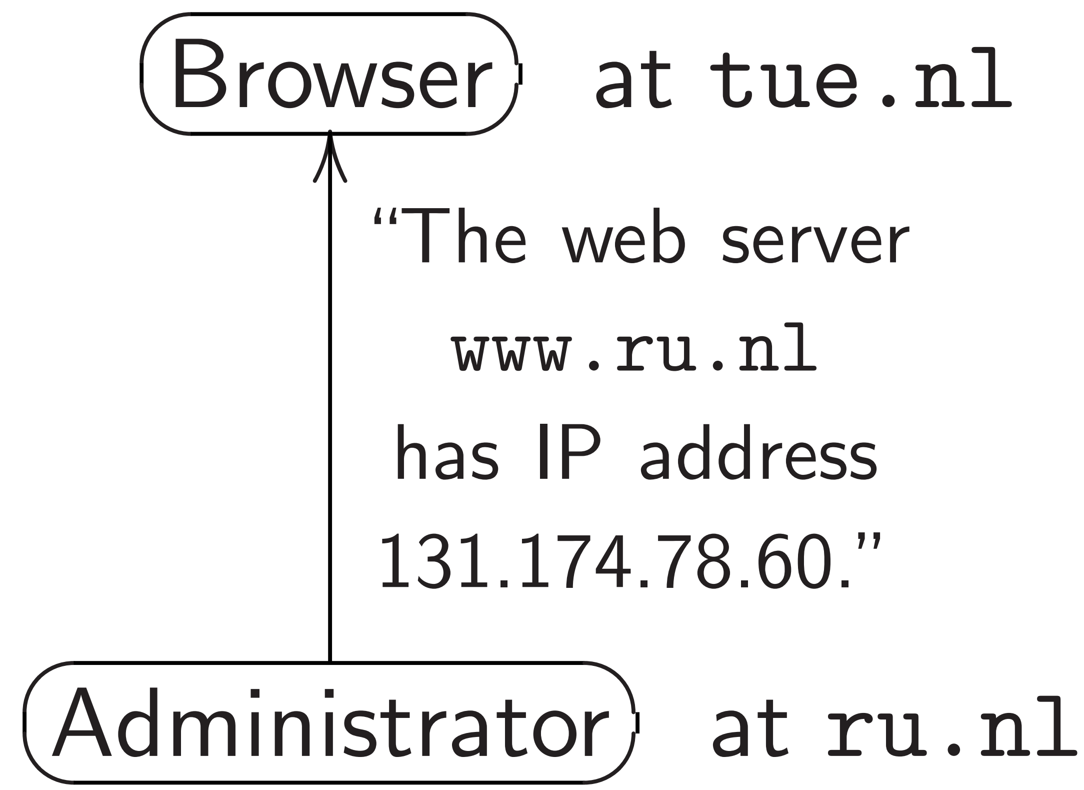
The DNS security mess

D. J. Bernstein

University of Illinois at Chicago

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.

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Administrator at ru.nl

Now tue.nl
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it is no longer possible
for attackers to forge
data from those servers!

... or is it?

Novemb

Let's fin

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

$ dig
  b0.o
199.19
```

an that the
ned'?
s the first part
est phase.
ographically
itative data
one file.
new records to
lows verification
enticity and

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!

... or is it?

November 2017: 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
```

e

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cation

d

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!

... or is it?

November 2017: 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!

… or is it?

November 2017: 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
```

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

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

it?

November 2017: 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

```
$ dig
  www
  @19
```

Everythi

```
;; AU
greenp
  864
  ns-
    g
```

thority!

enticity!

great!

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ware.

servers

NSSEC,

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ervers!

November 2017: 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-cloud-e1.
    googledoma
```

November 2017: 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-cloud-e1.
    googledomains.com.
```

November 2017: 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-cloud-e1.
    googledomains.com.
```

er 2017: 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-cloud-e1.
    googledomains.com.
```

Where's

Have to

```
$ dig
  www
  @19
```

Old answ

```
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-cloud-e1.
    googledomains.com.
```

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
69T6U8O1GSG9E1
 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-cloud-e1.
    googledomains.com.
```


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
69T6U8O1GSG9E1LMITK4DEM
 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-cloud-e1.
    googledomains.com.
```


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
cloud-e1.
oogledomains.com.
```


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
```

```
np90u
IG NS
13231
862 o
cnf5C
I6nmI
S1YwP
qowaJ
jyqeZ
086z1
XBba

bgca0
qng3p
C3 1
```

```
ace.org:

ce.org \

ormal:

ECTION:
.

ins.com.
```


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
13231839 20171
862 org. GfxhB
cnf5CwwthLUR0O
I6nmIG/yELCJGS
S1YwPad9aQRrVe
qowaJMWJ207DHb
jyqeZh7cMXLN0H
086z1nCr5pWsUl
XBba nvk=

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 2017
13231839 20171122221839
862 org. GfxhBt4c+7E7OU
cnf5CwwthLUR0O70GiRGYK5
I6nmIG/yELCJGSa 91cVp5J
S1YwPad9aQRrVedZXAV6qFn
qowaJMWJ207DHbFD02Lus7
jyqeZh7cMXLN0HxQ1qOzW/j
086z1nCr5pWsUlme76hB3lz
XBba nvk=

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 201712
13231839 20171122221839 1
862 org. GfxhBt4c+7E7OUyE
cnf5CwwthLUR0O70GiRGYK5f0
I6nmIG/yELCJGSa 9lcVp5JcS
S1YwPad9aQRrVedZXAV6qFnPi
qowaJMWJ207DHbFD02Lus7 M4
jyqeZh7cMXLN0HxQ1q0zW/j4g
086z1nCr5pWsUlme76hB3lz9E
XBba nvk=

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
801GSG9E1LMITK4DEMOT
OA RRSIG DNSKEY NSEC
M

7tr2u91d0v0ljs9l1gid
```



```
np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201712
13231839 20171122221839 1
862 org. GfxhBt4c+7E7OUyE
cnf5CwwthLUR0O7OGiRGYK5f0
I6nmIG/yELCJGSa 91cVp5JcS
S1YwPad9aQRrVedZXAV6qFnPi
qowaJMWJ207DHbFD02Lus7 M4
jyqeZh7cMXLN0HxQ1qOzW/j4g
086z1nCr5pWsUlme76hB3lz9E
XBba nvk=

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

```
OPPOB
 A RR

bgca0
qng3p
IG NS
08152
862 o
lzEH+
xgvym
d+LkH
FERTc
4Esix
rfjnF
aWxu
```

o?

gnatures:

\
ce.org \

r new lines:

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


v0ljs9l1gid
```



```
np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201712
13231839 20171122221839 1
862 org. GfxhBt4c+7E7OUyE
cnf5CwwthLUR0O7OGiRGYK5f0
I6nmIG/yELCJGSa 9lcVp5JcS
S1YwPad9aQRrVedZXAV6qFnPi
qowaJMWJ207DHbFD02Lus7 M4
jyqeZh7cMXLN0HxQ1qOzW/j4g
086z1nCr5pWsUlme76hB3lz9E
XBba nvk=

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

```
OPPOBENBFCGBMB
 A RRSIG

bgca0g0ug0p6o7
qng3p2f.org. 8
IG NSEC3 7 2 8
08152932 20171
862 org. RZIhC
lzEH+88fDlJ8x3
xgvymEadj77bza
d+LkHm8KHOAFLo
FERTcC3OW6+mhH
4EsixBFa6rYLdq
rfjnFAcHCAfFEf
aWxu RYU=
```

```
s:

id
SE
R6
OT
EC

id
```



```
np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201712
13231839 20171122221839 1
862 org. GfxhBt4c+7E7OUyE
cnf5CwwthLUR0O70GiRGYK5f0
I6nmIG/yELCJGSa 9lcVp5JcS
S1YwPad9aQRrVedZXAV6qFnPi
qowaJMWJ207DHbFD02Lus7 M4
jyqeZh7cMXLNOHxQ1qOzW/j4g
086z1nCr5pWsUlme76hB3lz9E
XBba nvk=

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 2017
08152932 2017111714293
862 org. RZIhCS7+uAxG39
lzEH+88fDlJ8x3uYPtHt/K3
xgvymEadj77bza2 yuj5nJ0
d+LkHm8KHOAFLoRmt24WiZr
FERTcC3OW6+mhH/rF1sqGm
4EsixBFa6rYLdqR/NylQxCt
rfjnFAcHCAfFEfor0MR9qtA
aWxu RYU=
```

```
np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201712
13231839 20171122221839 1
862 org. GfxhBt4c+7E7OUyE
cnf5CwwthLUR0O7OGiRGYK5f0
I6nmIG/yELCJGSa 9lcVp5JcS
S1YwPad9aQRrVedZXAV6qFnPi
qowaJMWJ207DHbFD02Lus7 M4
jyqeZh7cMXLN0HxQ1q0zW/j4g
086z1nCr5pWsUlme76hB3lz9E
XBba nvk=

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



```
0PP0BENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201712
08152932 20171117142932 1
862 org. RZIhCS7+uAxG39iO
lzEH+88fDlJ8x3uYPtHt/K3EE
xgvymEadj77bza2 yuj5nJ0t0
d+LkHm8KHOAFLoRmt24WiZrkP
FERTcC3OW6+mhH/rF1sqGm Hj
4EsixBFa6rYLdqR/NylQxCtA5
rfjnFAcHCAfFEfor0MR9qtARU
aWxu RYU=
```

```
3h.org. 86400 IN RRS
EC3 7 2 86400 201712
839 20171122221839 1
rg. GfxhBt4c+7E7OUyE
wwthLUR0O70GiRGYK5f0
G/yELCJGSa 9lcVp5JcS
ad9aQRrVedZXAV6qFnPi
MWJ207DHbFD02Lus7 M4
h7cMXLNOHxQ1qOzW/j4g
nCr5pWsUlme76hB3lz9E
nvk=

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



```
OPPOBENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201712
08152932 20171117142932 1
862 org. RZIhCS7+uAxG39iO
lzEH+88fDlJ8x3uYPtHt/K3EE
xgvymEadj77bza2 yuj5nJ0t0
d+LkHm8KHOAFLoRmt24WiZrkP
FERTcC30W6+mhH/rF1sqGm Hj
4EsixBFa6rYLdqR/NylQxCtA5
rfjnFAcHCAfFEfor0MR9qtARU
aWxu RYU=
```

Wow, th

Must be

```
$ tcpdu
  host
```

shows pa

dig send

to the .

receives

See mor

```
$ dig +
  org @
```

Sends 7

receives

totalling

```
6400 IN RRS
6400 201712
122221839 1
t4c+7E7OUyE
70GiRGYK5f0
a 9lcVp5JcS
dZXAV6qFnPi
FD02Lus7 M4
xQ1qOzW/j4g
me76hB3lz9E


425emkt9ue4
6400 IN NSE
AAB BGDHKIB
```



```
OPPOBENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201712
08152932 20171117142932 1
862 org. RZIhCS7+uAxG39iO
lzEH+88fDlJ8x3uYPtHt/K3EE
xgvymEadj77bza2 yuj5nJ0t0
d+LkHm8KHOAFLoRmt24WiZrkP
FERTcC3OW6+mhH/rF1sqGm Hj
4EsixBFa6rYLdqR/NylQxCtA5
rfjnFAcHCAfFEforOMR9qtARU
aWxu RYU=
```

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 657-byte

See more DNSSE

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

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

```
RS
12
1
yE
f0
cS
Pi
M4
4g
9E

e4
SE
IB
```

```
OPPOBENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201712
08152932 20171117142932 1
862 org. RZIhCS7+uAxG39iO
lzEH+88fDlJ8x3uYPtHt/K3EE
xgvymEadj77bza2 yuj5nJ0t0
d+LkHm8KHOAFLoRmt24WiZrkP
FERTcC3OW6+mhH/rF1sqGm Hj
4EsixBFa6rYLdqR/NylQxCtA5
rfjnFAcHCAfFEforOMR9qtARU
aWxu RYU=
```


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 657-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.

```
0PP0BENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201712
08152932 20171117142932 1
862 org. RZIhCS7+uAxG39i0
lzEH+88fDlJ8x3uYPtHt/K3EE
xgvymEadj77bza2 yuj5nJ0t0
d+LkHm8KH0AFLoRmt24WiZrkP
FERTcC30W6+mhH/rF1sqGm Hj
4EsixBFa6rYLdqR/NylQxCtA5
rfjnFAcHCAfFEfor0MR9qtARU
aWxu RYU=
```


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 657-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 201712
932 20171117142932 1
rg. RZIhCS7+uAxG39iO
88fDlJ8x3uYPtHt/K3EE
Eadj77bza2 yuj5nJ0t0
m8KHOAFLoRmt24WiZrkP
C3OW6+mhH/rF1sqGm Hj
BFa6rYLdqR/NylQxCtA5
AcHCAfFEforOMR9qtARU
RYU=
```


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

Interlude

What ha
this data

```
6RGT2JDC21E


425emkt9ue4
6400 IN RRS
6400 201712
117142932 1
S7+uAxG39iO
uYPtHt/K3EE
2 yuj5nJ0t0
Rmt24WiZrkP
/rF1sqGm Hj
R/NylQxCtA5
or0MR9qtARU
```


Wow, that's a lot of data.
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$ tcpdump -n -e \
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```

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  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
1
i0
EE
t0
kP
Hj
A5
RU
```


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

```
$ tcpdump -n -e \
  host 199.19.54.1 &
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`dig` sends 89-byte IP packet to the `.org` DNS server, receives 657-byte IP packet.

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```
$ 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 657-byte IP packet.

See more DNSSEC data:

```
$ dig +dnssec any \
  org @199.19.54.1
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Interlude: the attacker's view

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

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  host 199.19.54.1 &
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Interlude: the attacker's view

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

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

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`dig` sends 89-byte IP packet to the `.org` DNS server, receives 657-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.

hat's a lot of data.
strong cryptography!

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

acket sizes:
ds 89-byte IP packet
org DNS server,
657-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 name

```
( 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 r
do
  dig +
  +time
  awk -
    if
    if
    if
    if
    est
    pri
  }'
done <
```

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.

n DNSSEC server,
nain estimated to have
m DNSSEC amplification:

```
r AMP | awk '{
een[$2]) next
1 < 30) next
 $1,$2,$3
$2] = 1
XAMP
 MAXAMP
AXAMP
```

(last time I tried it):

```
 156.154.102.26 fi.
XAMP
```


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.

Run netw
on 1.2.3

On 1.2.3
address
and senc

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

server,
ated to have
C amplification:

```
wk '{
next
ext
```

I tried it):

```
102.26 fi.
```


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.

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 >/
```

ve

ation:

..

Can that really be true?
$>$2000 DNSSEC servers around the Internet, each providing $>30\times$ amplification of incoming UDP packets?

Let's verify this.

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

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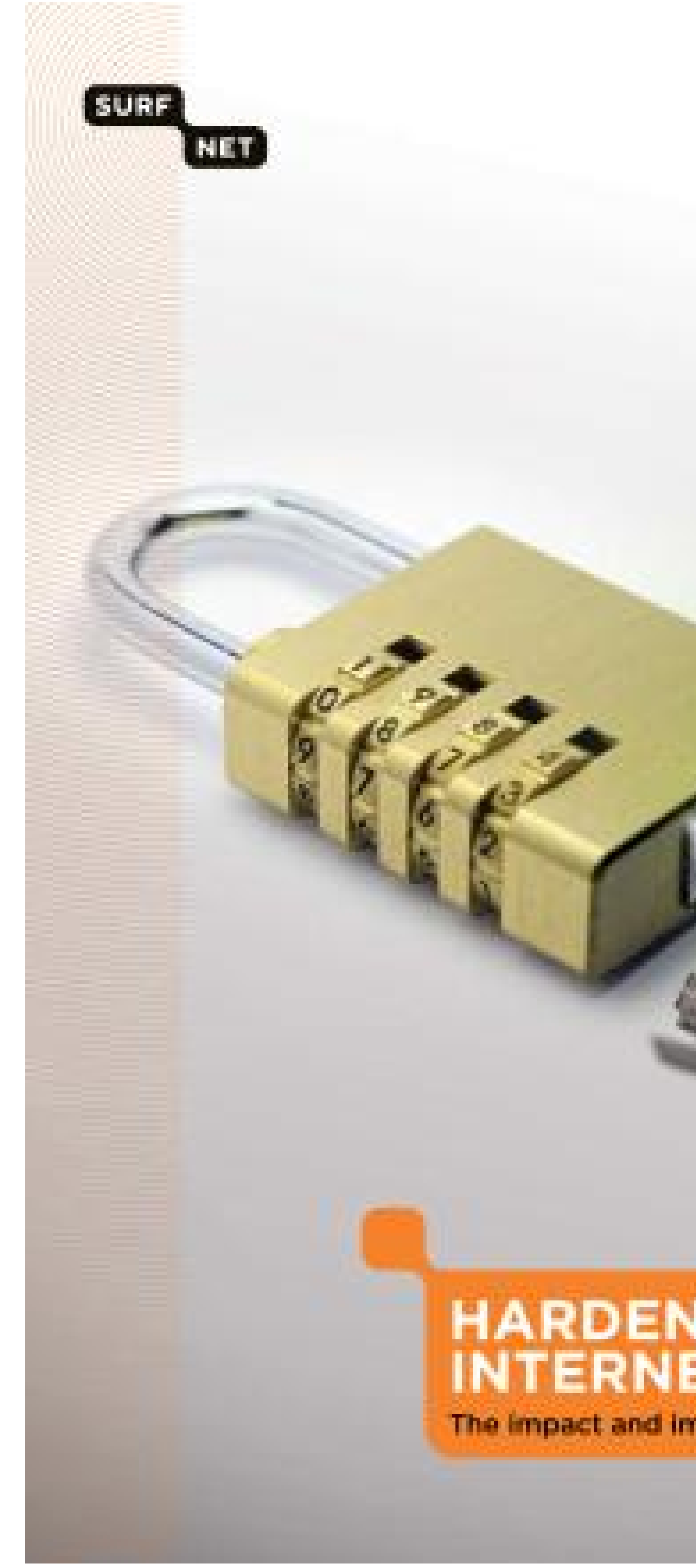

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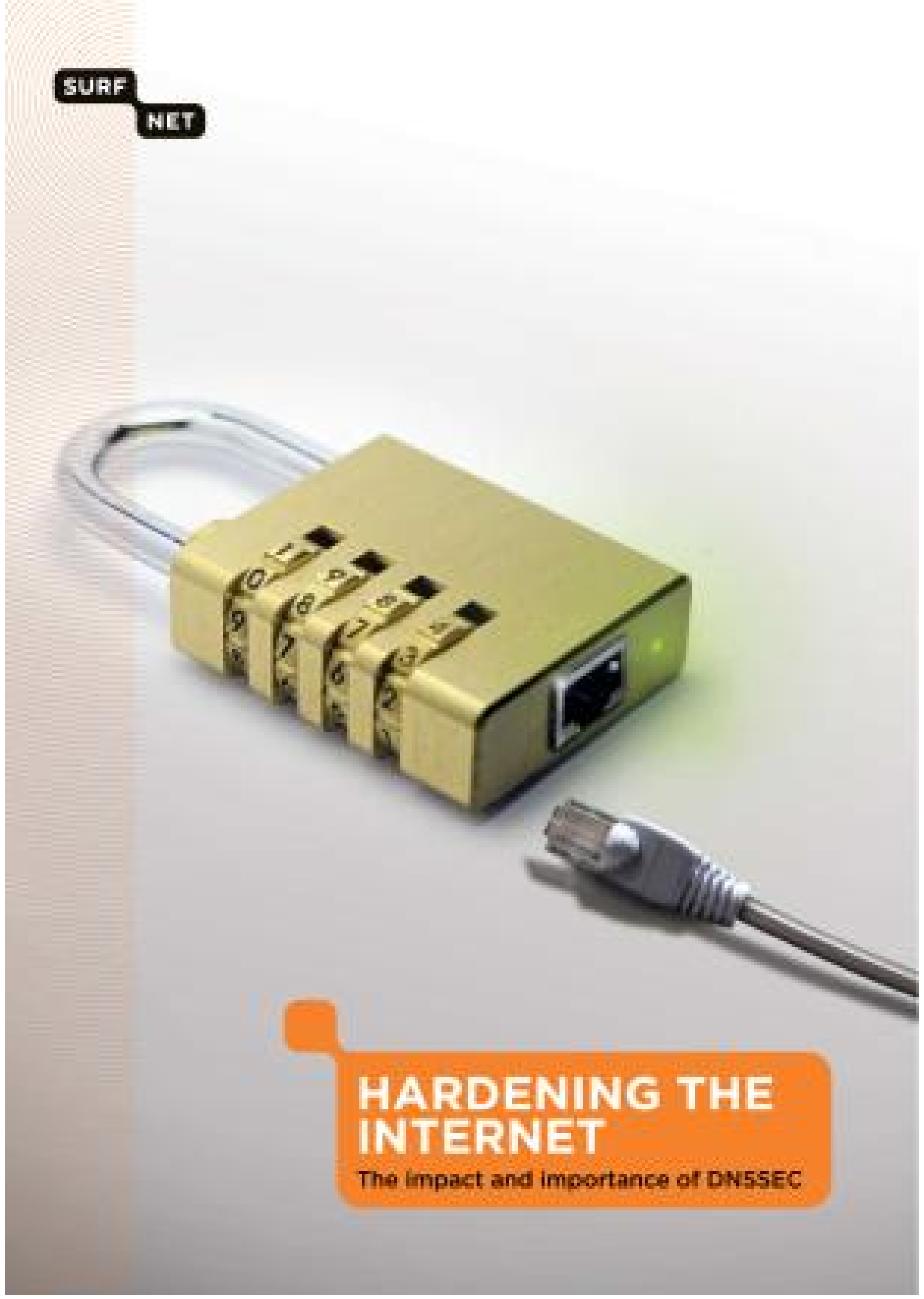

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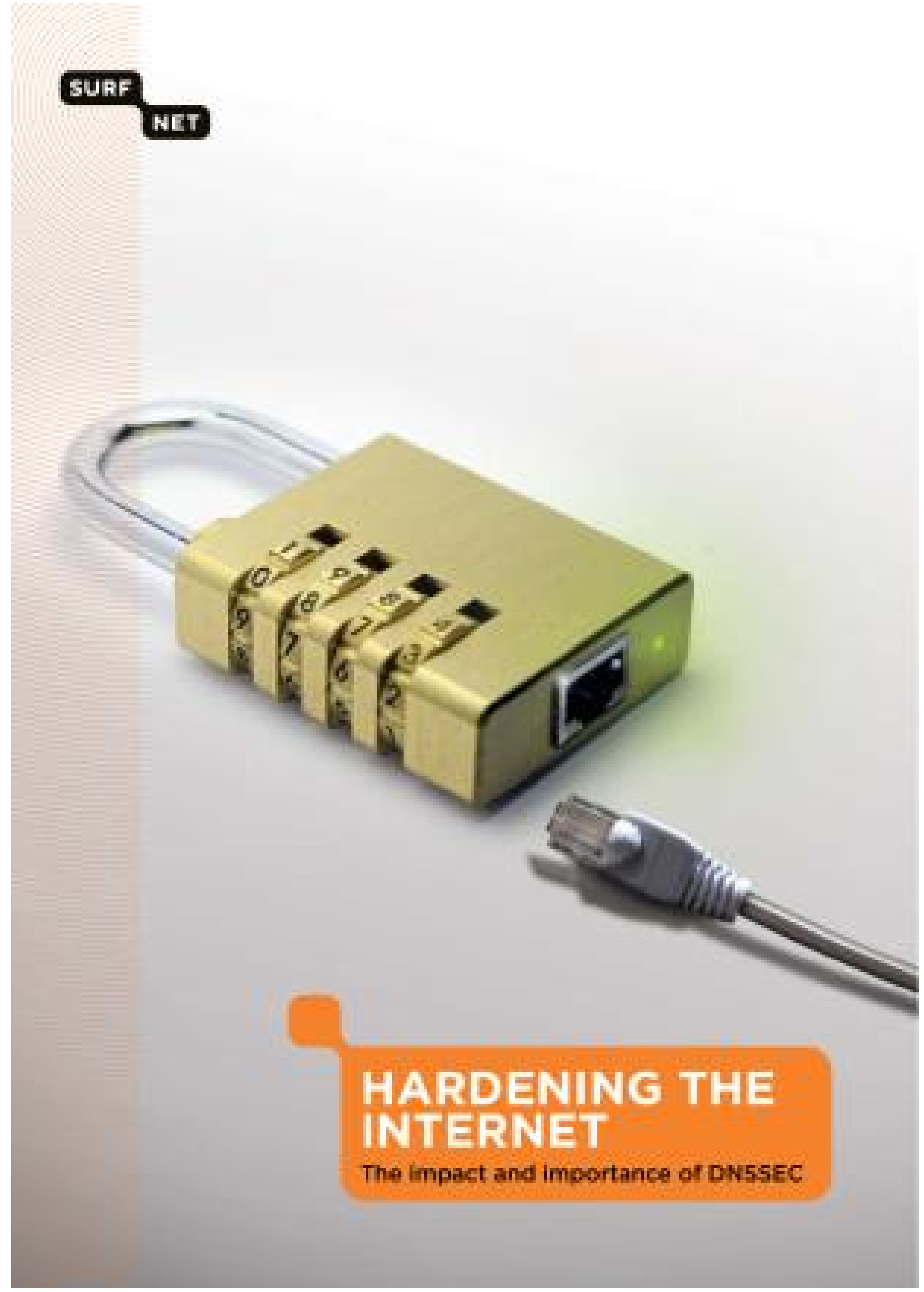

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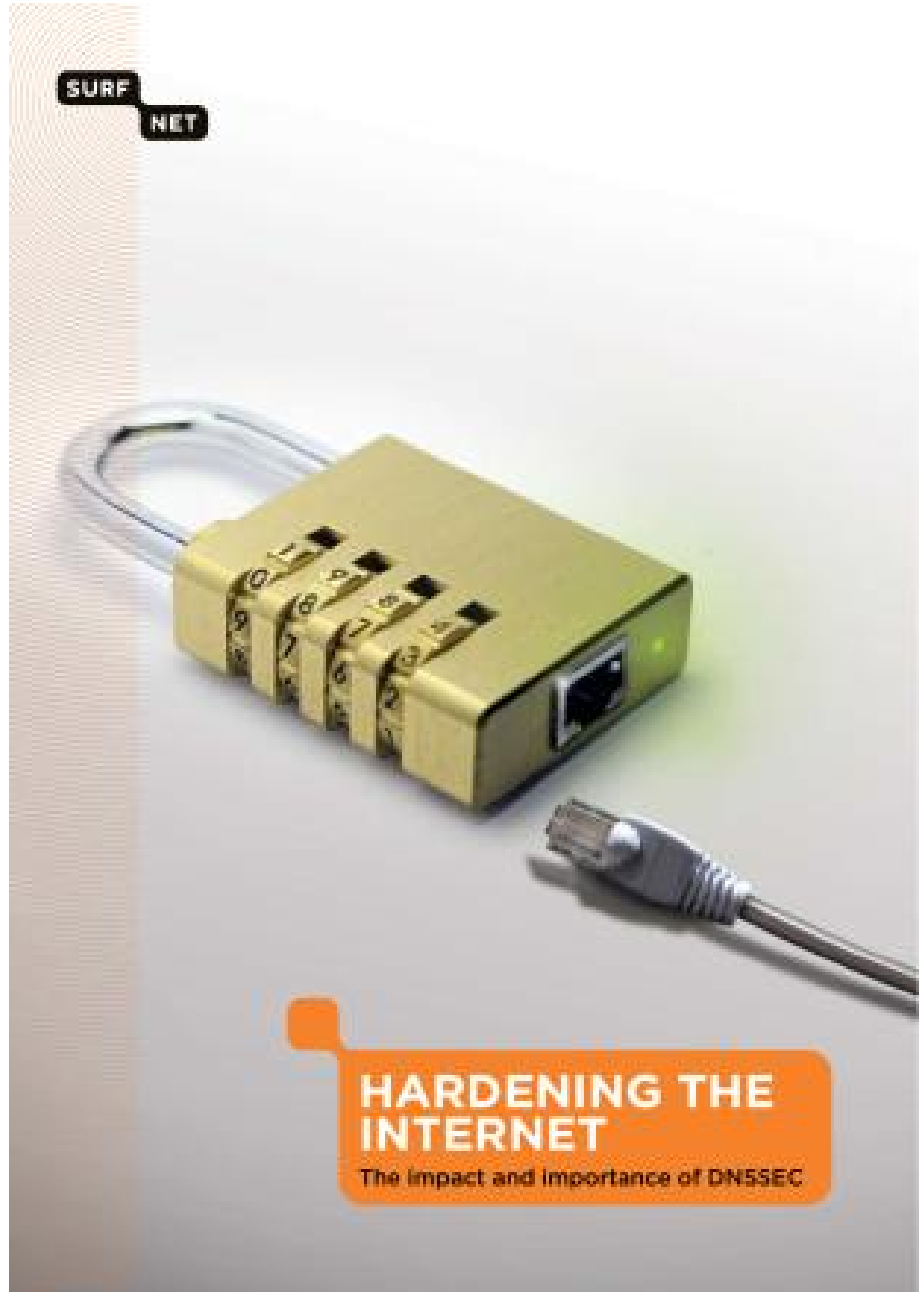

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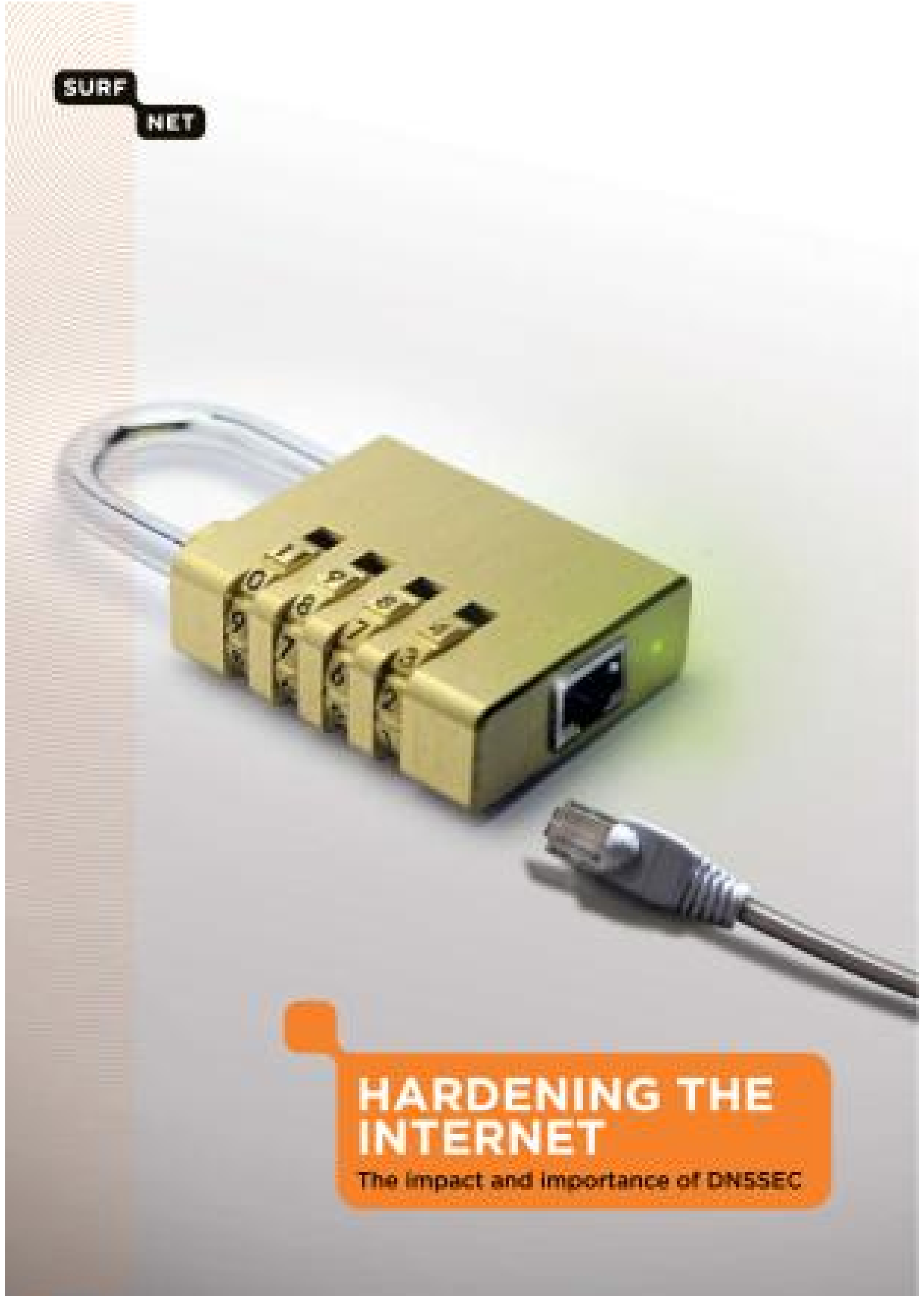

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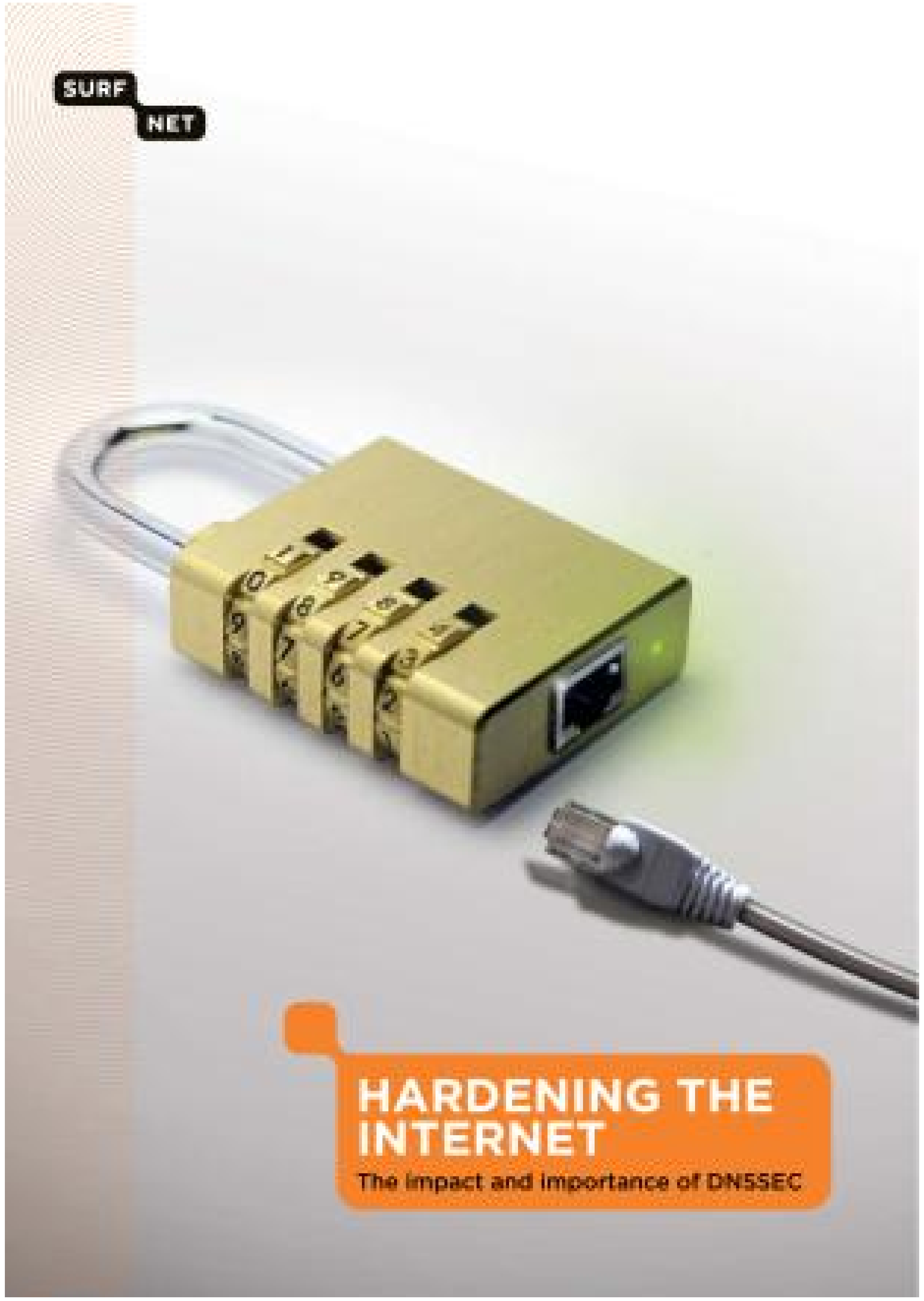

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Suppose an attacker forges a DNS packet from `.org`, including exactly the same DNSSEC signatures but *changing the NS+A records* to point to the attacker's servers.

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

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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.*

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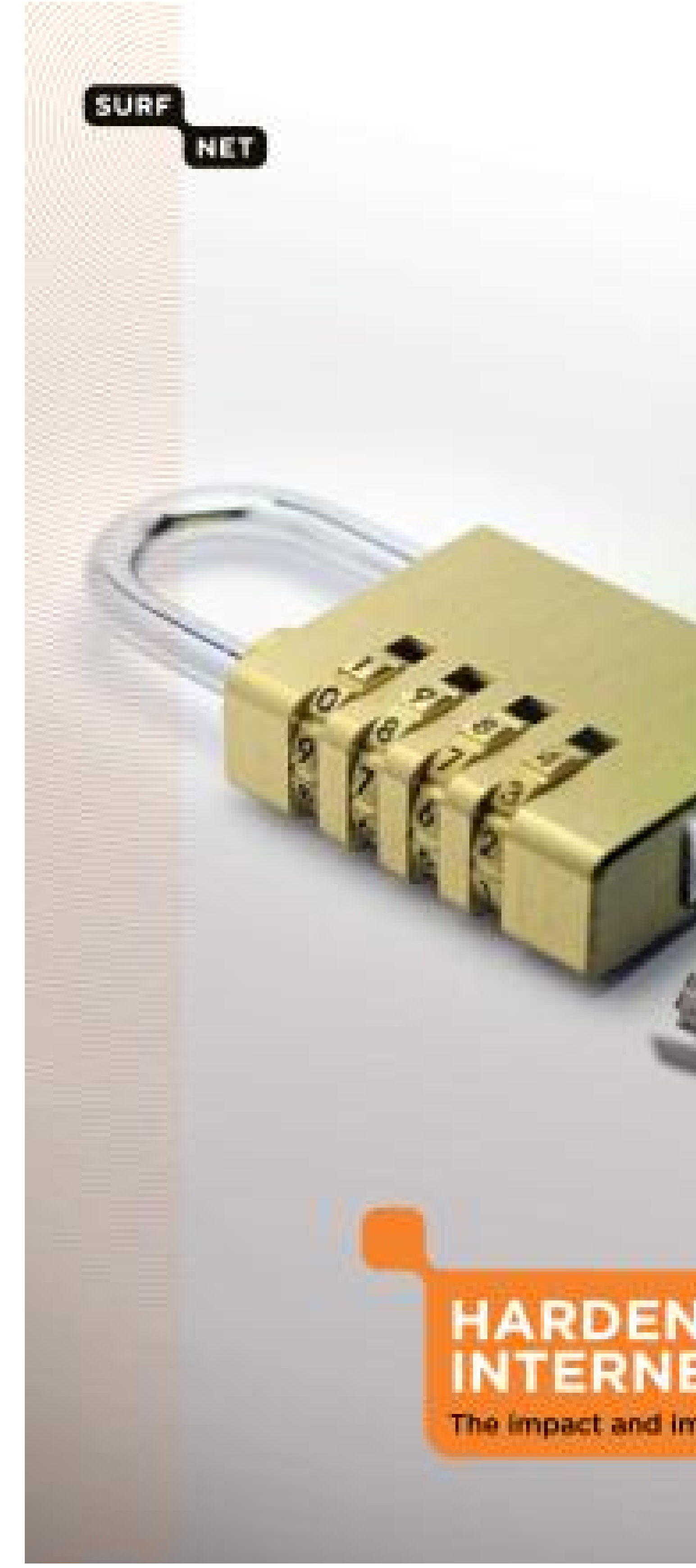

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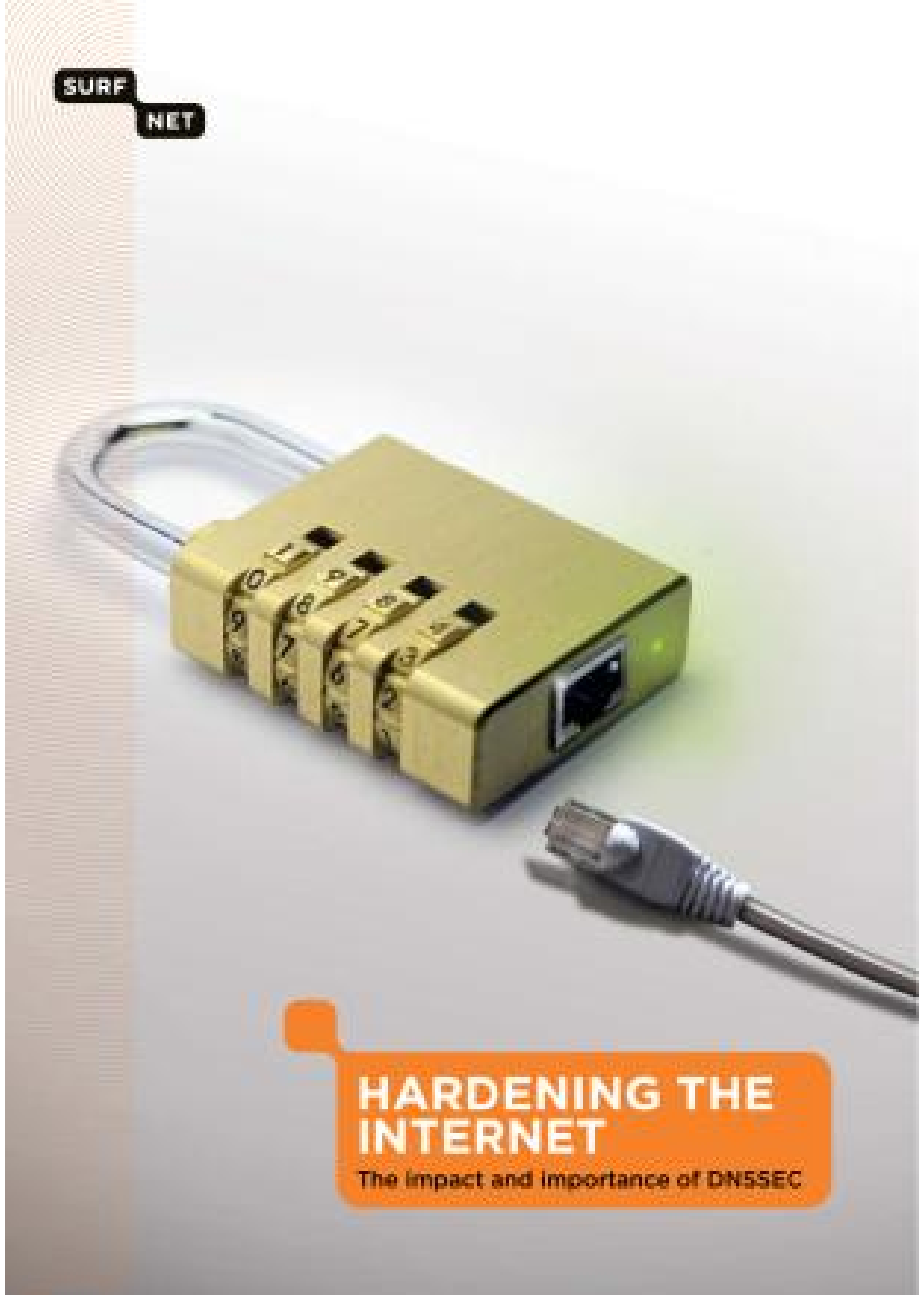

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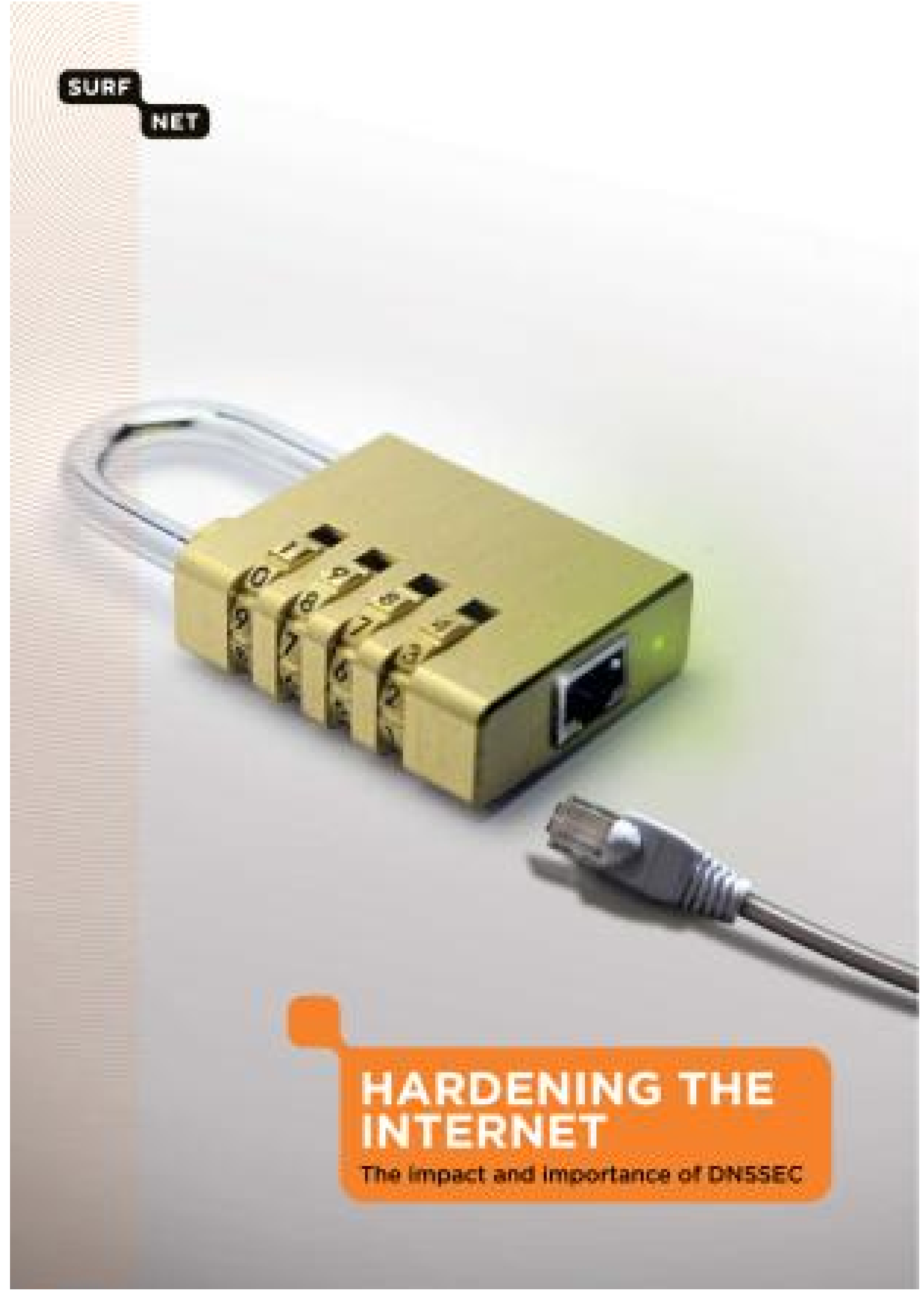

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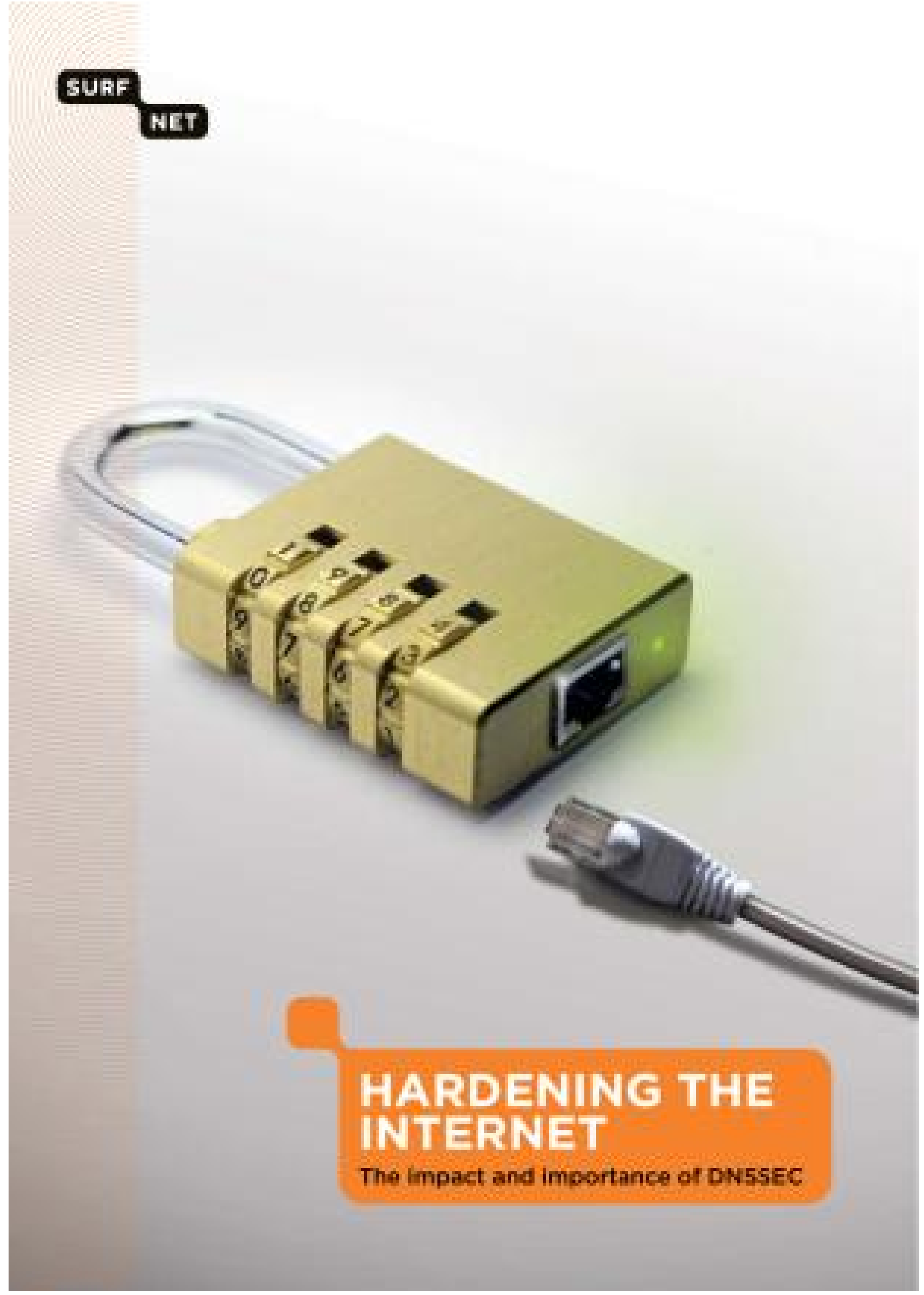

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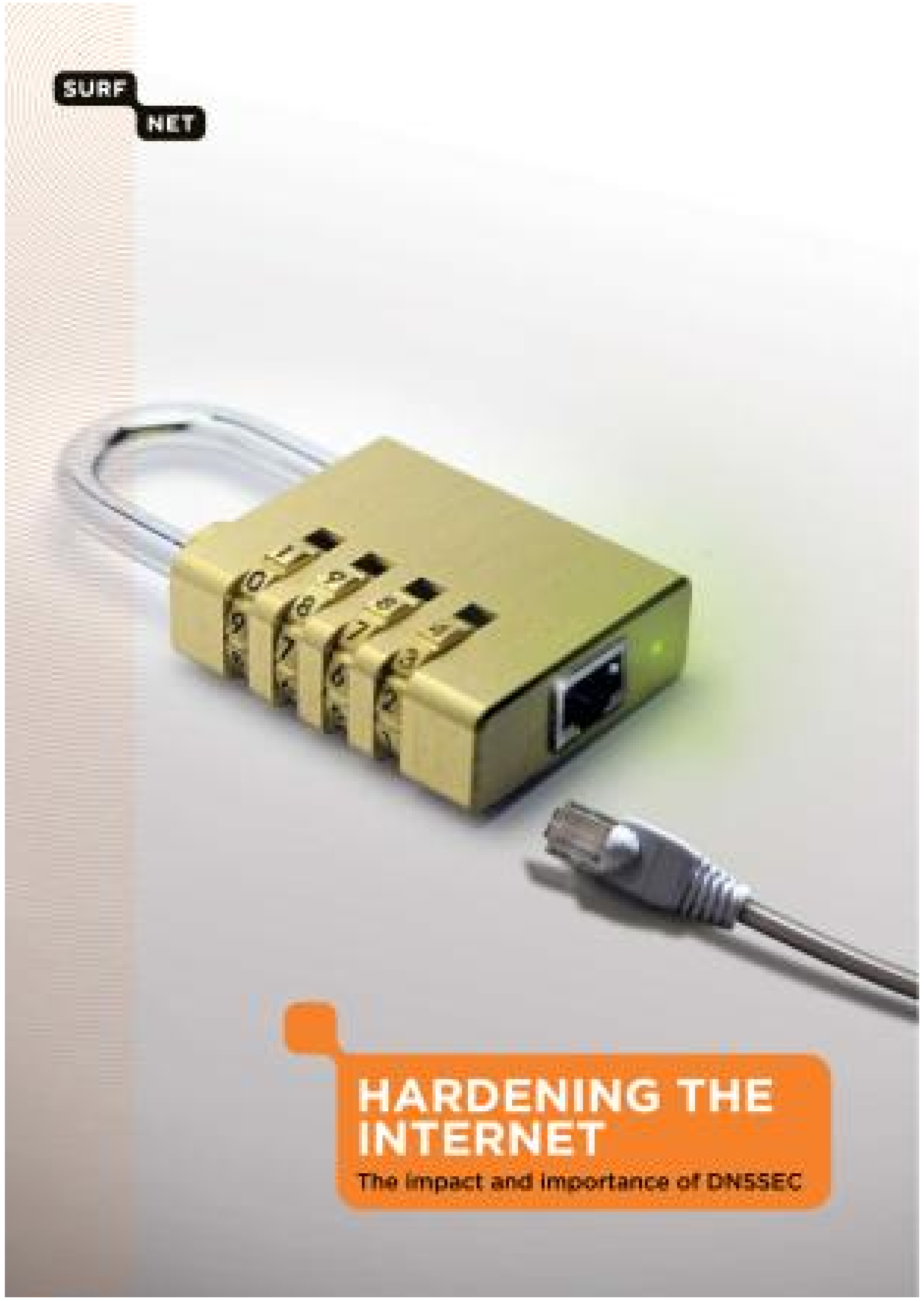

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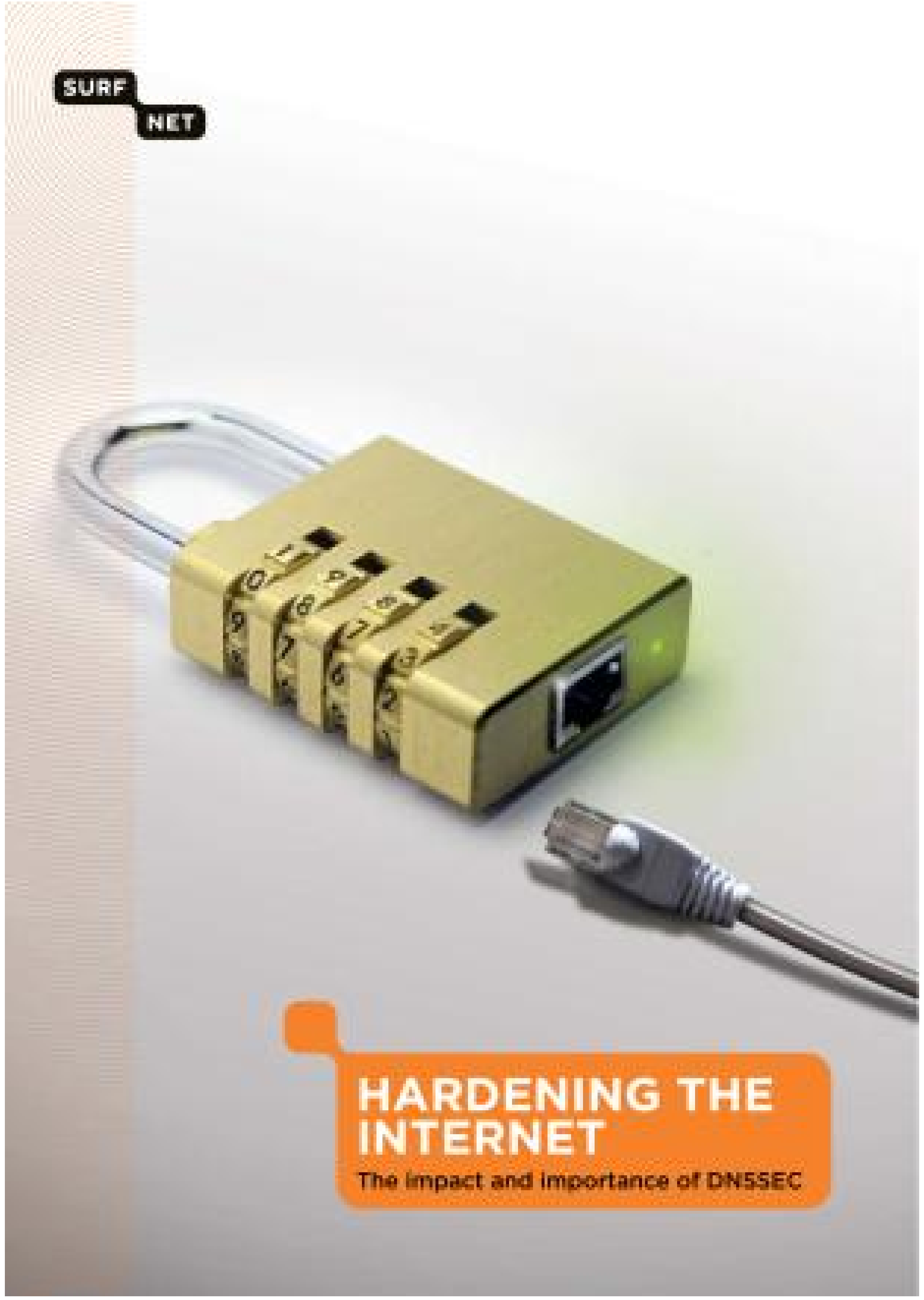

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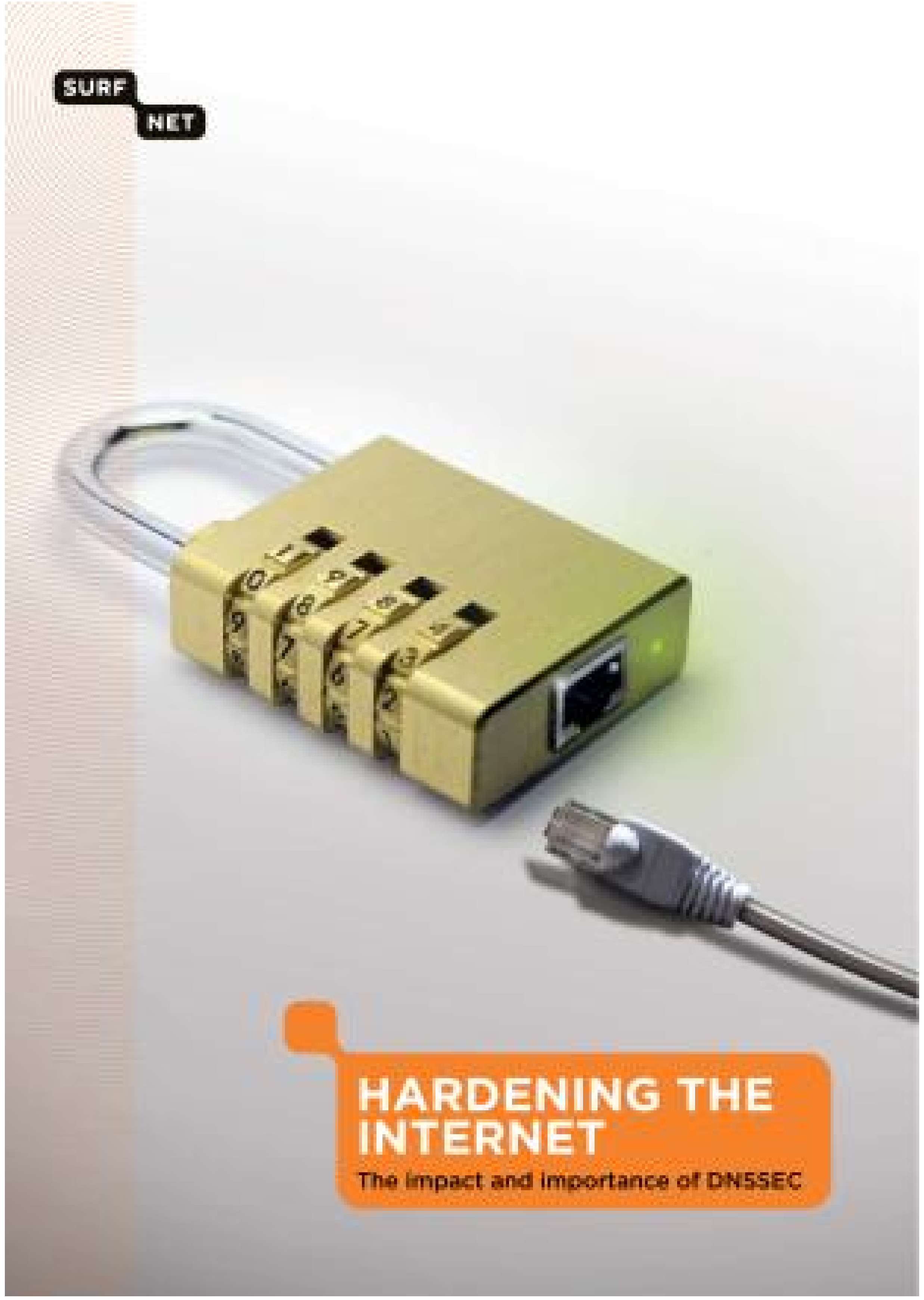

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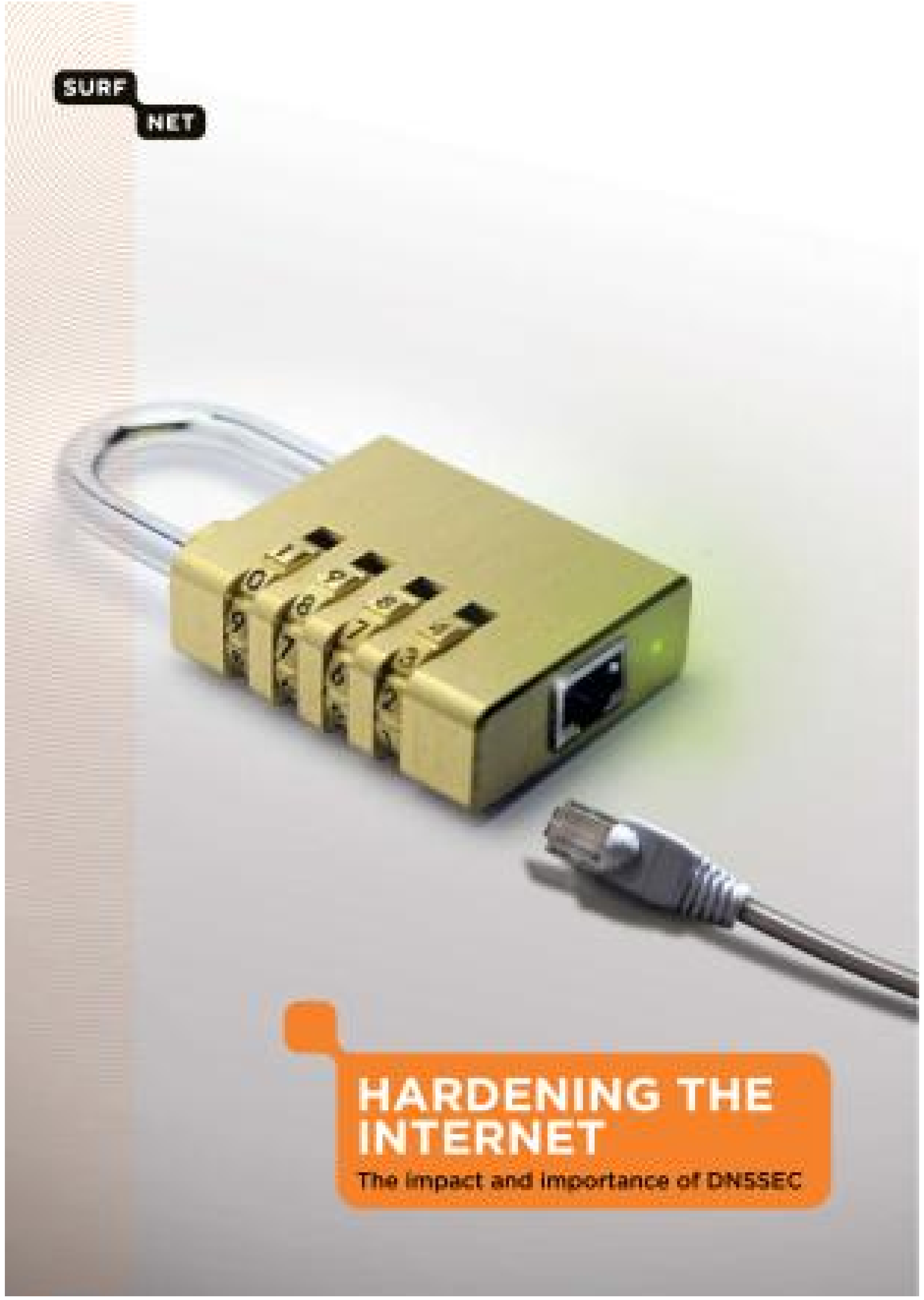

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Let's see how this happened.

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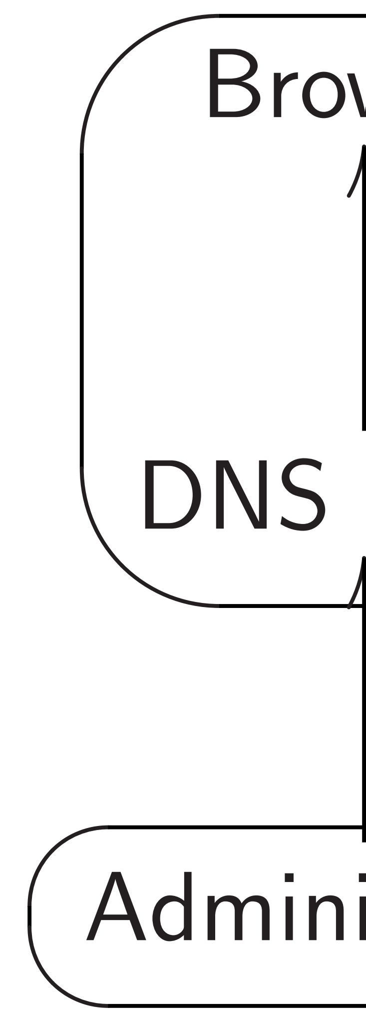

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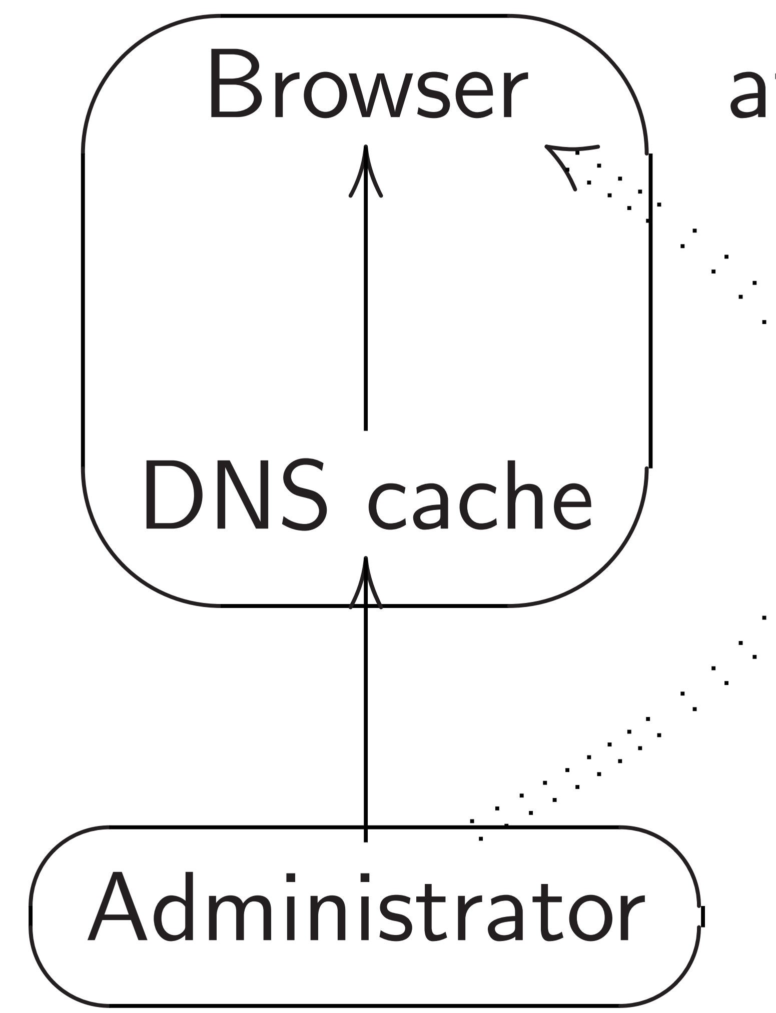

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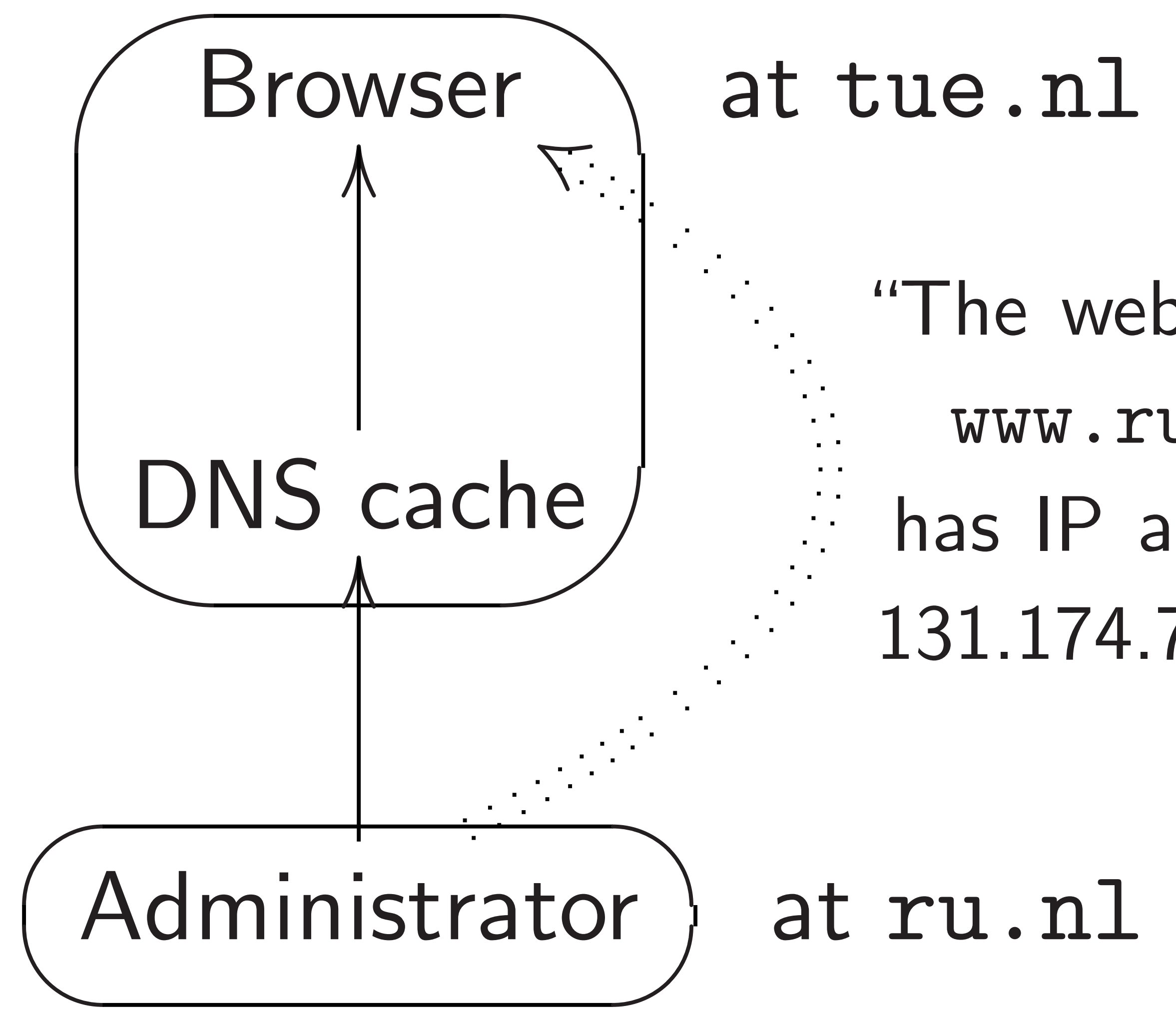

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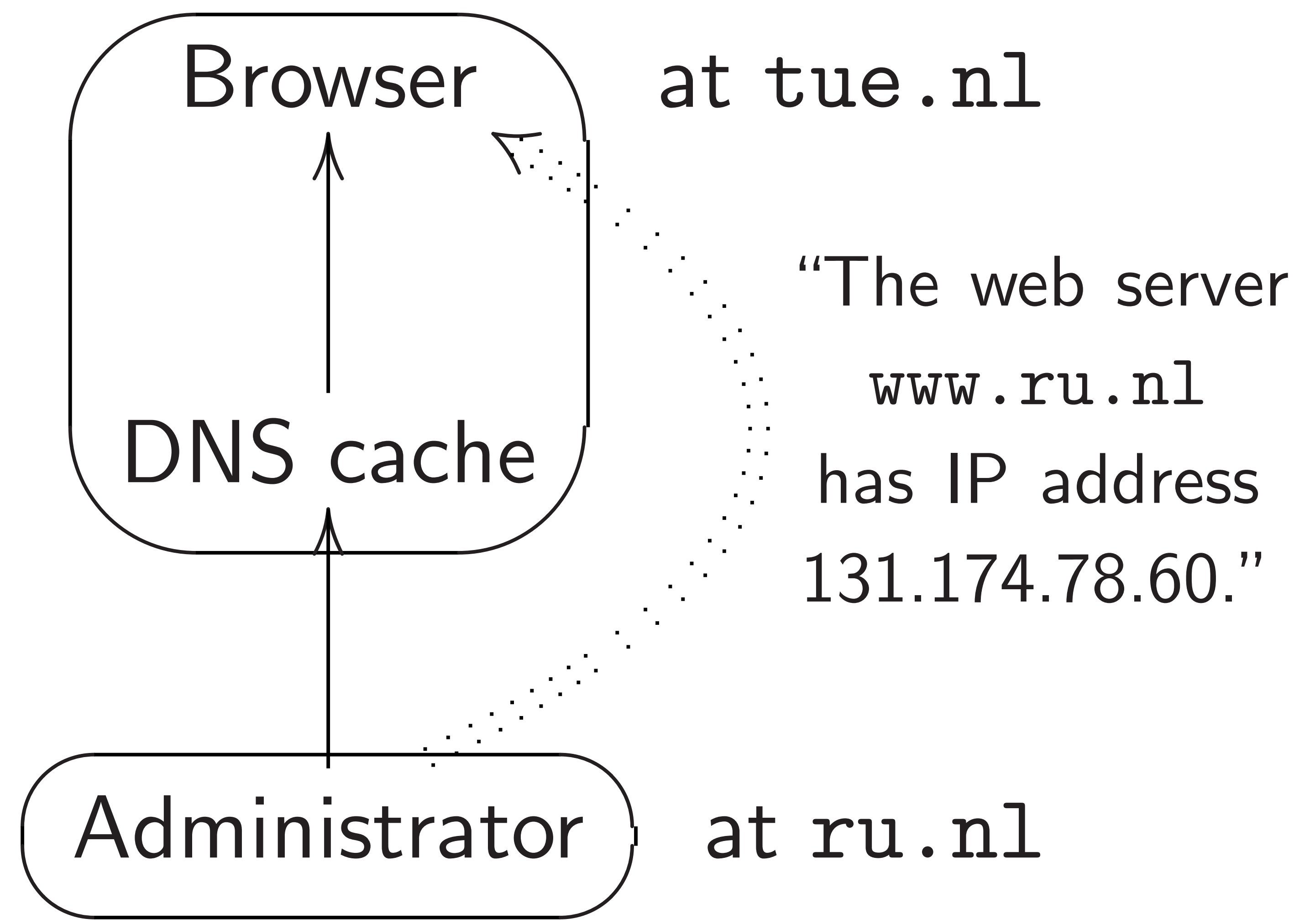

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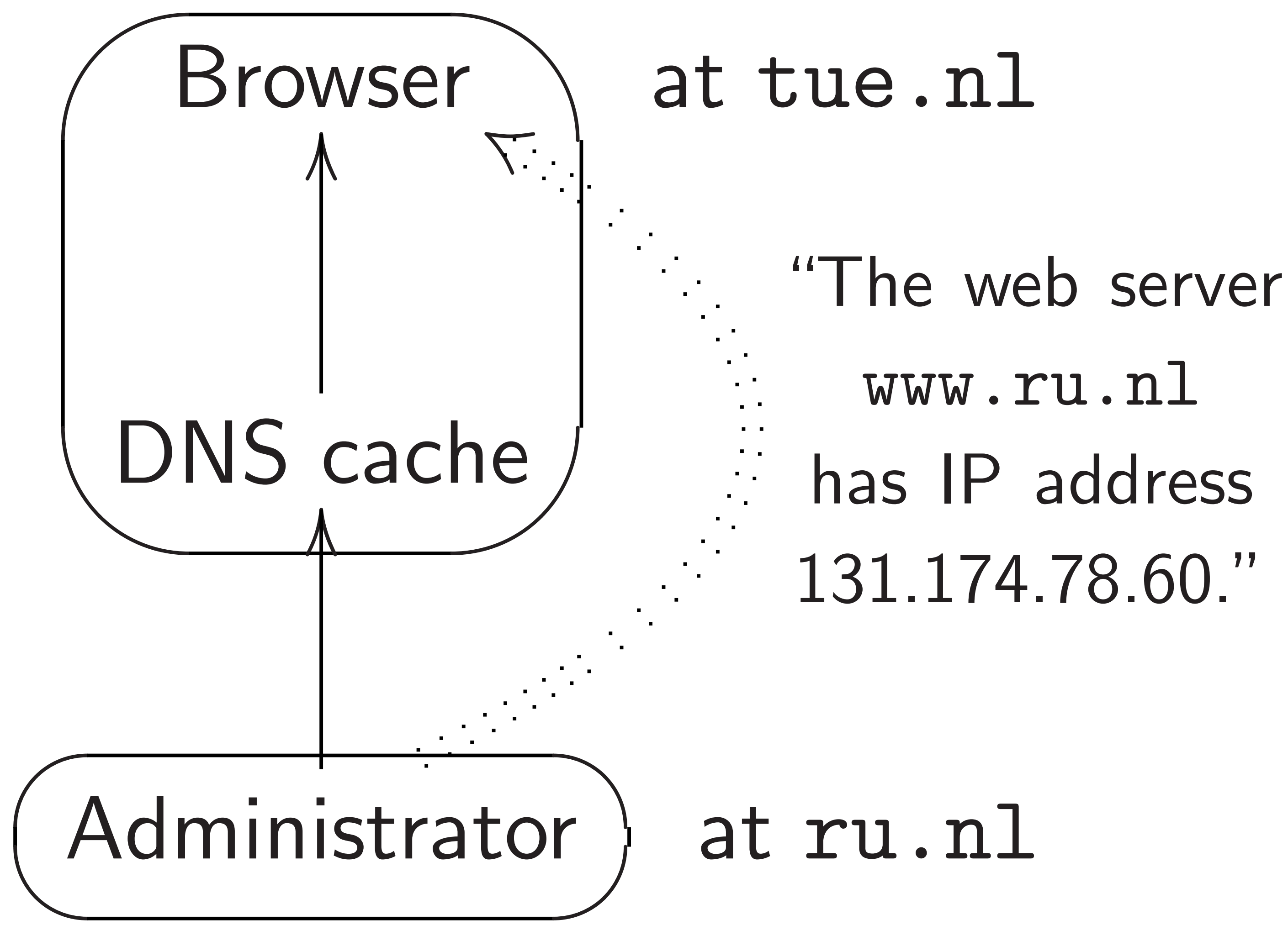

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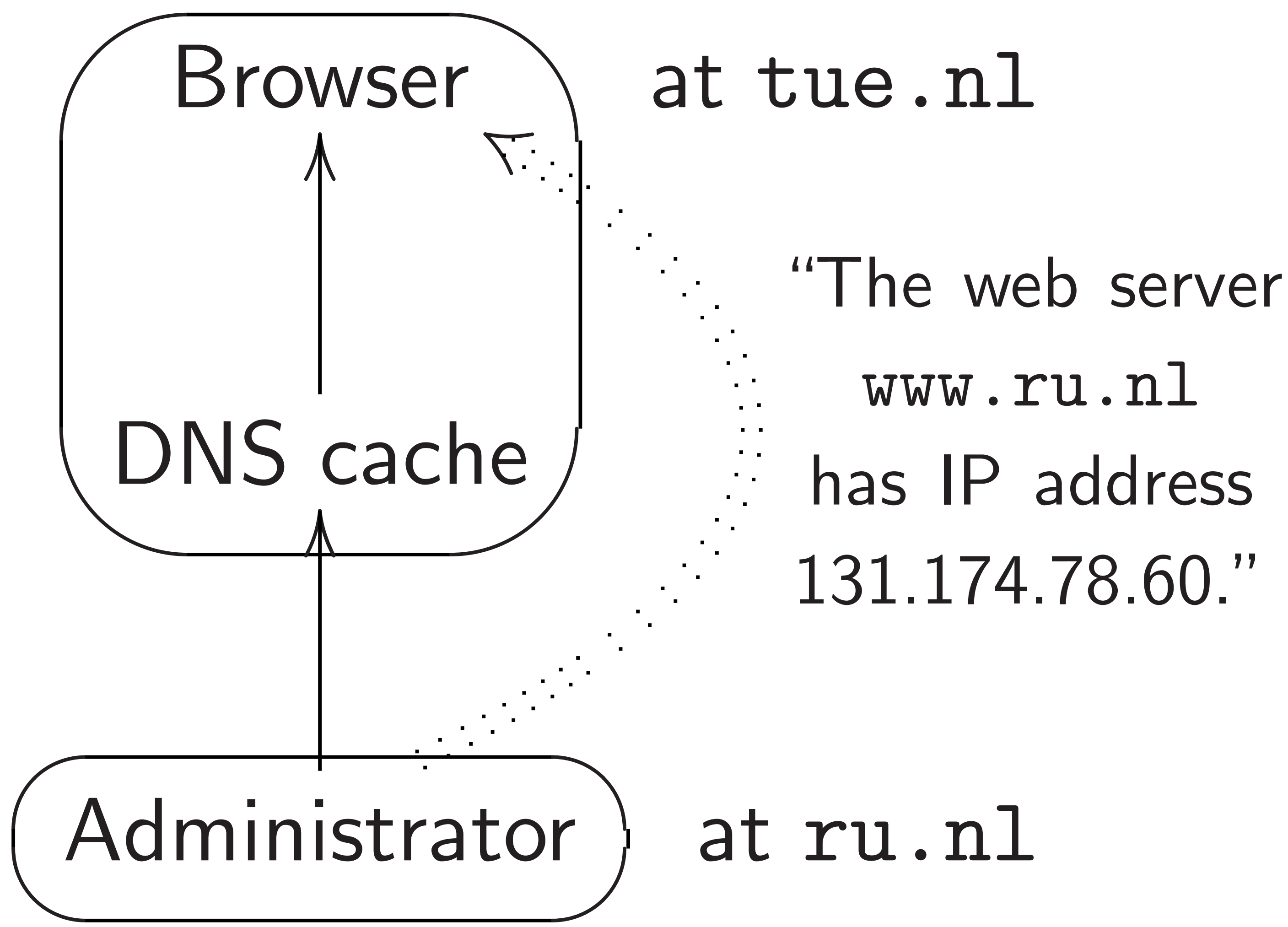

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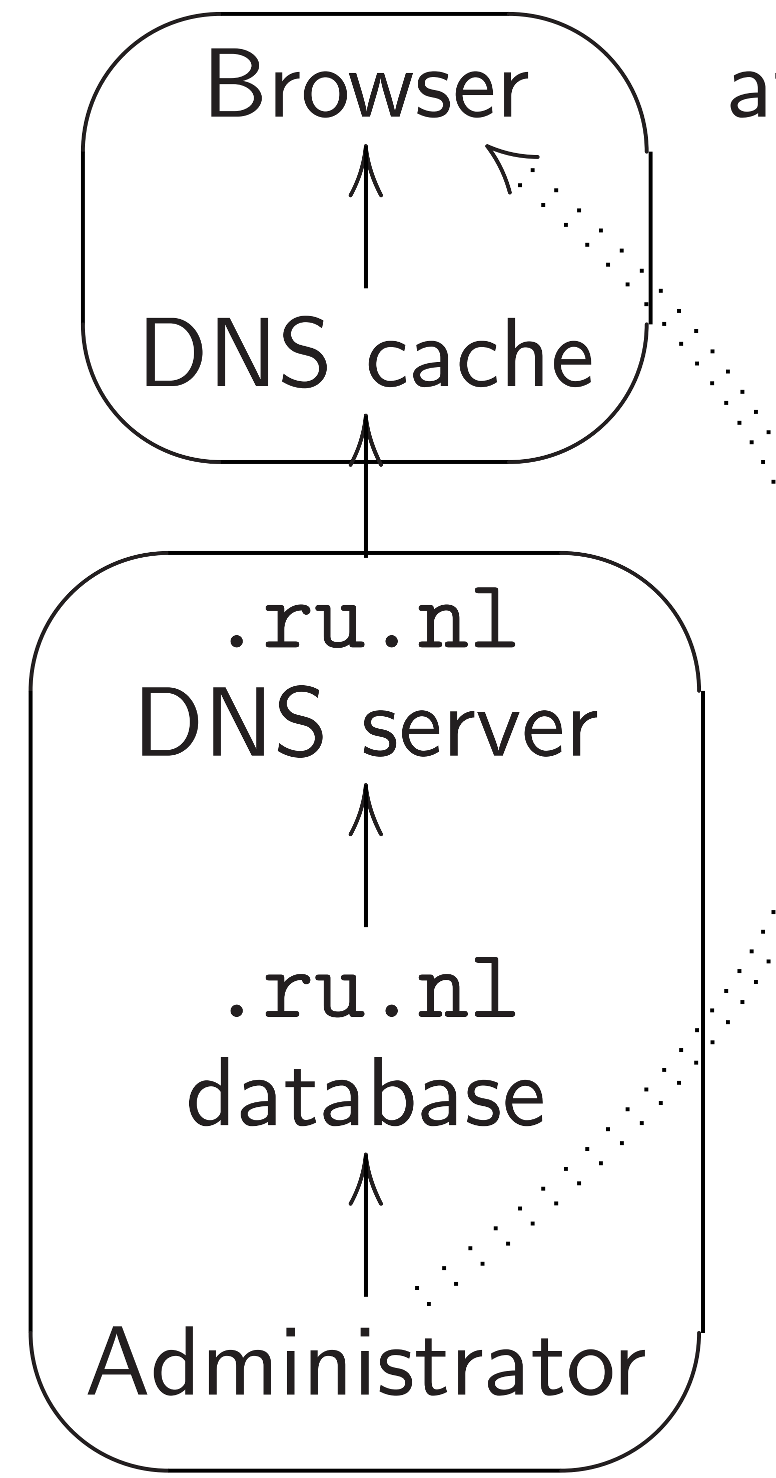

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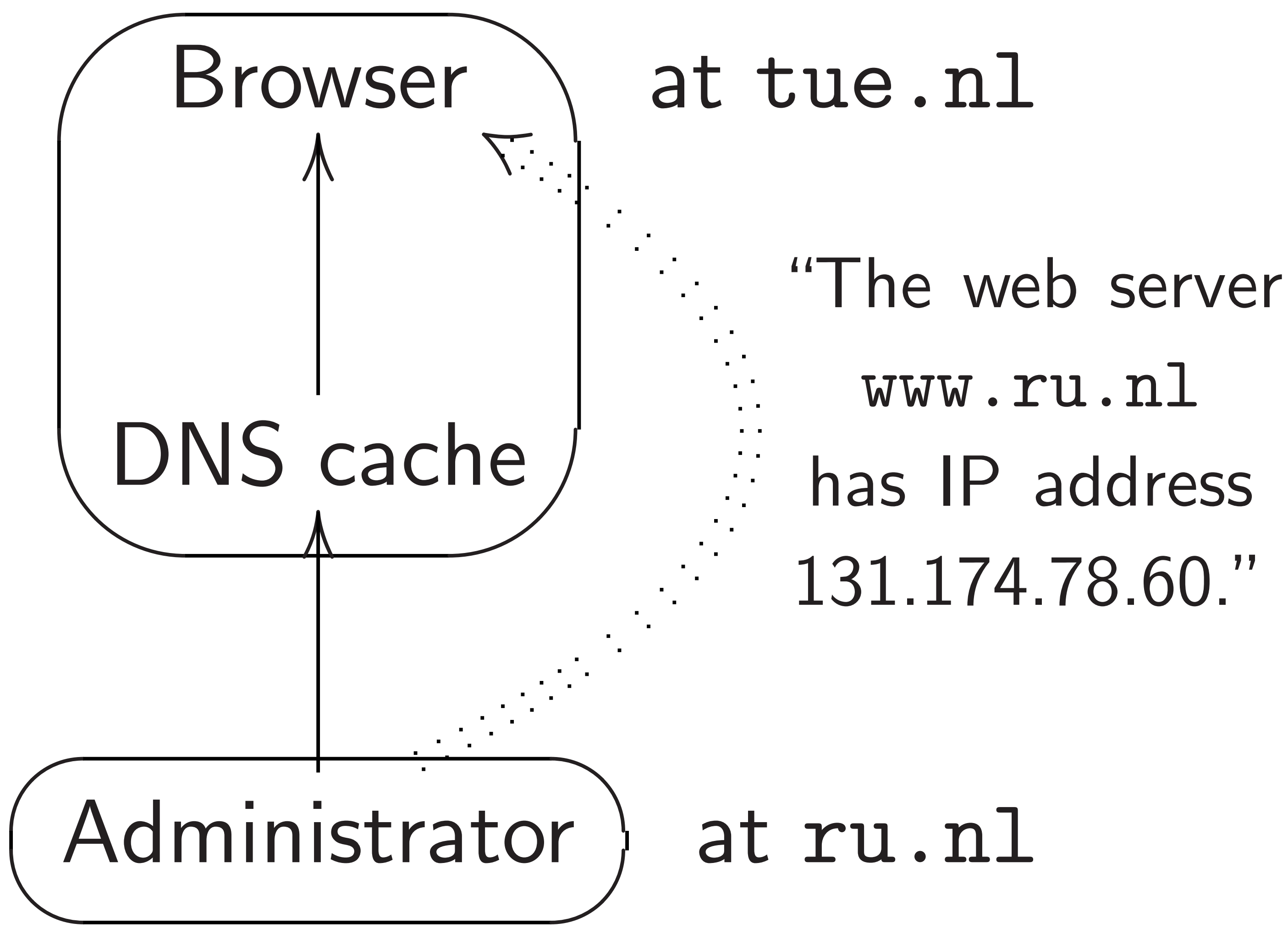

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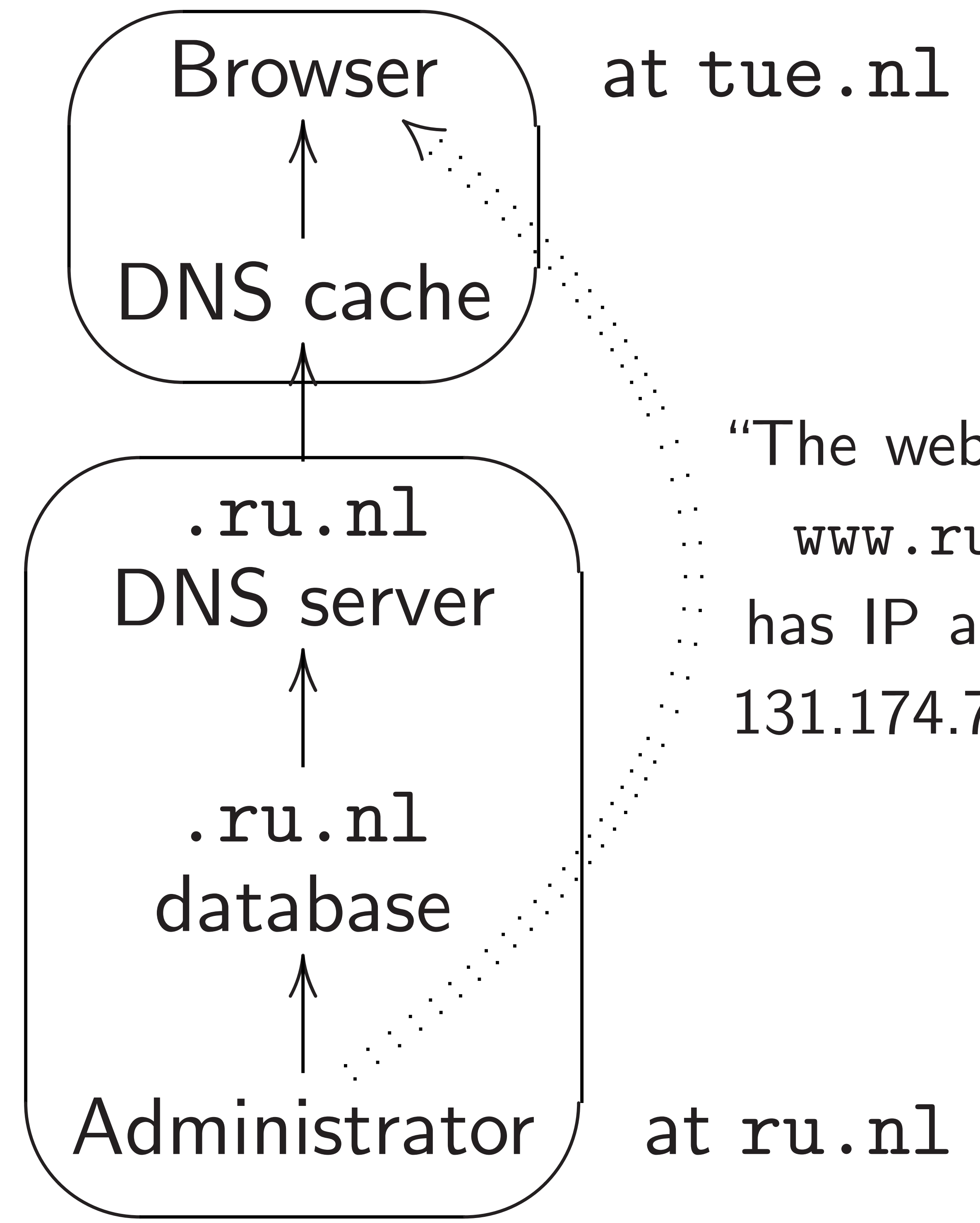

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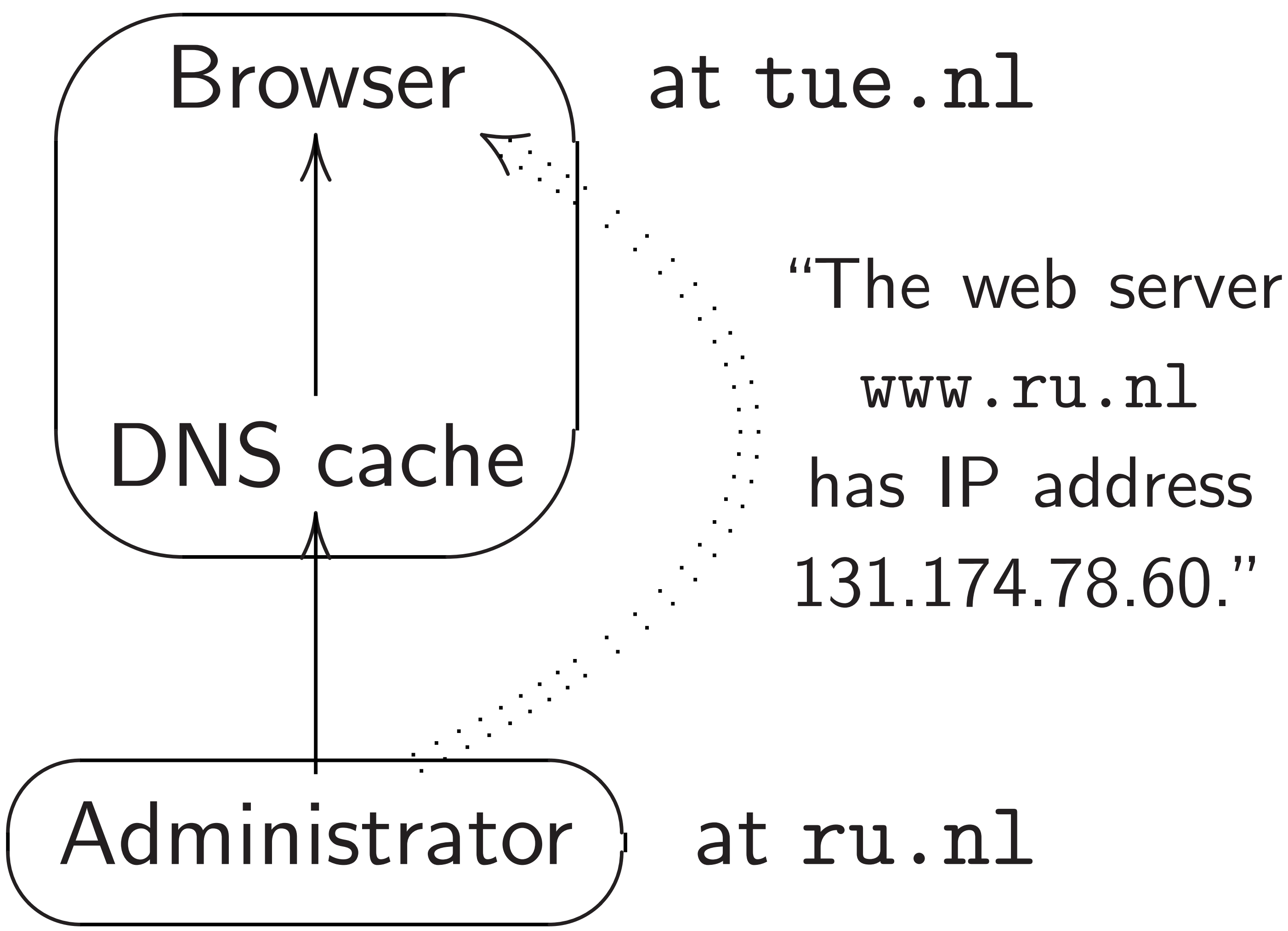

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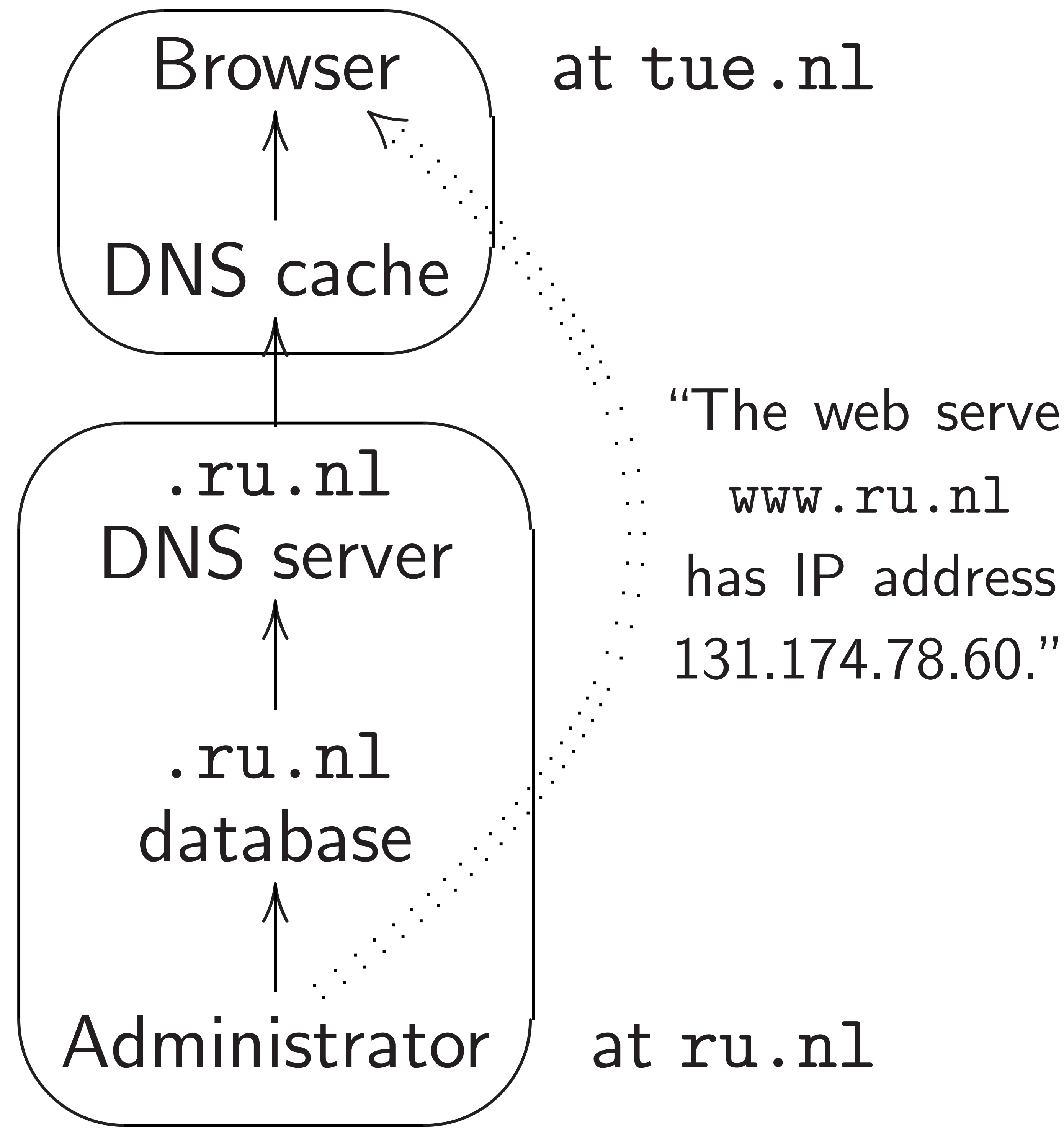

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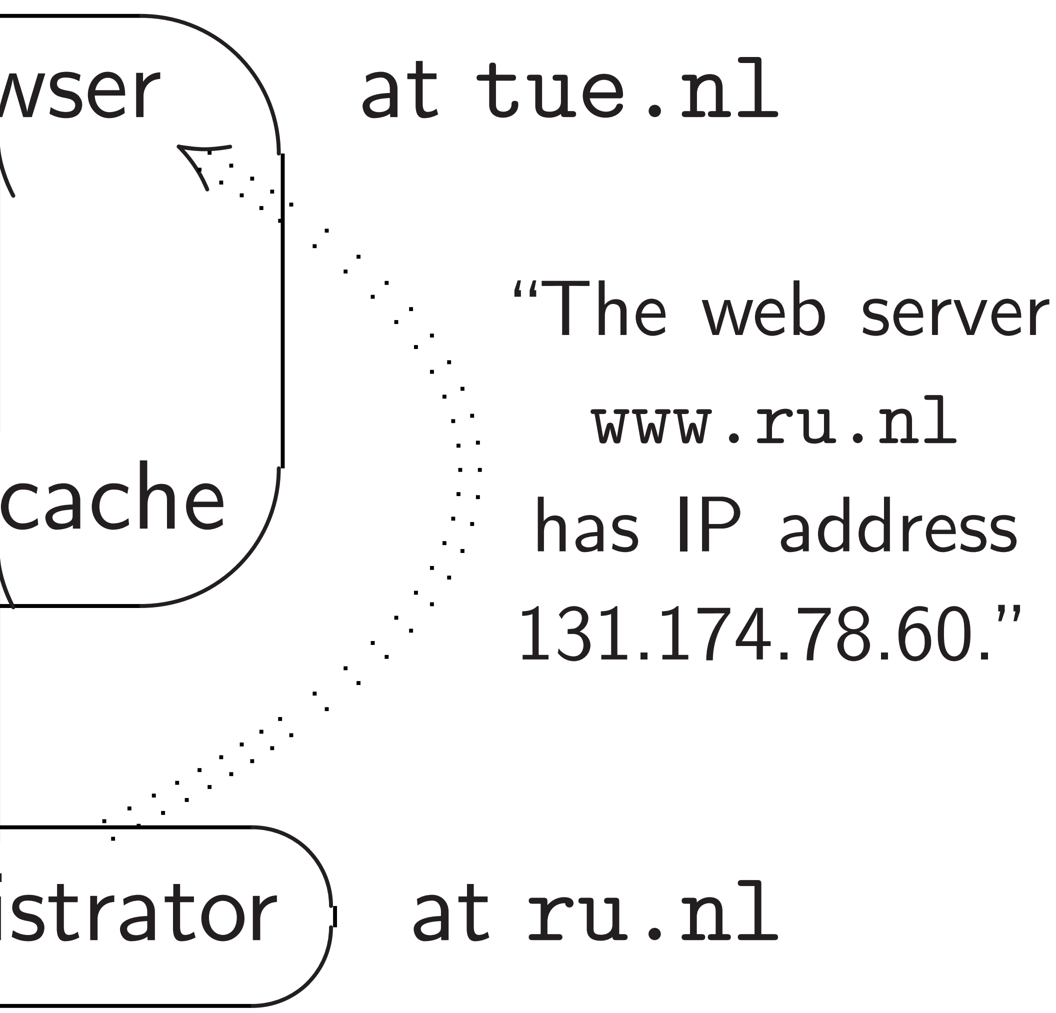

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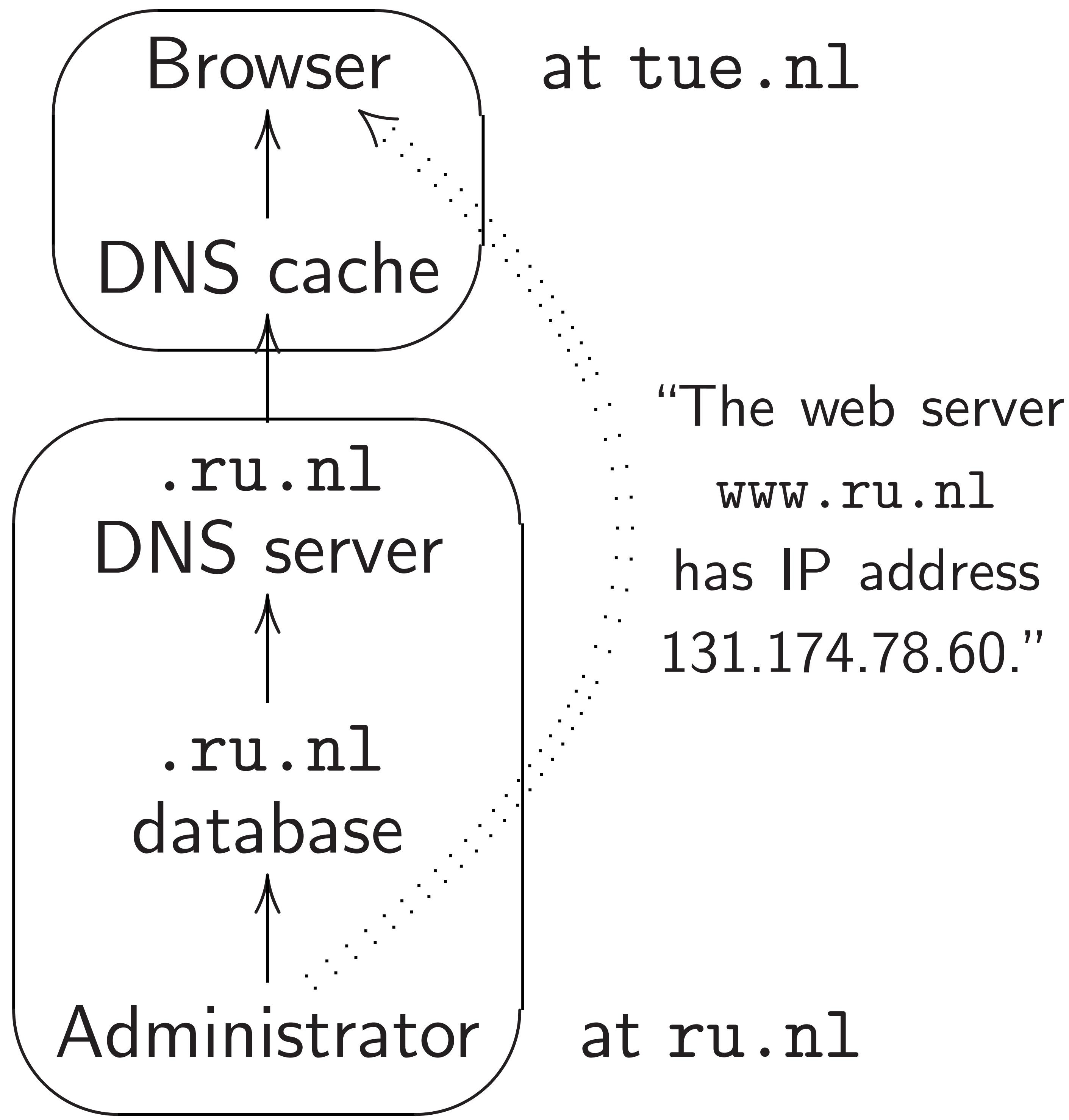

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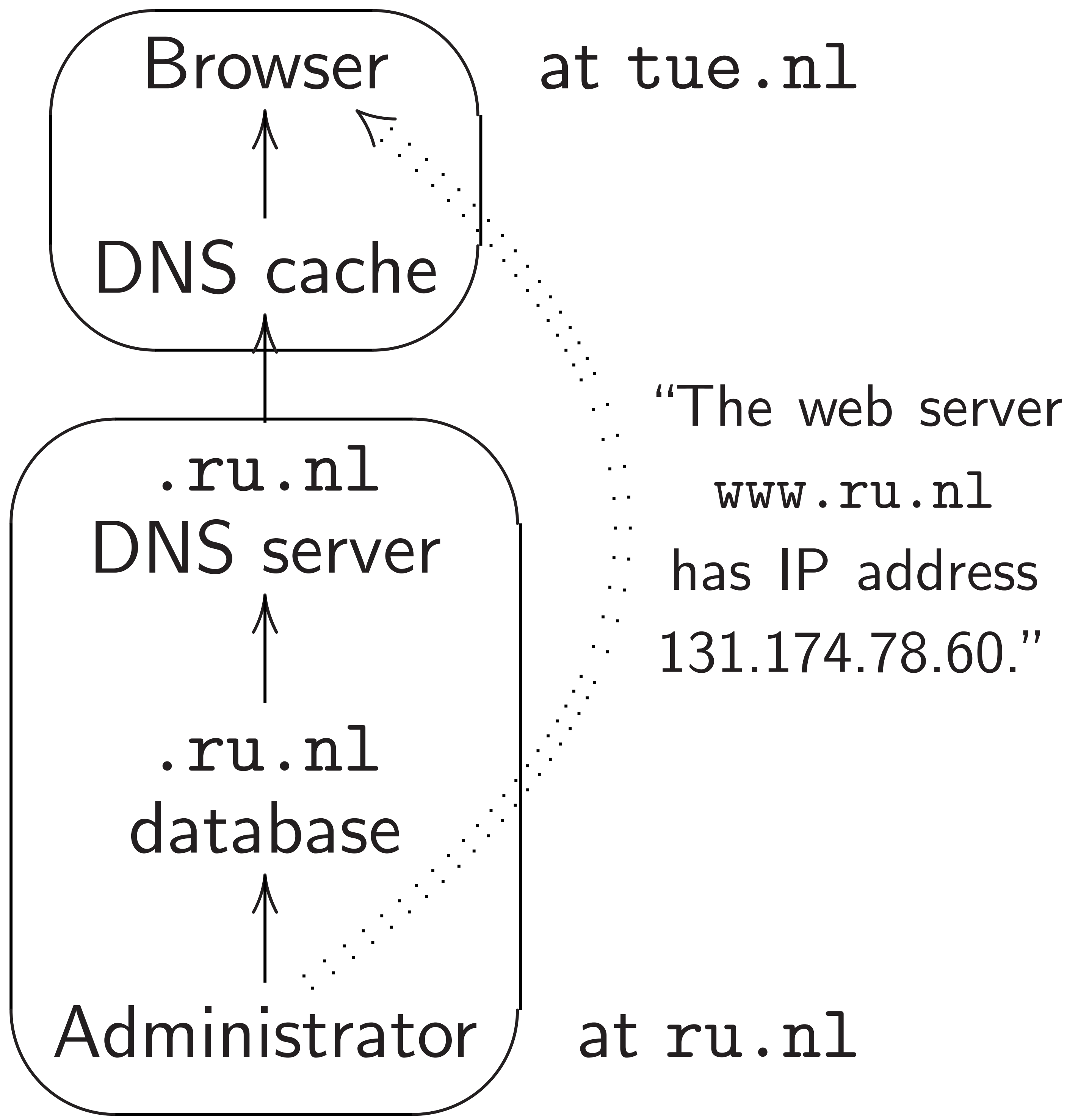

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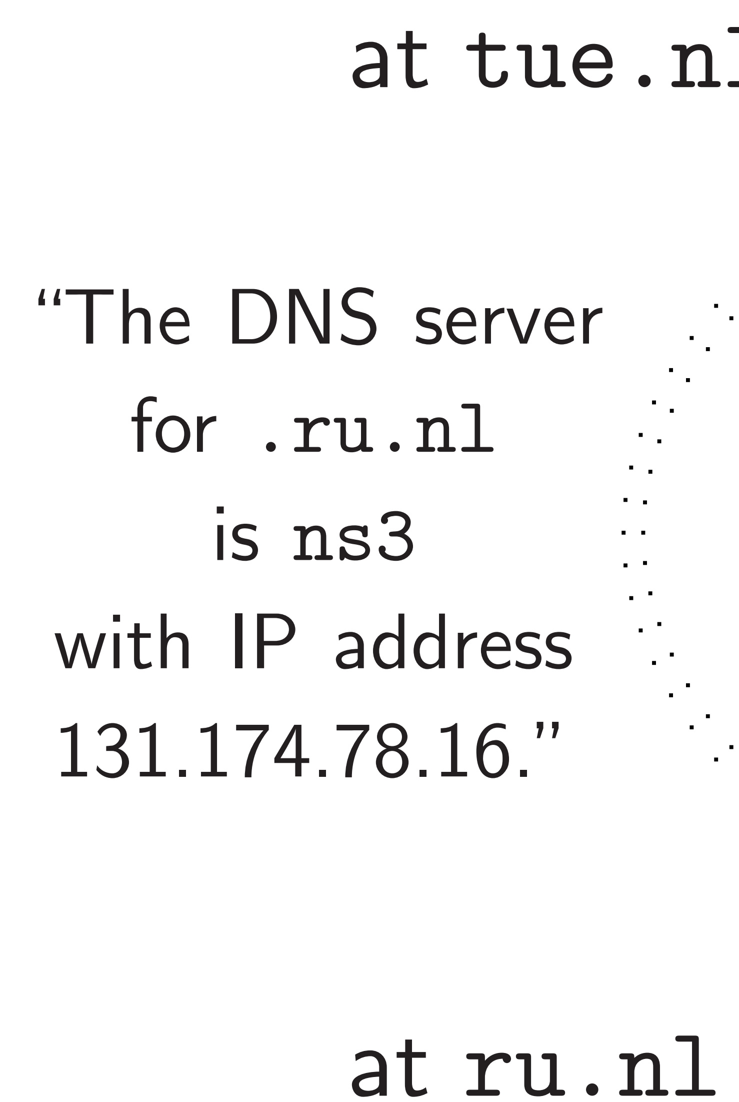

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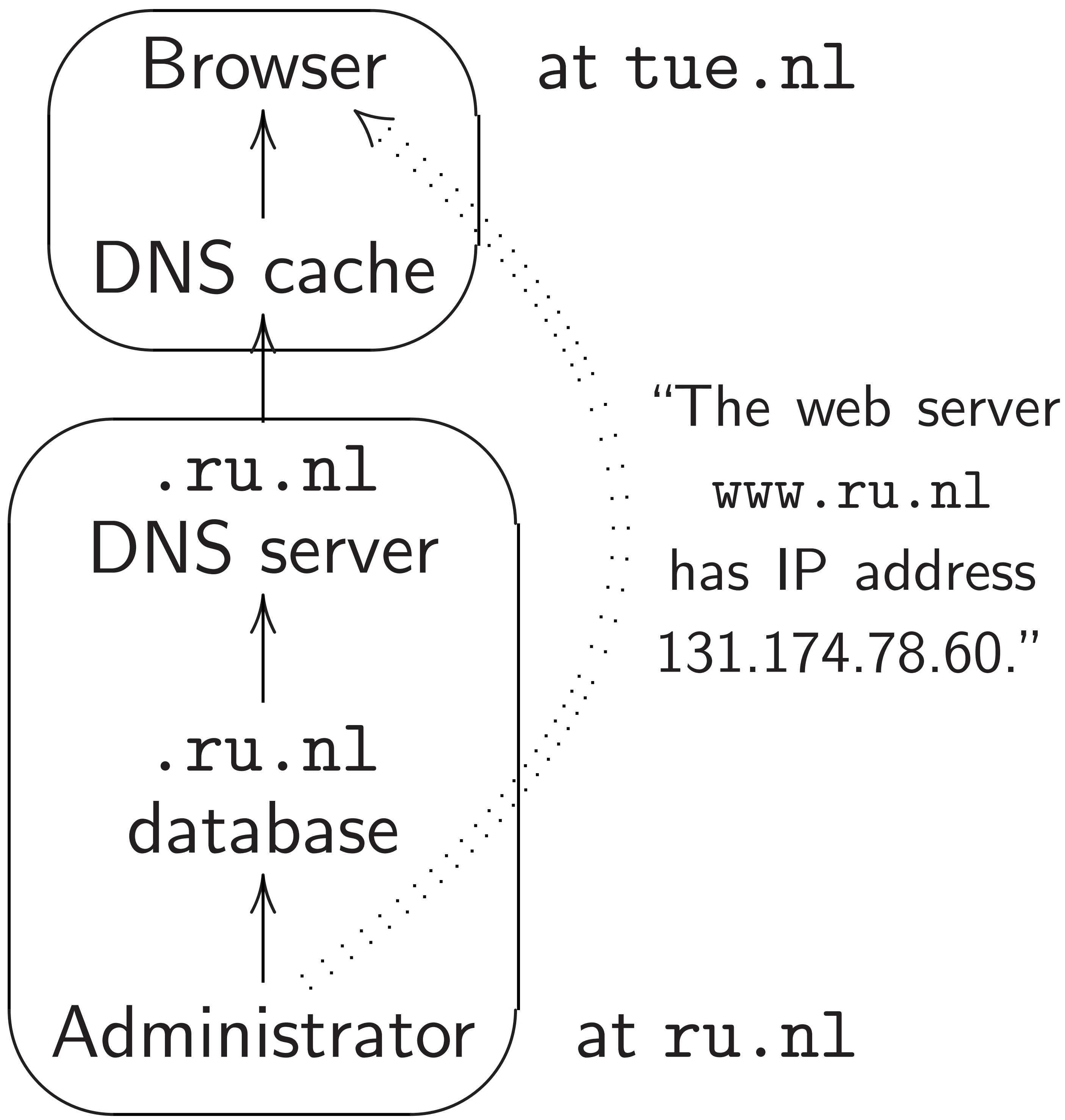

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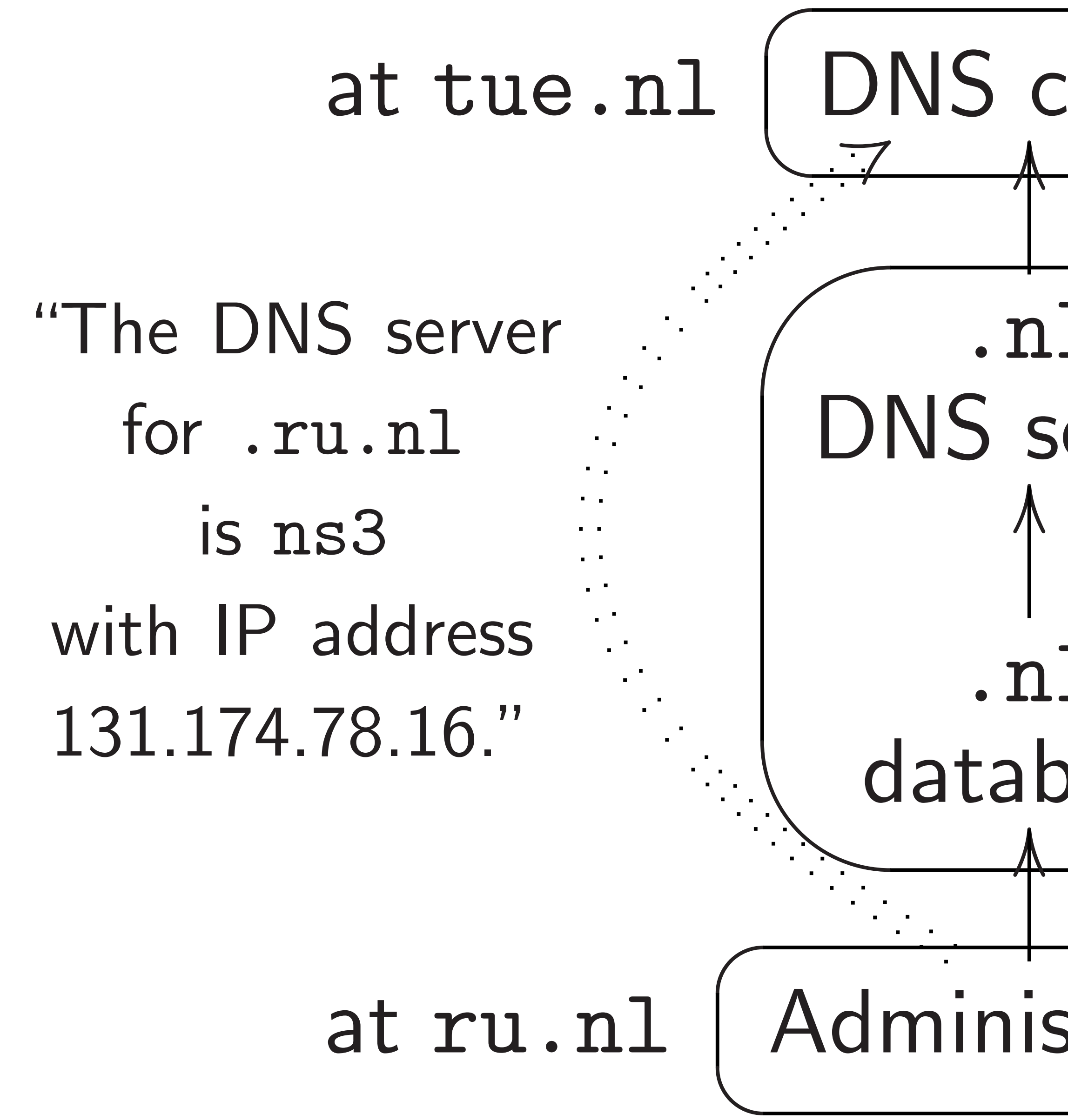

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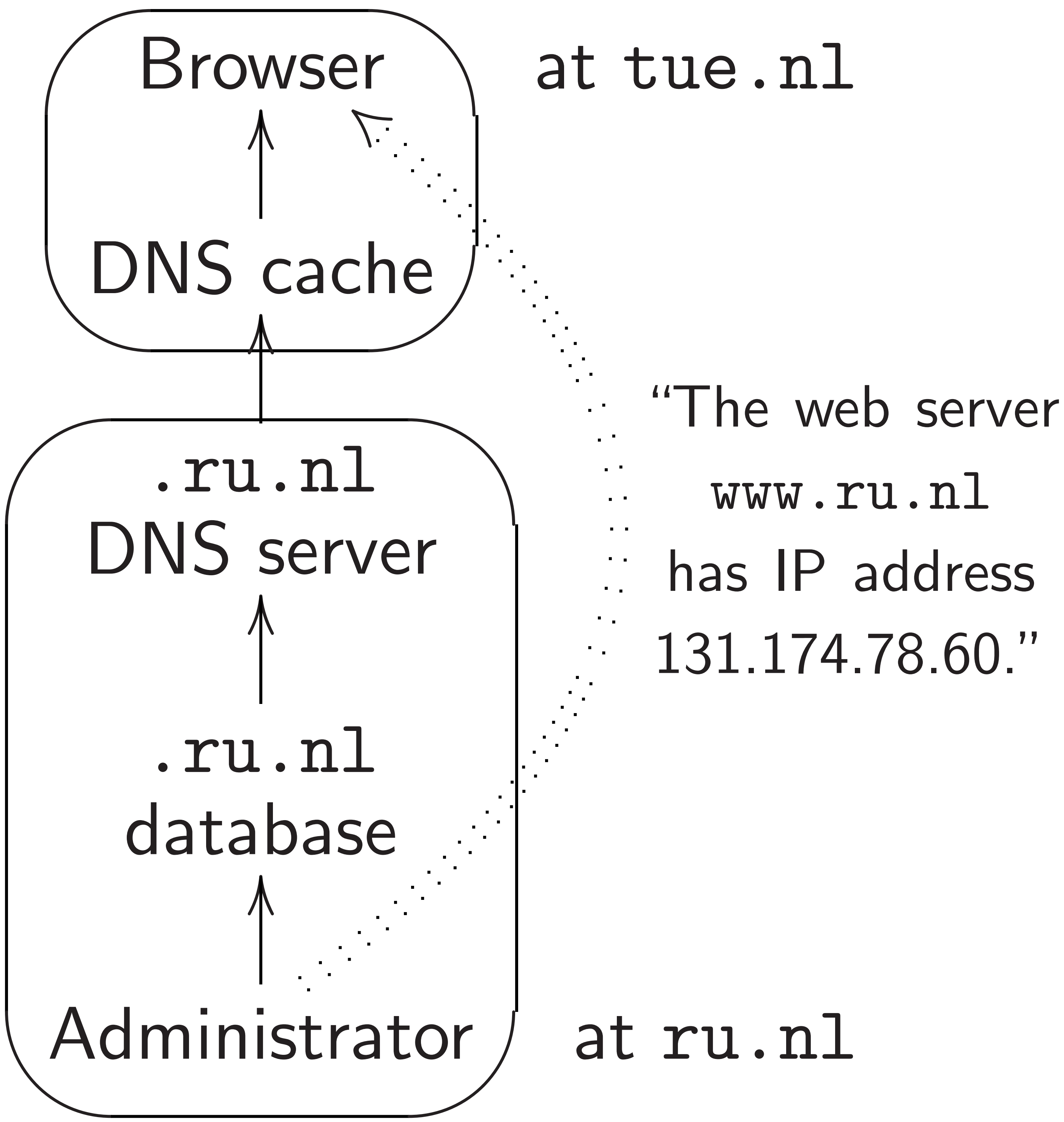

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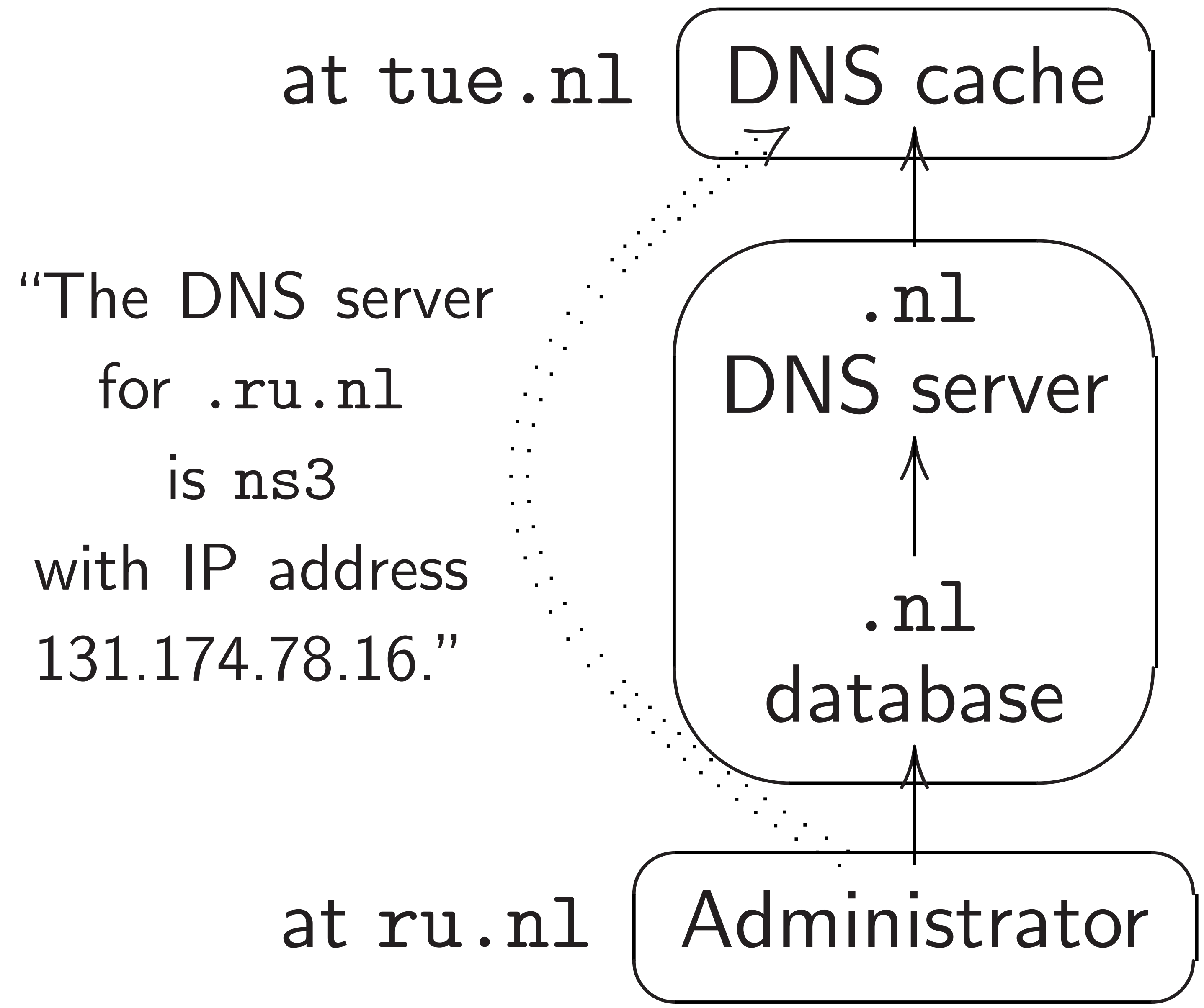

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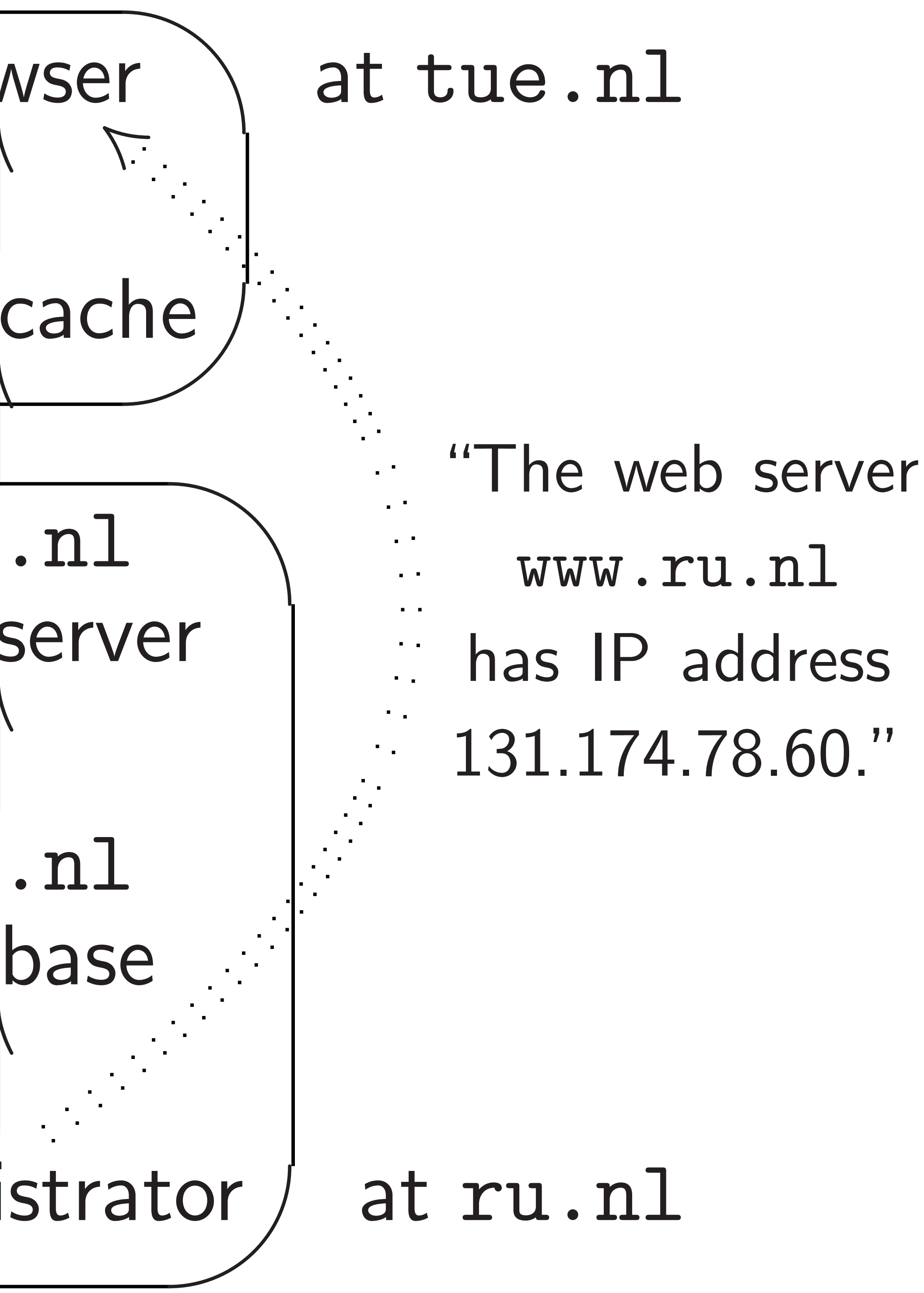

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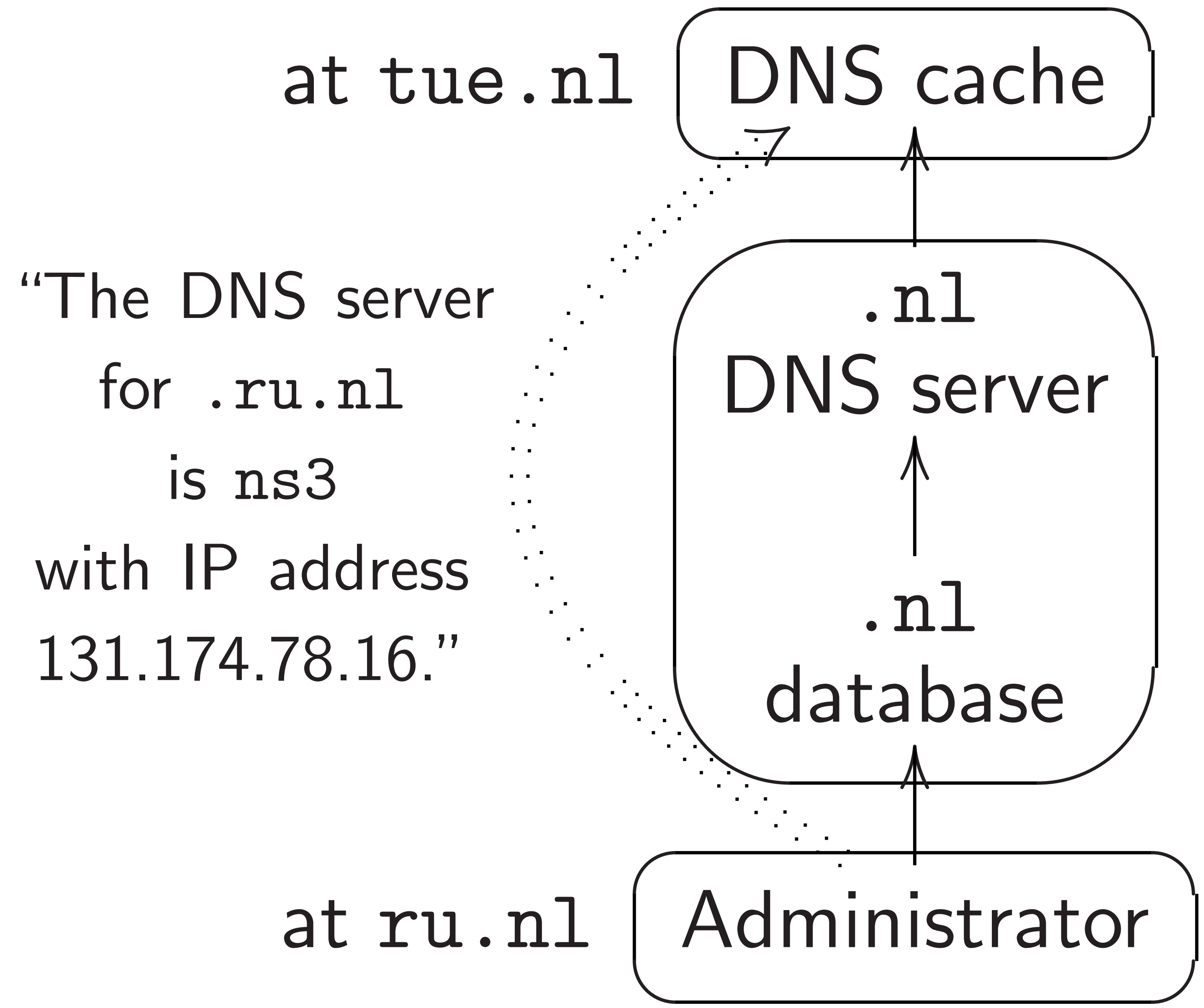

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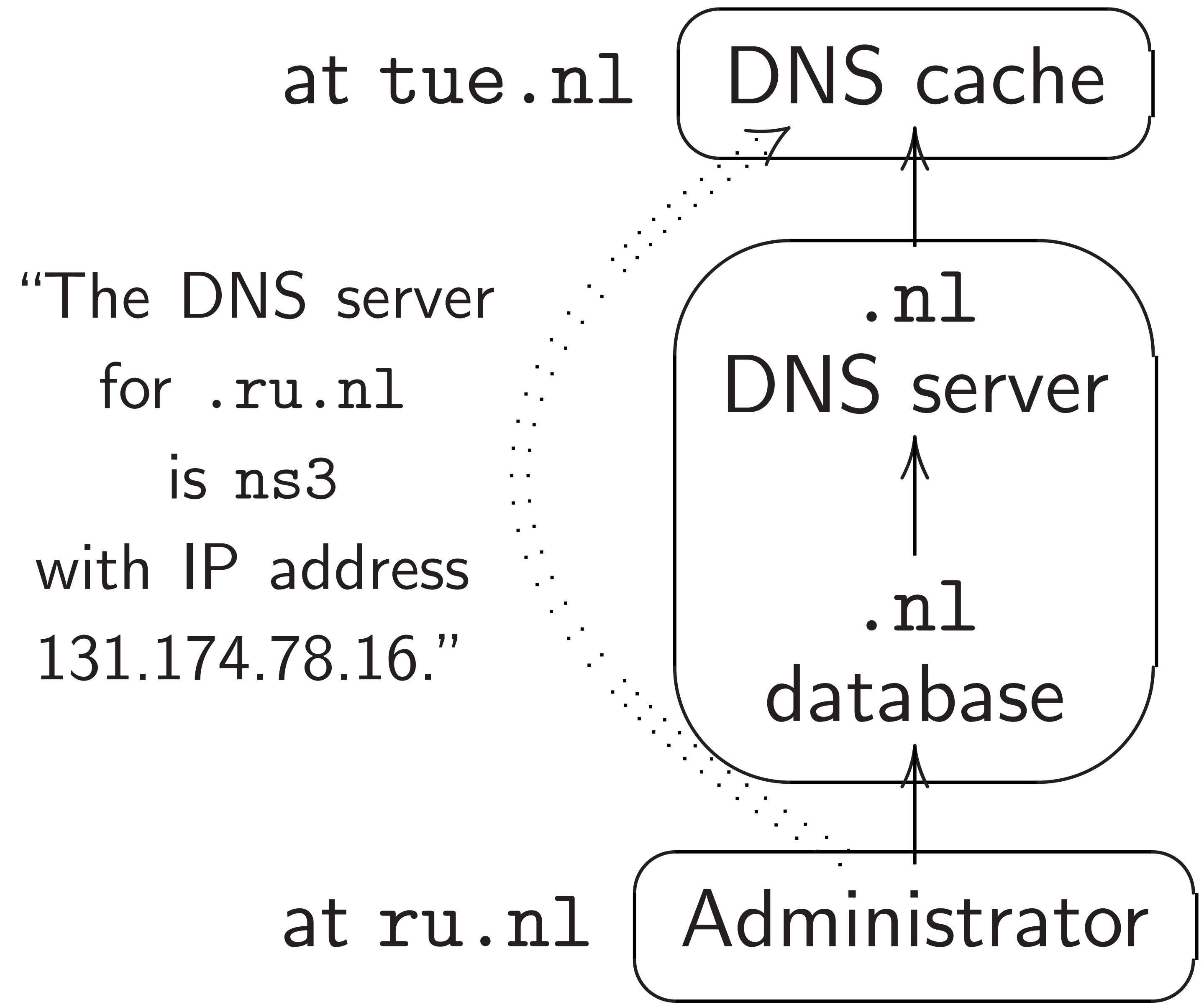

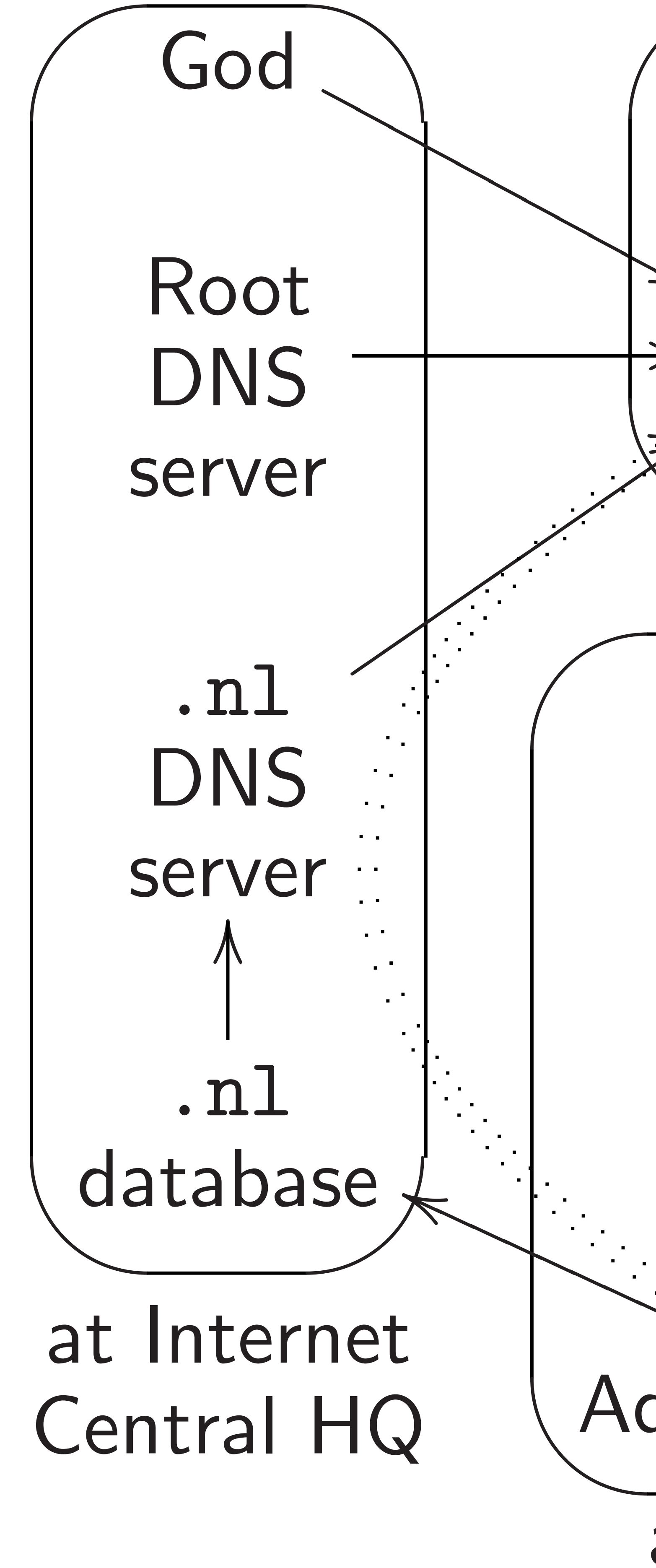

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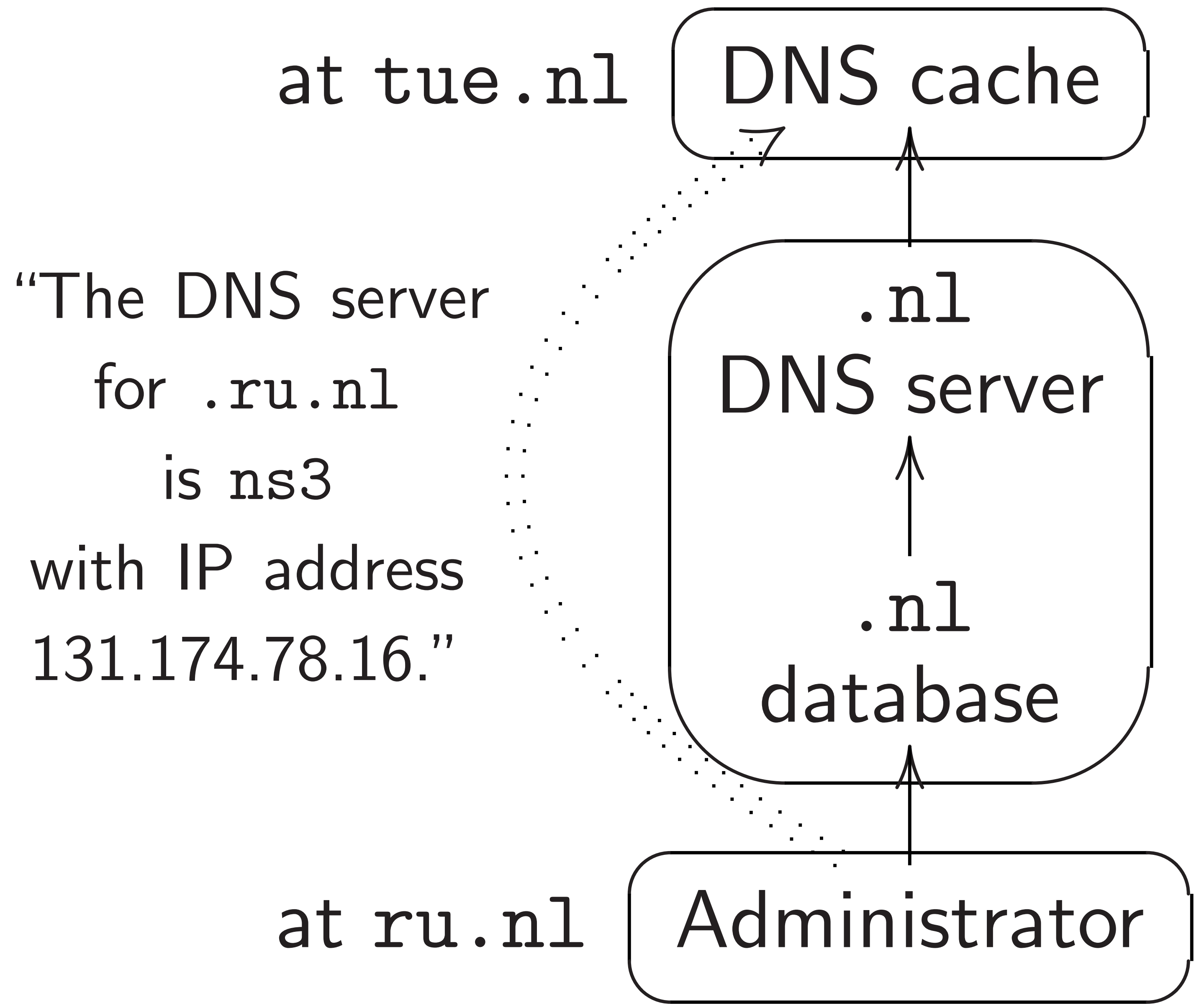

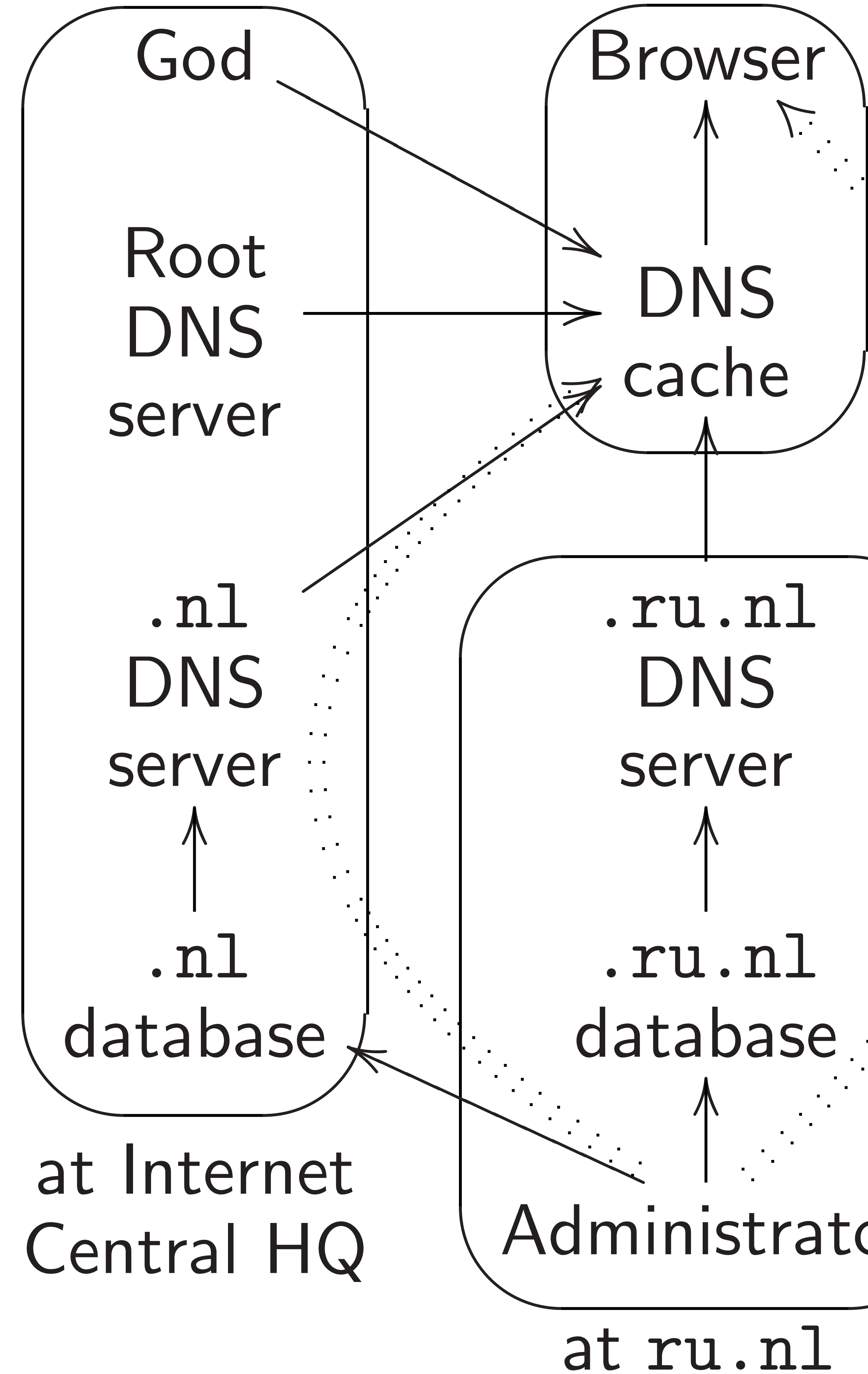

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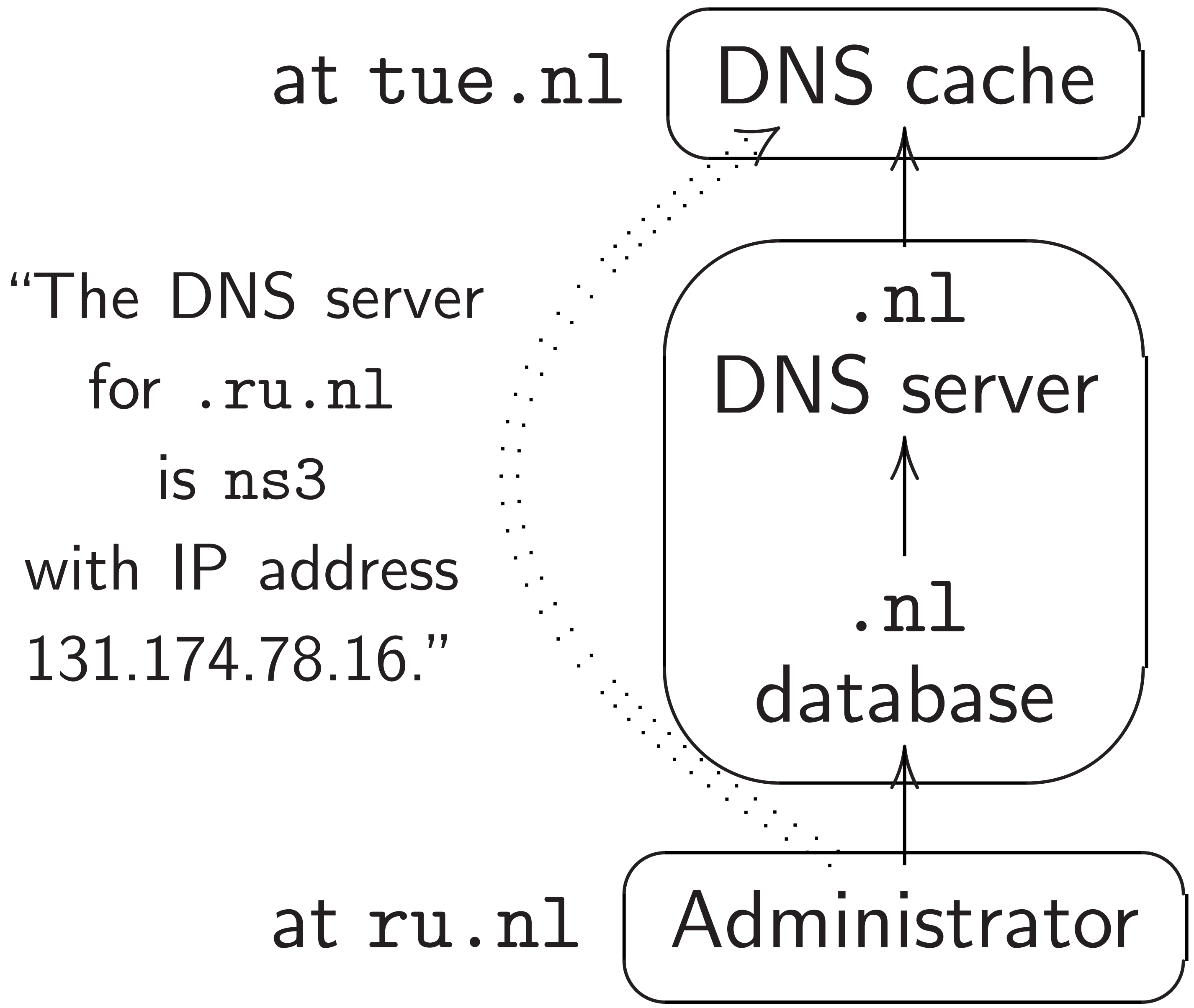

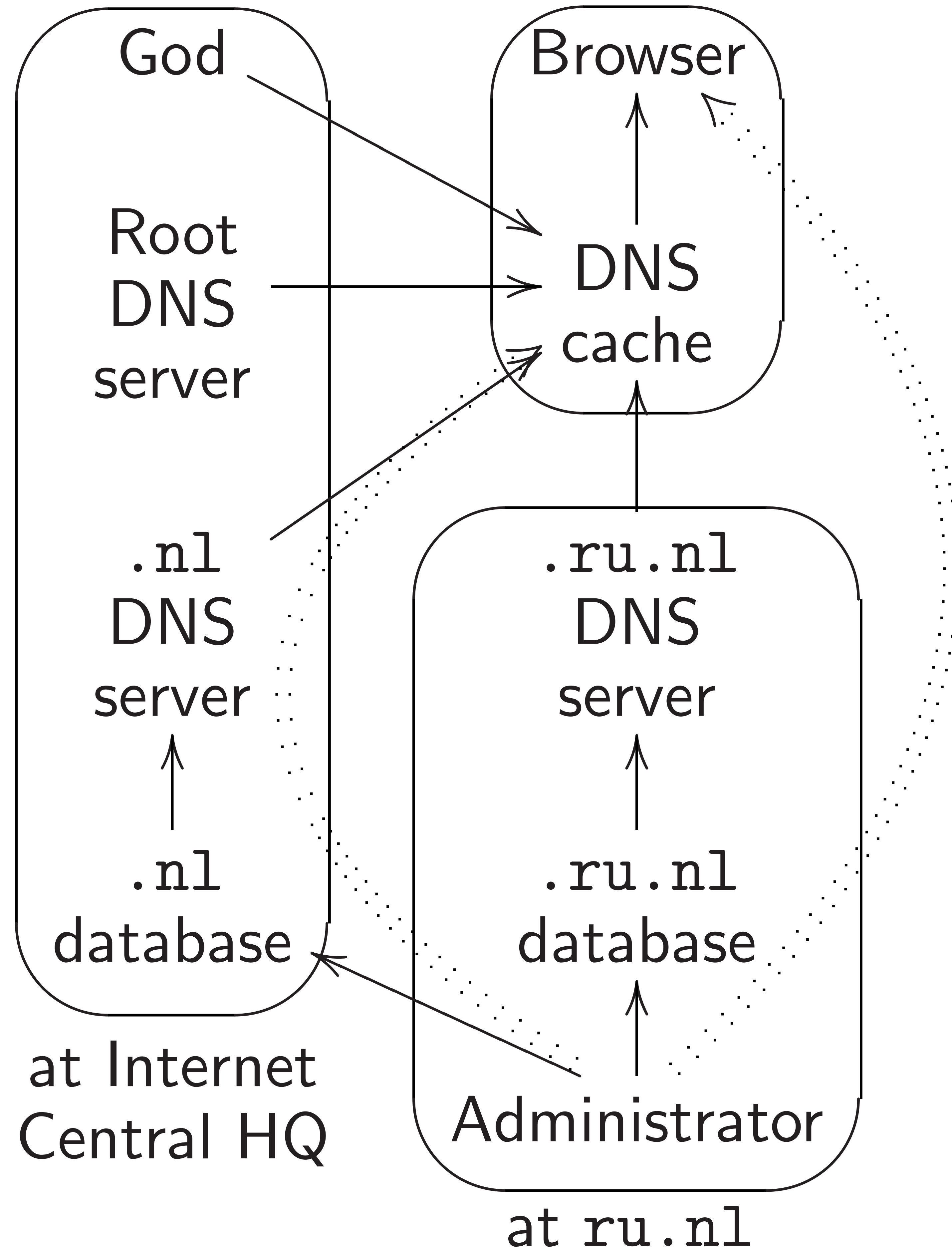

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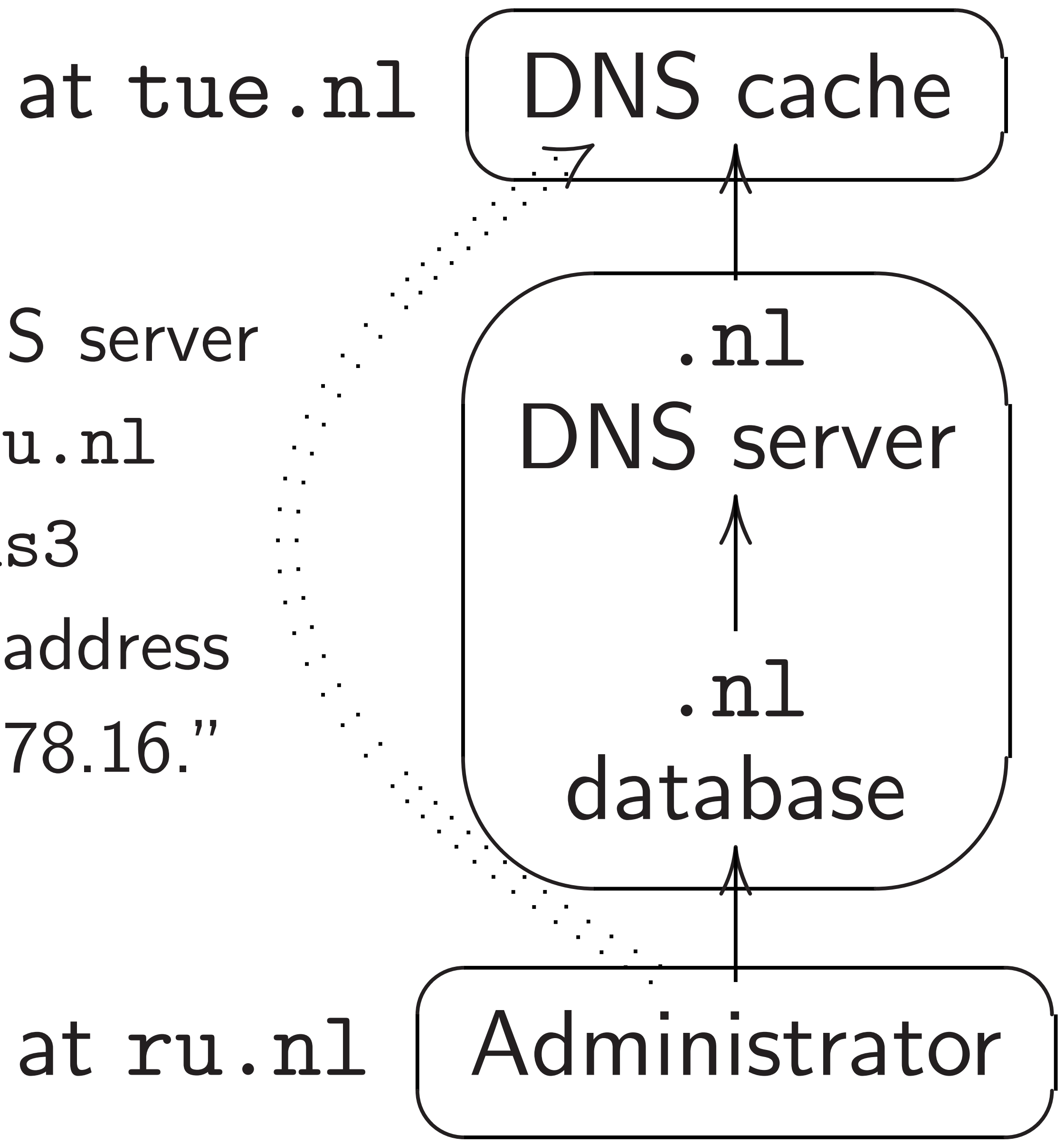

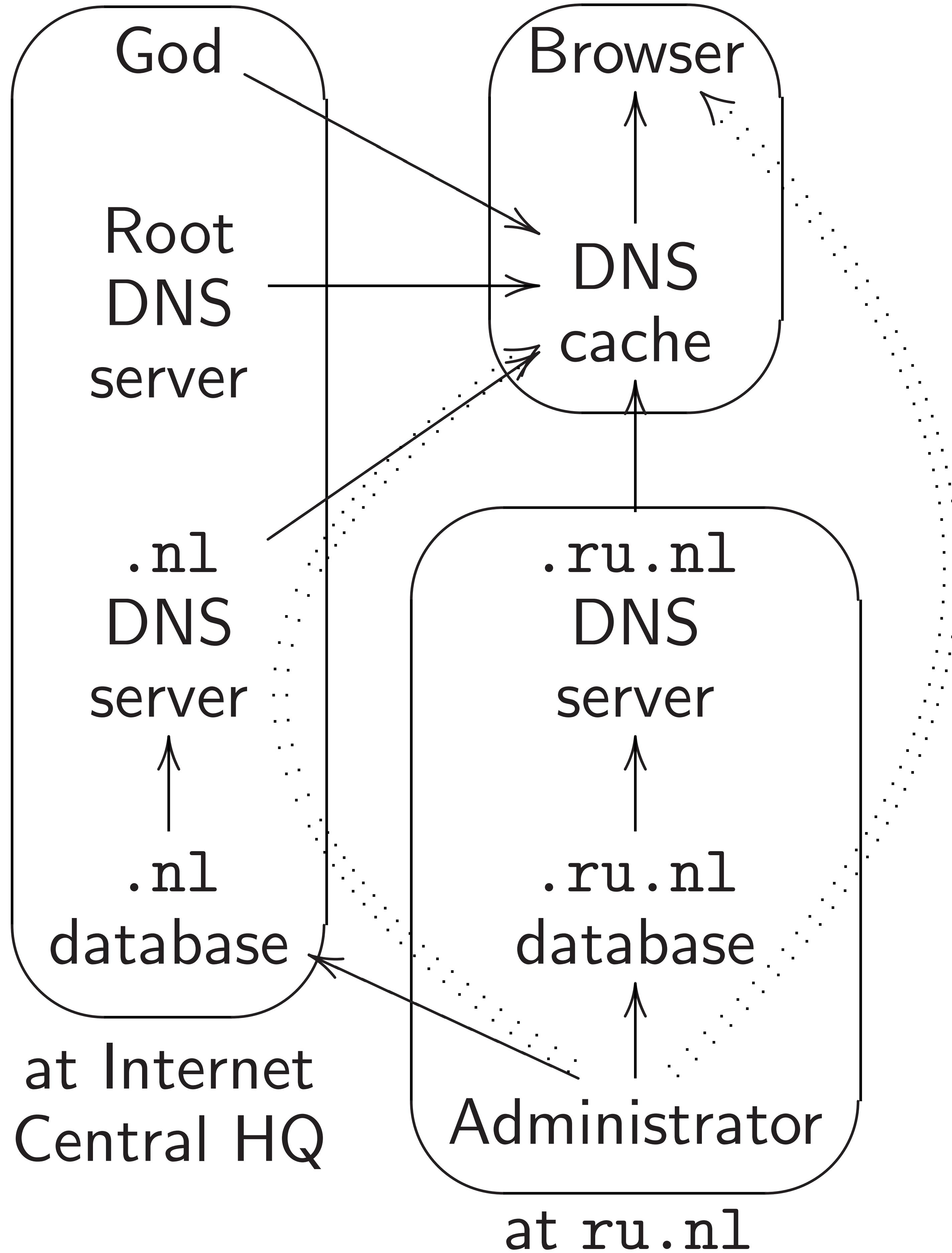

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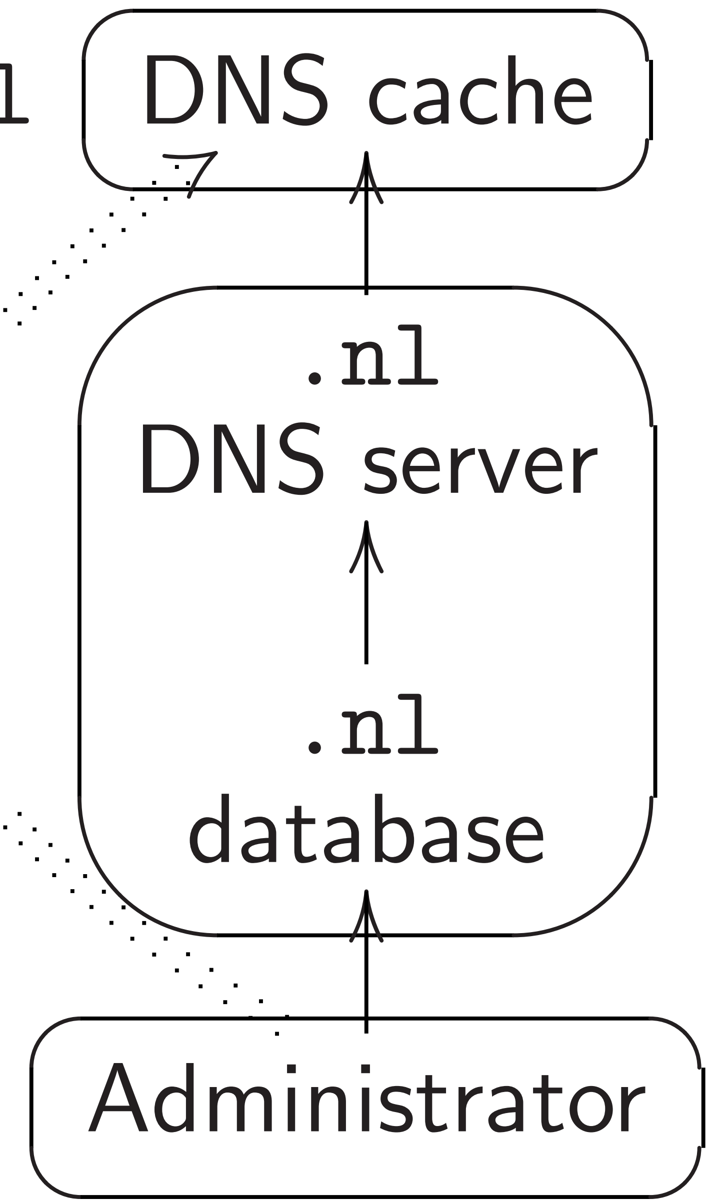

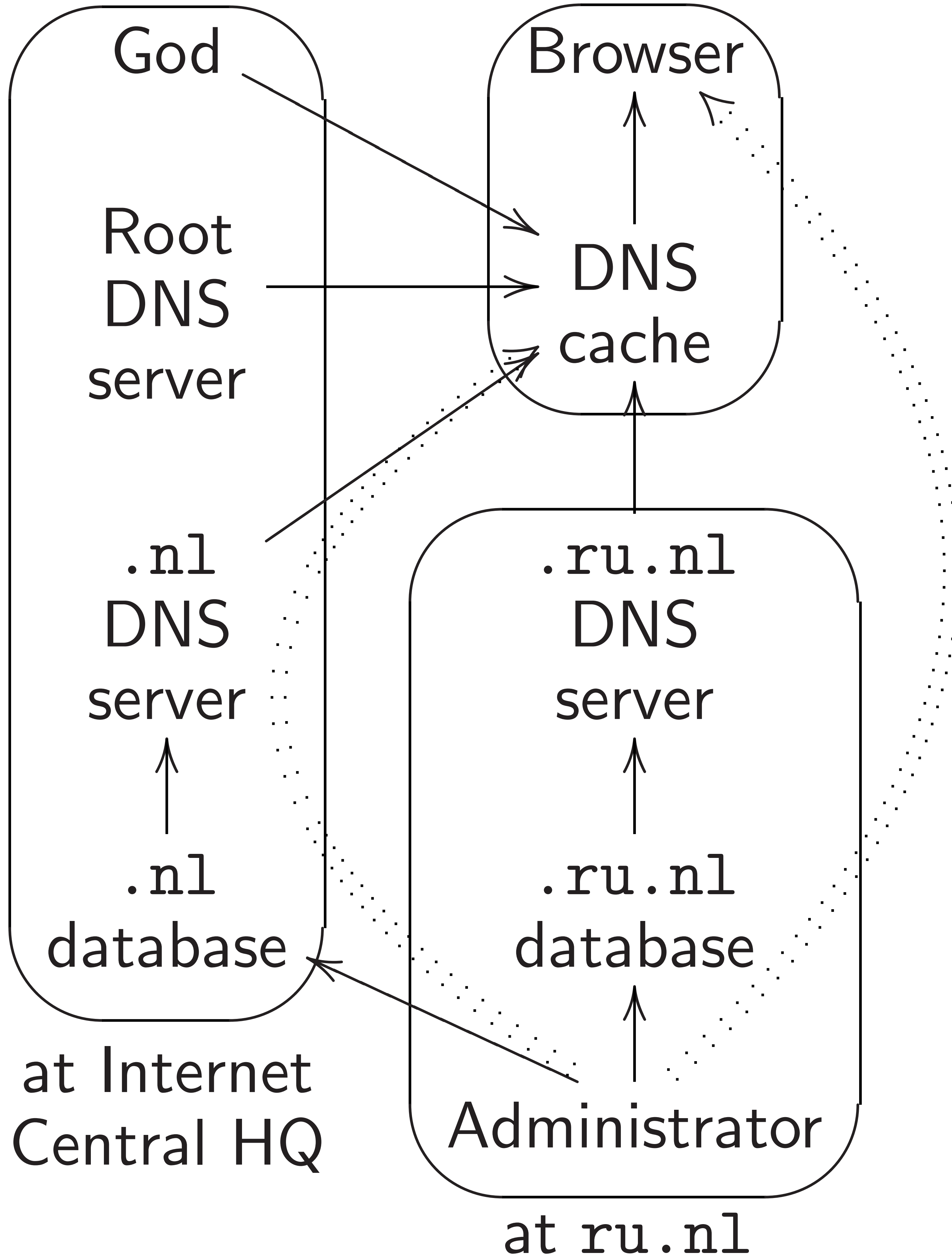

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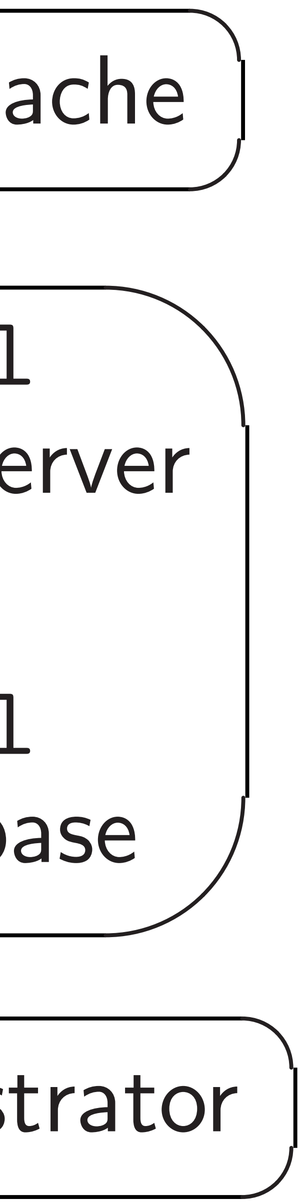

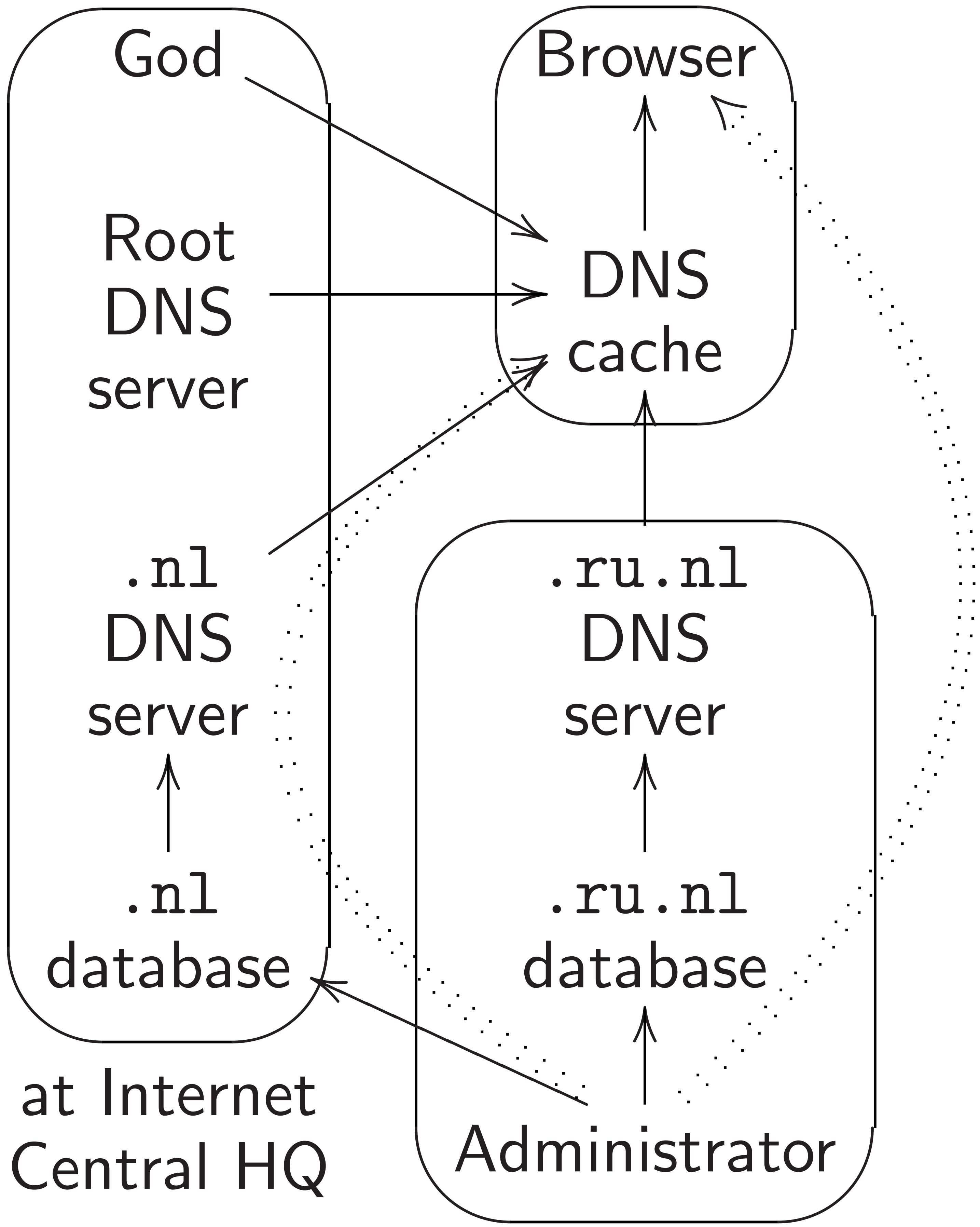

at Internet Central HQ

at ru.nl

DNS server software listed in Wikipedia: BIND, Microsoft DNS, djbdns, Dnsmasq, Sim DNS Plus, NSD, Knot DNS PowerDNS, MaraDNS, pdns Nominum ANS, Nominum V Posadis, Unbound, Cisco Ne Registrar, dnrd, gdnsd, YAD yaku-ns, DNS Blast.

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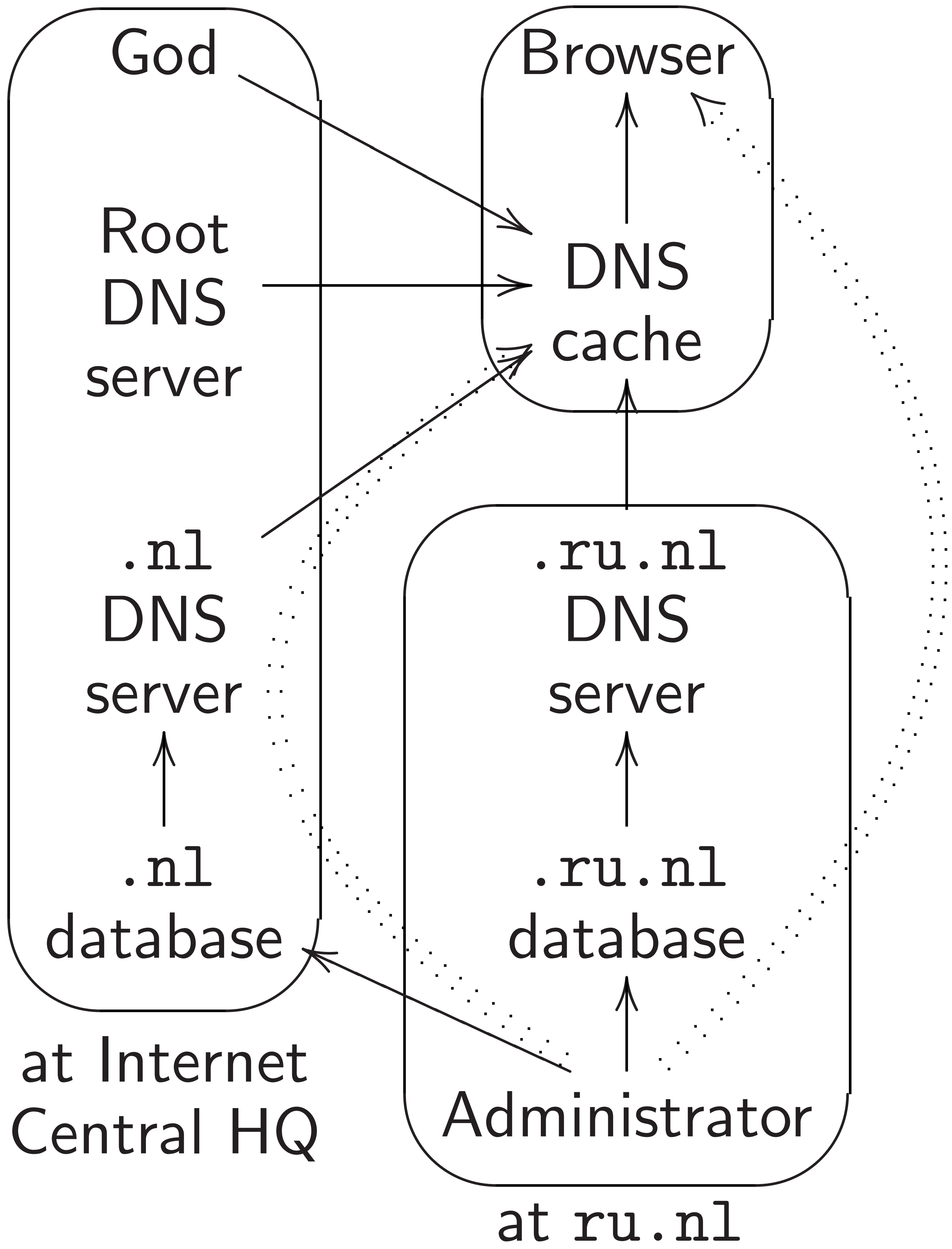

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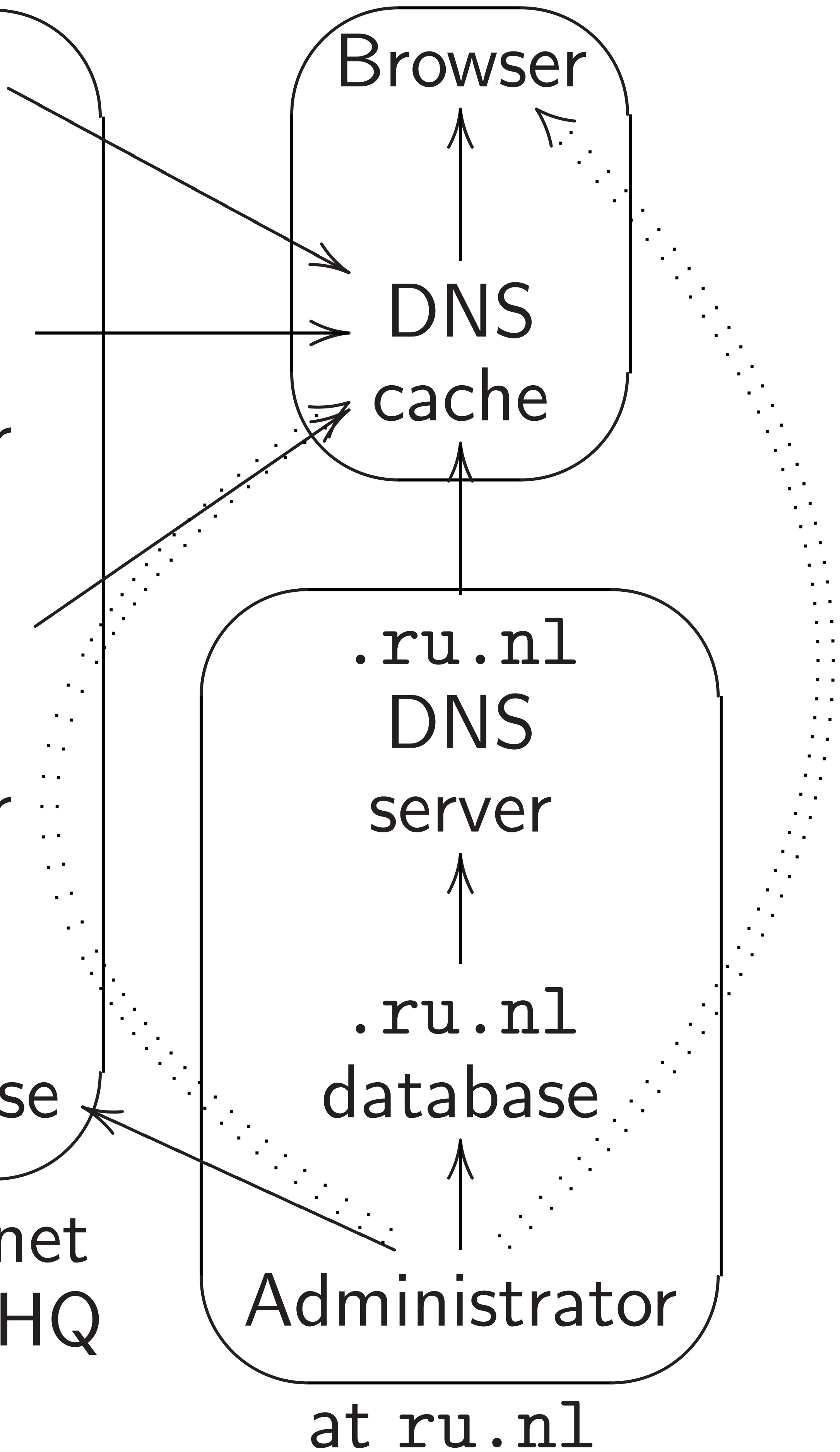

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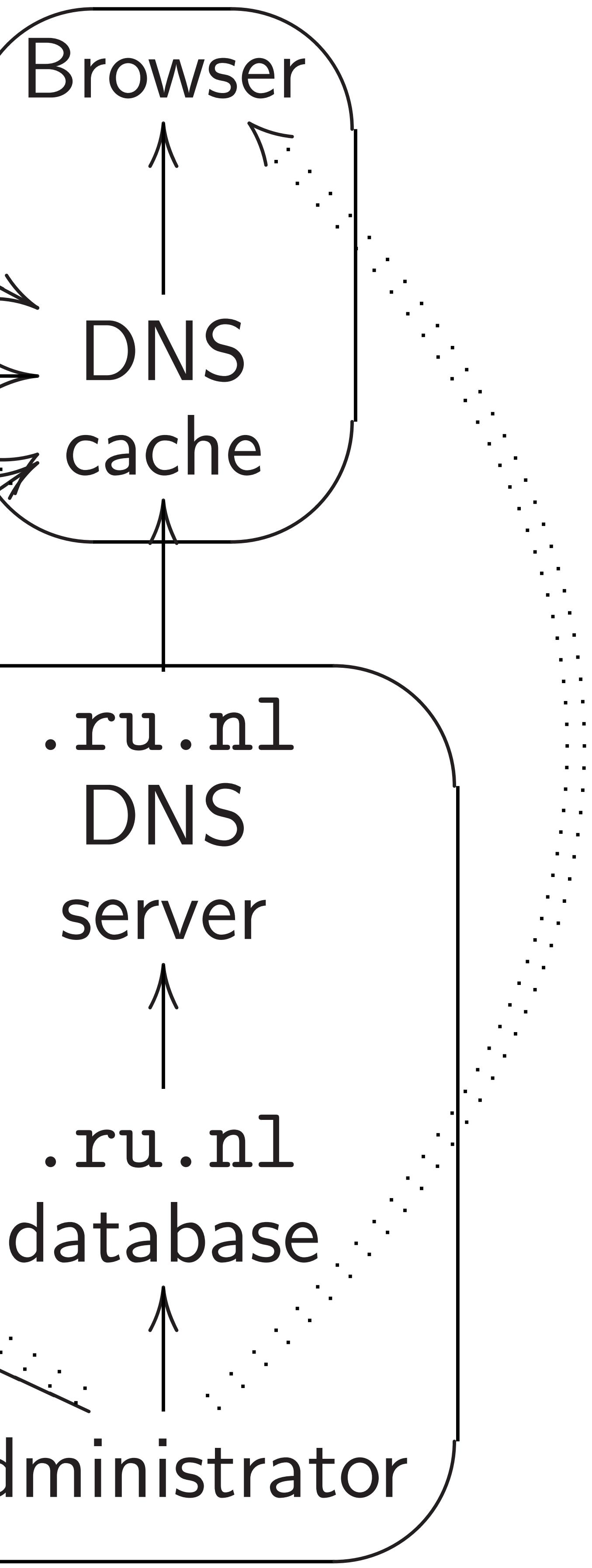

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DNSSEC purists say "Answers
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Even in "static" DNS,
each response packet is
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MX answer, NS answer, etc.

DNSSEC precomputes
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⇒ One DNSSEC packet
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Massive bloat on the wire.

That's why DNSSEC allows
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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.

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DNSCurve and DNSCrypt
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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.

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