Panoramix

Addressing the Challenges of e-Voting Through Crypto Design

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University of Edinburgh

29 November 2017

Scotland's Democratic Future: Exploring Electronic Voting

Scottish Government and University of Edinburgh

School of Informatics Workshop

When do we actually setup an electronic voting procedure?

- What is the extent of “digitilisation” of a traditional election protocol that qualifies as e-voting?

When do we actually setup an electronic voting procedure?

E-voting means the use of electronic means in one of the following three processes:

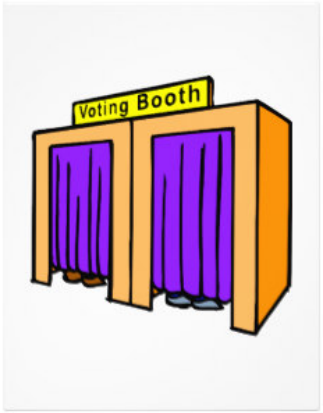
- Identification of voters
- Casting the vote
- Counting the vote

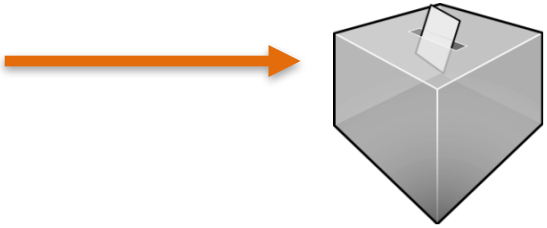
Source: https://www.e-voting.cc/en/it-elections/definitions/

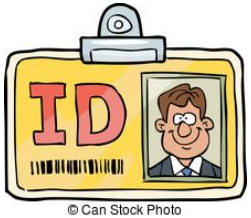
When do we actually setup an electronic voting procedure?

- What is the extent of “digitilisation” of a traditional election protocol that qualifies as e-voting?
  - Registration
  - Voting
  - Counting
  - Auditing

Replacing the human protocol with electronic procedures







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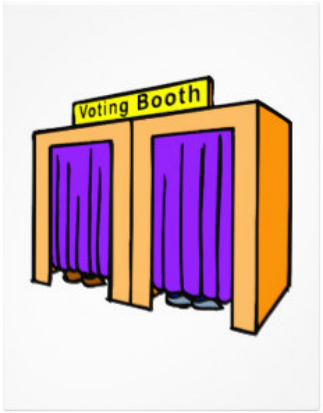
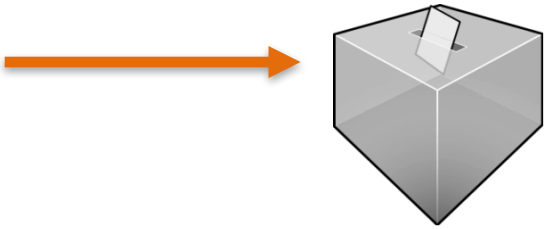
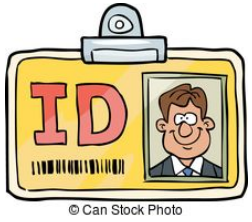
Replacing the human protocol with electronic procedures







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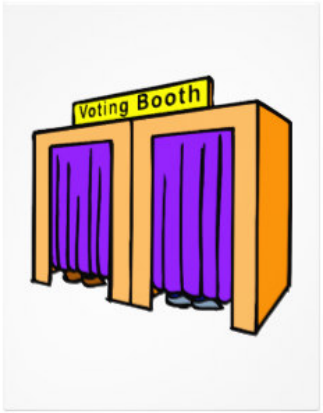

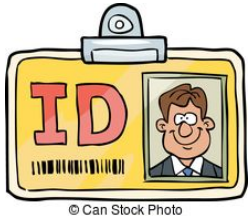

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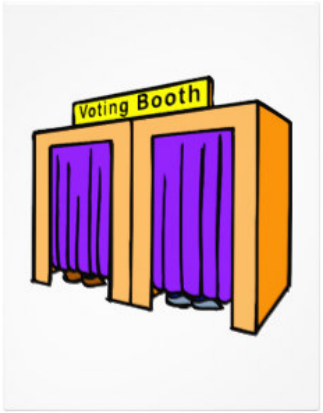

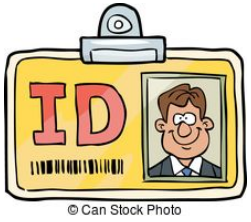

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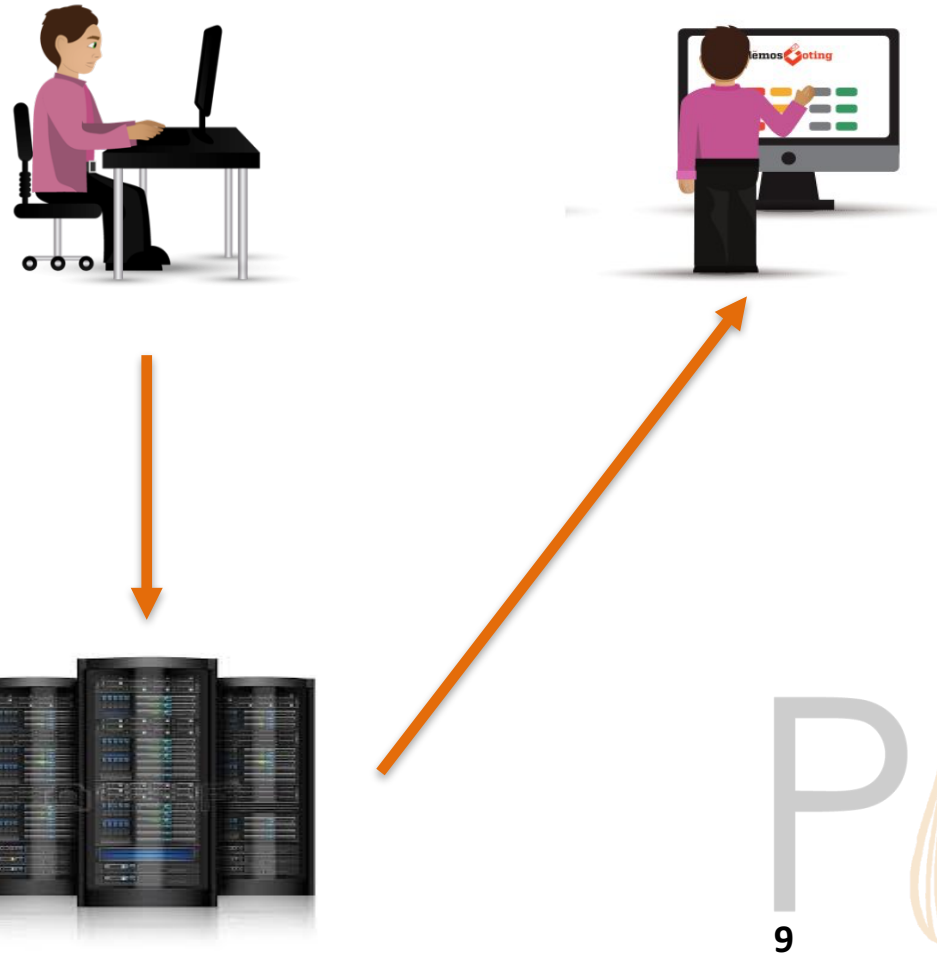


The benefits of e-voting

- Increase the participation of social groups that face considerable physical barriers.
- Increase the efficiency of the preparation of the election and the calculation of the final results.
- Reduce the financial cost of the elections (in long term).

The risks of e-voting

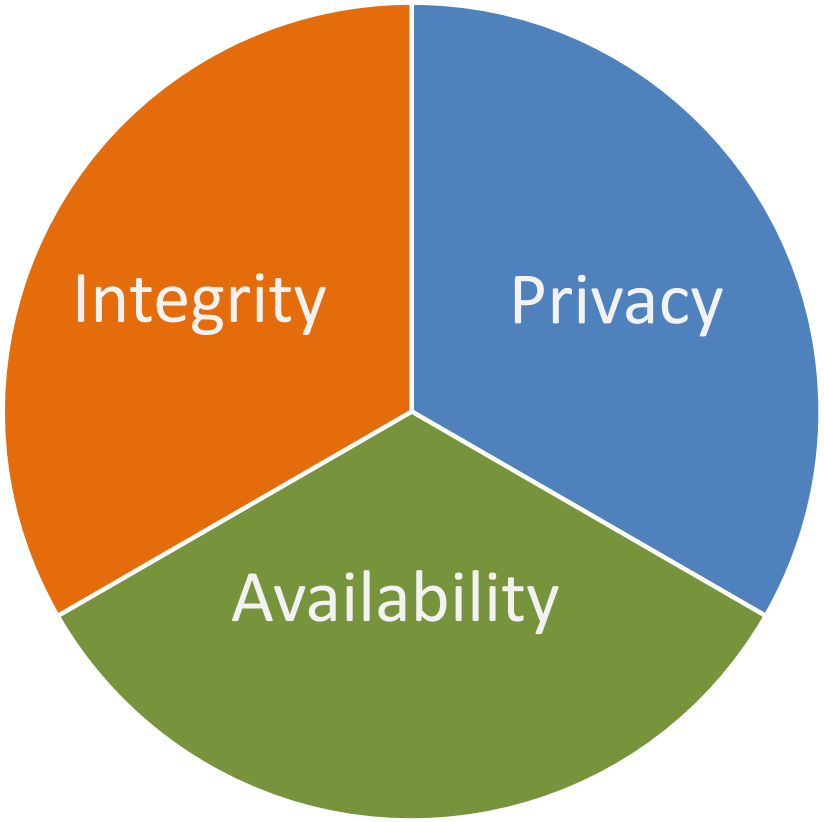
- Unauthorised intervention of third parties may cause denial of service.
- Large-scale manipulation by a small group of insiders.
- Lack of widely agreed standards for the election procedure (infrastructure, software).

The challenges of e-voting

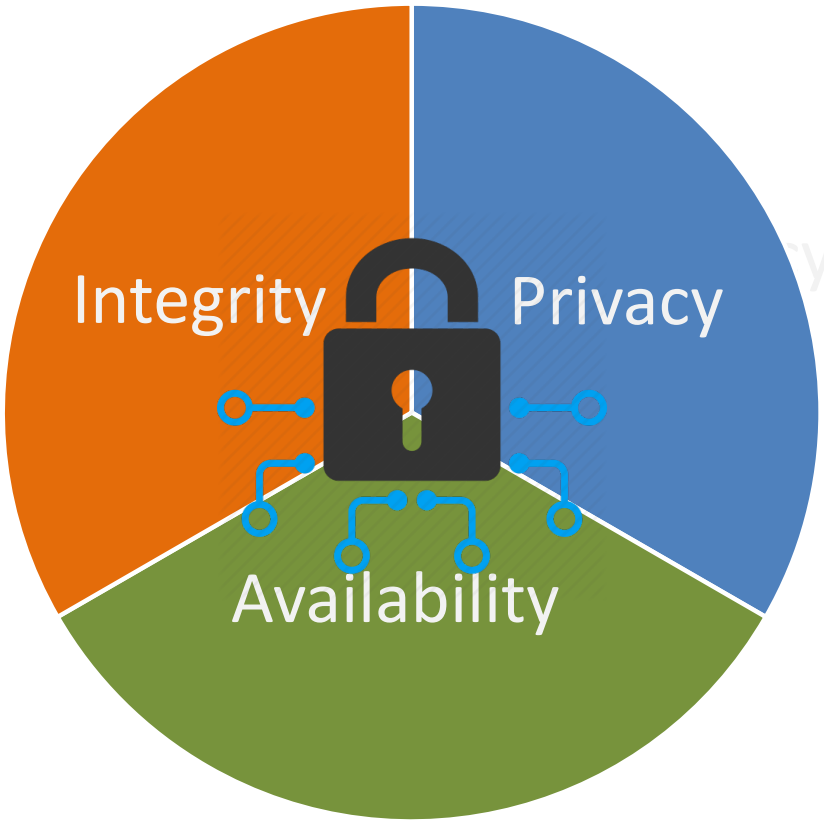
- At any point of replacing the traditional protocol with electronic means, extreme care in the algorithmic design, implementation, and execution oversight is required.

The challenges of e-voting

- Preserve the fundamental requirements of a voting system.



Addressing e-voting challenges via cryptographic tools



Modern cryptographic design

1. Understanding and formal definition of the studied notion.
2. Rigorous specification of the threat model.
3. Realisation via a well-described construction.
4. Mathematical proof of the construction's security under the defined threat model.

Modern cryptography in the real-world

- Secure internet communication (HTTPS over TLS/SSL, end-to-end encryption).
- Authentication (Digital signatures, password management).
- Privacy preservation (aggregate statistics, anonymous web browsing).
- Blockchain technologies (Bitcoin, Ethereum, smart contracts).

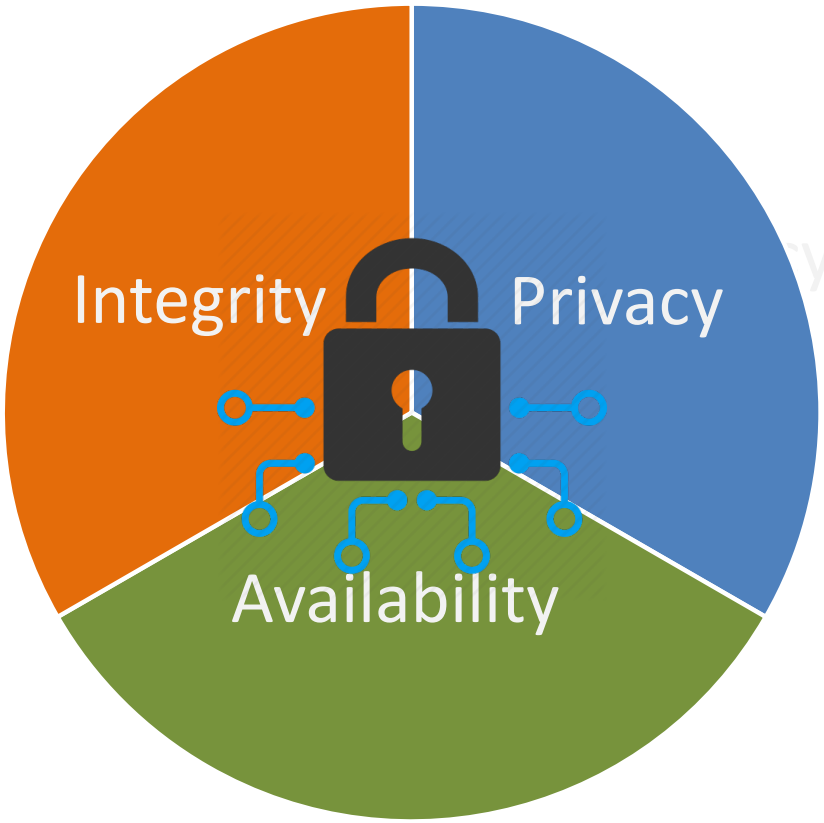
Modern cryptography in the real-world

- Secure web browsing.
- E-banking.
- E-mail.
- Privacy-preserving profile management.
- Secure messaging.
- Decentralised publicly verifiable transactions.

The necessity of cryptography for realising secure e-voting

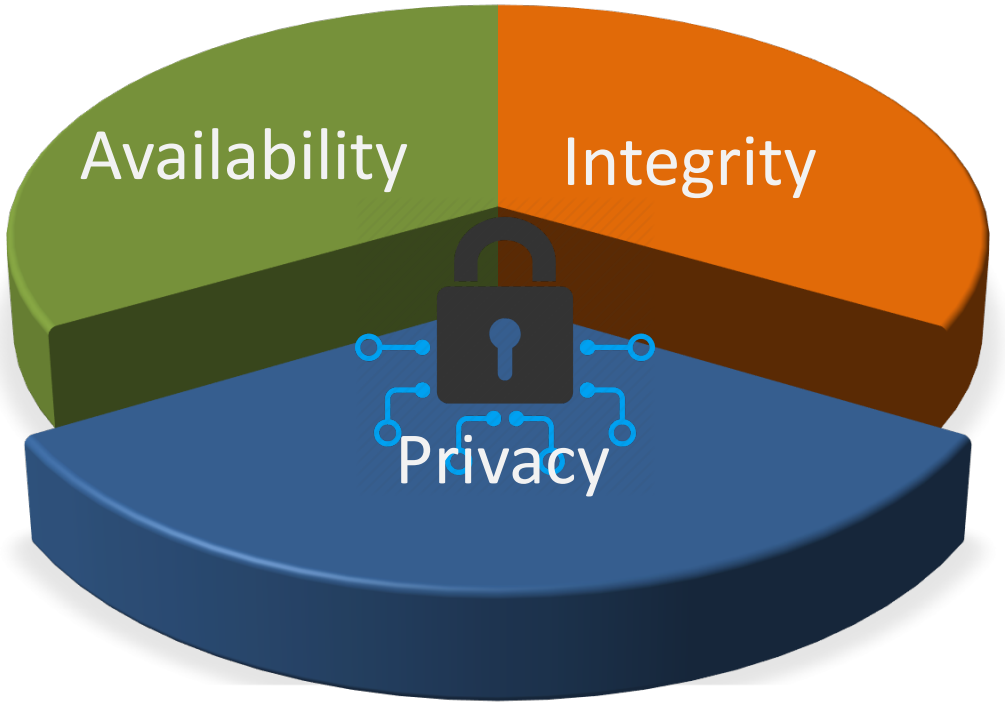
- Collecting, storing and/or communicating sensitive election data overtly, can easily jeopardise election security.
- Offline (on site): a vote collection device that keeps logs of unencrypted ballot casting can not protect voters' privacy when the logs are audited.
- Online: whenever two devices should interact, secure and authenticated communication must be applied to protect the exchanged data.

Addressing e-voting challenges via cryptographic tools



Addressing e-voting challenges via cryptographic tools:

Privacy

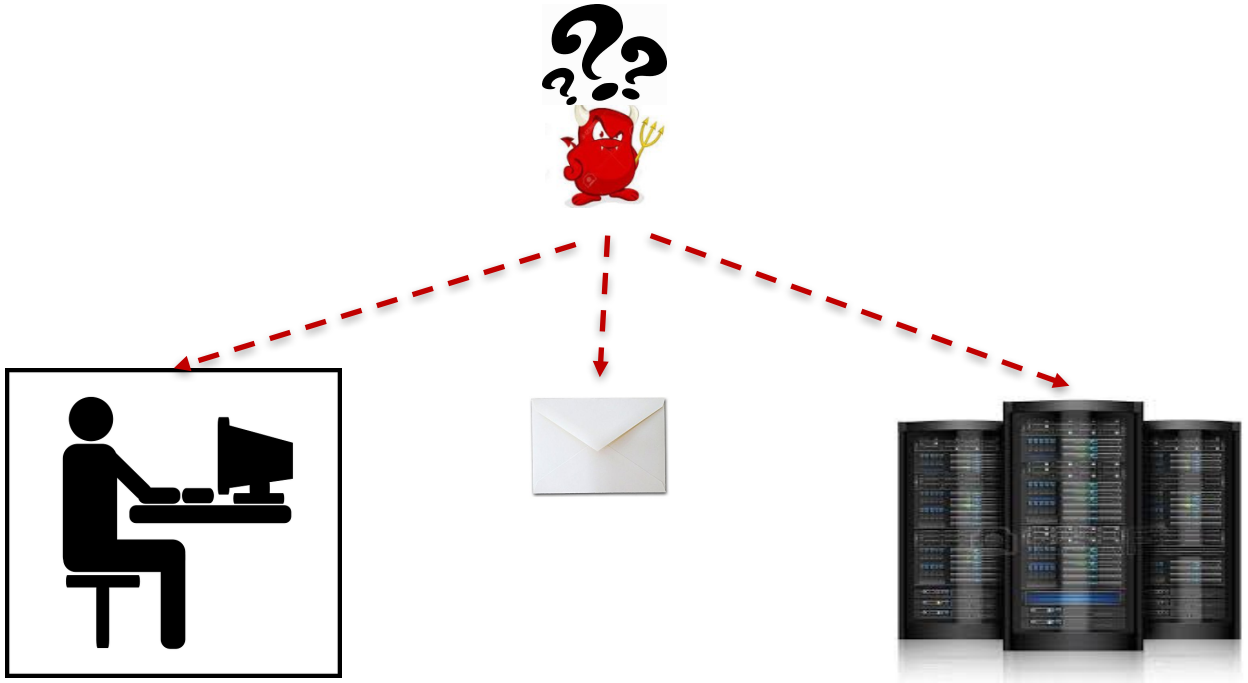


Ballot secrecy

- Encryption realises the concept of a “digital envelope”.
  - The voter’s selection is cryptographically “sealed”.
  - An attacker can not obtain information about the encryption’s content (vote selection).

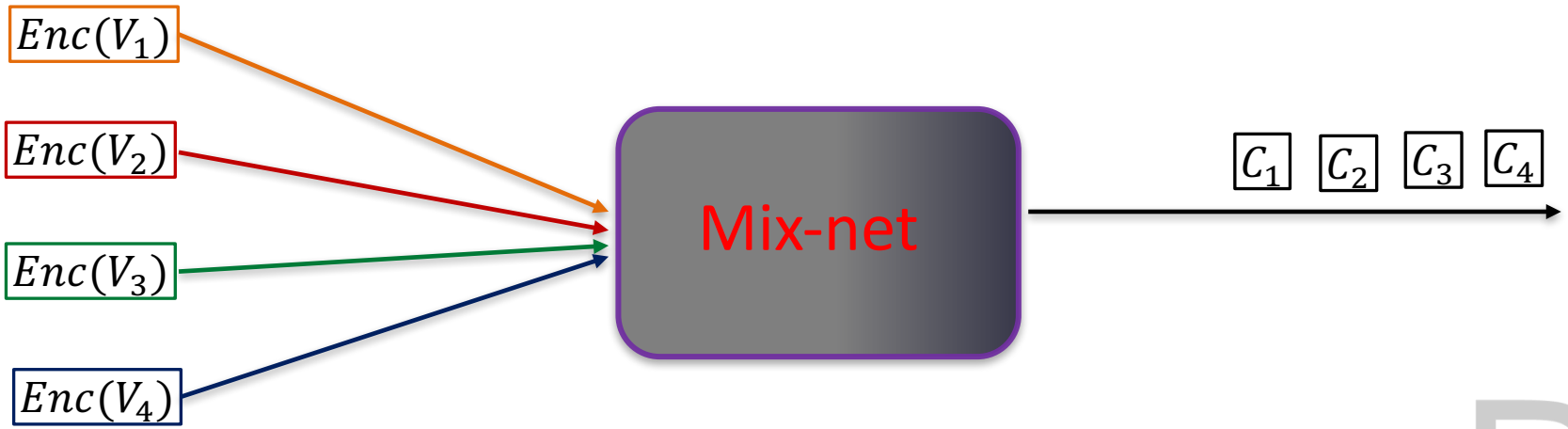
Voter-vote Unlinkability

- At some point of the election process, the votes must be anonymised, to prevent coercion and vote-selling.



Voter-vote Unlinkability

- Mix-nets: a powerful cryptographic primitive realising vote shuffling in a digital ballot box.



$$\{C_1, C_2, C_3, C_4\} = \{Enc(V_1), Enc(V_2), Enc(V_3), Enc(V_4)\}$$

Voter-vote Unlinkability

- Additive homomorphic tally: a mathematical property of special encryption schemes (E.g. ElGamal, Paillier) that allow for the counting of votes in encrypted manner.

$$Enc(X) \cdot Enc(Y) = Enc(X + Y)$$

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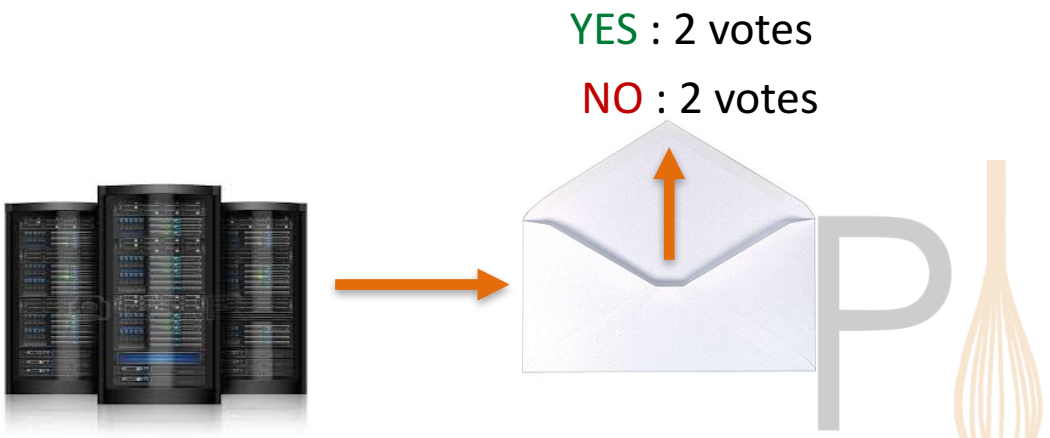
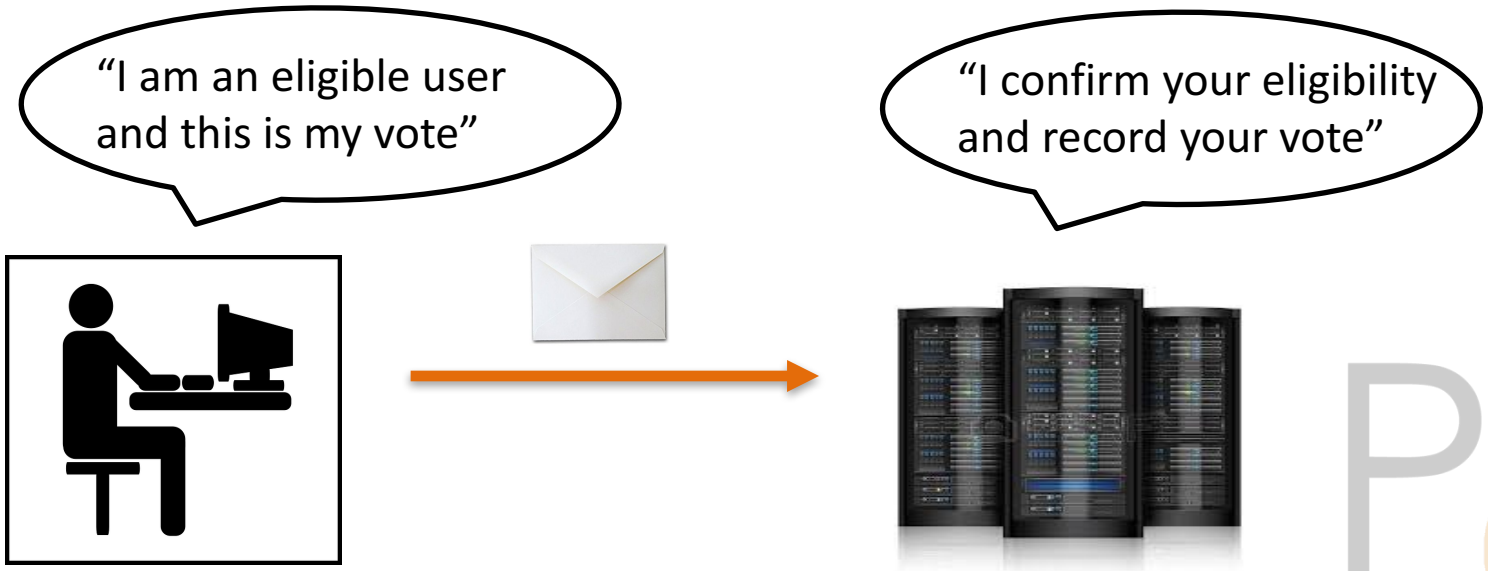


Voter-vote Unlinkability

- Anonymous authentication: the voter proves her eligibility via a one-show anonymous credential (e.g. blind signature of the voter's ballot).

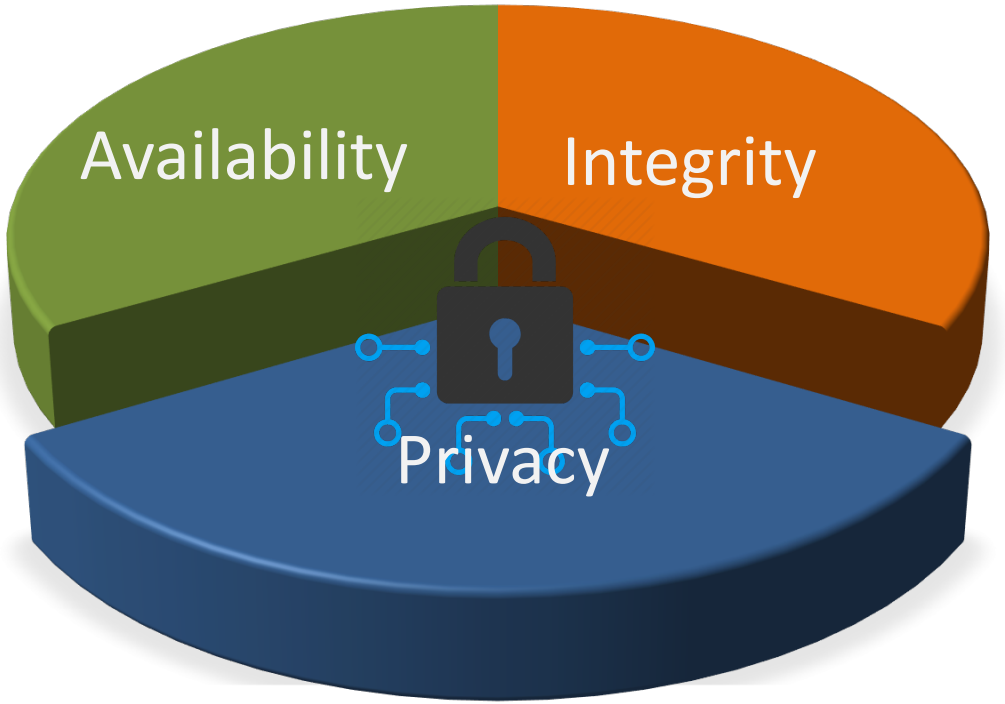


Coercion resistance

- Concerns about coercion in other types of remote voting (e.g. postal voting) also apply to internet voting.
- In cases where postal voting is allowed, internet voting could be used, supporting multiple voting as a coercion countermeasure (Estonian e-voting).

Addressing e-voting challenges via cryptographic tools:

Privacy



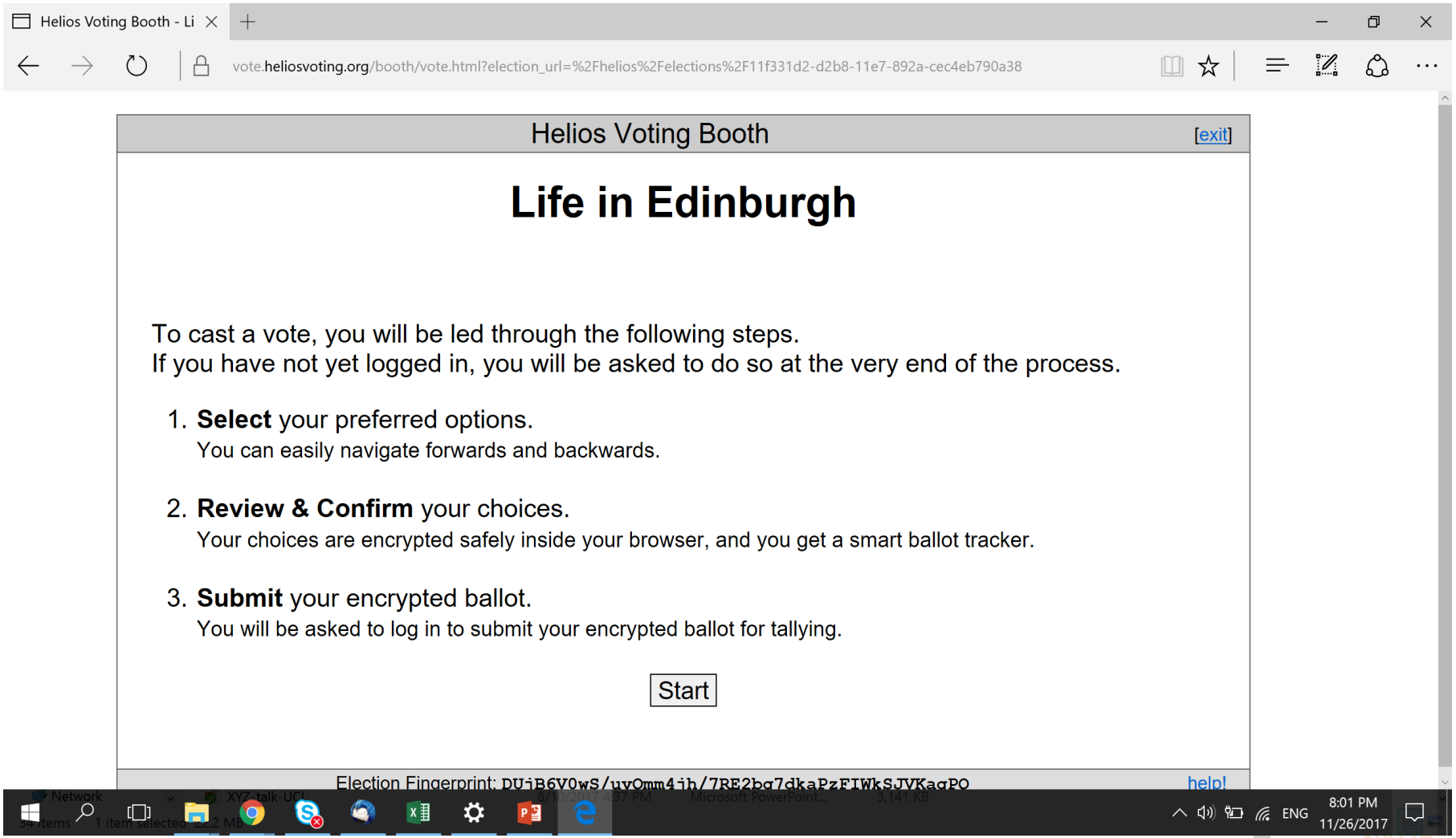
Addressing e-voting challenges via cryptographic tools:

Availability

Usability: making e-voting feasible for every citizen

- When ballot encoding is applied during vote casting, the voter interacts via a user-friendly interface in a designated voting device, or their browser.
- Basic familiarity with a standard operating system (e.g., Windows, iOS, Android) or web browser (e.g., Edge/Explorer, Safari, Chrome, Firefox) is the only required background.

Usability: making e-voting feasible for every citizen



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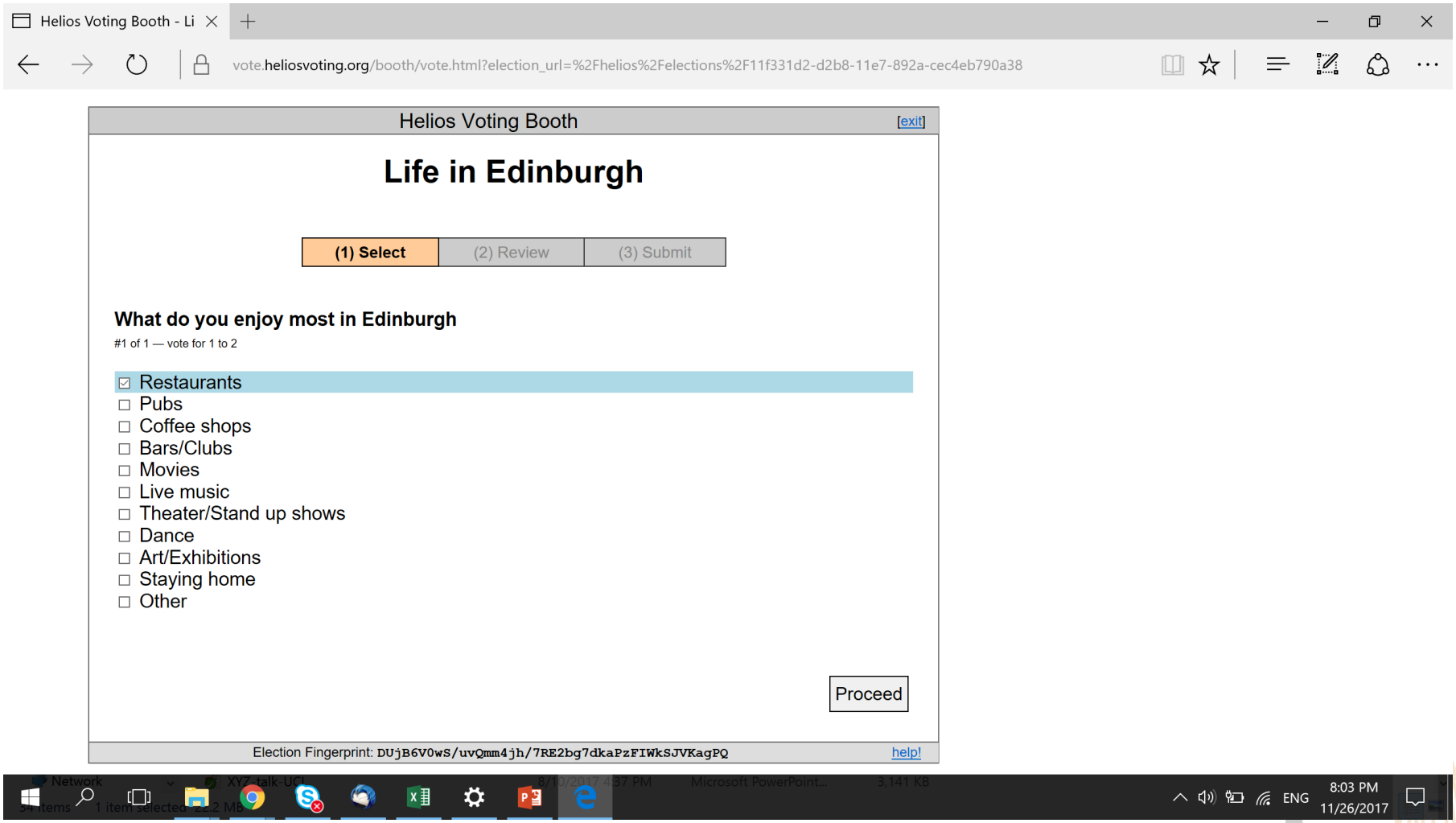

Usability: making e-voting feasible for every citizen

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- When code-voting is applied, the voter obtains a ballot with a pre-encoding of the election options (vote-code).

Usability: making e-voting feasible for every citizen

What is your stance on the potential of adopting e-voting for national elections?

Serial number: **100**	
1	VERY POSITIVE
4	POSITIVE
5	NEUTRAL
2	NEGATIVE
3	VERY NEGATIVE

Usability: making e-voting feasible for every citizen

- When code-voting is applied, the voter obtains a ballot with a list of random cryptographic pre-encoding of the election options (vote-code).
- The voter simply submits the vote-code that correspond to her option selection, which can be done in lightwight electronic devices.

Usability: making e-voting feasible for every citizen

Serial number: **100**
Vote-code: **5**

Serial number: **100**	
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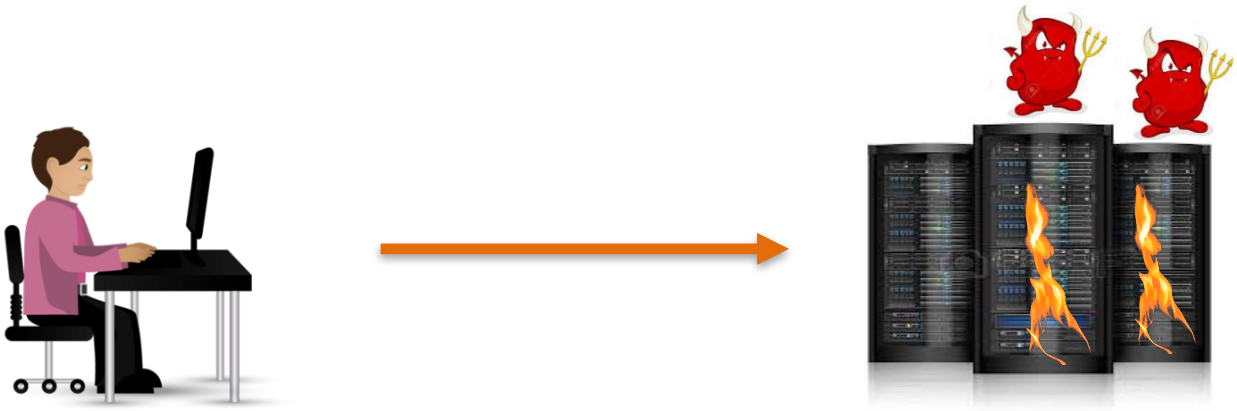
Usability: making e-voting feasible for every citizen

- When code-voting is applied, the voter obtains a ballot with a list of random cryptographic pre-encoding of the election options (vote-code).
- The voter simply submits the vote-code that correspond to her option selection, which can be done in any electronic device with internet access.
- In case the voting device is trusted for privacy, vote casting can run via a user-friendly interface.

Fault tolerance: protecting the election's liveness

- Threshold cryptography in combination with a distributed system architecture allows for a secure and uninterrupted election access and execution, even when a substantial amount of election servers is not available.

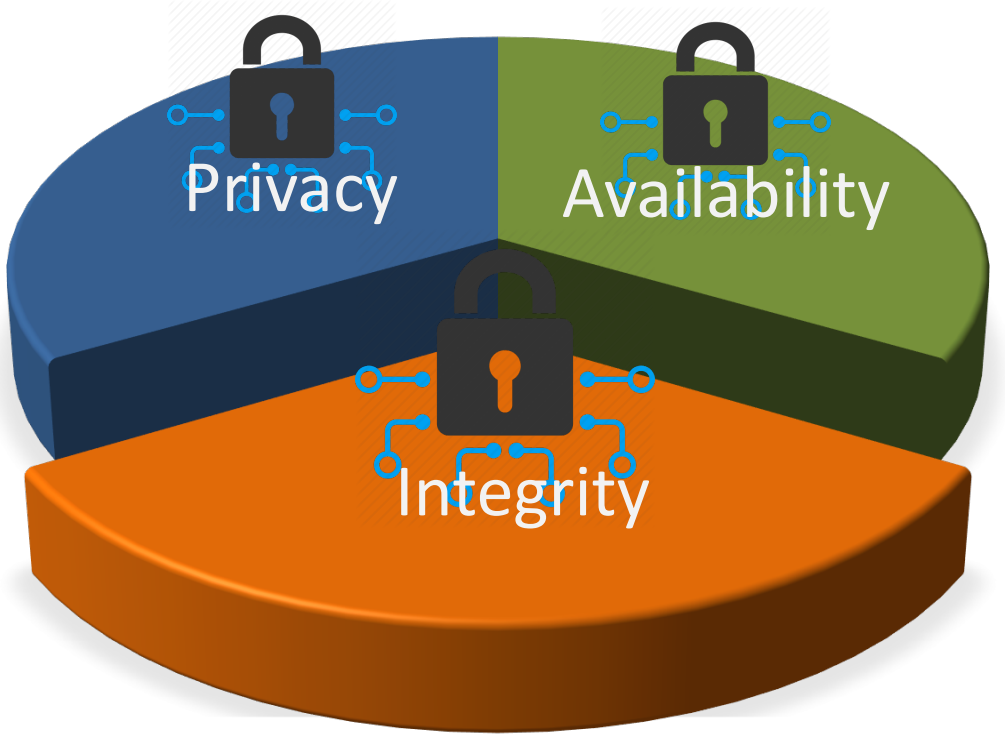


Addressing e-voting challenges via cryptographic tools:

Availability

Addressing e-voting challenges via cryptographic tools:

Integrity



Eligibility

- The authentication/registration authority is equipped with the algorithm that specifies the set of eligible voters.
  - Digital signatures: each voter has an ID-card with an embedded signing key (Estonia).
  - Password-based: the authentication server(s) maintains a cryptographic hash table with all the passwords that correspond to eligible voters.

End-to-end verifiability

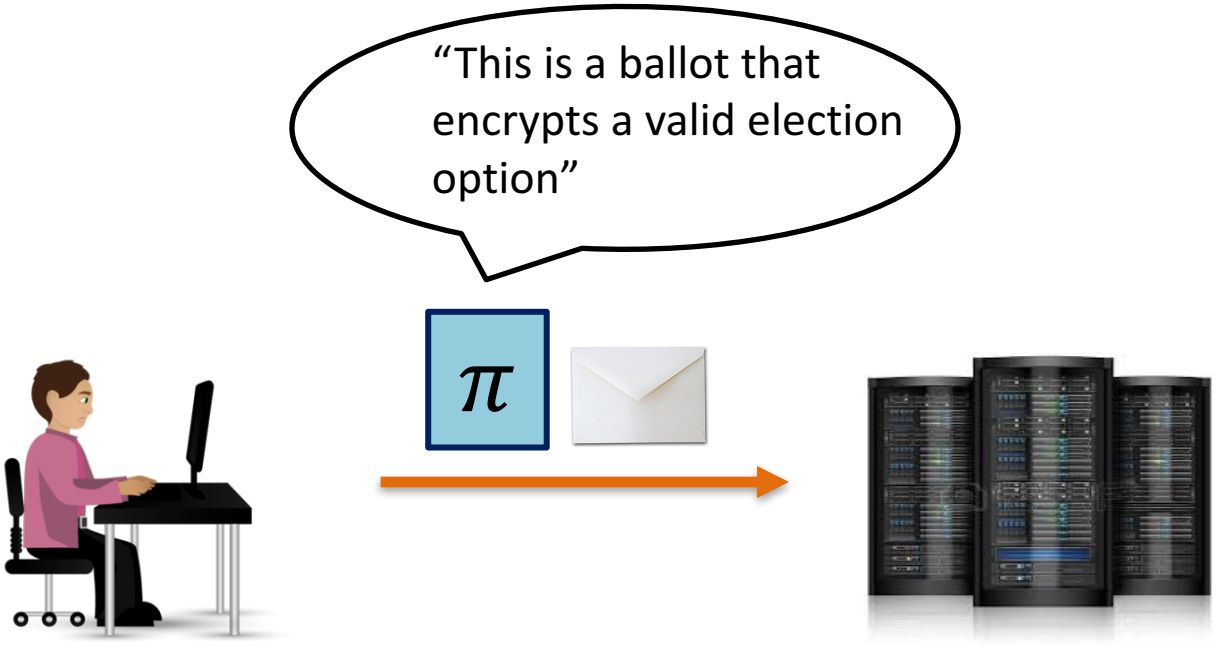
- **Universal level:** Any party can verify the correctness of the election transcript.

End-to-end verifiability

- **Individual level:** The voters obtain some audit data in order to verify themselves that their votes were:
  - **Cast-as-intended**
  - **Recorded-as-cast**
  - **Tallied-as-recorded**

Universal Verifiability

- Every step of the election procedure is associated with a cryptographic proof of its execution.



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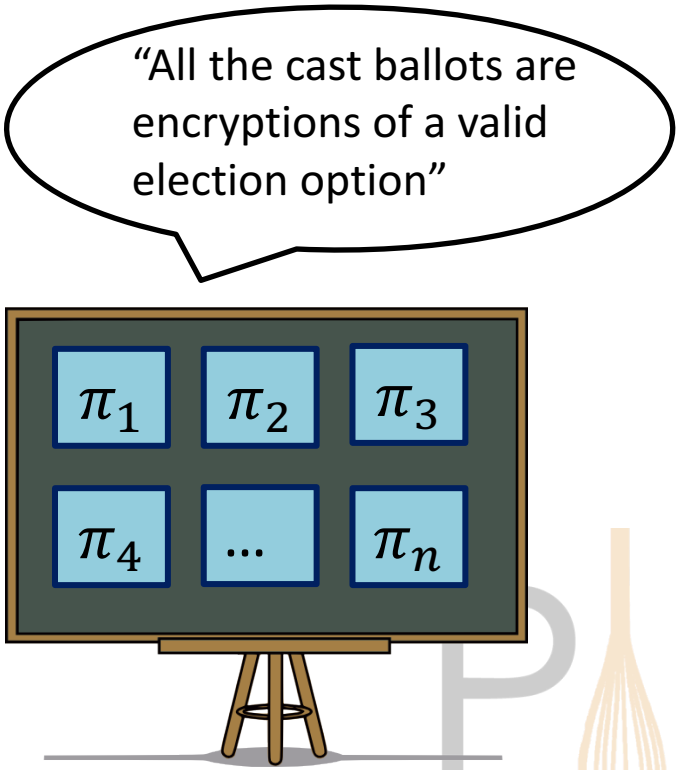

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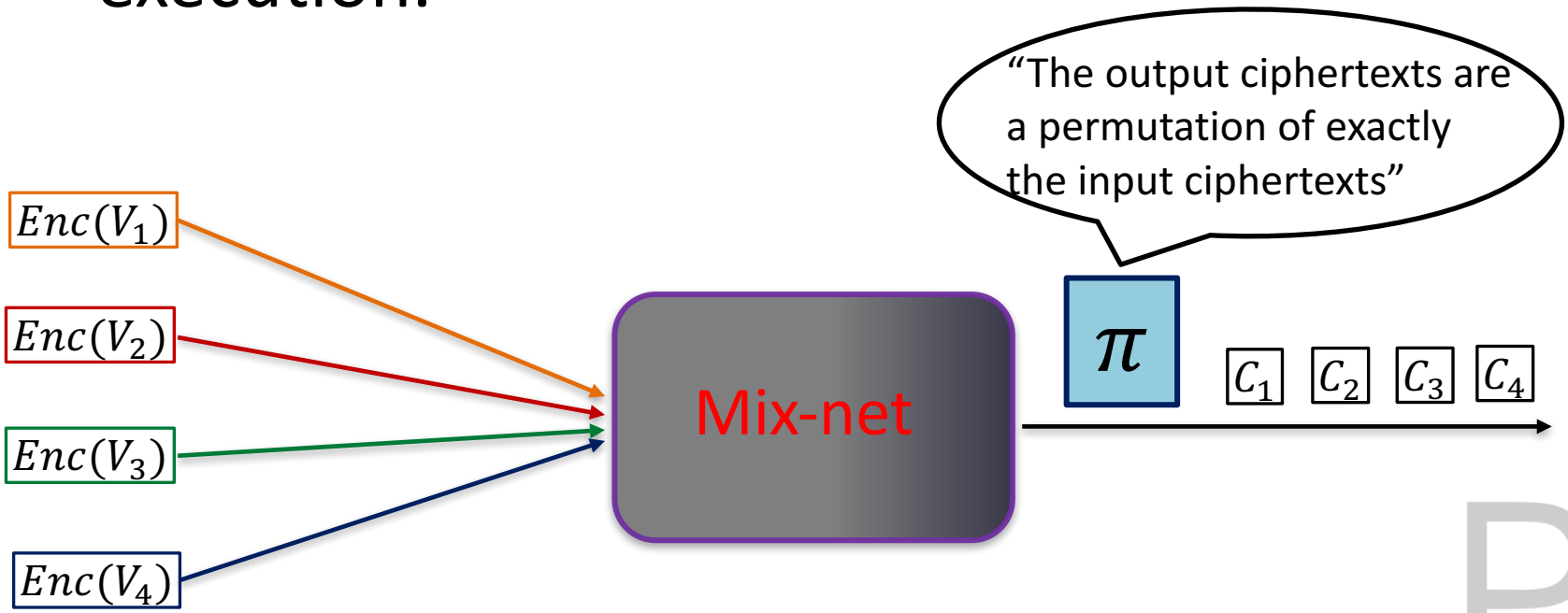

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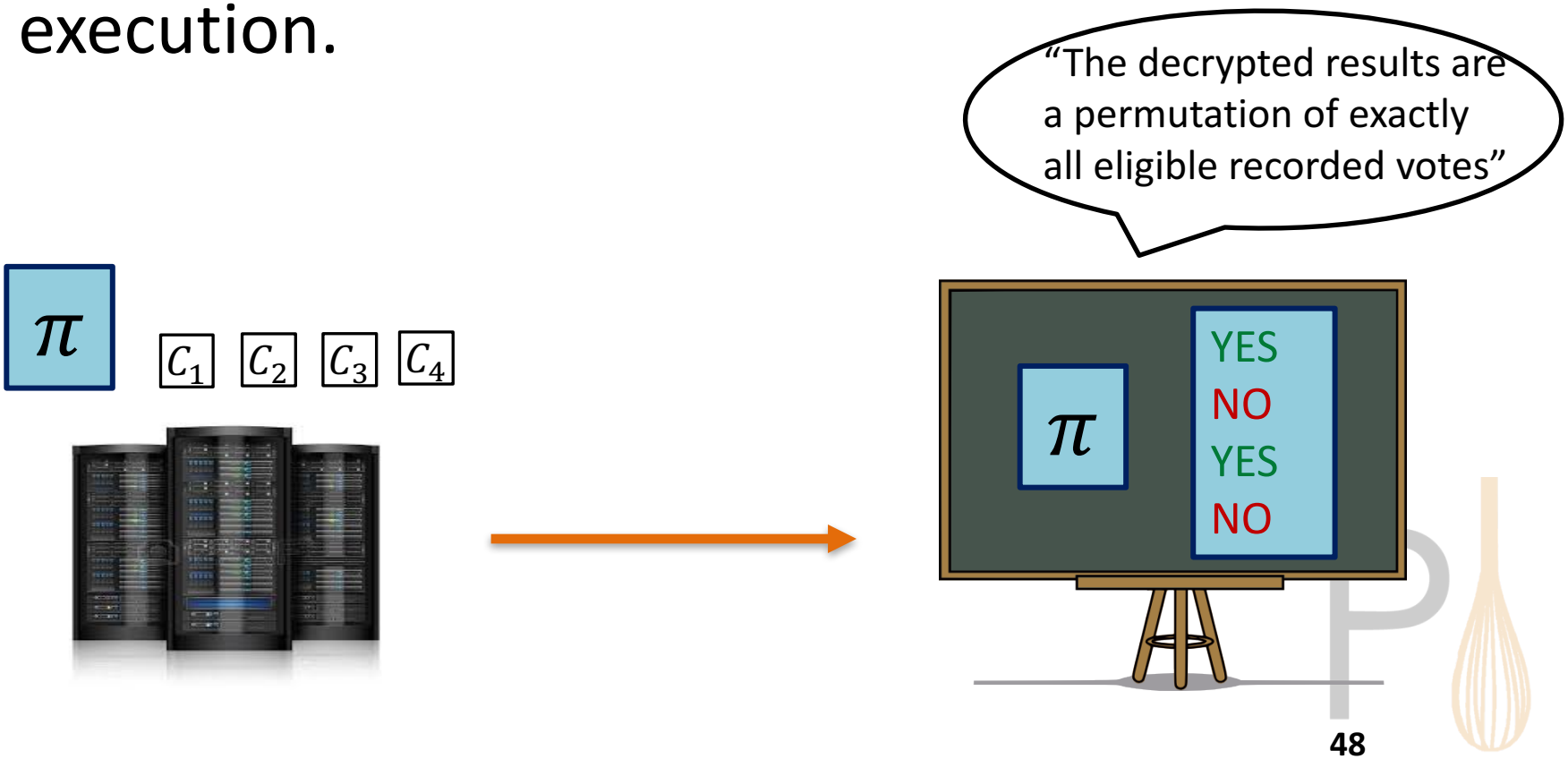


Universal Verifiability

- Each proof satisfies soundness (invalid statements will not be accepted) and prevents any malicious party from leaking information about the associated sensitive data (zero-knowledge proofs).
- The sequence of cryptographic proofs constitutes a verifiable election transcript that is posted in a publicly accessible web site (bulletin board) for auditing while preserving election privacy.

Individual Verifiability

- State-of-the-art e-voting systems support elaborate verification mechanism that allow the voter to challenge the correct encoding of their vote.
  1. Ballot encryption: audit the validity of the voting device by randomly checking the local cryptographic operations.
  2. Code-voting: audit the honest of the ballot preparation authorities by randomly checking the consistency of the encoding of the election options.

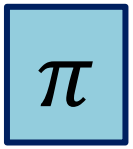
Accountability

- The e-voting system should provide a mechanism provides undeniable evidence of which entity is responsible for an incorrect execution.

Accountability example: authenticated communication

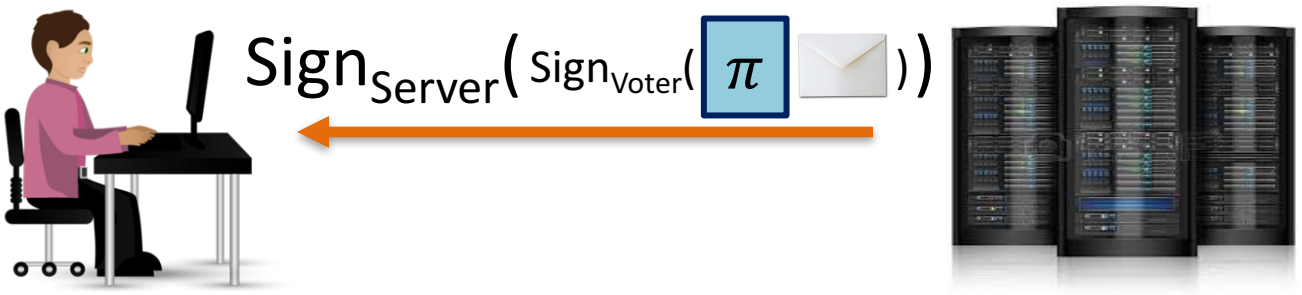
Accountability example: authenticated communication

- The voter signs her ballot.

$\text{Sign}_{\text{Voter}}($  $)$

Accountability example: authenticated communication

- The voter signs her ballot.
- The vote collection server replies with a signature on the received data.



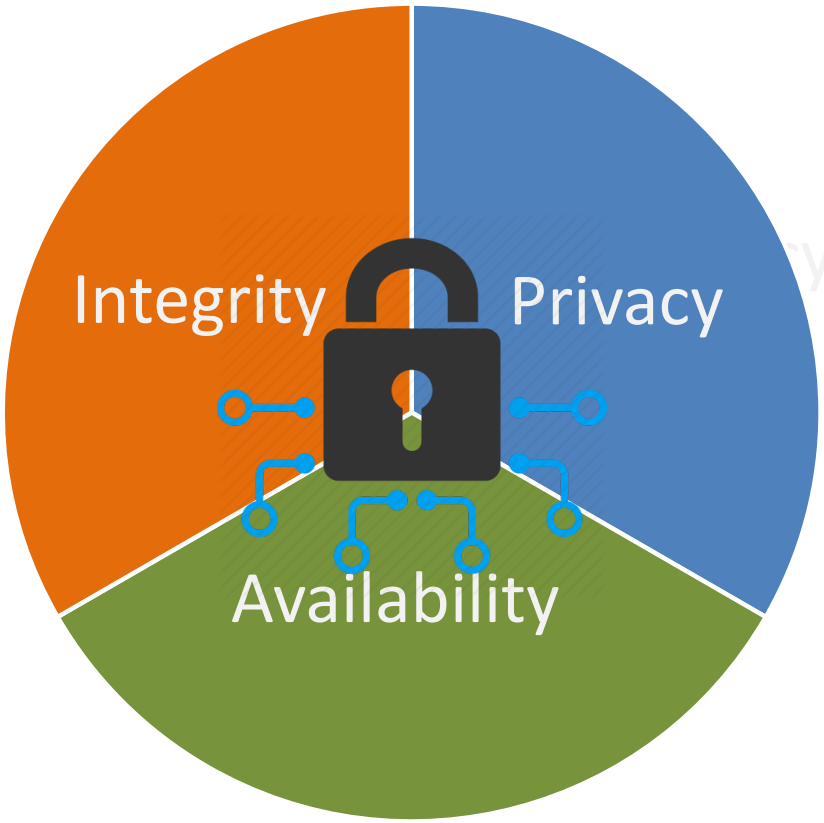
Accountability example: authenticated communication

- The voter signs her ballot.
- The vote collection server replies with a signature on the received data.
- If an authority is realized by a distributed subsystem, then malicious nodes can be blacklisted.

Accountability example: posting on the bulleting board

- The authorities commit to the validity of their data.
  - The election public key is posted prior to the voting period.
  - The ballot preparation authorities provide cryptographic proofs of proper encoding of the election options (Code-voting) .
  - The tallying authorities post cryptographic proofs of correct decryption and election tally.

Addressing e-voting challenges via cryptographic tools



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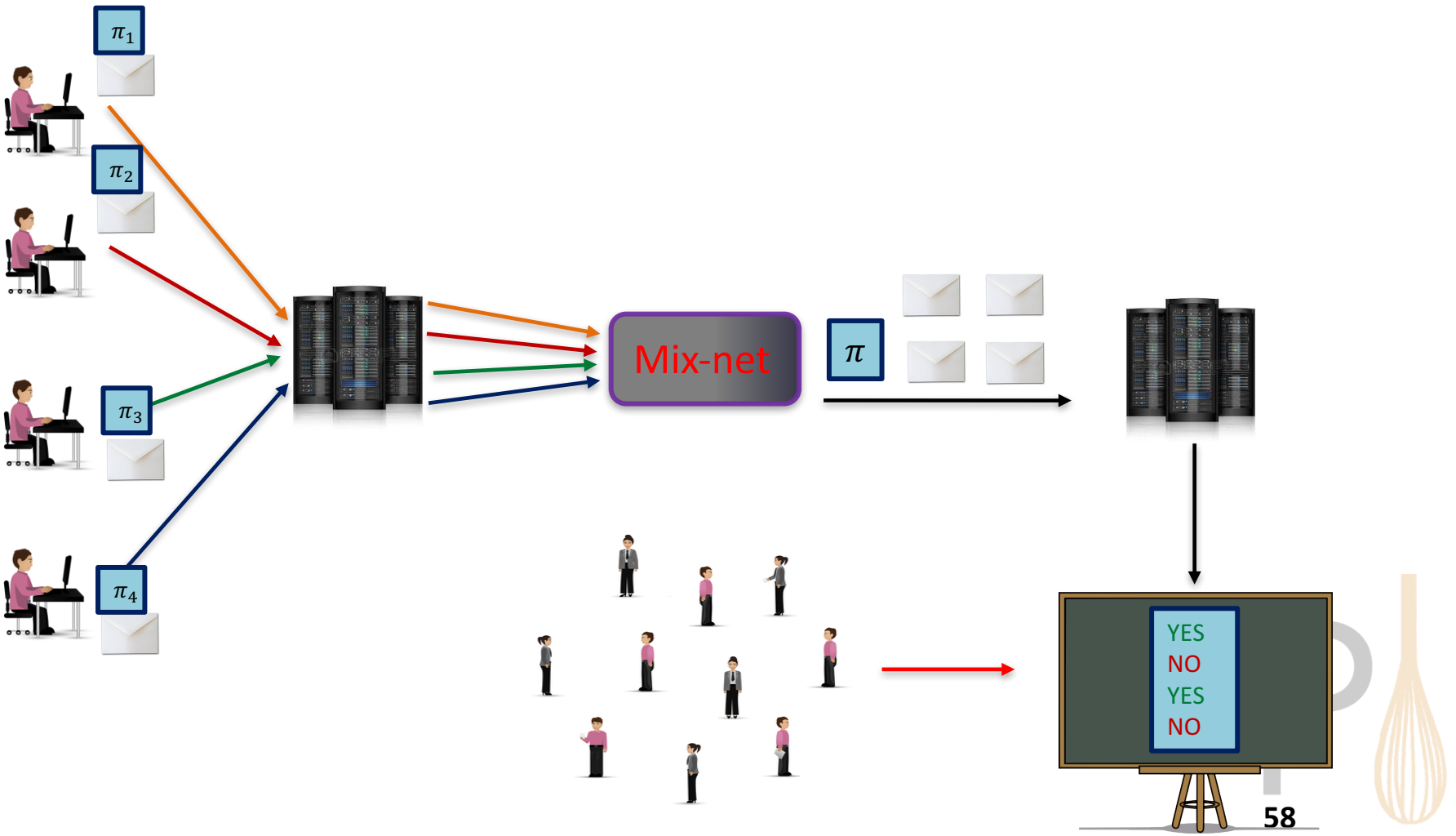

Is crypto enough to guarantee secure e-voting?

The importance of the human factor

- Cryptographic tools provide a solid background, but do not suffice.
- Active participation of the stakeholders is crucial.
  - Verification mechanisms are meaningless if not even a small ratio of voters are willing to verify (or outsource verification to a trusted party).
  - The trustees should audit the correct publishing of the election public key to protect voters' privacy.
- A formally analysed human protocol and e-voting cryptographic design should be side-by-side.

Thank you!!!

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