APTE: an Algorithm for Proving Trace Equivalence

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Context

Most communications take place over a public network

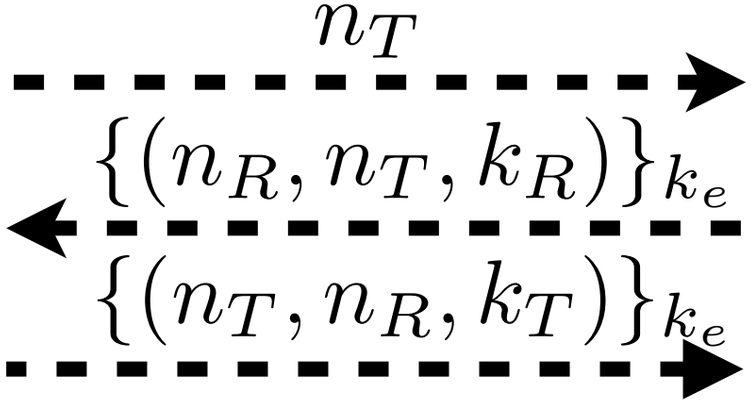
Cryptographic protocols

- programs designed to secure communication (e.g. secrecy)
- use cryptographic primitives (e.g. encryption, signature)

Security properties

Example : E-passport

Passport



Officer

Formal methods and symbolic models

Security properties

Example : E-passport

$$n_T \dashrightarrow$$
$$\dashleftarrow \{(n_R, n_T, k_R)\}_{k_e}$$
$$\{(n_T, n_R, k_T)\}_{k_e} \dashrightarrow$$

Passport Officer

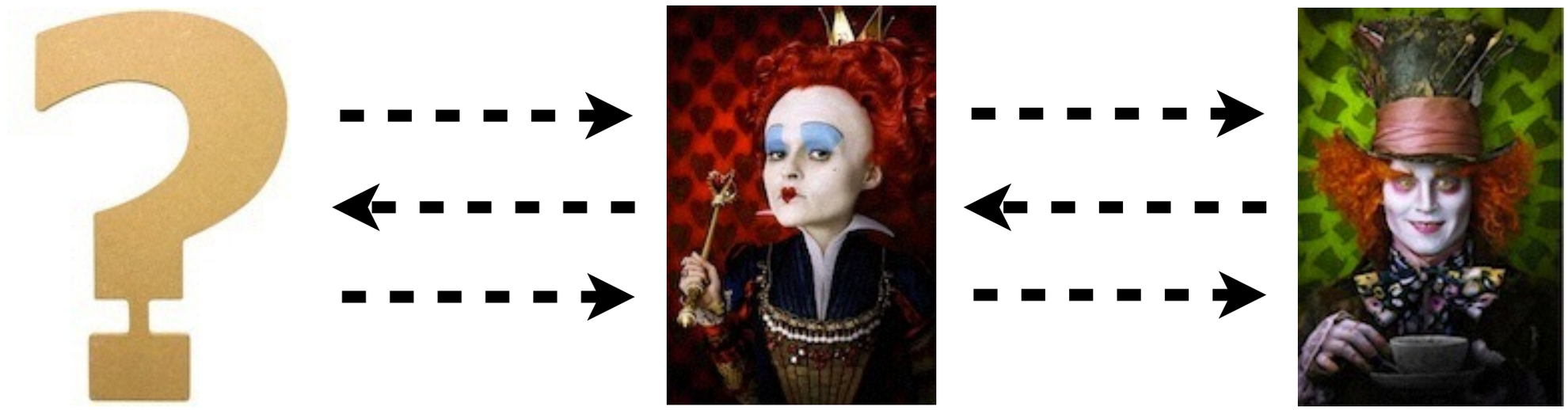
Formal methods and symbolic models

Security properties

- Confidentiality ⟶ Reachability properties
- Anonymity ⟶ Equivalence properties

Examples : Privacy, properties for electronic voting, unlinkability..

Anonymity



Unknown Attacker Bob

Anonymity

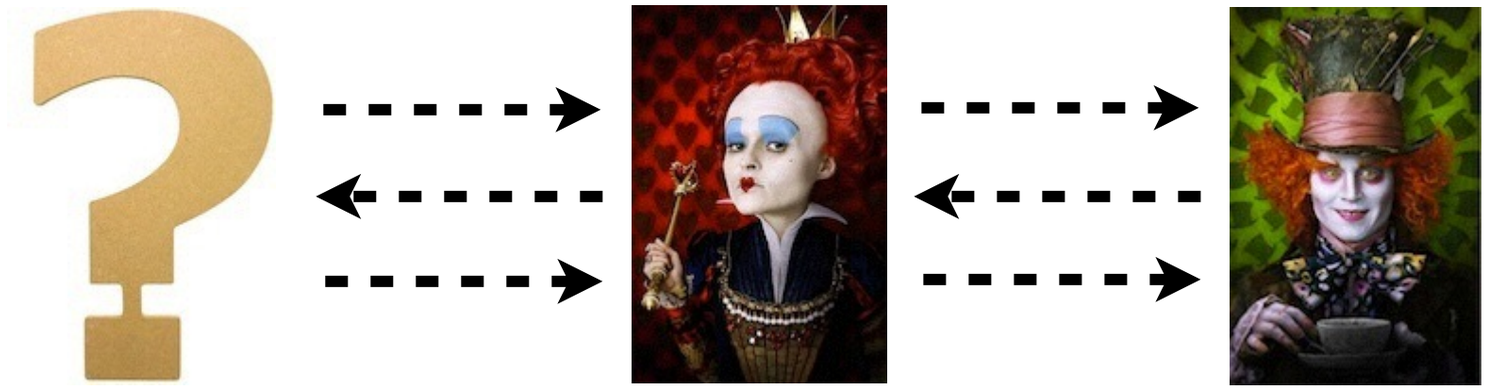
- Intercept all messages
- Can transmit or modify messages
- Test equalities between messages

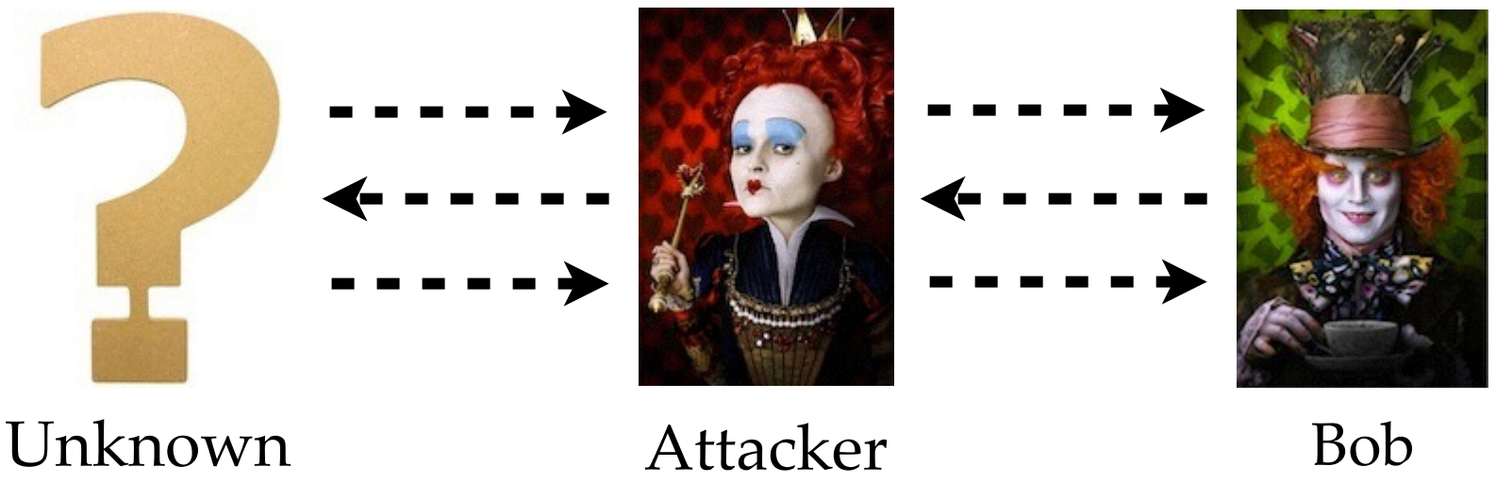
Unknown

Attacker

Bob

Anonymity





Anonymity

Charlene

Unknown

Attacker

Bob

Alice

Unknown

Attacker

Bob

Anonymity

Charlene

Unknown

Attacker

Bob

Alice

Unknown

Attacker

Bob

Can the intruder distinguish the two situations ?

Anonymity

Charlene

Unknown

Attacker

Bob

Alice

Unknown

Attacker

Bob

Trace equivalence

Private authentication protocol

Private authentication protocol

Alice

$$\{\langle N_a, \mathsf{pk}(k_A)\rangle\}_{\mathsf{pk}(k_B)}$$

Bob

Private authentication protocol

Alice

$$\{\langle N_a, \mathsf{pk}(k_A)\rangle\}_{\mathsf{pk}(k_B)}$$

$\mathsf{pk}(k_A)?$

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Private authentication protocol

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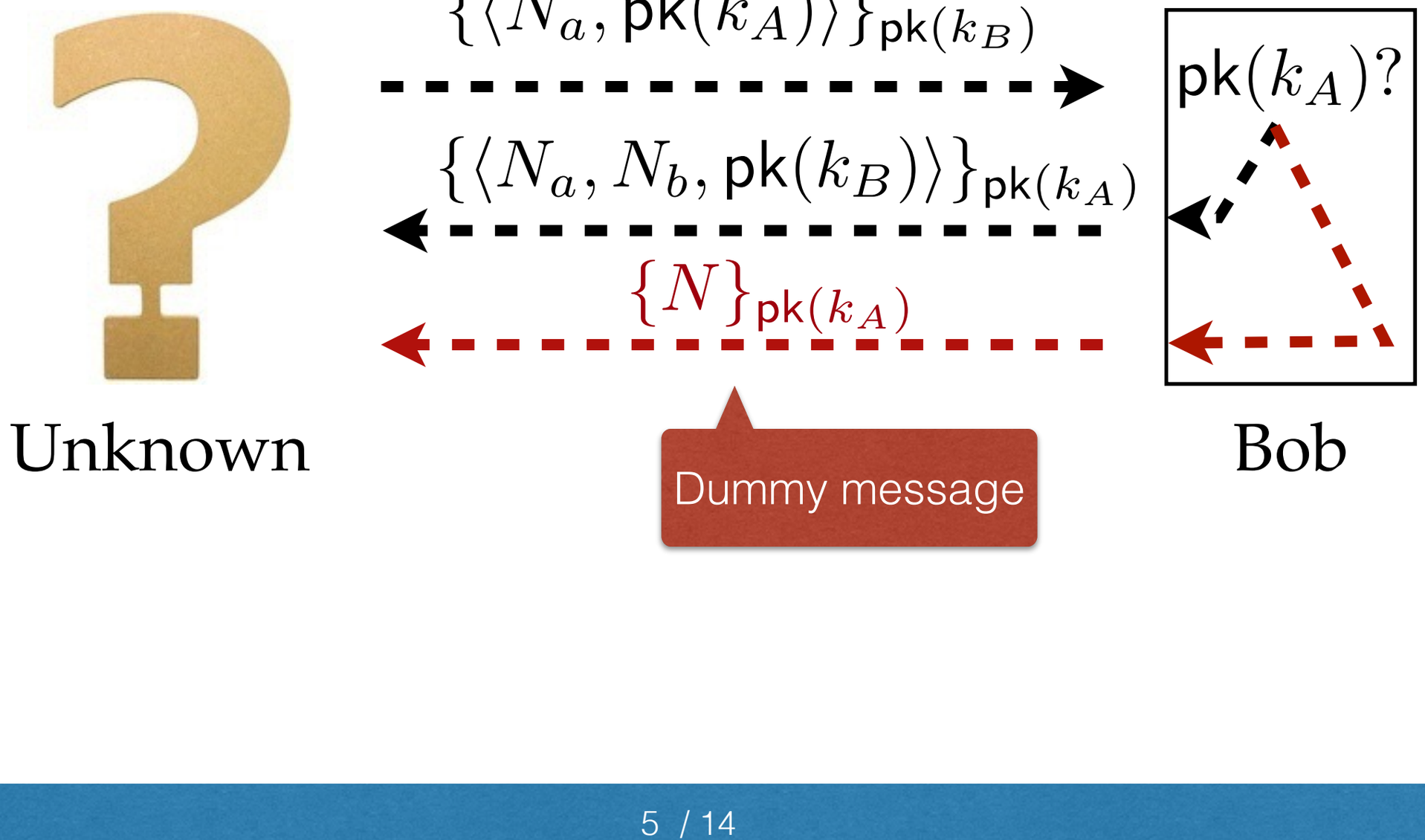
$\{N\}_{\mathsf{pk}(k_A)}$

$\mathsf{pk}(k_A)?$

Dummy message

Bob

Private authentication protocol



Automatic tools

- For reachability properties

  Avispa, CSP/FDR, ProVerif, Scyther, Maude-NPA, ...

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Do not handle private authentication protocol and e-passport protocol

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Do not handle private authentication protocol and e-passport protocol

APTE can do it !

Demonstration

Private_Authentication_Protocol.txt — Edited

```
# Private Authentication Protocol

free c.

### Description of the role of Alice

let process_Alice k_a k_b =
  new N_a;
  out(c,aenc((N_a,pk(k_a)),pk(k_b)));
  in(c,x).

### Description of the role of Bob

let process_Bob k_a k_b =
  in(c,x);
  let (na,pka) = adec(x,k_b) in
  if pka = pk(k_a)
  then new N_b; out(c,aenc((na,N_b,pk(k_b)),pk(k_a)))
  else new N; out(c,aenc(N,pk(k_a))).

### Main

let instance1 =
  new k_a ; new k_b ; new k_c ; out(c,pk(k_a)) ; out(c,pk(k_b)) ;
out(c,pk(k_c));
  ( process_Alice k_a k_b | process_Bob k_a k_b ).
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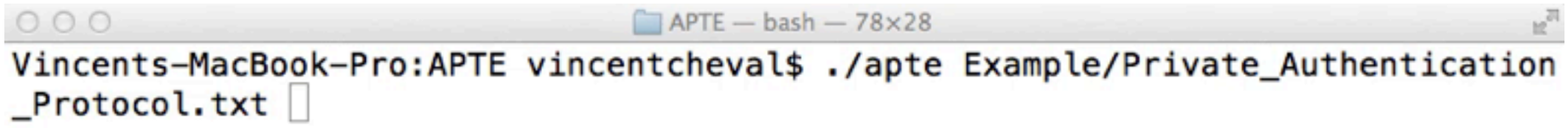

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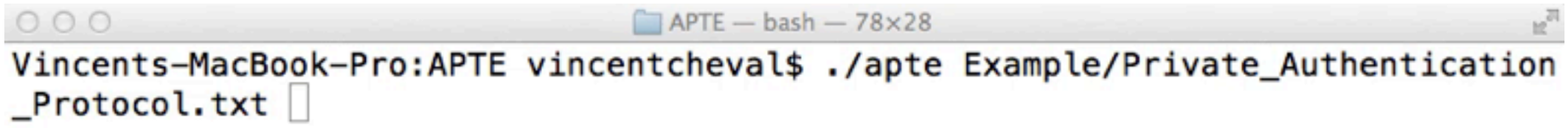
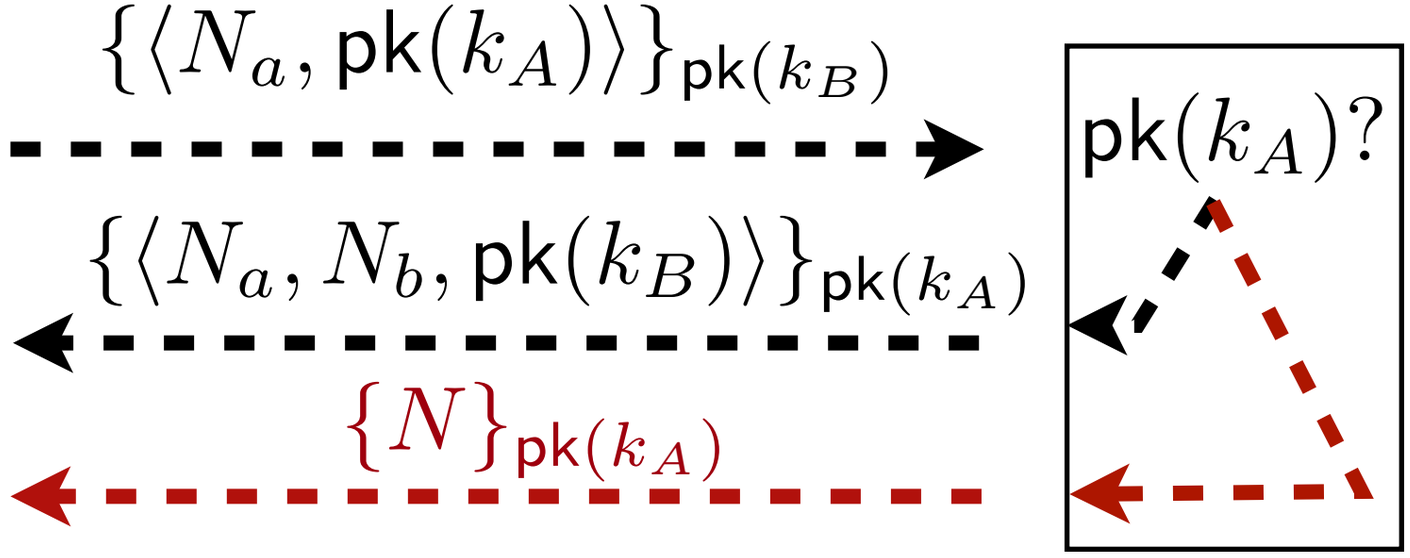


Length of messages

Alice



Bob

Length of messages

Alice

$\{\langle N_a, \mathsf{pk}(k_A)\rangle\}_{\mathsf{pk}(k_B)}$

$\{\langle N_a, N_b, \mathsf{pk}(k_B)\rangle\}_{\mathsf{pk}(k_A)}$

$\{N\}_{\mathsf{pk}(k_A)}$

Size of dummy message differs

$\mathsf{pk}(k_A)?$

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Length functions

$\mathcal{N} = \mathcal{N}_1 \cup \ldots \cup \mathcal{N}_n \cup \ldots$

nonces of any length

$\mathsf{enc} \longrightarrow \mathsf{len}_{\mathsf{enc}} : \mathbb{N} \times \mathbb{N} \to \mathbb{N}$

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Length functions

Length of a constructor only depends on the length of its arguments

Demonstration

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### Definitions of the classic length functions

length aenc [constant=0; arguments = 1,0].
length pk [constant=0; arguments = 1].
length tuple(2) [constant=1; arguments = 1,1].

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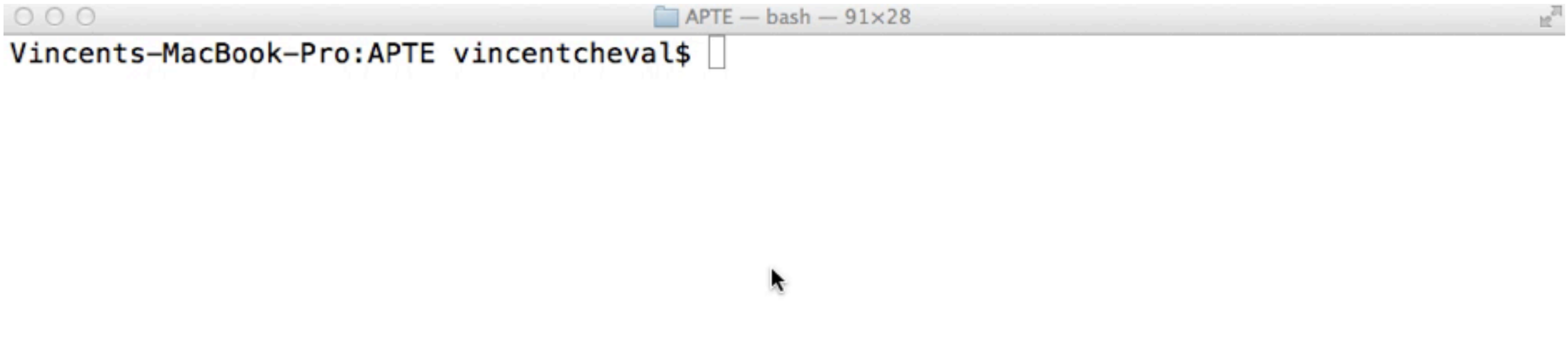

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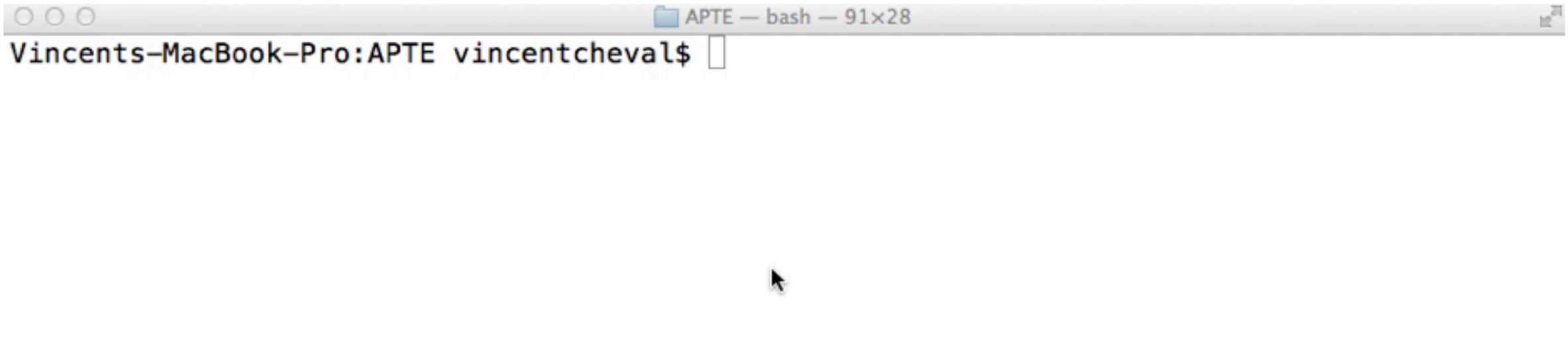
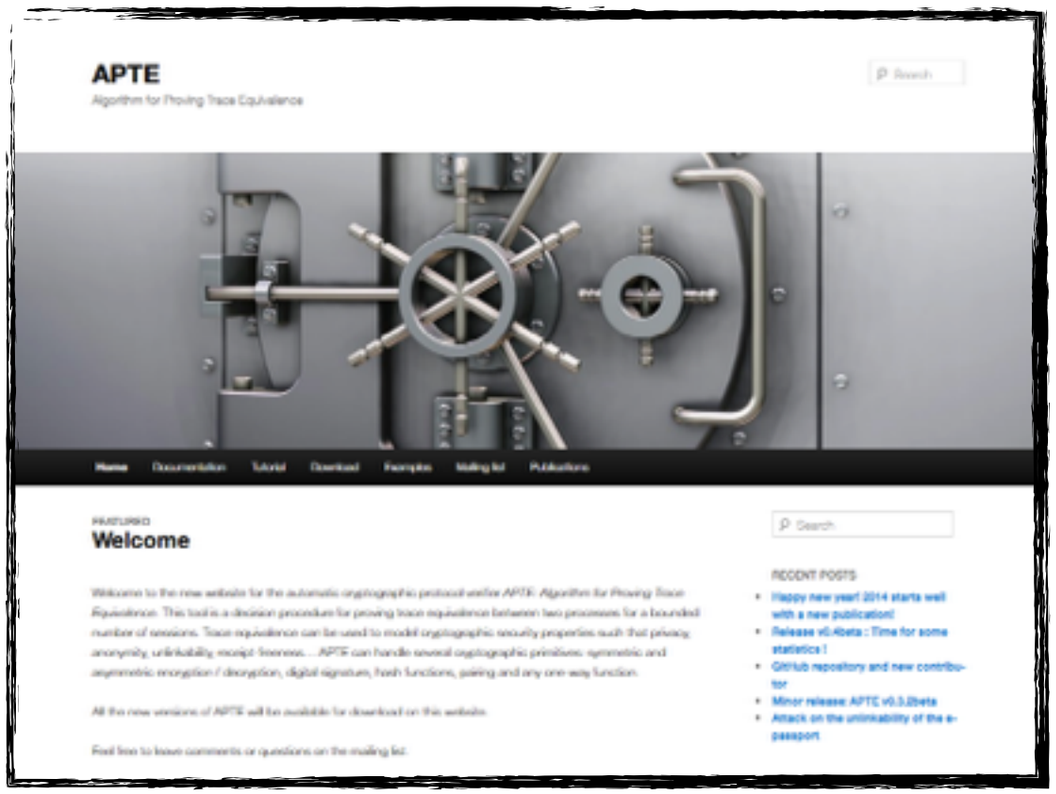


APTE

APTE v0.4beta
http://projects.lsv.ens-cachan.fr/APTE/

Based on equivalence of constraint system



Content:

- Equivalence between bounded processes with fix set of cryptographic primitives
- Display witness of non-equivalence
- Handle equivalence with respect to length of messages

IJCAR-CCD'10, CCS-CCD'11, Cheval'12, CAV-CCP'13

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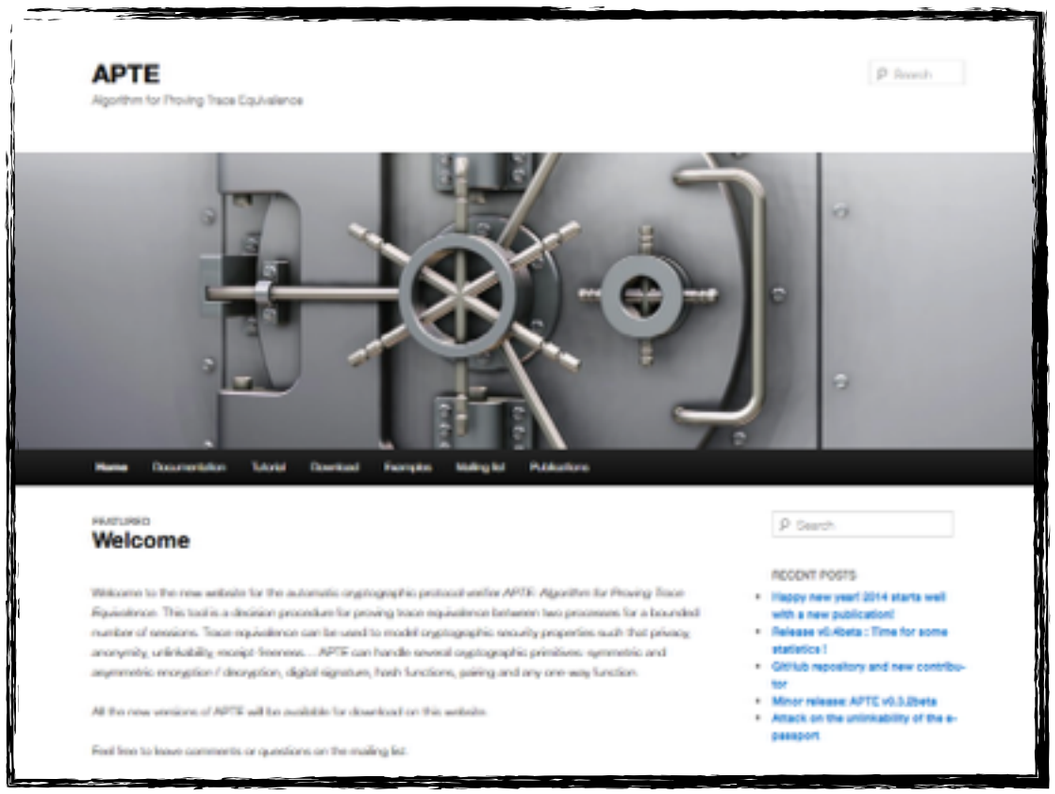

Rediscovered 2 known attacks on the e-passport protocol

Discovered a new attack on the e-passport and private authentication protocol

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Based on equivalence of … m

More cryptographic primitives

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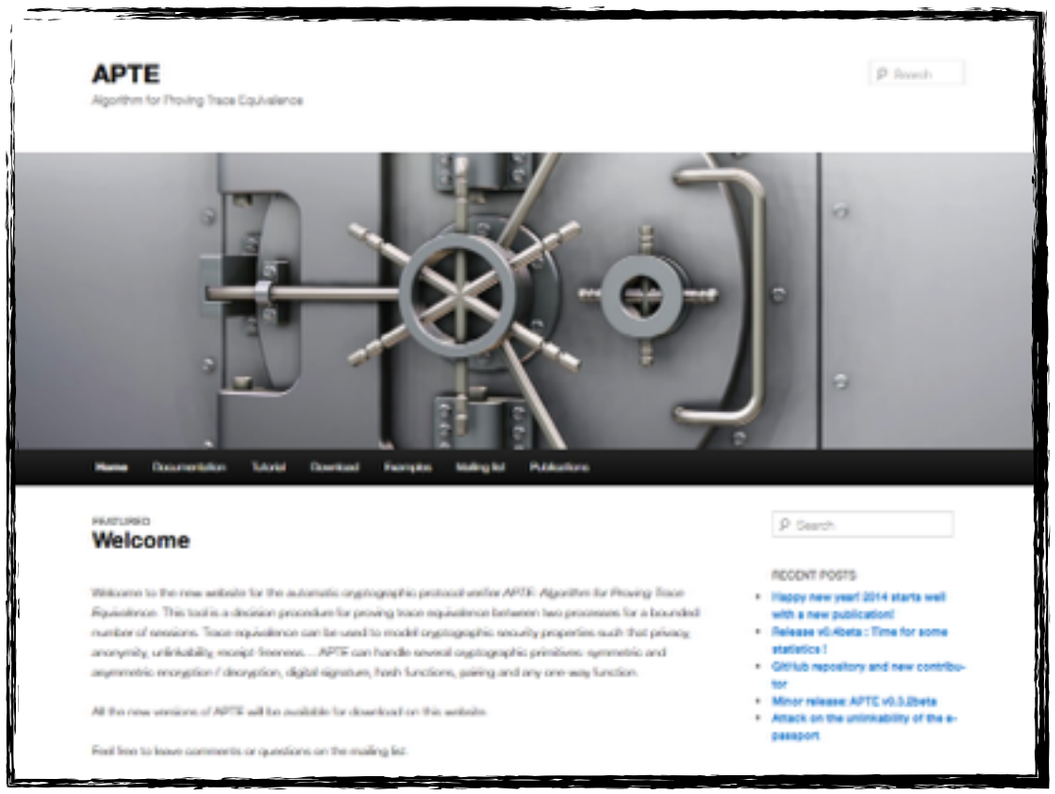

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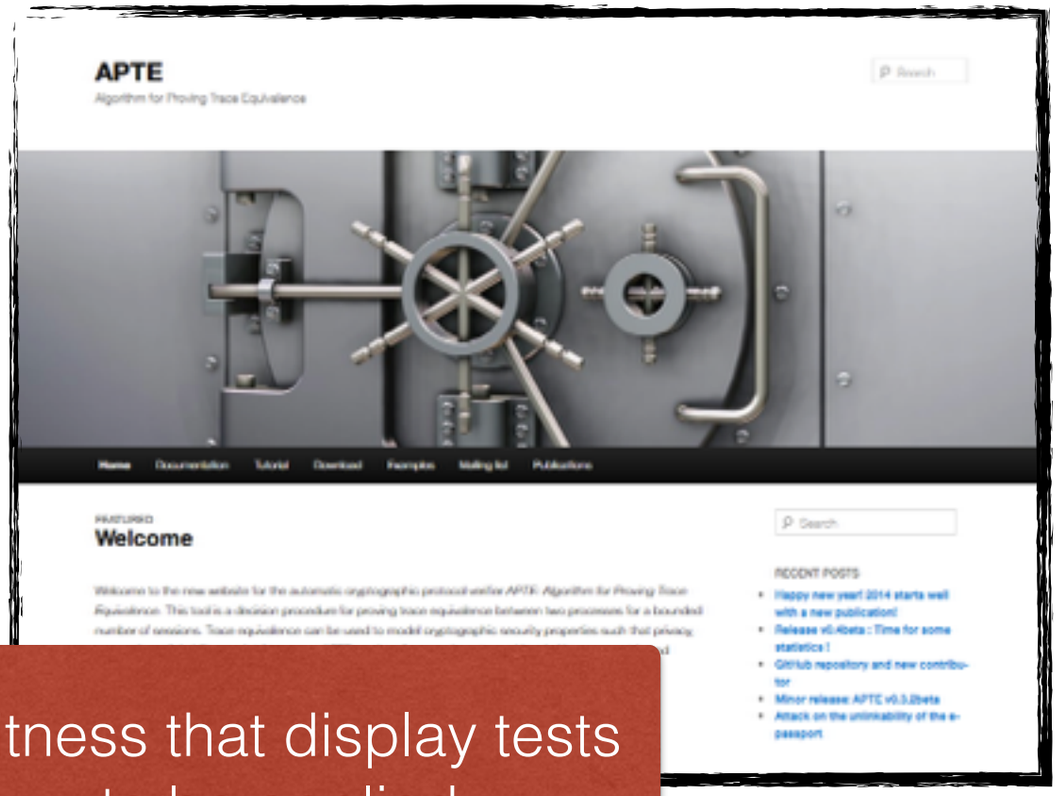

Witness that display tests to be applied

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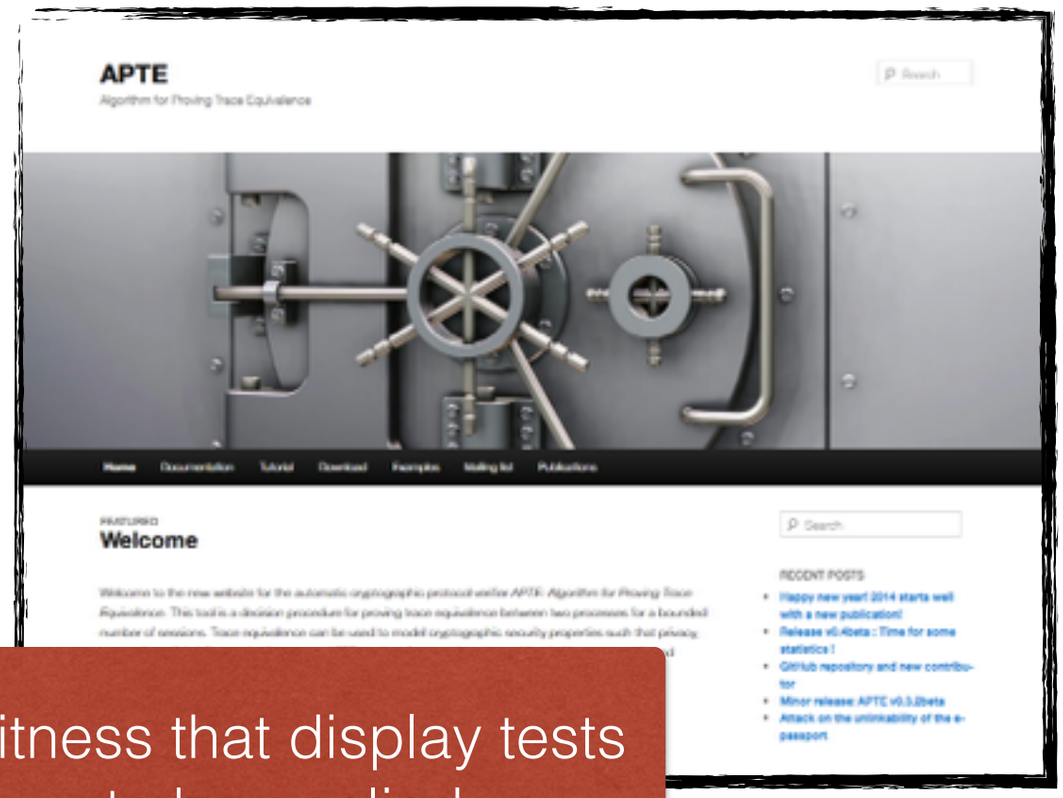

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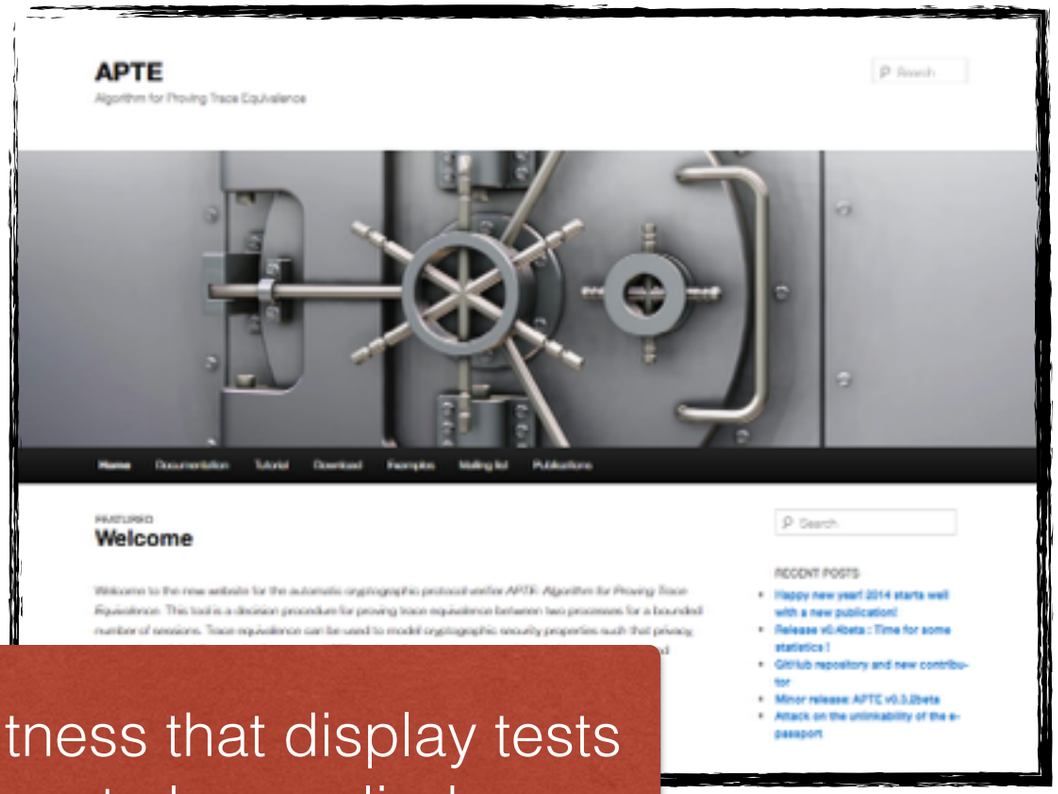

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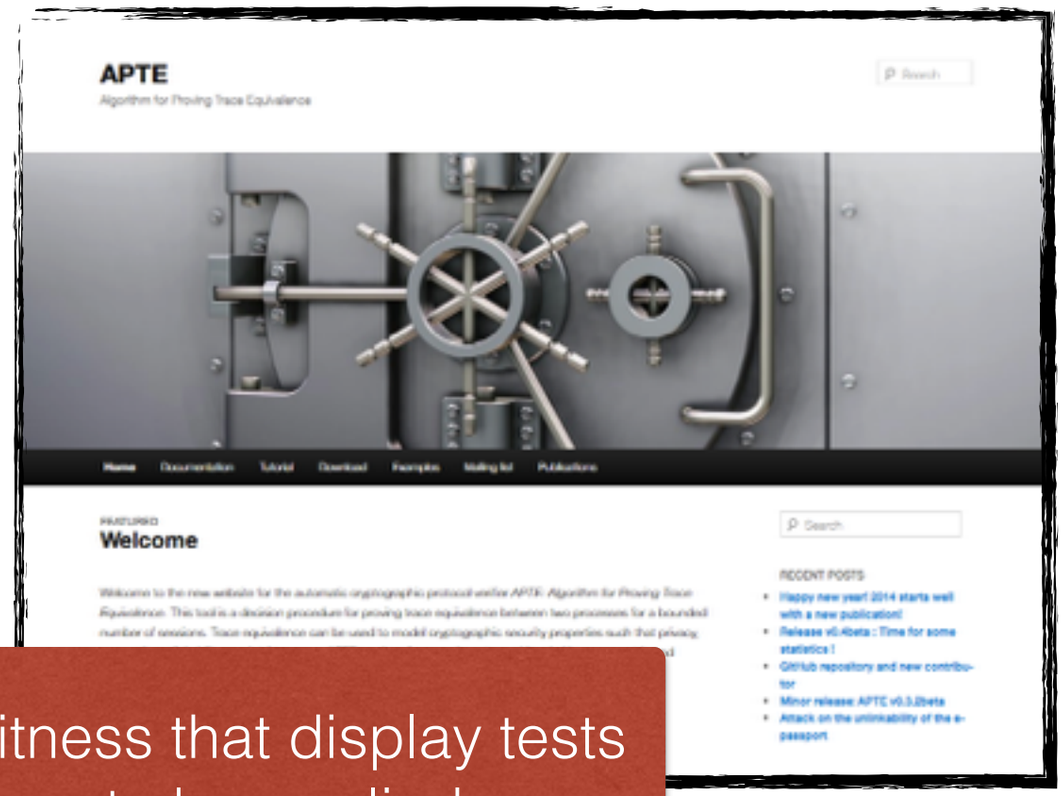

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- **Concurrent implementation (for multicore and distributed computing)**

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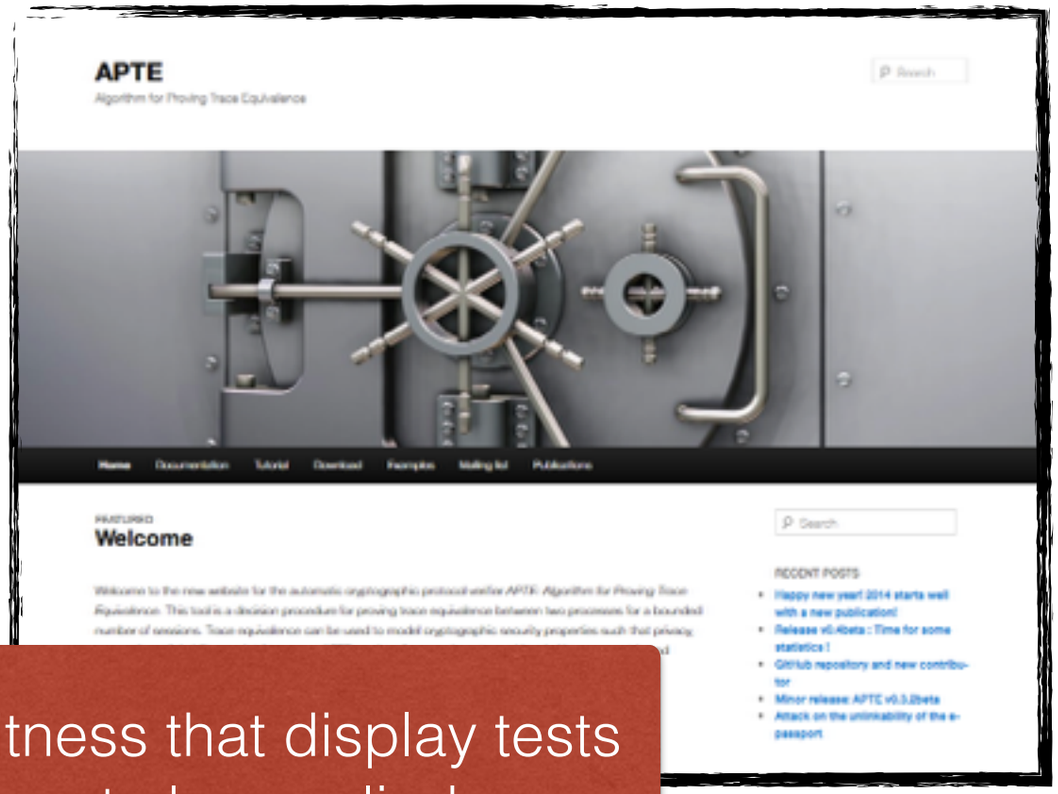

Witness that display tests to be applied

- **Concurrent implementation (for multicore and distributed computing)**
- **Optimisation of constraint equivalence solving**

APTE

Algorithm for Proving Trace Equivalence

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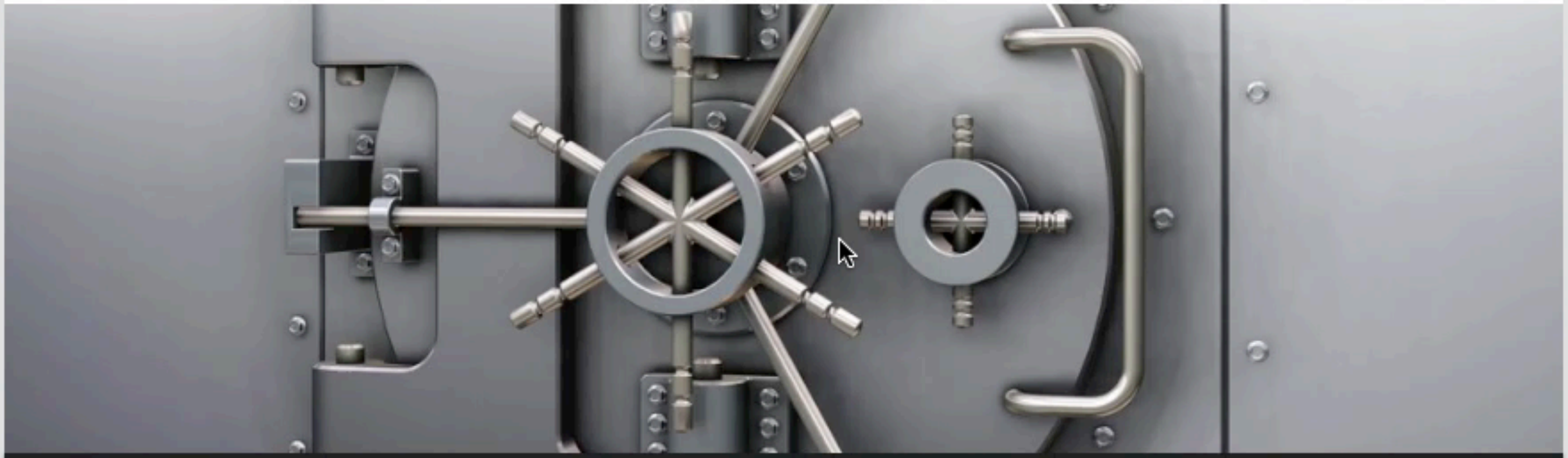

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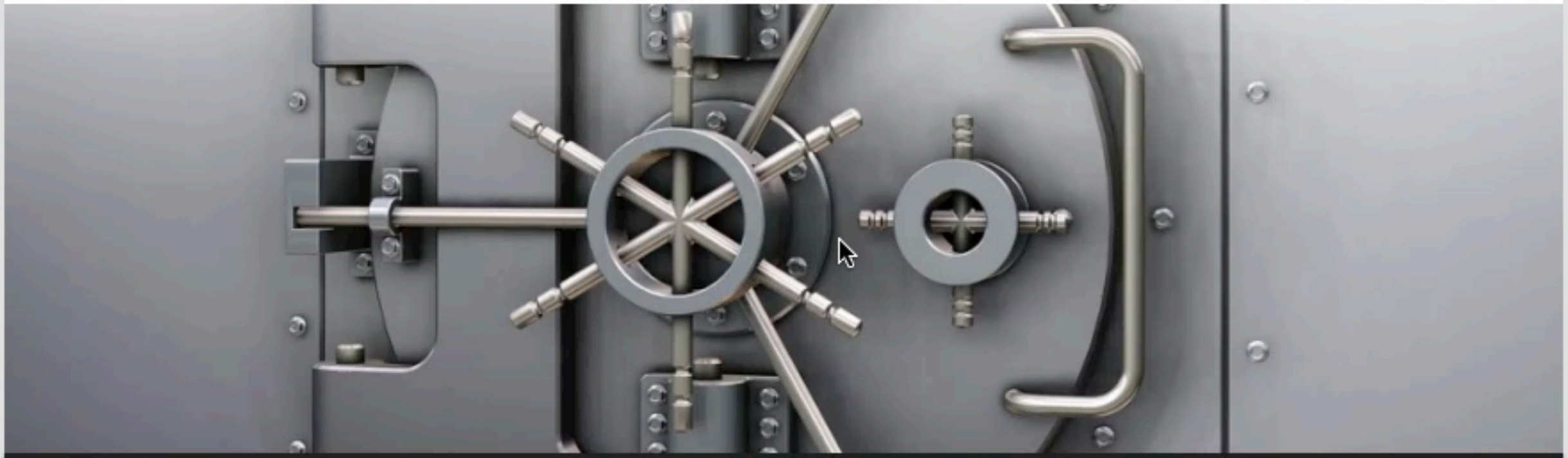

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