# Compression Bombs Strike Back

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**June 30, Rome**

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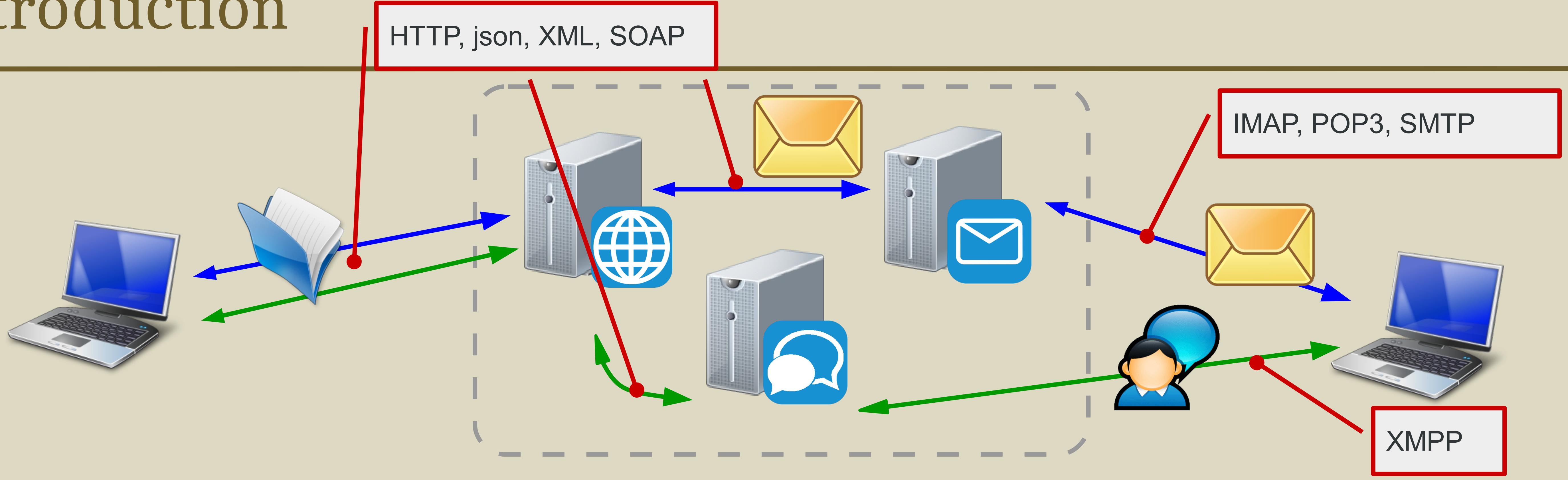
# Introduction



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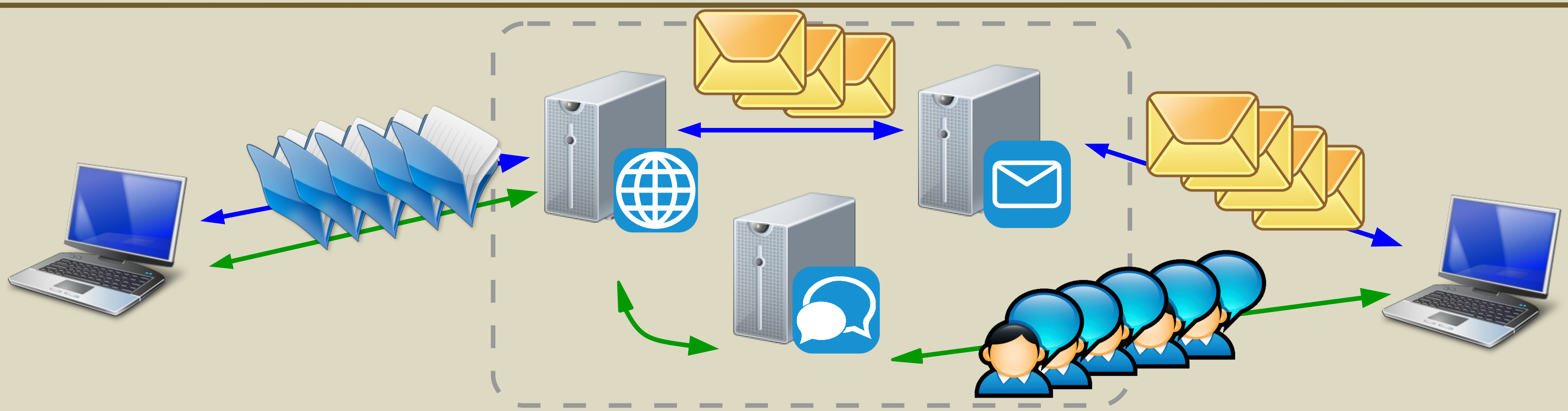

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- Amount of exchanged data continues to increase steadily
  - More data → more transfer time → unresponsiveness → user unhappiness

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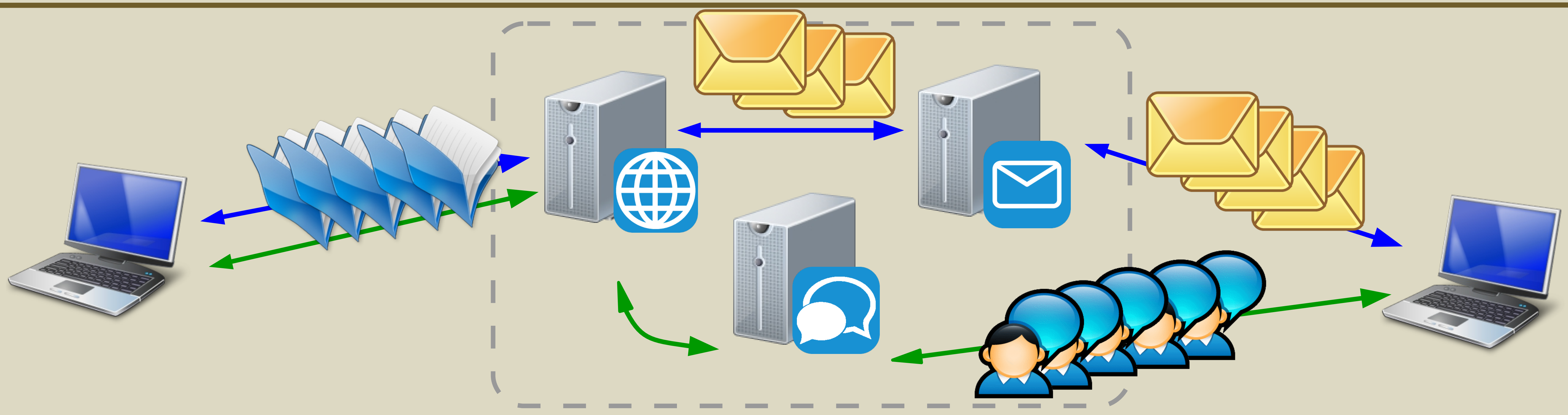

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- Amount of exchanged data continues to increase steadily
  - More data → more transfer time → unresponsiveness → user unhappiness
  - Avg web page size as Doom ~2.3MB [1]

[1] HTTP Archive: http://www.httparchive.org/interesting.php?a=All&l=Apr%201%202016

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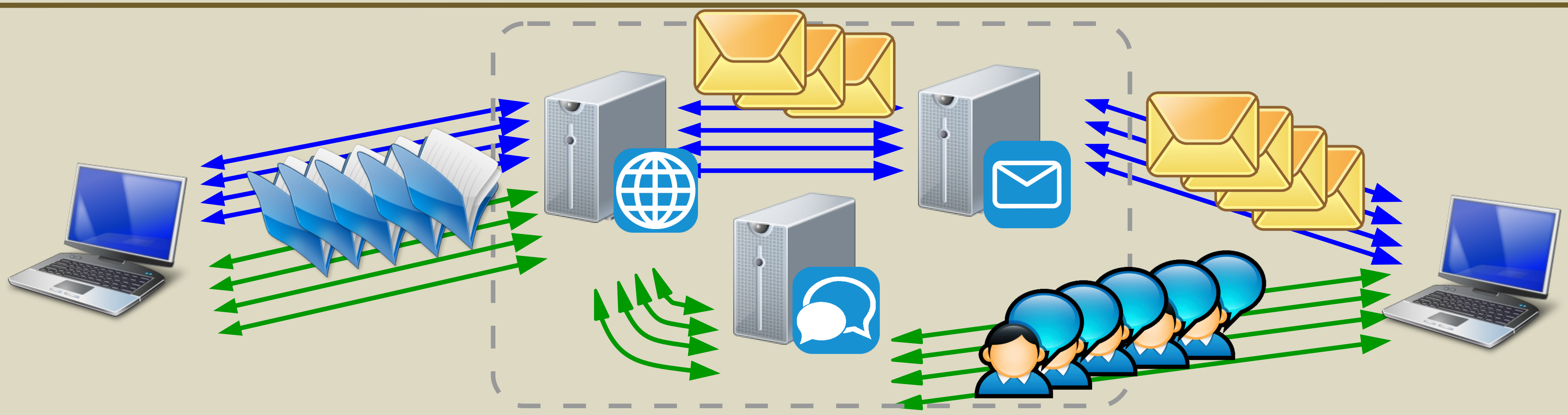

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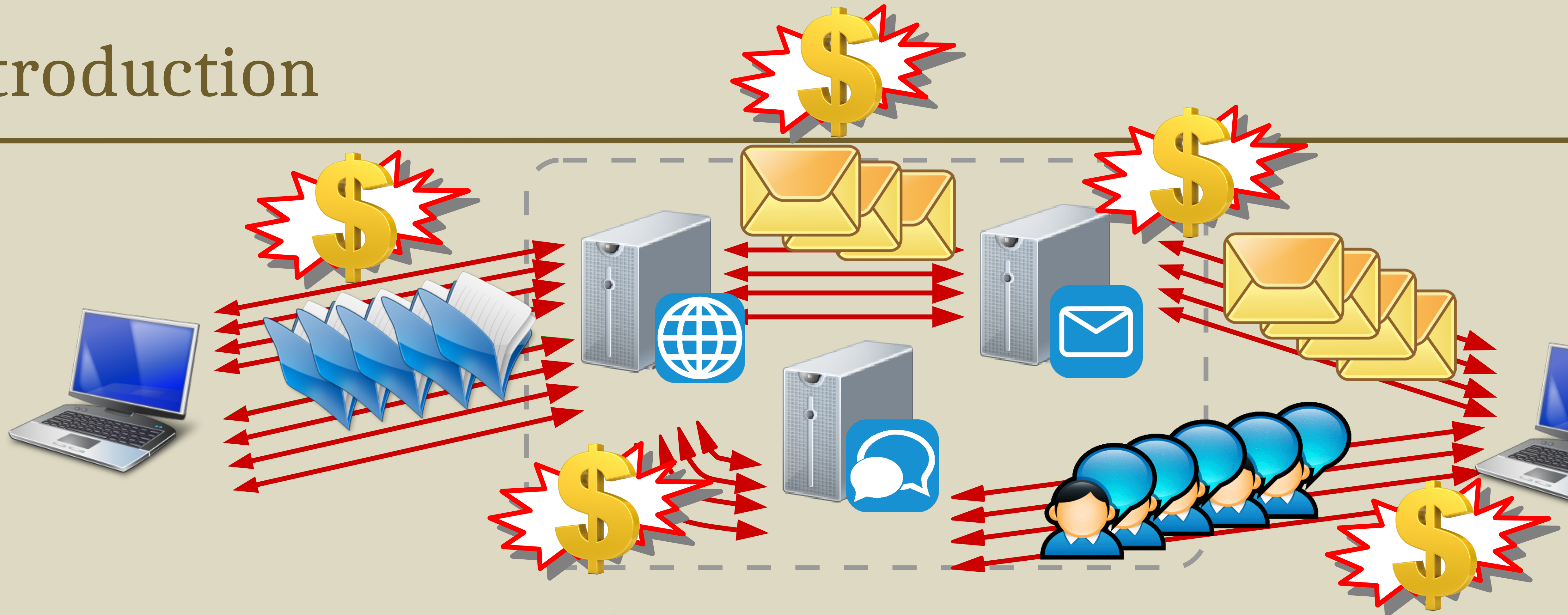

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  - ➔ Bandwidth costs

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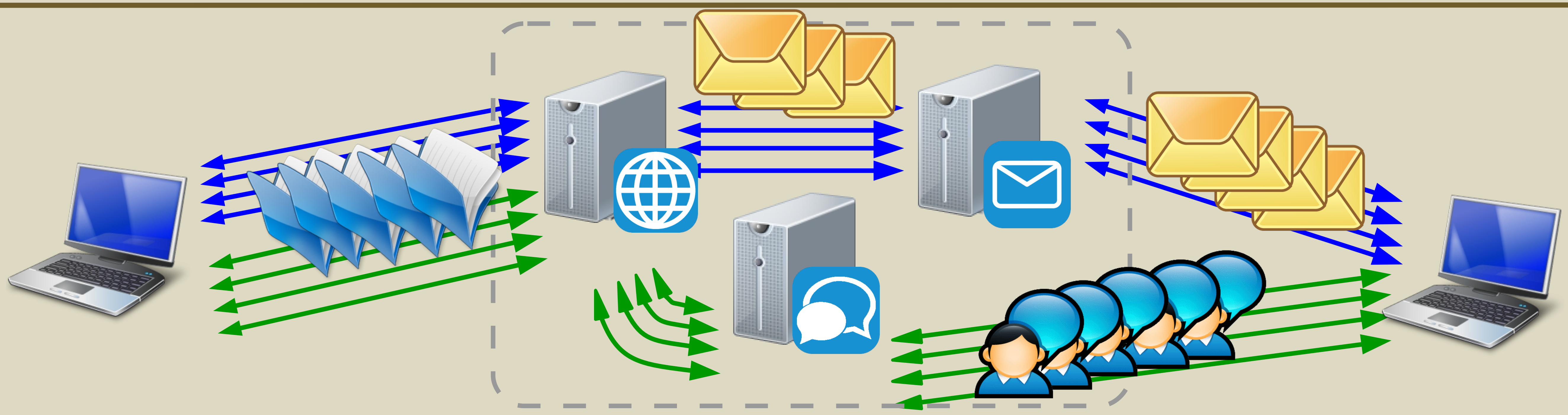

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- Another solution is …

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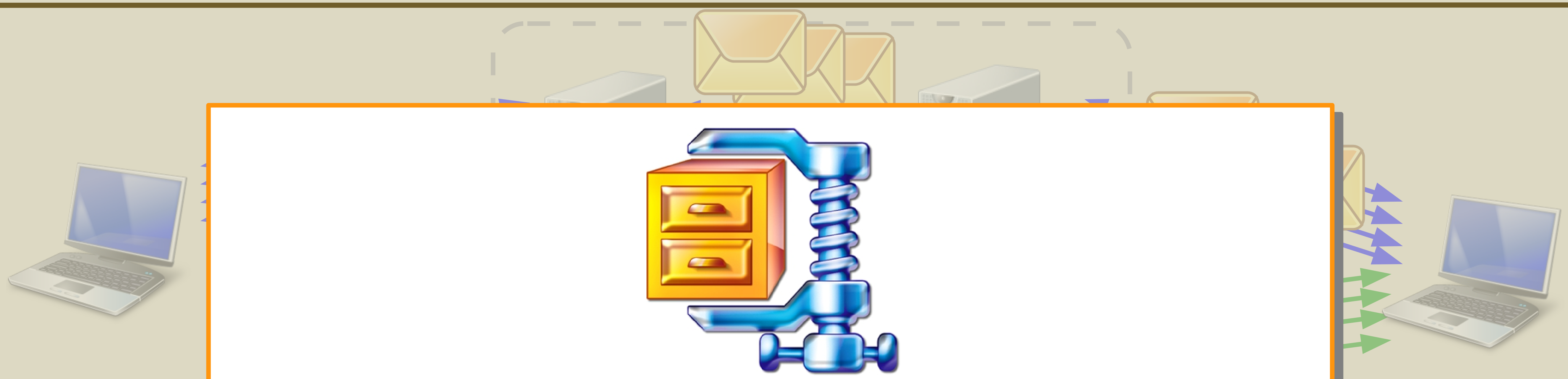
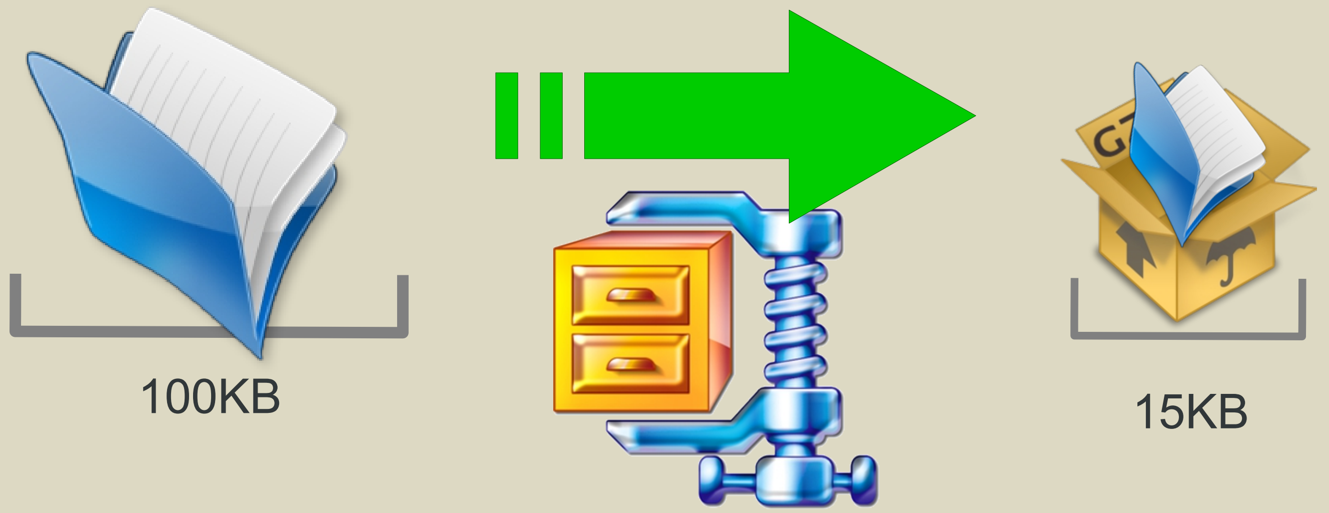


Data compression!

- Modern appli rvices
- Amount of ex
  - More data → more transfer time → unresponsiveness → user unhappiness
- Solution 1: buy more bandwidth!
  - ➔ Bandwidth costs
- Another solution is …

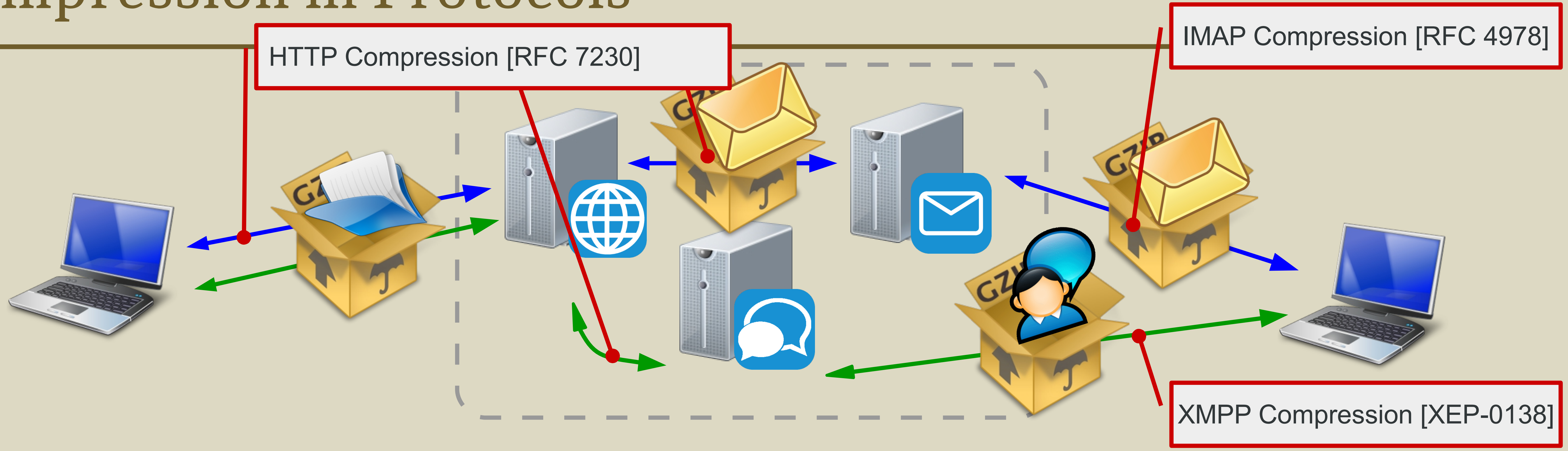
# Data Compression



- Reduces # of bits of a string by removing redundancy
  - *lossless* if `decompr(compr(`$d$`)) = `$d$ or *lossy* if `decompr(compr(`$d$`)) ~= `$d$
- Lots of algorithms (See [1])
- Among the most popular: Deflate [RFC 1951]
  - Implemented in libraries, e.g., zlib, or as a tool, e.g., gzip, and zip archive tool
  - Available in most of the programming languages

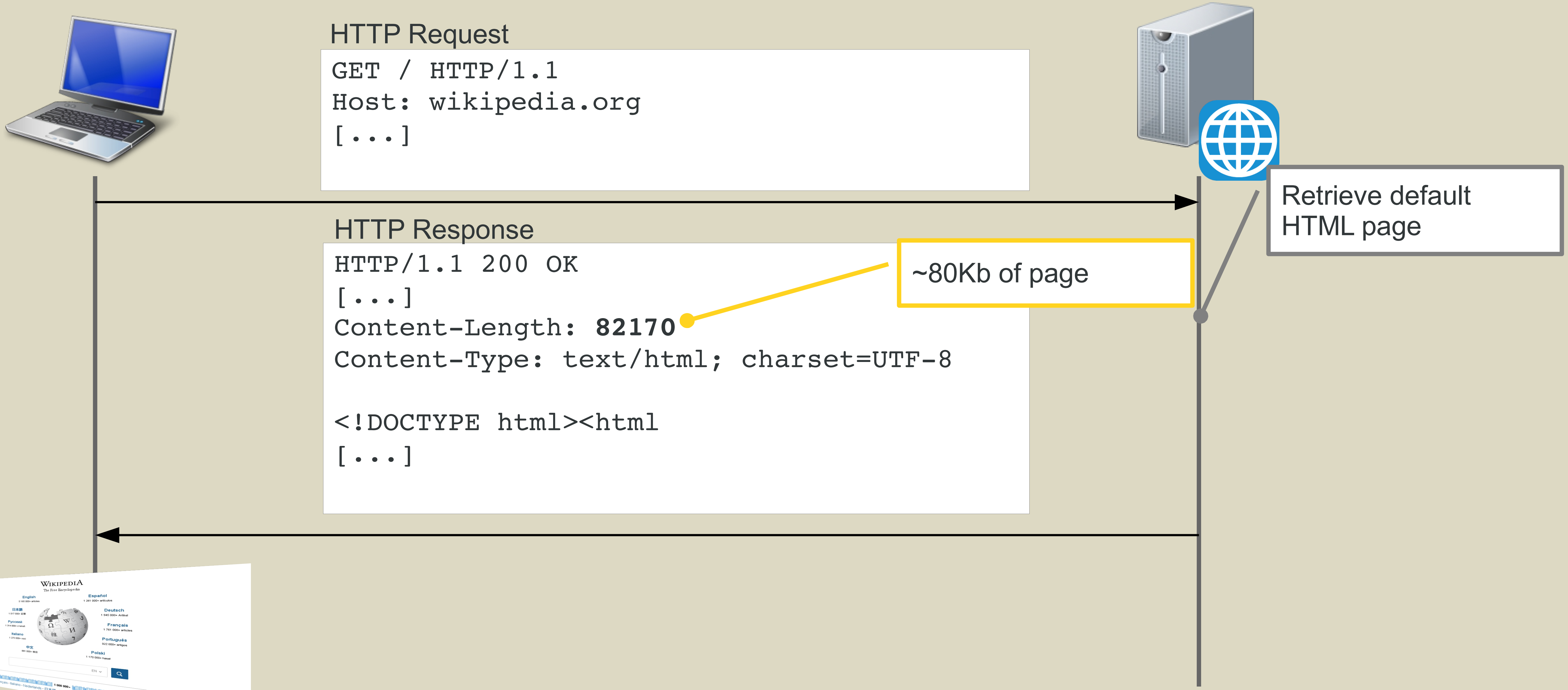
[1] SALOMON, D. Data Compression: The Complete Reference. Springer-Verlag, 2007.

# Compression in Protocols


HTTP Compression [RFC 7230]
IMAP Compression [RFC 4978]
XMPP Compression [XEP-0138]

- Compression used by network protocols to reduce message size
- Mandated by protocol specifications
  - e.g., HTTP (response!) compression, IMAP, XMPP, SSH, PPP, and others
- Or implemented as custom feature
  - e.g., HTTP request compression

# Compression in HTTP (RFC 7230)



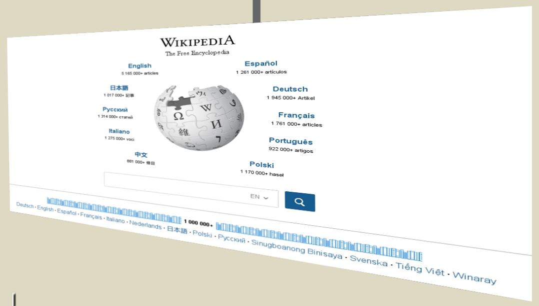
HTTP Request

```
GET / HTTP/1.1
Host: wikipedia.org
[...]
```

HTTP Response

```
HTTP/1.1 200 OK
[...]
Content-Length: 82170
Content-Type: text/html; charset=UTF-8

<!DOCTYPE html><html
[...]
```



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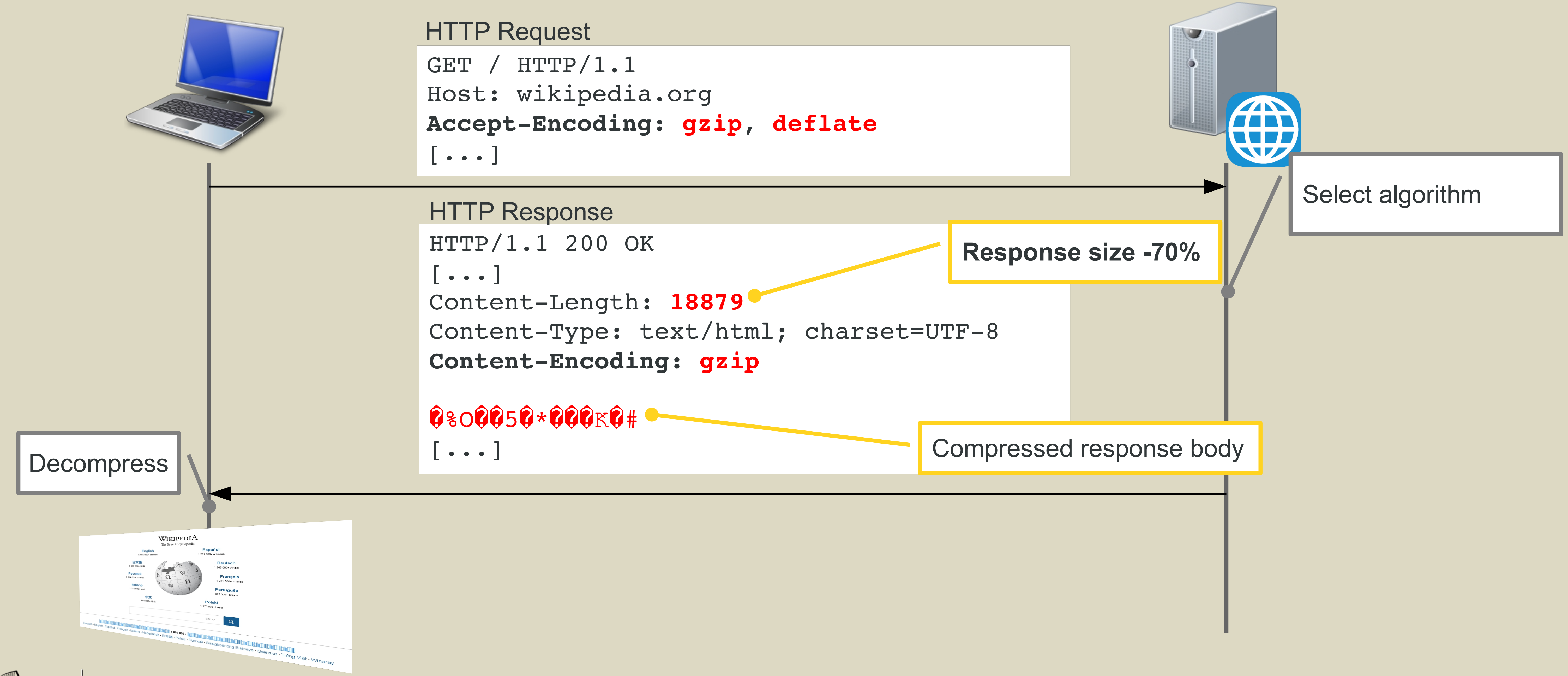


HTTP Request

```
GET / HTTP/1.1
Host: wikipedia.org
Accept-Encoding: gzip, deflate
[...]
```

HTTP Response

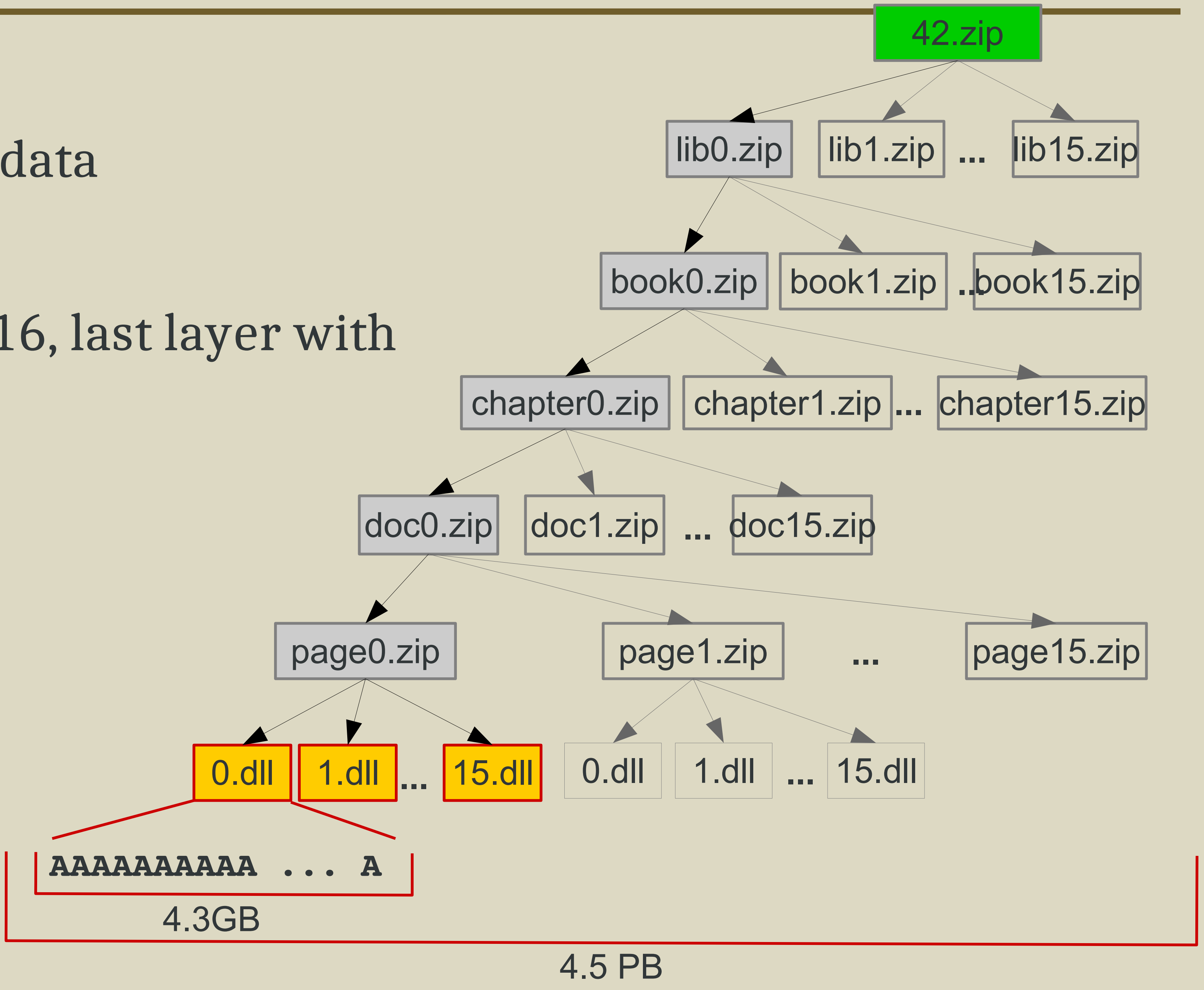
```
HTTP/1.1 200 OK
[...]
Content-Length: 18879
Content-Type: text/html; charset=UTF-8
Content-Encoding: gzip

�%O��5�*���K�#
[...]
```

## The Problem of Data Compression

- If not properly implemented, it can make application vulnerable to DoS
- Risks:
  1) **Intensive task**
     - Computationally intensive
     - If abused, it can stall an application
  2) **Data Amplification**
     - Decompression increases the data to be processed (**compression rate of zlib ~1:1024**)
     - Internal components may not be designed to handle high volume of data
  3) **Unbalanced Client-Server Scenario**
     - One party pre-compute compressed messages
     - The other one decompresses messages each time
- Popular examples from the past...

# The Past: Zip Bombs (1996)

- 42 KB zip file → **4.5 PB** uncompressed data
- 5 layers of nested zip files in blocks of 16, last layer with text files of 4.3 GB each
- Cause Disk/Memory exhaustion
- Sent as attachment to crash anti-virus software



## The Past: Billion Laughs (2003)

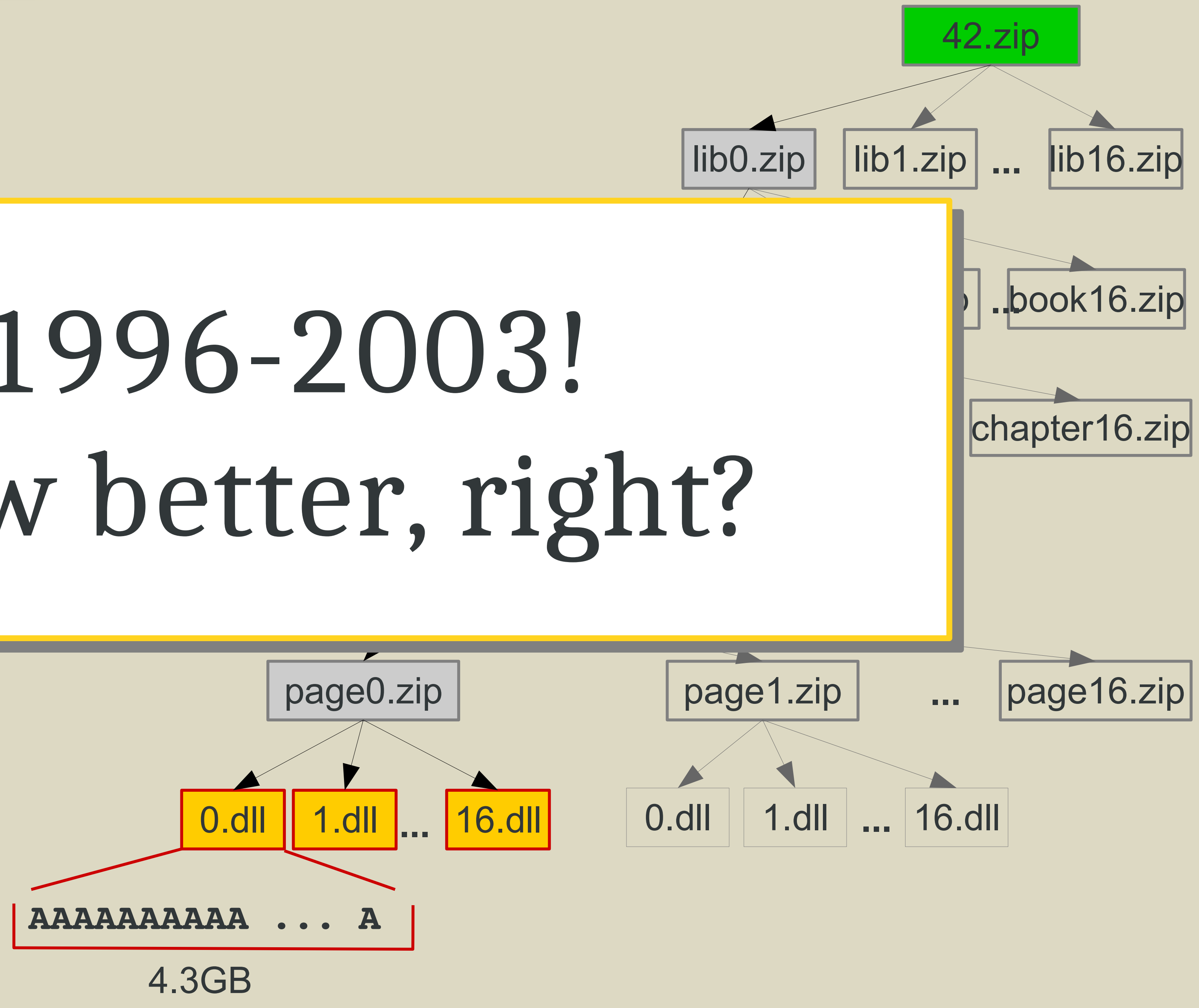
- Resource exhaustion in `libxml2` when processing nested XML entity definitions

```
<?xml version="1.0"?>
<!DOCTYPE lolz [
 <!ENTITY lol "lol">
 <!ELEMENT lolz (#PCDATA)>
 <!ENTITY lol1 "&lol;&lol;&lol;&lol;&lol;&lol;&lol;&lol;&lol;&lol;">
 <!ENTITY lol2 "&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;">
 <!ENTITY lol3 "&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;">
 <!ENTITY lol4 "&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;">
 <!ENTITY lol5 "&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;">
 <!ENTITY lol6 "&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;">
 <!ENTITY lol7 "&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;">
 <!ENTITY lol8 "&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;">
 <!ENTITY lol9 "&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;">
]>
<lolz>&lol9;</lolz>
```

- 810 bytes of XML document expanded to **3GB**

## The Past: Zip Bombs and Billion Laughs

```
<?xml version="1.0"?>
<!DOCTYPE lolz [
 <!ENTITY lo
 <!ELEMENT l
 <!ENTITY lo
 <!ENTITY lo
 <!ENTITY lo
 <!ENTITY lo
 <!ENTITY lo
 <!ENTITY lo
 <!ENTITY lo
 <!ENTITY lo
 <!ENTITY lo
]>
<lolz>&lol9;</lolz>
```



**This was 1996-2003!**
**Now we know better, right?**

## The Present

- Reviewed protocol specs, design patterns, and coding rules

  **Unawareness** of the risks, **guidelines** on handling data compression are **missing** or **misleading**

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3. Secure Coding Rules
   - Only one, i.e., Anti-Zip Bomb coding rule

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3. Secure Coding Rules
   - Only one, i.e., Anti-Zip Bomb coding rule
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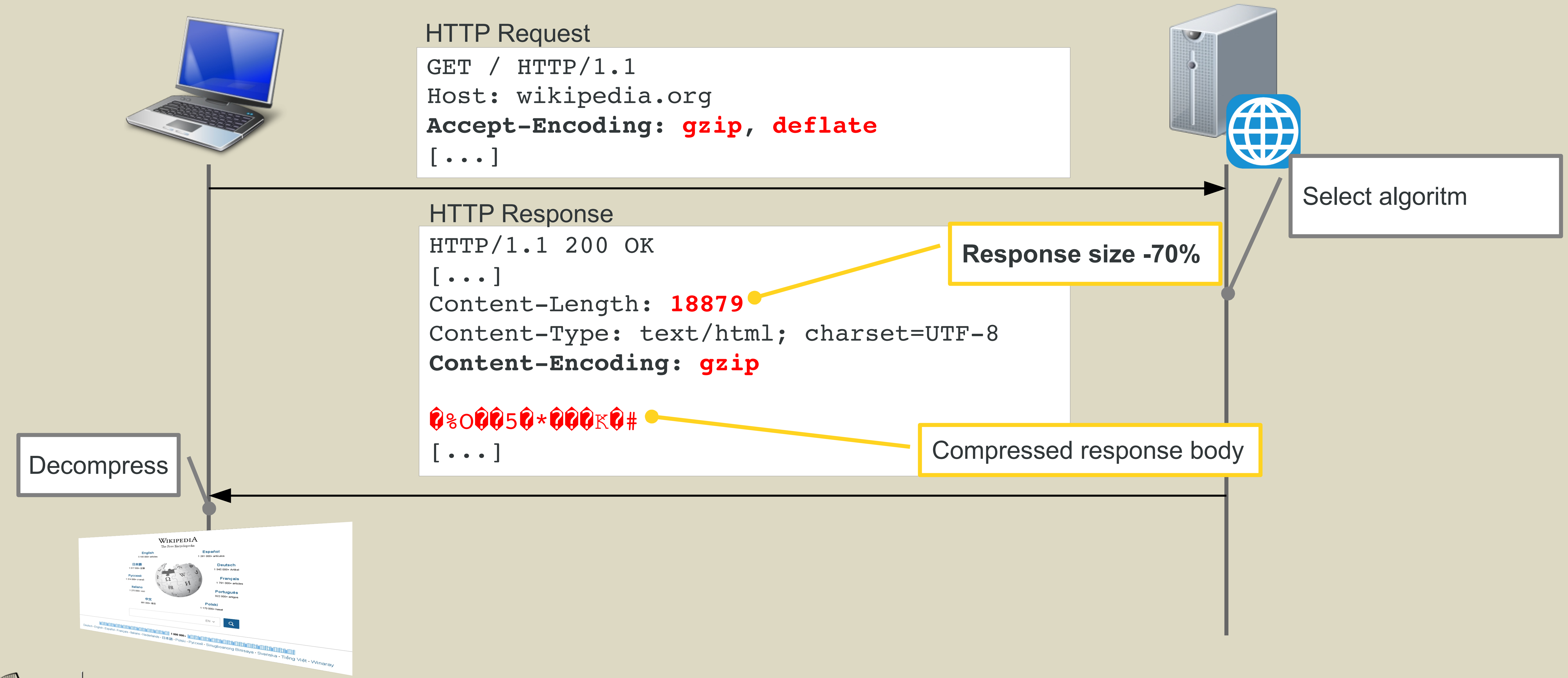
How does this lack of common knowledge and understanding affect implementations?

## Impact on Implementations

# HTTP (Response) Compression (RFC 7230)

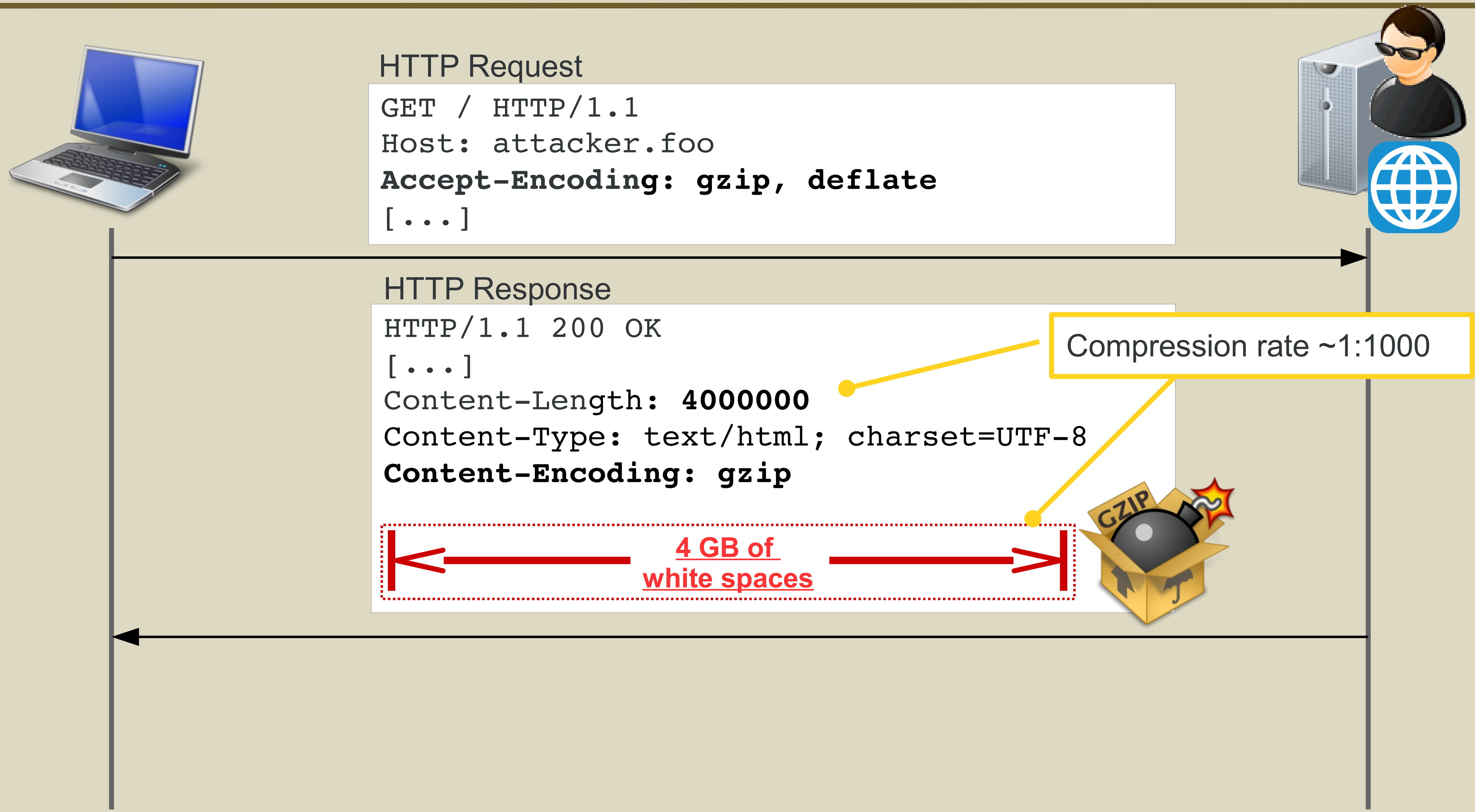


```
GET / HTTP/1.1
Host: wikipedia.org
Accept-Encoding: gzip, deflate
[...]
```

```
HTTP/1.1 200 OK
[...]
Content-Length: 18879
Content-Type: text/html; charset=UTF-8
Content-Encoding: gzip

�%O��5�*���K�#
[...]
```

# Compression Bombs against Web Browsers #1



```
GET / HTTP/1.1
Host: attacker.foo
Accept-Encoding: gzip, deflate
[...]
```

```
HTTP/1.1 200 OK
[...]
Content-Length: 4000000
Content-Type: text/html; charset=UTF-8
Content-Encoding: gzip
```

See: Geoff Jones http://blog.cyberis.co.uk/2013/08/vulnerabilities-that-just-wont-die.html

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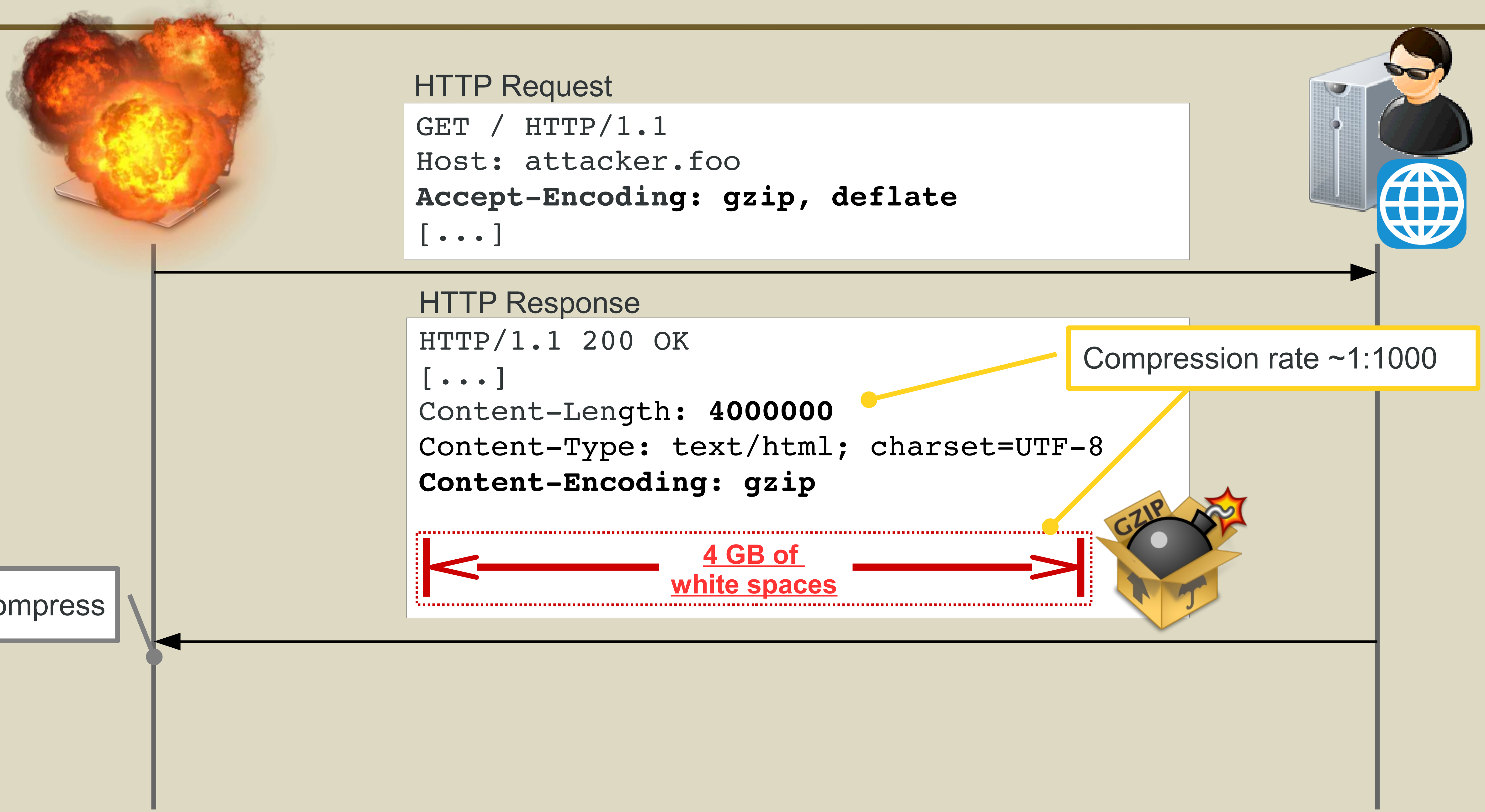

```
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Host: attacker.foo
Accept-Encoding: gzip, deflate
[...]
```

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HTTP/1.1 200 OK
[...]
Content-Length: 4000000
Content-Type: text/html; charset=UTF-8
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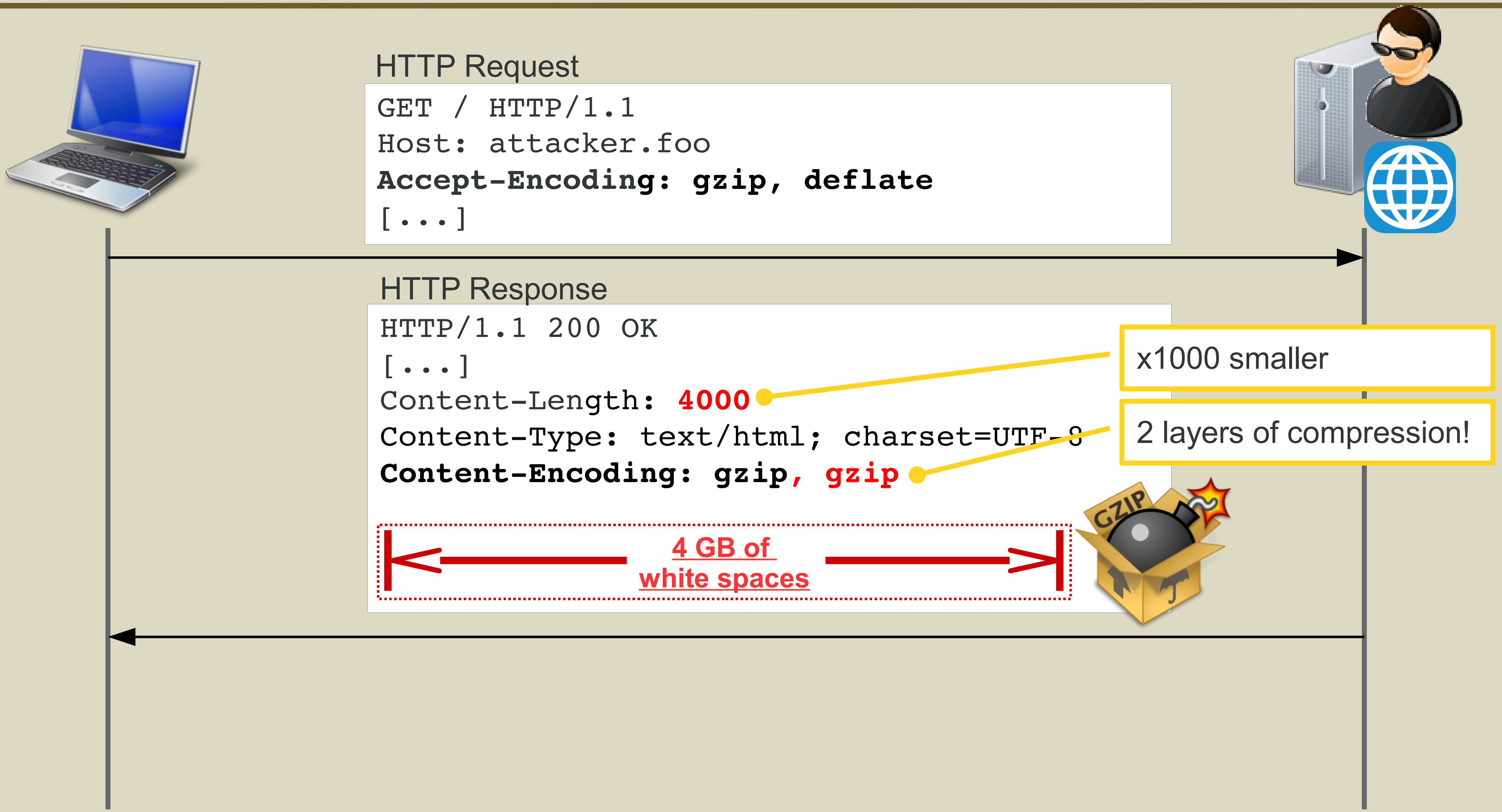
See: Geoff Jones http://blog.cyberis.co.uk/2013/08/vulnerabilities-that-just-wont-die.html

# Compression Bombs against Web Browsers #2



HTTP Request

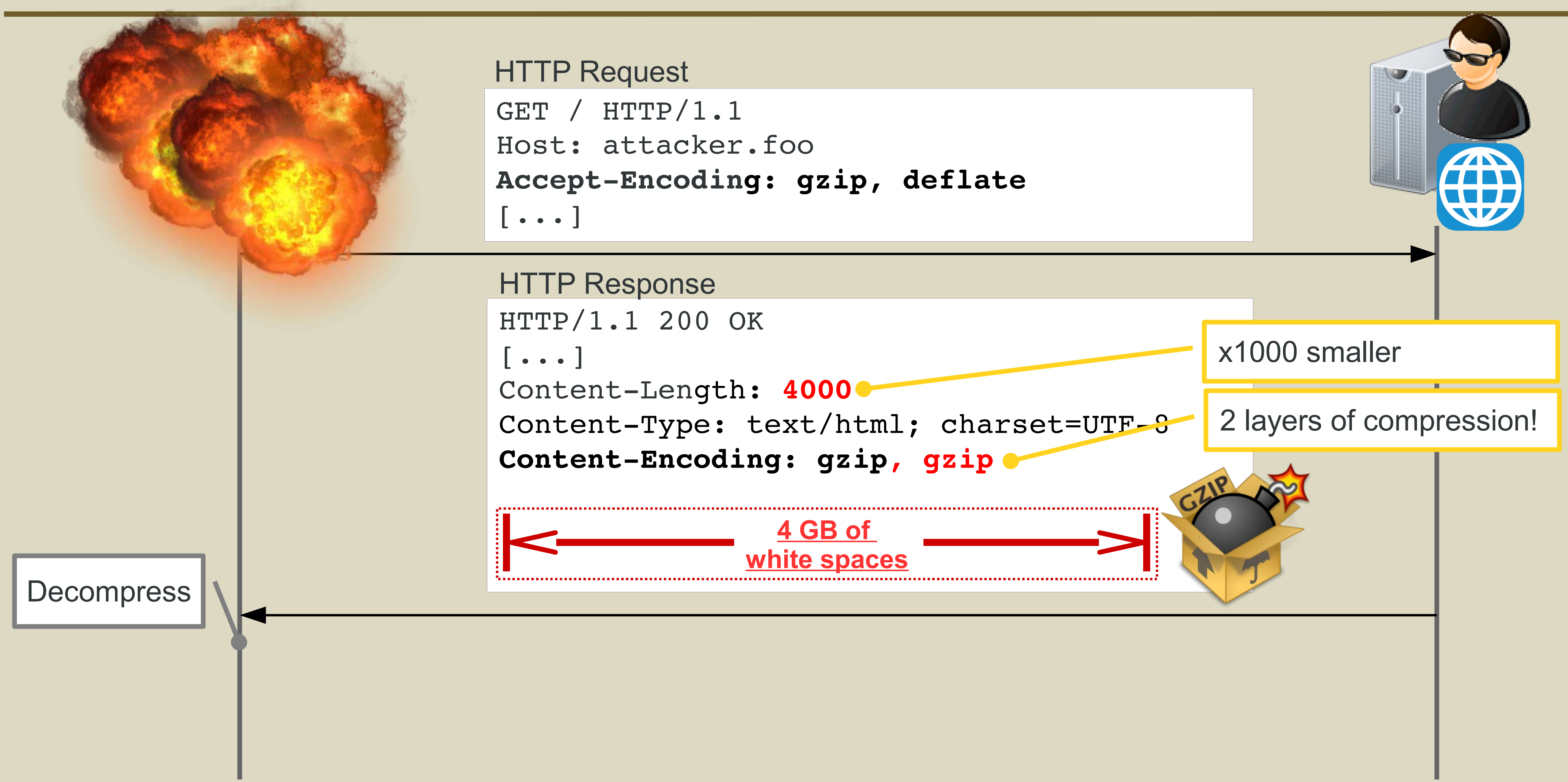
```
GET / HTTP/1.1
Host: attacker.foo
Accept-Encoding: gzip, deflate
[...]
```

HTTP Response

```
HTTP/1.1 200 OK
[...]
Content-Length: 4000
Content-Type: text/html; charset=UTF-8
Content-Encoding: gzip, gzip
```

See: Geoff Jones http://blog.cyberis.co.uk/2013/08/vulnerabilities-that-just-wont-die.html

# Compression Bombs against Web Browsers #2



HTTP Request

```
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Host: attacker.foo
Accept-Encoding: gzip, deflate
[...]
```

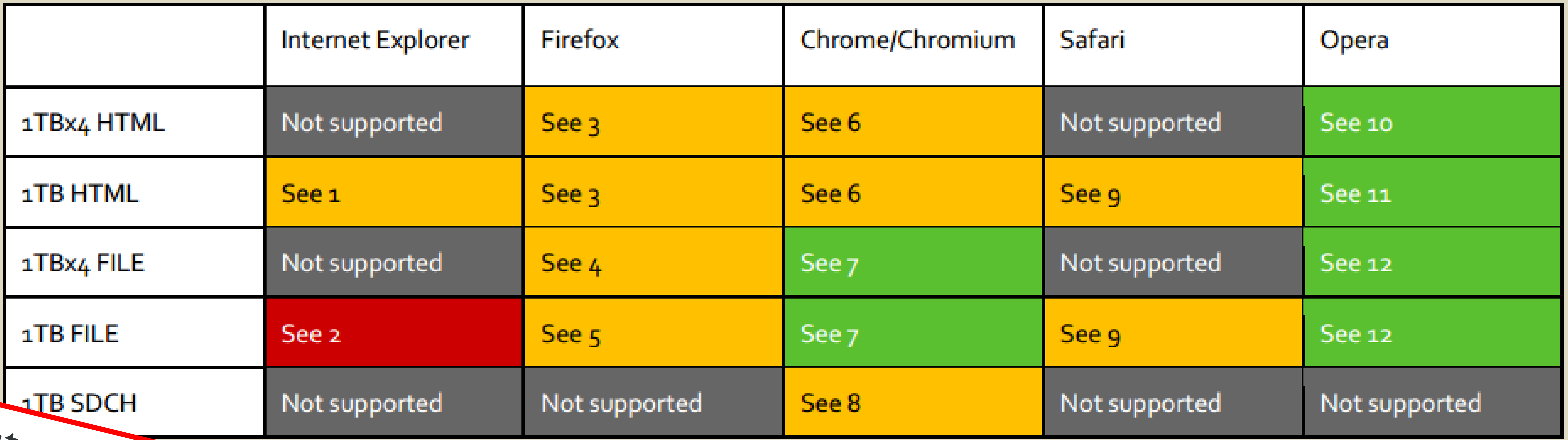
HTTP Response

```
HTTP/1.1 200 OK
[...]
Content-Length: 4000
Content-Type: text/html; charset=UTF-8
Content-Encoding: gzip, gzip
```

See: Geoff Jones http://blog.cyberis.co.uk/2013/08/vulnerabilities-that-just-wont-die.html

# HTTP (Response) Compression Bombs

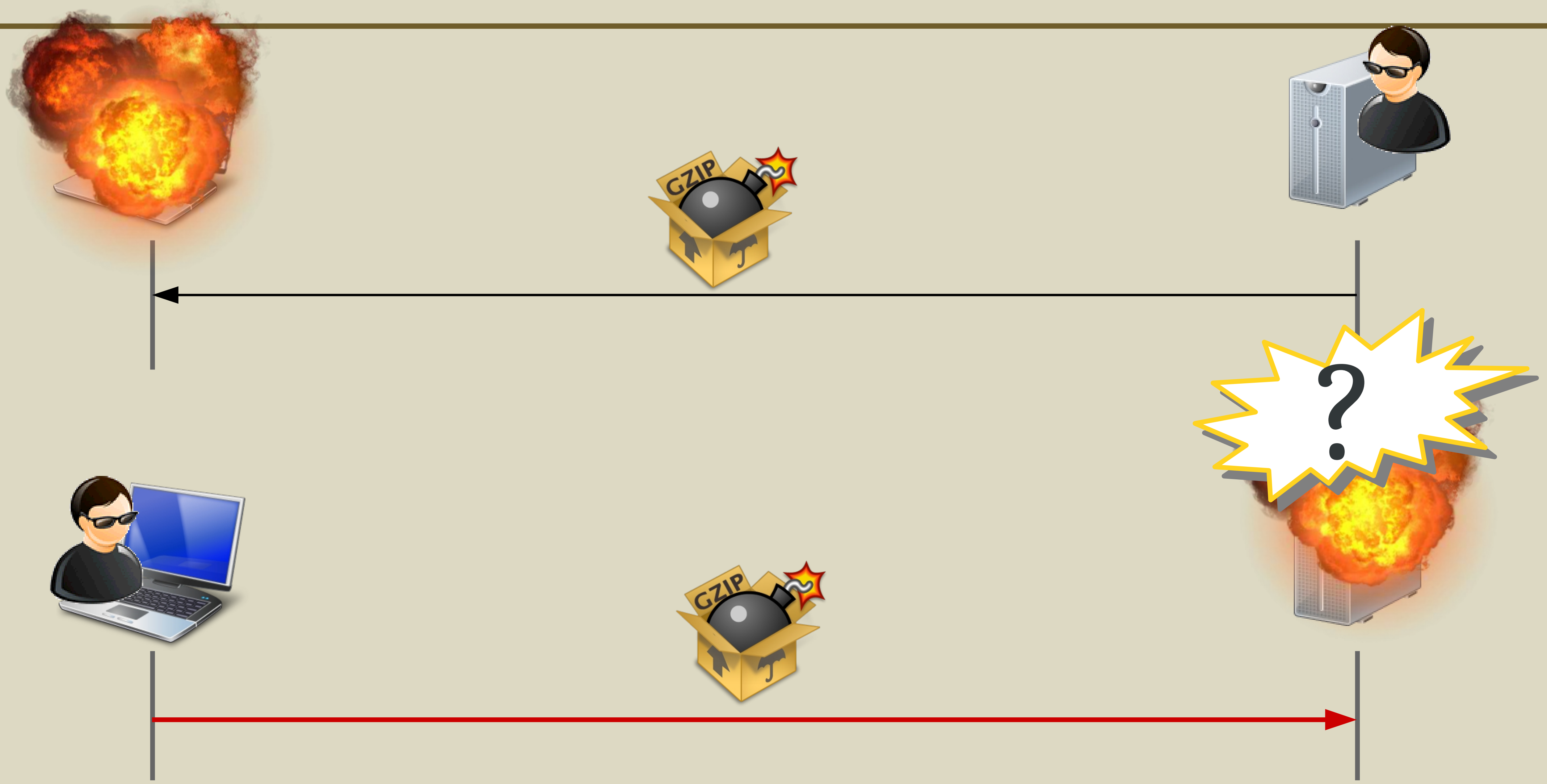
*“Vulnerabilities that just won't die - Compression Bombs”*
by Geoff Jones
http://blog.cyberis.co.uk/2013/08/vulnerabilities-that-just-wont-die.html



| | Internet Explorer | Firefox | Chrome/Chromium | Safari | Opera |
|---|---|---|---|---|---|
| 1TBx4 HTML | Not supported | See 3 | See 6 | Not supported | See 10 |
| 1TB HTML | See 1 | See 3 | See 6 | See 9 | See 11 |
| 1TBx4 FILE | Not supported | See 4 | See 7 | Not supported | See 12 |
| 1TB FILE | See 2 | See 5 | See 7 | See 9 | See 12 |
| 1TB SDCH | Not supported | Not supported | See 8 | Not supported | Not supported |

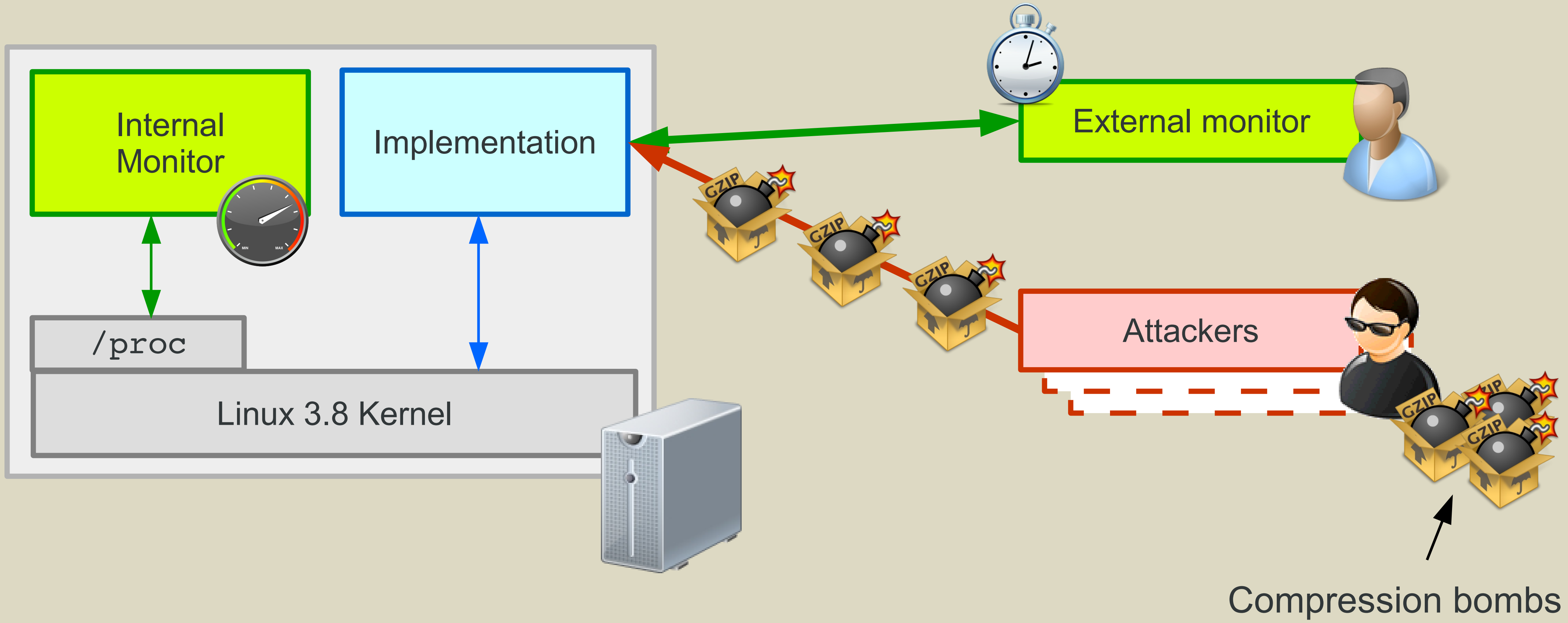
Most are still vulnerable!

# How about servers?



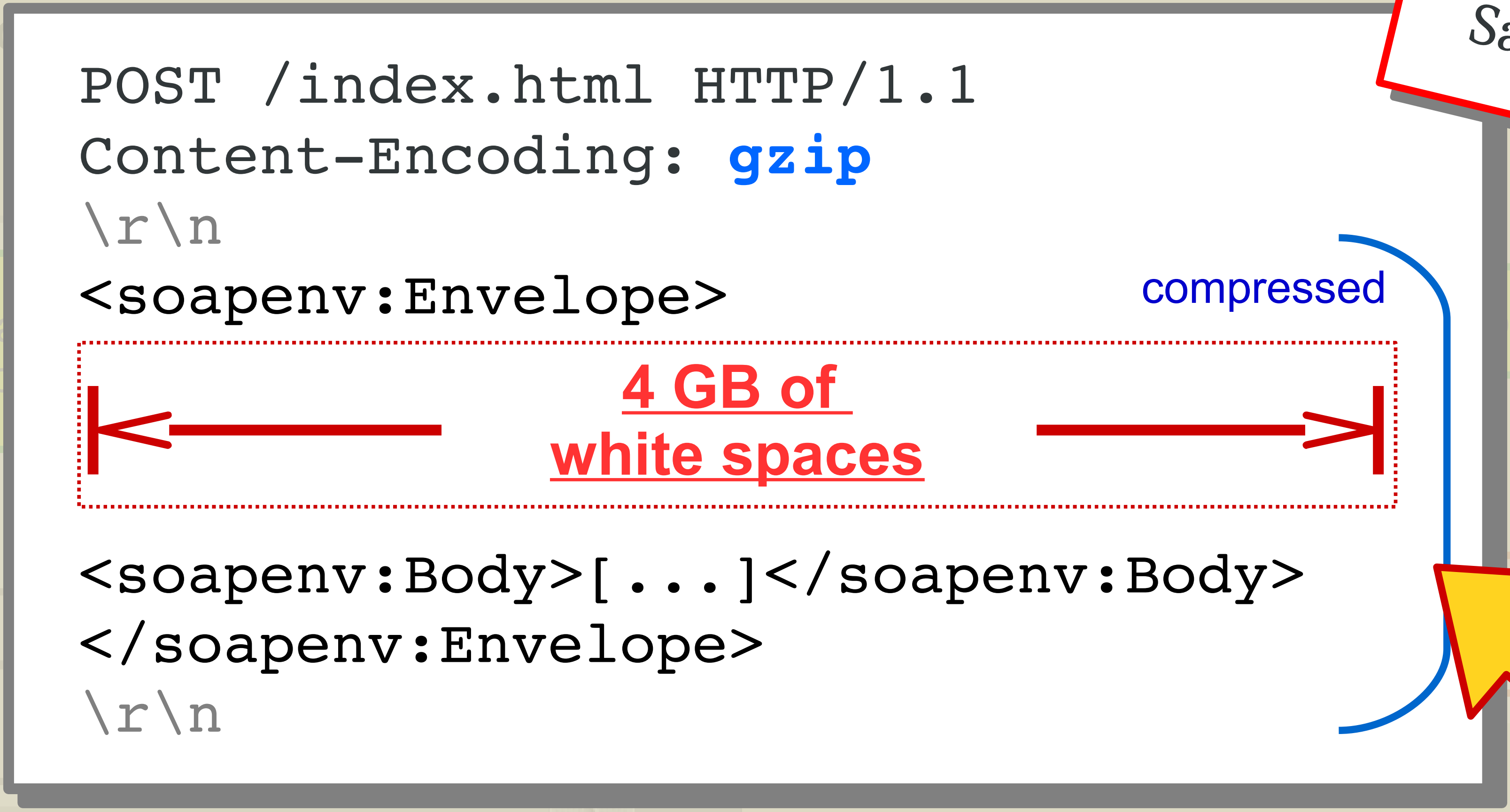
## Experiments

- Case studies:
  - HTTP, XMPP, and IMAP servers
- Testbed:



# HTTP (request) Compression Bomb (SOAP)

- Case studies:
  - HTTP, XMPP, an
- Testbed:



```
POST /index.html HTTP/1.1
Content-Encoding: gzip
\r\n
<soapenv:Envelope>
```

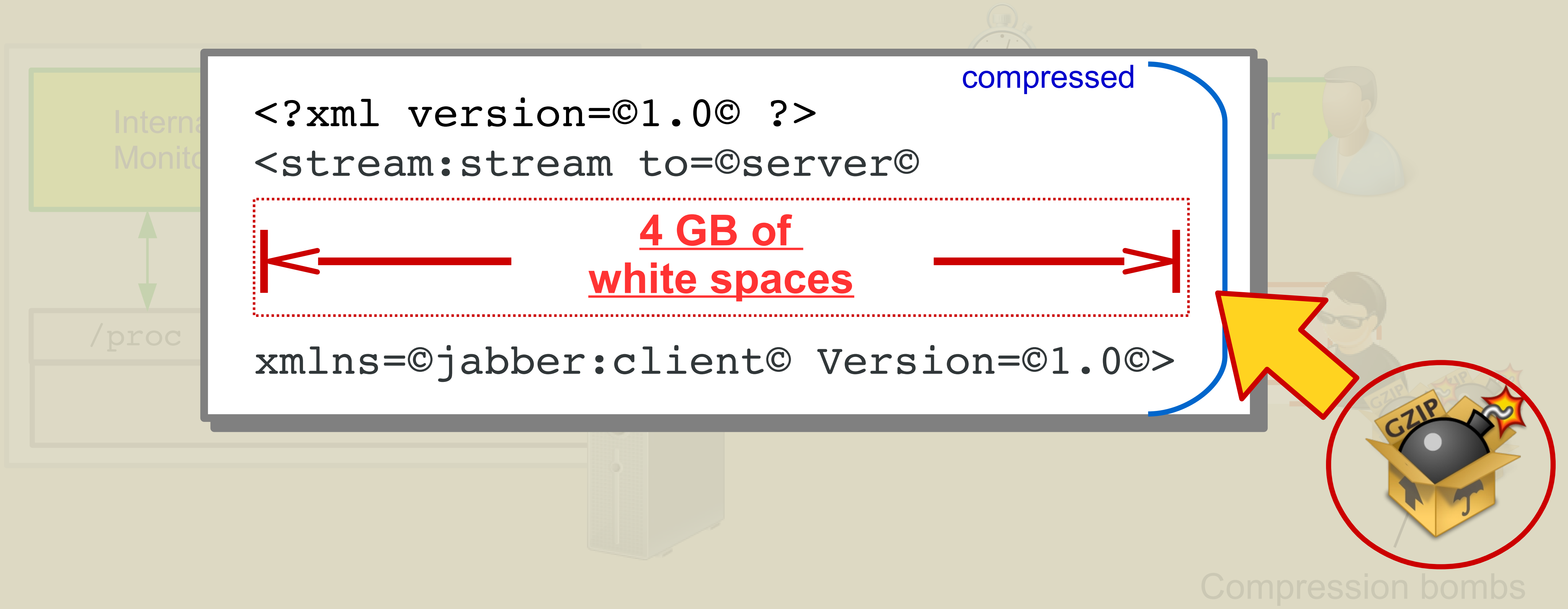
```
<soapenv:Body>[...]</soapenv:Body>
</soapenv:Envelope>
\r\n
```

Same for JSON

Compression bombs
~4 MB, ~1:1000 compr. ratio

# XMPP Compression Bomb

- Case studies:
  - HTTP, XMPP, and IMAP servers
- Testbed:

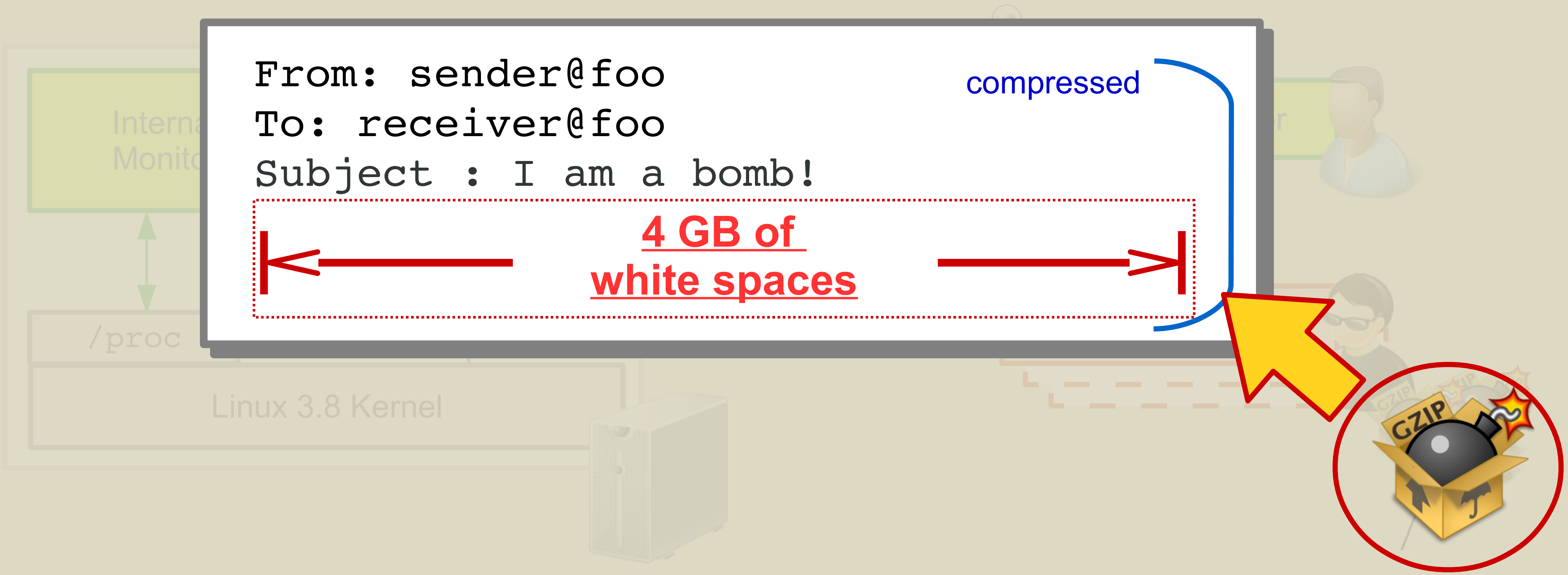


```
<?xml version=©1.0© ?>
<stream:stream to=©server©
                 4 GB of
               white spaces
xmlns=©jabber:client© Version=©1.0©>
```

~4 MB, ~1:1000 compr. ratio

# IMAP Compression Bomb

- Case studies:
  - HTTP, XMPP, and IMAP servers
- Testbed:



```
From: sender@foo
To: receiver@foo
Subject : I am a bomb!
```

Compression bombs

~4 MB, ~1:1000 compr. ratio

## Compression Bombs Everywhere

| Protocol | Network Service |
|---|---|
| XMPP | OpenFire |
| | Prosody |
| | Tigase |
| | Ejabberd, jabberd2 |
| HTTP | Apache HTTPD + mod_deflate |
| | + mod-php, CSJRPC, mod-gsoap, mod-dav |
| | Apache Tomcat + 2Way/Webutilities filter |
| | + Apache CXF |
| | + json-rpc, lib-json-rpc |
| | + Axis2/ +jsonrpc4j |
| | Axis 2 standalone |
| | gSOAP standalone |
| IMAP | Dovecot, Cyrus |

# Compression Bombs Everywhere

| Protocol | Network Service | |
|---|---|---|
| XMPP | OpenFire | CVE-2014-2741 |
| | Prosody | CVE-2014-2744/ -2745 |
| | Tigase | CVE-2014-2746 |
| | Ejabberd, jabberd2 | |
| HTTP | Apache HTTPD + mod_deflate | CVE-2014-0118 |
| | + mod-php, CSJRPC, mod-gsoap, mod-dav | |
| | Apache Tomcat + 2Way/Webutilities filter | Notif. devel |
| | + Apache CXF | CVE-2014-0109/ -0110 |
| | + json-rpc, lib-json-rpc | Notif. devels |
| | + Axis2/ +jsonrpc4j | |
| | Axis 2 standalone | |
| | gSOAP standalone | Notif. devel |
| IMAP | Dovecot, Cyrus | |

## Pitfalls

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1. Implementation

2. Specification

3. Configuration

# Pitfalls

1. Implementation
    - Use of Compression before Authentication
    - Improper Input Validation during Decompression
    - Logging Decompressed Messages
    - Improper Inter-Units Communication
    - Unbounded Resource Usage (CPU and Memory)
2. Specification
    - Erroneous Best Practice
    - Misleading Documentation
    - API Specs Inconsistency
3. Configuration
    - Insufficient Configuration Options
    - Insecure Default Values
    - Decentralized Configuration Parameters

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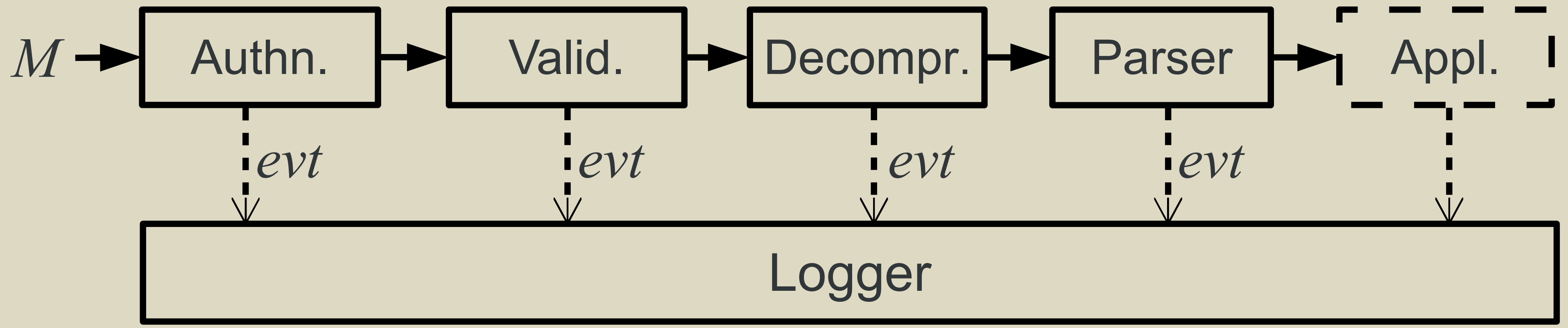
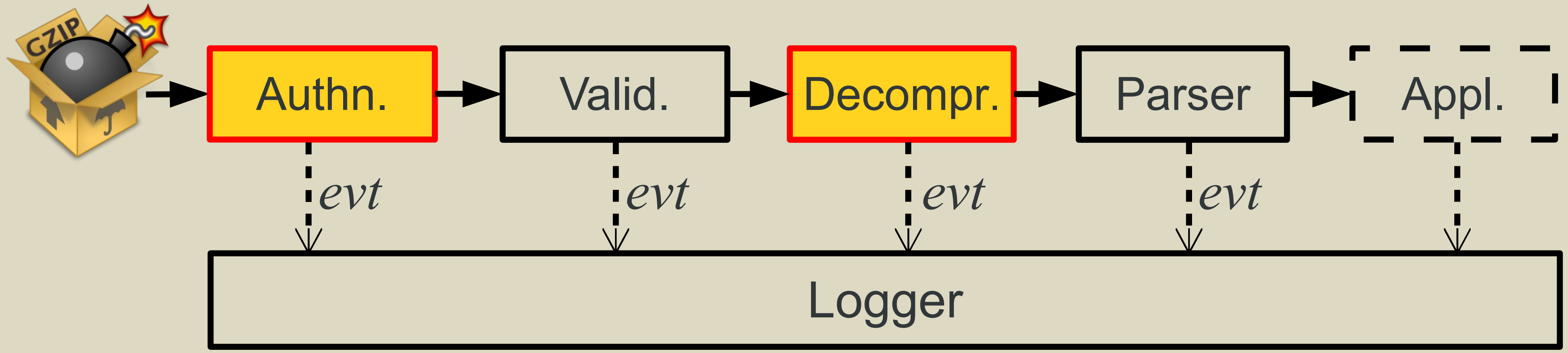
Have a look at our paper!
http://trouge.net/gp/papers/compr_usenix15.pdf

## Pitfalls at Implementation level



- Abstract message processing pipeline extracted from our case studies

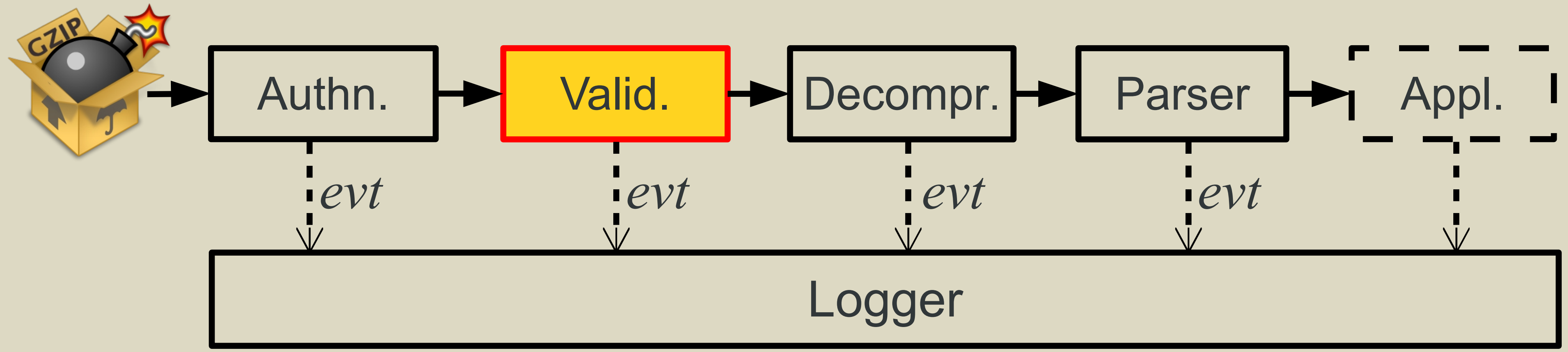
# Compression before Authentication



- Inconsistent best practice
  - Mandatory in SSL/TLS, recommended in XMPP, and undefined in IMAP and HTTP
  - Implementation may diverge from the specs, i.e., OpenSSH
- Developers may underestimate the risk or overlook recommendations
- Prosody accepted compressed messages <u>before</u> user authentication CVE-2014-2744

  ➔ DoS by unauthenticated attackers

# Improper Input Validation during Decompression



- 3 ways to validate a message:

mistake

  - Compressed message size
    - mod-deflate: If (compr. size > `LimitRequestBody`) → Reject CVE-2014-0118
    - ➔ However, hard to assess message size from its compressed form (1 MB compr → 1 GB decompr.)

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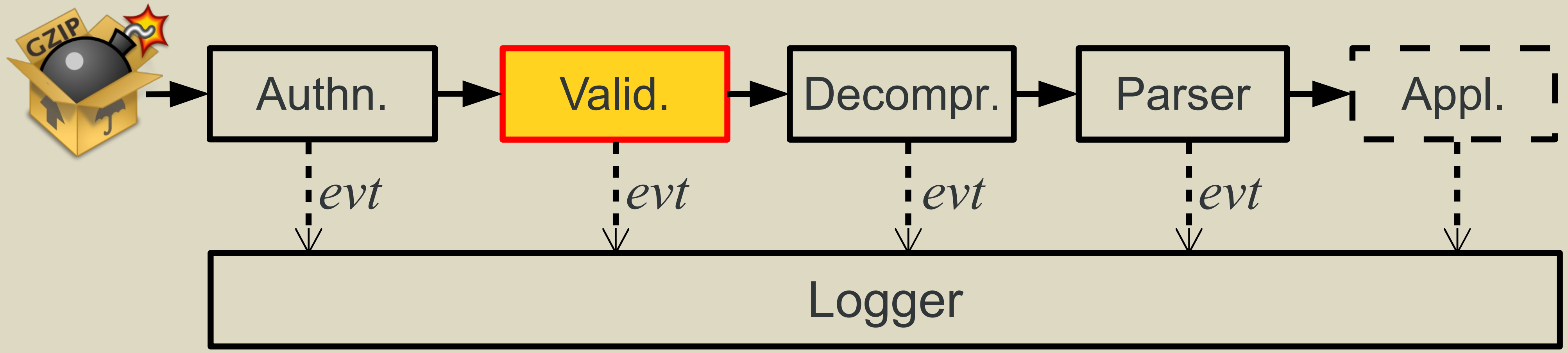

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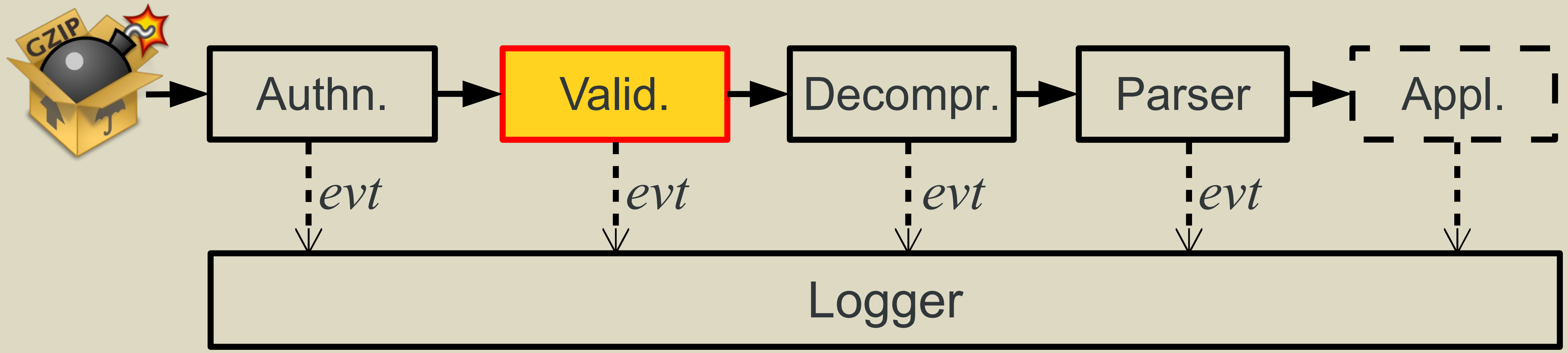
risky

  - Decompression ratio
    - Patched mod-deflate: if (decompr ratio > threshold) → Reject
    - ➔ Problem of ratio selection

# Improper Input Validation during Decompression



- 3 ways to validate a message:

mistake

- Compressed message size
  - mod-deflate: If (compr. size > `LimitRequestBody`) → Reject CVE-2014-0118
  - ➔ However, hard to assess message size from its compressed form (1 MB compr → 1 GB decompr.)

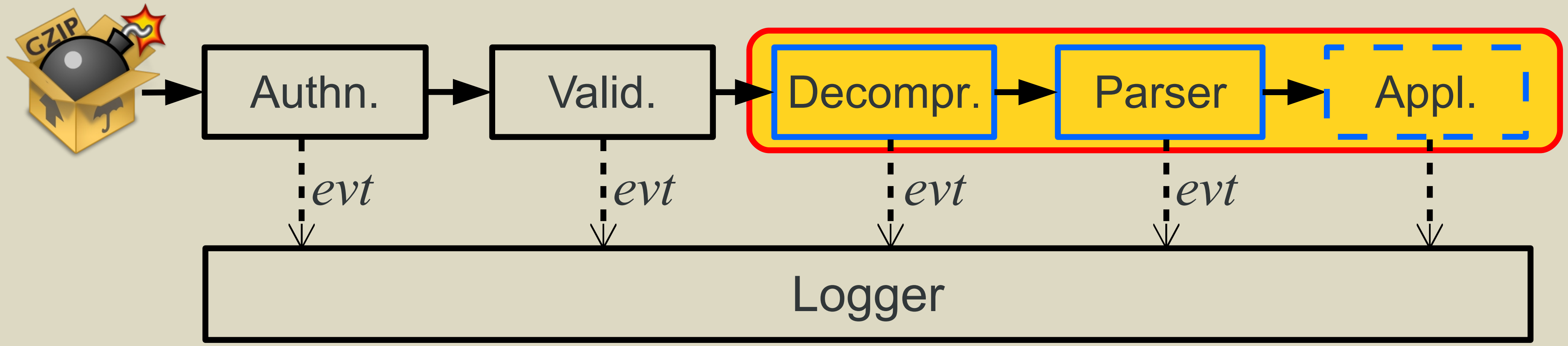
risky

- Decompression ratio
  - Patched mod-deflate: if (decompr ratio > threshold) → Reject
  - ➔ Problem of ratio selection

correct

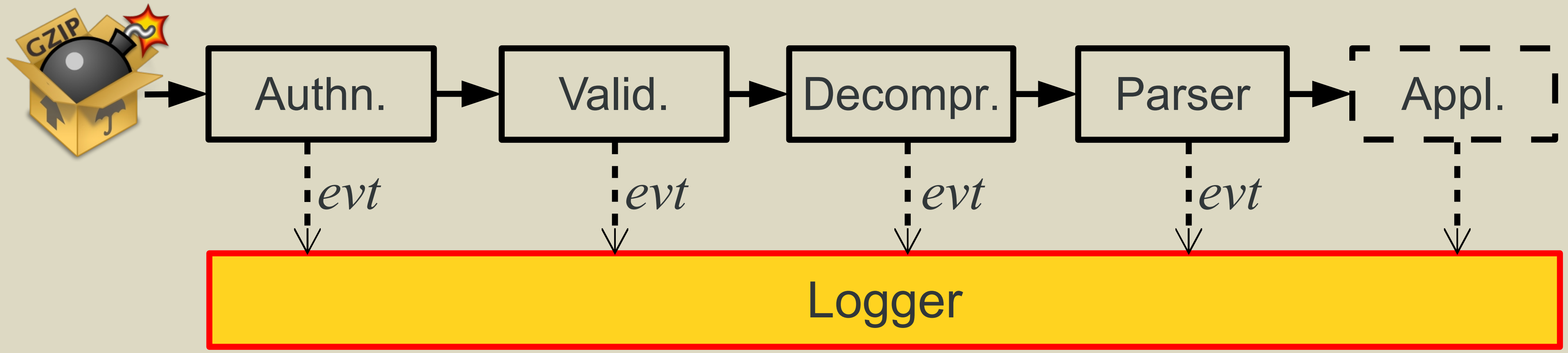
- Decompressed message size
  - mod-deflate + mod-dav: If (decompr. size > `LimitXMLRequestBody`) → Reject

# Improper Inter-Units Communication



- Upon exception, the pipeline halts and rejects message
- mod-php and mod-gsoap limit the size of incoming (decompressed) message
- … but had no means to halt mod-deflate
  - ➔ mod-deflate keeps on decompressing data
  - Problem addressed in CVE-2014-0118

# Logging Decompressed Messages



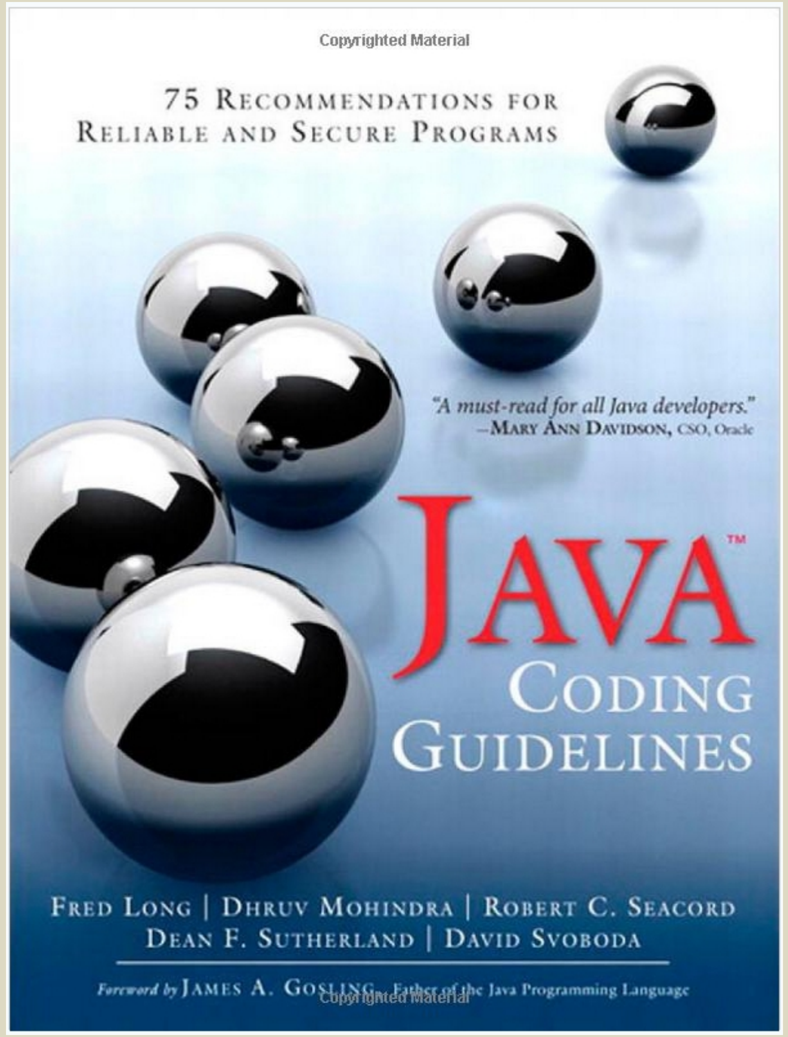
- Frequency and verbosity of log events can cause DoS
- If exception is caused by compressed data, the needed resources may be underestimated
- Upon invalid requests, Apache CXF logs first 100KB of incoming message
  - However, first it decompresses <u>the entire</u> message on a file, then logs the first 100KB
  - ➔ DoS due to disk space exhaustion CVE-2014-0109/ -0110

## Erroneous Best Practices (Spec. level)

- Only one code pattern specific for data compression
  - Rule: "IDS04-J. Safely extract files from ZipInputStream"

```
// Write the files to the disk, but
// only if the file is not insanely big
if (zipfile.getSize() > TOOBIG ) {
   throw new IllegalStateException("File to be unzipped is huge.");
}
```

- `.getSize()` returns ZIP file header with uncompressed size
- but ZIP headers not integrity protected!
  - ➔ DoS countermeasure bypass Notif. Authors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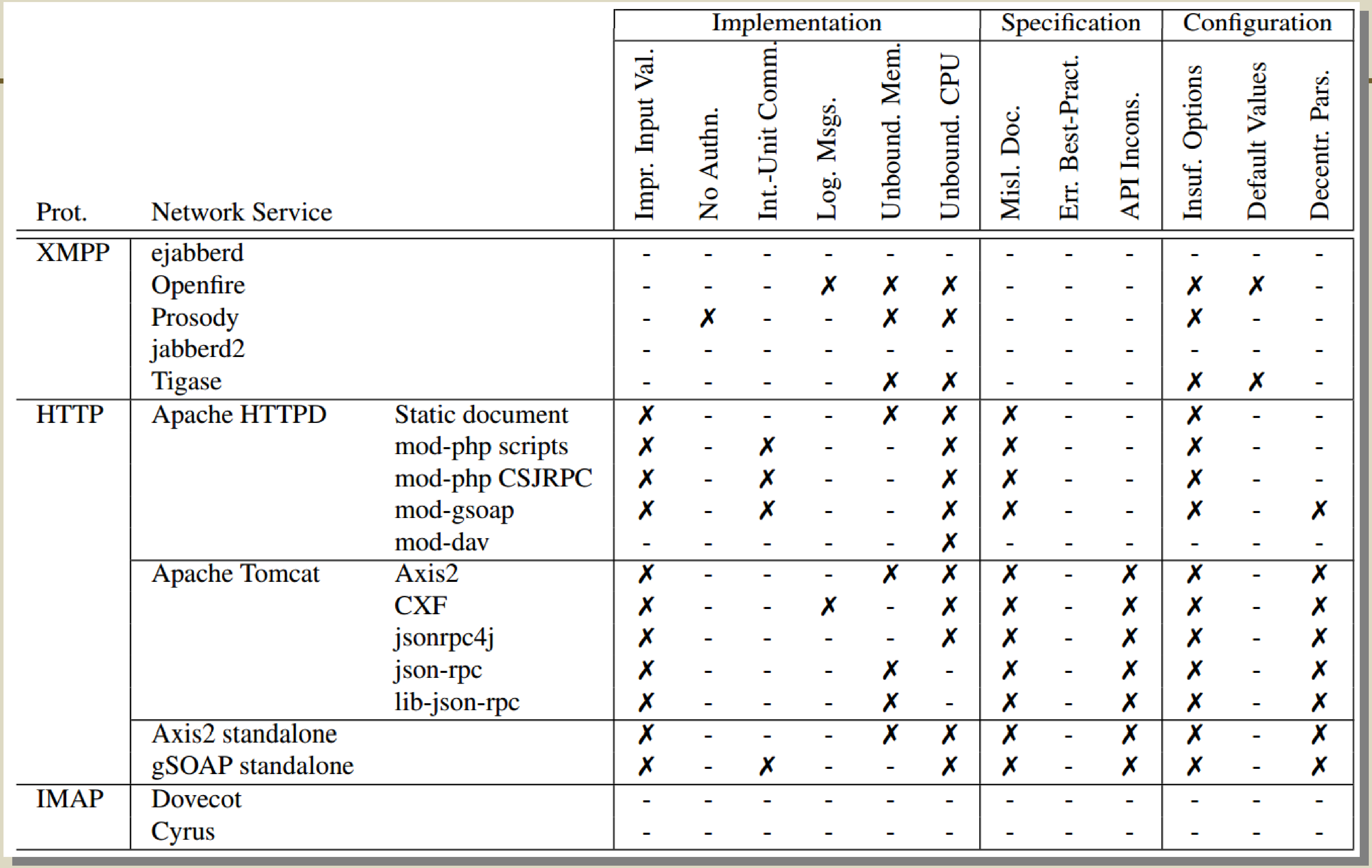
75 Recommendations for Reliable and Secure Programs
"A must-read for all Java developers." –Mary Ann Davidson, CSO, Oracle
Java™ Coding Guidelines
Fred Long | Dhruv Mohindra | Robert C. Seacord
Dean F. Sutherland | David Svoboda
Foreword by James A. Gosling, Father of the Java Programming Language

# Pitfalls



| Prot. | Network Service | | Implementation | | | | | | Specification | | | Configuration | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Impr. Input Val. | No Authn. | Int.-Unit Comm. | Log. Msgs. | Unbound. Mem. | Unbound. CPU | Misl. Doc. | Err. Best-Pract. | API Incons. | Insuf. Options | Default Values | Decentr. Pars. |
| XMPP | ejabberd | | - | - | - | - | - | - | - | - | - | - | - | - |
| | Openfire | | - | - | - | ✗ | ✗ | ✗ | - | - | - | ✗ | ✗ | - |
| | Prosody | | - | ✗ | - | - | ✗ | ✗ | - | - | - | ✗ | - | - |
| | jabberd2 | | - | - | - | - | - | - | - | - | - | - | - | - |
| | Tigase | | - | - | - | - | ✗ | ✗ | - | - | - | ✗ | ✗ | - |
| HTTP | Apache HTTPD | Static document | ✗ | - | - | - | ✗ | ✗ | ✗ | - | - | ✗ | - | - |
| | | mod-php scripts | ✗ | - | ✗ | - | - | ✗ | ✗ | - | - | ✗ | - | - |
| | | mod-php CSJRPC | ✗ | - | ✗ | - | - | ✗ | ✗ | - | - | ✗ | - | - |
| | | mod-gsoap | ✗ | - | ✗ | - | - | ✗ | ✗ | - | - | ✗ | - | ✗ |
| | | mod-dav | - | - | - | - | - | ✗ | - | - | - | - | - | - |
| | Apache Tomcat | Axis2 | ✗ | - | - | - | ✗ | ✗ | ✗ | - | ✗ | ✗ | - | ✗ |
| | | CXF | ✗ | - | - | ✗ | - | ✗ | ✗ | - | ✗ | ✗ | - | ✗ |
| | | jsonrpc4j | ✗ | - | - | - | - | ✗ | ✗ | - | ✗ | ✗ | - | ✗ |
| | | json-rpc | ✗ | - | - | - | ✗ | - | ✗ | - | ✗ | ✗ | - | ✗ |
| | | lib-json-rpc | ✗ | - | - | - | ✗ | - | ✗ | - | ✗ | ✗ | - | ✗ |
| | Axis2 standalone | | ✗ | - | - | - | ✗ | ✗ | ✗ | - | ✗ | ✗ | - | ✗ |
| | gSOAP standalone | | ✗ | - | ✗ | - | - | ✗ | ✗ | - | ✗ | ✗ | - | ✗ |
| IMAP | Dovecot | | - | - | - | - | - | - | - | - | - | - | - | - |
| | Cyrus | | - | - | - | - | - | - | - | - | - | - | - | - |

## Conclusion

## Conclusion/Takeaway

- Compression bombs are back
- ~20 years after the zip bombs, developers still unaware of the risks of handling data compression

➔ Discovered 10 previously-unknown vulnerabilities in popular network services

➔ Presented 12 pitfalls which can be used by developers to build more secure services