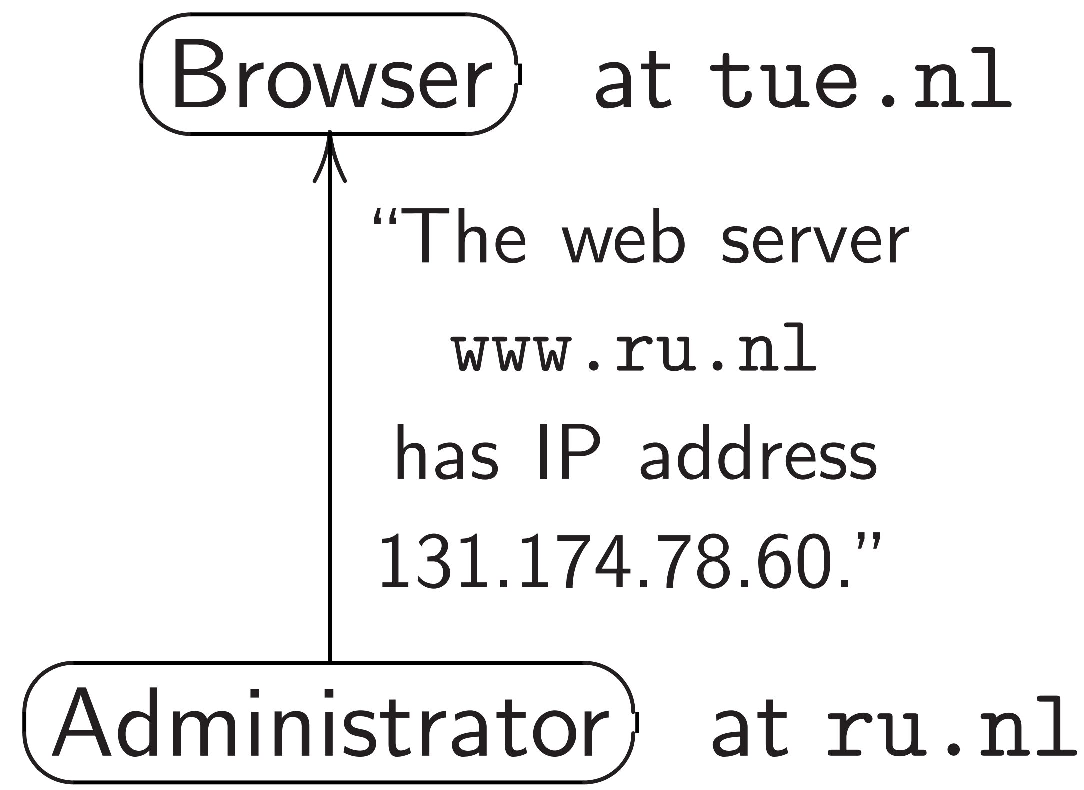
The DNS security mess

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`
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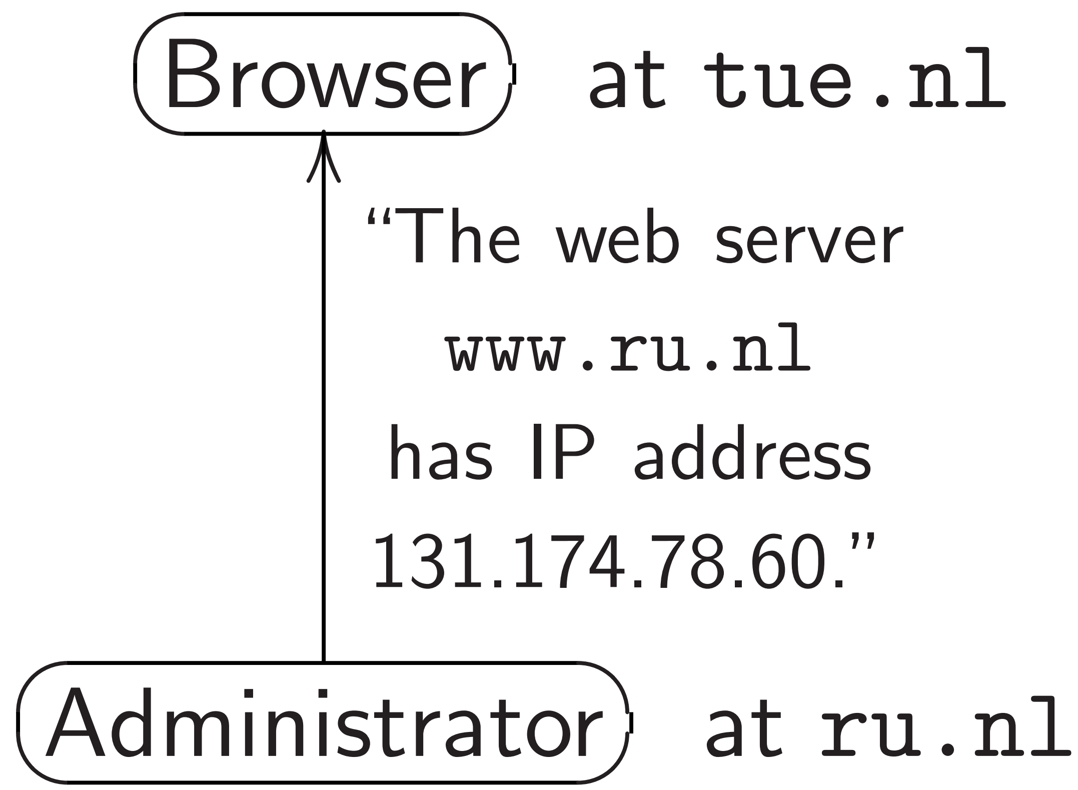

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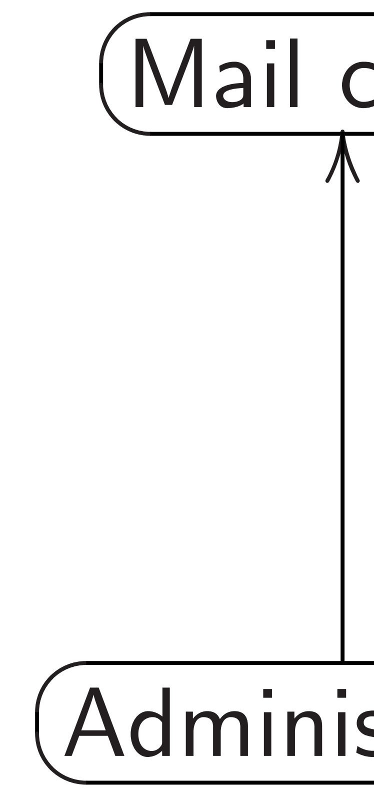

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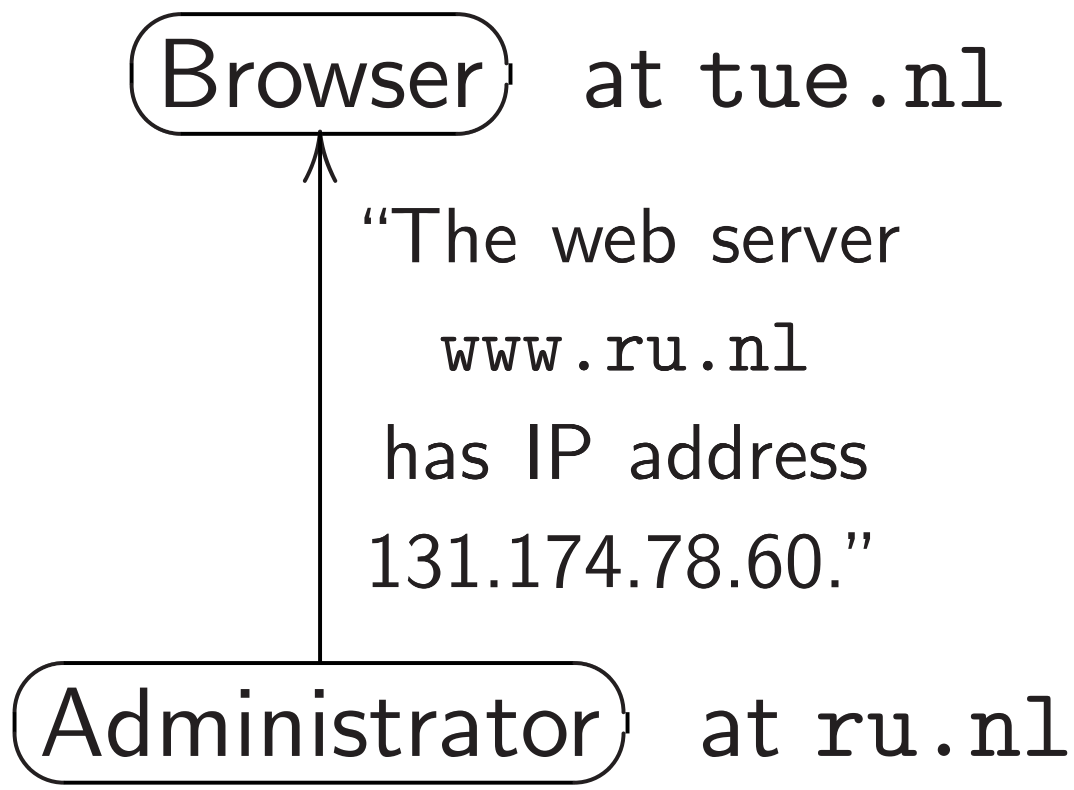

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Same for Internet

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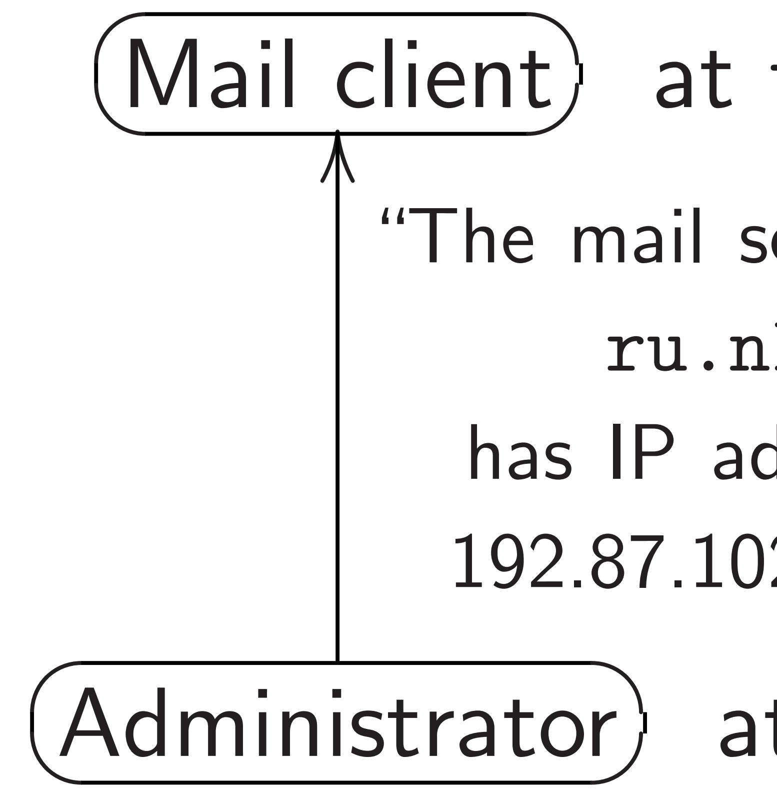

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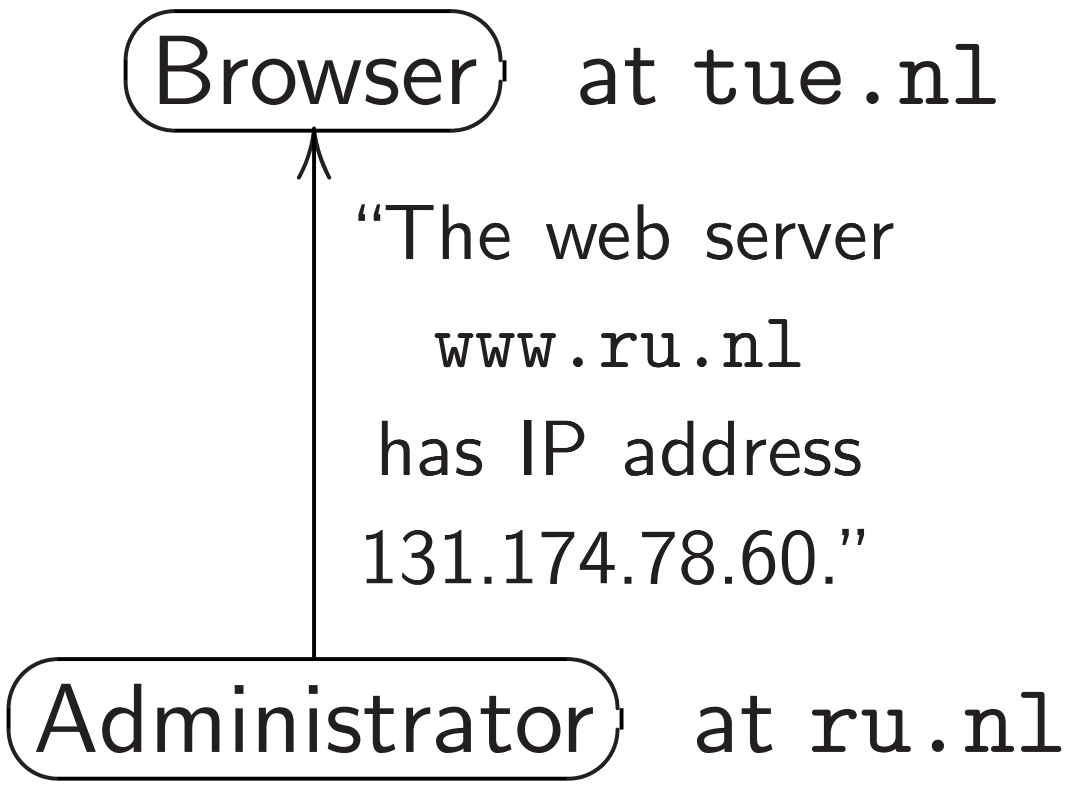

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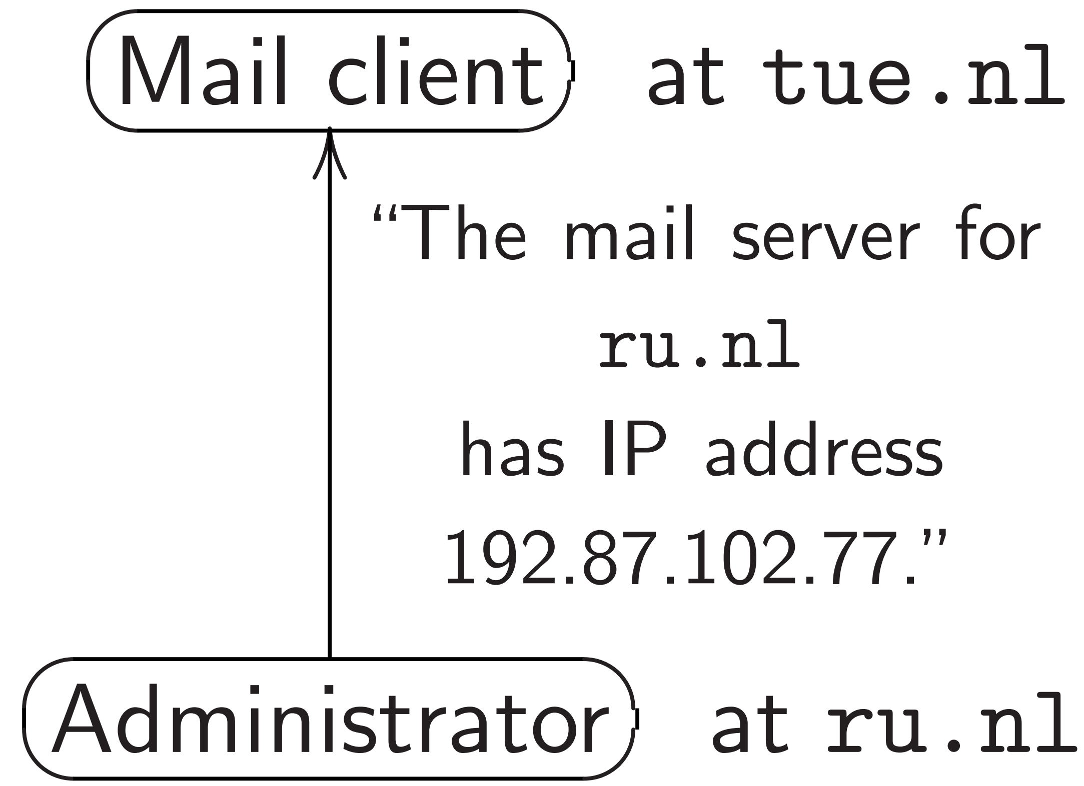

Now `tue.nl` delivers mail to IP address 192.87.102.77.

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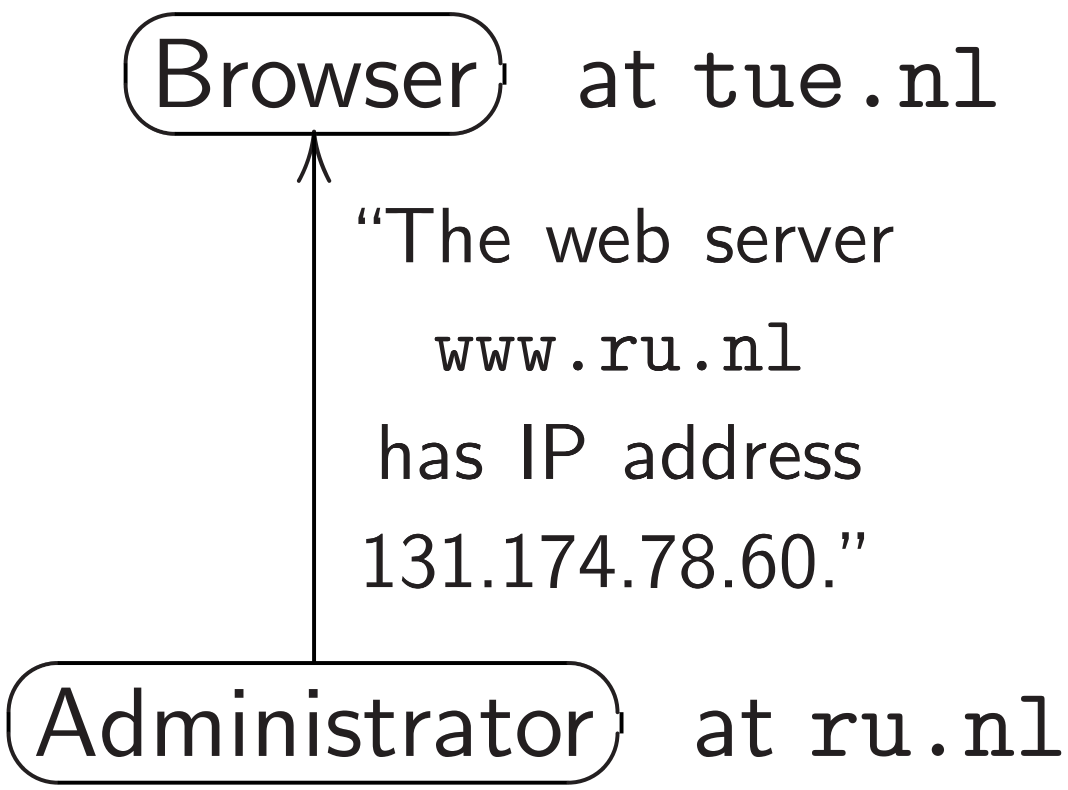

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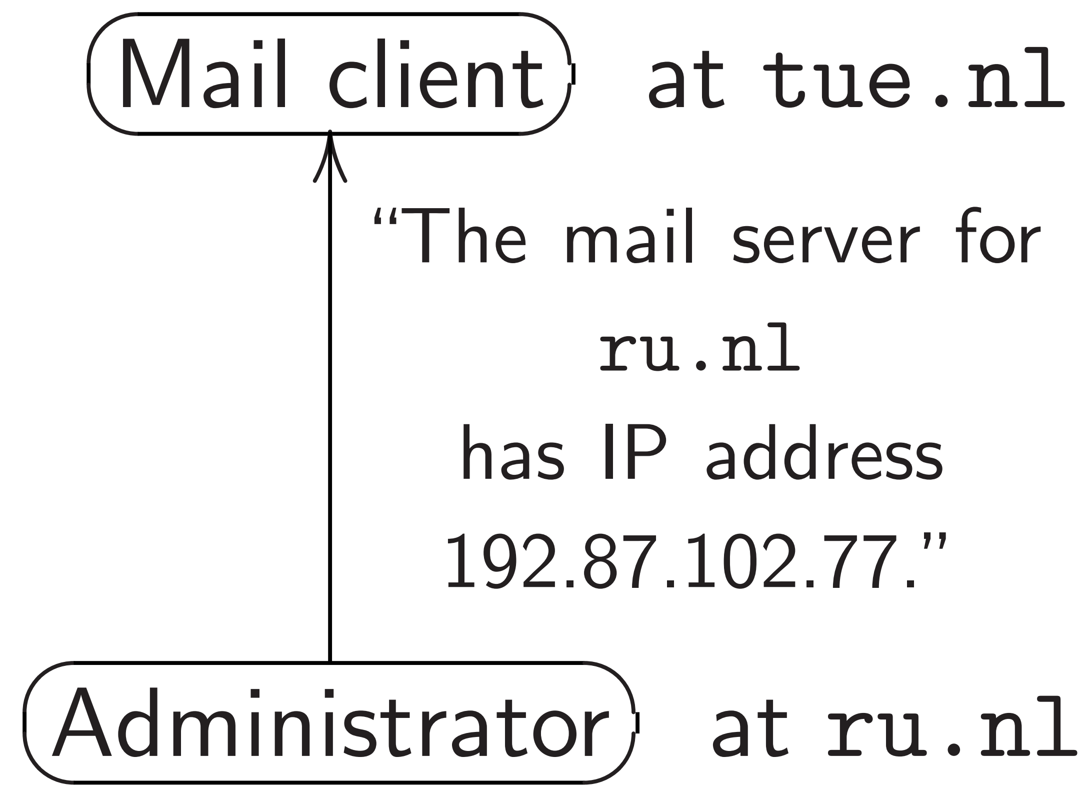

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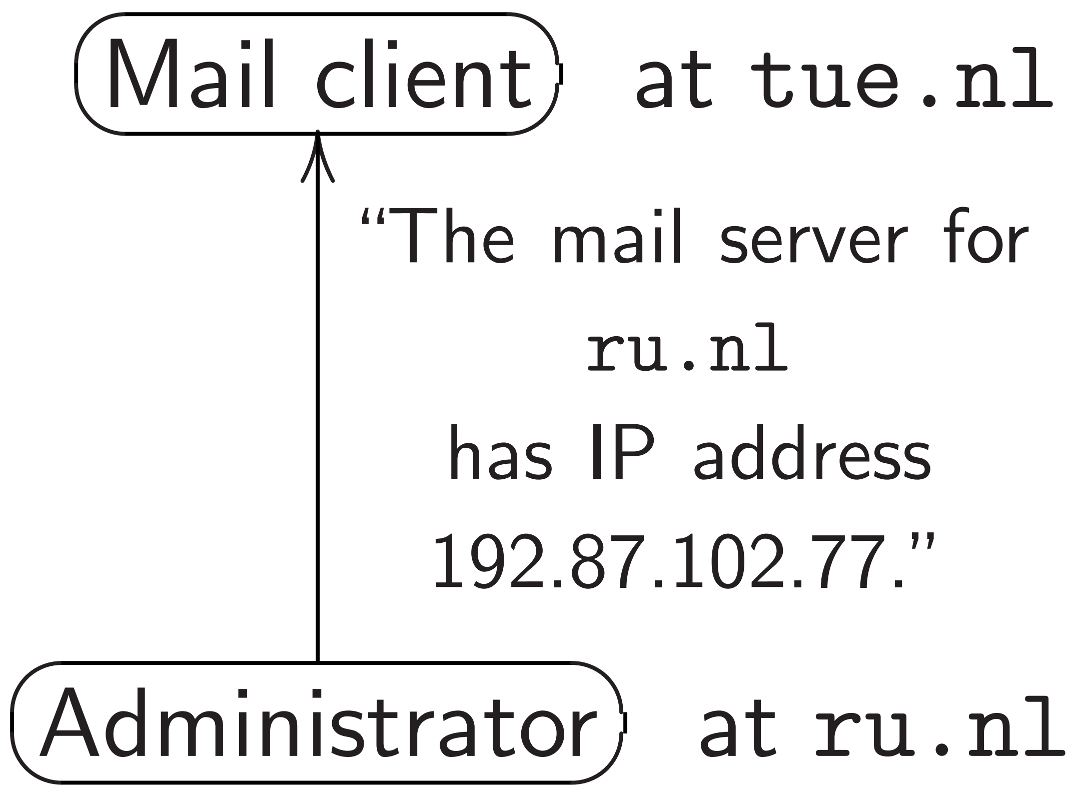

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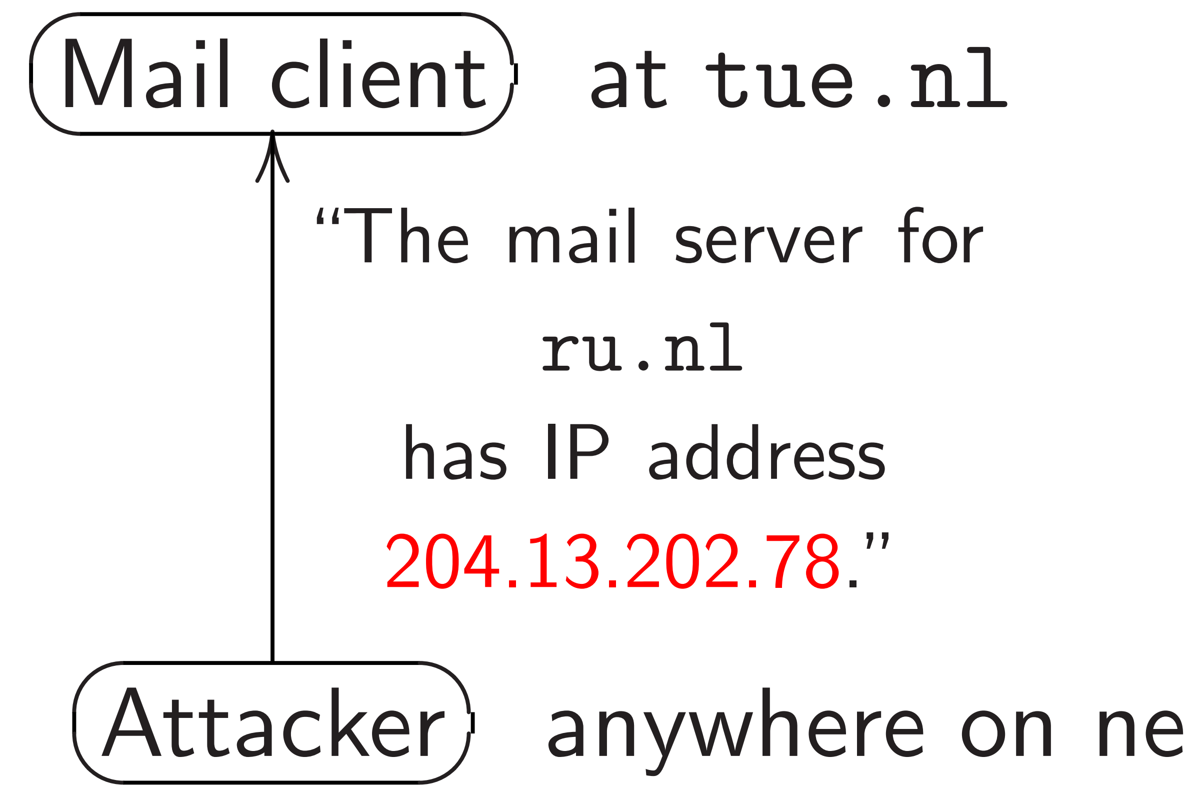

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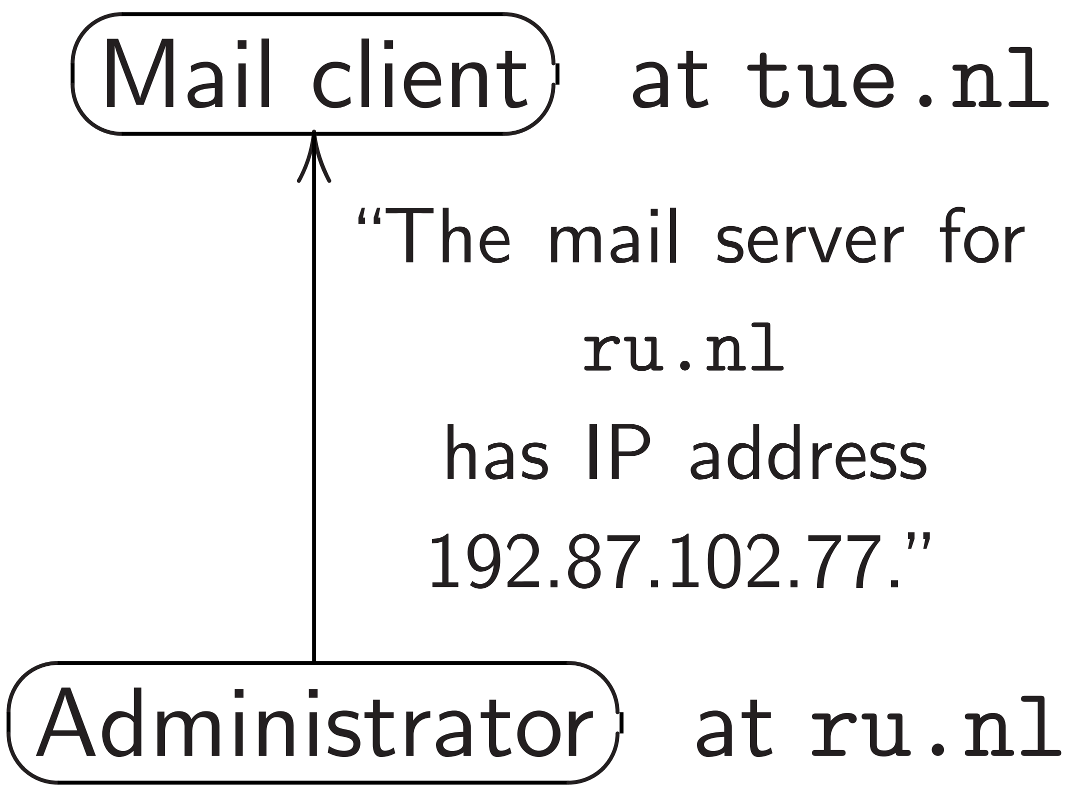

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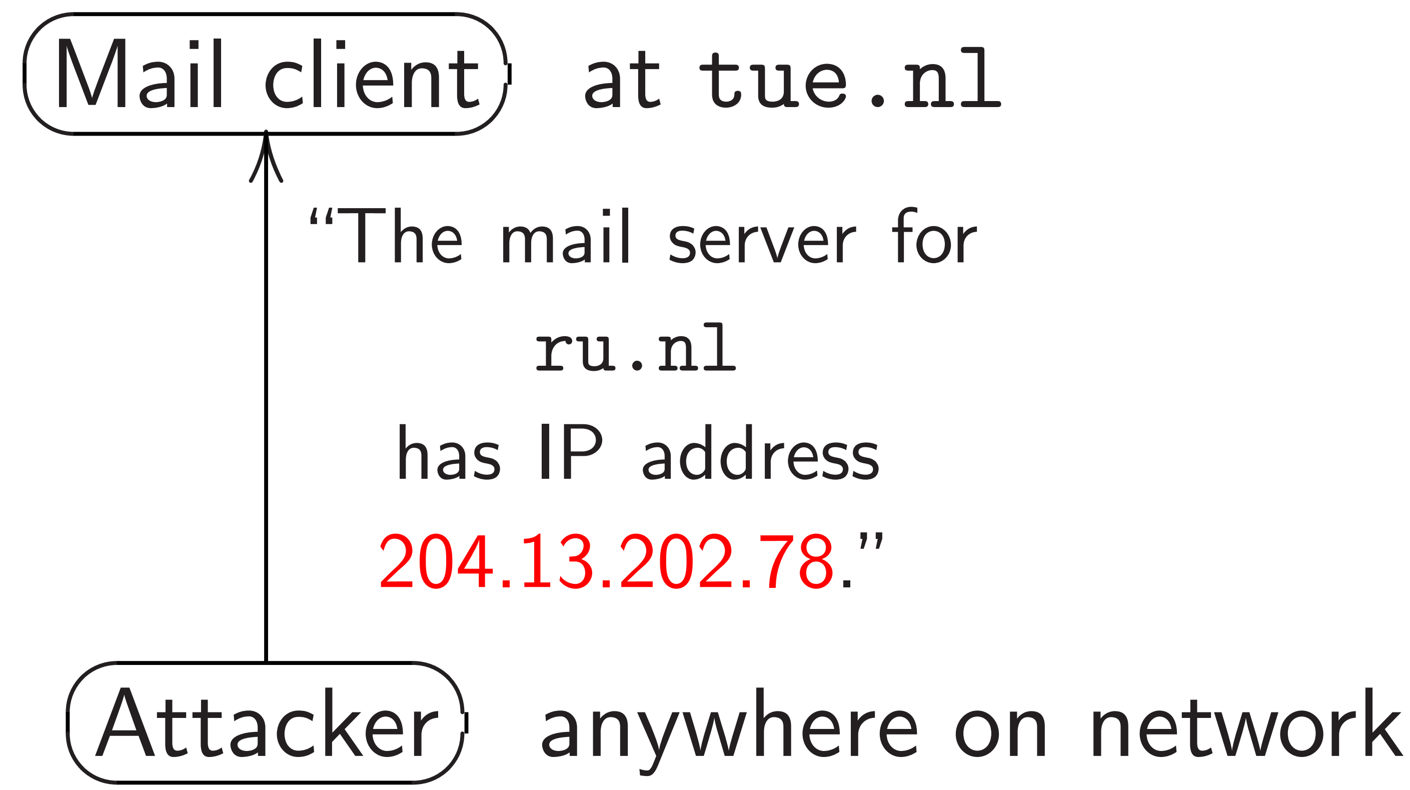

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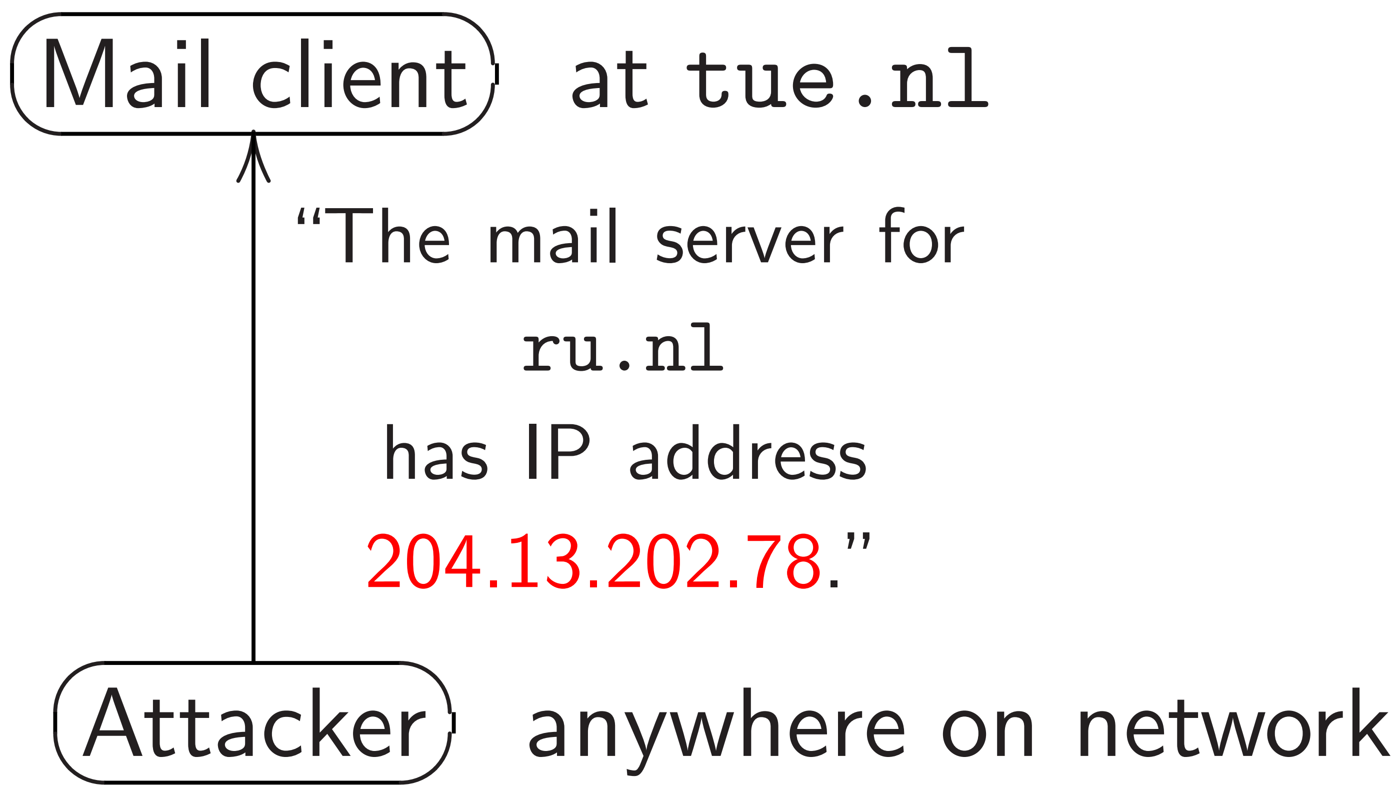

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Signing our zone is the first part of our DNSSEC test phase.

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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Verification! Auth
Integrity! Sounds

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one is ‘signed’ ?
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NSSEC test phase.
now cryptographically
the authoritative data
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rigin authenticity and
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Decemb

Let’s fin

```
$ dig
d0.org
a0.org
c0.org
b2.org
a2.org
b0.org

$ dig
  b0.
199.1
```

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Cryptography! Authority! Verification! Authenticity! Integrity! Sounds great!

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… or is it?

December 2016: r

Let's find a `.org` s

```
$ dig +short n
d0.org.afilias
a0.org.afilias
c0.org.afilias
b2.org.afilias
a2.org.afilias
b0.org.afilias

$ dig +short \
  b0.org.afili
199.19.54.1
```

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Cryptography! Authority! Verification! Authenticity! Integrity! Sounds great!

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… or is it?

December 2016: 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.or
199.19.54.1
```

Cryptography! Authority!
Verification! Authenticity!
Integrity! Sounds great!

Now I simply configure the new `.org` public key into my DNS software. Because the `.org` servers are signing with DNSSEC, it is no longer possible for attackers to forge data from those servers!

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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
```

raphy! Authority!
ion! Authenticity!
! Sounds great!

mply configure
.org public key
DNS software.
the .org servers
ng with DNSSEC,
onger possible
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m those servers!

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```
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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

```
$ dig
  www
  @19
```

Everythi

```
;; AU
greenp
  864
  ns-
;; AD
ns-em
  864
  37.
```

thority!
enticity!
great!

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lic key
ware.
servers
NSSEC,
sible
rge
ervers!

December 2016: 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 greenpea

```
$ dig \
  www.greenpea
  @199.19.54.1
```

Everything looks r

```
;; AUTHORITY S
greenpeace.org
  86400 IN NS
  ns-emea.gree
;; ADDITIONAL
ns-emea.greenp
  86400 IN A
  37.48.104.54
```

December 2016: 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.or
;; ADDITIONAL SECTION:
ns-emea.greenpeace.org.
  86400 IN A
  37.48.104.54
```

December 2016: 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
```

er 2016: reality

d a .org server:

```
 +short ns org
g.afilias-nst.org.
g.afilias-nst.info.
g.afilias-nst.info.
g.afilias-nst.org.
g.afilias-nst.info.
g.afilias-nst.org.

 +short \
org.afilias-nst.org
9.54.1
```


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

Have to

```
$ dig
  www
  @19
```

Old ansv

```
h9p7u
np90u
C3 1
69T6U
 NS S
3PARA

h9p7u
```

reality

server:

```
s org
-nst.org.
-nst.info.
-nst.info.
-nst.org.
-nst.info.
-nst.org.

as-nst.org
```


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 crypt

Have to ask for sig

```
$ dig +dnssec
  www.greenpea
  @199.19.54.1
```

Old answer + four

```
h9p7u7tr2u91d0
np90u3h.org. 8
C3 1 1 1 D399E
69T6U801GSG9E1
 NS SOA RRSIG
3PARAM

h9p7u7tr2u91d0
```

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

```
h9p7u7tr2u91d0v0ljs9l1g
np90u3h.org. 86400 IN N
C3 1 1 1 D399EAAB H9PAR
69T6U801GSG9E1LMITK4DEM
 NS SOA RRSIG DNSKEY NS
3PARAM


h9p7u7tr2u91d0v0ljs9l1g
```

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
69T6U8O1GSG9E1LMITK4DEMOT
 NS SOA RRSIG DNSKEY NSEC
3PARAM


h9p7u7tr2u91d0v0ljs9l1gid
```

greenpeace.org:

```
\
.greenpeace.org \
9.19.54.1
```

ng looks normal:

```
THORITY SECTION:
peace.org.
00 IN NS
emea.greenpeace.org.
DITIONAL SECTION:
ea.greenpeace.org.
00 IN A
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
69T6U8O1GSG9E1LMITK4DEMOT
 NS SOA RRSIG DNSKEY NSEC
3PARAM

h9p7u7tr2u91d0v0ljs9l1gid
```

```
np90u
IG NS
2911
947 o
xe9Gj
sW1iD
loixx
2IHWp
M3F4w
BbNFn
LLFk

bgca0
qng3p
C3 1
```

ace.org:

ce.org \

ormal:

ECTION:

.

npeace.org.

SECTION:

eace.org.

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
69T6U801GSG9E1LMITK4DEMOT
 NS SOA RRSIG DNSKEY NSEC
3PARAM

h9p7u7tr2u91d0v0ljs9l1gid
```

```
np90u3h.org. 8
IG NSEC3 7 2 8
29113950 20161
947 org. F9Txg
xe9GjwCmnGHPCB
sW1iD0VqA4ZjNv
loixxOUwbx+KjW
2IHWp5Phlajme4
M3F4wq7Ibf23CL
BbNFnX0vzSGjZw
LLFk xEs=

bgca0g0ug0p6o7
qng3p2f.org. 8
C3 1 1 1 D399E
```

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
69T6U801GSG9E1LMITK4DEM0T
 NS SOA RRSIG DNSKEY NSEC
3PARAM

h9p7u7tr2u91d0v0ljs9l1gid
```



```
np90u3h.org. 86400 IN R
IG NSEC3 7 2 86400 2016
29113950 20161208103950
947 org. F9TxgXX1iROZnf
xe9GjwCmnGHPCBRHwk9kPmU
sW1iD0VqA4ZjNvi GEDJdWD
loixx0Uwbx+KjWJYjZpd0LH
2IHWp5Phlajme4Yek/CTu0
M3F4wq7Ibf23CL6Hi51qS6P
BbNFnX0vzSGjZwfzZL5kRGJ
LLFk xEs=

bgca0g0ug0p6o7425emkt9u
qng3p2f.org. 86400 IN N
C3 1 1 1 D399EAAB BGDHK
```

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
69T6U8O1GSG9E1LMITK4DEMOT
 NS SOA RRSIG DNSKEY NSEC
3PARAM

h9p7u7tr2u91d0v0ljs9l1gid
```



```
np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
29113950 20161208103950 3
947 org. F9TxgXX1iROZnfXk
xe9GjwCmnGHPCBRHwk9kPmU+7
sW1iDOVqA4ZjNvi GEDJdWD7T
loixxOUwbx+KjWJYjZpd0LHC9
2IHWp5Phlajme4Yek/CTu0 jX
M3F4wq7Ibf23CL6Hi51qS6PbO
BbNFnX0vzSGjZwfzZL5kRGJUV
LLFk xEs=

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN NSE
C3 1 1 1 D399EAAB BGDHKIB
```

the crypto?
ask for signatures:

```
+dnssec \
.greenpeace.org \
9.19.54.1
```

wer + four new lines:

```
7tr2u91d0v0ljs9l1gid
3h.org. 86400 IN NSE
1 1 D399EAAB H9PARR6
8O1GSG9E1LMITK4DEMOT
OA RRSIG DNSKEY NSEC
M

7tr2u91d0v0ljs9l1gid
```



```
np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
29113950 20161208103950 3
947 org. F9TxgXX1iROZnfXk
xe9GjwCmnGHPCBRHwk9kPmU+7
sW1iDOVqA4ZjNvi GEDJdWD7T
loixxOUwbx+KjWJYjZpd0LHC9
2IHWp5Phlajme4Yek/CTu0 jX
M3F4wq7Ibf23CL6Hi51qS6PbO
BbNFnX0vzSGjZwfzZL5kRGJUV
LLFk xEs=

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN NSE
C3 1 1 1 D399EAAB BGDHKIB
```

```
OPPOB
 A RR

bgca0
qng3p
IG NS
22153
947 o
JwJcg
vYLn2
9gKbn
KRc3q
EHNmP
+ArS4
orI8
```

o?

gnatures:

```
\
ce.org \
```

new lines:

```
v0ljs9l1gid
6400 IN NSE
AAB H9PARR6
LMITK4DEMOT
DNSKEY NSEC

v0ljs9l1gid
```



```
np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
29113950 20161208103950 3
947 org. F9TxgXX1iROZnfXk
xe9GjwCmnGHPCBRHwk9kPmU+7
sW1iDOVqA4ZjNvi GEDJdWD7T
loixxOUwbx+KjWJYjZpd0LHC9
2IHWp5Phlajme4Yek/CTu0 jX
M3F4wq7Ibf23CL6Hi51qS6PbO
BbNFnX0vzSGjZwfzZL5kRGJUV
LLFk xEs=

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN NSE
C3 1 1 1 D399EAAB BGDHKIB
```



```
OPPOBENBFCGBMB
 A RRSIG

bgca0g0ug0p6o7
qng3p2f.org. 8
IG NSEC3 7 2 8
22153046 20161
947 org. Q2Vtu
JwJcg25OVwm9FM
vYLn2WUrgvjBfF
9gKbnit47gyfek
KRc3qYMdFEGftV
EHNmP1bpR99/f2
+ArS4Jn+2Xa8KF
orI8 ylc=
```

s:
id
SE
R6
OT
EC
id

np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
29113950 20161208103950 3
947 org. F9TxgXX1iROZnfXk
xe9GjwCmnGHPCBRHwk9kPmU+7
sW1iDOVqA4ZjNvi GEDJdWD7T
loixxOUwbx+KjWJYjZpd0LHC9
2IHWp5Phlajme4Yek/CTu0 jX
M3F4wq7Ibf23CL6Hi51qS6PbO
BbNFnX0vzSGjZwfzZL5kRGJUV
LLFk xEs=

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

OPPOBENBFCGBMB6RGT2JDC2
A RRSIG

bgca0g0ug0p6o7425emkt9u
qng3p2f.org. 86400 IN R
IG NSEC3 7 2 86400 2016
22153046 20161201143046
947 org. Q2VtusS5O0v2yk
JwJcg25OVwm9FMP0ioBMb1+
vYLn2WUrgvjBfFm Na8MxWl
9gKbnit47gyfeky9AwDKBJ3
KRc3qYMdFEGftVeGePEbdy
EHNmP1bpR99/f25TMIGqs8F
+ArS4Jn+2Xa8KFdfjdlfwFc
orI8 ylc=

np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
29113950 20161208103950 3
947 org. F9TxgXX1iROZnfXk
xe9GjwCmnGHPCBRHwk9kPmU+7
sW1iDOVqA4ZjNvi GEDJdWD7T
loixxOUwbx+KjWJYjZpd0LHC9
2IHWp5Phlajme4Yek/CTu0 jX
M3F4wq7Ibf23CL6Hi51qS6PbO
BbNFnX0vzSGjZwfzZL5kRGJUV
LLFk xEs=

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

OPPOBENBFCGBMB6RGT2JDC21E
A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
22153046 20161201143046 3
947 org. Q2VtusS5OOv2ykrp
JwJcg25OVwm9FMP0ioBMb1+sG
vYLn2WUrgvjBfFm Na8MxWlP2
9gKbnit47gyfeky9AwDKBJ3ph
KRc3qYMdFEGftVeGePEbdy 7w
EHNmP1bpR99/f25TMIGqs8FxM
+ArS4Jn+2Xa8KFdfjdlfwFc+y
orI8 ylc=

```
3h.org. 86400 IN RRS
EC3 7 2 86400 201612
950 20161208103950 3
rg. F9TxgXX1iROZnfXk
wCmnGHPCBRHwk9kPmU+7
0VqA4ZjNvi GEDJdWD7T
0Uwbx+KjWJYjZpd0LHC9
5Phlajme4Yek/CTu0 jX
q7Ibf23CL6Hi51qS6Pb0
X0vzSGjZwfzZL5kRGJUV
xEs=

g0ug0p6o7425emkt9ue4
2f.org. 86400 IN NSE
1 1 D399EAAB BGDHKIB
```



```
0PP0BENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
22153046 20161201143046 3
947 org. Q2VtusS50Ov2ykrp
JwJcg25OVwm9FMP0ioBMb1+sG
vYLn2WUrgvjBfFm Na8MxWlP2
9gKbnit47gyfeky9AwDKBJ3ph
KRc3qYMdFEGftVeGePEbdy 7w
EHNmP1bpR99/f25TMIGqs8FxM
+ArS4Jn+2Xa8KFdfjdlfwFc+y
orI8 ylc=
```

Wow, th
Must be

```
$ tcpdu
  host
```

shows pa
dig send
to the .
receives

See more

```
$ dig +
  org @
```

Sends 7
receives
totalling

```
6400 IN RRS
6400 201612
208103950 3
XX1iROZnfXk
RHwk9kPmU+7
i GEDJdWD7T
JYjZpd0LHC9
Yek/CTu0 jX
6Hi51qS6PbO
fzZL5kRGJUV


425emkt9ue4
6400 IN NSE
AAB BGDHKIB
```

```
OPPOBENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
22153046 20161201143046 3
947 org. Q2VtusS5OOv2ykrp
JwJcg25OVwm9FMP0ioBMb1+sG
vYLn2WUrgvjBfFm Na8MxW1P2
9gKbnit47gyfeky9AwDKBJ3ph
KRc3qYMdFEGftVeGePEbdy 7w
EHNmP1bpR99/f25TMIGqs8FxM
+ArS4Jn+2Xa8KFdfjdlfwFc+y
orI8 ylc=
```


Wow, that's a lot
Must be strong cr

```
$ tcpdump -n -e
  host 199.19.54
```

shows packet sizes
dig sends 89-byte
to the .org DNS
receives 654-byte

See more DNSSE

```
$ dig +dnssec an
  org @199.19.54
```

Sends 74-byte IP
receives two IP fra
totalling 2653 byt

```
0PP0BENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
22153046 20161201143046 3
947 org. Q2VtusS50Ov2ykrp
JwJcg25OVwm9FMP0ioBMb1+sG
vYLn2WUrgvjBfFm Na8MxWlP2
9gKbnit47gyfeky9AwDKBJ3ph
KRc3qYMdFEGftVeGePEbdy 7w
EHNmP1bpR99/f25TMIGqs8FxM
+ArS4Jn+2Xa8KFdfjdlfwFc+y
orI8 ylc=
```


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

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

shows packet sizes:
dig sends 89-byte IP packet
to the .org DNS server,
receives 654-byte IP packet.

See more DNSSEC data:

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

Sends 74-byte IP packet,
receives two IP fragments
totalling 2653 bytes.

```
OPPOBENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201612
22153046 20161201143046 3
947 org. Q2VtusS5OOv2ykrp
JwJcg25OVwm9FMP0ioBMb1+sG
vYLn2WUrgvjBfFm Na8MxW1P2
9gKbnit47gyfeky9AwDKBJ3ph
KRc3qYMdFEGftVeGePEbdy 7w
EHNmP1bpR99/f25TMIGqs8FxM
+ArS4Jn+2Xa8KFdfjdlfwFc+y
orI8 ylc=
```


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 654-byte IP packet.

See more DNSSEC data:

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

Sends 74-byte IP packet, receives two IP fragments totalling 2653 bytes.

```
ENBFCGBMB6RGT2JDC21E
SIG

g0ug0p6o7425emkt9ue4
2f.org. 86400 IN RRS
EC3 7 2 86400 201612
046 20161201143046 3
rg. Q2VtusS5OOv2ykrp
25OVwm9FMP0ioBMb1+sG
WUrgvjBfFm Na8MxW1P2
it47gyfeky9AwDKBJ3ph
YMdFEGftVeGePEbdy 7w
1bpR99/f25TMIGqs8FxM
Jn+2Xa8KFdfjdlfwFc+y
ylc=
```


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 654-byte IP packet.

See more DNSSEC data:

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

Sends 74-byte IP packet, receives two IP fragments totalling 2653 bytes.

Interlude

What ha

this data

6RGT2JDC21E

425emkt9ue4

6400 IN RRS

6400 201612

201143046 3

sS5O0v2ykrp

P0ioBMb1+sG

m Na8MxWlP2

y9AwDKBJ3ph

eGePEbdy 7w

5TMIGqs8FxM

dfjdlfwFc+y

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 654-byte IP packet.

See more DNSSEC data:

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

Sends 74-byte IP packet, receives two IP fragments totalling 2653 bytes.

Interlude: the atta

What happens if w

this data at somec

```
1E
e4
RS
12
3
rp
sG
P2
ph
7w
xM
+y
```


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 654-byte IP packet.

See more DNSSEC data:

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

Sends 74-byte IP packet, receives two IP fragments totalling 2653 bytes.

Interlude: the attacker's vie

What happens if we aim this data at someone else?

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 654-byte IP packet.

See more DNSSEC data:

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

Sends 74-byte IP packet, receives two IP fragments totalling 2653 bytes.

Interlude: the attacker's view

What happens if we aim this data at someone else?

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 654-byte IP packet.

See more DNSSEC data:

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

Sends 74-byte IP packet, receives two IP fragments totalling 2653 bytes.

Interlude: the attacker's view

What happens if we aim this data at someone else?

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 654-byte IP packet.

See more DNSSEC data:

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

Sends 74-byte IP packet, receives two IP fragments totalling 2653 bytes.

Interlude: the attacker's view

What happens if we aim this data at someone else?

Let's see what DNSSEC can do as an amplification tool for denial-of-service attacks.

nat's a lot of data.

strong cryptography!

```
mp -n -e \
199.19.54.1 &
```

acket sizes:

ds 89-byte IP packet

org DNS server,

654-byte IP packet.

e DNSSEC data:

```
dnssec any \
199.19.54.1
```

4-byte IP packet,

two IP fragments

2653 bytes.

Interlude: the attacker's view

What happens if we aim this data at someone else?

Let's see what DNSSEC can do as an amplification tool for denial-of-service attacks.

Downloa

```
wget -m
  secsp
cd secs
awk '
  /GREE
    spl
    sub
    pri
  }
' ./*--
| sort
```

of data.

yptography!

```
\
.1 &
```

s:

IP packet

server,

IP packet.

C data:

```
y \
.1
```

packet,

gments

es.

Interlude: the attacker's view

What happens if we aim this data at someone else?

Let's see what DNSSEC can do as an amplification tool for denial-of-service attacks.

Download DNSSE

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

y!

t

Interlude: the attacker's view

What happens if we aim this data at someone else?

Let's see what DNSSEC can do as an amplification tool for denial-of-service attacks.

Download DNSSEC zone lis

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

Interlude: the attacker's view

What happens if we aim this data at someone else?

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
```

e: the attacker's view

appens if we aim
a at someone else?

e what DNSSEC can do
nplification tool for
f-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 lis

```
( cd sec
  echo
  | xarg
    /^Zo
      su
      su
    }
    /GRE
      sp
      su
      pr
    }'
) | sort
| awk '
```

acker's view

ve aim
one else?

ISSEC can do
n tool for
ttacks.

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 DNSS

```
( cd secspider.c
  echo ./*--zone
  | xargs awk '
    /^Zone <STRO
      sub(/<STRO
      sub(/<\/ST
    }
    /GREEN.*GREE
      split($0,x
      sub(/<\/TD
      print x[5]
    }'
) | sort -k3n \
| awk '{print $1
```

w

n do

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

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
```

ad DNSSEC zone list:

```
 -k -I / \
ider.cs.ucla.edu
pider.cs.ucla.edu

N.*GREEN.*GREEN.*Yes/ {
it($0,x,/<TD>/)
(/<\/TD>/,"",x[5])
nt x[5]

zone.html \
-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

estimate

```
while re
do
  dig +c
  +time=
  awk -v
    if
    if
    if
    if
    est
    prin
  }'
done < S
```

C zone list:

```
\
cla.edu
ucla.edu

*GREEN.*Yes/ {
<TD>/)
,"",x[5])

 \
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:

estimate DNSSEC

```
while read ip z
do
  dig +dnssec +i
  +time=1 any "$
  awk -v "z=$z"
    if ($1 != ";
    if ($2 != "M
    if ($3 != "S
    if ($4 != "r
    est = (22+$5
    print est,ip
  }'
done < SERVERS >
```

t:

```
es/ {
```


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 amplifica

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

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
```

t of DNSSEC names:

```
cspider.cs.ucla.edu
./*--zone.html \
gs awk '
one <STRONG>/ { z = $2
ub(/<STRONG>/,"",z)
ub(/<\/STRONG>/,"",z)

EEN.*GREEN.*GREEN.*Yes/ {
plit($0,x,/<TD>/)
ub(/<\/TD>/,"",x[5])
rint x[5],z,rand()

t -k3n \
{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
find dom
maximu

```
sort -n
  if (s
  if ($
  print
  seen[
}' > MA
head -1
wc -l M
```

Output

```
95.6279
2326 MA
```

SEC names:

```
s.ucla.edu
.html \

NG>/ { z = $2
NG>/,"",z)
RONG>/,"",z)

N.*GREEN.*Yes/ {
,/<TD>/)
>/,"",x[5])
,z,rand()

,$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
find domain estim
maximum DNSSE

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

Output (last time

```
95.6279 156.154.
2326 MAXAMP
```

s:

```
u
= $2
)
,z)
*Yes/ {
])
ERVERS
```


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 ha maximum DNSSEC amplific

```
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
```

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
```

n domain: Try query,
e DNSSEC amplification.

```
ead ip z

dnssec +ignore +tries=1 \
=1 any "$z" "@$ip" | \
v "z=$z" -v "ip=$ip" '{
($1 != ";;") next
($2 != "MSG") next
($3 != "SIZE") next
($4 != "rcvd:") next
 = (22+$5)/(40+length(z))
nt est,ip,z

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 tha
>2000 D
around t
providin
of incom

Try query,
amplification.

```
gnore +tries=1 \
z" "@$ip" | \
-v "ip=$ip" '{
;") next
SG") next
IZE") next
cvd:") next
)/(40+length(z))
,z

 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
>2000 DNSSEC s
around the Interne
providing >30× a
of incoming UDP

,
tion.

```
ries=1 \
 | \
p" '{
.
t
xt
gth(z))
```


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 around the Internet, each providing >30× amplificatio of incoming UDP packets?

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
around the Internet, each
providing >30× amplification
of incoming UDP packets?

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
around the Internet, each
providing >30× amplification
of incoming UDP packets?

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.

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Run netw
on 1.2.3

On 1.2.3
address
and send

```
ifconfi
  5.6.7
  netma
while r
do
  dig -
  +dnss
  +time
done < 
```

C server,
ated to have
C amplification:

```
wk '{
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```

I tried it):

```
102.26 fi.
```


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e.g. Sender: 1.2.3.4.
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Run network-traffi
on 1.2.3.4 and 5.6

On 1.2.3.4, set res
address to 5.6.7.8,
and send 1 query/

```
ifconfig eth0:1
  5.6.7.8 \
  netmask 255.25
while read est i
do
  dig -b 5.6.7.8
  +dnssec +ignor
  +time=1 any "$
done < MAXAMP >/
```

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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=
  +time=1 any "$z" "@$ip"
done < MAXAMP >/dev/null
```

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b 5.6.7.8 \
ec +ignore +tries=1 \
=1 any "$z" "@$ip"
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```


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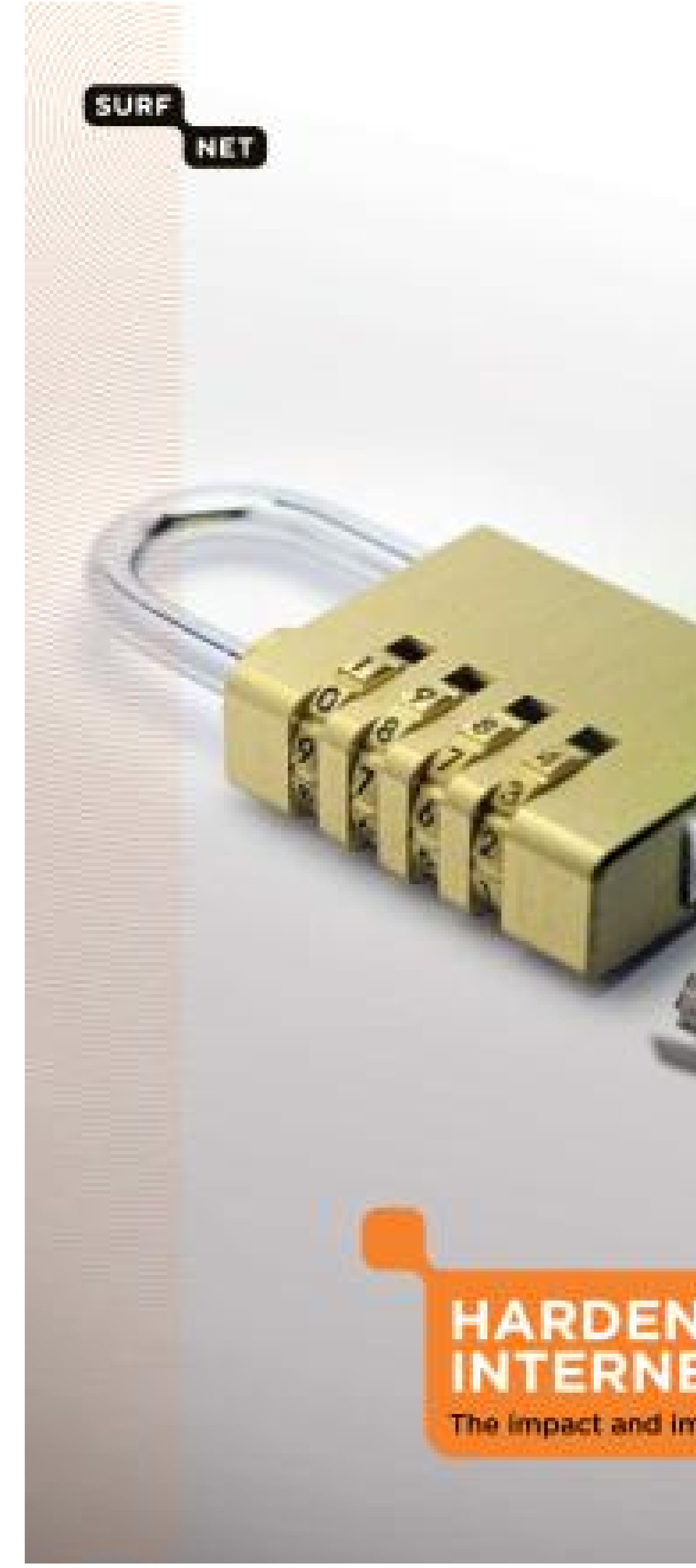

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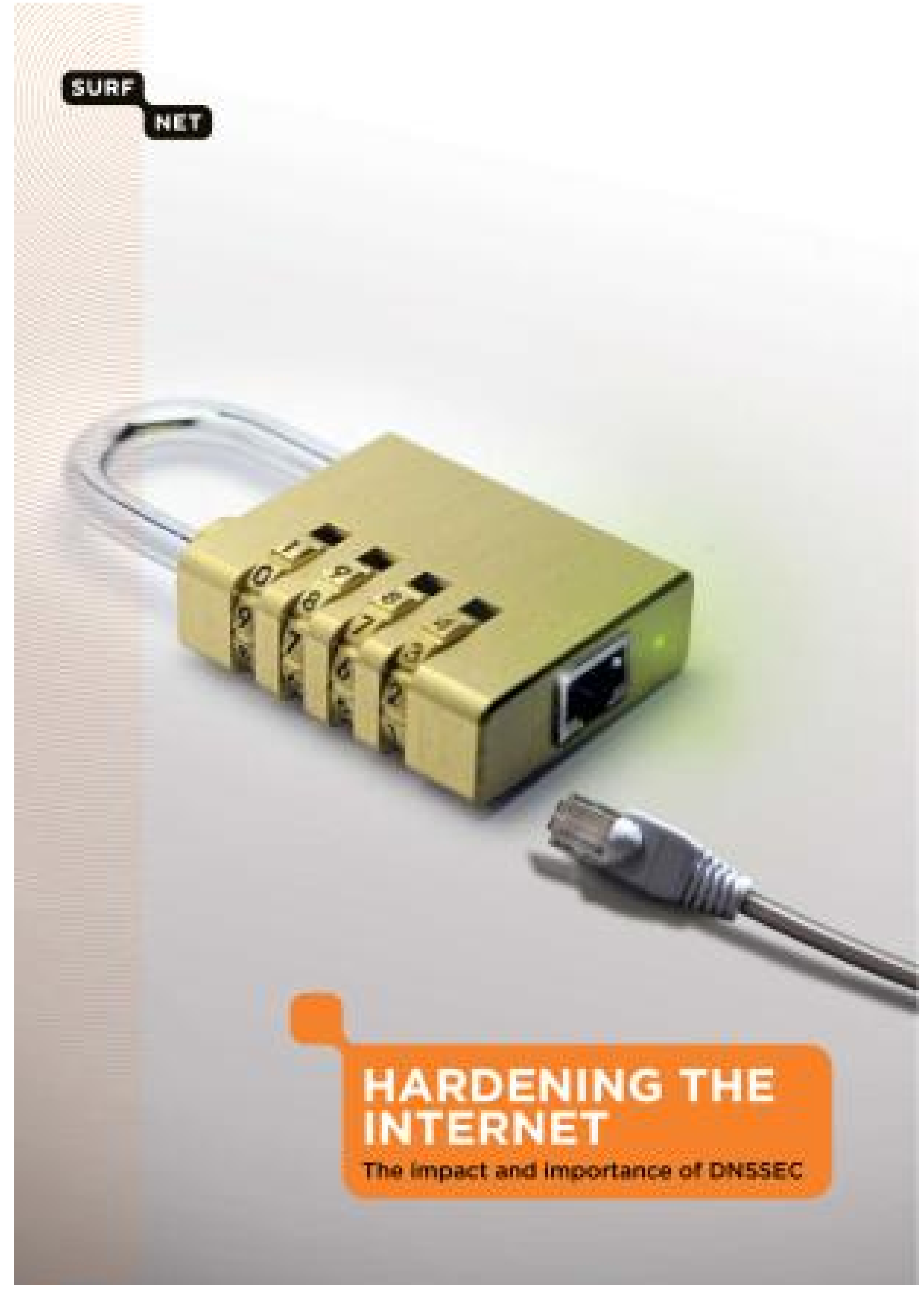

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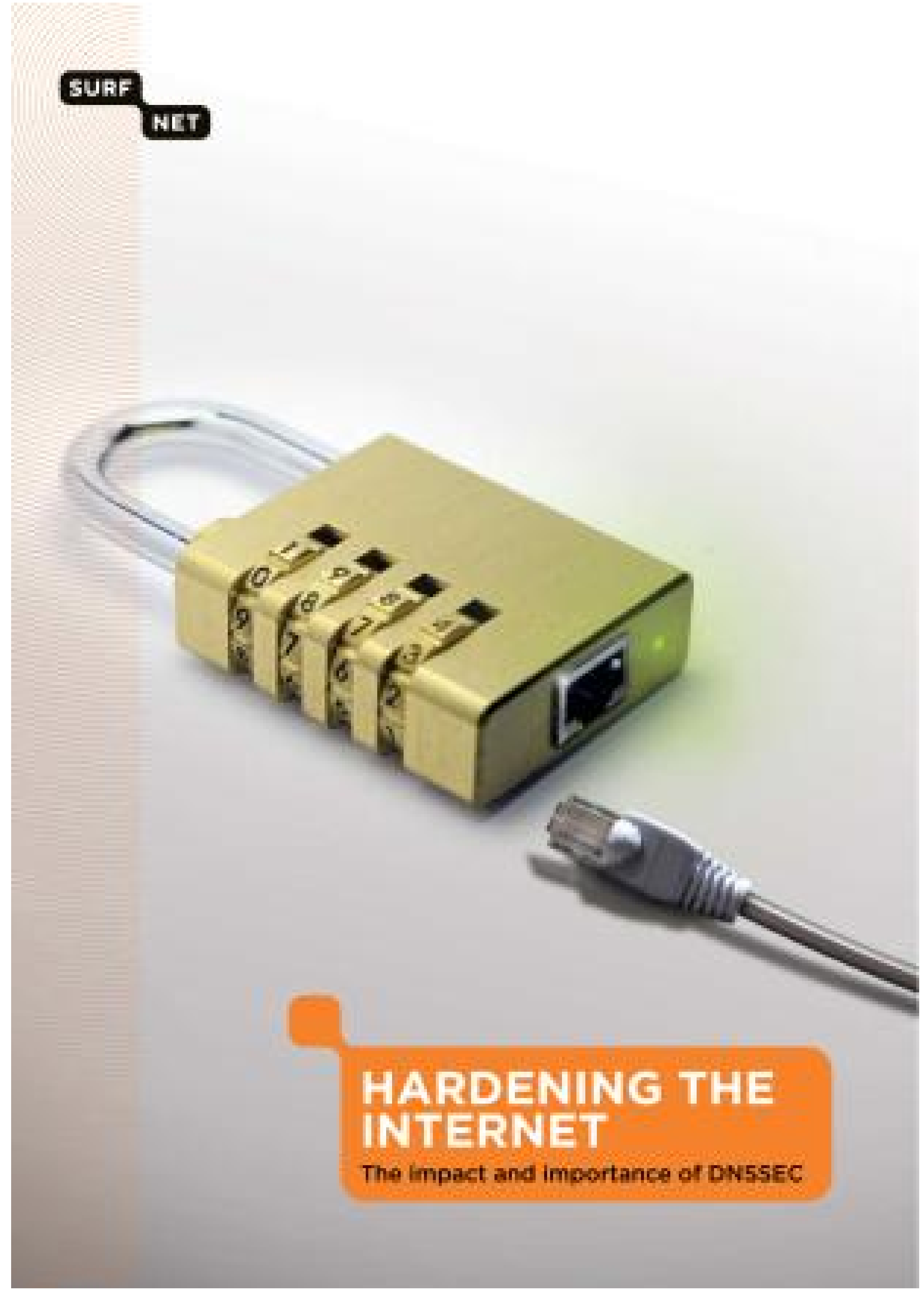

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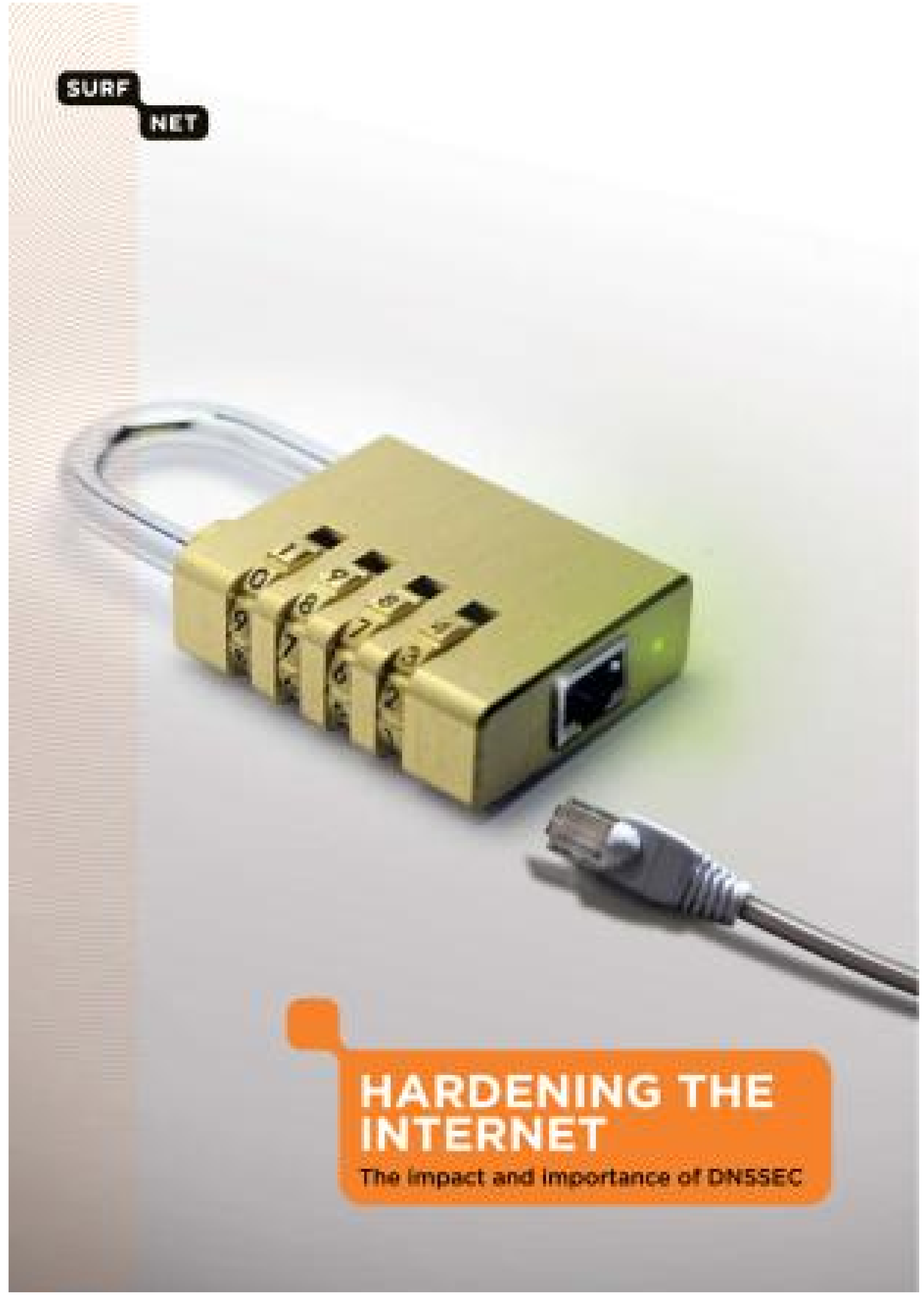

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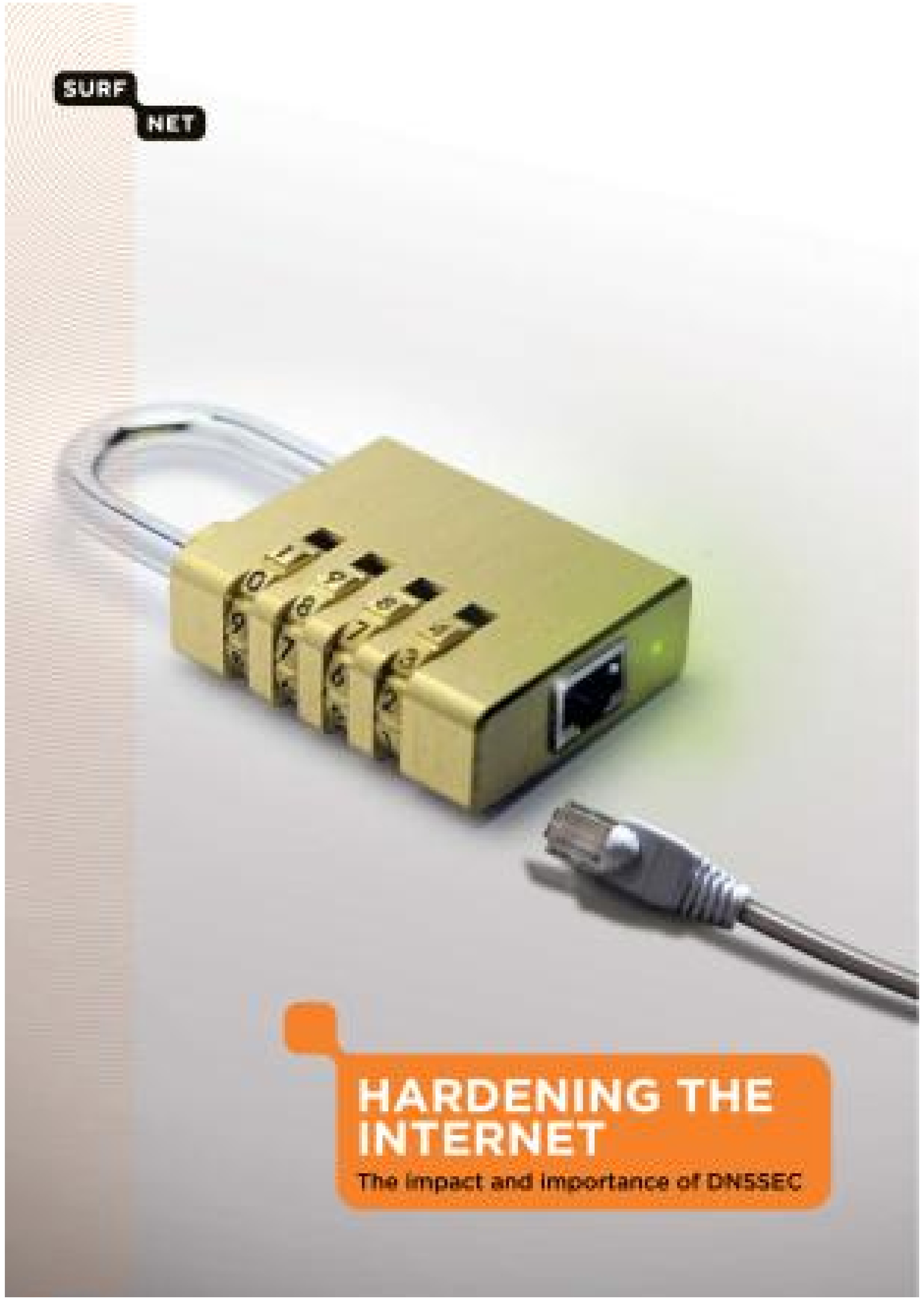

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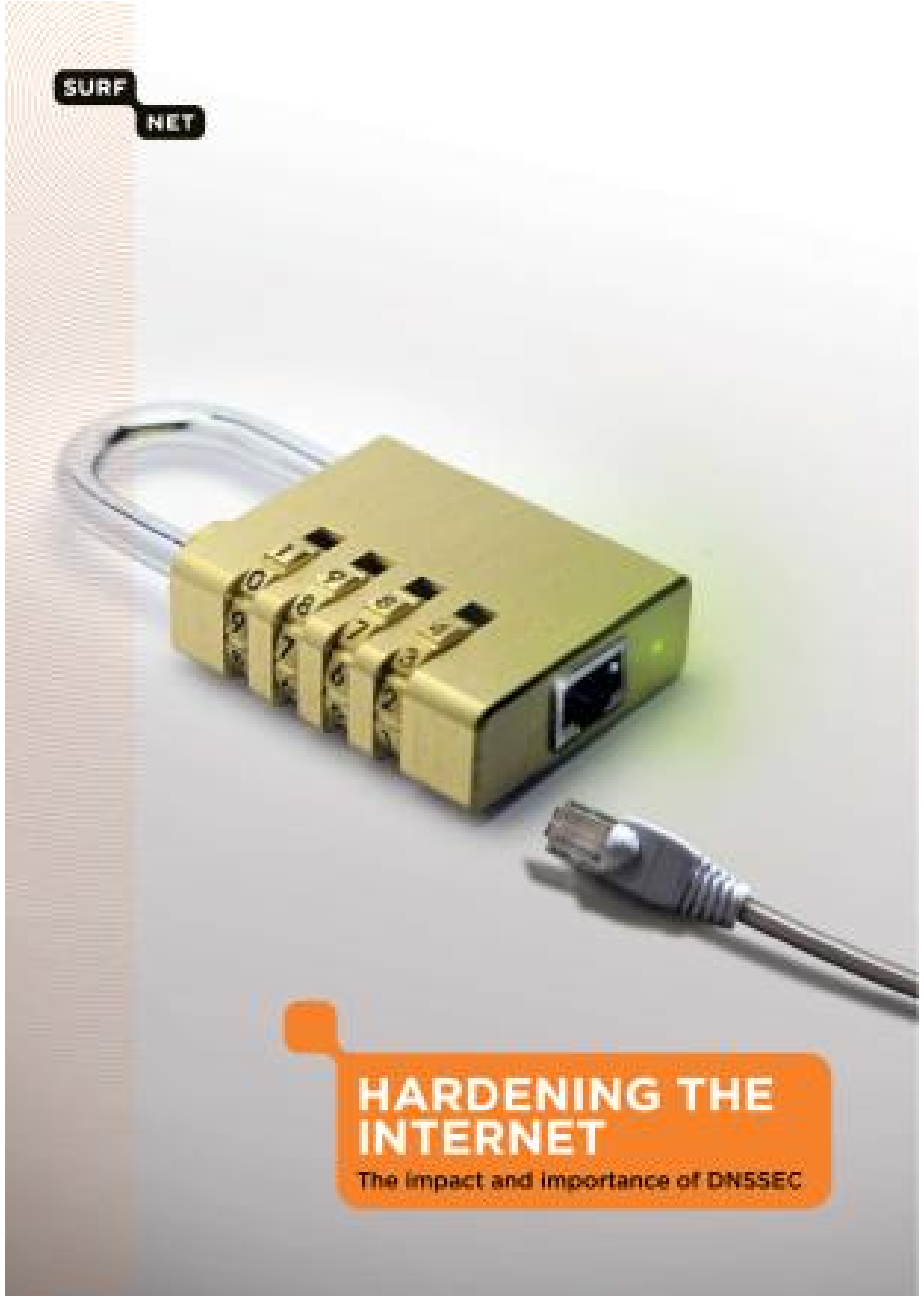

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What about serious attackers using many more computers? e.g. botnet operators?

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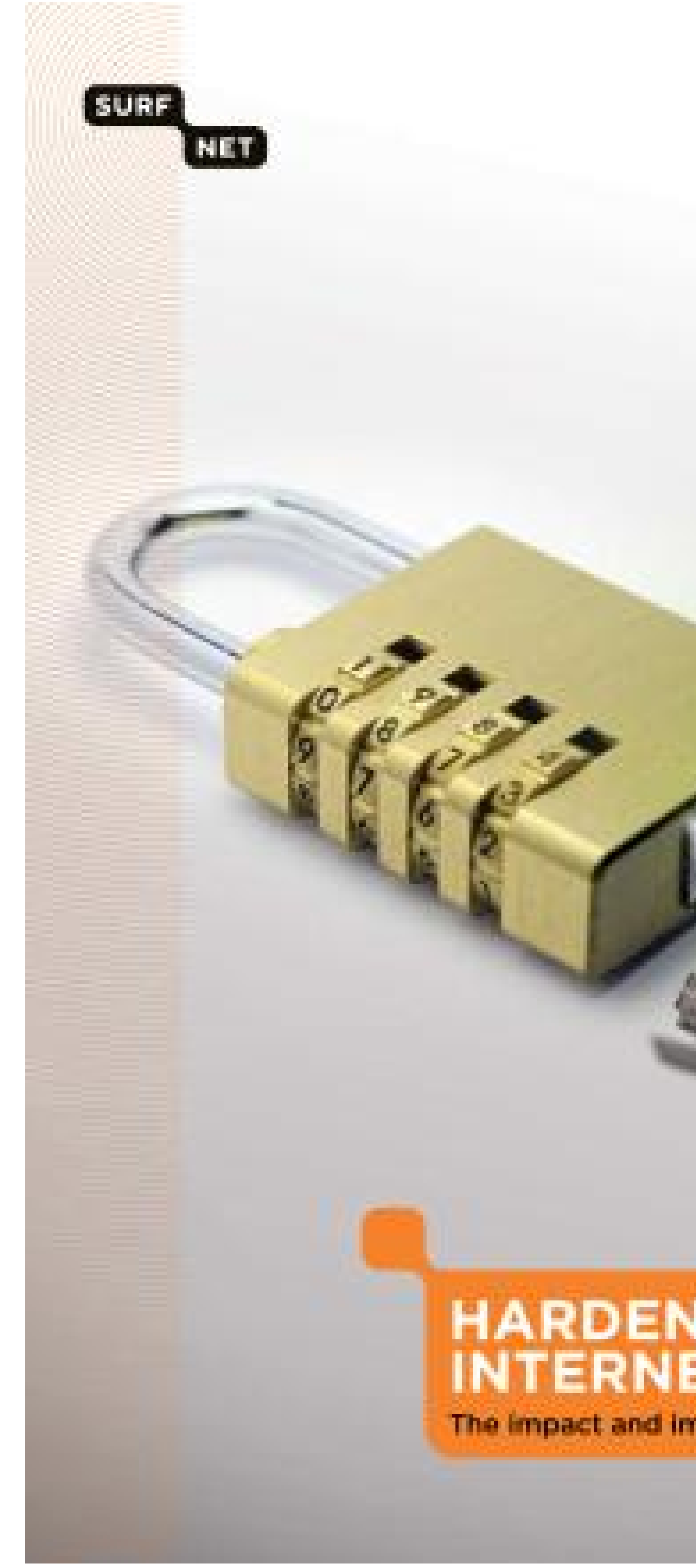

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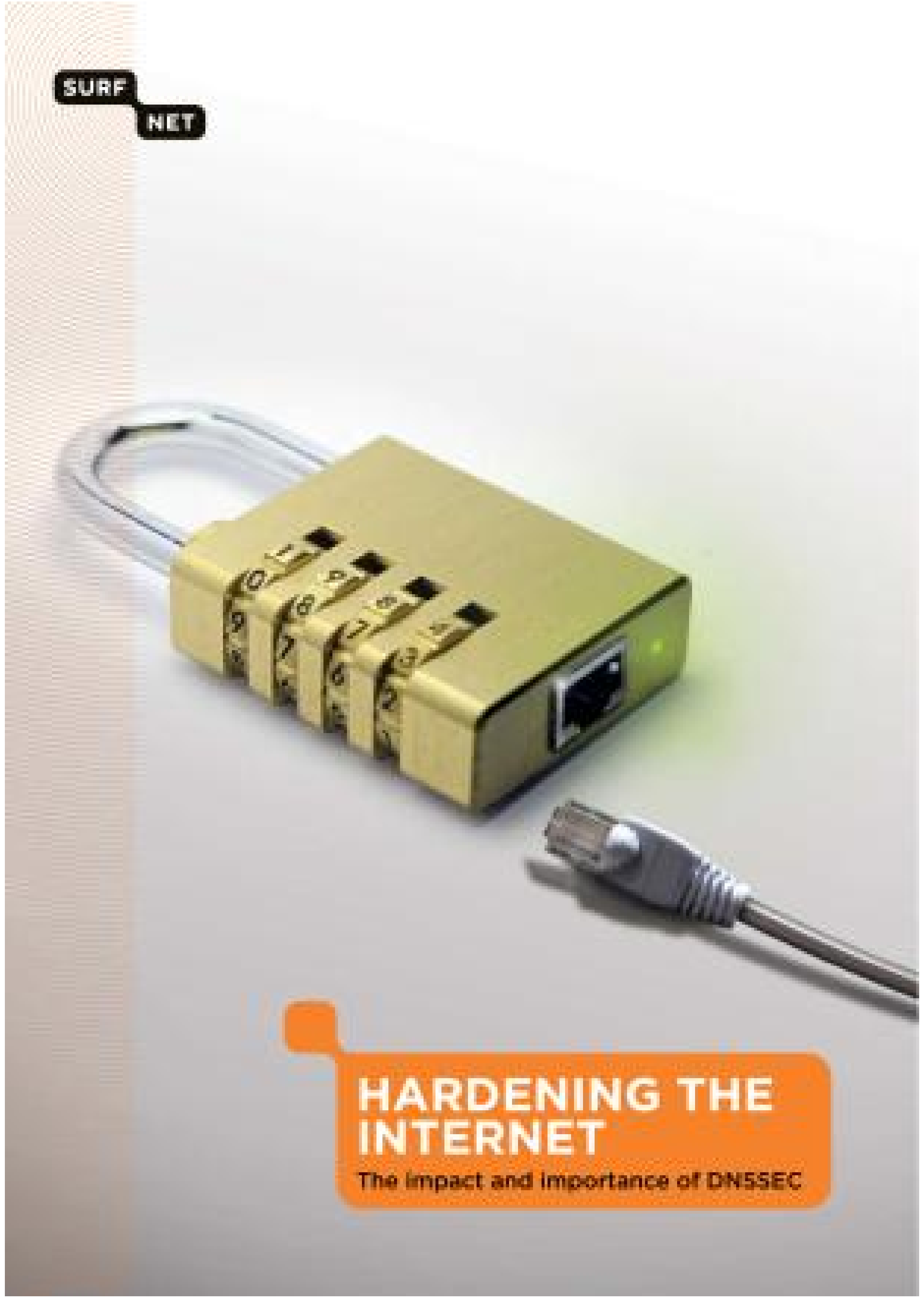

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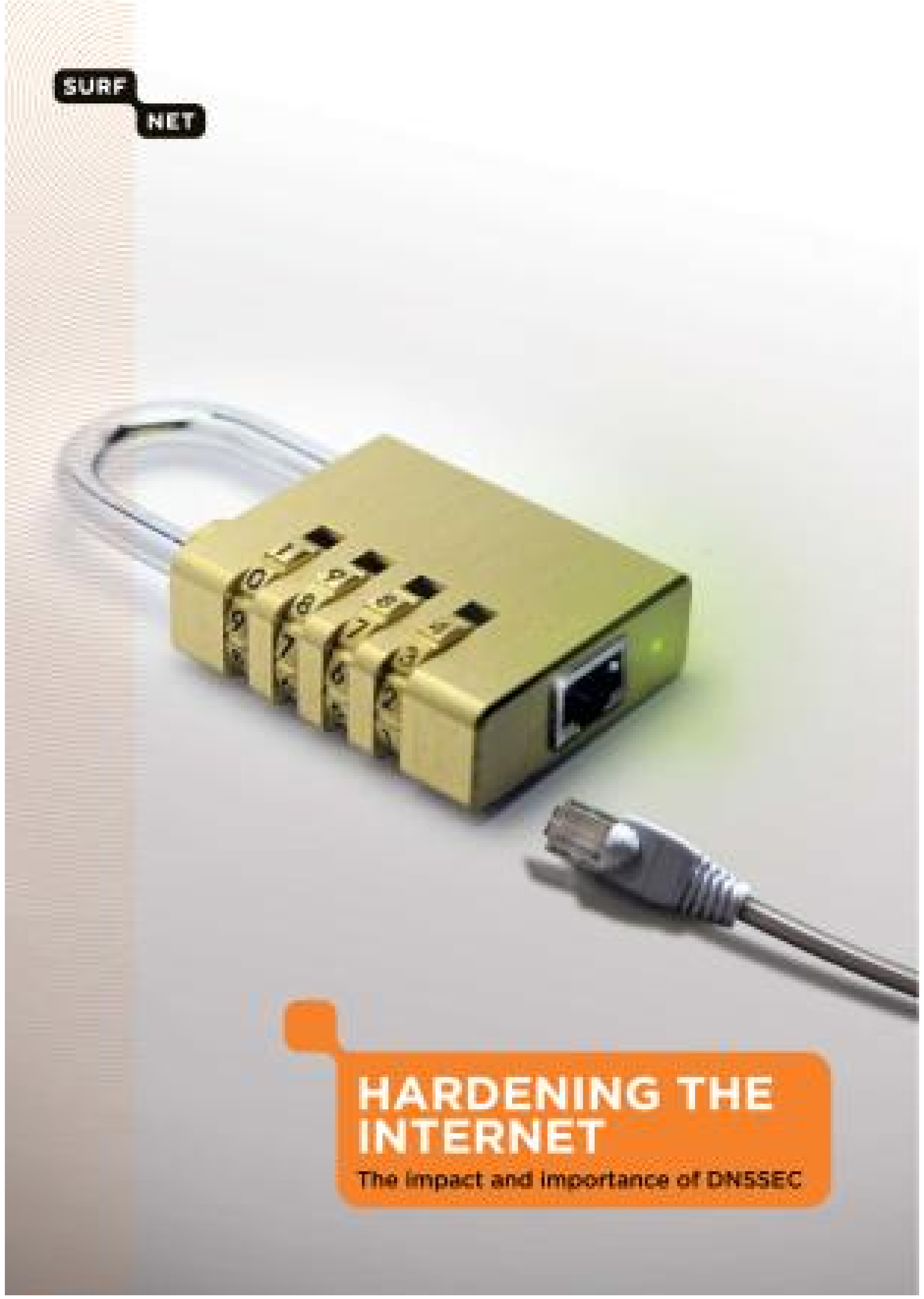

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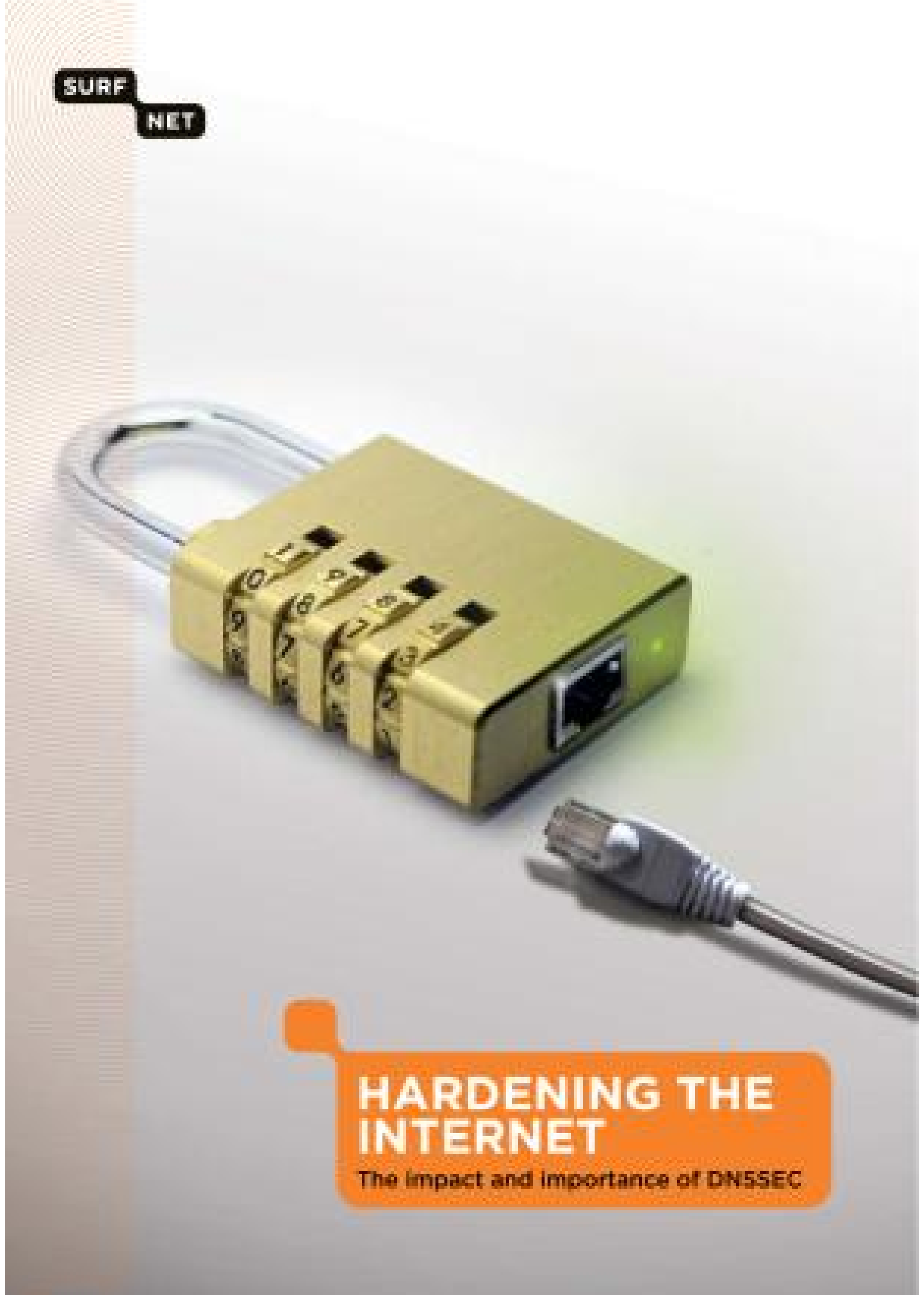

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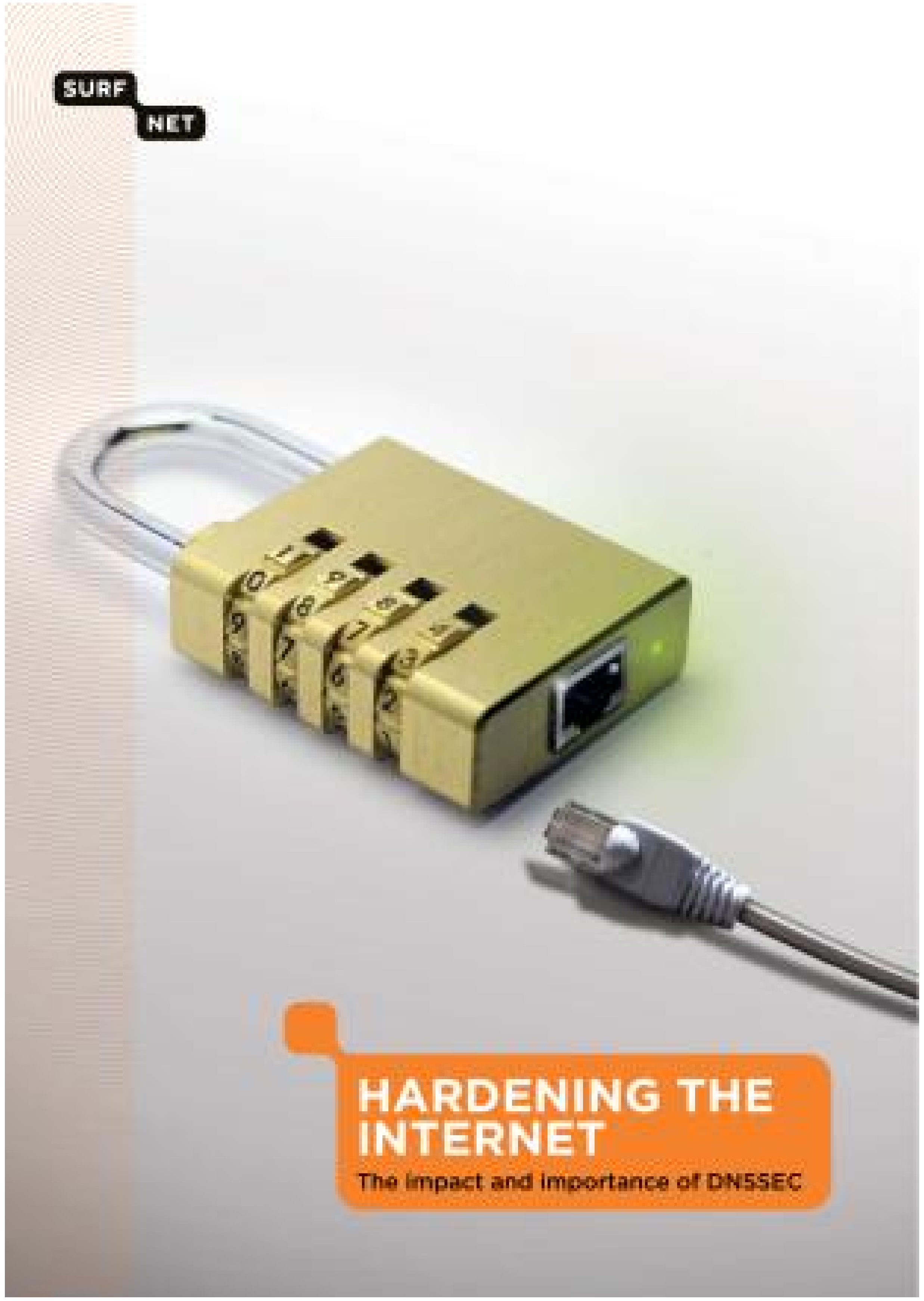

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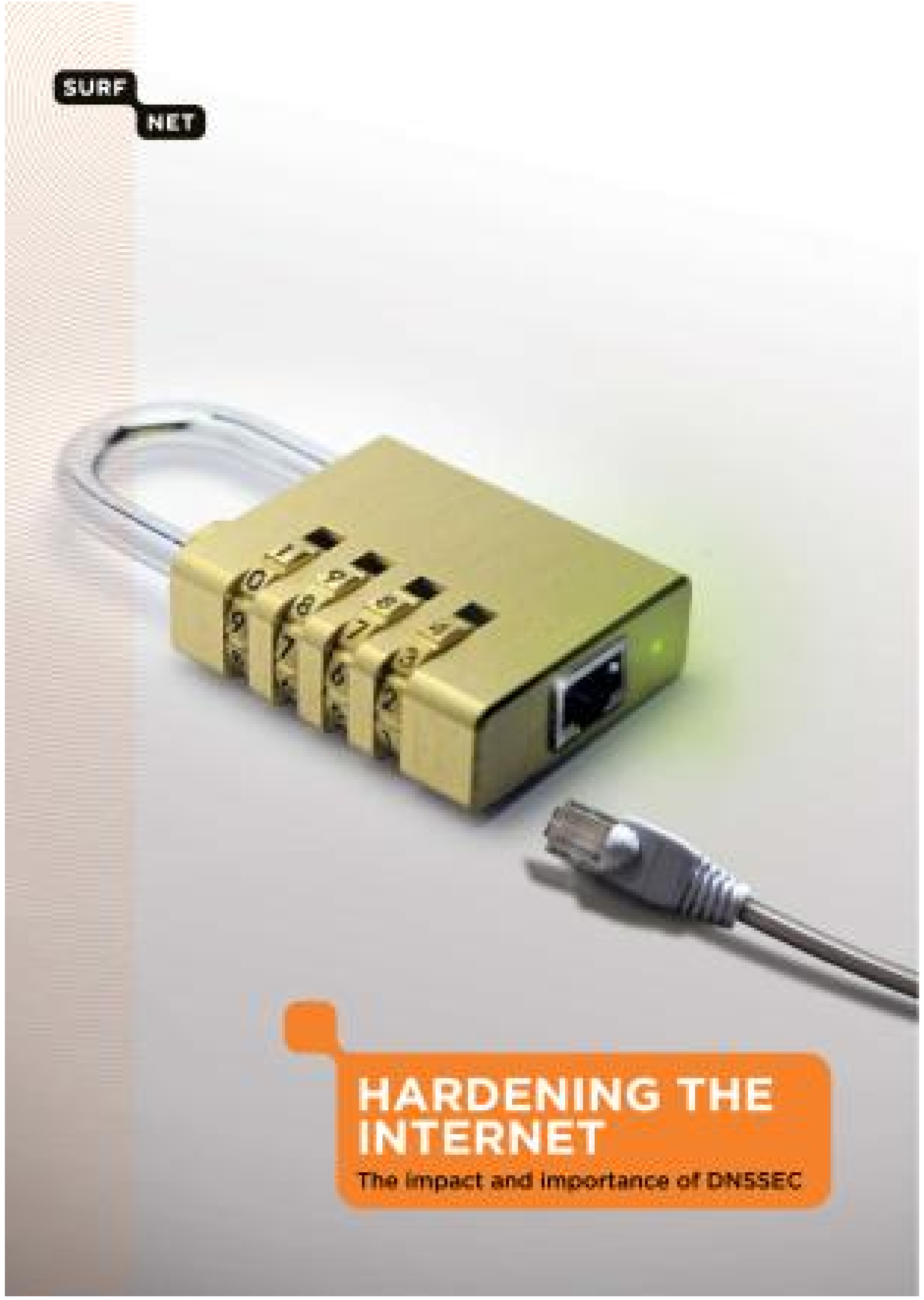

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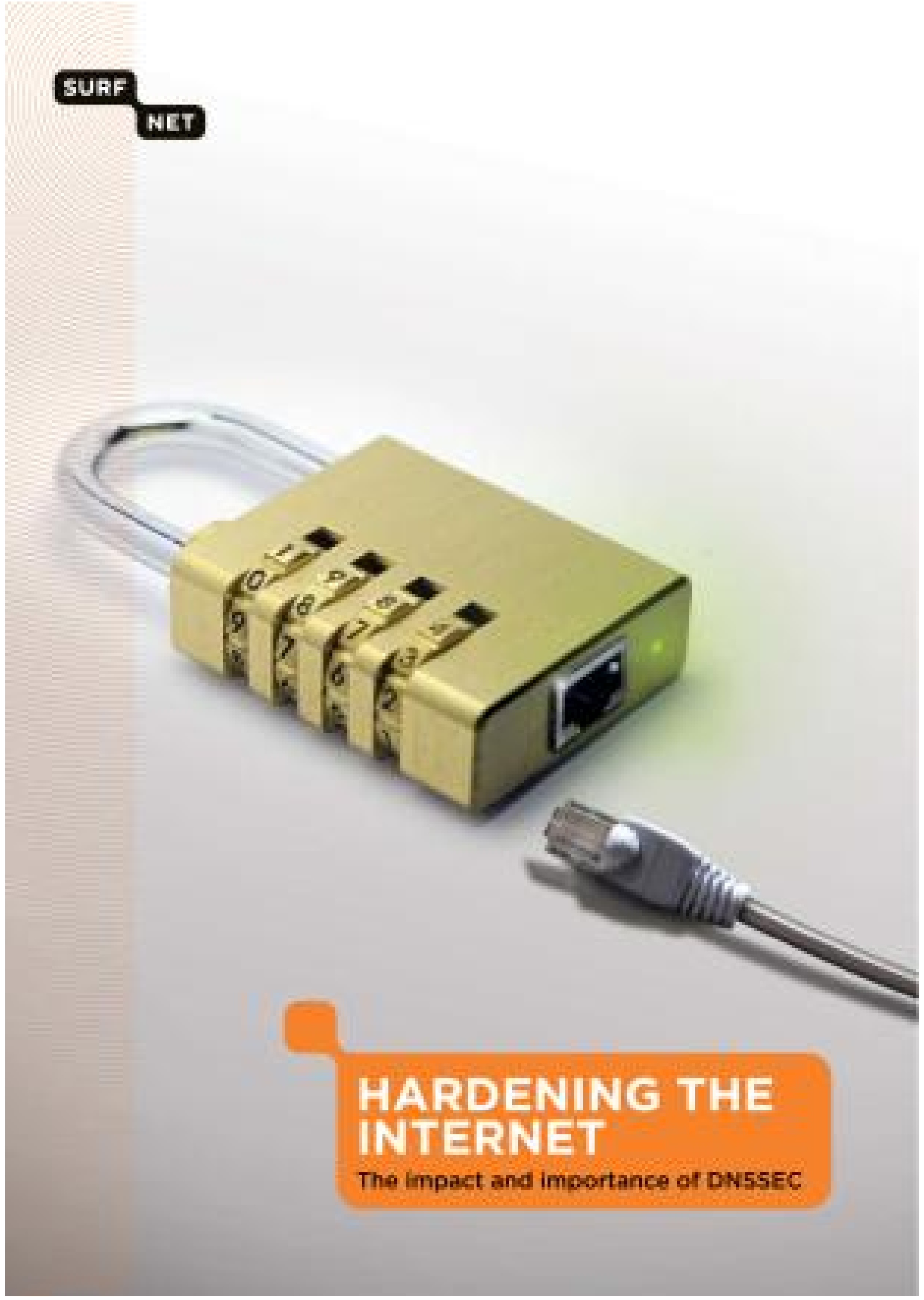

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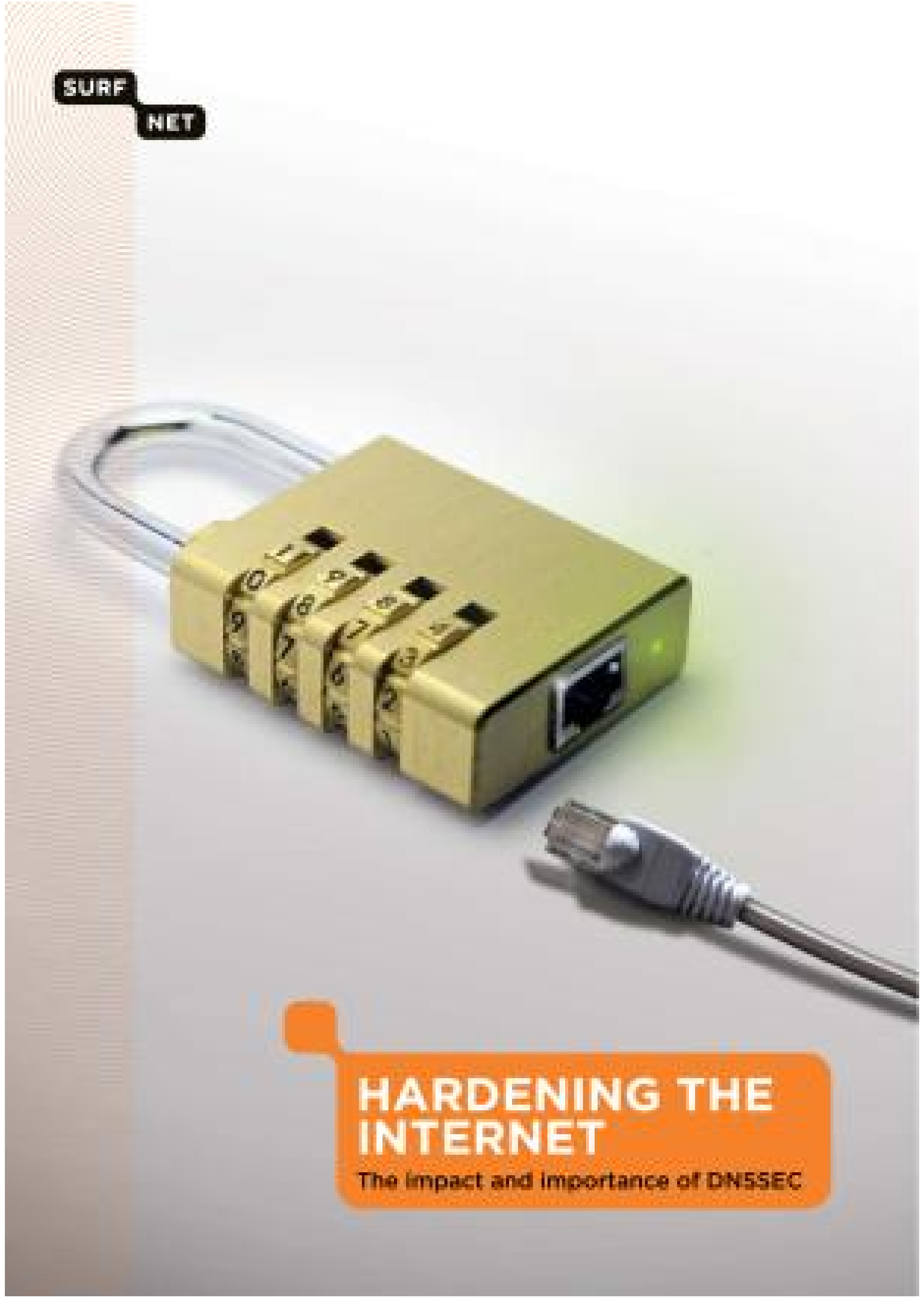

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Precomputation forced DNSSEC down a path of unreliability, insecurity, and unusability.
Let's see how this happened.

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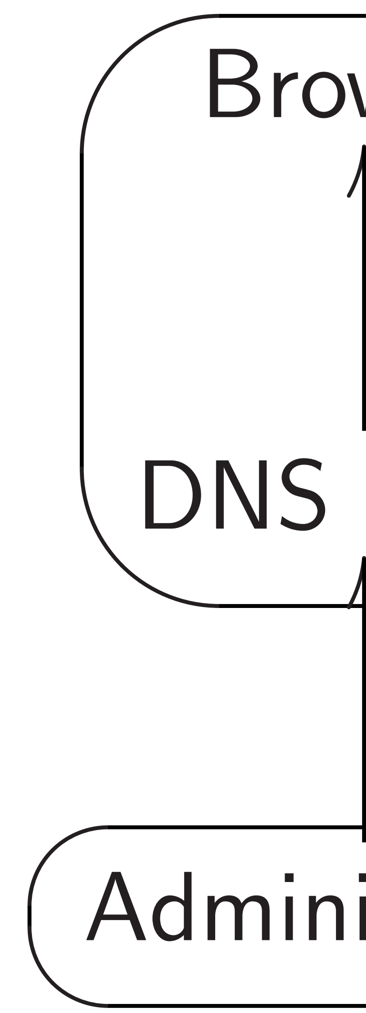

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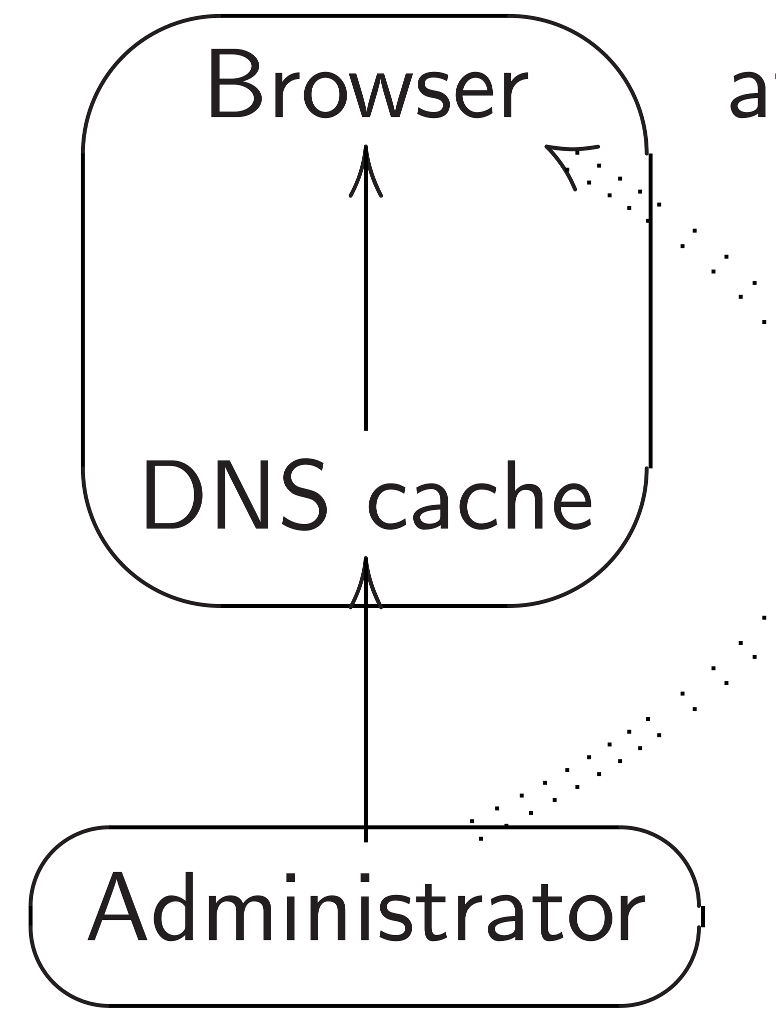

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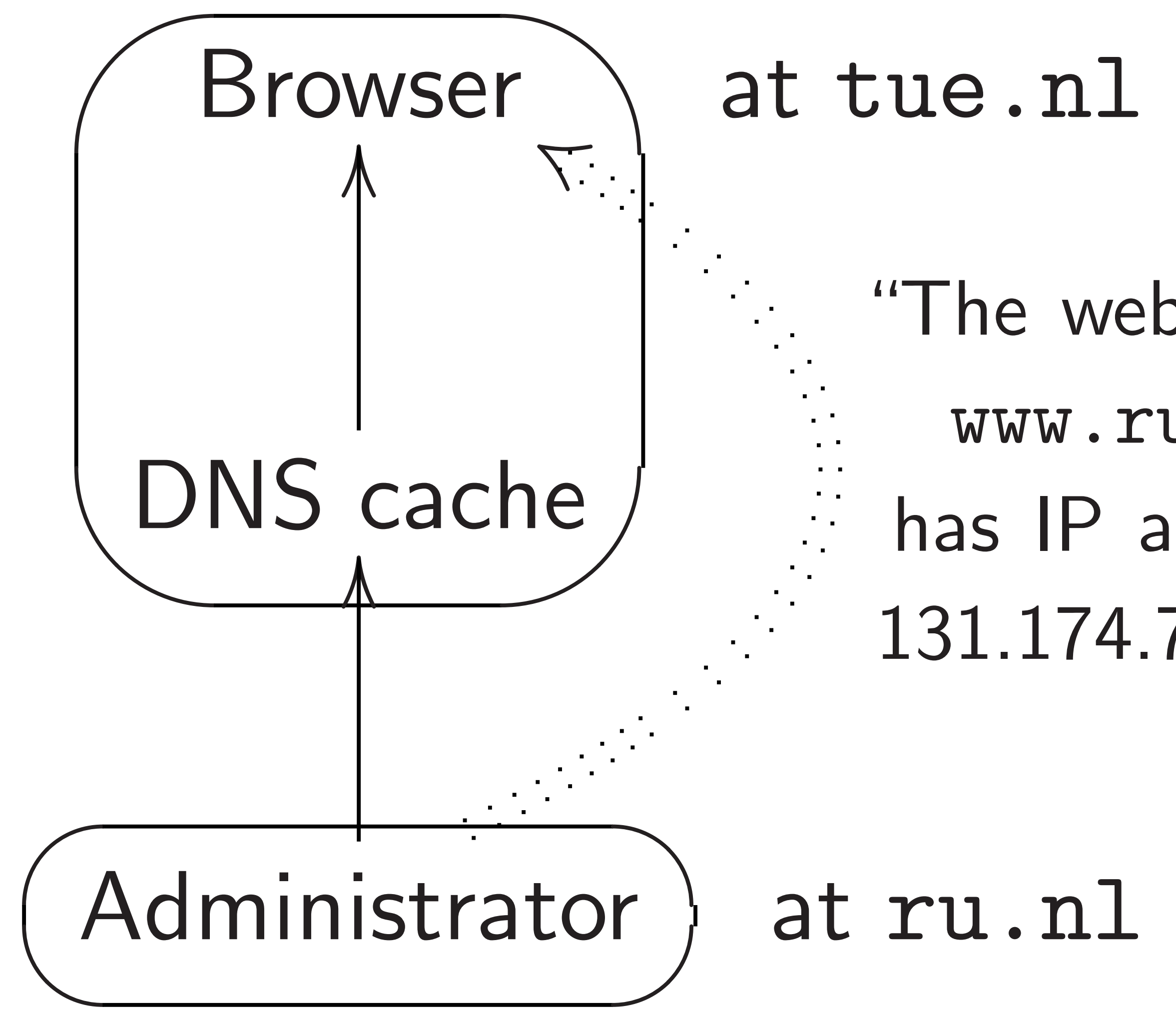

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DNSSEC made breakable choices such as 640-bit RSA for no reason other than fear of overload.

DNSSEC needed more options to survive the inevitable breaks. More complexity ⇒ more bugs, including security holes.

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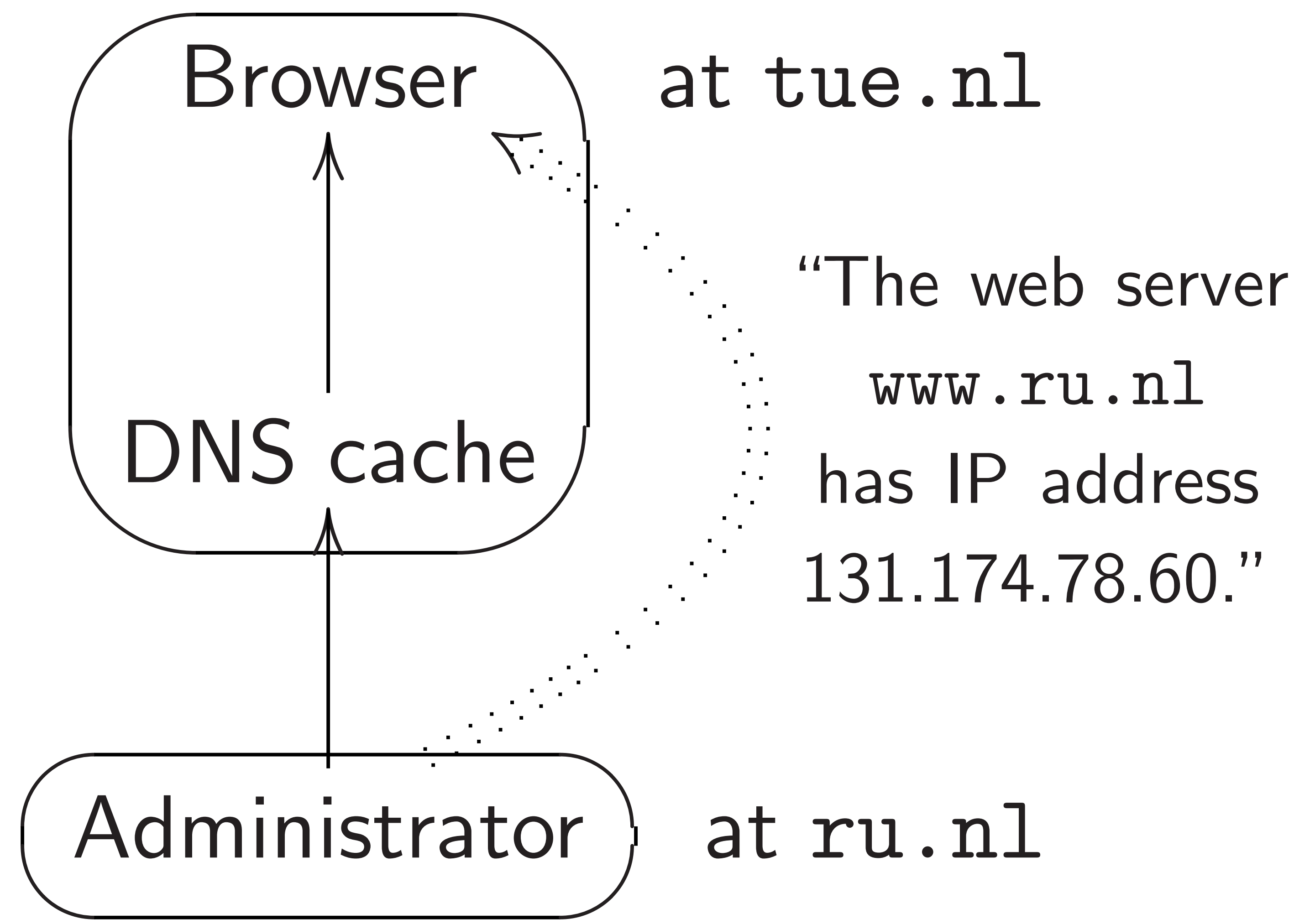

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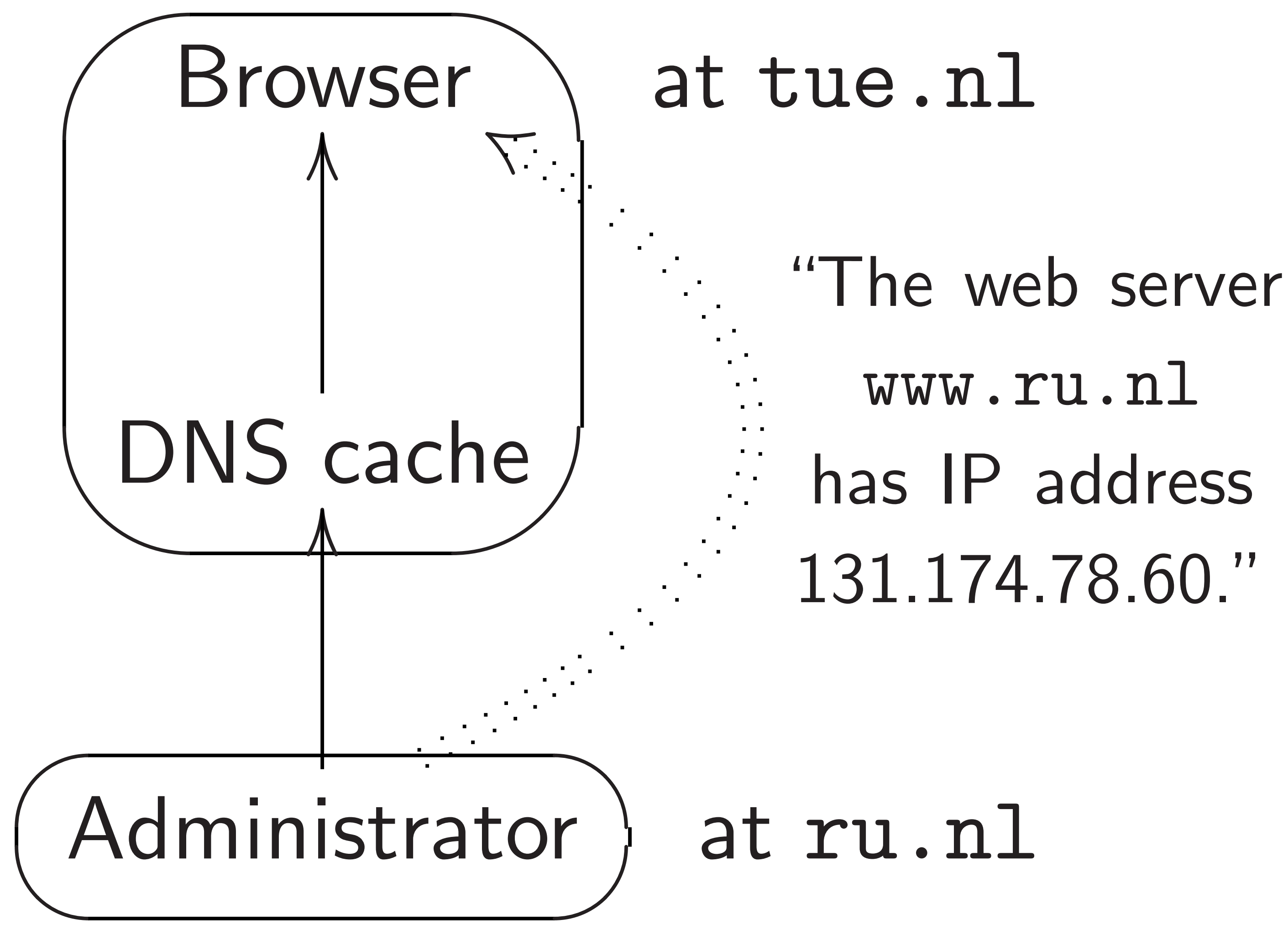

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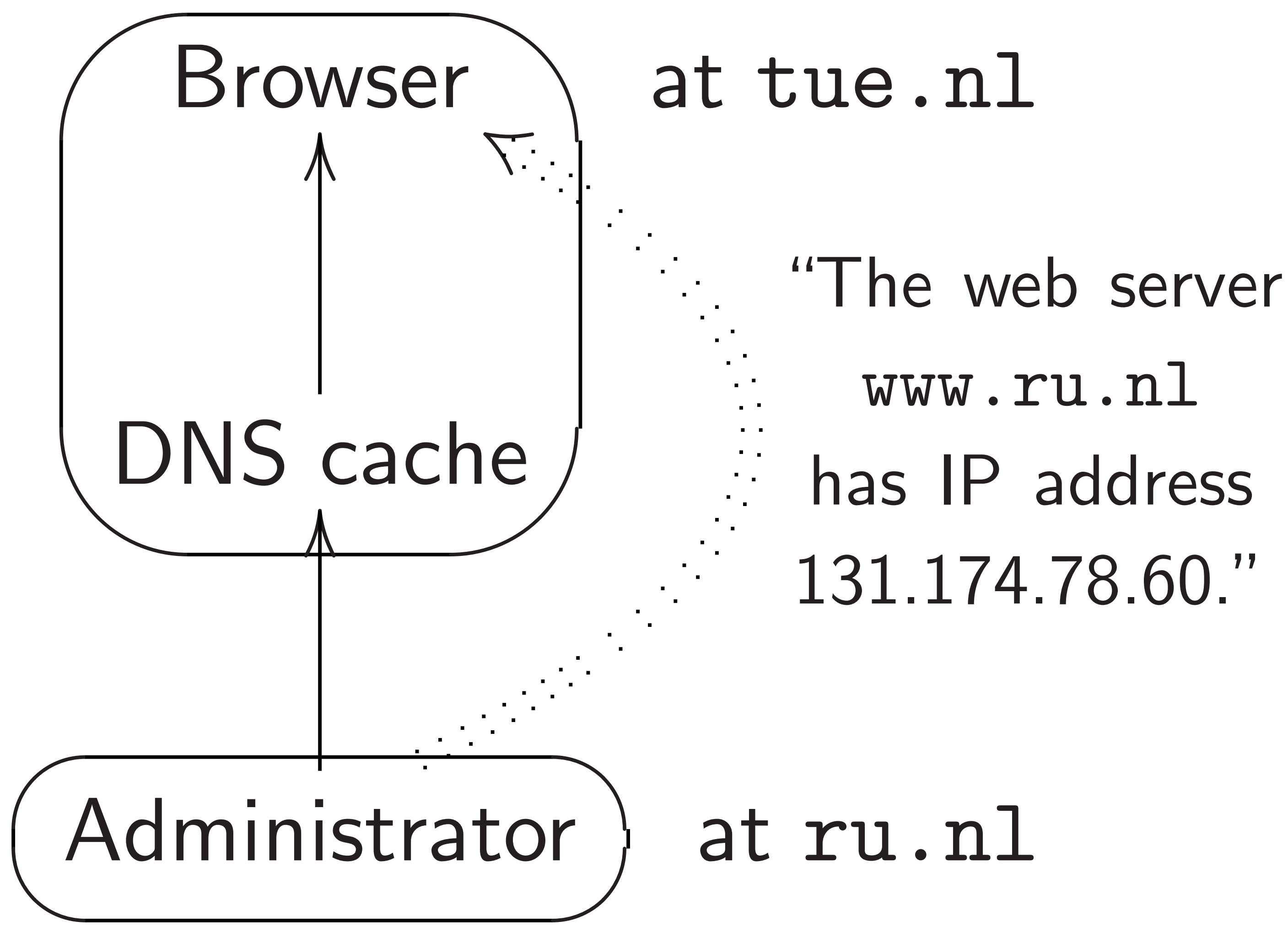

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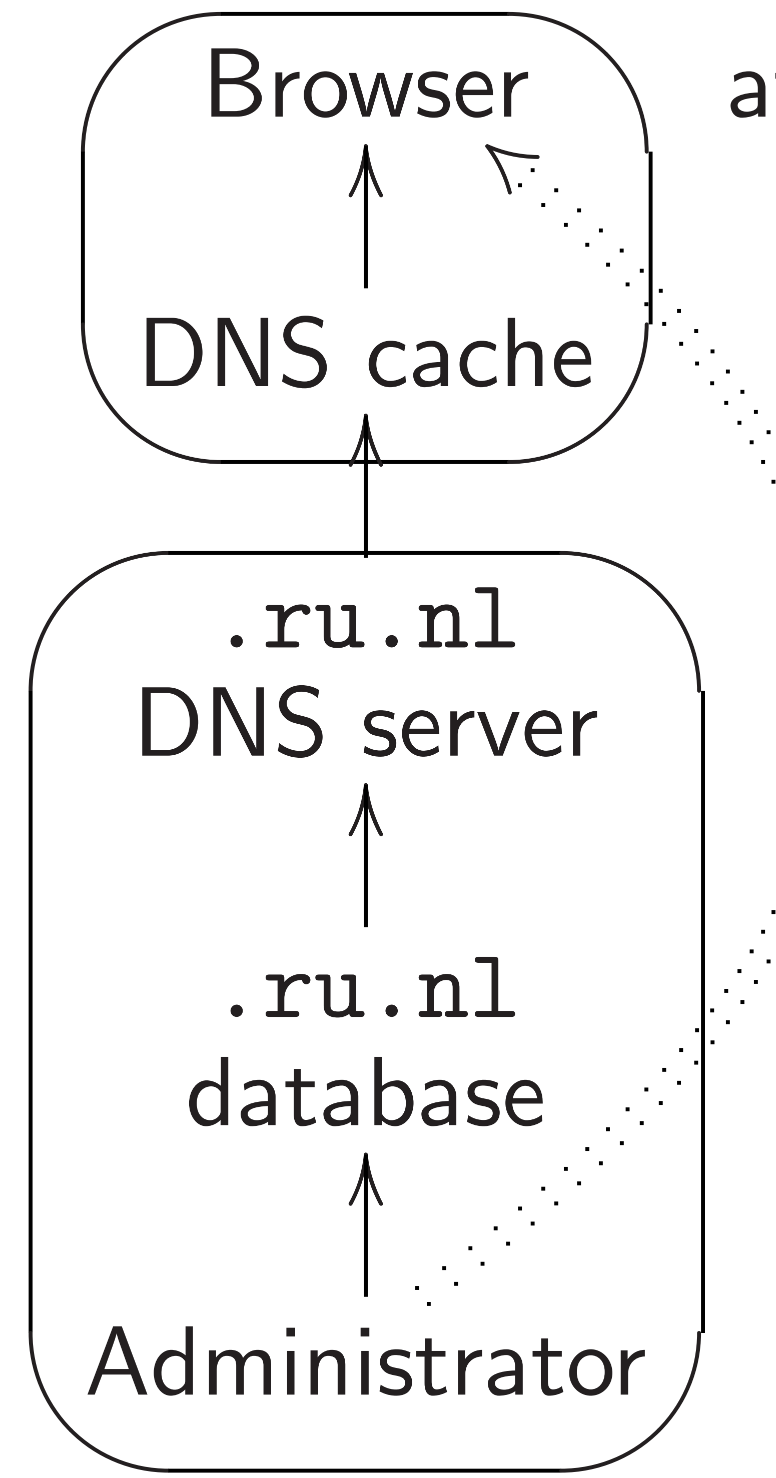

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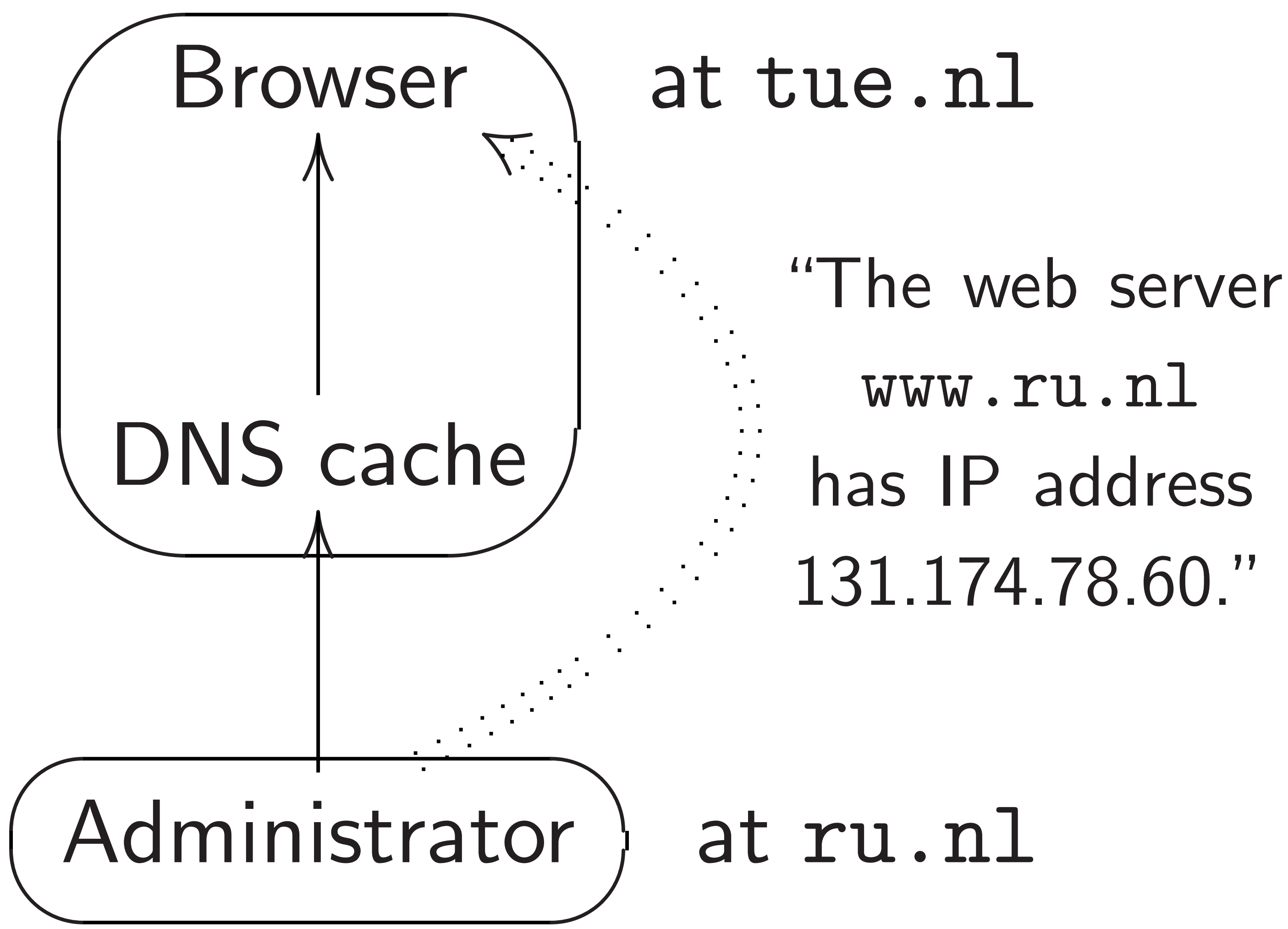

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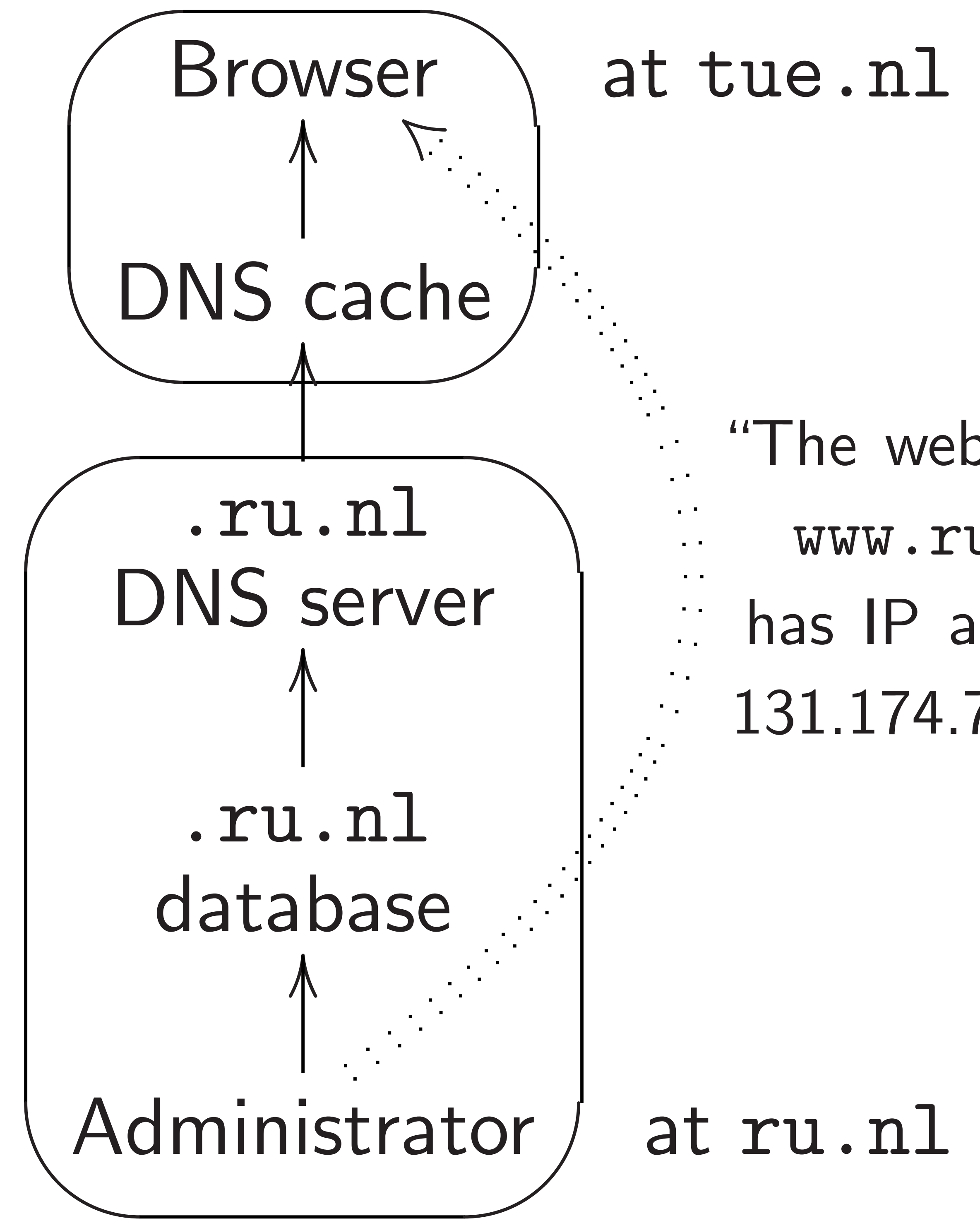

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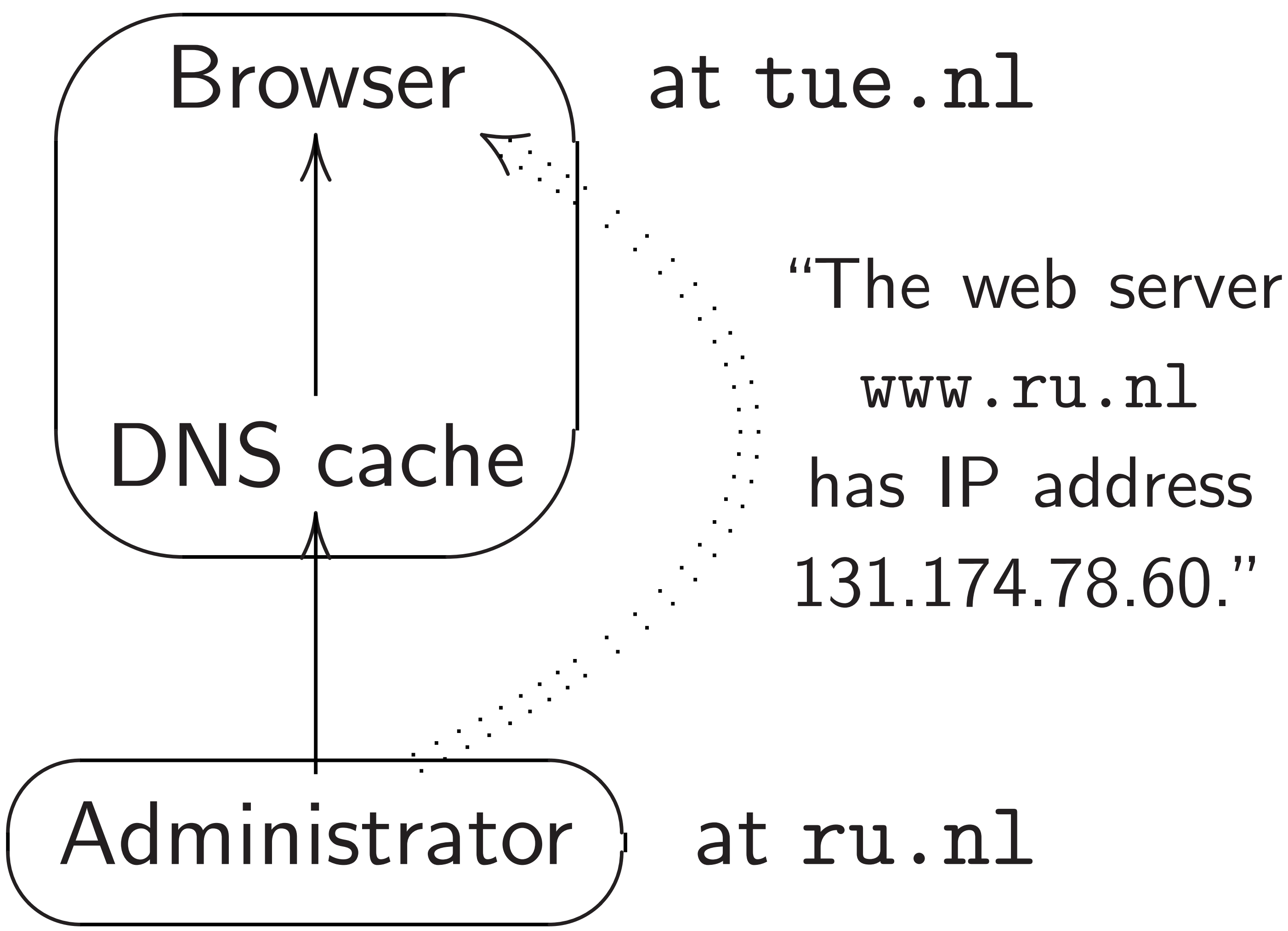

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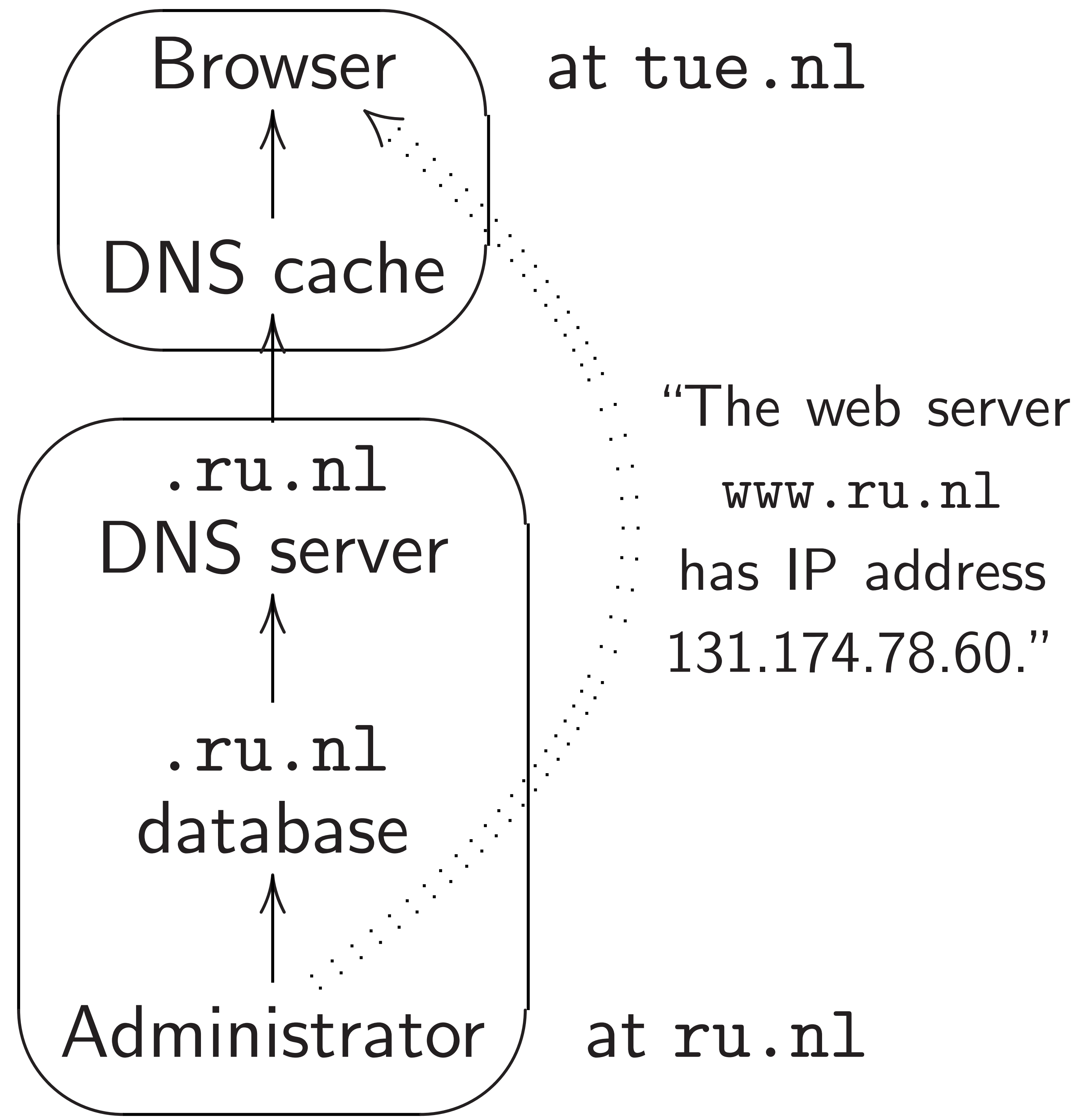

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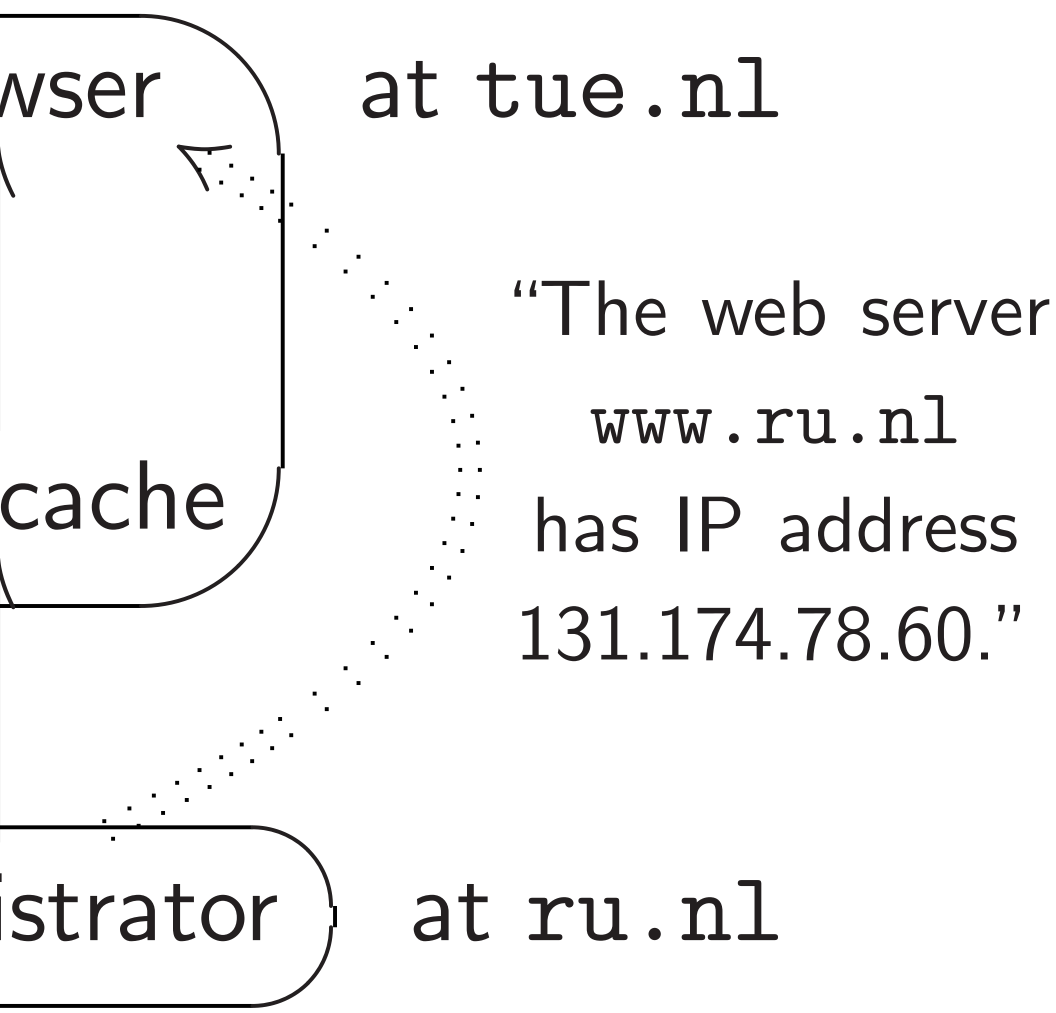

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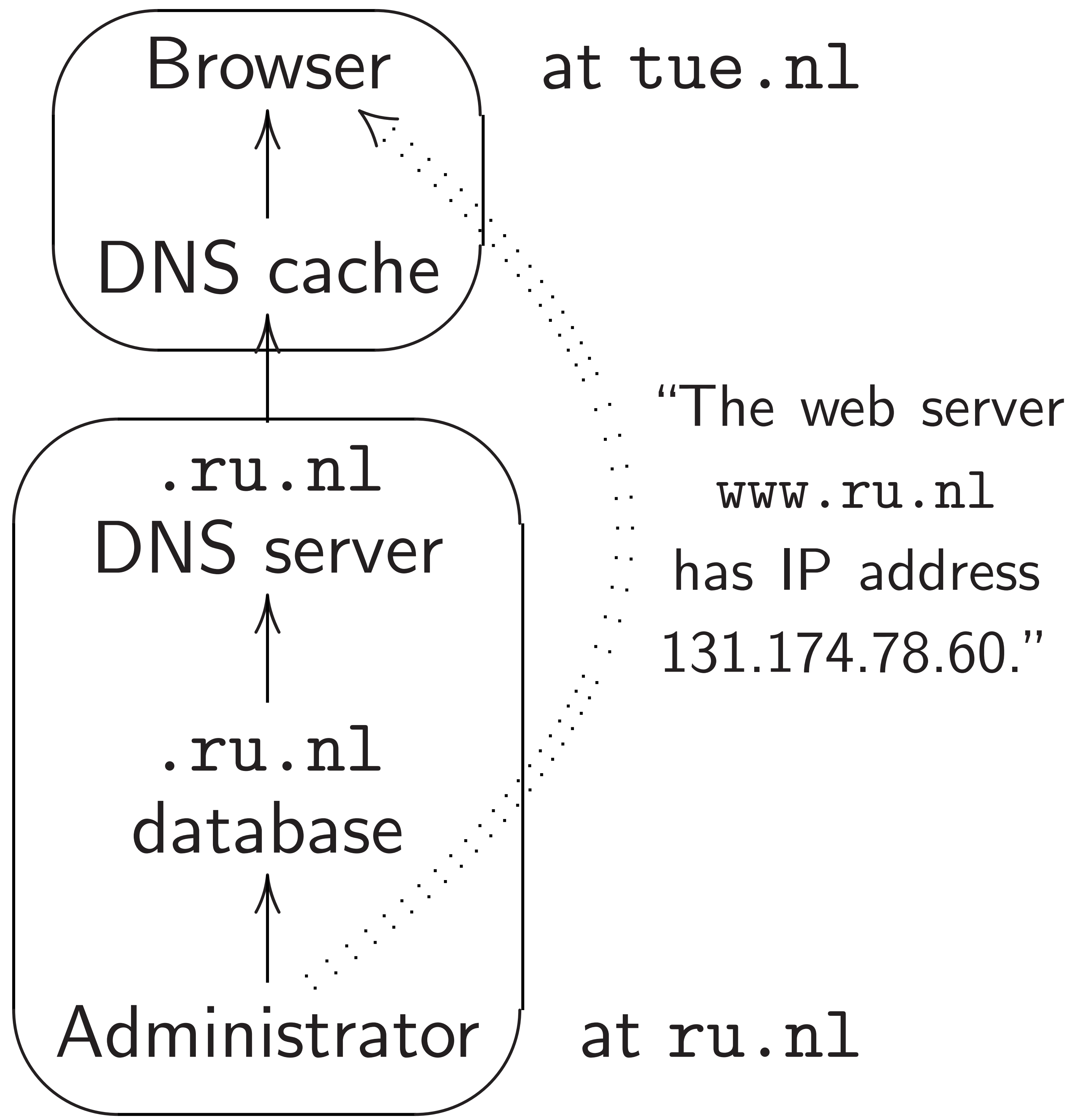

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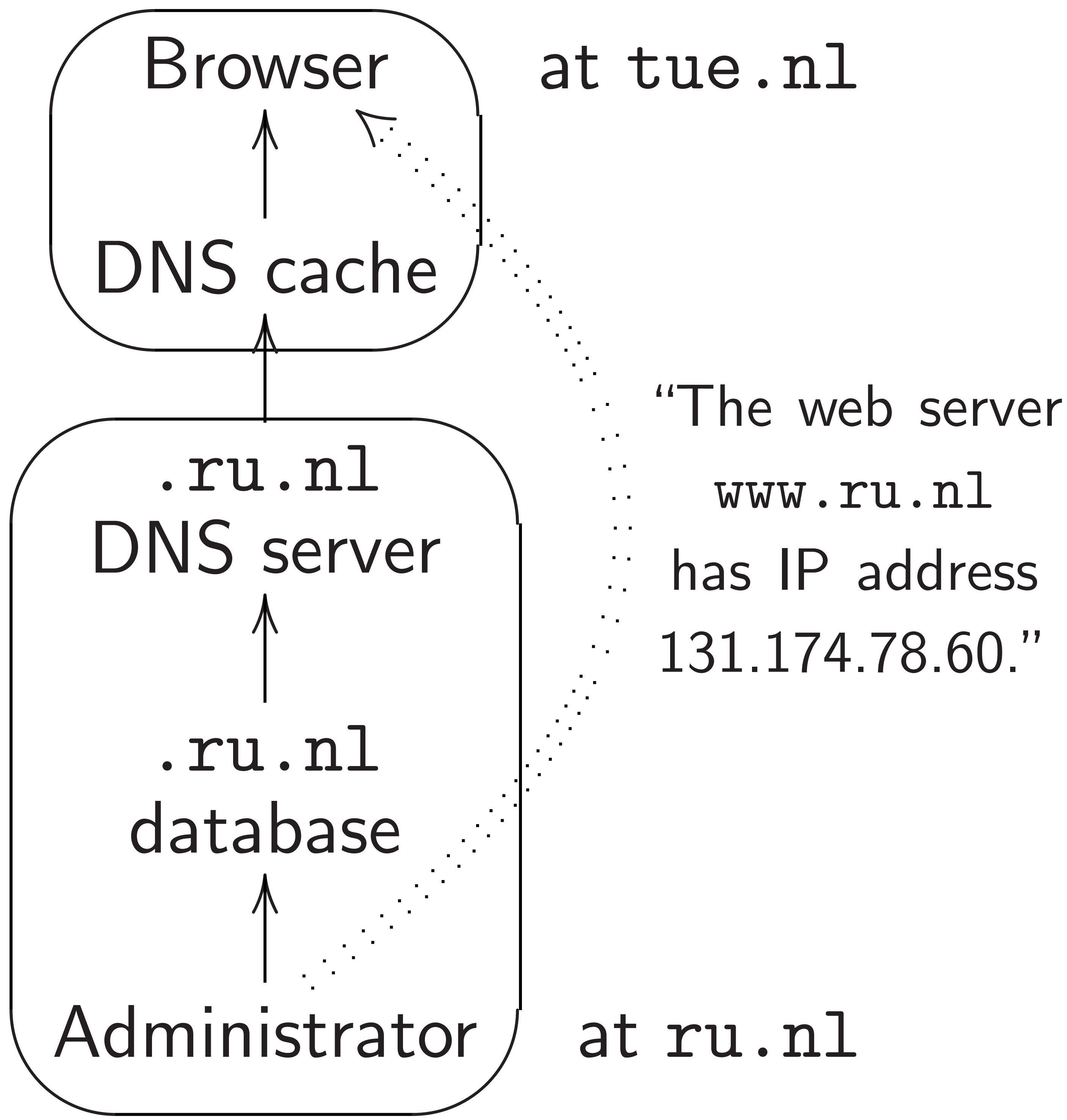

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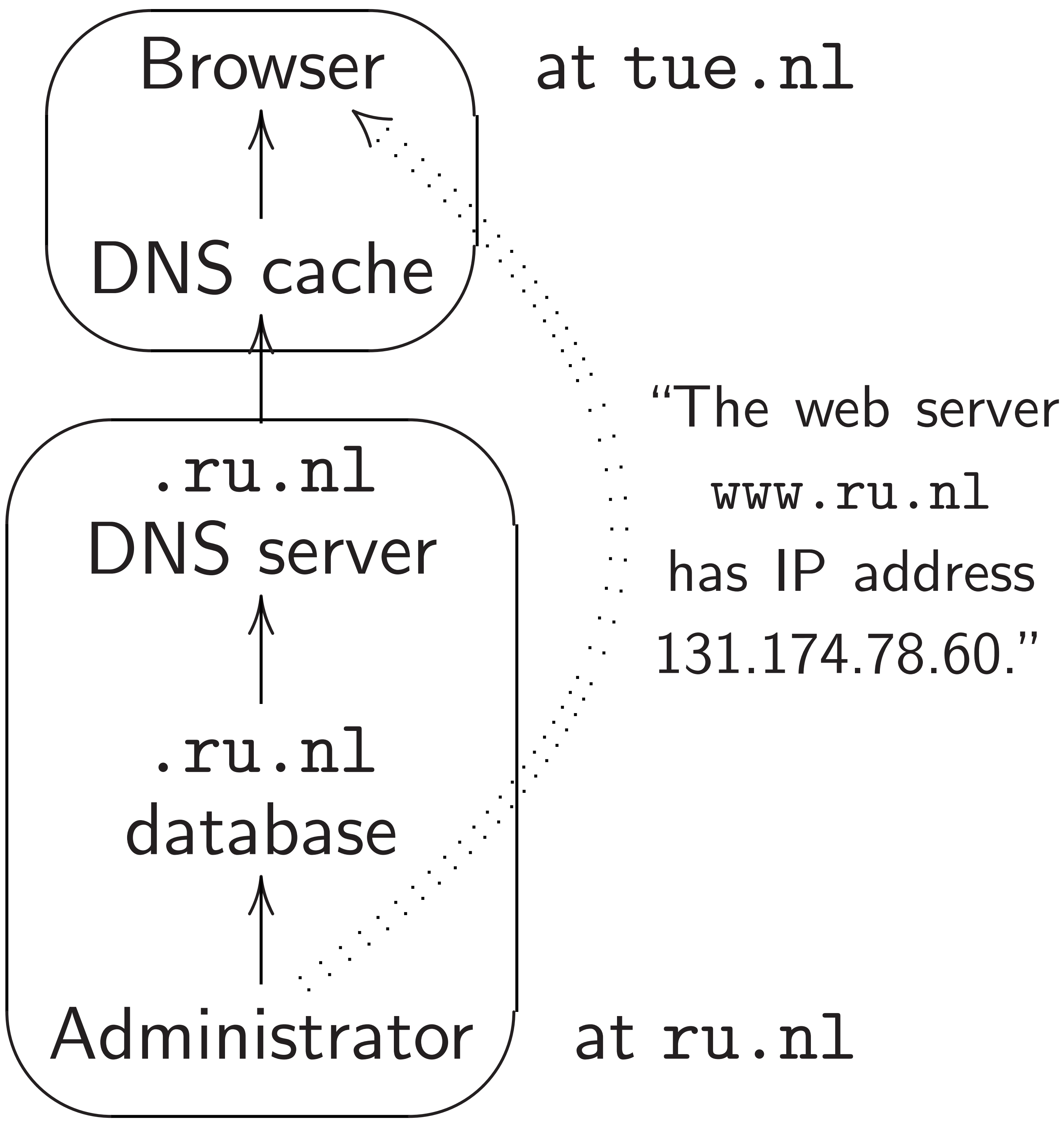

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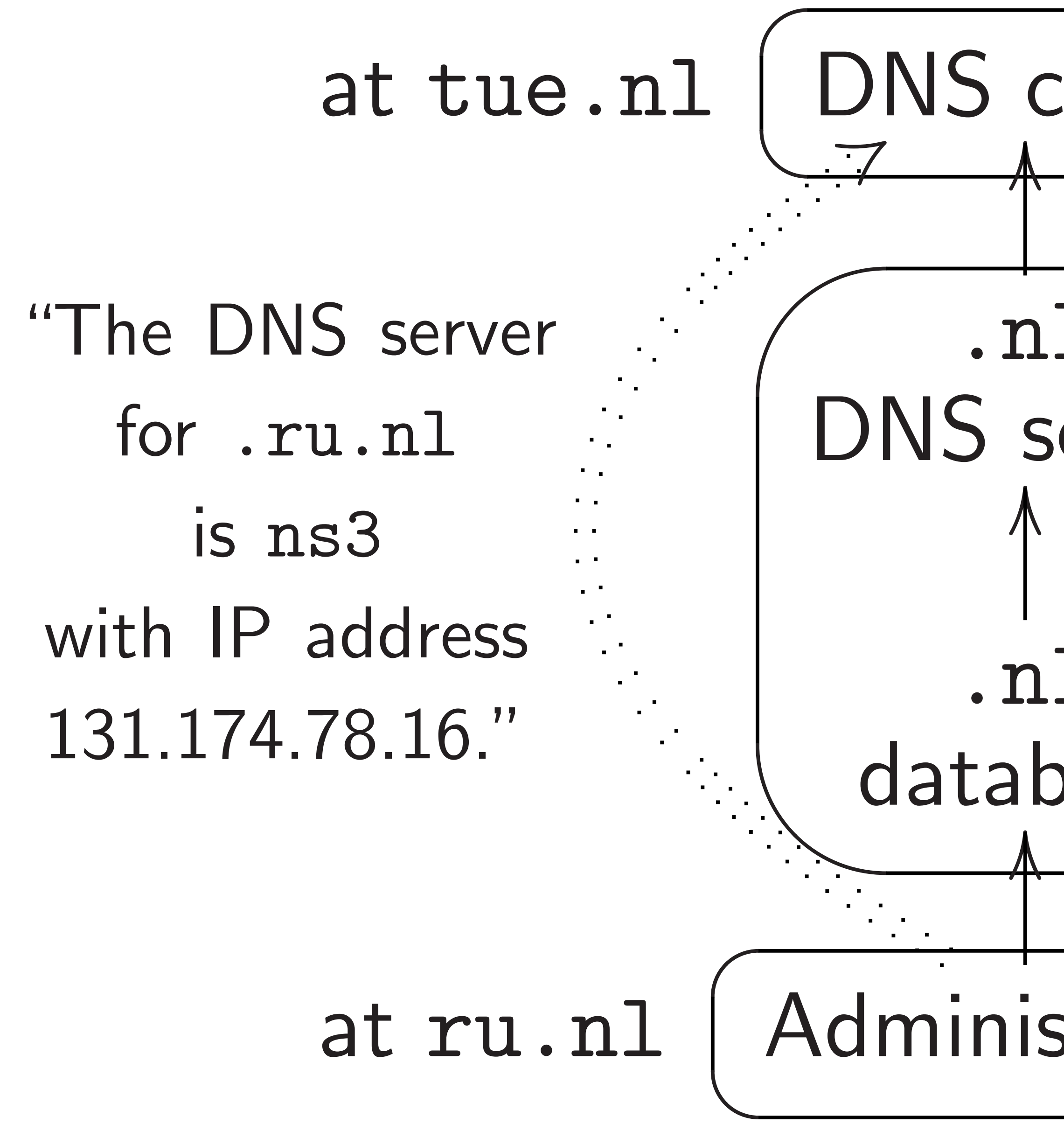

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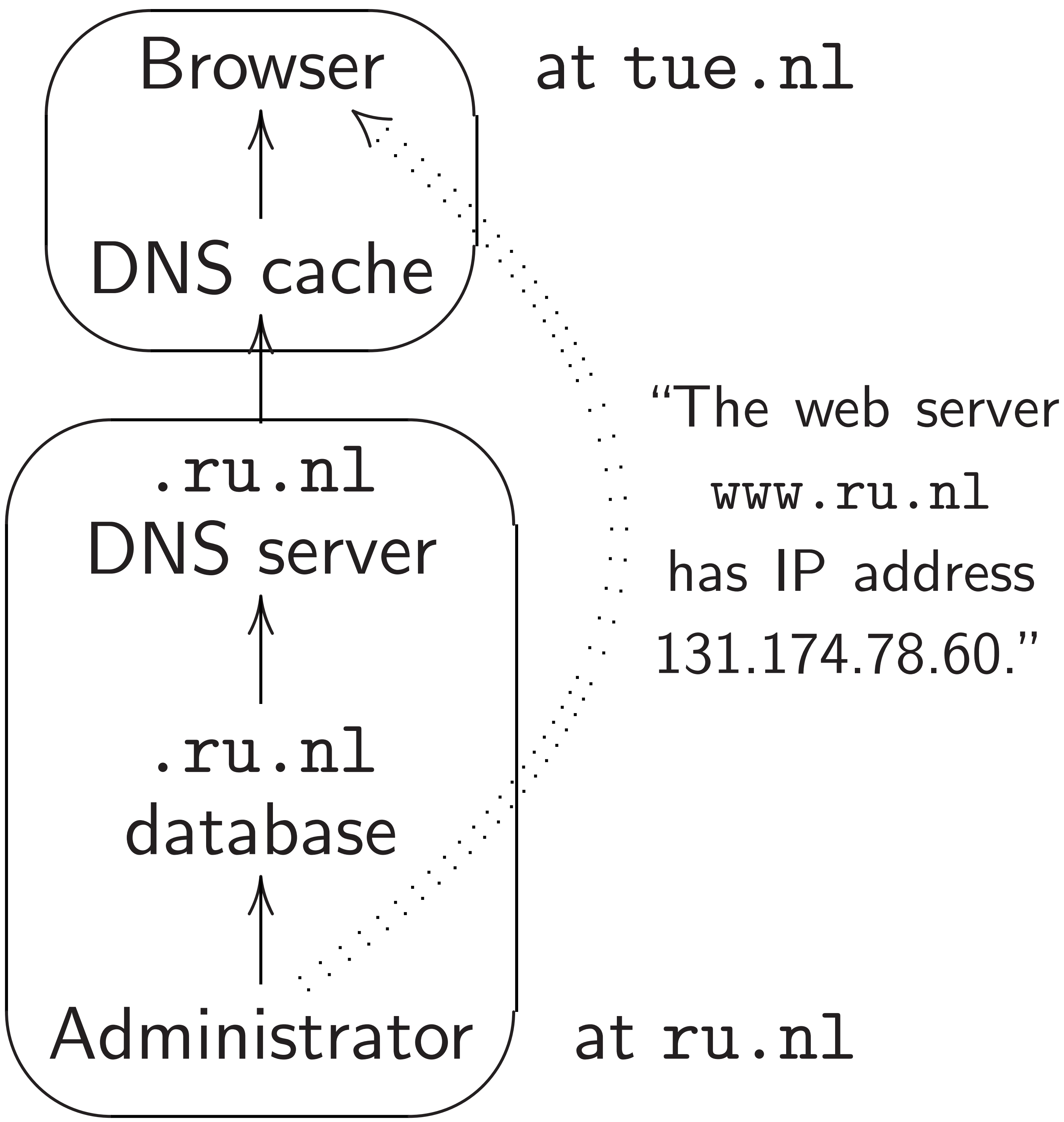

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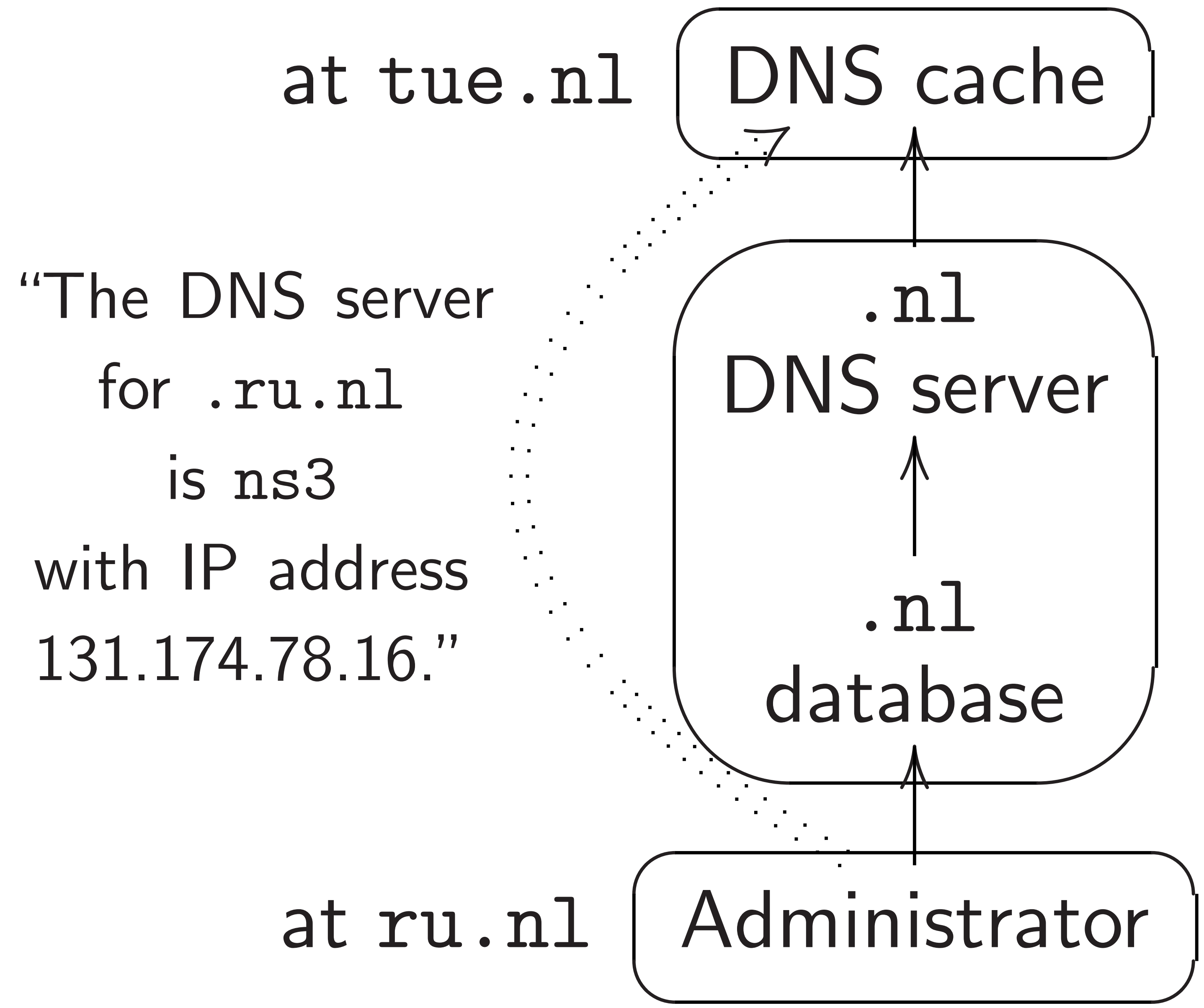

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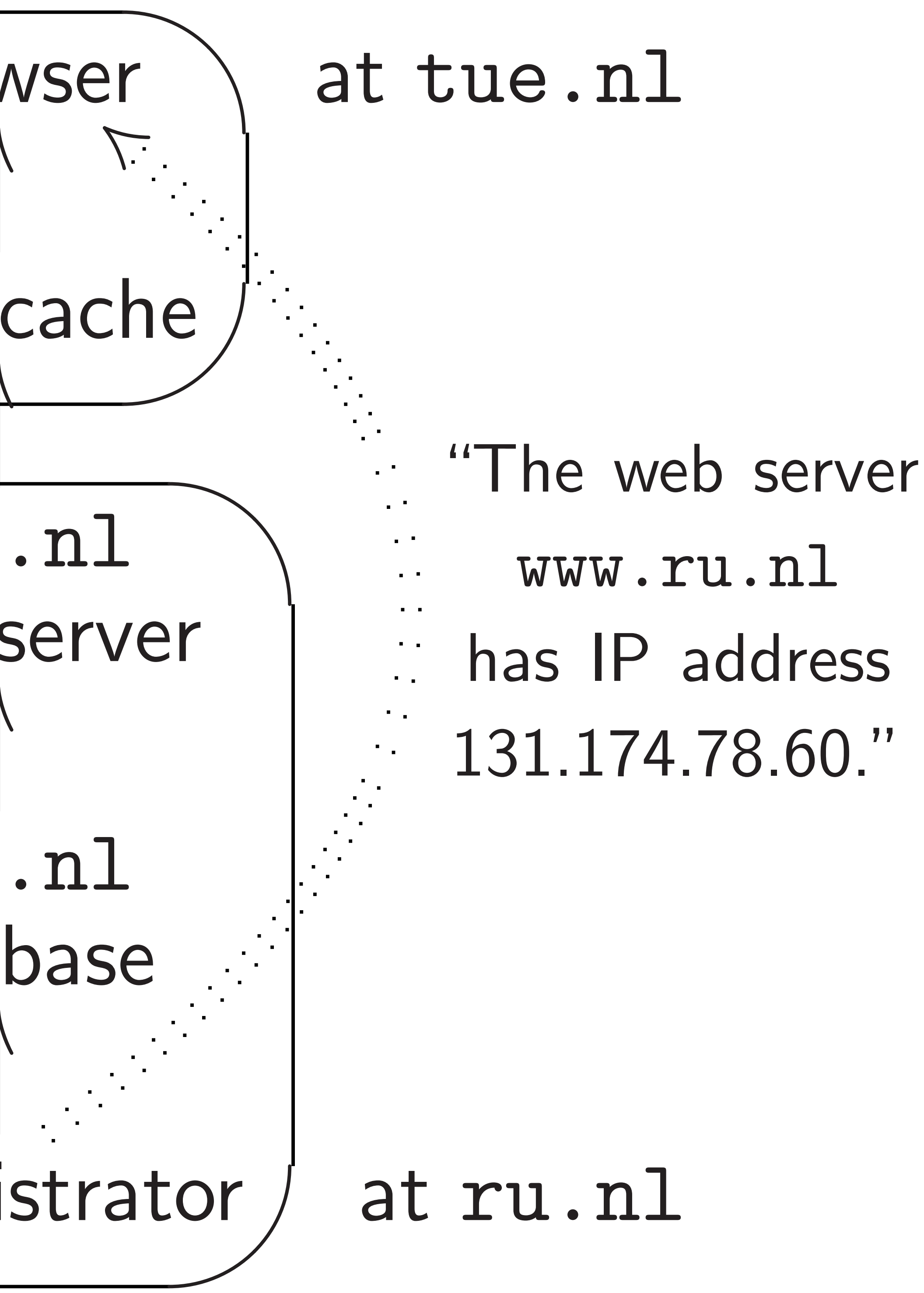

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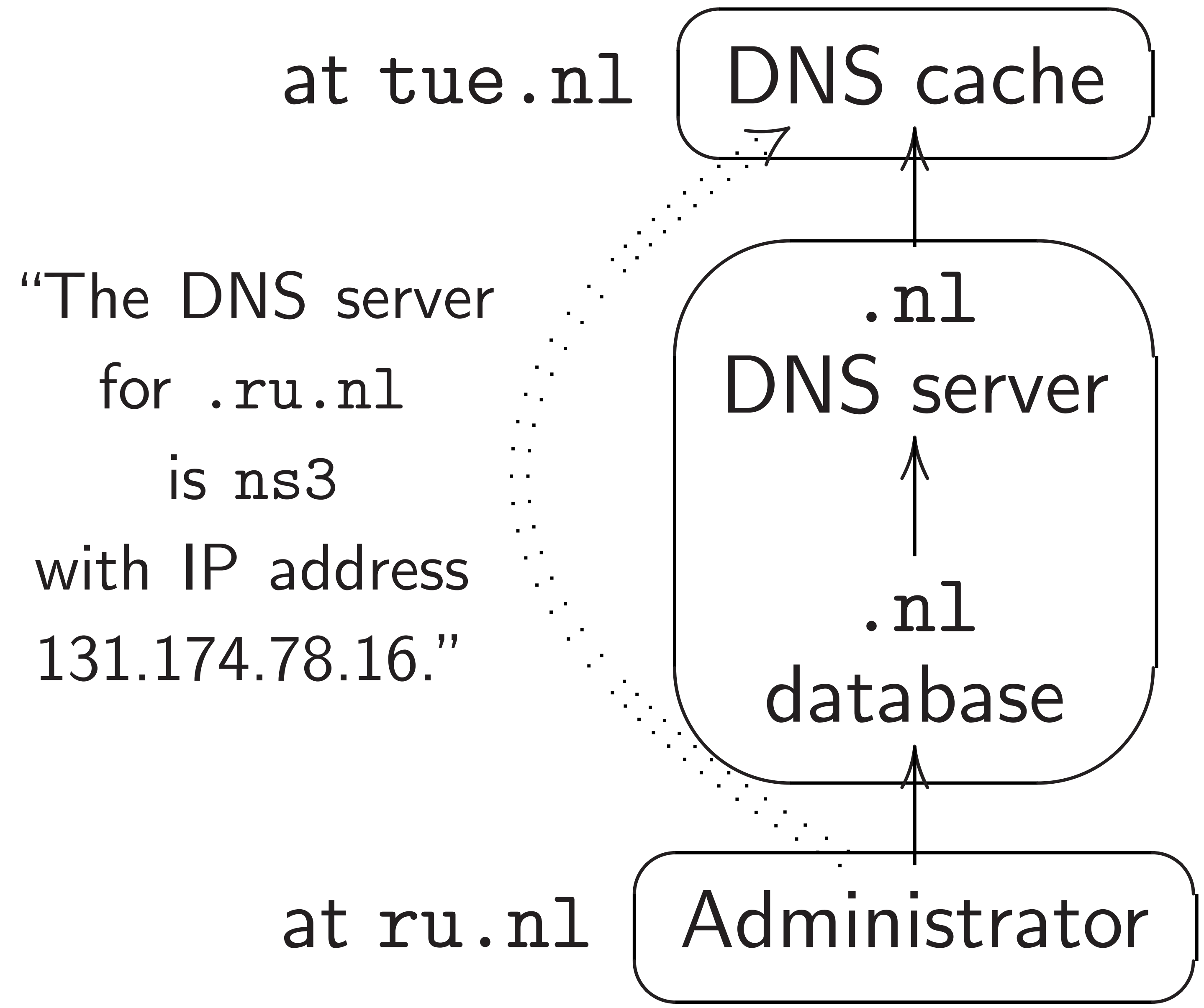

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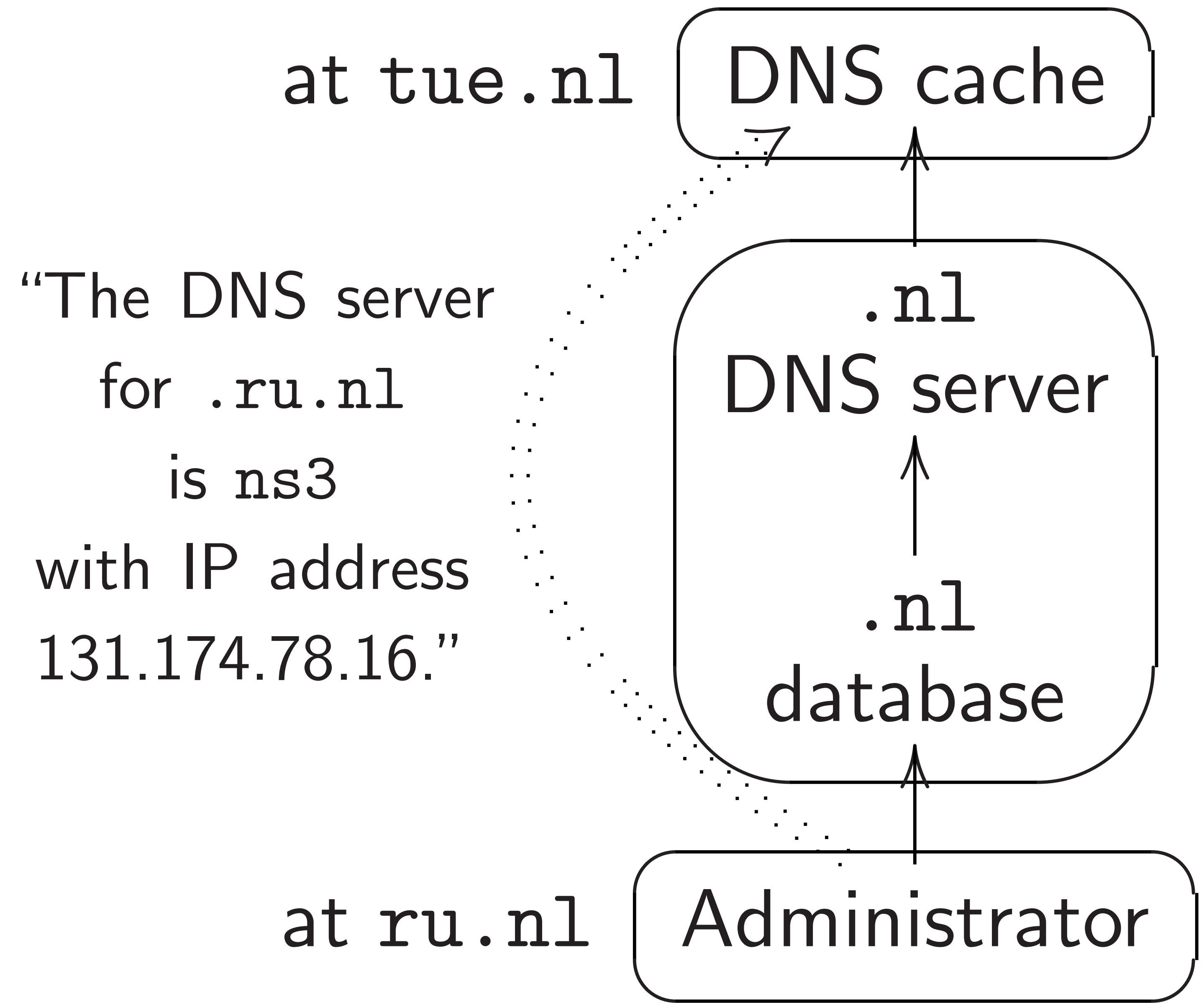

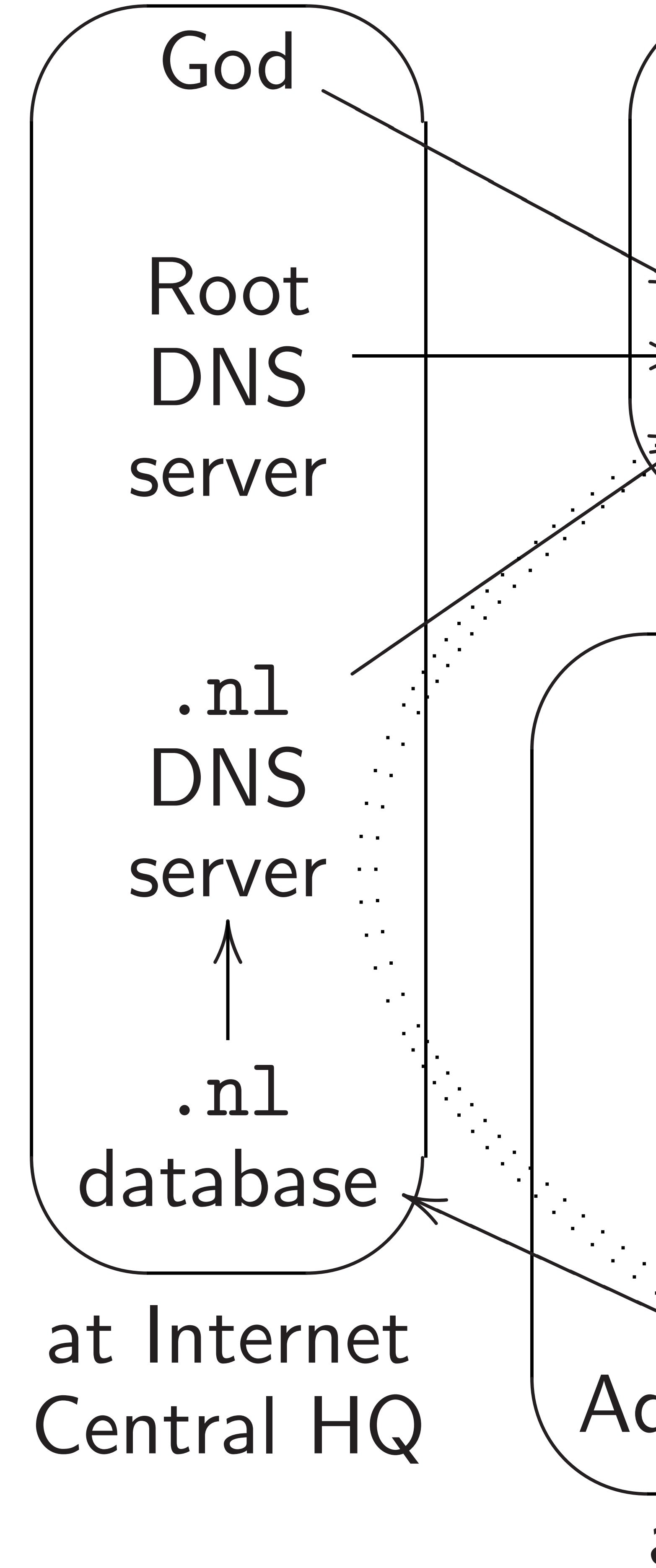

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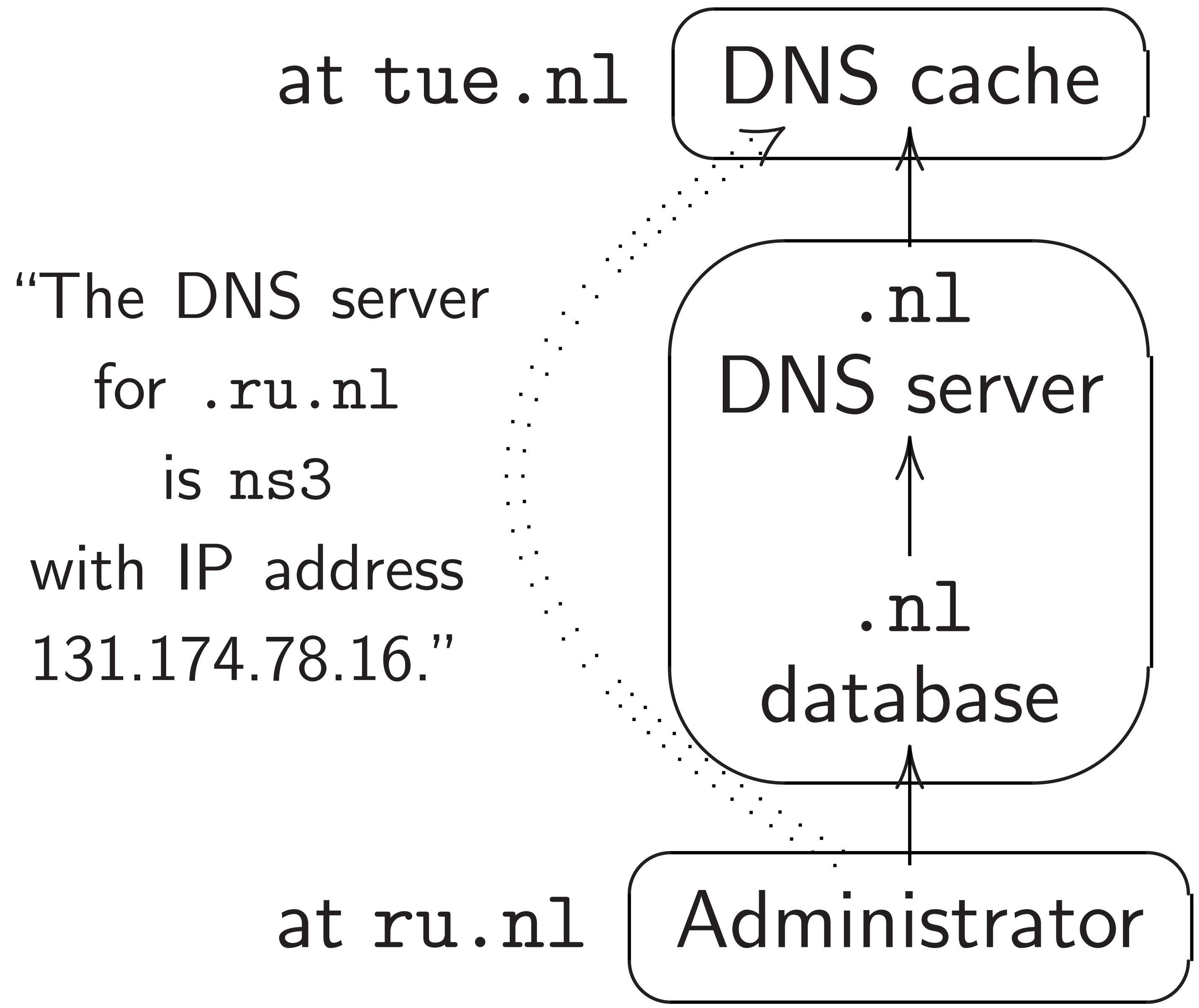

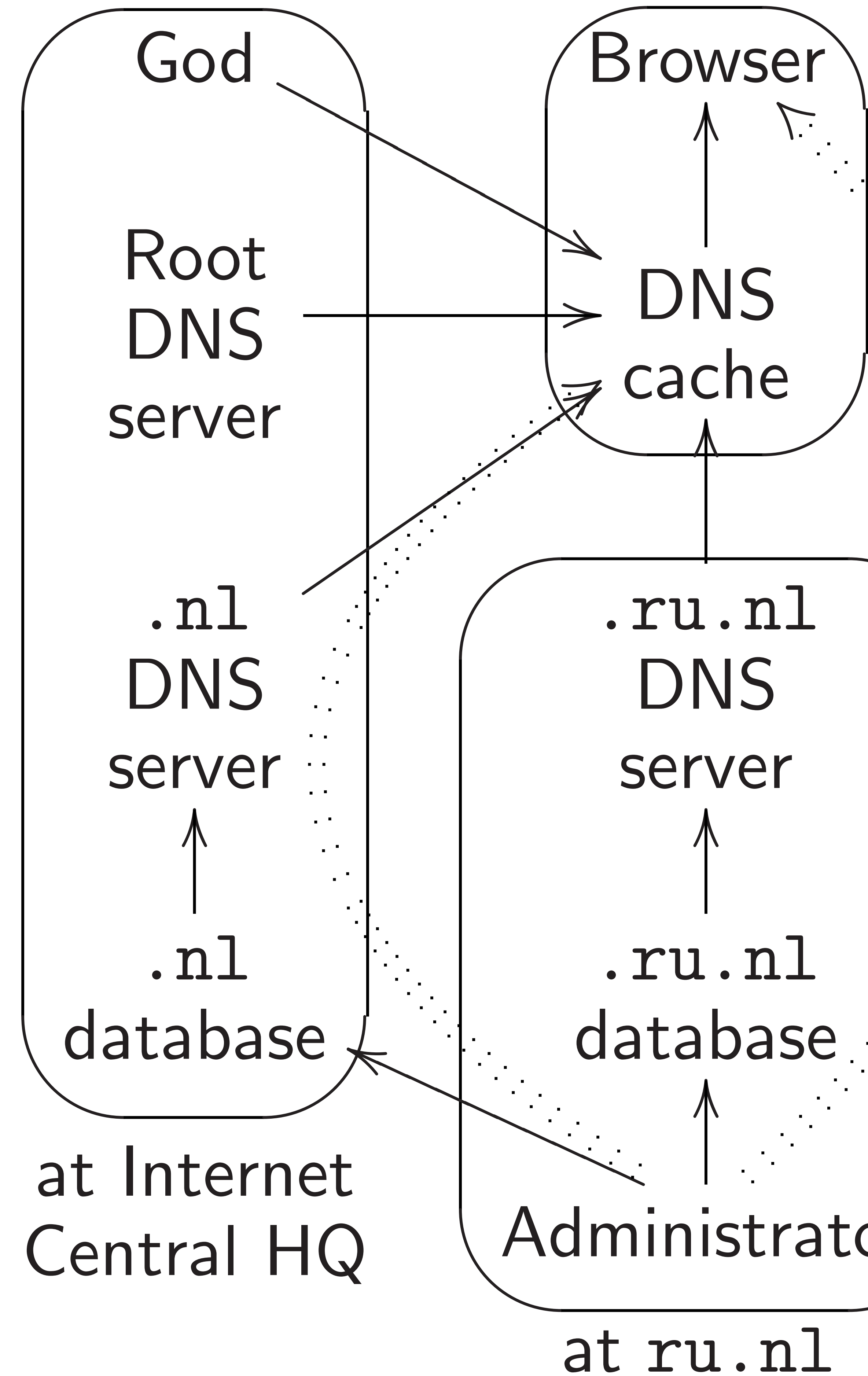

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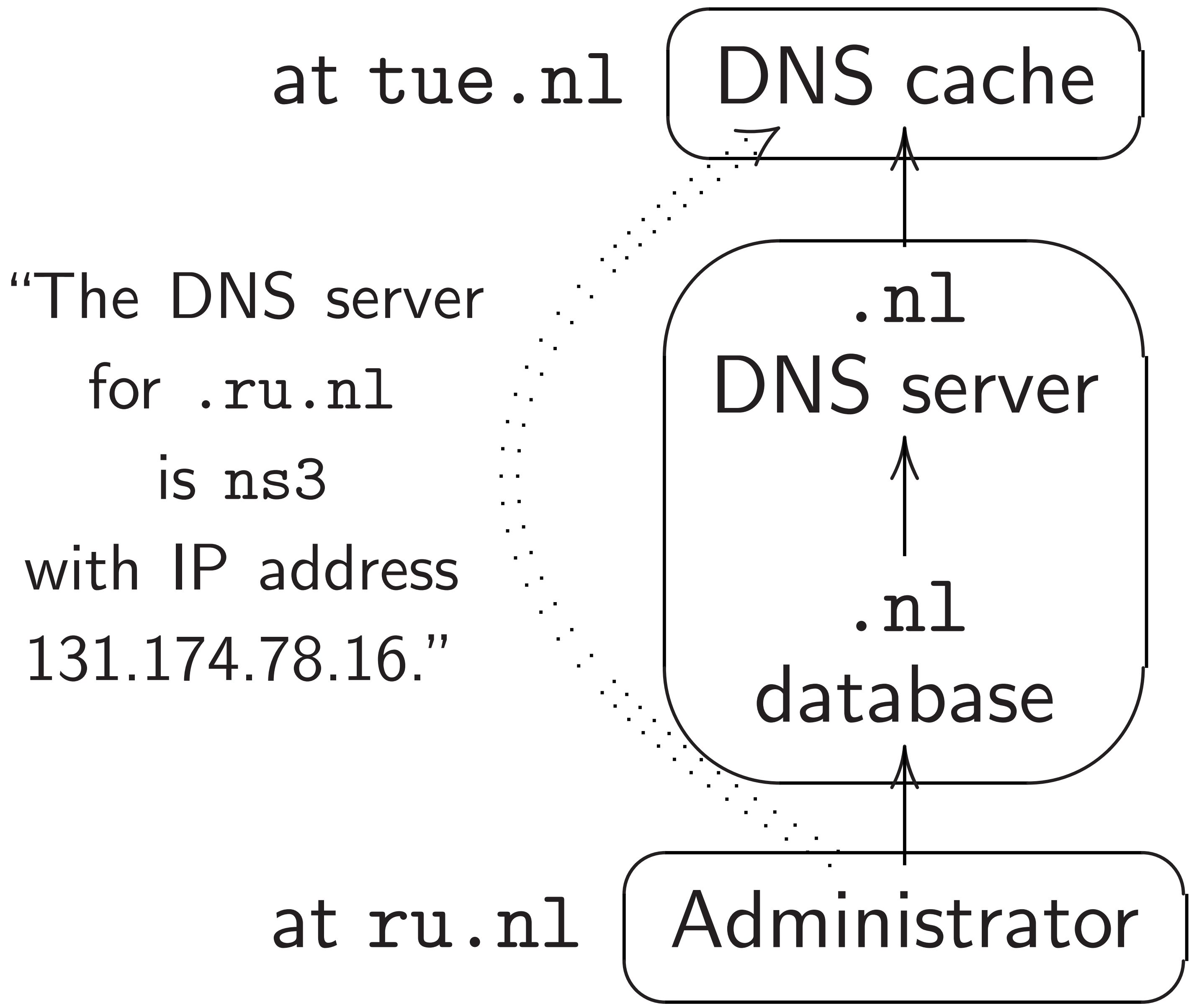

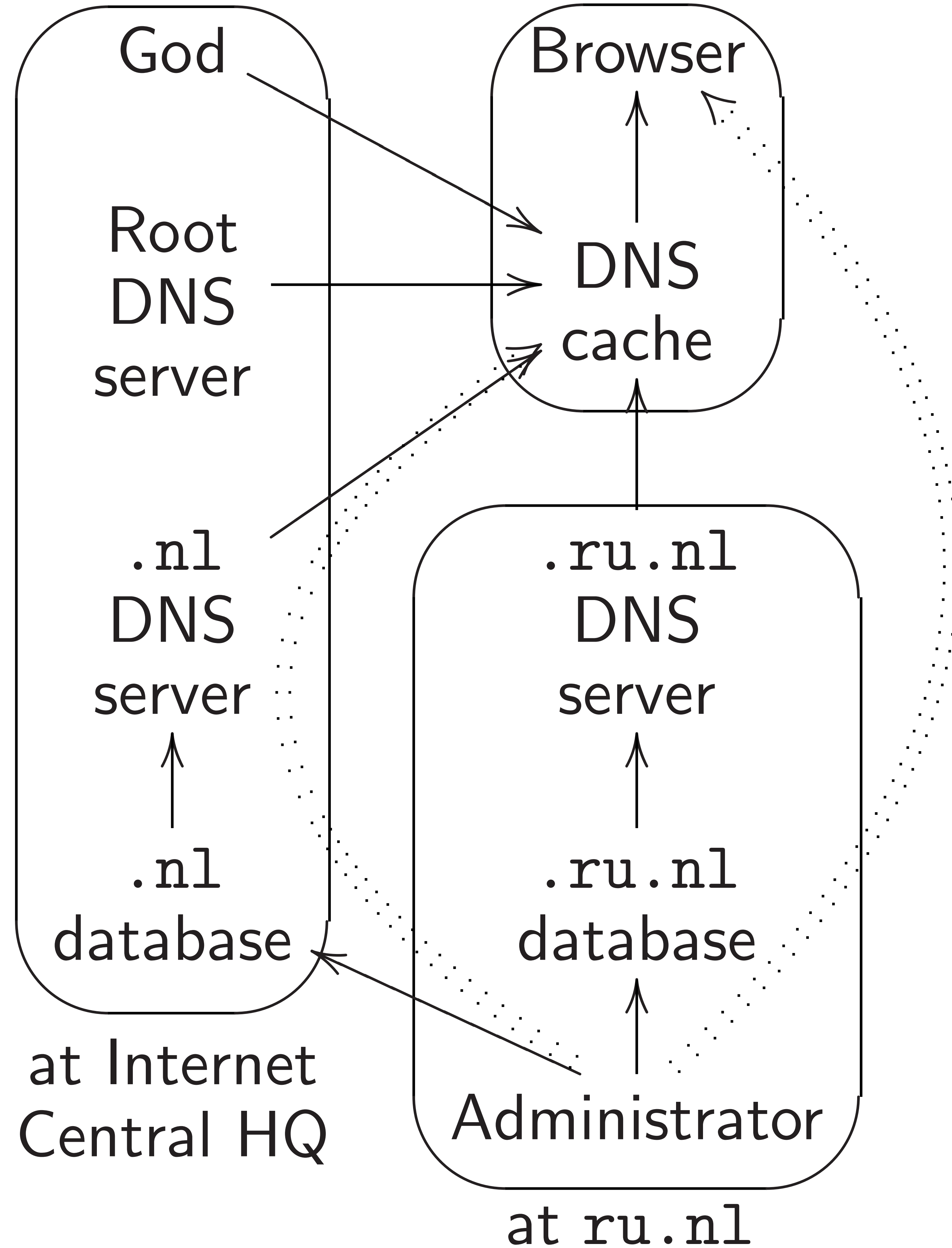

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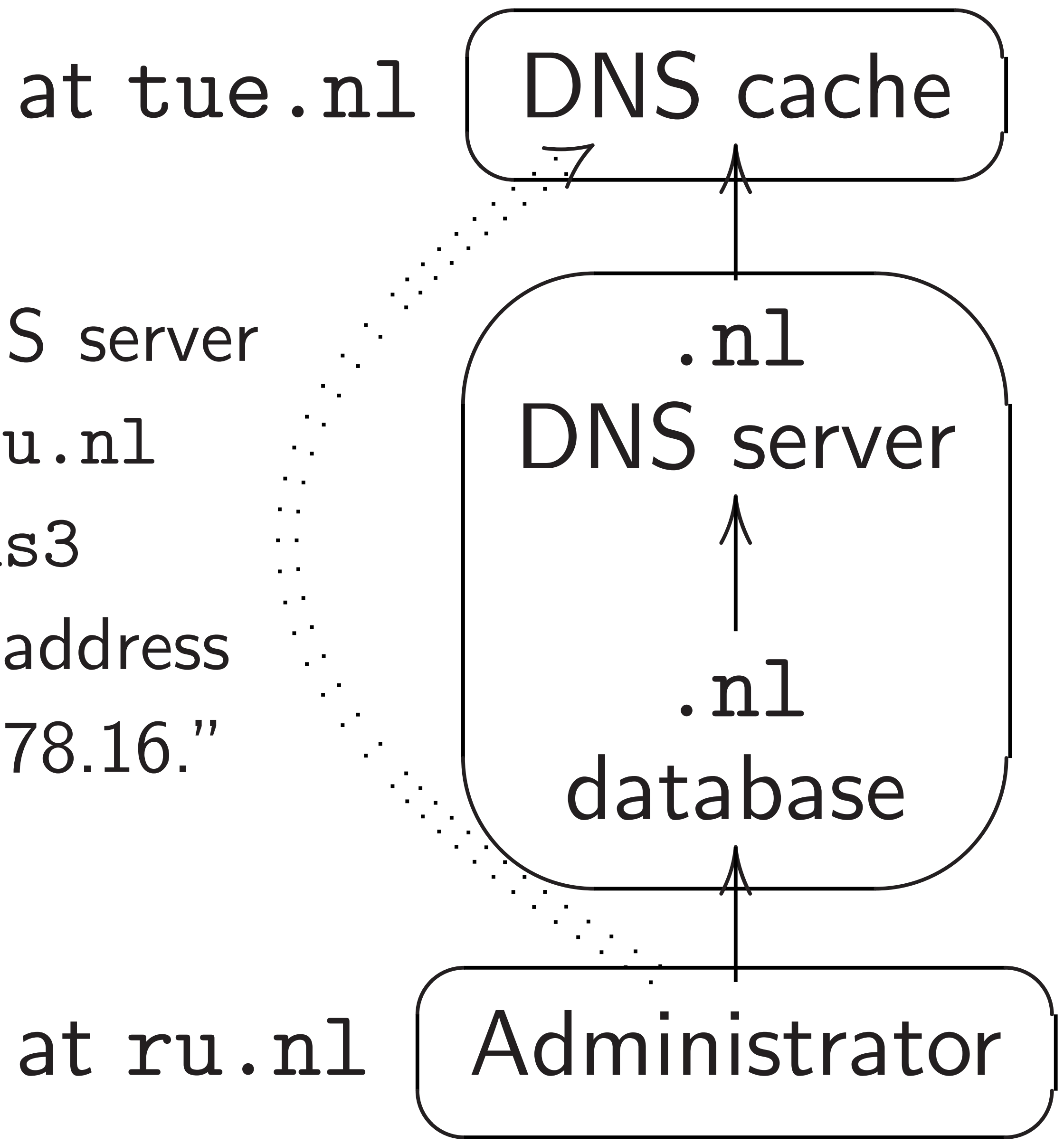

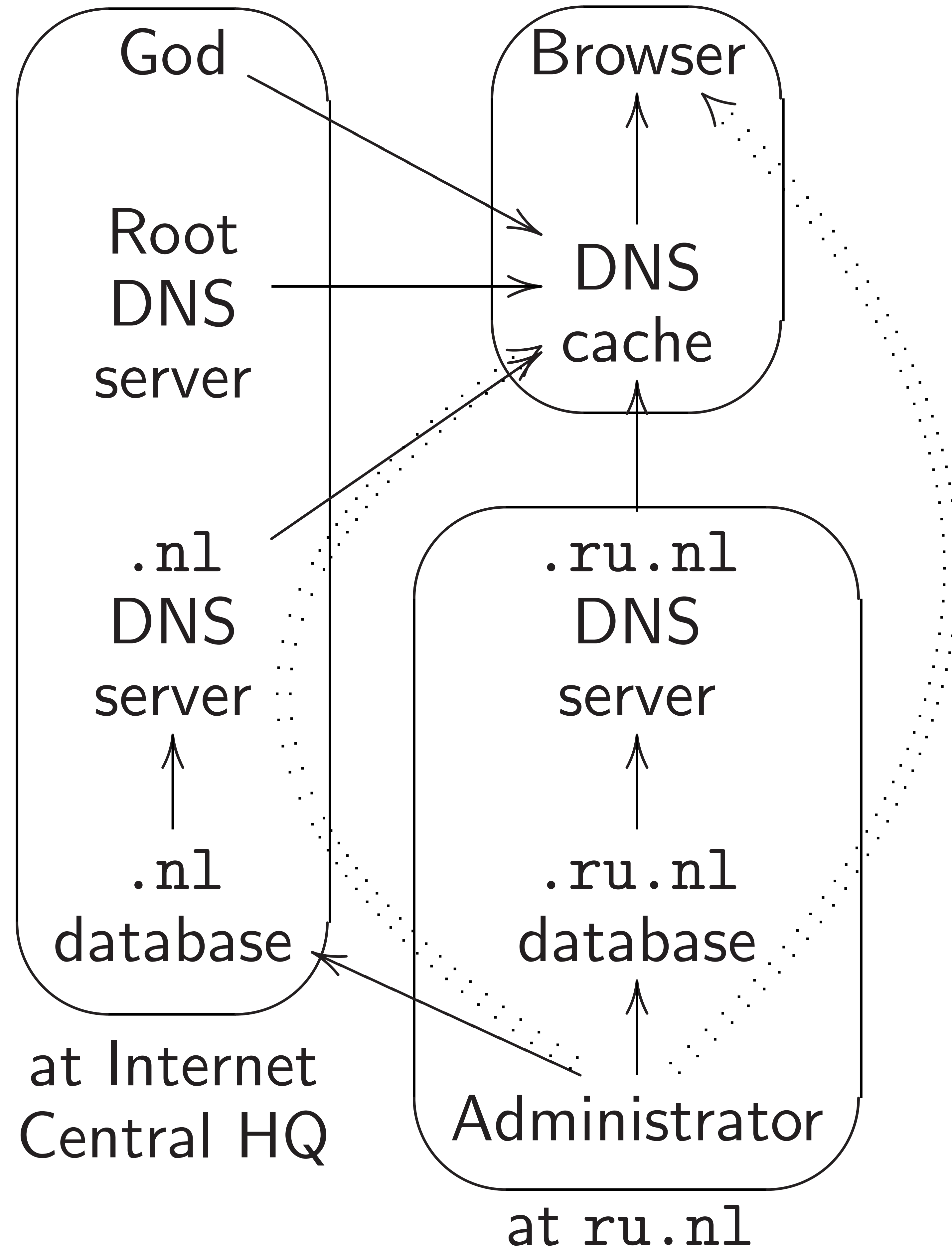

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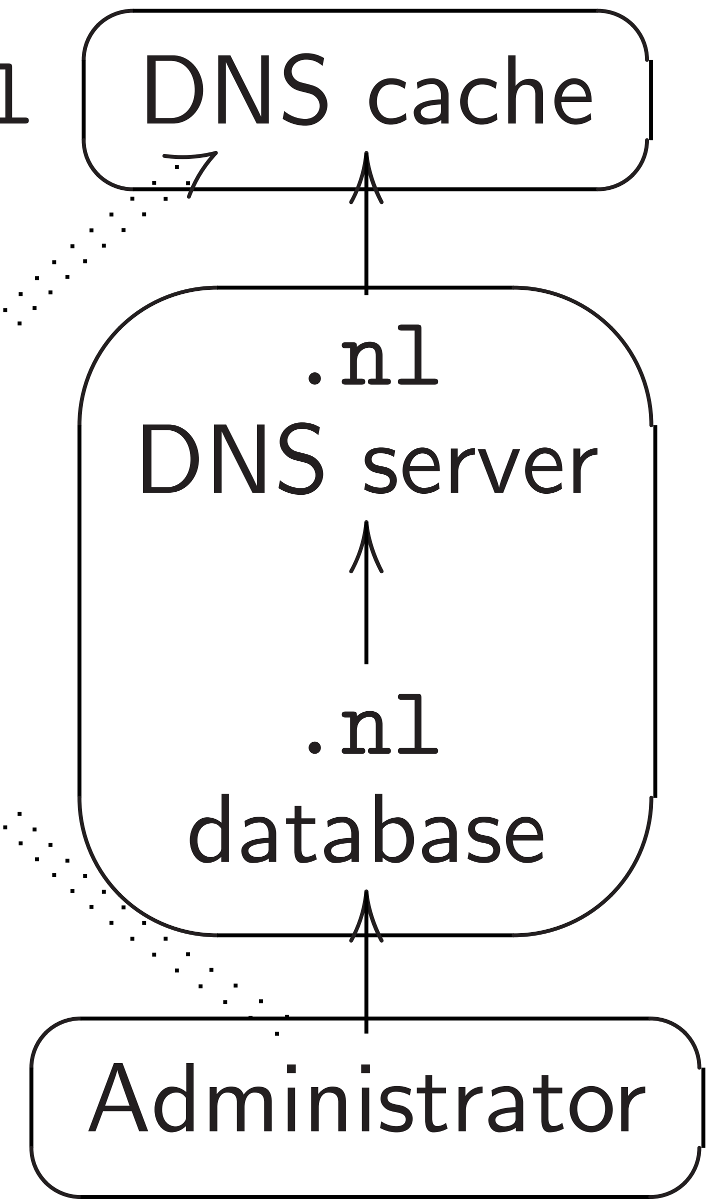

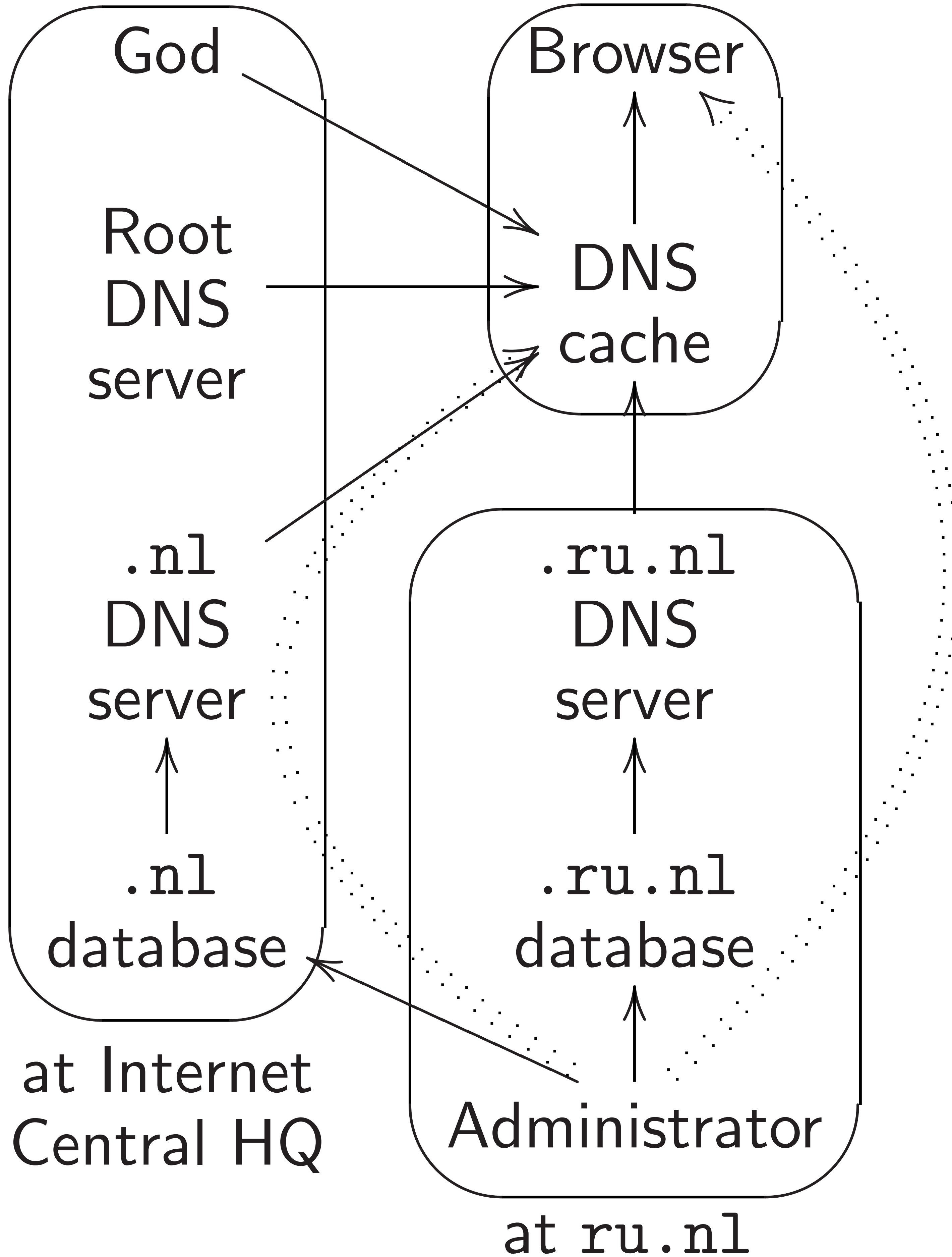

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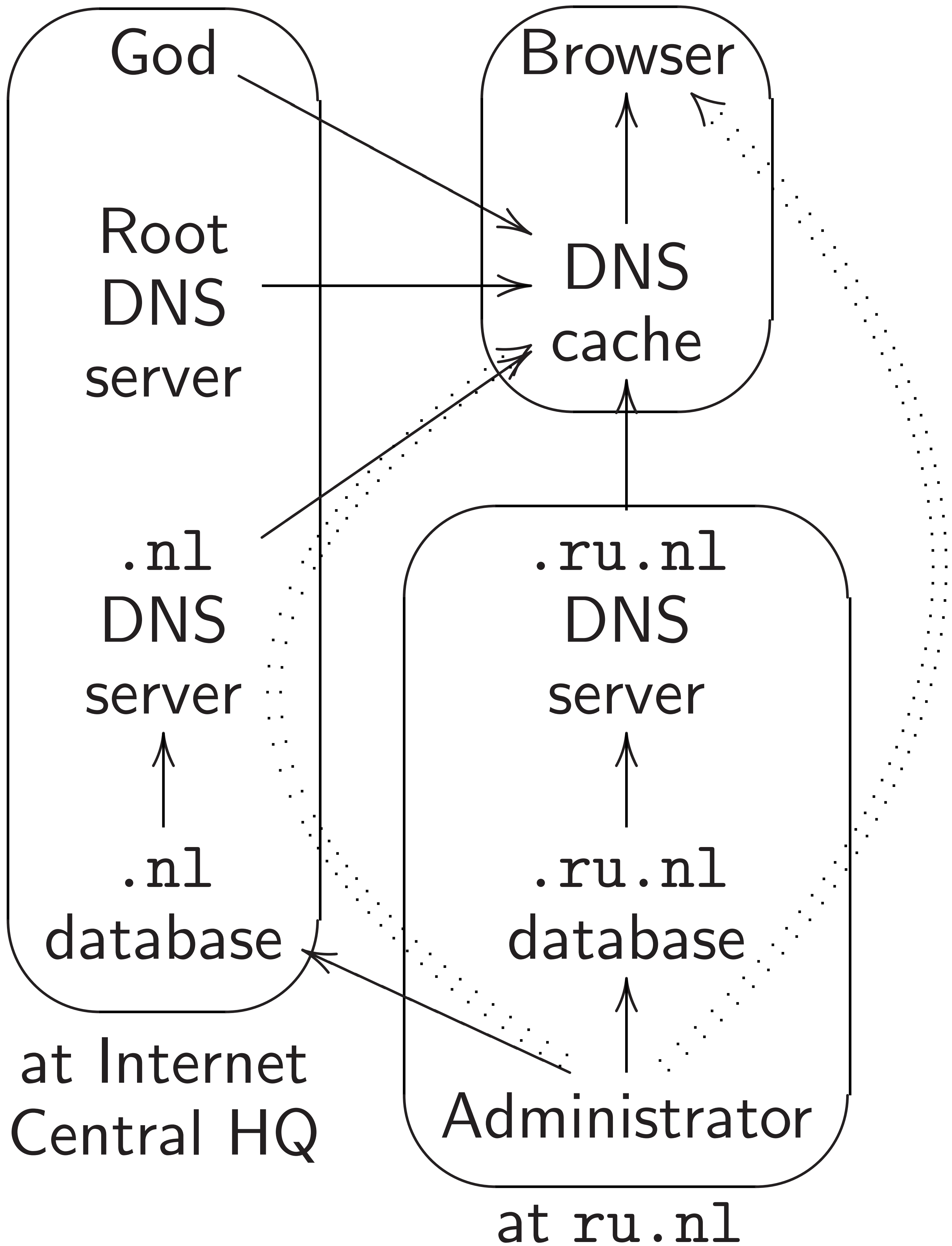

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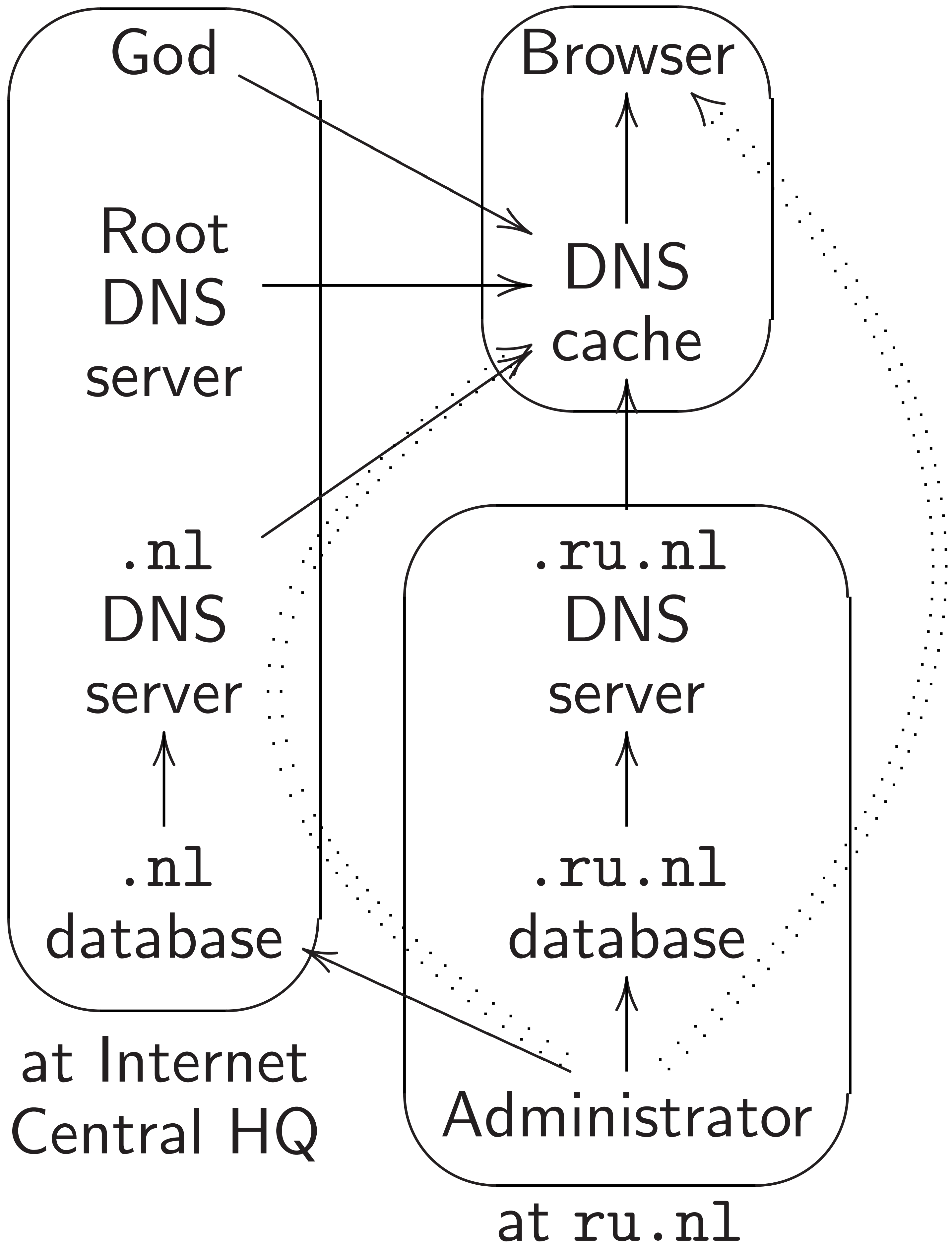

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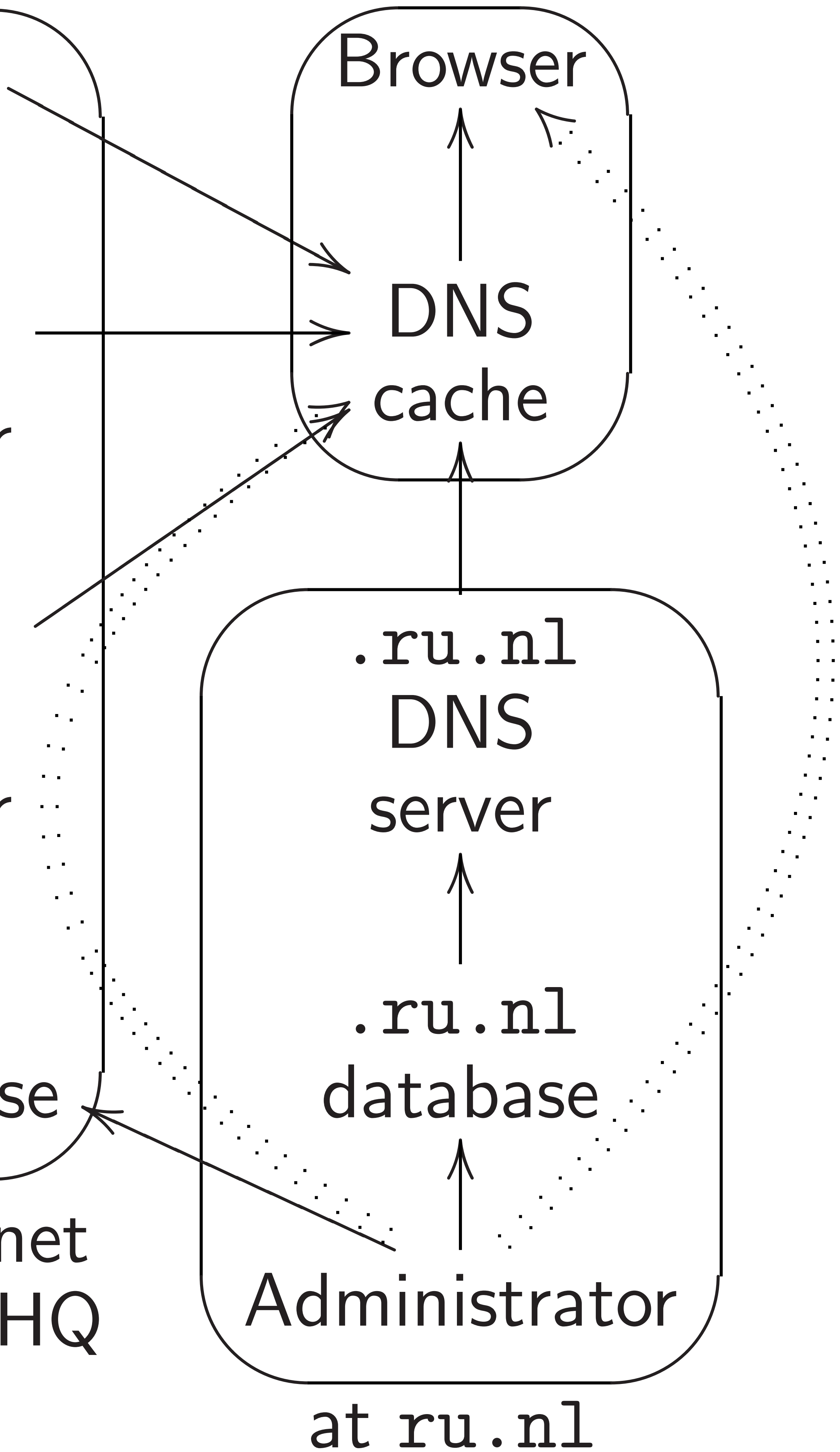

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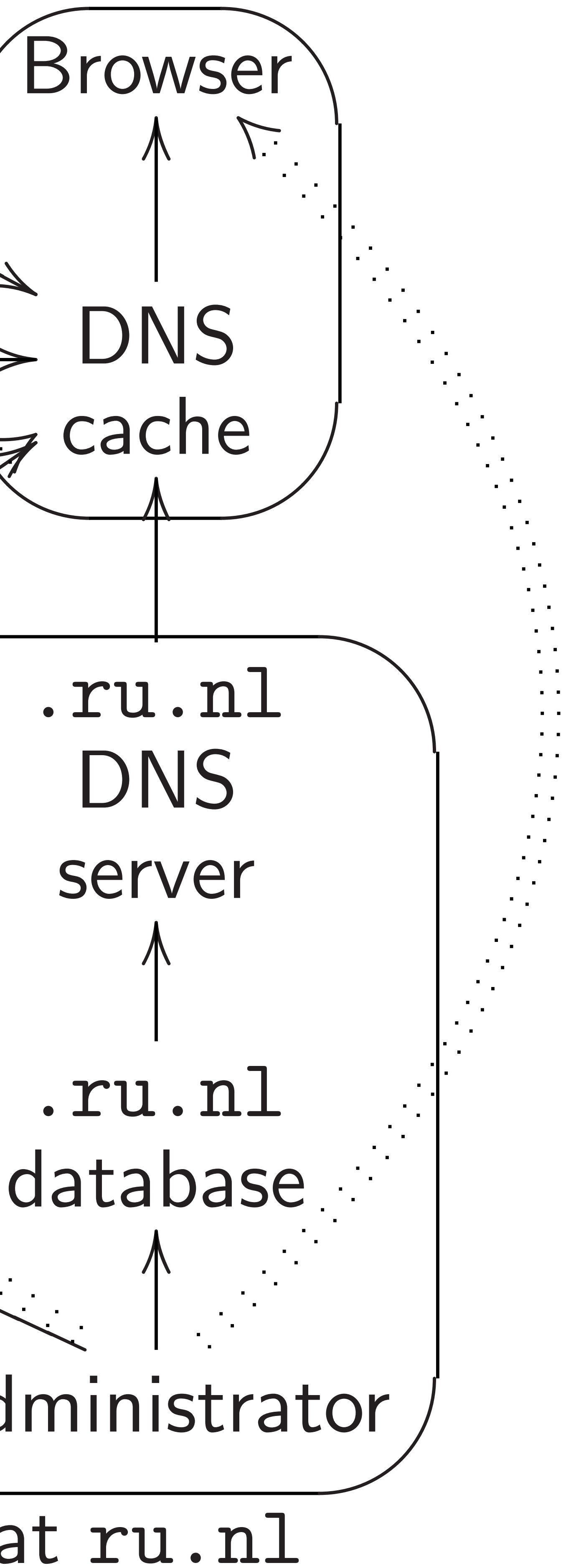

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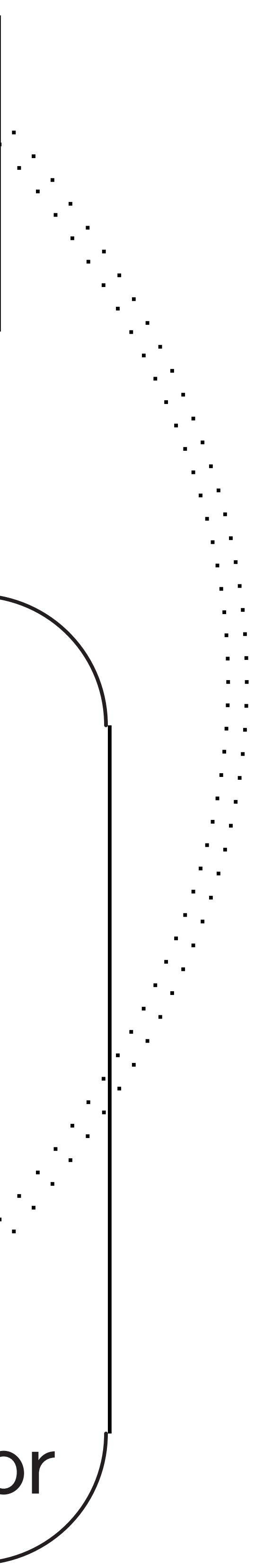

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Often they automatically adjust list of addresses in light of dead servers, client location, etc.

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

Summary: Attacker learns all n names in an NSEC zone (with signatures guaranteeing that there are no more) using n DNS queries.

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DNS packets, cache→client.

Work in progress: HTTPCurve
protects HTTP packets.

Crypto is at edge
handled by simple

Administrator puts
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Need new DNS ca
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web interfaces, etc

Easy to implement
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Getting out of the mess

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

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e.g., is the user accessing
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`diabetes.webmd.com`?

Improved integrity:
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