Verification of Indistinguishability Properties

Programme Blanc JCJC (2012-2016)

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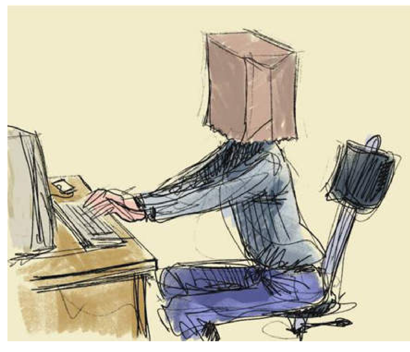
Issues

Privacy-type security properties



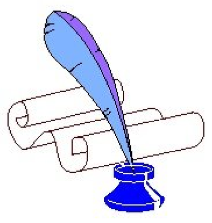
- **Unlinkability:** a user may make multiple uses of a service or resource without others being able to link these uses together.
- **Anonymity:** a user may use a service or resource without disclosing its identity.
- **Vote privacy:** a voter may vote without revealing his vote to others.

⟶ specified as a process equivalence, denoted $P \approx Q$, expressing that P and Q are indistinguishable from the attacker's point of view.

Beyond standard primitives

Modern applications often rely on non-classical cryptographic primitives:

- **Blind signatures** are used to allow *e.g.* a voter to obtain a signature on his ballot without revealing its content to the signing authority.



$$\mathsf{check}(\mathsf{sign}(m, \mathsf{priv}(k)), \mathsf{pub}(k)) = \mathsf{ok}$$
$$\mathsf{getmsg}(\mathsf{sign}(m, \mathsf{priv}(k))) = m$$
$$\mathsf{unblindsign}(\mathsf{sign}(\mathsf{blind}(m, r), \mathsf{priv}(k)), r) = \mathsf{sign}(m, \mathsf{priv}(k))$$

- **Exclusive-or** (xor) is used when computation time has to be optimised.

$$x \oplus x = 0 \qquad x \oplus (y \oplus z) = (x \oplus y) \oplus z$$
$$x \oplus 0 = x \qquad x \oplus y = y \oplus x$$

⟶ An attacker may exploit these algebraic properties to mount an attack.

A modular approach

Real life protocols are usually complex and composed of several sub-protocols. Verifying them in isolation is **not** sufficient!

Example: What about A's anonymity?

$$P_1 : A \to S : \{A\}^r_{\mathsf{pub}(S)} \qquad P_2 : A \to S : \{N_a\}^r_{\mathsf{pub}(S)}$$
$$S \to A : N_a$$

⟶ identified sufficient conditions under which a modular security analysis is possible.

Results

Decidability results

We provide the first decidability results in the unbounded setting.

1. A characterization of equivalence of protocols (without nonces) in terms of equivalence of pushdown automata (a difficult but decidable problem).

$$P \approx Q \Leftrightarrow L(\mathcal{A}_P) = L(\mathcal{A}_Q) \text{ and } L(\mathcal{A}) = L(\mathcal{B}) \Leftrightarrow P_{\mathcal{A}} \approx P_{\mathcal{B}}$$

2. A decidability result under the following assumptions:
   - **Simple process**: each process communicates on a distinct channel.
   - **Type compliance**: can be enforced by adding a tag in each cipher.
   - **Acyclic dependency graph**: this condition can be easily checked and is satisfied by most of protocols from the literature.

⟶ **Rémy Chrétien's PhD thesis (defended in Jan. 2016).**

Modularity

We provide some good design principles to make sure that protocols can be analysed in isolation, and used in more complex environment, *e.g.*

Principle: Adding identifiers (*e.g.* protocol's name) in each ciphertext

$$P_1 : A \to S : \{\mathbf{1}, A\}^r_{\mathsf{pub}(S)} \qquad P_2 : A \to S : \{\mathbf{2}, N_a\}^r_{\mathsf{pub}(S)}$$
$$S \to A : N_a$$

We also provide a tagging mechanism to allow self-composition, and to allow passwords to be safely reused.

⟶ **EASST Best Paper Award at ETAPS 2016.**

Automatic tools

Tools dedicated to a bounded number of sessions:

- **Apte** supports non-trivial else branches;
- **Akiss** allows one to consider a wide variety of primitives (*e.g.* xor).

Tools dedicated to an unbounded number of sessions:

- we extended **ProVerif** to prove more equivalences;
- **Ukano** is tailored for proving unlinkability on 2-party protocols.

Case studies

E-passport

We consider the BAC, as well as two authentication protocols: PA and AA, as specified by the ICAO standard.

Main results

- several linkability attacks on BAC using **Apte**;
- the first formal security proof of the fixed version of BAC using **Ukano**;
- the discovery of several vulnerabilities on PACE (successor of BAC);
- a modular security analysis of BAC/PA/AA.

RFID protocols

We discovered several flaws on various RFID protocols from the literature using **Akiss** – the only tool able to effectively verify equivalences for protocols that use xor.

⟶ **This work has been completed by Ivan Gazeau (post-doc)**

E-voting protocols

We used **Akiss** to establish vote privacy on the electronic voting protocols by Okamoto and Fujioka et al. which rely on trapdoor commitments and blind signatures.

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