Network Attacks & Control

CS 161: Computer Security

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http://inst.eecs.berkeley.edu/~cs161/

March 16, 2017

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode
;; flags: qr rd ra; QU                                              IONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.                  IN      A

;; ANSWER SECTION:
eecs.mit.edu.           21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.         126738  IN      A       18.71.0.151
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

"**Answer**" tells us the IP address associated with `eecs.mit.edu` is `18.62.1.6` and we can *cache* the result for 21,600 seconds

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.                  IN      A

;; ANSWER SECTION:
eecs.mit.edu.           21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.
mit.edu.
mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.         126738  IN      A       18.71.0.151
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

In general, a single *Resource Record* (RR) like this includes, left-to-right, a DNS name, a *time-to-live*, a family (`IN` for our purposes - ignore), a type (`A` here, which stands for "Address"), and an associated value

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cm
;; Got answer:
;; ->>HEADER<<- opcode
;; flags: qr rd ra; QU                                           3

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.           21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.         126738  IN      A       18.71.0.151
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

"**Authority**" tells us the *name servers* responsible for the answer. Each RR gives the *hostname* of a different name server ("`NS`") for names in `mit.edu.` We should cache each record for 11,088 seconds.

If the "**Answer**" had been empty, then the resolver's next step would be to send the original query to one of these name servers.

dig eecs.mit.edu A

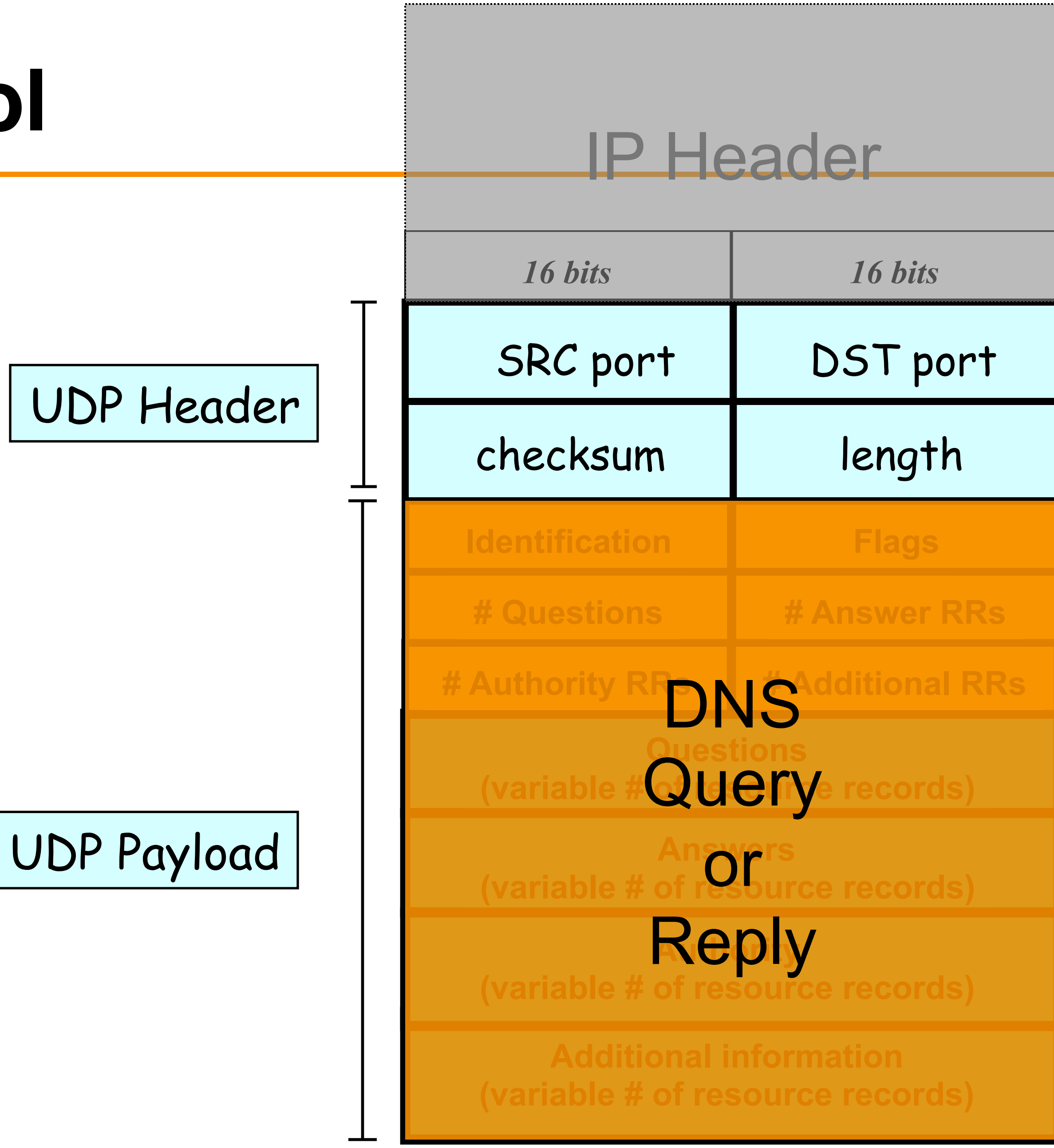
```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION
eecs.mit.edu.

;; AUTHORITY SECTION:
mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.         126738  IN      A       18.71.0.151
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

"**Additional**" provides extra information to save us from making separate lookups for it, or helps with bootstrapping.

Here, it tells us the IP addresses for the hostnames of the name servers. We add these to our cache.

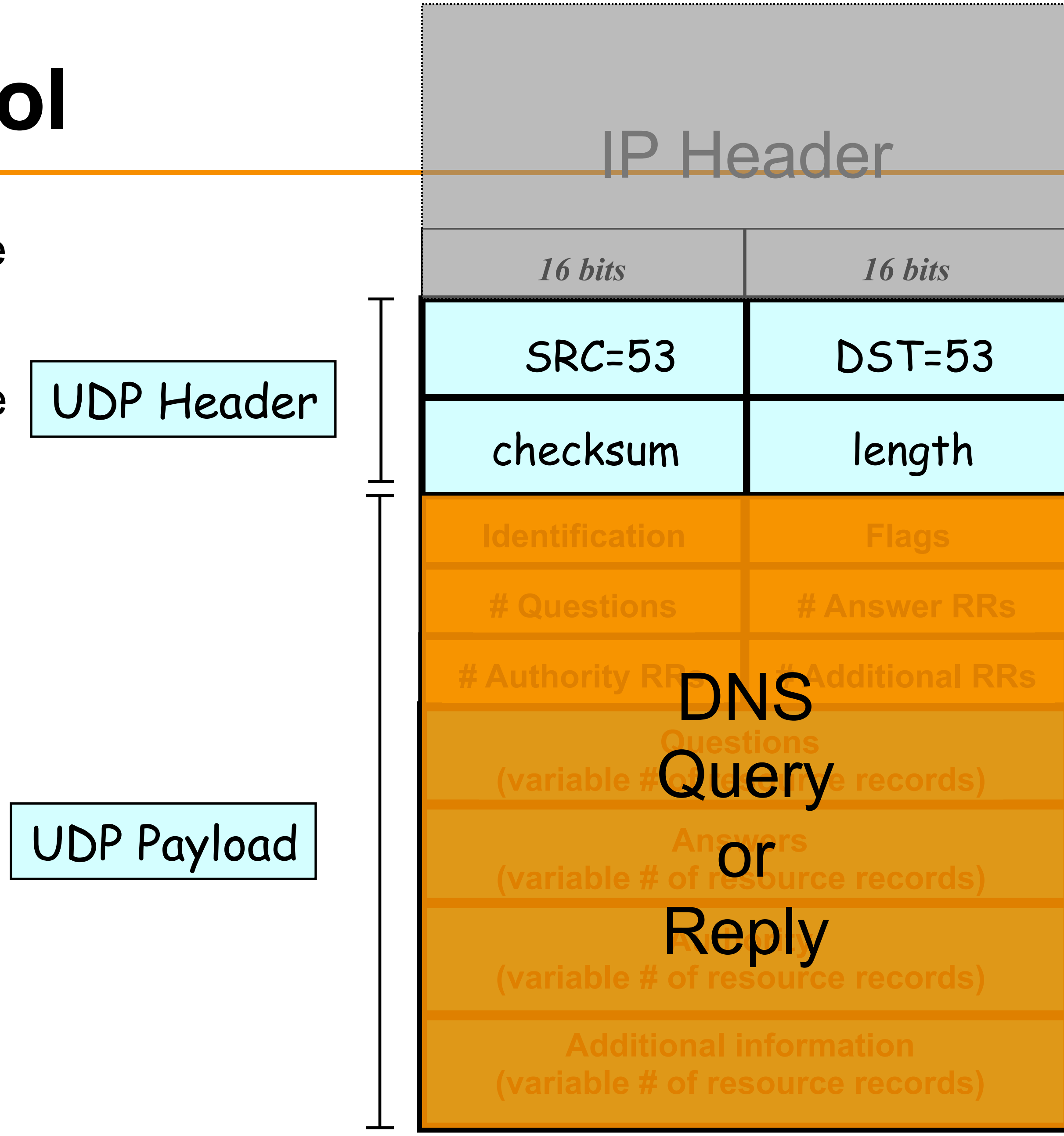
DNS Protocol

- Lightweight exchange of *query* and *reply* messages, both with same message format
- Primarily uses UDP for its transport protocol, which is what we'll assume
- Frequently, both clients and servers use port 53



DNS Protocol

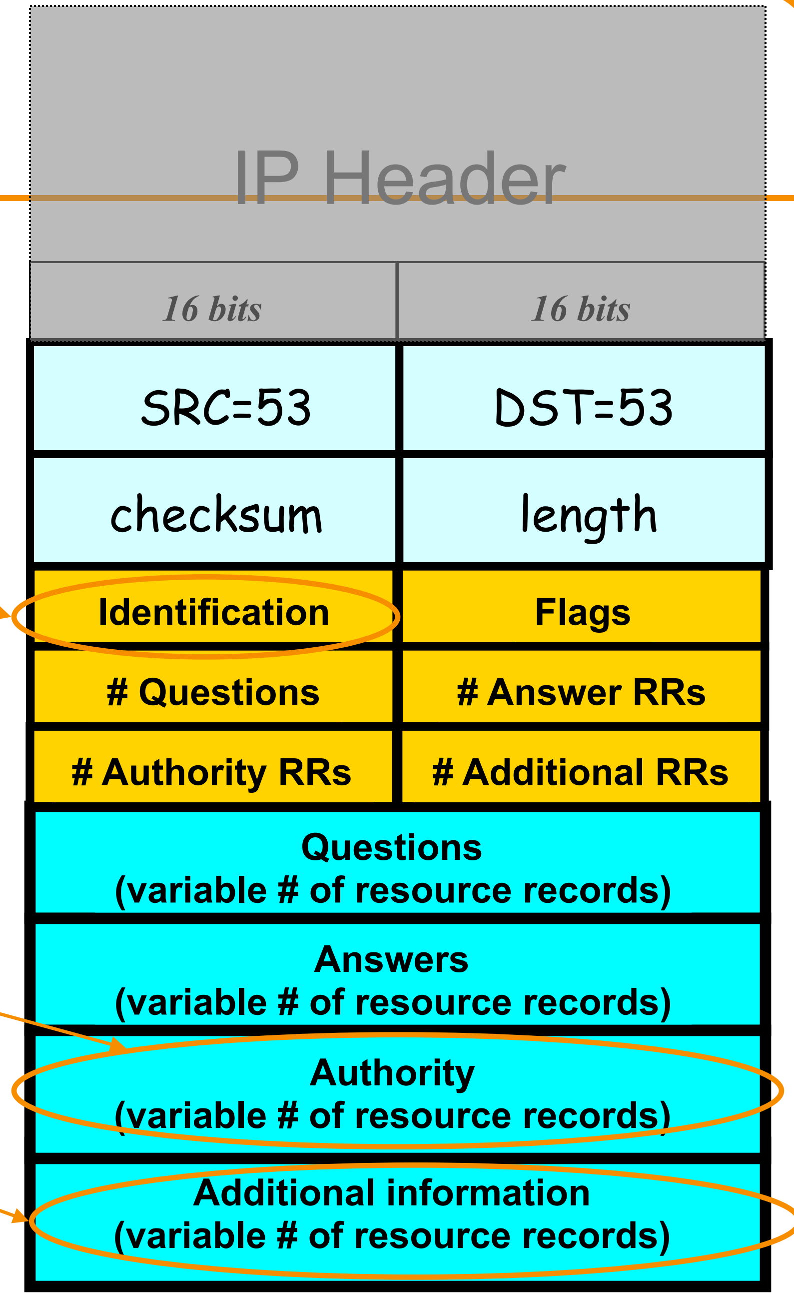
- Lightweight exchange of *query* and *reply* messages, both with same message format
- Primarily uses UDP for its transport protocol, which is what we'll assume
- Frequently, both clients and servers use port 53



DNS Protocol, con't

Message header:

- Identification: 16 bit # for query, reply to query uses same #
- Along with repeating the Question and providing Answer(s), replies can include "**Authority**" (name server responsible for answer) and "**Additional**" (info client is likely to look up soon anyway)
- Each *Resource Record* has a Time To Live (in seconds) for **caching** *(not shown)*



dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.            21[illegible]

;; AUTHORITY SECTION:
mit.edu.                 11088   IN      NS      BITSY.mit.edu.
mit.edu.                 11088   IN      NS      W20NS.mit.edu.
mit.edu.                 11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.          126738  IN      A       18.71.0.151
BITSY.mit.edu.           166408  IN      A       18.72.0.3
W20NS.mit.edu.           126738  IN      A       18.70.0.160
```

What if the `mit.edu` server is untrustworthy? Could its operator steal, say, all of our web surfing to Facebook?

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.          21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.               11088   IN      NS      BITSY.mit.edu.
mit.edu.               11088   IN      NS      W20NS.mit.edu.
mit.edu.               11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.        126738  IN      A       18.71.0.151
BITSY.mit.edu.         166408  IN      A       18.72.0.3
W20NS.mit.edu.         126738  IN      A       18.70.0.160
```

Let’s look at a flaw in the original DNS design (since fixed)

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.            21600    IN       A        18.62.1.6

;; AUTHORITY SECTION:
mit.edu.                 11088    IN       NS       BITSY.mit.edu.
mit.edu.                 11088    IN       NS       W20NS.mit.edu.
mit.edu.                 30       IN       NS       www.facebook.com.

;; ADDITIONAL SECTION:
www.facebook.com         30       IN       A        18.6.6.6
BITSY.mit.edu.           166408   IN       A        18.72.0.3
W20NS.mit.edu.           126738   IN       A        18.70.0.160
```

What could happen if the mit.edu server returns the following to us instead?

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.

;; AUTHORITY SECTION:
mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                30      IN      NS      www.facebook.com.

;; ADDITIONAL SECTION:
www.facebook.com        30      IN      A       18.6.6.6
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

We'd dutifully store in our cache a mapping of `www.facebook.com` to an IP address under MIT's control. (It could have been any IP address they wanted, not just one of theirs.)

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.

;; AUTHORITY SECTION:
mit.edu.                 11088   IN      NS      BITSY.mit.edu.
mit.edu.                 11088   IN      NS      W20NS.mit.edu.
mit.edu.                 30      IN      NS      www.facebook.com.

;; ADDITIONAL SECTION:
www.facebook.com         30      IN      A       18.6.6.6
BITSY.mit.edu.           166408  IN      A       18.72.0.3
W20NS.mit.edu.           126738  IN      A       18.70.0.160
```

In this case they chose to make the mapping *disappear* after 30 seconds. They could have made it persist for weeks, or disappear even quicker.

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.

;; AUTHORITY SECTION:
mit.edu.                 11088   IN      NS      BITSY.mit.edu.
mit.edu.                 11088   IN      NS      W20NS.mit.edu.
mit.edu.                 30      IN      NS      www.facebook.com.

;; ADDITIONAL SECTION:
www.facebook.com         30      IN      A       18.6.6.6
BITSY.mit.edu.           166408  IN      A       18.72.0.3
W20NS.mit.edu.           126738  IN      A       18.70.0.160
```

Next time one of our clients starts to connect to `www.facebook.com`, it will ask our resolver for the corresponding IP address. The resolver will find the answer in its cache and return **18.6.6.6** 😟

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.                  IN      A

;; ANSWER SECTION:
eecs.mit.edu.
```

How do we fix such ***cache poisoning***?

```
;; AUTHORITY SECTION:
mit.edu.                 11088   IN      NS      BITSY.mit.edu.
mit.edu.                 11088   IN      NS      W20NS.mit.edu.
mit.edu.                 30      IN      NS      www.facebook.com.

;; ADDITIONAL SECTION:
www.facebook.com         30      IN      A       18.6.6.6
BITSY.mit.edu.           166408  IN      A       18.72.0.3
W20NS.mit.edu.           126738  IN      A       18.70.0.160
```

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-AP
;; global options: +c
;; Got answer:
;; ->>HEADER<<- opcod
;; flags: qr rd ra; Q

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.            21600   IN     A      18.62.1.6

;; AUTHORITY SECTION:
mit.edu.                 11088   IN     NS     BITSY.mit.edu.
mit.edu.                 11088   IN     NS     W20NS.mit.edu.
mit.edu.                 30      IN     NS     www.facebook.com.

;; ADDITIONAL SECTION:
www.facebook.com         30      IN     A      18.6.6.6
BITSY.mit.edu.           166408  IN     A      18.72.0.3
W20NS.mit.edu.           126738  IN     A      18.70.0.160
```

Don’t accept **Additional** records unless they’re for the domain of the name server we queried

> E.g., contacting a name server for `mit.edu` ⇒ only accept additional records from `*.mit.edu`

No extra risk in accepting these since server could return them to us directly in an **Answer** anyway.

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-AP
;; global options: +c
;; Got answer:
;; ->>HEADER<<- opcod
;; flags: qr rd ra; Q

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.

;; AUTHORITY SECTION:
mit.edu.                11
mit.edu.                11
mit.edu.                30

;; ADDITIONAL SECTION:
www.facebook.com        30
BITSY.mit.edu.          16
W20NS.mit.edu.          12
```

Don’t accept **Additional** records unless they’re for the domain of the name server we queried

E.g., contacting a name server for `mit.edu` ⇒ only accept additional records from `*.mit.edu`

No extra risk in accepting these since server could return them to us directly in an **Answer** anyway.

This is called “bailiwick checking”.

bailiwick | ˈbāləˌwik |

noun

1 **(one's bailiwick)** one's sphere of operations or particular area of interest: *you never give the presentations—that's my bailiwick.*

The Many Moving Pieces In a DNS Lookup of `www.isc.org`

`? A www.isc.org`

.
Authority Server
(the "root")

`? A www.isc.org`
`Answers:`
`Authority:`
`org. NS a0.afilias-nst.info`
`Additional:`
`a0.afilias-nst.info A 199.19.56.1`

User's ISP's Recursive Resolver **`? A www.isc.org`**

Name	Type	Value	TTL
…	…	…	…

Resolver's cache

The Many Moving Pieces In a DNS Lookup of `www.isc.org`

User's ISP's
Recursive Resolver

```
? A www.isc.org
Answers:
Authority:
org. NS a0.afilias-nst.info
Additional:
a0.afilias-nst.info A 199.19.56.1
```

.
Authority Server
(the "root")

Name	Type	Value	TTL
org.	NS	a0.afilias-nst.info	172800
a0.afilias-nst.info.	A	199.19.56.1	172800
…	…	…	…

Resolver's cache

The Many Moving Pieces In a DNS Lookup of `www.isc.org`

User's ISP's Recursive Resolver

`? A www.isc.org`

Name	Type	Value	TTL
org.	NS	a0.afilias-nst.info	172800
a0.afilias-nst.info.	A	199.19.56.1	172800
…	…	…	…

Resolver's cache

org. Authority Server

```
? A www.isc.org
Answers:
Authority:
isc.org. NS sfba.sns-pb.isc.org.
isc.org. NS ns.isc.afilias-nst.info.
Additional:
sfba.sns-pb.isc.org.     A 199.6.1.30
ns.isc.afilias-nst.info. A 199.254.63.254
```

The Many Moving Pieces In a DNS Lookup of `www.isc.org`

User's ISP's Recursive Resolver

? A www.isc.org

Name	Type	Value	TTL
org.	NS	a0.afilias-nst.info	172800
a0.afilias-nst.info.	A	199.19.56.1	172800
isc.org.	NS	sfba.sns-pb.isc.org.	86400
isc.org.	NS	ns.isc.afilias-net.info.	86400
sfbay.sns-pb.isc.org.	A	199.6.1.30	86400
…	…	…	…

Resolver's cache

isc.org.
Authority Server

```
? A www.isc.org
Answers:
www.isc.org. A 149.20.64.42
Authority:
isc.org. NS sfba.sns-pb.isc.org.
isc.org. NS ns.isc.afilias-nst.info.
Additional:
sfba.sns-pb.isc.org.     A 199.6.1.30
ns.isc.afilias-nst.info. A 199.254.63.254
```

The Many Moving Pieces In a DNS Lookup of `www.isc.org`

User's ISP's Recursive Resolver

? A www.isc.org

Answers: www.isc.org A 149.20.64.42

Name	Type	Value	TTL
org.	NS	a0.afilias-nst.info	172800
a0.afilias-nst.info.	A	199.19.56.1	172800
isc.org.	NS	sfba.sns-pb.isc.org.	86400
isc.org.	NS	ns.isc.afilias-net.info.	86400
sfbay.sns-pb.isc.org.	A	199.6.1.30	86400
www.isc.org	A	149.20.64.42	600
…	…	…	…

Resolver's cache

DNS Threats, con't

What about *blind spoofing*?

- Say we look up `mail.google.com`; how can an **off-path** attacker feed us a bogus A answer before the legitimate server replies?

- How can such a **remote** attacker even know we are looking up `mail.google.com`?

Suppose, e.g., we visit a web page under their control:

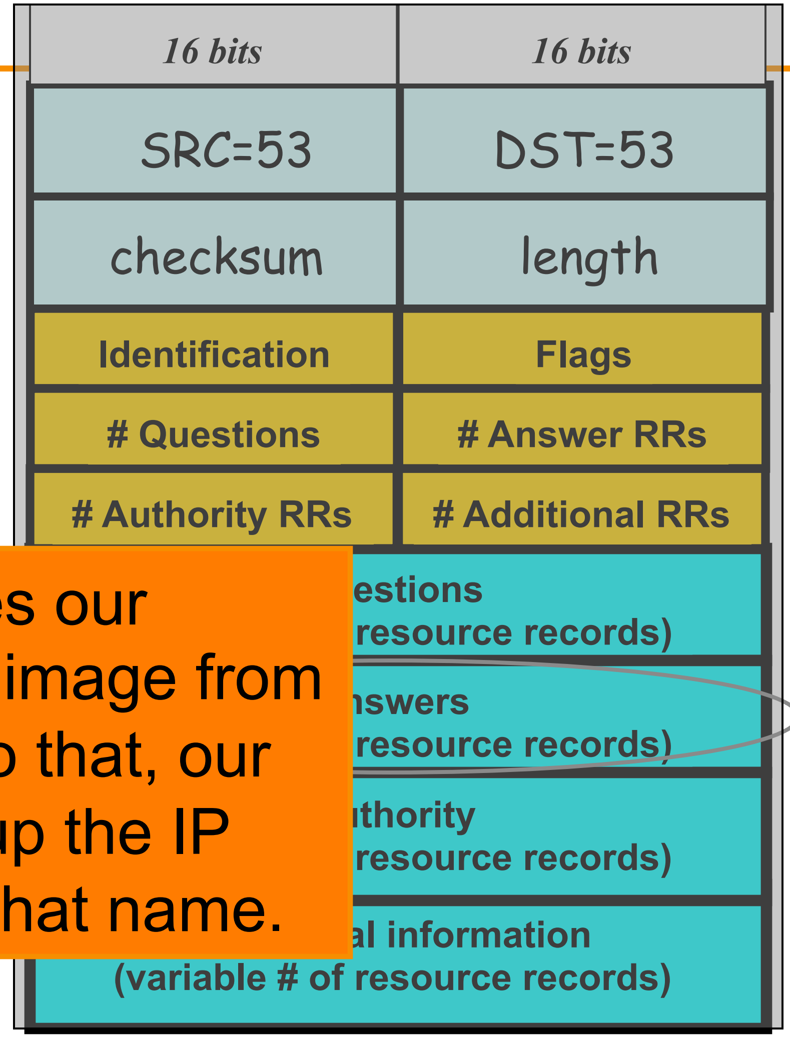
```
...<img src="http://mail.google.com" …> ...
```

16 bits	*16 bits*
SRC=53	DST=53
checksum	length
Identification	**Flags**
# Questions	**# Answer RRs**
# Authority RRs	**# Additional RRs**
Questions (variable # of resource records)	
Answers (variable # of resource records)	
Authority (variable # of resource records)	
Additional information (variable # of resource records)	

DNS Threats, con't

What about *blind spoofing*?

- Say we look up `mail.google.com`; how can an **off-path** attacker feed us a bogus A answer before the legitin
- How c even mail. Suppose, e.g., we visit a web page under their control:



This HTML snippet causes our browser to try to fetch an image from `mail.google.com`. To do that, our browser first has to look up the IP address associated with that name.

```
...<img src="http://mail.google.com" …> ...
```

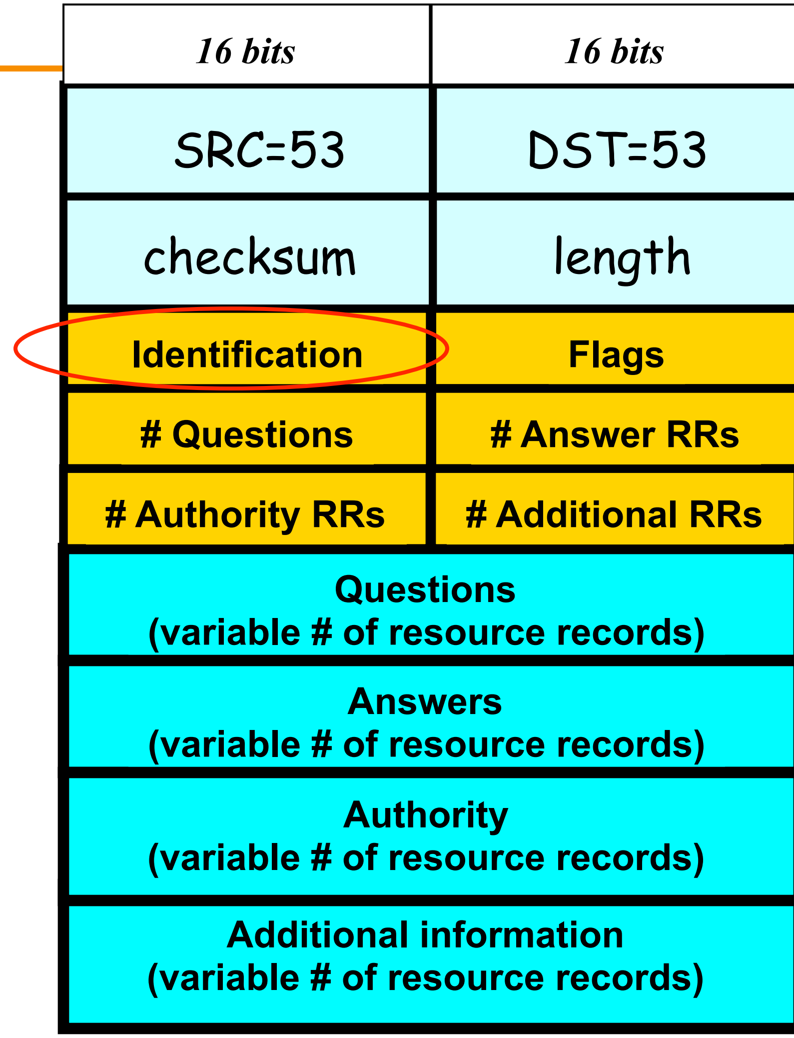
DNS Blind Spoofing, con’t

Fix?

Once they know we’re looking it up, they just have to guess the Identification field, and reply before legit server.

How hard is that?

Originally, identification field incremented by 1 for each request. How does attacker guess it?



<img src="http://badguy.com" …> ← They observe ID k here
<img src="http://mail.google.com" …> ← So this will be k+1

DNS Blind Spoofing, con't

Once we randomize the Identification, attacker has a 1/65536 chance of guessing it correctly.
Are we pretty much safe?

Attacker can send *lots* of replies, not just one …

However: once a reply from legit server arrives (with correct Identification), it's **cached** and no more opportunity to poison it. Victim is innoculated!

16 bits	*16 bits*
SRC=53	DST=53
checksum	length
Identification	**Flags**
# Questions	**# Answer RRs**
# Authority RRs	**# Additional RRs**
Questions (variable # of resource records)	
Answers (variable # of resource records)	
Authority (variable # of resource records)	
Additional information (variable # of resource records)	

Unless attacker can send 1000s of replies before legit arrives, we're likely safe - phew! ?

DNS Blind Spoofing (Kaminsky 2008)

- Two key ideas:
  - Spoof uses **Additional** field (rather than **Answer**)
  - Attacker can get around caching of legit replies by generating a series of *different* name lookups:

```
<img src="http://random1.google.com" …>
<img src="http://random2.google.com" …>
<img src="http://random3.google.com" …>
                    . . .
<img src="http://randomN.google.com" …>
```

Kaminsky Blind Spoofing, con't

For each lookup of *randomk*.google.com, attacker **spoofs** a bunch of records like this, each with a different Identifier

```
;; QUESTION SECTION:
;randomk.google.com.            IN      A

;; ANSWER SECTION:
randomk.google.com      21600   IN      A       doesn't matter

;; AUTHORITY SECTION:
google.com.             11088   IN      NS      mail.google.com

;; ADDITIONAL SECTION:
mail.google.com         126738  IN      A       6.6.6.6
```

Once they win the race, not only have they poisoned `mail.google.com` …

Kaminsky Blind Spoofing, con't

For each lookup of *randomk*.google.com, attacker **spoofs** a bunch of records like this, each with a different Identifier

```
;; QUESTION SECTION:
;randomk.google.com.            IN      A

;; ANSWER SECTION:
randomk.google.com      21600   IN      A       doesn't matter

;; AUTHORITY SECTION:
google.com.             11088   IN      NS      mail.google.com

;; ADDITIONAL SECTION:
mail.google.com         126738  IN      A       6.6.6.6
```

Once they win the race, not only have they poisoned mail.google.com … but also the cached NS record for google.com's name server - so any **future** *X*.google.com lookups *go through the attacker's machine*

Defending Against Blind Spoofing

Central problem: all that tells a client they should accept a response is that it matches the Identification field.

With only 16 bits, it lacks sufficient entropy: even if truly random, the *search space* an attacker must *brute force* is too small.

Where can we get more entropy?

16 bits	*16 bits*
SRC=53	DST=53
checksum	length
Identification	**Flags**
# Questions	**# Answer RRs**
# Authority RRs	**# Additional RRs**
Questions (variable # of resource records)	
Answers (variable # of resource records)	
Authority (variable # of resource records)	
Additional information (variable # of resource records)	

Defending Against Blind Spoofing

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With only 16 bits, it lacks sufficient entropy: even if truly random, the *search space* an attacker must *brute force* is too small.

Where can we get more entropy? (*Without* requiring a protocol change.)

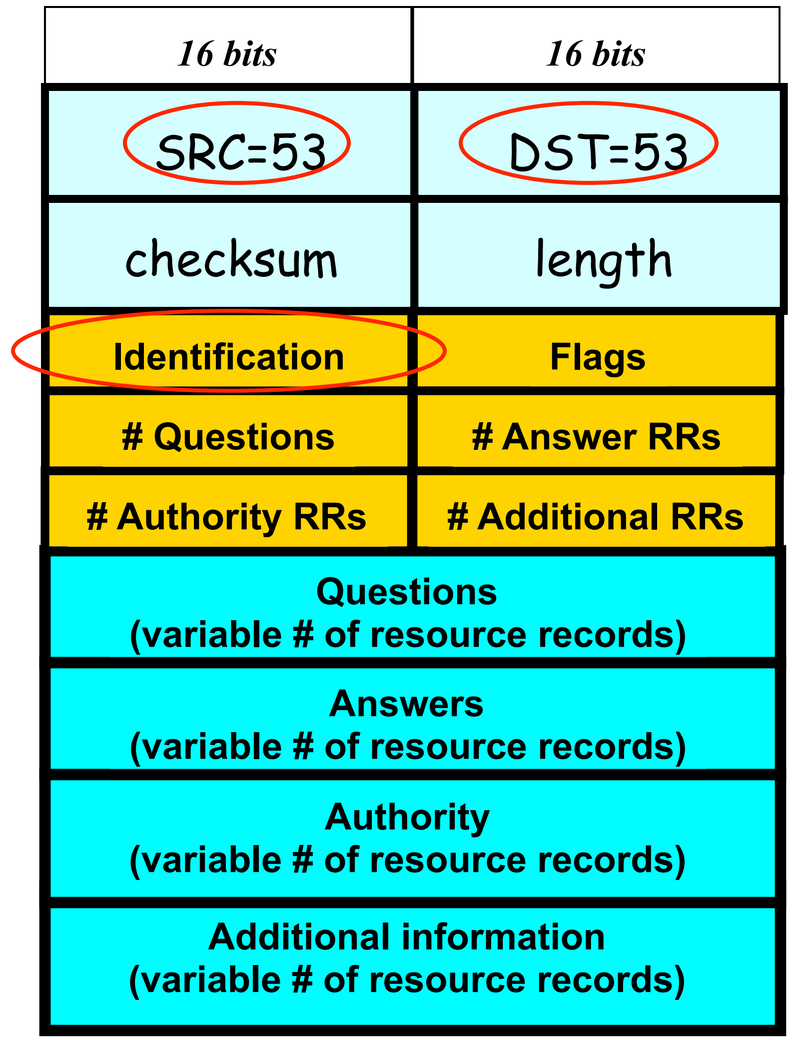
16 bits	*16 bits*
SRC=53	DST=53
checksum	length
Identification	**Flags**
# Questions	**# Answer RRs**
# Authority RRs	**# Additional RRs**
Questions (variable # of resource records)	
Answers (variable # of resource records)	
Authority (variable # of resource records)	
Additional information (variable # of resource records)	

Defending Against Blind Spoofing

Total *entropy*: 16 bits

For requestor to receive DNS reply, needs both correct Identification and correct ports.

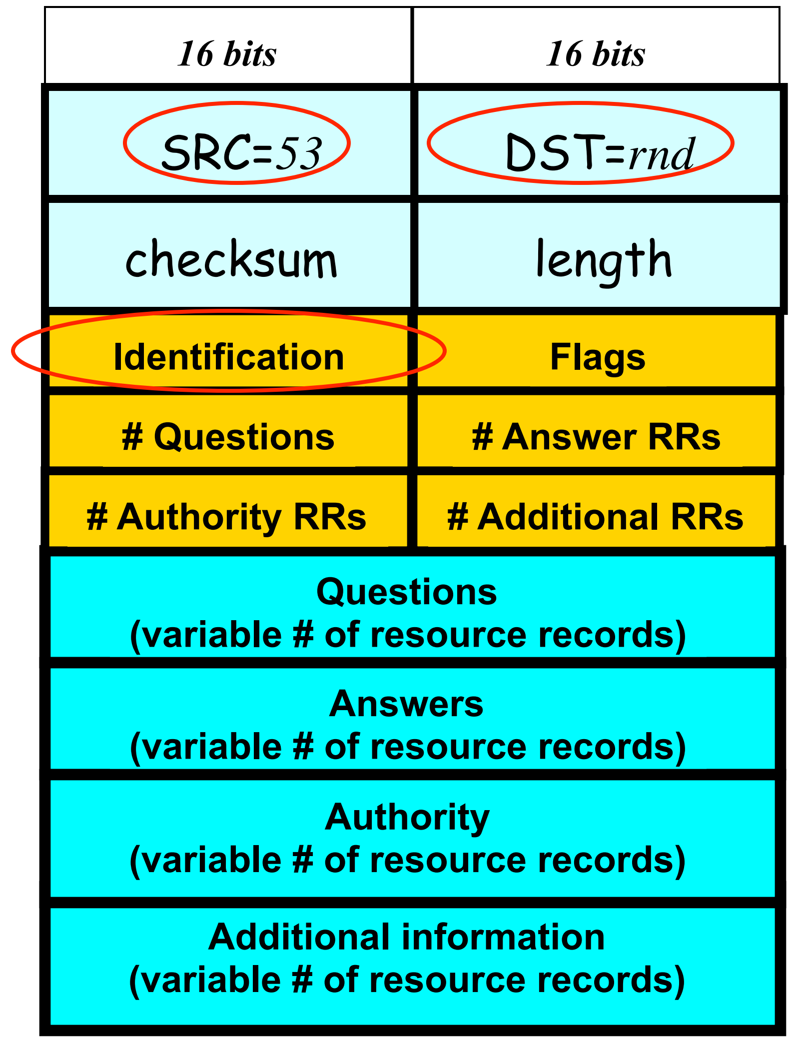
On a request, DST port = 53. SRC port usually also 53 - but not fundamental, just convenient.



Defending Against Blind Spoofing

Total *entropy*: ? bits

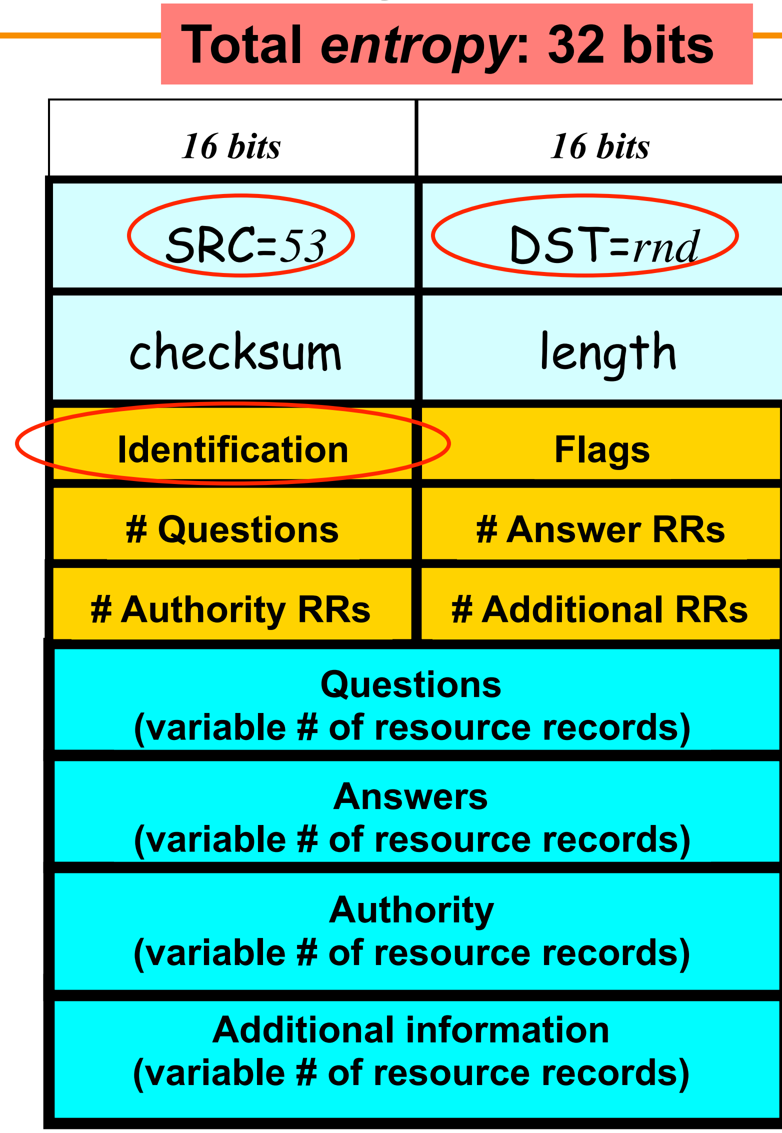
"Fix": client uses random source port ⇒ attacker doesn't know correct dest. port to use in reply



Defending Against Blind Spoofing

"Fix": client uses random source port ⇒ attacker doesn't know correct dest. port to use in reply

32 bits of entropy makes it orders of magnitude harder for attacker to guess all the necessary fields and dupe victim into accepting spoof response.

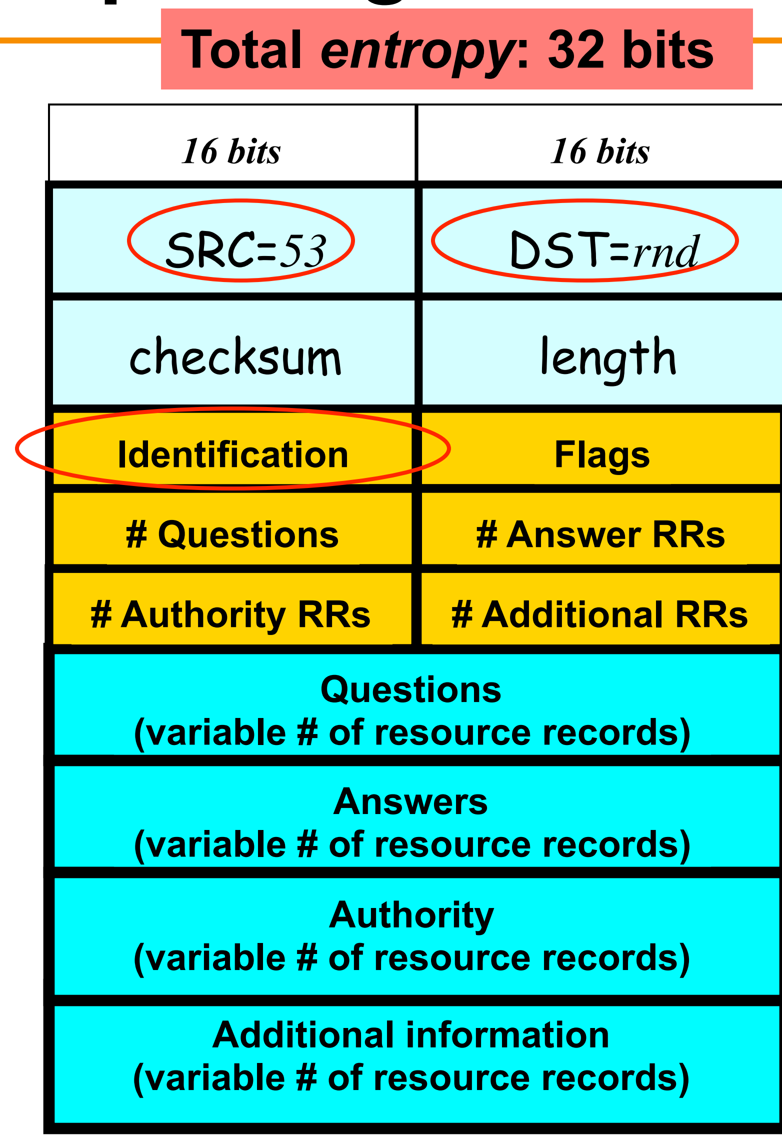


Defending Against Blind Spoofing

“Fix”: client uses random source port ⇒ attacker doesn’t know correct dest. port to use in reply

32 bits of entropy makes it orders of magnitude harder for attacker to guess all the necessary fields and dupe victim into accepting spoof response.

This is what primarily “secures” DNS against blind spoofing today. (Note: not all resolvers have implemented random source ports!)



Summary of DNS Security Issues

- DNS threats highlight:
  - Attackers can attack opportunistically rather than eavesdropping
    - Cache poisoning only required victim to look up some name under attacker's control (*has been* ***fixed***)
  - Attackers can often manipulate victims into vulnerable activity
    - E.g., `IMG SRC` in web page to force DNS lookups
  - Crucial for identifiers associated with communication to have sufficient entropy (= a lot of bits of unpredictability)
  - "**Attacks only get better**": threats that appears technically remote can become practical due to unforeseen cleverness