APTE: an automatic tool for verifying privacy-type security properties

Stéphanie Delaune

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

$\longrightarrow$ tool developed by Vincent CHEVAL

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Context: cryptographic protocols

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- small programs designed to secure communication (*e.g.* confidentiality, authentication, ...)
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It becomes more and more important to protect our privacy.

Example: private authentication protocol

$$A \to B: \quad \{N_a, \mathsf{pub}_A\}_{\mathsf{pub}_B}$$

$$B \to A: \quad \{N_a, N_b, \mathsf{pub}_B\}_{\mathsf{pub}_A}$$

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1. the protocol is played between the agents a and b;
2. the protocol is played between the agents a' and b.

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Description of the attack:

$\longrightarrow$ the attacker sends $\{N, \mathsf{pub}_A\}_{\mathsf{pub}_B}$ and observes the answer sent by B.

1. b will answer with a message of the form $\{N, N_b, \mathsf{pub}_B\}_{\mathsf{pub}_A}$;
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$$B \to A: \quad \{N_a, N_b, \mathrm{pub}_B\}_{\mathrm{pub}_A} \quad \text{in case } B \text{ is willing to talk to } A$$

$$\{N_b\}_{\mathrm{pub}_B} \quad \text{otherwise}$$

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$\longrightarrow$ a possible fix in red

Example continued - more formally

Modelling the protocol

$A(a, b) =$
$\quad \mathsf{new}\, n_a.$
$\quad \mathsf{out}(c, \{\langle n_a, \mathsf{pk}(sk_a)\rangle\}_{\mathsf{pk}(sk_b)}).$
$\quad \mathsf{in}(c, z). \ldots$

$B(b, a) = \mathsf{new}\, n_b.\, \mathsf{in}(c, y).$
$\quad \mathsf{if}\ \pi_2(\mathsf{adec}(y, sk_b)) = \mathsf{pk}(sk_a)$
$\quad\quad \mathsf{then}\ \mathsf{out}(c, \{..., n_b, \mathsf{pk}(sk_a)\}_{\mathsf{pk}(sk_a)}).$
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Modelling the property

$$C[A(a,b) \mid B(b,a)] \ \stackrel{?}{\approx}_t \ C[A(a',b) \mid B(b,a')]$$

where $C = \mathsf{new}\, sk_a, \mathsf{new}\, sk_{a'}, \mathsf{new}\, sk_b.$
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Each experiment performed by the attacker on the left leads to a sequence of messages Φ_1 which is indistinguishable from the sequence Φ_2 obtained when performing the same expriment on the right.

Difficulties when checking trace equivalence

$\longrightarrow$ even considering a fixed number of protocol executions.

Main difficulties:

1. the attacker can build arbitrary messages (provided that they are deducible from his knowledge)

   $\longrightarrow$ no hope to test each experiment in turn

2. once the experiment is fixed, we still have to decide whether the resulting sequence of messages are indistinguishable or not.

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Running example: fix version

$\longrightarrow$ consider the experiment where the attacker sends $\{N, \mathsf{pk}(sk_a)\}_{\mathsf{pk}(sk_b)}$

The resulting sequences of messages are:

1. $\Phi_1 = \mathsf{pk}(sk_a),\ \mathsf{pk}(sk_{a'}),\ \mathsf{pk}(sk_b),\ \{n, n_b, \mathsf{pk}(sk_b)\}_{\mathsf{pk}(sk_a)}$
2. $\Phi_2 = \mathsf{pk}(sk_a),\ \mathsf{pk}(sk_{a'}),\ \mathsf{pk}(sk_b),\ \{n_b\}_{\mathsf{pk}(sk_b)}$.

where sk_a, $sk_{a'}$, sk_b, and n_b are unknown.

Algorithms for checking trace equivalence

trace equivalence is undecidable in general

Bounded number of sessions

e.g. [Baudet, 05], [Dawson & Tiu, 10], [Chevalier & Rusinowitch, 10], ...

$\longrightarrow$ this allows us to decide trace equivalence between simple processes with trivial else branches. [Cortier & Delaune, 09]

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- + unbounded number of sessions; various cryptographic primitives;
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$\longrightarrow$ None of these results is able to analyse the private authentication protocol.

Our contribution

$\longrightarrow$ V. Cheval, H. Comon-Lundh, and S. Delaune   CCS 2011

Main result

A procedure for deciding trace equivalence for a large class of processes implemented in a tool called APTE

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Our class of processes:

- $+$ non-trivial else branches, private channels, and non-deterministic choice;
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Some applications

- unlinkability in RFID protocols (*e.g.* e-passport protocol)
- anonymity (*e.g.* private authentication protocol)

Our procedure in a nutshell

Two main steps:

1. A symbolic exploration of all the possible traces

   The infinite number of possible traces (*i.e.* experiment) are represented by a finite set of symbolic traces.

   $\longrightarrow$ this set is still huge (exponential) !

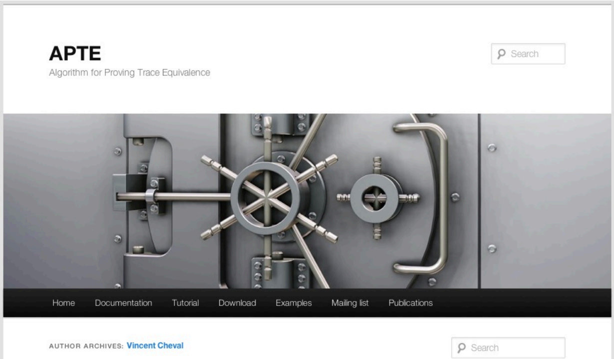
2. A decision procedure for deciding (symbolic) equivalence between sets of symbolic traces.

   $\longrightarrow$ this algorithm works quite well

APTE- Algorithm for Proving Trace Equivalence

`http://projects.lsv.ens-cachan.fr/APTE`

$\longrightarrow$ developed by Vincent Cheval



$\longrightarrow$ written in Ocaml, around 12 KLocs

Demo

Conclusion

APTE is an automatic tool for analysing privacy type properties expressed using trace equivalence

Case studies:

- private authentication protocol
- several protocols from the e-passport application
- some classical protocols from the literature (e.g. Needham-Schroeder, Wide Mouthed Frog protocol, ...)

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Main limitations:

- APTE can only handle standard cryptographic primitives
  $\longrightarrow$ e-voting protocols are out of reach of APTE
- APTE can only consider a bounded number of sessions (and actually a very small number)