# Poster: ResolverFuzz: Automated Discovery of DNS Resolver Vulnerabilities with Query-Response Fuzzing

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**Abstract**

Domain Name System (DNS) is a critical component of the Internet. DNS resolvers, which act as the cache between DNS clients and DNS nameservers, are the central piece of the DNS infrastructure, essential to the scalability of DNS. However, finding the resolver vulnerabilities is non-trivial, and this problem is not well addressed by the existing tools. To list a few reasons, first, most of the known resolver vulnerabilities are non-crash bugs that cannot be directly detected by the existing oracles (or sanitizers). Second, there lacks rigorous specifications to be used as references to classify a test case as a resolver bug. Third, DNS resolvers are stateful, and stateful fuzzing is still challenging due to the large input space.

In this paper, we present a new fuzzing system termed ResolverFuzz to address the aforementioned challenges related to DNS resolvers, with a suite of new techniques being developed. First, ResolverFuzz performs constrained stateful fuzzing by focusing on the short query-response sequence, which has been demonstrated as the most effective way to find resolver bugs, based on our study of the published DNS CVEs. Second, to generate test cases that are more likely to trigger resolver bugs, we combine probabilistic context-free grammar (PCFG) based input generation with byte-level mutation for both queries and responses. Third, we leverage differential testing and clustering to identify non-crash bugs like cache poisoning bugs. We evaluated ResolverFuzz against 6 mainstream DNS software under 4 resolver modes. Overall, we identify 23 vulnerabilities that can result in cache poisoning, resource consumption, and crash attacks. After responsible disclosure, 19 of them have been confirmed or fixed, and 15 CVE numbers have been assigned.

## Acknowledgment

This work [1] has been accepted by the 33rd USENIX Security Symposium (Security'24). The original abstract and author list are shown above. We post the paper link with the conference version[1] as well as the extended version available on ArXiv[2].

## References

[1] Q. Zhang, X. Bai, X. Li, H. Duan, Q. Li, and Z. Li. ResolverFuzz: Automated Discovery of DNS Resolver Vulnerabilities with Query-Response Fuzzing. In *Proceedings of the 33rd USENIX Security Symposium*, USENIX Security '24, 2024.

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[1]https://www.usenix.org/conference/usenixsecurity24/presentation/zhang-qifan.

[2]https://arxiv.org/abs/2310.03202.

# ResolverFuzz: Automated Discovery of DNS Resolver Vulnerabilities with Query-Response Fuzzing


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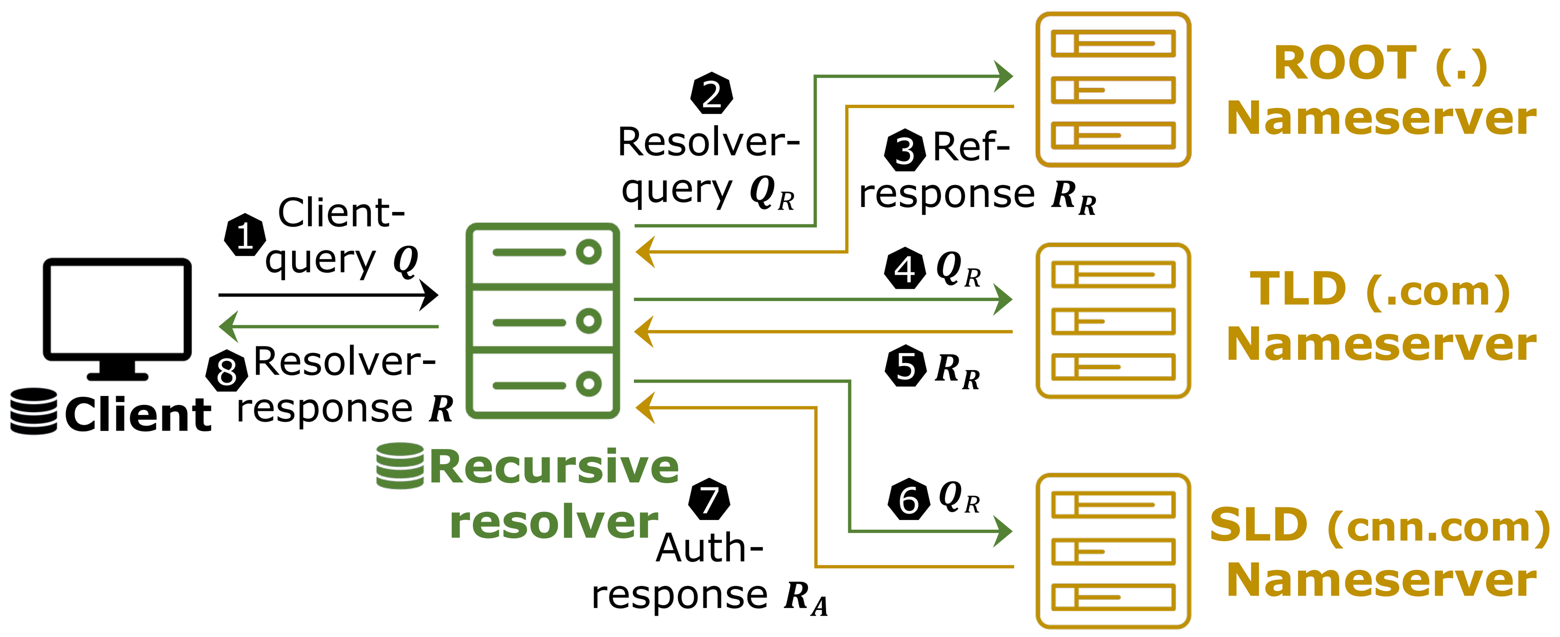
## DNS Resolution

- Translate human-friendly domains into machine-friendly IP addresses.
- **Recursive process.** Root servers, Top-Level Domain (TLD) servers, etc.
- **Multiple roles.** Forwarders, recursive resolvers, nameservers (NSes).




## DNS Complexity and Vulnerability

- Over **100** RFCs.
- **Many use cases.** Web browsing, email, zero-trust network, autonomous vehicle, etc.
- **Many implementations. 20+** widely used DNS software.
- **Fragmented service ecosystem.** Millions of NSes, open/local resolvers, and forwarders [1].
- **DNS failures and attacks happened a lot.**

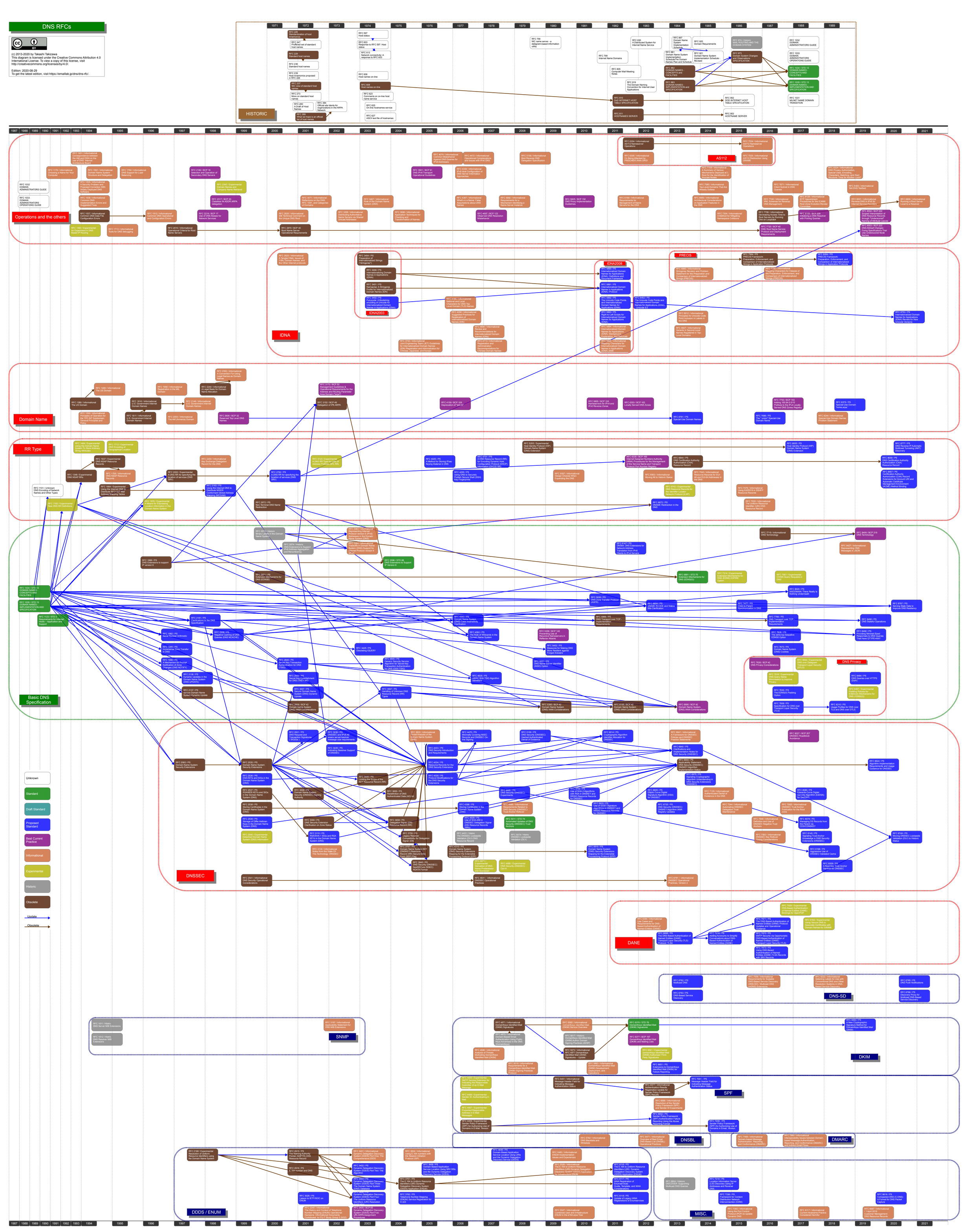
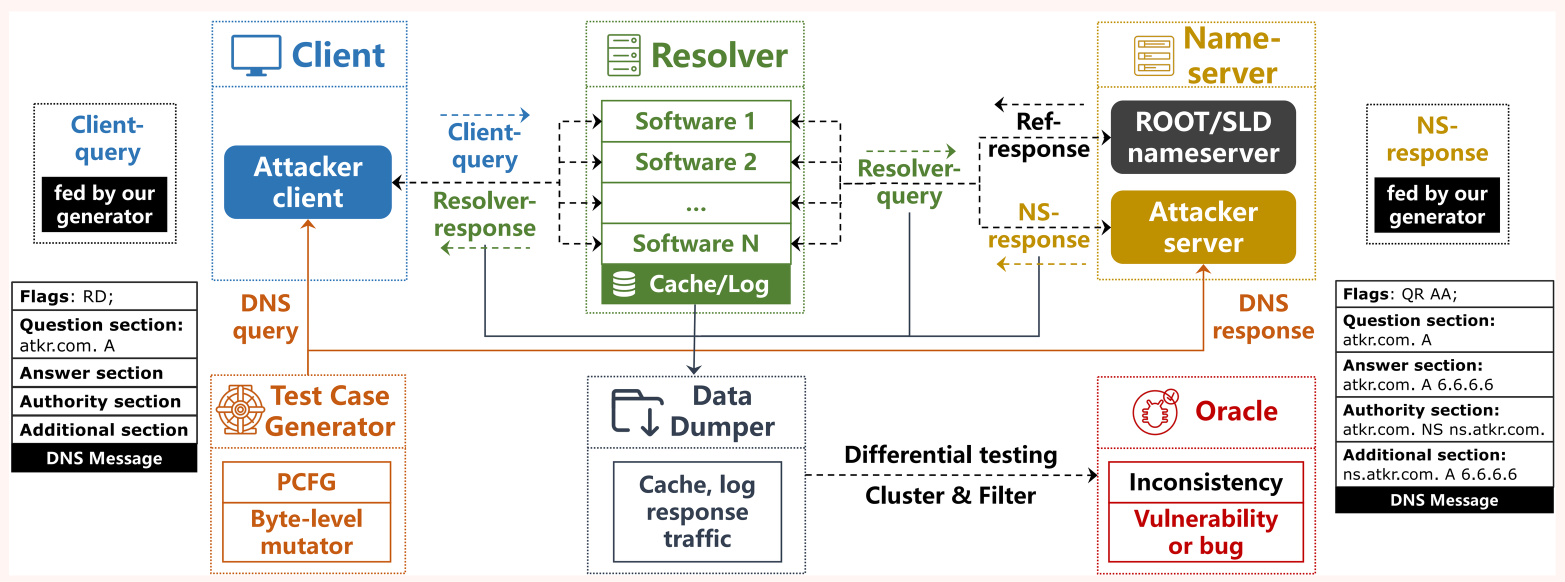


Figure 1. DNS RFCs (as of 2020) [6]

## ResolverFuzz [8] Infrastructure

- **Input**: Query/Response generator.
- **Output**: response, cache dump, network traffic packets (tcpdump), system logs.
- **Oracle**: 3 oracles for each kind of vulnerabilities.

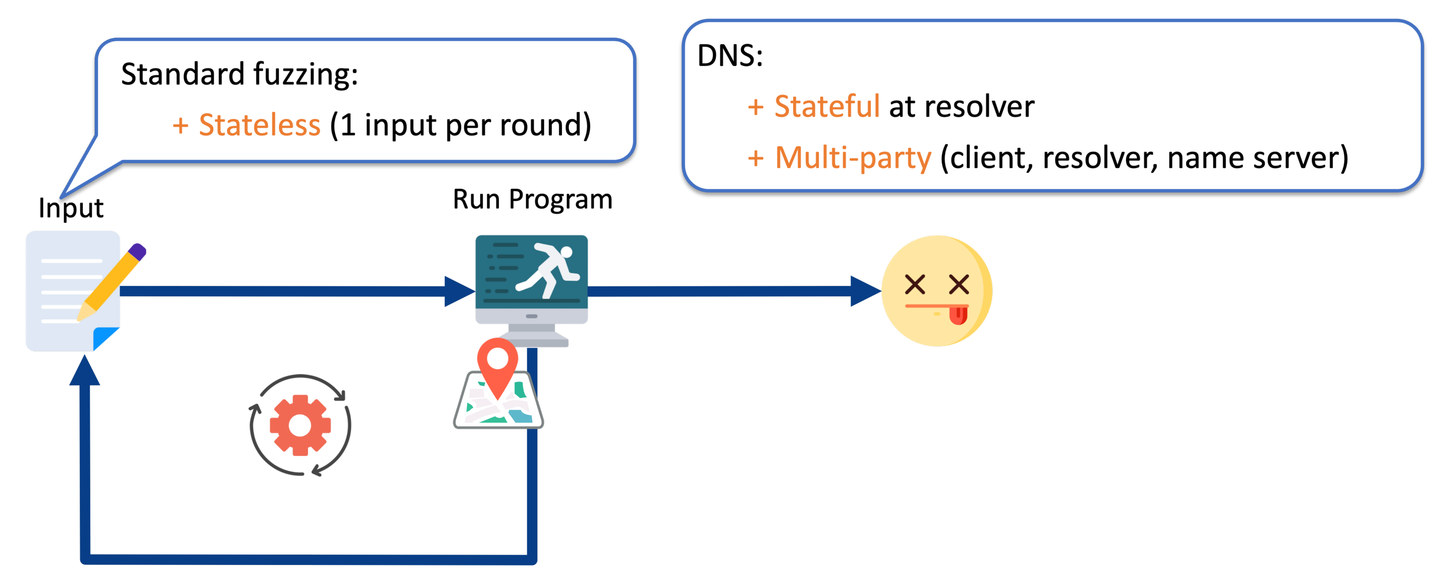



## Challenges 1: Non-Crash Vulnerabilities

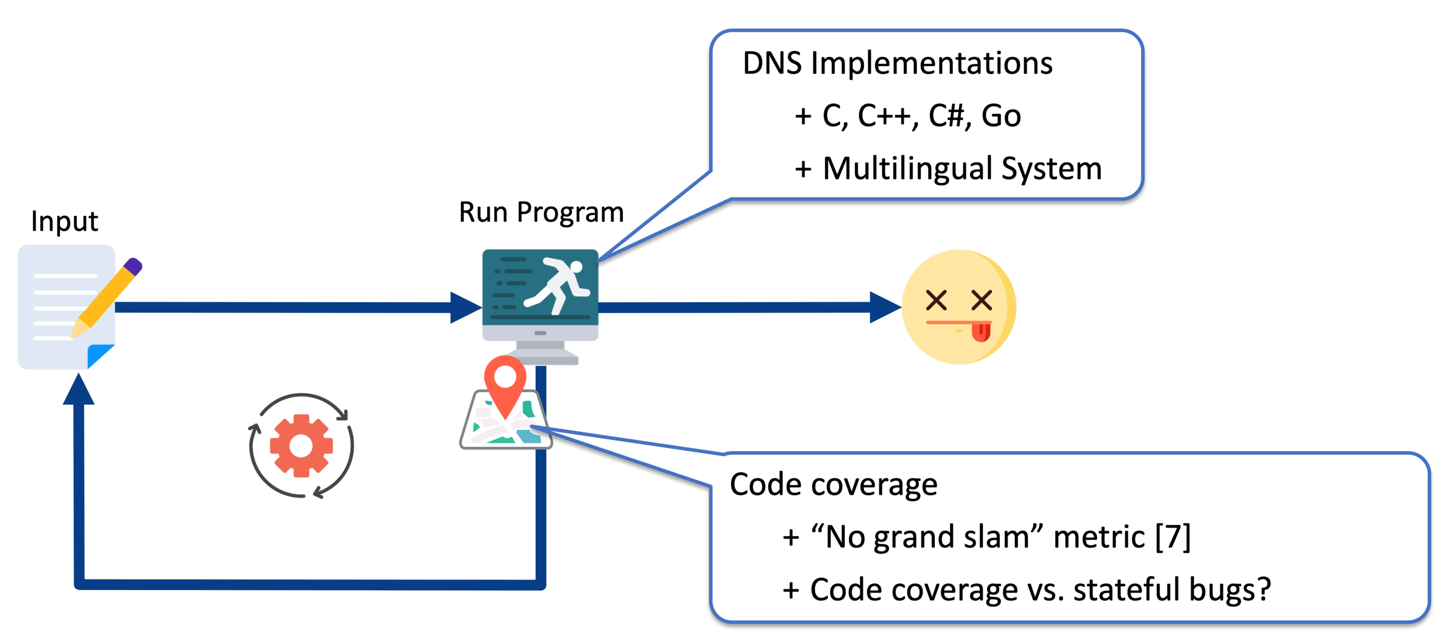
- DNS vulnerabilities **does not always lead to crashes**.
- Focus on categories of **identified bugs** via **CVE study** on CVEs ranging from 1999 to 2023.

| Software* | # CVE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Non-crash | | | | Crash | | | Total |
| | Cache Poisoning | Resource Consum.[1] | Others[2] | Total | Non-memory | Memory | Total | |
| BIND | 18 | 18 | 11 | 47 | 75 | 22 | 97 | 144 |
| Unbound | 4 | 5 | 4 | 13 | 5 | 8 | 13 | 26 |
| Knot Resolver | 6 | 4 | 0 | 10 | 2 | 0 | 2 | 12 |
| PowerDNS Recursor | 13 | 8 | 9 | 30 | 7 | 6 | 13 | 43 |
| MaraDNS | 2 | 3 | 0 | 5 | 4 | 7 | 11 | 16 |
| Technitium | 3 | 1 | 0 | 4 | 0 | 0 | 0 | 4 |
| Total | 46 | 39 | 24 | 109 | 93 | 43 | 136 | 245 |

## Challenges 2: Stateful Fuzzing




## Challenges 3: Fuzzing Instrumentation




## Identified Vulnerabilities

- Tested on **6 mainstream** DNS software.
- **23** vulnerabilities identified, **19** confirmed, **15** CVEs assigned, categorized into 3 classes.

MaginotDNS [Security'23, Black Hat USA'23] → CP1
Phoenix Domain [NDSS'23, OARC'39, Black Hat Asia'23] → CP4
TuDoor [S&P'24, OARC'42] → RC7

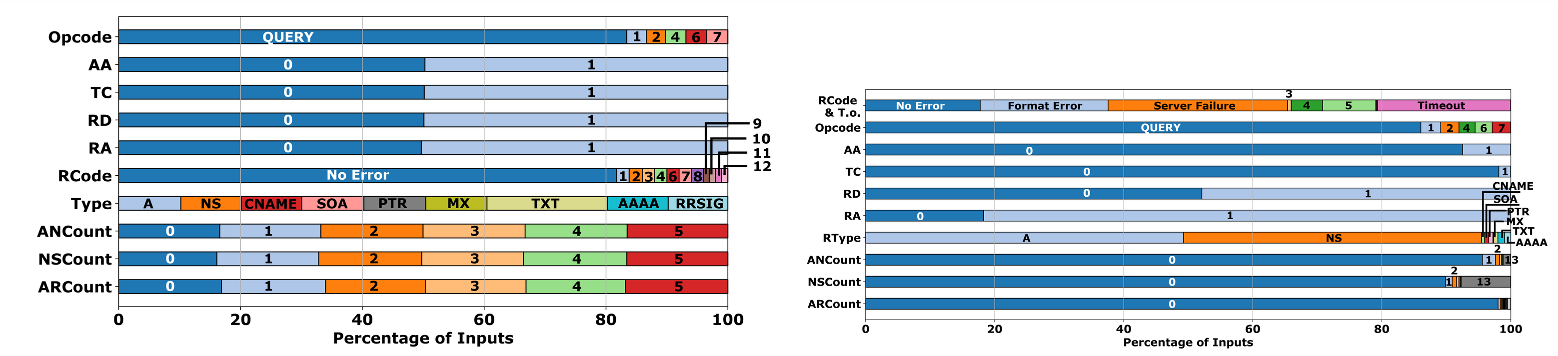
| Software* | Cache poisoning | | | | | Resource consumption | | | | | | | | Crash& Corruption | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CP1 | CP2 | CP3 | CP4[1] | Tot.[2] | RC1 | RC2 | RC3 | RC4 | RC5 | RC6 | RC7 | Tot. | CC1 | |
| BIND | ✓† | ✗ | ✓ | ✓ | 3 | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | 0 | ✓ | 4 |
| Unbound | ✗ | ✗ | ✓ | ✓† | 2 | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ | 4 | - | 6 |
| Knot | ✓† | ✗ | ✓† | ✓† | 3 | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓† | 1 | - | 4 |
| PowerDNS | ✗ | ✓† | ✗ | ✓† | 2 | ✓† | ✗ | ✓† | ✗ | ✗ | ✗ | ✗ | 2 | - | 4 |
| MaraDNS | ✗ | ✗ | - | ✓† | 1 | ✗ | ✗ | ✗ | ✓† | ✗ | ✗ | ✗ | 1 | - | 2 |
| Technitium | ✓† | ✗ | - | ✓† | 2 | ✗ | ✗ | ✗ | ✓† | ✗ | ✗ | ✗ | 1 | - | 3 |
| Total | 3 | 1 | 3 | 6 | 13 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 9 | 1 | 23 |

*: Recursive or forwarding modes. [1]: They are triggered by different responses and their cache are inconsistent. [2]: Total. ✓or ✓: Vulnerable. ✓: Discussed but no immediate action. ✓: Confirmed and/or fixed by vendors. ✗: Not vulnerable. †: CVEs assigned. '-': Not applicable.
# Amount of test cases: *CP1* (19), *CP2* (1,422), *CP3* (111,328), *CP4* (7,856), *RC1* (539,745), *RC2* (112,126), *RC3* (88,935), *RC4* (132), *RC5* (272) *RC6* (6,264), *RC7* (4,448), and *CC1* (5).

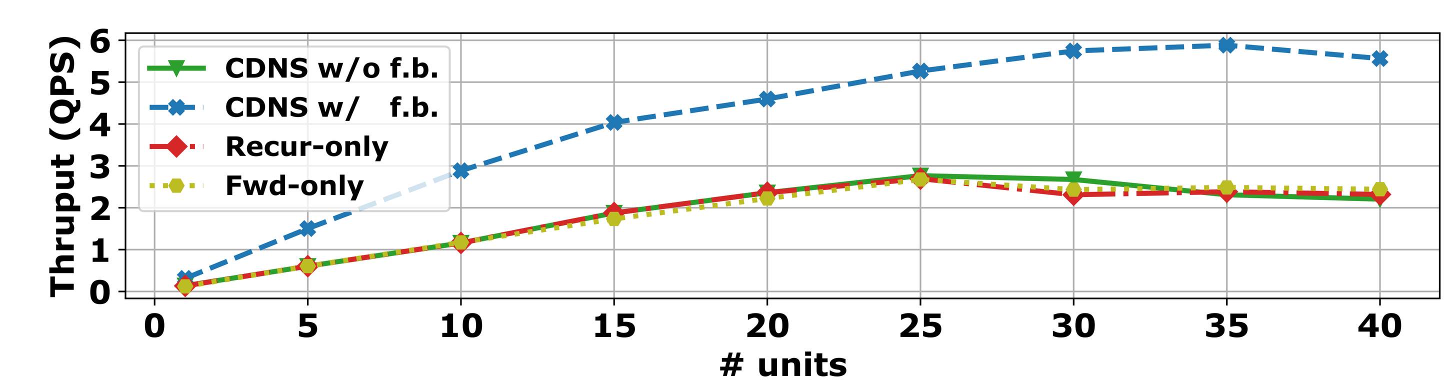
## Input Generation

- **Two dimensions.** Generate a pair of query and response in each round.
- **Grammar-based fuzzing.** Generation is based on **Probabilistic context-free grammar (PCFG)**.
- **Byte-level mutation** [2]. **Special characters** (\., \000, @, /, and \) are embedded.

## Evaluation Results



(a) Client-queries and NS-responses. (b) Resolver-responses.




(c) Throughput ("*Thruput*") of 4 modes with regard to the number of units. *CDNS w/o f.b.*, *CDNS w/ f.b.*, *Recur-only* and *Fwd-only* refers to *CDNS without fallback*, *CDNS with fallback*, *Recursive-only*, and *Forward-only*.

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