More on DNS and DNSSEC

CS 161: Computer Security

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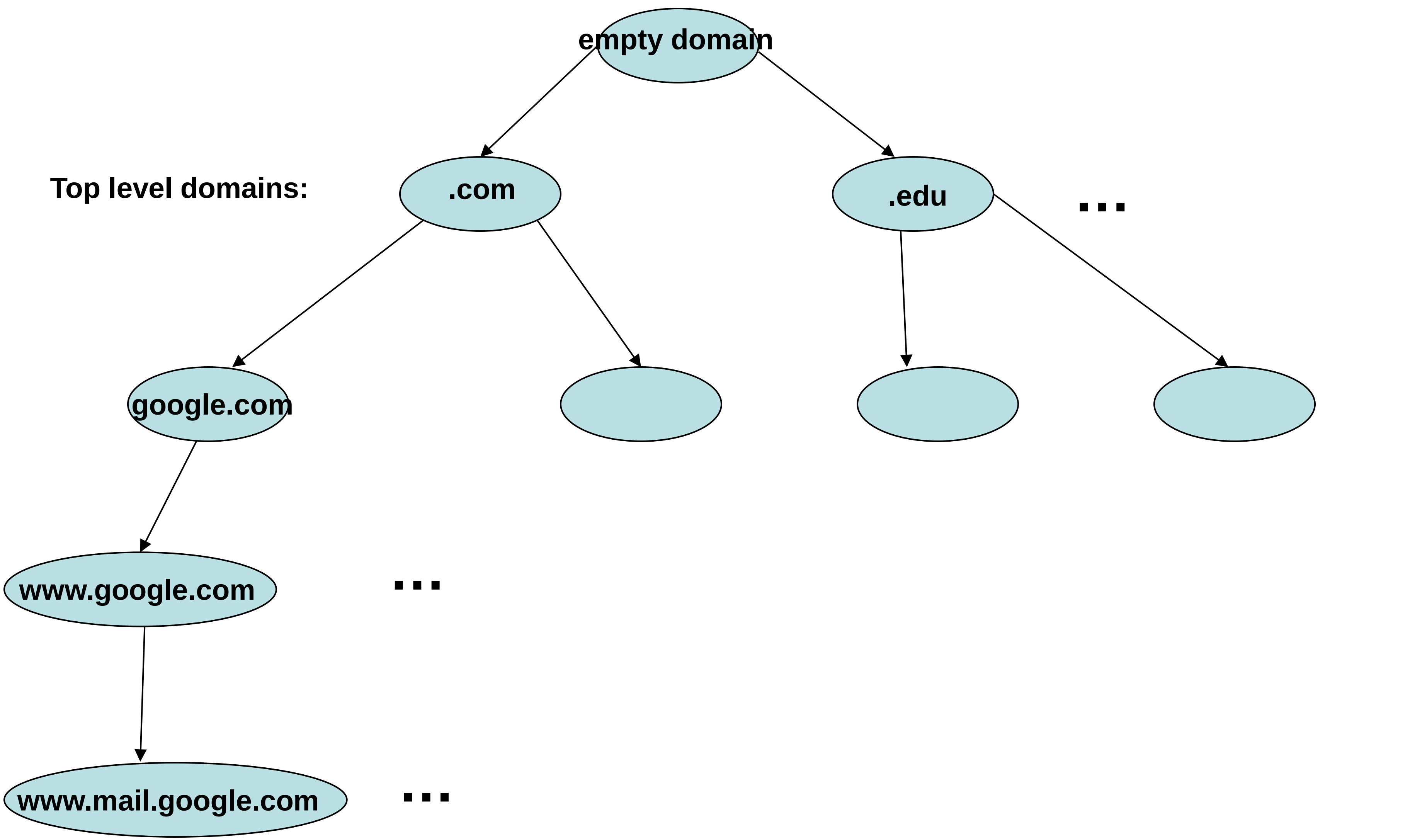
A subset of the slides adapted from David Wagner

Domain names

- Domain names are human friendly names to identify servers or services
  - Arranged hierarchically
  - www.google.com has:
    - .com as TLD (top-level domain)
    - google.com as a subdomain of com
    - www.google.com a subdomain of google.com

Hierarchy of domain names



Types of domain names (TLD)

1. Generic TLDs: .com, .edu
2. Country-code TLDs: .au .de .it .us

Creating a domain name

- Domain names are registered and assigned by **domain-name registrars**, accredited by the Internet Corporation for Assigned Names and Numbers (ICANN), same group allocating the IP address space
- Contact the domain-name registrar to register domain space

Cybersquatting or Domain Squatting

- Entities buying a domain in advance of it becoming desirable and later selling to the agency needing it for much more

2013: Microsoft vs. MikeRoweSoft

The boy accepted an Xbox in exchange for the domain name

DNS Overview

- DNS translates www.google.com to 74.125.25.99: **resolves** www.google.com

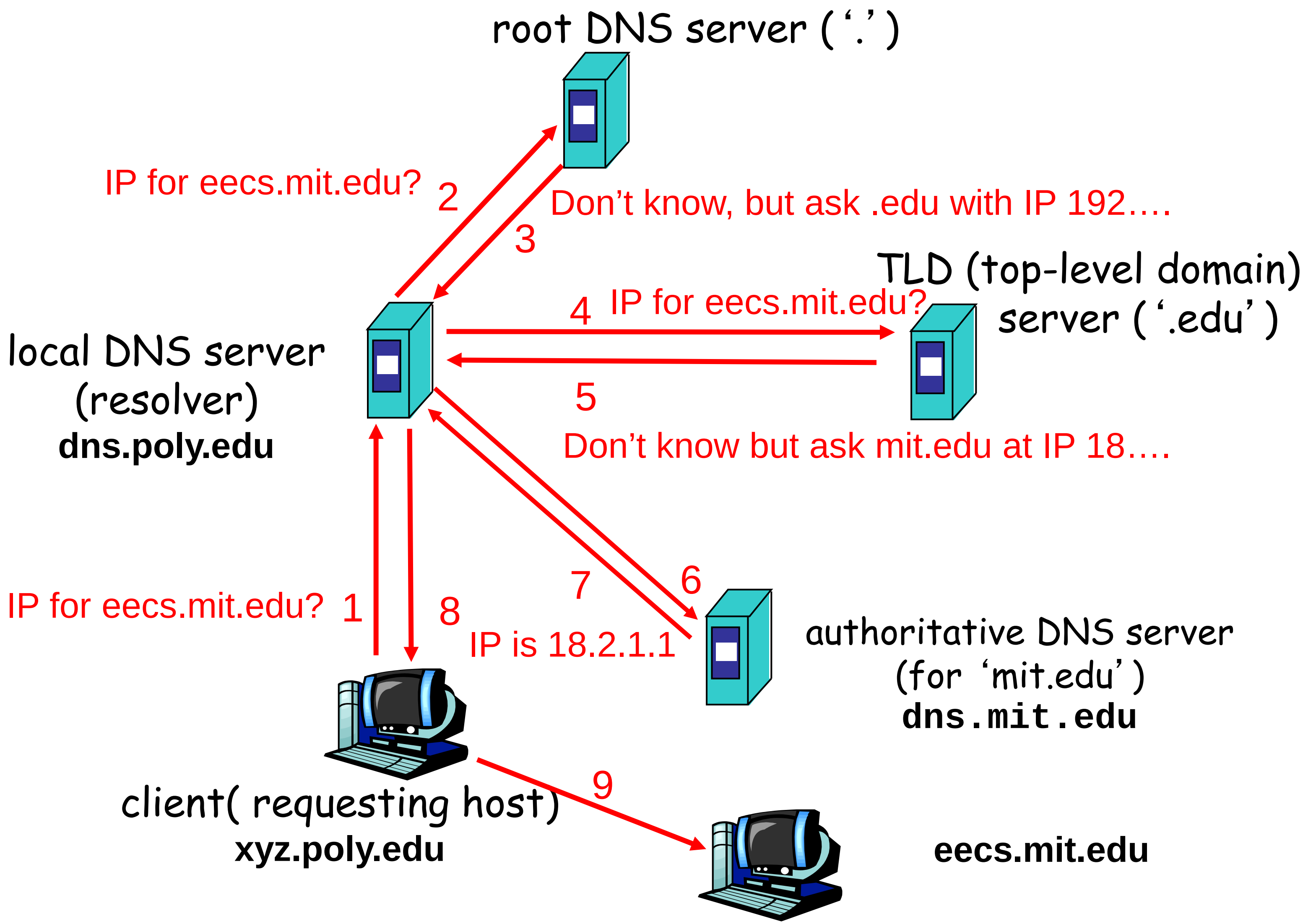
Name servers

- To resolve a domain name, a resolver queries a distributed hierarchy of **DNS servers** also called **name servers**
- At the top level are the root name servers, which resolve TLDs such as .com
  - Store the **authoritative name server** for each TLD (the trusted server for the TLD)
  - Government and commercial organizations run the name servers for TLDs
  - Name server for .com managed by Verisign

A DNS Lookup

1. Alice goes to *eecs.mit.edu* on her browser
2. Her machine contacts a resolver to ask for *eecs.mit.edu*’s IP address
   – The resolver can be a name server for the corporate network of Alice’s machine or of her Internet service provider
3. The resolver will try to resolve this domain name and return an IP address to Alice’s machine

DNS Lookups via a *Resolver*



DNS caching

- Almost all DNS servers (resolver and name servers) cache entries, but with different cache policies

DNSSEC

- DNSSEC = standardized DNS security extensions currently being deployed
- Aims to ensure integrity of the DNS lookup results (to ensure correctness of returned IP addresses for a domain name)

Q: what attack is it trying to prevent?

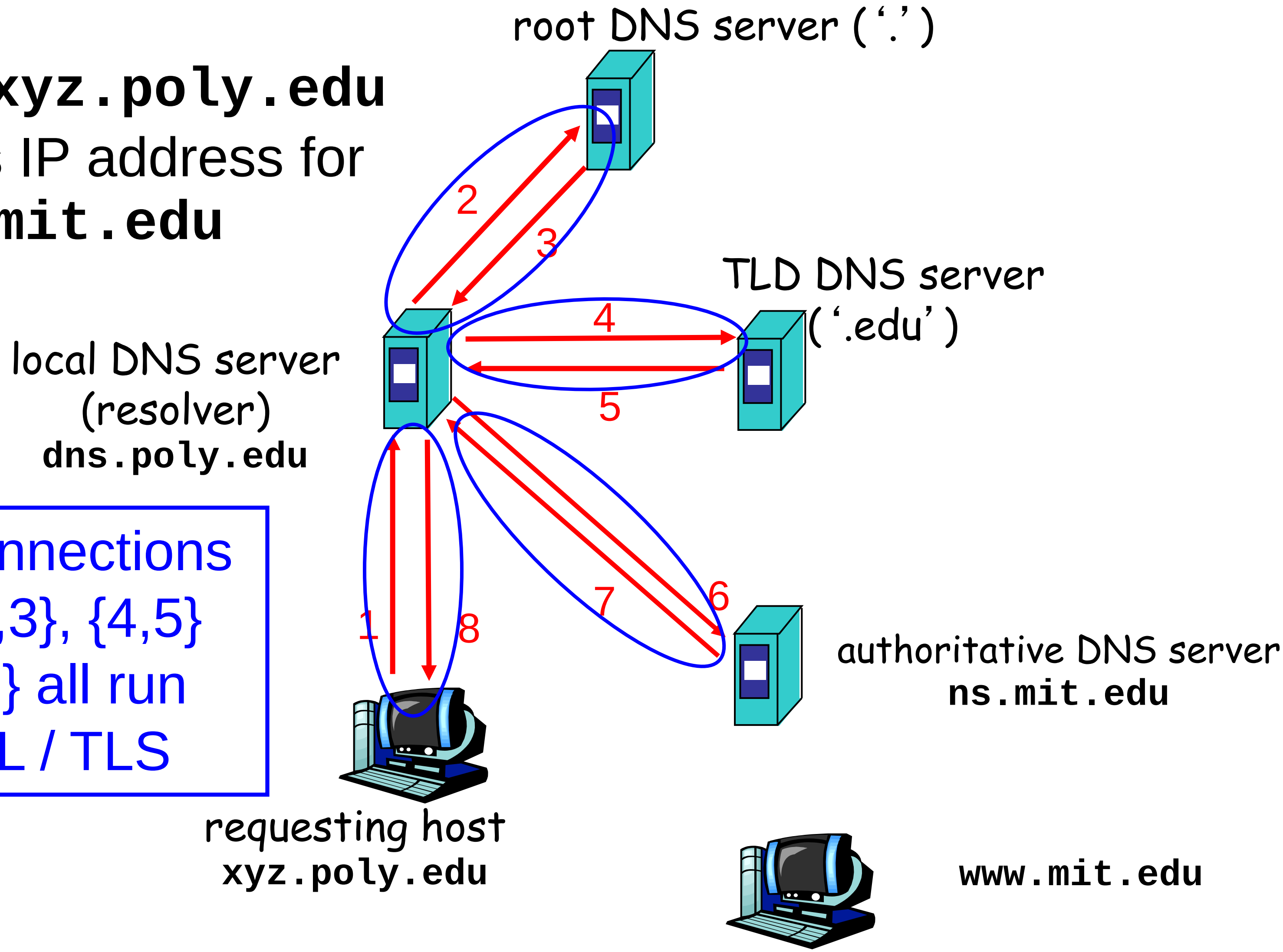
A: attacker changes DNS record result with an incorrect IP address for a domain

Securing DNS Lookups

- How can we ensure that when clients look up names with DNS, they can trust the answers they receive?
- Idea #1: do DNS lookups over TLS (SSL)

Securing DNS Using SSL/TLS

Host at **xyz.poly.edu** wants IP address for **www.mit.edu**



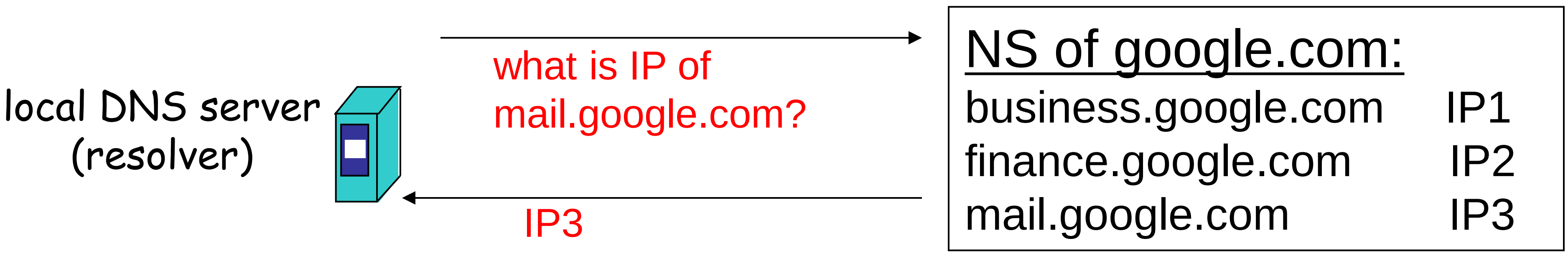
Idea: connections {1,8}, {2,3}, {4,5} and {6,7} all run over SSL / TLS

Securing DNS Lookups

- How can we ensure that when clients look up names with DNS, they can trust the answers they receive?
- Idea #1: do DNS lookups over TLS (SSL)
  - Performance: DNS is very lightweight. TLS is not.
  - Caching: crucial for DNS scaling. But then how do we keep authentication assurances?
  - Security: must trust the resolver.
    Object *security vs.* ***Channel*** *security*

    How do we know which name servers to trust?
- Idea #2: make DNS results like *certs*
  - I.e., a verifiable signature that guarantees who generated a piece of data; signing happens **off-line**

Scratchpad – let’s design it together



Q: How can we ensure returned result is correct?

A: Have google.com NS sign IP3

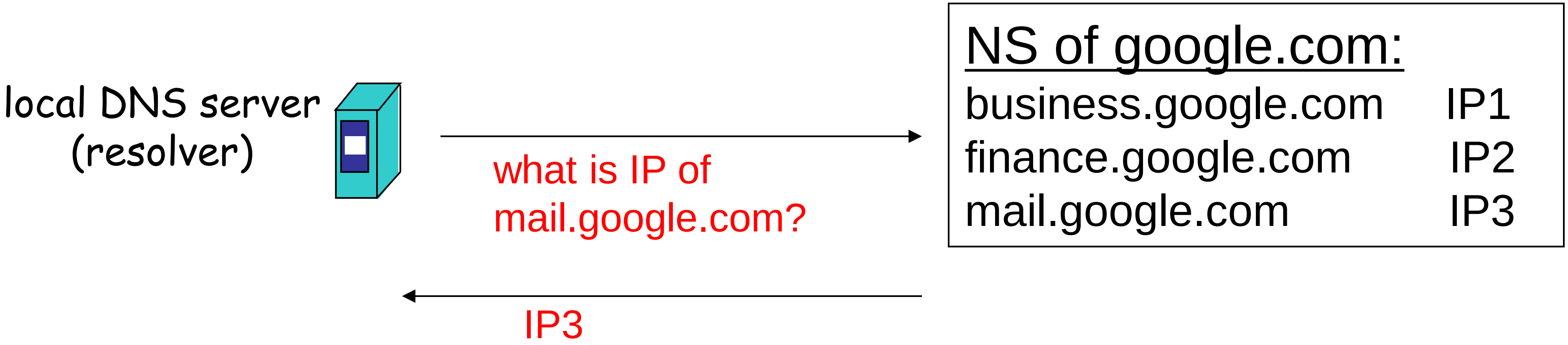
Q: What should the signature contain?

A: At least the domain name, IP address, cache time

Q: How do we know google.com’s PK?

A: The .com NS can give us a certificate on it

Scratchpad – let’s design it together



Q: How do we know .com’s PK?

A: Chain of certificates, like for the web, rooted in the PK of the root name server

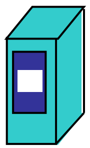
Q: How do we know the PK of the root NS?

A: Hardcoded in the resolvers

Q: How does the resolver verify a chain of certificates?

Scratchpad – let’s design it together

local DNS server
(resolver)



what is IP of
goose.google.com?

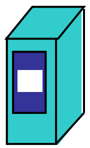
It does not exist

NS of google.com:	
business.google.com	IP1
finance.google.com	IP2
mail.google.com	IP3

Q: How can we ensure returned result is correct?
A: Have google.com NS sign the “no record” response
sign(“goose.google.com” does not exist)
But it is expensive to sign online.
Q: What problem can this cause?
A: DoS due to an amplification of effort between query and response.

Scratchpad – let’s design it together

local DNS server
(resolver)



what is IP of
goose.google.com?

It does not exist

NS of google.com:

business.google.com	IP1
finance.google.com	IP2
mail.google.com	IP3

Q: How can we sign the no-record response offline?
A: We don’t know which are all the domains we might be asked for, but we can sign consequent domains which indicates absence of a name in the middle, so its cacheable
sign([“ga.google.com”, “mail.google.com”])
But it is expensive to sign online.
Q: What problem can this cause?
A: **Enumeration attack.** An attacker can issue queries for things that do not exist and obtains intervals of all the things that exist until it mapped the whole space.

DNSSEC

Now let’s go through it slowly…

DNSSEC

- Key idea:
  - Sign all DNS records. Signatures let you verify answer to DNS query, without having to trust the network or resolvers involved.
- Remaining challenges:
  - DNS records change over time
  - Distributed database: No single central source of truth

Operation of DNSSEC

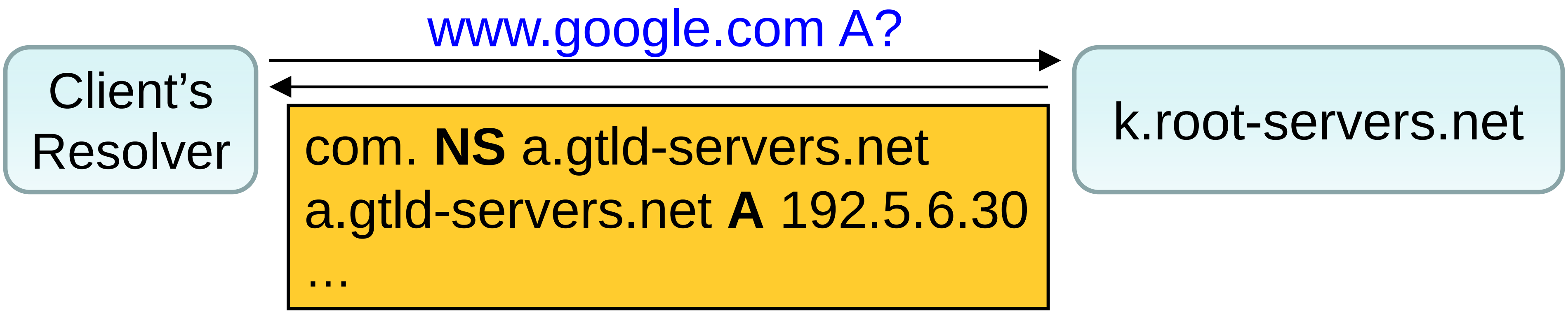
- As a resolver works its way from DNS root down to final name server for a name, at each level it gets a signed statement regarding the key(s) used by the next level
  - This builds up a chain of trusted keys
  - Resolver has root's key wired into it
- The final answer that the resolver receives is signed by that level's key
  - Resolver can trust it's the right key because of chain of support from higher levels
- All keys *as well as signed results* are *cacheable*

Ordinary DNS:

Ordinary DNS:

We start off by sending the query to one of the root name servers. These range from `a.root-servers.net` through `m.root-servers.net`. Here we just picked one.

Ordinary DNS:



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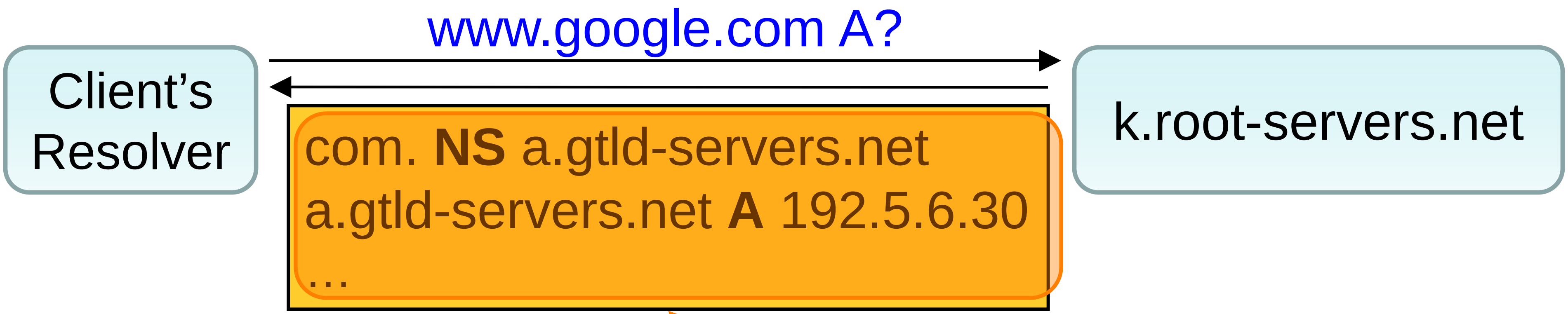


The reply *didn't include an answer* for `www.google.com`. That means that `k.root-servers.net` is instead telling us *where to ask next*, namely one of the name servers for `.com` specified in an **NS** record.

Ordinary DNS:

Client's Resolver

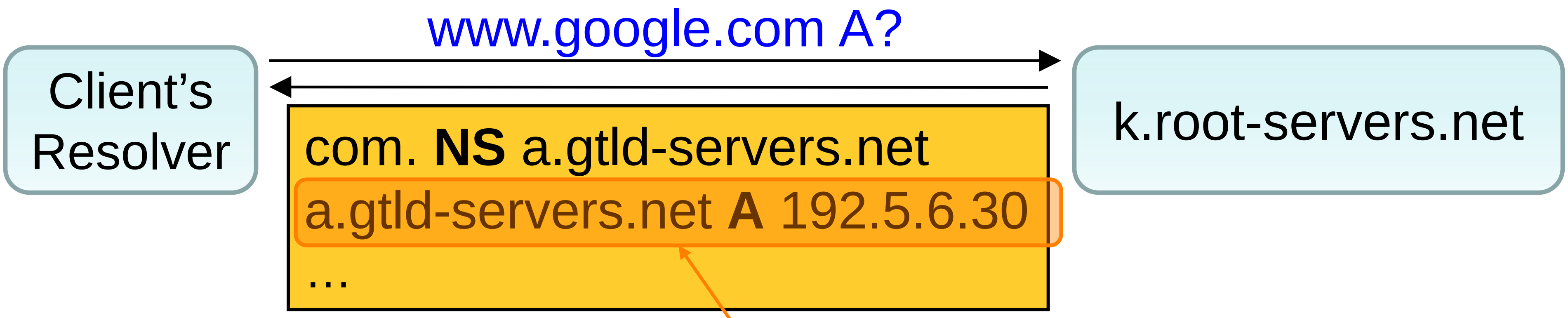
www.google.com A?

k.root-servers.net

com. **NS** a.gtld-servers.net
a.gtld-servers.net **A** 192.5.6.30
...

This *Resource Record* (**RR**) tells us that one of the name servers for `.com` is the host `a.gtld-servers.net`. (GTLD = Global Top Level Domain.)

Ordinary DNS:



This **RR** tells us that an Internet address ("**A**" record) for `a.gtld-servers.net` is `192.5.6.30`. That allows us to know where to send our next query.

Ordinary DNS:

Client's Resolver

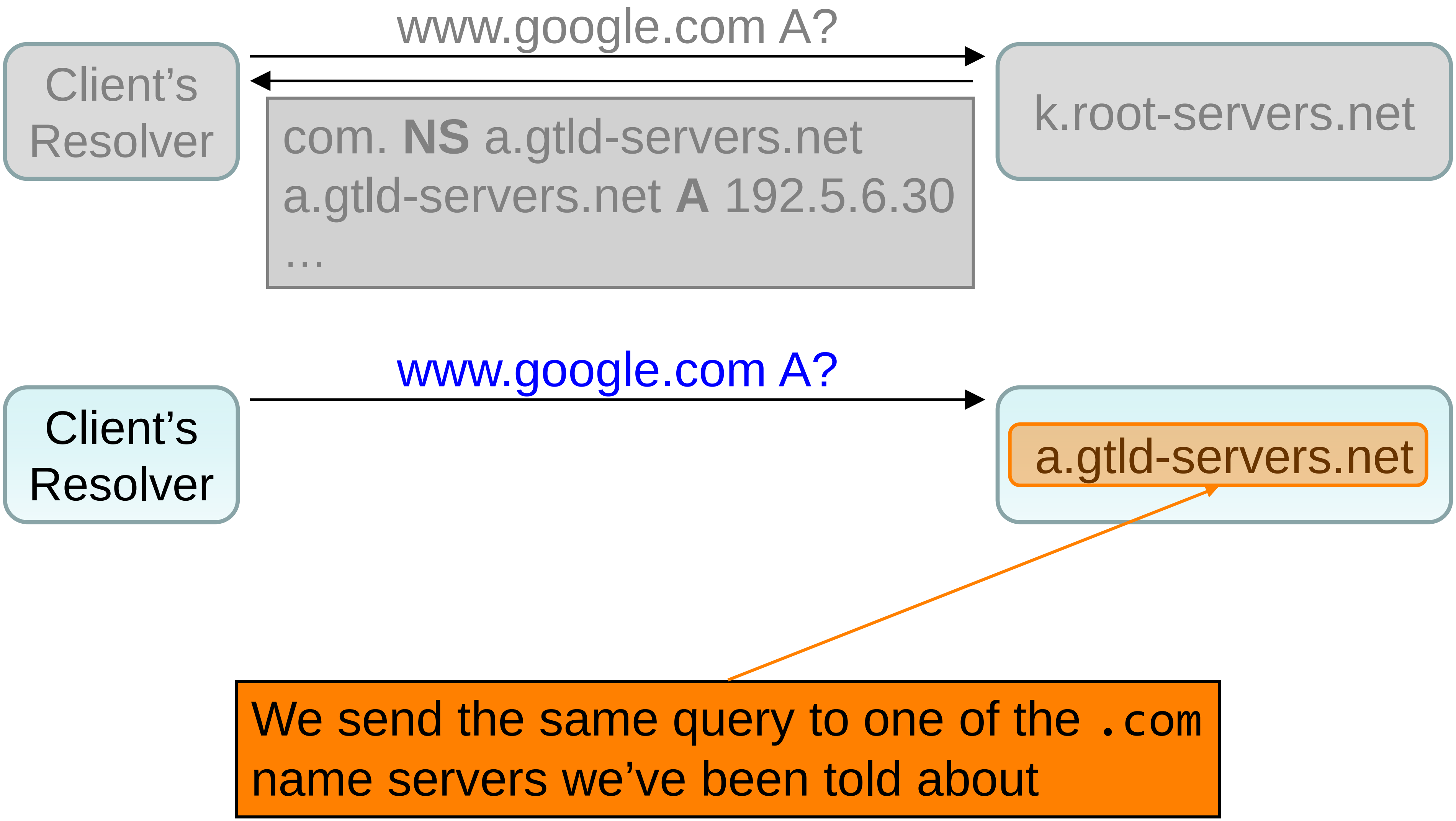
www.google.com A?

k.root-servers.net

com. **NS** a.gtld-servers.net
a.gtld-servers.net **A** 192.5.6.30
...

The actual response includes a bunch of **NS** and **A** records for additional `.com` name servers, which we omit here for simplicity.

Ordinary DNS:



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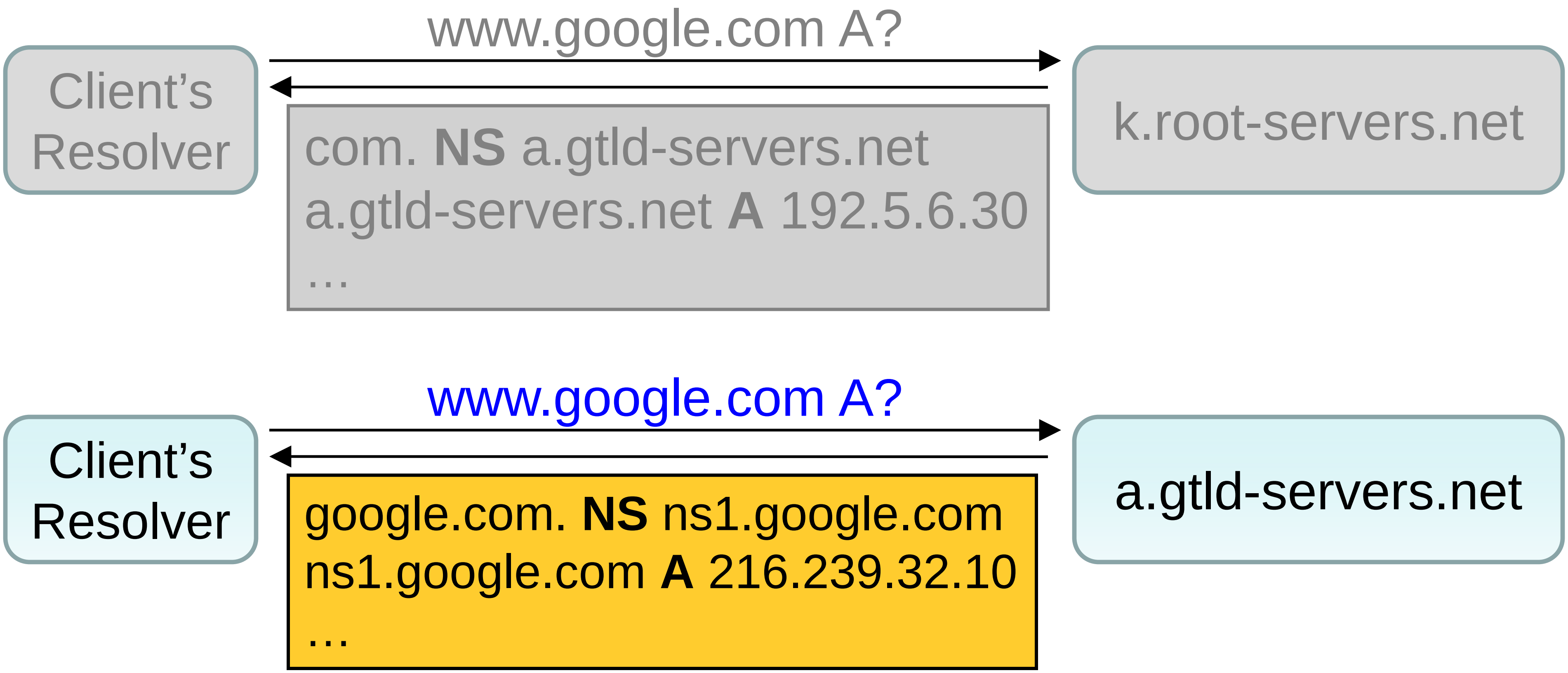

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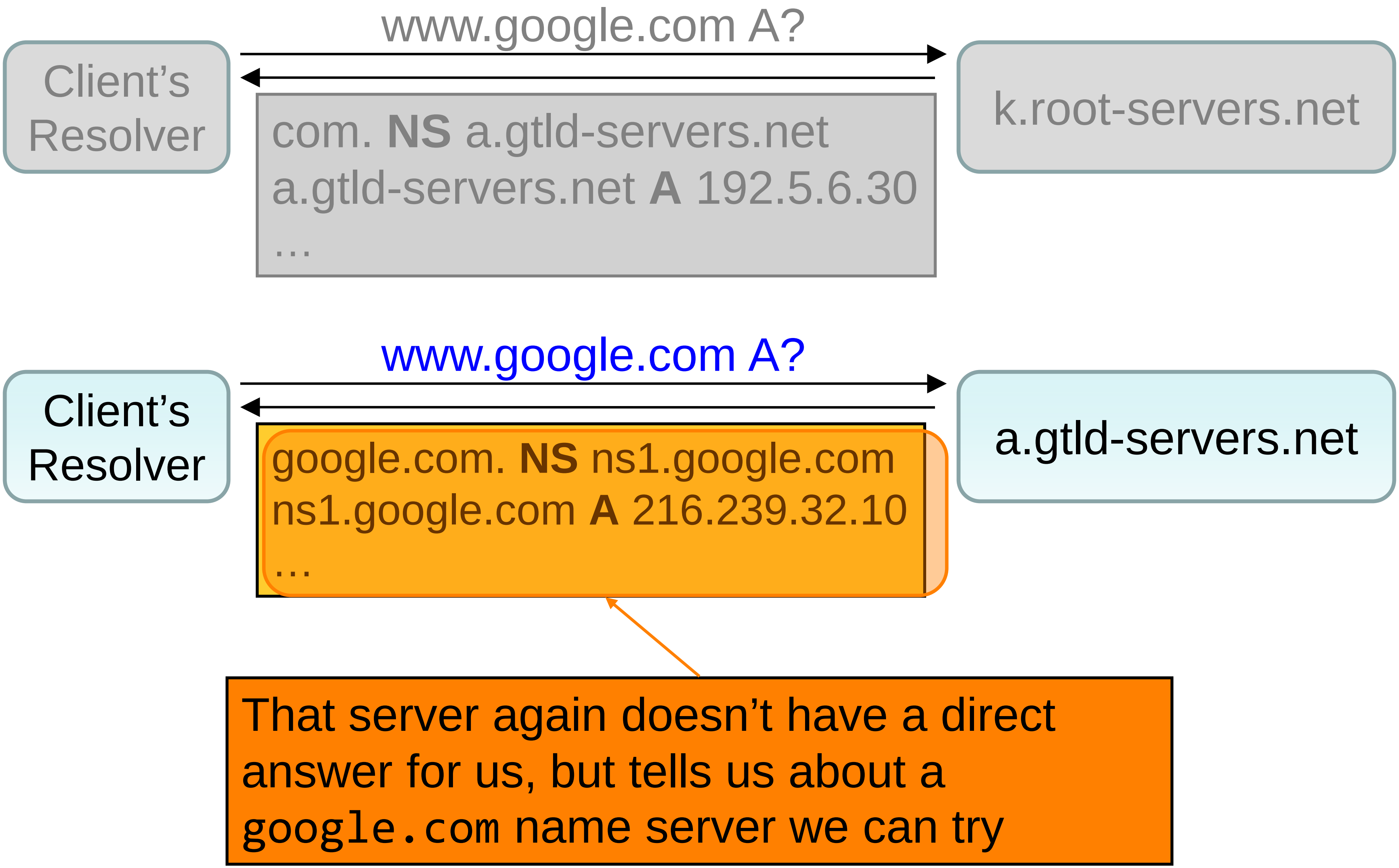

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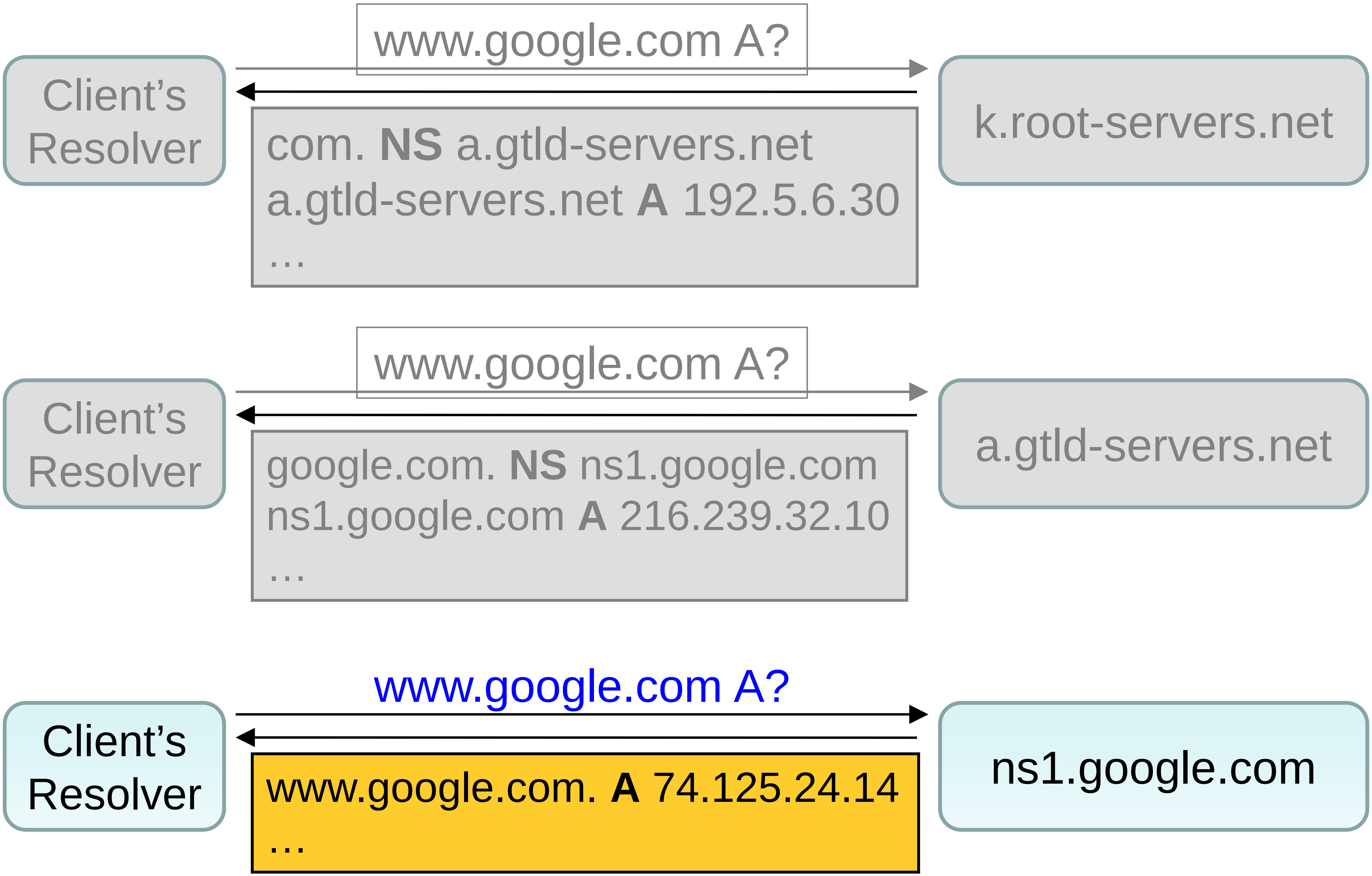

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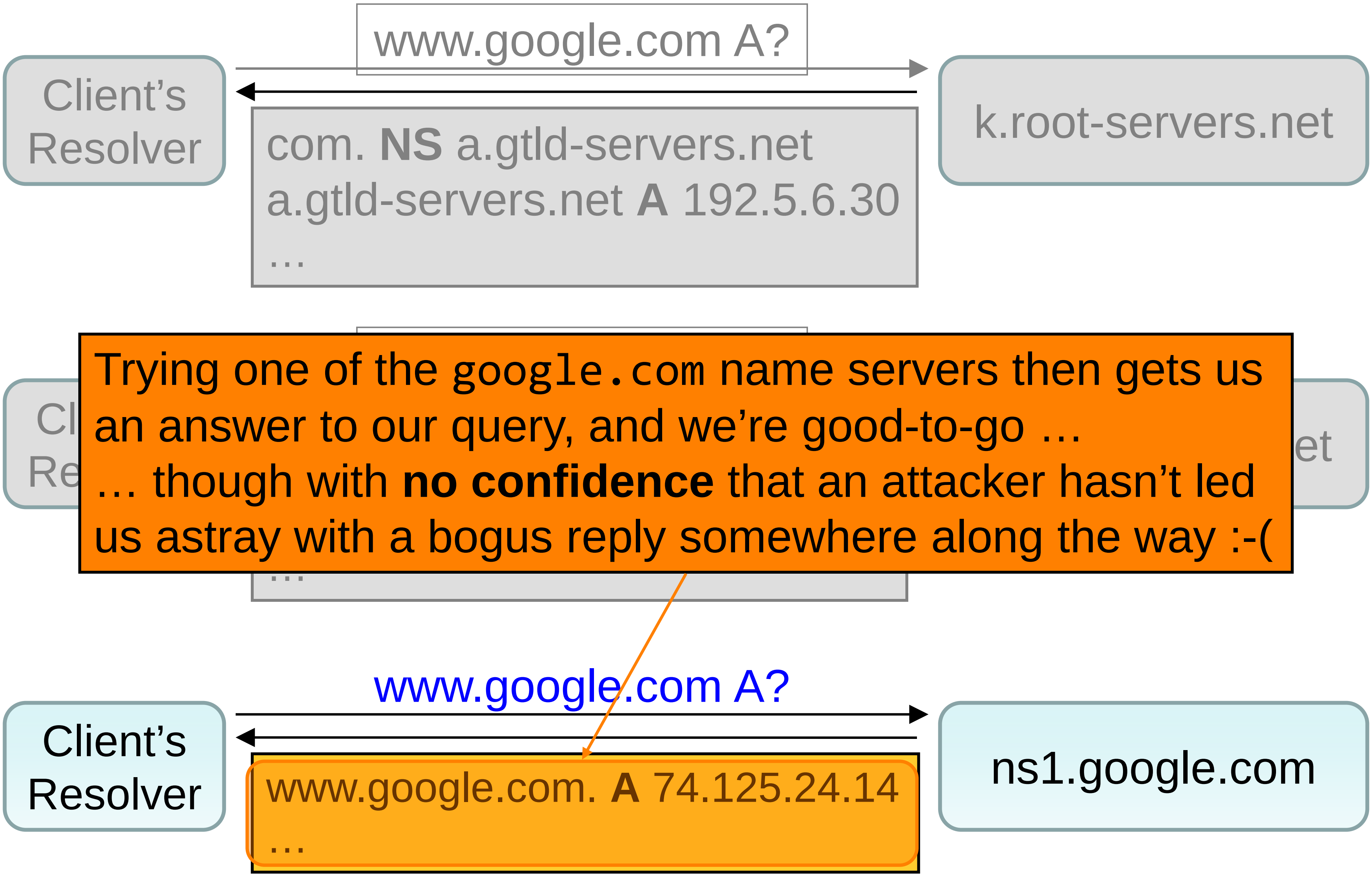


Trying one of the `google.com` name servers then gets us an answer to our query, and we're good-to-go …
… though with **no confidence** that an attacker hasn't led us astray with a bogus reply somewhere along the way :-(

DNSSEC (with simplifications):

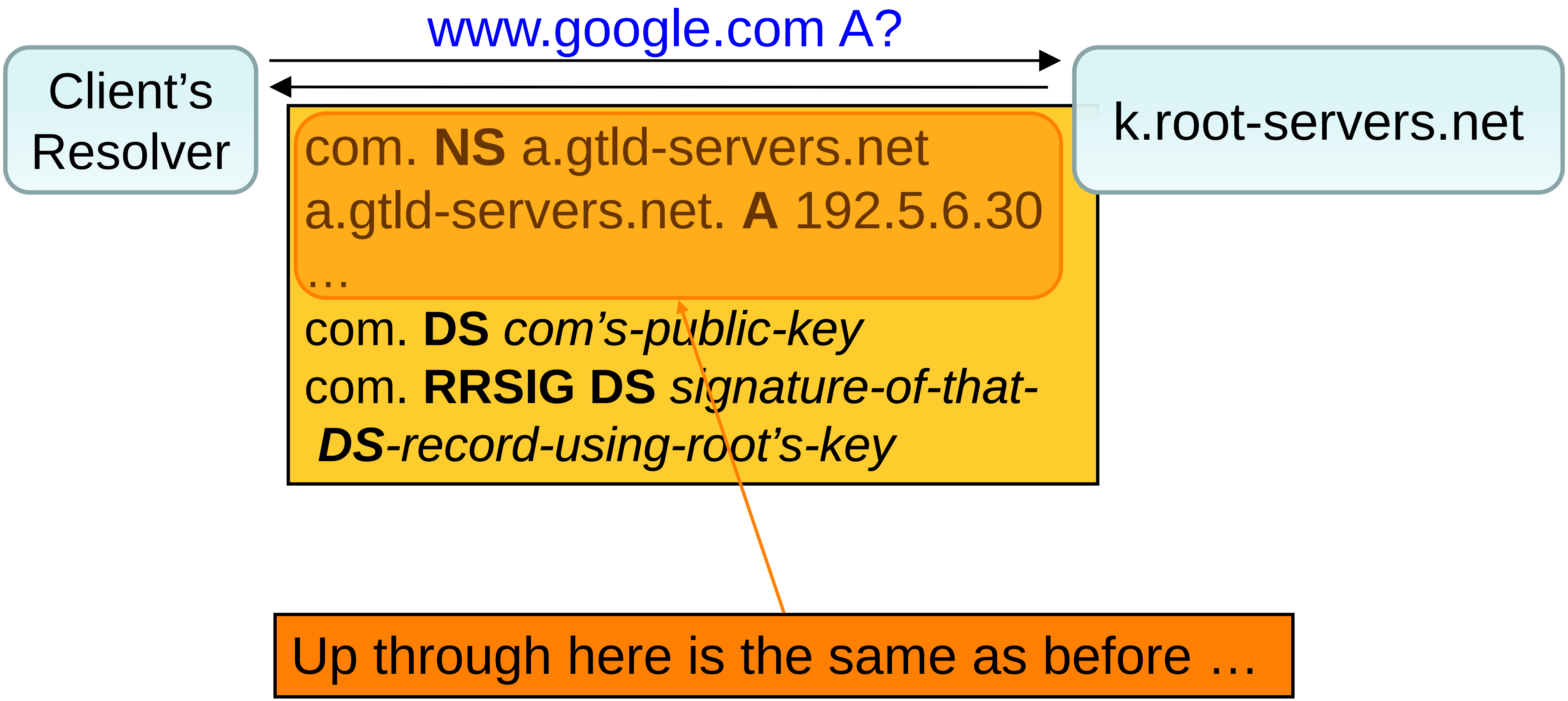
Client's Resolver

www.google.com A?

k.root-servers.net

com. **NS** a.gtld-servers.net
a.gtld-servers.net. **A** 192.5.6.30
...
com. **DS** *com's-public-key*
com. **RRSIG DS** *signature-of-that-*
***DS**-record-using-root's-key*

DNSSEC (with simplifications):



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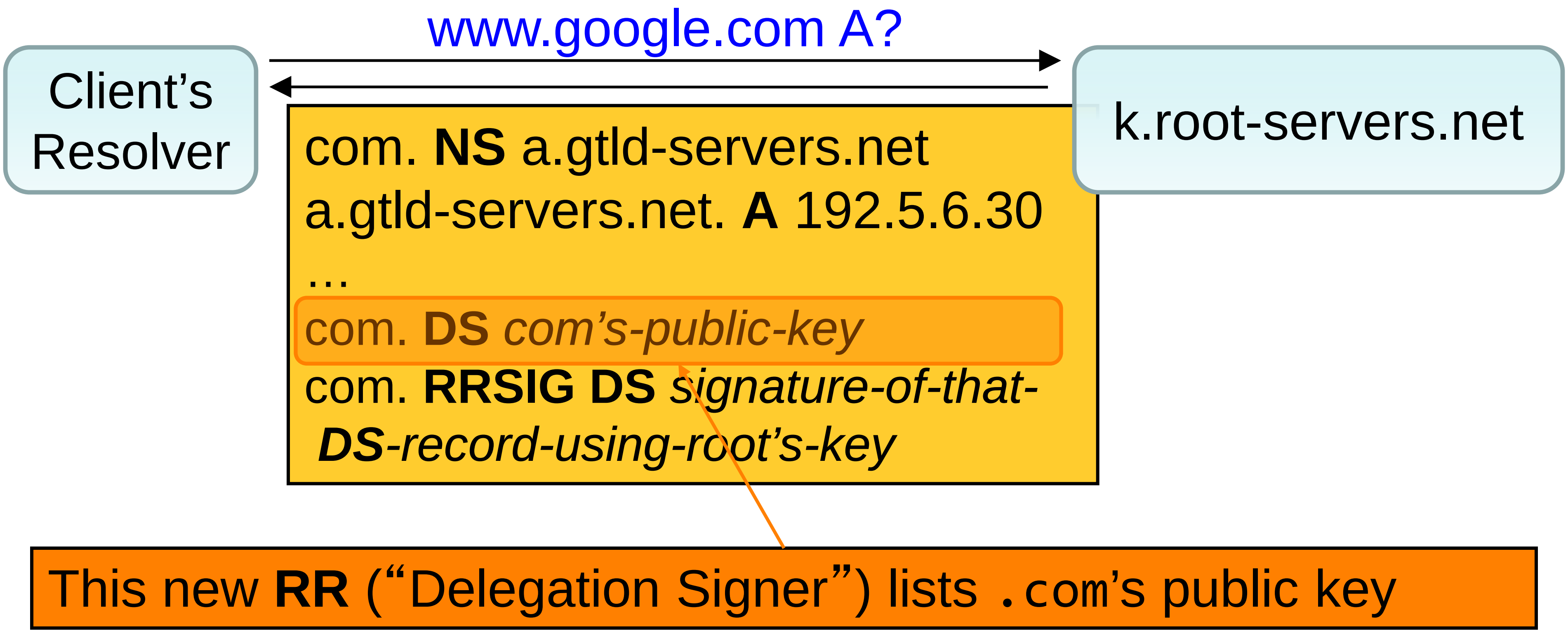


DNSSEC (with simplifications):

Client's Resolver

www.google.com A?

k.root-servers.net

com. **NS** a.gtld-servers.net
a.gtld-servers.net. **A** 192.5.6.30
…
com. **DS** *com's-public-key*
com. **RRSIG DS** *signature-of-that-* ***DS****-record-using-root's-key*

This new **RR** specifies a signature **(RRSIG)** over *another* **RR** … in this case, the signature covers the above **DS** record, and is made using the root's private key

DNSSEC (with simplifications):

www.google.com A?

Client's Resolver

k.root-servers.net

com. **NS** a.gtld-servers.net
a.gtld-servers.net. **A** 192.5.6.30
…
com. **DS** *com's-public-key*
com. **RRSIG DS** *signature-of-that-* ***DS****-record-using-root's-key*

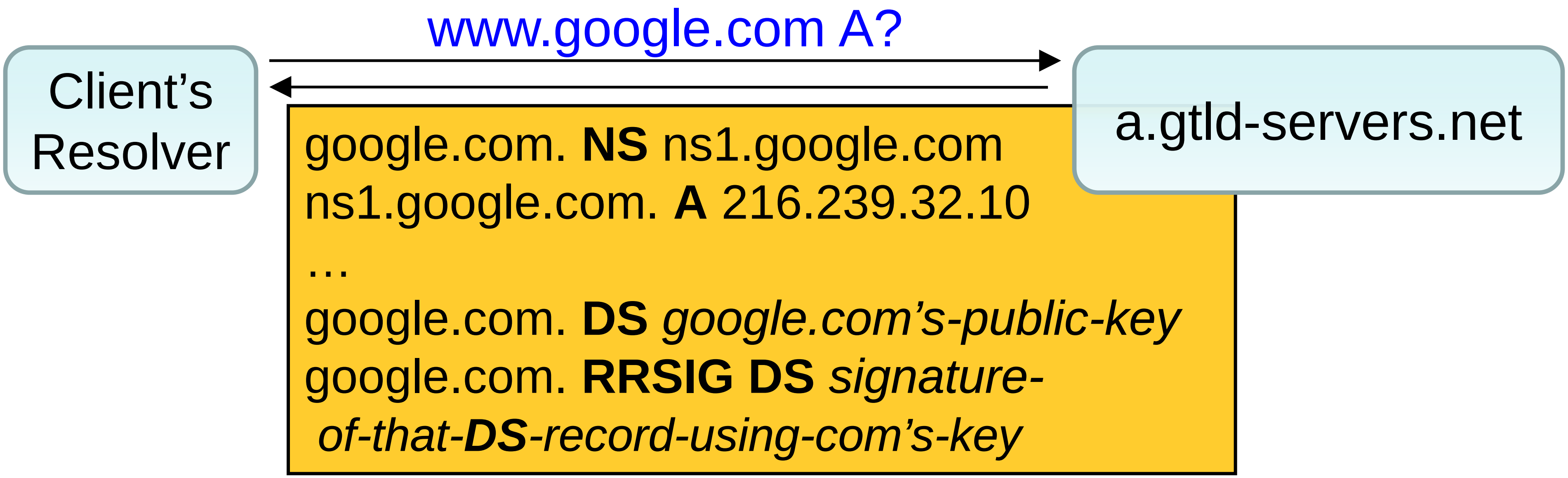
The resolver has the root's public key **hardwired** into it. The client only proceeds with DNSSEC if it can validate the signature.

DNSSEC (with simplifications):

The resolver again proceeds to trying one of the name servers it's learned about.

Nothing guarantees this is a legitimate name server for the query!

DNSSEC (with simplifications):



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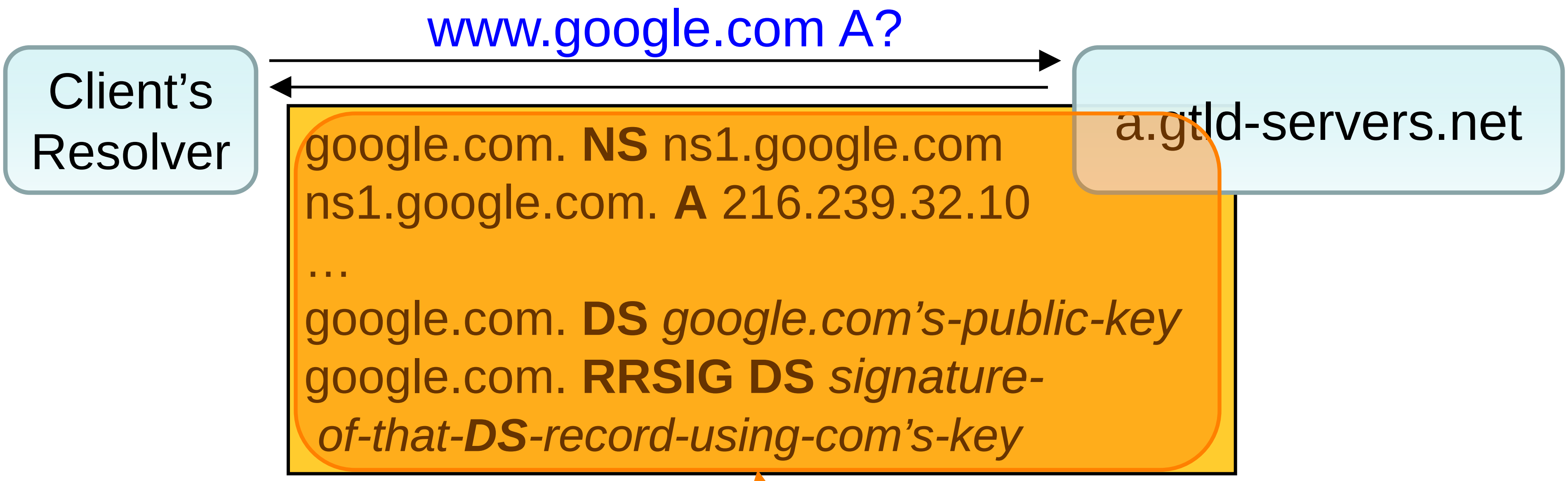


Back comes similar information as before: `google.com`'s public key, signed by `.com`'s key (which the resolver trusts because the root signed information about it)

DNSSEC (with simplifications):

The resolver contacts one of the `google.com` name servers it's learned about.

Again, nothing guarantees this is a legitimate name server for the query!

DNSSEC (with simplifications):

Client's Resolver

www.google.com A?

ns1.google.com

www.google.com. **A** 74.125.24.14
…
www.google.com. **RRSIG A**
*signature-of-the-**A**-records-using-google.com's-key*

DNSSEC (with simplifications):

www.google.com A?

Client's Resolver

ns1.google.com

www.google.com. **A** 74.125.24.14

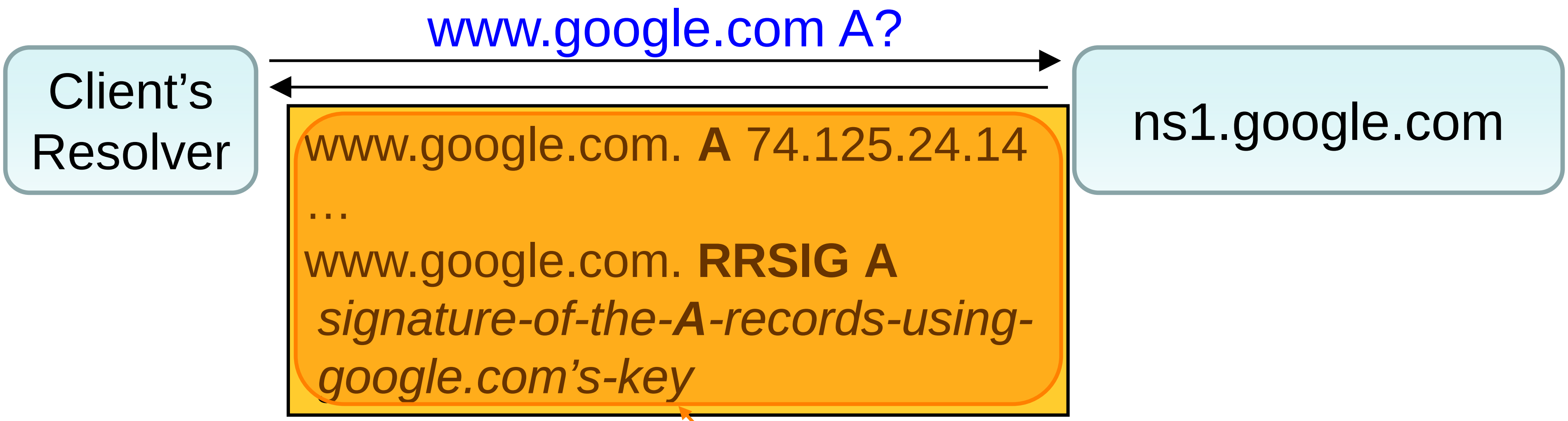
...

www.google.com. **RRSIG A**

*signature-of-the-**A**-records-using-google.com's-key*

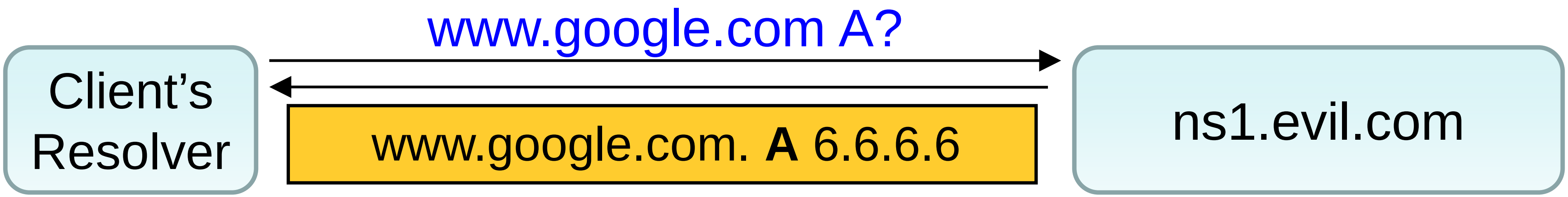
Finally we've received the information we wanted (**A** records for `www.google.com`)! … *and* we receive a signature over those records

DNSSEC (with simplifications):

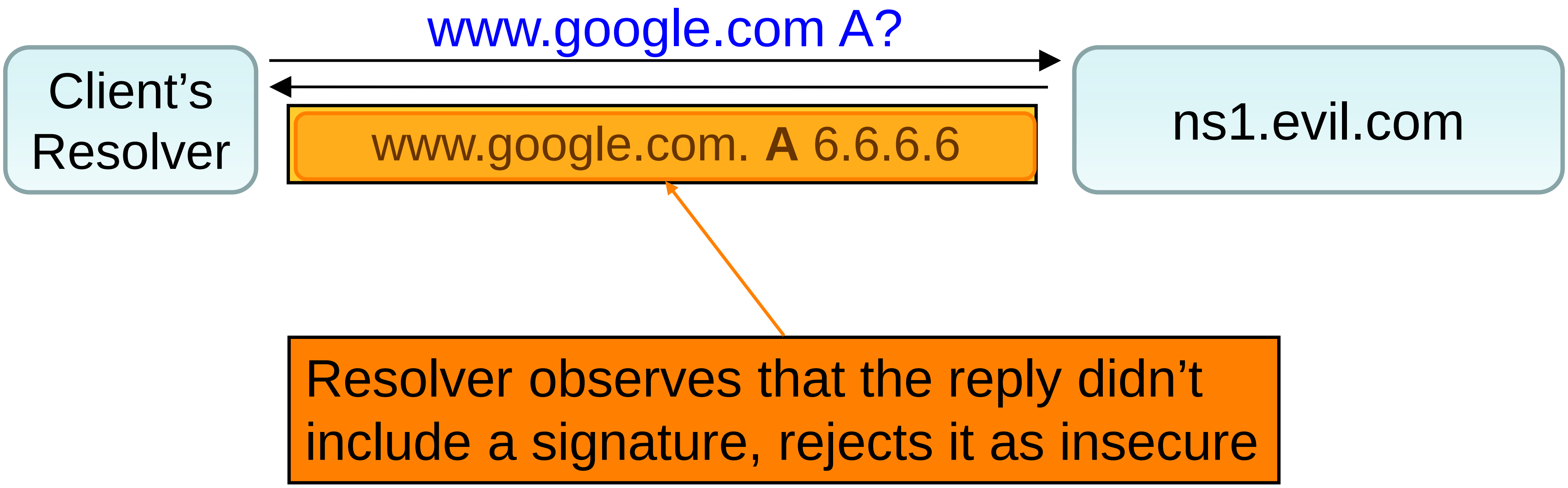


Assuming the signature validates, then because we believe (due to the signature chain) it's indeed from `google.com`'s key, we can trust that this is a correct set of **A** records … Regardless of what name server returned them to us!

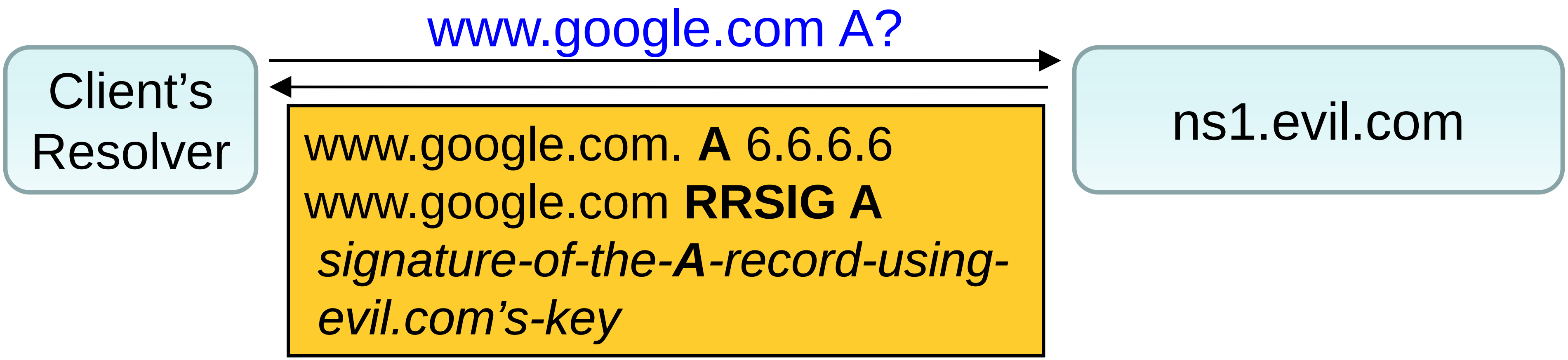
DNSSEC – Mallory attacks!



DNSSEC – Mallory attacks!



DNSSEC – Mallory attacks!



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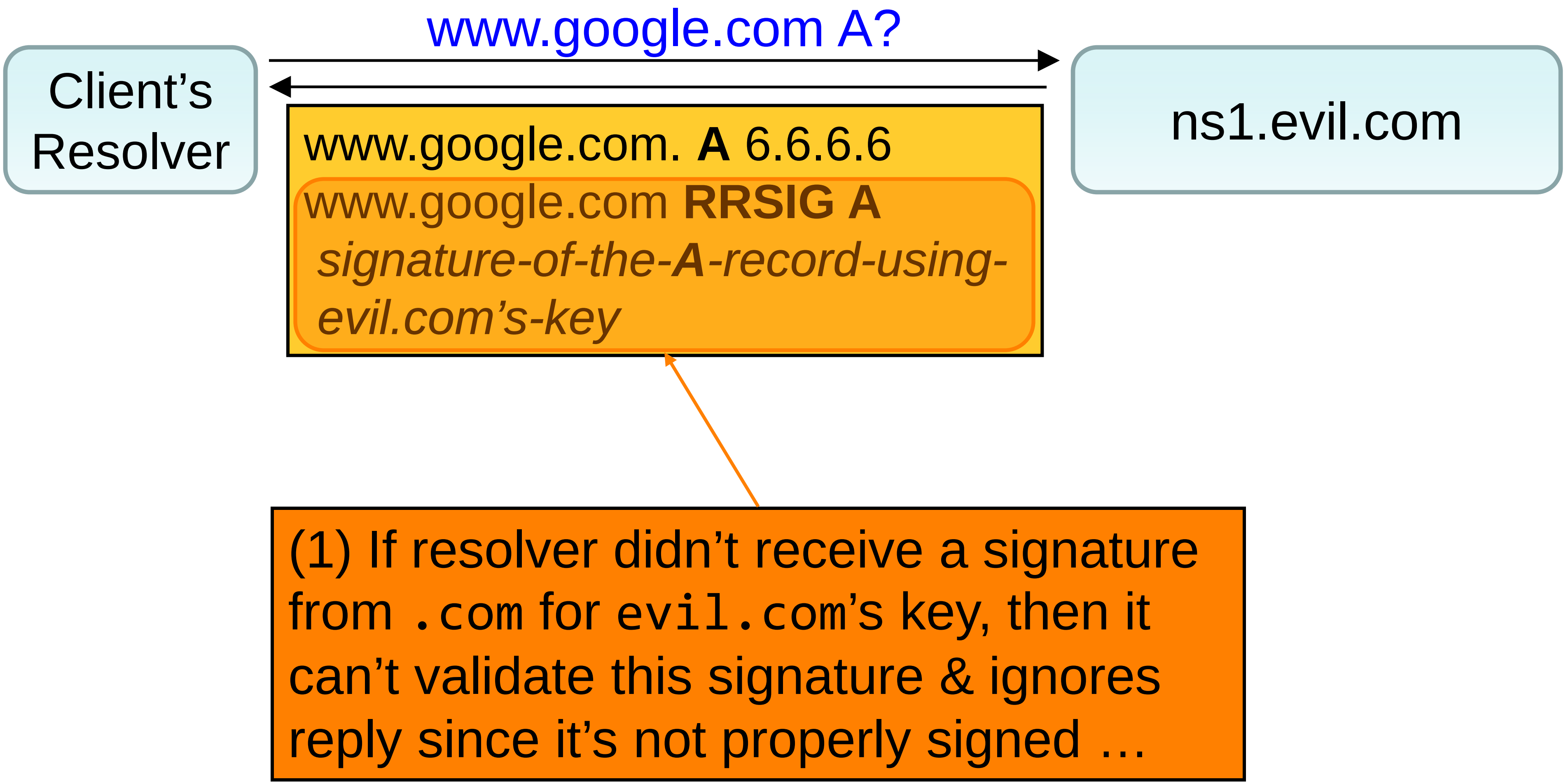
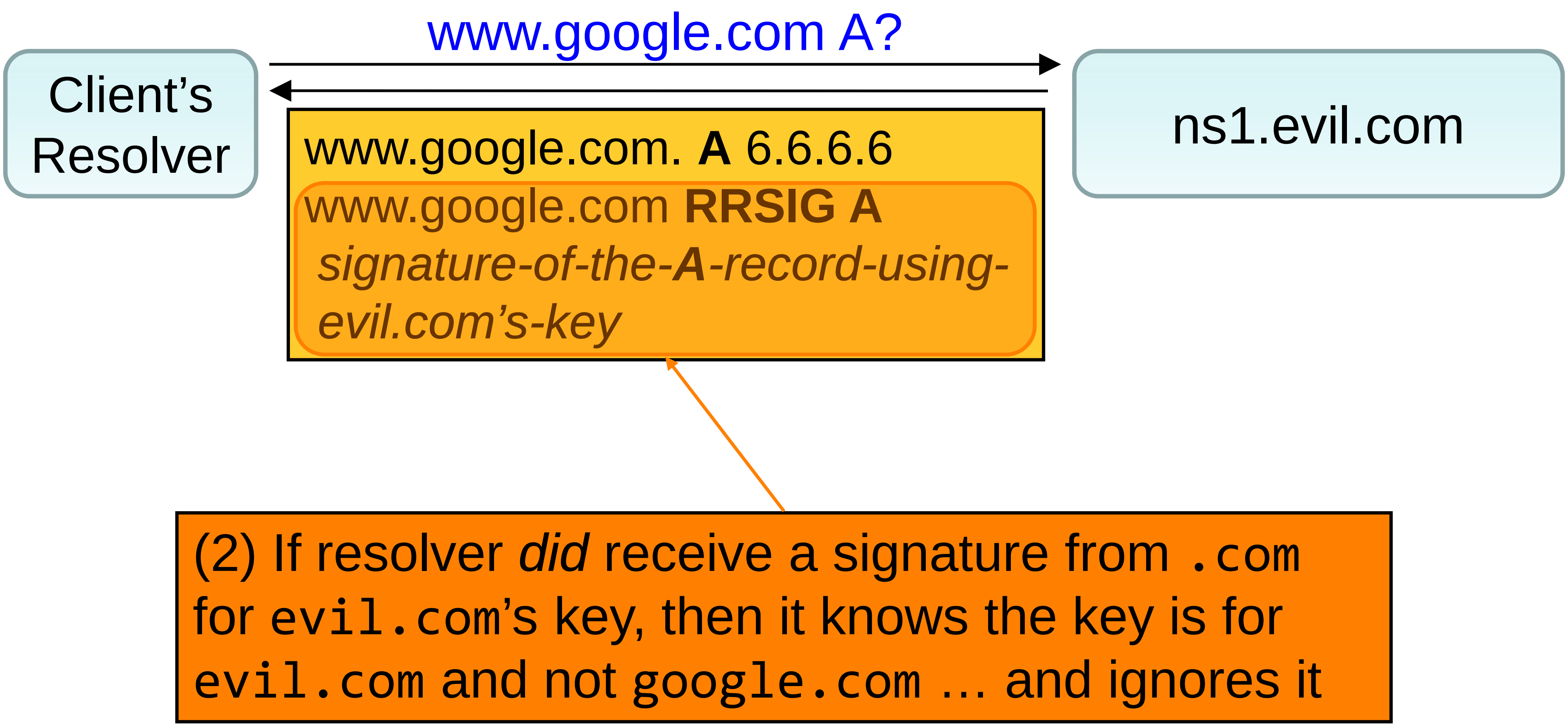


DNSSEC – Mallory attacks!



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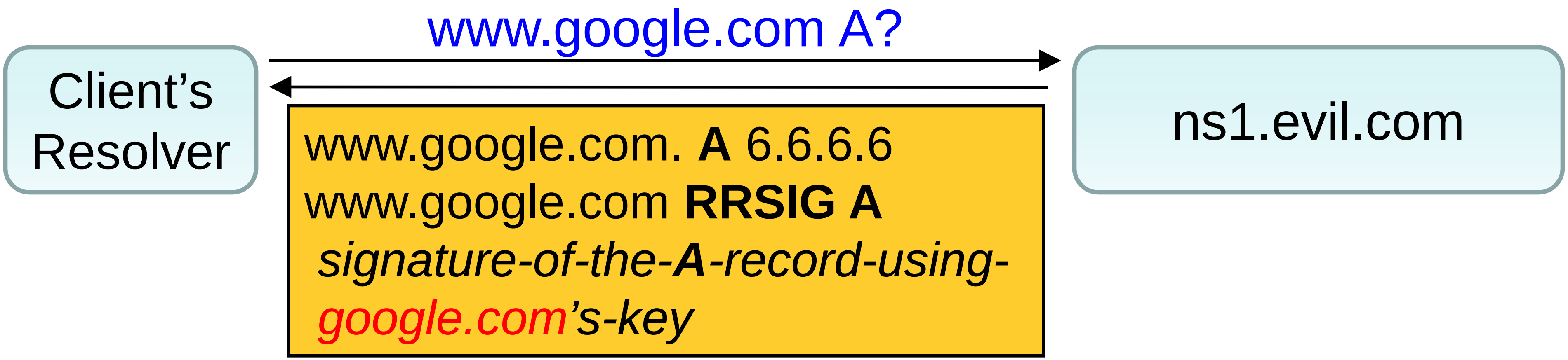
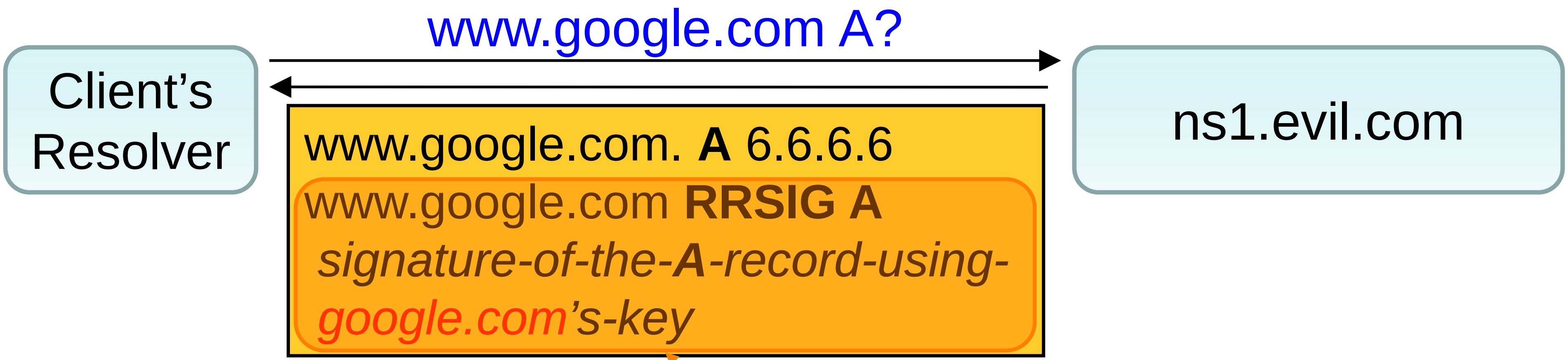


DNSSEC – Mallory attacks!



If signature **actually** comes from `google.com`'s key, resolver will believe it …

… but no such signature should exist unless either:

(1) `google.com` *intended* to sign the RR, or

(2) `google.com`'s private key was compromised

Issues With DNSSEC, cont.

- Issue #1: *Partial deployment*
  - Suppose `.com` not signing, though `google.com` is. Or, suppose `.com` and `google.com` are signing, but `cnn.com` isn't. Major practical concern. What do we do?
  - What do you do with unsigned/unvalidated results?
  - If you trust them, weakens incentive to upgrade (man-in-the-middle attacker can defeat security even for google.com, by sending forged but unsigned response)
  - If you don't trust them, a whole lot of things break

Issues With DNSSEC, cont.

- Issue #2: Negative results ("no such name")
  - What statement does the nameserver sign?
  - If "`gabluph.google.com`" doesn't exist, then have to do dynamic key-signing (expensive) for any bogus request
  - Instead, sign (off-line) statements about order of names
    - E.g., sign "`gabby.google.com` is followed by `gabrunk.google.com`"
    - Thus, can see that `gabluph.google.com` can't exist
  - But: now attacker can enumerate all names that exist :-(

Issues with DNSSEC

- Issue #3: Replies are Big
  - E.g., "`dig +dnssec berkeley.edu`" can return 2100+ B
  - DoS amplification
  - Increased latency on low-capacity links
  - Headaches w/ older libraries that assume replies < 512B

Adoption of DNSSEC

- Adopted, but not nearly as much as TLS
- Difficulties with deploying DNSSEC:
  - The need to design a backward-compatible standard that can scale to the size of the Internet
  - Zone enumeration attack
  - Deployment of DNSSEC implementations across a wide variety of DNS servers and resolvers (clients)
  - Disagreement among implementers over who should own the top level domain keys
  - Overcoming the perceived complexity of DNSSEC and DNSSEC deployment

Summary of TLS & DNSSEC Technologies

- **TLS**: provides channel security (for communication over TCP)
  - Confidentiality, integrity, authentication
  - Client & server agree on crypto, session keys
  - Underlying security dependent on:
    - Trust in Certificate Authorities / decisions to sign keys
    - (as well as implementors)
- **DNSSEC**: provides object security (for DNS results)
  - Just integrity & authentication, not confidentiality
  - No client/server setup "dialog"
  - Tailored to be caching-friendly
  - Underlying security dependent on trust in Root Name Server's key, and all other signing keys

Takeaways

- Channel security vs object security
- PKI organization should follow existing line of authority