Electronic Voting: Design, attacks and Formal Verification

Véronique Cortier, CNRS, Loria (Nancy, France)

Joint work with Bruno Blanchet, Vincent Cheval, Alexandre Debant, Pierrick Gaudry, Stéphane Glondu, Lucca Hirschi, Léo Louistisserand, Florian Moser

January 27th, 2026

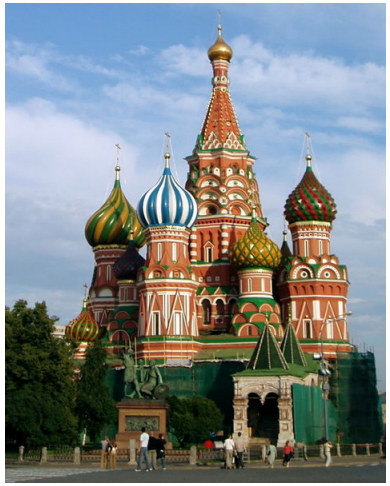
Internet voting is used in various countries

- France: National Assembly, for expats only (2012, 2022, 2024)
- Estonia: local elections (since 2005), national parliamentary elections (since 2007),
  more than 50% of votes cast by Internet in 2023
- Australia: New South Wales state (2021, more than 650 000 votes cast by Internet)
- Switzerland: several trials, a demanding and evolving regulation since 2013
- Canada: local election in Ontario (since 2003) and Nova Scotia (since 2006)

Widely used in non-political election

- professional elections
- associations
- administration councils
- scientific councils

Numerous attacks !



Elections in Moscow, in 2019 [P. Gaudry]

- ballots posted on a blockchain (why?)
- bug bounty program

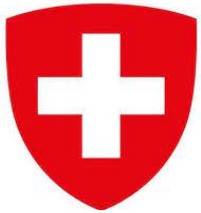
3 keys of 256 bits $\neq$ 1 key of 768 bits

$\neq$

Numerous attacks !

Swiss context

- open specification, open source code
- call for public scrutiny
- multiple elections in one round



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Privacy breach with A. Debant and P. Gaudry [RWC'22]

- possibility to (silently) add an extra ballot box, with just Alice' ballot
- a generous bug bounty 😀

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And also

- bad https channel in Australian elections
- complete take-over in overseas US military elections
- PacMan installed on Sequoia Machines AVC Edge
- tampering on voting machines in India
- ...

What is a good voting system?

Confidentiality of the votes

Vote privacy

"No one should know how I voted"

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Better: Receipt-free / Coercion-resistant

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- vote buying
- coercion

ebay

Silk Road
anonymous marketplace

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Everlasting privacy: no one should know my vote, even when the cryptographic keys will be eventually broken.

Verifiability

Individual Verifiability: a voter can check that

- cast as intended: their ballot contains their intended vote
- recorded as cast: their ballot is in the ballot box.

Universal Verifiability: everyone can check that

- tallied as recorded: the result corresponds to the ballot box.
- eligibility: ballots have been casted by legitimate voters.

You should verify the election,
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Even better: accountability

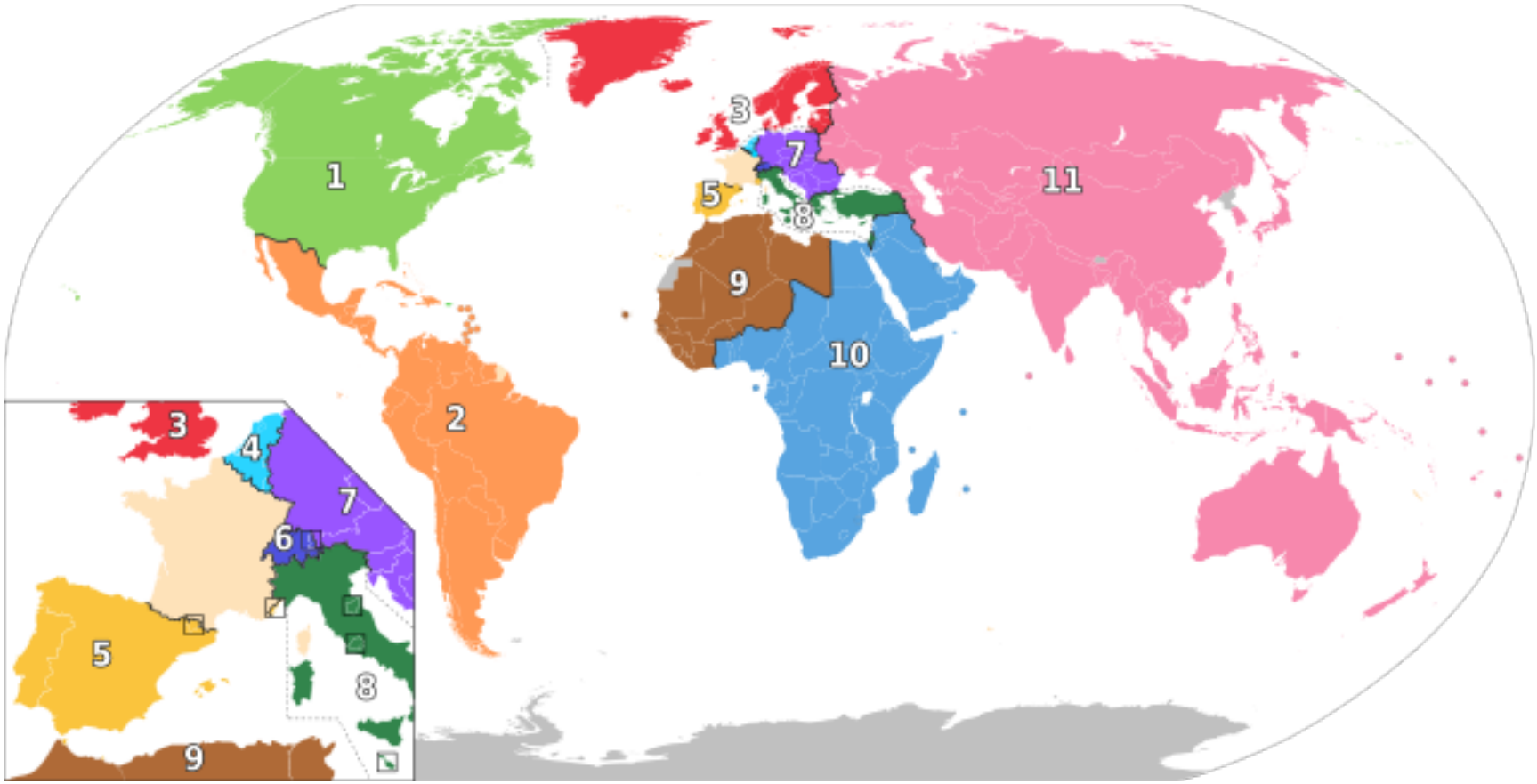
- the system tells whom to blame
- eases dispute resolution

And many more properties

- Availability: servers available at any time
- Accessibility: easy to use, adapted to people with various issues
- ...

2022 French legislative elections

11 circonscriptions (11 deputies), 1.6 M voters.



Crédits: Pierre-Yves Beaudouin / Wikimedia Commons / CC BY-SA 3.0

Context

Voters can vote:

- by postal mail
- at a polling station (at the consulate)
- **by Internet**

Security level required:

> Level 3 (the highest) of the CNIL recommendations

This implies verification by **third party tools**.

> *Objectif de sécurité n° 3-02 : Permettre la transparence de l'urne pour tous les électeurs à partir d'outils tiers.*

Building blocks: cryptography

Threshold decryption

- Each trustee computes her secret key
- The n trustees jointly compute the public key pk
- Decryption with t out of the n keys:
  t out of n trustees suffice to produce decryption shares, that yield the plaintext

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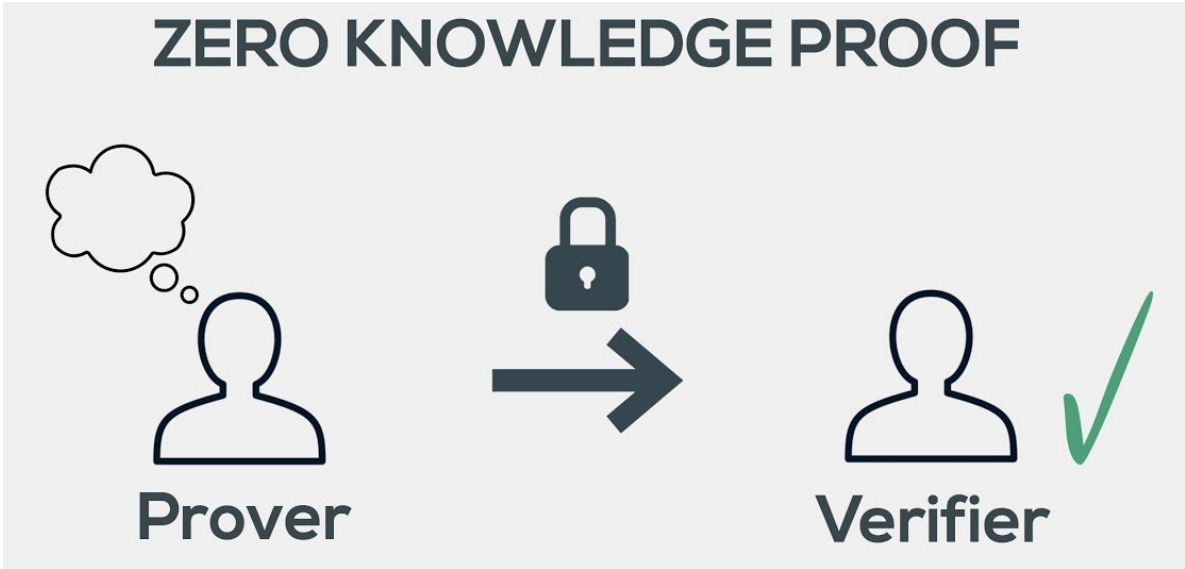
$\rightarrow$ The decryption key is never present on a single computer, neither during the key generation nor the decryption!

Zero-Knowledge proofs



Examples

- Possibility to prove that an encrypted message is either a or b

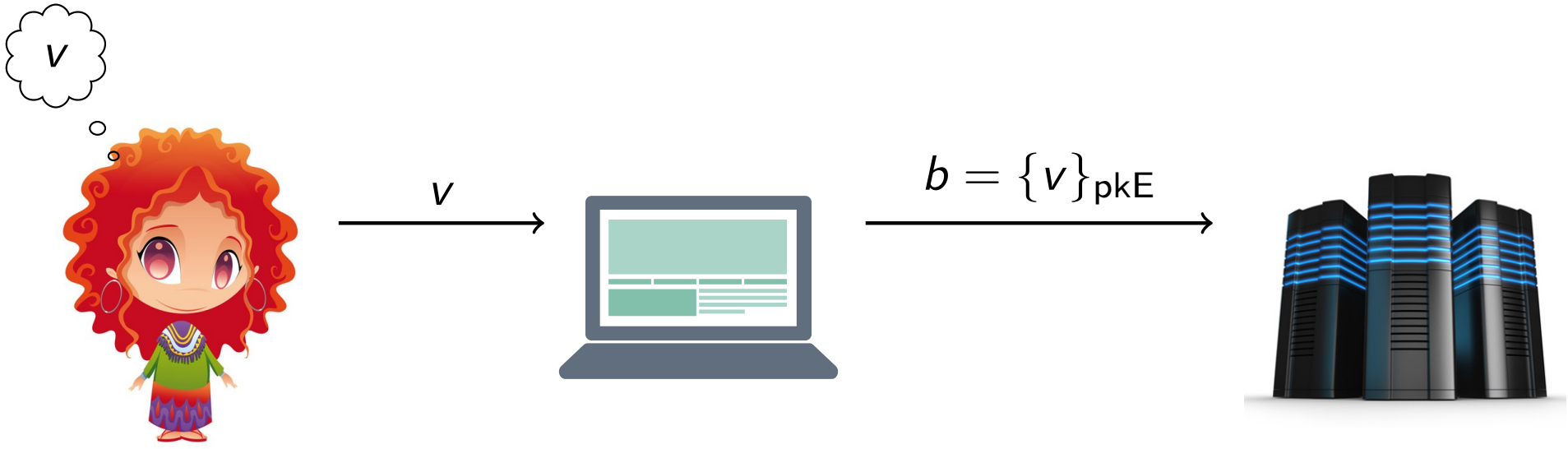
$$\{m\}_k \quad Proof(m = a \text{ or } m = b)$$

- Possibility to prove that the decryption is correct

$$c, m \quad Proof(\mathrm{dec}_k(c) = m)$$

How the FLEP protocol (should) work

Phase 1: vote for $v = 0$ or 1



pkE: public key, the private keys are shared among the authorities.

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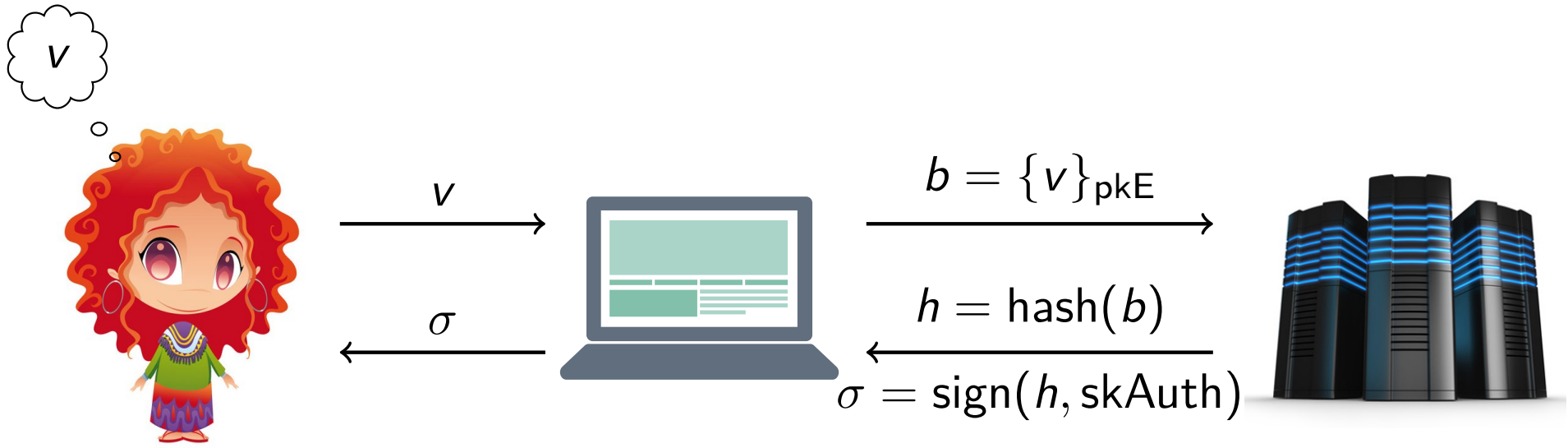

Ballot box

$\{v_a\}_{\text{pkE}}$
$\{v_b\}_{\text{pkE}}$
$\{v_c\}_{\text{pkE}}$
$\{v\}_{\text{pkE}}$

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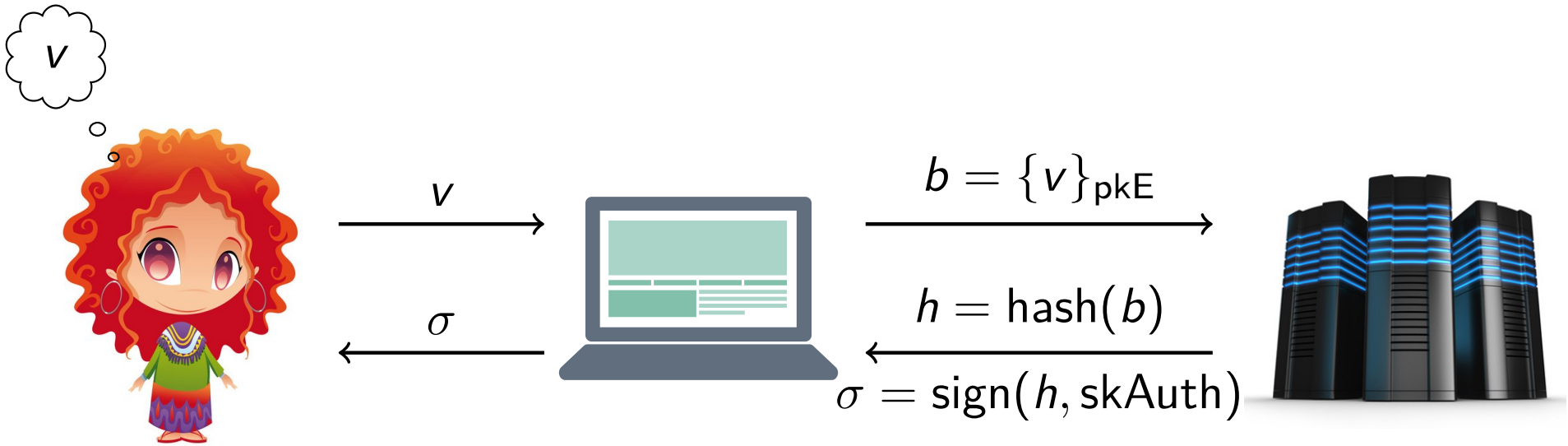

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Phase 2: Tally - homomorphic encryption (El Gamal)

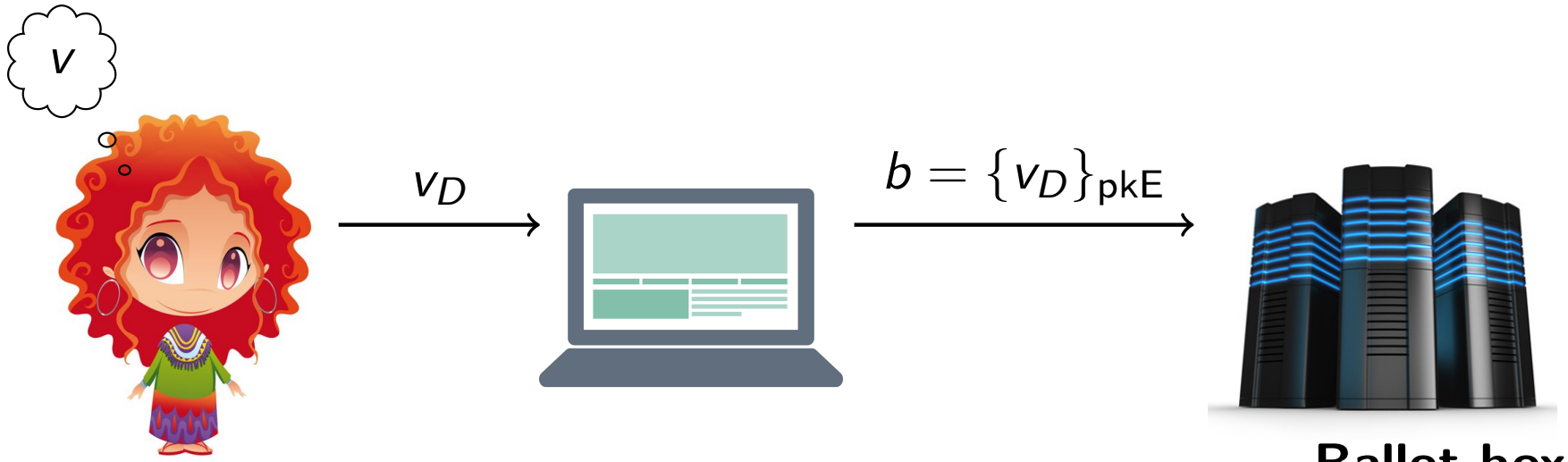
$$\{v_1\}_{\text{pkE}} \times \cdots \times \{v_n\}_{\text{pkE}} = \{v_1 + \cdots + v_n\}_{\text{pkE}}$$

since $g^a \times g^b = g^{a+b}$

$\rightarrow$ Only the final result needs to be decrypted! And proved.

pkE: public key, the private keys are shared among the authorities.

A closer look at ballots - validity

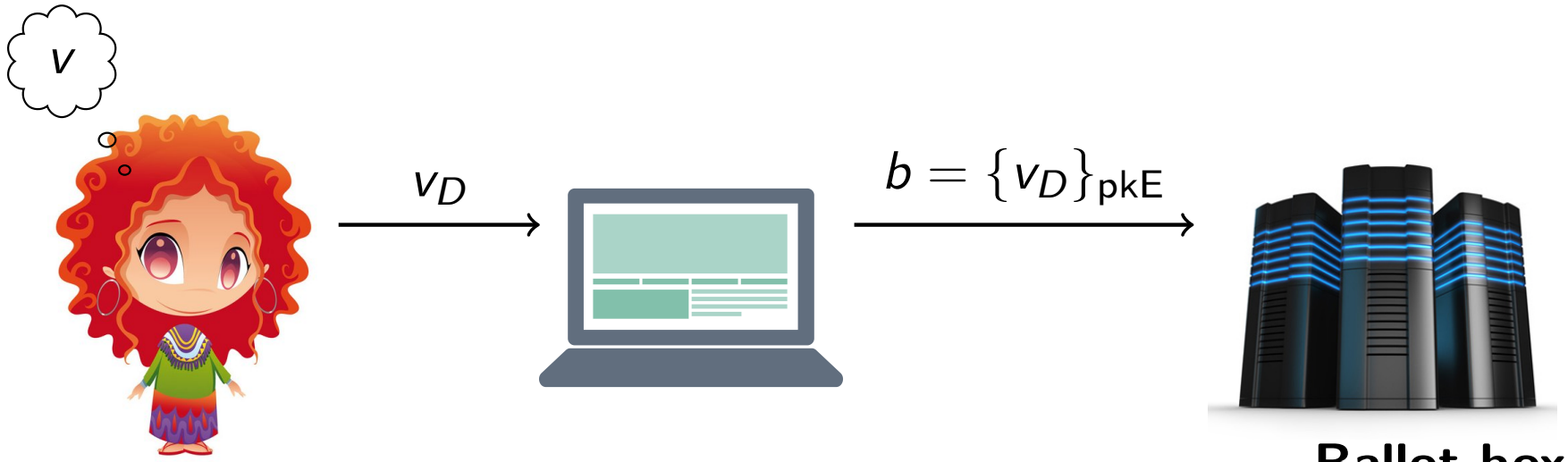


Ballot box

$\{v_a\}_{\mathsf{pkE}}$ $v_A = 0$ or 1
$\{v_b\}_{\mathsf{pkE}}$ $v_B = 0$ or 1
$\{v_c\}_{\mathsf{pkE}}$ $v_C = 0$ or 1
$\{v_D\}_{\mathsf{pkE}}$

Result: $\{v_A + v_B + v_C + v_D + \cdots\}_{\mathsf{pk}(E)}$

A closer look at ballots - validity



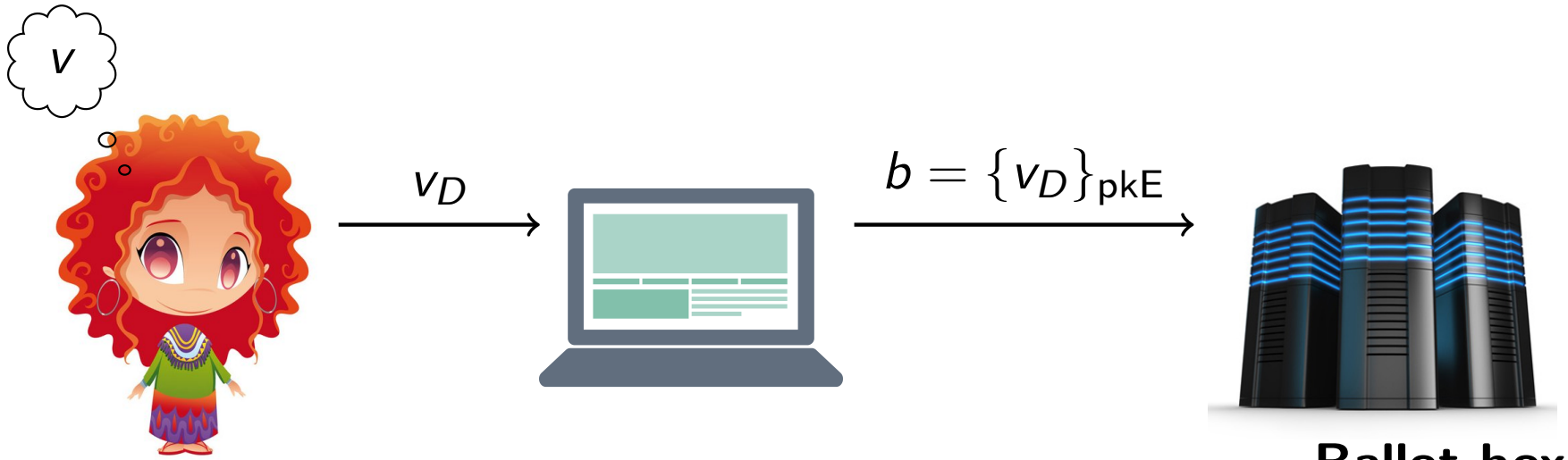
Ballot box

$\{v_a\}_{\mathsf{pkE}}$	$v_A = 0$ or 1
$\{v_b\}_{\mathsf{pkE}}$	$v_B = 0$ or 1
$\{v_c\}_{\mathsf{pkE}}$	$v_C = 0$ or 1
$\{v_D\}_{\mathsf{pkE}}$	$v_D = 100$

Result: $\{v_A + v_B + v_C + 100 + \cdots\}_{\mathsf{pk}(E)}$

A voter could cheat!

A closer look at ballots - validity



Ballot box

$\{v_a\}_{\mathsf{pkE}}$	$v_A = 0$ or 1
$\{v_b\}_{\mathsf{pkE}}$	$v_B = 0$ or 1
$\{v_c\}_{\mathsf{pkE}}$	$v_C = 0$ or 1
$\{v_D\}_{\mathsf{pkE}}$	~~$v_D = 100$~~

Result: $\{v_A + v_B + v_C + v_D + \cdots\}_{\mathsf{pk}(E)}$

~~A voter could cheat!~~

Use a zero-knowledge proof

$$\{v_D\}_{\mathsf{pk}(E)}, \mathsf{Proof}\{v_D = 0 \text{ or } v_D = 1\}$$

A closer look at ballots - multiple candidates

4 candidates: A, B, C, D

Assume Alice wants to vote for C

candidates	A	B	C	D
vote	0	0	1	0
ballot	$\{0\}_{\mathsf{pkE}}$	$\{0\}_{\mathsf{pkE}}$	$\{1\}_{\mathsf{pkE}}$	$\{0\}_{\mathsf{pkE}}$

$+ \ \mathsf{Proof}\{v_A = 0 \text{ or } v_A = 1\}, \ldots, \mathsf{Proof}\{v_D = 0 \text{ or } v_D = 1\}$

$+ \ \mathsf{Proof}\{v_A + v_B + v_C + v_D = 1\}$

Voter receipt

Elections législatives 2022 1er tour

Preuve de dépôt du bulletin de vote dans l'urne

Voici la preuve de dépôt de votre bulletin dans l'urne.

Votre bulletin de vote a bien été introduit dans l'urne électronique.

La référence ci-dessous vous permet de contrôler que votre bulletin est bien dans l'urne.

80011&1&3318f83ea80861c9e6274f049c8df87c2da4fe03e43b7aa46b7192c0cfc3129c53

Pour contrôler la référence de votre bulletin : cliquez ici
https://votefae.diplomatie.gouv.fr/pages/verifierEmpreinte

Une fois le dépouillement effectué, vous pouvez vérifier que votre bulletin a bien été pris en compte dans le calcul des résultats, à l'aide d'un outil tiers développé par le CNRS, conformément aux exigences de la CNIL en matière de transparence de l'urne. Pour ce faire, vous devrez renseigner le cachet électronique ci-dessous.

Vous pouvez accédez à l'outil en cliquant ici.

Ce cachet électronique vous permet également de vérifier que votre preuve de vote a bien été produite par le système de vote homologué.

eyJpbmZvU1UiOiI4MDAxMXwxfDFlcmVfQ2lyY29uc2NyaXB0aW9uX2Rlc19GcmFuY2Fpc19kZV9sJ2V0cmFuZ2VyfDEwOXwzMzE4ZjgzZWE4MDg2MWM5ZTYyNzRmMDQ5YzhkZjg3YzJkYTRmZTAzZTQzYjdhYTQ2YjcxOTJjMGNmYzMxMjljfDUzIiwic2Nobm9yciI6IjFraWsxaTV2OHQzMGs3NXZhb2htMWhic292aTc1bGE5YWQ2cXBsbmNodXZlajU5c2tub3ElMTRsdDVkMG9zczEyMGtqdWRtOWUxa2M3MDFsMXRpMWc0bTQza2w4am5qMGhmNmFyNWg4dCIsInB1YmxpY0tleVN1IjoiLS0tLS1CRUdJTl9WRVJJRklDQVRJT05fS0VZLS0tLS1cclxuNzdmYTM0ZTQ0YWQxZGI4ZDkxMDg1MmQ4Y2U0ODNkNzc0YTMyYTRmOTNhMmRlYzRhNjRmNzhmMGFjZmI2NDJjOCUzNjYxNmViNTUxMzY2OWJmZDE2YTdlYTNiZmMzY2Q1NmM3MDUyMzhlYzk5OTFhNDM0M2QwZTgzOWVjNjM3OTVhXHJcbi0tLS0tRU5EX1ZFUklGSUNBVElPTl9LRVktLS0tLSIsImNsZUNhY2hldEJydXQiOiIyOSJ9

Pour contrôler le cachet électronique, cliquez ici

What we did: universal verifiability

Joint work with P. Gaudry and S. Glondu [EVoteID'23]

- Requirement to work on public specifications
- No NDA, responsible disclosure instead

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After the tally

- we receive the ballot box
- we check the zero-knowledge proofs of correct decryption (and validity of the ballots)
- with our own software, written independently

What we did: individual verifiability

- **During the voting phase:** Verification tool for the validity of the server signature;
- **After the tally:** Publication of the list of hashed ballots + verification tool for checking the presence of a hash in this list.

Vérifiabilité individuelle
Élections législatives partielles 2022 — Premier tour

En tant que tiers, nous avons eu accès à l'ensemble des bulletins dépouillés et nous avons vérifié qu'ils correspondent aux résultats de l'élection. Vous pouvez vérifier ici que votre bulletin a bien été compté dans votre circonscription.
Le cachet apparait sur le récépissé de votre bulletin.

Plus d'information

Veuillez entrer le cachet de votre bulletin :

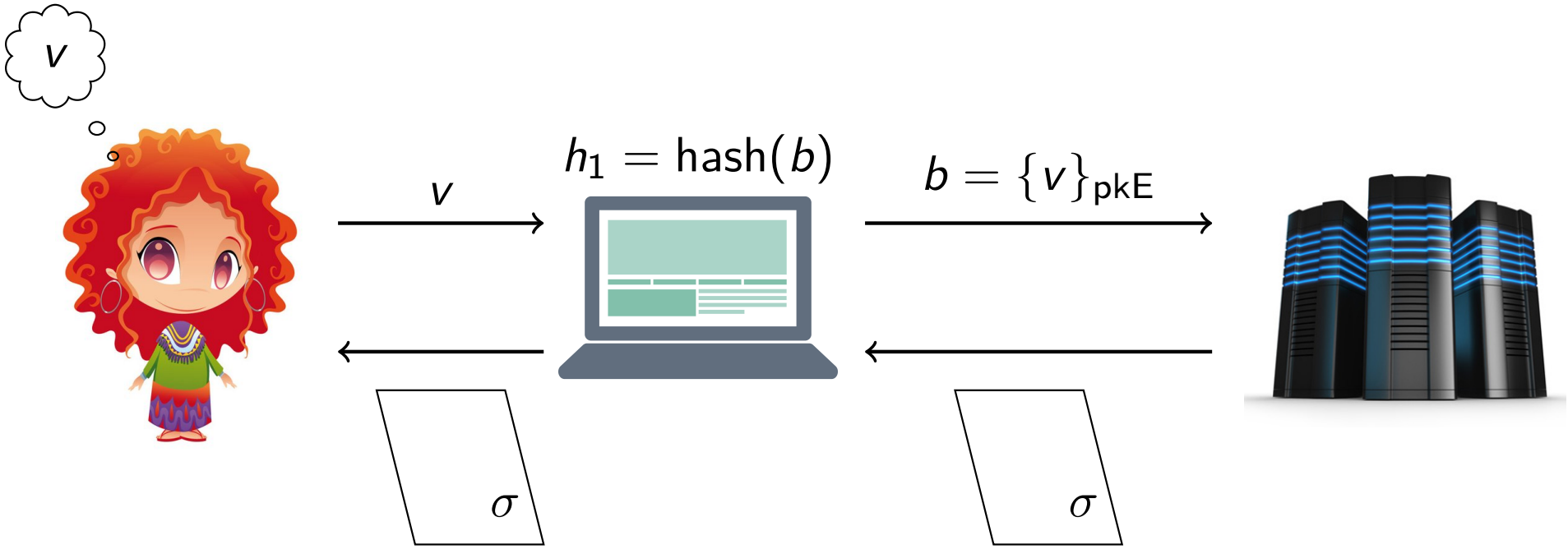
Copiez-collez votre cachet ici

Vérifier

Mentions légales Assistance MEAE

What we missed: several flaws!

A. Debant, L. Hirschi [Usenix'24]



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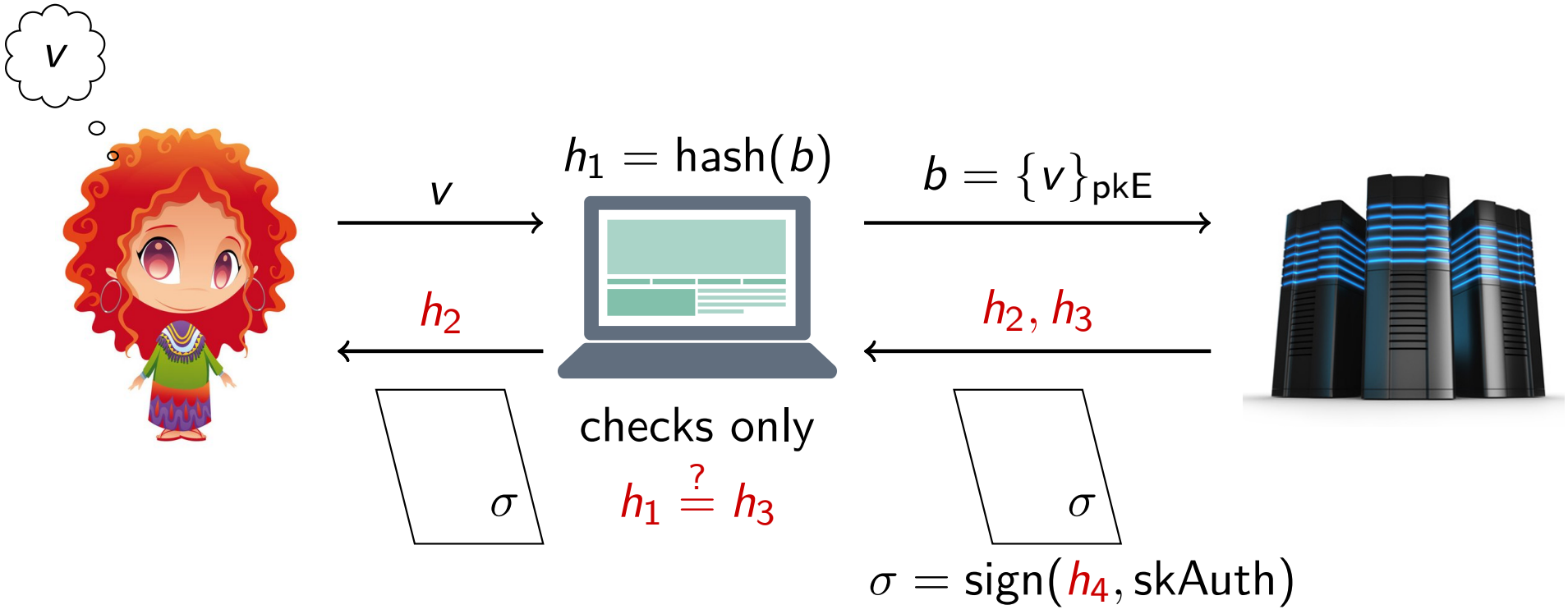

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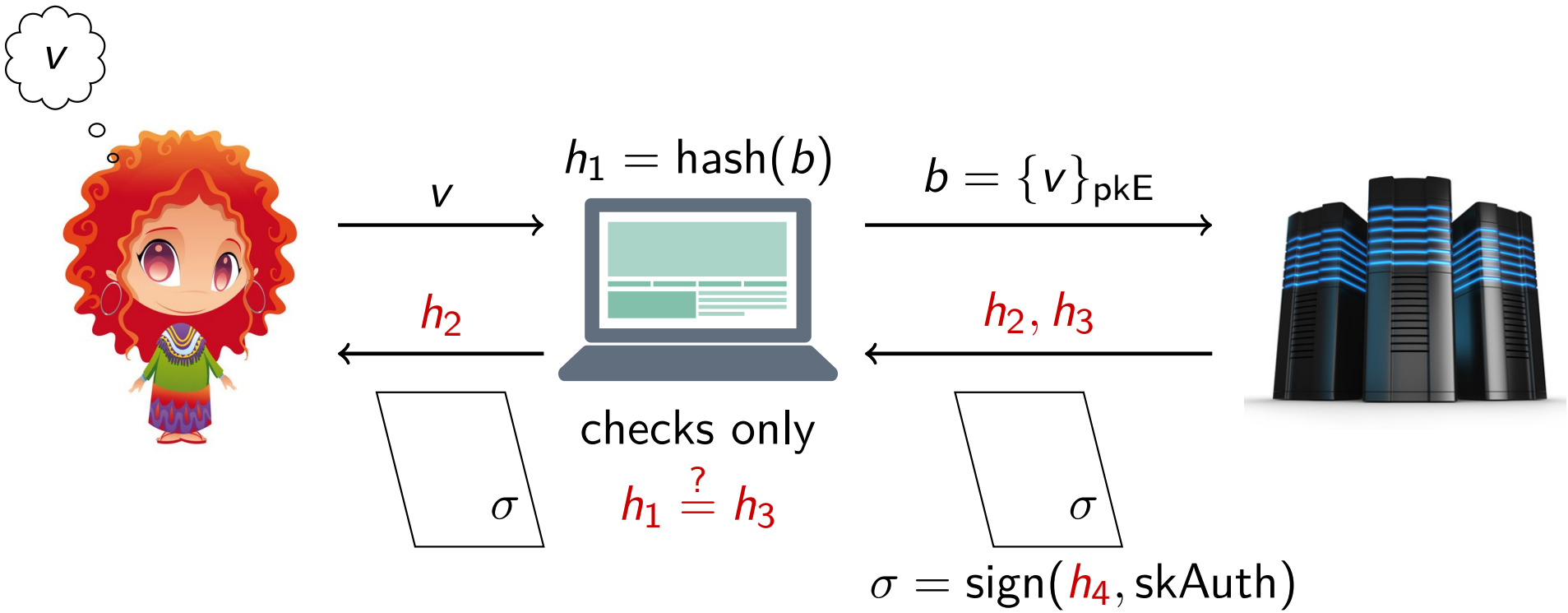

An unsatisfying fix: now both h_1 and h_3 are displayed to the voter for comparison, while the voting client already checks $h_1 = h_3$.
$\rightarrow$ The voter needs to check themself that $h_1 = h_4$, without any instruction.

Formal analysis of e-voting systems

Why a formal analysis of an e-voting system?

$\longrightarrow$ Because formal methods can find attacks before implementations

$\longrightarrow$ Now a current practice for many protocols (TLS, 5G, ...)

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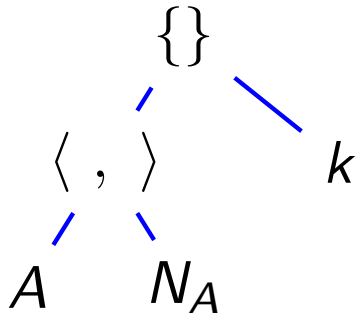
$\rightarrow$ Legal requirements in Switzerland to provide **symbolic and cryptographic proofs** of e-voting protocols.

5.1. Examining the cryptographic protocol

5.1.1	Examination criteria: The protocol must meet the security objective according to the trust assumptions in the abstract model in accordance with Section 4. In addition, a cryptographic and a symbolic proof must be provided. The proofs relating to cryptographic basic components may be provided according to generally accepted security assumptions (for example, the "random oracle model", "decisional Diffie-Hellman assumption", "Fiat-Shamir heuristic"). The protocol should be based if possible on existing and proven protocols.

Two main models for security

	Formal approach	Computational approach
Messages		0101000101110101 1101010110101010 0011101011101101 bitstrings
Encryption	terms	algorithm
Adversary	idealized	any polynomial algorithm
Guarantees	some attacks missed	stronger
Proof	often automatic	mostly by hand difficult for complex protocols

Messages

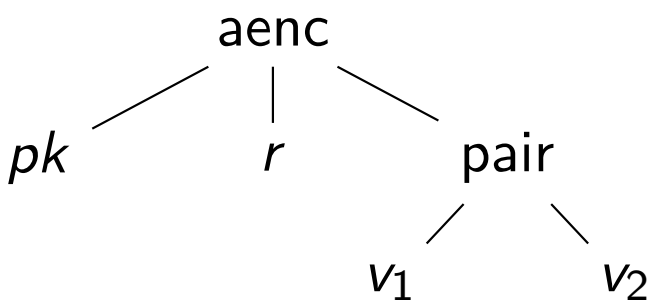
Messages are abstracted by terms.

Agents : $a, b, \ldots$
Keys : $k_1, k_2, \ldots$
Ciphertext : $\mathsf{aenc}(pk, r, m)$

Nonces : $n_1, n_2, \ldots$

Concatenation : $\mathsf{pair}(m_1, m_2)$
denoted simply (m_1, m_2) in ProVerif

Example: The encrypted message $\mathsf{aenc}(pk, r, \mathsf{pair}(v_1, v_2))$ is represented by:



Intuition: only the structure of the message is kept.

Model for cryptographic primitives

Projection

$$\pi_1(\mathsf{pair}(x, y)) = x$$

$$\pi_2(\mathsf{pair}(x, y)) = y$$

Asymmetric and symmetric encryption

$$\mathsf{adec}(\mathsf{aenc}(\mathsf{pk}(y), z, x), y) = x$$

$$\mathsf{dec}(\mathsf{enc}(x, y), y) = x$$

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Zero knowledge proof: proof of valid vote

$$\mathsf{aenc}(\mathsf{pk}, r, m), \mathsf{ZKP}(m = 0 \text{ OR } m = 1)$$

$$\begin{aligned} \mathsf{Valid}(\mathsf{ZKP}(\mathsf{aenc}(\mathsf{pk}, r, 0), \mathsf{pk}, r), \mathsf{aenc}(\mathsf{pk}, r, 0), \mathsf{pk}) &= \mathsf{ok} \\ \mathsf{Valid}(\mathsf{ZKP}(\mathsf{aenc}(\mathsf{pk}, r, 1), \mathsf{pk}, r), \mathsf{aenc}(\mathsf{pk}, r, 1), \mathsf{pk}) &= \mathsf{ok} \end{aligned}$$

Syntax for processes

The grammar of processes is as follows:

$$
\begin{aligned}
&P, Q, R := \\
&\quad 0 \\
&\quad \texttt{if } M_1 = M_2 \texttt{ then } P \texttt{ else } Q \\
&\quad \text{let } x = M \text{ in } P \\
&\quad \text{in}(c, x); P \\
&\quad \text{out}(c, N); P \\
&\quad \text{new } n; P \\
&\quad P \mid Q \\
&\quad !P \\
&\quad \text{event} E.P
\end{aligned}
$$

Syntax of ProVerif, a dialect of the applied-pi calculus *[AbadiFournet01]*

ProVerif: automatic analysis of protocols

Developed by Bruno Blanchet and Vincent Cheval

Performs very well in practice!

- Works on most of existing protocols in the literature
- Is also used on industrial protocols (e.g. TLS, Signal, ...)
- used to pass Swiss requirements on voting
  - Neuchâtel/Scytl protocol [C., Turuani 2018]
  - CHVote protocol [C., Turuani 2019]
  - Swiss Post [Debant,C.,Gaudry, 2022→now]

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→ ProVerif translates processes in applied pi-calculus into Horn clauses (first-order logic).

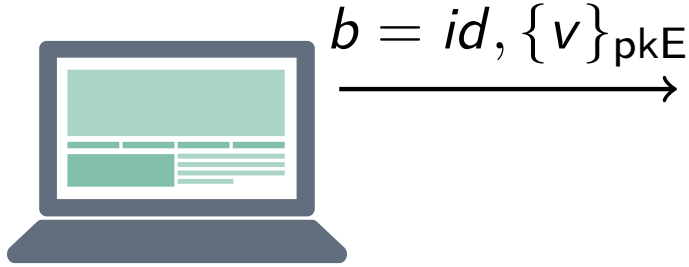
Attacker

Horn clauses perfectly reflects the attacker symbolic manipulations on terms.

$$
\begin{array}{lrcll}
\forall x \forall y & I(x), I(y) & \Rightarrow & I(\mathrm{enc}(x,y)) & \text{encryption} \\
\forall x \forall y & I(\mathrm{enc}(x,y)), I(y) & \Rightarrow & I(x) & \text{decryption} \\
\forall x \forall y & I(x), I(y) & \Rightarrow & I(<x,y>) & \text{concatenation} \\
\forall x \forall y & I(<x,y>) & \Rightarrow & I(x) & \text{first projection} \\
\forall x \forall y & I(<x,y>) & \Rightarrow & I(y) & \text{second projection}
\end{array}
$$

Protocol as Horn clauses

let $Voter(\mathsf{pkE}, \mathsf{Vote}, id, \mathsf{cauth}) =$
  new r : bitstring;
  let $b = (id, \mathsf{aenc}(\mathsf{pkE}, r, \mathsf{Vote}))$
  event $Voted(id, \mathsf{Vote}, r)$
  $\mathsf{out}(\mathsf{cauth}, b)$;
  $\mathsf{out}(c, b)$.



Each action of the protocol is translated into logical implications.

$$\begin{array}{lcl} \forall v \quad I(v) & \Rightarrow & I(\langle id, \mathsf{aenc}(\mathsf{pkE}, r(v), v\rangle) \\ \forall v \quad I(v) & \Rightarrow & \mathsf{Voted}(id, v, r(v)) \end{array}$$

Security reduces to consistency

secure?

$$\forall x \forall y \quad I(x), I(y) \Rightarrow I(< x, y >)$$
$$\forall x \forall y \quad I(x), I(y) \Rightarrow I(\mathsf{enc}(x, y))$$
$$\forall x \forall y \quad I(\mathsf{enc}(x, y)), I(y) \Rightarrow I(x)$$
$$\forall x \forall y \quad I(< x, y >) \Rightarrow I(x)$$
$$\forall x \forall y \quad I(< x, y >) \Rightarrow I(y)$$

$$\forall v \quad I(v) \Rightarrow I(\langle id, \mathsf{aenc}(\mathsf{pkE}, r(v), v\rangle)$$
$$\forall v \quad I(v) \Rightarrow \mathsf{Voted}(id, v, r(v))$$

Security reduces to consistency

secure?

$\rightsquigarrow$

$$\begin{array}{llcl} & & & \textsc{Not}\ I(\text{secret}) \\ \forall x \forall y & I(x), I(y) & \Rightarrow & I(< x, y >) \\ \forall x \forall y & I(x), I(y) & \Rightarrow & I(\text{enc}(x, y)) \\ \forall x \forall y & I(\text{enc}(x, y)), I(y) & \Rightarrow & I(x) \\ \forall x \forall y & I(< x, y >) & \Rightarrow & I(x) \\ \forall x \forall y & I(< x, y >) & \Rightarrow & I(y) \end{array}$$

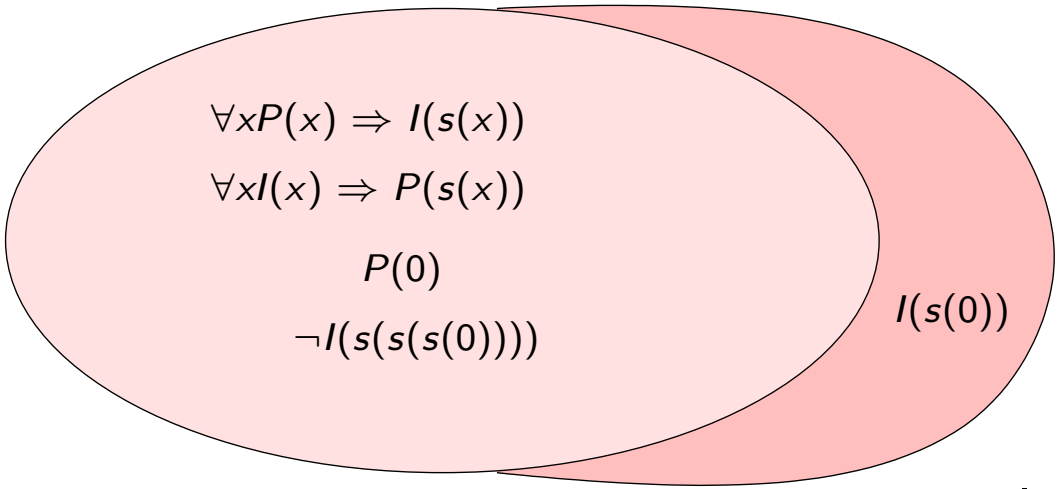
$$\begin{array}{llcl} \forall v & I(v) & \Rightarrow & I(\langle id, \text{aenc}(\text{pkE}, r(v), v\rangle) \\ \forall v & I(v) & \Rightarrow & \text{Voted}(id, v, r(v)) \end{array}$$

Does not yield a contradiction ?

(i.e. consistent theory ?)

A standard technique: resolution

Idea: add logical consequences ...



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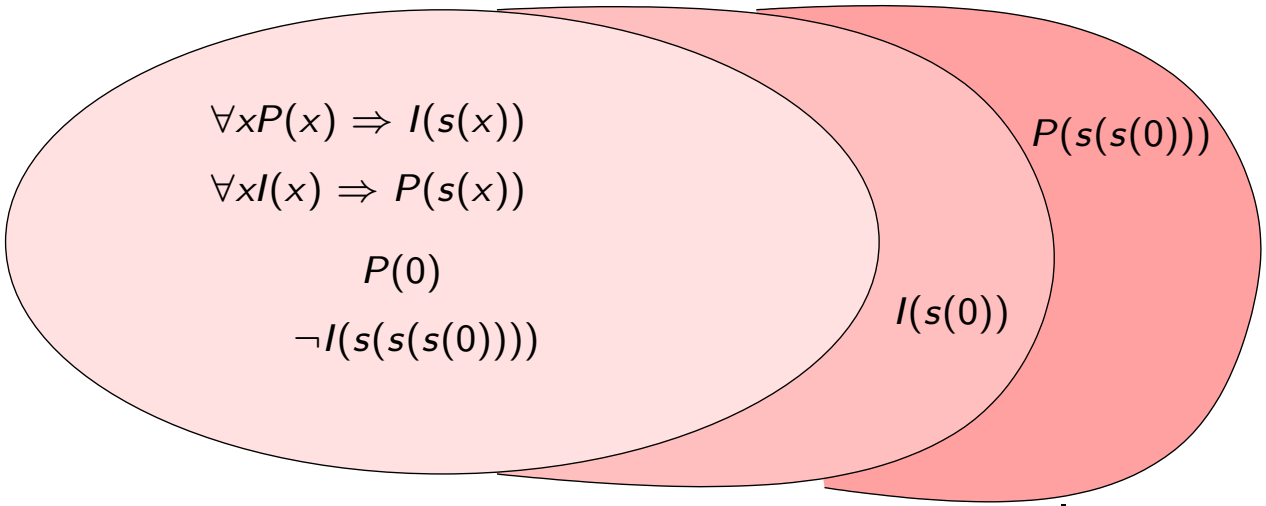

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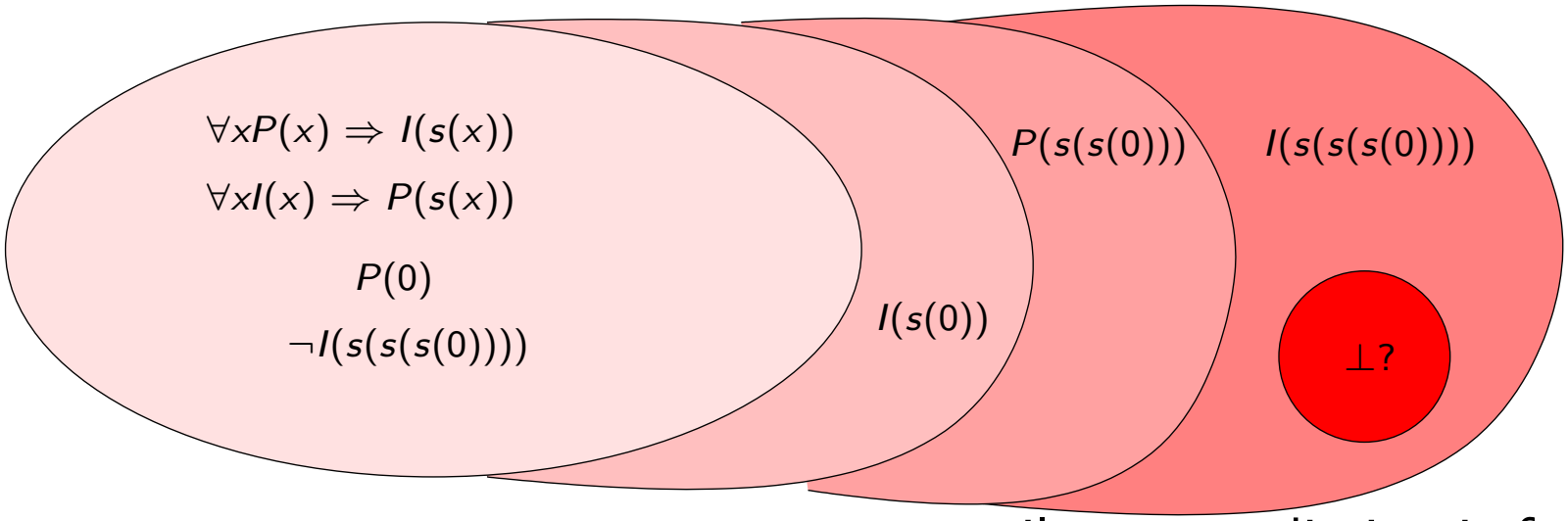

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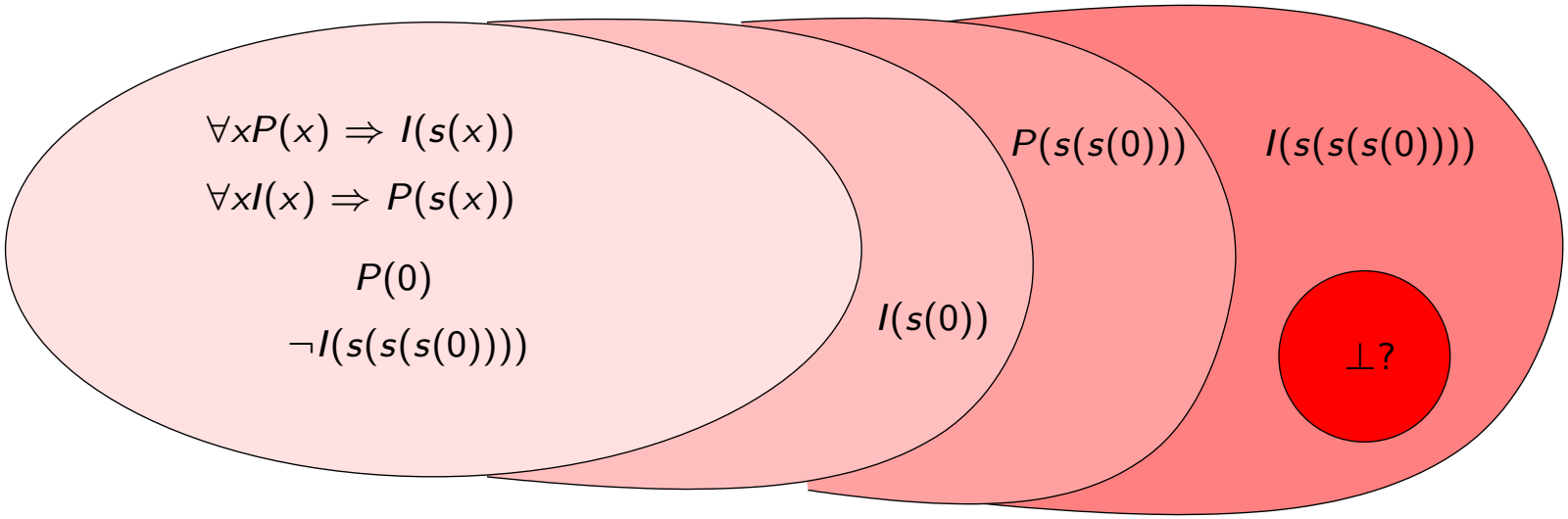

... until a contradiction is found.

Ideally, we need a method (a strategy) which is:

- correct: adds formula that are indeed consequences
- complete: finds a contradiction (if it exists)
- in a finite number of steps

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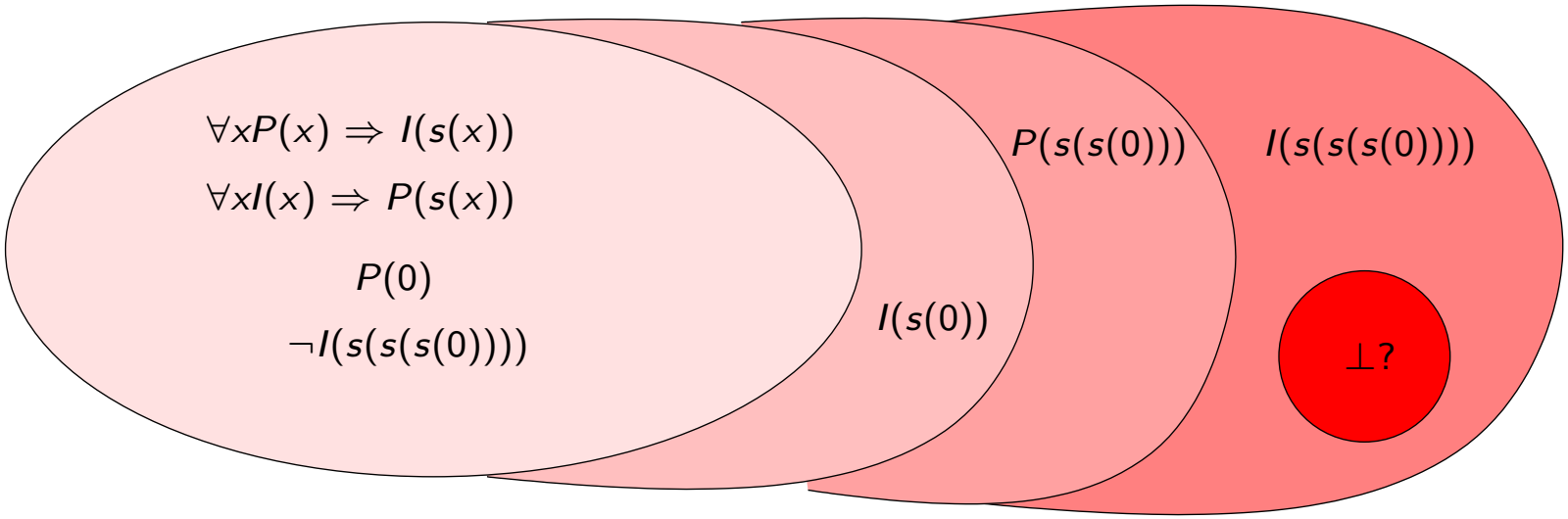

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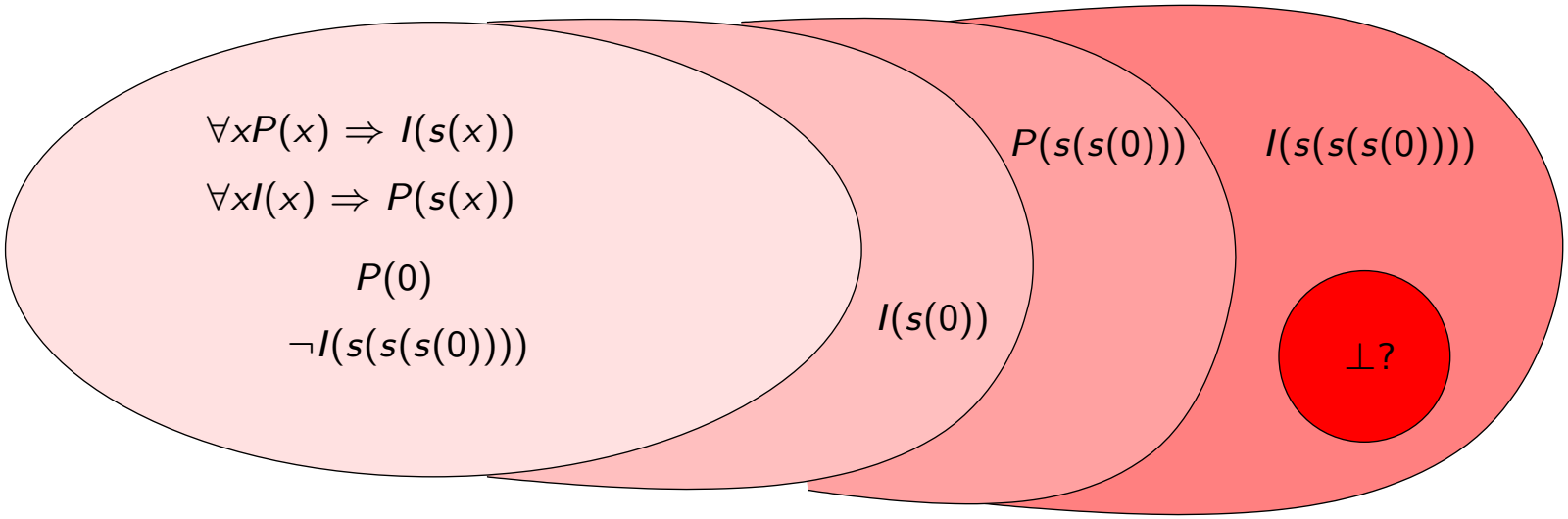

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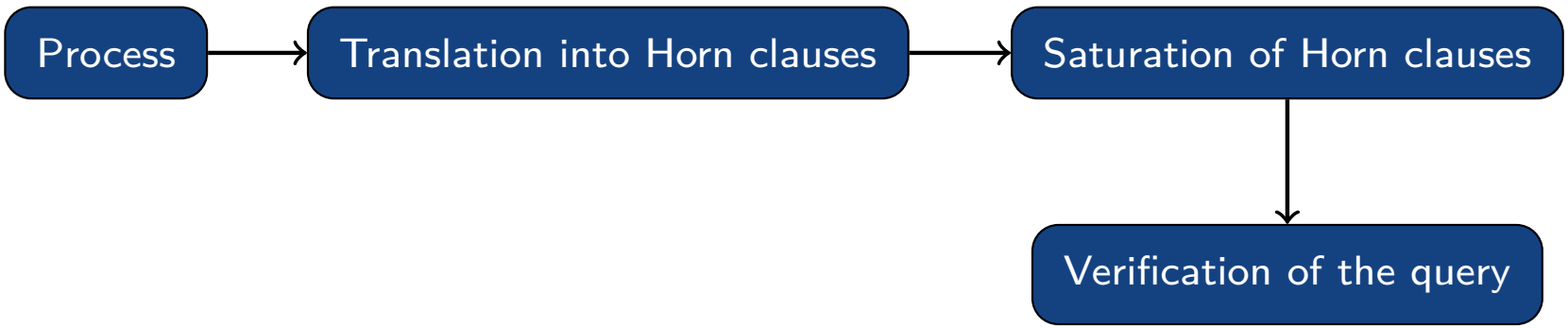
ProVerif

- Implements a correct procedure (that may not terminate or just stop without answer).
- Based on a resolution strategy well adapted to protocols.



Binary resolution

$$\frac{H \Rightarrow C \quad F, H' \Rightarrow C'}{H\sigma, H'\sigma \Rightarrow C'\sigma} \text{ with } \sigma \text{ substitution s.t. } C\sigma = F\sigma$$

- correct
- but adds too many clauses (never terminates)

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$$F \neq I(x)$$

- correct
- but adds too many clauses (never terminates)

ProVerif's strategy:

- do not resolve on $I(x)$
- well crafted resolution strategy

Limitations

1. Horn clauses yield over-approximations
   Example: non uniqueness $\forall v \quad I(v) \Rightarrow \text{Voted}(id, v, r(v))$

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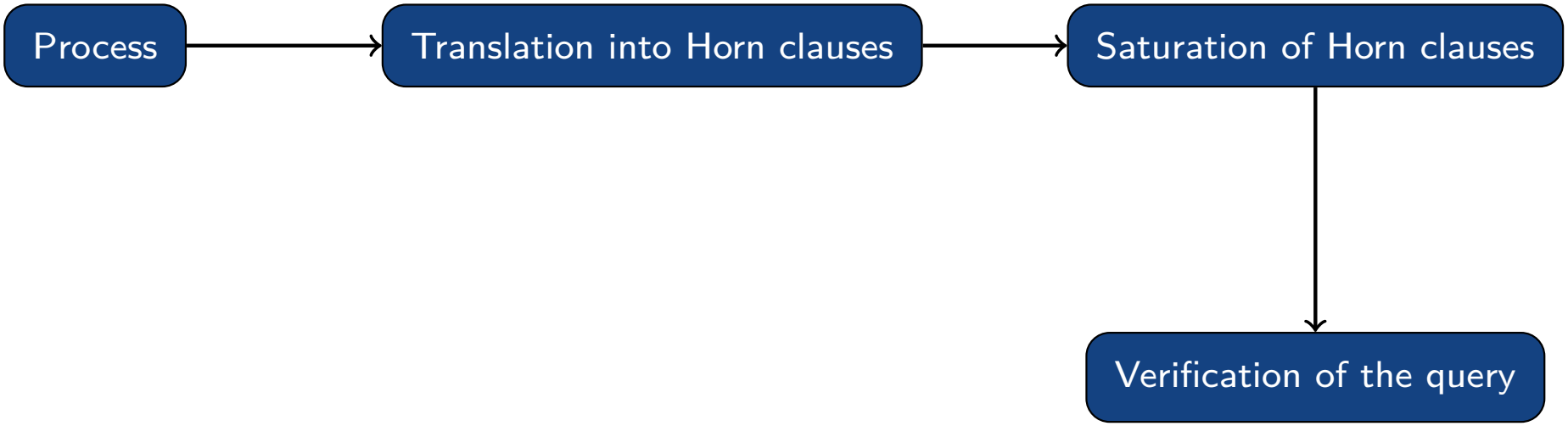
   Idea: lemma as proof helpers

Proverif 2.02: introduction of lemmas

[S&P'22, with B. Blanchet and V. Cheval]



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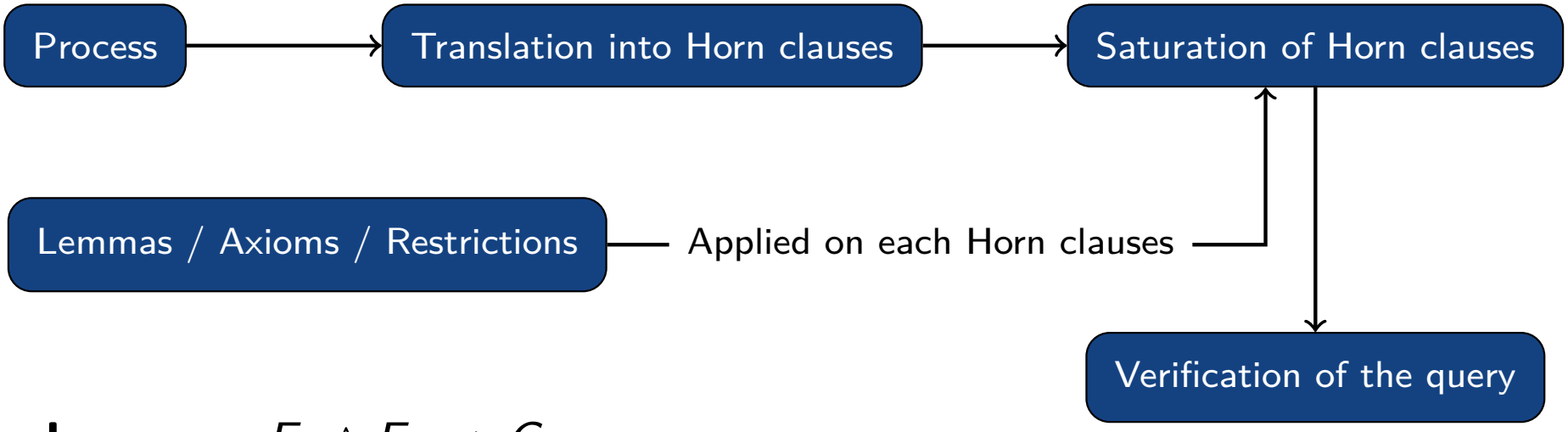

Lemma $F_1 \wedge F_2 \rightarrow G$

Clause $H \Rightarrow C$

If there is a substitution σ s.t. $F_1\sigma, F_2\sigma \subseteq H$ then $H \Rightarrow C$ is replaced by $H \wedge G\sigma \Rightarrow C$

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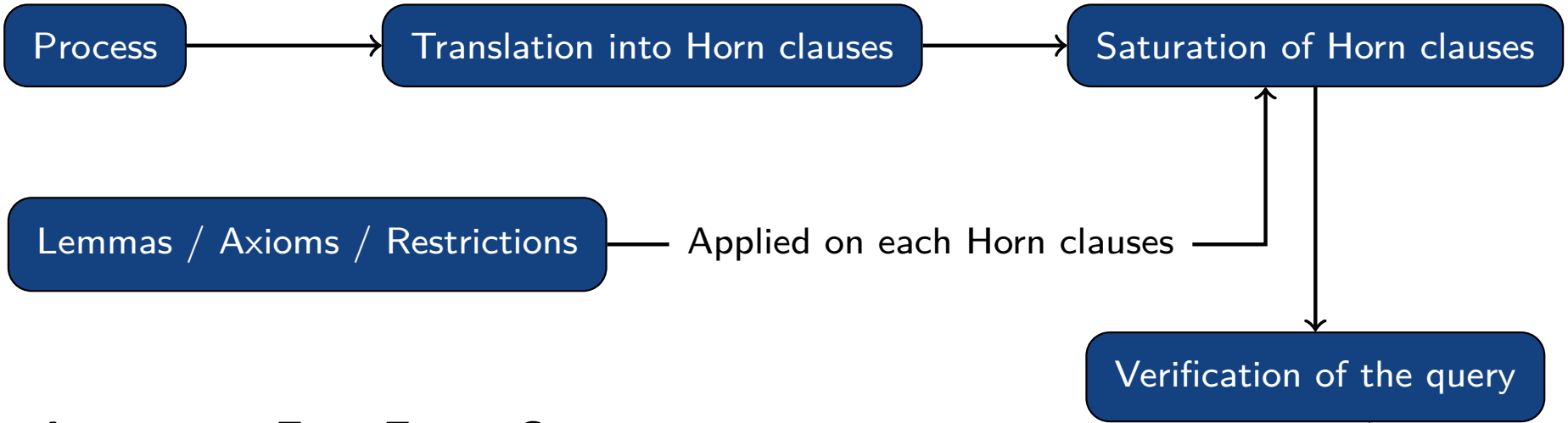

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not always sound!

events ✓

attacker facts ✗

Proverif 2.02: introduction of lemmas

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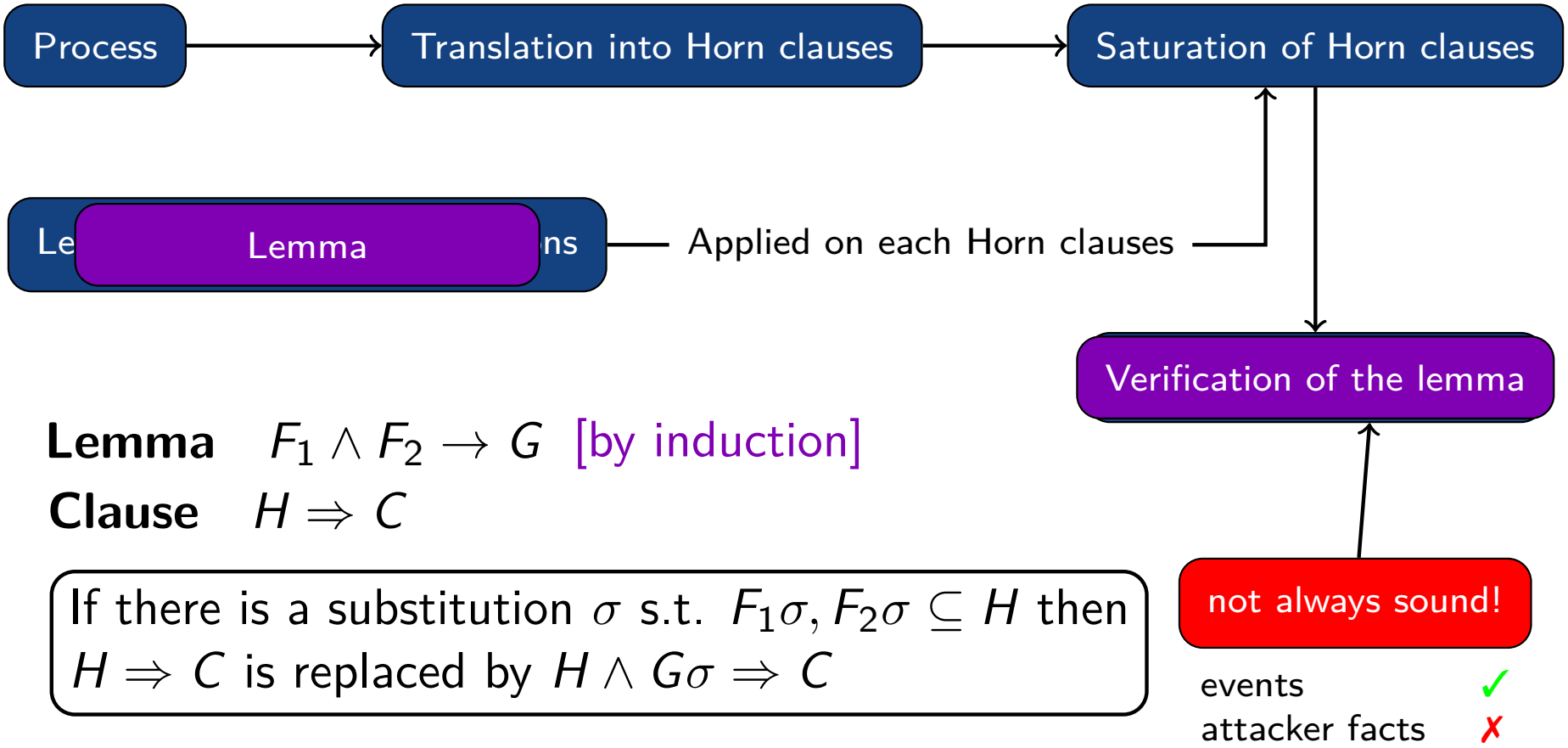


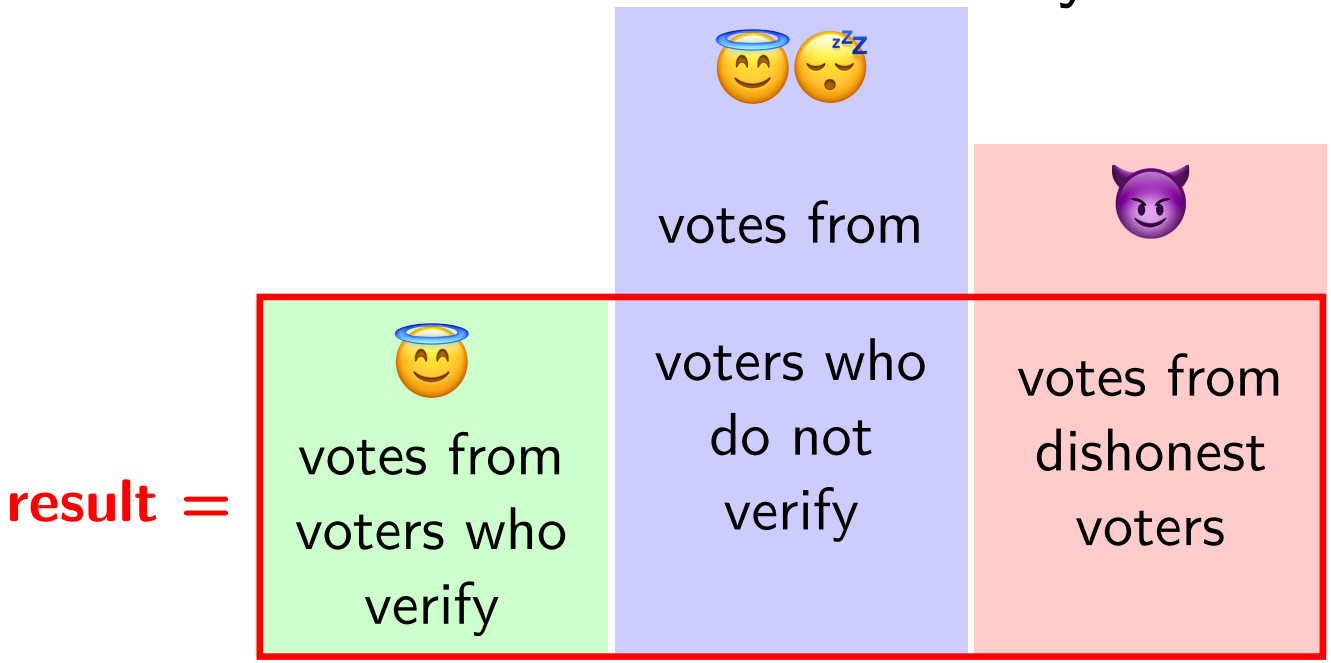
Lemma $F_1 \wedge F_2 \rightarrow G$ [by induction]

Clause $H \Rightarrow C$

If there is a substitution σ s.t. $F_1\sigma, F_2\sigma \subseteq H$ then $H \Rightarrow C$ is replaced by $H \wedge G\sigma \Rightarrow C$

Even better: lemma by induction

Still insufficient: End2End verifiability



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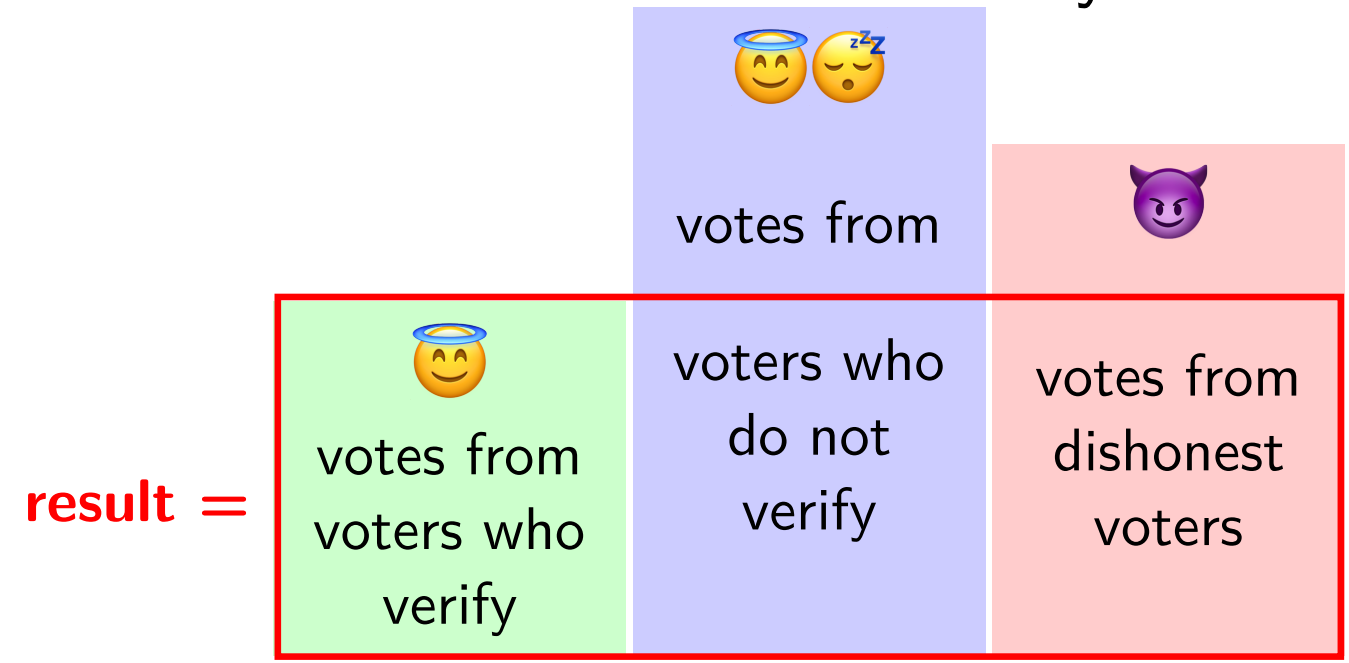

⚠ require to count

→ Hard to verify for tools

→ check subproperties instead

Theorem ([Cortier *et al* CSF'19, Baloglu *et al* CSF'21])

eligibility + cast-as-intended + recorded-as-cast + tallied-as-recorded + no clash ⇒ E2E Verifiability

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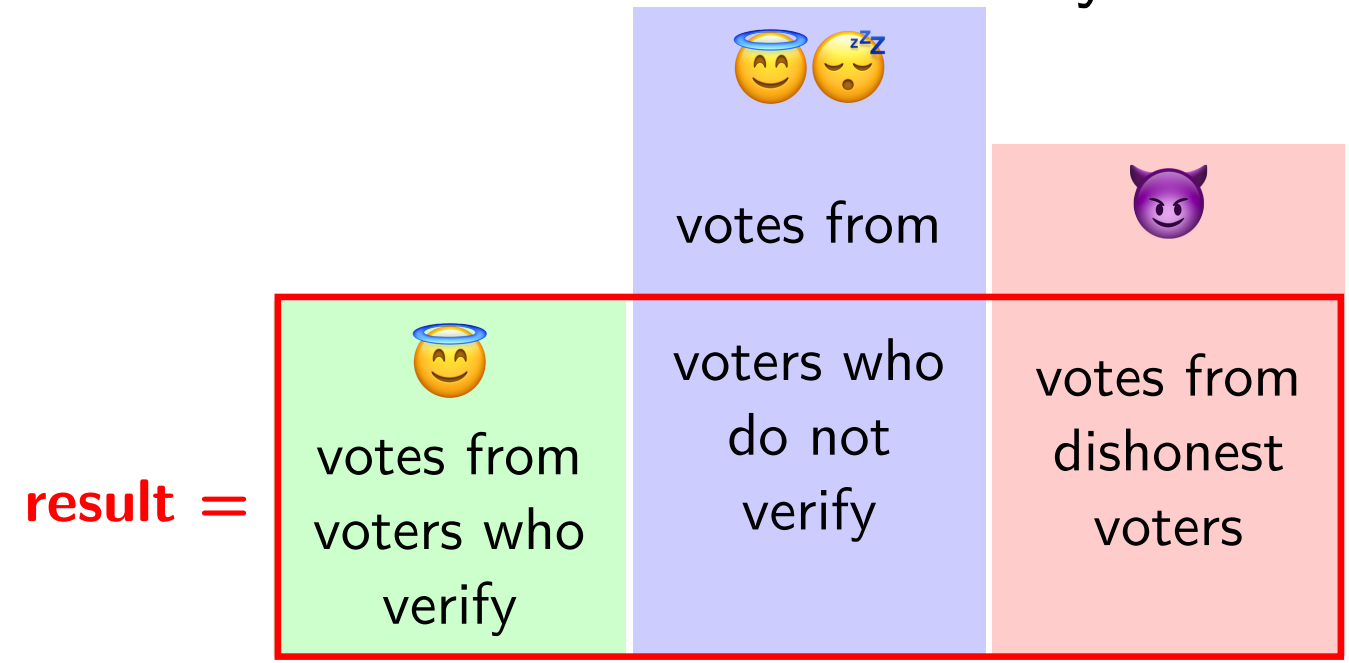

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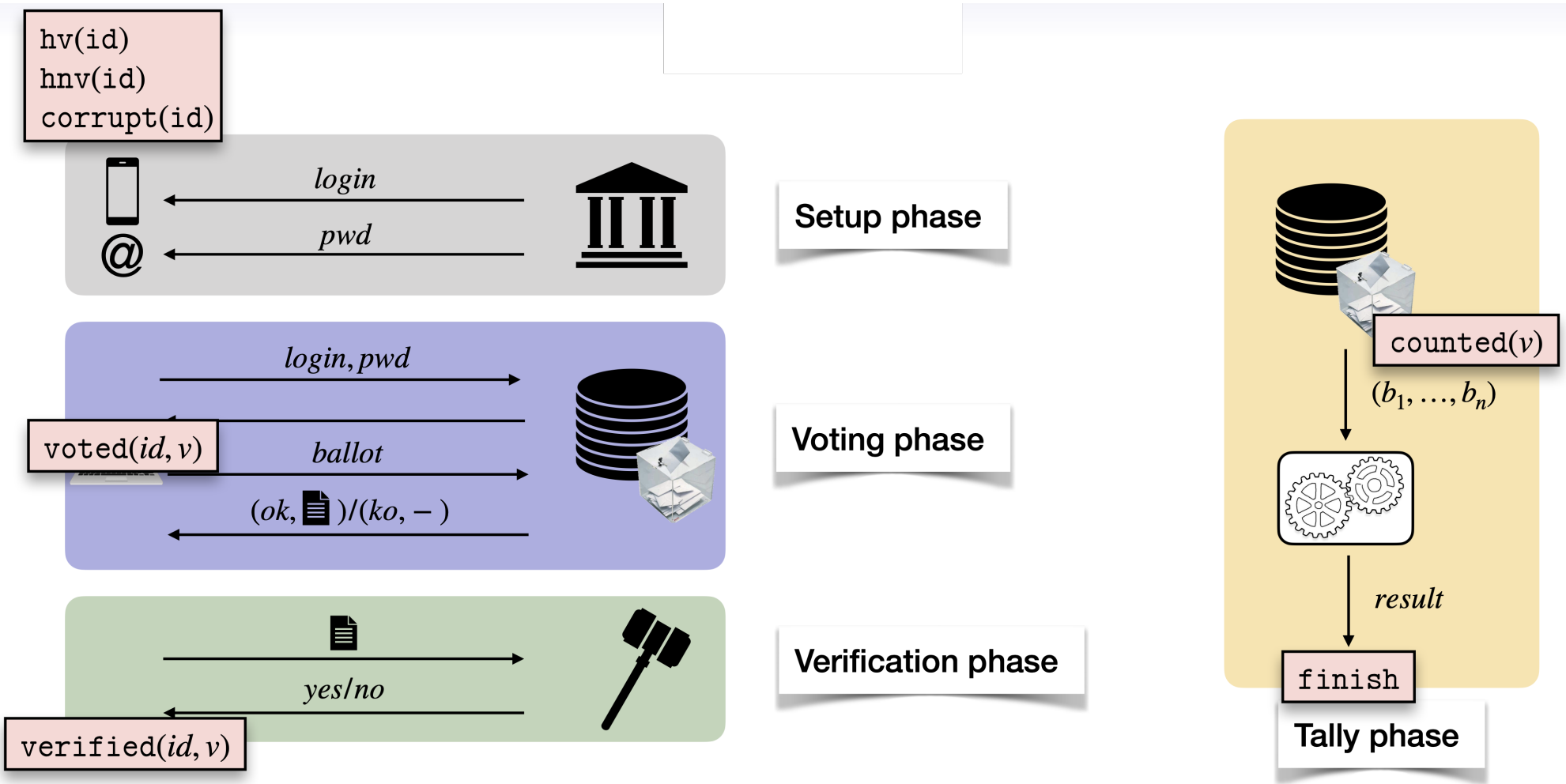
⚠ sufficient (but not tight) conditions

A generic ProVerif framework for voting

with V. Cheval and A. Debant [CSF'23]



[slide borrowed from Alexandre Debant.]

First contribution: exact characterization

Theorem

E2E-verifiability $\Leftrightarrow$ **query1** *and* **query2**

query1 $\quad \text{finish} \wedge \texttt{inj}-\text{verified}(z, x) \Rightarrow \texttt{inj}-\text{counted}(x)$

Intuition: *individual verifability*

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Intuition: *individual verifability*

query2 $\text{finish} \wedge \texttt{inj}-\text{counted}(x) \Rightarrow \texttt{inj}-\text{hv}(z) \wedge \text{verified}(z, x)$
$\vee \quad \texttt{inj}-\text{hnv}(z) \wedge \text{voted}(z, x)$
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E2E-verifiability $\Leftrightarrow$ **query1** *and* **query2**

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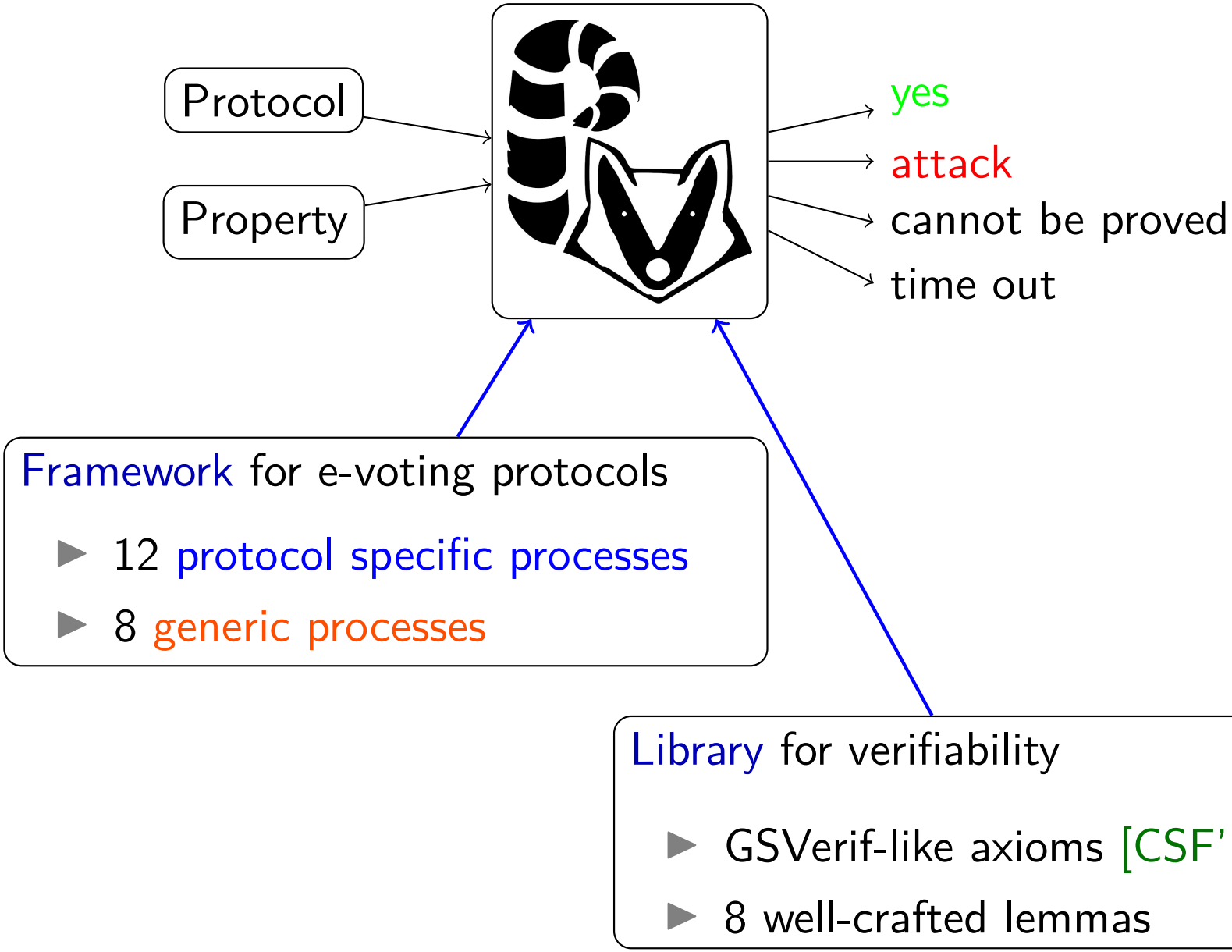
query2 $\text{finish} \wedge \texttt{inj}-\text{counted}(x) \Rightarrow \texttt{inj}-\text{hv}(z) \wedge \text{verified}(z, x) \vee \texttt{inj}-\text{hnv}(z) \wedge \text{voted}(z, x) \vee \texttt{inj}-\text{corrupt}(z)$

Intuition: *extended universal verifiability*

Issue: make sure finish is executed only once all ballots are counted

Second contribution: make it work in ProVerif



Generic processes

```
let Tally(e_id) =
  in(cell_tally(e_id),i);
  event Tally_Read(e_id,i)
  if i = 0 then event finish(e_id)
  else
    get public_identifier_id(=e_id,=i,ident) in
    in(cell_tally_last_vote(e_id,ident),x);
    if x = empty_ballot then out(cell_tally(e_id),i-1)
    else
      Decrypt_Ballot(e_id,i,ident,x) |
      in(res_decrypt(e_id,i),v);
      event Counted(e_id,v);
      event CountedExtended(e_id,v,i,ident);
      out(c_pub,v); out(cell_tally(e_id),i-1).
```

```
let Voter(e_id) =
  in(c_pub,v);
  if is_valid(v) then
  get voting_data(e_id,v_idx,v_data) in
  in(cell_voter(e_id,v_idx),nb_vote);
  Voting(e_id,v_idx,nb_vote+1,v,v_data) |
  in(res_voting(e_id,v_idx),res_data);
  in(c_pub, is_last);
  if is_last then
    Final_Check(e_id,v_idx,v,v_data,res_data,nb_vote+1)
  else
    out(cell_voter(e_id,v_index),nb_vote+1).
```

Protocol specific processes

```
let Voting(e_id,v_idx,nb_vote,v,voting_data) =
  get election_key(=e_id,_,pkE) in
  let (pseudo,c_auth) = voting_data in
  new r_ctxt;
  let ctxt = aenc(pkE,v,r_ctxt) in
  event voted(e_id,v_idx,v);
  let b = (pseudo,ctxt) in
  out(c_pub, b); out(c_auth, b);

  out(res_voting(e_id,v_idx,nb_vote),b).
```

A library for verifability

Axioms (correction guaranteed!)

- counter intervals
- term freshness

Generic lemmas

- to help with termination
- proved each time in ProVerif
- some using induction

	Voter	Registrar (setup)	Server (1 CCR/M)	E2E Verifiability
Helios (toy ex.)	😇	–	😇	✓ 16s
Belenios tally	😇	😇 😈	😈 😇	✓ 24s
Belenios last	😇	😇	😇	✗ 5s
Belenios-counter last	😇	😇	😇	✗ 8s
Belenios-hash last	😇	😇 😈	😈 😇	✓ 62s
Swiss Post	😇	😇	😇	✓ 58s
CHVote	😇	😇	😇	✓ 17s

in bold: we used existing ProVerif files

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"No one should know my vote (0 or 1)"?

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Idea 2: An attacker cannot see the difference when voters are different $\text{Voter}(A, 0) \approx \text{Voter}(B, 0)$

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Idea 3: An attacker cannot see the difference when I vote 0 or 1.

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- The attacker always sees the difference since the tally differs.
- Unanimity does break privacy.

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~~Idea 3: An attacker cannot see the difference when I vote 0 or 1.~~

~~$\text{Voter}(A, 0) \approx \text{Voter}(A, 1)$~~

Idea 4: An attacker cannot see when votes are swapped.

$$\text{Voter}(A, 0) \mid \text{Voter}(B, 1) \approx \text{Voter}(A, 1) \mid \text{Voter}(B, 0)$$

S. Kremer & M. Ryan

Extension of the framework to privacy

Issues:

- Equivalence properties are notoriously harder to prove in ProVerif
  - performance and termination issues
  - ProVerif proves a stronger notion of privacy (diff-equivalence), often too strong

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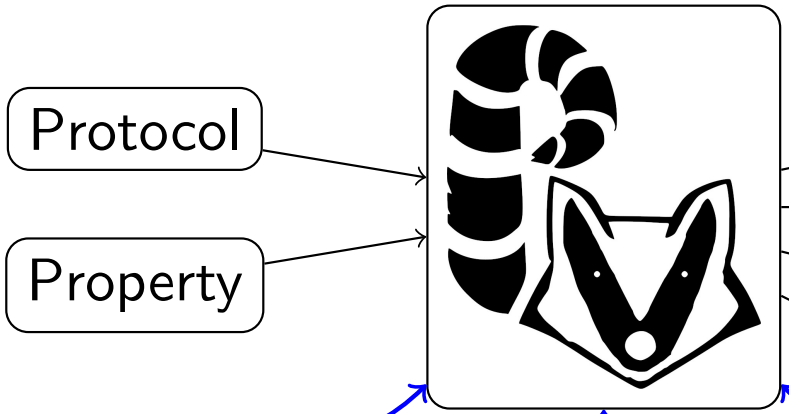
- Equivalence properties are notoriously harder to prove in ProVerif
  - performance and termination issues
  - ProVerif proves a stronger notion of privacy (diff-equivalence), often too strong
- The initial verifiability framework publishes the votes in order.
  - This does not satisfy privacy! (over-approximation)
  - we need to model the tally process, in a way compatible with diff-equivalence

Evoting framework

with F. Möser, A. Debant, and V. Cheval



yes

attack

cannot be proved

time out

revised framework for e-voting protocols

- 12 protocol specific processes
- 8 generic processes
- a few more?

Library for verifiability

- GSVerif-like axioms
- 8 well-crafted lemmas

Library for privacy

- a few GSVerif-like axioms
- 1 protocol specific lemma

Some challenges

Better formal verification

- decision procedures for larger equational theory classes
- better tools
- formalise security properties, possibly identifying new ones

Better e-voting systems

- more security properties: no vote buying, everlasting privacy, ...
- less trust assumptions (corrupted computers, ...)
- better authentication

Better regulations

- full public specification
  → should appear in CNIL 2026!
- third party verification
- clear threat models
  → ANSSI more specific e-voting guide