CS6903: Network Security

DNSSEC

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Based on Slides by D. Choffnes (NEU). Revised by P. Gill Fall 2014. Some content on DNS censorship from N. Weaver.

DNSSEC Outline

- DNS Basics
- DNS Security
- DNS and Censorship

Naming in Internet

- If you want to…
  - Call someone, you need to ask for their phone number
    - You can't just dial "M R B O B"
  - 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

Internet Names and Addresses

- Addresses, e.g., 129.10.117.100
  - Computer usable labels for machines
  - Conform to structure of the network
- Names, e.g., www.iith.ac.in
  - Human usable labels for machines
  - Conform to organizational structure
- How do you map from one to the other?
  - Domain Name System (DNS)

History

- Before DNS, all mappings were in *hosts.txt*
  - */etc/hosts* on Linux
  - C:*Windows**System32**drivers**etc**hosts* on Windows
- Centralized, manual system
  - Changes were submitted to SRI (Stanford Research Institute) via email
  - Machines periodically FTP new copies of *hosts.txt*
  - Administrators could pick names at their discretion
  - Any name was allowed
    - alans_server_at_sbu_pwns_joo_lol_kthxbye

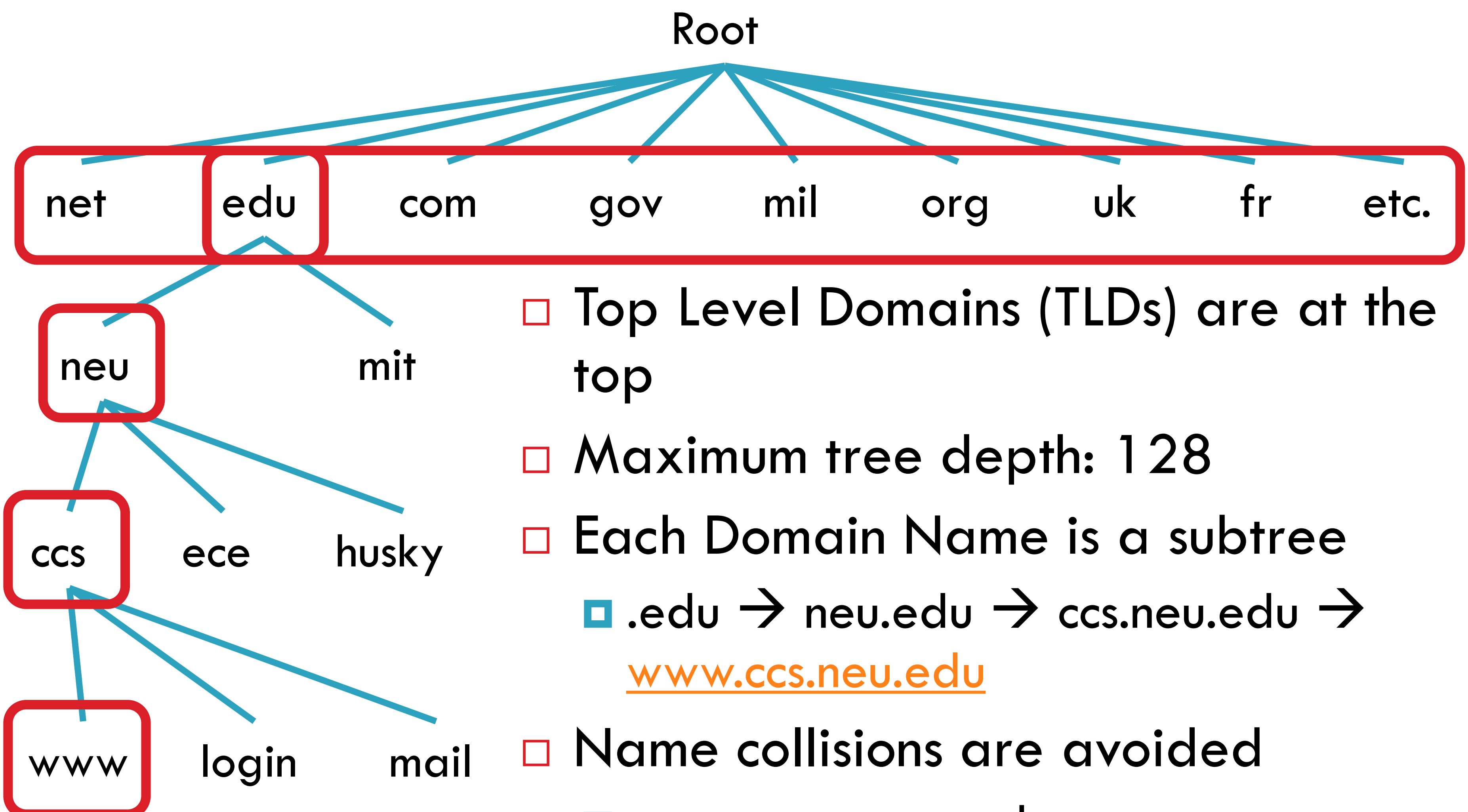
Towards DNS

- Eventually, the *hosts.txt* system fell apart
  - Not scalable, SRI couldn't handle the load
  - Hard to enforce uniqueness of names
    - e.g., MIT
      - Massachusetts Institute of Technology?
      - Melbourne Institute of Technology?
  - Many machines had inaccurate copies of *hosts.txt*
- Thus, DNS was born

DNS at a High-Level

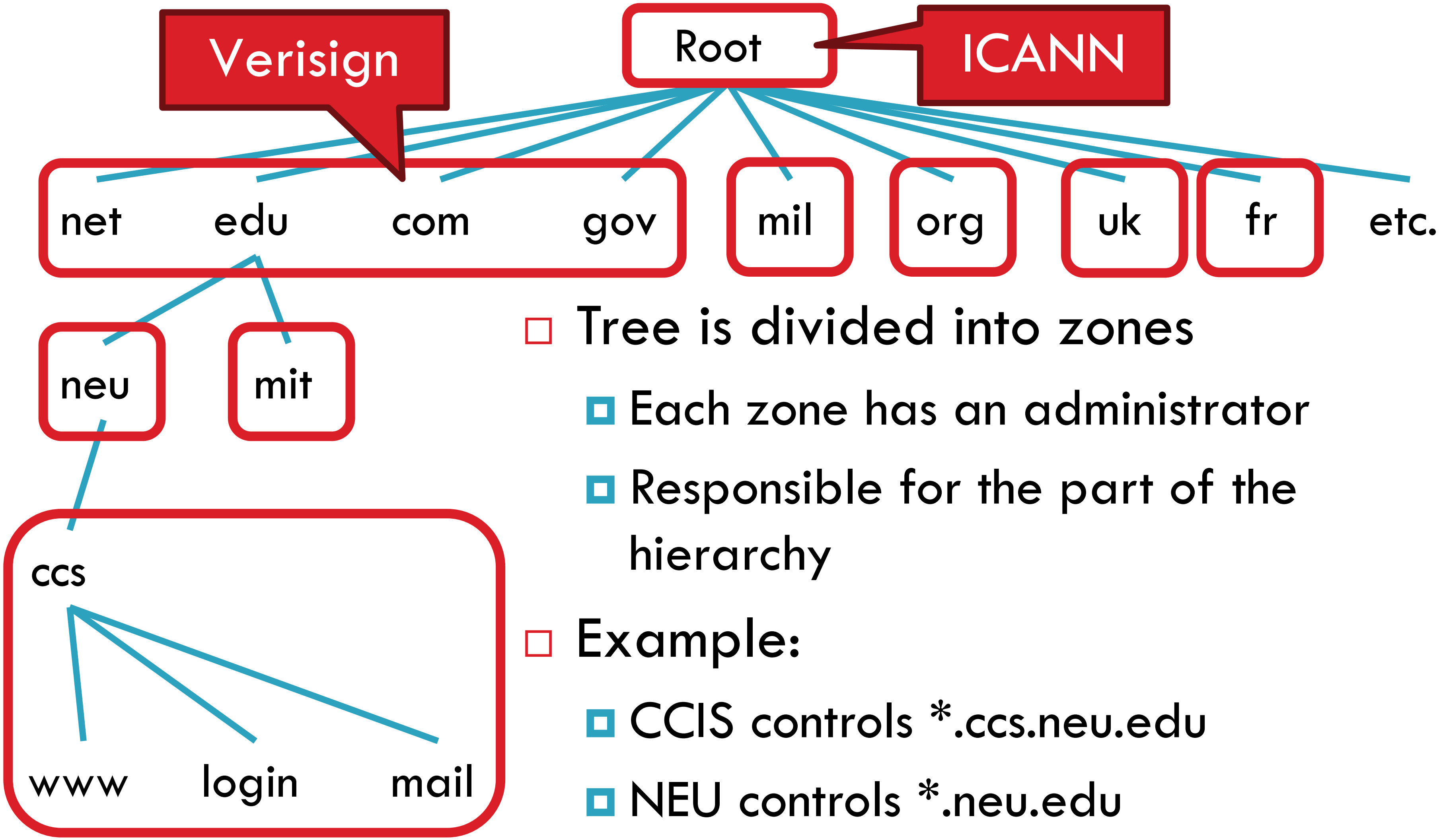
- Domain Name System
- Distributed database
  - No centralization
- Simple client/server architecture
  - UDP port 53, some implementations also use TCP
  - Why?
- Hierarchical namespace
  - As opposed to original, flat namespace
  - e.g. .com → google.com → mail.google.com

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

Hierarchical Administration



- Tree is divided into zones
  - Each zone has an administrator
  - Responsible for the part of the hierarchy
- Example:
  - CCIS controls *.ccs.neu.edu
  - NEU controls *.neu.edu

Server Hierarchy

- Functions of each DNS server:
  - Authority over a portion of the hierarchy
    - No need to store all DNS names
  - Store all the records for hosts/domains in its zone
    - May be replicated for robustness
  - Know the addresses of the root servers
    - Resolve queries for unknown names
- Root servers know about all TLDs
  - The buck stops at the root servers

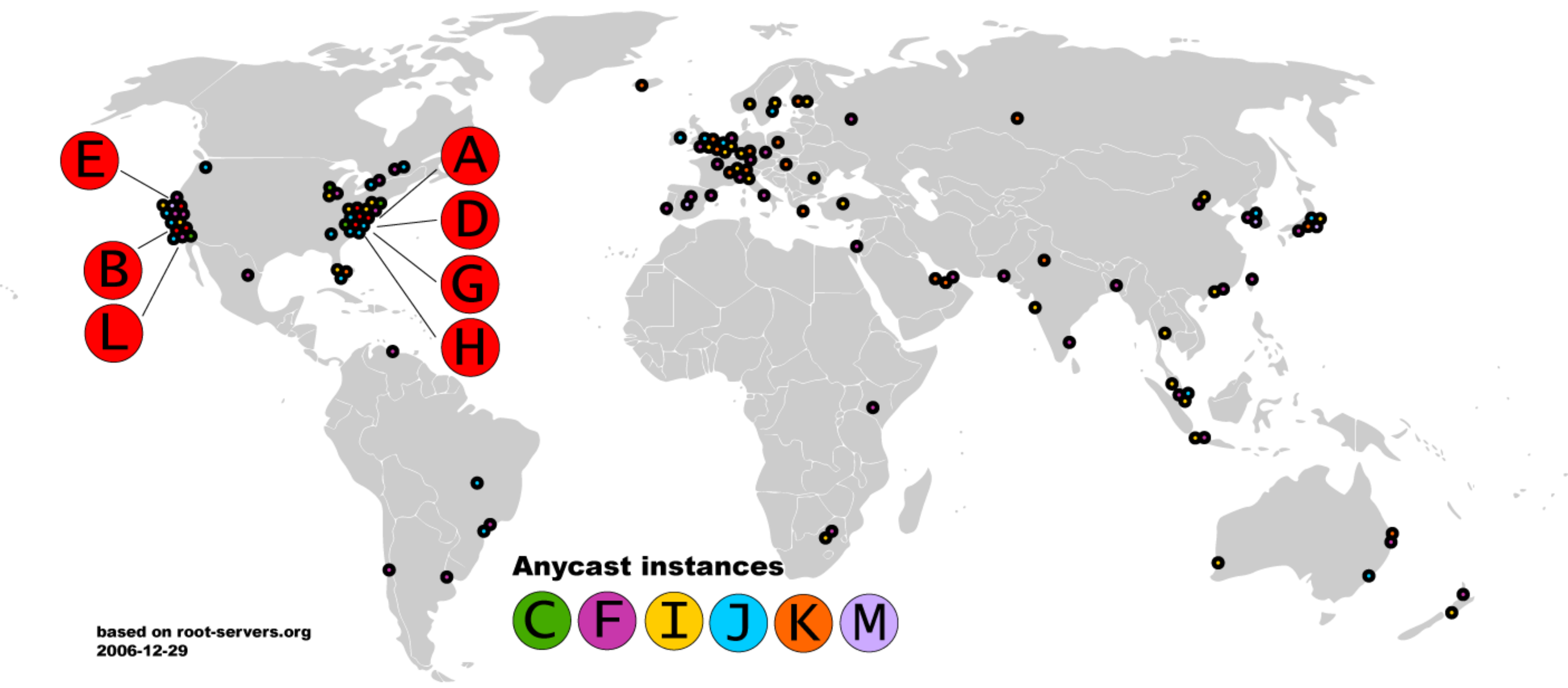
Root Name Servers

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

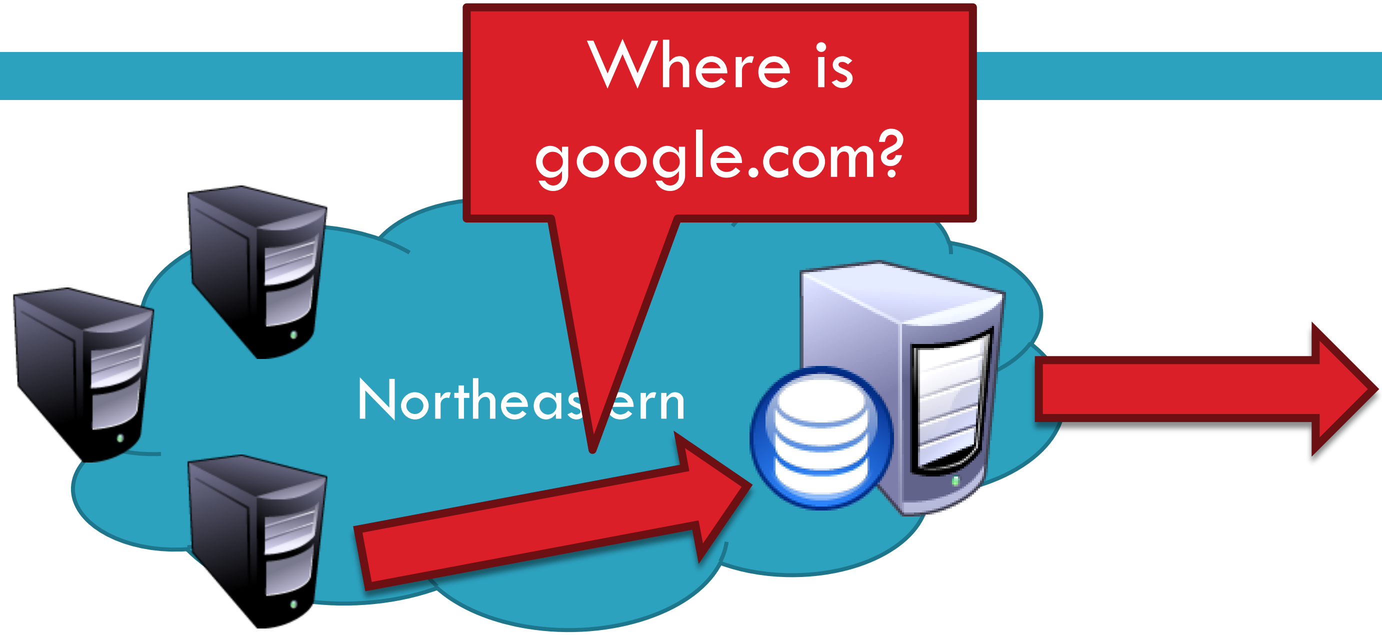
com.	172800	IN	NS	a.gtld-servers.net.
com.	172800	IN	NS	b.gtld-servers.net.
com.	172800	IN	NS	c.gtld-servers.net.

- 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

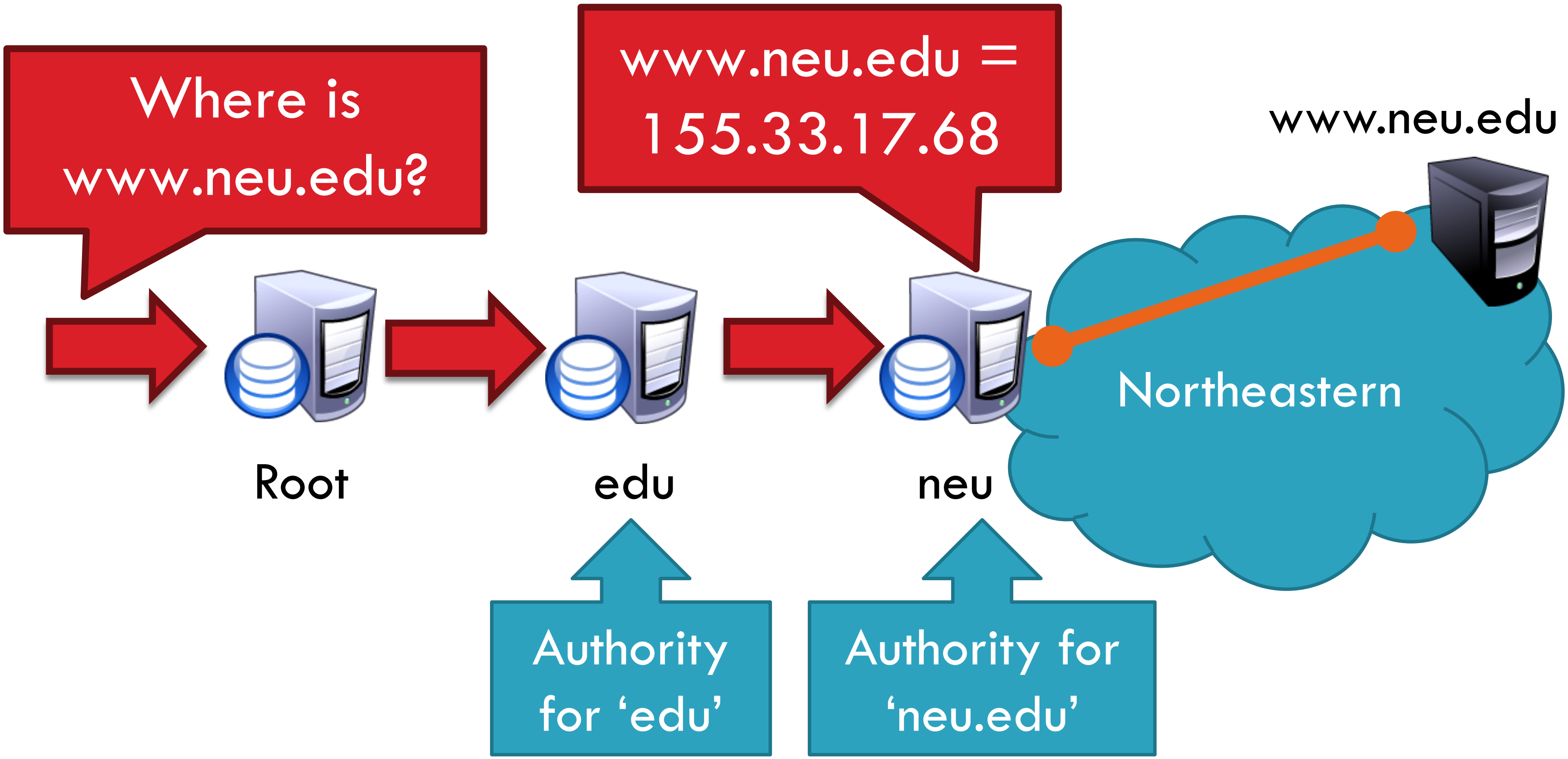


Local Name Servers



- Each ISP/company has a local, default name server
- Often configured via DHCP
- Hosts begin DNS queries by contacting the local name server
- Frequently cache query results

Authoritative Name Servers



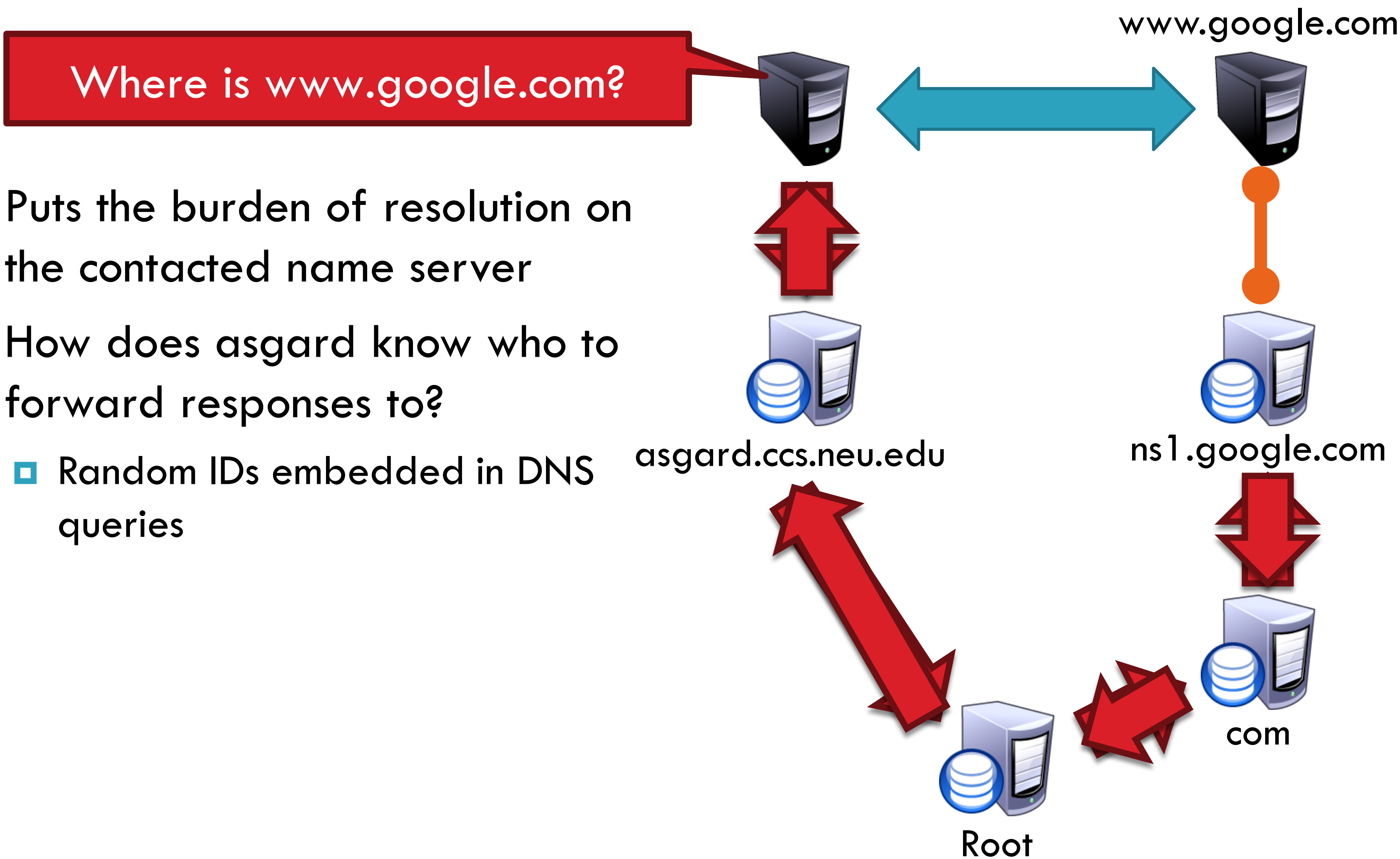
- Stores the name→IP mapping for a given host

Basic Domain Name Resolution

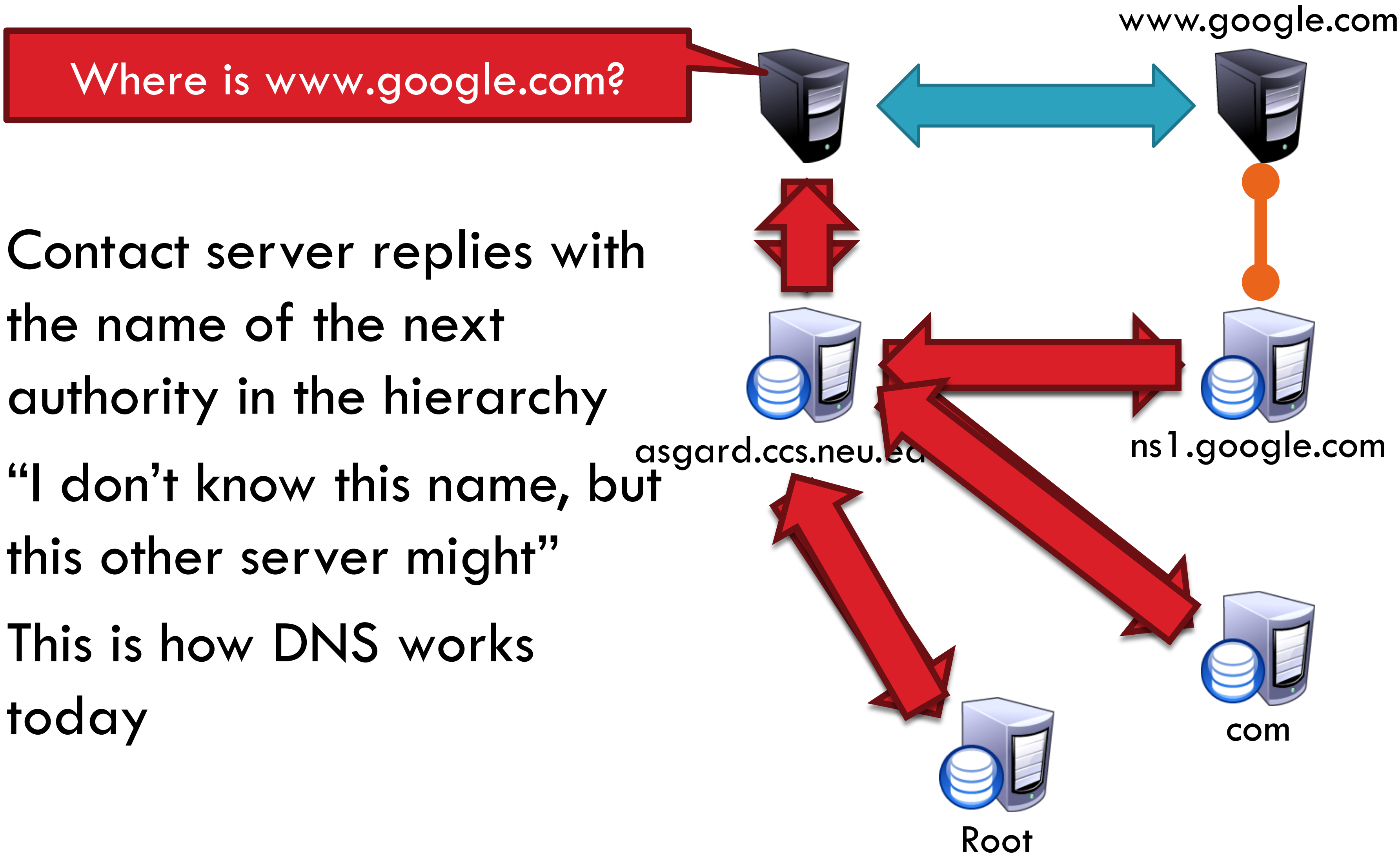
- Every host knows a local DNS server
  - Sends all queries to the local DNS server
- If the local DNS can answer the query, then you're done
  1. Local server is also the authoritative server for that name
  2. Local server has cached the record for that name
- Otherwise, go down the hierarchy and search 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

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



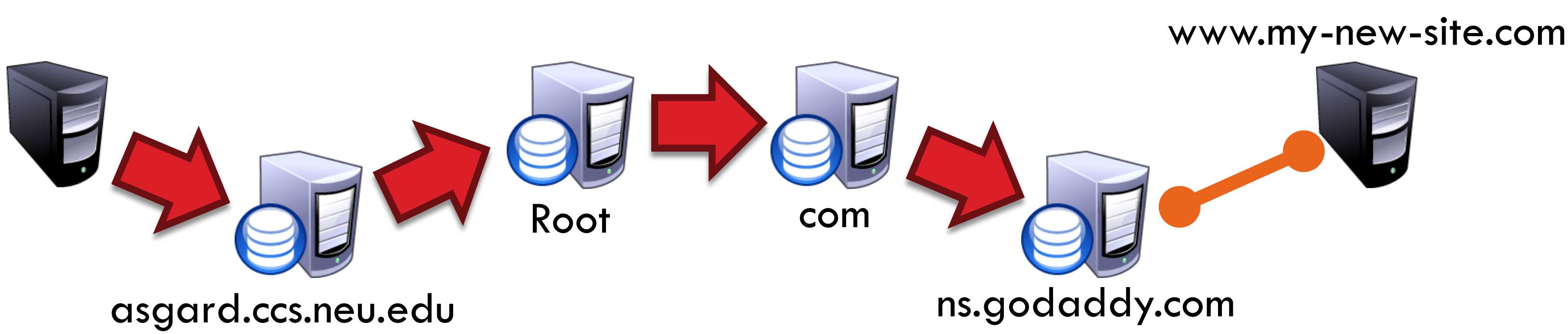
Iterated DNS query



- 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

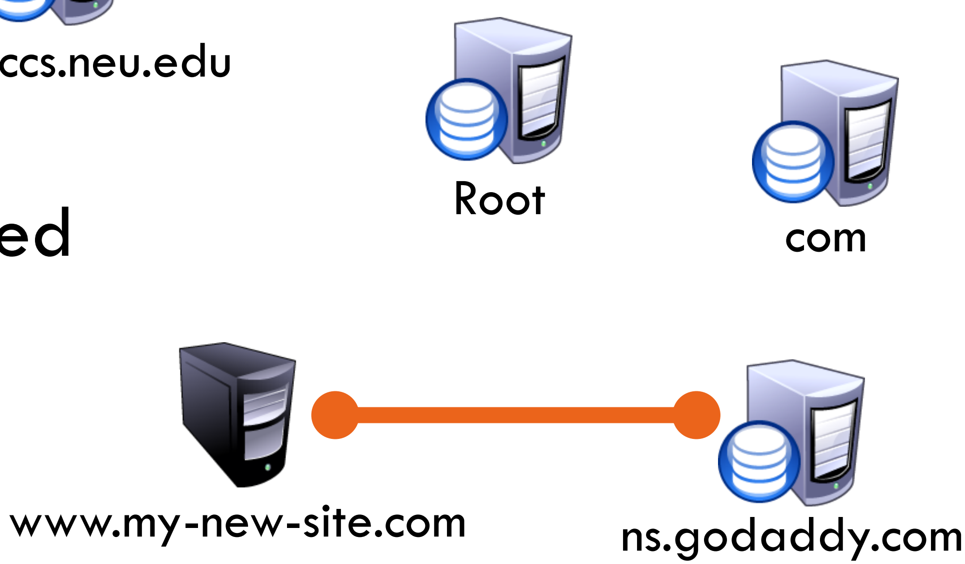
- How many of you have purchased a domain name?
  - Did you notice that it took ~72 hours for your name to become accessible?
  - This delay is called DNS Propagation



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

Caching vs. Freshness

- DNS Propagation delay is caused by caching



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

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"

Query
Name: ccs.neu.edu
Type: NS

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

DNS Types, Continued

- Type = CNAME
  - Name = hostname
  - Value = canonical hostname
  - Useful for aliasing
  - CDNs use this

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
  - Value = domain name
- Not guaranteed to exist for all IPs

Query
Name: 129.10.116.51
Type: PTR

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

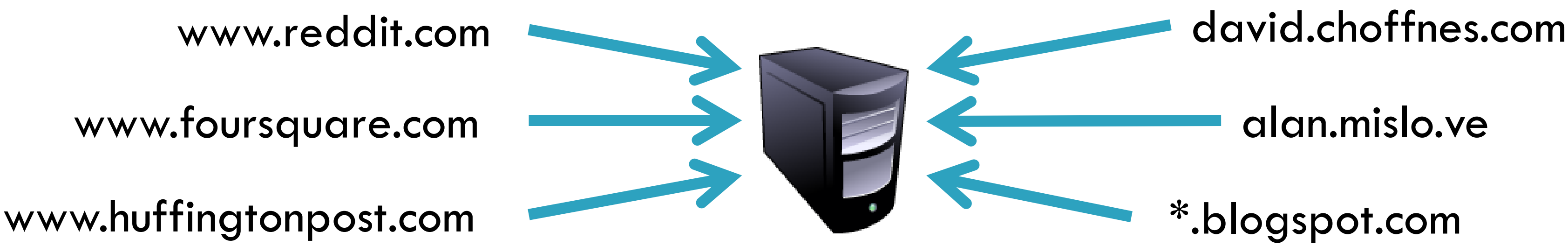
DNS as Indirection Service

- DNS gives us very powerful capabilities
  - Not only easier for humans to reference machines!

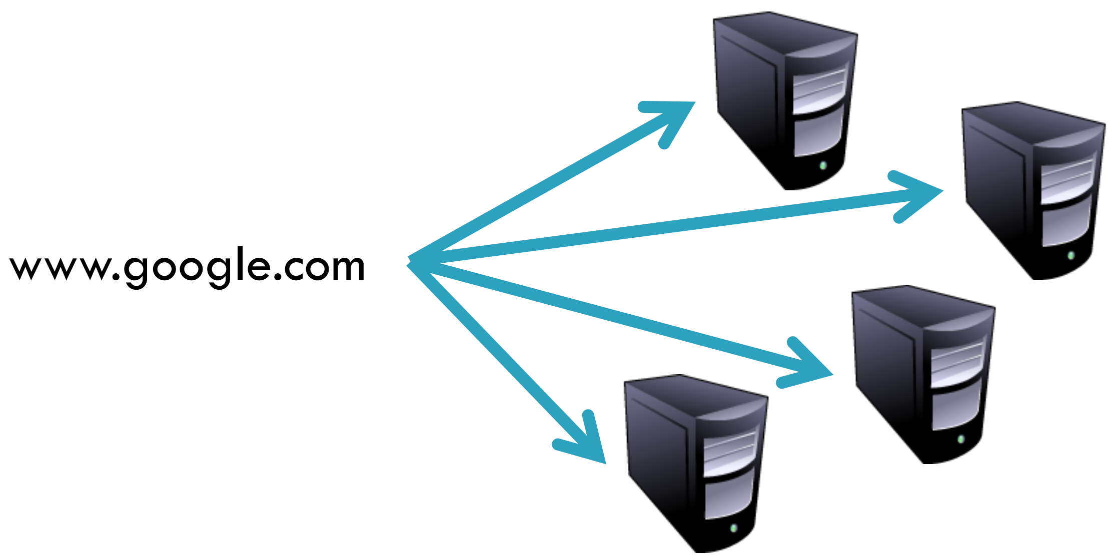
- Changing the IPs of machines becomes trivial
  - e.g. you want to move your web server to a new host
  - Just change the DNS record!

Aliasing and Load Balancing

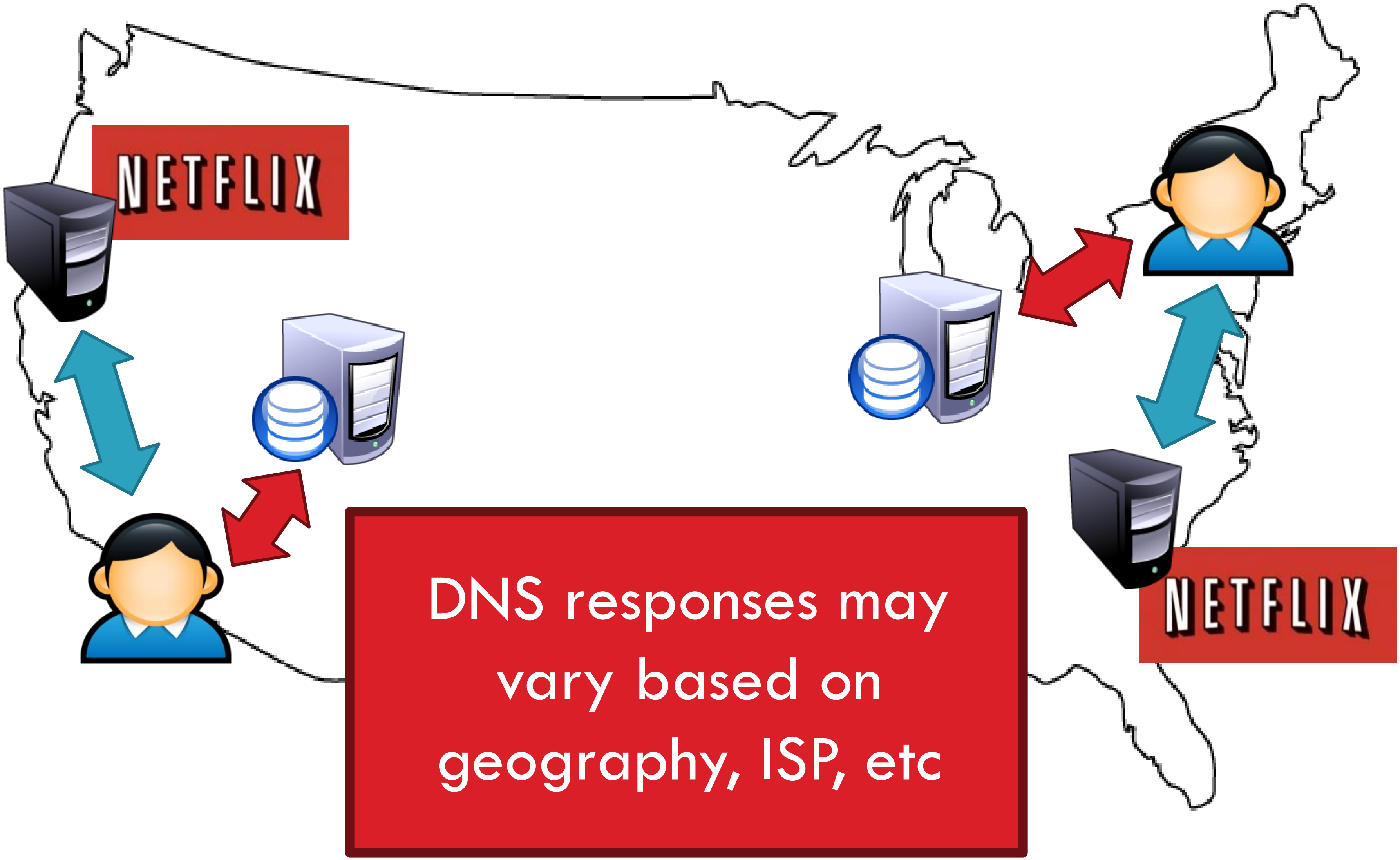
- One machine can have many aliases



- One domain can map to multiple machines



Content Delivery Networks



Outline

- DNS Basics
- DNS Security
- DNS and Censorship

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?

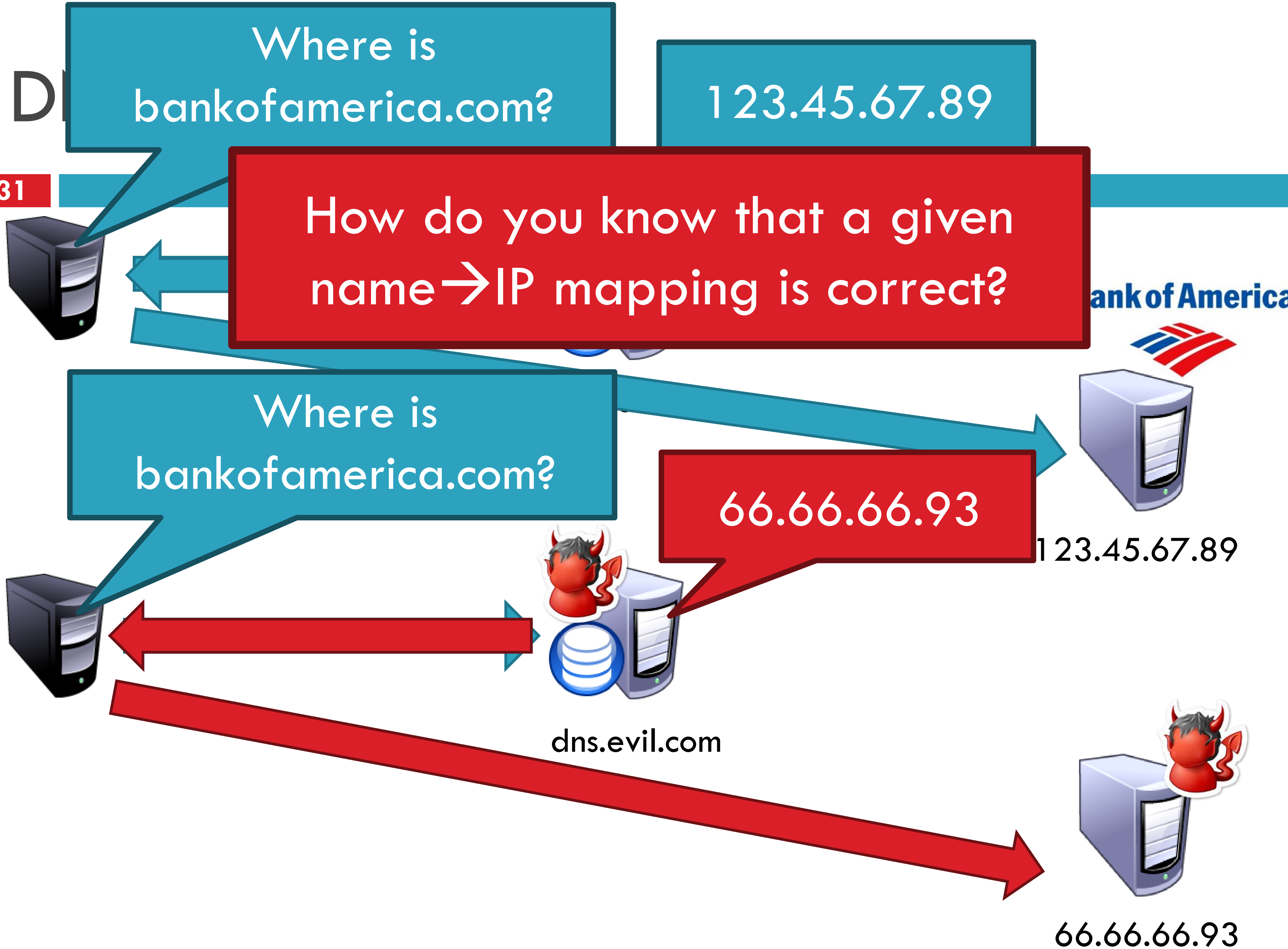
Denial Of Service

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

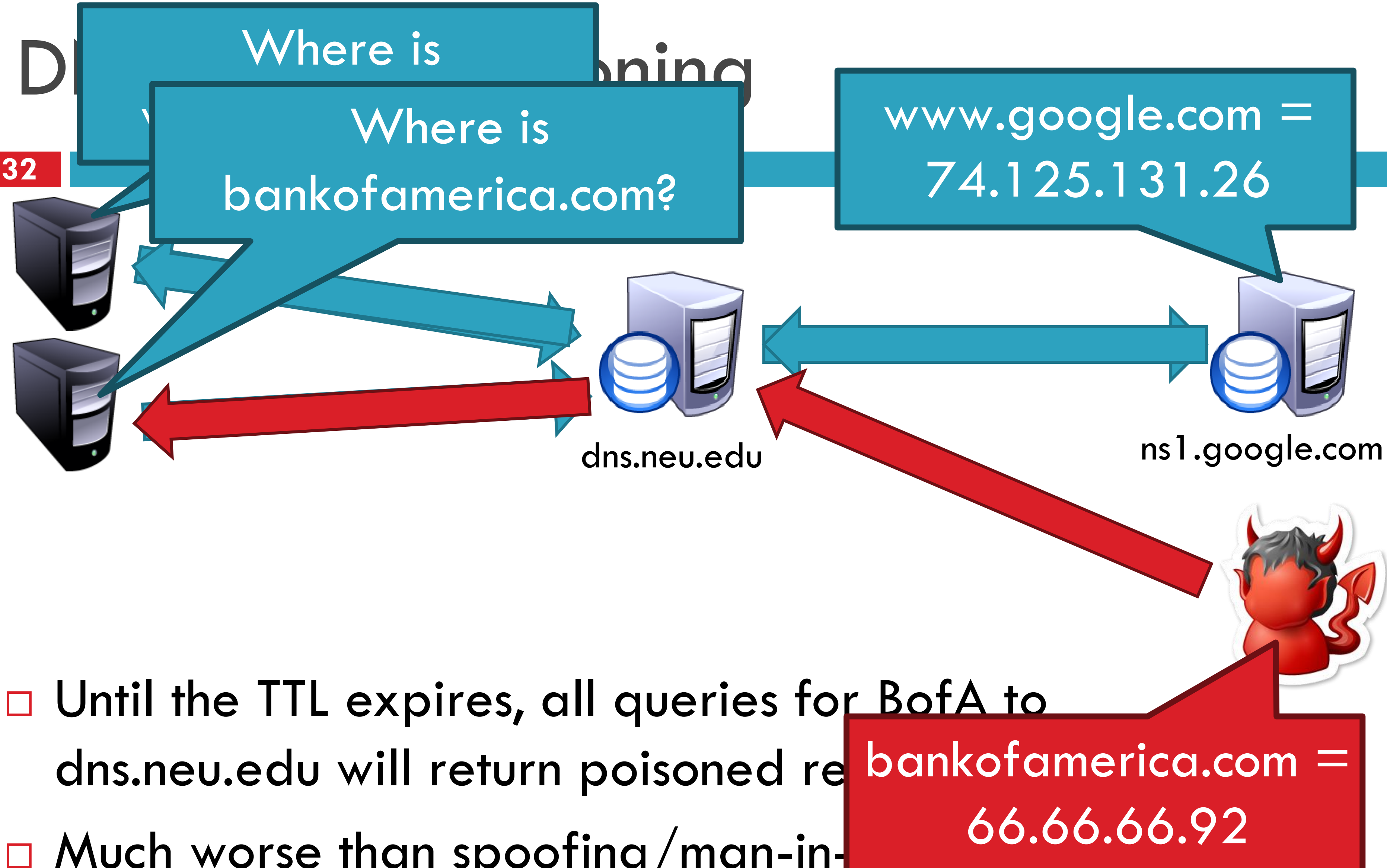
- Infect their OS or browser with a virus/trojan
  - e.g. Many trojans change entries in /etc/hosts
  - *.bankofamerica.com → evilbank.com
- Man-in-the-middle

- Response Spoofing
  - Eavesdrop on requests
  - Race the server's response – Useful for censorship



Where is bankofamerica.com?
123.45.67.89
How do you know that a given name→IP mapping is correct?
Bank of America
Where is bankofamerica.com?
66.66.66.93
123.45.67.89
dns.evil.com
66.66.66.93

D oning



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

How will the attacker get his entry into the cache? 2 ways

- 1. Tell resolver that NS for victim is at adversary's IP
  - Issue query: subdomain.attacker.example IN A
  - Attacker's response:
- Answer: (no response)
- Authority Section: attacker.example. 3600 IN NS ns.target.example.
- Additional Section: ns.target.example. IN A w.x.y.z

Adversary says "authoritative server for my domain is ns.target.example and oh by the way here is the IP for it (adversary's IP)

How will the attacker get his entry into the cache? 2 ways

- 2. Redirect the NS record to the adversary's domain
  - Issue query: subdomain.attacker.example IN A
  - Answer: (no response)
  - Authority section:
    - Target.example. 3600 IN NS ns.attacker.example.
  - Additional section:
    - Ns.attacker.example. IN A w.x.y.z

The attacker has inserted an unrelated piece of information that will be cached by the server (that target.example.'s ADNS is ns.attacker.example.)

Modern DNS Hijacking (IMC '16)

Country	ISP	DNS Servers	Hosts Affected
Argentina	Telefonica de Argentina	14	276
Australia	***Dodo Australia***	***21***	***1,404***
Brazil	***Oi Fixo***	***21***	***2,558***
	CTBC	4	290
Germany	Deutsche Telekom	8	1,385
India	Airtel Broadband	9	735
	BSNL	2	71
	Ntl. Int. Backbone	8	245
Malyasia	TMNet	8	1,676
Spain	Ono	2	71
U.K.	BT Internet	6	479
	Talk Talk	***46***	***3,738***
U.S.	***AT&T***	***37***	***561***
	Cable One	4	108
	Cox Communications	***63***	***1,789***
	Mediacom Cable	6	219
	Suddenlink	9	98
	Verizon	***98***	***2,102***
	WideOpen West	1	39

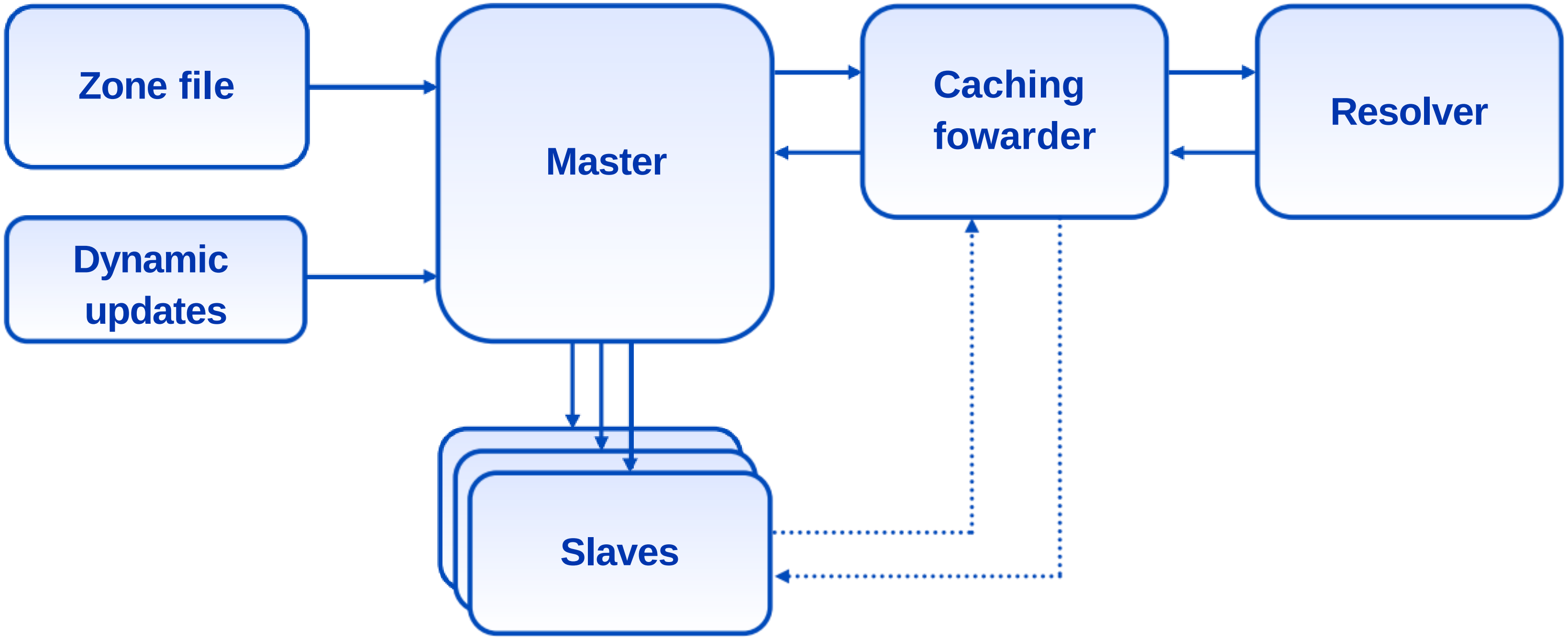
Basic DNS problems

- DNS is plain text
- Simple UDP, no sessions
- Tree structure with delegations
  - Each entity is responsible for a limited part of it
- Resolvers are victims of attacks, hijacks and mistakes
- Trust is needed

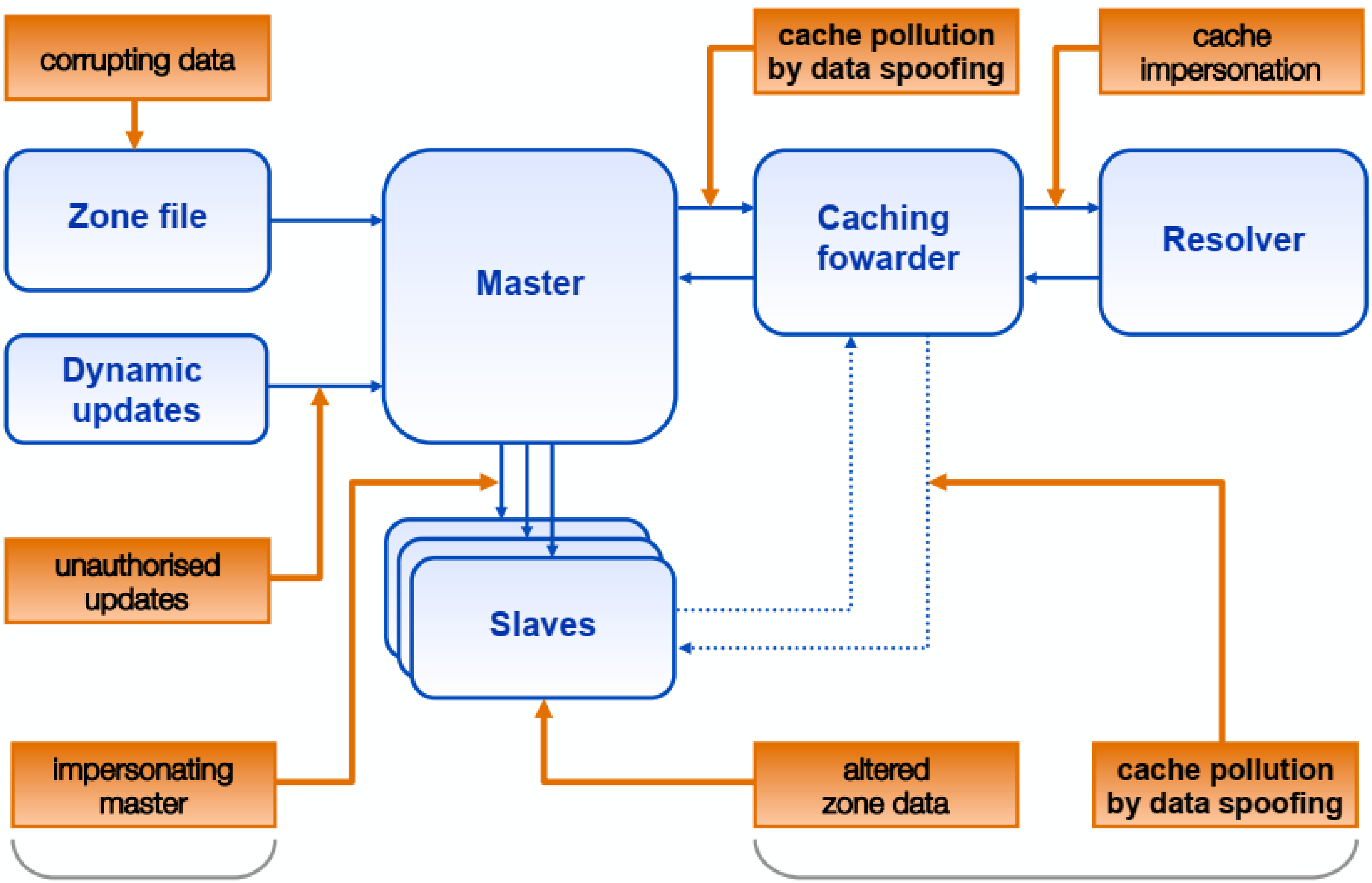
DNSSEC

- DNS Security Extensions
  - RFC4033
- Adds layers on top of DNS to make it verifiable
  - Adds new record types
  - Adds PKI
- Chain of trust to validate data

DNS Data Flow

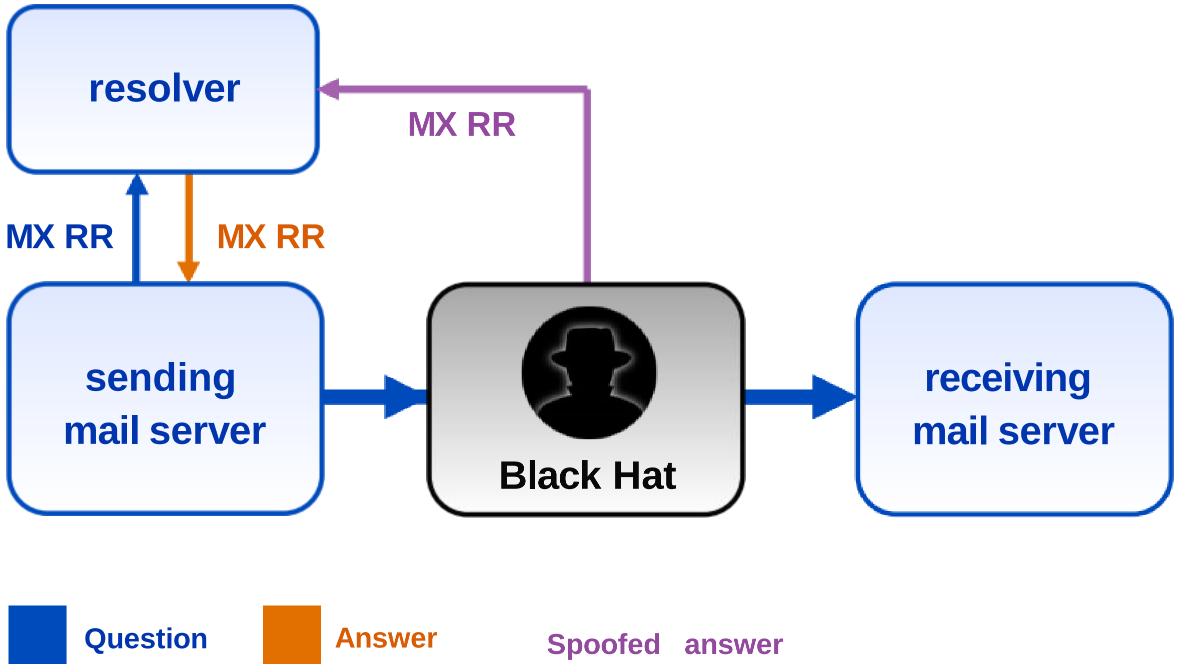


DNS Vulnerabilities

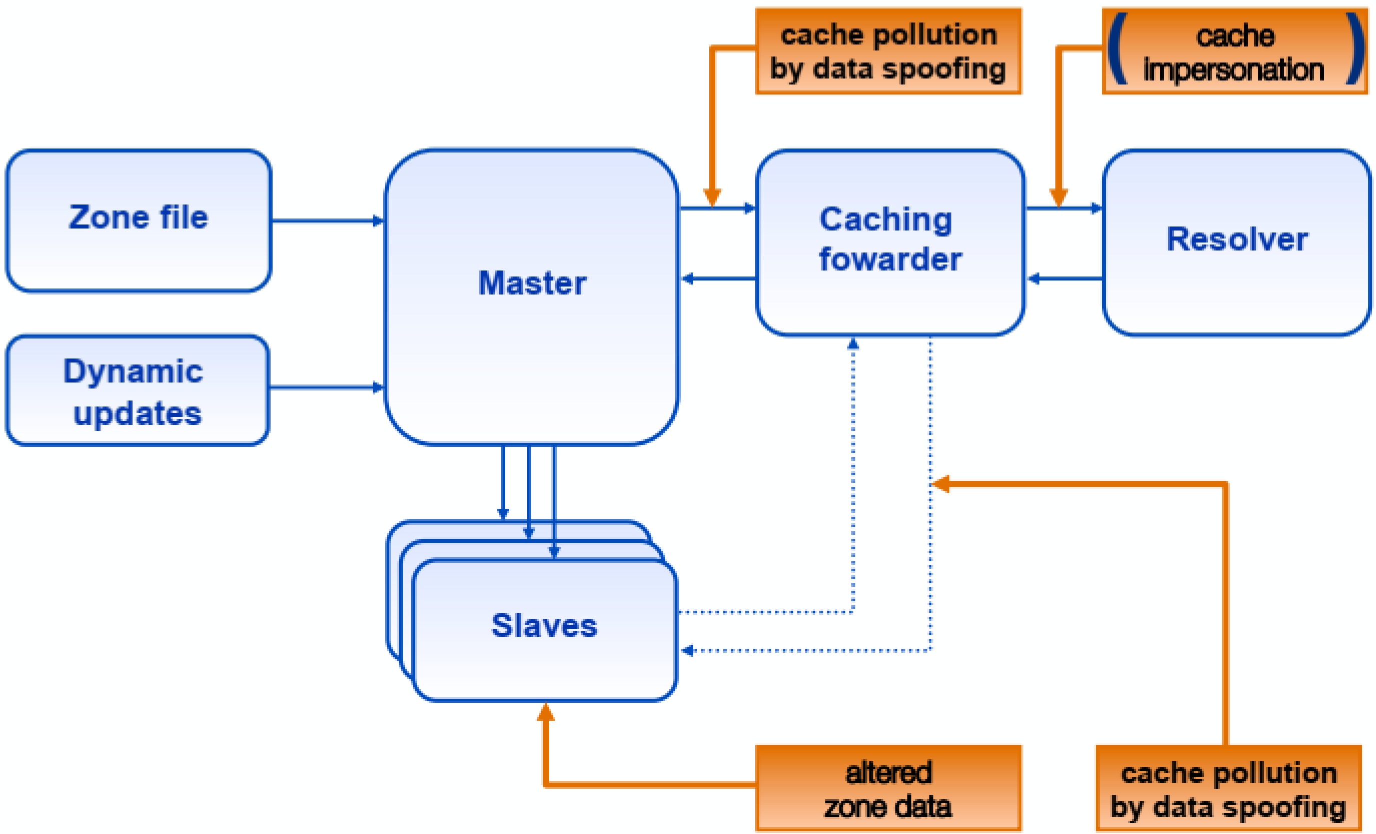


DNS Exploit Example

- Mail goes to the server in the MX resource record
- Path only visible in the email headers



DNSSEC Protected Vulnerabilities



The Recursive Resolver's View

- Recursive resolver will query them for records
  - and for authentication of records
- DNSSEC happens between server and resolver
  - Security status of records
  - Security status determines what client gets to see

Security Status of Data

- Secure
  - Resolver can build chain of signed DNSKEY and DS RRs from trusted anchor to RRSet
- Insecure
  - Resolver knows it has no chain of signed DNSKEY and DS RRs from any trusted starting point to RRset
- Bogus
  - Resolver thinks it can build a chain of trust but it is unable to do so
  - May indicate attack or configuration error or data corruption
- Indeterminate
  - Resolver cannot determine whether the RRset should be signed

RRs and RRSets

- Resource Record

name	TTL	class	type	rdata
www.ripe.net.	7200	IN	A	192.168.10.3

- RRset: RRs with same name, class and type

www.ripe.net.	7200	IN	A	192.168.10.3
www.ripe.net.	7200	IN	A	10.0.0.3
www.ripe.net.	7200	IN	A	172.25.215.2

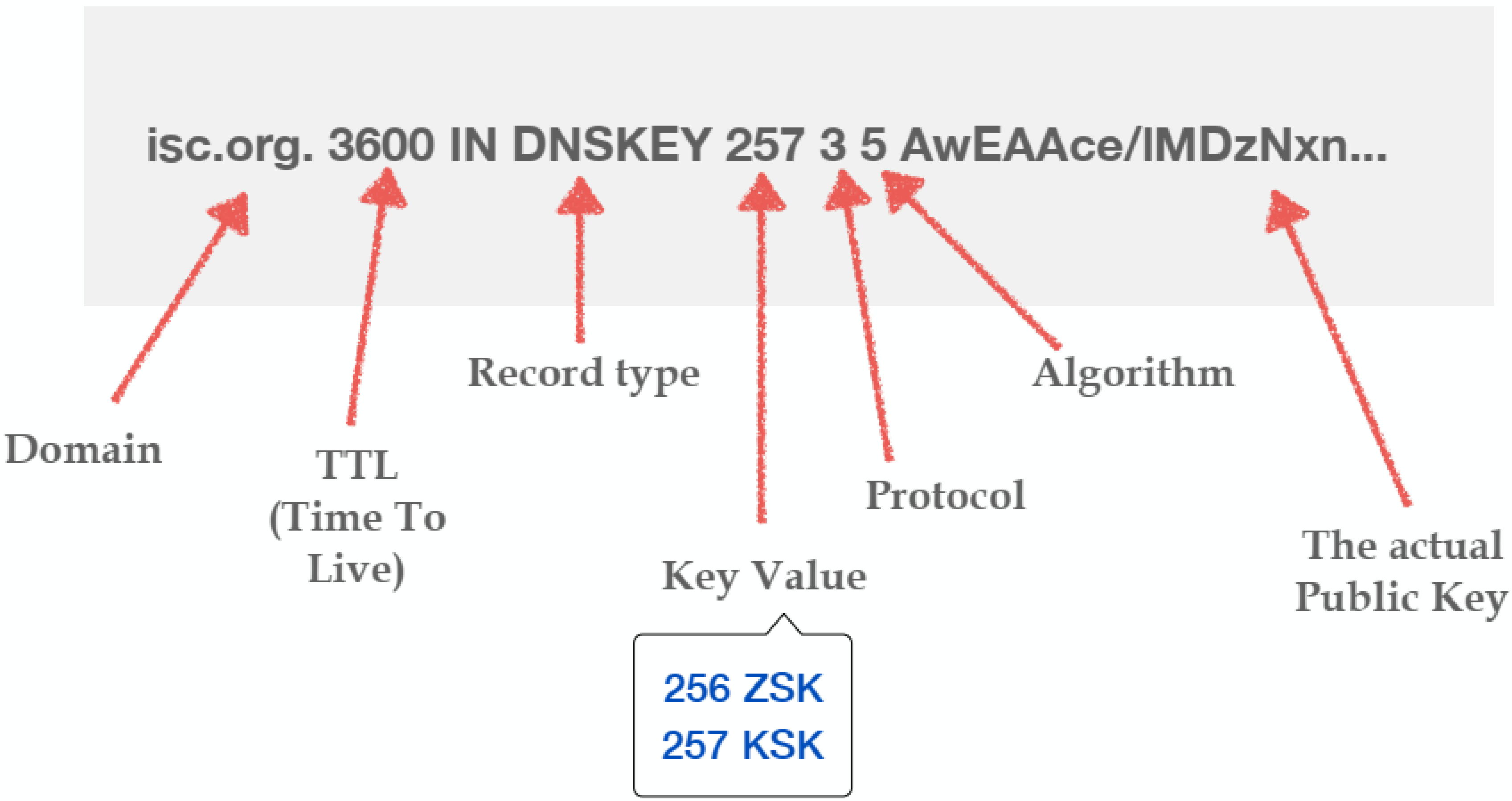
- RRSets are signed, not the individual RRs

New resource records

RRSIG	Signature over RRset
DNSKEY	Public key(s)
DS	Delegation Signer (hash of DNSKEY)

DNSKEY Record

- Contains Zone's public key(s)



DNSKEY Record

OWNER TYPE FLAGS PROTOCOL ALGORITHM

```
MYZONE.   600  DNSKEY  256  3  5  (
          AwEAAdevJXb4NxFnDFT0Jg9d/jRhJwzM/YTu
          PJqpvjRl14WabhabS6vioBX8Vz6XvnCzhlAx
          ...) ; key id = 5538
```

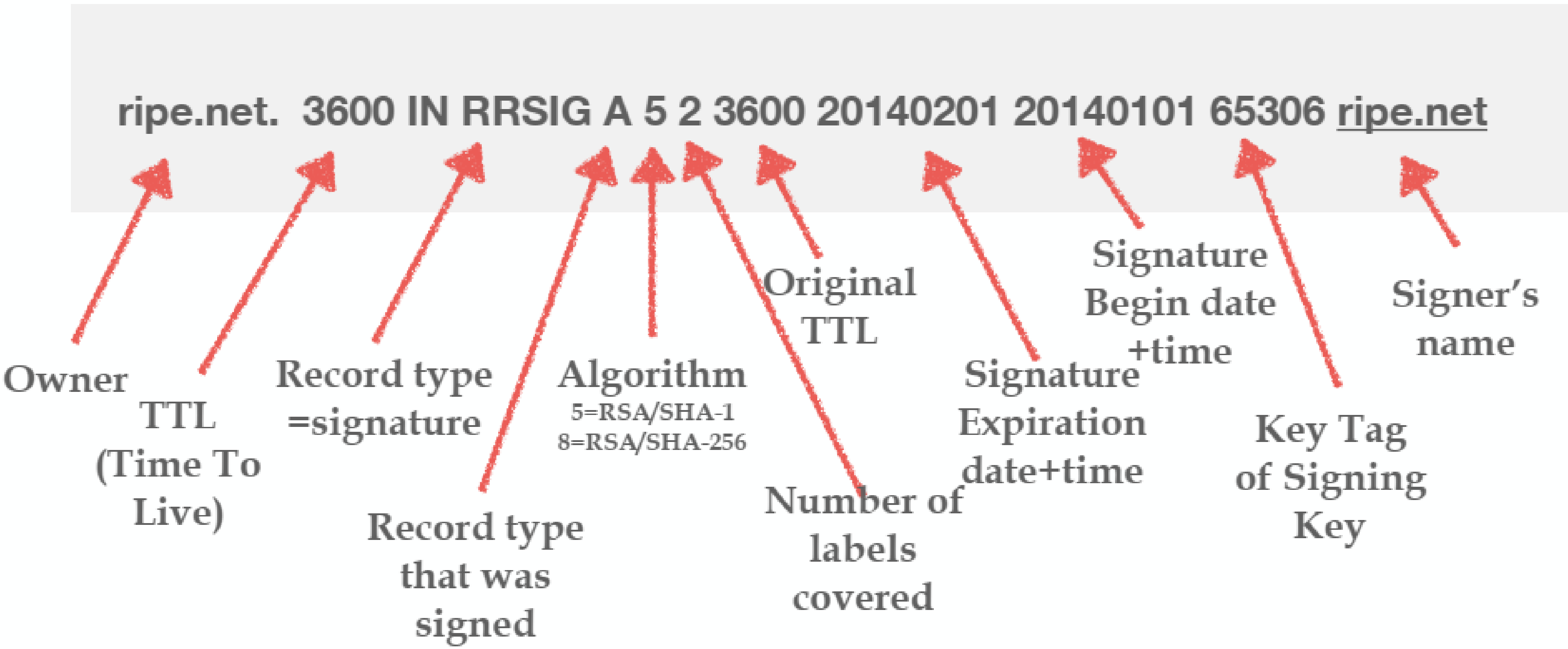
KEY ID

PUBLIC KEY (BASE64)

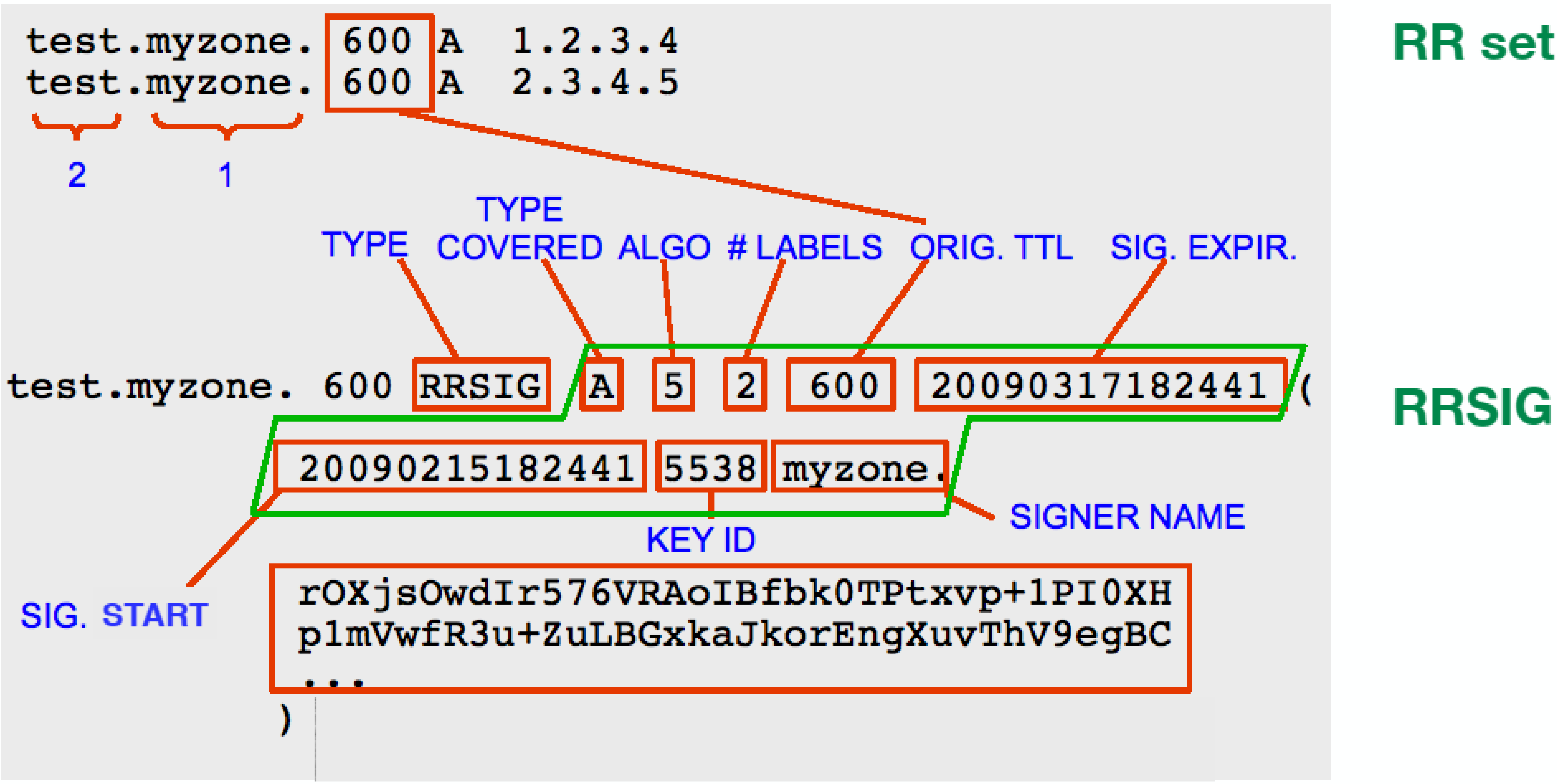
- FLAGS determines the usage of the key (more on this...)
- PROTOCOL is always 3 (DNSSEC(
- ALGORITHM can be:
  - 0 – reserved
  - 1 – RSA/MD5 (deprecated)
  - 2 – Diffie/Hellman
  - 3 – DSA/SHA-1 (optional)
  - 4 – reserved
  - 5 – RSA/SHA-1 (mandatory in validator)
  - 8 – RSA/SHA-256

RRSIG

- Resource Record SIGnature
- Digital signature of a set of records



RRSIG


test.myzone. 600 A 1.2.3.4
test.myzone. 600 A 2.3.4.5
2
1
TYPE
TYPE COVERED
ALGO
LABELS
ORIG. TTL
SIG. EXPIR.
test.myzone. 600 RRSIG A 5 2 600 20090317182441 (
20090215182441 5538 myzone.
SIGNER NAME
KEY ID
SIG. START
rOXjsOwdIr576VRAoIBfbk0TPtxvp+1PI0XH
p1mVwfR3u+ZuLBGxkaJkorEngXuvThV9egBC
...
)
RR set
RRSIG

Delegation Signer Record

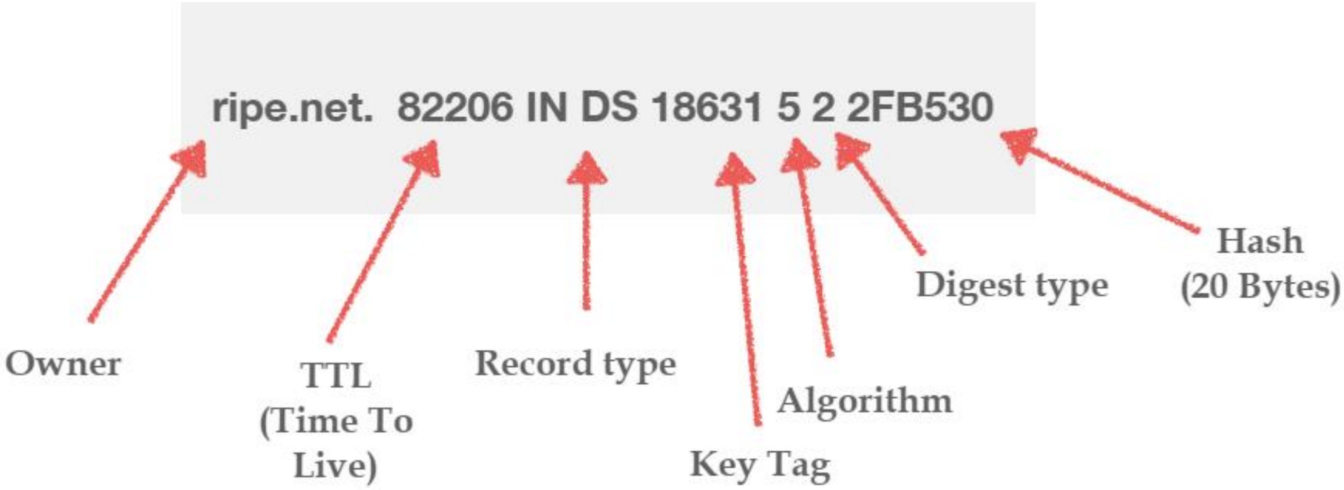
- The child's DNSKEY is hashed
- The hash of the key is signed by the parent's DNSKEY
  - and included in the parent's zone file
- Repeat for grandchild
- Chain of trust

Delegation Signer (DS)

- Delegation Signer (DS) RR shows that:
  - child's zone is digitally signed
  - hashed key is used for the child's zone
- Parent is authoritative for the DS of the child's zone
  - DS should be in the parent's , not the child's zone

DS

- Delegation Signer
- Contains hash of the DNSKEY
- To be published in the parent zone of DNS chain



NSEC Record

- “Next SECure” record
- Authenticates non-existence of data
- Side Effect: allows discovery of zone contents

NSEC Example 1

ZONE FILE

ant.ripe.net	NSEC	baby.ripe.net	A AAAA NSEC RRSIG
baby.ripe.net	NSEC	cat.ripe.net	A NSEC RRSIG
cat.ripe.net	NSEC	dodo.ripe.net	A AAAA NSEC RRSIG
dodo. ripe.net	NSEC	mouse.ripe net	A NSEC RRSIG
mouse.ripe.net	NSEC	ripe.net	A AAAA NSEC RRSIG
ripe.net	NSEC	www.ripe.net	A AAAA MX NSEC RRSIG
www.ripe.net	NSEC	ant.ripe.net	A AAA NSEC RRSIG

Q: A for fruit.ripe.net ?

Doesn't exist! There is nothing between **dodo** and **mouse** !

A: **dodo.ripe.net** NSEC mouse.ripe net A NSEC RRSIG

RRSIG over NSEC

NSEC Example 2

ZONE FILE

ant.ripe.net	NSEC	baby.ripe.net	A AAAA NSEC RRSIG
baby.ripe.net	NSEC	cat.ripe.net	A NSEC RRSIG
cat.ripe.net	NSEC	dodo.ripe.net	A AAAA NSEC RRSIG
dodo. ripe.net	NSEC	mouse.ripe net	A NSEC RRSIG
mouse.ripe.net	NSEC	ripe.net	A AAAA NSEC RRSIG
ripe.net	NSEC	www.ripe.net	A AAAA MX NSEC RRSIG
www.ripe.net	NSEC	ant.ripe.net	A AAA NSEC RRSIG

Q: AAAA for baby.ripe.net ?

Doesn't exist! Its not in the list in the NSEC record

A: **baby.ripe.net** NSEC cat.ripe.net A NSEC RRSIG

RRSIG over NSEC

NSEC Record

- Points to the next domain name in the zone
  - also lists what are all the existing RRs for “owner”
  - NSEC record for last name “wraps around” to first name in zone
- Used for authenticated denial-of-existence of data
- authenticated non-existence of TYPEs and labels

“owner”

next owner in zone file

Existing Resource Record types for www.ripe.net

www.ripe.net. 3600 IN NSEC ant.ripe.net. A RRSIG NSEC

Problem: NSEC Walk

- NSEC records allow for zone "re-construction"
- Causes privacy issues
- It's a deployment barrier

Solution: NSEC3 Record

- Same as NSEC
- But hashes all names to avoid zone discovery
- Hashed names are ordered

```
DRVR6JA3E4VO5UIPOFAO5OEEVV2U4T1K.dnssec-course.net. 3600 IN
NSEC3 1 0 10 03F92714 GJPS66MS4J1N6TIIJ4CL58TS9GQ2KRJ0 A RRSIG
```

New Resource Records

- Three Public key crypto related RRs
  - RRSIG Signature over RRset using private key
  - DNSKEY Public key, needed for verifying an RRSIG
  - DS Delegation Signer; ‘Pointer’ for building chains of authentication
- One RR for internal consistency
  - NSEC shows which name is the next one in the zone and which types exist for the name queried
  - authenticated non-existence of data

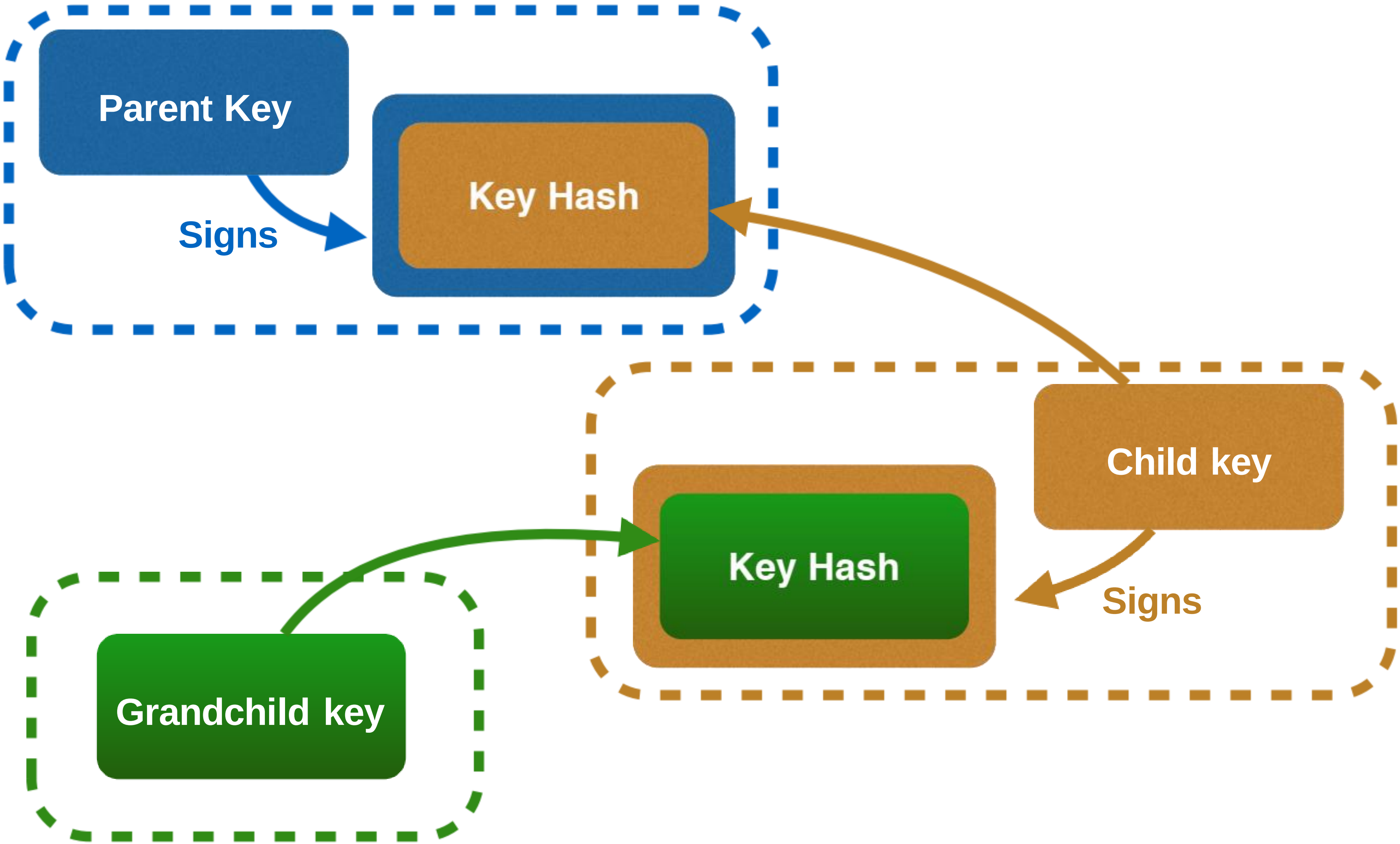
What if There Was No DS?

- Without delegating signing authority (DS) the
  - resolver would need to store millions of public keys
- But with DS only one key is needed: the root key

DNS and Keys

- DNS is made of islands of trust, with delegations
- A parent needs to have pointers to child keys
  - in order to sign/verify them
  - DS Records are used for this
- You want to keep interaction between parent and children at a minimum

DNSSEC Made simple



Key Problem

- Interaction with parent administratively expensive
  - Should only be done when needed
  - Bigger keys are better
- Signing zones should be fast
  - Memory restrictions
  - Space and time concerns
  - Smaller keys with short lifetimes are better

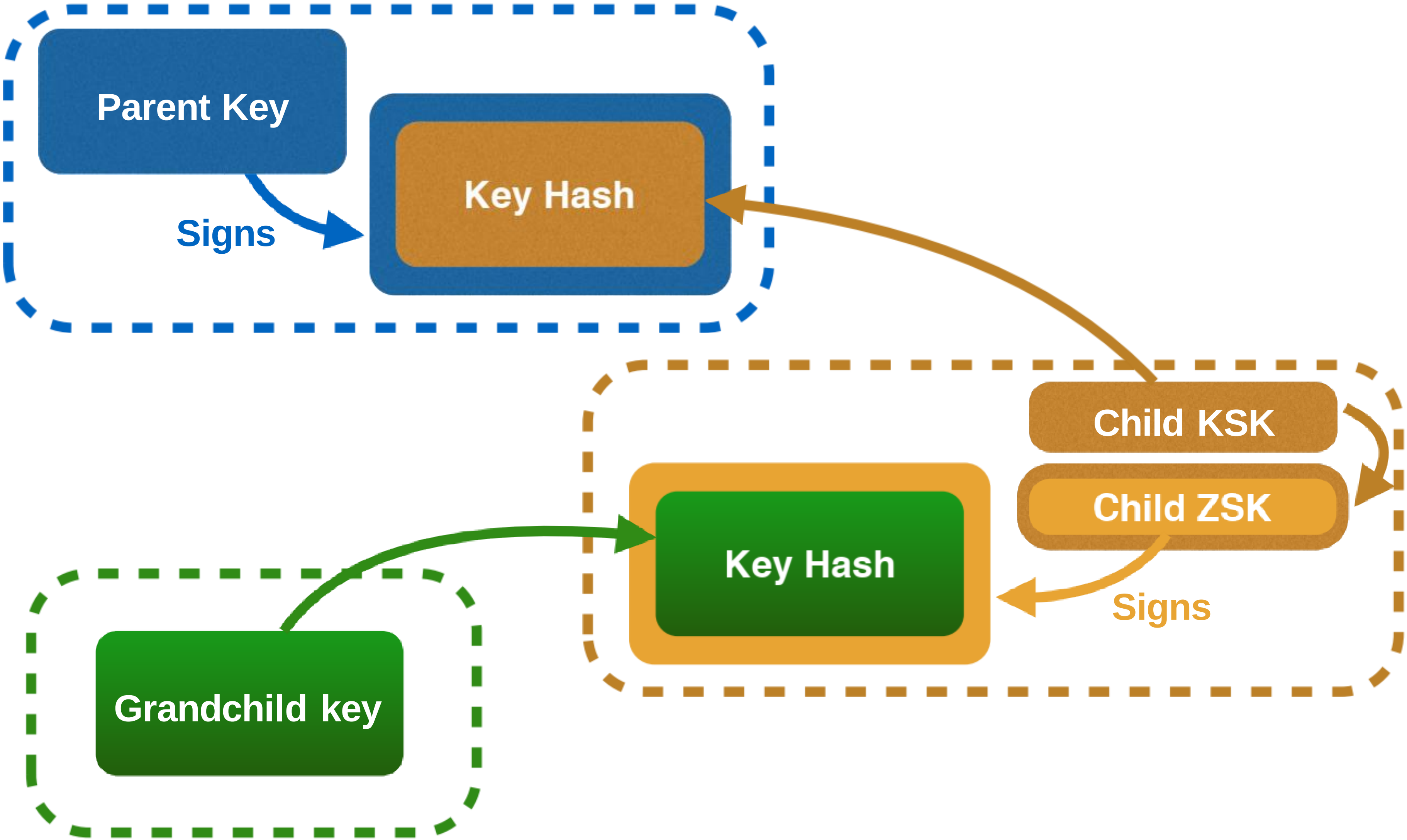
Key Functions

- Large keys are more secure
  - Can be used longer
  - Large signatures => large zone files ✕
  - Signing and verifying computationally expensive ✕
- Small keys are fast
  - Small signatures
  - Signing and verifying less expensive
  - Short lifetime✕

Key Solution: More Than One Key

- Key Signing Key (KSK) only signs DNSKEY RRset
- Zone Signing Key (ZSK) signs all RRsets in zone
- RRsets are signed, not RRs
- DS points to child's KSK
  - Parent's ZSK signs DS
  - Signature transfers trust from parent key to child key

Key split - ZSK and KSK



Zone Signing Key - ZSK

- Used to sign a zone
- Can be lower strength than the KSK
- No need to coordinate with parent zone if you want to change it

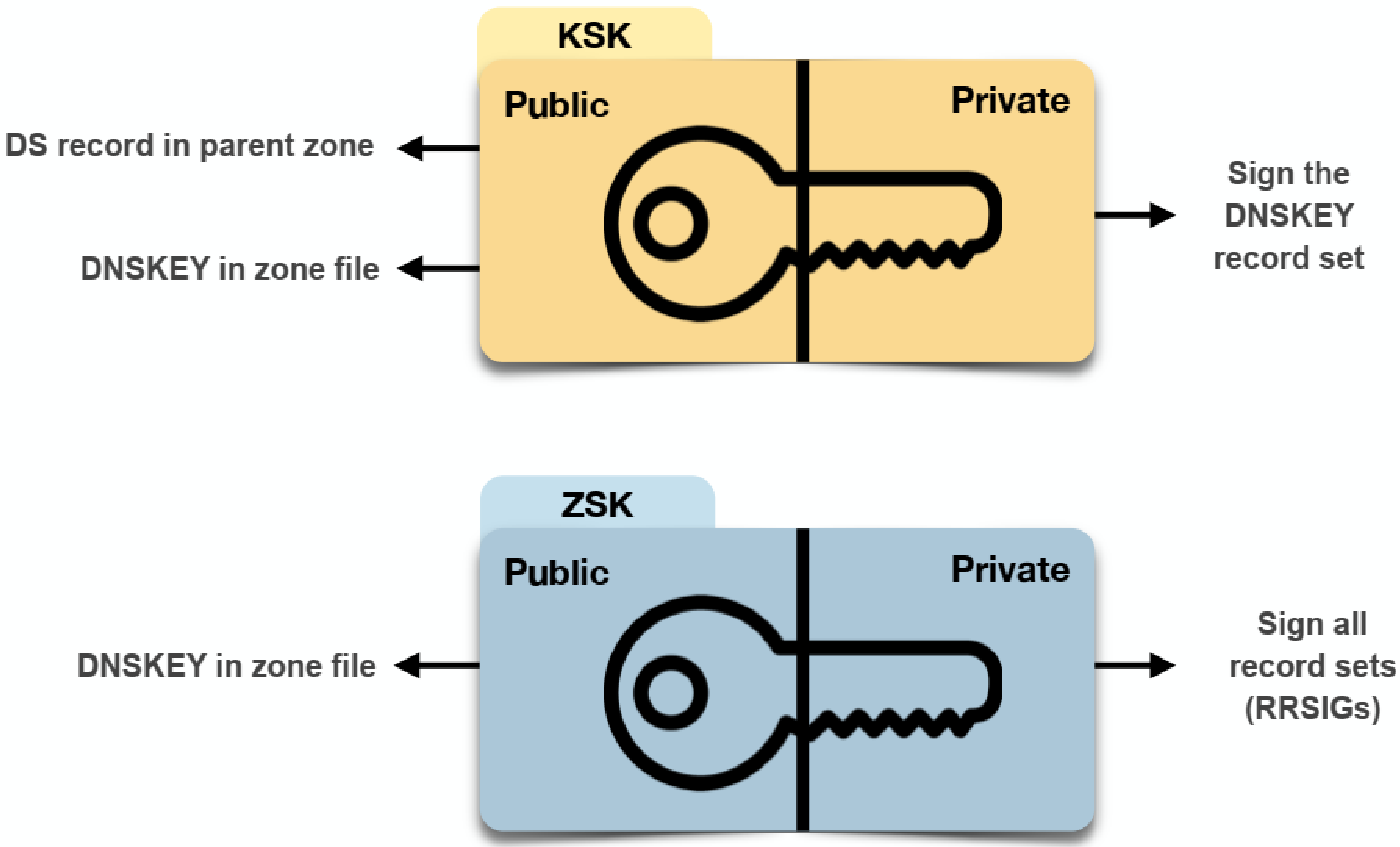
Key Signing Key - KSK

- Only signs the Resource Record Set containing DNSKEYs for a zone
- Used as the trust anchor
- Needs to be specified in the parent zone using DS (Delegation Signature) records

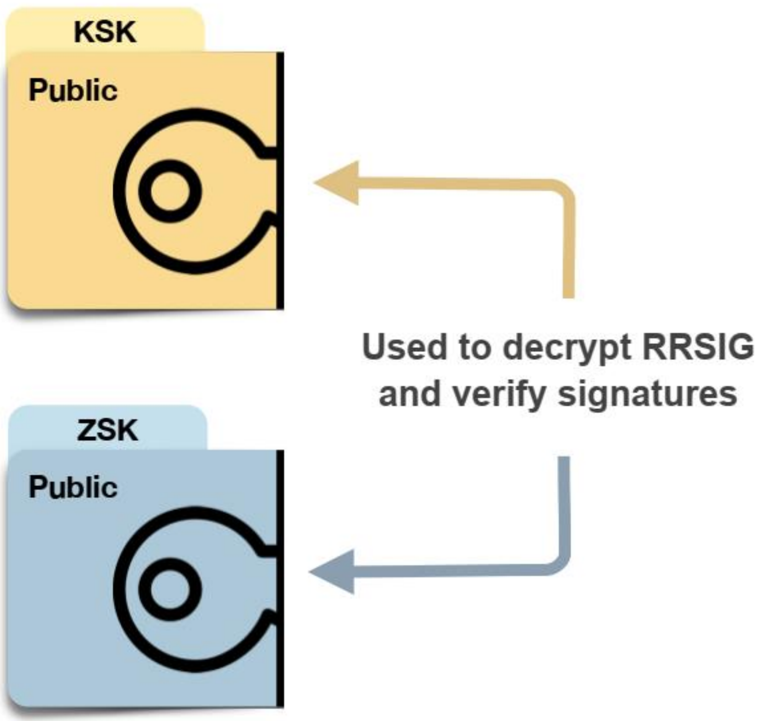
Initial Key Exchange

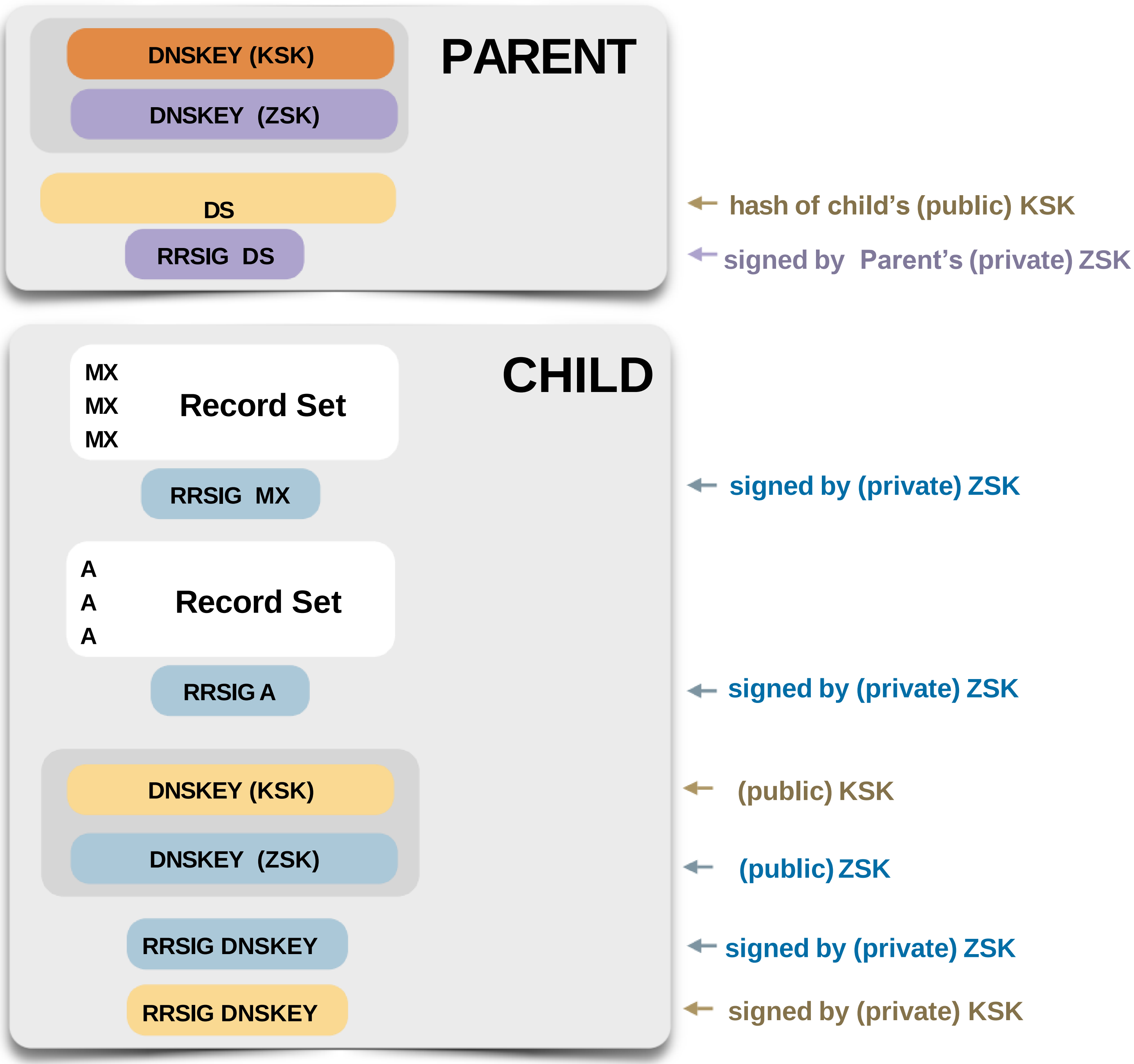
- Child needs to:
  - Send key signing keyset to parent
- Parent needs to:
  - Check childs zone
    - for DNSKEY & RRSIGs
  - Verify if key can be trusted
  - Generate DS RR

Keys

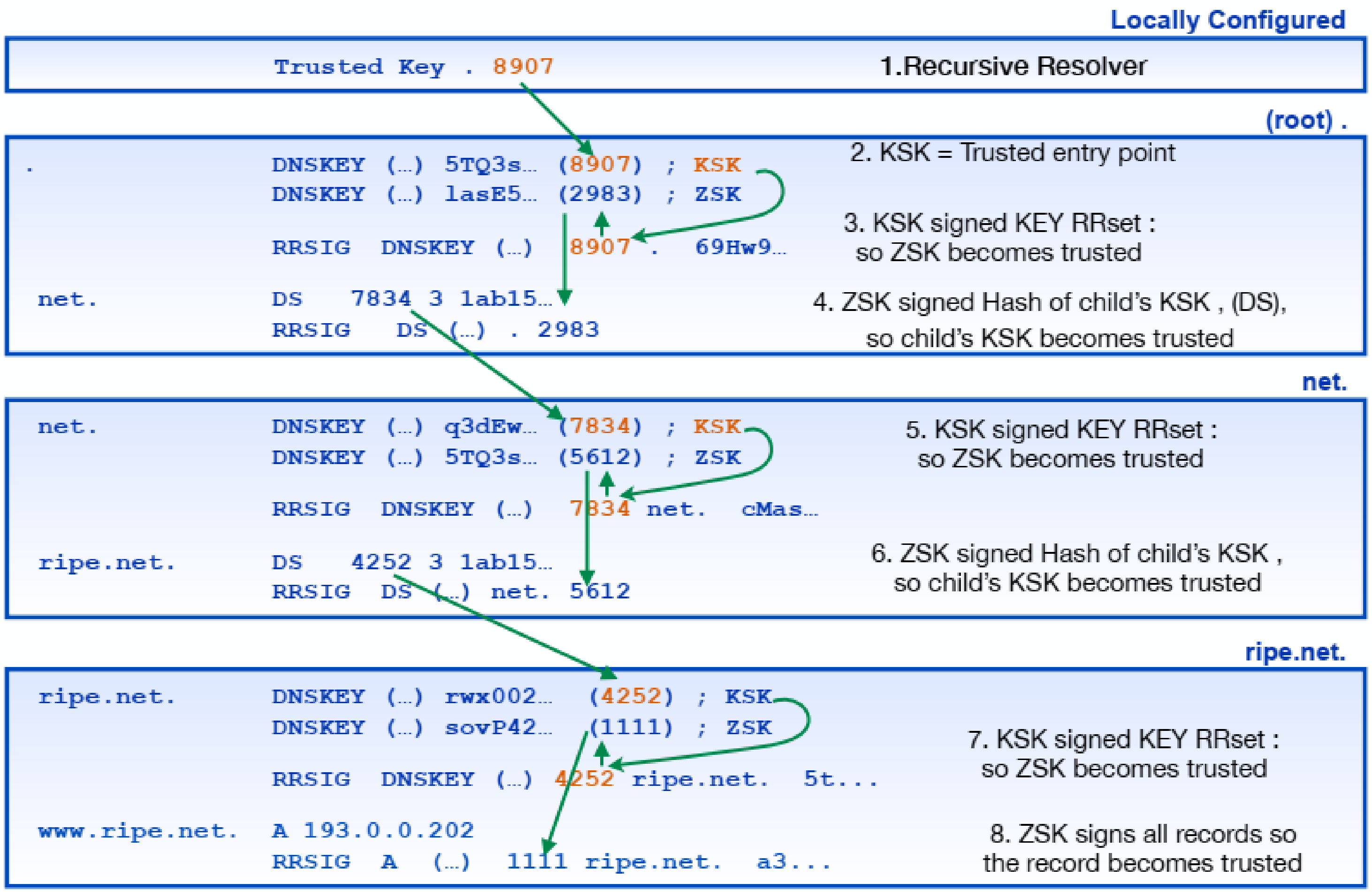

KSK
Public
Private
DS record in parent zone
DNSKEY in zone file
Sign the DNSKEY record set
ZSK
Public
Private
DNSKEY in zone file
Sign all record sets (RRSIGs)

Keys


KSK
Public
Used to decrypt RRSIG
and verify signatures
ZSK
Public


PARENT
DNSKEY (KSK)
DNSKEY (ZSK)
DS
RRSIG DS
hash of child's (public) KSK
signed by Parent's (private) ZSK
CHILD
MX
MX
MX
Record Set
RRSIG MX
signed by (private) ZSK
A
A
A
Record Set
RRSIG A
signed by (private) ZSK
DNSKEY (KSK)
DNSKEY (ZSK)
(public) KSK
(public) ZSK
RRSIG DNSKEY
signed by (private) ZSK
RRSIG DNSKEY
signed by (private) KSK

Walking the Chain of Trust



Key Rollovers: Keys need to be changed

- Keys become old quickly
  - New exploits are discovered every day
  - Brute force becomes less and less expensive
- Your keys could be stolen or compromised
- You need to have a plan

Key rollover methods

- Pre-publish
- Double signature
- Both for ZSK and KSK
  - Rolling a KSK means changing parent DS records
- Rollover times depend on TTL and method

Pre-publishing Method

- A new DNSKEY record is introduced with new key
  - Not used for signing, yet
- After TTL expires, new RRSIGs are created with new DNSKEY
  - Old DNSKEY remains published
- After TTL expires again, old DNSKEY is removed

Double signature Method

- A new DNSKEY is introduced, and immediately used to sign the records
- We have two RRSIGs for every record, with signatures from both DNSKEYs
- After TTL expires, old DNSKEY is removed, and records are again signed only once

Do We Have to Remember to Rollover?

- No, we can automate it
  - in the configuration
  - including the schedule
- just provide ahead of time enough DNSSEC keys for the next few rollovers

Recommendations

- Use pre-publishing for ZSK
  - Especially for large zones
- Use double signature for KSK
  - KSK double-signs the DNSKEY, not the zone
- For KSK rollovers, update DS records

Does DNSSEC Solve all our problems?

- No.
- DNS still vulnerable to reflection attacks + injected responses

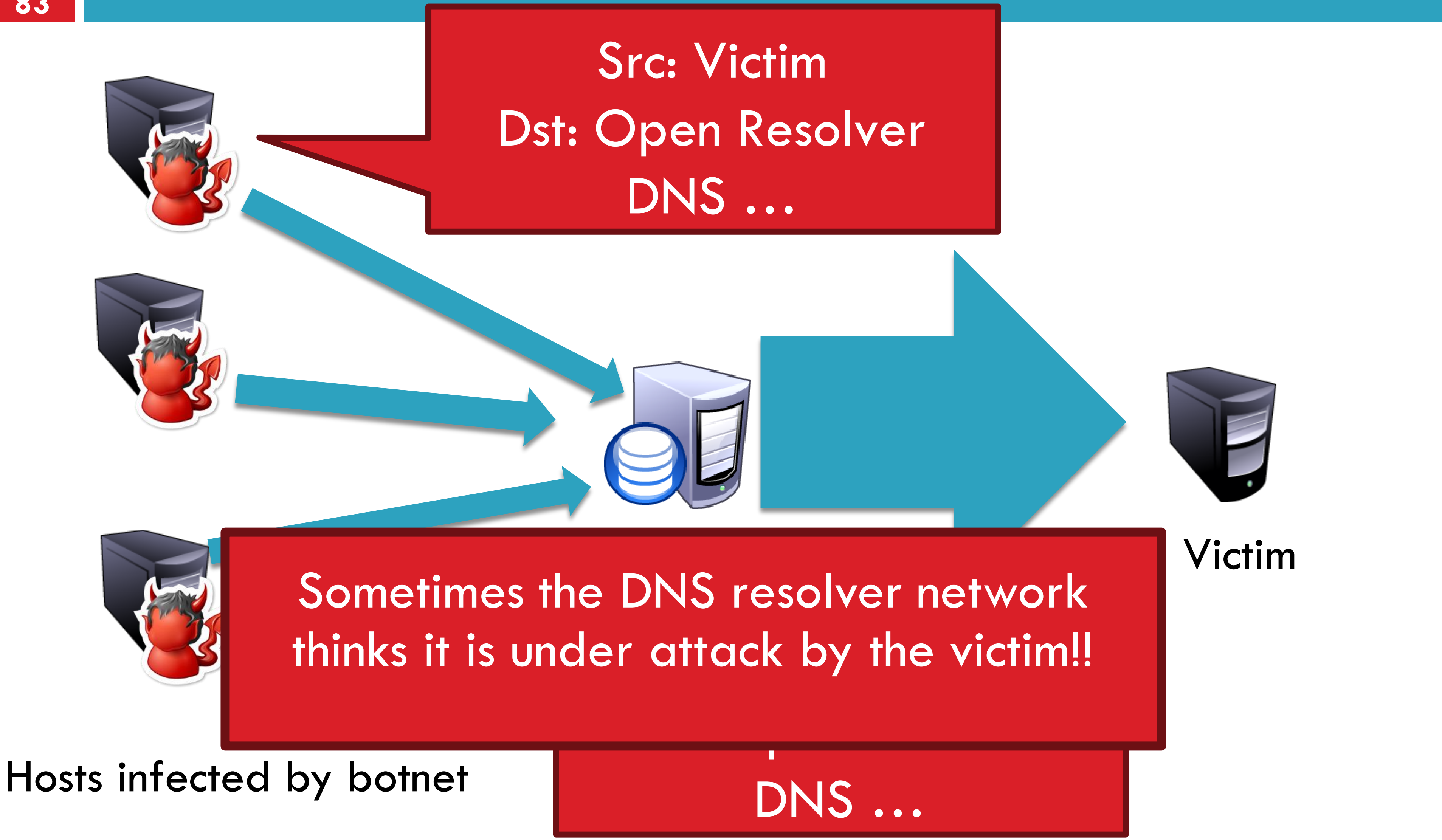
DNS Reflection

- Very big incident in 2012
  - (http://blog.cloudflare.com/65gbps-ddos-no-problem/)
  - 65 Gbps DDoS
  - Would need to compromise 65,000 machines each with 1 Mbps uplink
    - How was this attack possible?
- Use DNS reflection to amplify a Botnet attack.
- Key weak link: Open DNS resolvers will answer queries for anyone http://openresolverproject.org/

So how does this work?

- Remember: DNS is UDP
- No handshaking between endpoints
- One can send a DNS query with a forged IP address and the response will go to that IP address
  - **Secret sauce:** a small request that can elicit a large response
  - E.g., query for zone files, or DNSSEC records (both large record types).
- Botnet hosts spoof DNS queries with victim's IP address as source
  - Resolver responds by sending massive volumes of data to the victim

DNS amplification illustrated



Amplification not unique to DNS

- NTP is the latest protocol to be used in this way:
- Exploiting NTP Monlist command which returns a list of 600 most recent hosts to connect to the NTP server https://www.cloudflare.com/en-in/learning/ddos/ntp-amplification-ddos-attack/

How well is DNSSEC managed?

- Looked at 147M domains, 60K+ resolvers over 21 months
- TLDs, ccTLDs broadly deploy
  - But only 1-2% of second-level domains use it
- Pervasive record mismanagement
  - Nearly 1/3 of DNSSEC-enabled domains can't be validated
- Resolvers not validating properly
  - 80+% of resolvers ask for DNSSEC records
  - Only 12% actually bother to check the result!

Outline

- DNS Basics
- DNS Security
- DNS and Censorship

DNS and Censorship

- DNS is a popular protocol for targeting by Internet censors
- A few things to keep in mind …
- No cryptographic integrity of DNS messages
  - DNSSEC proposed but not widely implemented
- Caching of replies means leakage of bad DNS data can persist

Blocking DNS Names

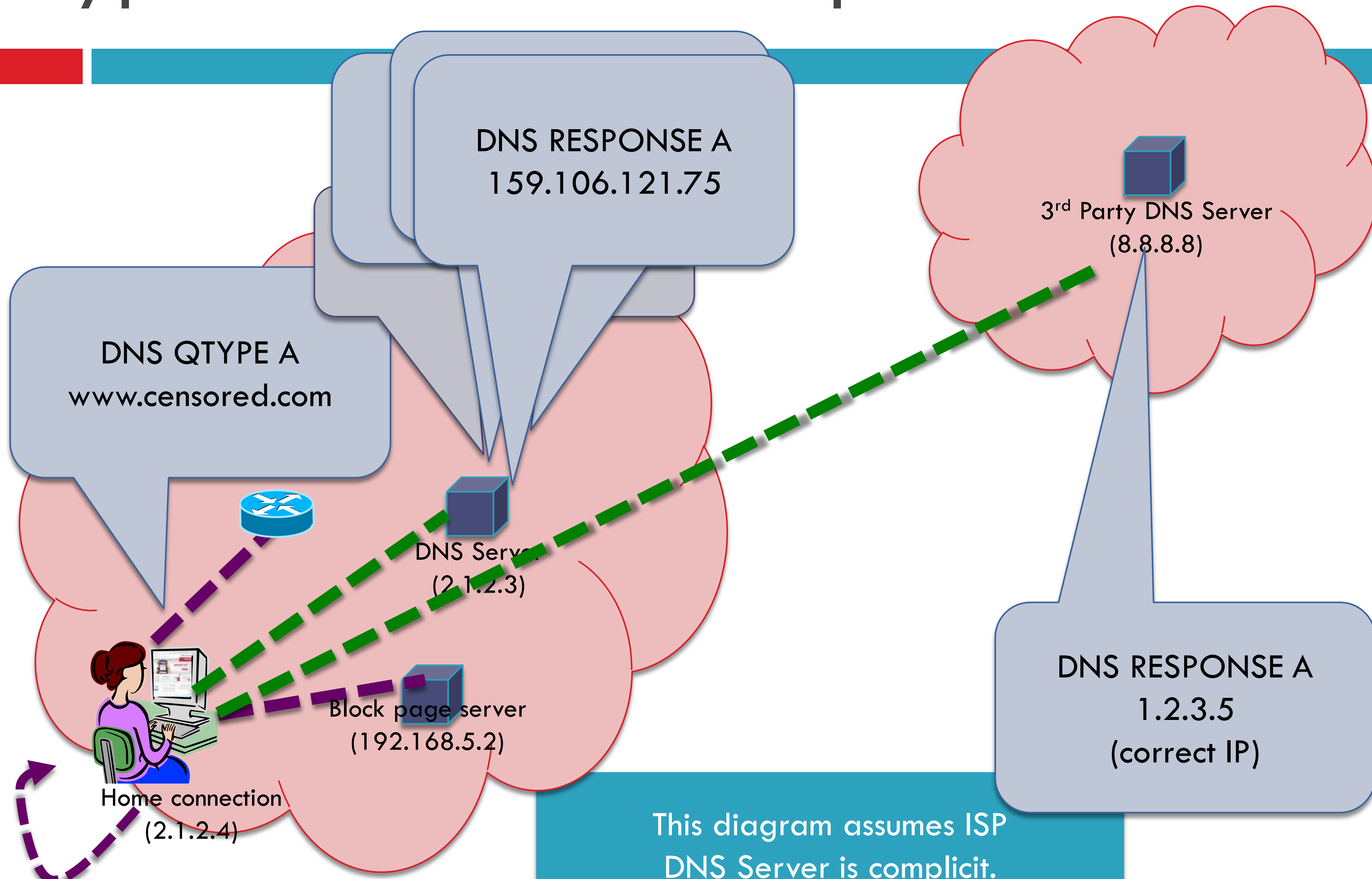
- Can the censor pressure the registrar?

  Name blocked, forever

Blocking DNS Names

- Can the censor pressure the ISPs?
  - Just force an entry in the recursive resolver to poison results for a given domain
- Clients can trivially evade this using alternate DNS services
  - E.g., Google's 8.8.8.8
  - …but this does require client changes
  - Also, ISPs must not block third party DNS queries for this to work
- Initially used by ISPs in the UK to block the Pirate Bay

Types of false DNS responses



This diagram assumes ISP DNS Server is complicit.

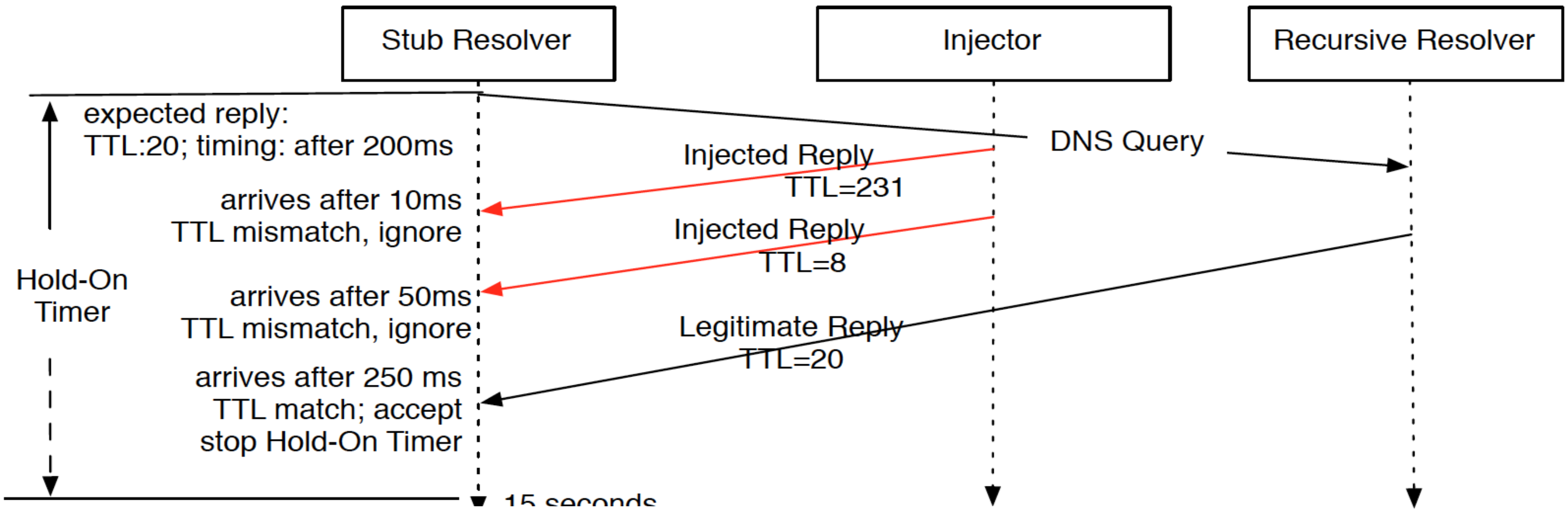
Blocking DNS names

- Option A: get ISP resolver on board
  - (Previous slide)
- Option B: On-path packet injection
  - Censor injects a DNS response that **races** the legitimate reply
  - Can be mostly countered with DNS-hold-open:
    - Don't take the first answer but instead wait for up to a second
  - Generally reliable when using an out of country recursive resolve (e.g., 8.8.8.8, censor packet should win the race)
  - Can be **completely** countered by DNS-hold-open + DNSSEC
    - Accept the first DNS reply **which validates**

Reading from Web …

- Hold-On: Protecting Against On-Path DNS Poisoning, H. Duan, N. Weaver, Z. Zhao, M. Hu, J. Liang, J. Jiang, K. Li, and V. Paxson.
- **Idea**: Once you receive a DNS packet, wait for a predefined “hold-on” period before accepting the result.
  - DNSSEC is still vulnerable to these injected packets and does not make hold-on unnecessary
  - Censor can just inject a reply with an invalid signature: client will reject (denial of service)
- **Method:** Use active measurements to determine the expected TTL and RTT to the server.

Hold-on in action



Much More to DNS

- Caching: when, where, how much, etc.
- Other uses for DNS (i.e. DNS hacks)
  - Content Delivery Networks (CDNs)
  - Different types of DNS load balancing
  - Dynamic DNS (e.g. for mobile hosts)
- DNS and botnets
- Politics and growth of the DNS system
  - Governance
  - New TLDs (.xxx, .biz), eliminating TLDs altogether
  - Copyright, arbitration, squatting, typo-squatting

DNSSEC Summary

- Data authenticity and integrity by signing the
  - Resource Records Sets with private DNSKEY
  - You need Public DNSKEYs to verify the RRSIGs
- Children sign their zones with their private key
  - Parent guarantees authenticity of child's key by signing the hash of it (DS)
- Repeat for parent …
  - …and grandparent
- Ideal case: one public DNSKEY distributed

DNSSEC Summary

ripe.net.

www.ripe.net	IN	A 193.0.0.214
www.ripe.net	IN	RRSIG A … 26523 ripe.net.
ripe.net	IN	DNSKEY 256 26523 … ripe.net.
ripe.net	IN	RRSIG DNSKEY 32987 … ripe.net.
ripe.net	IN	DNSKEY 257 32987 … ripe.net.

net.

ripe.net	IN	DS 26523 8 1 …
ripe.net	IN	RRSIG DS … 43249 net.
net	IN	DNSKEY 256 43249 … net.

DNSSEC Summary

- 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
    - Value = Cryptographic signature of the query results
- 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)

Creates a hierarchy of trust within each zone

and spoofing

DNSSEC Hierarchy of Trust