dnssoftver: a tool to fingerprint DNS resolver software versions

Yevheniya Nosyk, Jan Bayer, Andrzej Duda, Maciej Korczyński

yevheniya.nosyk@univ-grenoble-alpes.fr
Université Grenoble Alpes (France)

OARC 42 (Charlotte, USA)
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version.bind

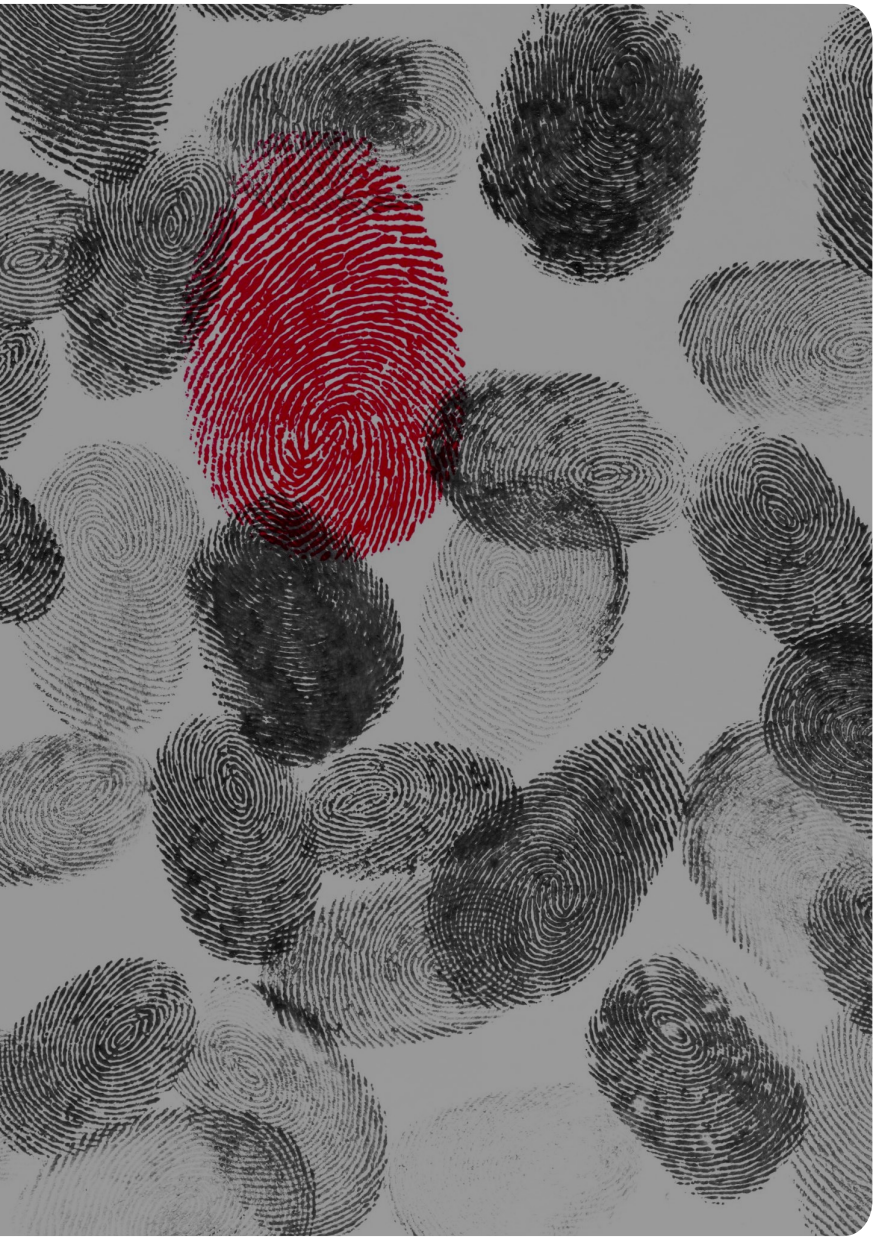
```
$ dig @1.2.3.4 CH TXT version.bind +short
unbound 1.16.2

$ dig @5.6.7.8 CH TXT version.bind +short
9.19.13

$ dig @9.10.11.12 CH TXT version.bind +short
PowerDNS Recursor 4.5.0-beta2 (built Dec 30 2023 11:22:09 by root@c828502c66b1)
```

version.bind in the wild

```
$ dig @1.2.3.4 CH TXT version.bind +short
…
My named is Bind, James BIND
…
None of your business
…
go to sleep
…
Its Secret, Don't try to fetch it
…
Hmmm... neh.
```

We need a tool that …

1. Covers various resolver software
2. Does not rely on specific configurations
3. Scales to support future software releases



Presenting today – dnssoftver

https://github.com/yevheniya-nosyk/dnssoftver

Overview

1. Choose and set up software
2. Design and run test cases
3. Generate the decision tree
4. Implement the scanner

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Vendors and versions: 674 in total

Vendor	Versions	Since	Count
BIND9	9.10.0 - 9.19.9	2014	293
Unbound	1.5.0 - 1.17.1rc2	2014	107
Knot Resolver	2.0.0 - 5.7.0	2018	35
PowerDNS Recursor	4.0.0 - 4.9.1	2015	122
Technitium DNS Server	1.0 - 11.4.1	2017	68
MaraDNS	2.0.11 - 3.5.0036	2015	46
Windows Server	2016 - 2022	2016	3

Vendors and versions: setup

641 custom Dockerfiles

30 Knot Resolver images pulled from cznic/knot-resolver

3 virtual private servers with Windows Server

Sources: https://www.docker.com/company/newsroom/media-resources/, https://nitin27may.medium.com/pushing-custom-docker-image-to-docker-hub-631dce3492f5, https://corporate.ovhcloud.com/en/newsroom/assets/

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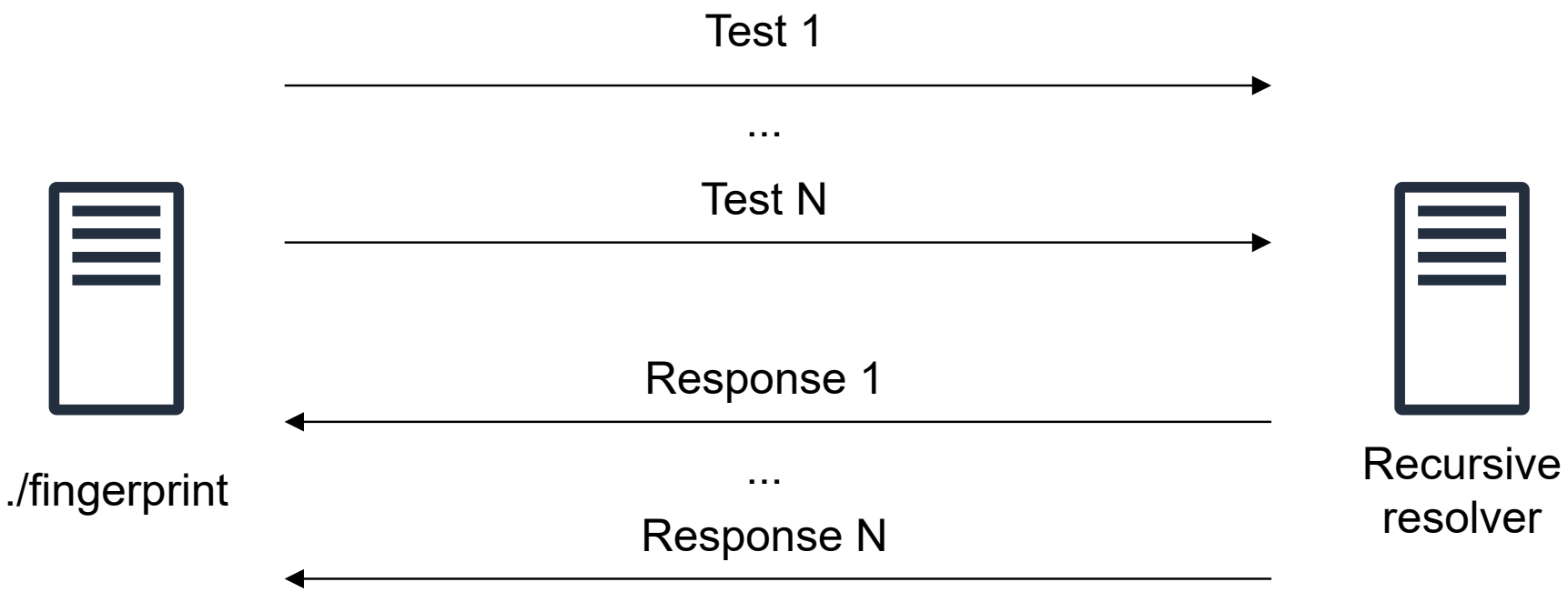
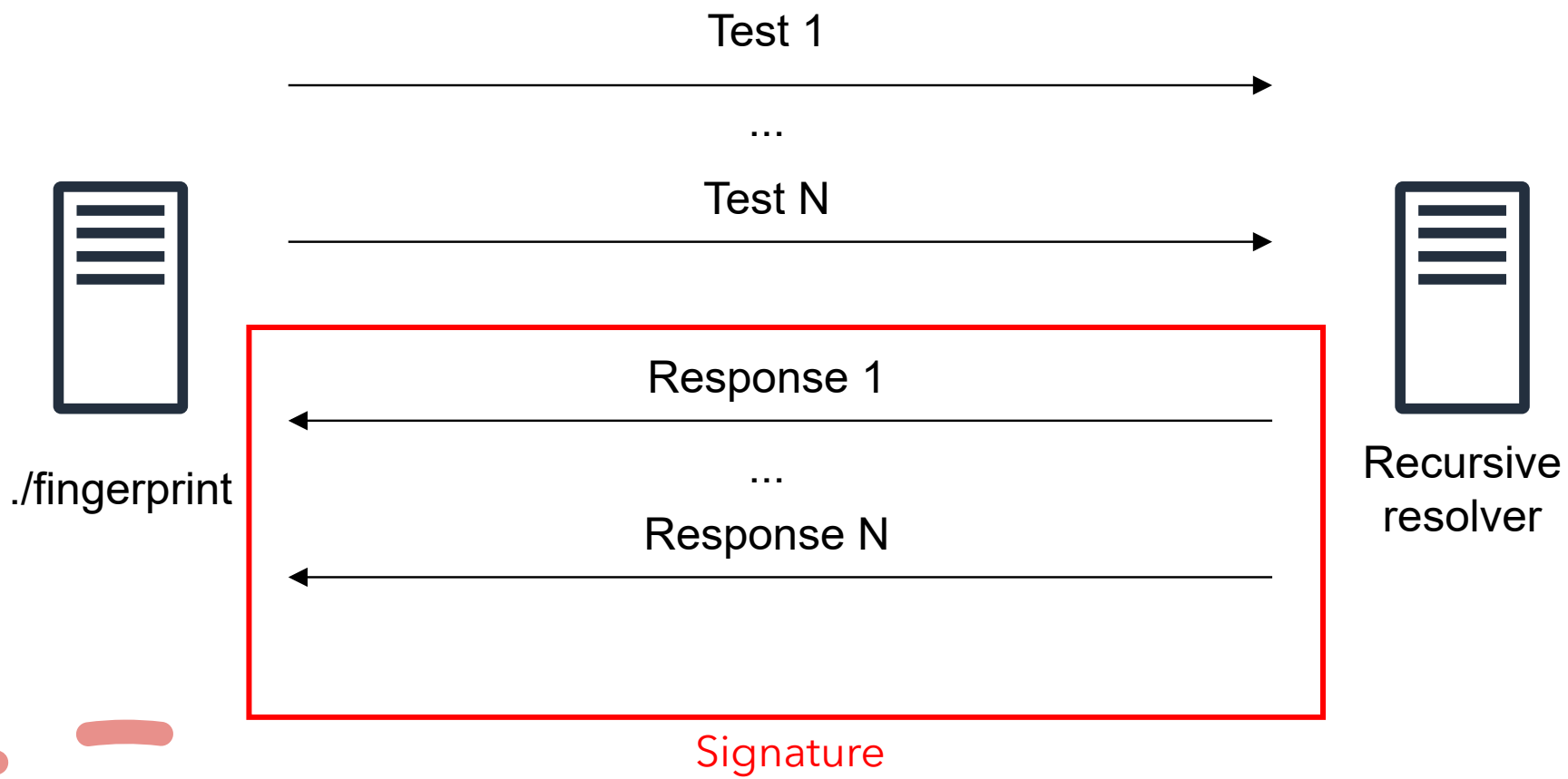
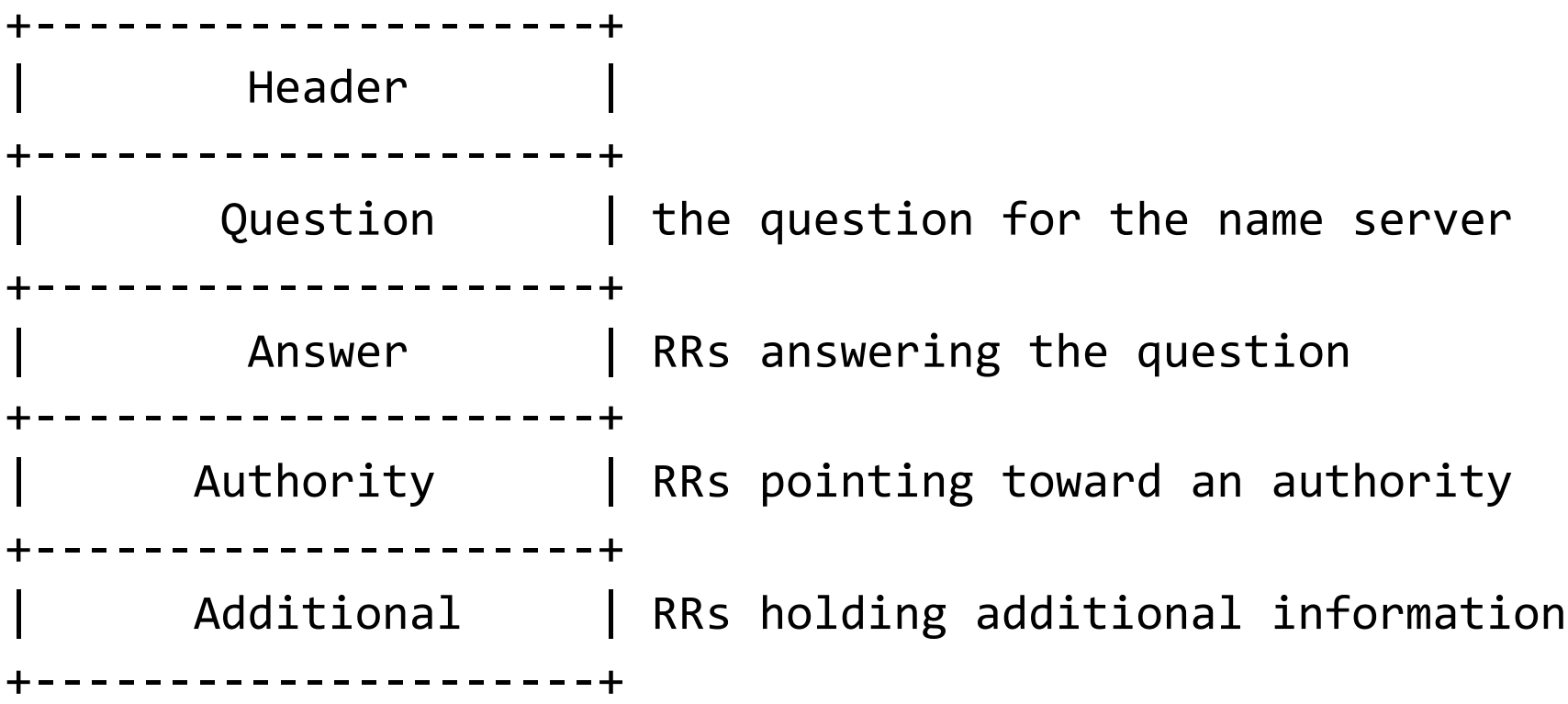
Test case == DNS request



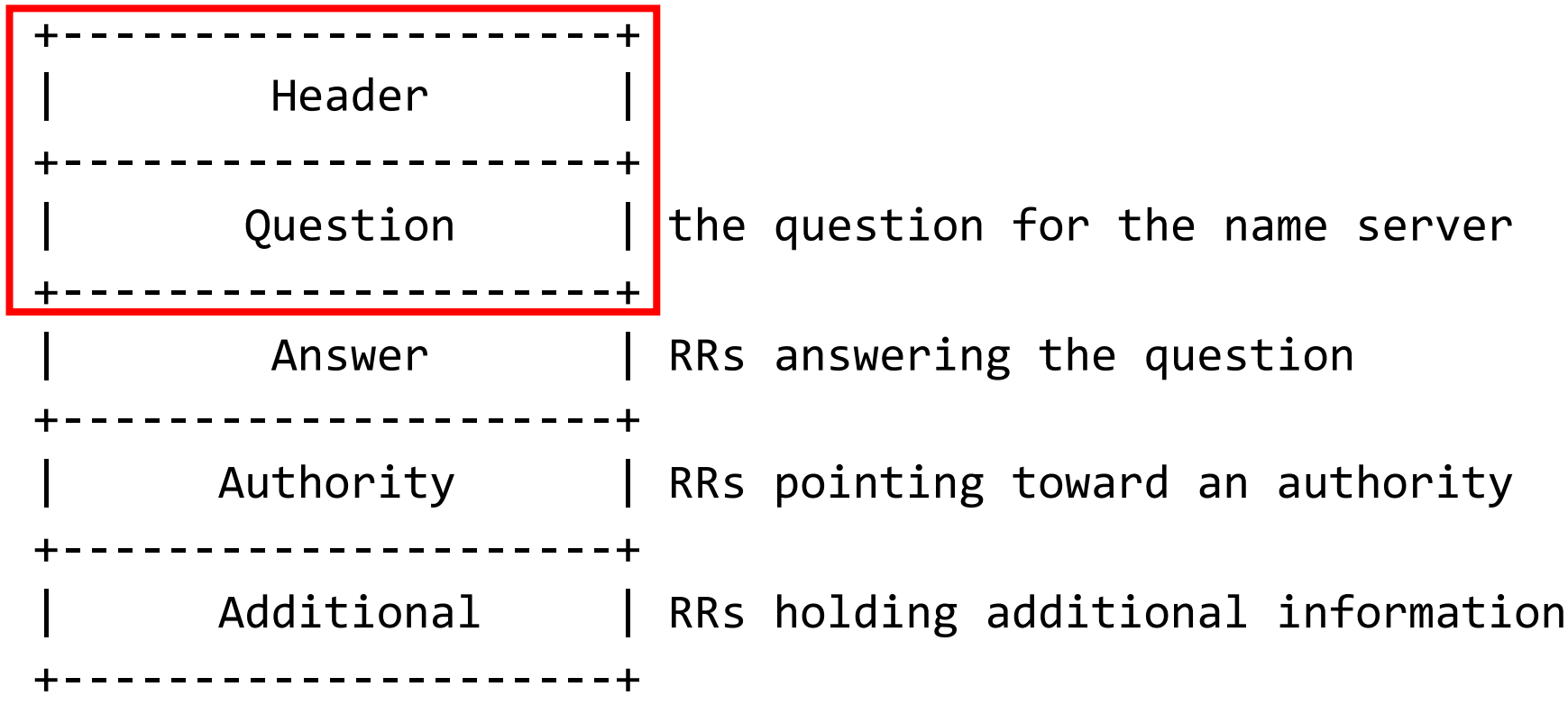
Signature == DNS responses



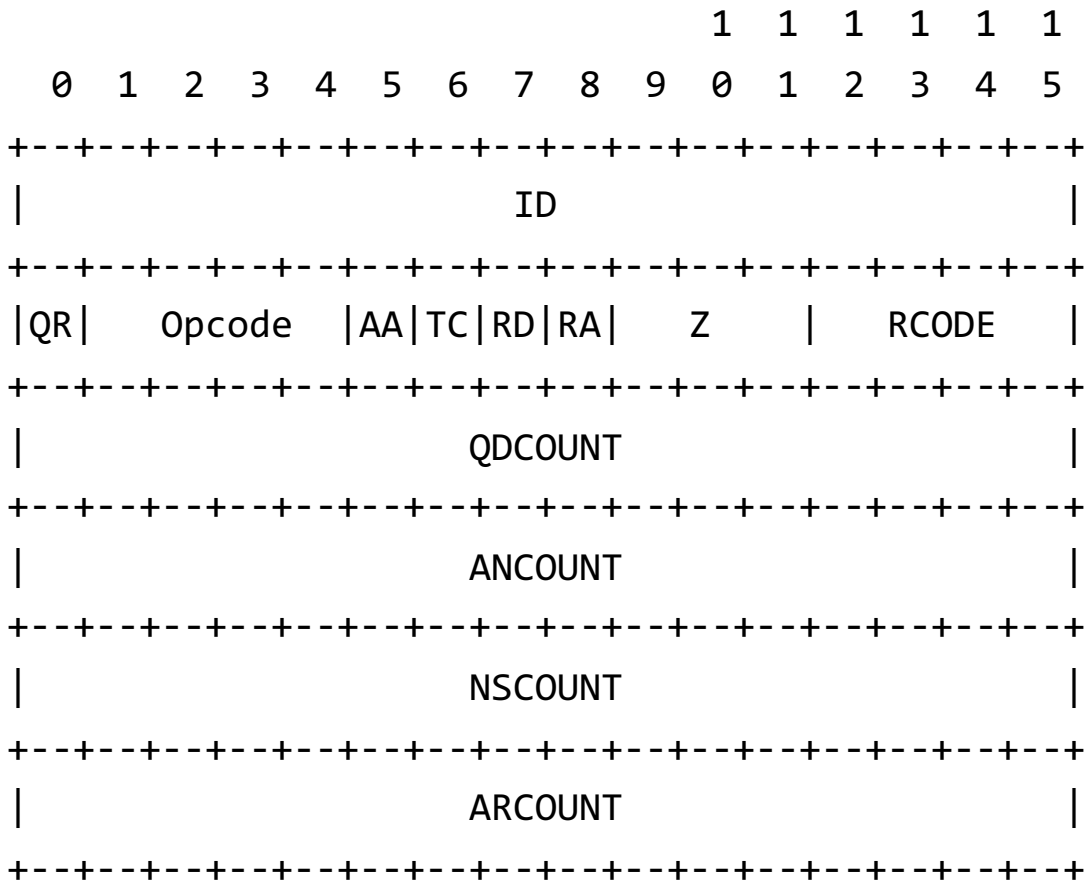
RFC-1035: DNS message



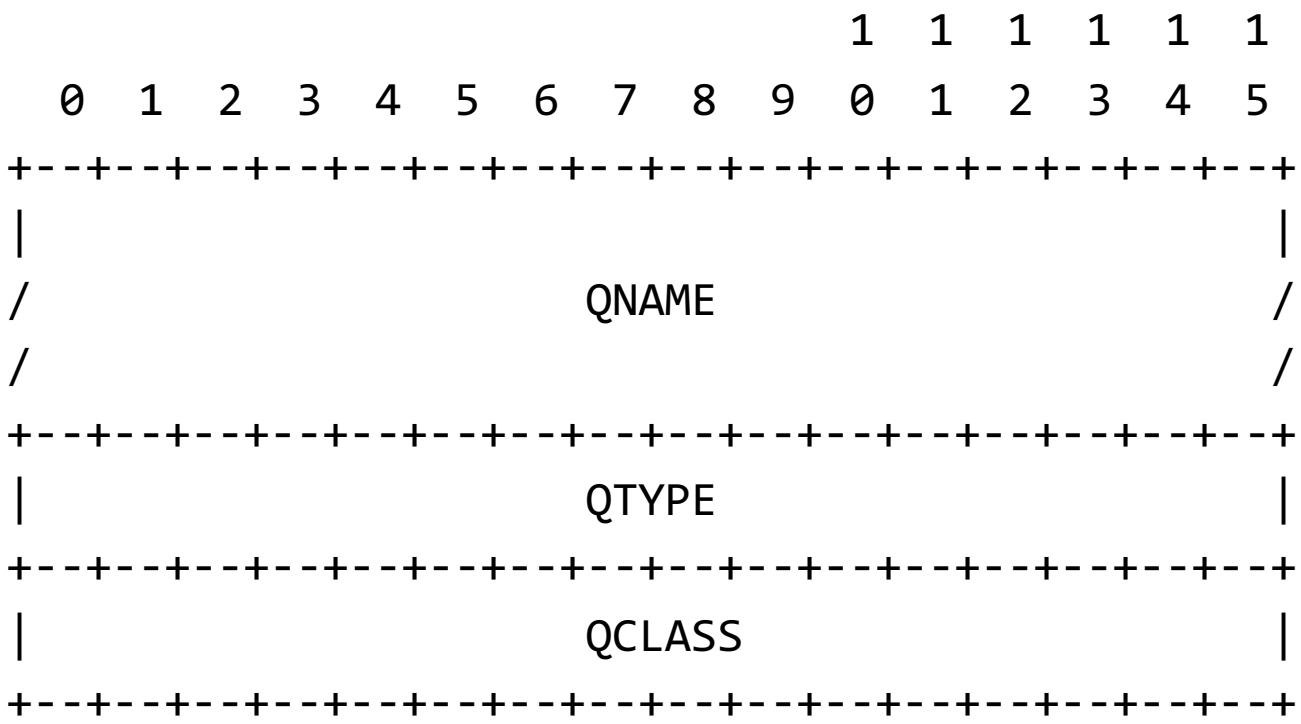
RFC-1035: DNS message



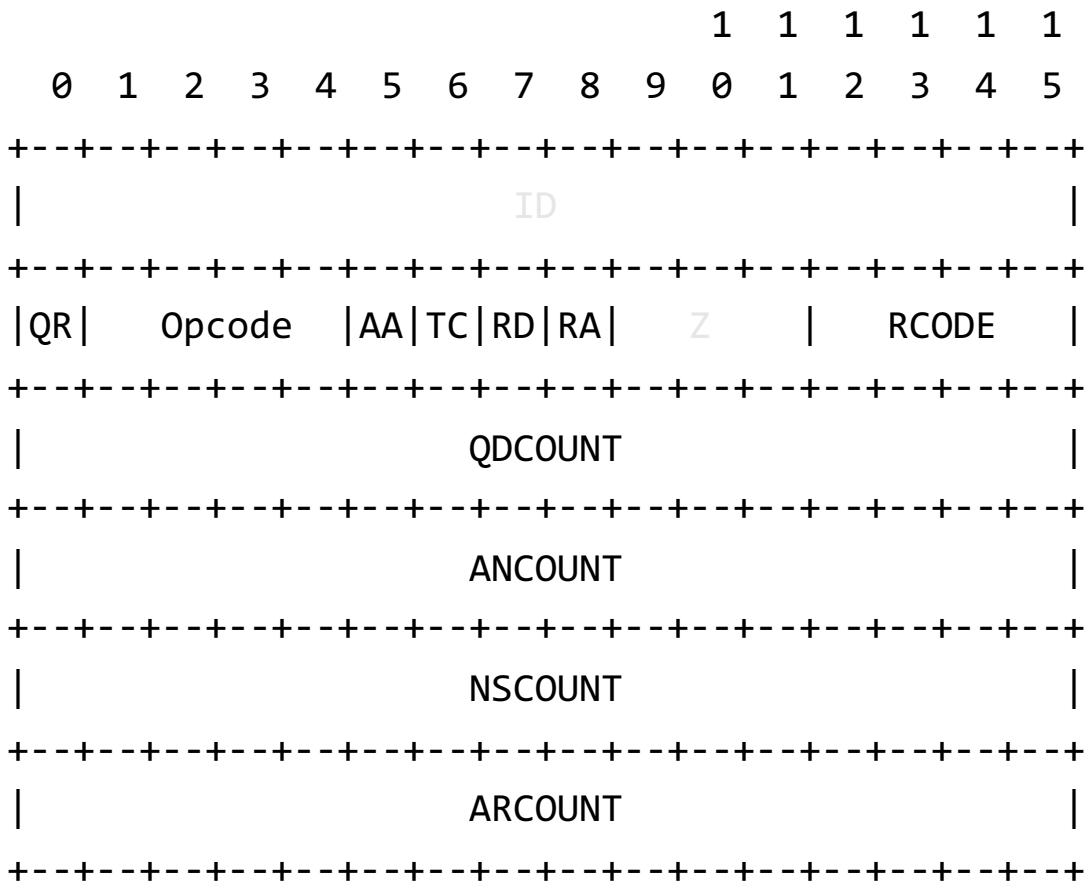
RFC-1035: DNS header



RFC-1035: DNS question

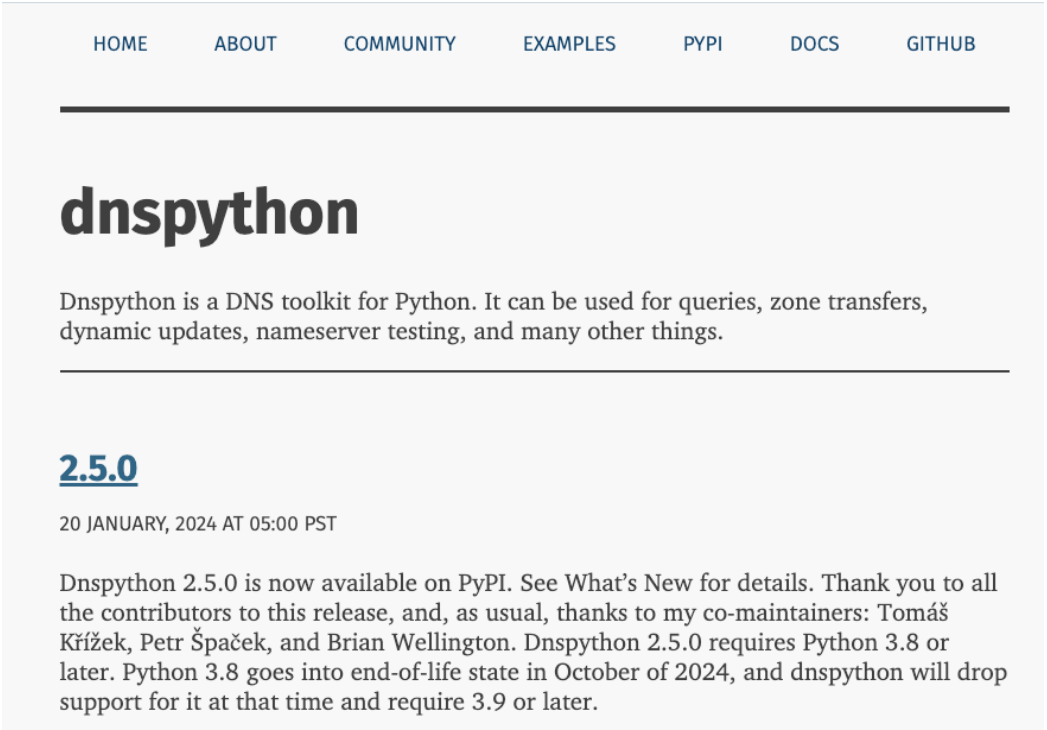


Testcase response



768 test cases

```
QR: [0,1]
AA: [0,1]
TC: [0,1]
RD: [0,1]
RA: [0,1]
Opcode: [QUERY, IQUERY, STATUS, NOTIFY]
Class: [RESERVED0, IN, CH, HS, NONE, ANY]
Resource record: [A]
Domain name: [baseline.dnssoftver.com]
```



Source: https://www.dnspython.org

Domain name configuration

```
;NS records
@               IN      NS      ns1
ns1             IN      A       65.21.51.117
ns1             IN      AAAA    2a01:4f9:c012:7407::1
@               IN      NS      ns2
ns2             IN      A       65.21.51.117
ns2             IN      AAAA    2a01:4f9:c012:7407::1

;Baseline test domain
@                IN      A       129.88.46.51
@                IN      A       129.88.68.231
@                IN      A       129.88.68.222
@                IN      AAAA    2001:660:5301:46::46:51
*                IN      A       129.88.46.51
*                IN      A       129.88.68.231
*                IN      A       129.88.68.222
*                IN      AAAA    2001:660:5301:46::46:51
```

Workflow

```
for _ in range(30):
        for software in software_all:
                start_docker_container()
                issue_768_test_cases()
                kill_docker_container()
                write_intermediary_result()
```

Multiple rounds

1. For the training data
2. For inconsistencies:
    - Network failures (Timeouts)
    - Different responses (NOERROR vs. SERVFAIL, etc.)

Overview

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Input: 15 million DNS requests/responses


```
"Opcode": "QUERY", "AA": 0, "TC": 0, "RD": 1, "RA": 0, "RCODE": "REFUSED", "QDCOUNT": 1, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0},
"baseline_A_NONE_IQUERY_AA_RD": {"QR": 1, "Opcode": "IQUERY", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0, "NSCOUNT": 0,
"ARCOUNT": 0}, "baseline_A_NONE_IQUERY_RD": {"QR": 1, "Opcode": "IQUERY", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0,
"NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_ANY_QUERY_AA_RD_RA": {"QR": 1, "Opcode": "QUERY", "AA": 0, "TC": 0, "RD": 1, "RA": 1, "RCODE": "NOERROR", "QDCOUNT": 1,
"ANCOUNT": 3, "NSCOUNT": 2, "ARCOUNT": 0}, "baseline_A_NONE_NOTIFY_QR_AA_TC_RD": {"error": "Timeout after 5 seconds"}, "baseline_A_HS_QUERY_AA_TC_RD_RA": {"QR":
1, "Opcode": "QUERY", "AA": 0, "TC": 0, "RD": 1, "RA": 0, "RCODE": "REFUSED", "QDCOUNT": 1, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0},
"baseline_A_NONE_STATUS_QR_RD_RA": {"error": "Timeout after 5 seconds"}, "baseline_A_CH_IQUERY_AA_RA": {"QR": 1, "Opcode": "IQUERY", "AA": 0, "TC": 0, "RD": 0,
"RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_NONE_QUERY_AA_RA": {"QR": 1, "Opcode": "QUERY", "AA": 0, "TC":
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"AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_CH_NOTIFY_QR_TC": {"error": "Timeout
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"IQUERY", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_HS_NOTIFY_AA": {"QR": 1,
"Opcode": "NOTIFY", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "REFUSED", "QDCOUNT": 1, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0},
"baseline_A_NONE_NOTIFY_AA_TC": {"QR": 1, "Opcode": "NOTIFY", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "REFUSED", "QDCOUNT": 1, "ANCOUNT": 0, "NSCOUNT": 0,
"ARCOUNT": 0}, "baseline_A_ANY_STATUS_QR_AA_TC": {"error": "Timeout after 5 seconds"}, "baseline_A_IN_STATUS_AA_RA": {"QR": 1, "Opcode": "STATUS", "AA": 0,
"TC": 0, "RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_RESERVED0_IQUERY_AA_TC_RD": {"QR": 1,
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"baseline_A_ANY_NOTIFY_AA_RA": {"QR": 1, "Opcode": "NOTIFY", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "FORMERR", "QDCOUNT": 1, "ANCOUNT": 0, "NSCOUNT": 0,
"ARCOUNT": 0}, "baseline_A_IN_NOTIFY_QR_TC": {"error": "Timeout after 5 seconds"}, "baseline_A_CH_STATUS_AA_TC_RD_RA": {"QR": 1, "Opcode": "STATUS", "AA": 0,
"TC": 0, "RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_RESERVED0_QUERY_AA_TC_RD_RA": {"QR": 1,
"Opcode": "QUERY", "AA": 0, "TC": 0, "RD": 1, "RA": 0, "RCODE": "FORMERR", "QDCOUNT": 1, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0},
"baseline_A_ANY_QUERY_QR_AA_TC_RD": {"error": "Timeout after 5 seconds"}, "baseline_A_CH_IQUERY_QR_RA": {"error": "Timeout after 5 seconds"},
"baseline_A_IN_IQUERY_TC": {"QR": 1, "Opcode": "IQUERY", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0, "NSCOUNT": 0,
"ARCOUNT": 0}, "baseline_A_CH_STATUS": {"QR": 1, "Opcode": "STATUS", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0,
"NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_HS_IQUERY_TC_RD": {"QR": 1, "Opcode": "IQUERY", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0,
"ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_RESERVED0_STATUS_AA": {"QR": 1, "Opcode": "STATUS", "AA": 0, "TC": 0, "RD": 0, "RA": 0, "RCODE":
"NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_CH_IQUERY_QR_AA": {"error": "Timeout after 5 seconds"},
"baseline_A_CH_STATUS_QR_AA_RA": {"error": "Timeout after 5 seconds"}, "baseline_A_ANY_STATUS_AA_TC_RD_RA": {"QR": 1, "Opcode": "STATUS", "AA": 0, "TC": 0,
"RD": 0, "RA": 0, "RCODE": "NOTIMP", "QDCOUNT": 0, "ANCOUNT": 0, "NSCOUNT": 0, "ARCOUNT": 0}, "baseline_A_HS_STATUS_QR": {"error": "Timeout after 5 seconds"},
```

Output: scikit-learn Decision Tree

scikit learn Install User Guide API Examples Community More Go

Prev Up Next

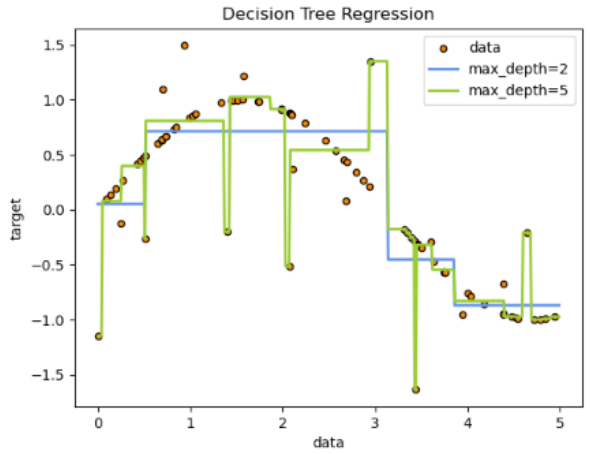
scikit-learn 1.3.2
Other versions

Please cite us if you use the software.

1.10. Decision Trees

Decision Trees (DTs) are a non-parametric supervised learning method used for classification and regression. The goal is to create a model that predicts the value of a target variable by learning simple decision rules inferred from the data features. A tree can be seen as a piecewise constant approximation.

For instance, in the example below, decision trees learn from data to approximate a sine curve with a set of if-then-else decision rules. The deeper the tree, the more complex the decision rules and the fitter the model.



Fingerprinting granularity

bind	9.16.11
unbound	1.17.0
unbound	1.17.1
knot-resolver	2.1.1
knot-resolver	4.2.2
knot-resolver	5.5.3

Fingerprinting granularity: vendor

bind	9.16.11
unbound	1.17.0
unbound	1.17.1
knot-resolver	2.1.1
knot-resolver	4.2.2
knot-resolver	5.5.3

Decision tree: vendor

```
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} <= 0.50
|   |--- Q: {class: ANY, opcode: QUERY, flags: [AA,TC,RA]} and A: {RCODE: NOERROR, QDCOUNT: 1, flags: [QR,RA]} <= 0.50
|   |   |--- Q: {class: ANY, opcode: STATUS, flags : [AA,TC,RA]} and A: {RCODE: FORMERR, QDCOUNT: 1, flags: [AA,QR,RA]} <= 0.50
|   |   |   |--- Q: {class: IN, opcode: QUERY, flags: [TC,RA]} and A: {Timeout} <= 0.50
|   |   |   |   |--- Q: {class: IN, opcode: NOTIFY, flags: [AA,RD,RA]} and A: {RCODE: NOERROR, QDCOUNT: 1, ANCOUNT: 3, flags: [QR,RA,RD]} <= 0.50
|   |   |   |   |   |--- Q: {class: RESERVED0, opcode: STATUS, flags: [AA,RA]} and A: {Timeout} <= 0.50
|   |   |   |   |   |   |--- class: technitium
|   |   |   |   |   |--- Q: {class: RESERVED0, opcode: STATUS, flags: [AA,RA]} and A: {Timeout} >  0.50
|   |   |   |   |   |   |--- class: windows
|   |   |   |   |--- Q: {class: IN, opcode: NOTIFY, flags: [AA,RD,RA]} and A: {RCODE: NOERROR, QDCOUNT: 1, ANCOUNT: 3, flags: [QR,RA,RD]} >  0.50
|   |   |   |   |   |--- class: knot
|   |   |   |--- Q: {class: IN, opcode: QUERY, flags: [TC,RA]} and A: {Timeout} >  0.50
|   |   |   |   |--- class: maradns
|   |   |--- Q: {class: ANY, opcode: STATUS, flags: [AA,TC,RA]} and A: {RCODE: FORMERR, QDCOUNT: 1, flags: [AA,QR,RA]} >  0.50
|   |   |   |--- class: unbound
|   |--- Q: {class: ANY, opcode: QUERY, flags: [AA,TC,RA]} and A: {RCODE: NOERROR, QDCOUNT: 1, flags: [QR,RA]} >  0.50
|   |   |--- class: pdns
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} >  0.50
|   |--- class: bind9
```

Decision tree: vendor

```
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} <= 0.50
|    |--- Q: {class: ANY, opcode: QUERY, flags: [AA,TC,RA]} and A: {RCODE: NOERROR, QDCOUNT: 1, flags: [QR,RA]} <= 0.50
|    |    |--- Q: {class: ANY, opcode: STATUS, flags : [AA,TC,RA]} and A: {RCODE: FORMERR, QDCOUNT: 1, flags: [AA,QR,RA]} <= 0.50
|    |    |    |--- Q: {class: IN, opcode: QUERY, flags: [TC,RA]} and A: {Timeout} <= 0.50
|    |    |    |    |--- Q: {class: IN, opcode: NOTIFY, flags: [AA,RD,RA]} and A: {RCODE: NOERROR, QDCOUNT: 1, ANCOUNT: 3, flags: [QR,RA,RD]} <= 0.50
|    |    |    |    |    |--- Q: {class: RESERVED0, opcode: STATUS, flags: [AA,RA]} and A: {Timeout} <= 0.50
|    |    |    |    |    |    |--- class: technitium
|    |    |    |    |    |--- Q: {class: RESERVED0, opcode: STATUS, flags: [AA,RA]} and A: {Timeout} >  0.50
|    |    |    |    |    |    |--- class: windows
|    |    |    |    |--- Q: {class: IN, opcode: NOTIFY, flags: [AA,RD,RA]} and A: {RCODE: NOERROR, QDCOUNT: 1, ANCOUNT: 3, flags: [QR,RA,RD]} >  0.50
|    |    |    |    |    |--- class: knot
|    |    |    |--- Q: {class: IN, opcode: QUERY, flags: [TC,RA]} and A: {Timeout} >  0.50
|    |    |    |    |--- class: maradns
|    |    |--- Q: {class: ANY, opcode: STATUS, flags: [AA,TC,RA]} and A: {RCODE: FORMERR, QDCOUNT: 1, flags: [AA,QR,RA]} >  0.50
|    |    |    |--- class: unbound
|    |--- Q: {class: ANY, opcode: QUERY, flags: [AA,TC,RA]} and A: {RCODE: NOERROR, QDCOUNT: 1, flags: [QR,RA]} >  0.50
|    |    |--- class: pdns
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} >  0.50
|    |--- class: bind9
```

Decision tree: vendor

```
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} <= 0.50
|    ...
|    (issue more queries)
|    ...
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} >  0.50
|   |--- class: bind9
```

Decision tree: vendor

```
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} <= 0.50
|    ...
|    (issue more queries)
|    ...
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} >  0.50
|   |--- class: bind9
```

Decision tree: vendor

```
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} <= 0.50
|    ...
|    (issue more queries)
|    ...
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} >  0.50
|   |--- class: bind9
```

Decision tree: vendor

```
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} <= 0.50
|    ...
|    (issue more queries)
|    ...
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} >  0.50
|   |--- class: bind9
```

Decision tree: vendor

```
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} <= 0.50
|    ...
|    (issue more queries)
|    ...
|--- Q: {class: RESERVED0, opcode: STATUS, flags: [TC]} and A: {RCODE: NOTIMP, flags: [QR]} >  0.50
|   |--- class: bind9
```

Decision tree: vendor

- 768 testcases issued in total
- 6 testcases are significant
- 7 unique labels out of 7

Fingerprinting granularity: major

bind	9.16.11
unbound	1.17.0
unbound	1.17.1
knot-resolver	2.1.1
knot-resolver	4.2.2
knot-resolver	5.5.3

Decision tree: major

- 768 testcases issued in total
- 48 testcases are significant
- 19 unique labels out of 23
- Full tree on GitHub

Fingerprinting granularity: minor

bind	9.16.11
unbound	1.17.0
unbound	1.17.1
knot-resolver	2.1.1
knot-resolver	4.2.2
knot-resolver	5.5.3

Decision tree: minor

- 768 testcases issued in total
- 117 testcases are significant
- 51 unique labels out of 96
- Full tree on GitHub

Fingerprinting granularity: build

bind	9.16.11
unbound	1.17.0
unbound	1.17.1
knot-resolver	2.1.1
knot-resolver	4.2.2
knot-resolver	5.5.3

Decision tree: build

- 768 testcases issued in total
- 149 testcases are significant
- 382 unique labels out of 674
- Full tree on GitHub

Overview

1. Choose and set up software
2. Design and run test cases
3. Generate the decision tree
4. Implement the scanner

The scanner

```
$ python3 scan.py --input_file <input_file> -output_file <output_file> --
granularity [vendor,major,minor,build] --threads <num_of_threads>
```

The scanner

```
$ python3 scan.py --input_file <input_file> -output_file <output_file> --
granularity [vendor,major,minor,build] --threads <num_of_threads>
```

```
{"ip": "1.2.3.4","versions": ["unbound"]}
```

The scanner

```
$ python3 scan.py --input_file <input_file> -output_file <output_file> --
granularity [vendor,major,minor,build] --threads <num_of_threads>
```

```
{"ip": "1.2.3.4","versions": ["unbound"]}
{"ip": "1.2.3.4","versions": ["technitium-2"]}
```

The scanner

```
$ python3 scan.py --input_file <input_file> -output_file <output_file> --
granularity [vendor,major,minor,build] --threads <num_of_threads>
```

```
{"ip": "1.2.3.4","versions": ["unbound"]}
{"ip": "1.2.3.4","versions": ["technitium-2"]}
{"ip": "1.2.3.4","versions": ["bind-9.16"]}
```

The scanner

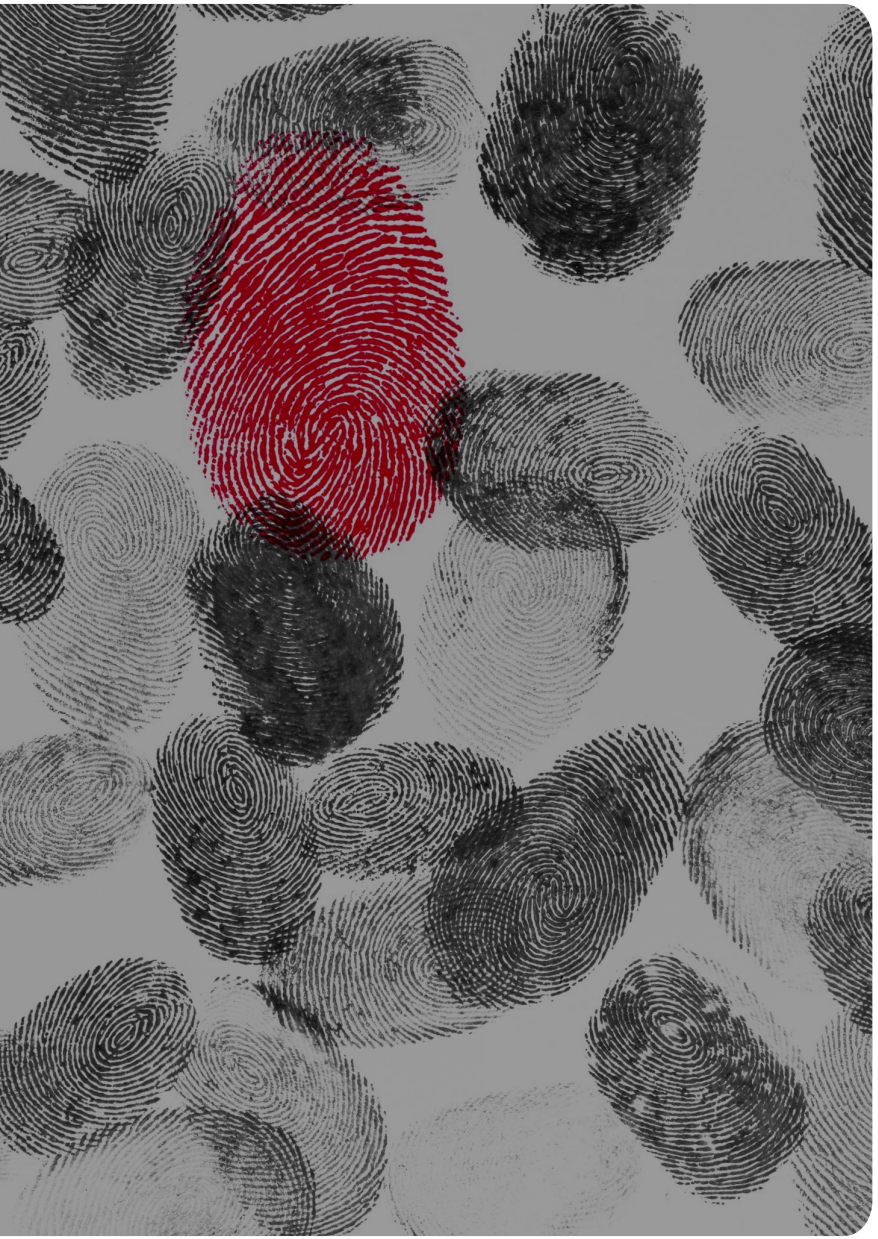
```
$ python3 scan.py --input_file <input_file> -output_file <output_file> --
granularity [vendor,major,minor,build] --threads <num_of_threads>
```

```
{"ip": "1.2.3.4","versions": ["unbound"]}
{"ip": "1.2.3.4","versions": ["technitium-2"]}
{"ip": "1.2.3.4","versions": ["bind-9.16"]}
{"ip": "1.2.3.4","versions": ["pdns-recuror-4.1.6"]}
```

The scanner

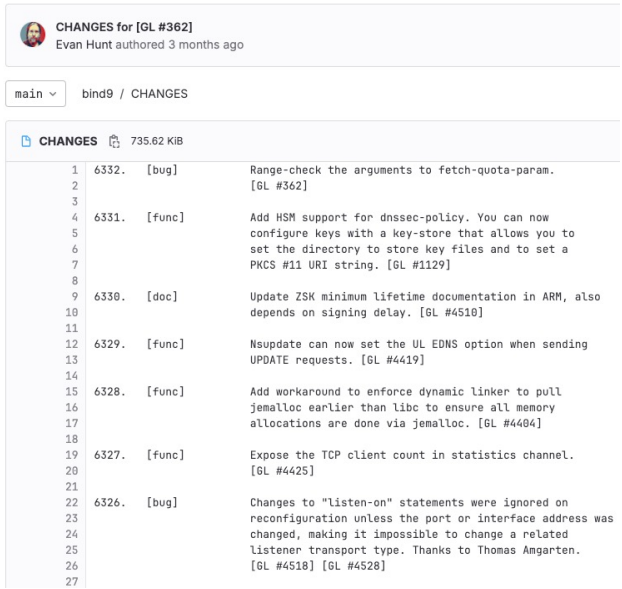
```
$ python3 scan.py --input_file <input_file> -output_file <output_file> --
granularity [vendor,major,minor,build] --threads <num_of_threads>
```

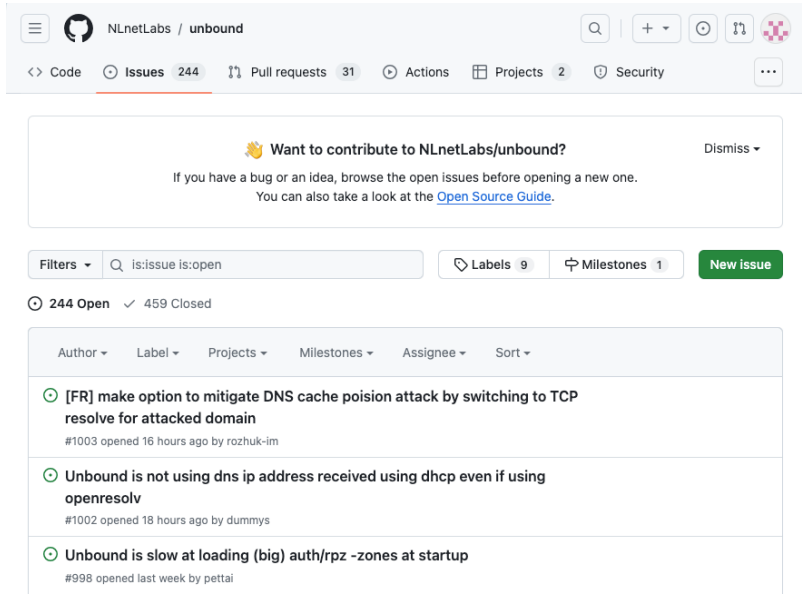
```
{"ip": "1.2.3.4","versions": ["unbound"]}
{"ip": "1.2.3.4","versions": ["technitium-2", "technitium-3"]}
{"ip": "1.2.3.4","versions": ["bind-9.16"]}
{"ip": "1.2.3.4","versions": ["pdns-recuror-4.1.6"]}
```

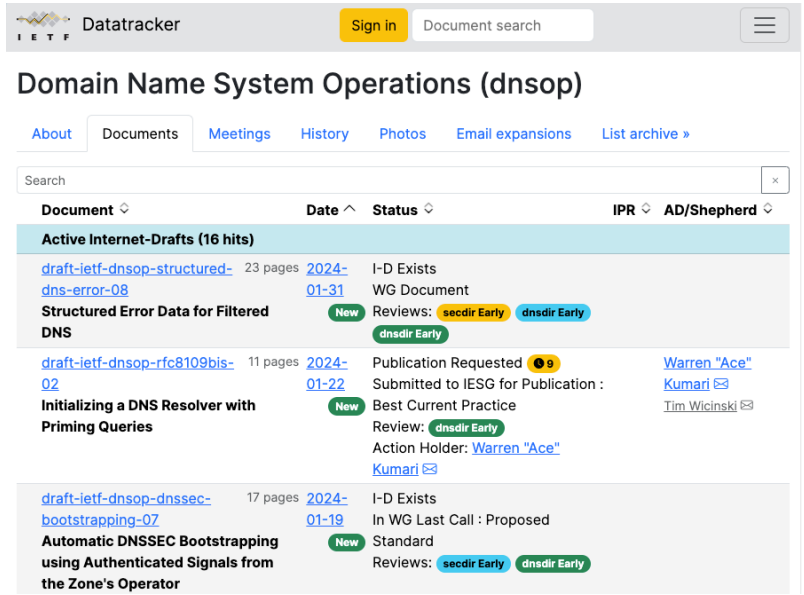


Next steps

Next steps: more test cases







Sources: https://gitlab.isc.org/isc-projects/bind9/-/blob/main/CHANGES?ref_type=heads, https://datatracker.ietf.org/wg/dnsop/documents/, https://github.com/NLnetLabs/unbound/issues

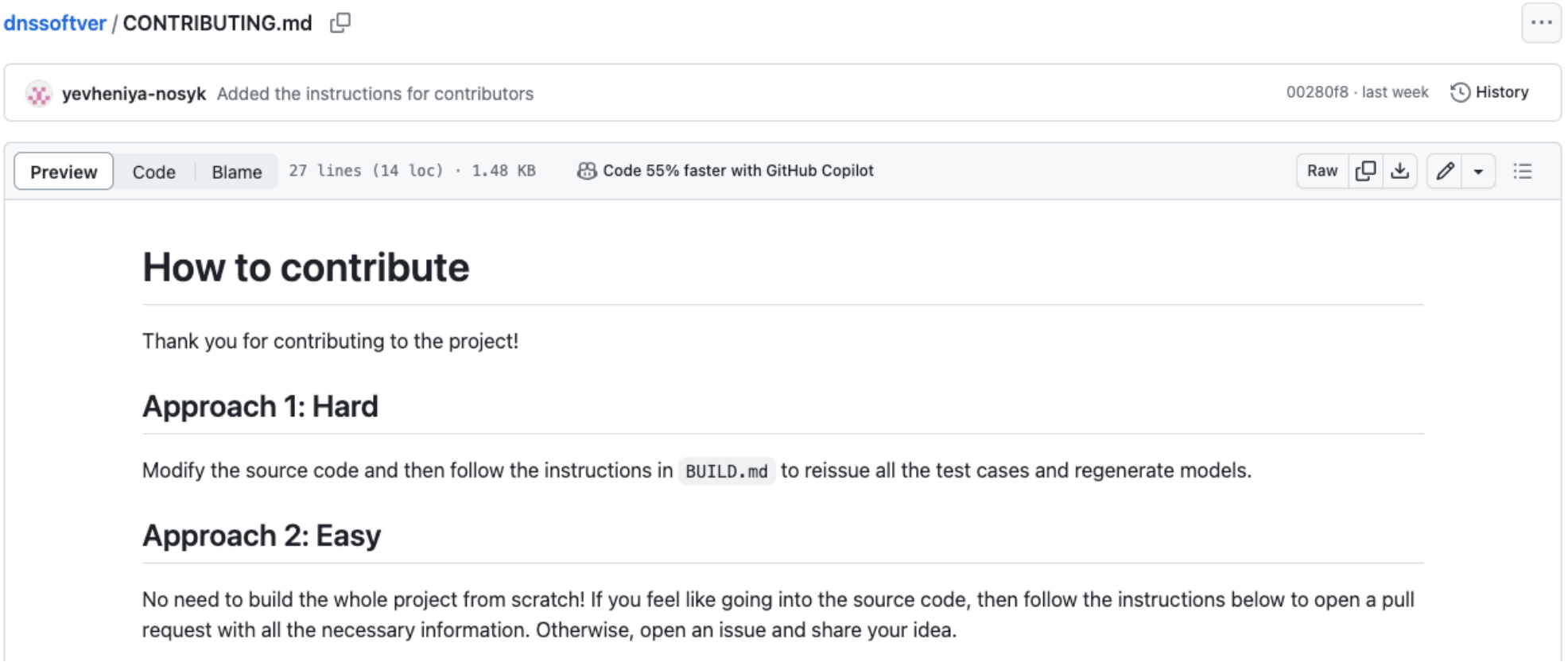
Next steps: less test cases

1. Timeouts are not deterministic
2. Inconsistencies are unpredictable

Next steps: testing in the wild

1. No ground truth data available
2. Need to test on real systems:
    - To confirm the accuracy
    - To catch weird behaviours
    - To adapt the models

Next steps: maintain and update



Next steps: extensions

1. Authoritative nameservers?
2. Forwarders?
3. Forwarders + resolvers?

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Thank you!

https://github.com/yevheniya-nosyk/dnssoftver/

yevheniya.nosyk@univ-grenoble-alpes.fr