Public PhD Defence

Unconditional Privacy in Remote Electronic Voting

Theory and Practice

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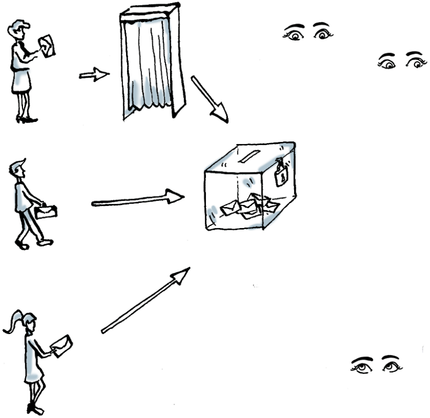
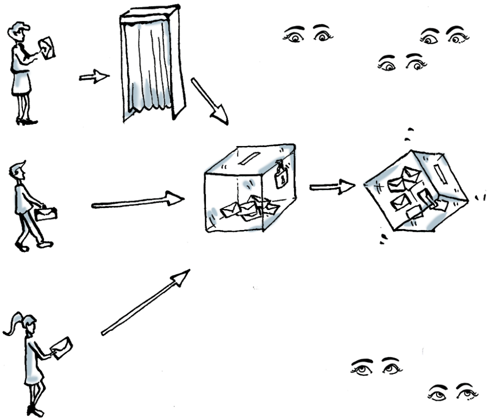
2016

Traditional Paper-Based Voting



Traditional Paper-Based Voting



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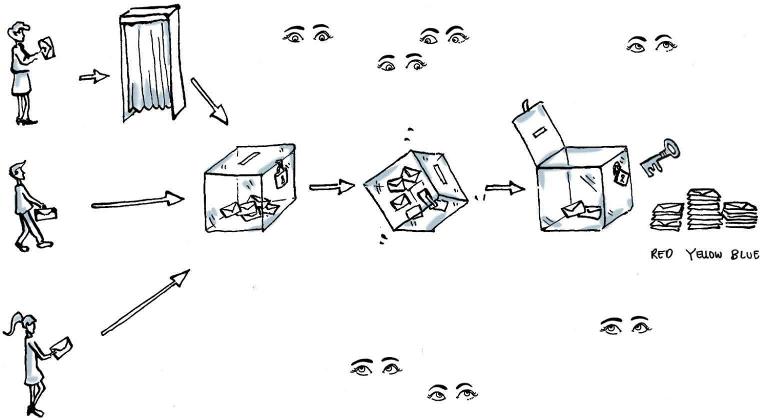
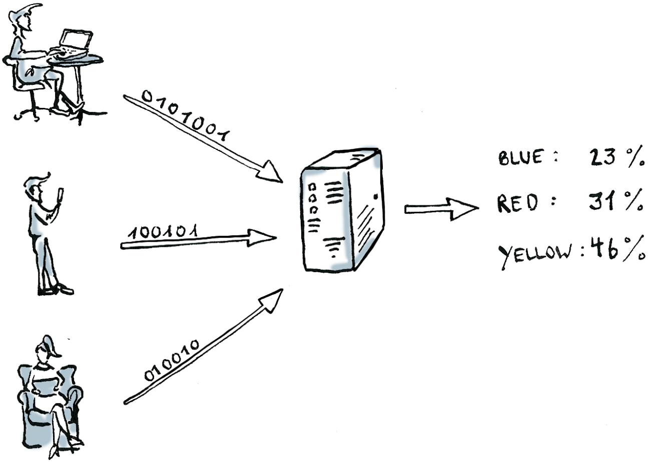


Remote E-Voting



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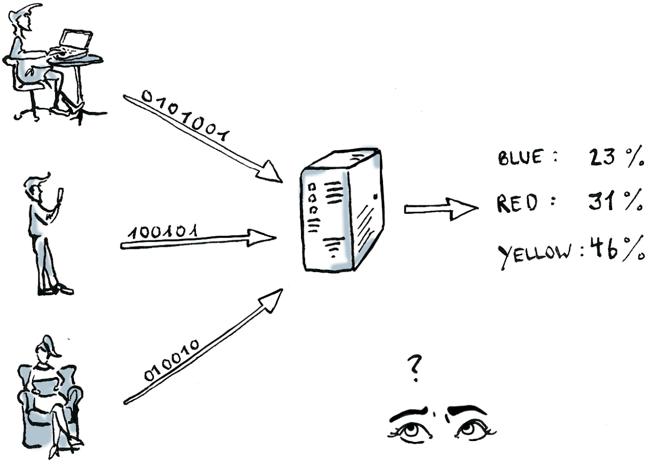
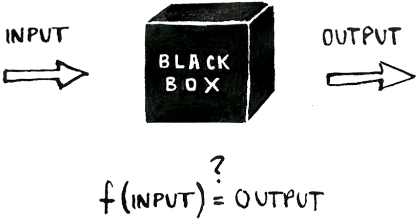
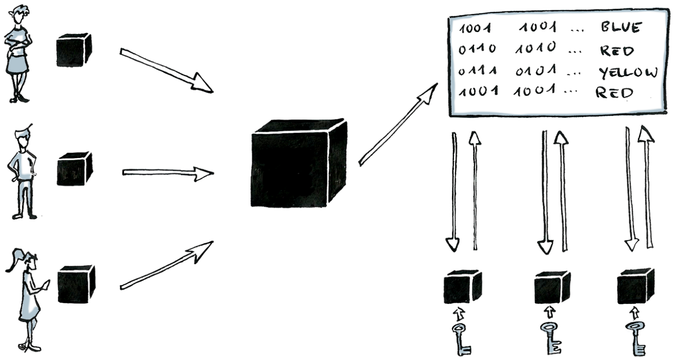


End-to-End Verifiability



Verifiable E-Voting



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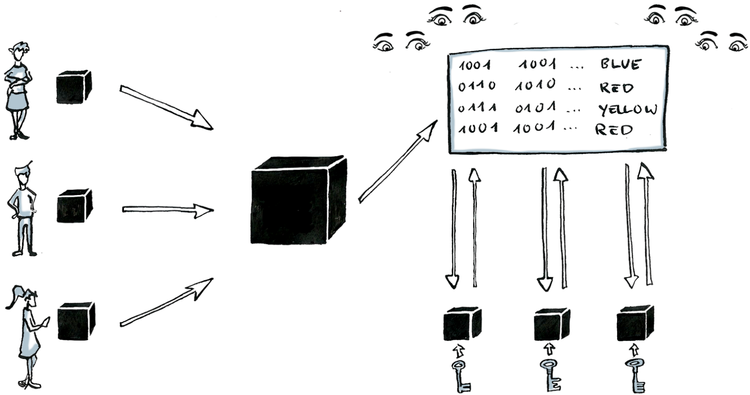
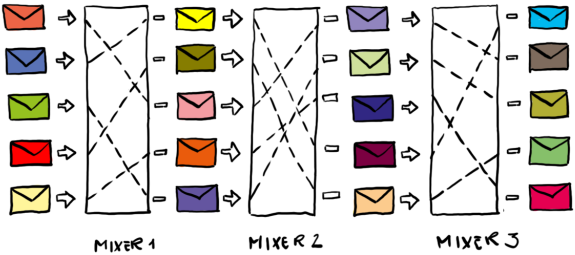


Mix-Net



Properties of an E-Voting System

Verifiability
: The result can be verified (combination of individual and universal verifiability)

Privacy
: Voter's privacy is guaranteed, if possible in an everlasting or unconditional manner

Coercion-Resistance
: A briber or coercer does not succeed in trying to influence the vote of a voter

Current E-Voting Schemes

- Verifiability is a must requirement
- Privacy is a must requirement, however it relies either on some computational intractability assumptions or on a number of trusted authorities
- There are approaches for receipt-freeness and coercion-resistance, however most are lacking in usability and/or performance

Contributions

Theoretical:

- A new e-voting scheme offering unconditional privacy
- Further development of the scheme to provide receipt-freeness and coercion-resistance

Practical:

- Developing UniVote, an e-voting system for student board elections
- Implementing a shuffle proof, an important but complex building block in many e-voting schemes

Outline

Introduction

Theoretical Contributions

Practical Contributions

Conclusion

Cryptographic Preliminaries

- One-way functions: $y = f(x)$ can be computed efficiently but there is no algorithm known to compute $x = f^{-1}(y)$ efficiently (e.g. $y = g^x \bmod p$)

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- Pubic-key encryptions: encrypt a message using a publicly known key pk such that the message can be decrypted only with the knowledge of a secret key sk (e.g. ElGamal encryption: $e = enc_{pk}(r, m) = (g^r, pk^r m)$ with $pk = g^{sk}$)

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- Non-interactive zero-knowledge proofs of knowledge: prove knowledge without revealing anything about the knowledge (e.g. $NIZKP[(x) : y = g^x]$)

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  - → an election credential $\hat{u} = \hat{g}^{\beta}$
  - → two commitments $c = com(r, u)$ and $d = com(s, \alpha, \beta)$
  - → a *NIZKP* proving that u committed to in c is a registered credential, that (α, β) committed to in d is the corresponding private credential and that the same β has been used for $\hat{u}$

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- Public Tallying: all data is retrieved from the Bulletin Board and the final tally is derived from the votes with valid proofs

The Basic Scheme

- Almost no central infrastructure, only a Bulletin Board
- No trusted authorities (except for fairness)
- Computational intractability assumptions are only required to guarantee correctness during vote casting
- Performance: ballot generation and verification require a logarithmic number of exponentiations and a linearithmic number multiplications
- The Tor network based on onion routing is a practical anonymous channel

The Receipt-Free Scheme

- A voter is allowed to cast multiple ballots
- The sum of all cast votes represents voter's final vote
- The votes and the election credentials must be encrypted
- A voter gets a receipt for each cast ballot, however the voter cannot prove not to have cast any other ballot
- The votes and the election credentials are mixed before all votes with the same election credential are summed up under encryption
- The summed up votes are decrypted and the final tally determined

The Coercion-Resistant Scheme

- A voter may cast multiple ballots, but only the last vote is included in the final tally
- Under coercion, the voter follows exactly coercer's instructions
- A coercer is unable to recognize whether or not a voter has cast another ballot after coercion
- This principle is called *deniable vote updating*

The Coercion-Resistant Scheme

- The votes and the election credentials must be encrypted: $E = enc(\hat{h}^{\beta}, \rho)$, $F = enc(vote, \sigma)$
- To make sure, the information whether or not a vote has been updated is not lost during mixing, the mix-net must be applied to a quadratic number of input encryptions
- To render the scheme practical for large scale elections, it must be further improved

The Coercion-Resistant Scheme

The expensive mixing process consists of two steps:

1. Compute the lists $\mathbf{E}_i$ and apply to each list an exponential shuffle $\mathbf{E}'_i = \mathit{shuffle}_{\mathit{exp}}(\mathbf{E}_i)$

$$\begin{pmatrix} \mathbf{E}_1 \\ \mathbf{E}_2 \\ \mathbf{E}_3 \\ \vdots \\ \mathbf{E}_n \end{pmatrix} = \begin{pmatrix} E_2/E_1 & E_3/E_1 & E_4/E_1 & \dots & E_n/E_1 \\ E_1 & E_3/E_2 & E_4/E_2 & \dots & E_n/E_2 \\ E_1 & E_2 & E_4/E_3 & \dots & E_n/E_3 \\ \vdots & & & & \vdots \\ E_1 & E_2 & E_3 & \dots & E_{n-1} \end{pmatrix}$$

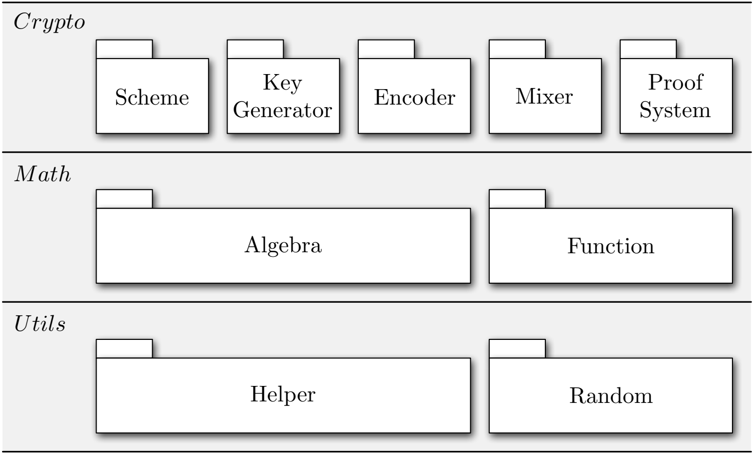
2. Apply to the list $\mathbf{F} = ((F_1, \mathbf{E}'_1), \dots, (F_n, \mathbf{E}'_n))$ a re-encryption shuffle $\mathbf{F}' = \mathit{shuffle}_{\mathit{reEnc}}(\mathbf{F})$

Outline

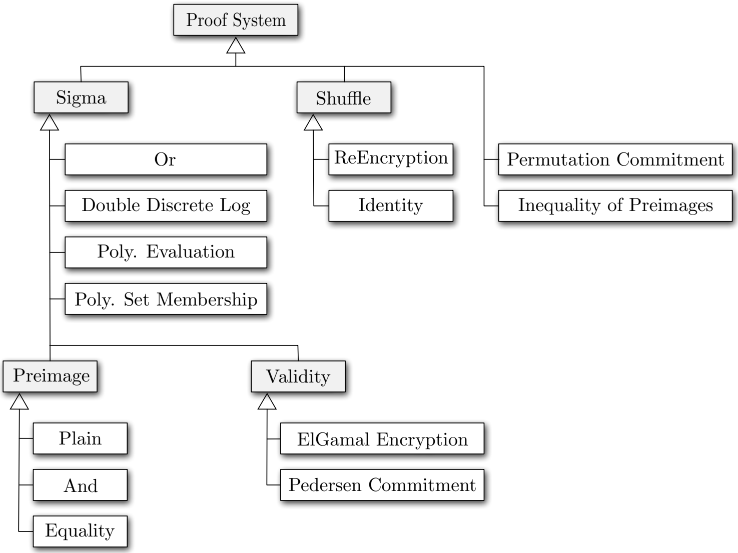
UniCrypt

- Cryptographic library providing the cryptographic building blocks used to implement e-voting systems
- Intended to bridge the gap between cryptography and software development
- Offers type safety on a mathematical level
- Contains an implementation of a shuffle proof
- Implemented in Java

UniCrypt


Crypto
Scheme
Key Generator
Encoder
Mixer
Proof System
Math
Algebra
Function
Utils
Helper
Random

Proof System



Wikström/Terelius's Shuffle Proof

Two steps:

1. Commit to a permutation matrix and prove that the resulting commitment indeed contains a permutation matrix
2. Shuffle the input batch according to the permutation matrix committed to in step 1 and prove additionally that the shuffle function has been correctly applied

Wikström/Terelius's Shuffle Proof

An $N \times N$ - matrix M is a permutation matrix if there is exactly one non-zero element in each row and column and if this non-zero element is equal to one

Example:

$$\begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} x_3 \\ x_1 \\ x_2 \end{pmatrix}$$

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Theorem (Permutation Matrix) [TW10]:

$$\prod_{i=1}^{N} x'_i = \prod_{i=1}^{N} x_i \quad \text{and} \quad M\bar{1} = \bar{1}$$

With $X = (x_1, \ldots, x_N)$ a vector of N independent variables and $X' = (x'_1, \ldots, x'_N) = MX$

UniVote

- An e-voting system for student board elections at Swiss universities
- Mix-Net based approach offering participation privacy
- Requirement of late registration
- Kind of a prototype to demonstrate verifiable e-voting
- Not a perfect system, some strong assumptions and cutbacks
- Verification software by a student project
- The project started in 2012 and UniVote2 in 2014

UniVote

	Electorate	*Turnout*	
SUB StudentInnenratswahl 2013	11'249	1'008	9.0%
VSBFH Studierendenratswahl 2013	5'720	269	4.7%
VSUZH-Ratswahl 2013	26'186	3'138	12.0%
SOL StudRat Wahlen 2013	2'715	276	10.2%
University of Lucerne: Best Teacher Award 2013	2'723	137	5.0%
VSBFH Studierendenratswahl 2014	6'662	137	2.1%
University of Lucerne: Best Teacher Award 2014	2'832	40	1.4%
SUB StudentInnenratswahl 2015	11'679	1'934	16.6%
VSUZH-Ratswahl 2015	25'707	2'273	8.8%
VSBFH Studierendenratswahl 2015	6'431	148	2.3%
SKUBA Urabstimmung 12. - 16. Oktober 2015	9'880	1'202	12.2%
University of Lucerne: Best Teacher Award 2015	2'878	116	4.0%
SOL StudRat Wahlen 2015	2'878	435	15.1%
VSBFH Studierendenratswahl 2016	6'108	148	2.4%
	123'648	**11'261**	**9.1%**

Table: Elections and referendums held with UniVote until mid-2016.

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Don't let e-voting undermine voter's privacy through the back door!

- The secret ballot longs for unconditional vote privacy
- The public understanding for the problems and challenges in e-voting must be increased

Publications

Theoretical Work:

VOTE-ID 2015 *Verifiable Internet Elections with Everlasting Privacy and Minimal Trust*; with R. Haenni

FC 2016 *Coercion-Resistant Internet Voting with Everlasting Privacy*; with R. Haenni und R. E. Koenig

AoT 2016 *Receipt-Free Remote Electronic Elections with Everlasting Privacy*; with R. Haenni

Practical Work:

INFORMATIK 2013 *Verifizierbare Internet-Wahlen an Schweizer Hochschulen mit UniVote*; with E. Dubuis, S. Fischli, R. Haenni, S. Hauser, R. E. Koenig and J. Ritter

INFORMATIK 2014 *A Lightweight Implementation of a Shuffle Proof for Electronic Voting Systems*; with R. Haenni