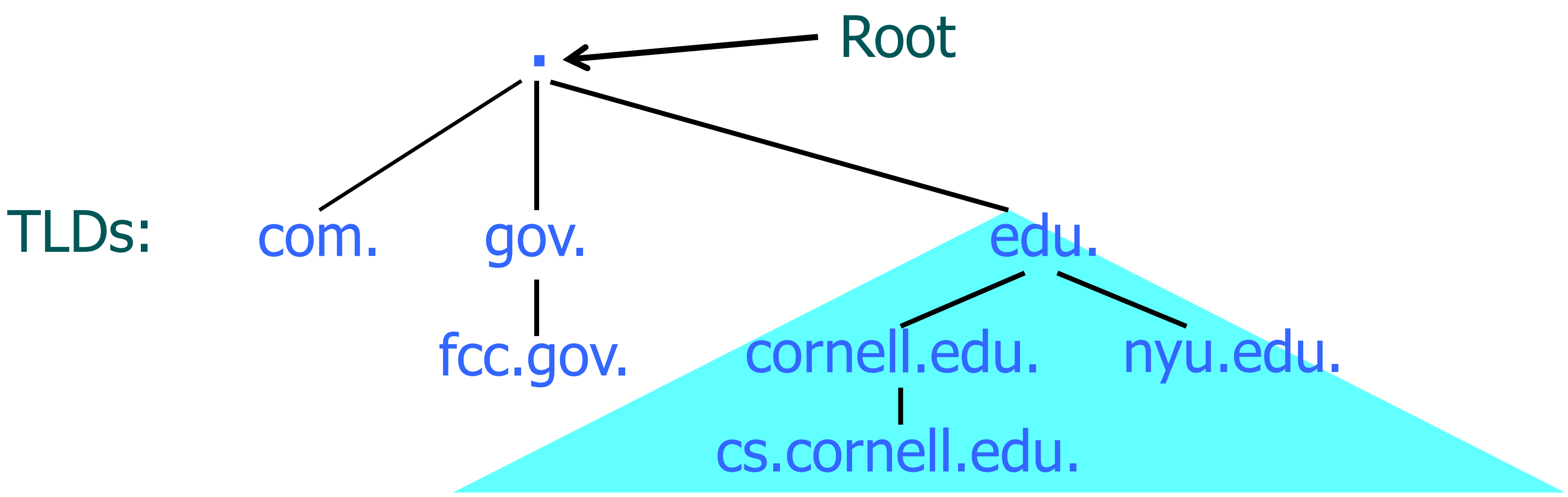
Goals

- Scalability; decentralized maintenance
- Robustness
- Global scope
- Names mean the same thing everywhere
- Distributed updates/queries
- Good performance

# DNS

- Hierarchical name space divided into contiguous sections called zones
  - Zones are distributed over a collection of DNS servers
- Hierarchy of DNS servers
  - Root servers (identity hardwired into other servers)
  - Top-level domain (TLD) servers
  - Authoritative DNS servers
- Performing the translations
  - Local DNS servers located near clients
  - Resolver software running on clients

# Hierarchical Structure of DNS



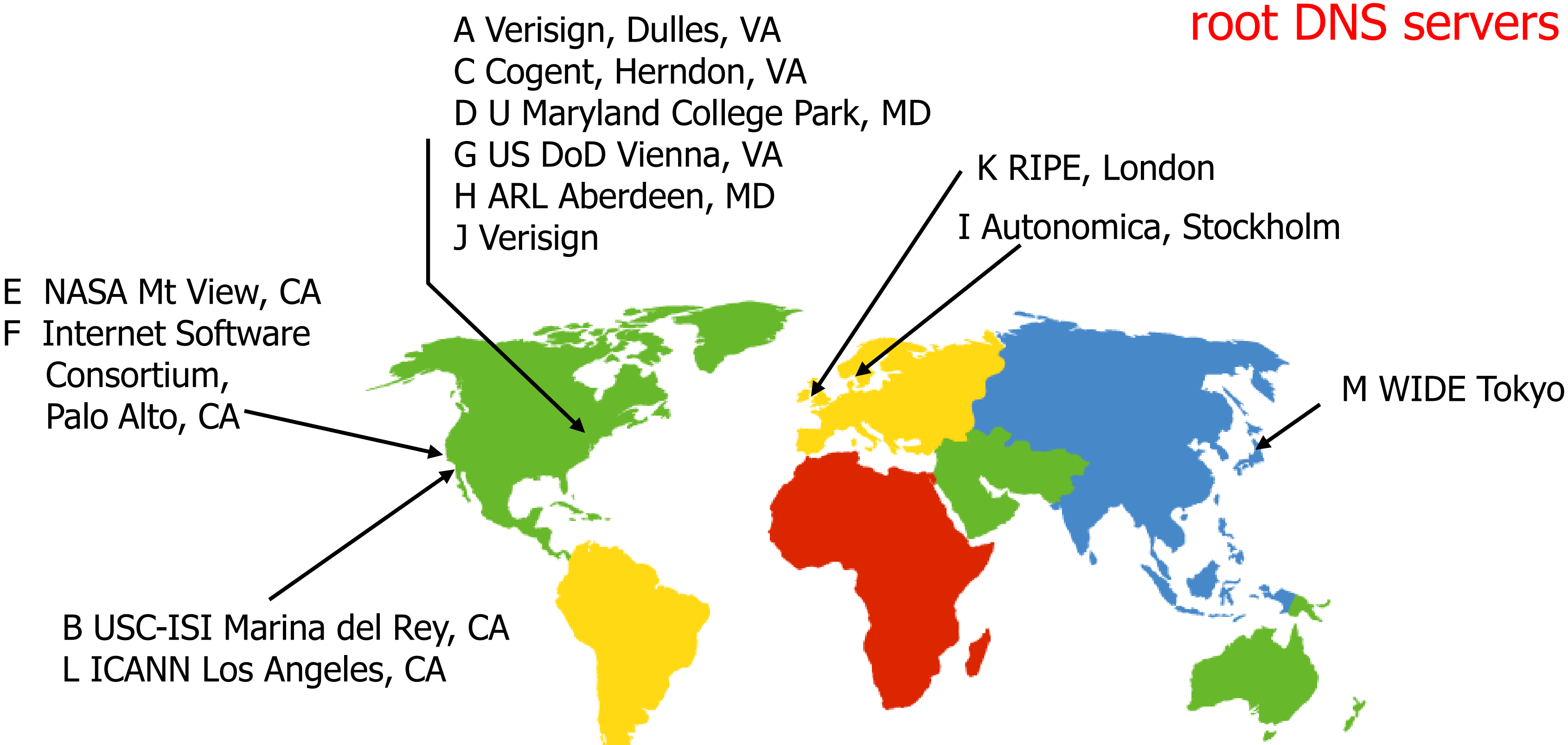

Hierarchy of namespace matches hierarchy of servers

Set of nameservers answers queries for names within zone

Nameservers store names and links to other servers in tree

# 13 DNS Root Nameservers

Feb 6, 2007: Botnet DoS attack on root DNS servers




Each server is really a cluster of servers (some distributed over a small geographical region), replicated via IP anycast which routes DNS queries to any server in that cluster of servers, to spread load

# TLD and Authoritative Servers

Top-level domain (TLD) servers

- Responsible for com, org, net, edu, etc, and all top-level country domains: uk, fr, ca, jp
- Network Solutions maintains servers for .com TLD
- Educause (non-profit) for .edu TLD

Authoritative DNS servers

- An organization’s DNS servers, providing authoritative information for that organization
- May be maintained by organization itself, or ISP

# Local Name Servers

Each ISP (or company, or university) has one

- No strict hierarchy

Also called default or caching name server

When a host makes DNS query, query is sent to its local DNS server, which acts as proxy and forwards query into hierarchy

# DNS Resource Records

DNS is a distributed database storing resource records

Resource record includes: (name, type, value, time-to-live)

Type = A (address)

- name = hostname
- value is IP address

Type = CNAME

- name = alias for some "canonical" (real) name
- value = canonical name

Type = NS (name server)

- name = domain (e.g. cornell.edu)
- Value = hostname of authoritative name server for this domain

Type = MX (mail exchange)

- name = domain
- value = name of mail server for that domain

# DNS in Operation

Most queries and responses are UDP datagrams

## Recursive

- Nameserver responds with answer or error

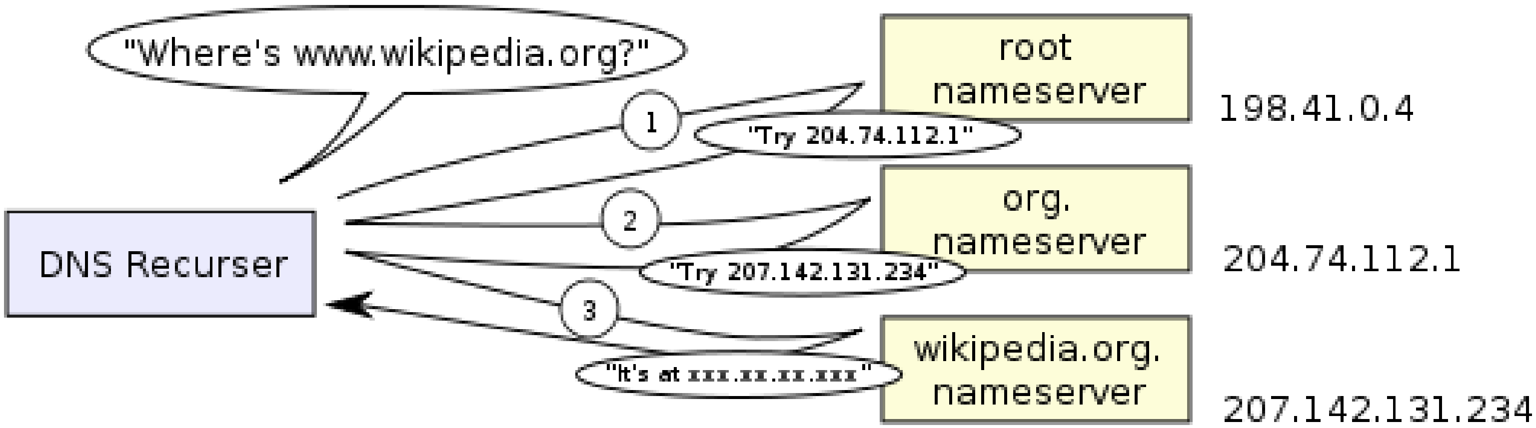

Answer: www.cornell.edu A 132.236.207.20

## Iterative

- Nameserver may respond with a referral


Referral: edu NS a.edu-servers.net

# Resolving Names




http://en.wikipedia.org/wiki/File:An_example_of_theoretical_DNS_recursion.svg

# Recursive vs. Iterative Queries

**Recursive**

Less burden query initiator

More burden on nameserver

- Has to return an answer

Most root and TLD servers won't answer (shed load)

Local name server answers recursive query

**Iterative**

More burden on query initiator

Less burden on nameserver

- Refers query to another nameserver

```
$ dig @a.root-servers.net www.freebsd.org +norecurse
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 57494
;; QUERY: 1, ANSWER: 0, AUTHORITY: 2, ADDITIONAL: 2

;; QUESTION SECTION:
;www.freebsd.org.               IN      A
```

*Time to live in seconds*

```
;; AUTHORITY SECTION:
org.                    172800 IN      NS      b0.org.afilias-nst.org.
org.                    172800 IN      NS      d0.org.afilias-nst.org.

;; ADDITIONAL SECTION:
b0.org.afilias-nst.org.    172800 IN      A       199.19.54.1
d0.org.afilias-nst.org.    172800 IN      A       199.19.57.1
```

*Glue records*

[Output edited for clarity]

(authoritative for org.)

```
$ dig @199.19.54.1 www.freebsd.org +norecurse
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 39912
;; QUERY: 1, ANSWER: 0, AUTHORITY: 3, ADDITIONAL: 0

;; QUESTION SECTION:
;www.freebsd.org.            IN    A

;; AUTHORITY SECTION:
freebsd.org.         86400   IN    NS    ns1.isc-sns.net.
freebsd.org.         86400   IN    NS    ns2.isc-sns.com.
freebsd.org.         86400   IN    NS    ns3.isc-sns.info.
```

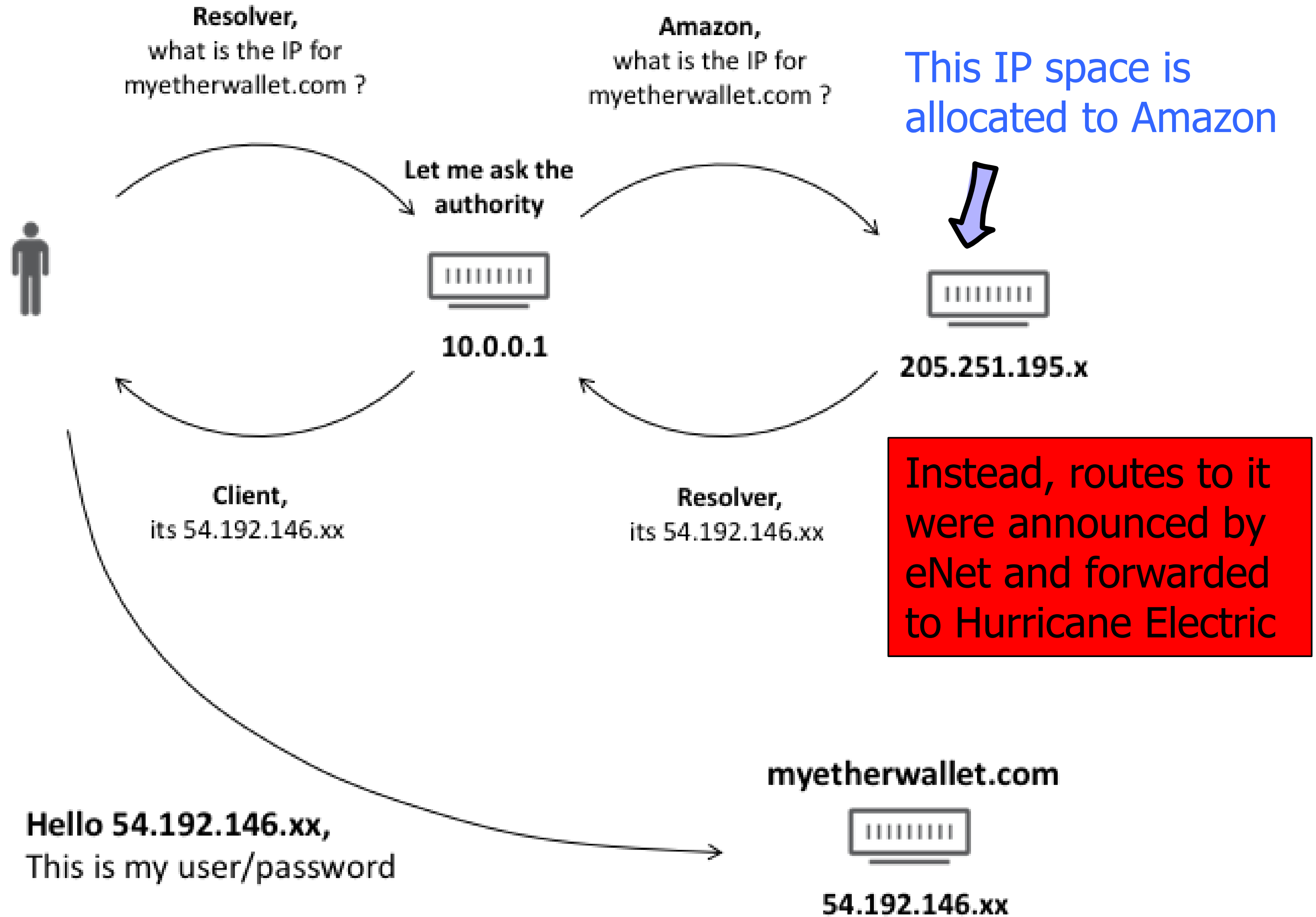
[Output edited for clarity]

(authoritative for freebsd.org.)

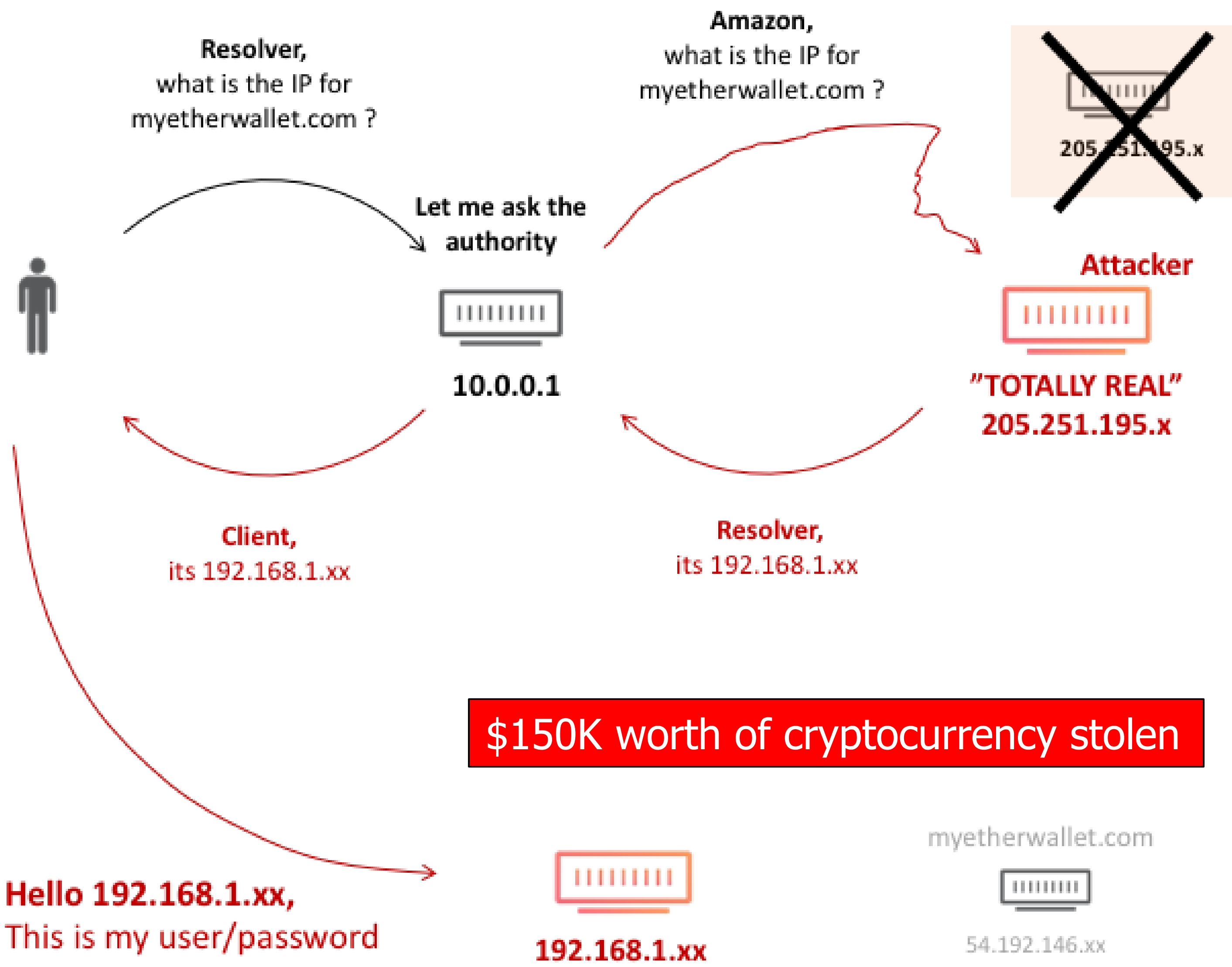
```
$ dig @ns1.isc-sns.net www.freebsd.org +norecurse
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 17037
;; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;www.freebsd.org.          IN    A

;; ANSWER SECTION:
www.freebsd.org.    3600   IN    A      69.147.83.33

;; AUTHORITY SECTION:
freebsd.org.        3600   IN    NS     ns2.isc-sns.com.
freebsd.org.        3600   IN    NS     ns1.isc-sns.net.
freebsd.org.        3600   IN    NS     ns3.isc-sns.info.

;; ADDITIONAL SECTION:
ns1.isc-sns.net.    3600   IN    A      72.52.71.1
ns2.isc-sns.com.    3600   IN    A      38.103.2.1
ns3.isc-sns.info.   3600   IN    A      63.243.194.1
```

[Output edited for clarity]

# Amazon DNS hijack via BGP route hijack (2018)




https://blog.cloudflare.com/bgp-leaks-and-crypto-currencies/




https://blog.cloudflare.com/bgp-leaks-and-crypto-currencies/

# Other Attacks Against DNS

DNS is plaintext protocol without authentication
- What can on-path adversaries do?

DNS cache poisoning by off-path adversaries
- Flaw in DNS protocol that allows inserting records

DNS typo-squatting

Compromise DNS admin accounts, edit records

*A MORE SECURE WEB —*

# Why big ISPs aren't happy about Google's plans for encrypted DNS

DNS over HTTPS will make it harder for ISPs to monitor or modify DNS queries.

TIMOTHY B. LEE - 9/30/2019, 6:57 PM

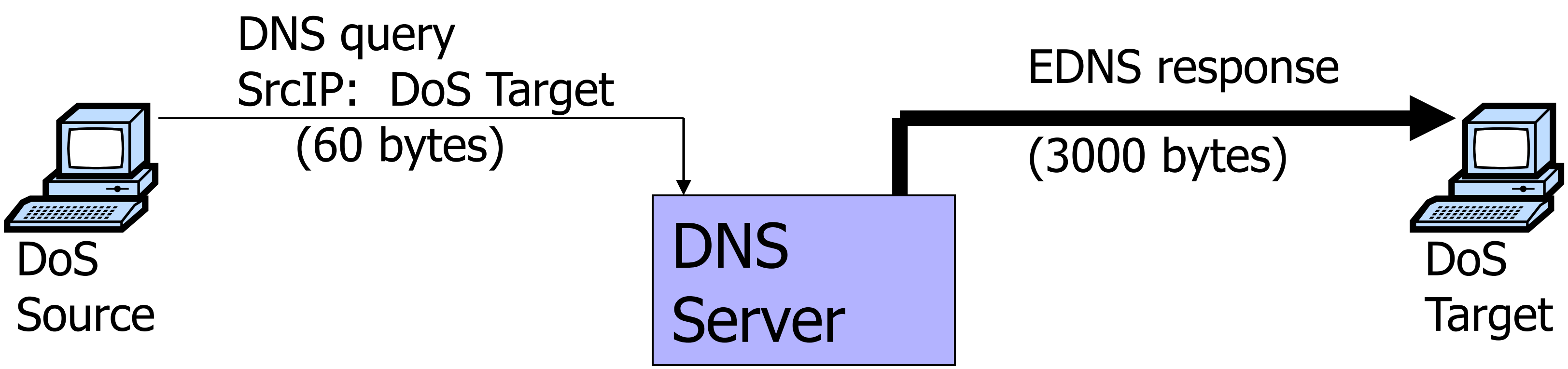
## Russia wants to outlaw TLS 1.3, ESNI, DNS over HTTPS, and DNS over TLS

Posted on Sep 22, 2020 by Caleb Chen

[draft law] "… bans the use of encryption protocols allowing for hiding the name (identifier) of a web page or Internet site on the territory of the Russian Federation."

# DNS Amplification Attack

**x50 amplification**




2006: 0.58M open resolvers on Internet (Kaminsky-Shiffman)
2013: 21.7M open resolvers (openresolverproject.org)

March 2013: 300 Gbps DDoS attack on Spamhaus

# DNS Caching

Performing all these queries takes time

- … before actual communication takes place

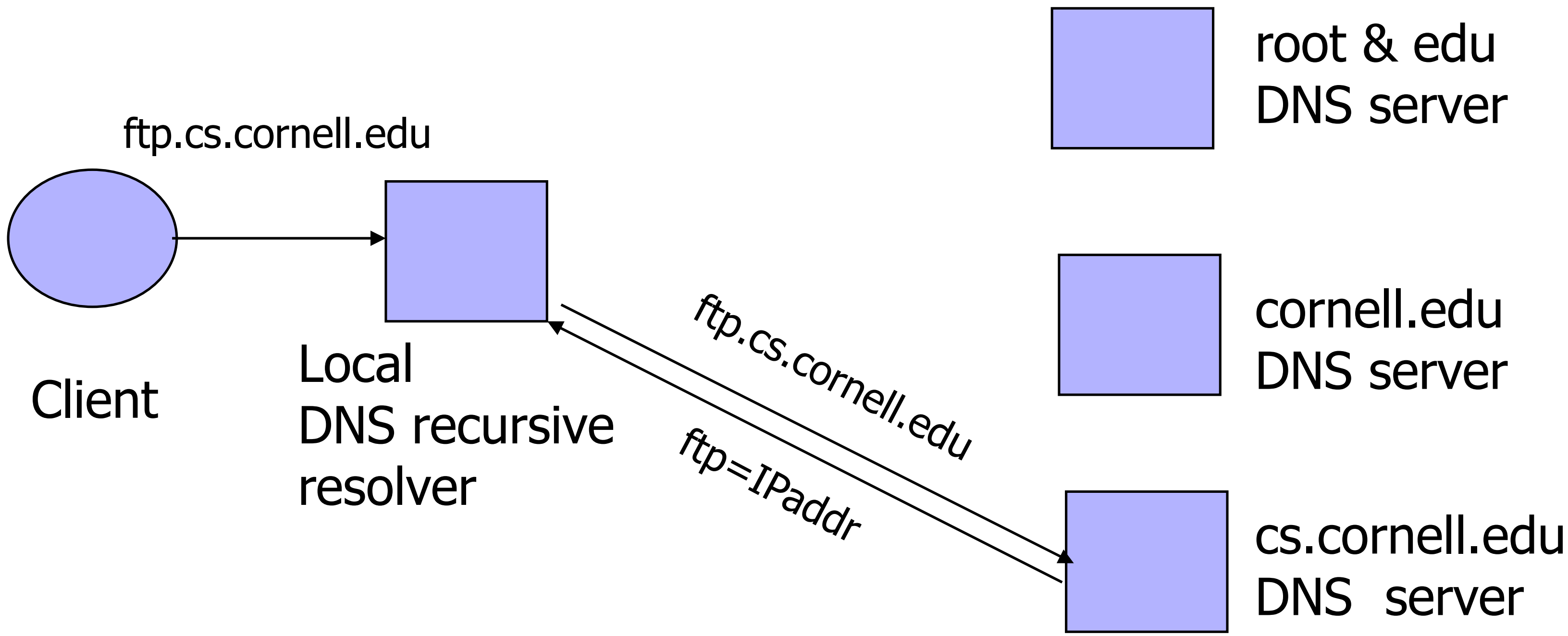
Caching can greatly reduce overhead

- Top-level servers very rarely change
- Popular sites visited often

How DNS caching works

- All DNS servers cache responses to queries
  - Including negative responses (e.g., misspellings)
- Responses include a time-to-live (TTL) field
- Server deletes cached entry after TTL expires

# Cached Lookup Example



# What if DNS is Subverted?

Redirect victim's web traffic to rogue servers

Redirect victim's email to rogue email servers (MX records in DNS)

Does Secure Sockets Layer (SSL) provide protection?

- Yes—user will get "wrong certificate" if SSL enabled
- No—SSL not enabled or user ignores warnings
- No—how is SSL trust established?  Often, by email!

# Problem #1: Coffee Shop

As you sip your latte and surf the Web, how does your laptop find google.com?

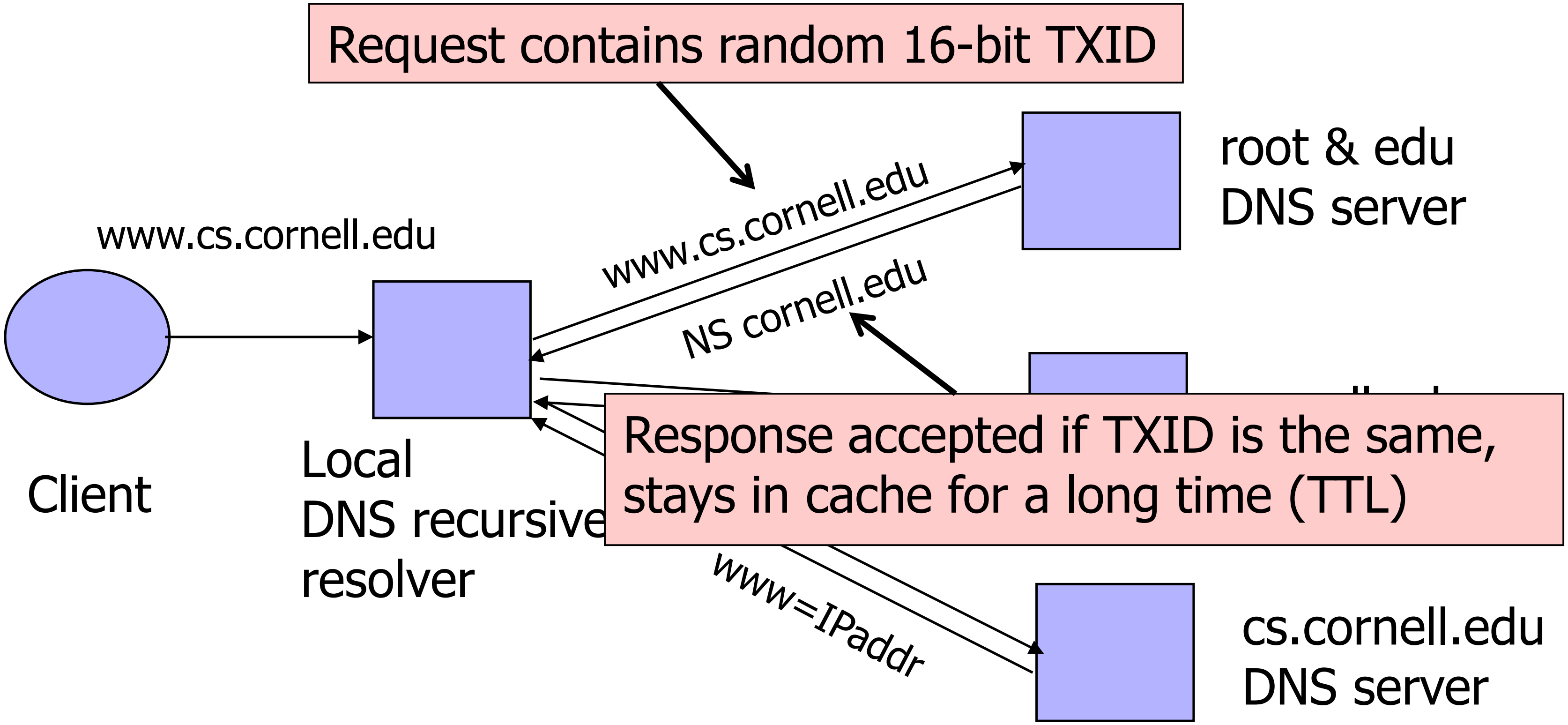
Answer: it asks the local DNS nameserver

... which is run by the coffee shop or their contractor

... and can return to you any answer they please

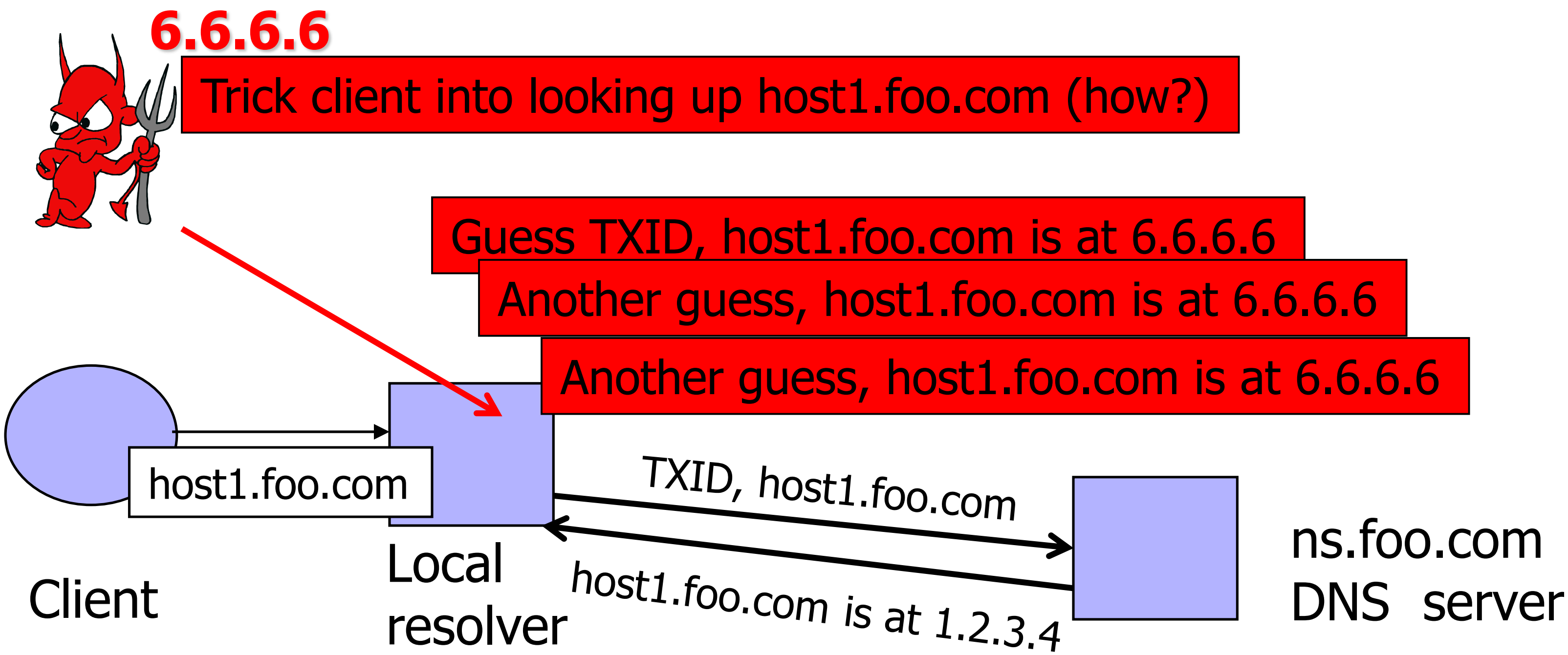
How can you know you're getting correct data?

# Problem #2: DNS "Authentication"



How is this different from coffee-shop scenario?

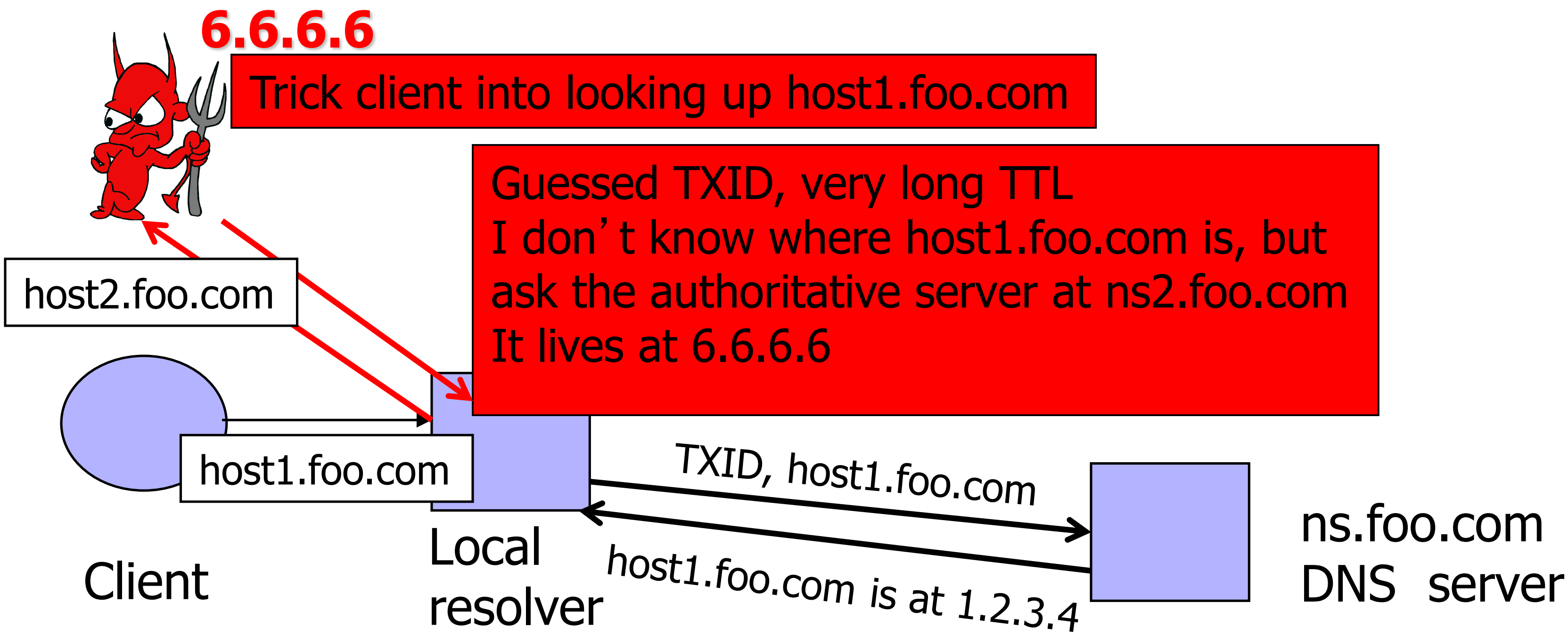
# DNS Spoofing by Off-Path Attacker




Several opportunities to win the race.
If attacker loses, has to wait until TTL expires…
… but can try again with host2.foo.com, host3.foo.com, etc.
… but what's the point of hijacking host3.foo.com?

# Exploiting Recursive Resolving

[Kaminsky]




If win the race, any request for XXX.foo.com will go to 6.6.6.6

The cache is poisoned… for a very long time!

No need to win future races!

If lose, try again with <ANYTHING>.foo.com

# Triggering a Race

Any link, any image, any ad, anything can cause a DNS lookup

- No JavaScript required, though it helps

Mail servers will look up what bad guy wants

- On first greeting: HELO
- On first learning who they’re talking to: MAIL FROM
- On spam check (oops!)
- When trying to deliver a bounce
- When trying to deliver a newsletter
- When trying to deliver an actual response from an actual employee

# Reverse DNS Spoofing

Trusted access is often based on host names

- Example: permit all hosts in .rhosts to run remote shell

Network requests such as rsh or rlogin arrive from numeric source addresses

- System performs reverse DNS lookup to determine requester's host name and checks if it's in .rhosts

If attacker can spoof the answer to reverse DNS query, he can fool target machine into thinking that request comes from an authorized host

- No authentication for DNS responses and typically no double-checking (numeric $\rightarrow$ symbolic $\rightarrow$ numeric)

# Pharming

Many anti-phishing defenses rely on DNS

Can bypass them by poisoning DNS cache and/or forging DNS responses

- Browser: “give me the address of www.paypal.com”
- Attacker: “sure, it’s 6.6.6.6” (attacker-controlled site)

Dynamic pharming

- Provide bogus DNS mapping for a trusted server, trick user into downloading a malicious script
- Force user to download content from the real server, temporarily provide correct DNS mapping
- Malicious script and content have the same origin!

# JavaScript/DNS Intranet attack (I)

Consider a Web server intra.good.net

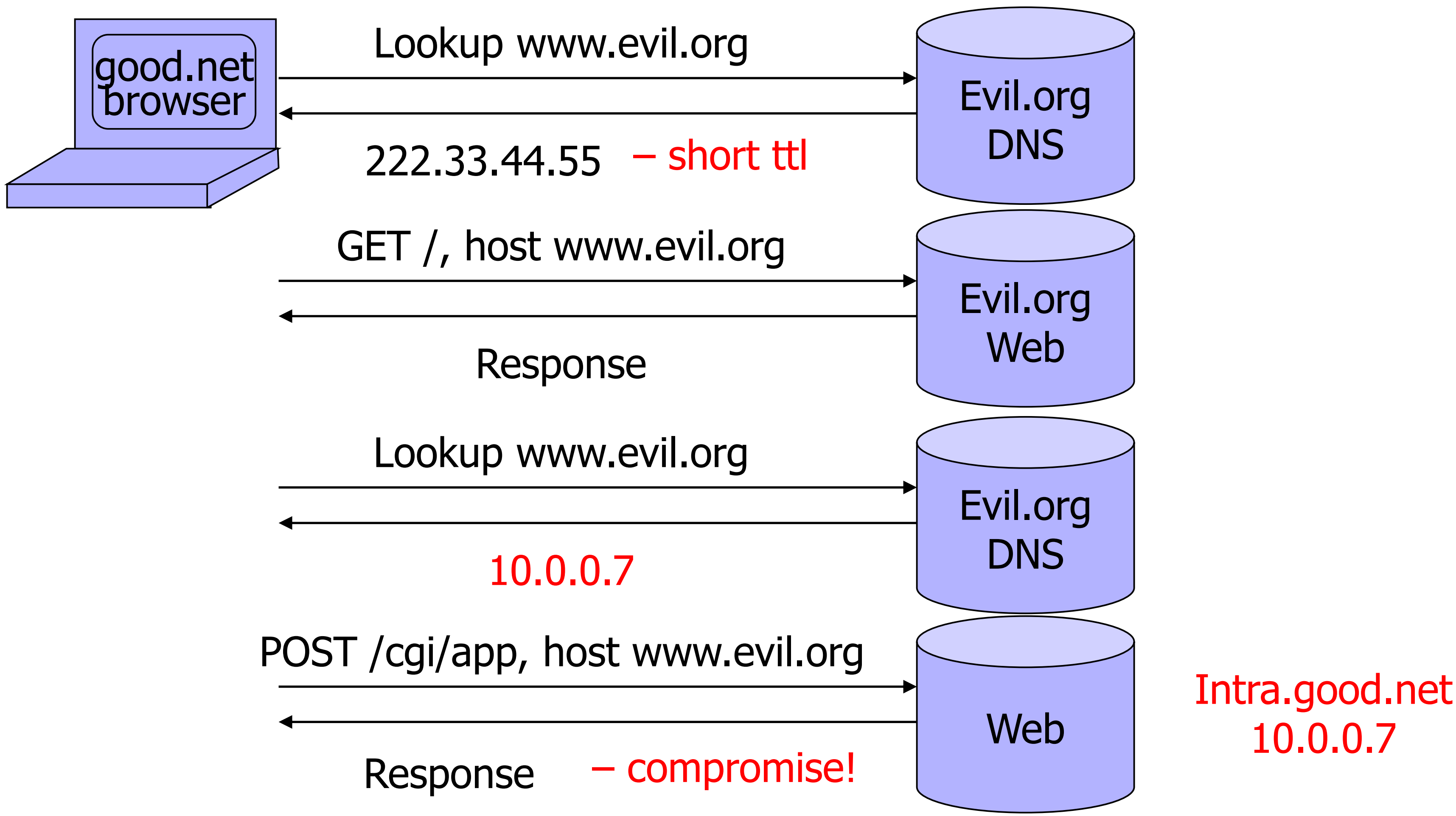
- IP: 10.0.0.7, inaccessible outside good.net network
- Hosts sensitive Web applications

Attacker at evil.org gets good.net user to browse www.evil.org

Places JavaScript on www.evil.org that accesses sensitive application on intra.good.net

- This doesn’t work because JavaScript is subject to the same origin policy
- … but suppose the attacker controls DNS

# JavaScript/DNS Intranet attack (II)



# Solving the DNS Spoofing Problem

Long TTL for legitimate responses

- Does it really help?

Randomize port in addition to TXID

- 32 bits of randomness, makes it harder for attacker to guess TXID+port

DNSSEC

- Cryptographic authentication of host-address mappings

# DNSSEC

Goals: authentication and integrity of DNS requests and responses

PK-DNSSEC (public key)

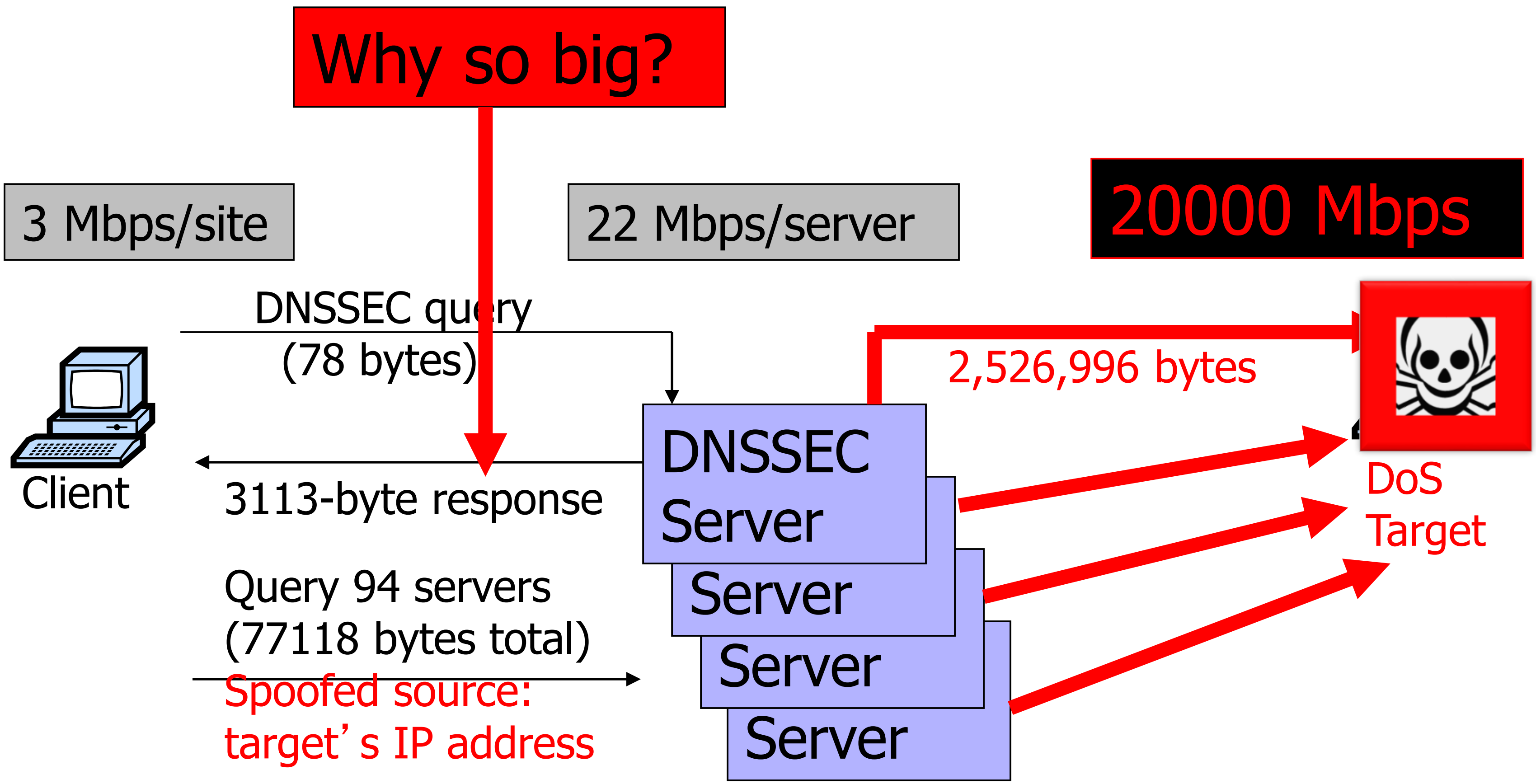
- DNS server signs its data – done in advance
- How do other servers learn the public key?

SK-DNSSEC (symmetric key)

- Encryption and MAC: $E_k(m, MAC(m))$
- Each message contains a nonce to avoid replay
- Each DNS node shares a symmetric key with its parent
- Zone root server has a public key (hybrid approach)

# Querying DNSSEC Servers

[Bernstein]




5 times per second, from 200 sites

# Using DNSSEC for DDoS

[Bernstein]

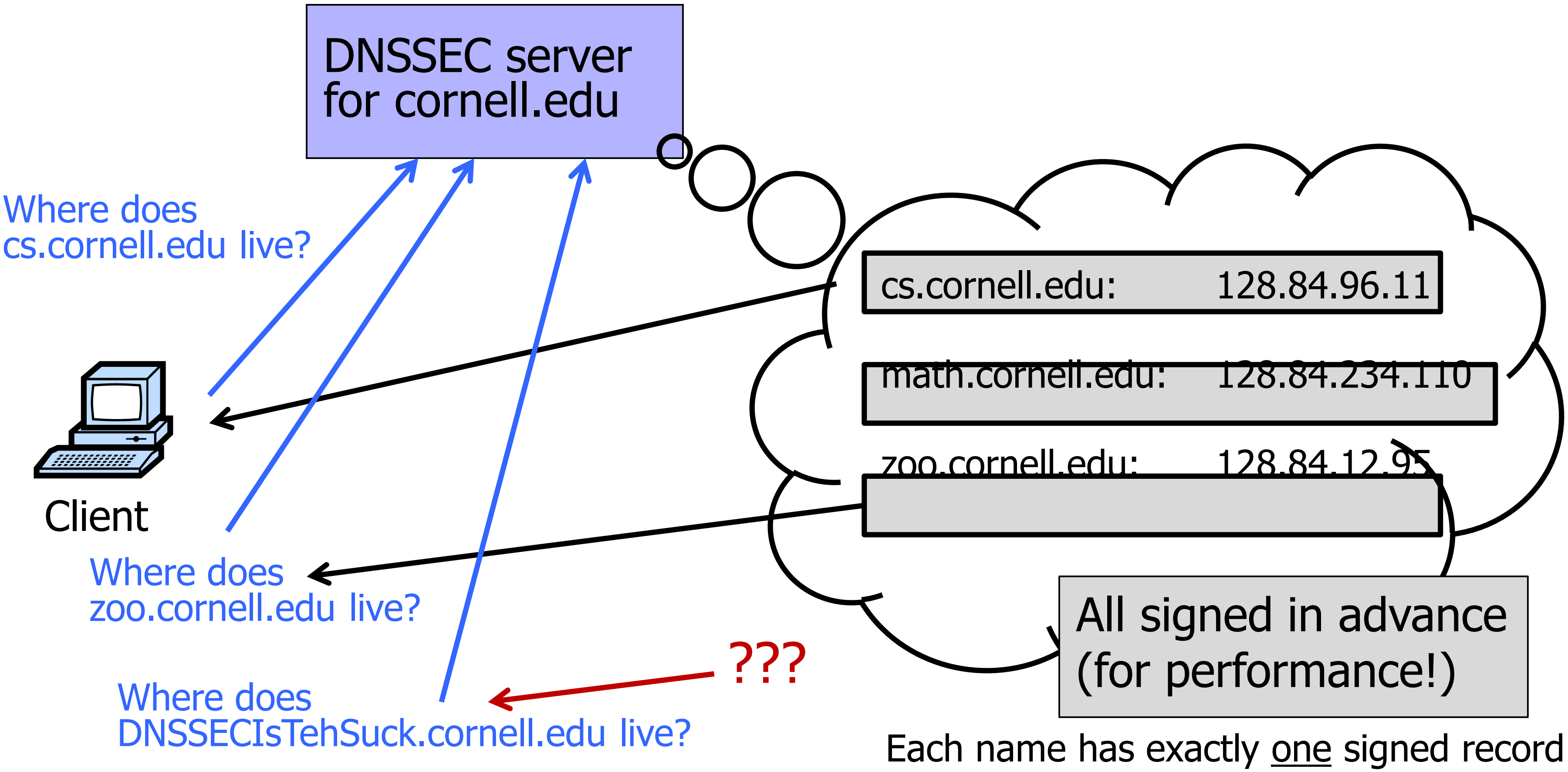
RFC 4033 says:

"DNSSEC provides no protection against denial of service attacks"

RFC 4033 doesn't say:

"DNSSEC is a remote-controlled double-barreled shotgun, the worst DDoS amplifier on the Internet"

# DNSSEC In Action




Why can't the resolver simply send an empty record when queried for a domain that does not exist?

# Authenticated Denial of Existence

**NSEC**

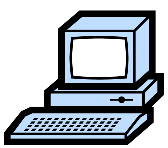
DNSSEC server for cornell.edu

Where does DNSSECIsTehSuck.cornell.edu live?

Where does TehSuckThyNameIsDNSSEC.cornell.edu live?

| | |
|---|---|
| cs.cornell.edu: | 128.84.96.11 |
| math.cornell.edu: | 128.84.234.110 |
| zoo.cornell.edu: | 128.84.12.95 |

All signed in advance (for performance!)



Client

There are no DNSSEC subdomains of .cornell.edu between “cs” and “math”

There are no DNSSEC subdomains of .cornell.edu between “math” and “zoo”

Use DNSSEC as an oracle to enumerate all subdomains (equivalent to zone transfer)

# NSEC3

[Bernstein]

Domain names hashed, hashes sorted in lexicographic order

Denials of existence certify that there are no DNSSEC domains whose hash values fall into a certain interval

- As opposed to actual domain names

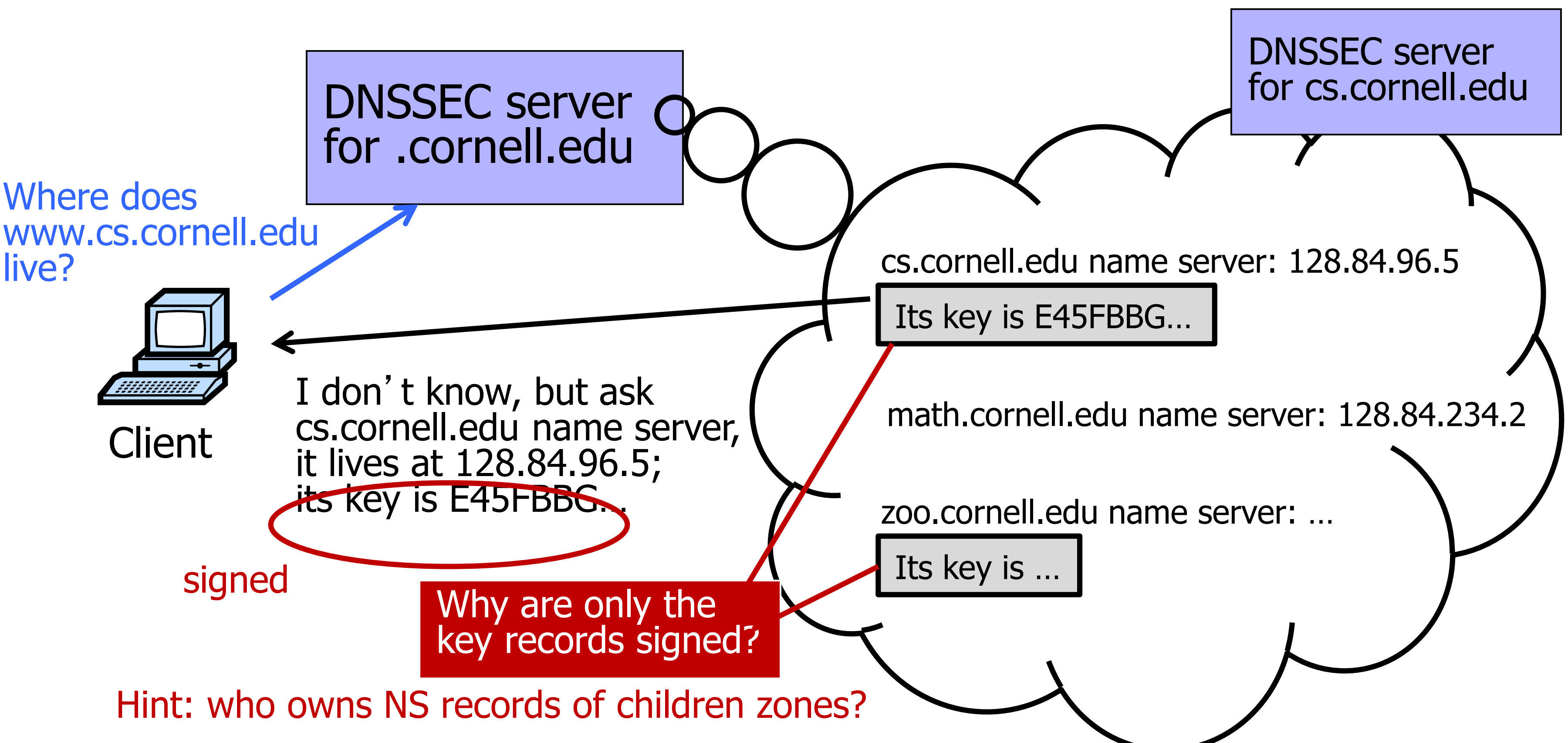
Are domain names random?

Vulnerable to brute-force guessing attacks

# Delegation in DNSSEC

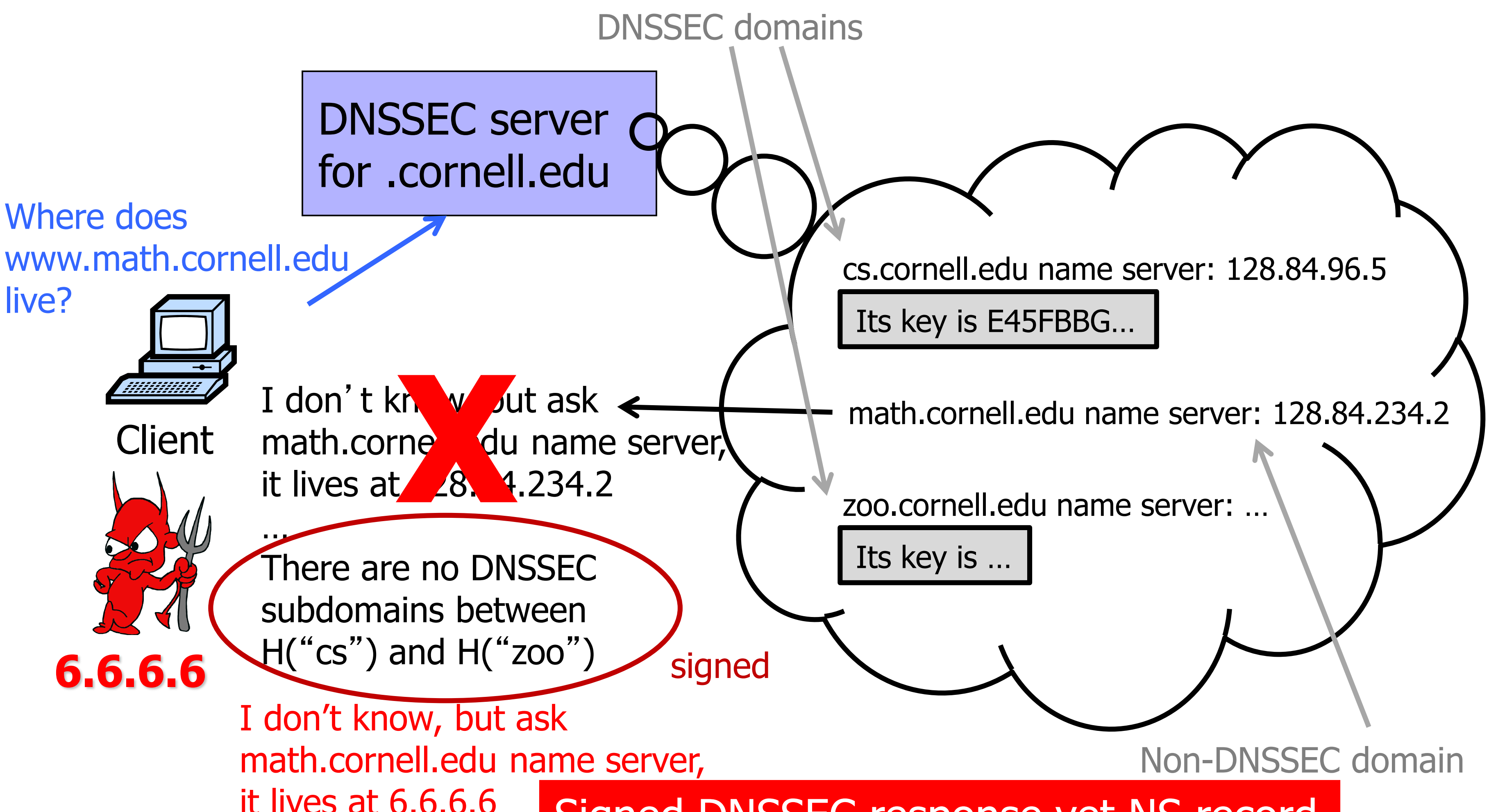
Delegation is essential for scalability

- For example, there are 100,000,000 .com domains



# Forging Delegation Responses

[Bernstein]




**Signed DNSSEC response yet NS record has been forged… what happened??!!**

# Delegating to Secure Zones

Q: When does verification of signatures on DNSSEC records actually happen?

A: At the very end, when the resolver has the complete chain

But the delegation record is not signed… what if it has been forged?

Current DNSSEC deployments are only "secure" down to the ISP's resolver

- Stub resolvers on users' machines only get an unsigned flag saying that the response is "secure"

# DNSSEC “Features”

[Bernstein]

Does nothing to improve DNS availability

Allows astonishing levels of DDoS amplication, damaging Internet availability

- Also CPU exhaustion attacks

Does nothing to improve DNS confidentiality, leaks private DNS data (even with NSEC3)

Does not prevent forgery of delegation records

Does not protect the “last mile”

Implementations suffered from buffer overflows