In the Compression Hornet's Nest: A Security Study of Data Compression in Network Services

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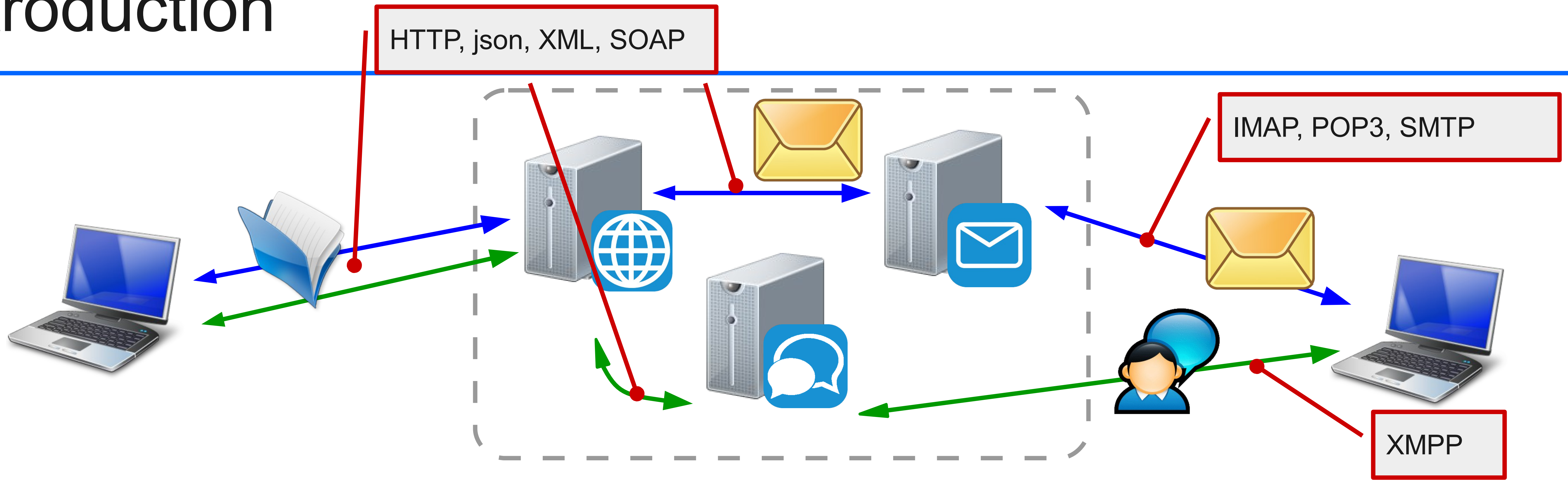
Introduction



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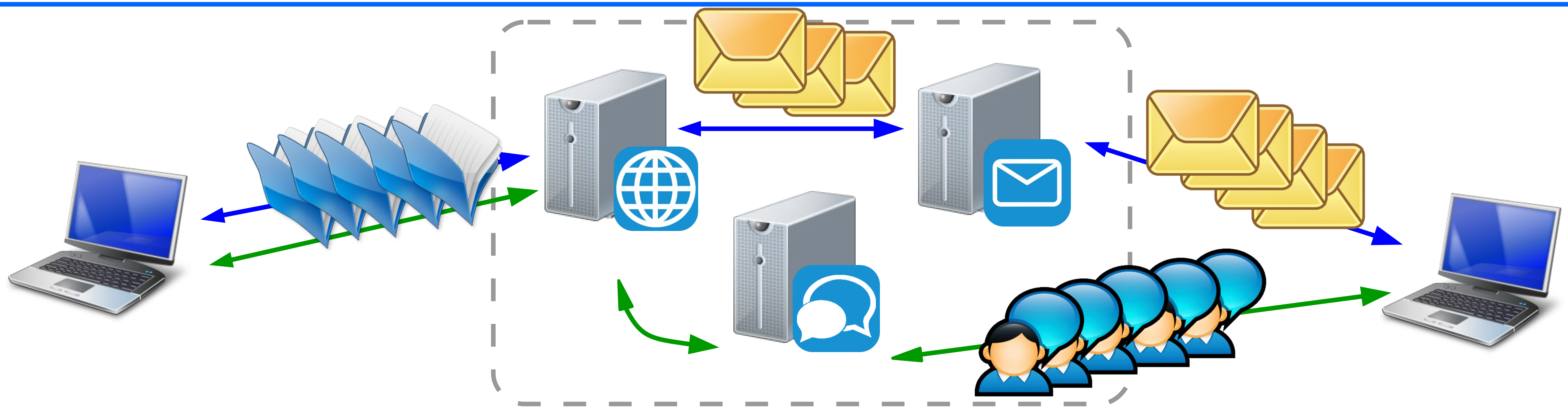

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  - More data → more transfer time → unresponsiveness → user unhappiness

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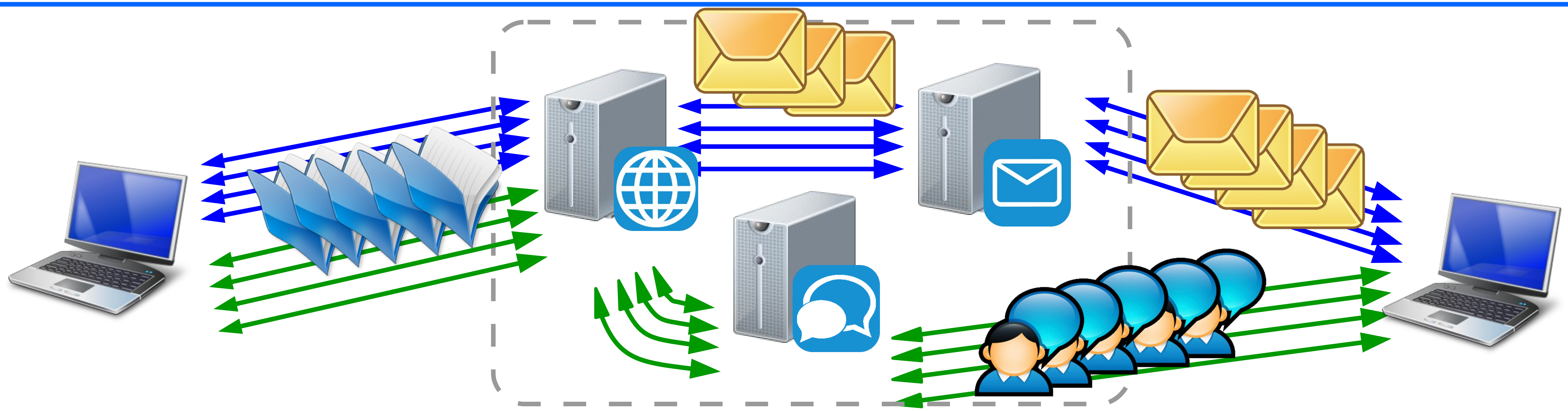

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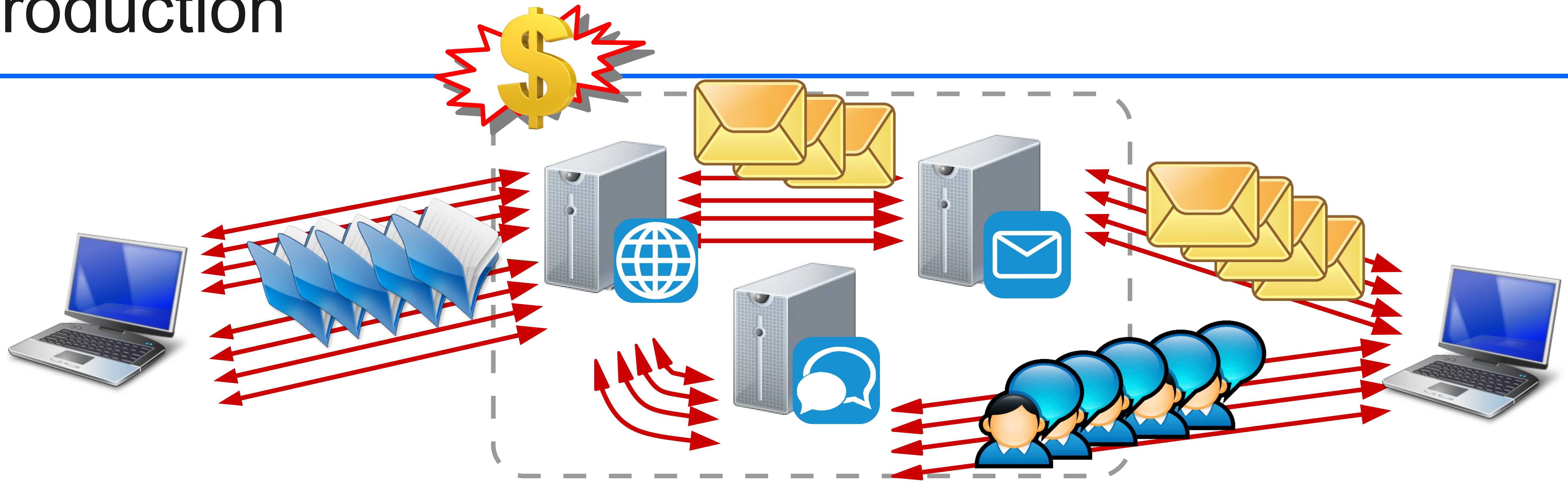

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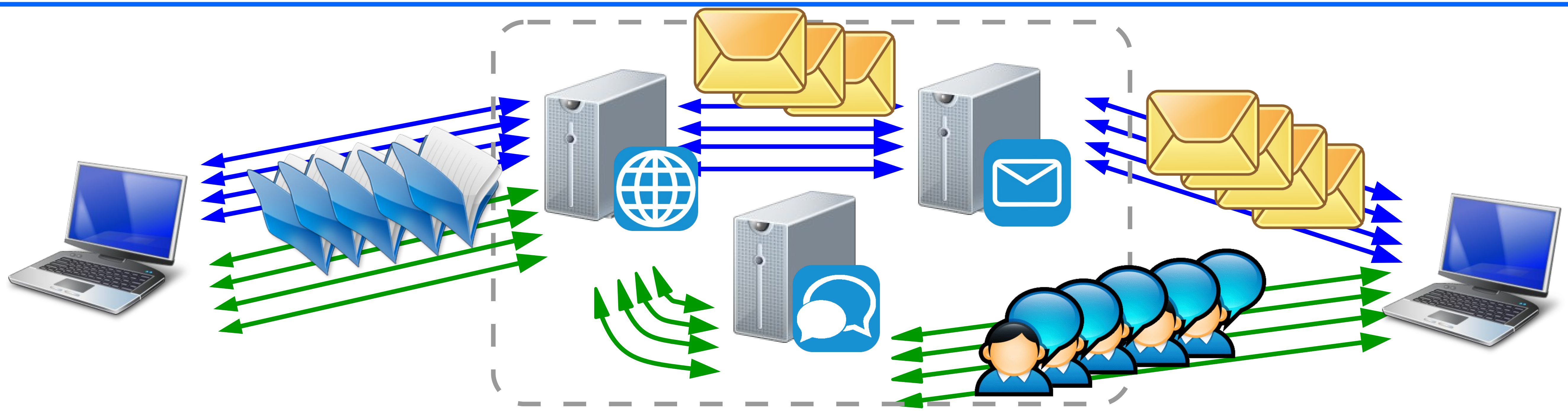

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- Another solution is ...

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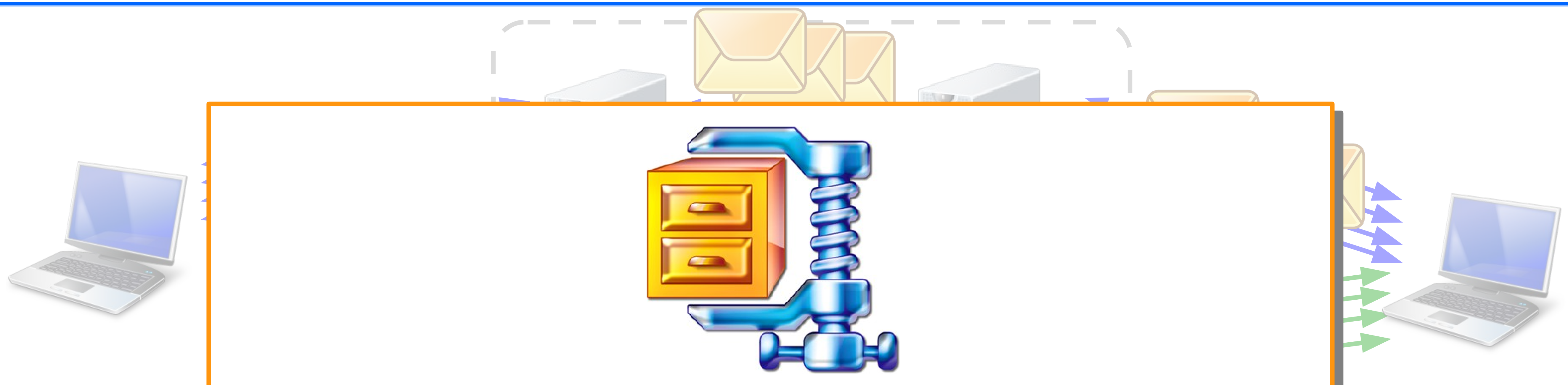

Data compression!

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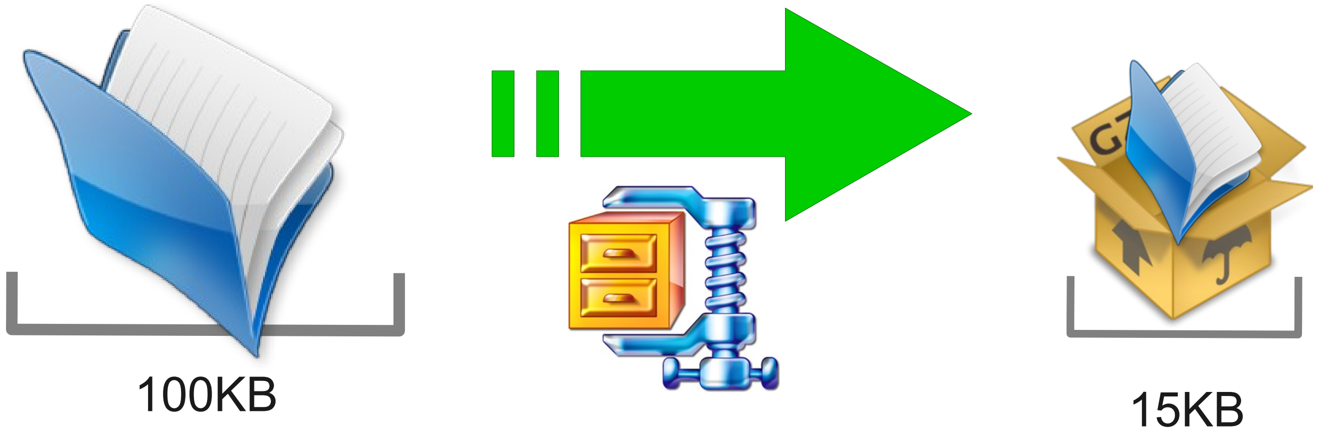
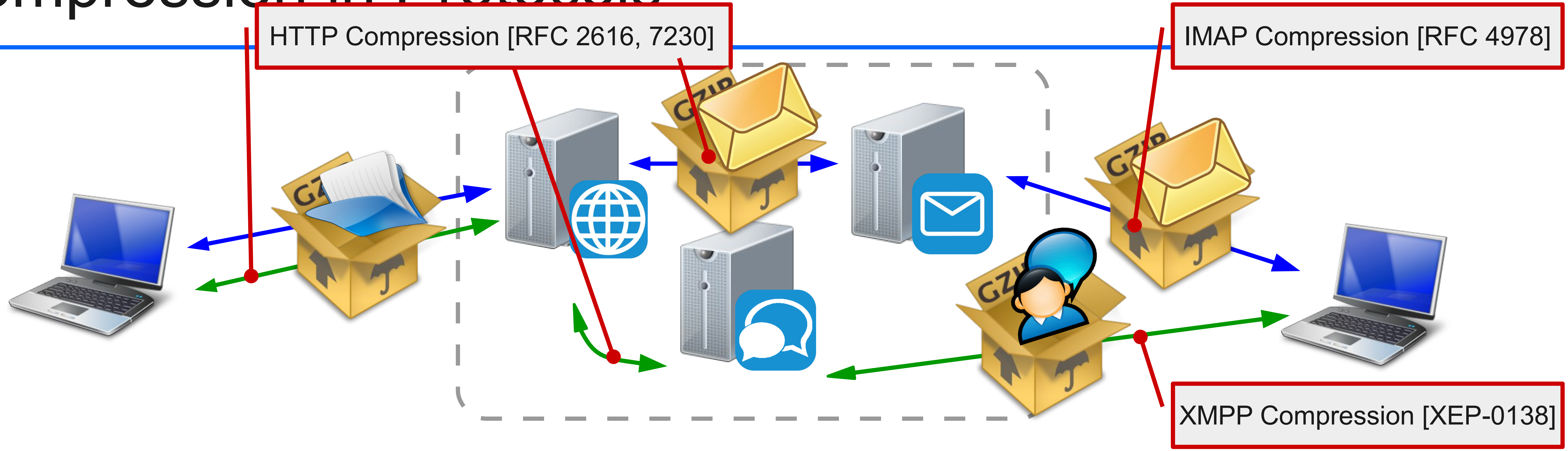
Data Compression



- Reduces # of bits of a string by removing redundancy
  - *lossless* if $decompr(compr(d)) = d$ or *lossy* if $decompr(compr(d)) \sim= d$
- 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-Verlang, 2007.

Compression in Protocols



- Data compression is 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

The Problem of Data Compression

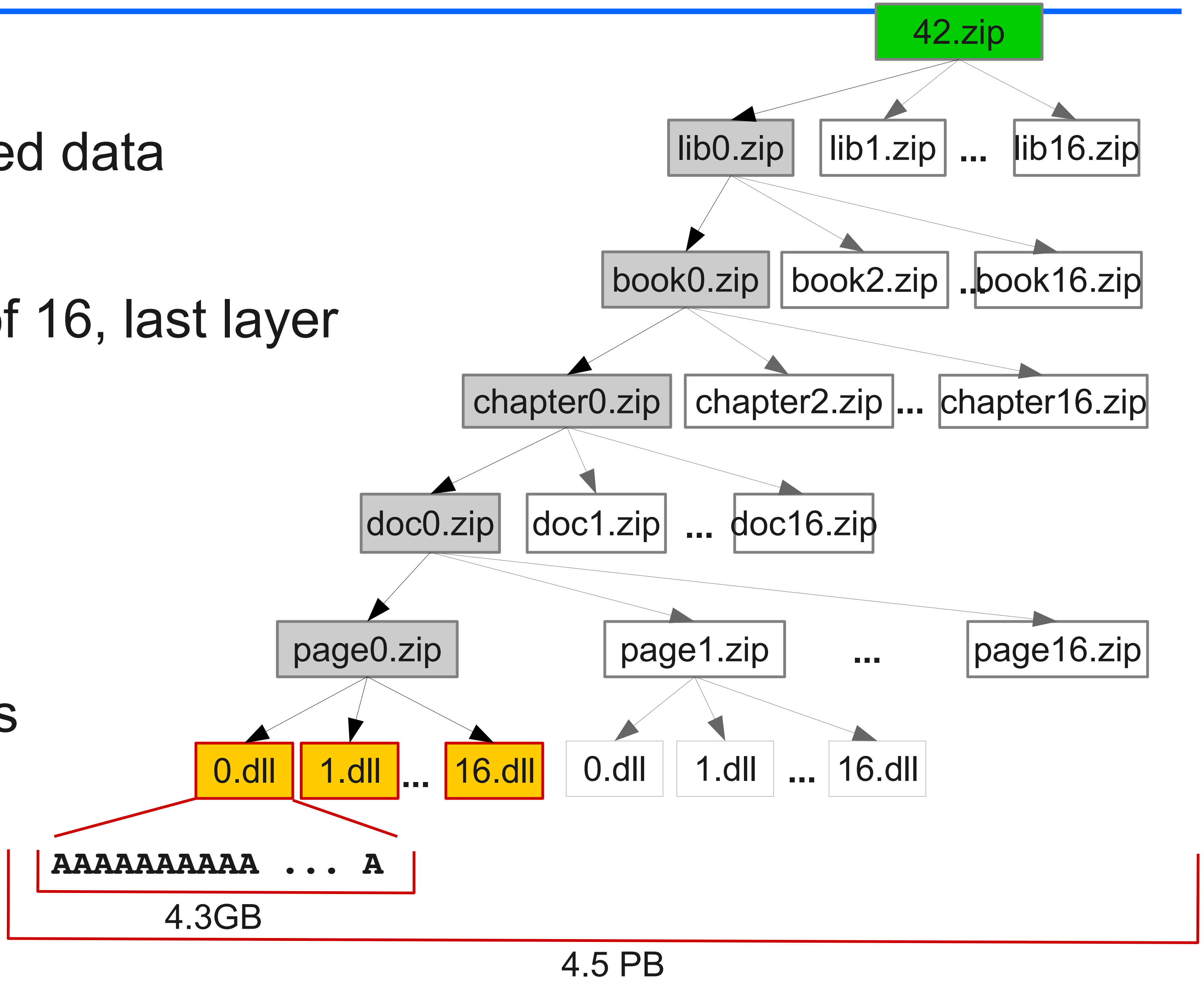
- If not properly implemented, it can make application vulnerable to DoS

- 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**
     - Clients pre-compute compressed messages
     - Server decompresses msgs 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
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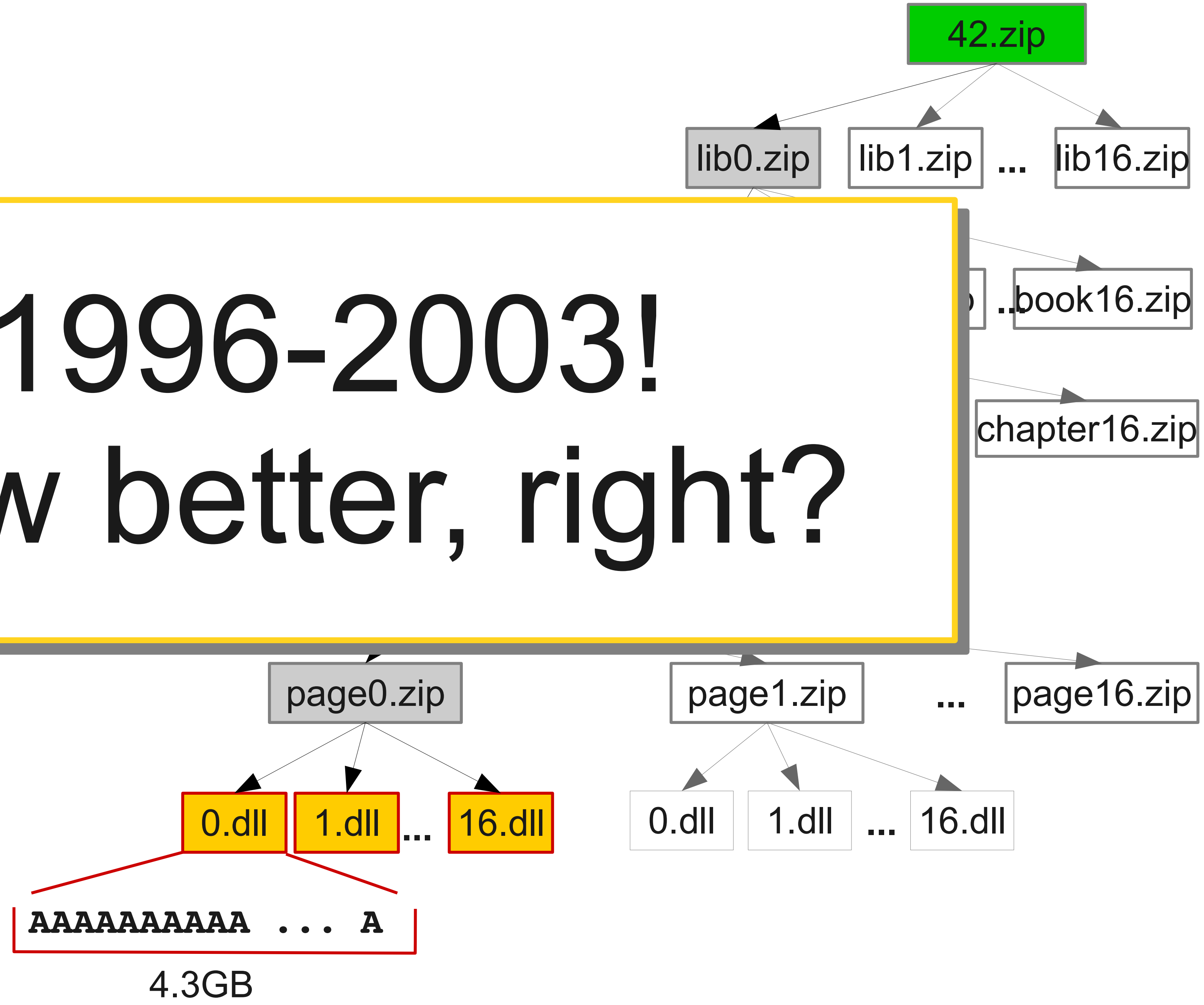

This was 1996-2003!
Now we know better, right?

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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How does this lack of common knowledge and understanding affect implementations?

Our contribution

1. Analyzed network service, extensions, protocol specifications, and documentations looking for proper or incorrect ways to handle data compression
   - ➔ Grouped findings in 12 pitfalls

2. Tested network services against compression bombs
   - ➔ Discovered 10 previously unknown vulnerabilities

Contents

- Mistakes in software
- Testing for resource exhaustion vulnerabilities

Mistakes in Software

Case Studies

Protocol	Network Service
XMPP	OpenFire, Prosody. Jabberd2, ejabberd, Tigase
HTTP	Apache HTTPD + *mod_deflate* + *mod-php* + *CSJRPC* + *mod-gsoap* + *mod-dav*
	Apache Tomcat + *2Way/Webutilities* + *Apache CXF* + *(lib-)json-rpc* + *jsonrpc4j* + *Axis2*
	Axis 2 standalone
	gSOAP standalone
IMAP	Dovecot, Cyrus

- 11 popular services with 10 extensions
  - Selected via *service detection* of top 1000 of AlexaDB and of public IM services
- Analyzed specifications, documentation, and source code
- Observed 12 pitfalls...

Pitfalls

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

Pitfalls

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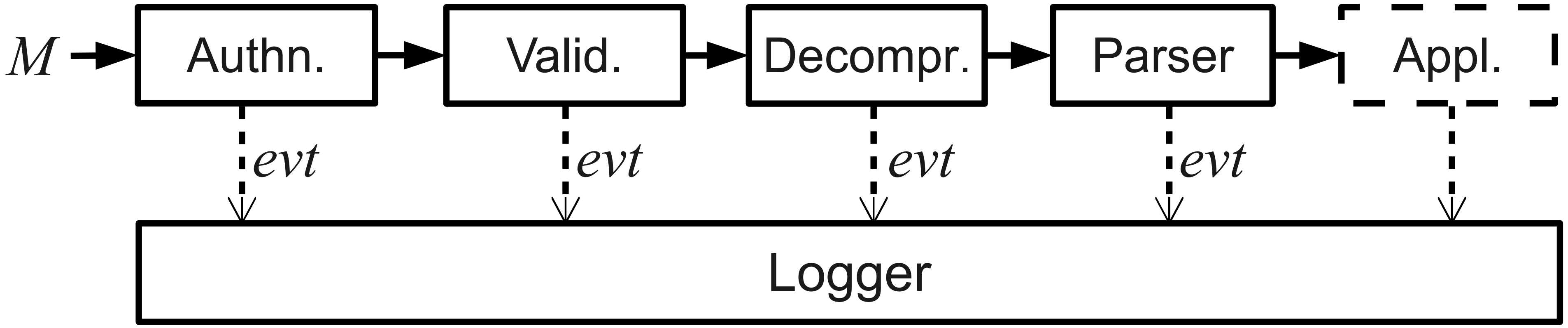
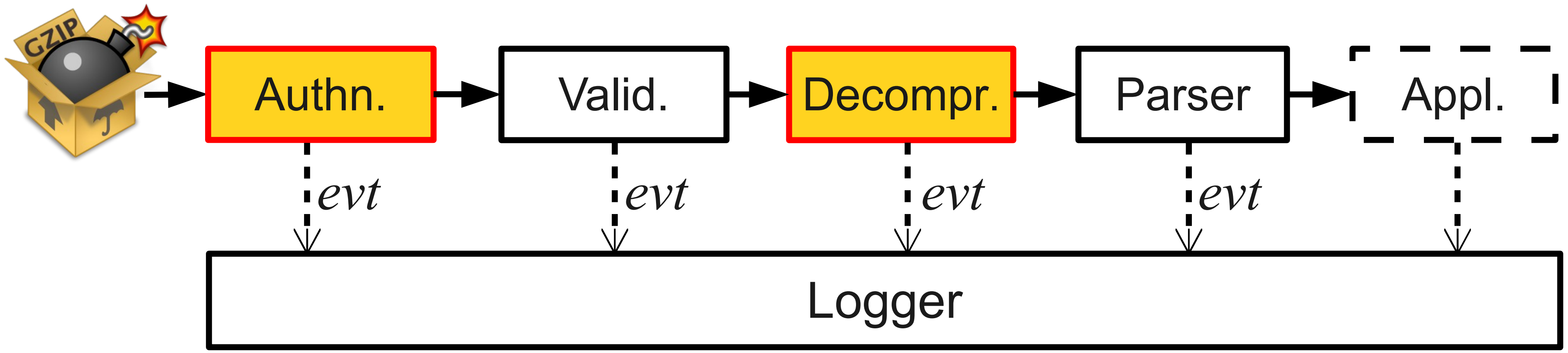
Pitfalls at Implementation level



- Abstract message processing pipeline extracted from our case studies

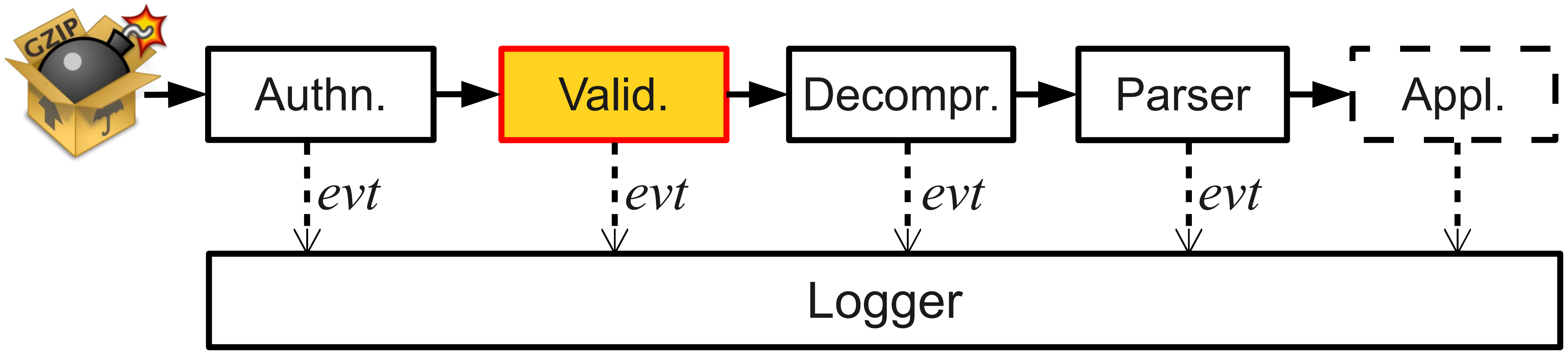
Compression before Authentication



- 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 before 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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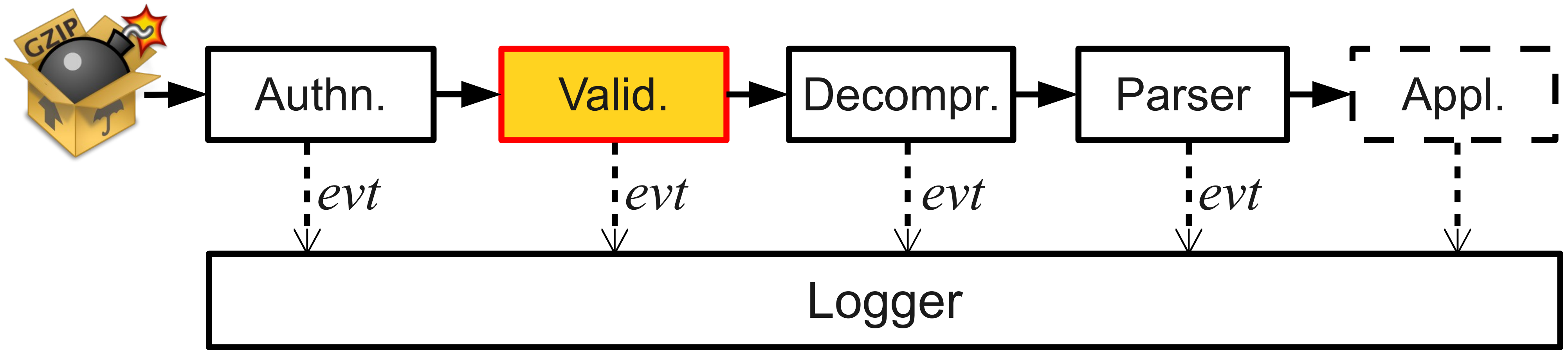

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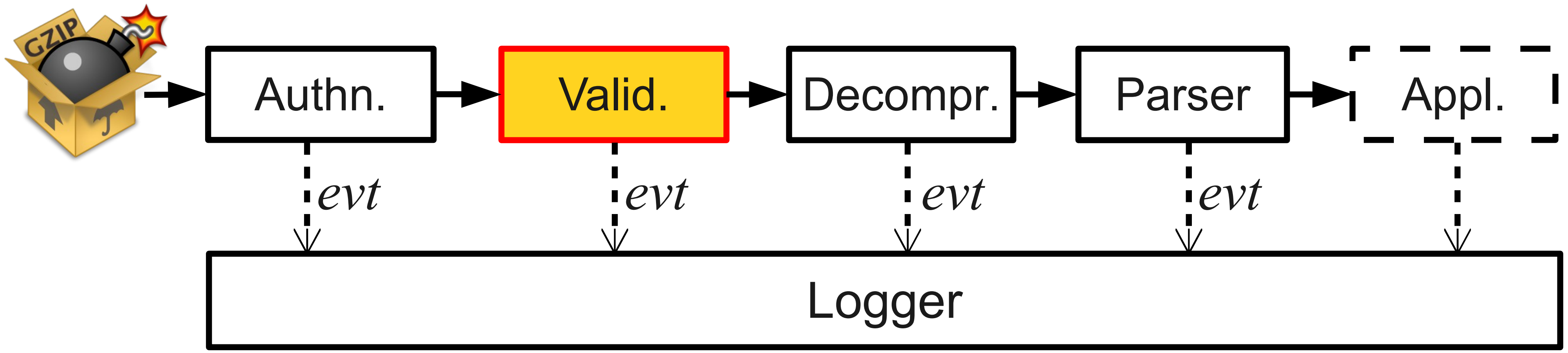

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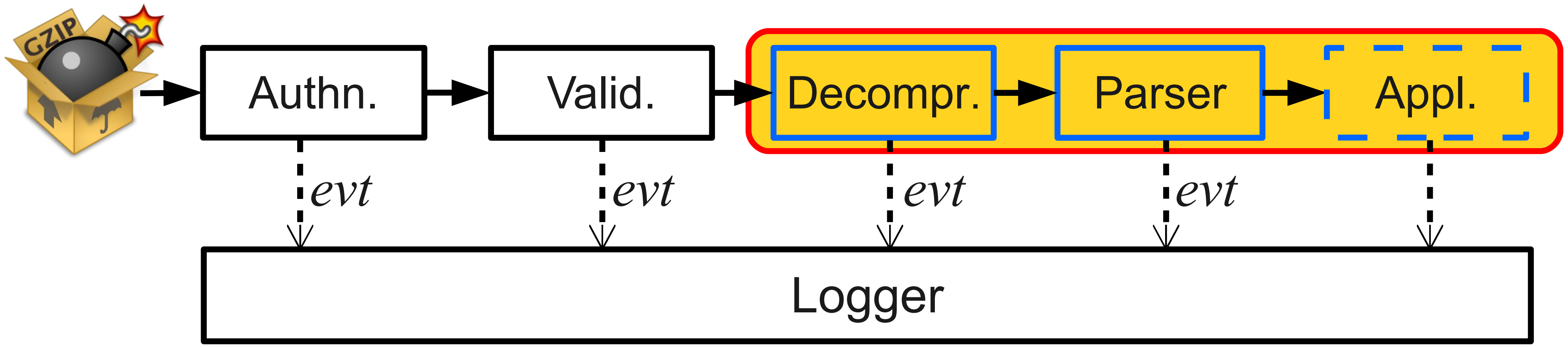
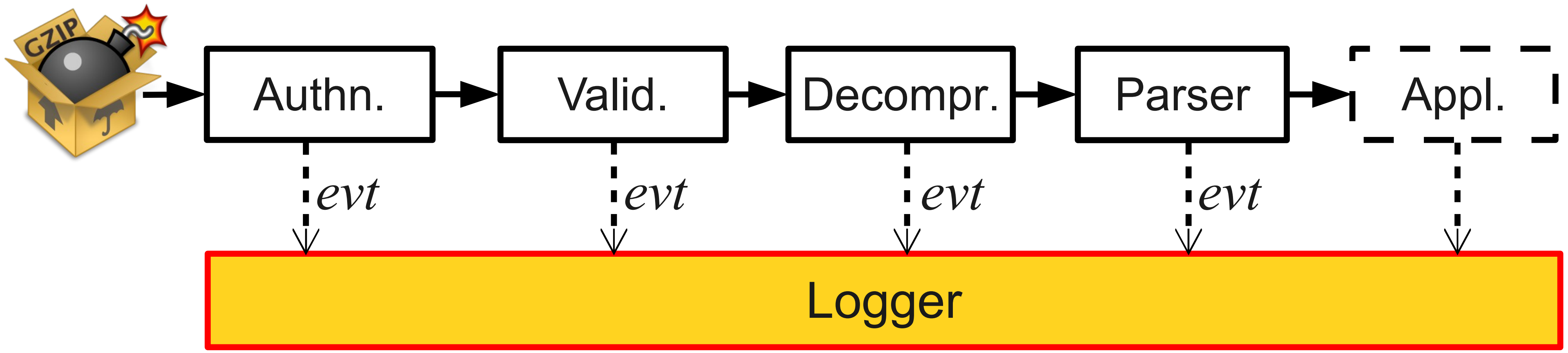
    - ➔ Problem of ratio selection
  - correct Decompressed message size
    - mod-deflate + mod-dav: If (decompr. size > `LimitXMLRequestBody`) → Reject

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 the entire message on a file, then logs the first 100KB
  - ➔ DoS due to disk space exhaustion CVE-2014-0109/ -0110

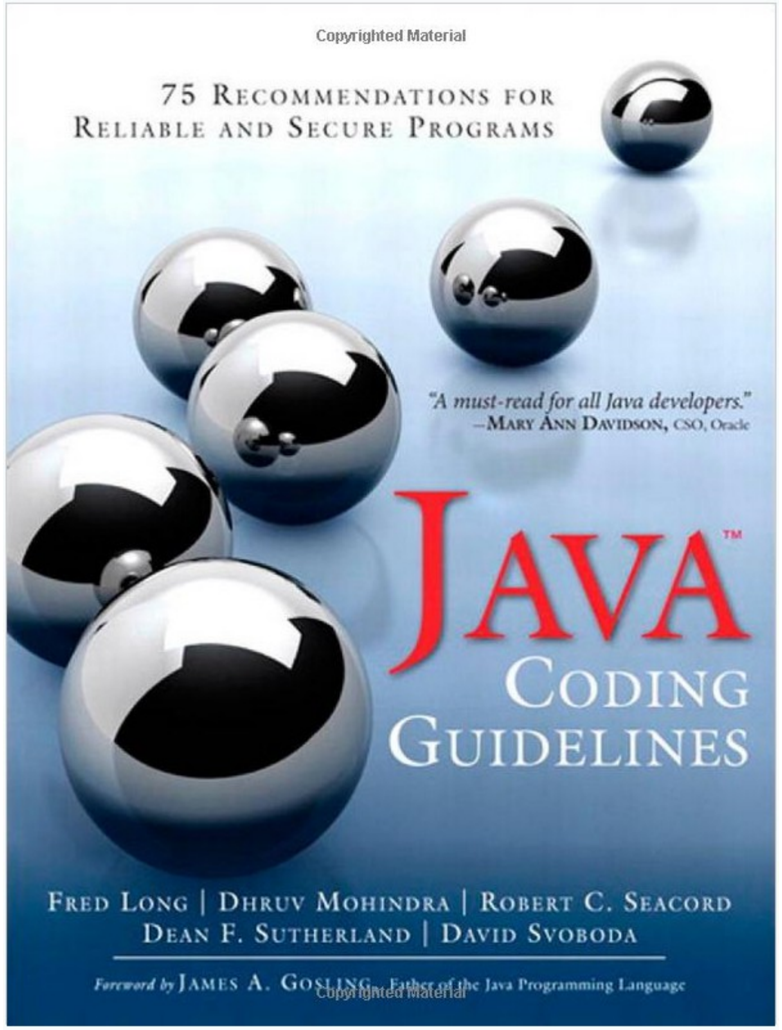
Erroneous Best Practices (Spec. level)

- 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

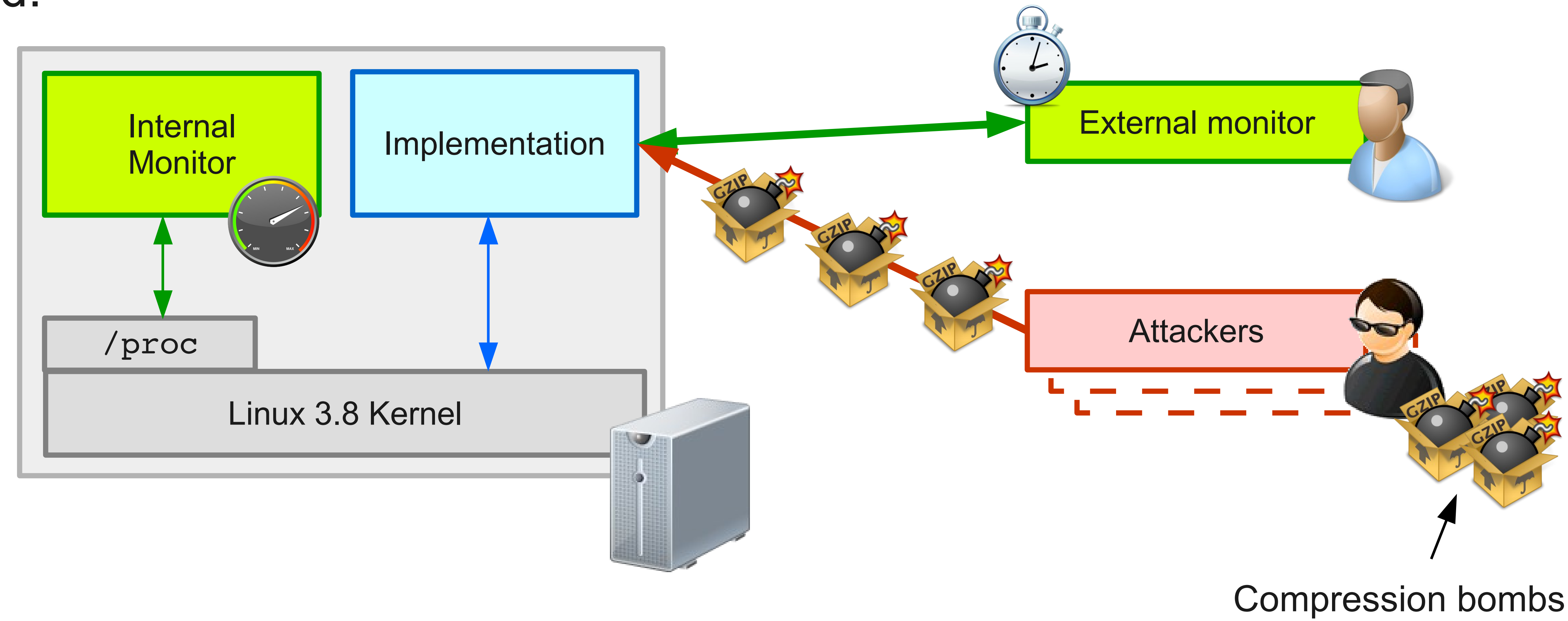
- but ZIP headers can be forged
  - ➔ DoS countermeasure bypass Notif. Authors



Resource exhaustion vulnerabilities

Experiments

- Case studies on local servers
- Testbed:



HTTP Compression Bomb (SOAP)

- Case studies on local servers
- Testbed:

```
POST /index.html HTTP/1.1
Content-Encoding: gzip
\r\n
<soapenv:Envelope>
|<—— 4 GB of white spaces ——>|
<soapenv:Body>[...]</soapenv:Body>
</soapenv:Envelope>
\r\n
```

compressed

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

Zip 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	

Conclusion

Conclusion/Takeaway

- ~20 years after the zip bombs, developers still unaware of the risks of handling data compression
- Discovered 10 previously-unknown vulns. in popular network services
- Presented 12 pitfalls which can be used by developers to build more secure services