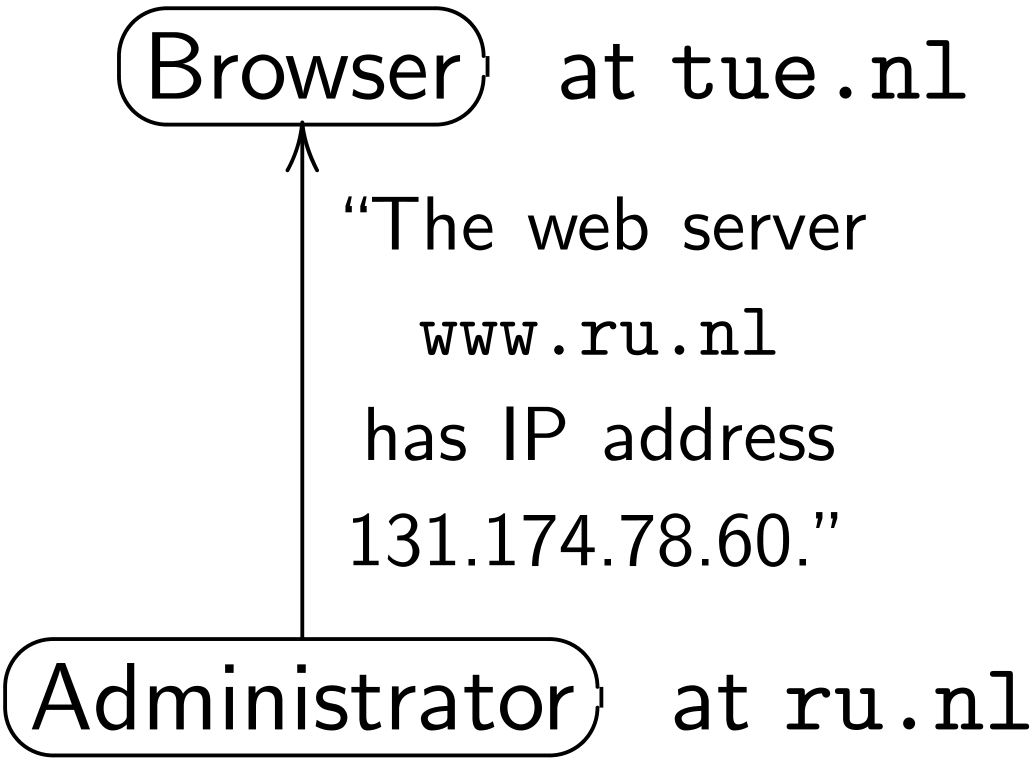
The DNS security mess

D. J. Bernstein

University of Illinois at Chicago;
Technische Universiteit Eindhoven

The Domain Name System

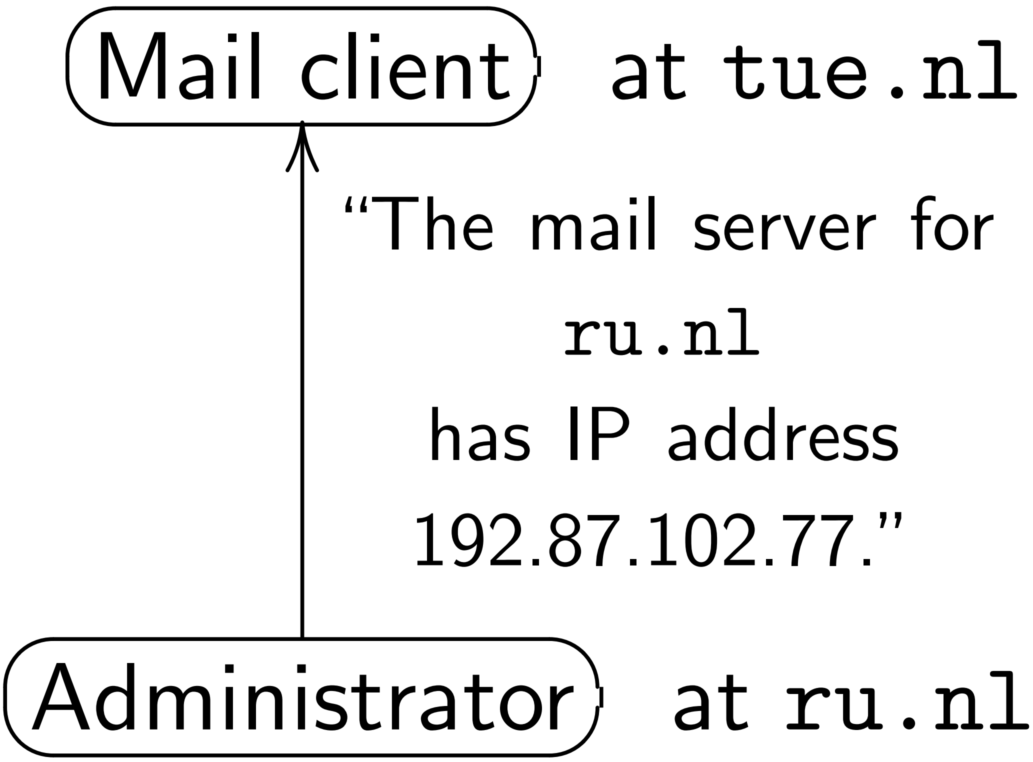
`tue.nl` wants to see
`http://www.ru.nl`.



Now `tue.nl`
retrieves web page from
IP address 131.174.78.60.

Same for Internet mail.

`tue.nl` has mail to deliver to `someone@ru.nl`.



Now `tue.nl`
delivers mail to
IP address 192.87.102.77.

Forging DNS packets

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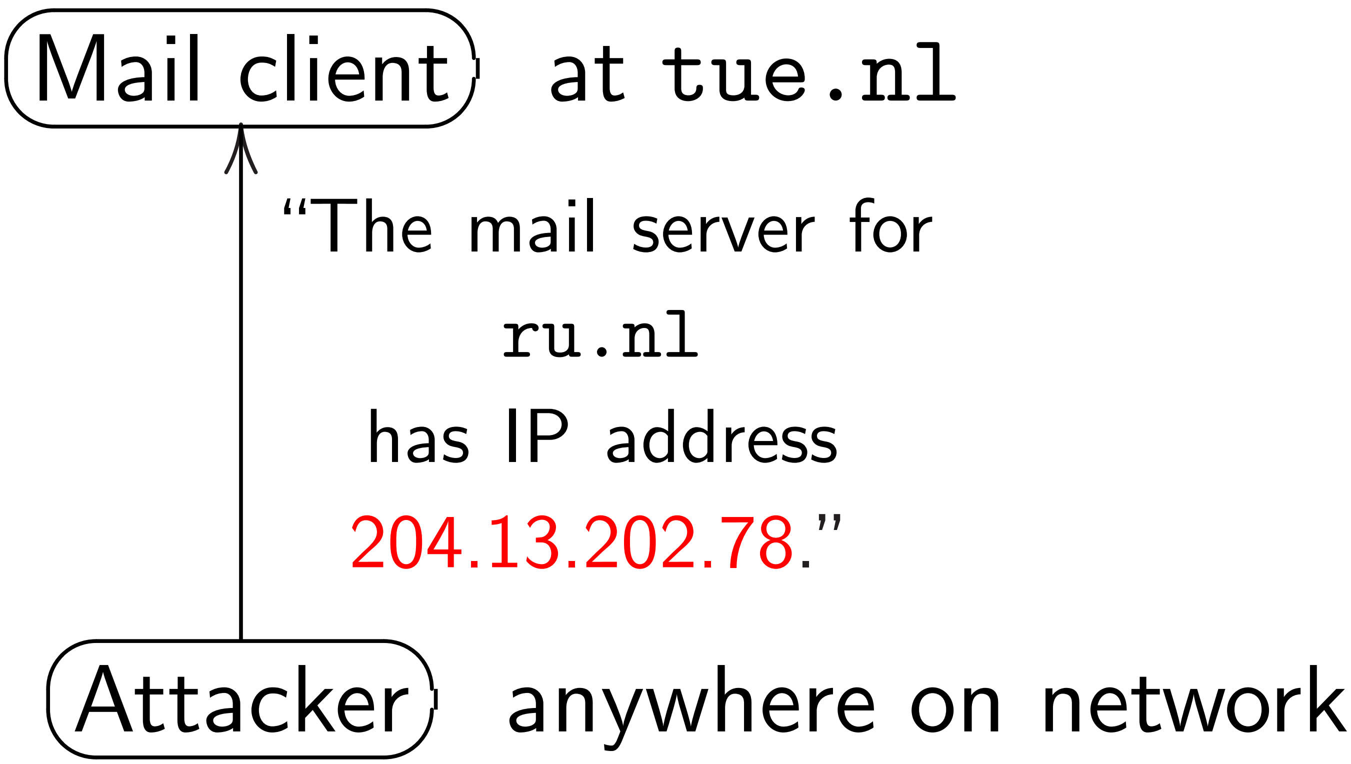

Now `tue.nl`
delivers mail to
IP address 204.13.202.78,
actually the attacker's machine.

How forgery really works

Client sends query.
Attacker has to repeat
some parts of the query.

Attacker must match

- the name: `ru.nl`.
- the query type: mail. (“MX”.)
- $\approx$ the query time,
  so client sees forgery
  before legitimate answer.
- the query UDP port.
- the query ID.

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Control name, type, time
by triggering client.
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16-bit port, 16-bit ID.

If guess fails, try again.
After analysis, optimization:
this is about as much traffic
as downloading a movie.

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1. Break into a computer
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2. Using that computer,
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Immediately forge answer.

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Sometimes skip step 1:
the network *is* the attacker.
e.g. DNS forgery by hotels,
Iranian government, et al.

Security theater

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stop the hard attack
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Security researchers
can't publish easy attacks.

June 2009: exciting news!

".ORG becomes the first open TLD to sign their zone with DNSSEC . . . Today we reached a significant milestone in our effort to bolster online security for the .ORG community. We are the first open generic Top-Level Domain to successfully sign our zone with Domain Name Security Extensions (DNSSEC). To date, the .ORG zone is the largest domain registry to implement this needed security measure."

“What does it mean that the .ORG Zone is ‘signed’? Signing our zone is the first part of our DNSSEC test phase. We are now cryptographically signing the authoritative data within the .ORG zone file. This process adds new records to the zone, which allows verification of the origin authenticity and integrity of data.”

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Integrity! Sounds great!

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are signing with DNSSEC,
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… or is it?

December 2015: reality

Let's find a `.org` server:

```
$ dig +short ns org
d0.org.afilias-nst.org.
a0.org.afilias-nst.info.
c0.org.afilias-nst.info.
b2.org.afilias-nst.org.
a2.org.afilias-nst.info.
b0.org.afilias-nst.org.

$ dig +short \
  b0.org.afilias-nst.org
199.19.54.1
```

Look up greenpeace.org:

```
$ dig \
  www.greenpeace.org \
  @199.19.54.1
```

Everything looks normal:

```
;; AUTHORITY SECTION:
greenpeace.org.
  86400 IN NS
  ns-emea.greenpeace.org.
;; ADDITIONAL SECTION:
ns-emea.greenpeace.org.
  86400 IN A
  37.48.104.54
```

Where's the crypto?

Have to ask for signatures:

```
$ dig +dnssec \
  www.greenpeace.org \
  @199.19.54.1
```

Old answer + four new lines:

```
h9p7u7tr2u91d0v0ljs9l1gid
np90u3h.org. 86400 IN NSE
C3 1 1 1 D399EAAB H9PARR6
69T6U8O1GSG9E1LMITK4DEM0T
 NS SOA RRSIG DNSKEY NSEC
3PARAM

h9p7u7tr2u91d0v0ljs9l1gid
```

np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201601
06023715 20151216013715 1
448 org. OGLyaFRtHdR6UBeq
EZ1/mnvAG8NJ2z5nBi5ALpYtE
UJRUAfKVCzaWJjZ rpgB6WgcF
TcziyRmM8iYvBNwzmUxoPzgkv
ALtRDom1rdpsVDxGveMJu6 pE
80Jdf2sbfXmZd1viiz+RXRvNI
YBNTujz2NPadBATPlUNr0sbQj
Cota iBk=

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN NSE
C3 1 1 1 D399EAAB BGDM7MS

F9V1T1JFVI8FA211MH4JD7UJ7
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201512
30150037 20151209140037 1
448 org. Wg2ha2mg0DnjiVNl
P7sk04Y/nSp+sR5uhChRWyzqH
Vn/Q4DEXqftVYeh v/x7Cmz2Q
0rk7bZ/K+v0+5mOMyao6Fod8+
fevV8t4ZmWrS+NLjNfx/yl So
StsWztJ5OoxdmZw1EwOALH/5g
sK+PUKaB6dx2BoEOiFn1plPSf
ggs9 MBO=

Wow, that's a lot of data.
Must be strong cryptography!

```
$ tcpdump -n -e \
  host 199.19.54.1 &
```

shows packet sizes:
`dig` sends 89-byte IP packet
to the `.org` DNS server,
receives 696-byte IP packet.

See more DNSSEC data:

```
$ dig +dnssec any \
  org @199.19.54.1
```

Sends 89-byte IP packet,
receives two IP fragments
totalling 2362 bytes.

Interlude: the attacker's view

What happens if we aim
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Let's see what DNSSEC can do
as an amplification tool for
denial-of-service attacks.

Download DNSSEC zone list:

```
wget -m -k -I / \
  secspider.cs.ucla.edu
cd secspider.cs.ucla.edu
awk '
  /GREEN.*GREEN.*GREEN.*Yes/ {
    split($0,x,/<TD>/)
    sub(/<\/TD>/,"",x[5])
    print x[5]
  }
' ./*--zone.html \
| sort -u | wc -l
```

Make list of DNSSEC names:

```
( cd secspider.cs.ucla.edu
  echo ./*--zone.html \
  | xargs awk '
    /^Zone <STRONG>/ { z = $2
      sub(/<STRONG>/,"",z)
      sub(/<\/STRONG>/,"",z)
    }
    /GREEN.*GREEN.*GREEN.*Yes/ {
      split($0,x,/<TD>/)
      sub(/<\/TD>/,"",x[5])
      print x[5],z,rand()
    }'
) | sort -k3n \
| awk '{print $1,$2}' > SERVERS
```

For each domain: Try query, estimate DNSSEC amplification.

```
while read ip z
do
  dig +dnssec +ignore +tries=1 \
  +time=1 any "$z" "@$ip" | \
  awk -v "z=$z" -v "ip=$ip" '{
    if ($1 != ";;") next
    if ($2 != "MSG") next
    if ($3 != "SIZE") next
    if ($4 != "rcvd:") next
    est = (22+$5)/(40+length(z))
    print est,ip,z
  }'
done < SERVERS > AMP
```

For each DNSSEC server,
find domain estimated to have
maximum DNSSEC amplification:

```
sort -nr AMP | awk '{
  if (seen[$2]) next
  if ($1 < 30) next
  print $1,$2,$3
  seen[$2] = 1
}' > MAXAMP
head -1 MAXAMP
wc -l MAXAMP
```

Output (last time I tried it):

```
95.6279 156.154.102.26 fi.
2326 MAXAMP
```

Can that really be true?
$>$2000 DNSSEC servers
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Let's verify this.

Choose quiet test machines
on two different networks
(without egress filters).

e.g. Sender: 1.2.3.4.
Receiver: 5.6.7.8.

Run network-traffic monitors on 1.2.3.4 and 5.6.7.8.

On 1.2.3.4, set response address to 5.6.7.8, and send 1 query/second:

```
ifconfig eth0:1 \
  5.6.7.8 \
  netmask 255.255.255.255
while read est ip z
do
  dig -b 5.6.7.8 \
  +dnssec +ignore +tries=1 \
  +time=1 any "$z" "@$ip"
done < MAXAMP >/dev/null 2>&1
```

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Attacker sending 200Mbps
can trigger 10Gbps flood,
taking down very large site.

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2015: No SecSpider downloads???

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Exercise: Collect+publish data.

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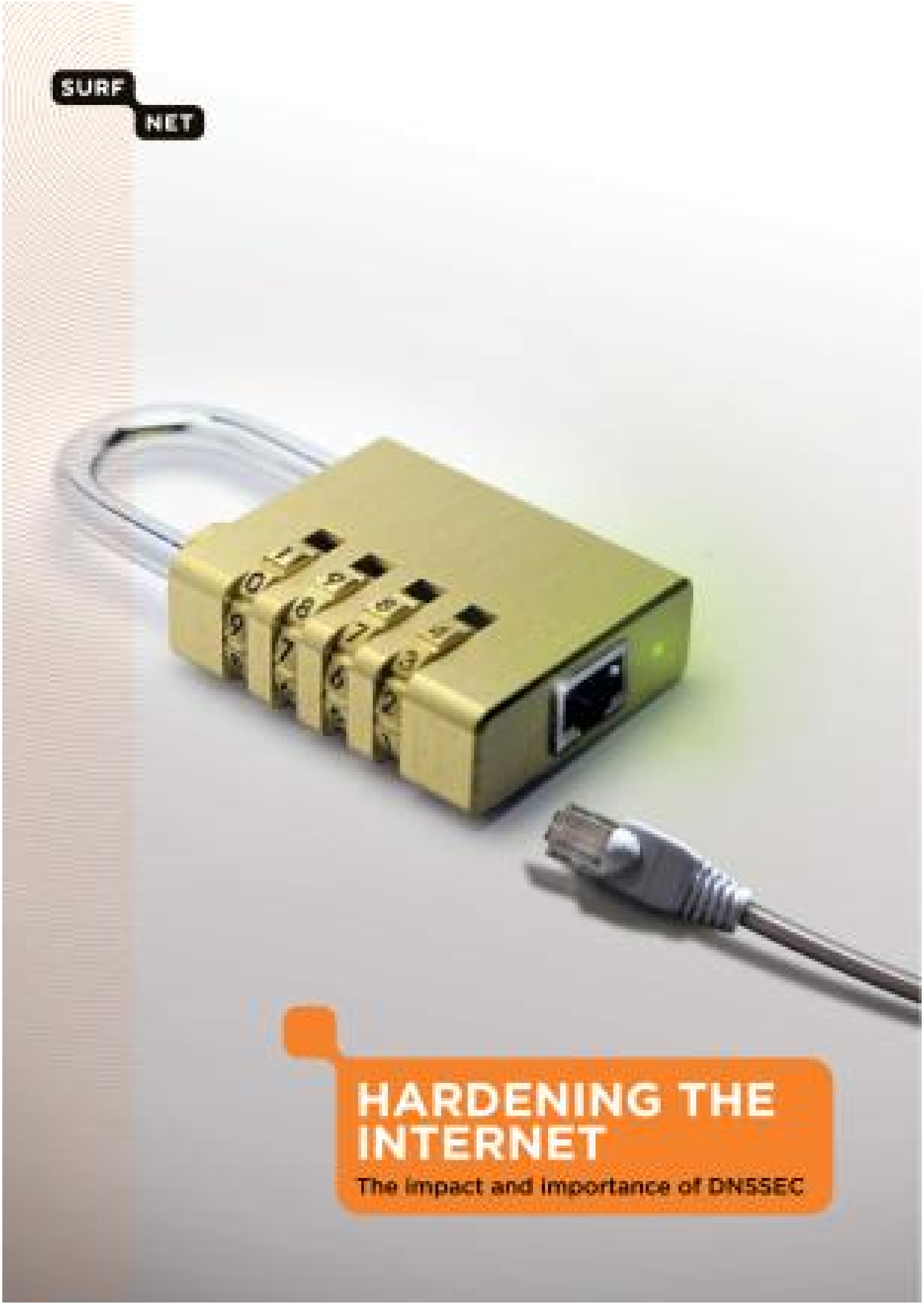
Exercise: investigate other types of DoS attacks.
e.g. DNSSEC advertising says zero server-CPU-time cost.
How much server CPU time can attackers actually consume?

Back to integrity

Let's pretend we don't care about availability.

This is not an attack:

All we care about is integrity:



The `.org` signatures
are 1024-bit RSA signatures.

2003: Shamir–Tromer et al.
concluded that 1024-bit RSA
was already breakable by
large companies and botnets.
$10 million: 1 key/year.
$120 million: 1 key/month.

2003: RSA Laboratories
recommended a transition to
2048-bit keys "over the remainder
of this decade." 2007: NIST
made the same recommendation.

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What about serious attackers
using many more computers?
e.g. botnet operators?

I say:
Using RSA-1024 is irresponsible.

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Suppose an attacker forges a DNS packet from `.org`, including exactly the same DNSSEC signatures but *changing the NS+A records* to point to the attacker's servers.

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Suppose an attacker forges a DNS packet from `.org`, including exactly the same DNSSEC signatures but *changing the NS+A records* to point to the attacker's servers.

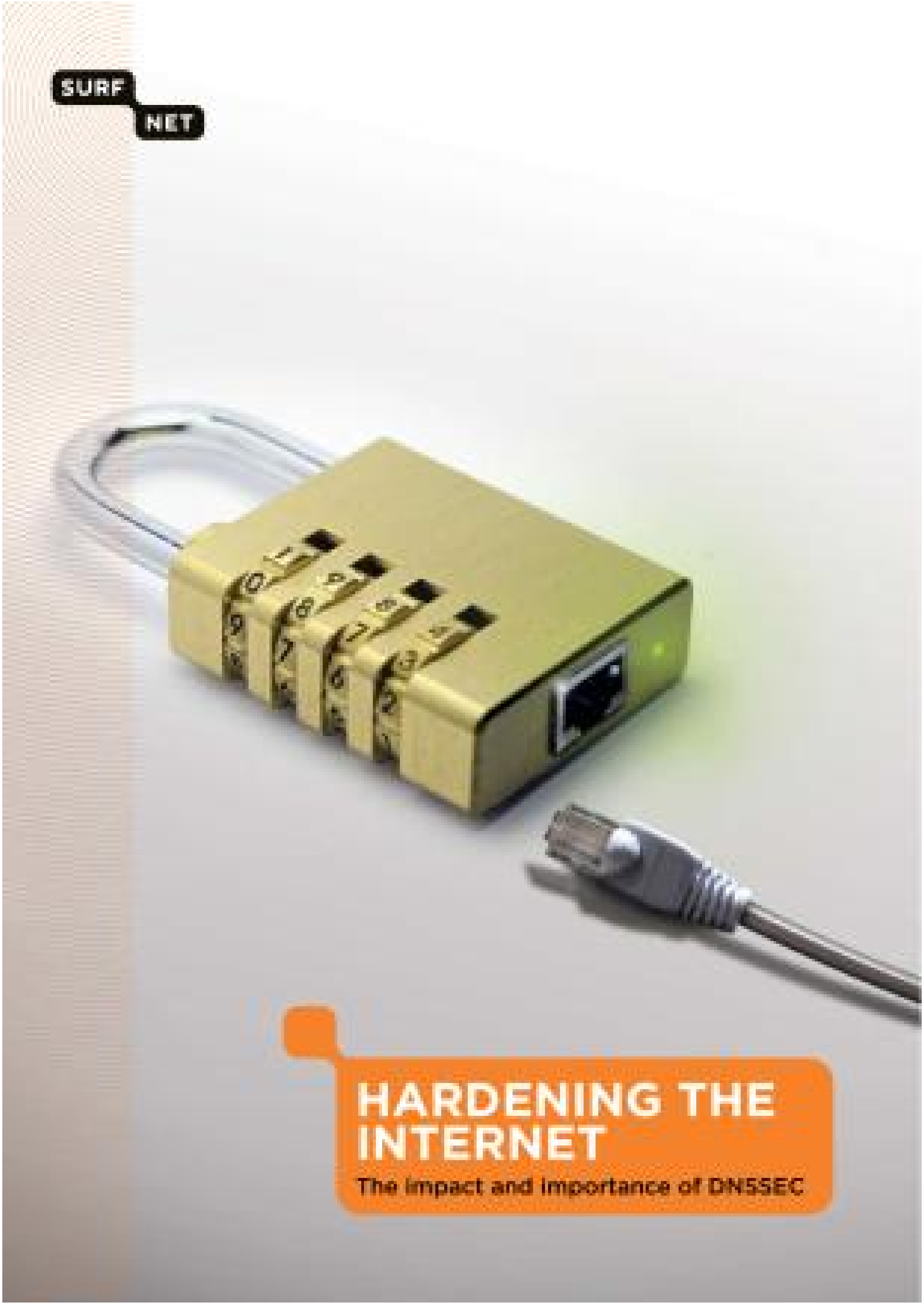
Fact: DNSSEC "verification" won't notice the change.
The signatures say *nothing* about the NS+A records.
The forgery will be accepted.

Here's what `.org` signed,
translated into English:
"`.org might have data with hashes between h9p7u7tr2u91d0v0ljs9l1gidnp90u3h, h9parr669t6u8o1gsg9e1lmitk4dem0t but has not signed any of that data.`"

Can check that `greenpeace.org` has a hash in that range.

`.org` now has thousands of these useless signatures.
This is `.org` "implementing"
a "needed security measure."

“DNSSEC: Built, not plugged in.”



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1993.11 Galvin: "The DNS Security design team of the DNS working group met for one morning at the Houston IETF."

1994.02 Eastlake–Kaufman, after months of discussions on `dns-security` mailing list: "DNSSEC" protocol specification.

Millions of dollars
of U.S. government grants: e.g.,
DISA to BIND company;
NSF to UCLA; DHS to
Secure64 Software Corporation.

Continuing cycle of
DNSSEC implementations,
IETF DNSSEC discussions,
protocol updates, revised
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Compatibility trap? No.
Several DNSSEC updates
have broken compatibility
with older implementations.

The performance trap

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The critical design decision in DNSSEC: *precompute* signatures of DNS records. "Per-query crypto is bad."

Signature is computed once; saved; sent to many clients. Hopefully the server can afford to sign each DNS record once.

Clients don't share the work of *verifying* a signature.

DNSSEC tries to reduce client-side costs (and precomputation costs) through choice of crypto primitive.

Many DNSSEC crypto options: 640-bit RSA, original specs; 768-bit RSA, many docs; 1024-bit RSA, current RFCs (for "leaf nodes in the DNS"); DSA, "10 to 40 times as slow for verification" but faster for signatures.

DNSSEC made breakable choices
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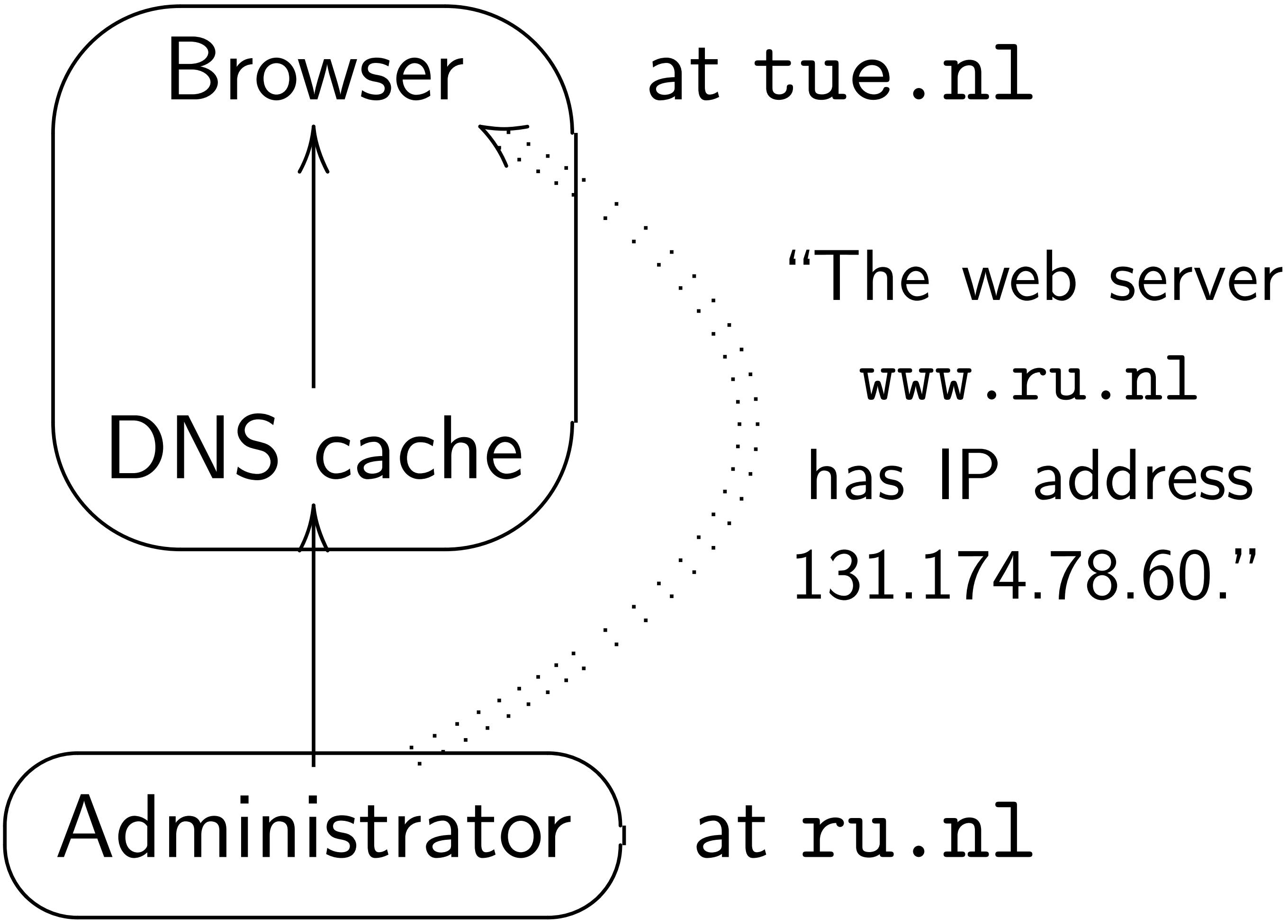
Looking beyond the crypto:
Precomputation forced DNSSEC
down a path of unreliability,
insecurity, and unusability.
Let's see how this happened.

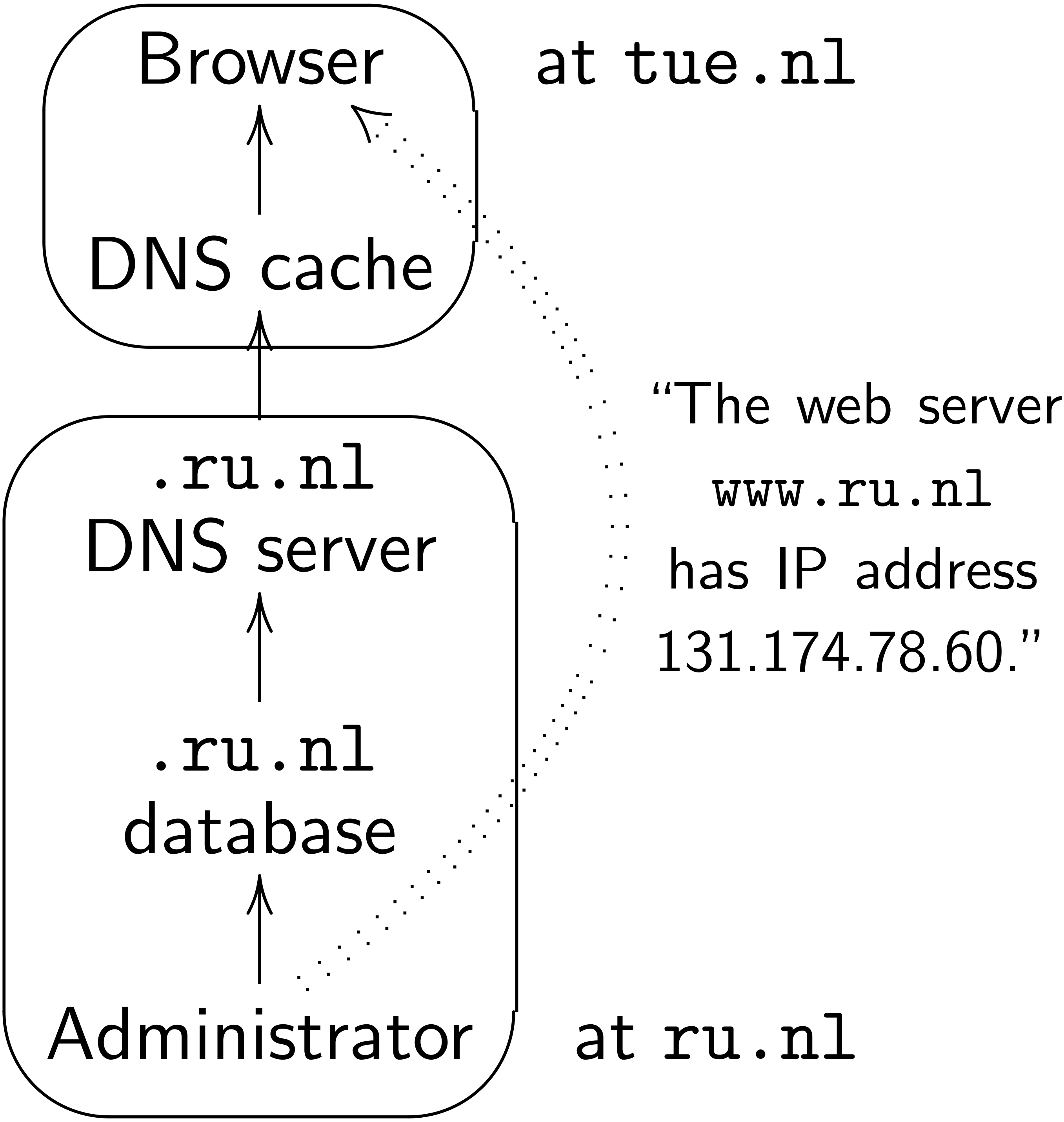
DNS architecture

Browser pulls data from DNS cache at `tue.nl`:

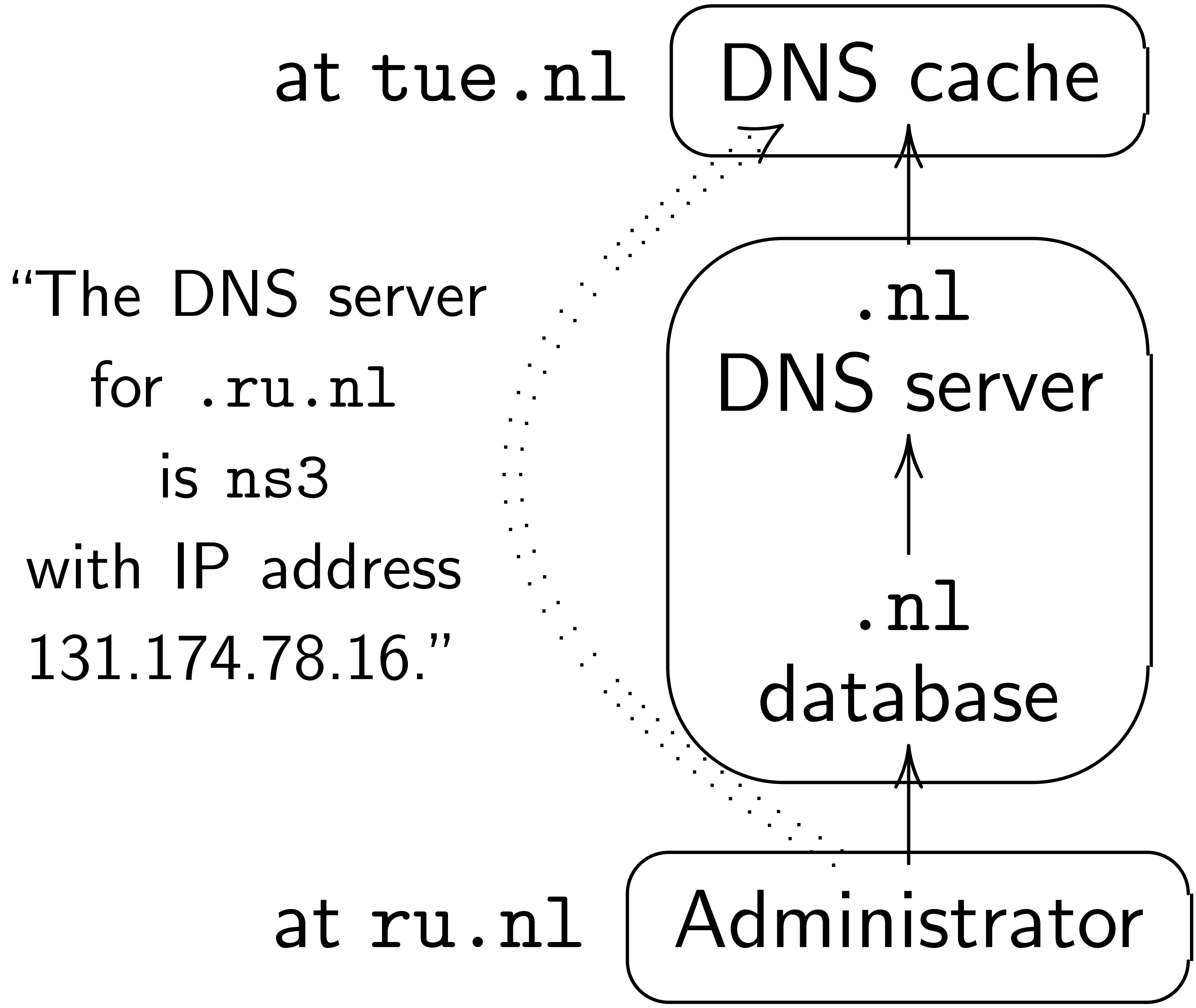


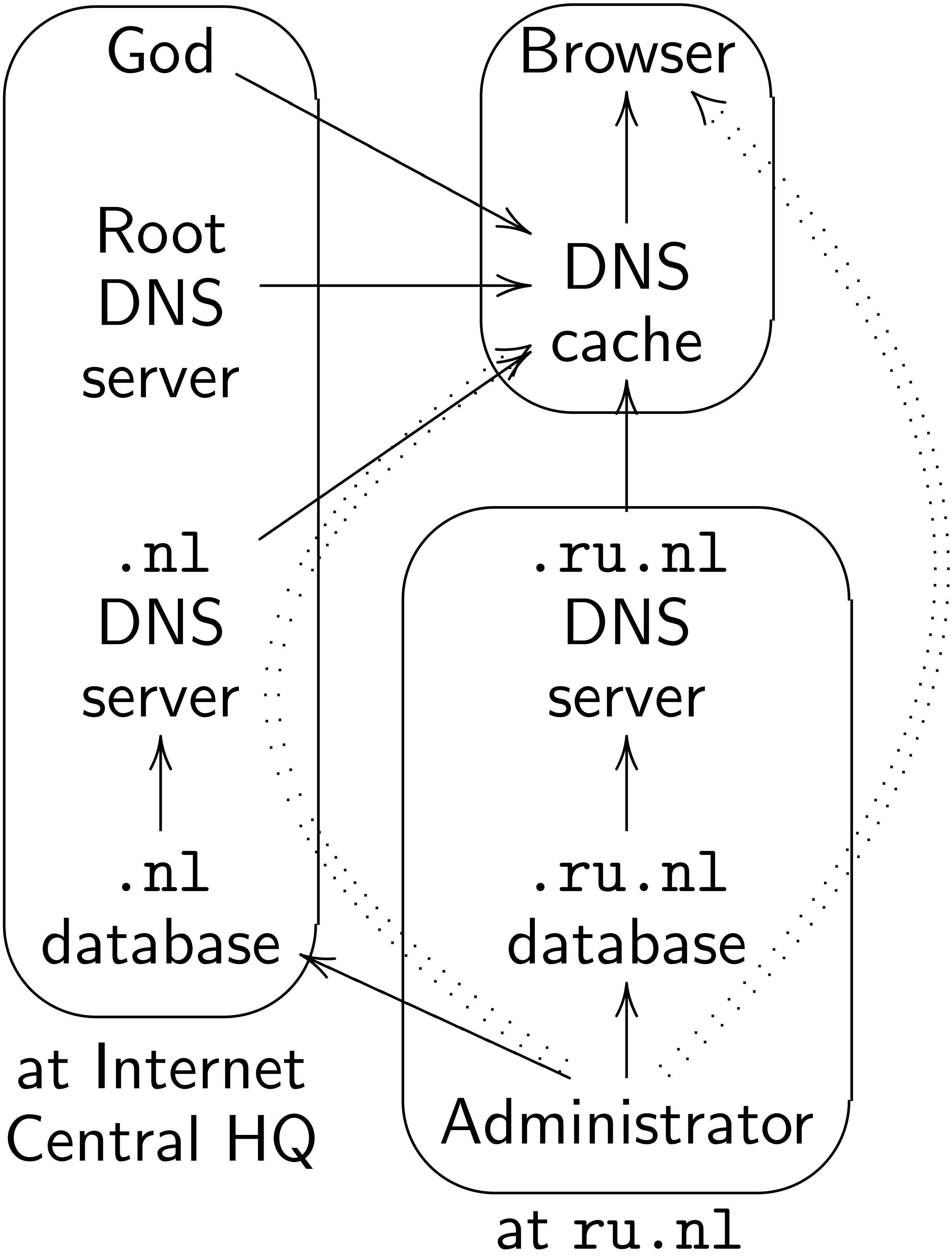
Cache pulls data from administrator if it doesn't already have the data.

Administrator pushes data through local database into `.ru.nl` DNS server:



DNS cache learns location of `.ru.nl` DNS server from `.nl` DNS server:




God
Root
DNS
server
.nl
DNS
server
.nl
database
at Internet
Central HQ
Browser
DNS
cache
.ru.nl
DNS
server
.ru.nl
database
Administrator
at ru.nl

DNS server software listed in Wikipedia: BIND, Microsoft DNS, djbdns, Dnsmasq, Simple DNS Plus, NSD, Knot DNS, PowerDNS, MaraDNS, pdnsd, Nominum ANS, Nominum Vantio, Posadis, Unbound, Cisco Network Registrar, dnrd, gdnsd, YADIFA, yaku-ns, DNS Blast.

Much wider variety of DNS database-management tools, plus hundreds of homegrown tools written by DNS registrars etc.

DNSSEC changes everything

DNSSEC demands new code in every DNS-management tool.

Whenever a tool adds or changes a DNS record, also has to precompute and store a DNSSEC signature for the new record.

Often considerable effort for the tool programmers.

Example: Signing 3GB database can produce 20GB database.
Tool reading database into RAM probably has to be reengineered.

Nijmegen administrator also has
to send public key to `.nl`.

The `.nl` server
and database software
and web interface
need to be updated
to accept these public keys
and to sign everything.

DNS cache needs new software
to fetch keys, fetch signatures,
and verify signatures.

Tons of pain for implementors.

Original DNSSEC protocols would have required `.org` to sign its whole database: millions of records.

Conceptually simple but much too slow, much too big.

So the DNSSEC protocol added complicated options allowing `.org` to sign a small number of records, and to sign "might have data but has not signed any of it" covering the other records.

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DNSSEC purists say "Answers should always be static".

Even in “static” DNS,
each response packet is
dynamically assembled
from several answers:
MX answer, NS answer, etc.

DNSSEC precomputes
a signature for each answer,
not for each packet.

$\Rightarrow$ One DNSSEC packet
includes several signatures.
Massive bloat on the wire.

That’s why DNSSEC allows
so much amplification.

What about *old* DNS data?
Are the signatures still valid?

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If clocks are synchronized
then signatures can
include expiration times.
But frequent re-signing
is an administrative disaster.

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2015.12.11: `af.mil` killed itself.

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2015.12.11: `af.mil` killed itself.

Many more: see `ianix.com`
`/pub/dnssec-outages.html`.

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Crazy! Obvious approach: "We sign each record that exists, and don't sign anything else."

User asks for nonexistent name. Receives *unsigned* answer saying the name doesn't exist. Has no choice but to trust it.

User asks for `www.google.com`.
Receives unsigned answer,
a packet forged by attacker,
saying the name doesn't exist.
Has no choice but to trust it.

Clearly a violation of availability.
Sometimes a violation of integrity.
This is not a good approach.

User asks for `www.google.com`.
Receives unsigned answer,
a packet forged by attacker,
saying the name doesn't exist.
Has no choice but to trust it.

Clearly a violation of availability.
Sometimes a violation of integrity.
This is not a good approach.

Alternative: DNSSEC's "NSEC".
e.g. `nonex.clegg.com` query
returns "`There are no names between nick.clegg.com and start.clegg.com`" + signature.

Try `foo.clegg.com` etc.
After several queries have complete `clegg.com` list:
`_jabber._tcp`, `_xmpp-server._tcp`, `alan`, `alvis`, `andrew`, `brian`, `calendar`, `dlv`, `googleffffffffe91126e7`, `home`, `imogene`, `jennifer`, `localhost`, `mail`, `wiki`, `www`.

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The `clegg.com` administrator disabled DNS "zone transfers" — but then leaked the same data by installing DNSSEC.
(This was a real example.)

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DNSSEC purists disagree: "It is part of the design philosophy of the DNS that the data in it is public." But this notion is so extreme that it became a public-relations problem.

New DNSSEC approach:

1. "NSEC3" technology:
Use a "one-way hash function"
such as (iterated salted) SHA-1.
Reveal *hashes* of names
instead of revealing names.
"`There are no names with`
`hashes between` . . . `and` . . ."

New DNSSEC approach:

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Reveal *hashes* of names
instead of revealing names.
“`There are no names with hashes between ... and ...`”

2. Marketing:
Pretend that NSEC3 is
less damaging than NSEC.

ISC: “NSEC3 does not allow
enumeration of the zone.”

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4Mbps flood of queries is under 500 million noisy guesses/day. NSEC3 allows typical attackers 1000000 million to 1000000000 million silent guesses/day.

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Recompute and store signature
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Dynamic content? Give up.

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Replay attacks work for 30 days.
Filename guessing is much faster.
Nothing is encrypted.
Denial of service is trivial.

Does DNS security matter?

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Does DNS security matter?

There *are* some IP addresses signed with DNSSEC, and some caches checking signatures. Never mind all the problems. **Do these signatures accomplish anything?**

Occasionally these caches are on client machines, so attacker can't simply forge packets from cache . . . so attacker intercepts and forges all the subsequent packets: web pages, email, etc.

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But DNSSEC is not signing
any of the user's data!

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With PGP, what attack is stopped by DNSSEC?

With HTTPS but not PGP, what attack is stopped by DNSSEC?

With neither HTTPS nor PGP, what attack is stopped by DNSSEC?

Getting out of the mess

State-of-the-art ECC
is fast enough to
authenticate and encrypt
every packet.

Deployed: DNSCurve protects
DNS packets, server→cache.

Deployed: DNSCrypt protects
DNS packets, cache→client.

Work in progress: HTTPCurve
protects HTTP packets.

Crypto is at edge of network,
handled by simple proxy.

Administrator puts public key
into name of server.

Need new DNS cache software
but no need to change
server software,
database-management software,
web interfaces, etc.

Easy to implement,
easy to deploy.

No precomputation.

No precomputation.

No problems with dynamic data.

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Packets are small.
Smaller amplification
than existing protocols.

DNSCurve and DNSCrypt and HTTPCurve and SMTPCurve add real security even to PGP-signed web pages, email.

Improved confidentiality: e.g., is the user accessing `firstaid.webmd.com` or `diabetes.webmd.com`?

Improved integrity: e.g., freshness.

Improved availability: attacker forging a packet doesn't break connections.