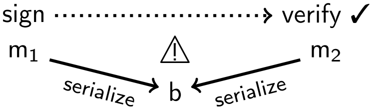
Comparse: Provably Secure Formats for Cryptographic Protocols



Théophile Wallez, *Inria Paris*
Jonathan Protzenko, *Microsoft Research*
Karthikeyan Bhargavan, *Inria Paris, Cryspen*

Message formats in cryptographic protocols

Message formats in MLS: the genesis of Comparse

TreeSync: Authenticated Group Management for Messaging Layer Security
USENIX Security '23

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Developed Comparse to precisely study message formats in MLS...
...and found an interesting attack exploiting these.

Signature ambiguity in MLS draft 12

TreeSync

$\mathsf{sig} = \mathsf{sign}(\mathsf{sk}, \mathsf{serialize}_{T1}(\mathsf{msg}_1))$

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Different types

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Possible attack:
TreeDEM signature could be used to forge a signature in TreeSync!

Security critical formats are omnipresent

$$\begin{array}{c}\text{High-level}\\\text{protocol data}\end{array} \xrightarrow{\text{(format)}} \begin{array}{c}\text{Binary}\\\text{data}\end{array} \longrightarrow \begin{cases} \text{Hash} & \text{Signature} \\ \text{HPKE} & \text{MAC} \\ \text{KDF} & \dots \\ \text{AEAD} & \end{cases}$$

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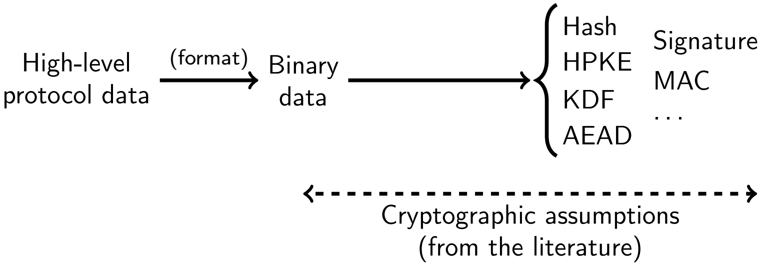

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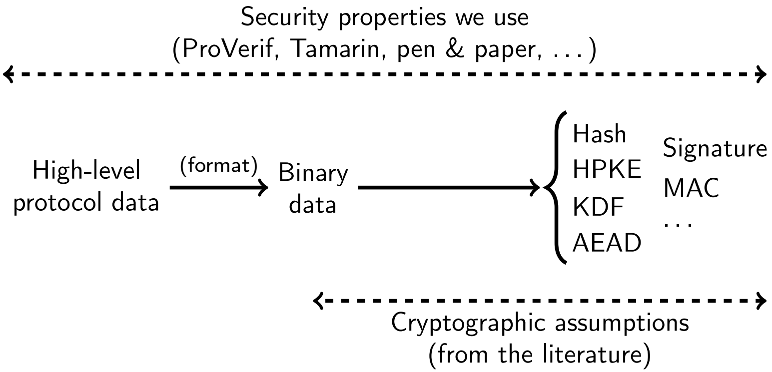

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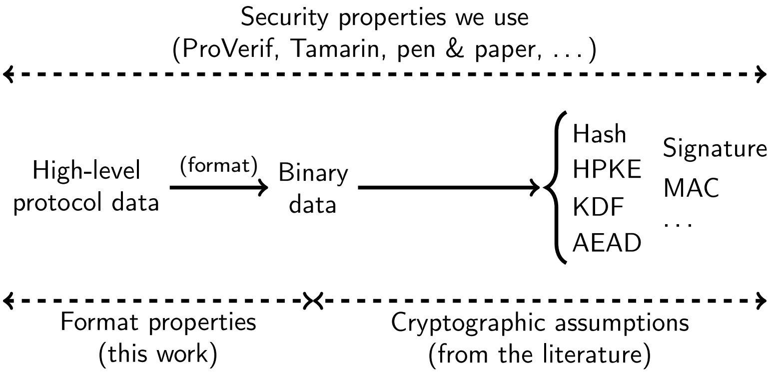


Messages formats play a crucial role in cryptographic protocols security.

We study their impact in two steps:

1. study properties of message formats
2. show how format properties compose with cryptographic assumptions to obtain the security properties we use

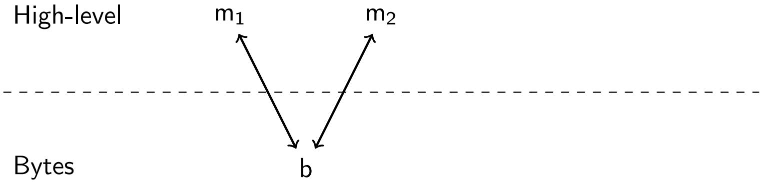
Running example: signatures.

Message formats properties

High-level

Bytes

Message formats properties



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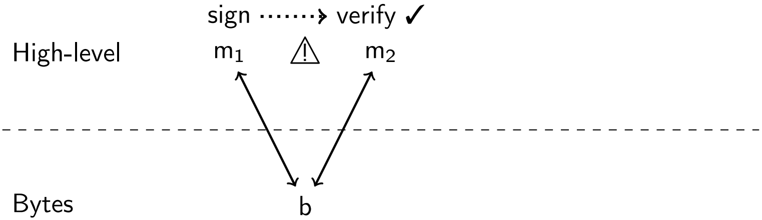
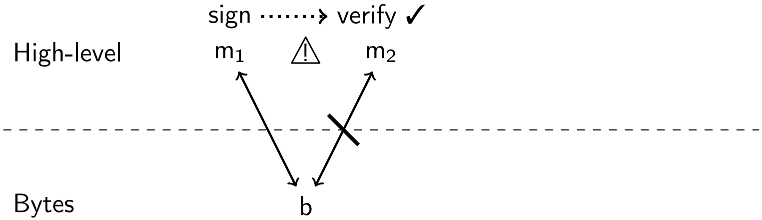


Message formats properties

Non-ambiguity



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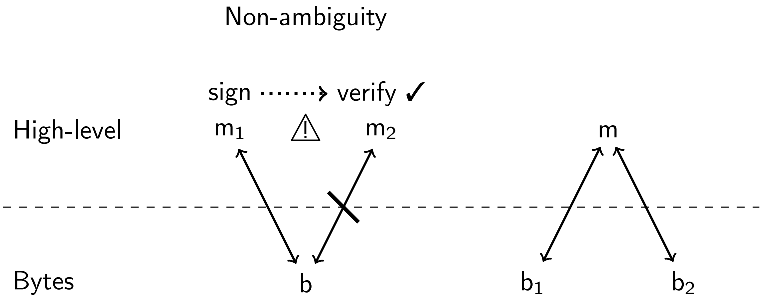

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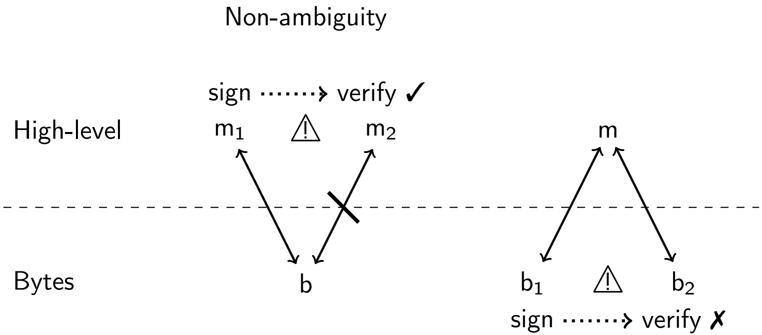

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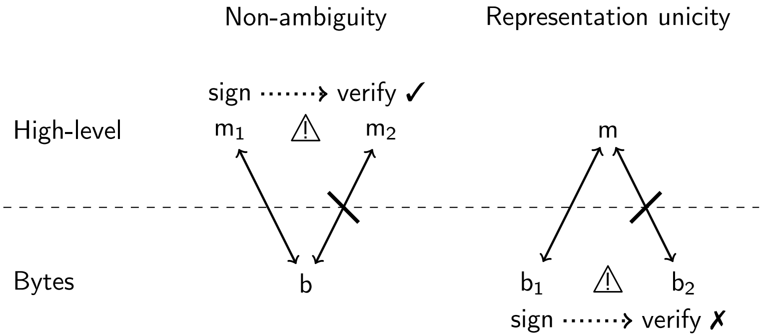
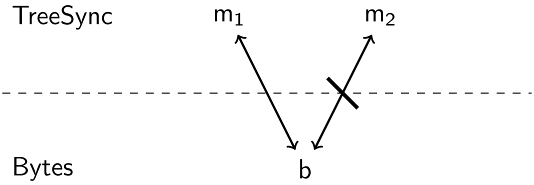


Message formats properties across protocols



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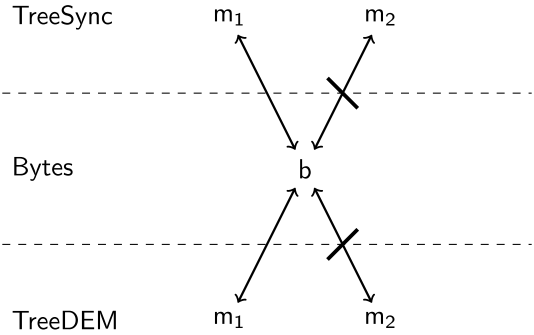

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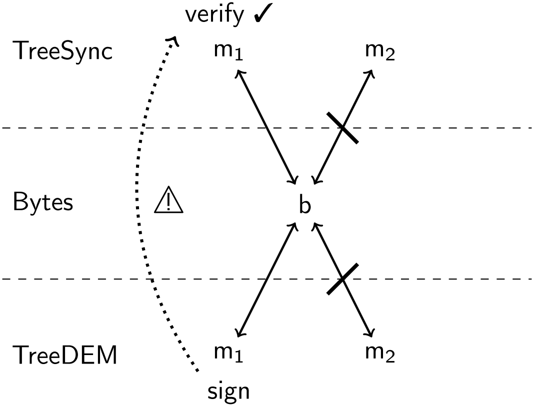

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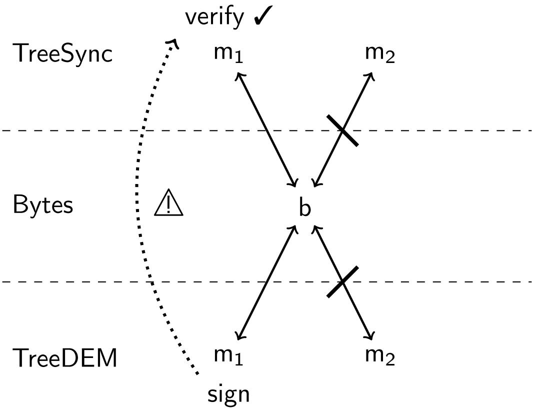

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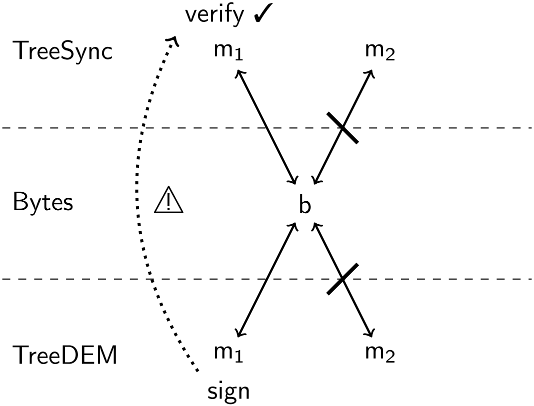

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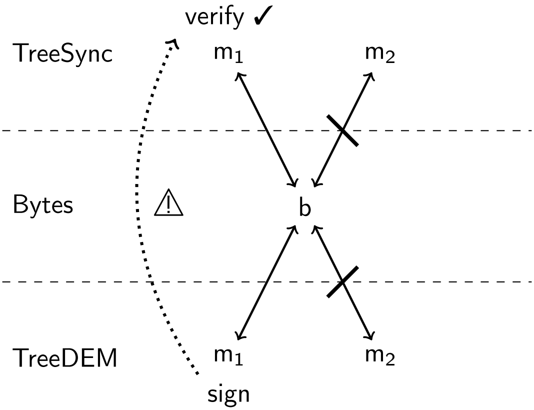

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The result: the meaning of b becomes **self-contained**.

A rigorous approach to domain separation

Bytes	High-level
sign	
verify	
EUF-CMA	

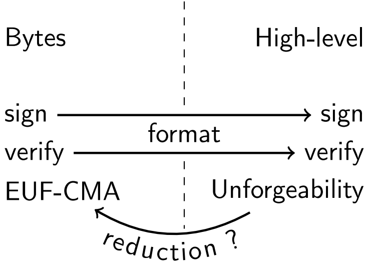
A rigorous approach to domain separation

Bytes	High-level

$$\begin{tikzcd}
\text{sign} \arrow[r] & \text{sign} \\
\text{verify} \arrow[r, "\text{format}"] & \text{verify}
\end{tikzcd}$$

EUF-CMA	Unforgeability

A rigorous approach to domain separation



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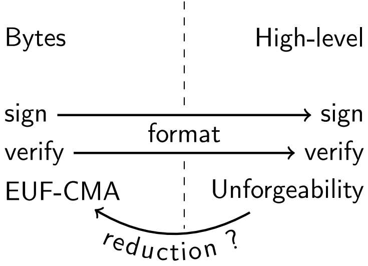

Reduction if: this format is self-contained and non-ambiguous.

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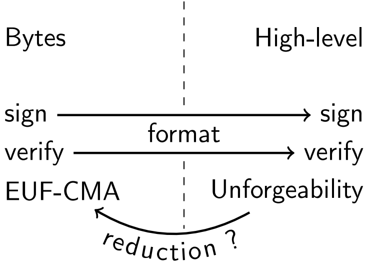

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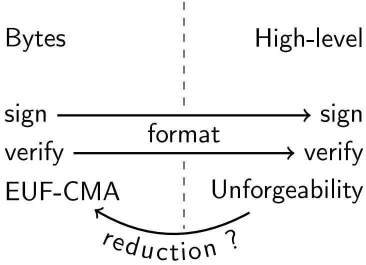

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Note 1: MLS draft 12 failed to obey this design discipline!
This weakness can be used in an attack.

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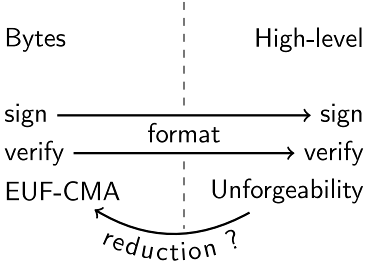

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Note 2: similar design discipline for MAC, AEAD, KDF, ...

Analyzing message formats in a given protocol

Comparse: a proof framework for message formats

We define:

- 4 safe message format combinators (e.g. pairs, lists),
- prove their security properties once and for all

(full details in the paper!)

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Solution: in a proof assistant,

- automate message format generation,
- prove security conditions automatically!

Defining formats with Comparse in F*

TLS 1.3 RFC

```
struct {
  ProtocolVersion legacy_version;
  Random random;
  opaque legacy_session_id<0..32>;


  // ...

  Extension extensions<8..2^16-1>;


} ClientHello;
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```
type client_hello = {
  legacy_version: protocol_version;
  random: random;
  legacy_session_id:
    tls_bytes {min=0; max=32};

  // ...

  extensions:
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and prove automatically non-ambiguity and representation unicity.

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We support several fallbacks if the meta-program fail.

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Problem: TLS 1.3 messages are big!

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Random random;
opaque legacy_session_id<0..32>;
uint16 cipher_suites_length;
CipherSuite cipher_suites[cipher_suites_length];
opaque legacy_compression_methods<1..2^8-1>;
uint16 extensions_length;
ExtensionType extension type = supported groups;
uint16 extension_length;
NamedGroup supported_groups[extension_length];
ExtensionType extension_type = key_share;
uint16 extension_length;
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NamedGroup group = x25519;
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Case study: cTLS format properties

cTLS modifies the message formatting of TLS 1.3.

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Short answer:

- we proved that the formats still follow the protocol design disciplines

Long answer:

- §4 in the paper

Conclusion

Our contributions:

- shed light on the importance of formatting in cryptographic protocols
- show our approach on large case studies (TLS 1.3, MLS, cTLS)
- prove security of cTLS formats, pave the way to a full security proof
- theoretically integrates in proofs in the computational model
- concretely integrate with the DY* symbolic proof framework, a core component of an MLS security proof

</> `https://github.com/Inria-Prosecco/comparse-artifact`

`theophile.wallez@inria.fr`

`https://www.twal.org/`

@twallez

Case studies

Protocol	Nb. formats	RFC LoC	F^* LoC	Verif. time
TLS 1.3	51	311	452	3min15s
MLS	82	482	624	2min45s
cTLS	30	623	608	2min45s