Themis: An On-Site Voting System with Systematic Cast-as-intended Verification an Partial Accountability

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On-site e-voting

Main goal: enhance the trust compared to pure paper-based voting

Security targets:

- **Vote secrecy:** no-one can know who I voted for
- **Verifiability:** no-one can modify the result of the election

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New requirements in IDEMIA's use context

- limited access to the technology (the Internet, printers, etc)
- require a high level of robustness
- must cope with strained contexts (risks of corruptions, false accusations, etc)

Themis

Limited access to technology

- use pre-printed paper ballots ➡ do not need printers
- use smart cards and voting machines ➡ given by the service provider
- use a hash-chain to ensure the integrity of the electronic ballot-box ➡ can be monitored offline a posteriori

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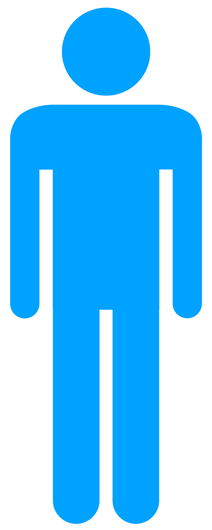
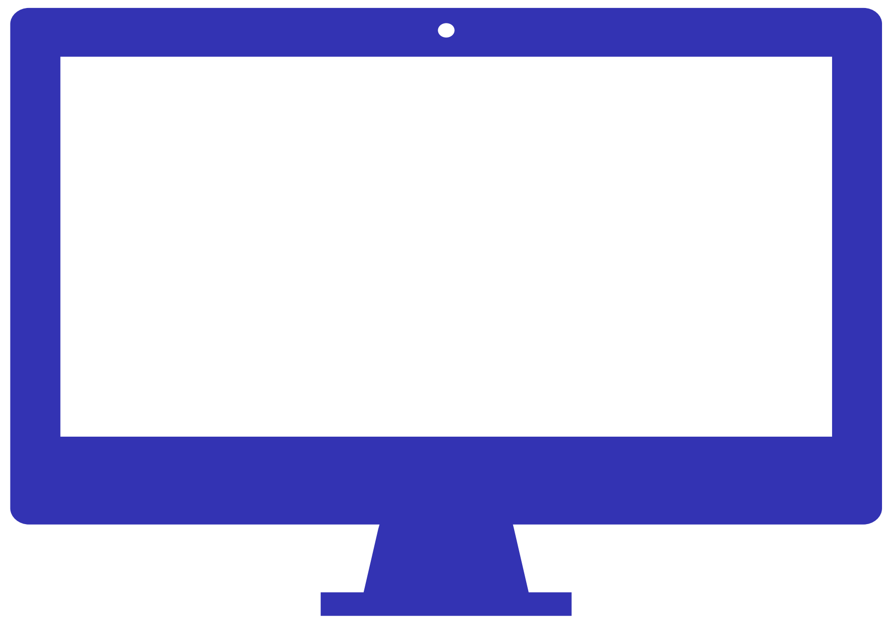
Strained contexts

- implement a dispute resolution procedure to decide who is the culprit
  ➡ proven to never wrongly blame someone
- require the corruption of several authorities to defeat vote secrecy of verifiability
  ➡ proven in symbolic models

Overview of the system



Entry



Global election screen

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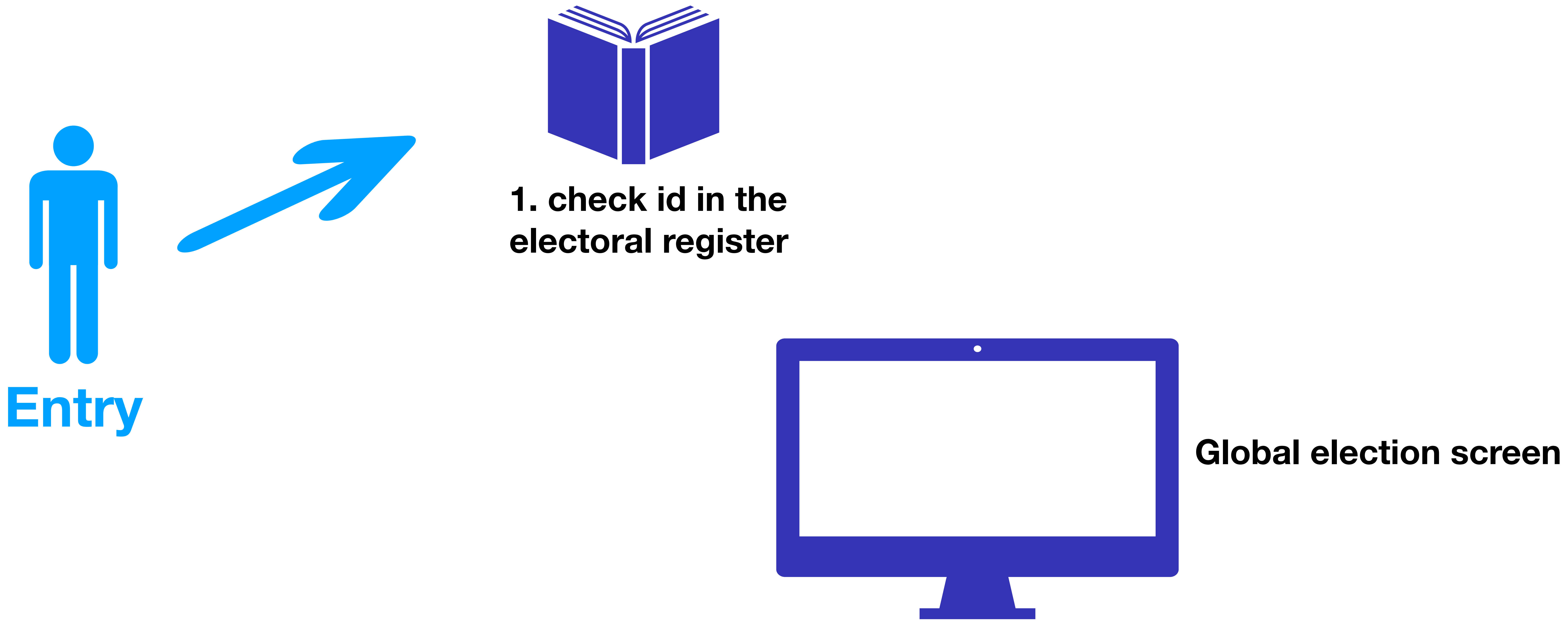

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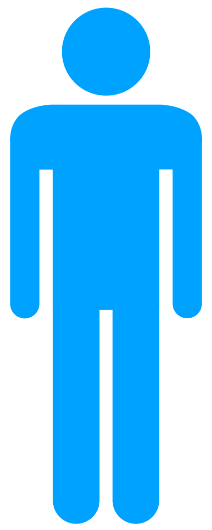

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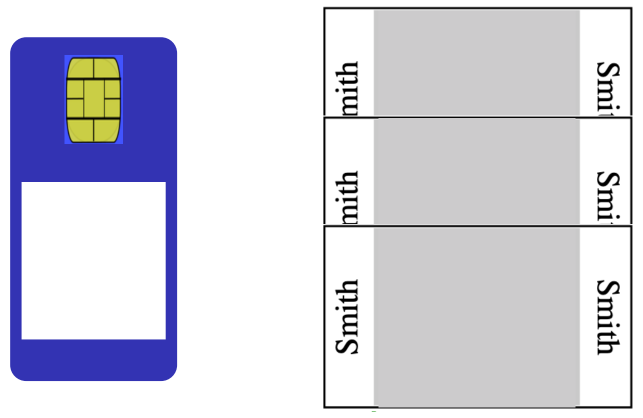
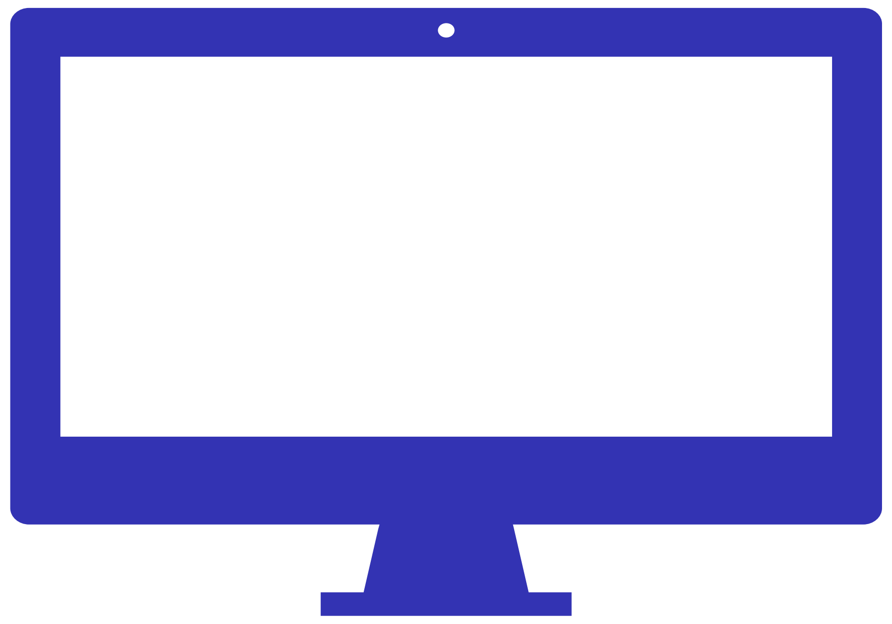
1. check id in the electoral register



2. take a smart card and 1 ballot per candidate



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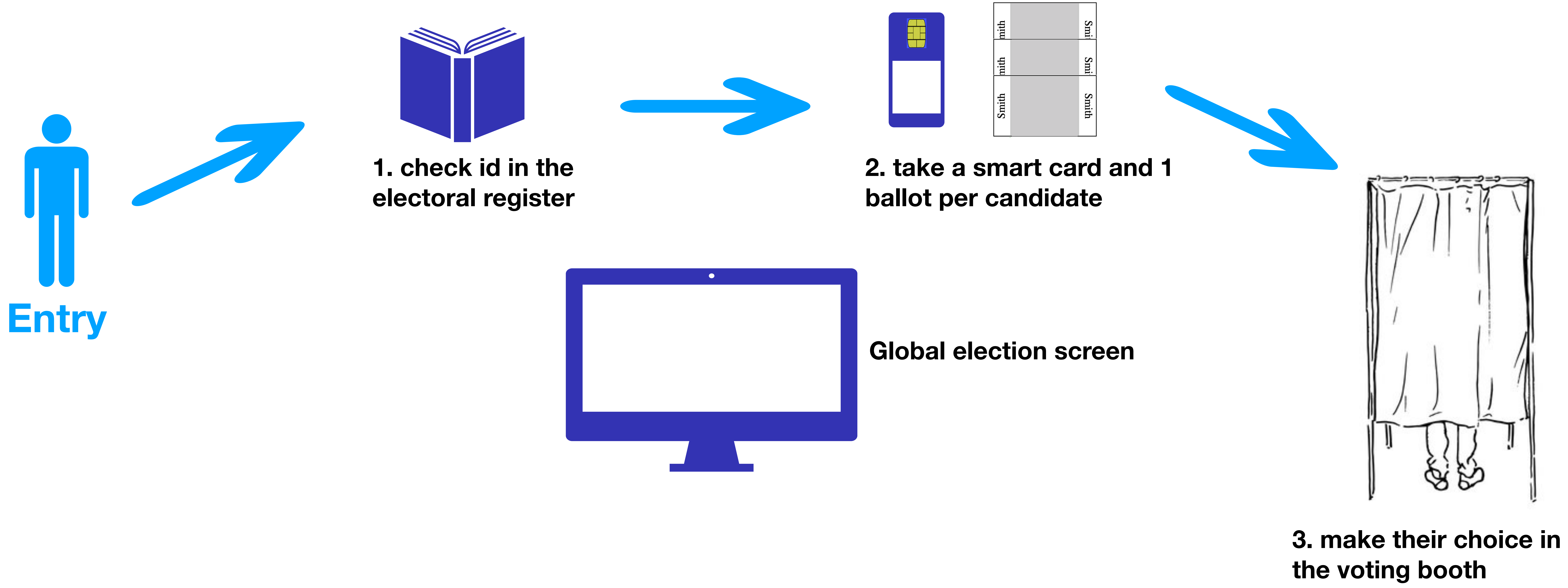

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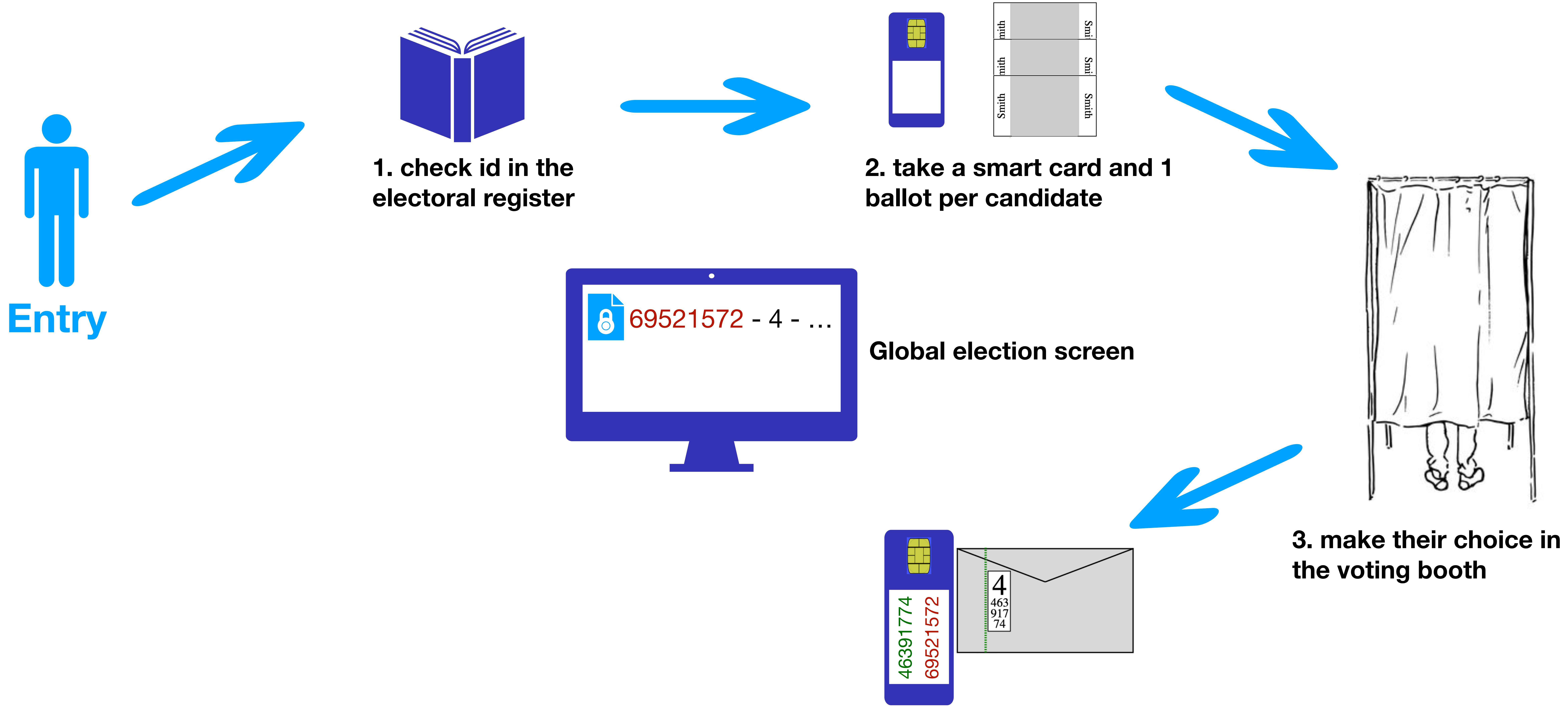

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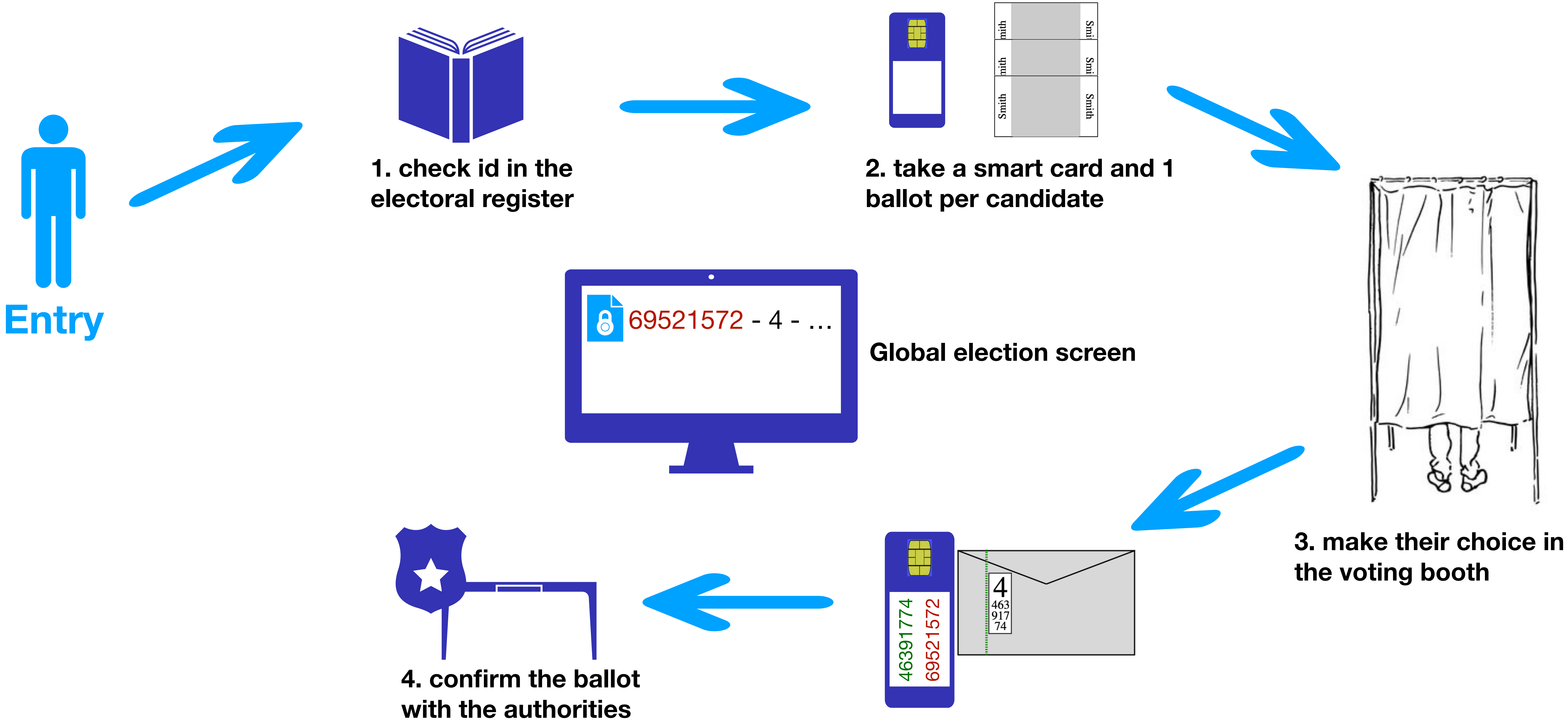

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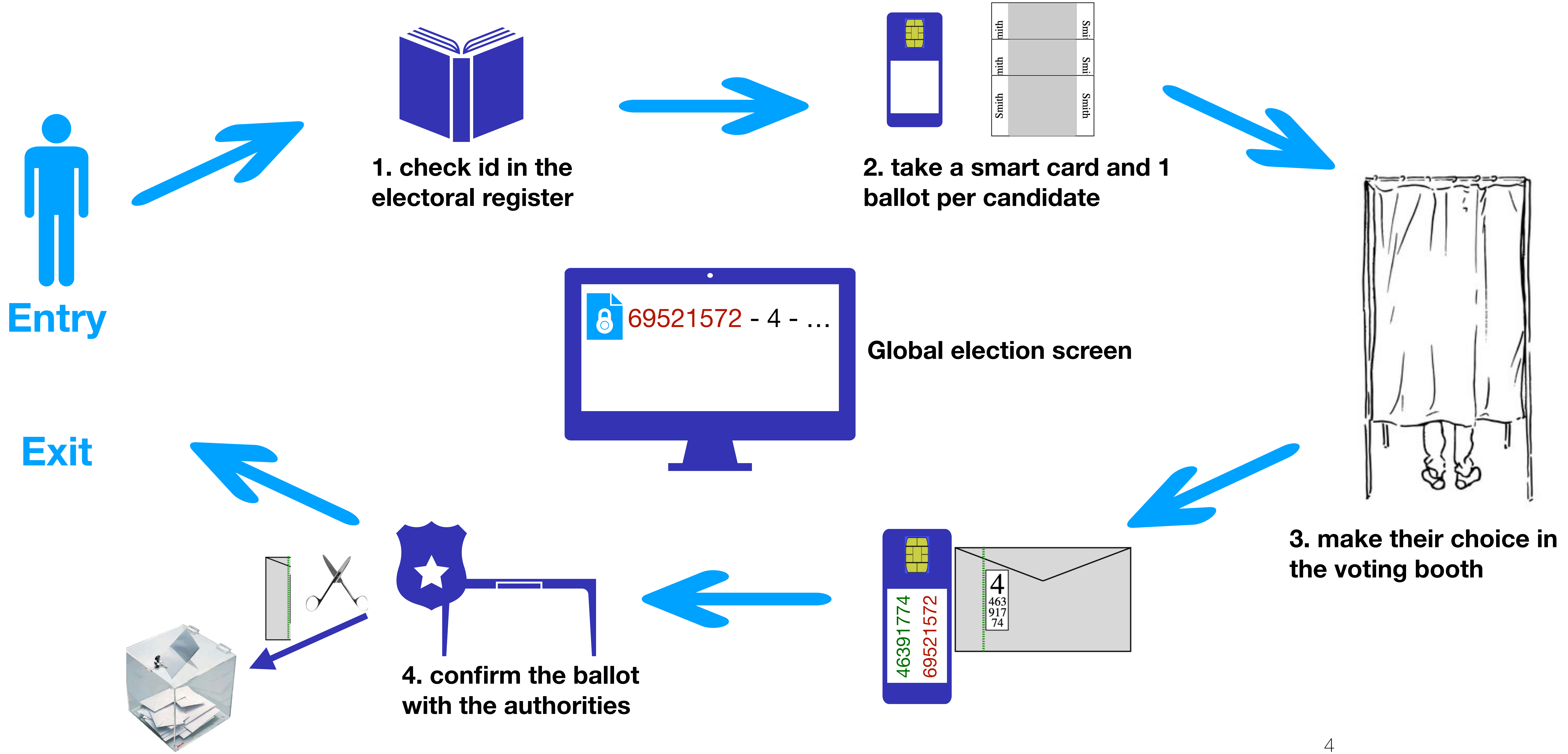
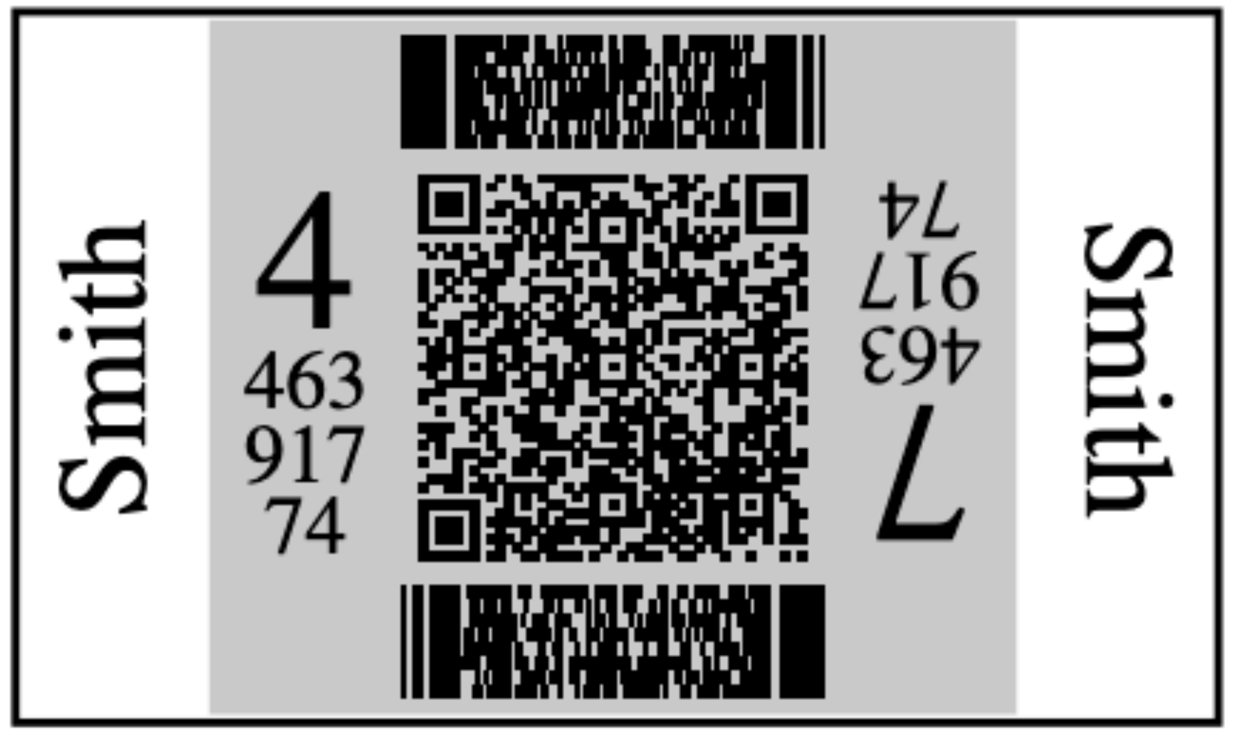


Well-crafted ballots for cast-as-intended

Cast-as-intended: a corrupted device cannot modify the intended choice of a voter



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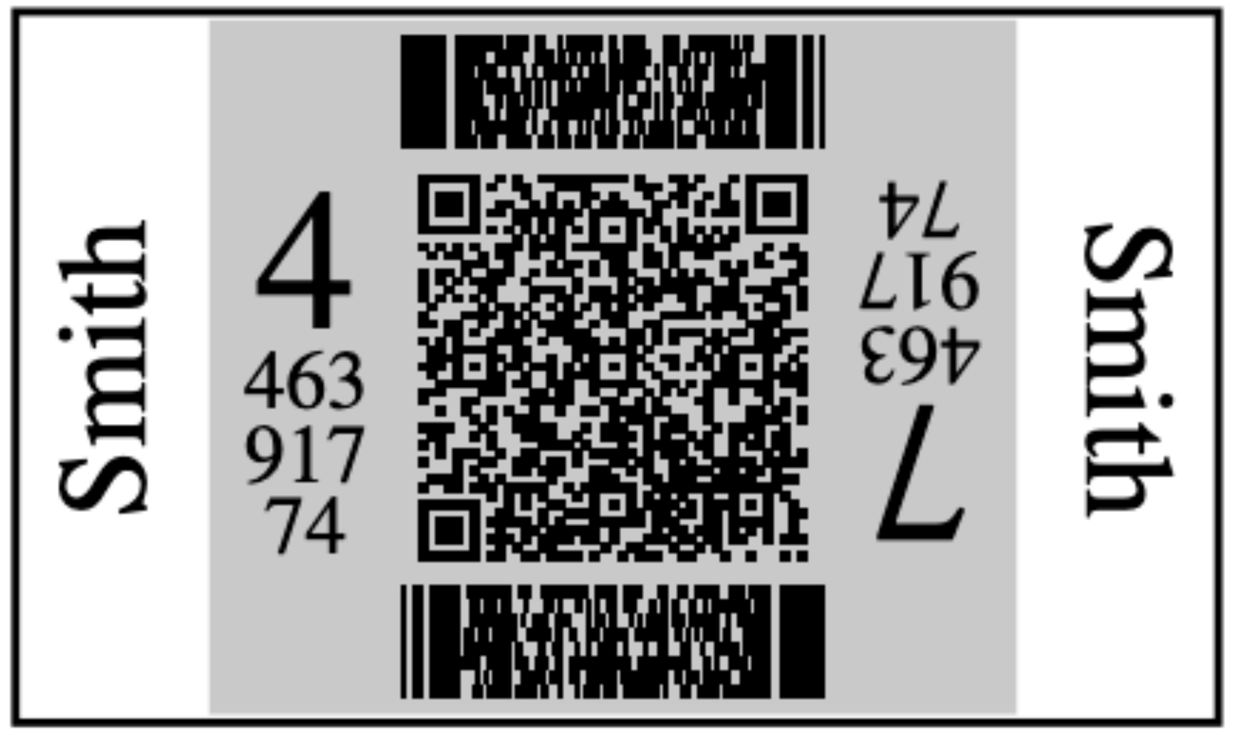
Paper ballot format:

- each candidate is associated to a unique integer
  e.g. Smith = 1
- each ballot for candidate X contains 2 verification codes A and B such that: $X = A + B \mod n$ (for a predefined n)
  e.g. $1 = 4 + 7 \mod 10$



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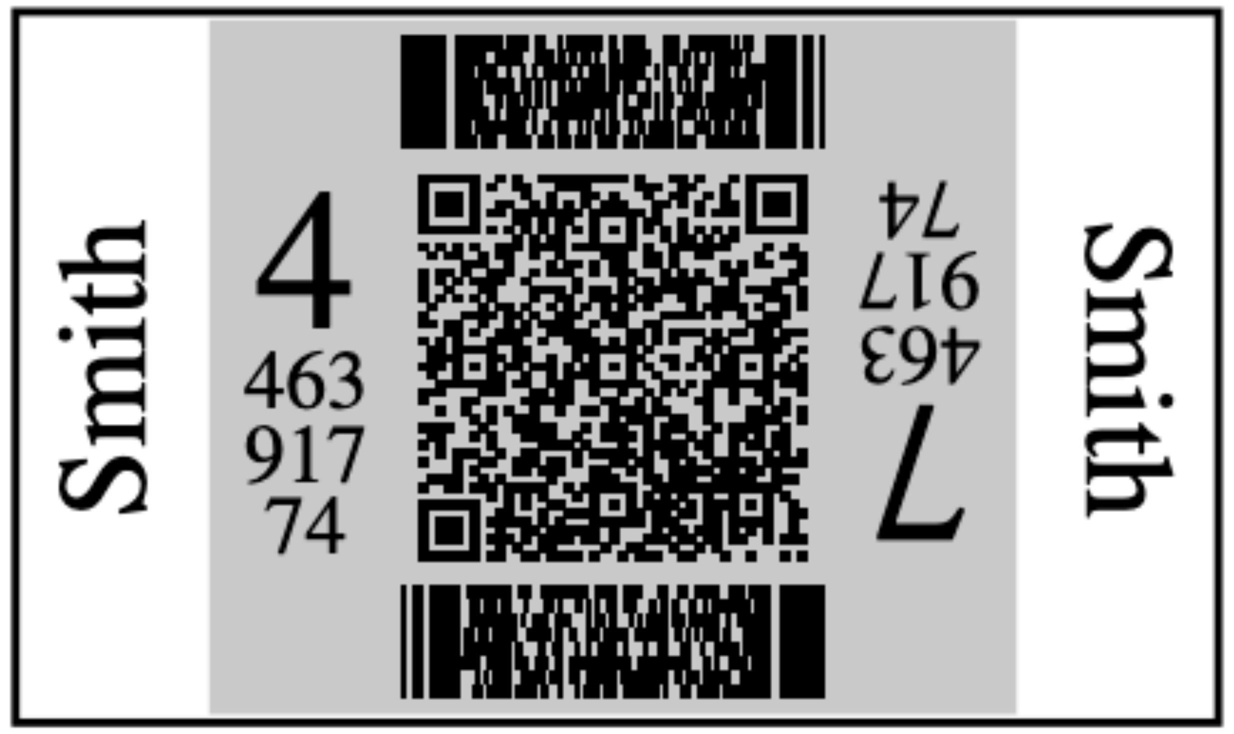

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- each ballot contains 3 ciphertexts c_X, c_A, c_B and 1 ZKP π such that
  $\pi = ZKP(ptxt(c_X) = ptxt(c_A) + ptxt(c_B) \mod n)$
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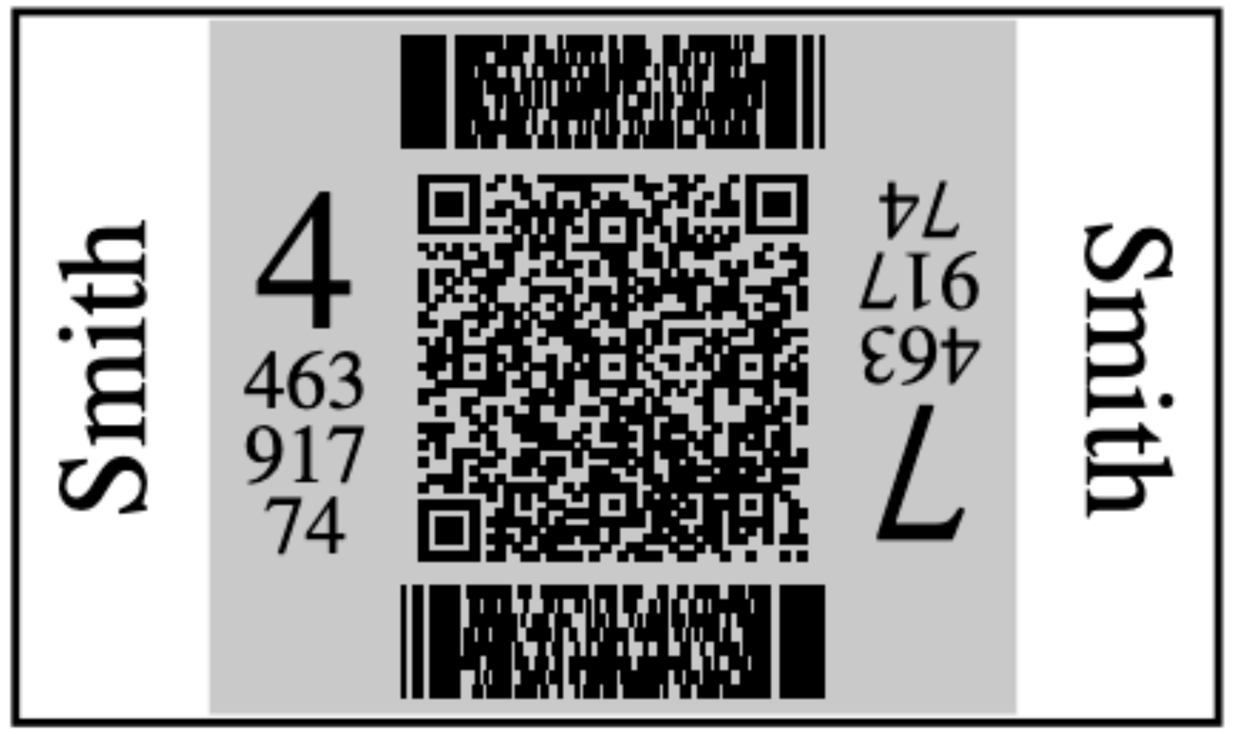

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Ballot manipulations are detected with probability $\frac{1}{2}$

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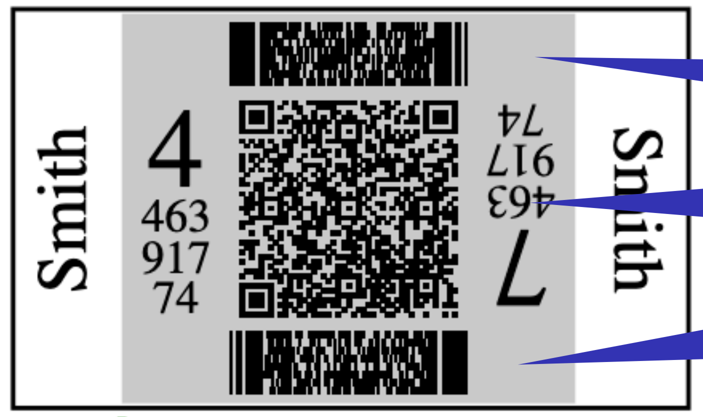
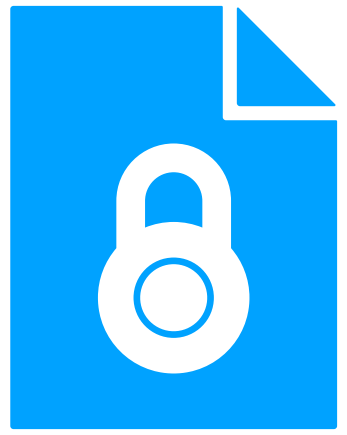
Accountability by-design

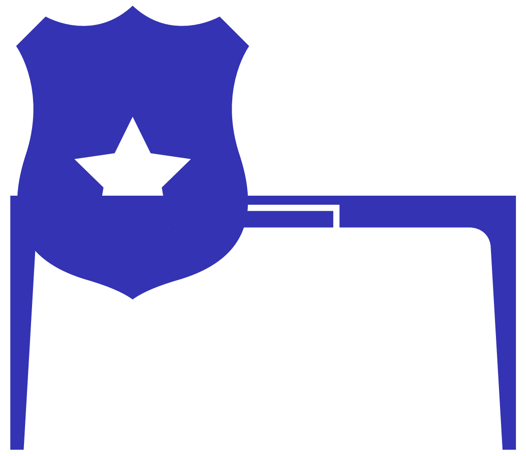


Digital signatures by the printer



Digital signatures by the smart card

A hash chain of blocks signed by the server



Voters and local authorities mutually control their actions

A dispute resolution procedure

- executed when a critical error is detected
- 9 steps:
  - 5 can be executed live
  - + 4 offline because breaks privacy
- can (almost) always deduce the culprit (sometimes a subset of possible culprits)
- protects against false accusations

A formally proven protocol

ProVerif

- An automatic prover for symbolic analysis
- Handle trace-based properties for e.g., verifiability or accountability
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  ➡ carefully define the queries
  ➡ exhaustively identify each possible final state of the protocol by an event
- Audit mechanism: ProVerif does not support arithmetics in $\mathbb{Z}_n$
  ➡ reachability: over-approximate the "+" operator
  ➡ equivalence: prove a relation preservation

Modeling arithmetics in $\mathbb{Z}_n$

Modelling:

- integers are modeled by abstract atomic values, $x, y, a, b, c, \ldots$
- whenever someone checks $x \stackrel{?}{=} a + b$, we execute the event $isSum(x, a, b)$

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Reachability properties:

« For all $x, a \in \mathbb{Z}_n$, there exists a unique $b \in \mathbb{Z}_n$ such that $b = x + a$ »

Restrictions such that

$$isSum(x, a, b) \ \wedge \ isSum(x, a, b') \Rightarrow b = b'$$

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Equivalence properties: relation preservation

Lemma (intuition): given two processes P and Q, for all traces $tr_P \in Traces(P)$ and $tr_Q \in Traces(Q)$ such that $tr_P \approx tr_Q$ we have:

$$isSum(x, a, b) \in tr_P \ \Leftrightarrow \ isSum(x, a, b) \in tr_Q$$

(related to the notion of bi-process and diff-equivalence)

Conclusion

Themis is:

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