CTX: Eliminating BREACH with Context Hiding

Dimitris Karakostas
Aggelos Kiayias
Eva Sarafianou
Dionysis Zindros

black hat EUROPE 2016

European Commission HORIZON 2020 · coda moda · Panoramix · erc

Who are we?

Dimitris Karakostas, Eva Sarafianou, Dionysis Zindros
Researchers at Security & Cryptography lab
University of Athens, Greece

Aggelos Kiayias
Chair in Cyber Security and Privacy
University of Edinburgh, Scotland

HTTPS is broken

- BREACH broke HTTPS + RC4 in 2013
- People upgraded to AES – thought they were safe
- Rupture attacked HTTPS with block ciphers
-

Today...

- We show a generic defense for compression side-channel attacks
- Best balance between compression and security
- We launch an open source implementation of the defense for popular web frameworks

Overview

- Introduction
  - History
  - Attack vectors
  - Attack demo
- The CTX defense
  - Origins, Secrets, Cross compression
  - Permutations
  - CTX architecture
  - Code examples (Python, JS)
- Release
- Defense demo
- Future work

CRIME, 2012

- Targets HTTPS requests
- Side-channel compression attacks against TLS first-time successful
- Takes advantage of the characteristics of the DEFLATE algorithm
- Hinted at attacking responses
- Mitigated by disabling compression at the TLS level

TIME, 2013

- Exploits compression on HTTP responses
- Exploits compression by measuring time transmission
- No need for permanent Man-in-the-Middle agents

BREACH, 2013

- Exploits compression on HTTP response body
- Attacks stream ciphers
- Adds methods for bypassing compression noise

RC4 insecurity, 2015

- RC4 is considered insecure
- Most websites use block ciphers
- AES is the industry standard

Rupture, 2016

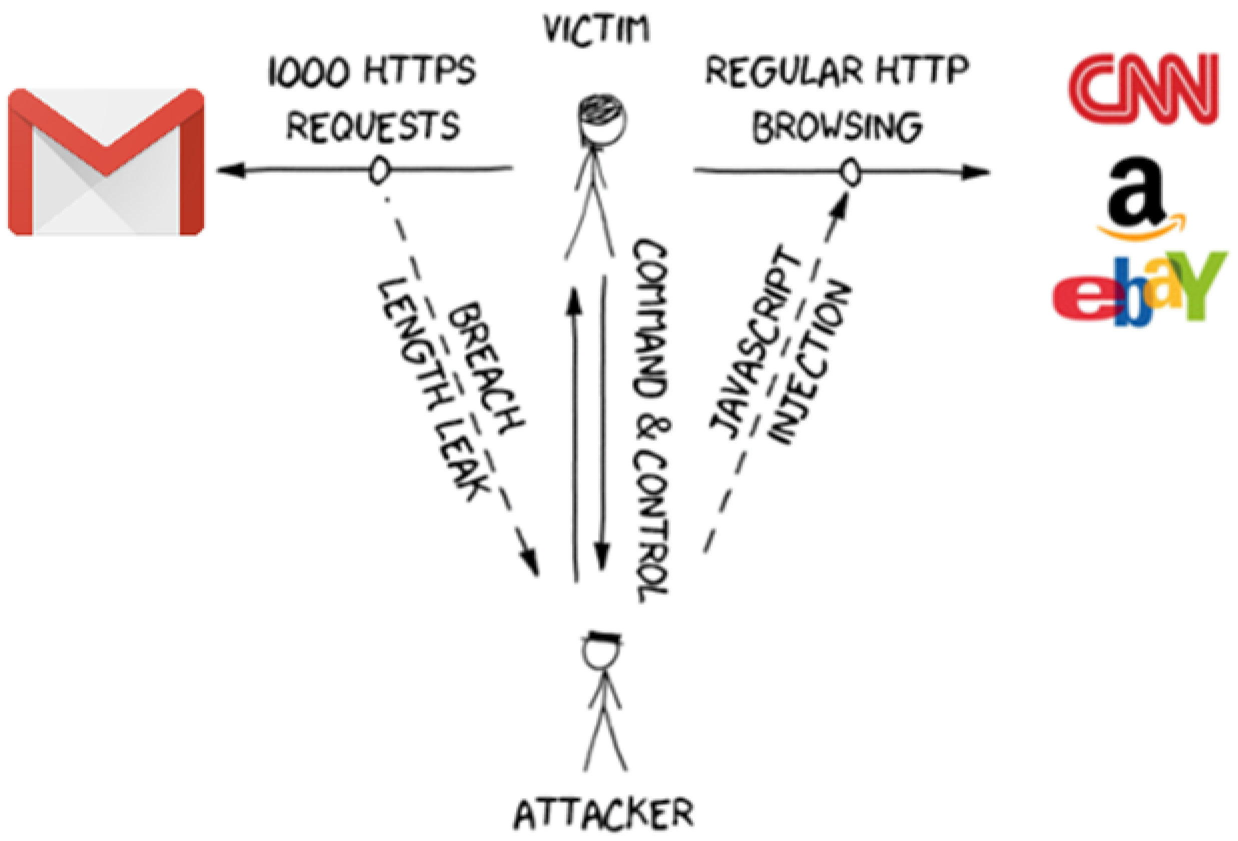
- Exploits compression on HTTP responses
- Performs statistical analysis
- Bypasses noise/length hiding
- Attacks block ciphers, eg AES
- Automates the attack process
- Production code

HEIST, 2016

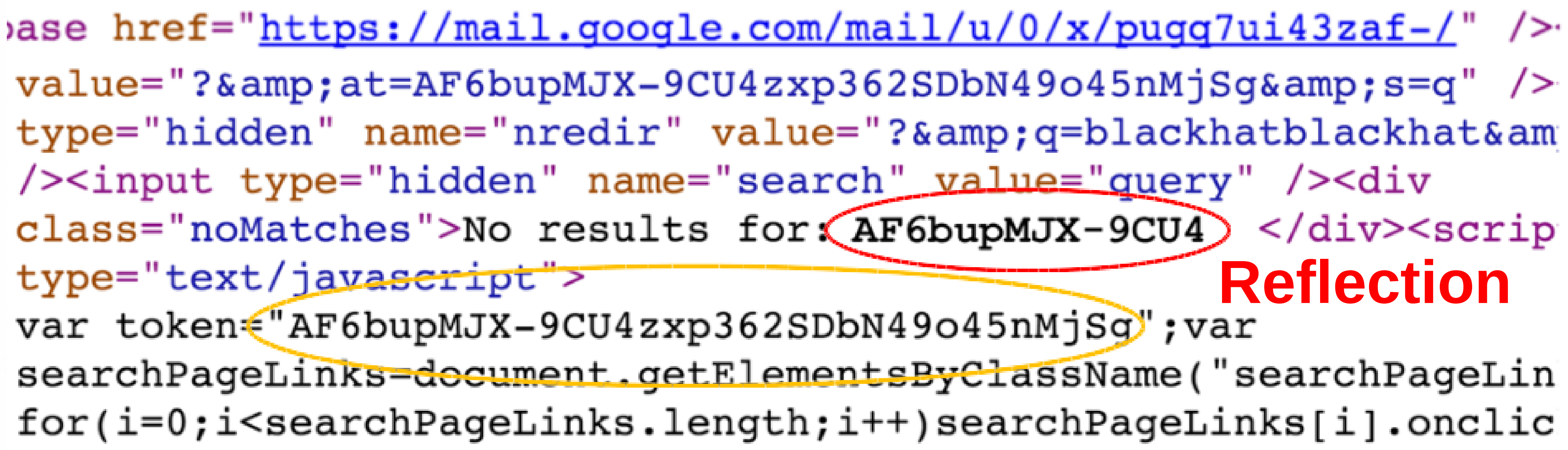
- No need for Man-in-the-Middle agents to perform BREACH
- Abuses the way responses are sent at the TCP level

Attack methodology

- Compression is better across same content
  - Example: “test_test” compresses better than “test_random”
- Method
  - Target an HTTPS website
  - Find a web page that:
    - Allows parameter *reflection*
    - Contains a *secret*
  - Issue requests with different reflections using the victim’s cookies
  - Measure the responses’ lengths
  - Decrypt the secret using statistical analysis


VICTIM
1000 HTTPS REQUESTS
REGULAR HTTP BROWSING
BREACH LENGTH LEAK
COMMAND & CONTROL
JAVASCRIPT INJECTION
ATTACKER

- Attacker guesses part of secret
- Uses it in reflection
- Compressed/encrypted response is **shorter if right**!



```
ase href="https://mail.google.com/mail/u/0/x/pugq7ui43zaf-/" />
value="?&amp;at=AF6bupMJX-9CU4zxp362SDbN49o45nMjSg&amp;s=q" />
type="hidden" name="nredir" value="?&amp;q=blackhatblackhat&am
/><input type="hidden" name="search" value="query" /><div
class="noMatches">No results for: AF6bupMJX-9CU4 </div><scrip
type="text/javascript">
var token="AF6bupMJX-9CU4zxp362SDbN49o45nMjSg";var
searchPageLinks=document.getElementsByClassName("searchPageLin
for(i=0;i<searchPageLinks.length;i++)searchPageLinks[i].onclic
```

Rupture demo

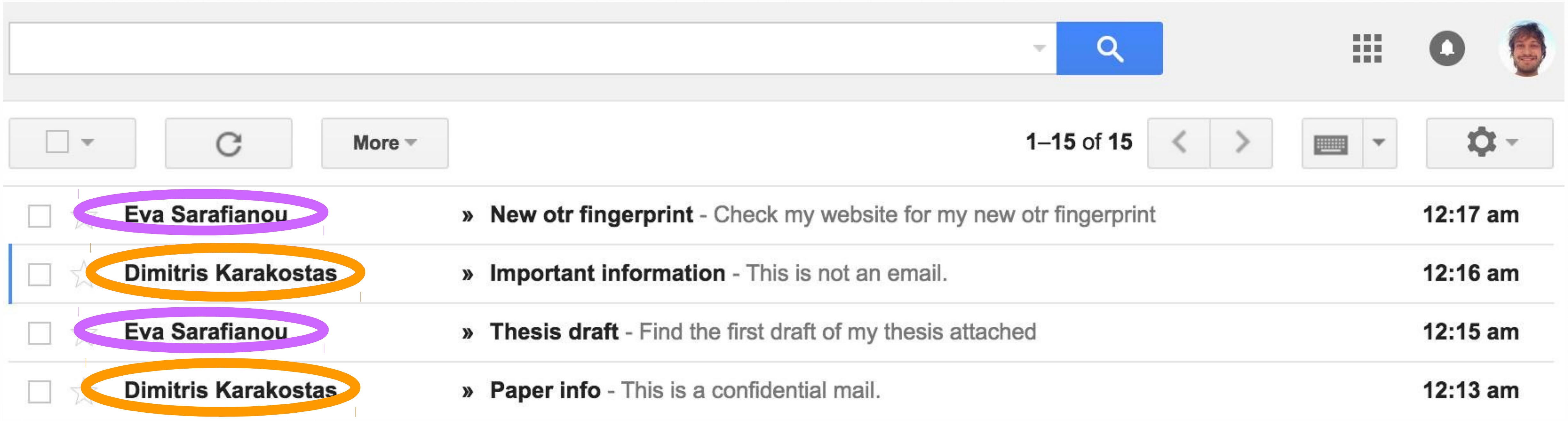
The CTX defense

CTX, Context Transformation Extension

Context hiding in a **per-origin** manner
to separate **secrets** and avoid **cross-compression**

Origin

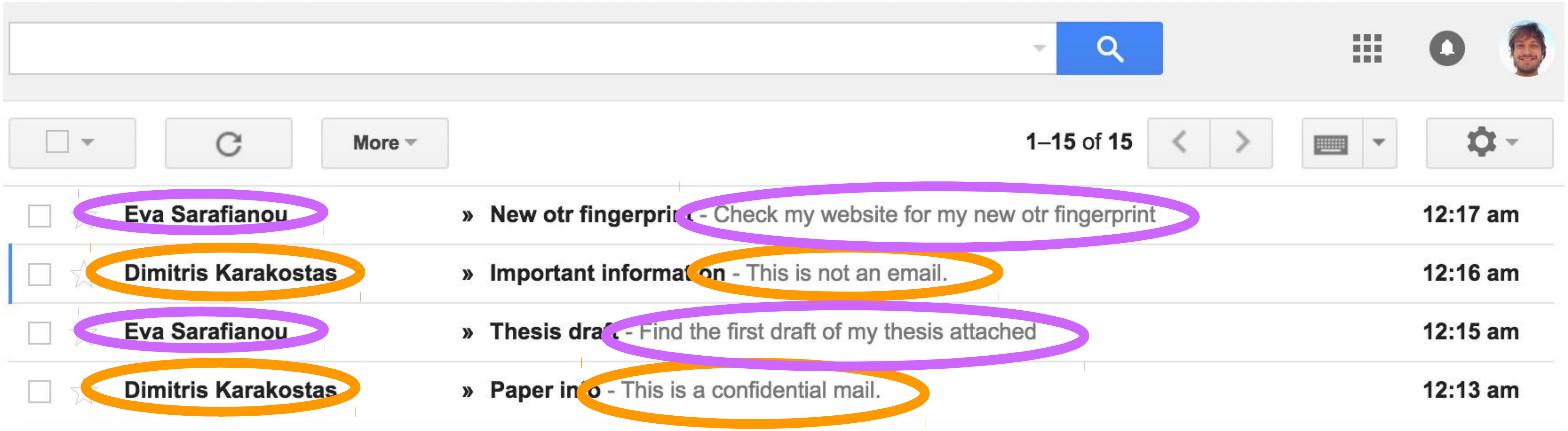
- Party that generated the secret
  - Web application
  - User
- Secrets of the same origin → Cross-compression
- Secrets of different origin → Separate compression



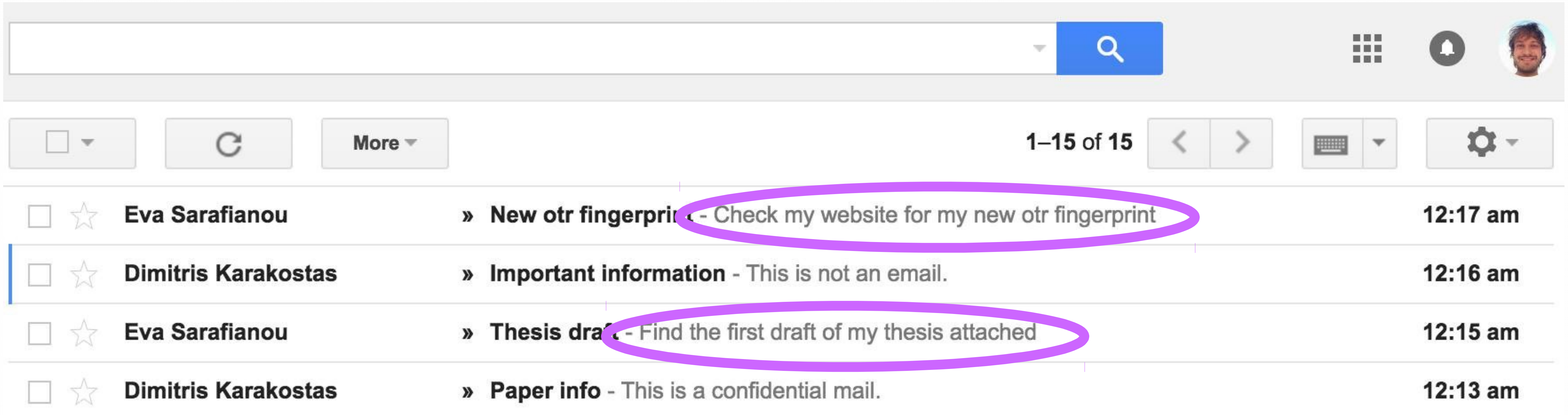
Eva Sarafianou » New otr fingerprint - Check my website for my new otr fingerprint 12:17 am
Dimitris Karakostas » Important information - This is not an email. 12:16 am
Eva Sarafianou » Thesis draft - Find the first draft of my thesis attached 12:15 am
Dimitris Karakostas » Paper info - This is a confidential mail. 12:13 am

Secret

- Parts of the response
  - CSRF tokens
  - Private messages
  - E-mails
  - Financial data
- Any piece of information which is only accessible when logged in

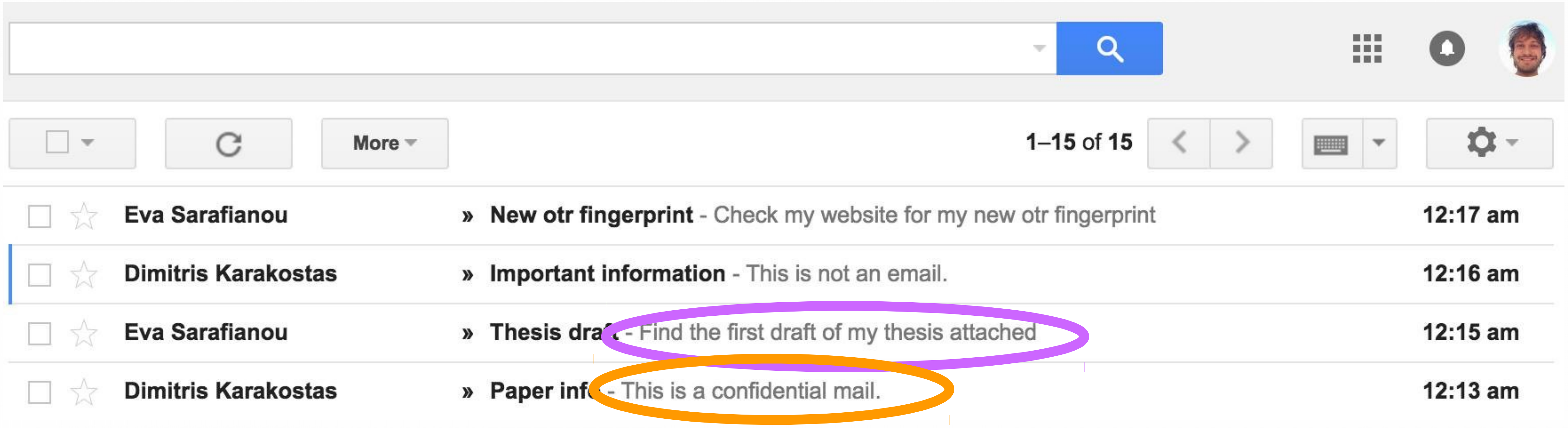


Eva Sarafianou	»	New otr fingerprint - Check my website for my new otr fingerprint	12:17 am
Dimitris Karakostas	»	Important information - This is not an email.	12:16 am
Eva Sarafianou	»	Thesis draft - Find the first draft of my thesis attached	12:15 am
Dimitris Karakostas	»	Paper info - This is a confidential mail.	12:13 am



Eva Sarafianou » New otr fingerprint - Check my website for my new otr fingerprint 12:17 am
Dimitris Karakostas » Important information - This is not an email. 12:16 am
Eva Sarafianou » Thesis draft - Find the first draft of my thesis attached 12:15 am
Dimitris Karakostas » Paper info - This is a confidential mail. 12:13 am

OK to compress together



Eva Sarafianou » New otr fingerprint - Check my website for my new otr fingerprint 12:17 am

Dimitris Karakostas » Important information - This is not an email. 12:16 am

Eva Sarafianou » Thesis draft - Find the first draft of my thesis attached 12:15 am

Dimitris Karakostas » Paper info - This is a confidential mail. 12:13 am

NOT OK to compress together!

Cross-compression

- Cross-compression between “a”, “b” → Presence of “a” affects compression of “b”
- Example:
  - LZ77 compression
  - Plaintext: a + b
  - a = “secret1”, b = “secret2”
  - Cross-compression:
    - C(a) = “secret1”, C(b) = (7, 6) + “2”
  - Separate compression:
    - C(a) = “secret1”, C(b) = “secret2”

How can we protect secrets?

- Disable compression ✗
  - Unacceptable performance penalty
- Change the compression function ✗
  - All good compression functions are vulnerable
- Modify the web server compression module ✗
  - Requires changing both the web server & application
  - Hard to achieve good compression rate
- Hide length with random padding (TLS 1.3) ✗
  - Susceptible alignment + statistical analysis (Rupture)
- Change the response plaintext ✓

CTX, Context Transformation Extension

- Protects HTTPS responses
- Runs at the application layer
- Is opt-in
- Balances between performance and security
  - Slight compression size increase
  - Small time performance overhead
  - Fully prevents complete plaintext recovery
  - Successful defense for all known compression attacks
  - (TIME, CRIME, BREACH etc)

CTX, Context Transformation Extension

Application developer must do the following:

- Import ctx library server-side (Django, Flask, Node.js …)
- Import ctx library client-side (<script src=”ctx.js”></script>)
- Select sensitive secrets
- Define origin for each secret

```
<body>
    <table>
        <tr><td>From</td><td>Body</td></tr>

        {% for email in emails: %}
            <tr>
                <td> {{ email.sender }} </td>
                <td> {{ ctx_protect(email.body, email.sender) }} </td>
            </tr>
        {% endfor %}
    </table>

    {{ ctx_permutations() }}
    <script src="ctx.js"></script>
</body>
```

```
<body>
    <table>
        <tr><td>From</td><td>Body</td></tr>

        {% for email in emails %}
            <tr>
                <td> {{ email.sender }} </td>
                <td> {{ ctx_protect(email.body, email.sender) }} </td>
            </tr>
        {% endfor %}
    </table>

    {{ ctx_permutations() }}
    <script src="ctx.js"></script>
</body>
```

Secret

Origin

Permutations

- Define secret alphabet
  - Contains all possible characters in the secret
- Pseudo-random permutation of the secret alphabet for each origin
- Fisher-Yates shuffle algorithm
- Permute secrets using the origin’s permutation
- TLS encryption and network transmission of the permuted secret
- Apply inverse permutation → Decode the secret

Secret	Origin	Permuted secret
secret1	origin1	)o5eoc8
secret2	origin1	)o5eock
secret3	origin2	heb^eV#

Origin	Permutation
origin1	s →) e → o c → 5 r → e t → c 1 → 8 2 → k 3 → # (...)
origin2	s → h e → e c → b r → ^ t → V 1 → g 2 → ! 3 → # (...)

Attack fails

- New per-origin permutations per HTTP response
- Multiple responses contain differently permuted secrets
- Permutations cannot be statistically predicted

Performance experiments

- We test size/time performance under CTX
- Test web page:
  - 650KB (e.g. Facebook/YouTube timeline)
  - 50 origins
  - 1% secrets in the response equally distributed in origins
  - 1 secret position per origin

Performance experiments

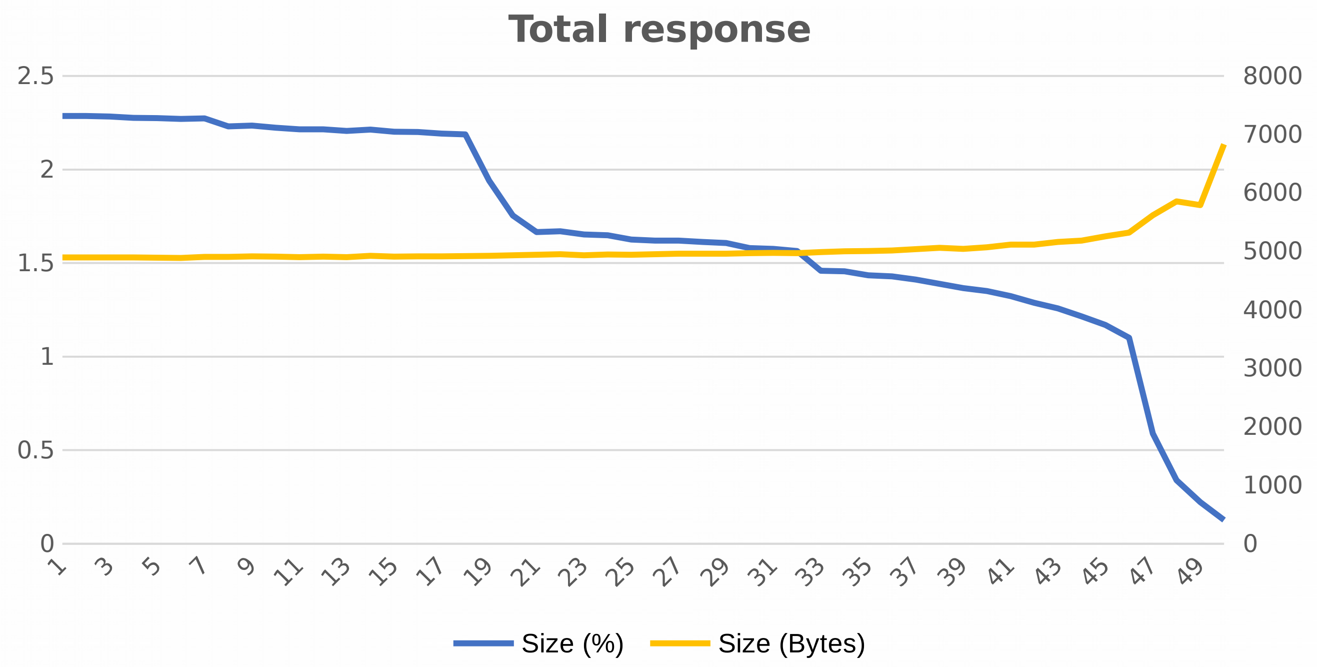
- Results:
  - Disable total compression:
    - 11,000% size overhead
    - Seconds time delay during transmission
  - CTX:
    - 5% size overhead ~ 7KB
    - 4ms time delay

Performance experiments

- Total response ↑ → Performance ↑
- Origins ↑ → Performance ↓
- Total secrets ↑ → Performance ↓
- Secrets per origin ↑ → Performance ↑

Total response performance

- Bigger response:
    - Similar byte size overhead
    - Better percentage size overhead



CTX Architecture

CTX Architecture

- Server
  - Parses HTML for ctx-protect div tags
  - Creates permutation for every new origin
  - Permutes secrets in a per-origin manner
  - Includes a JSON file with all permutations
  - Sends response containing permuted secrets and permutations

Server - Code Example

Python - Django

Context processor

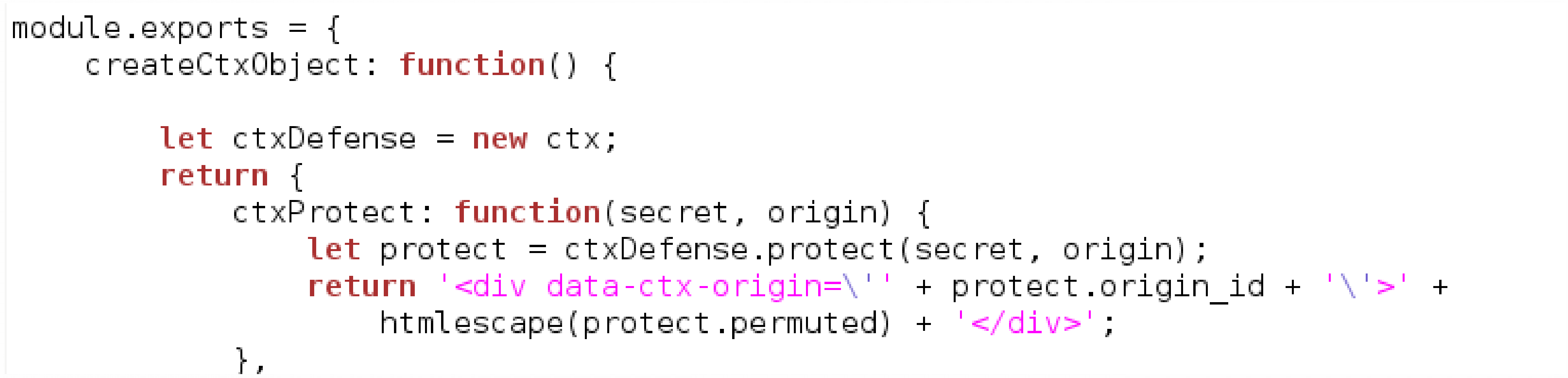
```python
@register.inclusion_tag('ctx/protected.html', takes_context=True)
def ctx_protect(context, secret, origin=None, alphabet=None):
    try:
        ctx = context['ctx']
    except KeyError:
        raise KeyError('ctx not in Template context. Is the context processor for ctx properly set?')

    # HTML escape is on by default in Django, but just in case force it anyway
    protected_secret = escape(ctx.protect(secret, origin, alphabet))

    return protected_secret
```

HTML template

```html
<div data-ctx-origin='{{ origin_id }}'>{{ permuted }}</div>
```

Server – Code Example

Node.js



```
module.exports = {
    createCtxObject: function() {

        let ctxDefense = new ctx;
        return {
            ctxProtect: function(secret, origin) {
                let protect = ctxDefense.protect(secret, origin);
                return '<div data-ctx-origin=\'' + protect.origin_id + '\'>' +
                    htmlescape(protect.permuted) + '</div>';
            },
```

Client

- Parses the HTML for data−ctx−origin div tags
- Parses the JSON and collects each origin’s permutation
- Applies reverse permutation on each secret

Today, we defend BREACH attacks

- Today in Black Hat Europe 2016, we launch CTX for popular web frameworks
  - Python: Django, Flask
  - Node.js: Express [express-Handlebars, pug (jade), EJS], Koa [koa-pug]
- Open source - MIT licensed

https://github.com/dimkarakostas/ctx

https://ctxdefense.com

CTX Defense demo

Future Work

- Implement CTX for other languages/web frameworks
- Extend CTX for other encoding standards
- Implement CTX for API web frameworks

Key Takeaways

1. HTTPS + gzip = broken
2. CTX provides full security
3. Add CTX protection to your web applications

Thank you! Questions?

https://dimkarakostas.com

DF46 7AFF 3398 BB31 CEA7 1E77 F896 1969 A339 D2E9

http://www.kiayias.com

E5F2 7045 437B 168B 39AD 1BFA C876 8019 6DBB 04E0

https://esarafianou.github.io

2FA9 7528 9554 F1EB F5F8 675B E371 5849 8CD0 92EE

https://dionyziz.com

45DC 00AE FDDF 5D5C B988 EC86 2DA4 50F3 AFB0 46C7