UNIVERSITY OF TRENTO

Hidden Web Caches Discovery

Matteo Golinelli
matteo.golinelli@unitn.it
University of Trento
Trento, Italy

Bruno Crispo
bruno.crispo@unitn.it
University of Trento
Trento, Italy

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Background: Web Caches

- Cache **public** and **static** content
- Increase **scalability**, **availability**, and **performance**
- Frequently implemented by Content Delivery Networks (**CDNs**)
  - **Geographically distributed**, physically closer to the end client

62%

of Top 10k is behind a **CDN**[1]

+ many other **stand-alone caches technologies** (e.g., Squid, Varnish, NGINX)

[1] BuiltWith. BuiltWith Technology Lookup. https://trends.builtwith.com/CDN/Content-Delivery-Network

Background: Cache Status Headers (CSH)

Used by caches to communicate whether a response is coming from the cache or from the origin server

- Are **not standardized**

CDN / Cache	Header Name(s)	*Hit* value(s)	*Miss* value(s)
Akamai	`server-timing, X-Cache, X-Cache-Remote`	`desc=HIT, TCP_HIT`	`desc=MISS, TCP_MISS`
CDN77	`X-Cache`	`HIT`	`MISS`
Cloudflare	`cf-cache-status`	`HIT`	`MISS`
CloudFront	`x-cache`	`Hit from cloudfront`	`Miss from cloudfront`
Fastly	`X-Cache`	`HIT`	`MISS`

Examples of cache status headers of popular cache technologies[2]

[2] Mirheidari, S. A., Golinelli, M., Onarlioglu, K., Kirda, E., & Crispo, B. (2022). **Web Cache Deception Escalates!**. In *31st USENIX Security Symposium (USENIX Security 22)*

Background: Cache Key

Cache key: **unique identifier** for an object in a cache

- Based on some request components (called **keyed**)
  - Domain name and path: `example.com/path/to/index.html`
  - Query string: `?id=1&order=reverse`
  - Headers: `Accept-Language: en-US,en`

↪ Cache **HIT**: the request has the **same cache key** of a previously cached request

↪ Cache **MISS**: the cache key is **different** from all the objects already in the cache

[3] Amazon AWS. **Understanding the cache key**. https://docs.aws.amazon.com/AmazonCloudFront/latest/DeveloperGuide/understanding-the-cache-key.html

Background: Cache Busting

Modify keyed elements of HTTP requests to change the cache key

- Forcefully receive a **fresh copy** of the response, instead of a cached one

Example: add random parameter to the **query string**

`https://site.com/` ➪ `https://site.com/?ran=dom`

Cache Busting Techniques

We tested different cache busting techniques on the Tranco Top 10k to identify the **most effective** ones

Cache-busting technique	Cache busted
Query string	2112 (60.4%)
`Origin` header	817 (23.4%)
`User-Agent` header	78 (2.2%)
`X-Forwarded-Host` header	327 (9.4%)
`X-Forwarded-Scheme` header	329 (9.4%)
`X-Method-Override` header	338 (9.7%)
Headers in `Vary` header	616 (17.6%)
All techniques combined	2946 (84.3%)

We can **cache-bust** requests on **84.3%** of sites

The Issue: Detect Cached Responses

Detecting cached responses is crucial to create detection methodologies for web cache vulnerabilities (Web Cache Deception, Cache Poisoning, …)

State-of-the-art methodologies to detect cached responses are based on **lookups of cache status headers**:

- **Not effective** when cache status headers are missing, wrong, or custom

Goal: Develop a methodology that detects caching **without relying** on cache status headers

Methodology: Timing Measurements

We send:

- **n** pairs of requests where both requests have random cache busters (**Randomized** group)
- **n** pairs of requests where only one request has a random cache buster (**Fixed** group)

↪ We measure the relative time difference between receiving the two responses

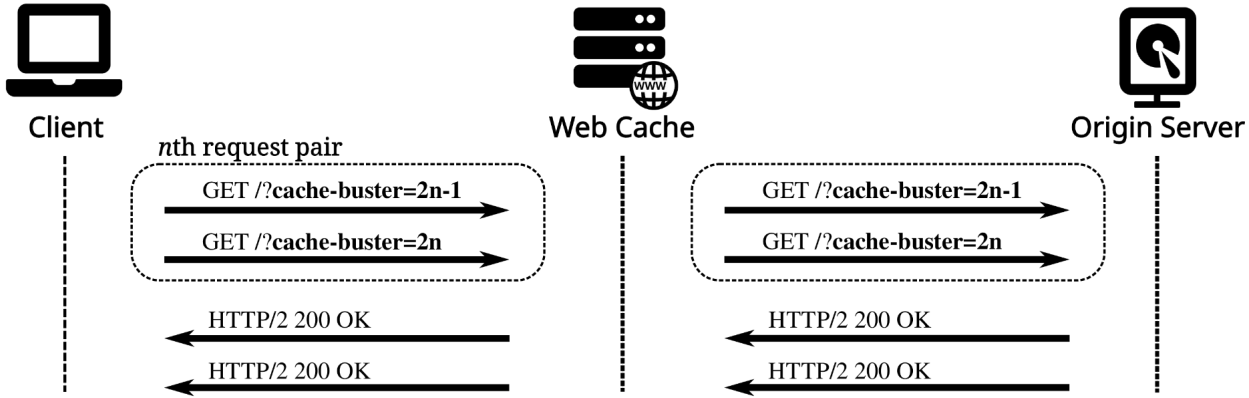
Request pairs are sent in a single packet using **HTTP/2 multiplexing**

- Based on Van Goethem et al. "Timeless Timing Attacks"[4]

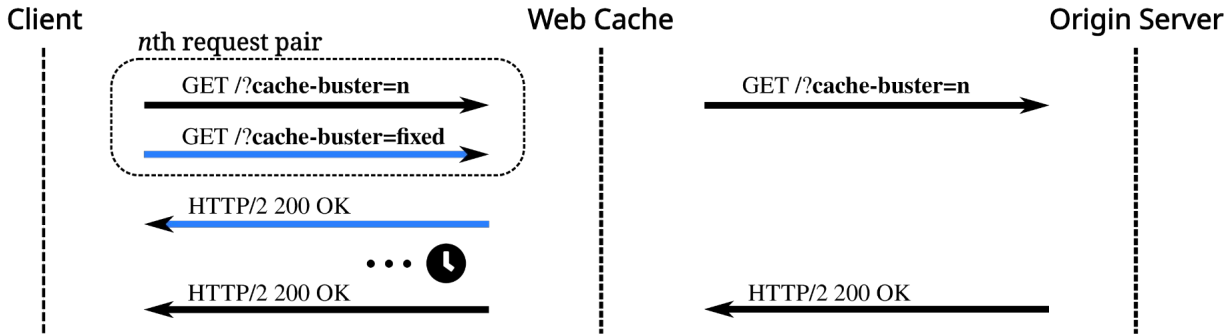
[4] Goethem, T. V., Pöpper, C., Joosen, W., & Vanhoef, M. (2020). **Timeless Timing Attacks: Exploiting Concurrency to Leak Secrets over Remote Connections**. In *29th USENIX Security Symposium*

Methodology: Overview

① Randomized group



② Fixed group



Methodology: Timing Analysis

We analyze the collected **timing differences** using a statistical test to determine whether their difference is **statistically significant** or not

- If it is: the non-cache-busted request is cached

Time measurements with cached responses

Group	Time diff. (ms)	Cache Status 1	Cache Status 2
Randomized	-60.09	MISS	MISS
	62.42	MISS	MISS
	-58.35	MISS	MISS
	67.32	MISS	MISS
	-77.45	MISS	MISS
Fixed	-600.95	MISS	HIT
	-504.63	MISS	HIT
	-591.15	MISS	HIT
	-516.49	MISS	HIT
	-536.35	MISS	HIT

Time measurements with no cached responses

Group	Time diff. (ms)	Cache Status 1	Cache Status 2
Randomized	34.37	MISS	MISS
	97.29	MISS	MISS
	-486.03	MISS	MISS
	132.2	MISS	MISS
	-325.18	MISS	MISS
Fixed	-169.52	MISS	MISS
	12.2	MISS	MISS
	-409.99	MISS	MISS
	-31.29	MISS	MISS
	217.21	MISS	MISS

Preliminary Experiment

Goal: test our methodology on sites that report caches status headers and **compare** it **to the SOTA methodology** in the Tranco Top 10k

	Number of sites	Percentage*
Analysed	1.946	19.5%
Correct classification	1.743	89.6%
Wrong classification	203	10.4%

↪ Our methodology has an **accuracy** of **89.6%**

Methodology: Accuracy

We selected **100** sites where our methodology had a **different classification** compared to the state-of-the-art methodology and **manually verified** them

- **82**/100 were due to **wrong cache status headers** (our methodology was right)

↪ The **accuracy** of our methodology is likely far higher than **89.6%**

Large-Scale Experiment

Goal: discover **hidden web caches** (caches that do not use cache status headers) in the Tranco Top 50k

	Number of sites	Percentage*
Reachable	39.159	78.3%
Tested	28.243	56.5%
No cache status headers	17.700	62.7%
Cache	1.627	5.8%
No cache	16.073	56.9%

% over tested

Vulnerabilities Detection

We use our methodology to detect how many sites with hidden caches **cache dynamic content**

- Caching dynamic content is not always an indication of a vulnerability, but in certain cases might lead to the **leakage of sensitive information**

  1.020/1.627 sites with hidden caches **cache dynamic content**

We manually investigated **35** cases:

↪ We identified **5** sites vulnerable to Web Cache Deception

Conclusions

We developed an **accurate methodology** that **detects caching** without relying on cache status headers

- Useful to create detection methodologies for web cache vulnerabilities
- Open source on https://github.com/golim/hidden-web-caches-discovery

We detected **hidden web caches on 5.8% of sites** in the Tranco Top 50k that support HTTP/2

- The same methodology can be implemented using HTTP/3

We used our methodology to find **well-hidden vulnerabilities** that would otherwise be impossible to spot and detect

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