Internet integration: the DNS security mess

D. J. Bernstein

University of Illinois at Chicago

The Domain Name System

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

$ dig
  b0.o
199.19
```

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

September 2017:

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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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?

September 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?

September 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?

September 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
green
  864
  ns-
    g
```

thority!

enticity!

great!

igure

lic key

ware.

servers

NSSEC,

sible

rge

ervers!

September 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
```

September 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.
```

September 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.
```

per 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
  @199
```

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
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-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
69T6U8O1GSG9E1LMITK4DEMOT
 NS SOA RRSIG DNSKEY NSEC
3PARAM


h9p7u7tr2u91d0v0ljs9l1gid
```

```
np90u
IG NS
07105
947 o
kRMPi
O1AmS
LJPsH
QfOuv
A9BKv
DvboB
Xniz

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
07105026 20170
947 org. jE7Y8
kRMPitAQ1mEepm
OlAmSm7vBXRGx2
LJPsHydDcAYfBj
QfOuvc9QurOQhd
A9BKvt8ruo8ZMK
DvboByYE7Qt0eZ
Xniz Orw=

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
69T6U8O1GSG9E1LMITK4DEMOT
 NS SOA RRSIG DNSKEY NSEC
3PARAM

h9p7u7tr2u91d0v0ljs9l1gid
```



```
np90u3h.org. 86400 IN R
IG NSEC3 7 2 86400 2017
07105026 20170916095026
947 org. jE7Y8rHxJj6K2o
kRMPitAQ1mEepmPNnA82fJf
OlAmSm7vBXRGx2G kc9saqj
LJPsHydDcAYfBj/haDogBPh
Qf0uvc9QurOQhdOvcIJBSu
A9BKvt8ruo8ZMKkZPfdq+UX
DvboByYE7Qt0eZdMjqQ87f7
Xniz Orw=

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
69T6U801GSG9E1LMITK4DEM0T
 NS SOA RRSIG DNSKEY NSEC
3PARAM

h9p7u7tr2u91d0v0ljs9l1gid
```



```
np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201710
07105026 20170916095026 3
947 org. jE7Y8rHxJj6K2omn
kRMPitAQ1mEepmPNnA82fJfji
0lAmSm7vBXRGx2G kc9saqjom
LJPsHydDcAYfBj/haDogBPhNI
QfOuvc9QurOQhdOvcIJBSu cH
A9BKvt8ruo8ZMKkZPfdq+UXu+
DvboByYE7Qt0eZdMjqQ87f7Vx
Xniz Orw=

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 201710
07105026 20170916095026 3
947 org. jE7Y8rHxJj6K2omn
kRMPitAQ1mEepmPNnA82fJfji
OlAmSm7vBXRGx2G kc9saqjom
LJPsHydDcAYfBj/haDogBPhNI
QfOuvc9QurOQhdOvcIJBSu cH
A9BKvt8ruo8ZMKkZPfdq+UXu+
DvboByYE7Qt0eZdMjqQ87f7Vx
Xniz Orw=

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

```
OPPOBI
 A RRS

bgca0g
qng3p2
IG NSE
02190
947 o
rsAaR
H98Cp.
8WQEF
/ukf+8
piKx0p
vKwR2
2t9y 
```

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 201710
07105026 20170916095026 3
947 org. jE7Y8rHxJj6K2omn
kRMPitAQ1mEepmPNnA82fJfji
OlAmSm7vBXRGx2G kc9saqjom
LJPsHydDcAYfBj/haDogBPhNI
Qf0uvc9Qur0Qhd0vcIJBSu cH
A9BKvt8ruo8ZMKkZPfdq+UXu+
DvboByYE7Qt0eZdMjqQ87f7Vx
Xniz Orw=

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

```
OPPOBENBFCGBMB
 A RRSIG

bgca0g0ug0p6o7
qng3p2f.org. 8
IG NSEC3 7 2 8
02190823 20170
947 org. TuwMq
rsAaRYB4i7QBSU
H98CpJpnL2sLZS
8WQEFsSfN7ux0c
/ukf+8B9Hz16YP
piKx0pY9qIISLn
vKwR2i3Vxupnx4
2t9y 0aY=
```

s:

id
SE
R6
OT
EC

id

```
np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201710
07105026 20170916095026 3
947 org. jE7Y8rHxJj6K2omn
kRMPitAQ1mEepmPNnA82fJfji
0lAmSm7vBXRGx2G kc9saqjom
LJPsHydDcAYfBj/haDogBPhNI
Qf0uvc9Qur0Qhd0vcIJBSu cH
A9BKvt8ruo8ZMKkZPfdq+UXu+
DvboByYE7Qt0eZdMjqQ87f7Vx
Xniz 0rw=

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



```
0PP0BENBFCGBMB6RGT2JDC2
 A RRSIG

bgca0g0ug0p6o7425emkt9u
qng3p2f.org. 86400 IN R
IG NSEC3 7 2 86400 2017
02190823 20170911180823
947 org. TuwMqb07N+Rguz
rsAaRYB4i7QBSUu0ypYMFsS
H98CpJpnL2sLZSV PrfjjsU
8WQEFsSfN7ux0c6gUlqZdtn
/ukf+8B9Hz16YPWK8IxlBY
piKx0pY9qIISLne4UvCb+Au
vKwR2i3Vxupnx497uKE7p+n
2t9y 0aY=
```

np90u3h.org. 86400 IN RRS
IG NSEC3 7 2 86400 201710
07105026 20170916095026 3
947 org. jE7Y8rHxJj6K2omn
kRMPitAQ1mEepmPNnA82fJfji
0lAmSm7vBXRGx2G kc9saqjom
LJPsHydDcAYfBj/haDogBPhNI
Qf0uvc9Qur0Qhd0vcIJBSu cH
A9BKvt8ruo8ZMKkZPfdq+UXu+
DvboByYE7Qt0eZdMjqQ87f7Vx
Xniz 0rw=

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 201710
02190823 20170911180823 3
947 org. TuwMqb07N+RguzFN
rsAaRYB4i7QBSUu0ypYMFsSks
H98CpJpnL2sLZSV PrfjjsU9i
8WQEFsSfN7ux0c6gUlqZdtngA
/ukf+8B9Hz16YPWK8IxlBY pW
piKx0pY9qIISLne4UvCb+Aul3
vKwR2i3Vxupnx497uKE7p+nXl
2t9y 0aY=

3h.org. 86400 IN RRS
EC3 7 2 86400 201710
026 20170916095026 3
rg. jE7Y8rHxJj6K2omn
tAQ1mEepmPNnA82fJfji
m7vBXRGx2G kc9saqjom
ydDcAYfBj/haDogBPhNI
c9QurOQhdOvcIJBSu cH
t8ruo8ZMKkZPfdq+UXu+
yYE7Qt0eZdMjqQ87f7Vx
Orw=

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

OPPOBENBFCGBMB6RGT2JDC21E
A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201710
02190823 20170911180823 3
947 org. TuwMqbO7N+RguzFN
rsAaRYB4i7QBSUuOypYMFsSks
H98CpJpnL2sLZSV PrfjjsU9i
8WQEFsSfN7ux0c6gUlqZdtngA
/ukf+8B9Hz16YPWK8IxlBY pW
piKx0pY9qIISLne4UvCb+Aul3
vKwR2i3Vxupnx497uKE7p+nXl
2t9y 0aY=

Wow, th
Must be

$ tcpdu
host
shows pa
dig sen
to the .
receives

See mor
$ dig +
org @
Sends 7
receives
totalling

```
6400 IN RRS
6400 201710
916095026 3
rHxJj6K2omn
PNnA82fJfji
G kc9saqjom
/haDogBPhNI
OvcIJBSu cH
kZPfdq+UXu+
dMjqQ87f7Vx


425emkt9ue4
6400 IN NSE
AAB BGDHKIB
```

```
OPPOBENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201710
02190823 20170911180823 3
947 org. TuwMqbO7N+RguzFN
rsAaRYB4i7QBSUuOypYMFsSks
H98CpJpnL2sLZSV PrfjjsU9i
8WQEFsSfN7ux0c6gUlqZdtngA
/ukf+8B9Hz16YPWK8IxlBY pW
piKx0pY9qIISLne4UvCb+Aul3
vKwR2i3Vxupnx497uKE7p+nXl
2t9y OaY=
```


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 DNSSEC

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

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

```
RS
10
3
mn
ji
om
NI
cH
u+
Vx

e4
SE
IB
```



```
0PP0BENBFCGBMB6RGT2JDC21E
 A RRSIG

bgca0g0ug0p6o7425emkt9ue4
qng3p2f.org. 86400 IN RRS
IG NSEC3 7 2 86400 201710
02190823 20170911180823 3
947 org. TuwMqb07N+RguzFN
rsAaRYB4i7QBSUu0ypYMFsSks
H98CpJpnL2sLZSV PrfjjsU9i
8WQEFsSfN7ux0c6gUlqZdtngA
/ukf+8B9Hz16YPWK8IxlBY pW
piKx0pY9qIISLne4UvCb+Aul3
vKwR2i3Vxupnx497uKE7p+nXl
2t9y 0aY=
```


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 201710
02190823 20170911180823 3
947 org. TuwMqb07N+RguzFN
rsAaRYB4i7QBSUu0ypYMFsSks
H98CpJpnL2sLZSV PrfjjsU9i
8WQEFsSfN7ux0c6gUlqZdtngA
/ukf+8B9Hz16YPWK8IxlBY pW
piKx0pY9qIISLne4UvCb+Aul3
vKwR2i3Vxupnx497uKE7p+nXl
2t9y 0aY=
```


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 201710
823 20170911180823 3
rg. TuwMqb07N+RguzFN
YB4i7QBSUu0ypYMFsSks
JpnL2sLZSV PrfjjsU9i
sSfN7ux0c6gUlqZdtngA
8B9Hz16YPWK8IxlBY pW
pY9qIISLne4UvCb+Aul3
i3Vxupnx497uKE7p+nXl
0aY=

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```

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Interlude

What ha
this data

```
6RGT2JDC21E

425emkt9ue4
6400 IN RRS
6400 201710
911180823 3
bO7N+RguzFN
uOypYMFsSks
V PrfjjsU9i
6gUlqZdtngA
WK8IxlBY pW
e4UvCb+Aul3
97uKE7p+nXl
```


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Interlude: the atta

What happens if w
this data at somec

1E
e4
RS
10
3
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pW
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Xl

Wow, that's a lot of data.

Must be strong cryptography!

```
$ tcpdump -n -e \
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```
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```

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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:

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$ dig +dnssec any \
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Interlude: the attacker's view

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Must be strong cryptography!

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  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:

```
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  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 &
```

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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.

at'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
    /^Z
      su
      su
    }
    /GR
      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
maximur

```
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.

```
ies=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 $>30\times$ 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 net
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 '{
next
ext
```

I tried it):

```
102.26 fi.
```


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).

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).

e.g. Sender: 1.2.3.4.
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Run network-traffic monitors on 1.2.3.4 and 5.6.7.8.

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

Let's verify this.

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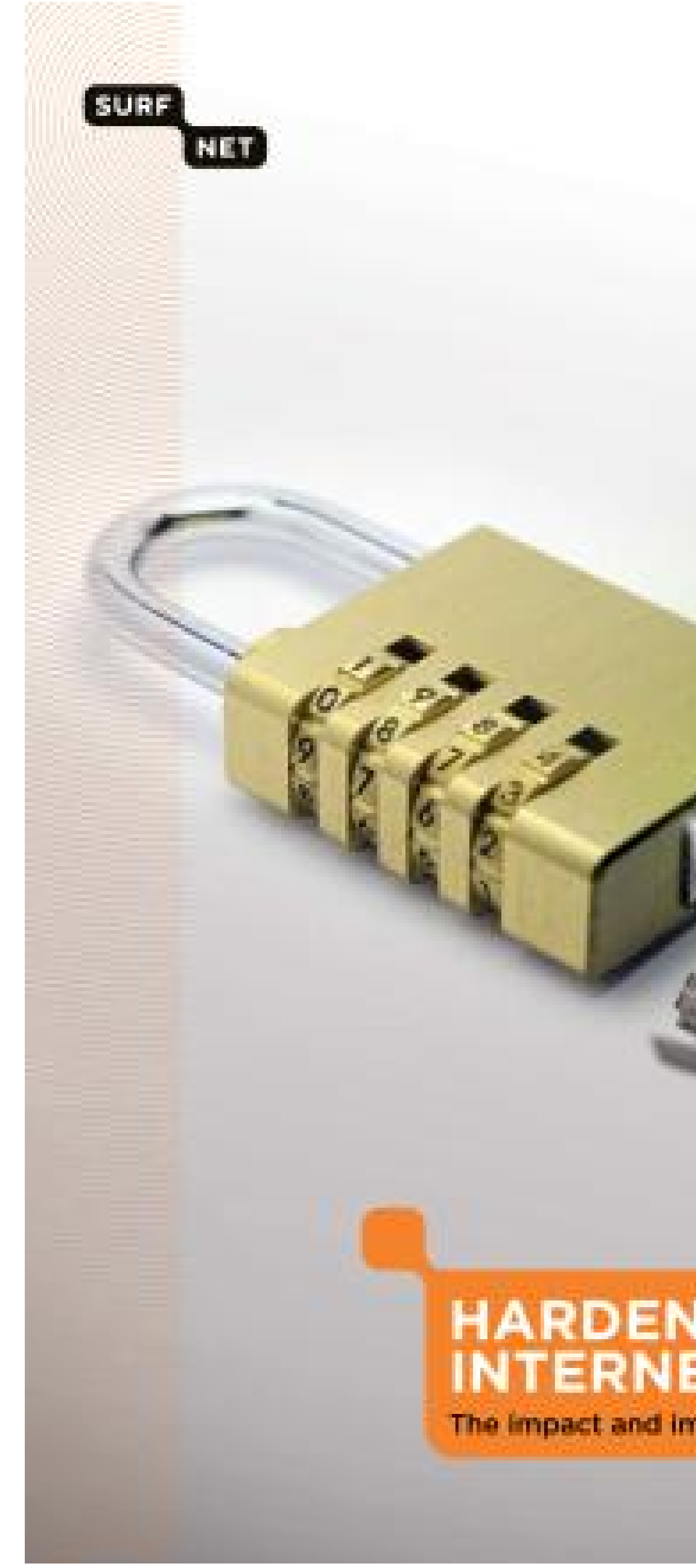

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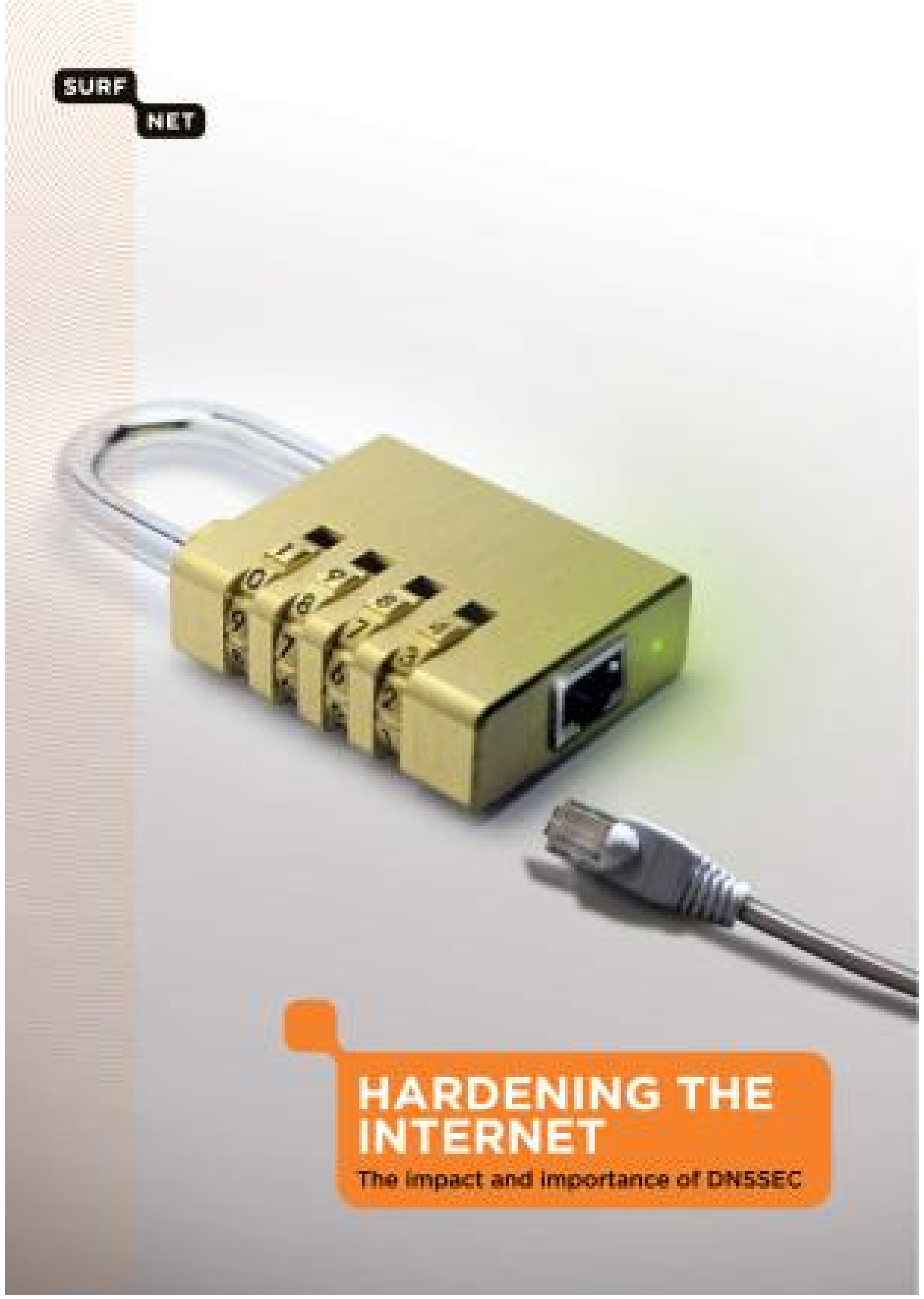

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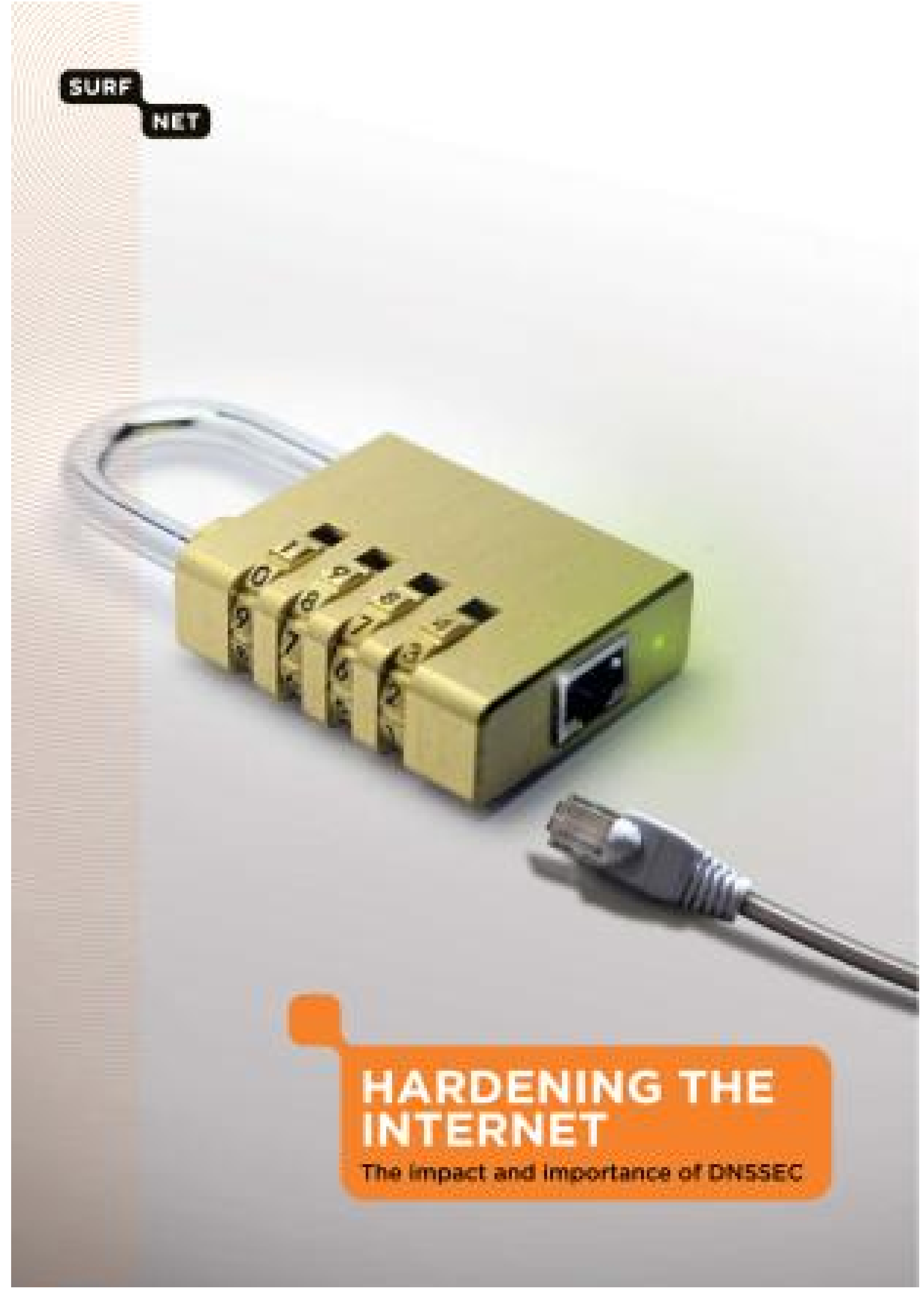

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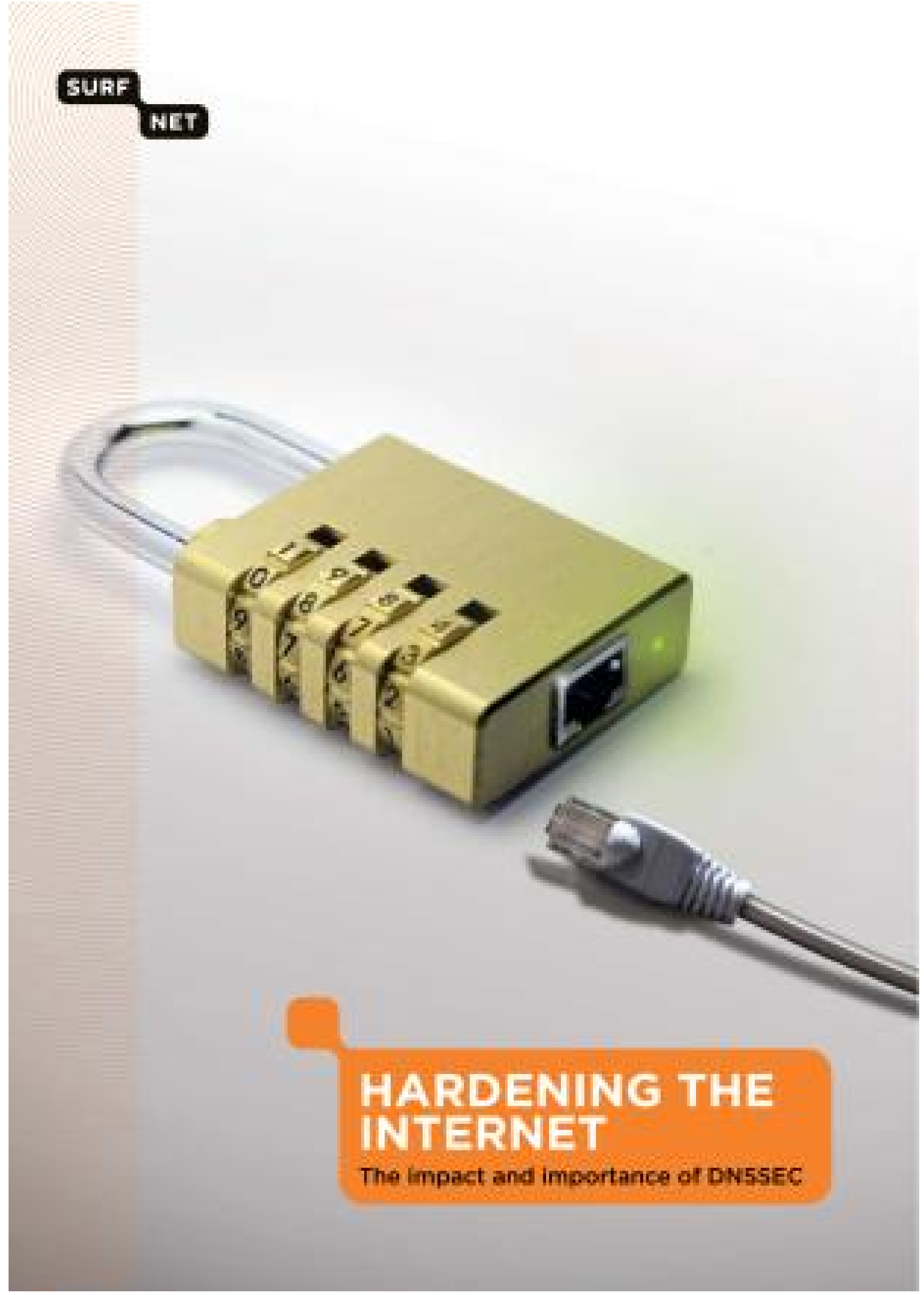

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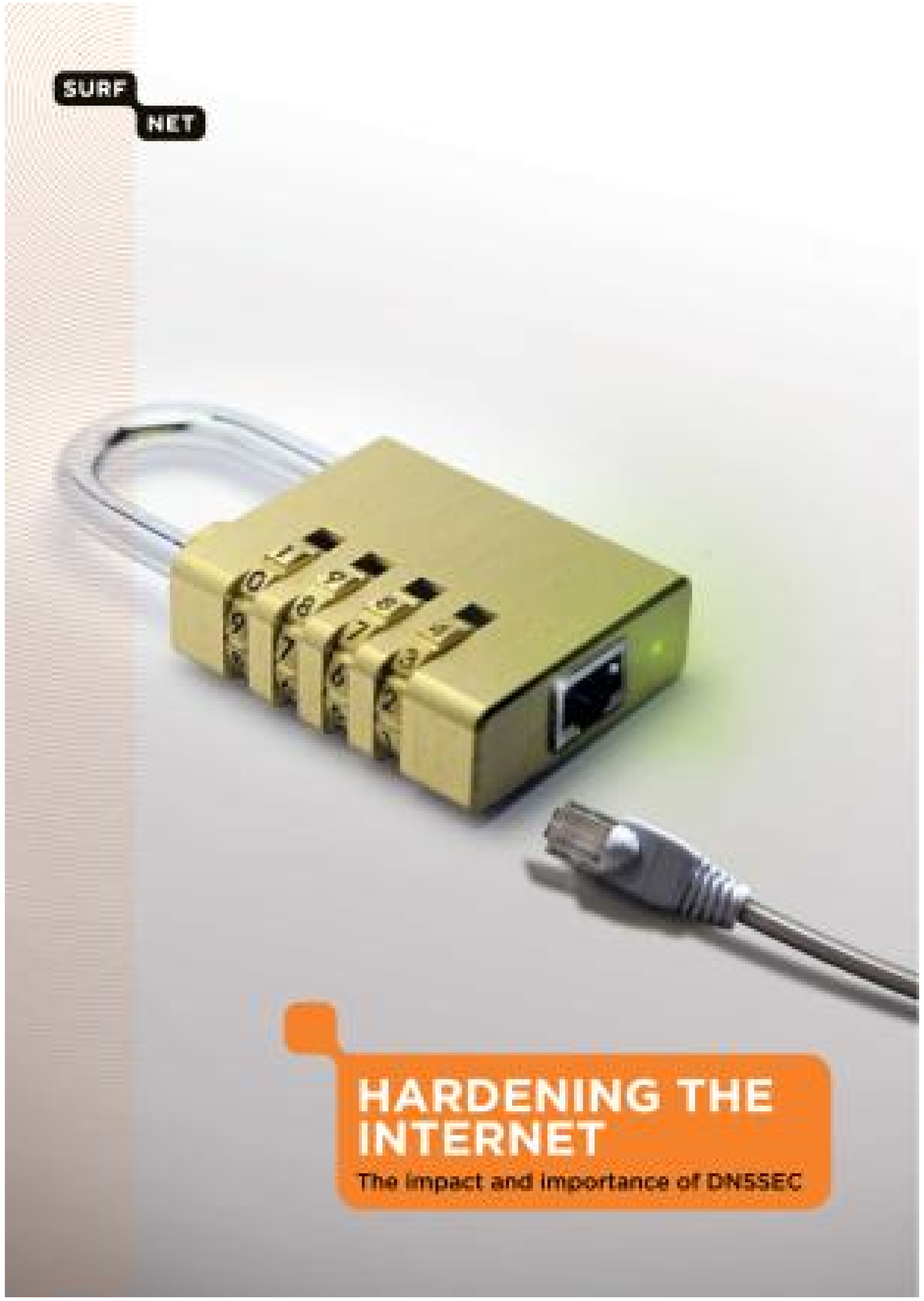

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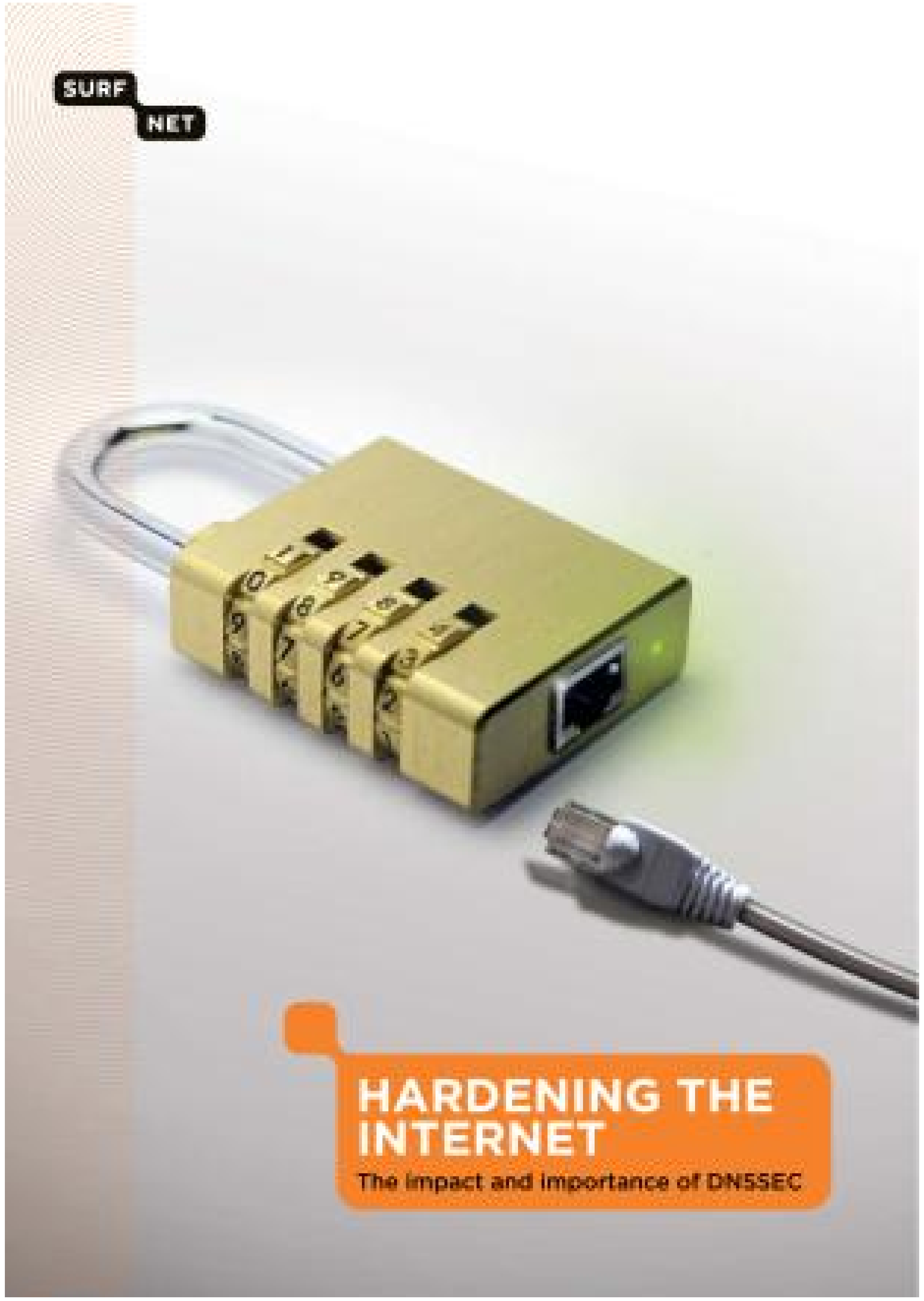

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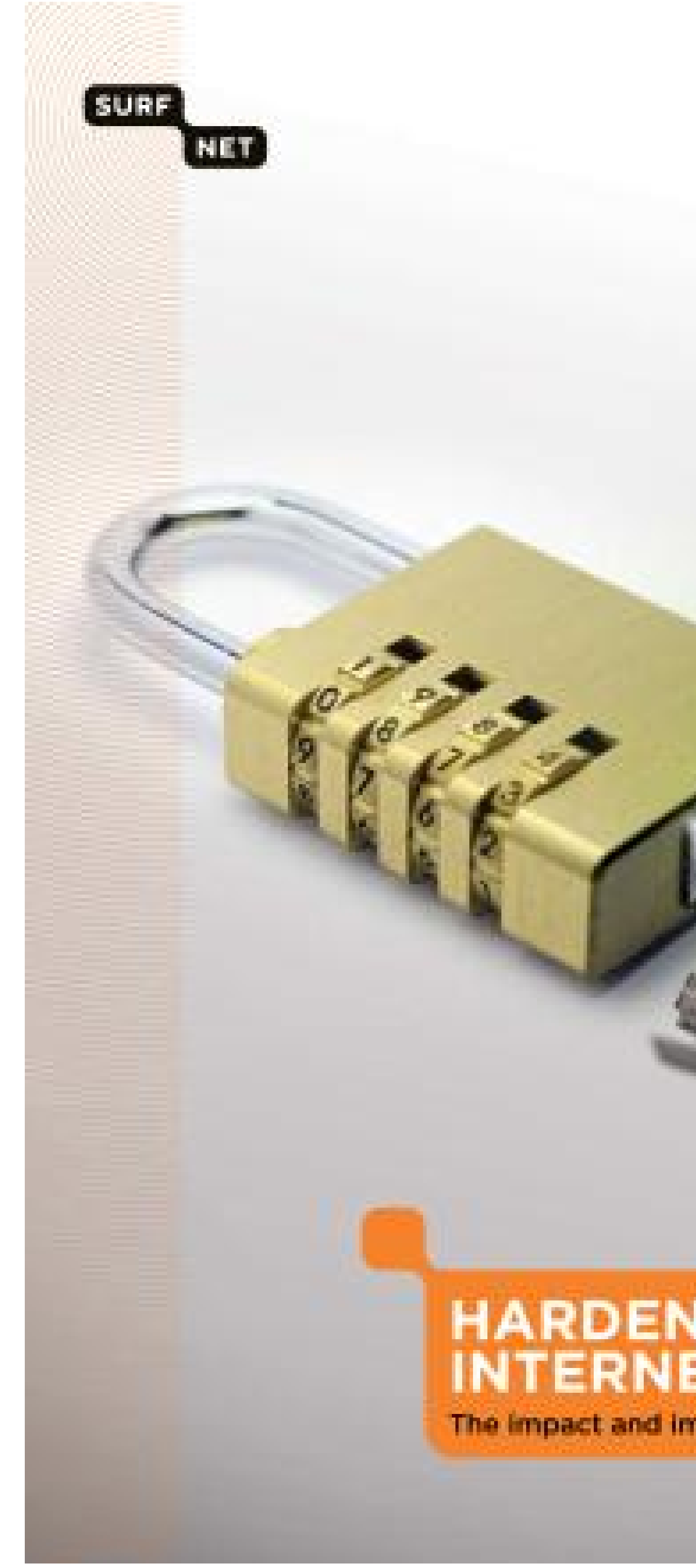

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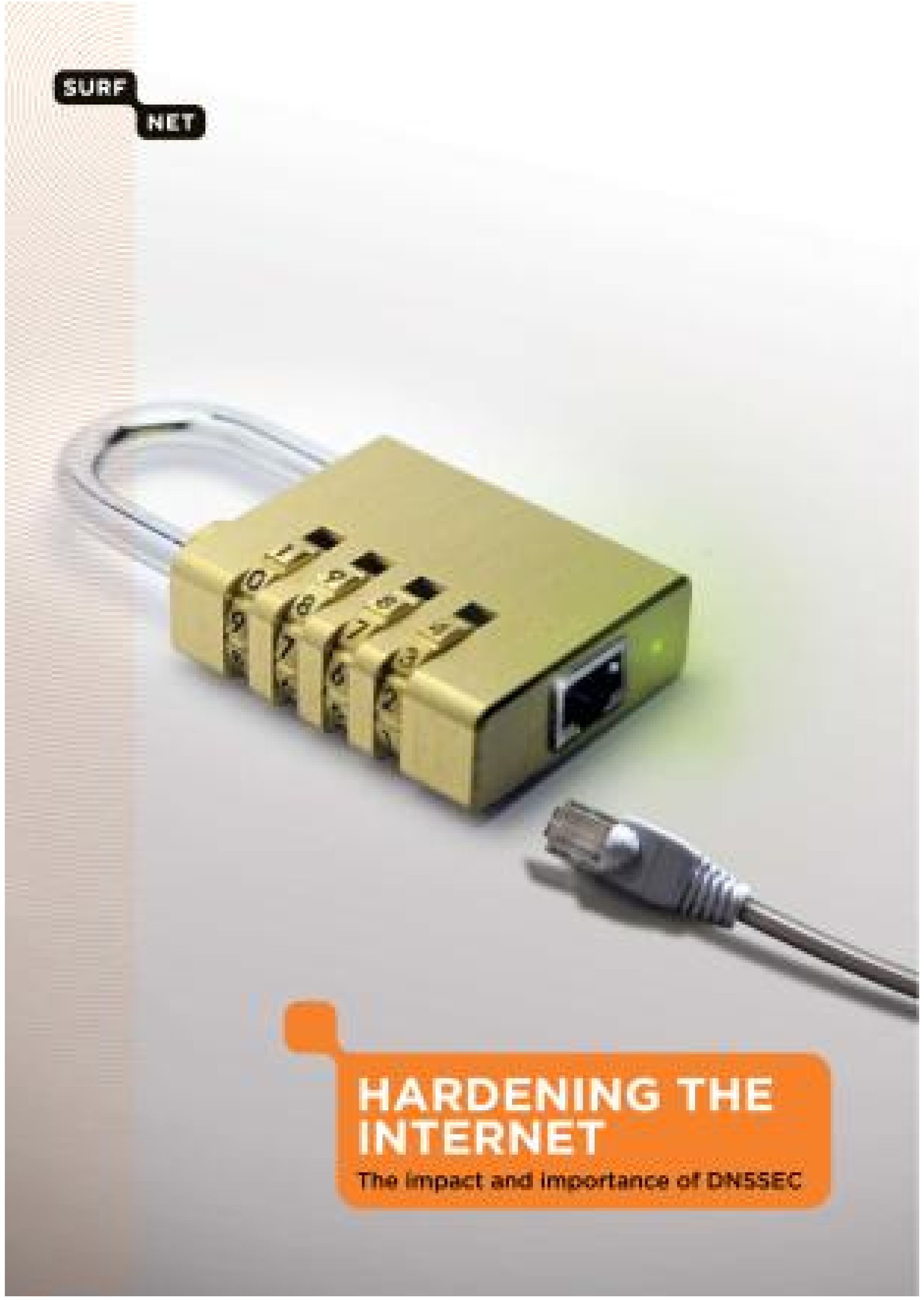

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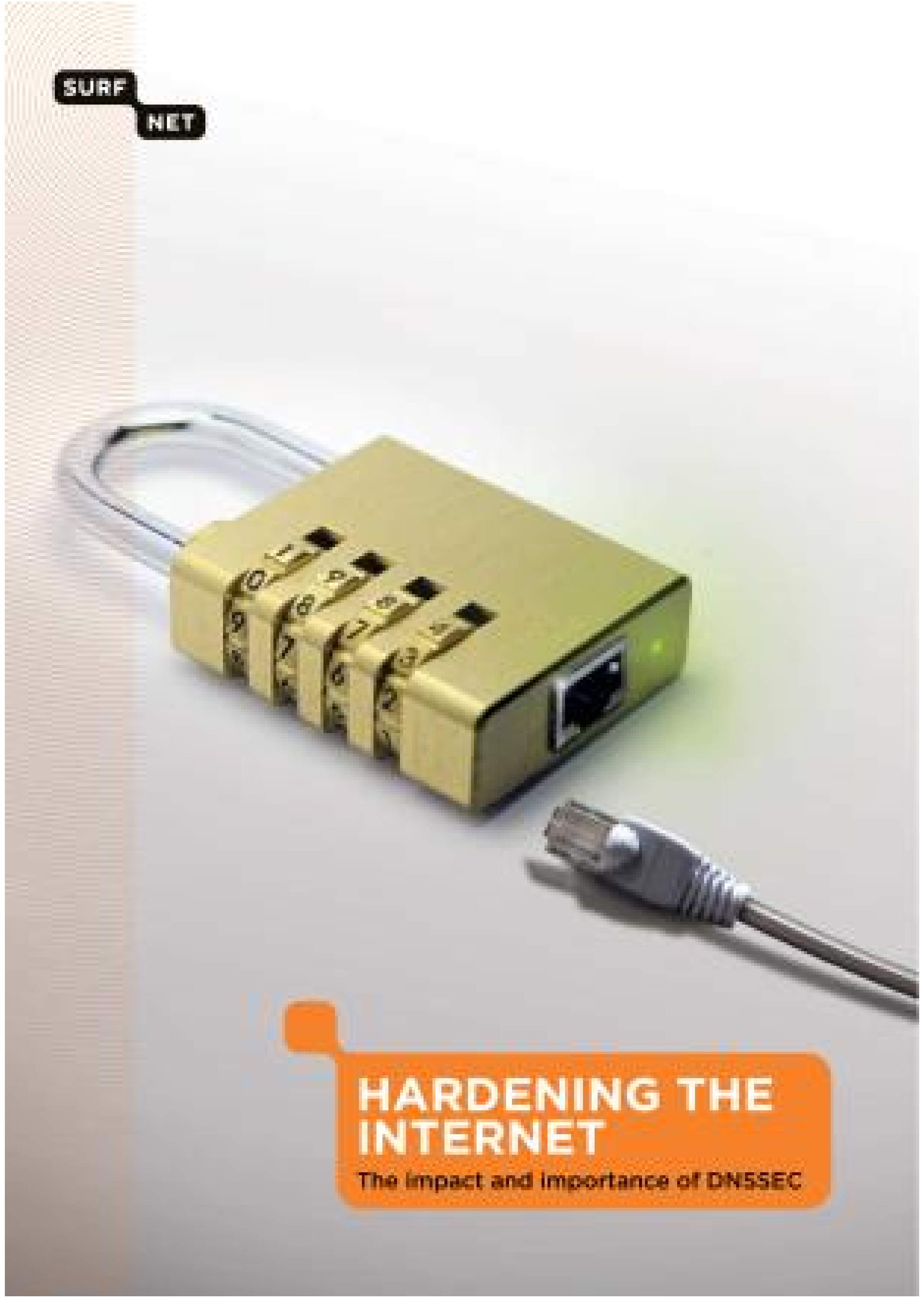

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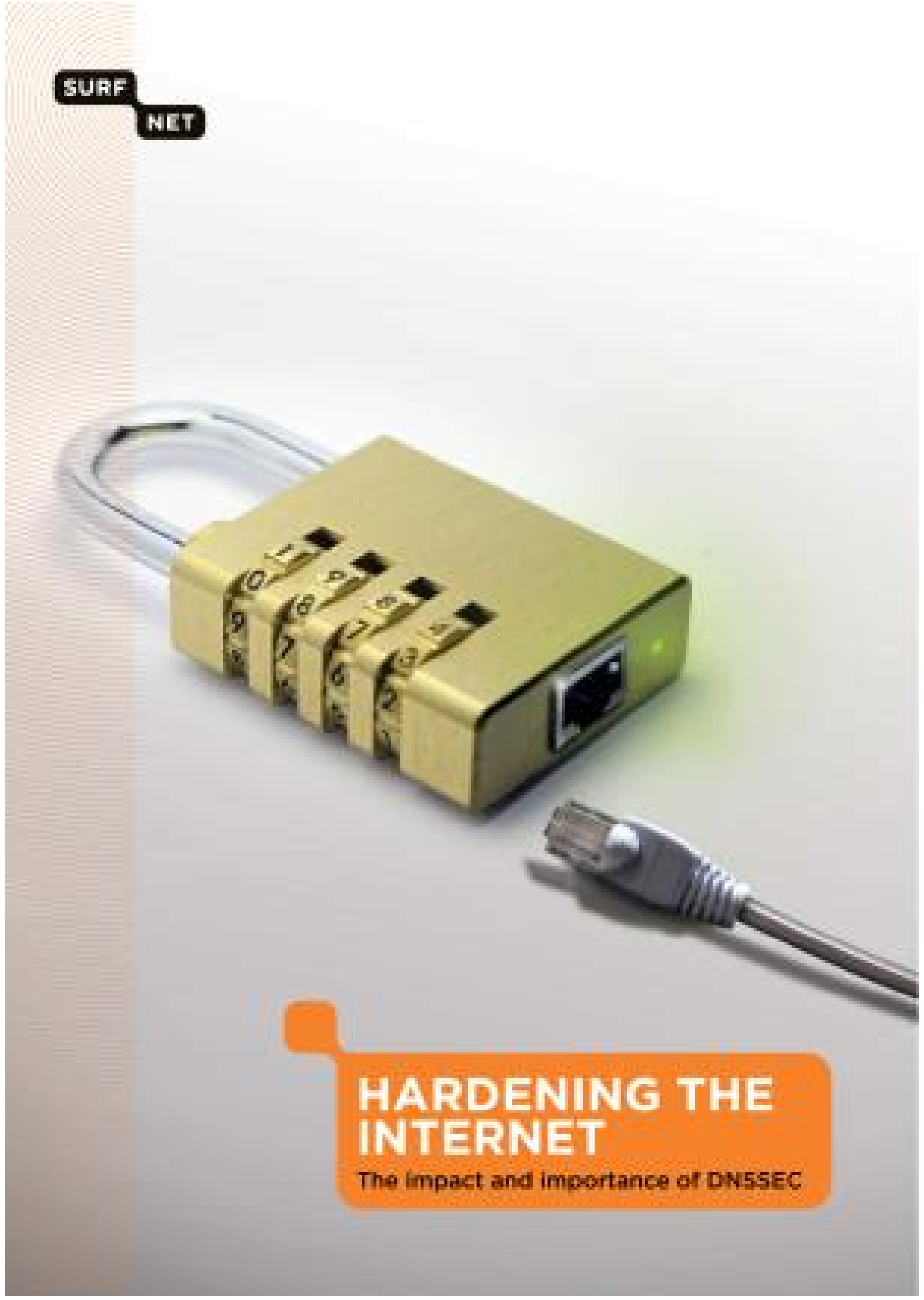

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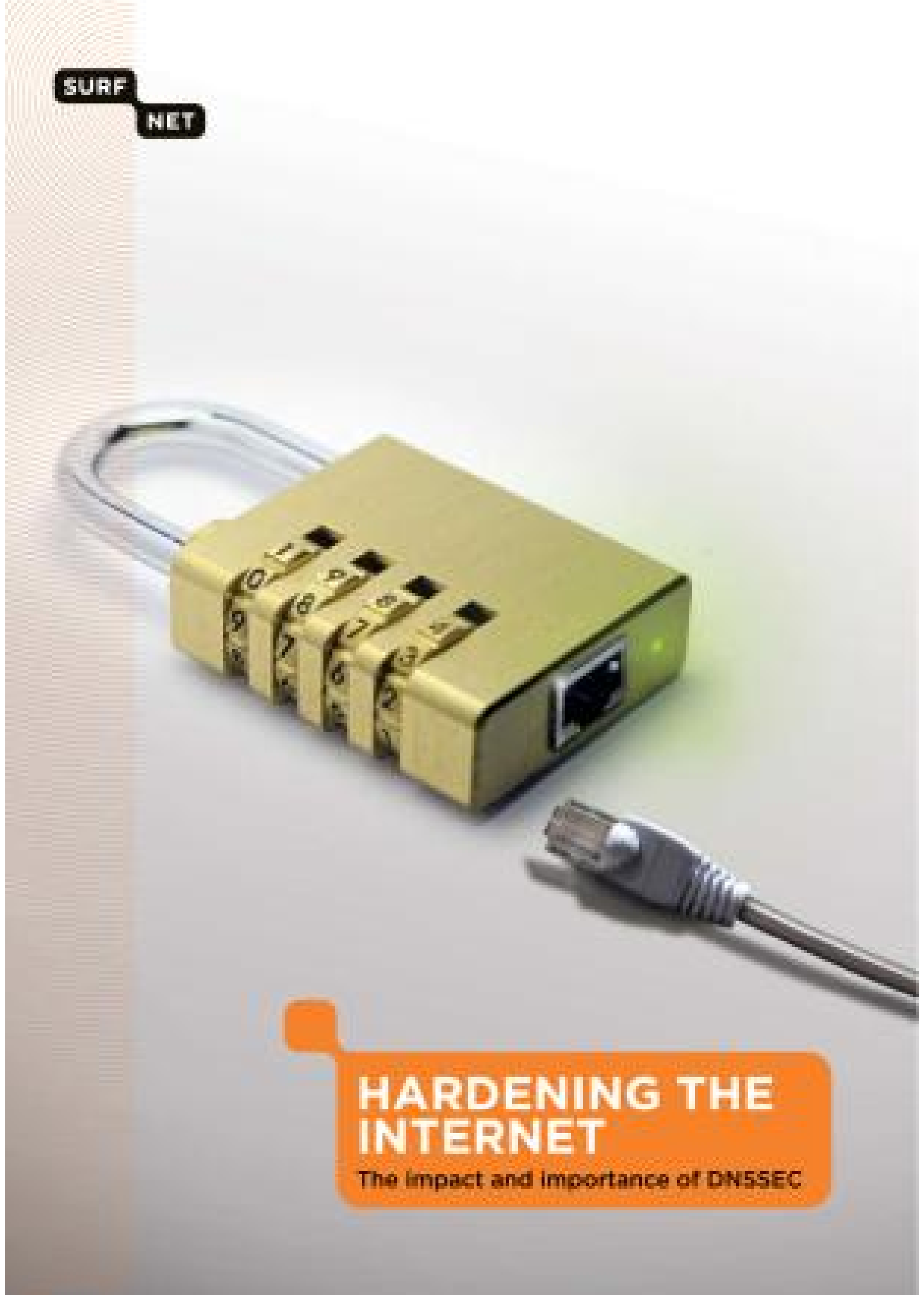

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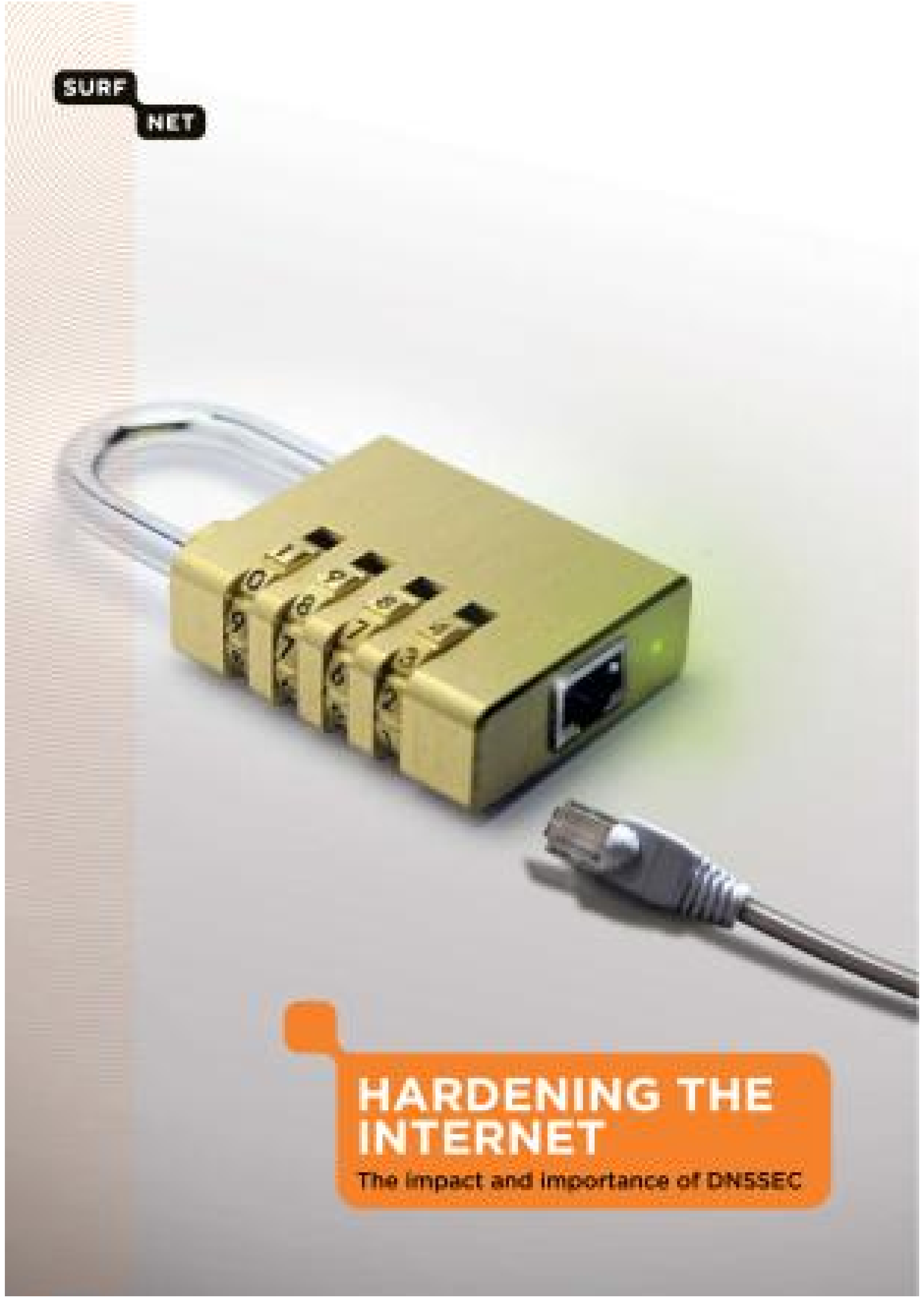

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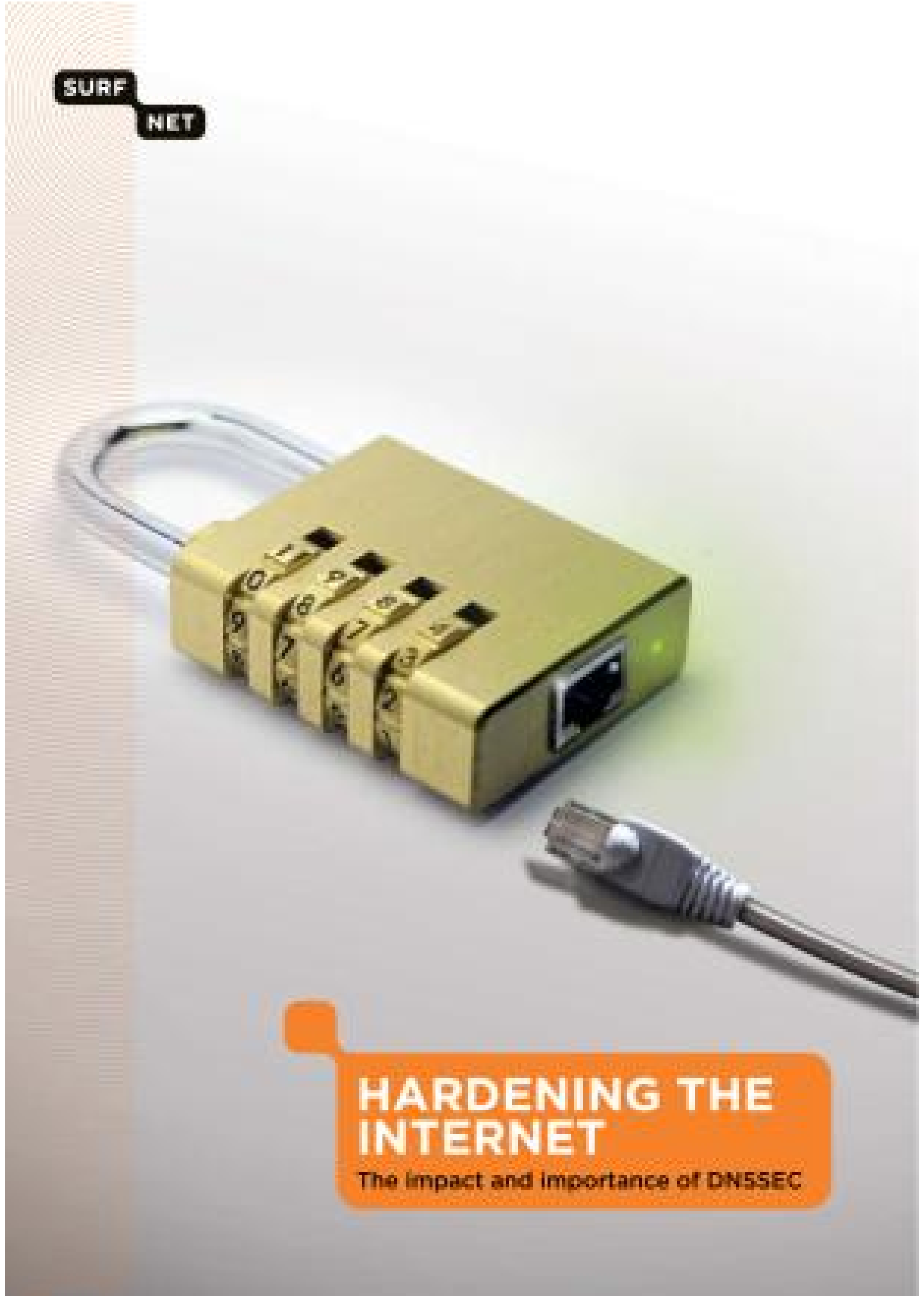

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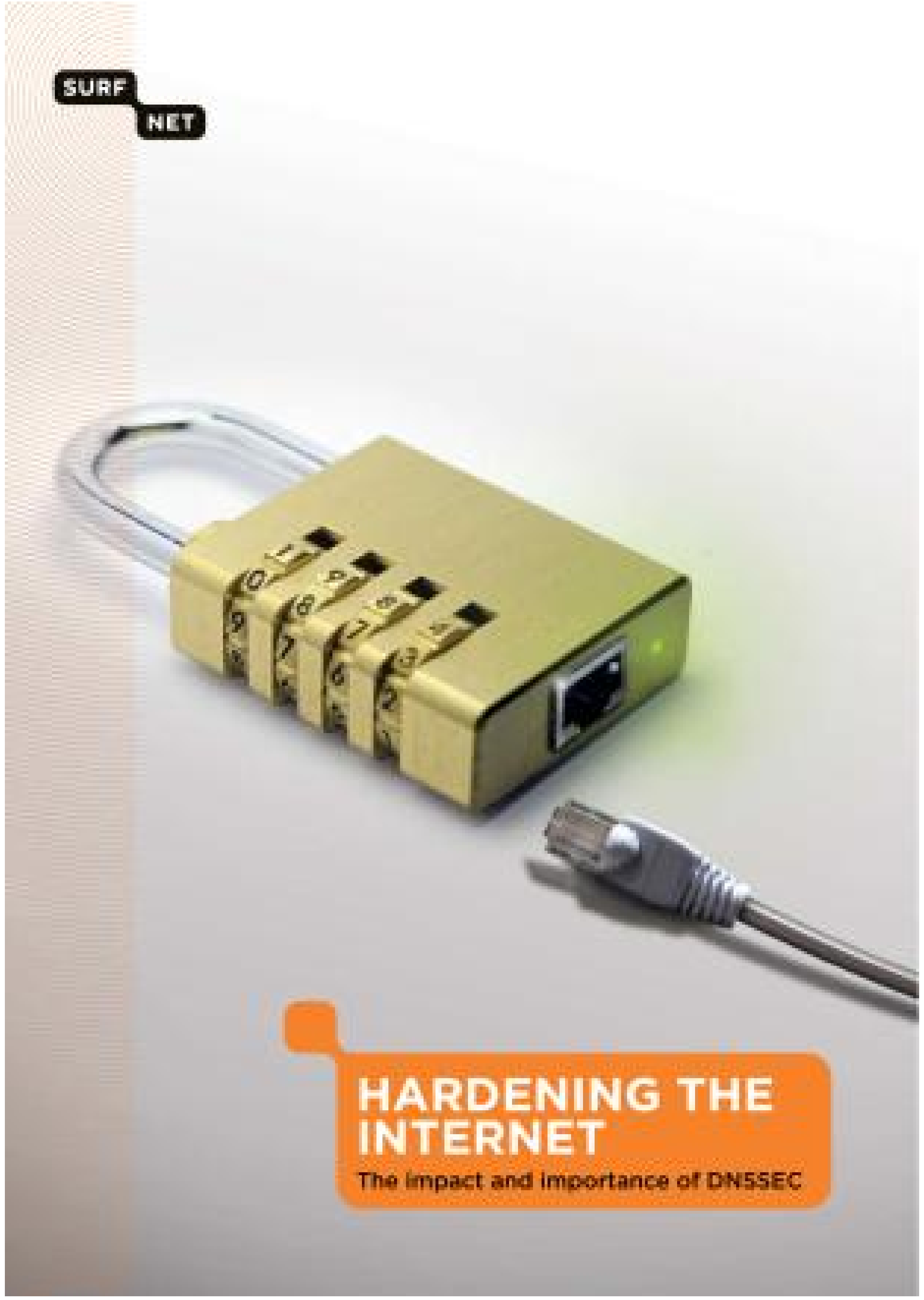

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Precomputation forced DNSSEC down a path of unreliability, insecurity, and unusability.
Let's see how this happened.

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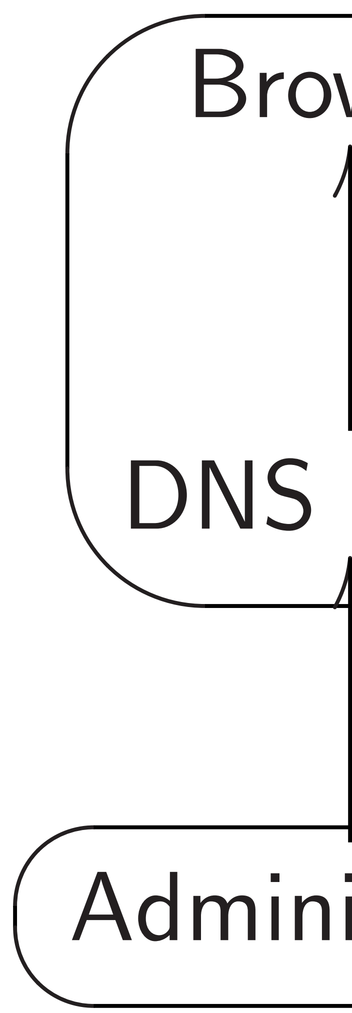

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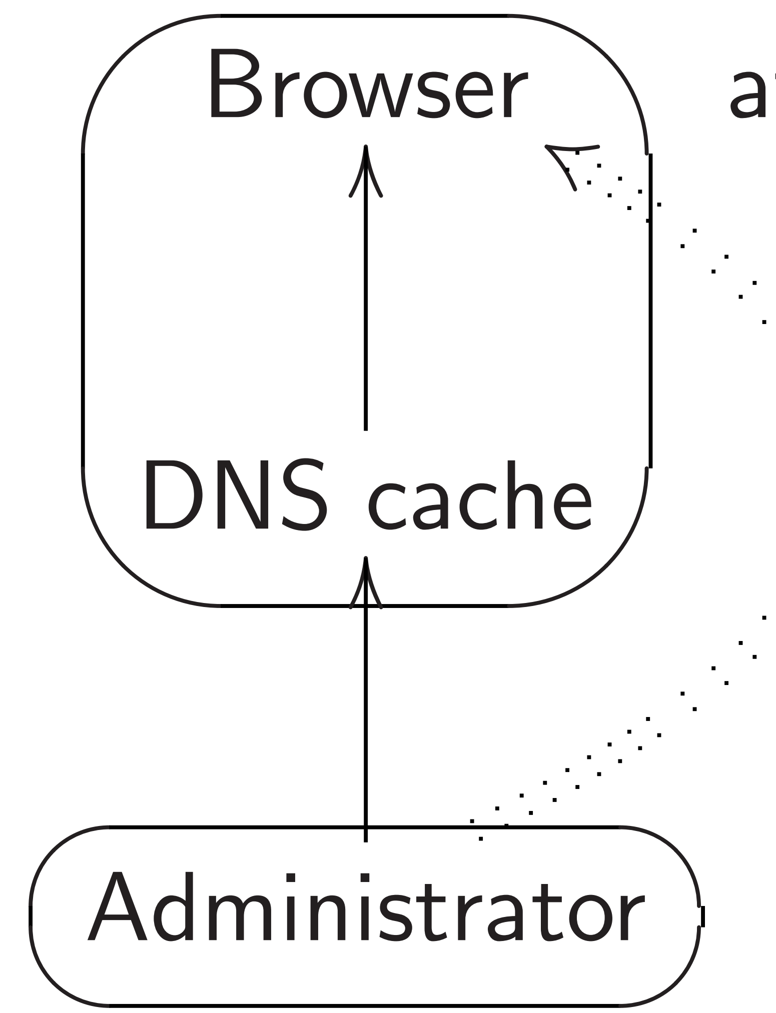

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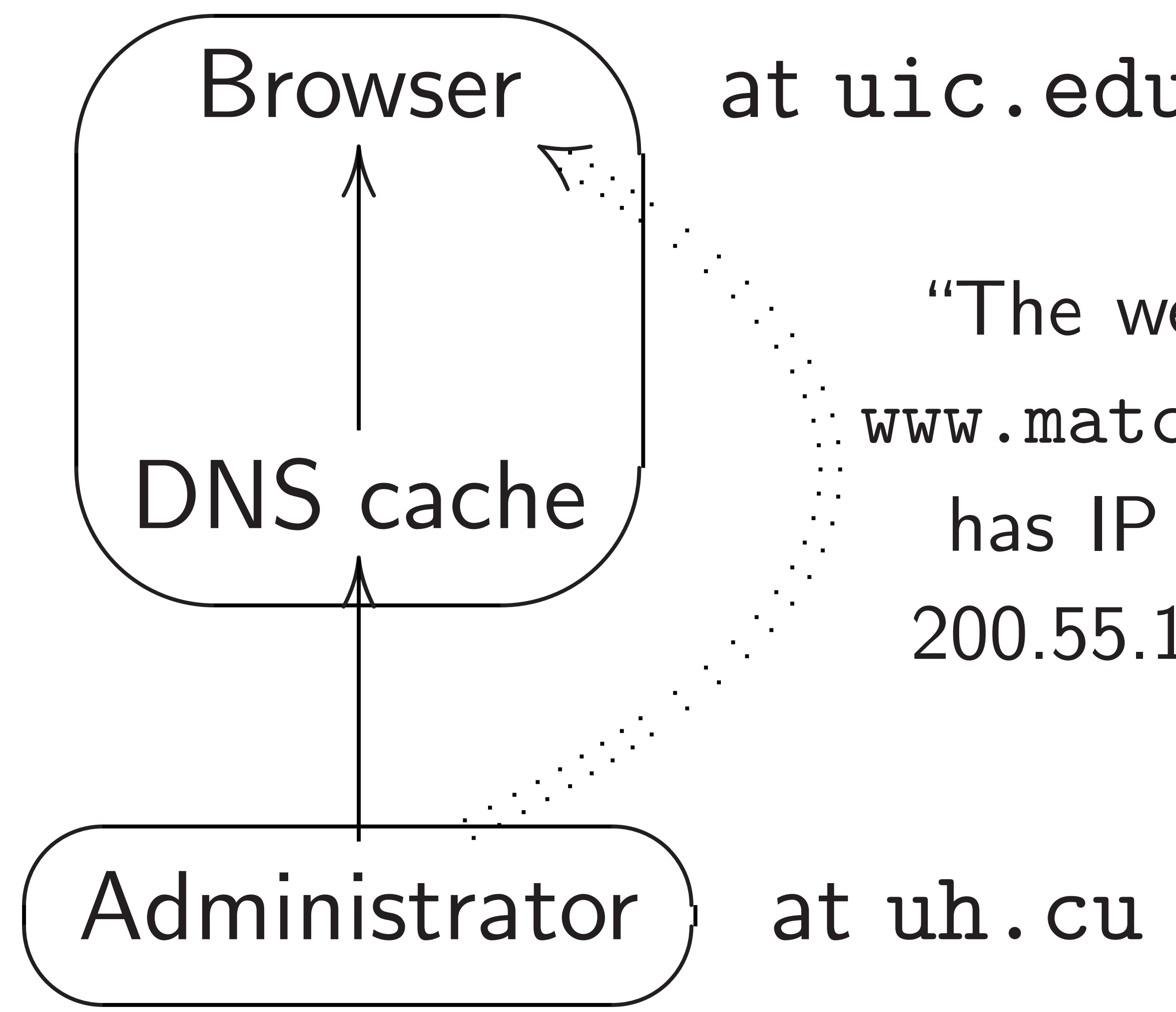

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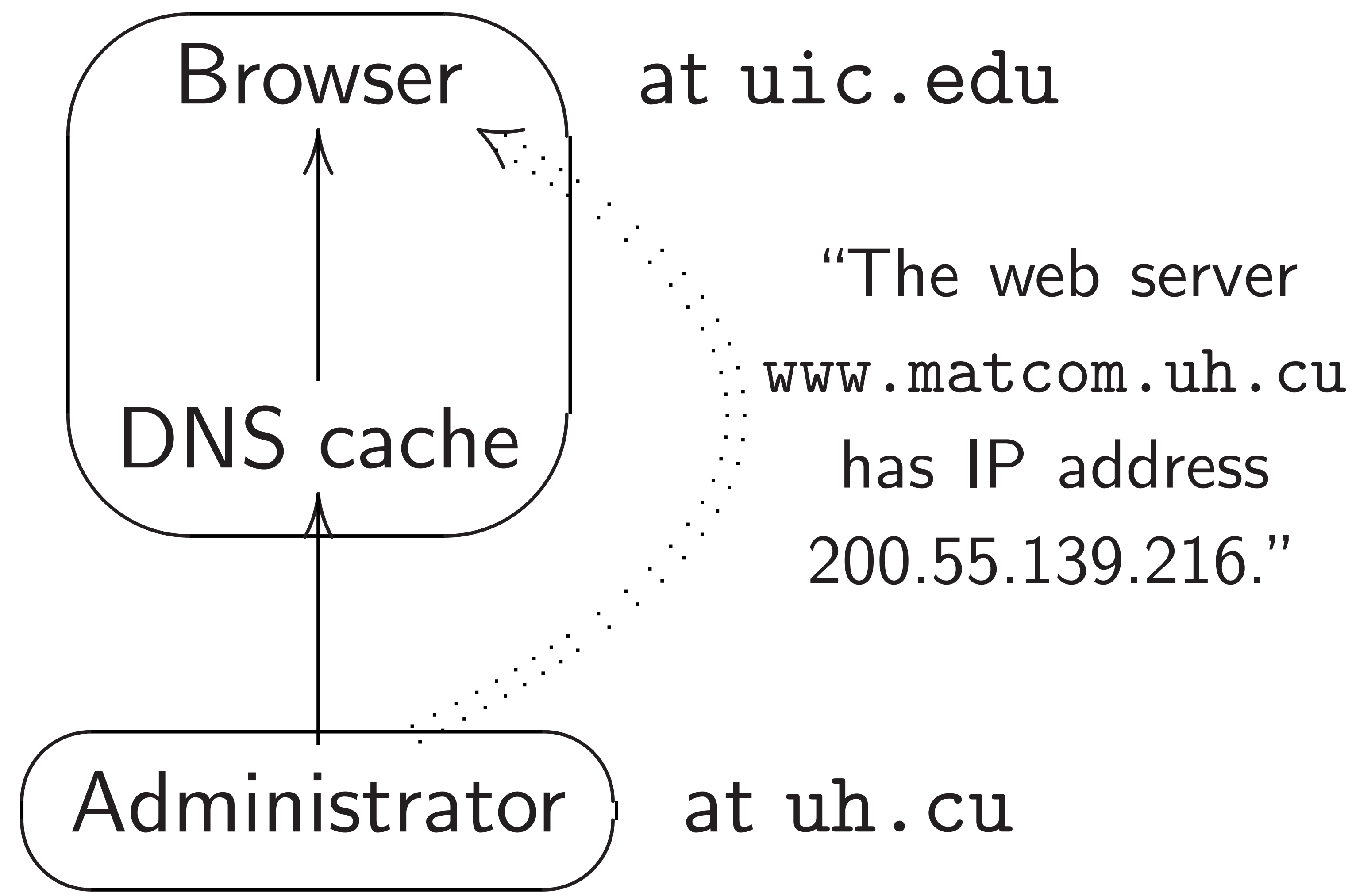

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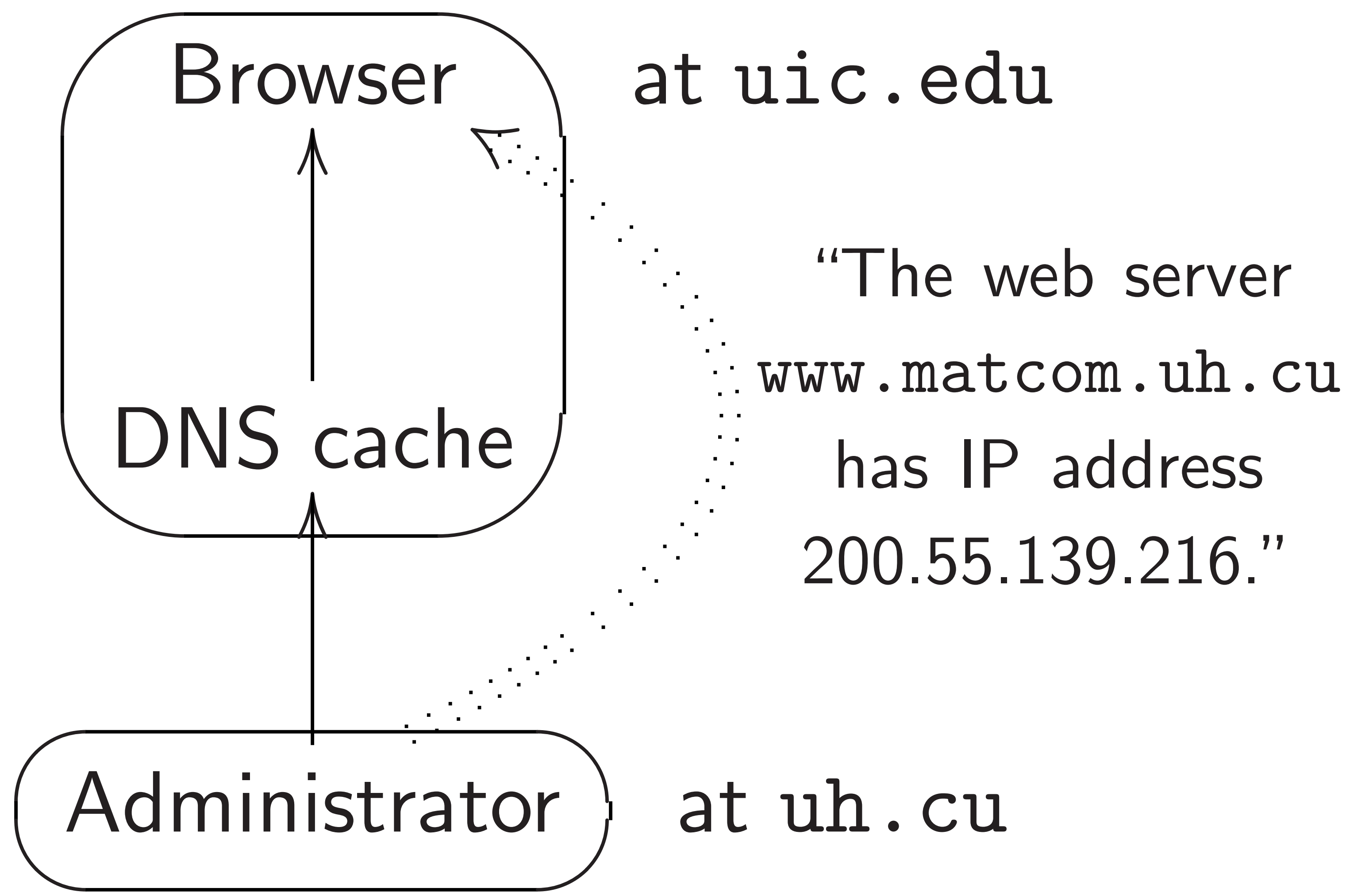

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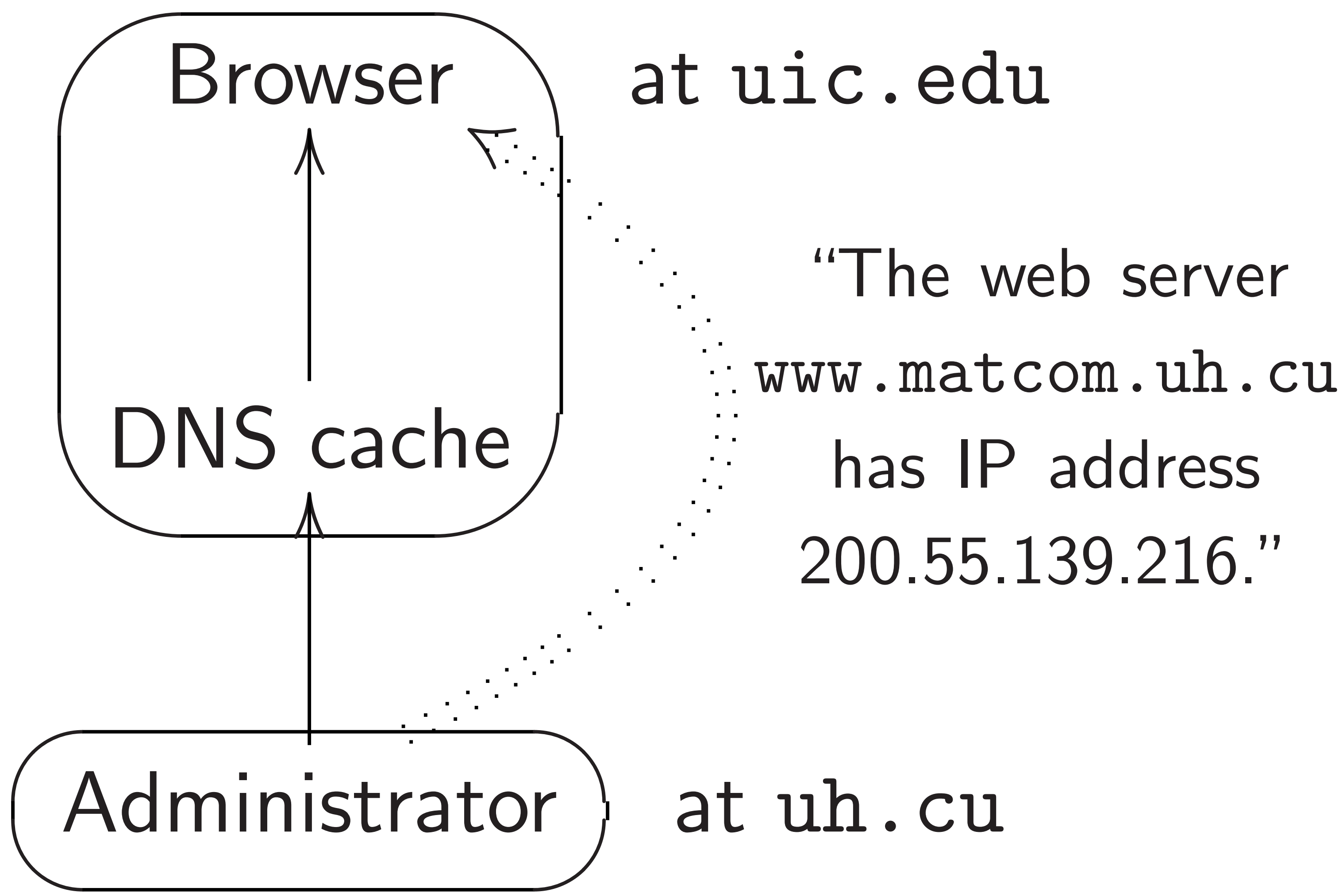

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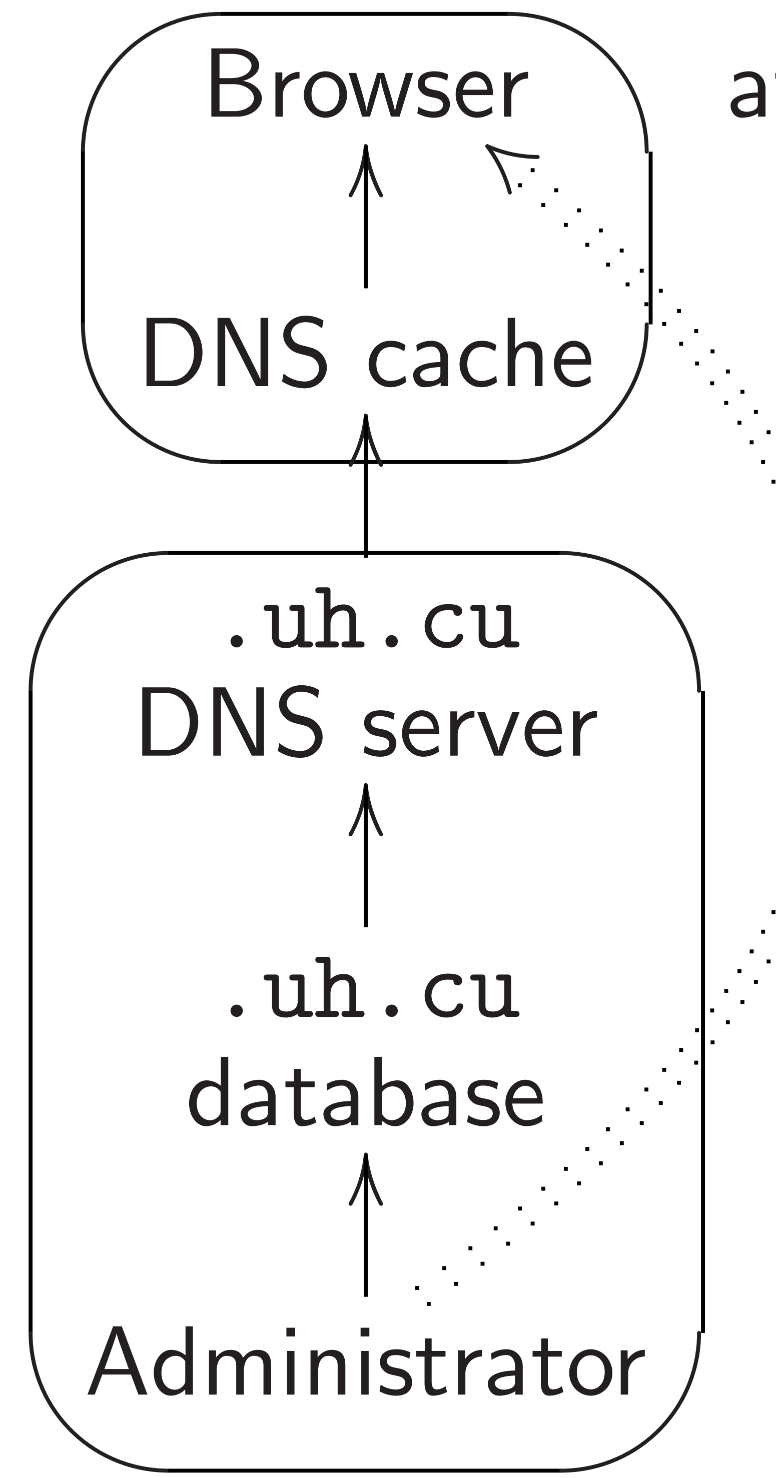

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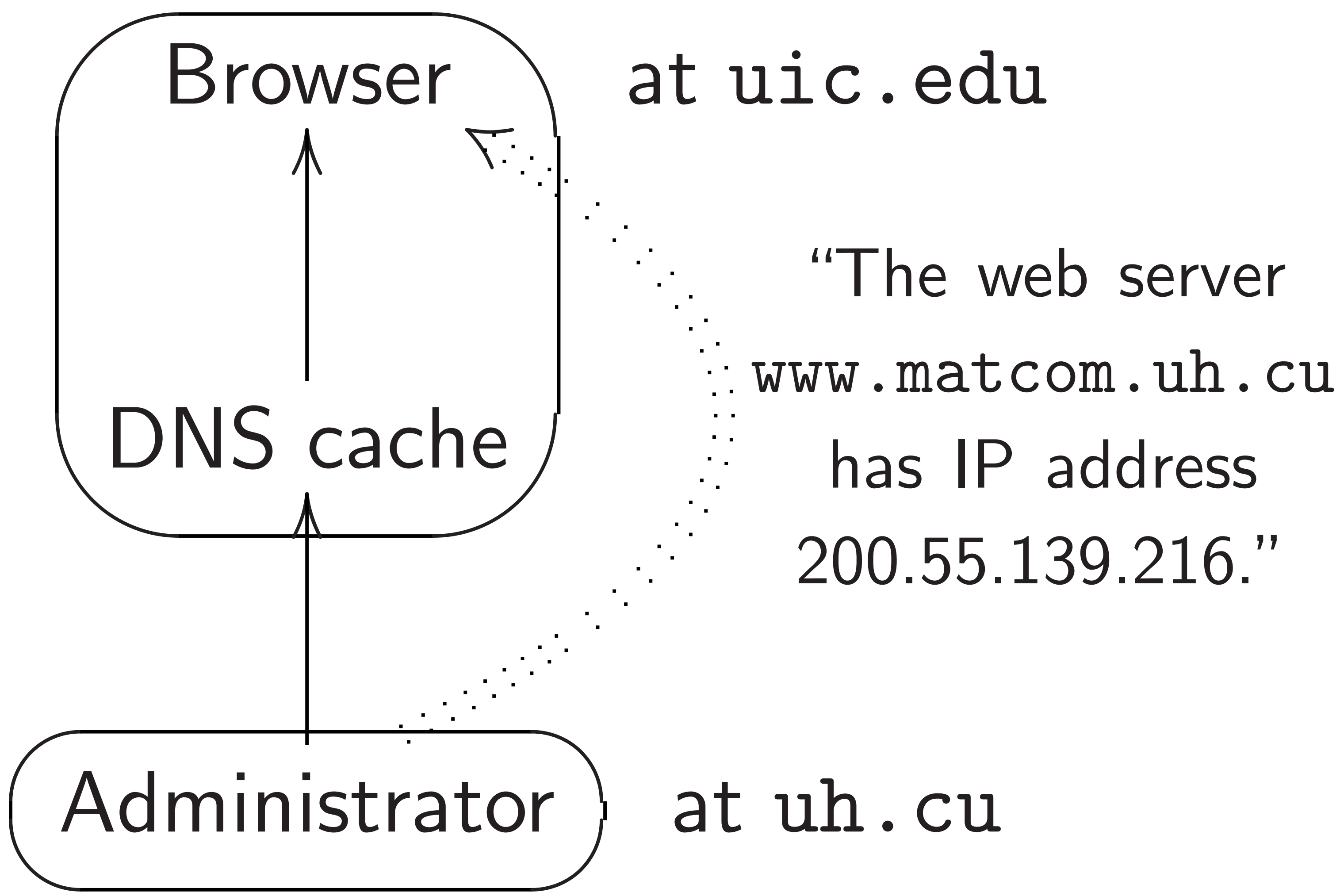

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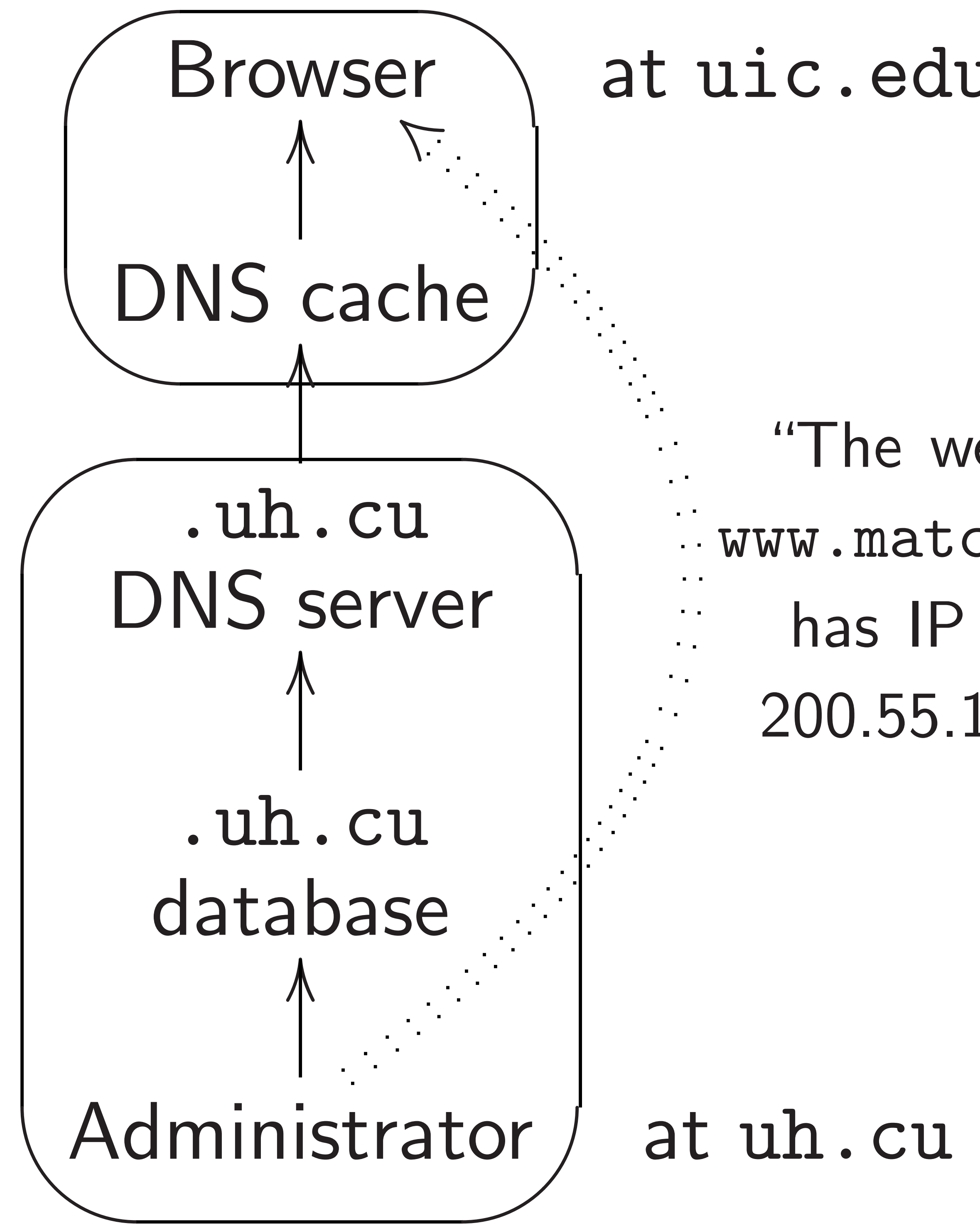

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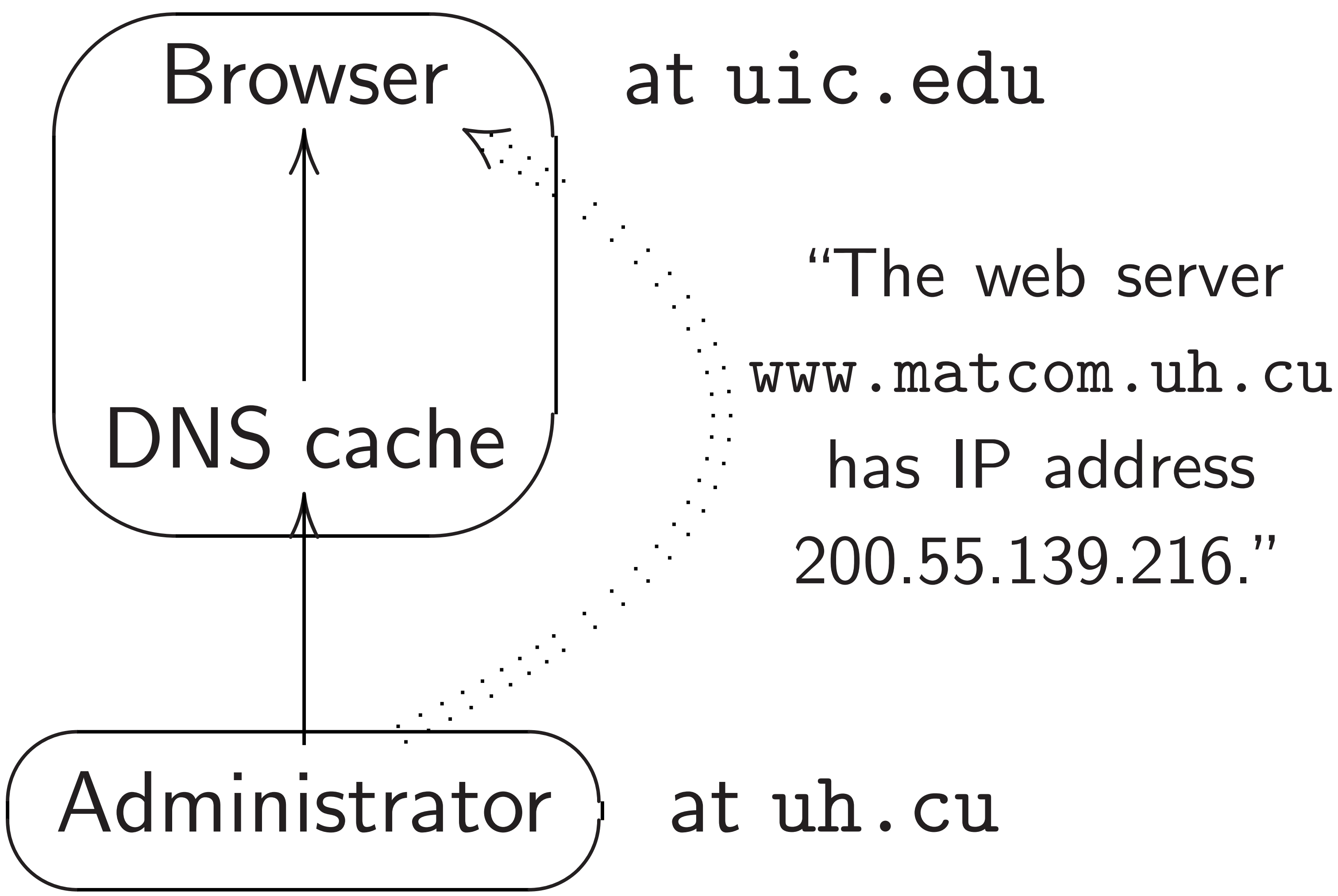

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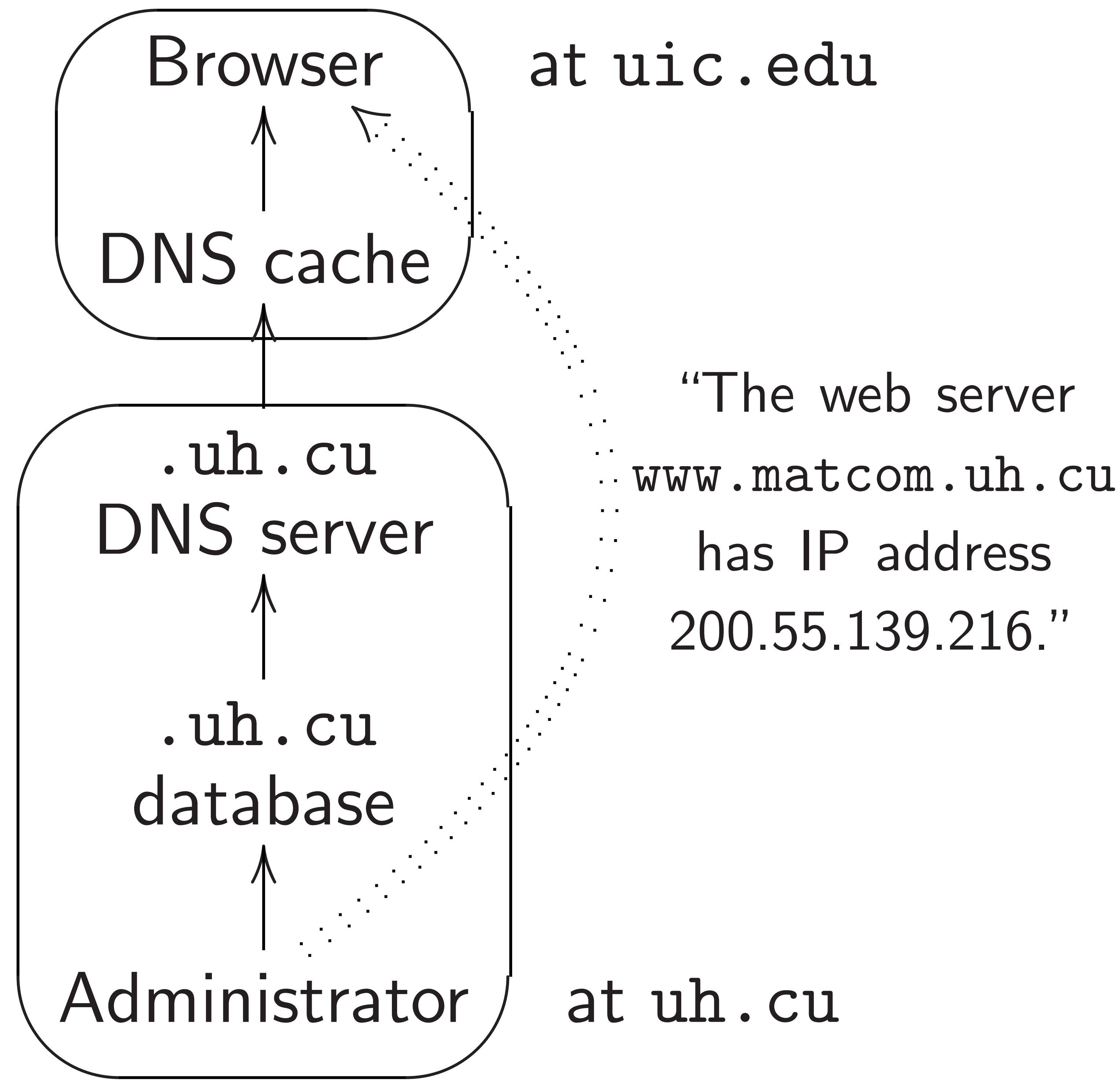

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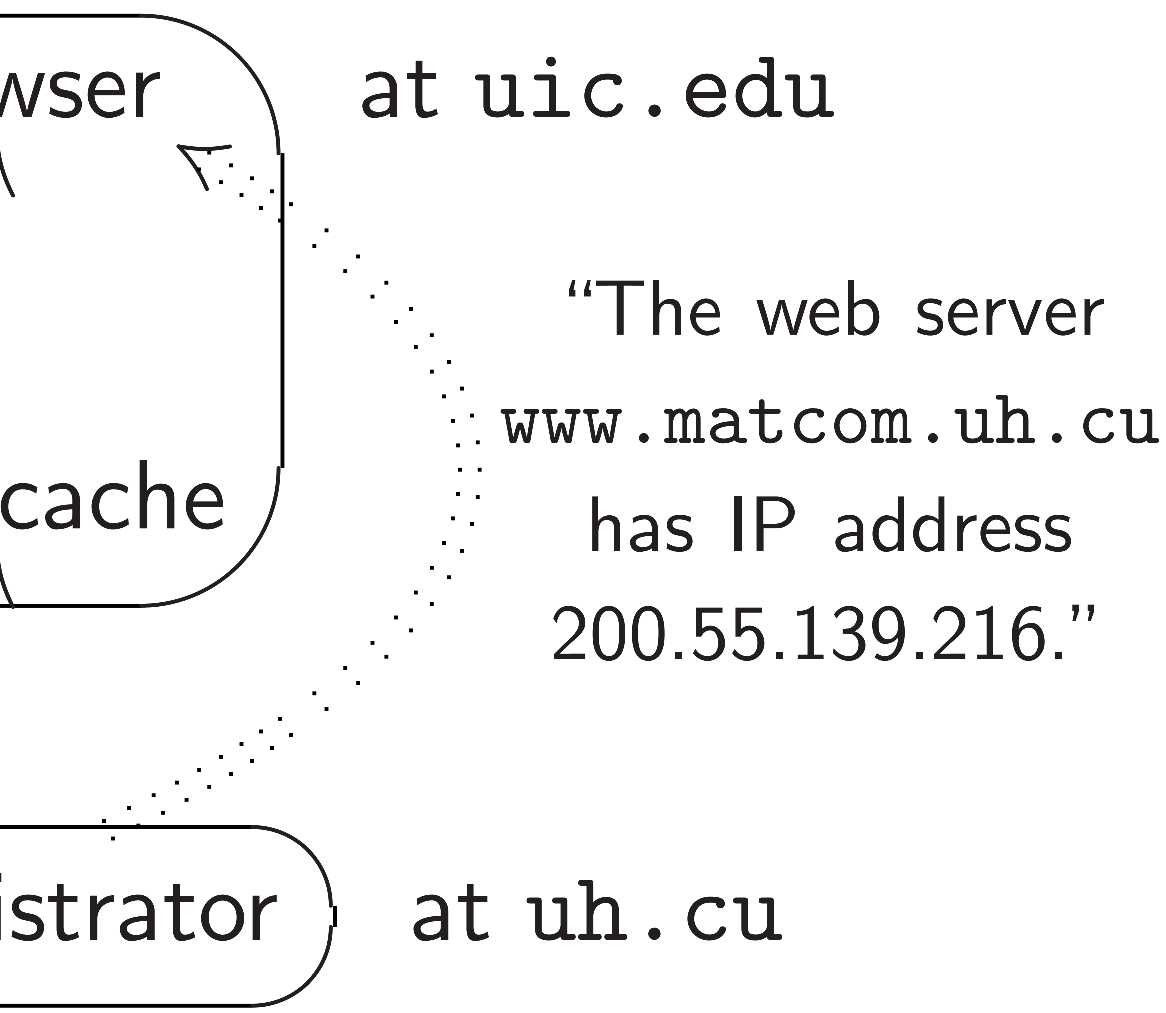

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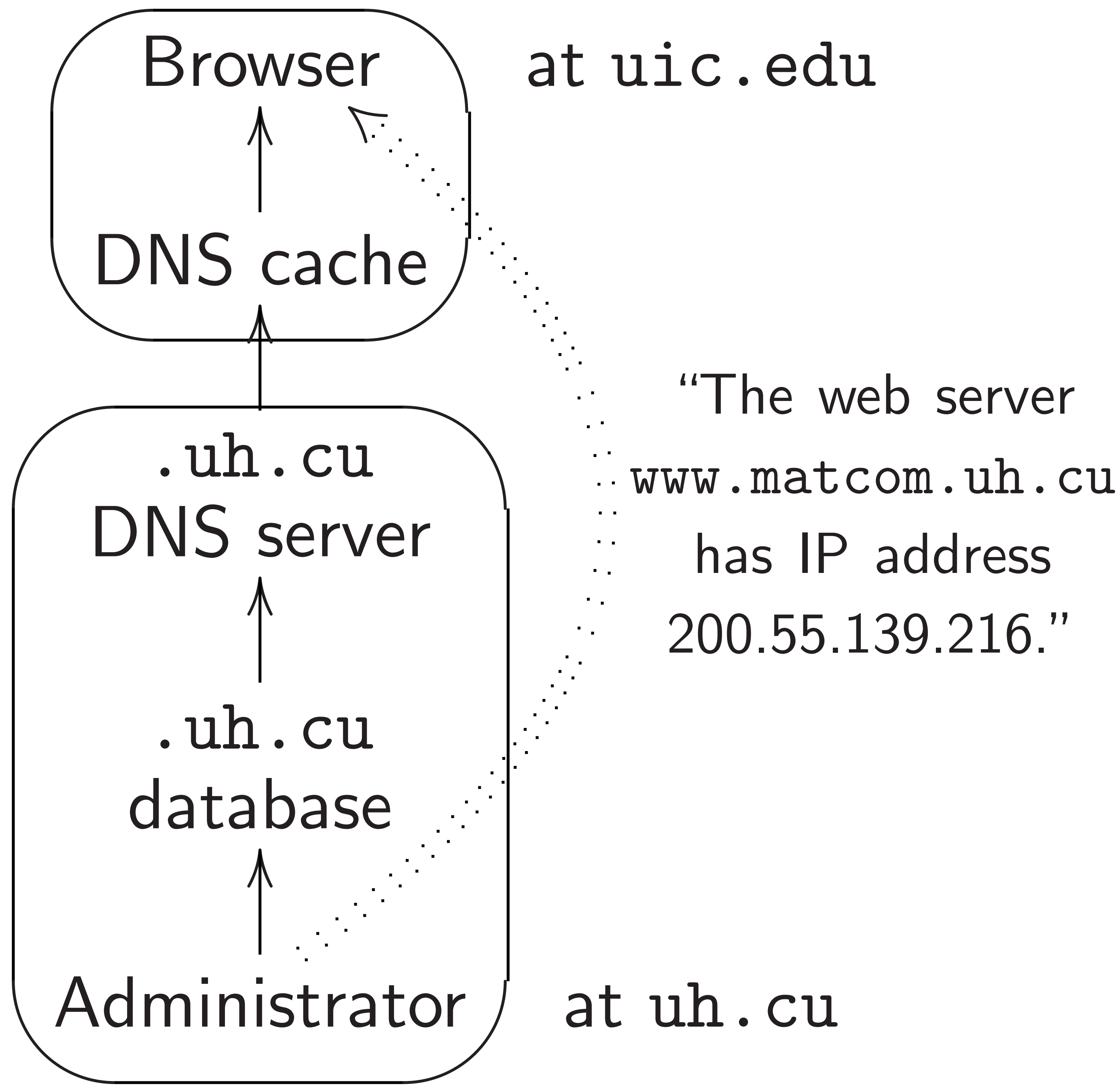

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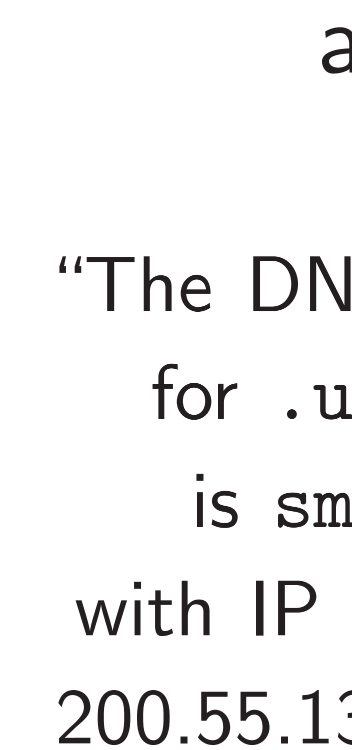

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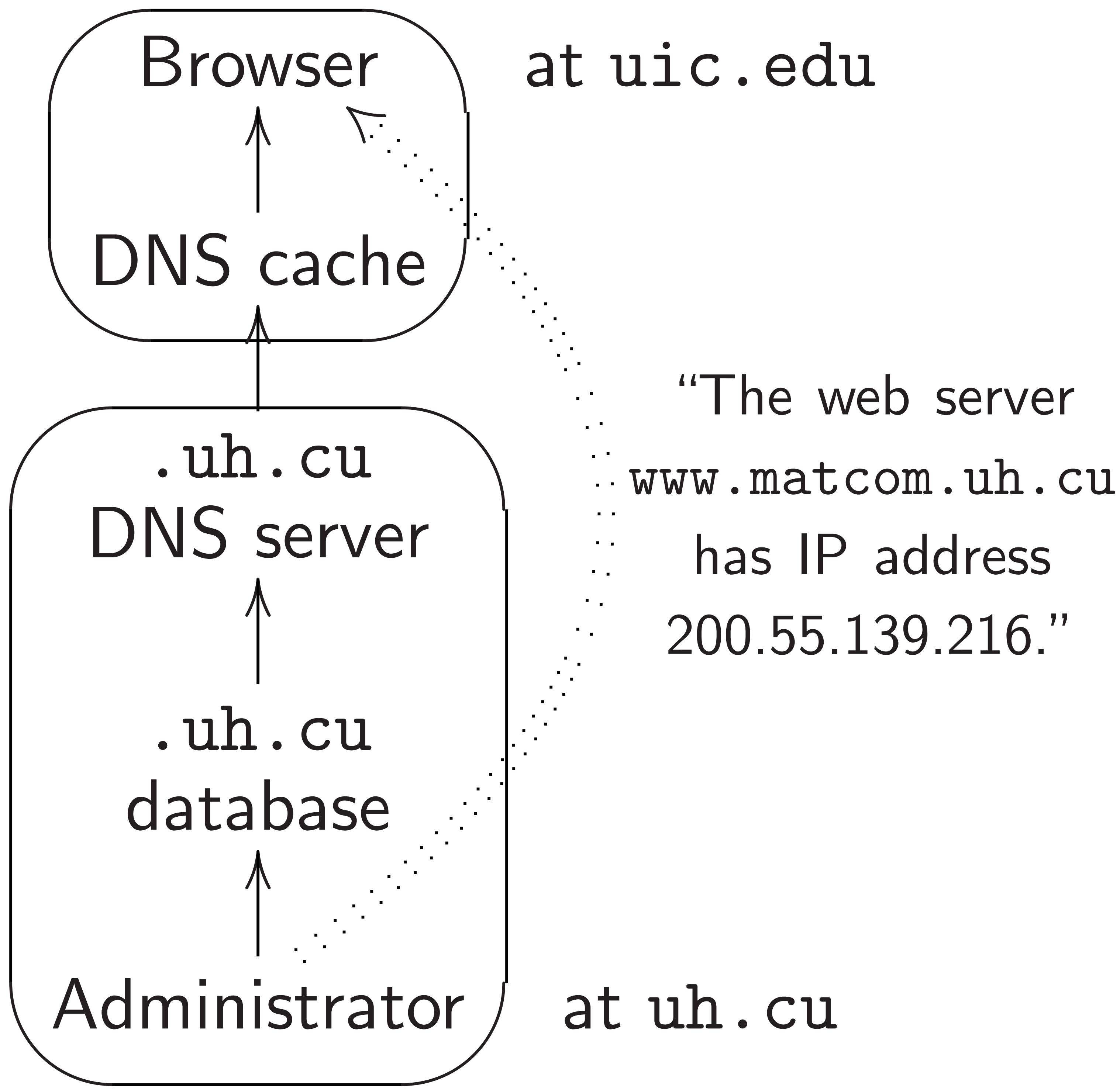

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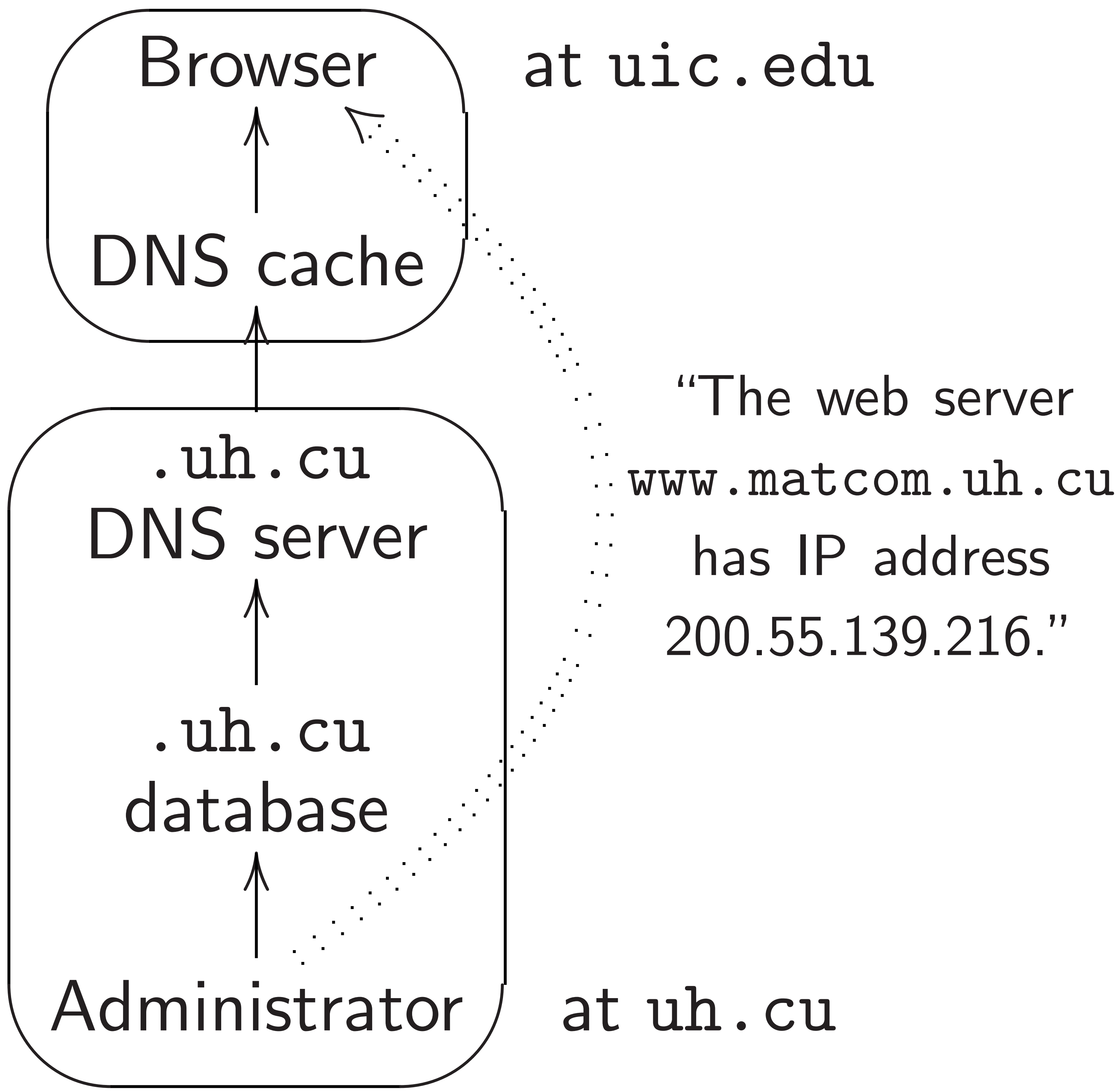

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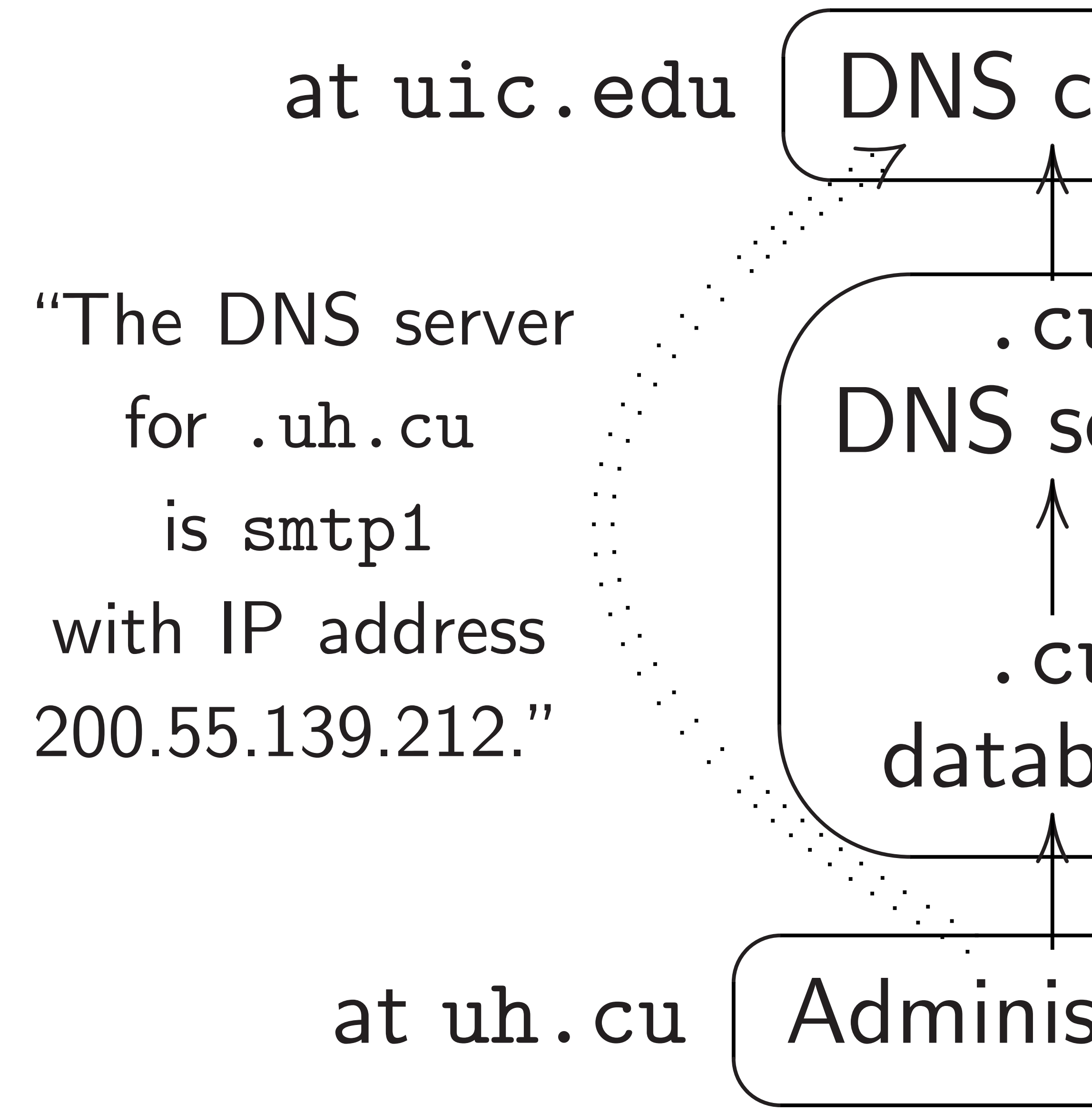

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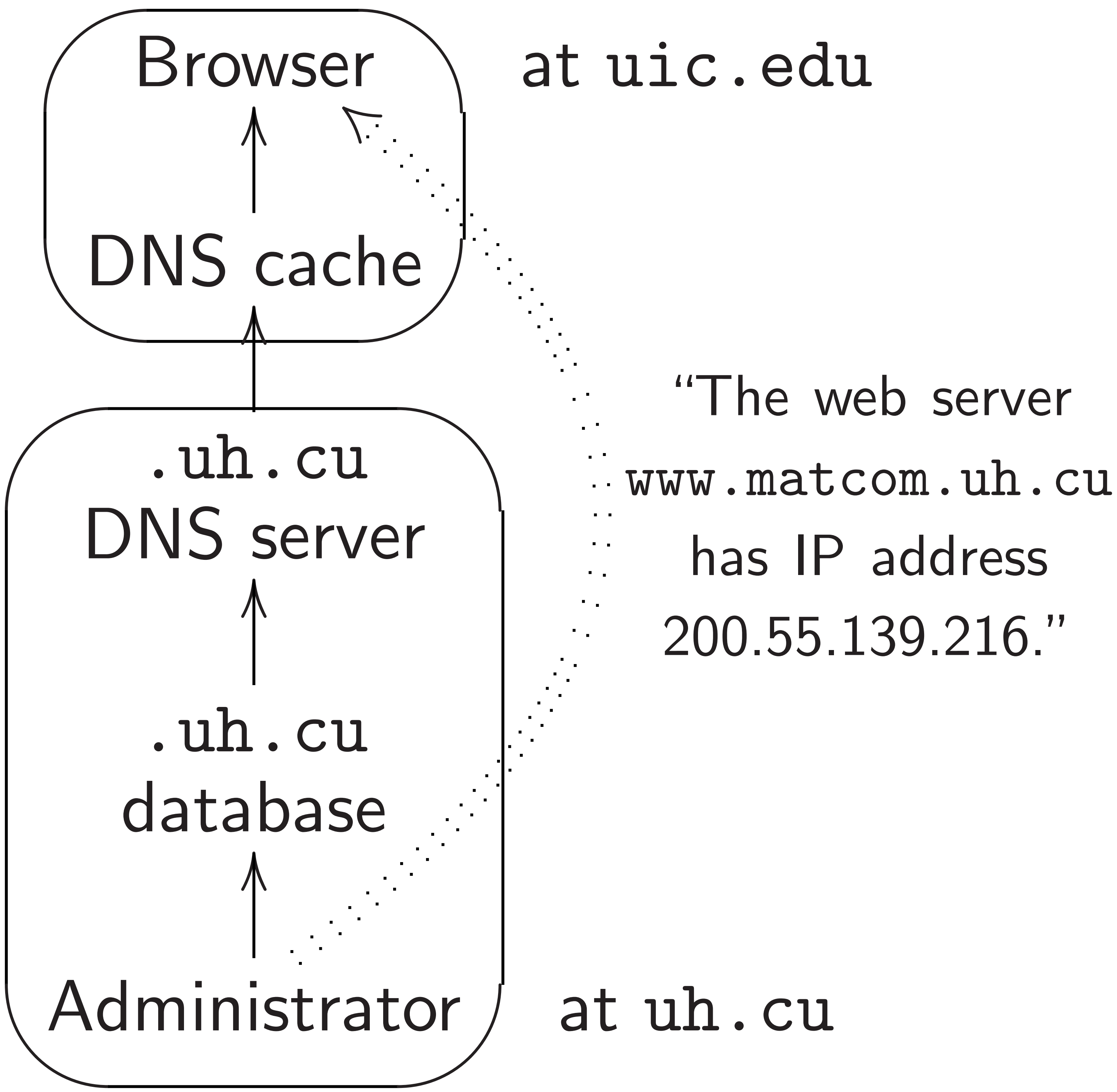

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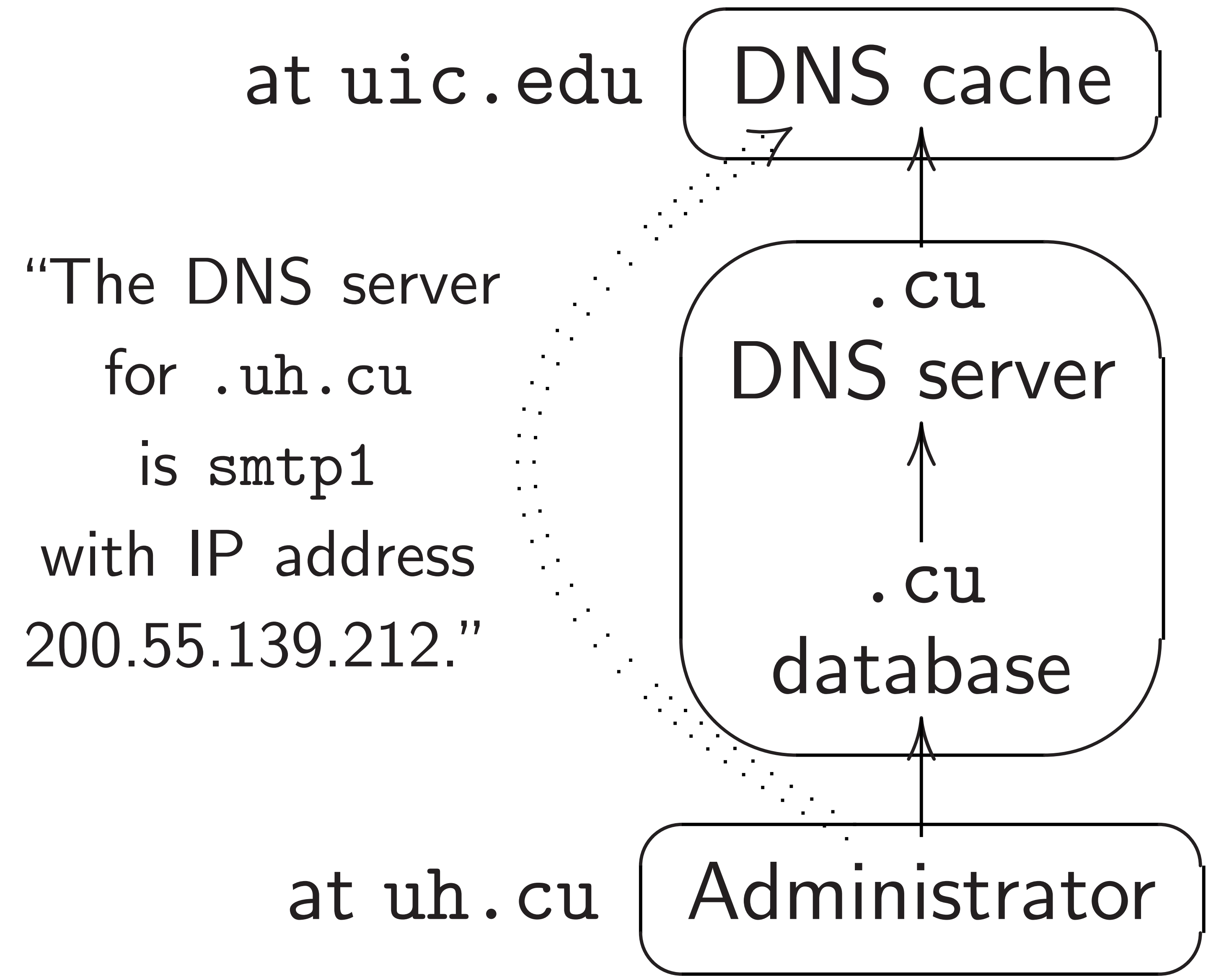

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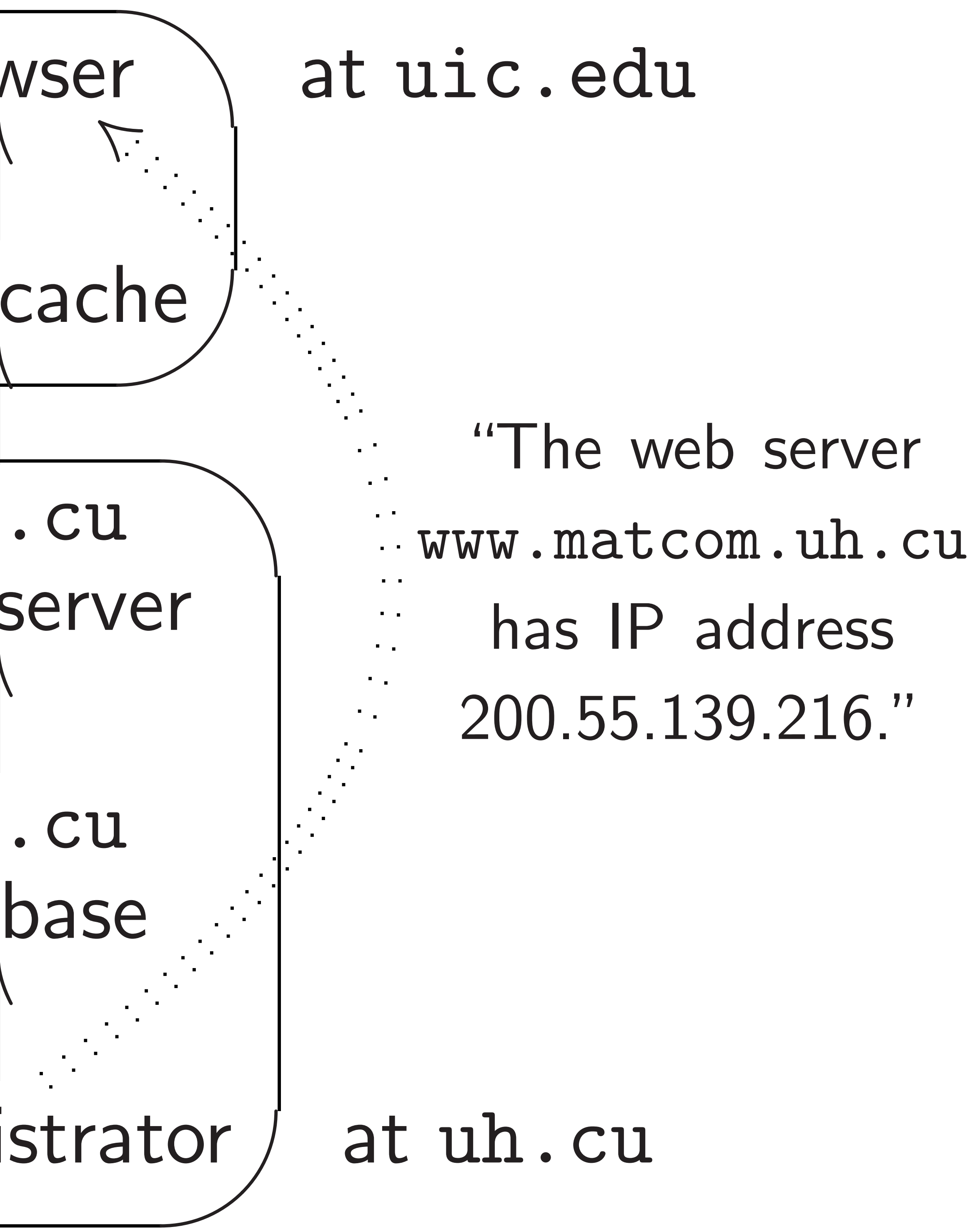

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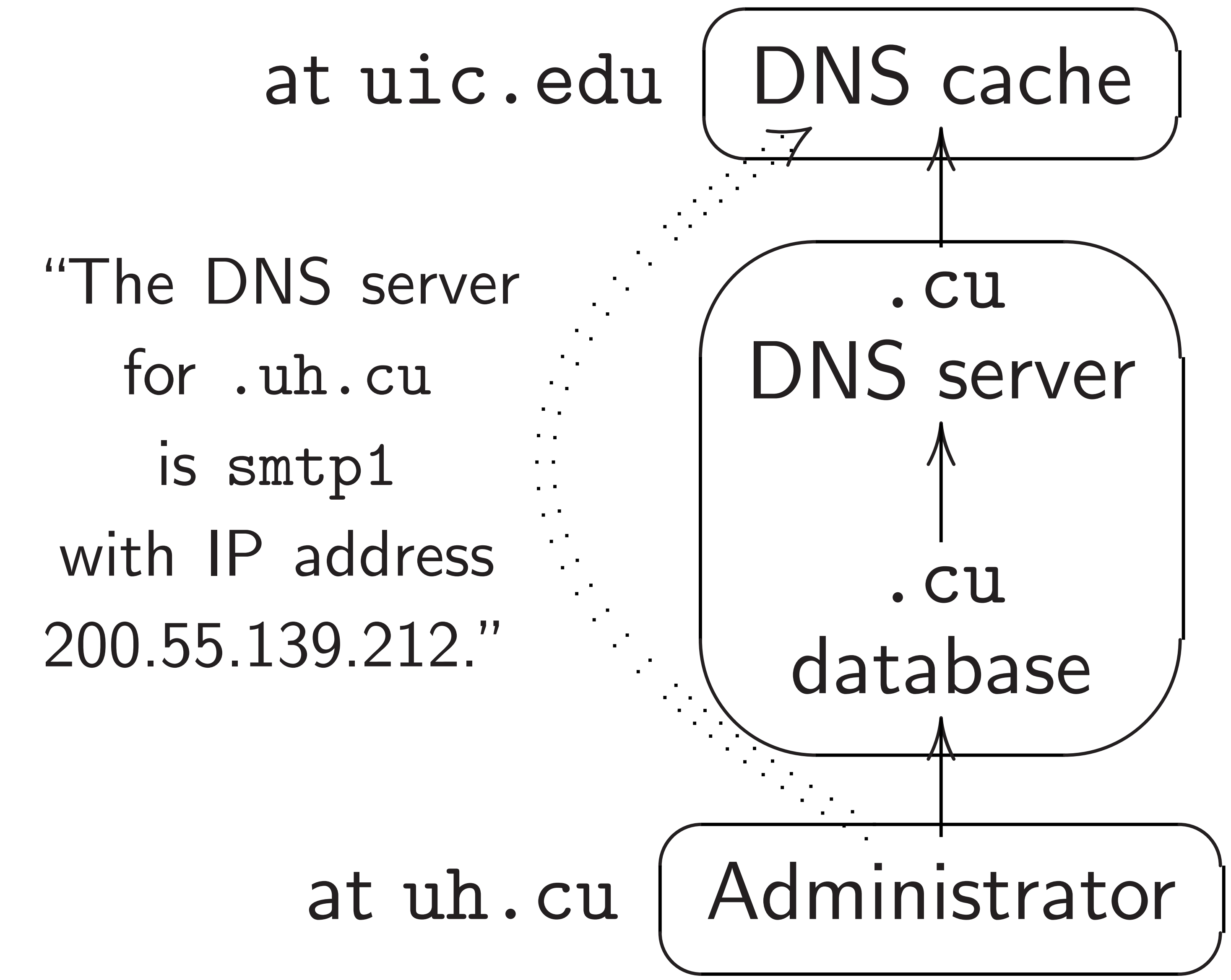

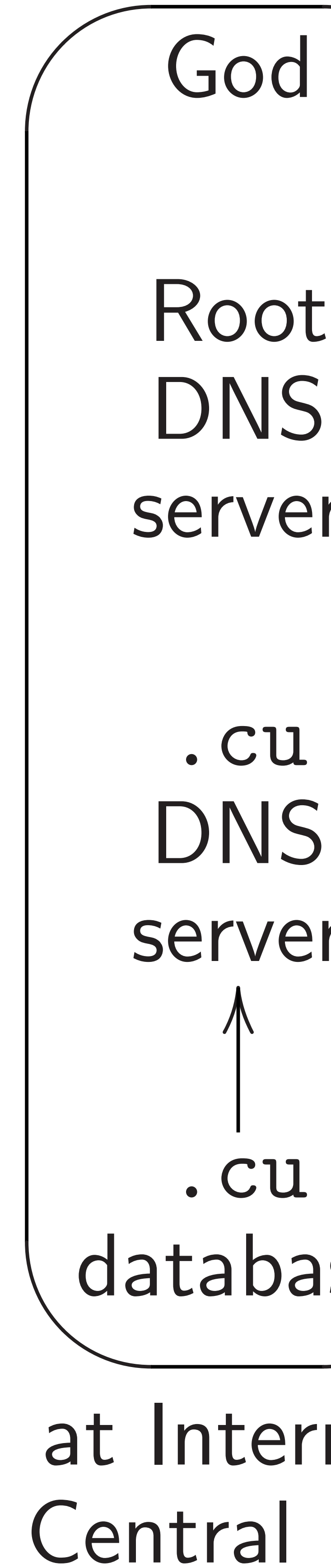

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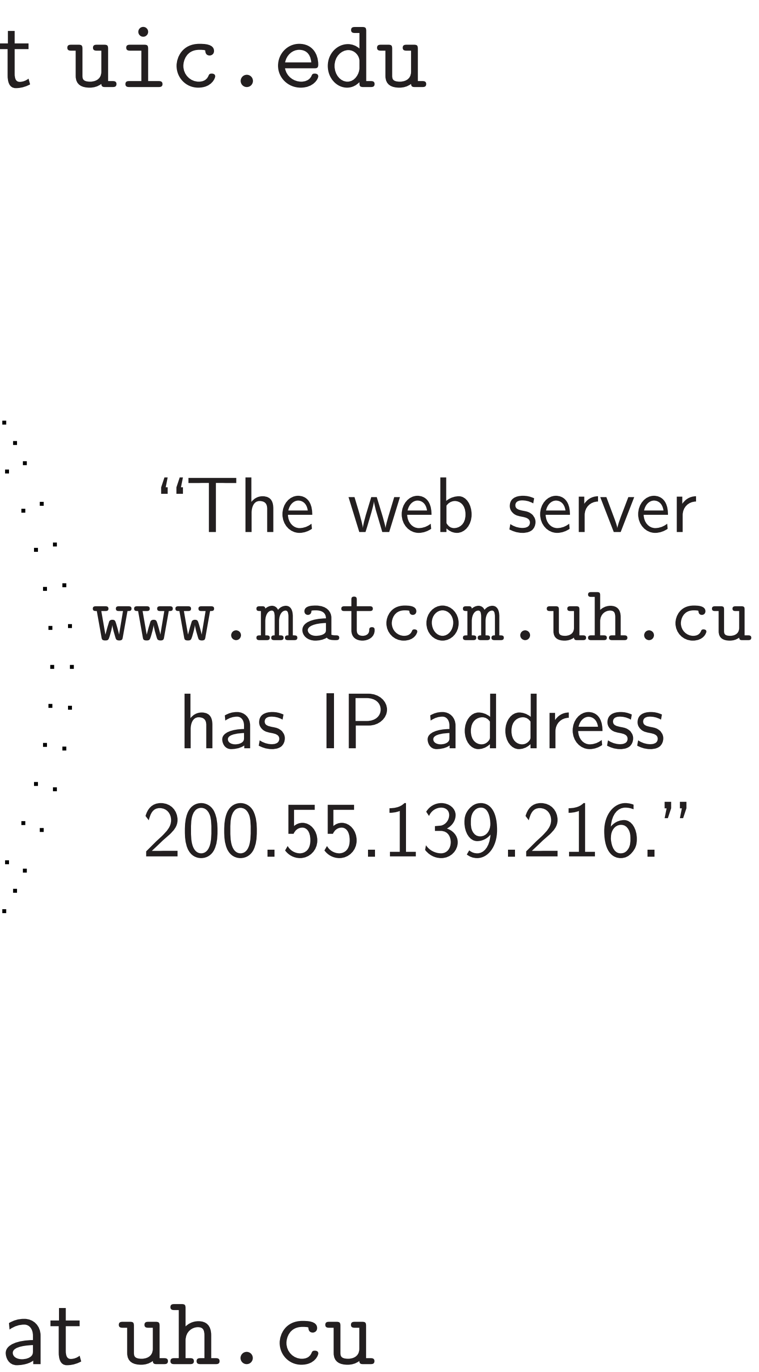

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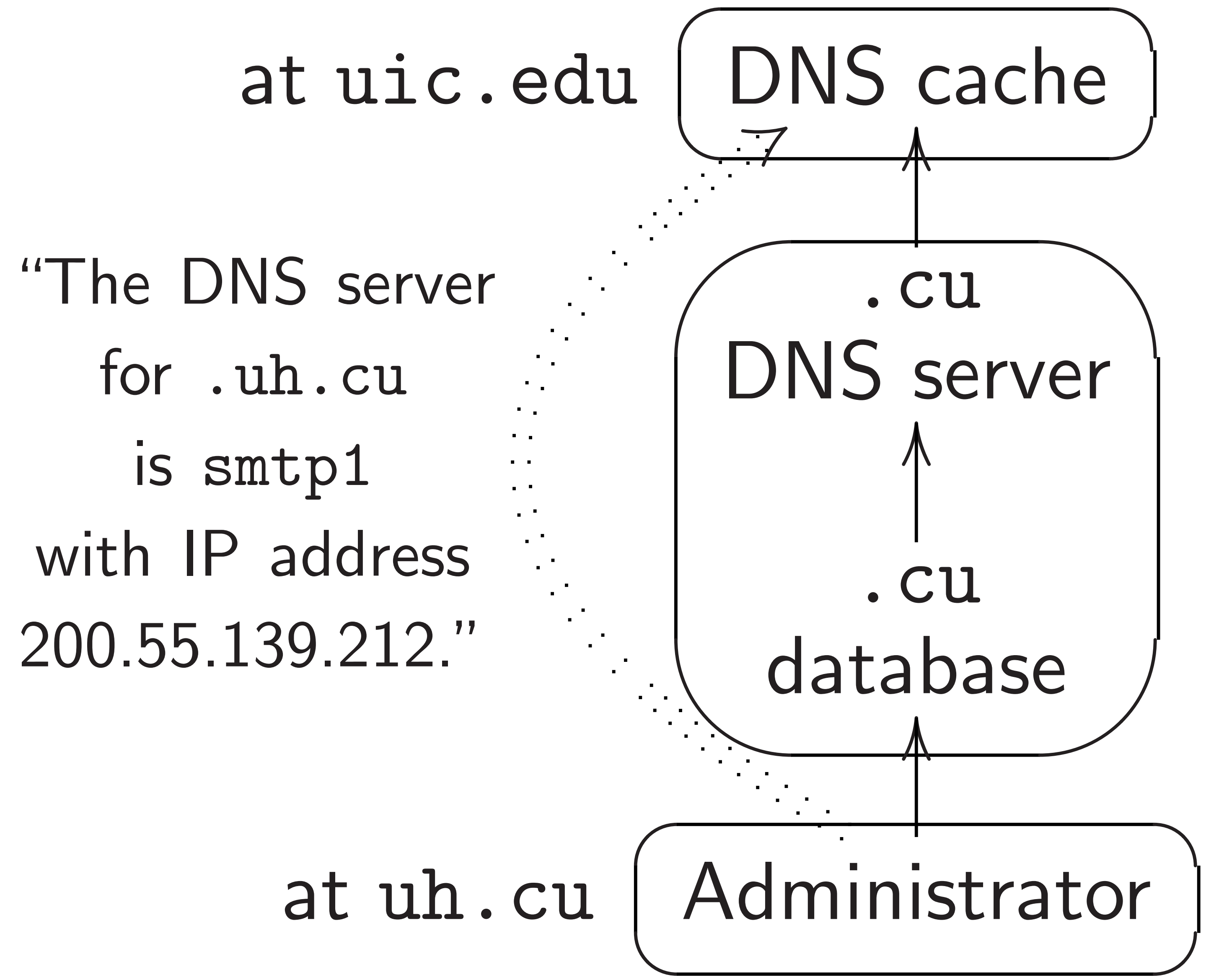

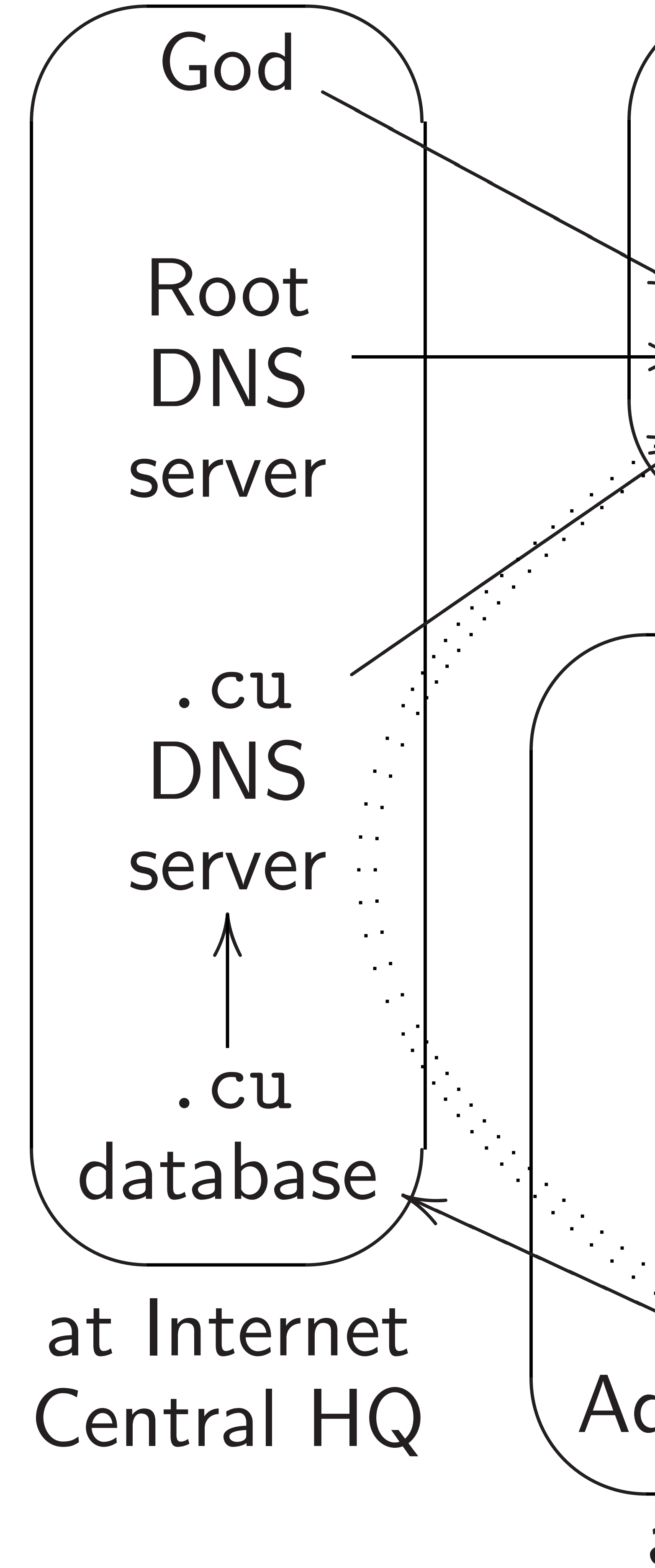

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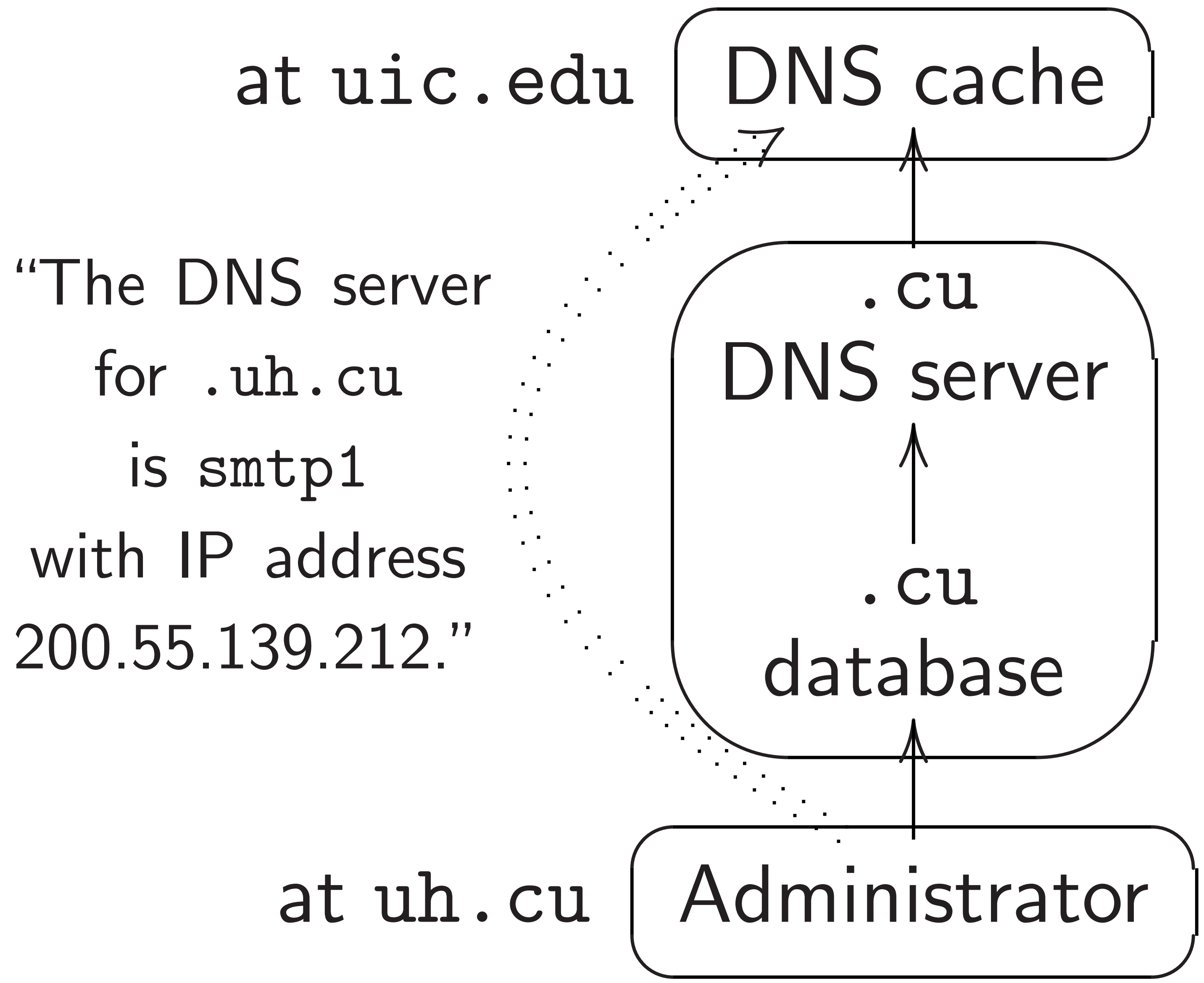

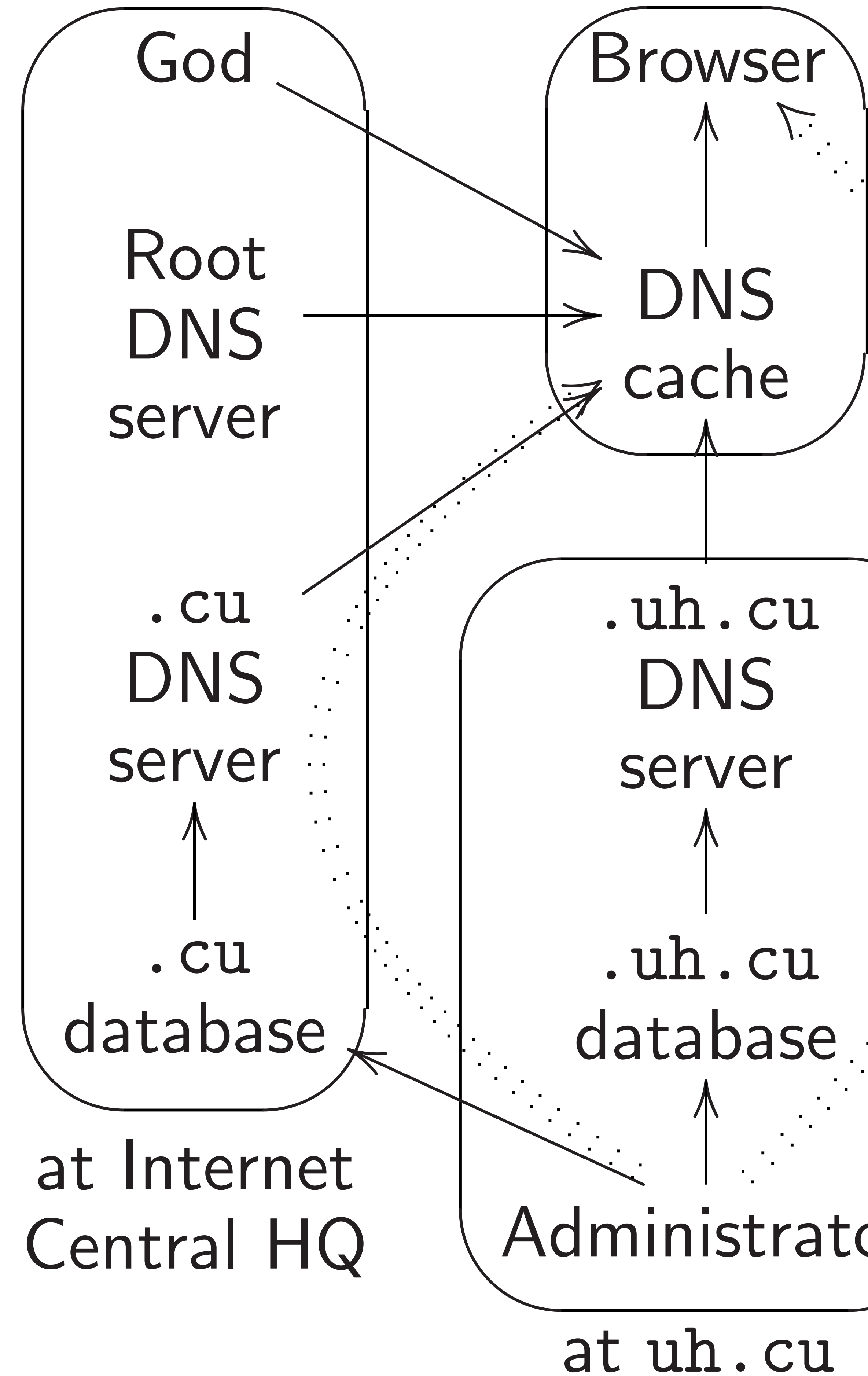

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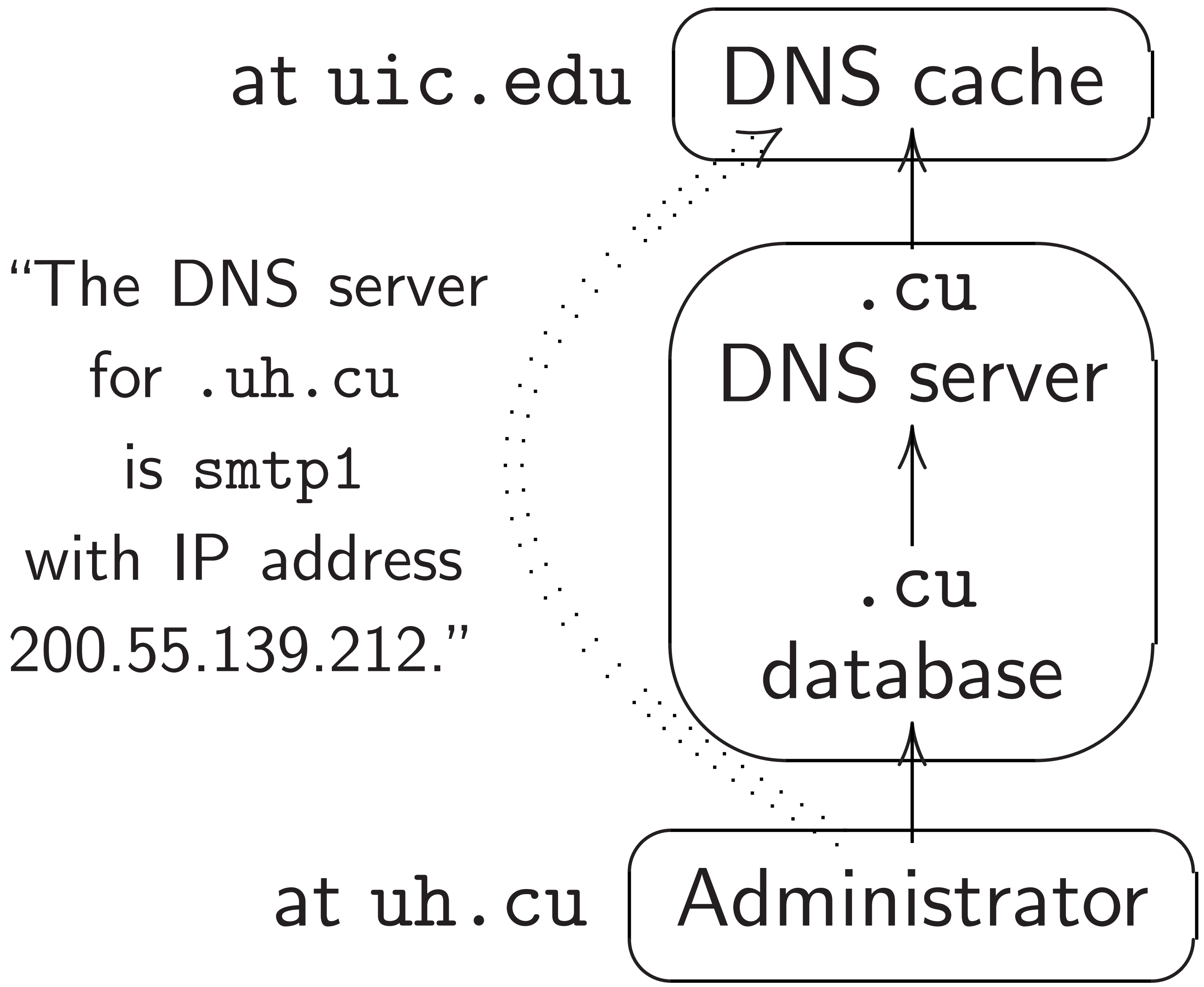

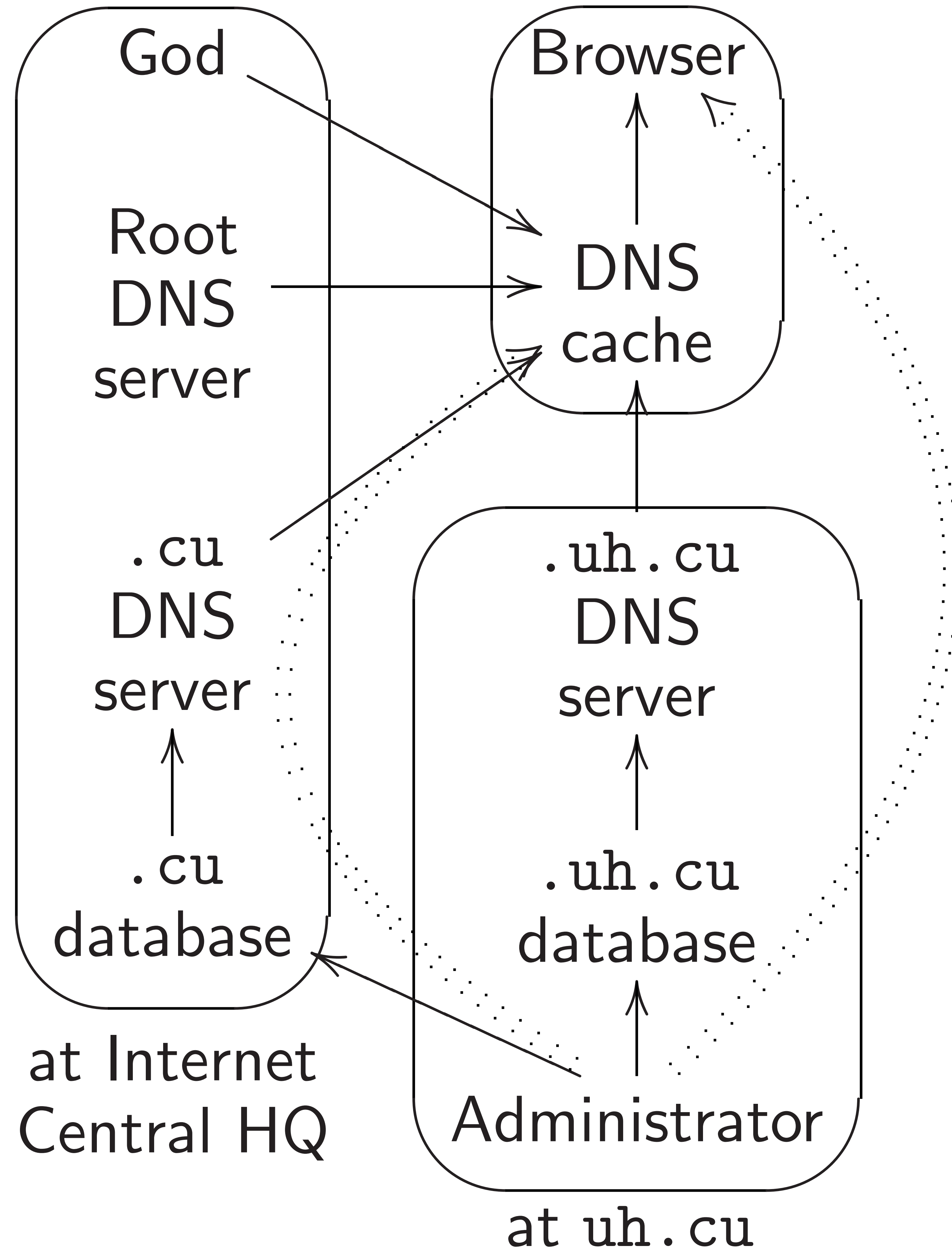

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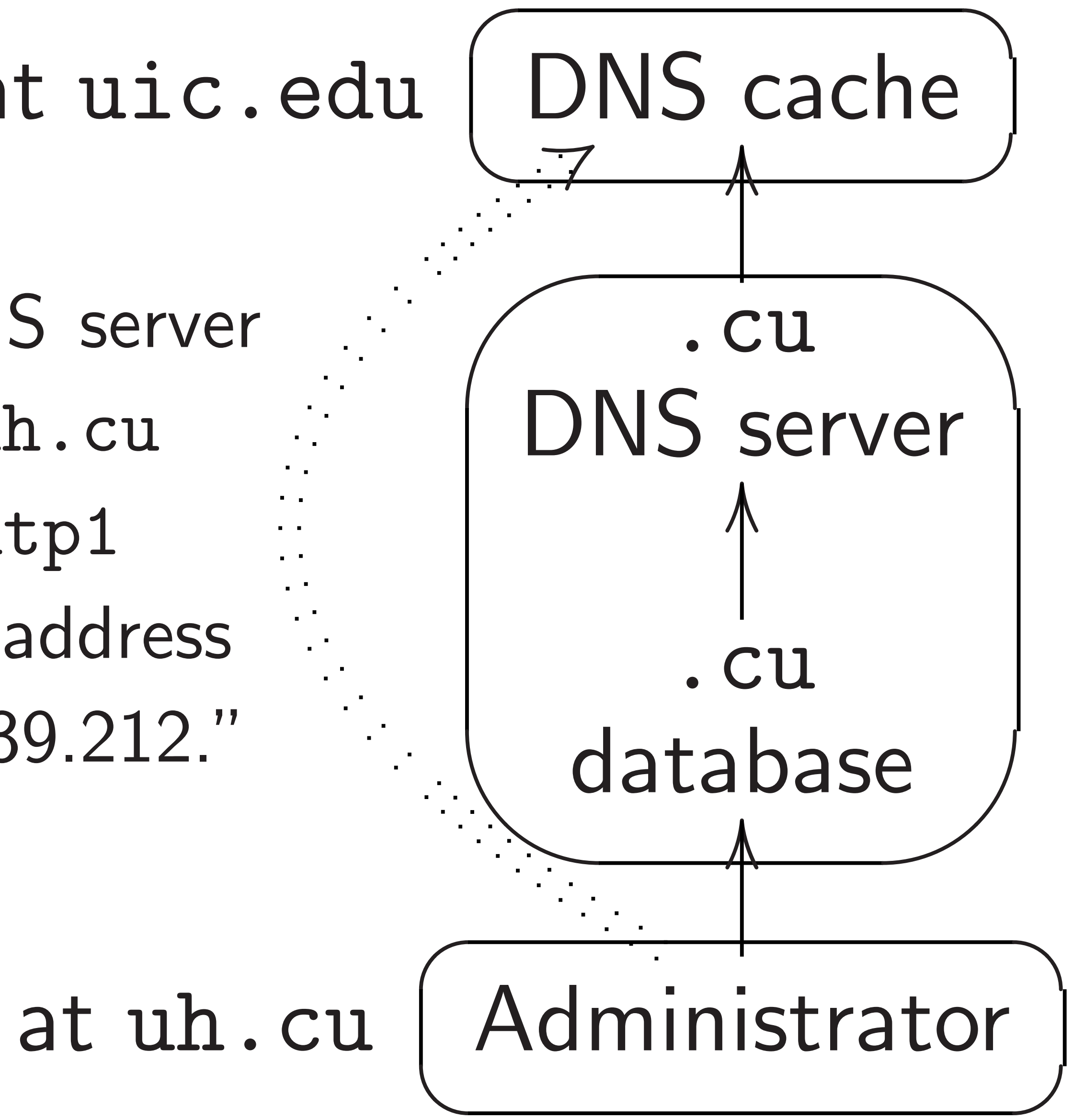

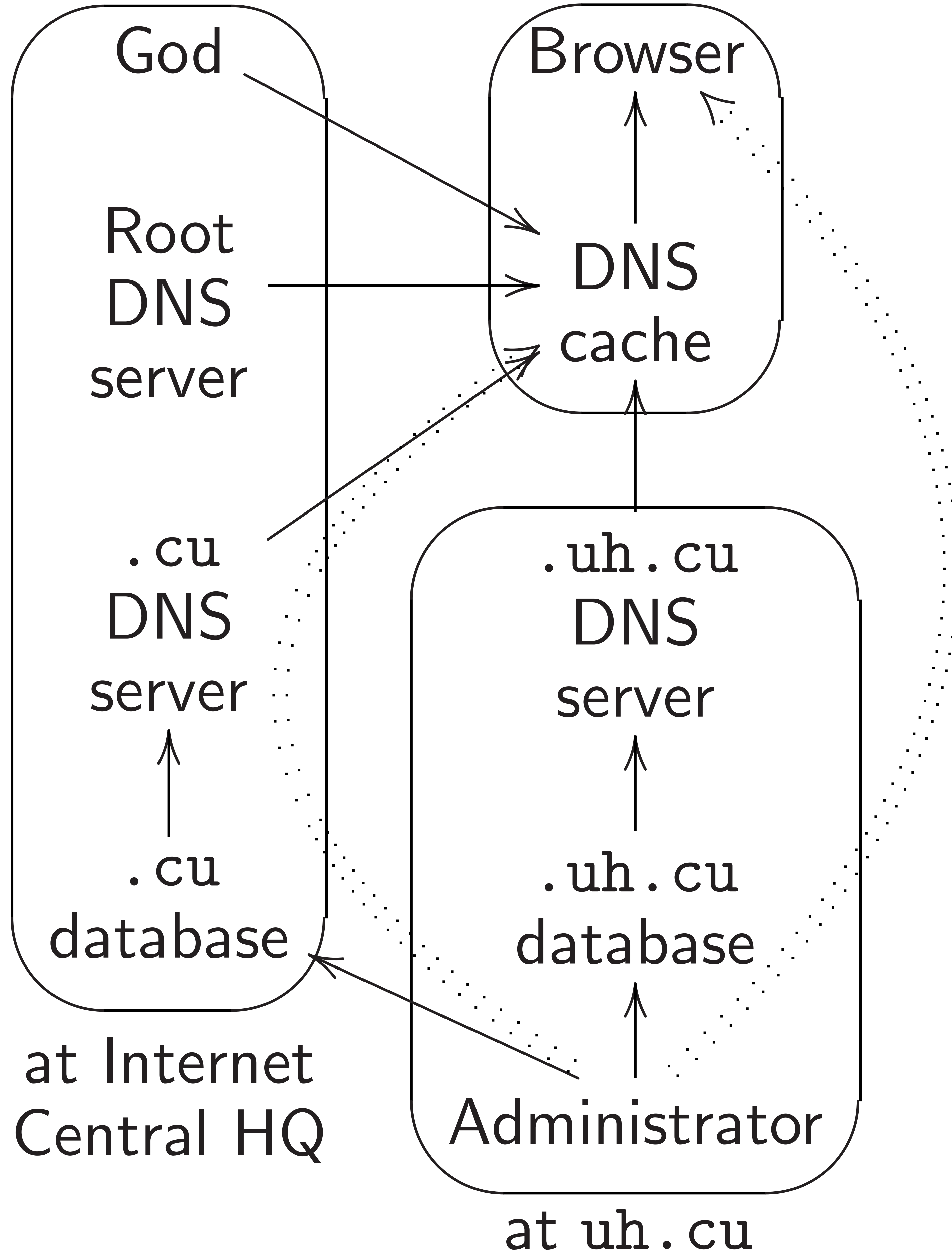

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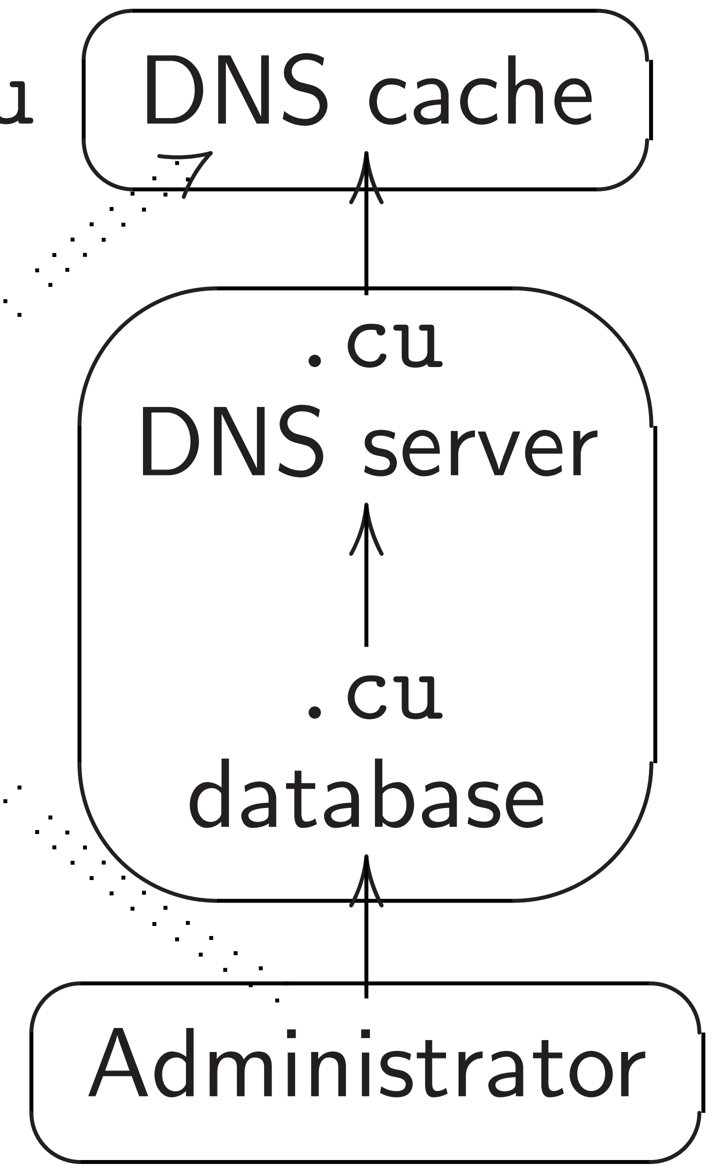

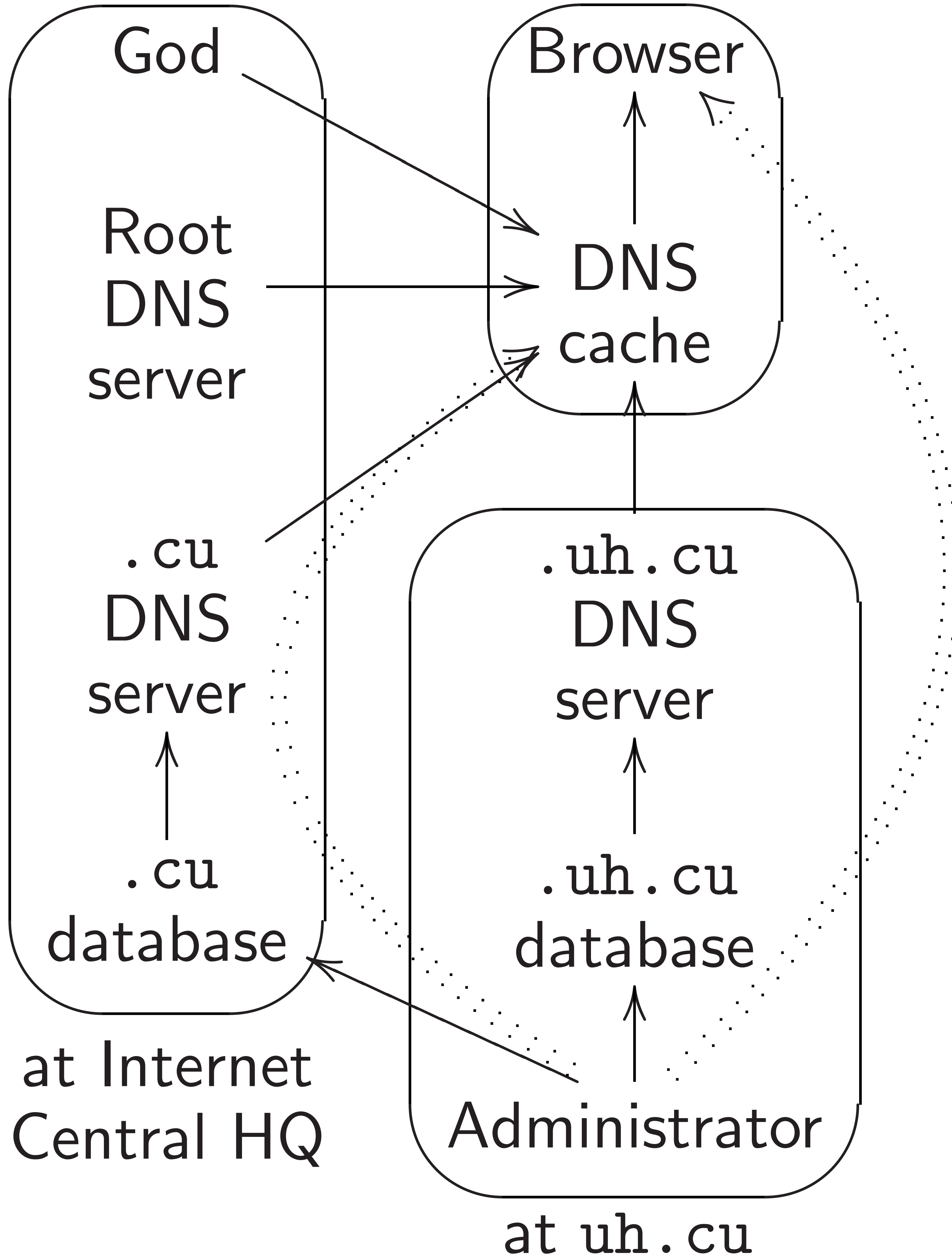

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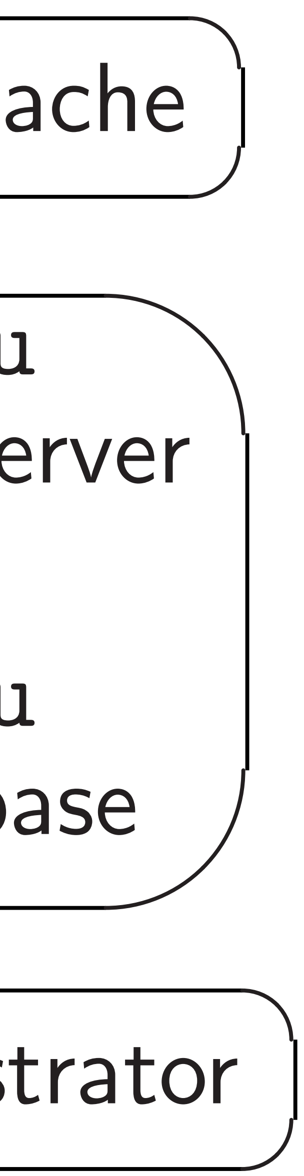

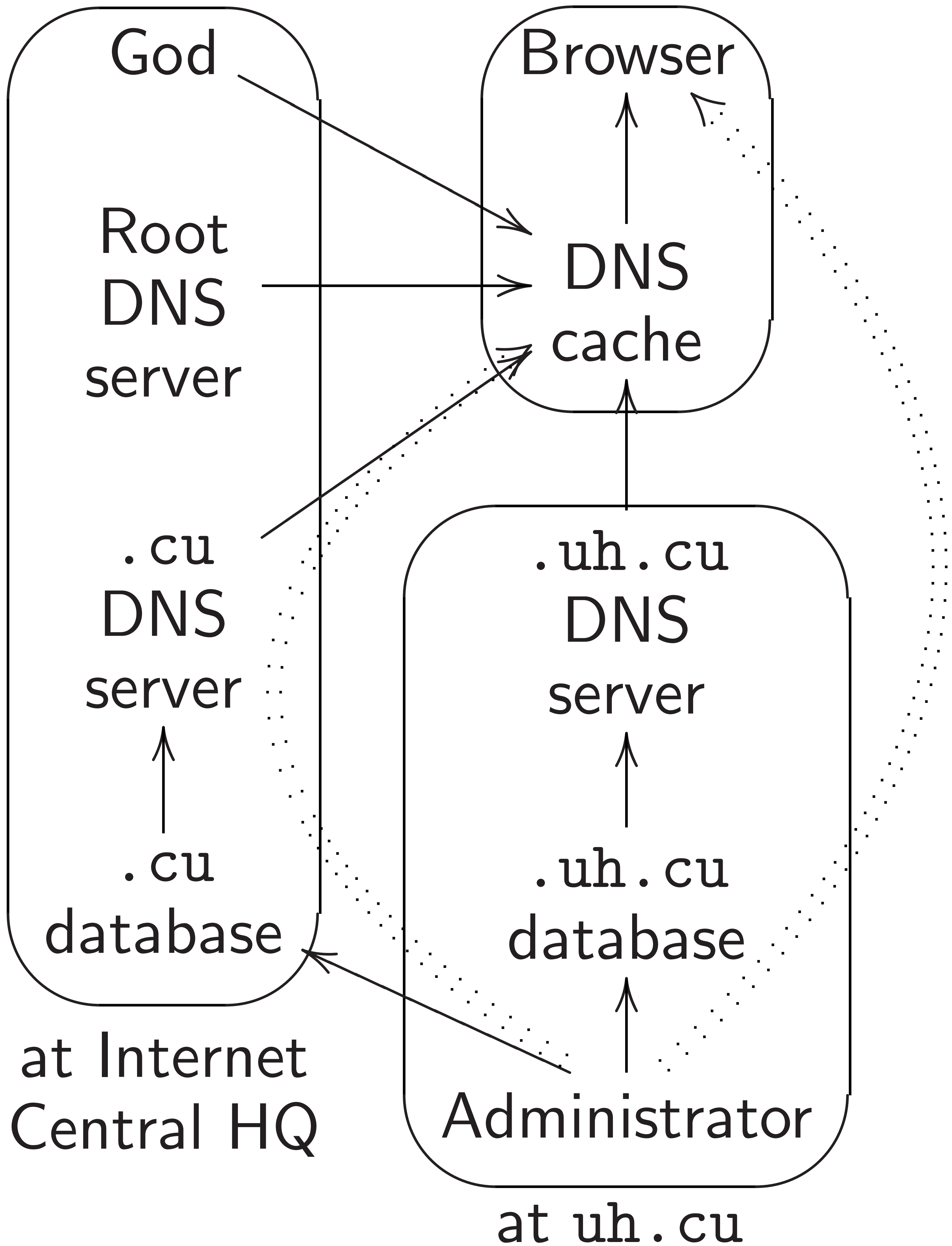

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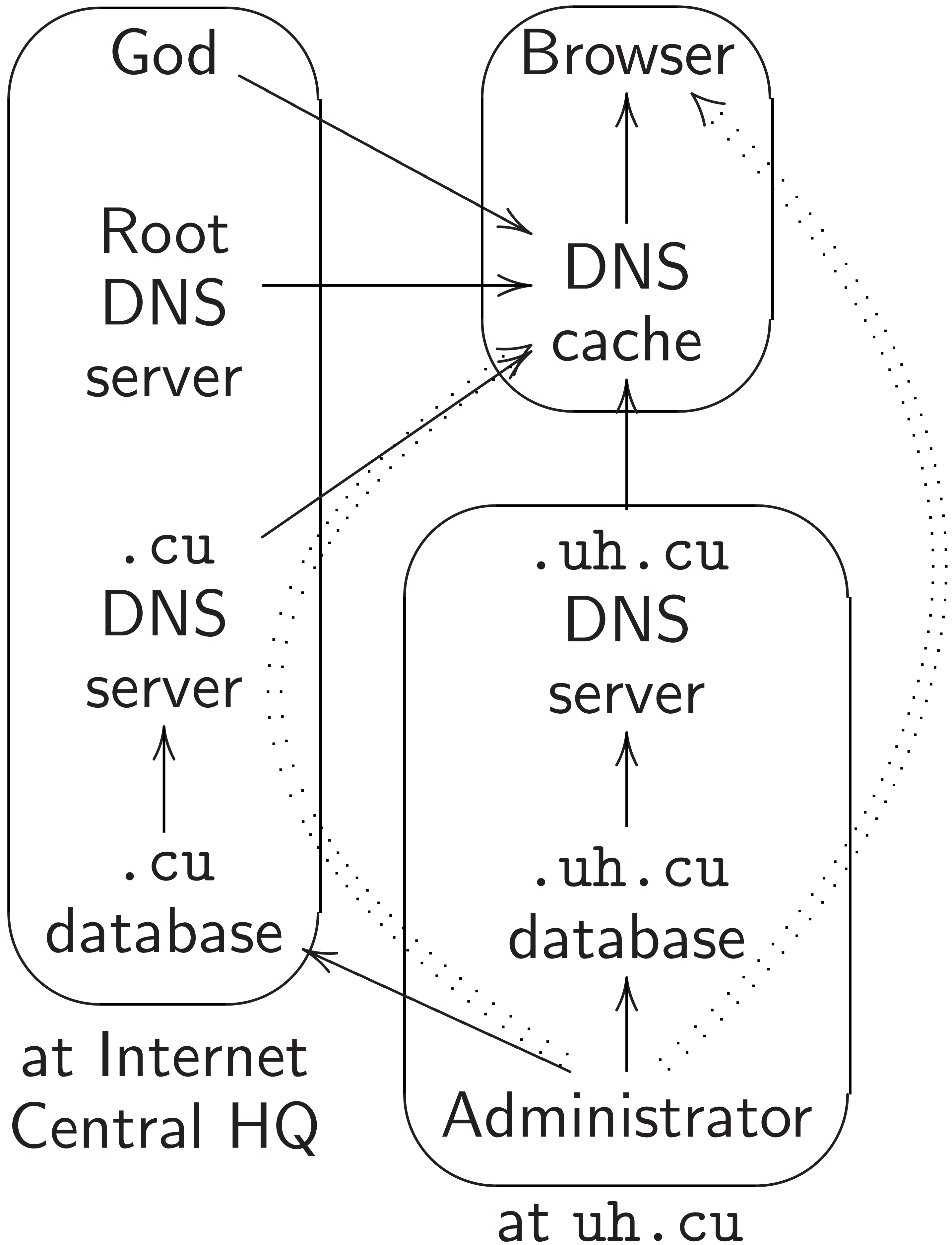

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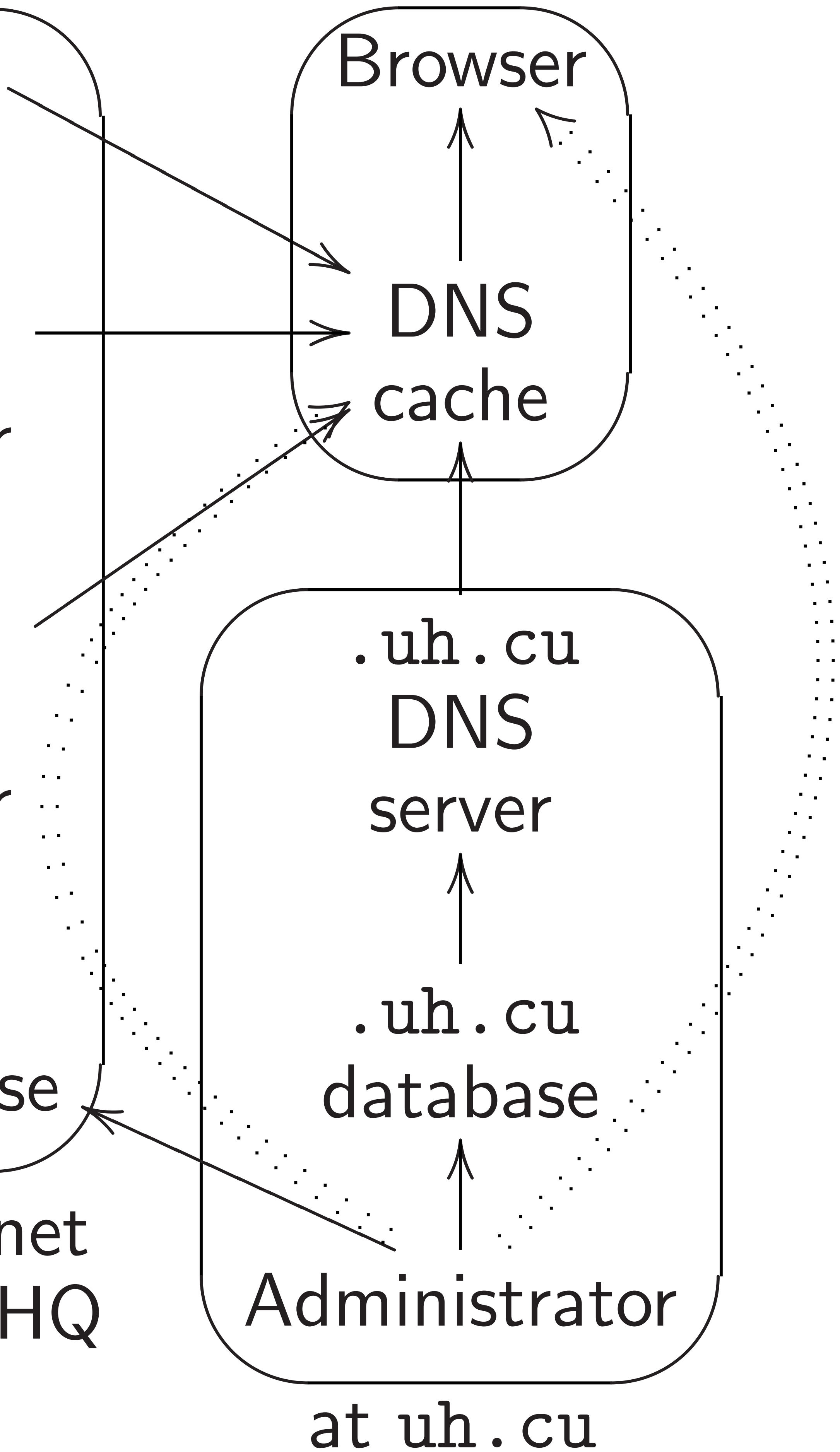

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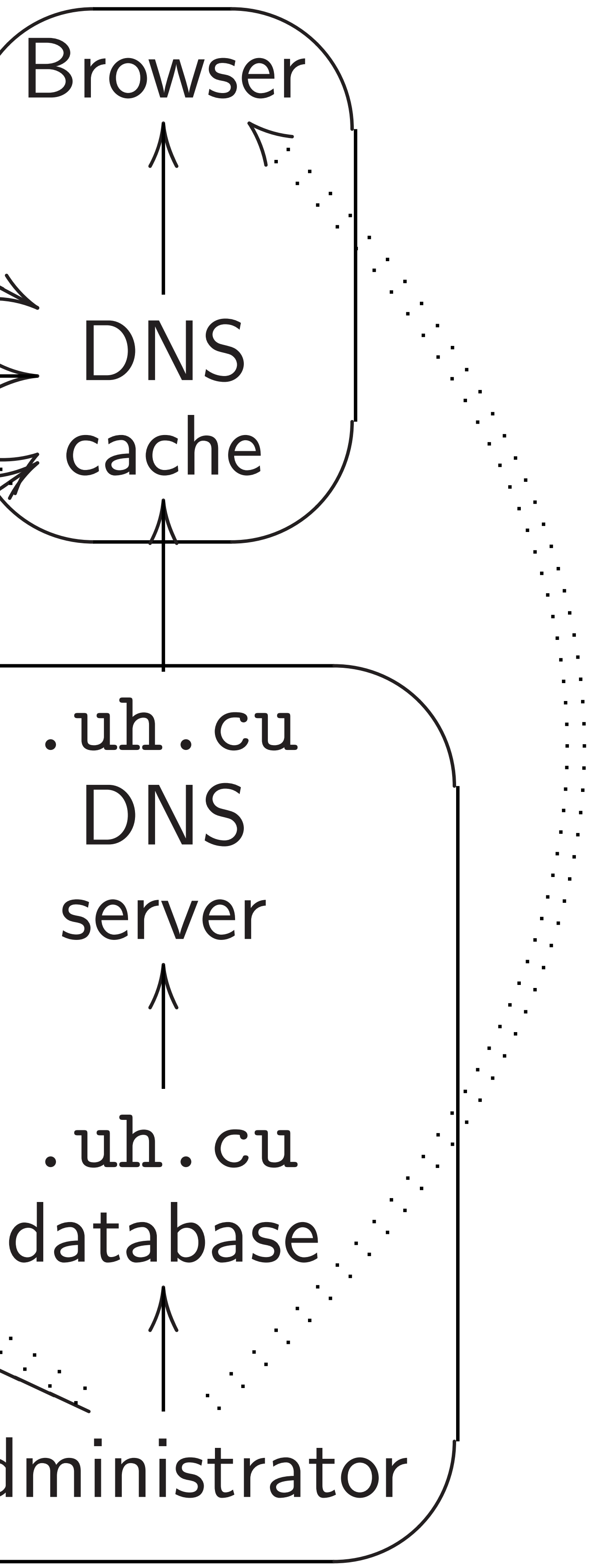

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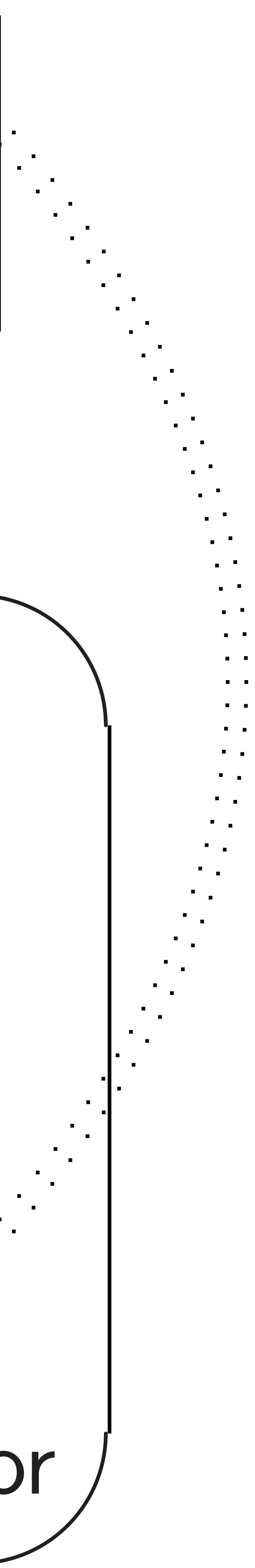

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Often they automatically adjust list of addresses in light of dead servers, client location, etc.

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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Deployed: DNSCrypt protects
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Work in progress: HTTPCurve
protects HTTP packets.

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Easy to implement
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PGP-signed web pages, ema

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e.g., is the user accessing
`firstaid.webmd.com` or
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