Analysing privacy-type properties using formal methods

Stéphanie Delaune

LSV, CNRS & ENS Cachan & INRIA Saclay Île-de-France, France

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Context: cryptographic protocols

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Cryptographic protocols

- small programs designed to secure communication (*e.g.* confidentiality, authentication, ...)
- use cryptographic primitives (*e.g.* encryption, signature, ...)

The network is unsecure!

Communications take place over a public network like the Internet.

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It becomes more and more important to protect our privacy.

Example: electronic passport

$\longrightarrow$ studied in [Arapinis *et al.*, 10]

An electronic passport is a passport with an RFID tag embedded in it.

The RFID tag stores:

- the information printed on your passport,
- a JPEG copy of your picture.

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The Basic Access Control (BAC) protocol is a key establishment protocol that has been designed to also ensure unlinkability.

ISO/IEC standard 15408

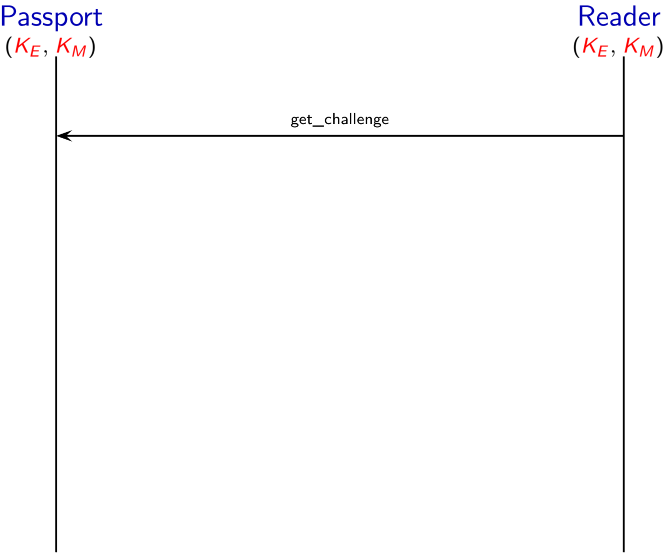
Unlinkability aims to ensure *that a user may make multiple uses of a service or resource without others being able to link these uses together.*

The electronic passport protocol

Passport
(K_E, K_M)

Reader
(K_E, K_M)

The electronic passport protocol



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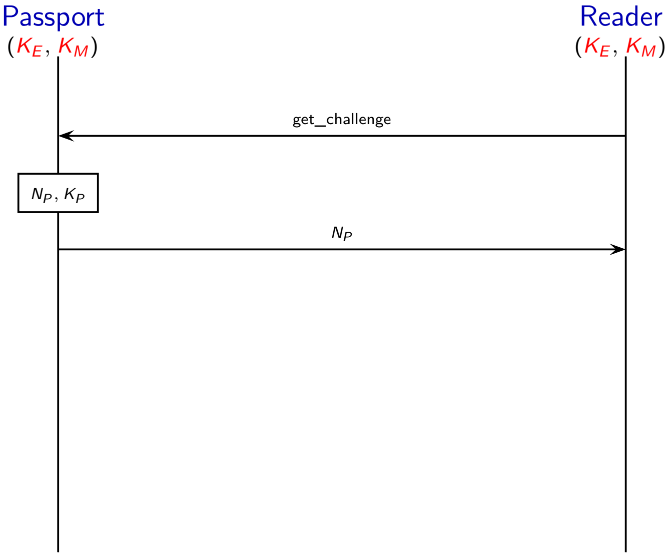

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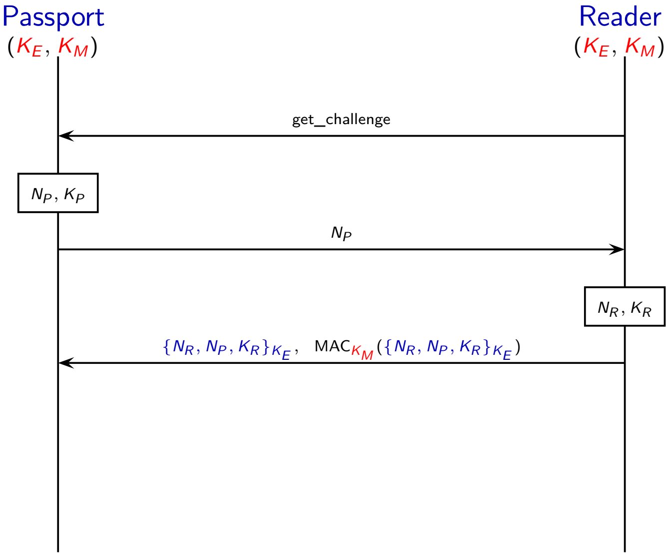

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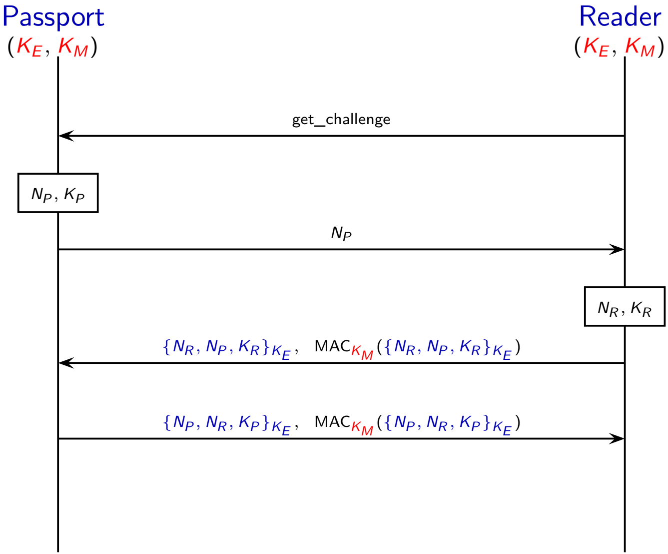

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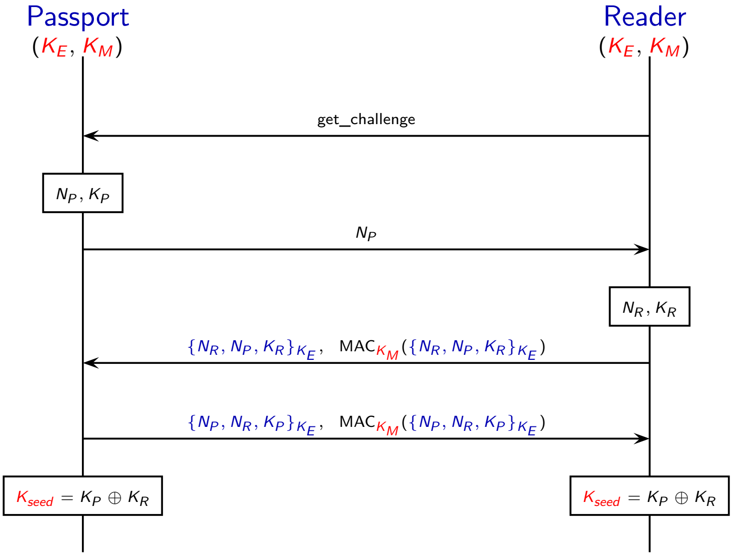

How cryptographic protocols can be attacked?

Some famous examples

The Serge Humpich case (1997)

He factorizes the number (320 bits) used to protect credit cards and he builds a false credit card. (the « YesCard »).

⟶ this makes it possible to withdraw a bank account that does not exist!

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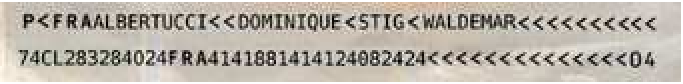
Attack on the Belgian e-passport (2006)



$\longrightarrow$ this makes it possible to obtain the personnal data of the user (*e.g.* the signature)

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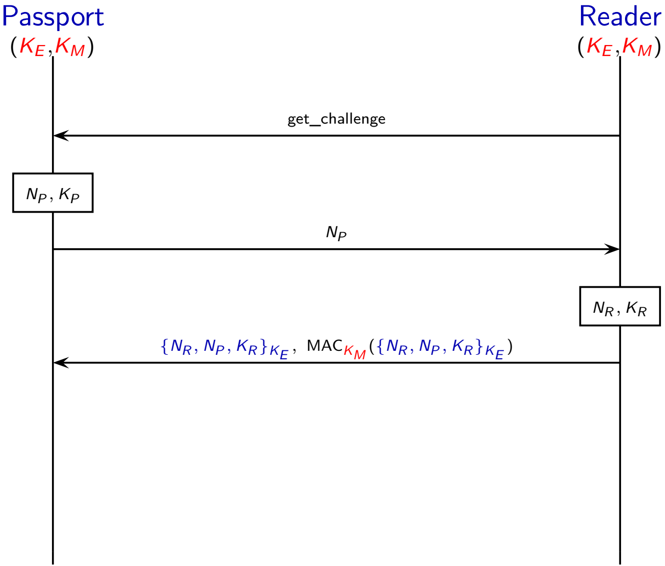
Logical attacks

- can be mounted even assuming perfect cryptography,
  $\hookrightarrow$ replay attack, man-in-the middle attack, ...
- are numerous,
  $\hookrightarrow$ a flaw discovered in 2010 in Single Sign On Protocols used in Google App (Avantssar european project)
- subtle and hard to detect by "eyeballing" the protocol

French electronic passport

$\longrightarrow$ the passport must reply to all received messages.



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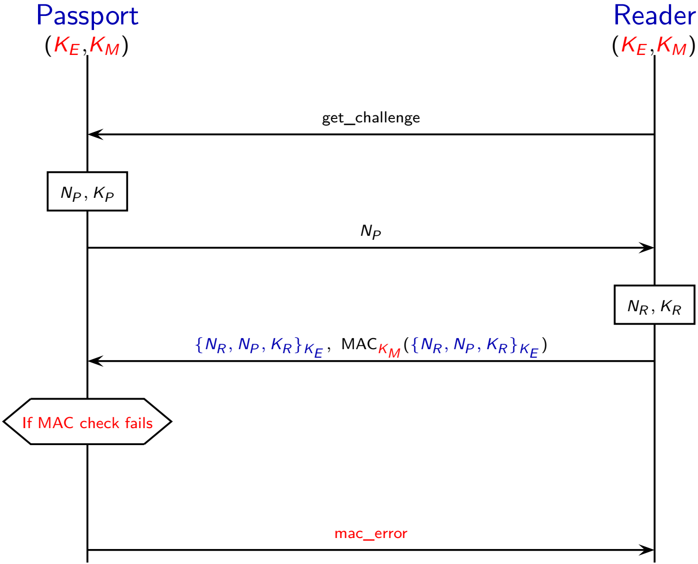

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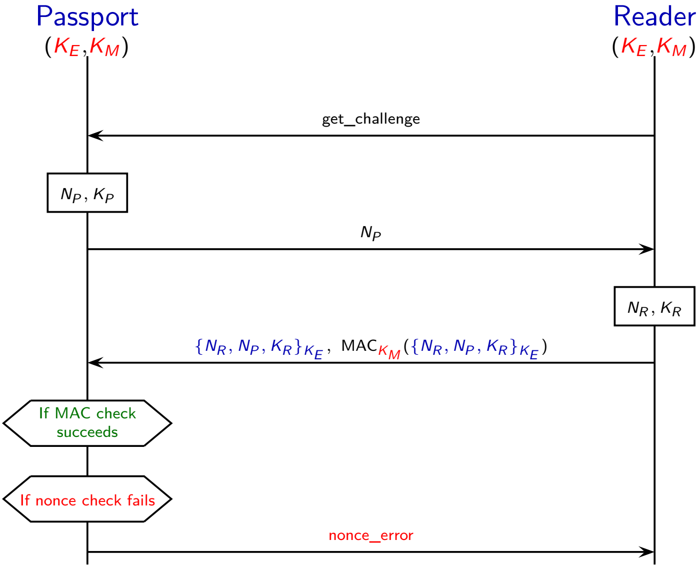

An attack on the French passport [Chothia & Smirnov, 10]

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An attacker can track a French passport, provided he has once witnessed a successful authentication.

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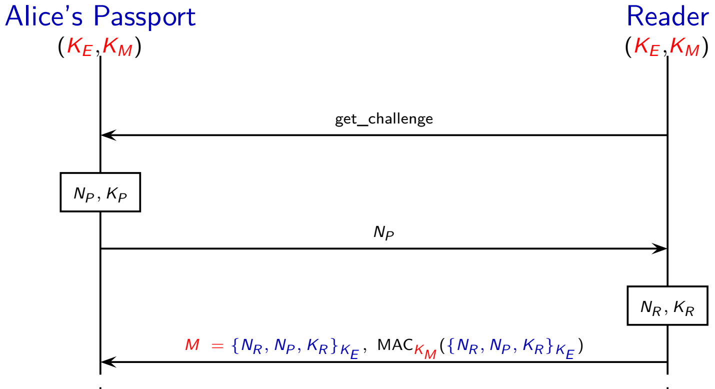
Part 1 of the attack. The attacker eavesdropes on Alice using her passport and records message M.



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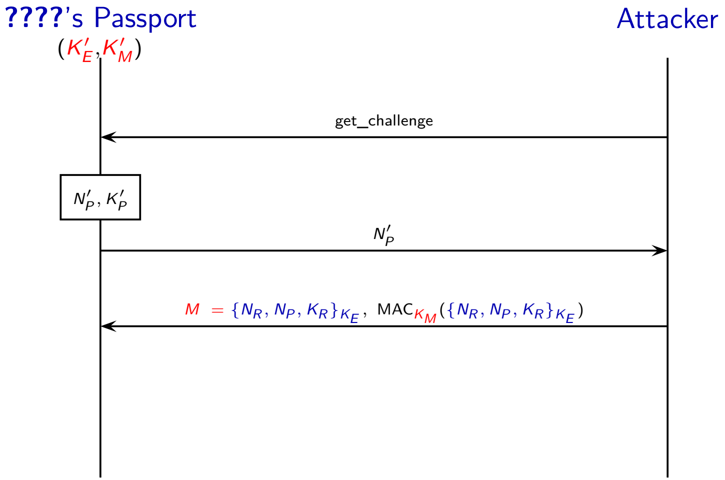
Part 2 of the attack.

The attacker replays the message M and checks the error code he receives.



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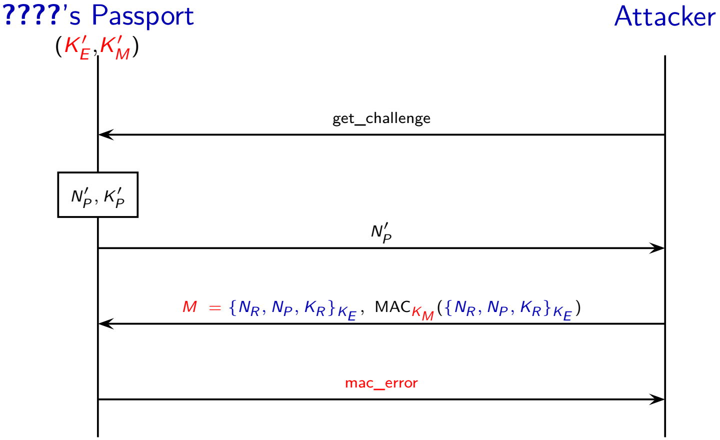

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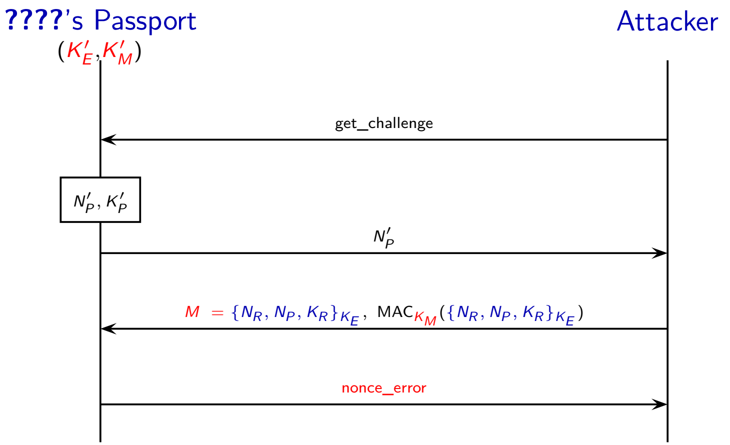

$\Longrightarrow$ MAC check succeeded $\Longrightarrow$ $K'_M = K_M$ $\Longrightarrow$ **????** is Alice

DEMO

(thanks to Myrto Arapinis, Tom Chothia, and Vincent Cheval
... and to those who lend me their e-passport.)

Attack found in 2010 by T. Chothia and V. Smirnov

Objectives

Formal and automatic analysis of new applications

Target applications: electronic voting protocols, RFID protocols, routing protocols, vehicular ad hoc networks, electronic auction protocols, . . .

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Challenges:

1. Formal definitions of the expected security properties
   $\longrightarrow$ privacy-type security properties
2. Designing appropriate verification algorithms
3. Modularity issues

Some basic features (symbolic models)

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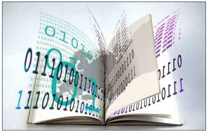

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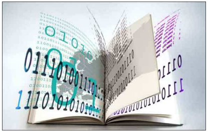

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Examples:

$\rightarrow$ symmetric encryption/decryption: $\mathsf{dec}(\mathsf{enc}(x, y), y) = x$

$\rightarrow$ exclusive or operator:

$$\begin{array}{rcl} (x \oplus y) \oplus z & = & x \oplus (y \oplus z) \\ x \oplus y & = & y \oplus x \end{array} \qquad \begin{array}{rcl} x \oplus x & = & 0 \\ x \oplus 0 & = & x \end{array}$$

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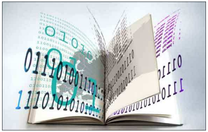

Messages

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The attacker

- may read every message sent on the network,
- may intercept and send new messages according to its deduction capabilities.
  $\longrightarrow$ only symbolic manipulations on terms.

Formal definition of privacy-type properties

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"An observer cannot observe any difference between P and Q"

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Recently, some formal definitions have been proposed:

- vote-privacy [Delaune *et al.*, 2008],
- unlinkability in RFID systems [Arapinis *et al.*, 2010], [Bruso *et al.*, 2010],

... but some definitions are still missing for many applications (*e.g.* anonymous routing protocols)

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ProVerif tool [Blanchet, 01] `http://www.proverif.ens.fr/`

- $+$ unbounded number of sessions; various cryptographic primitives;
- $-$ termination is not guaranteed; diff-equivalence (too strong)

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$\longrightarrow$ ProSwapper extension [Smyth, 10]

$\longrightarrow$ None of these results is able to analyse the e-passport protocol.

A recent contribution

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A procedure for deciding testing equivalence for a large class of processes.

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$\longrightarrow$ this allows us in particular to deal with the e-passport example

Modularity issues (1/2)

Some motivations:

- Existing tools allow us to verify relatively small protocols and sometimes only for a bounded number of sessions
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$P_1: \quad A \to B: \quad \{s\}_{\mathsf{pub}(B)}$

$P_2: \quad A \to B: \quad \{N_a\}_{\mathsf{pub}(B)}$
$\qquad\; B \to A: \quad N_a$

Question: What about the secrecy of s?

Modularity issues (2/2)

Our goals

investigate sufficient conditions to ensure that protocols (that may share some keys) can be safely used in an environment where:

1. other sessions of the same protocol may be executed;
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Several results have been proposed for sequential/parallel composition, *e.g.*:

- parallel composition using tagging
  $\longrightarrow$ [Guttman & Thayer, 2000], [Cortier *et al.*, 2007]
- sequential composition for arbitrary primitives
  $\longrightarrow$ [Ciobaca & Cortier, 2010]

... but none of them are well-suited for analysing privacy-type properties

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It remains a lot to do for analysing privacy-type properties:

- formal definitions of some sublte security properties (receipt-freeness, coercion-resistance, . . .)
- algorithms (and tools!) for checking automatically trace equivalence for various cryptographic primitives;
- more composition results.

Main topics of the ANR JCJC - VIP project
(Jan. 2012 - Dec 2015)
`http://www.lsv.ens-cachan.fr/Projects/anr-vip/`

Research Theme 2 (RT2)

More precisely in "privacy analysis using logical approach" (RT 2.1)

Some expectations

1. new collaborations
   $\longrightarrow$ in particular with the COMÈTE team
   - on privacy analysis using logical approach
     Mayla Brusò, Konstantinos Chatzikokolakis, Jerry den Hartog, *Formal Verification of Privacy for RFID Systems*. CSF 2010: 75-88
   - on privacy analysis using probabilistic approach
2. new case studies
   $\longrightarrow$ Examples: protocols used to protect online social networks and/or electronic health record systems