A Practical Voting Scheme with Receipts

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Polish voting system today

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- any additional sign makes a ballot invalid
- votes counted manually by local commissions, then inserted to a (fairly secure) computer system

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- dishonest counting paper ballots, invalid data inserted into the system
  (not all parties represented in a local commission, the observers do not have access to all parts of the procedure)

Some Data

1. percentage of invalid votes:
   - Polish Presidential Elections 1995, district Warsaw - 1^{st} round 1.09%, 2^{nd} round 2.23%
   - parliament elections 2001, 3.99%, in 1% of districts more than 10% invalid ballots
2. high costs
3. selling votes
4. every protest considered on a single vote basis, standard conclusion of the Supreme Court:
   “this single vote does note change the final election outcome”

Other problems

- voting outside the place of residence requires some efforts
- convincing the citizens that the results are fair

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- **global verifiability** – mechanism that allows everyone to check whp that every vote was properly counted
- security mechanism should be **simple** enough so that one can explain it and convince the voters

$\Rightarrow$ receipts used

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- voter should not be able to sell a vote and prove how he voted,

Election results

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- an election commission cannot cast additional ballots,

Detecting cheaters

- misbehavior can be detected whp
- a proof of misbehaviour can be presented

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- full anonymity
- no way to sell a vote
- no way to cheat without being detected

Disadvantages

- each ballot is linked with a voting machine
  but this is required by Polish law (and has some justification and function in the political system)
- a voting machine knows the preferences of a voter
  hard to avoid ...

Components of the system

Servers:

- voting machines (with printers)
- registration machines
- tallying machines
- plus control servers (independent, watch dog organisations)

Authorities:

- local election committee
- tallying authorities
- plus a court in the case of irregularities

A voter in a voting booth - step 1/5

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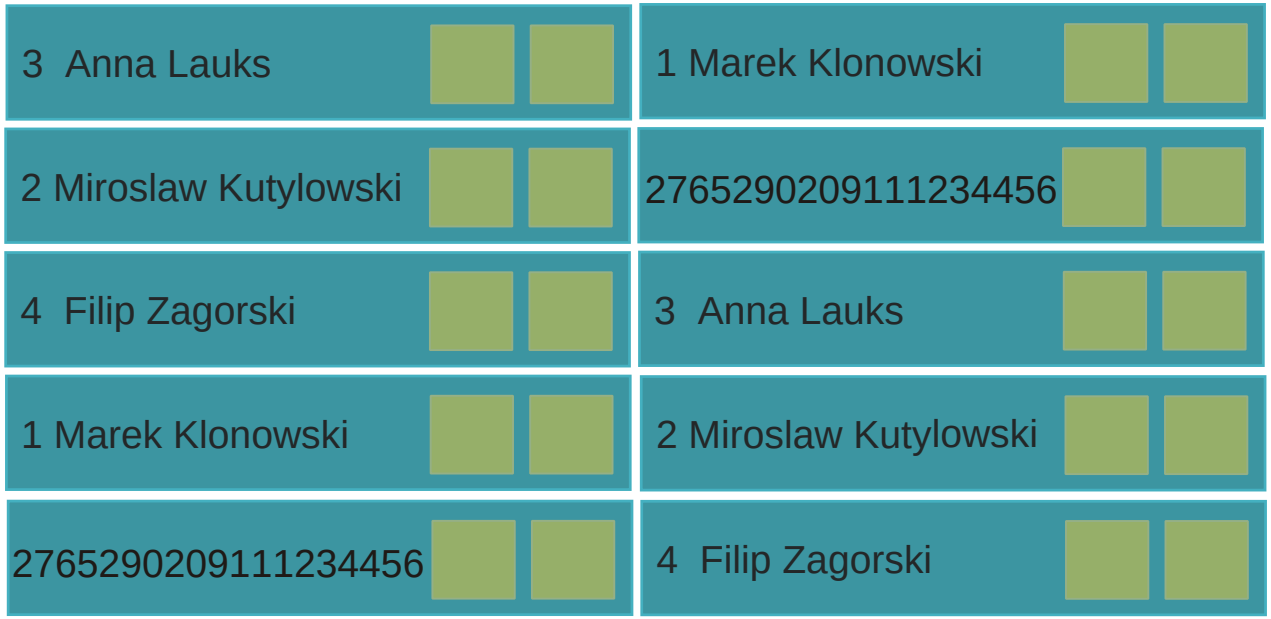
- a machine prepares a *virtual ballot* at random,
- a voter gets a printout of a *hash ballot* – a commitment to the virtual ballot
  - the machine cannot change the virtual ballot
  - the voter cannot recover the virtual ballot

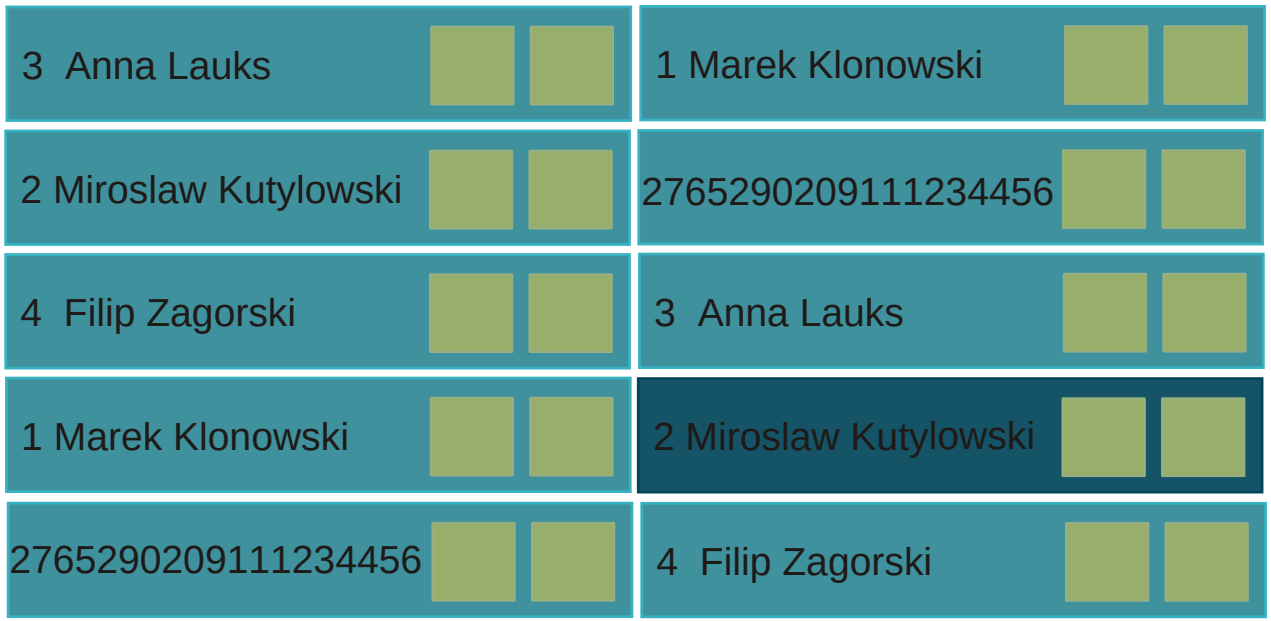
A voter in the voting booth - step 2/5

- a voter sees depiction of the virtual ballot: 2 lists with the names of the candidates and a random ID



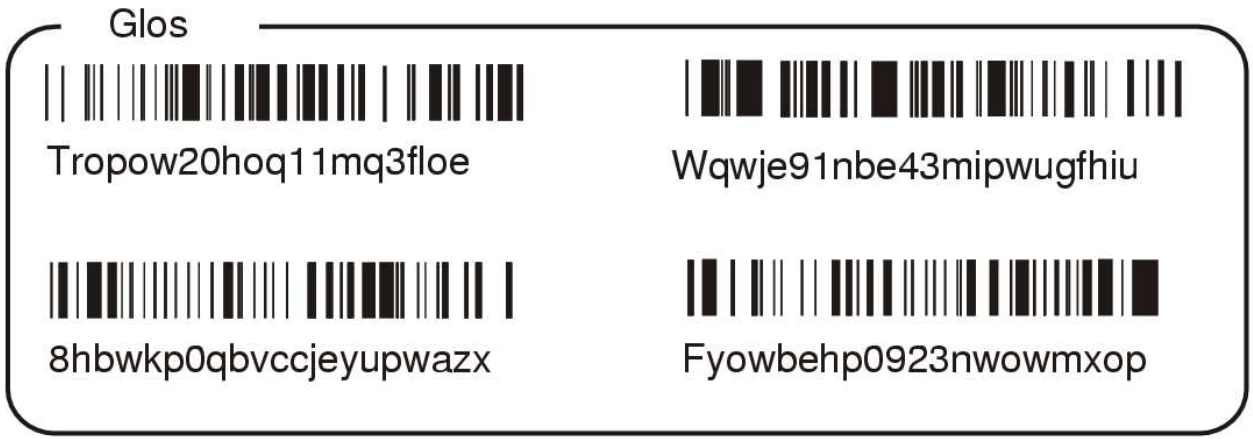
A voter in the voting booth - step 3/5

- a voter makes his choice by choosing a candidate and either the left or the right side:



A voter in the voting booth - step 4/5

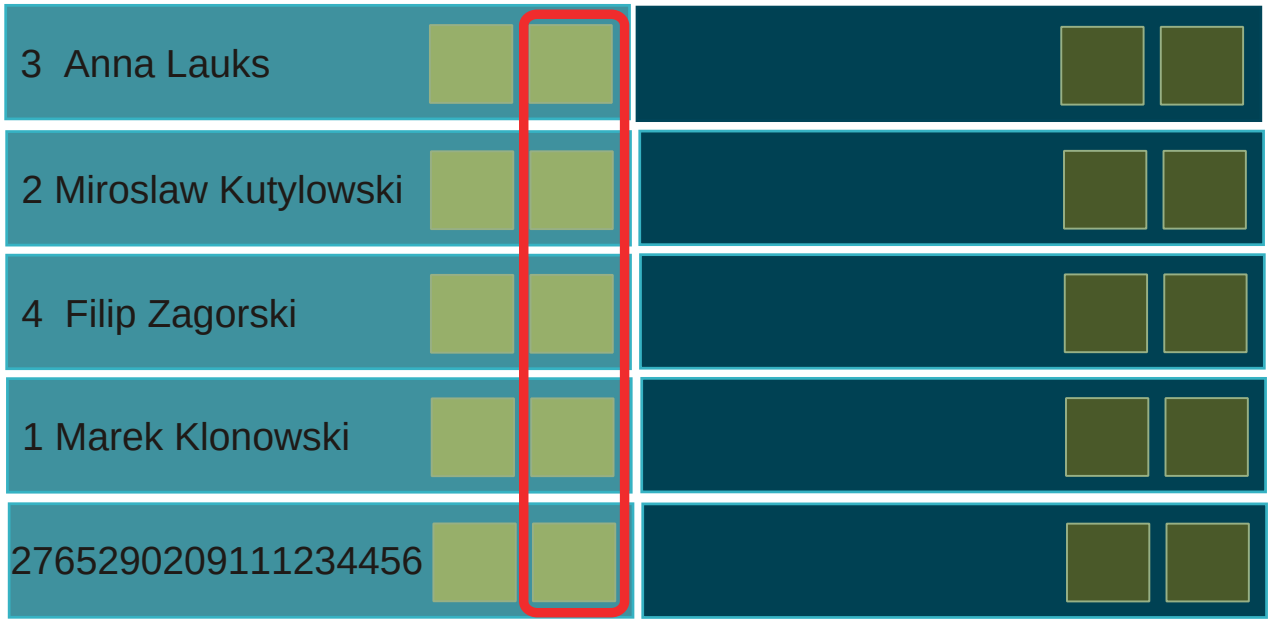
- a voter gets a vote (encrypted):



- the values printed can be later compared with appropriate hashes from the hash ballot, what about the encrypted values?

A voter in the voting booth - step 5/5

- preparation of a *control ballot*:



A voter in the voting booth - step 5/5

- a voter gets the control ballot:

Karta do weryfikacji

3 Anna Lauks	Reiopenl92nhdvampsddkffp
2 Miroslaw Kutylowski	Wqwje91nbe43mipwugfhiu
4 Filip Zagorski	Jobwjb821q10nxnimmajwax
1 Marek Klonowski	Pquioeiuwdf7218nzoiqpjq11
27652902091112344 56	Oqihiqhrt098hk2229kPiuo

Scanning of encoded votes

- (under supervision) a voter presents his voting ballot for scanning by a scanning machine
- the ballot gets stamped -
  - for possible investigations, and
  - for preventing to scan the same ballot twice

Vote counting

the parts of votes get separated!

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Scanned votes are:

- recoded (partial decoding + re-encryption)
- randomly mixed

by different Tallying Authorities

- anonymity is guaranteed

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- The last counting commission gets and publishes decrypted votes and identifiers:
  - identifiers
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- The last counting commission gets and publishes decrypted votes and identifiers:
  - identifiers
  - votes
- A voter can check if his pair of identifiers is on the list.
- Everybody can
  - check if identifiers are paired,
  - check if votes are paired,
  - compute the result of elections.

RE-onions

- y_i - public key, x_i corresponding private key, $y_i = g^{x_i}$, g is generator of a group G with hard discrete logarithm problem. The order of G is a prime.
- ElGamal ciphertexts: for k_1 chosen uniformly at random $(\alpha, \beta) := (m \cdot (y_1 \cdot \ldots \cdot y_\lambda)^{k_1}, g^{k_1})$
- ith server gets: $(\alpha_i, \beta_i) := (m \cdot (y_i \cdot \ldots \cdot y_\lambda)^{k_i}, g^{k_i})$ and outputs: $(\alpha_{i+1}, \beta_{i+1}) := (\alpha_i / \beta_i^{x_i} \cdot (y_{i+1} \cdot \ldots \cdot y_\lambda)^{r_i}, \beta_i g^{r_i})$ r_i randomly chosen, $k_{i+1} = k_i + r_i$

Initialization of *voting machines*

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- A private key K' generated: for signing votes and identifiers with a signature scheme sig'
- A private key K generated: for creating seeds for constructing RE-onions (deterministic signature scheme)
- The corresponding public keys are delivered to the local registration machine and to the final tallying authority

A voter in a voting booth - step 1/5

- a machine prepares a *virtual ballot*, which consists in the following data:
  - r - ballot identifier, a random string
  - q - an auxiliary string used for constructing RE-onions
  - r_L, r_R - random strings chosen separately for each side
  - $$\begin{array}{ccc|ccc} B & B_1^L & B_2^L & I & I_1^R & I_2^R \\ I & I_1^L & I_2^L & Y & Y_1^R & Y_2^R \\ Y & Y_1^L & Y_2^L & B & B_1^R & B_2^R \end{array}$$

    where I, B, Y are labels

Content of the onions

- For constructing the RE-onion Z_i^X the voting machine creates signatures $sig_K(q, i, X, Z)$
- Using random bit generator $\mathcal{R}$, the machine computes: $k_1 = \mathcal{R}(sig_K(q, i, X, Z))$
- After full decoding of the onions we get, for $X = L, R$, $i = 1, 2$:
  - $(B, r_X, ser_V, sig'_{K'}(B, r_X, i))$ from B_i^X
  - $(Y, r_X, ser_V, sig'_{K'}(Y, r_X, i))$ from Y_i^X
  - $(r, ser_V, sig'_{K'}(r, X, i))$ from I_i^X

A voter in the voting booth - step 2/5

- a voting machine creates and prints a *hash ballot*, which is a commitment to the *virtual ballot*, it contains:
  - r - ballot identifier
  - h_0 - the root of a Merkle tree of hashes. Its leaves are hashes of r, q, r_L, r_R, and of the RE-onions (without labels)

A voter in the voting booth - step 3/5

- Once the hash ballot is printed, a visualization of the virtual ballot appears on the screen
- The voter chooses a side c and an icon P of the party for which he votes,
- the *voting ballot* is created and printed. It consists in RE-onions of the party selected and the identifier.

Example:

P_1^c I_2^c
I_1^c P_2^c

A voter in the voting booth - step 4/5

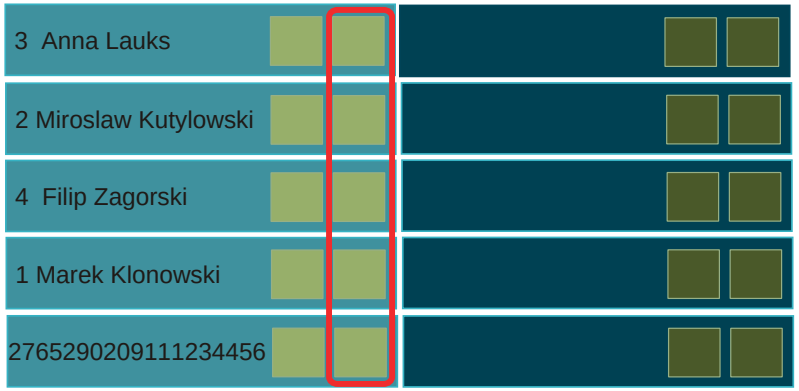
- a *control ballot* is created for the column chosen by the voter
- it contains
  - the onions from the side and column chosen
  - the data $q, sig_K(q, i, X, Z)$ that enable to reveal $k_1 = \mathcal{R}(sig_K(q, i, X, Z))$
- k_1 can be used to *open an onion* –decipher the ElGamal ciphertext– without the private keys

(trick borrowed from D.Chaum's paper)

Why a voting machine cannot cheat?

Each voting machine:

- a *virtual ballot* once created cannot be changed (thanks to the *hash ballot*,
- a voter can verify the contents of an unused half of vote – verification procedure for *control ballot*



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Cheating attempt:

- vote removal - successful if one can find both pairs

  for 1000 voters probability of successful removal of a single vote is $\approx 1/8000$, two votes - 1.5e-8, 3 votes - 1.9e-12
- if one part of an identifier is removed, then the cheating attempt will be discovered,
- an investigation procedure finds a tallying authority which made an attempt to cheat.
- if a half of a vote is missing, then a similar investigation possible but not performed for preserving anonymity

Why a voter cannot cheat?

- on verification cards there are only halves of votes/identifiers
  they cannot be used for casting an additional vote

Investigations

- partially reveal the permutation used
- reveal some re-encryption exponents
- zero knowledge proof of correctness of partial decoding

Implementation

test implementation prepared by students of Wrocław University of Technology

http://e-voting.im.pwr.wroc.pl

Still to be done

Apply schemes yielding short

- signatures,
- ciphertexts (of asymmetric schemes),
- and enabling fast re-encryption and fast partial decoding (for the China case)

Here, security level for signatures can be lower than in the case of digital signatures used for signing contracts ... that must remain secure for years.

Thanks for your attention

Details and contact: `http://e-voting.im.pwr.wroc.pl`