HDiff: A Semi-automatic Framework for Discovering Semantic Gap Attack in HTTP Implementations

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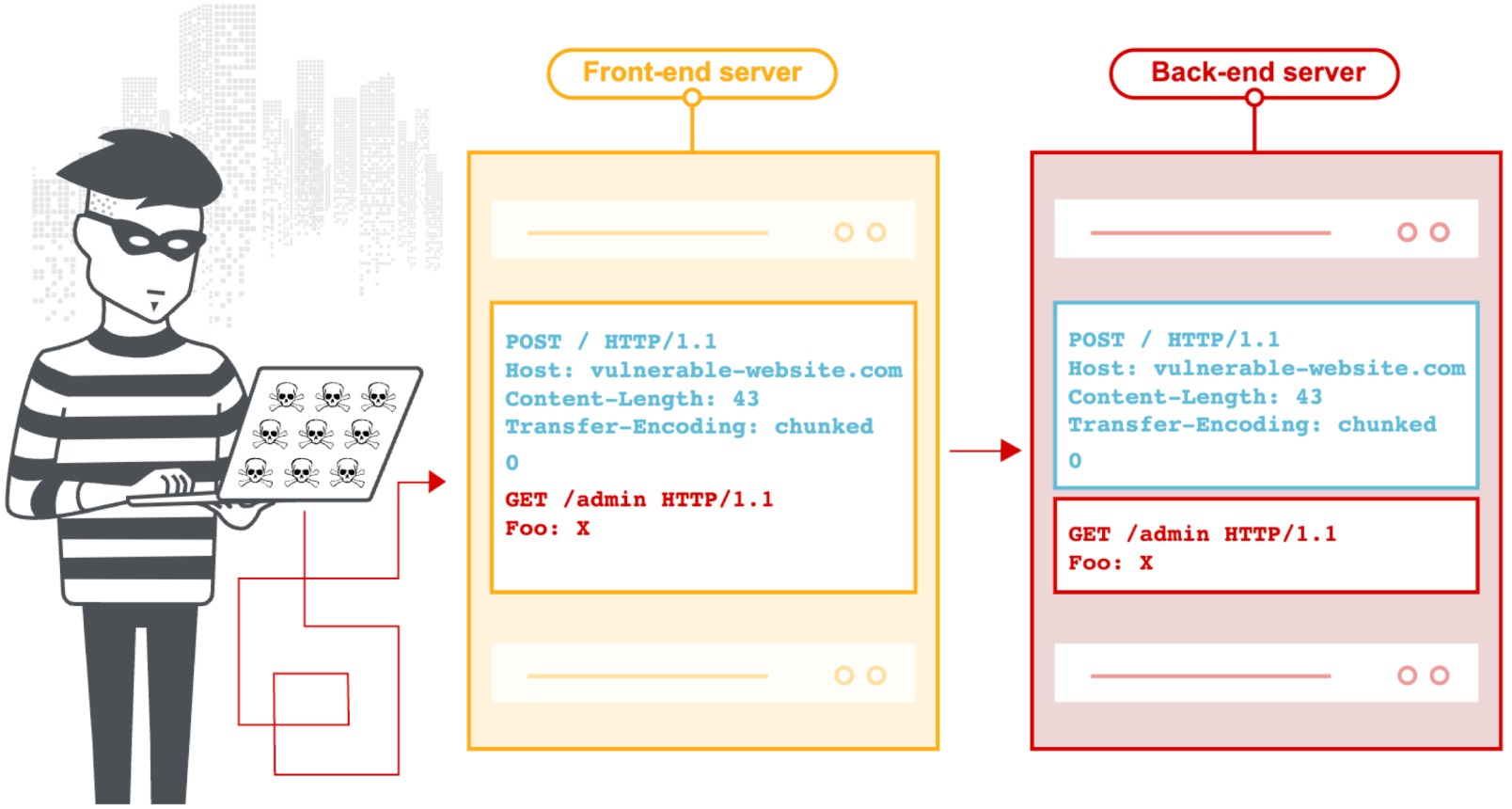
Background

- **HTTP Request Smuggling (HRS)**
  - An attack that exploits the HTTP parsing discrepancies between two servers(front-end and back-end).
  - Content-Length
  - Transfer-Encoding
  - HTTP/1.1



HDiff

- **Observations**
  - Some HTTP implementations do not follow RFC requirements.
  - RFC defines optional requirements allowing developers to use their discretion.
  - Previous studies are based on ad-hoc manual analysis or only analyze one type of semantic gap attack.

- **Challenges**
  - It is difficult to extract such informal descriptions from RFC documents and convert them to formal invariants.
  - Most semantic gap bugs do not display any explicitly erroneous behavior like crashes or memory corruption bugs and thus are hard to detect.

HDiff

➢ Overview

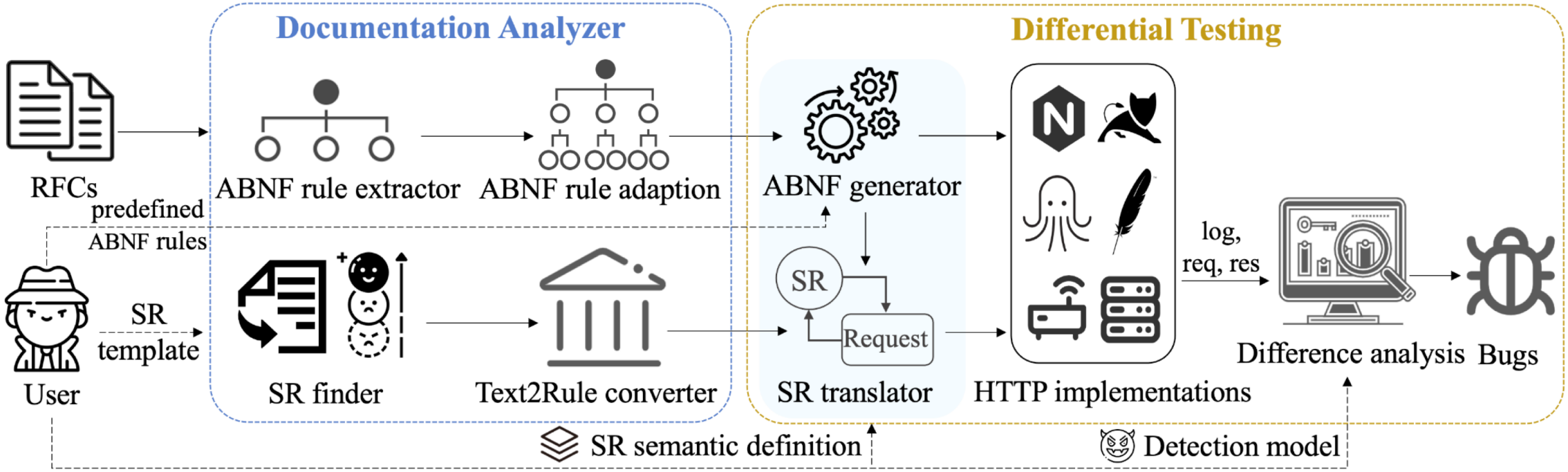


Fig. 3: The Architecture of HDiff.

HDiff

➢ Document Analyzer

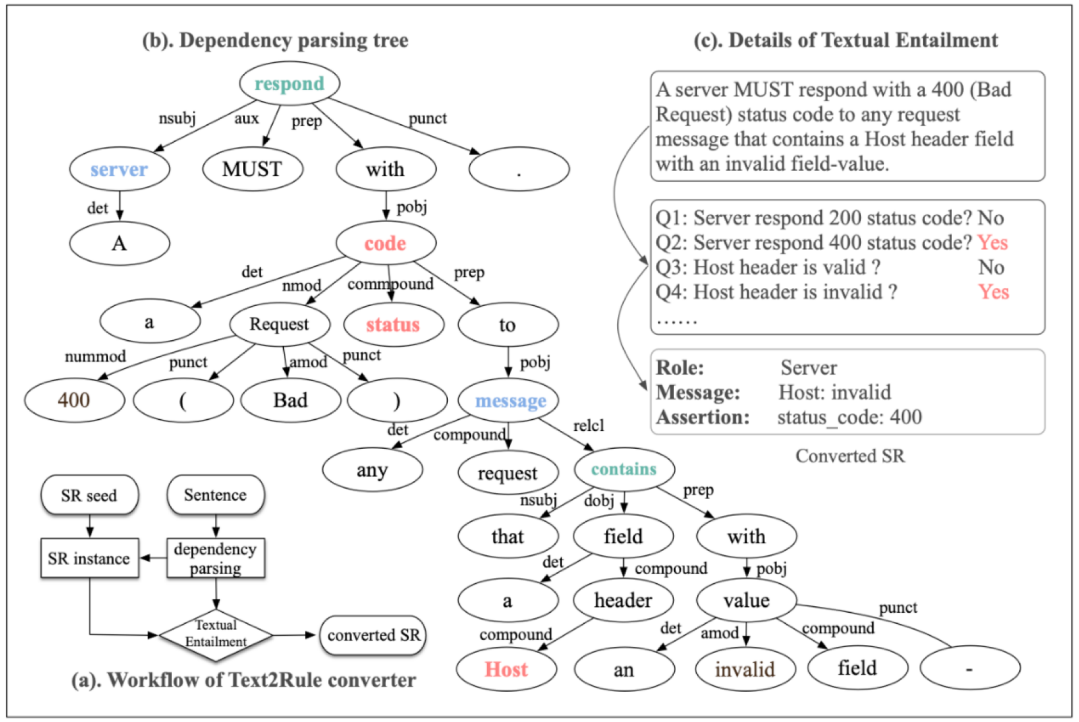


Fig. 4: An example showing details of Text2Rule Converter.

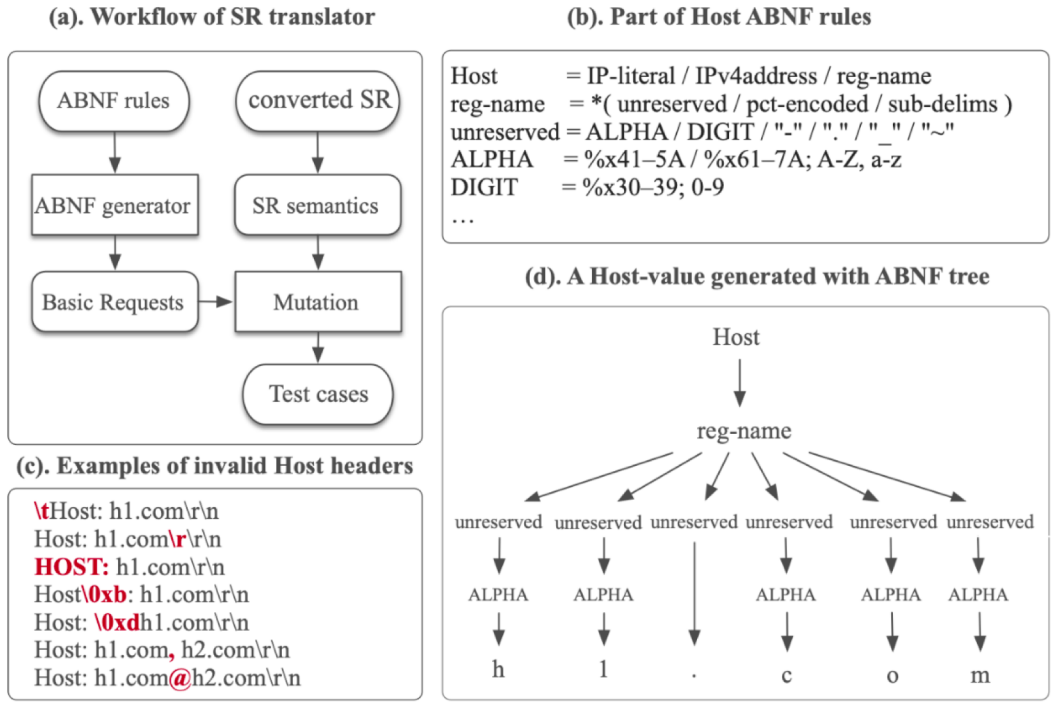


Fig. 5: An example showing details of SR Translator.

HDiff

➢ Evaluation

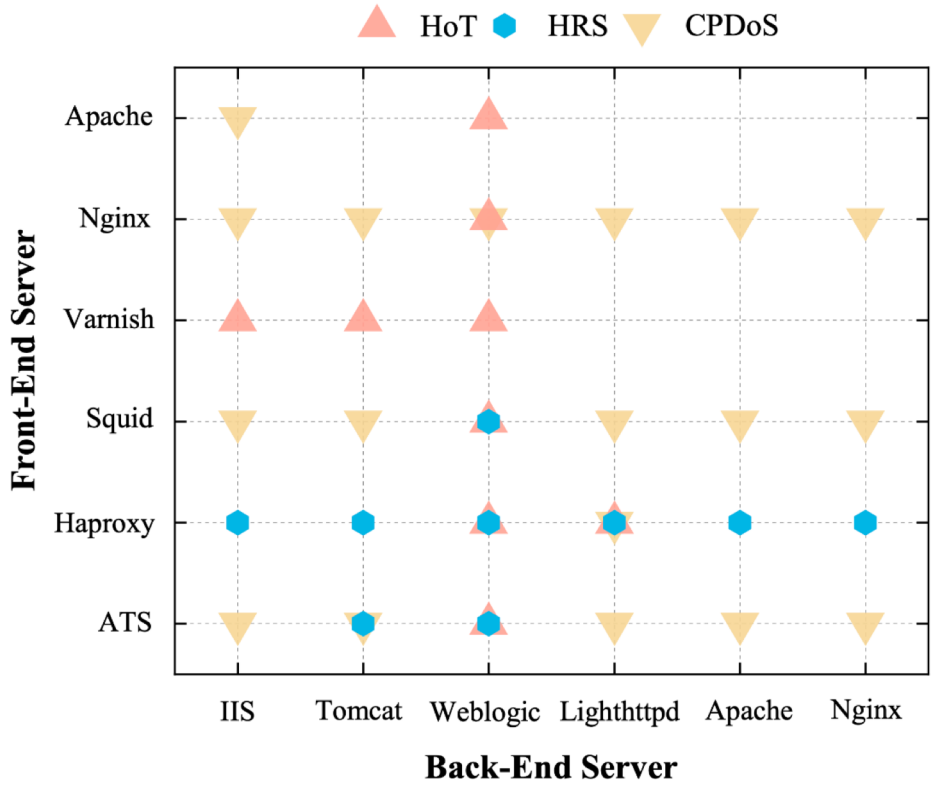


Fig. 7: Server pairs affected by three types of attacks.

TABLE II: Examples of semantic gap attacks found by HDiff.

HTTP Field	Description	Example	Vulnerability
Request-Line	Invalid HTTP-version	**1.1/HTTP**; HTTP/**3-1**; **h**TTP/1.1;	CPDoS
	lower/higher HTTP-version	HTTP/**0.9**;**1.0 with chunked**; HTTP/**2.0**	HRS, CPDoS
	Bad absolute-URI vs Host	**test://**h2.com/?a=1; **h1@h2.com**;	HoT
	Fat HEAD/GET request	HEAD/GET with **message-body**	HRS, CPDoS
Header-field	Invalid CL/TE header	Content-Length: **+6**\r\n Content-Length: **6,9**\r\n Content-Length: **[sc]**9\r\n **[sc]**Transfer-Encoding: chunked\r\n Transfer-Encoding: chunked**\r**\r\n Transfer-Encoding**[sc]**: chunked\r\r\n	HRS
	Multiple CL/TE headers	Content-Length: 10\r\n Content-Length: **0xff**\r\n; Content-Length: 10\r\n Transfer-Encoding**[sc]**: chunked\r\n;	HRS
	Invalid Host header	Host: h1.com**@**h2.com\r\n Host: h1.com**,** h2.com\r\n Host: h1.com**/../../test?**\r\n Host:**[sc]** h1.com\r\n	HoT, CPDoS
	Multiple Host headers	**[sc]**Host: h1.com\r\n Host: h2.com\r\n	HoT
	Hop-by-Hop headers	Connection: close,**Host**\r\n Connection: **Cookie**\r\n	CPDoS
	Expect header	**Expect:** 100-continuce\r\n	HRS, CPDoS
	Obs-fold header	Host: h1.com**\t\n**h2.com\r\n	HoT
	Obsoleted header or value	Transfer-encoding: chunked,**identity**\r\n	HRS, CPDoS
Message-body	Bad chunk-size value	**[bignumber]**\r\nabc\r\n0\r\n; **0xfgh**\r\nabc\r\n9\r\n;	HRS
	NULL in chunk-data	3\r\n**\x00**abc\r\b0\r\n	HRS

1. The symbol **[sc]** represents special characters, including common spaces(e.g., ,\t,\0xb,\0xd), grammatical characters(e.g., {,},<,>,@,',"$) and unicode characters (e.g., \u0000,\uffff,\u202e).

T-Reqs: HTTP Request Smuggling with Differential Fuzzing

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Background

- **Related work**
  - Specific attacks : such as cache poisoning, session hijacking.
  - HTTP/2 Request smugging
  - Narrow scope : focus on two HTTP headers (CT, TE)
  - HRS is a system interaction problem. The key aspect of HRS (the HTTP parsing discrepancies) has not been explored.

T-Reqs

➢ Workflow

- Construct the context-free grammar (CFG).
- Generating requests.
- Mutating requests: string mutations and tree mutations.
- Collecting feedback.

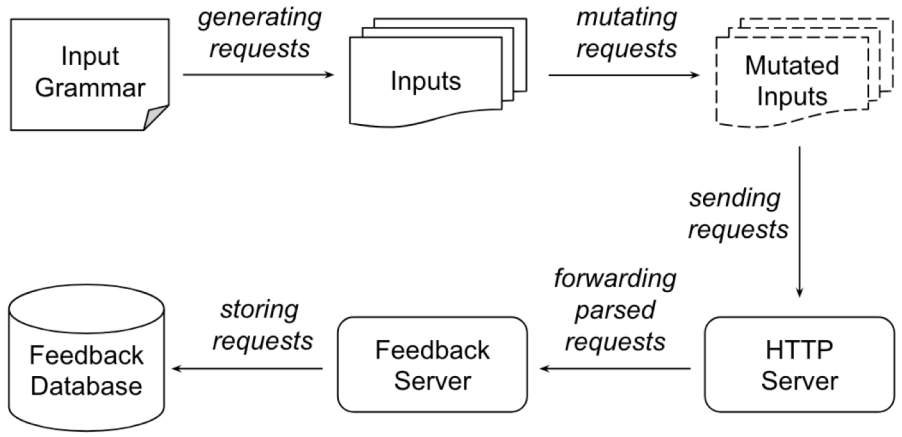


Figure 1: Inputs are generated from a grammar, mutated, and sent to the tested server. The feedback server collects feedback from the requests forwarded by the tested server and stores it for analysis.

```
1 POST //search HTTP/1.1
2 Host: example.com
3 Content-Length: 13
4
5 query=bananas
```

Listing 7: String mutations.

```
1 HTTP /search /search HTTP/1.1
2 Host: example.com
3 Content-Length: 13
4
5 query=bananas
```

Listing 8: Tree mutations.

```
<start> ::= <request>
<request> ::= <line><headers><newline><body>
<line> ::= "POST /search HTTP/1.1\r\n" | "PUT / HTTP/1.1\r\n"
<headers> ::= <host><content-length> | <host>
<host> ::= "Host: example.com\r\n"
<content-length> ::= "Content-Length: 16\r\n"
<newline> ::= "\r\n"
<body> ::= "query=funny+cats" | "query=carrots"
```

Listing 6: Example CFG for a simple HTTP request.

Evaluation

- **Finding Discrepancies**
  - Exposing discrepancies in message body parsing behavior.
  - Three separate experiments on each part of the HTTP request : request line, request headers, request body.

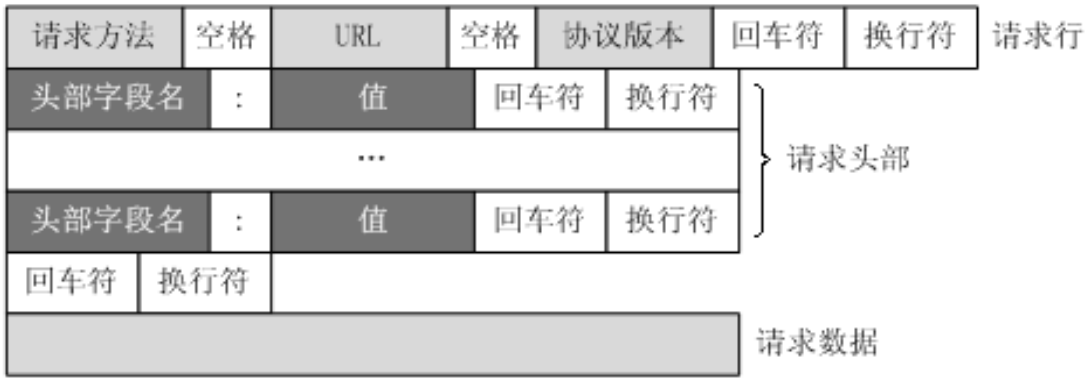


Table 2: General information about experiments.

Name	Duration	# Inputs
Request line	70 hours	8,857K
Request headers	94 hours	3,096K
Request body	72 hours	2,051K

Evaluation

- **Discrepancy Reduction and Classification**
  - Successful Mutation Sets.
  - Classification of Mutation Sets.
- **Request line mutation categories**

Table 5: Experiment success values.

Experiment Name	# Inputs	# Successful
Request line	8,857K	5K
Request headers	3,096K	1K
Request body	2,051K	595K

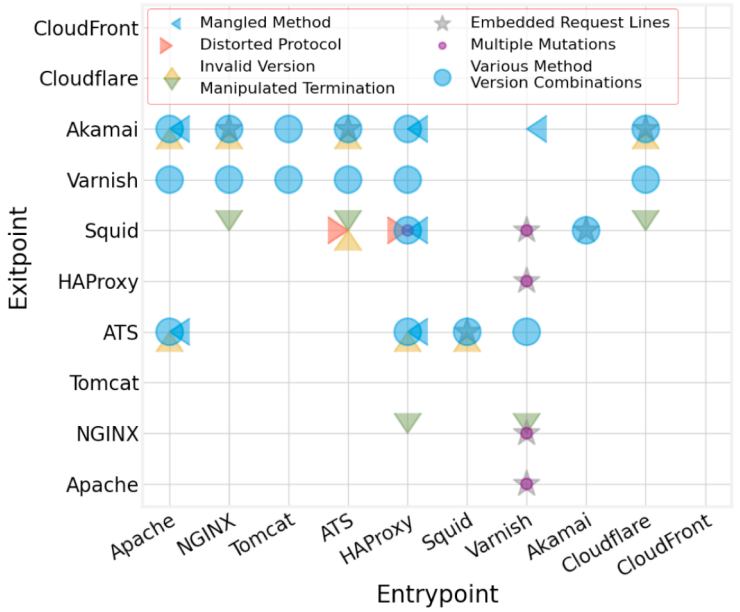


Figure 2: Request line mutation categories affecting server pairs.

Table 6: Examples for each request line mutation category.

Category	Request Line	Entrypoint-Exitpoint
mangled method	`hEAD / HTTP/1.1\r\n`	Apache-Akamai Apache-ATS HAProxy-Akamai HAProxy-ATS
distorted protocol	`GET / HhTTP/1.1\r\n`	ATS-Squid
invalid version	`GET / HTTP/+.19\r\n`	ATS-Akamai ATS-Squid
manipulated termination	`CONNECT / HTTP/1.0 \r\n\r\n`	Varnish-NGINX HAProxy-NGINX
embedded request lines	`OPTIONS / HTTP/OPTIONS / HTTP/0.9\r\n1.1\r\n`	Akamai-Squid
multiple mutations	`GET / HT+P//1.1\r\n`	HAProxy-Squid
various method version combinations	`TRACE / HTTP/1.0\r\n`	Apache-ATS HAProxy-ATS Squid-ATS Varnish-ATS

Evaluation

➢ Request header mutation categories

Figure 3: Request header mutation categories affecting server pairs.

Table 7: Examples for each request header mutation category.

Category	Method ; Request Header	Entrypoint-Exitpoint
distorted header value	`GET;Transfer-Encoding: chunked,\r\n`	Tomcat-Akamai ATS-Akamai HAProxy-Akamai
manipulated termination	`GET;Transfer-Encoding: chunked\r\n␣{Header}:{Value}\r\n`	NGINX-ATS Cloudflare-ATS CloudFront-ATS
expect header	`POST;Expect: 100-continue\r\n`	NGINX-Apache (truncated)
identity encoding	`POST;Transfer-Encoding: identity\r\n`	Cloudflare-Squid CloudFront-Squid (truncated)
v1.0 chunked encoding	`POST;Transfer-Encoding: chunked\r\n`	Apache-Tomcat (truncated)
double transfer-encoding	`POST;Transfer-Encoding: identity\r\nTransfer-Encoding: chunked\r\n`	Cloudflare-Tomcat CloudFront-Tomcat Cloudflare-Akamai (truncated)
various method version combinations	`OPTIONS-0.9;Content-Length:5\r\n`	HAProxy-Squid Akamai-Squid

Evaluation

- **Request body mutation categories**

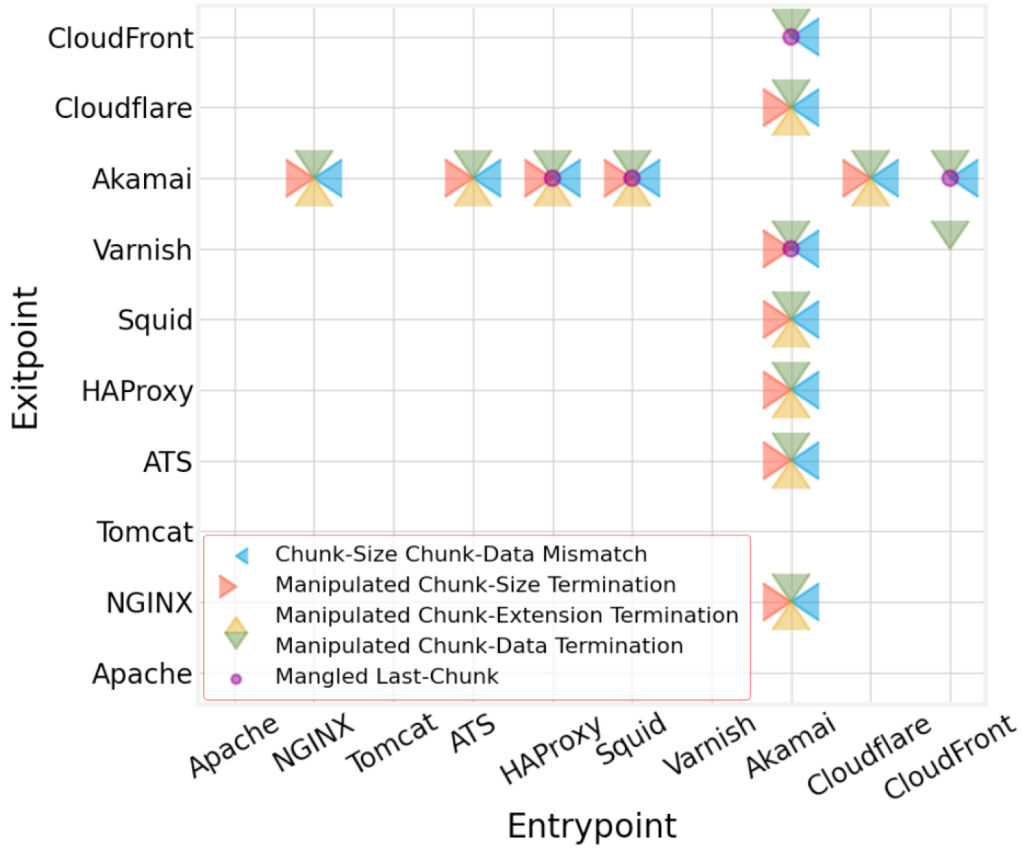


Figure 4: Request body mutation categories affecting server pairs.

Table 8: Examples for each request body mutation category.

Category	Request Body	Entrypoint-Exitpoint
chunk-size chunk-data mismatch	`4\r\nBBBB \r\n0\r\n\r\n`	Akamai-NGINX Akamai-Varnish (truncated)
manipulated chunk-size termination	`4\t\nBBBB \r\n0\r\n\r\n`	Cloudflare-Akamai Squid-Akamai (truncated)
manipulated chunk-extension termination	`4;foo=bar\r\nBBBB \r\n0\r\n\r\n`	Akamai-Cloudflare Akamai-ATS (truncated)
manipulated chunk-data termination	`4\r\nBBBB\r\n4 \r\nBBBB \r\n0\r\n\r\n`	CloudFront-Varnish Akamai-Varnish (truncated)
mangled last-chunk	`4\r\nBBBB \r\n20\r\n\r\n`	HAProxy-Akamai Squid-Akamai (truncated)

Evaluation

➢ Determining Discrepancy HRS Potential

- Set up lab to position every unique server pair as entrypoint and exitpoint on path.
- Craft a smuggler request for every mutation.

```
1 hEAD / HTTP/1.1
2 Host: example.com
3 Content-Length: 2
4
5 A␣
```

Listing 12: Smuggler request.

```
1 POST / HTTP/1.1
2 Host: example.com
3 Content-Length:5
4
5 AAAAA
```

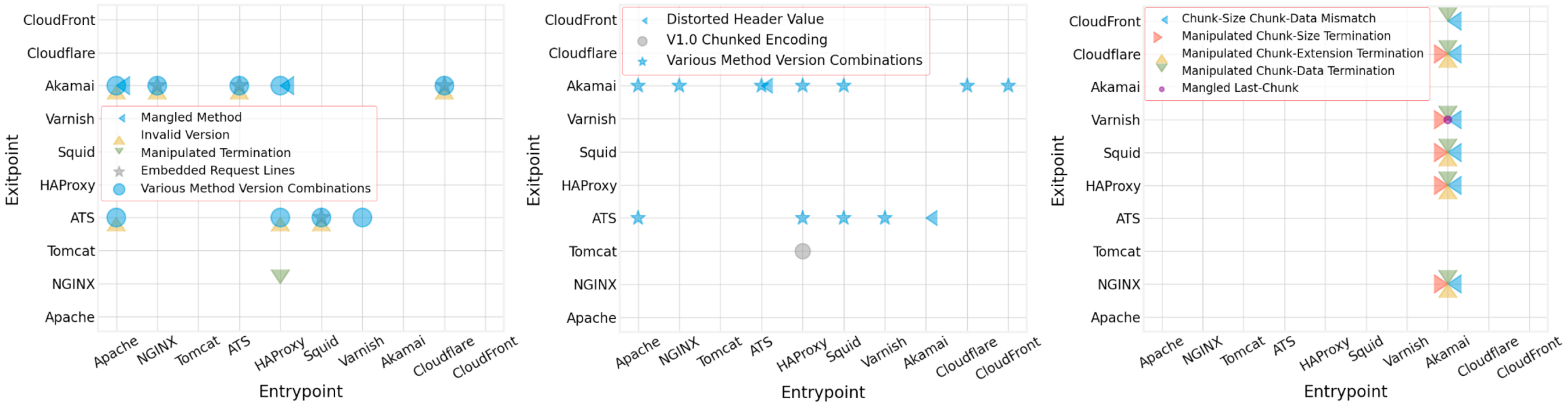
Listing 13: Benign request.

```
1 A␣POST / HTTP/1.1
2 Host: example.com
3 Content-Length:5
4
5 AAAAA
```

Listing 14: Poisoned request.

Evaluation

➢ Determining Discrepancy HRS Potential

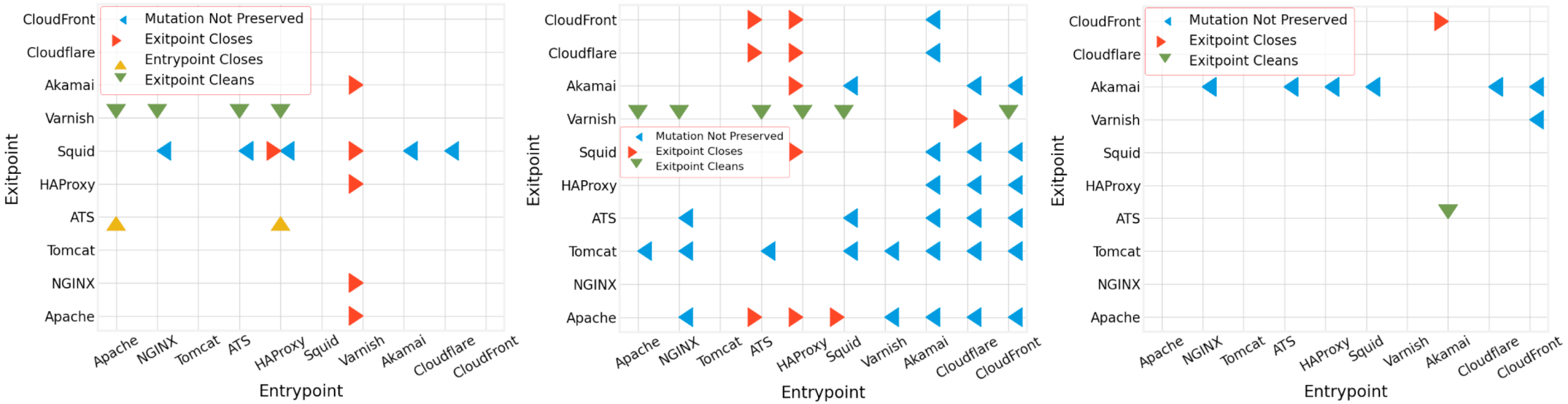


(a) Pairs affected by line mutations. (b) Pairs affected by header mutations. (c) Pairs affected by body mutations.

Figure 5: Server pairs affected by request smuggling.

Evaluation

➢ Determining Discrepancy HRS Potential

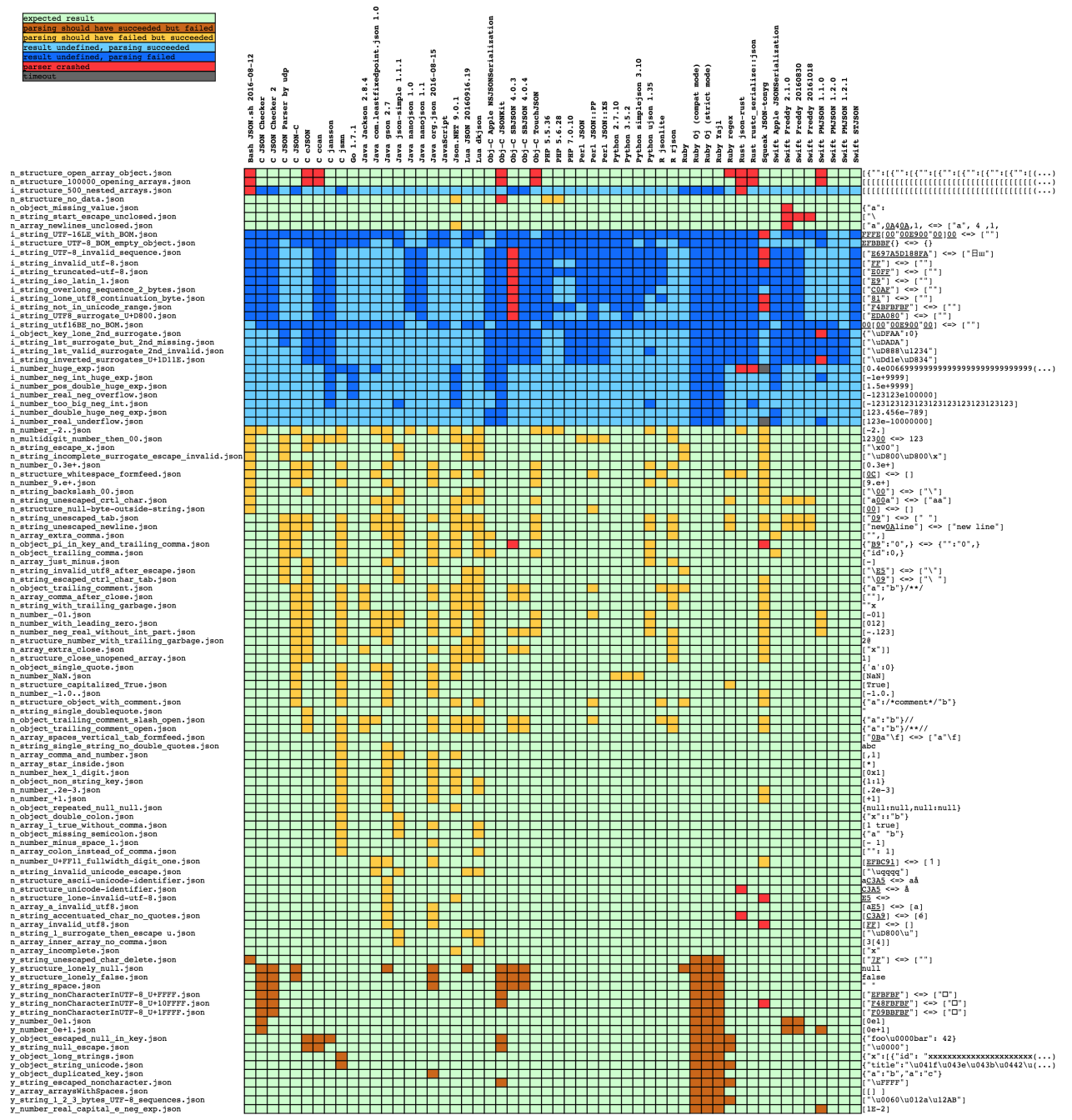


(a) Pairs affected by line mutations. (b) Pairs affected by header mutations. (c) Pairs affected by body mutations.

Figure 6: Failed request smuggling reasons for each server pair.

Recent work

- Discrepancies between parsers
  - JSON
  - XML
  - ZIP
  - HTTP
  - CAN
  - Linux kernel
- Hybridfuzz



Q&A