Berner Fachhochschule - Technik und Informatik

David Chaum's Punchscan and Scantegrity

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Outline

E2E Voting Systems

Punchscan

Randomized Partial Checking

Scantegrity

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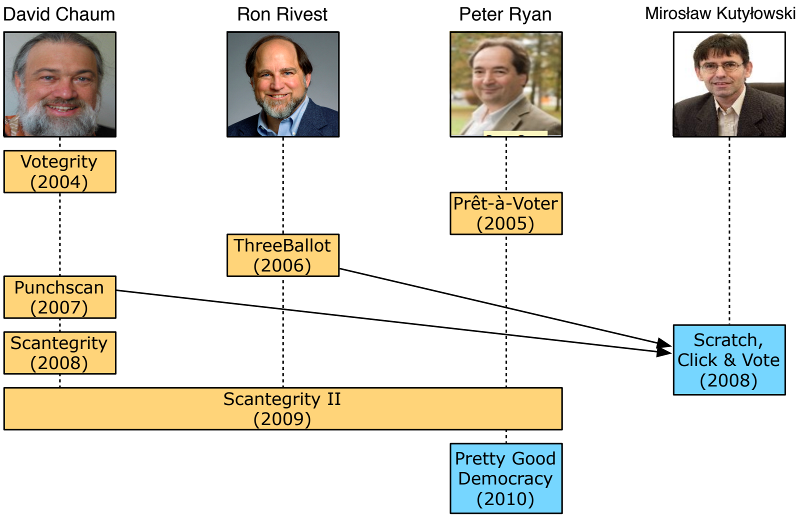
E2E Voting Systems

- E2E = "end-to-end voter verifiable" or "end-to-end auditable"
- Receipt-based (voter gets a receipt without revealing vote)
- Voter auditable (any voter may check that his or her ballot is correctly included in the electronic ballot box)
- Receipt-free (no voter can demonstrate how he or she voted)
- Combination of paper-based and electronic voting
- Usually, voting takes place in private voting booths at the polling station
- Often designed to be used together with optical scanners
- Allows paper recount

Overview of E2E Systems

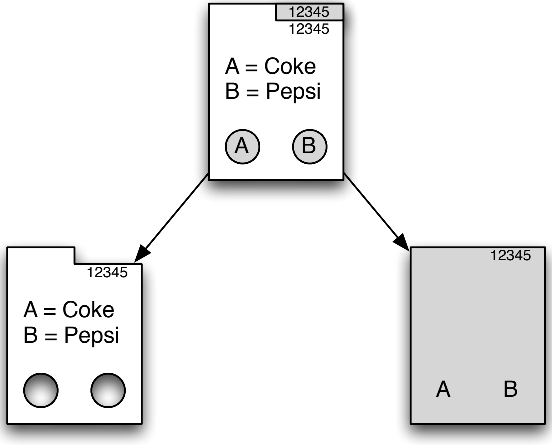


Outline

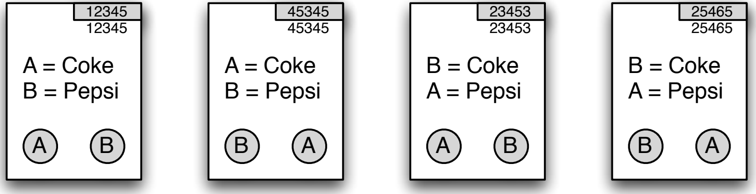
Ballots

- The pre-printed ballots consist of two-layers
- First layer
  - → Serial number
  - → List of candidates/options (e.g. in alphabetical order)
  - → Symbols attached to each list item (random order)
  - → Two holes
- Second layer
  - → Serial number
  - → Symbols to appear in holes (random order)

Ballots



Ballots

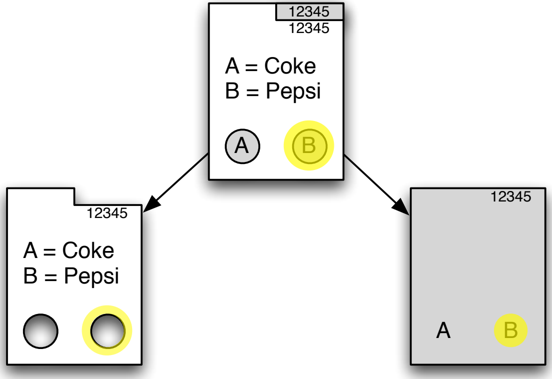


- There are two random choices $P_1 \in \{0, 1\}$ and $P_2 \in \{0, 1\}$
  - $\rightarrow$ $P_1 = 0$ means "AB on top layer"
  - $\rightarrow$ $P_1 = 1$ means "BA on top layer"
  - $\rightarrow$ $P_2 = 0$ means "AB on bottom layer"
  - $\rightarrow$ $P_2 = 1$ means "BA on bottom layer"
- Thus, we have four different ballots $(P_1, P_2) \in \{00, 01, 10, 11\}$

Voting Process

- The voter marks the hole containing the preferred choice with a translucent stamp
- The two layers are separated
- The voter choses one of the layers to be shredded
- The other layer is scanned and kept as a receipt
- Let $P_3 \in \{0,1\}$ denote the position of the mark
  - → $P_3 = 0$ means "Mark on the left"
  - → $P_3 = 1$ means "Mark on the right"
- Note that $R = P_1 \oplus P_2 \oplus P_3$ denotes the vote
  - → $R = 0$ means "1st candidate/option on the list"
  - → $R = 1$ means "2nd candidate/option on the list"

Voting Process



$$P_1 = 0,\ P_2 = 0,\ P_3 = 1$$
$$\Rightarrow R = 1 = B$$

Reconstructing the Shredding

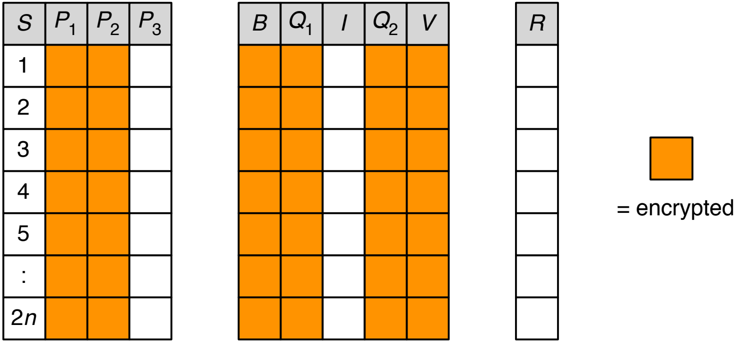
- Shredding destroys either P_1 or P_2, i.e., the paper receipt does not contain any information about R
- To reconstruct R in the final tally, two other values are defined
  - → $Q_1 \in \{0,1\}$ is chosen at random
  - → $Q_2 \in \{0,1\}$ is chosen such that $Q_1 \oplus Q_2 = P_1 \oplus P_2$ holds
- This yields $R = (P_1 \oplus P_2) \oplus P_3 = (Q_1 \oplus Q_2) \oplus P_3$
- $I = P_3 \oplus Q_1$ defines an "intermediate result" from which the vote is constructed by $R = I \oplus Q_2$

Public Board

- The public board contains three tables
- Table 1 contains four columns for
  - → S = Serial number
  - → P_1
  - → P_2
  - → P_3
- Table 2 contains five columns for
  - → B = Ballot row (1st permutation)
  - → Q_1
  - → I
  - → Q_2
  - → V = Vote row (2nd permutation)
- Table 3 contains one column for R

Public Board

- Setting up the board takes place before printing the ballots
- After the setup, the board looks as follows



Pre-Election Audit

- The goal is to verify whether $Q_1 \oplus Q_2 = P_1 \oplus P_2$ holds
- For this, half of the rows are decrypted (chosen at random)
- By inspecting the board, everybody can verify its integrity with high probability

S	P_1	P_2	P_3
1	1	0	
2			
3	0	0	
4			
5			
:			
$2n$	1	1	

B	Q_1	I	Q_2	V
3	1		1	2
1	0		1	4
$2n$	1		1	3

R

Pre-Election Audit

- After the pre-election audit, decrypted rows are deleted
- The remaining ballots are printed and distributed to the polling stations
- Every voter receives exactly one of those ballots

S	P_1	P_2	P_3
2			
4			
5			
8			
⋮			

B	Q_1	I	Q_2	V

R

Vote Casting

- After scanning the ballot, the board is updated as follows
  - → For each top layer ballot, P_1 is decrypted
  - → For each bottom layer ballot, P_2 is decrypted
  - → P_3 is posted

S	P_1	P_2	P_3
2	1		1
4		0	1
5		1	0
8	0		1
:		1	0

B	Q_1	I	Q_2	V

R

- This allows the voter to verify the correct recording of the vote

Announcing the Results

- When polling stations close, the board is enhanced as follows
  - → I is posted
  - → R is posted

S	P_1	P_2	P_3
2	1		1
4		0	1
5		1	0
8	0		1
:		1	0

B	Q_1	I	Q_2	V
		0		
		1		
		1		
		1		
		0		

R
1
1
0
0
1

- The final outcome is derived from column R

Post-Election Audit

- The goal is to verify the correct shuffling of the table rows and the correctness of I and R
- For this, half of the rows are selected at random and B and Q_1 are decrypted
- For the other half of the rows, Q_2 and V are decrypted

S	P_1	P_2	P_3
2	1		1
4		0	1
5		1	0
8	0		1
:		1	0

B	Q_1	I	Q_2	V
		0	0	4
2	0	1		
8	1	0		
		1	1	5
4	0	0		

R
1
1
0
0
1

Extensions

- 1-out-of-n elections are possible by doing the calculations modulo n (instead of modulo 2)
- Multiple public boards with different permutations (columns B and V) can be run in parallel, each of which must come out with the same result
- To protect the integrity of the ballots and the initial board, the voting authority must commit itself to the respective content (using a proper commitment scheme)

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Randomized Partial Checking (RPC)

- Usually, mix nets provide (expensive) proofs of correct mixing
- RPC mix nets provide strong evidence of correct mixing
  - → Every mix-server must reveal half of the links between its input and output
  - → The links to be revealed are determined at random by other protocol participants
  - → If k votes are manipulated by a mix, then it remains undetected with probability $\frac{1}{2^k}$

M. Jakobsson, A. Juels, and R. L. Rivest
Making mix nets robust for electronic voting by randomized partial checking.
11th USENIX Security Symposium, 2002

Outline

Links

- White Paper (Scantegrity)
- Video presentation (Scantegrity)
- Video presentation (Scantegrity II)