(In)Security of e-voting

Pascal Lafourcade

UNIVERSITÉ Clermont Auvergne

LIMOS

AMUSEC, mai 2022

CIRM 2022

REDOCS

Rencontre Entreprises DOCtorants en Sécurité informatique
28 Novembre au 2 Décembre 2022 au CIRM

Recherche d'entreprises pour REDOCS'22

cnrs GDR Sécurité Informatique

E-voting a reality

Le Monde

Consulter le journal

Se connecter

S'abonner

ACTUALITÉS · PRÉSIDENTIELLE 2022 · ÉCONOMIE · VIDÉOS · DÉBATS · CULTURE · M LE MAG · SERVICES

LES DÉCODEURS · RÉGIONALES & DÉPARTEMENTALES

Partage

Elections régionales 2021 : le vote électronique, remède à l'abstention ?

Après un premier tour marqué par une abstention historique, des membres de la majorité ont appelé à moderniser les scrutins, pour voter plus facilement, et donc de mobiliser davantage les électeurs.

Par Assma Maad et Clément Perruche

Publié le 25 juin 2021 à 18h40 - Mis à jour le 26 juin 2021 à 16h42 · Lecture 7 min.

Hauts-De-Seine : Neuilly-Sur-Seine Met En Place Un Système De Vote Électronique

On **Juil 5, 2021**

Le vote électronique fera son retour en 2022

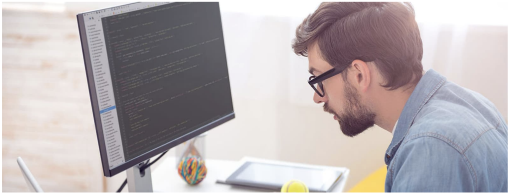
Après la découverte de failles en 2019, tous les projets de scrutin en ligne ont été suspendus. La Poste a cependant poursuivi l'aventure. Elle développe à Neuchâtel un système mieux sécurisé qu'elle soumettra à des hackers

Flaws in E-voting a reality

TECH > VIE NUMÉRIQUE

SUISSE: UNE FAILLE DE SÉCURITÉ "MAJEURE" DANS LE SYSTÈME DE VOTE EN LIGNE

Raphaël Grably Le 13/03/2019 à 11:10



NEWS

Flaw in NSW's iVote platform confirmed by researcher

By Rohan Pearce

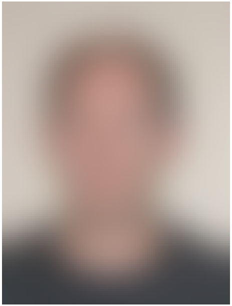
Editor, Computerworld | NOV 14, 2019 6:08 AM PST

A security researcher has confirmed that the version of New South Wales' online voting platform, iVote, employed during the 2019 election contained a vulnerability that potentially allowed the creation of false decryption proofs for ballots.

Vanessa Teague, an associate professor at the University of Melbourne, has released a paper outlining the iVote flaw, building on previous work of

Livre

Le Vote électronique



De Pierrick GAUDRY, Véronique CORTIER
256 pages, Odile Jacob 18/05/2022

Outline

Motivations

Formal Methods

e-voting

Hierarchy of Privacy Notions

Some Attacks
- Sicilian
- Vote Copy
- Bulletin Board
- Cryptographic Flaw
- Clash
- Machine Bugs

Blockchain and vote

Conclusion

Cryptography

Cryptography

Primitives
RSA, Elgamal,
AES, DES, SHA-3...

Cryptography

Primitives
RSA, Elgamal,
AES, DES, SHA-3...

Protocols
Distributed
Programs

Security: Cryptography for a Property

Cryptography

Primitives
RSA, Elgamal,
AES, DES, SHA-3...

Protocols
Distributed
Programs

Security: Cryptography for a Property in an Hostile Environment

Cryptography

Primitives
RSA, Elgamal,
AES, DES, SHA-3...

Protocols
Distributed
Programs

Security: Cryptography for a Property in an Hostile Environment

Cryptography

Verification

Primitives
RSA, Elgamal,
AES, DES, SHA-3...

Protocols
Distributed
Programs

Designing Secure Schemes is Difficult!

How can we be convinced that a protocol is a good one?

Designing Secure Schemes is Difficult!

How can we be convinced that a protocol is a good one?

✔ Publish the protocol and wait until someone finds an attack.

Designing Secure Schemes is Difficult!

How can we be convinced that a protocol is a good one?

- ✗ Publish the protocol and wait until someone finds an attack.
- ✓ Prove that there is no attack.

Designing Secure Schemes is Difficult!

How can we be convinced that a protocol is a good one?

- ✗ Publish the protocol and wait until someone finds an attack.
- ✓ Prove that there is no attack.

Usual problems with proofs:

- proving is a difficult task,
- pencil-and-paper proofs are error-prone.

How can we be convinced that a proof is a good one?

Designing Secure Schemes is Difficult!

How can we be convinced that a protocol is a good one?

✗ Publish the protocol and wait until someone finds an attack.

✓ Prove that there is no attack.

Usual problems with proofs:

- proving is a difficult task,
- pencil-and-paper proofs are error-prone.

How can we be convinced that a proof is a good one?

✓ Publish the proof and wait until someone finds a mistake.

Designing Secure Schemes is Difficult!

How can we be convinced that a protocol is a good one?

- ✗ Publish the protocol and wait until someone finds an attack.
- ✓ Prove that there is no attack.

Usual problems with proofs:

- proving is a difficult task,
- pencil-and-paper proofs are error-prone.

How can we be convinced that a proof is a good one?

- ✗ Publish the proof and wait until someone finds a mistake.
- ✓ Computer-Aided Security.

Why Verification is Useful !

Formal Security Verification Team

Formal Security Verification Team

Formal Security Verification Team

Formal Security Verification Team

Success Story of Verification in Security

1995      ≥ 17 

(Casper/FDR)

2003: ProVerif certified email protocol (B. Blanchet et al)

2005: Flaw in Kerberos 5.0 with MSR 3.0 (I. Cervesato et al)

AVISPA AVANTSSAR SATMC (A. Armando et al)

2008:
- Unknown Security flaw of Single Sign-On for Google Apps
- Proof of TLS using Proverif (Fournet et al)

2010: TOOl for cryptoKi ANalysis (G. Steel et al)

TOOKAN

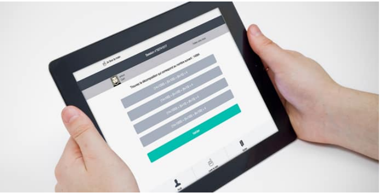
2019: UKano (L. Hirschi et al)

Other Tools: Athena, Brutus, Certycrypt, CL-ATSE, Coprové, Cryptoverif, Easycrypt, Hermes, Murphy, OFMC, Scyther, TA4SP, Tamarin ...

Outline

- Motivations
- Formal Methods
- e-voting
- Hierarchy of Privacy Notions
- Some Attacks
  - Sicilian
  - Vote Copy
  - Bulletin Board
  - Cryptographic Flaw
  - Clash
  - Machine Bugs
- Blockchain and vote
- Conclusion

E-Voting *vs* Traditional Voting



Vote électronique

Vote traditionnel

+ Accessibility
+ Reducing the abstention rate
+ Automatic counting
+ Less organisation costs

Two e-voting (1/2)

Offline

+ Efficient and fast counting
+ Vote in any voting station
- Trust the machines

Two e-voting (2/2)

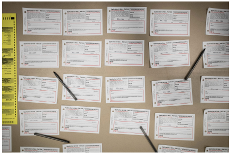
Online

+ Vote at home
+ Easy process
+ Less costs
- Possible influence

Voting Protocol Organisation

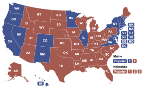
5 Phases

1. Registration
2. Validation
3. Vote
4. Counting
5. Verification



Security Requirements

Eligibility



Fairness

Universal Verifiability

Individual Verifiability

Secure e-voting protocol

Correctness

Privacy

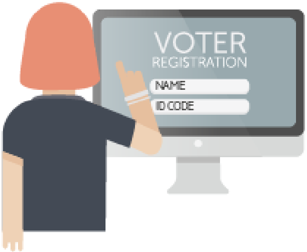
Coercion-Resistance

Robustness

Receipt-Freeness

Eligibility

Only the registered voters can vote

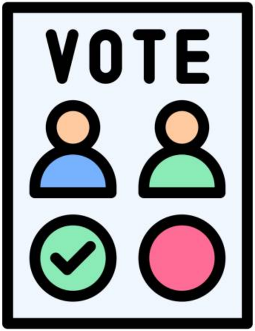


Prevent double voting

Robustness

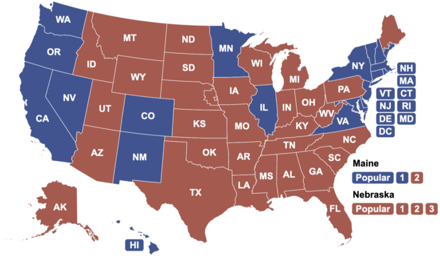
Tolerate a certain number of misbehaving voters

Correctness



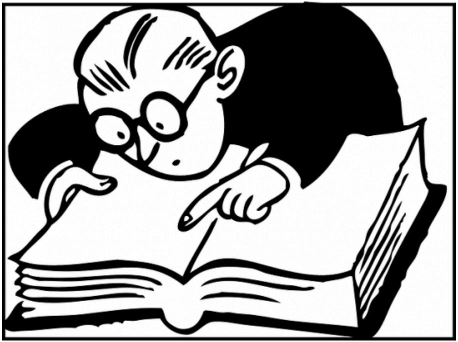
Results should be correct

Fairness



No preliminary results

Individual Verifiability



Each voter can check whether his vote was counted correctly

Universal Verifiability

Anybody can verify that the announced result corresponds to the sum of all votes

Anonymity

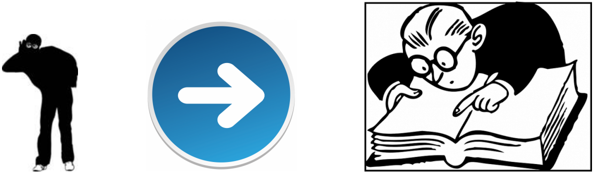
Privacy: unlinkability between the voter and his vote

Receipt-Freeness: A voter cannot construct a receipt

Corecion-Resistance: A coercer cannot be sure the voter followed his instructions

Privacy implies Individual Verifiability

2018 Cortier et al.



A system without Individual Verifiability cannot acheive privacy !

Dispute Resolution in Voting

In 2020, by David Basin, Sasa Radomirovic, Lara Schmid

Reduction Results: How many agents ?

- Security properties: **two** agents are sufficient.
  2004 by Hubert Comon-Lundh, Véronique Cortier
- When Are **Three Voters** Enough for Privacy Properties?
  2016 by Myrto Arapinis, Véronique Cortier, Steve Kremer

Outline

Motivations

Formal Methods

e-voting

Hierarchy of Privacy Notions

Some Attacks
- Sicilian
- Vote Copy
- Bulletin Board
- Cryptographic Flaw
- Clash
- Machine Bugs

Blockchain and vote

Conclusion

State of the Art

Several Definitions for Privacy for e-voting protocols:

[DKR09,DKR10,MN06,BHM08,KT09,KSR10,LJP10,SC11,...]

But

- designed for a specific protocol
- often cannot be applied to other protocols

OUR GOAL

Propose fine-grain definitions
to compare security levels of protocols

4 Dimensions for Privacy [DLL'12a, DLL'11]

Modeling in Applied π-Calculus

1. Communication between the attacker and the targeted voter

Vote-Privacy (VP) Receipt-Freeness (RF) Coercion-Resistance (CR)

4 Dimensions for Privacy [DLL'12a, DLL'11]

Modeling in Applied π-Calculus

1. Communication between the attacker and the targeted voter

Vote-Privacy (VP) Receipt-Freeness (RF) Coercion-Resistance (CR)

2. Intruder is controlling another voter:

Outsider (O)

Insider (I)

4 Dimensions for Privacy [DLL'12a, DLL'11]

Modeling in Applied π-Calculus

1. Communication between the attacker and the targeted voter

Vote-Privacy (VP) Receipt-Freeness (RF) Coercion-Resistance (CR)

2. Intruder is controlling another voter:

Outsider (O)

Insider (I)

3. Secure against Forced-Abstention: (FA) or not (PO)

4 Dimensions for Privacy [DLL'12a, DLL'11]

Modeling in Applied π-Calculus

1. Communication between the attacker and the targeted voter

   Vote-Privacy (VP) Receipt-Freeness (RF) Coercion-Resistance (CR)

2. Intruder is controlling another voter:

   Outsider (O)

   Insider (I)

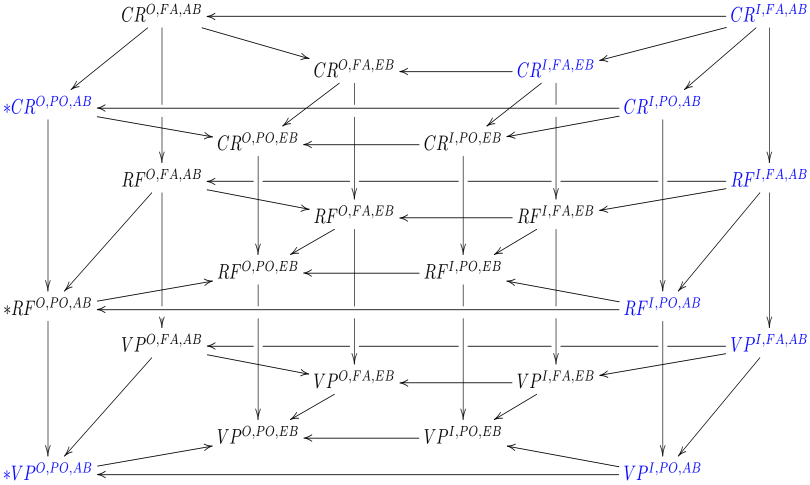
3. Secure against Forced-Abstention: (FA) or not (PO)

4. Honest voters behavior:

   $\exists$

   $\forall$

Relations among the notions



Outline

Motivations

Formal Methods

e-voting

Hierarchy of Privacy Notions

Some Attacks

- Sicilian
- Vote Copy
- Bulletin Board
- Cryptographic Flaw
- Clash
- Machine Bugs

Blockchain and vote

Conclusion

Sicilian Attack

Arlette
François
Emanuel
Marine
Jean-Luc
Arnaud
Ségolène
Jacques
Georges
Charles
Jean-Marie
Valérie

With 12 candidates, $>$ 479 millions possible combinations!

$> 2,000,000$ votes have been cast

https://vote.heliosvoting.org/

Helios code is Open Source
Based on scientific papers
Use mixnet

Attacking and fixing Helios

By V. Cortier et al in 2010

Replaying a voter's ballot

- Alice votes A
- Bob votes B
- Charlie votes like Alice

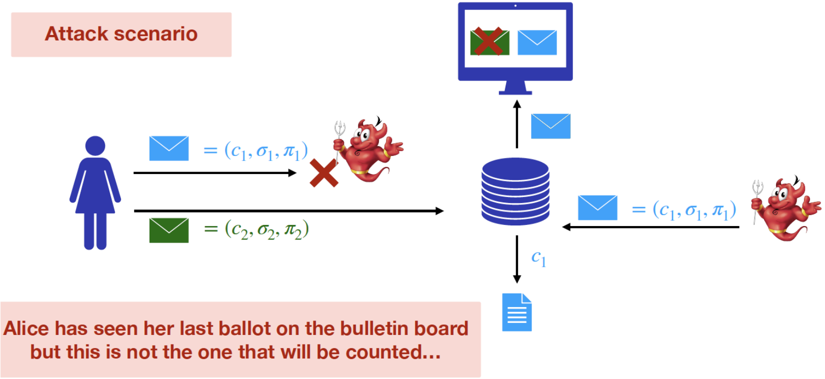
This attack works on other protocols like Lee et al and Sako et al.

Belenios

https://www.belenios.org/
Belenios code is Open Source

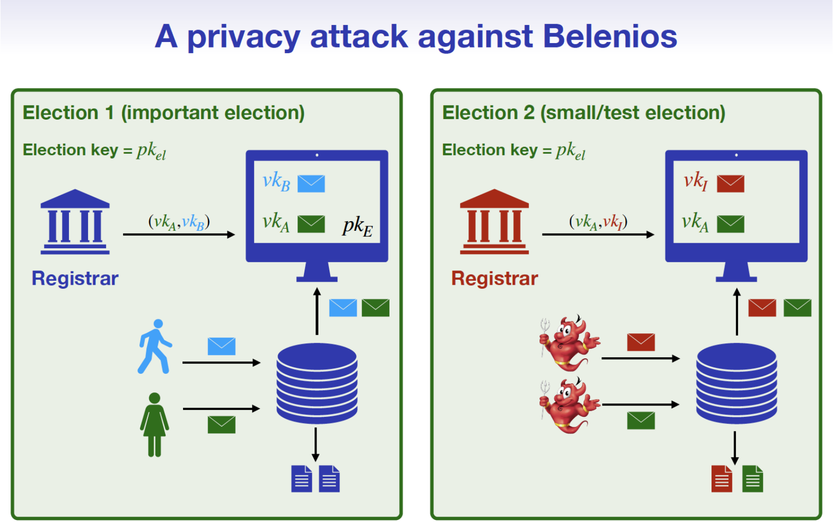
Re-ordering Attack on Belenios 2021

Individual verifiability : if I see my last ballot on the bulletin board, it will be counted.

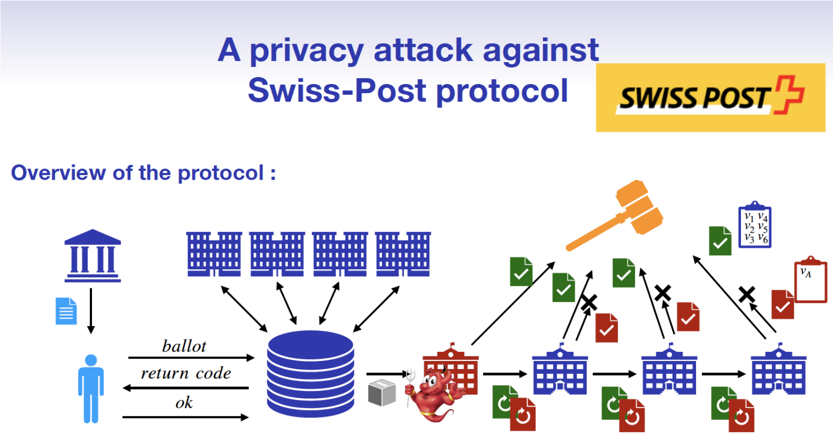


Attack by Baloglu et al. CSF2021
Fix with counter + Pok by Debant et al. 2022

Multi-server Attack on Belenios < 1.13



Swiss Post Attack (Bug Bounty 40Keuros)



Cortier et al. RWC'22

Bulletin Board

- Fifty Shades of Ballot Privacy: Privacy against a Malicious Board, by Véronique Cortier, Joseph Lallemand, Bogdan Warinschi in 2020
- Fixing the Achilles Heel of E-Voting: The Bulletin Board by, Lucca Hirshi, Lara Schmid, David Basin in 2021

Russian Online Election

In 2019, Breaking the encryption scheme of the Moscow Internet voting system by P. Gaudry et al

- Elgamal key sizes are too small (CADO-NFS)
- Counting the number of votes cast for a candidate.

 1994 Benaloh's Scheme

$$enc(a, pk_S) * enc(b, pk_S) = enc(a + b, pk_S)$$

Partial homomorphic are widely used in voting schemes

$$\prod enc(v_i, pk_S) = enc(\sum v_i, pk_S)$$

Original Benaloh's scheme is ambiguous

$$dec(enc(14, pk_S), sk_S) = 14 \mod 15 \text{ or } 14 \mod 5 = 4$$

Revisited Benaloh's encryption [FLA'11]

- Drawing false parameters: 33%
- Proposition of corrected version
- Proof using Kristian Gjosteen result.

Impact

Example with 15 voters

$\{0\}_{pk_S}$ $\{1\}_{pk_S}$

- $\prod enc(v_i, pk_S) = enc(\sum v_i, pk_S) = enc(14, pk_S)$
- Result can be either 14 or 4

Clash Attack on the verifiability of e-voting systems

By 2012 Kuesters et al.

Different voters with the same receipt

$\Rightarrow$ Authorities can manipulate the election without being detected

Attacks

- In 2007, Security Analysis of the Diebold AccuVote-TS Voting Machine by A. Feldman et al.
- In 2012, Attacking the Washington, D.C. Internet Voting System, by Scott Wolchok et al.
- In 2017 Voting Machine Hacking Village by Matt Blaze et al.

  - AVS WinVote DRE
  - Premier AccuVote TSx DRE
  - ES&S iVotronic DRE
  - PEB version 1.7c-PEB-S
  - Sequoia AVC Edge DRE
  - Diebold Express Poll 5000 electronic pollbook

With limited resources and information, they can be hacked.

Outline

- Motivations
- Formal Methods
- e-voting
- Hierarchy of Privacy Notions
- Some Attacks
  - Sicilian
  - Vote Copy
  - Bulletin Board
  - Cryptographic Flaw
  - Clash
  - Machine Bugs
- Blockchain and vote
- Conclusion

Hyperledger Fabric

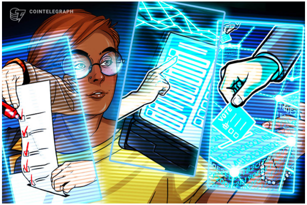
Ledger

- Public
- Infalsifiable
- Distributed

⇒ Verfiability !

DABSTERS

Distributed **A**uthorities using **B**lind **S**ignature
To **E**ffect **R**obust **S**ecurity in e-voting



Ingredients

- BlindCons : BFT consensus + Blind Signtaure
- Shamir Secret Sharing
- Identity Based Encryption
- Eliptic Curve $P = k.Q$
- Pairing $e(aP, bQ) = e(P, Q)^{ab}$
- Hash Function

Summary

DABSTERS in e-voting	
Eligibility	✓
Fairness	✓
Robustnsse	✓
Integrity	✓
Individual Verifiability	✓
Universal Verifiability	✓
Anonymity	✓
Receipt-Freeness	✓
Coercion Resistance	✗
Vote choice	Multiple

Formal Verification of DABSTERS

Properties	Results	Time
Vote Secrecy	✓	0.012 s
Authentification	✓	0.010 s
Vote Privacy	✓	0.024 s

Using Proverif

Outline

Motivations

Formal Methods

e-voting

Hierarchy of Privacy Notions

Some Attacks

- Sicilian
- Vote Copy
- Bulletin Board
- Cryptographic Flaw
- Clash
- Machine Bugs

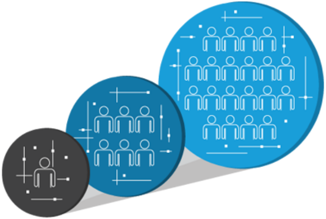
Blockchain and vote

Conclusion

Summary

- Voting is important for democracy
- Protocols must be open
- Design of voting protocols is not easy
- Formal Verification can help
- Proving all properties togheter is difficult

Future Work



- Scalability
- Human aspect are not yet taken into account
- End-to-end verification
- All properties in one tool !

Thank you for your attention.