Bern University
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Private Internet Voting on Untrusted Voting Devices

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Outline

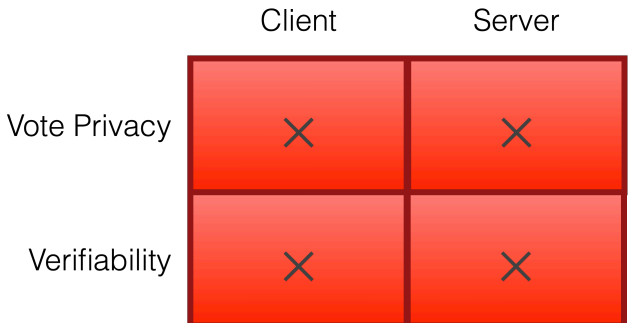
- Introduction
- Voting Procedure
- Cryptographic Protocol
- Security and Usability Properties
- Conclusion

Outline

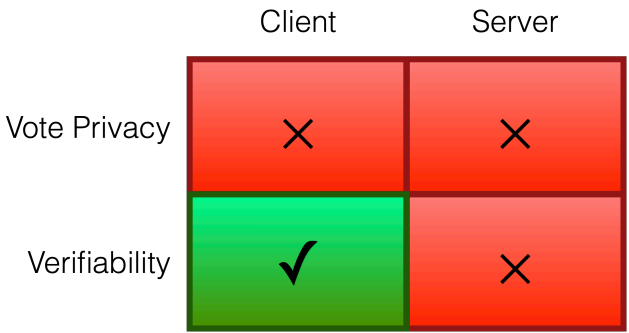
E-Voting in Switzerland

Source: https://www.zdnet.com/article/swiss-government-invites-hackers-to-pen-test-its-e-voting-system

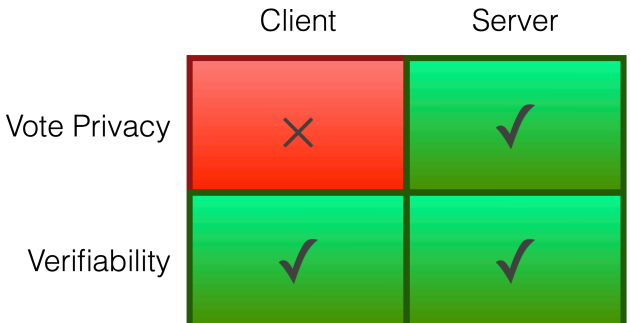
Systems of 1st Generation (2004–2014)



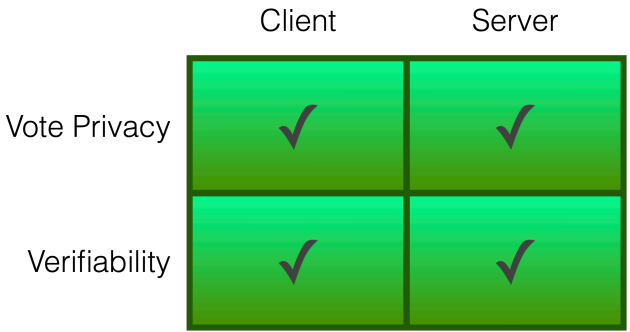
Systems of 2nd Generation (2014–2017)



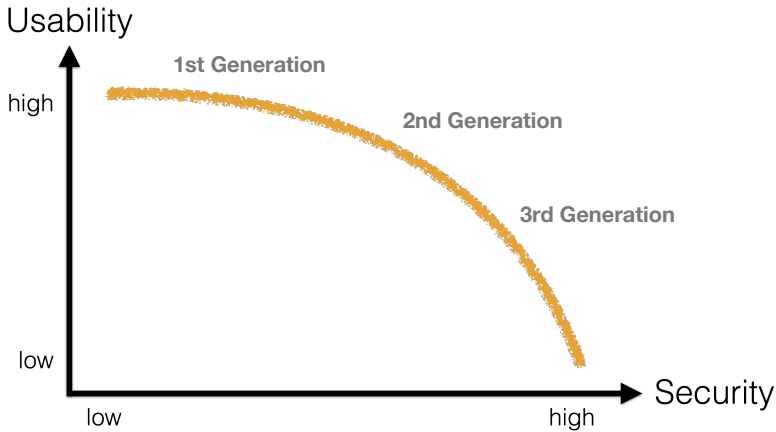
Systems of 3rd Generation (since 2017)



Systems of 4th Generation (this paper)



Security vs. Usability



QR-Codes are Everywhere

Source: https://www.freepik.com/premium-vector/flat-boarding-pass-with-qr-code-red-shapes_1005491.htm

QR-Codes are Everywhere

Source: https://www.qrcode-tiger.com/6-interesting-use-cases-of-qr-codes-in-2019-and-how-it-can-benefit-your-business

QR-Codes are Everywhere

Source: https://krvportal.ch/rechnungen/qr-rechnung/

QR-Codes are Everywhere

Source: https://www.computerworld.ch/security/sicherheitsluecken/136-schwachstellen-covid-zertifikat-2682799.html

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Step 1: Invitation by Postal Mail

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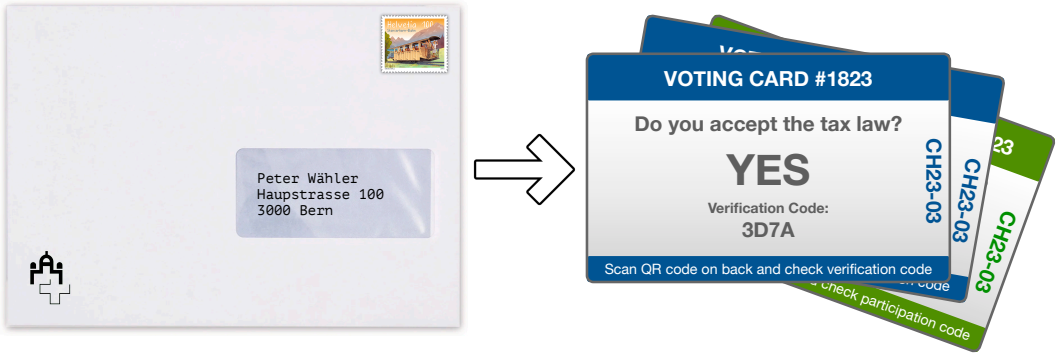

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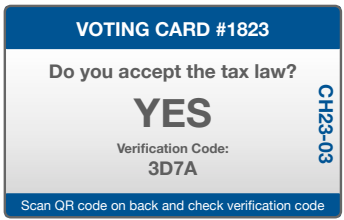
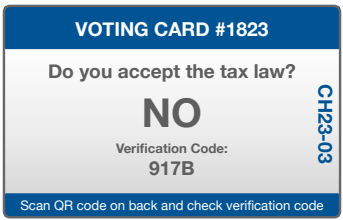
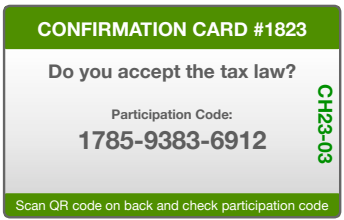
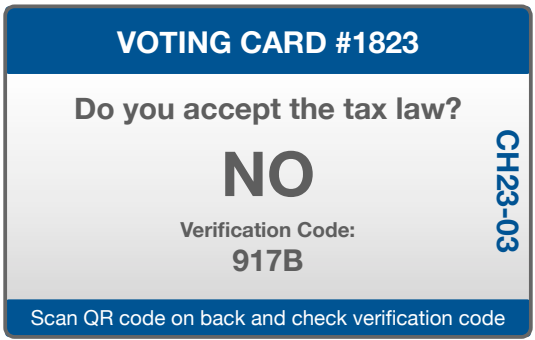






Step 2: Vote Casting



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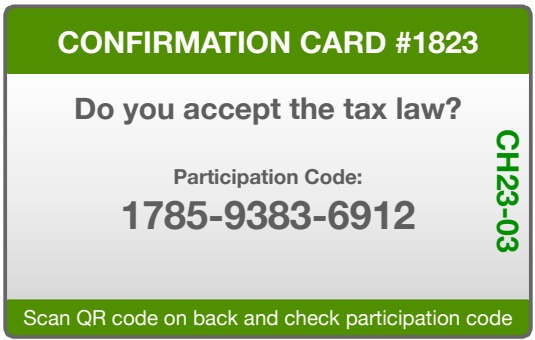
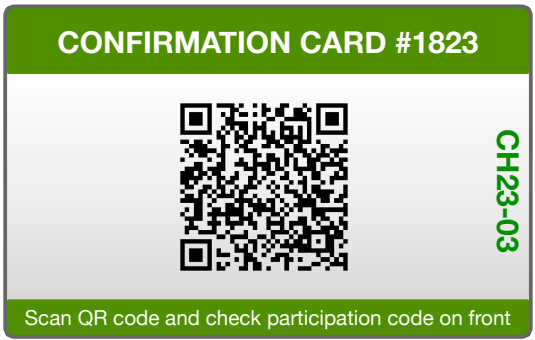
Step 3: Confirmation



Step 3: Confirmation



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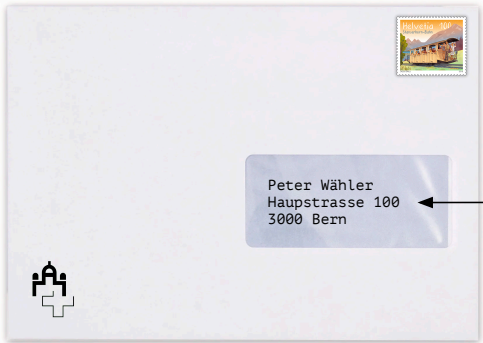
Preliminaries: Election Parameters

- N = number of voters
- n = number of voting options (candidates)
- m = maximum number of selection

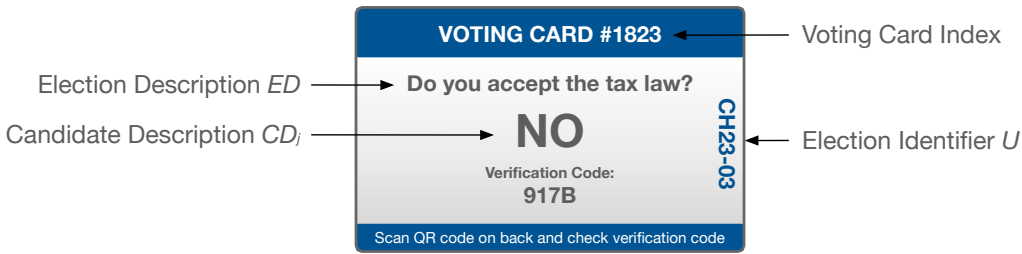
- U = unique election identifier
- ED = election description
- VD_i = voter description $i \in [1, N]$
- CD_j = candidate description $j \in [1, n]$

Preliminaries: Election Parameters



Voter Description VD_i

Preliminaries: Election Parameters



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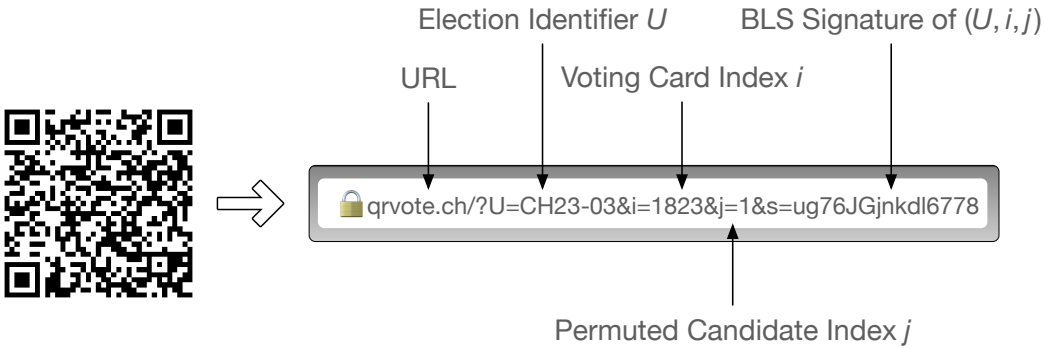

Preliminaries: Cryptographic Parameters

- $\mathbb{G}_q$ = prime-order subgroup of integers modulo $p = 2q + 1$
- Generator $g \in \mathbb{G}_q \setminus \{1\}$
- Vote encoding $\Gamma : [1, n] \to \mathbb{G}_q$ and decoding $\Gamma^{-1} : \mathbb{G}_q \to [1, n]$

- Bilinear map $e : G_1 \times G_2 \to G_T$, for example BLS12-381
- Hash function $hash : \{0, 1\}^* \to G_1$
- Generator $g_2 \in G_2 \setminus \{1\}$
- Note that the BLS signature size in BLS12-381 is 382 bits (48 bytes)

Preliminaries: Cryptographic Keys

- s = number of election authorities

- dk_k = private ElGamal decryption key of authority $k \in [1, s]$
- ek = jointly generated ElGamal encryption public key

- sk_k = private BLS signature generation key of authority $k \in [1, s]$
- vk = jointly generated BLS signature verification public key

Preparation: Mixing the Encrypted Votes

- For all $j \in [1, n]$, let $e_j = Enc_{ek}(\Gamma(j), 0) = (1, \Gamma(j))$ be the trivial encryption of j
- For all $i \in [1, N]$, let $\tilde{\mathbf{e}}_{i,0} = (e_1, \ldots, e_n)$ be the input for a verifiable mixnet,

$$\tilde{\mathbf{e}}_{i,0} \xrightarrow[\psi_{i,1}]{\text{Shuffle 1}} \tilde{\mathbf{e}}_{i,1} \xrightarrow[\psi_{i,2}]{\text{Shuffle 2}} \cdots \xrightarrow[\psi_{i,s}]{\text{Shuffle } s} \tilde{\mathbf{e}}_{i,s},$$

and $\tilde{\mathbf{e}}_{i,s} = (\tilde{e}_{i,1}, \ldots, \tilde{e}_{i,n})$ its output

- The shuffle permutations ψ_{ik} are sent to the trusted printer (by opening the commitments from the NIZKP)
- The printer combines $\psi_i = \psi_s \circ \cdots \circ \psi_1$ and therefore knows which encrypted vote $\tilde{e}_{ij}$ belongs to which candidate

Preparation: Preparing the Voting Cards

- Every authority k generates BLS signatures $\sigma_{ijk} = sign_{sk_k}(U, i, j)$ and random verification codes vc_{ijk} for all voters i and all candidates j
- All σ_{ijk} and vc_{ijk} are sent to the trusted printer

- The printer combines $\sigma_{ij} = \prod_{k=1}^{s} \sigma_{ijk}$ and $vc_{ij} = hash(vc_{ij1}, \ldots, vc_{ijk})$
- The printer assigns $QR_{ij} = QREncode(U, i, j, \sigma_{ij})$ and vc_{ij} to the right candidate description (using ψ_i)

- Similar for verification cards: $QR_i = QREncode(U, i, \sigma_i)$ and pc_i

Vote Casting and Confirmation

- The voter sends QR_{ij} to the authorities
- The vote is accepted if σ_{ij} is a valid signature for (U, i, j)
- Shares of the verification code vc_{ijk} are sent to the voter
- The voting client displays $vc_{ij} = hash(vc_{ij1}, \ldots, vc_{ijk})$ to the voter

- The voter sends QR_i to the authorities
- The confirmation is accepted if σ_i is a valid signature for (U, i)

  $\Rightarrow$ The encrypted vote $\tilde{e}_{ij}$ is put into the ballot box
- Shares of the participation code pc_{ik} are sent to the voter
- The voting client displays $pc_i = hash(vc_{i1}, \ldots, vc_{ik})$ to the voter

Tallying

- Apply a mixnet to the accepted encrypted votes
- Perform a distributed decryption using the shares dk_k of the private decryption key
- Decode the actual votes using Γ^{-1}
- Publish the election result

Outline

Security: Vote Privacy

- Assumption 1: The printer is honest
- Assumption 2: The election authorities are honest as a group (at least is honest)

- The combined permutation ψ_i of the pre-election mixnet is only known to the trusted printer
- Therefore, no adversary can link the submitted permuted candidate index to the candidate selected by the voter
- In particular, the voting device learns nothing about the voter's intention

- The post-election mixnet unlinks the decrypted votes from the submitted votes

Security: Vote Integrity

- Assumption 1: The printer is honest
- Assumption 2: The election authorities are honest as a group (at least is honest)

- Only ballots $b_{ij} = (U, i, j, \sigma_{ij})$ with a valid signature make it into the final tally
- Valid signatures are only known to the trusted printer and the voters
- No single party can generate valid signatures

- The untrusted voting device could try to change or block the submitted vote, but this would ne noticed by the voter

Usability

- Voter's can use their regular phone, tables, or notebook computer
- Multiple voters can use the same device
- No additional voting software needs to be installed
- No URL needs to be entered
- No passwords or keys need to be entered
- For a small number of selections m (e.g. in a referendum), vote casting can be done in a very short amount of time

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Achievements

- Approach inspired by Chaum's original code voting scheme
- BLS signatures and mixnets help to weaken trust assumptions
- Popularity of QR codes helps to offer good usability
- Proof-of-concept implementation done by student (2023) ¶

Open problems

- Usability in complex elections
- Security proofs


Question?