Votegral:
Coercion-Resistant E-voting Without Trusted Hardware

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Talk Outline

- Goal: free, people-centric self-governance
- Basics: approaches to coercion resistance
- Signup: governmental or decentralized voting
- Usability: how the user experiences signup
- Technical: what actually happens underneath

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Decentralized Digital Democracy

Will decentralized online systems ever be able to **self-govern** in an egalitarian, democratic fashion?

[Kenneth Hacker, The Progressive Post]

Contrasting Influence Foundations

Wealth-centric

- One dollar, one vote

[Kera]

Person-centric

- One person, one vote

[Verity Weekly]

Contrasting Influence Foundations

Wealth-centric

- Stock corporations
- Loyalty programs
- Online gaming
- CAPTCHA solving
- Proof-of-work
- Proof-of-stake
- Proof-of-X for most X

Person-centric

- Democratic states
- Elected parliaments
- Membership clubs
- Committees
- Town hall meetings
- Direct democracy
- Liquid democracy

Contrasting Influence Foundations

Wealth-centric

✓

Largely Solved

Person-centric

✗

Largely Unsolved

Person-Centric Self-Governance

A few major unsolved questions & challenges:

- Defining a suitable **decentralized architecture**
  - See “Technologizing Democracy…?” [2020]
- Creating Sybil-resistant **proofs of personhood**
  - See “Identity and Personhood…” [2020]
- Scalable participatory **deliberation structures**
  - See “A Liquid Perspective…” [2018]
- Ensuring **freedom** from coercion, vote-buying
  - Topic of this talk

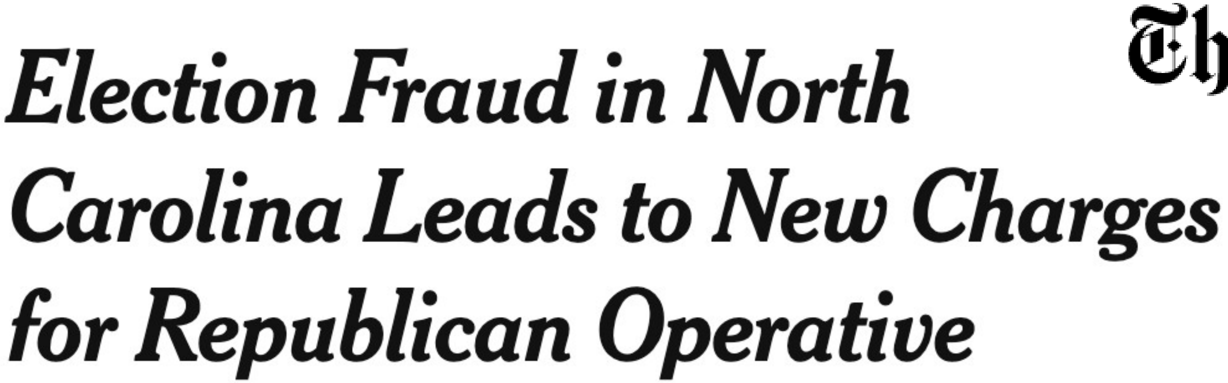
The Coercion, Vote-Buying Problem

How can we know people vote their **true intent** if we can’t secure the environment they vote in?

The Coercion, Vote-Buying Problem

Both **Postal** and **Internet** voting are vulnerable!

The New York Times

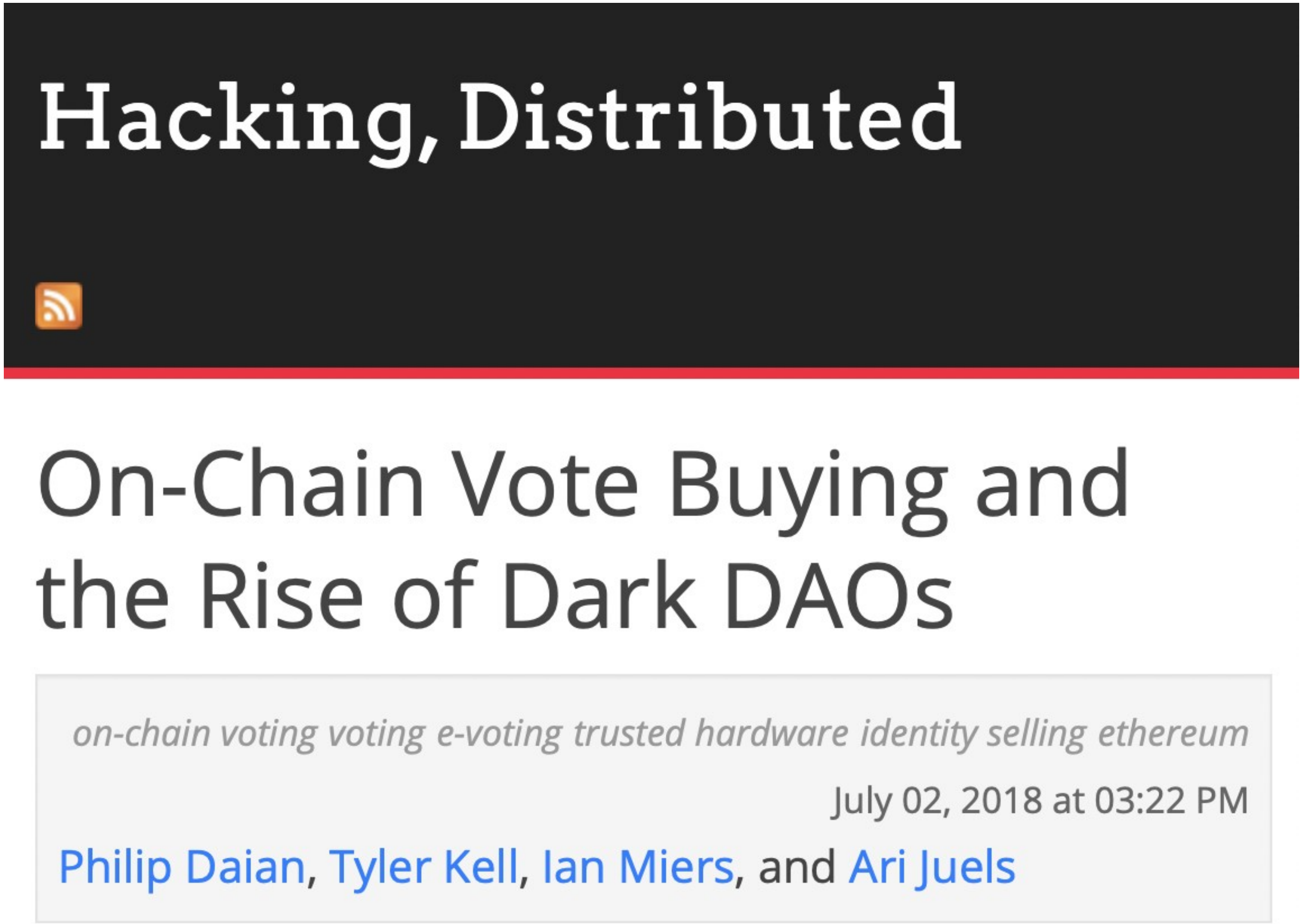


Election Fraud in North Carolina Leads to New Charges for Republican Operative

July 30, 2019

The Coercion, Vote-Buying Problem

Blockchain systems are especially vulnerable!



Hacking, Distributed

On-Chain Vote Buying and the Rise of Dark DAOs

on-chain voting voting e-voting trusted hardware identity selling ethereum

July 02, 2018 at 03:22 PM

Philip Daian, Tyler Kell, Ian Miers, and Ari Juels

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Approaches to Coercion Resistance

- Re-voting (Estonia, Spycher/Haenni/Dubuis, …)
  - Later vote can override an earlier (coerced) vote
  - Key limitation: true preference must be cast *last*
    - Coercer can keep voter under surveillance until deadline

- Fake credentials (JCJ, RSV, …)
  - User can get both *real* and *fake* voting credentials
    - Fake credentials “work” but cast votes that don’t count
  - Can give or sell fake credentials to any coercer

Coercion Resistance, JCJ-Style

JCJ tradition: voters get *real* and *fake* credentials

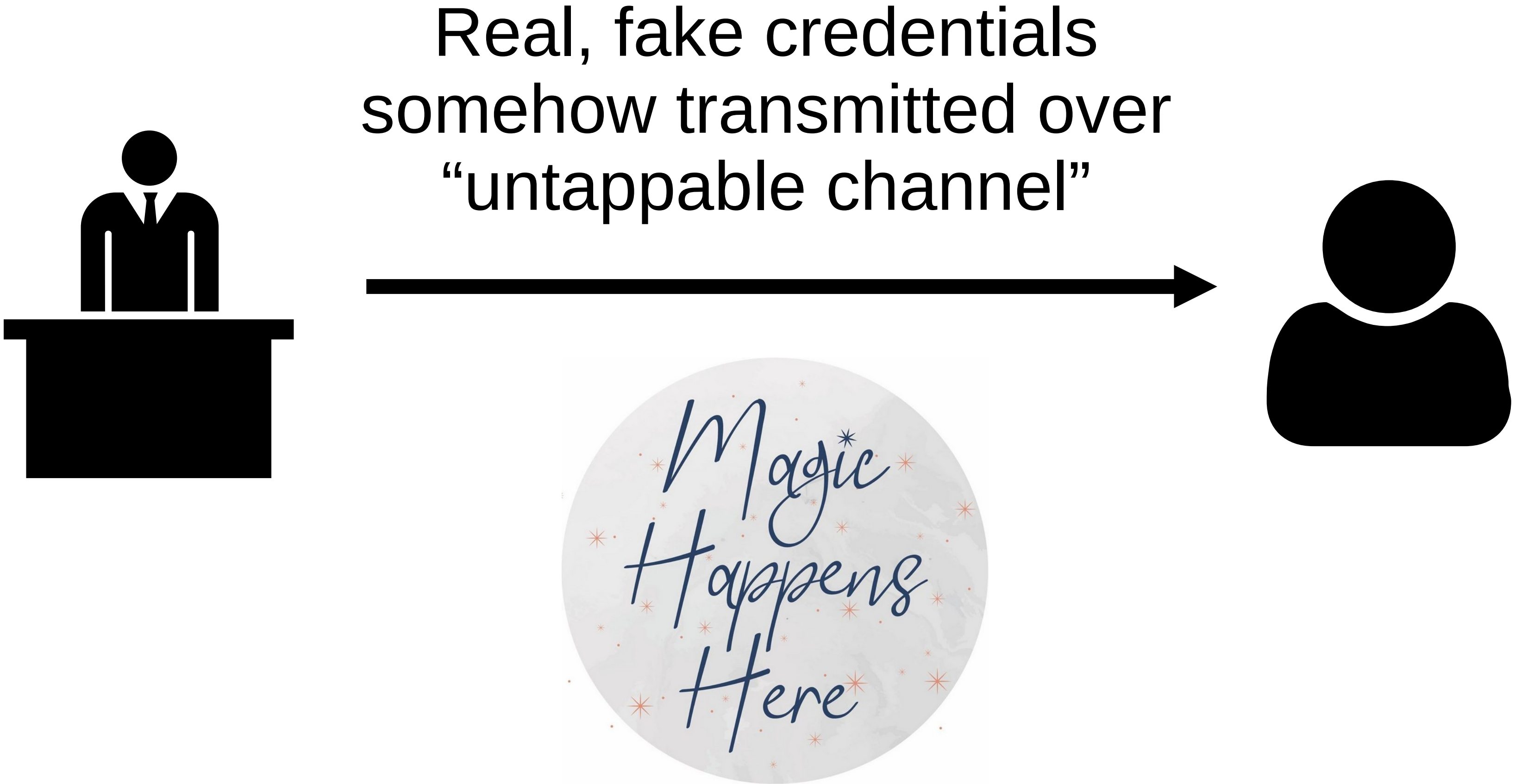
- Can give or sell fake credentials to any coercer

Some key challenges with JCJ

- How do voters *securely* get real credentials?
- Usability: needs complex cryptographic dances
- Quadratic computation cost (mostly solved)
- Bulletin board flooding attacks (mostly solved)

The Signup Problem: First Cut

The scenario typically *assumed* in theoretical work

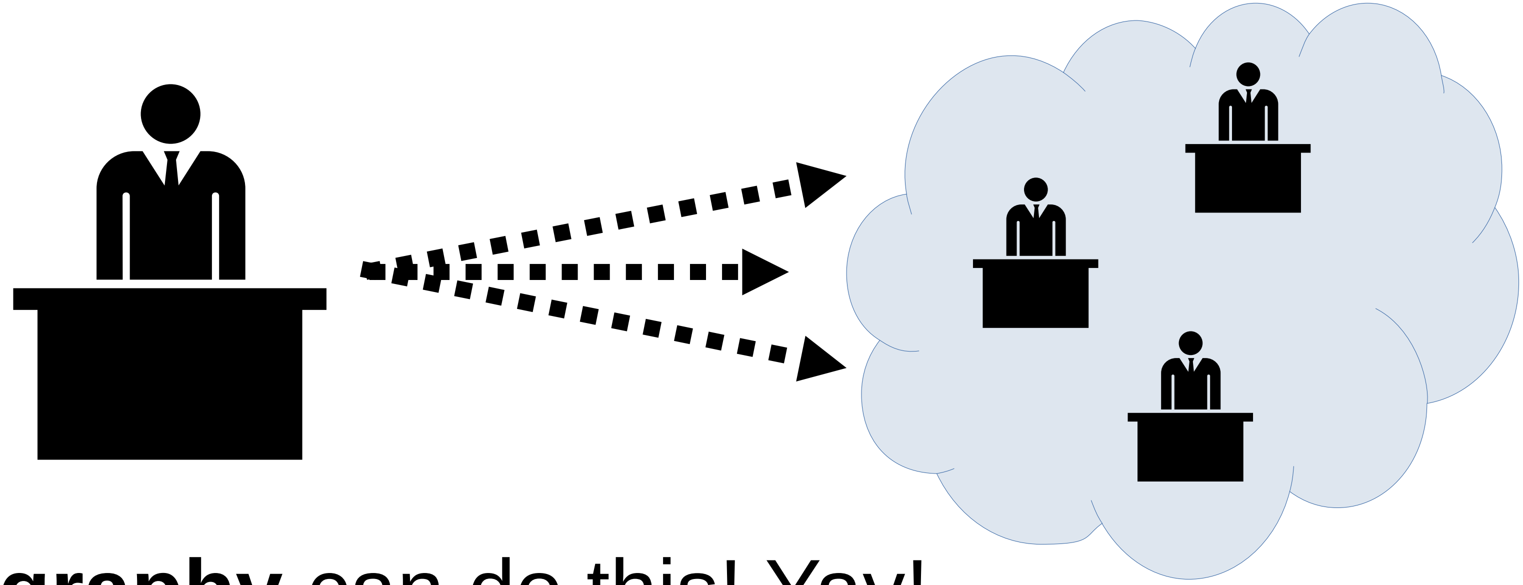


Real, fake credentials
somehow transmitted over
“untappable channel”

First Main Problem

We want things to be *decentralized* – i.e., don’t want to trust a single election authority!

So we *decentralize* the election authority by splitting its role over multiple parties…

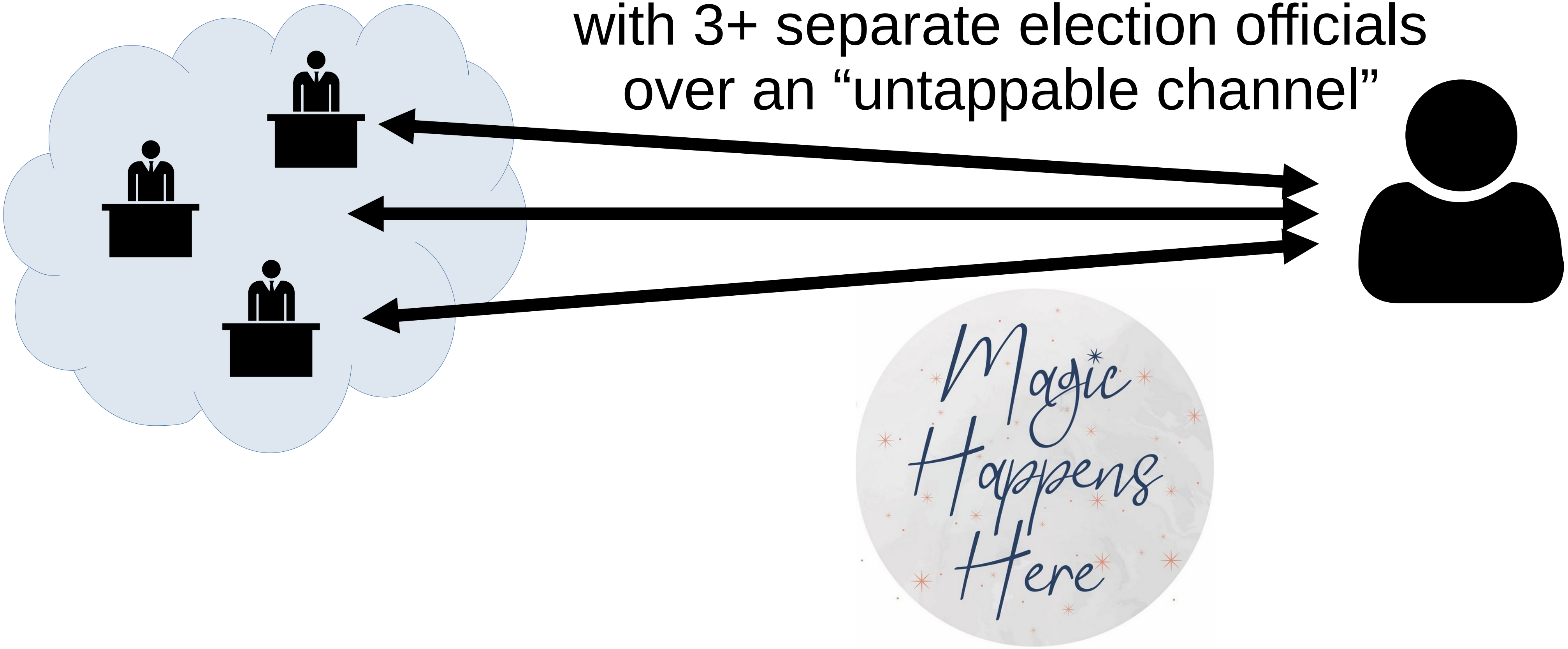


Cryptography can do this! Yay!

The Signup Problem: Next Cut

The scenario typically *assumed* in theoretical work

Ordinary, unsophisticated voter
performs elaborate cryptographic dance
with 3+ separate election officials
over an “untappable channel”



Closest-to-Practical Precedent

JCJ in the Civitas E-voting system

- [Neumann/Volkamer ‘12],[Neuman et al ‘13]

Assumes every voter has **trusted hardware**

- Specifically, a **smart card** that can perform the elaborate cryptographic dance for the user

Could work, but (a) costly, and (b) defeats goal of transparency, independent verifiability of E-voting

The Continuing Challenge

Can we make coercion-resistant E-voting…

- Usable: no elaborate cryptographic dances?
- Secure: no single points of compromise?

That is the Votegral’s goal.

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Votegral Use-Cases

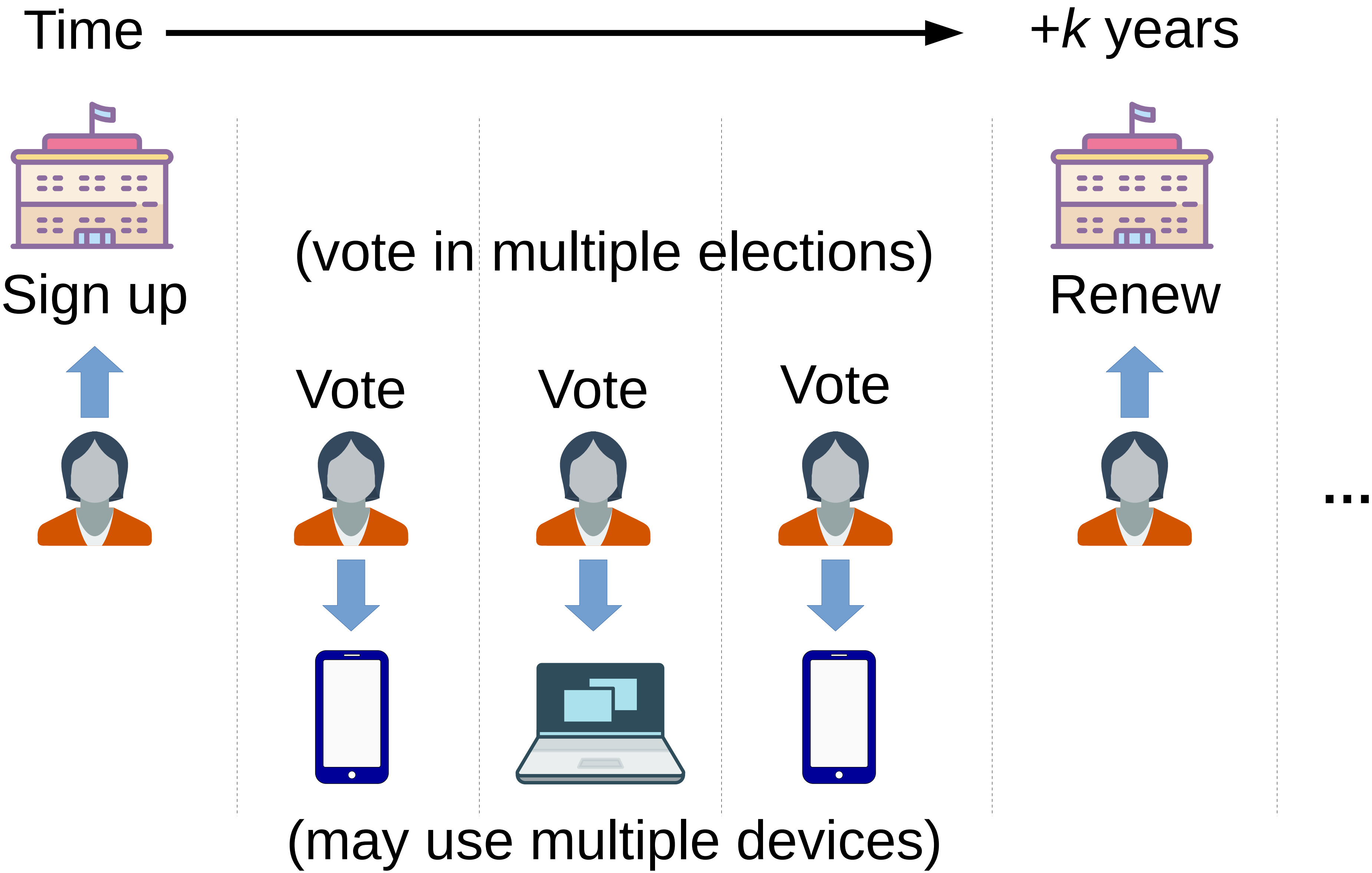
Could in principle be deployed either by:

- Governments, for E-voting in public elections
- Decentralized systems w/ proof of personhood

Difference is when in-person “signup” happens

- Governmental: periodically at a suitable office
- Decentralized: periodically at pseudonym party

Government use-case: outline



Time → +*k* years

Sign up

(vote in multiple elections)

Vote

Vote

Vote

Renew

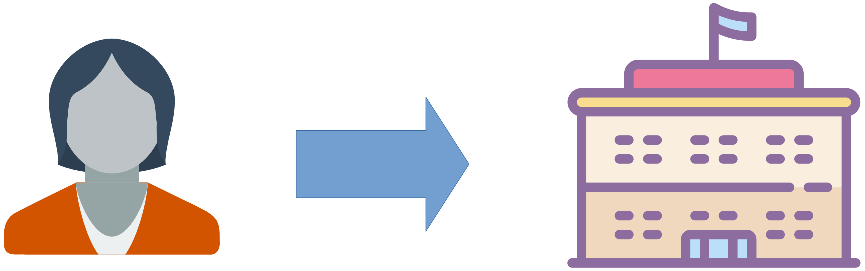
...

(may use multiple devices)

In-person E-voting signup

To use E-voting, voter must visit designated office in person to sign up or renew **every few years**:

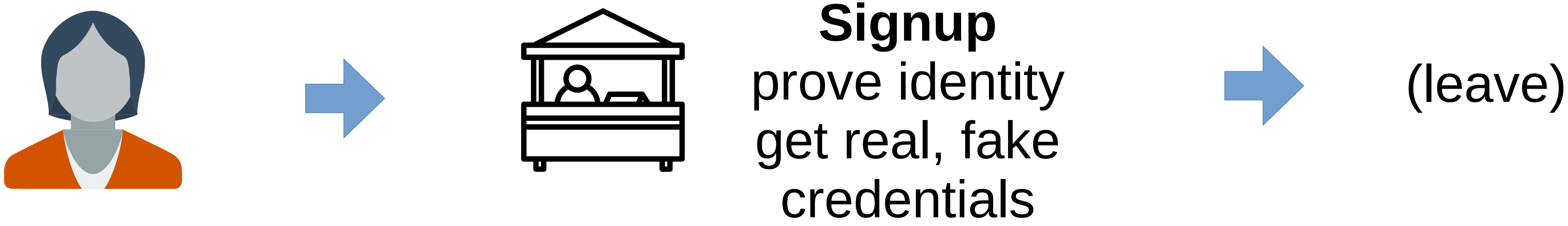
- **Locals:** residents services or ID card office
- **Expats:** embassy, consulate, authorized notary



Might be coincident with obtaining or renewing voter’s national ID card, passport, drivers license

Signup process outline

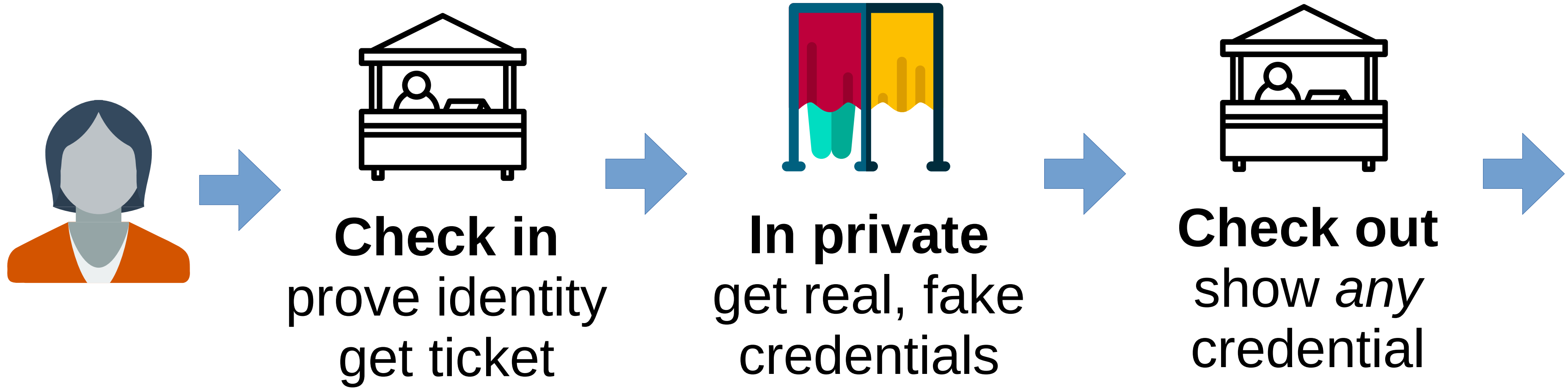
E-voting signup, low coercion threat (e.g., CH?)



Signup
prove identity
get real, fake
credentials

(leave)

In-person voting or high coercion threat (not CH?)



Check in
prove identity
get ticket

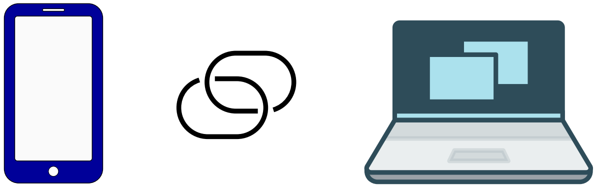
In private
get real, fake
credentials

Check out
show *any*
credential

E-voting across personal devices

Voter can link several trusted personal devices

- **Cast** votes on any linked personal device
- **Check** recent voting record on any device



Cast-as-intended protection: assumes *not all* voter’s personal devices compromised together

- But one device can compromise vote privacy

In-person signup: acceptable cost?

Cost/benefit to voters:

- **Cost:** one in-person visit every few years
- **Benefit:** instant voting in frequent elections
- **Benefit:** cast & verify votes across devices

Cost/benefit to governments:

- **Cost:** offer signup service in local offices
- **Benefit:** save ballot printing and mailing costs
- **Benefit:** no dependence on international mail

Decentralized use-case: outline

Suppose we build a blockchain system using pseudonym parties as 1-per-person stake basis

- Mining/voting power distributed evenly in each epoch among all *people* who show up in-person
- “Proof-of-Personhood: Redemocratizing Permissionless Cryptocurrencies” [2017]

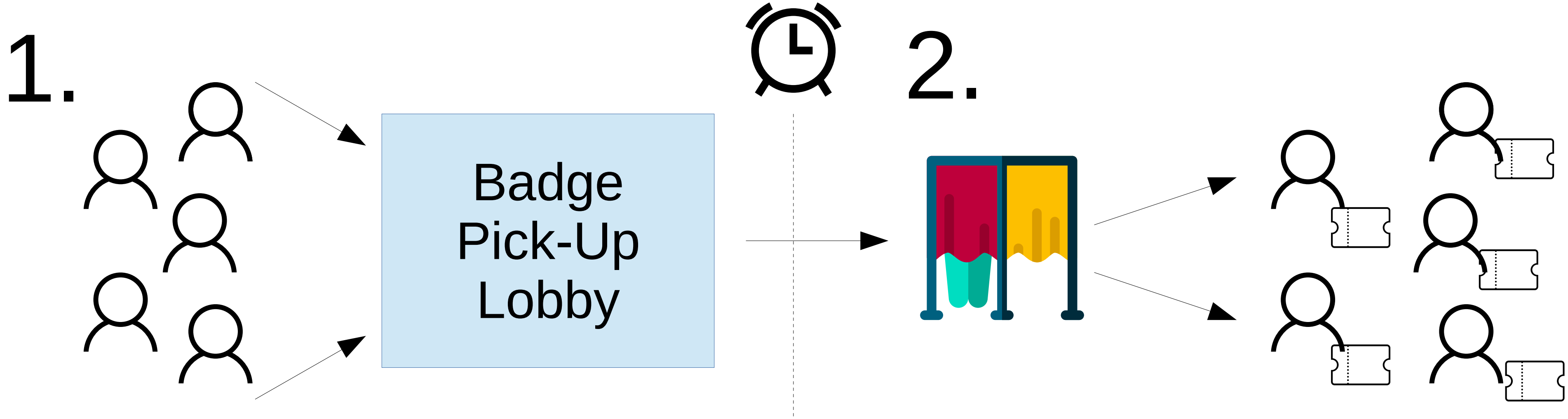
Can we ensure these *people* aren’t just minions paid by a whale to show up and push an agenda?

Pseudonym Parties with Votegral

To get a token, attendees must arrive and enter a closed or cordoned-off *lobby* by a set deadline

At deadline, entrance doors closed: *no re-entry*

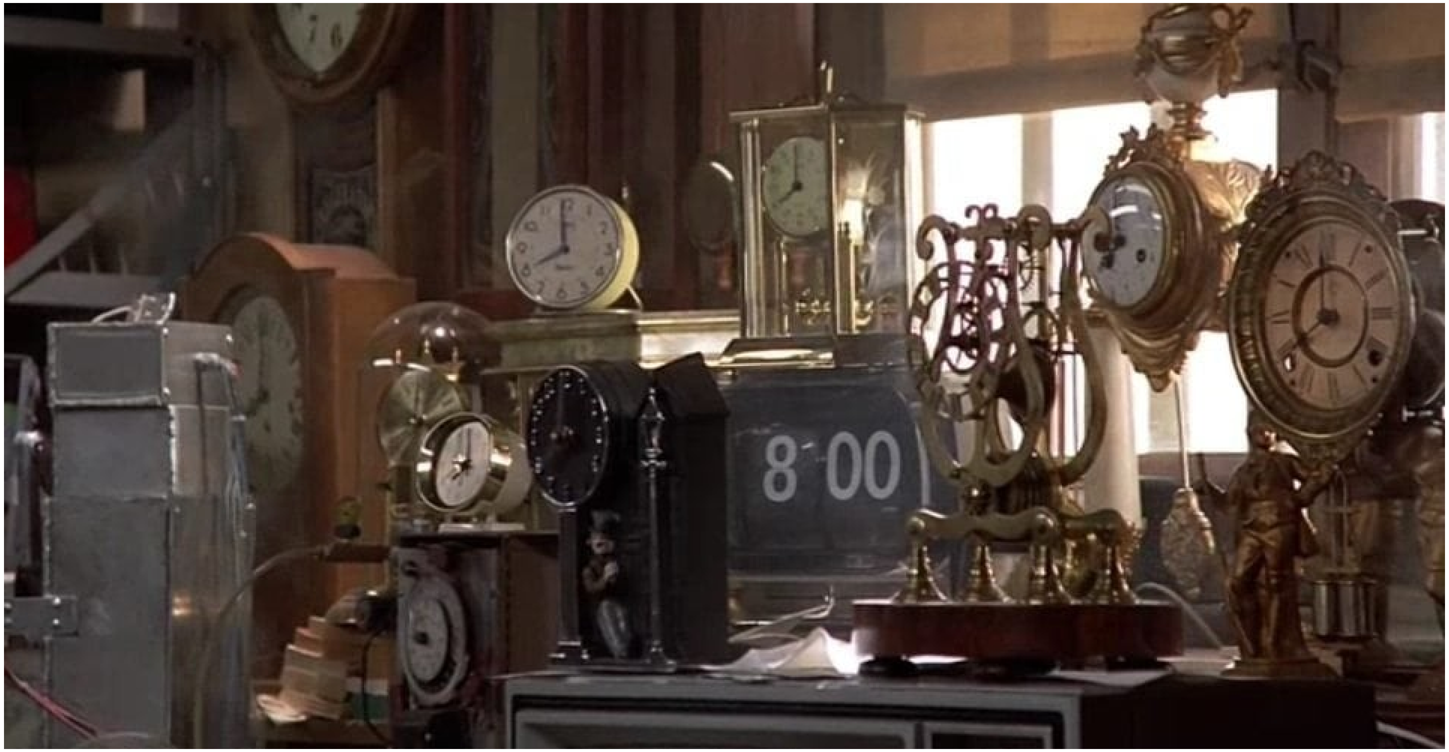
- Attendees file out from lobby to "main event"
- Via a "privacy booth" to get *real* & *fake* tokens



Pseudonym Parties: Scaling

Federation of PoP groups might hold *concurrent* events with *simultaneous* arrival deadlines

- No one can physically attend two at once



Votegral’s key contribution

Make ***signup*** usable, verifiable, coercion-resistant

- Assume in-person signup is an acceptable cost
- Treat in-person signup like in-person voting: a *private but verifiable choice* among alternatives
  - Voting is a choice between candidates or options
  - Signup is a meta-choice between *voting channels*

In-person “voting” techniques can secure signup!

- Ensure voter can *verify* choice but can’t *prove* it

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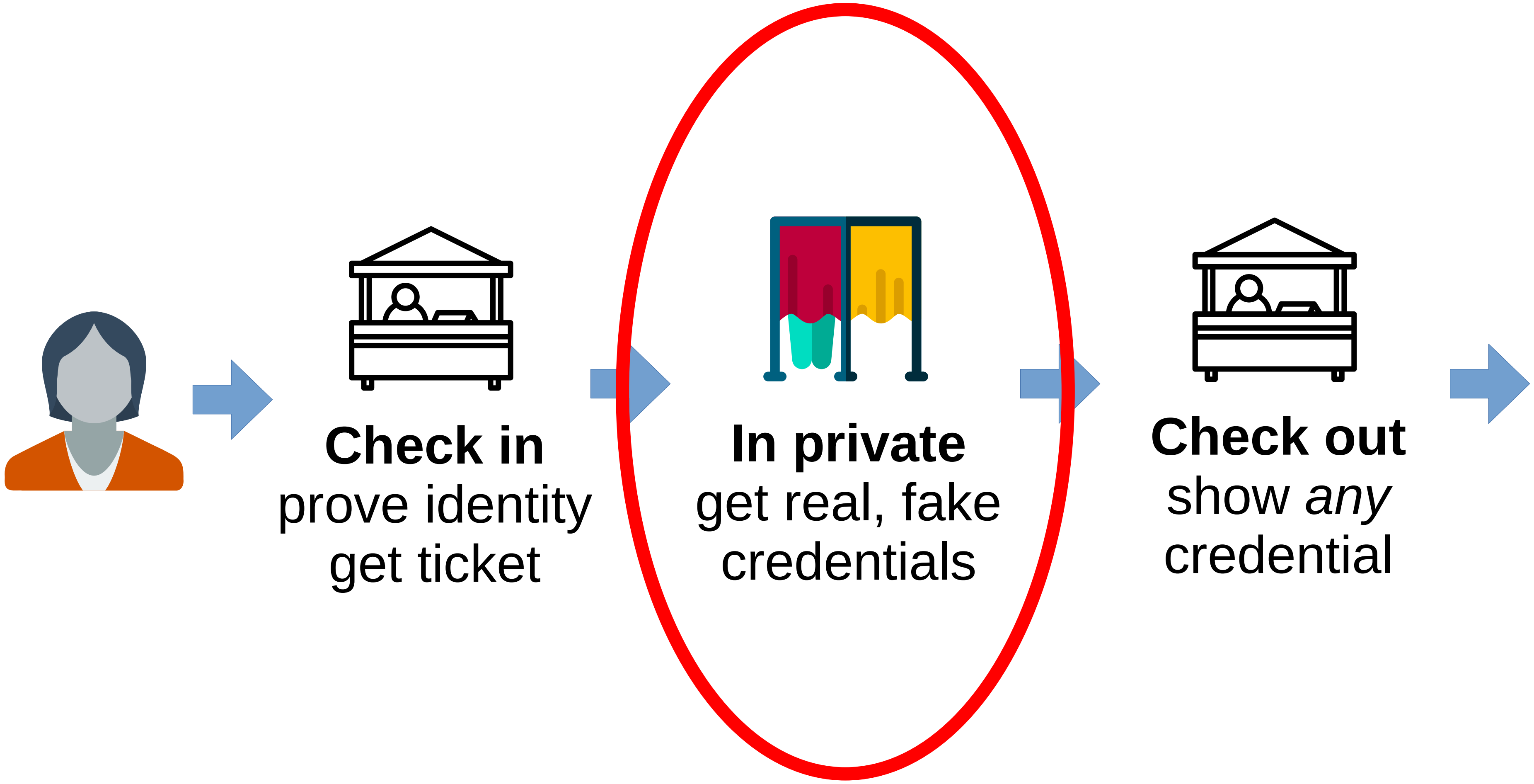
What is in the “privacy booth”?

High coercion threat case as example



Check in
prove identity
get ticket

In private
get real, fake
credentials

Check out
show *any*
credential

Demo video

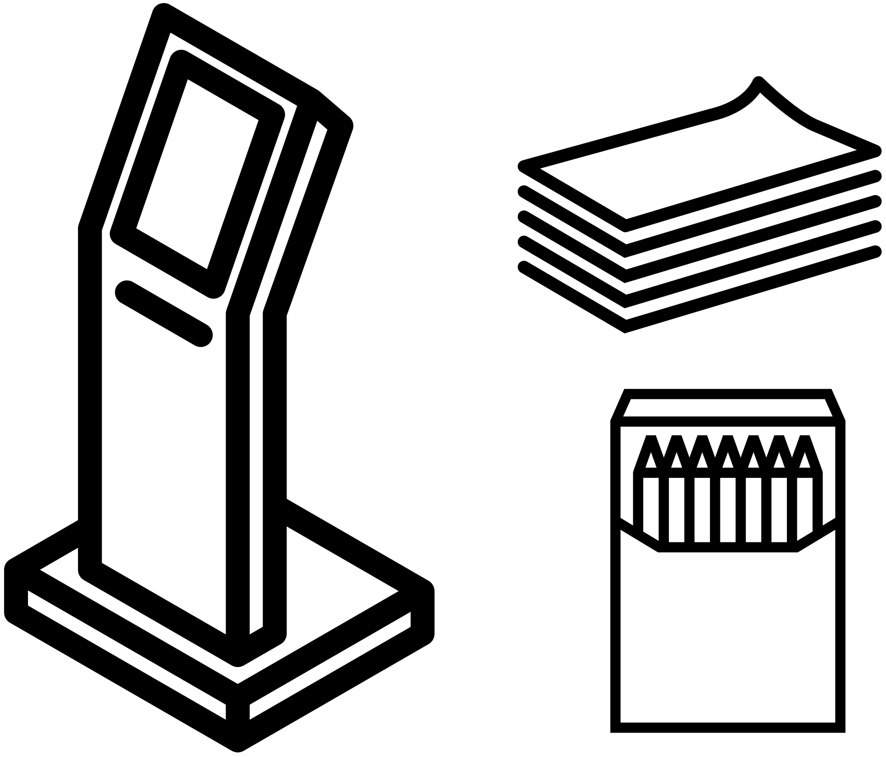
https://votegral.org/demo/

password: **Wahl**

What is in the “privacy booth”?

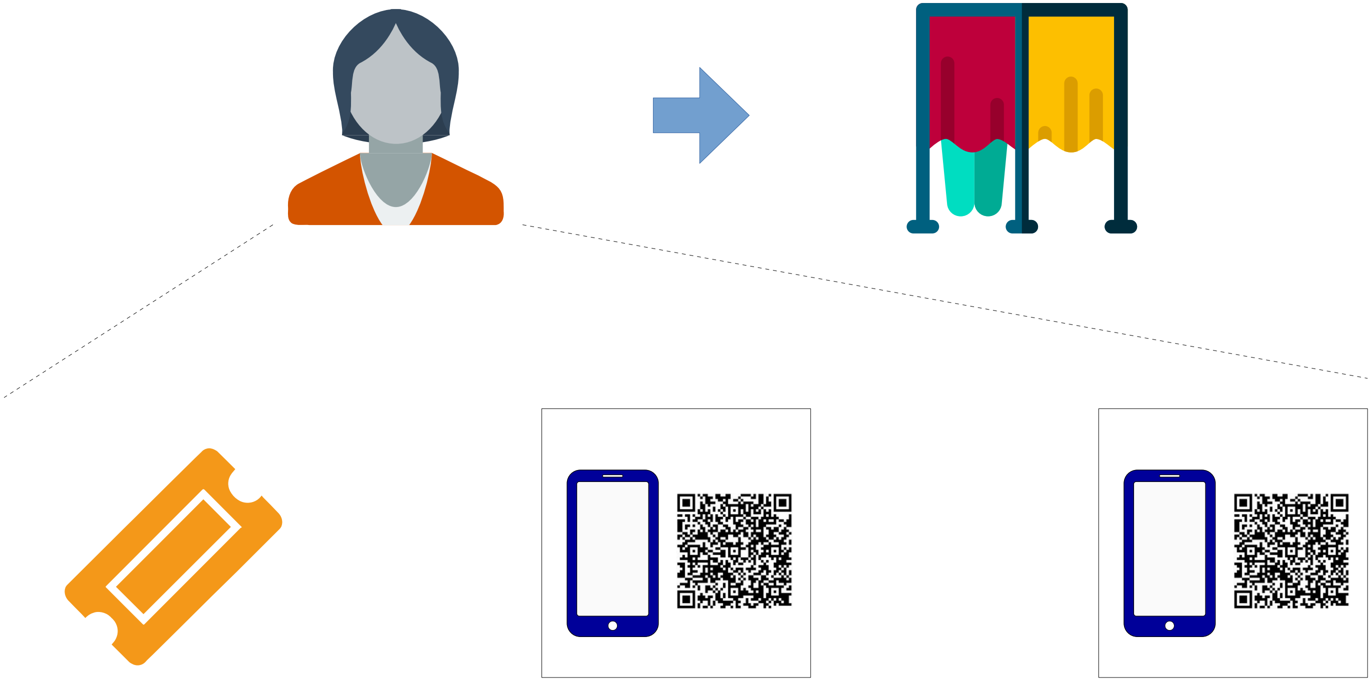
Kiosk or terminal with scanner, receipt printer, stack of envelopes with printed QR codes, pencils

- Could be used for signup *and* in-person voting



What happens in “privacy booth”?

Enter booth with check-in ticket, voting device(s) or printed device IDs (QR-coded public key)



Check-in ticket

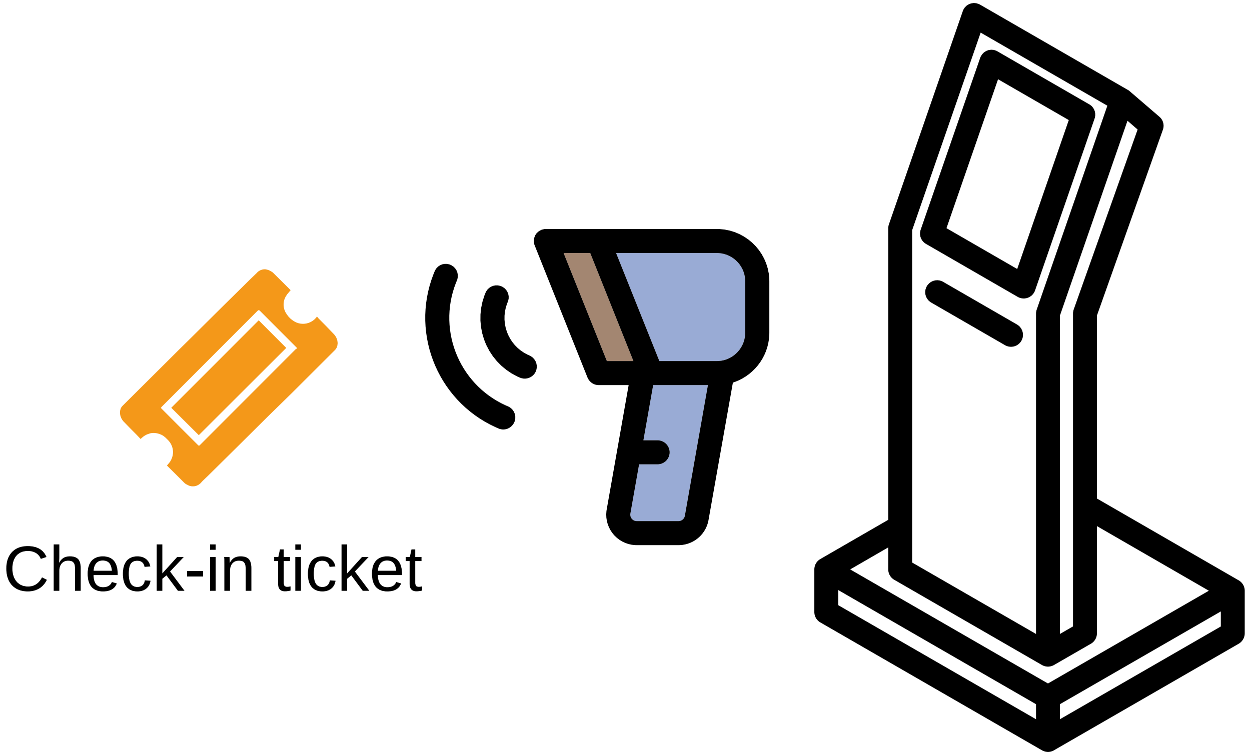
Voter-trusted device ID

Coercer’s device ID

What happens in “privacy booth”?

Enter booth with check-in ticket, voting device(s) or printed device IDs (QR-coded public key)

- Terminal asks for, scans voter’s check-in ticket



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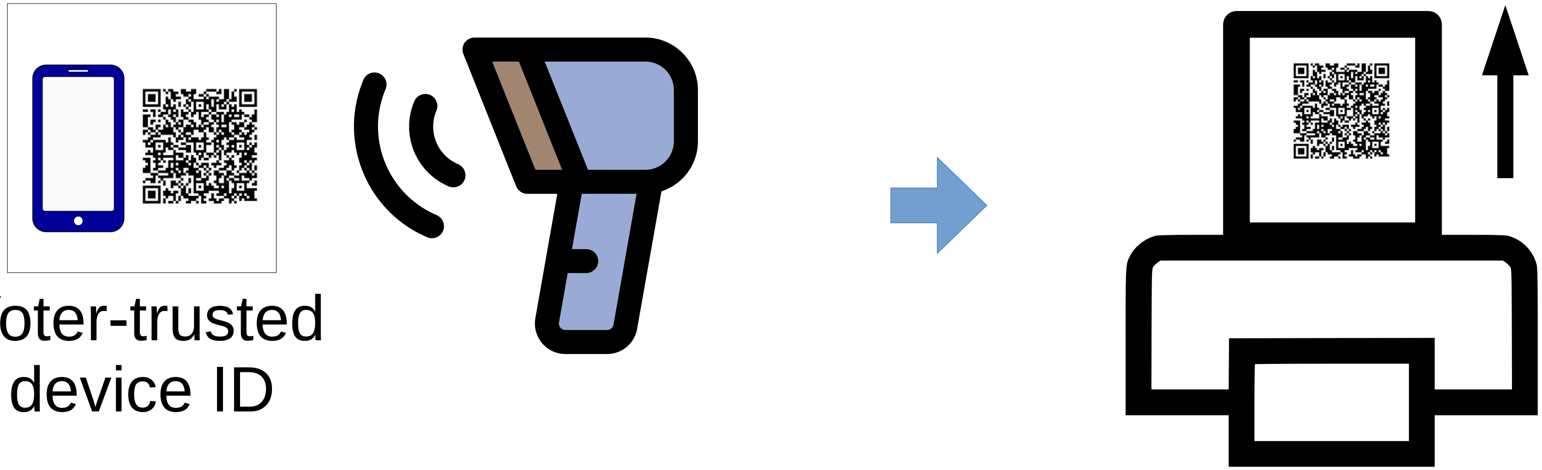
Enter booth with check-in ticket, voting device(s) or printed device IDs (QR-coded public key)

- Terminal asks for, scans voter’s check-in ticket
- Terminal scans device ID for **real** credential
  - Prints QR code on **first half** of receipt



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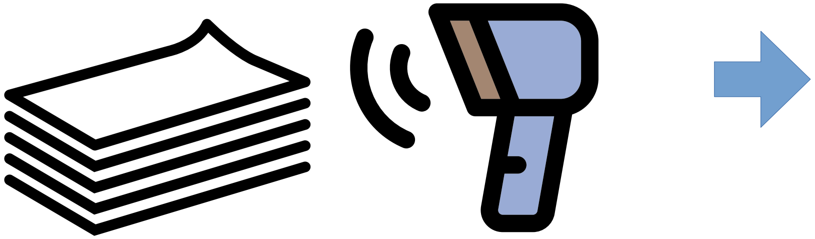
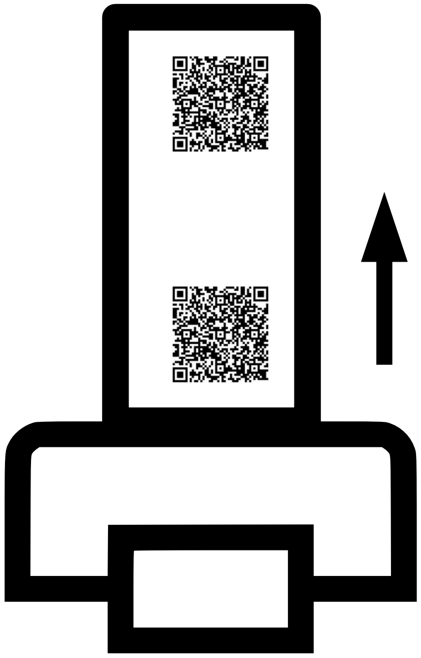
- Terminal asks for, scans voter’s check-in ticket
- Terminal scans device ID for **real** credential
  - Prints QR code on **first half** of receipt
- Terminal asks user to choose and scan any **envelope** from stack
  - Prints QR code on **rest of** receipt





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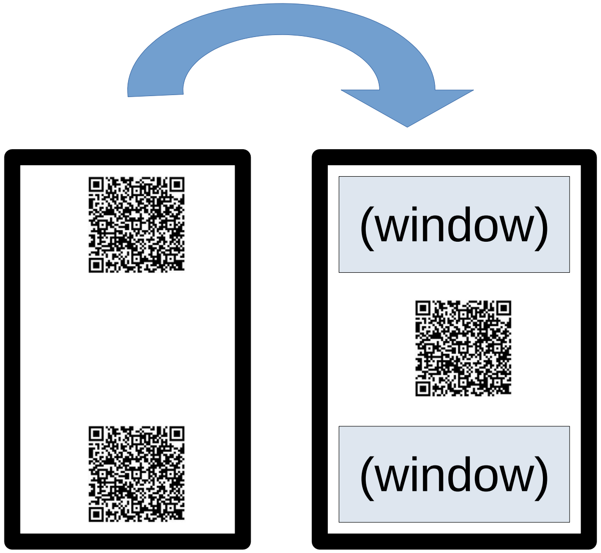
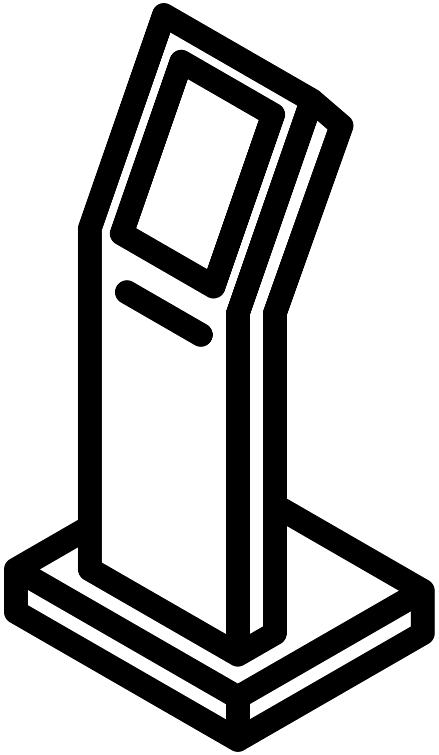
- Terminal asks user to choose and scan any **envelope** from stack
  - Prints QR code on **rest of** receipt
- Terminal prompts user to insert **receipt** into **envelope**



What happens in “privacy booth”?

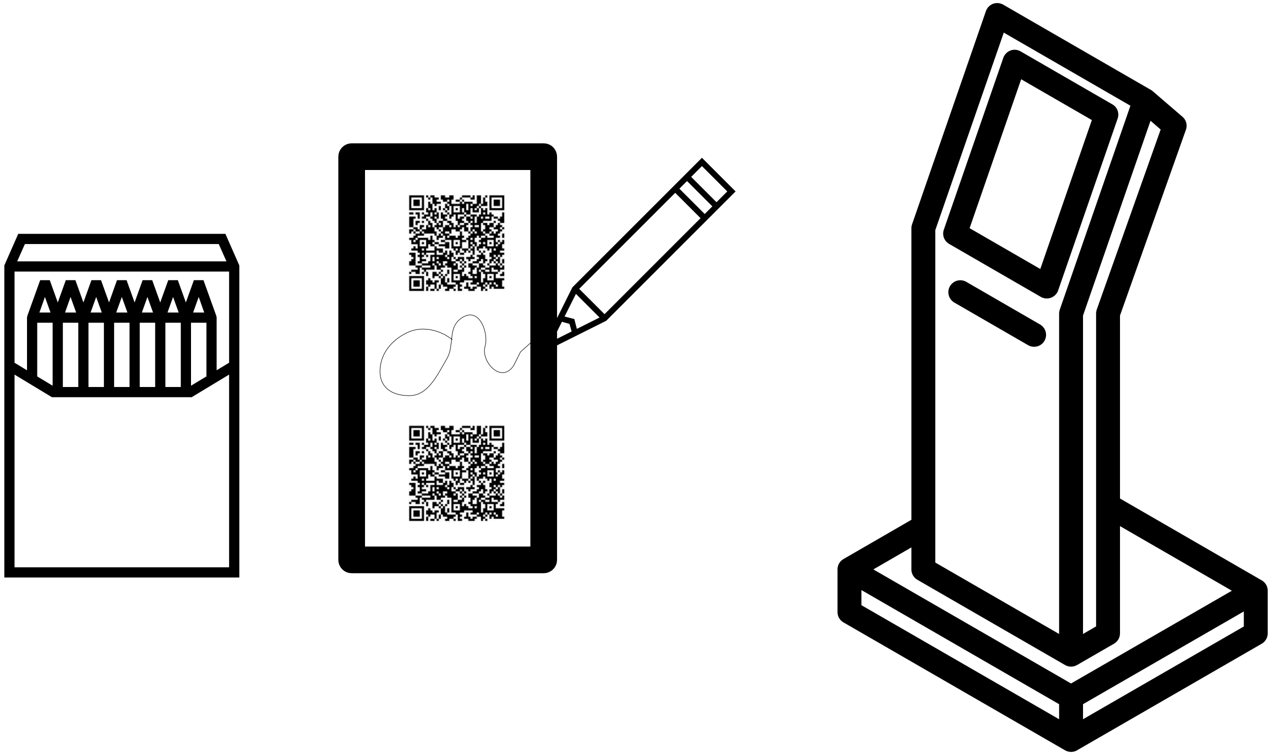
Ask if voter wants a **test credential**? If yes…



What happens in “privacy booth”?

Ask if voter wants a **test credential**? If yes…

- Ask voter to **mark** the **real credential** to help remember which it is



What happens in “privacy booth”?

Ask if voter wants a **test credential**? If yes…

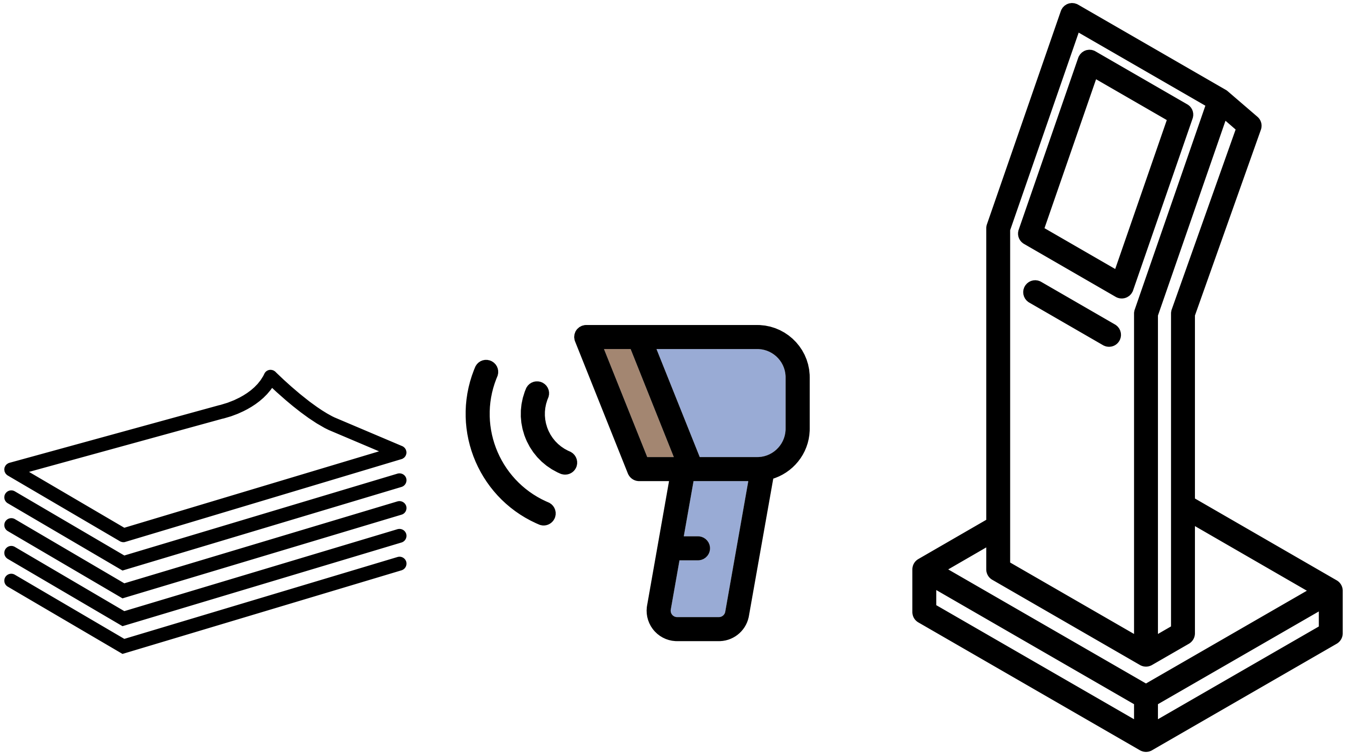
- Ask for, scan device ID for **test** credential
  - Coercer’s device ID if under coercion
  - Or kids’ devices, friends’, …

Coercer’s
device ID

What happens in “privacy booth”?

Ask if voter wants a **test credential**? If yes…

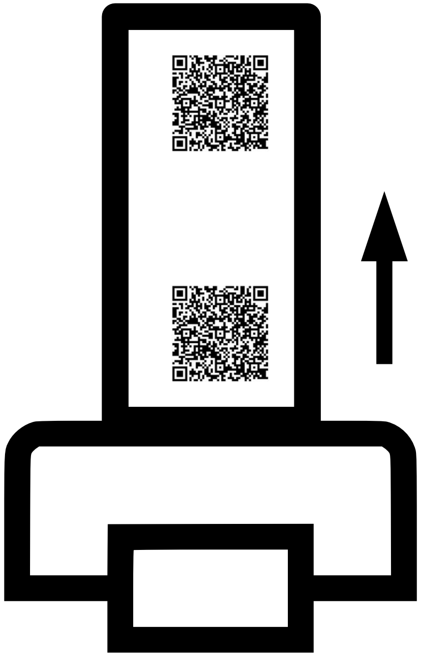
- Ask for, scan device ID for **test** credential
- Ask voter to choose and scan any **envelope**



What happens in “privacy booth”?

Ask if voter wants a **test credential**? If yes…

- Ask for, scan device ID for **test** credential
- Ask voter to choose and scan any **envelope**
- Print **entire receipt** at once



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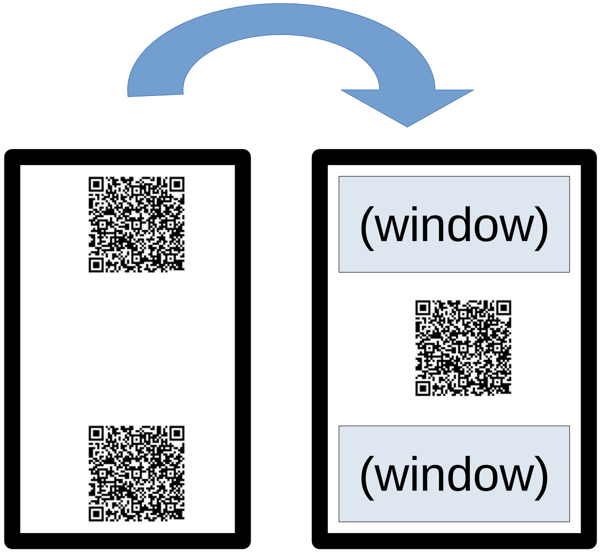

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- Ask for, scan device ID for **test credential**
- Ask voter to choose and scan any **envelope**
- Print **entire receipt** at once
- Ask user to insert **receipt** into **envelope**

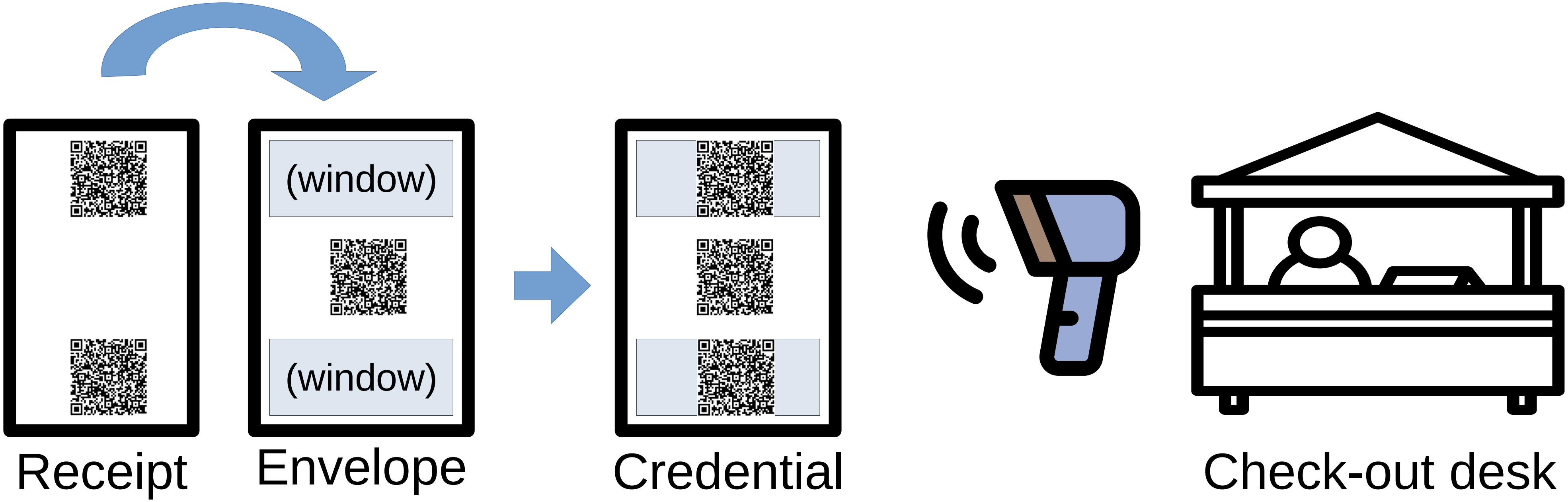
Ask if voter wants another **test credential?**

- If yes, repeat process above (to random quota)

Check-out and subsequent voting

Voter presents *any* credential (e.g., coercer’s) at check-out desk for official to scan

- Activates *all* credentials, real and fake



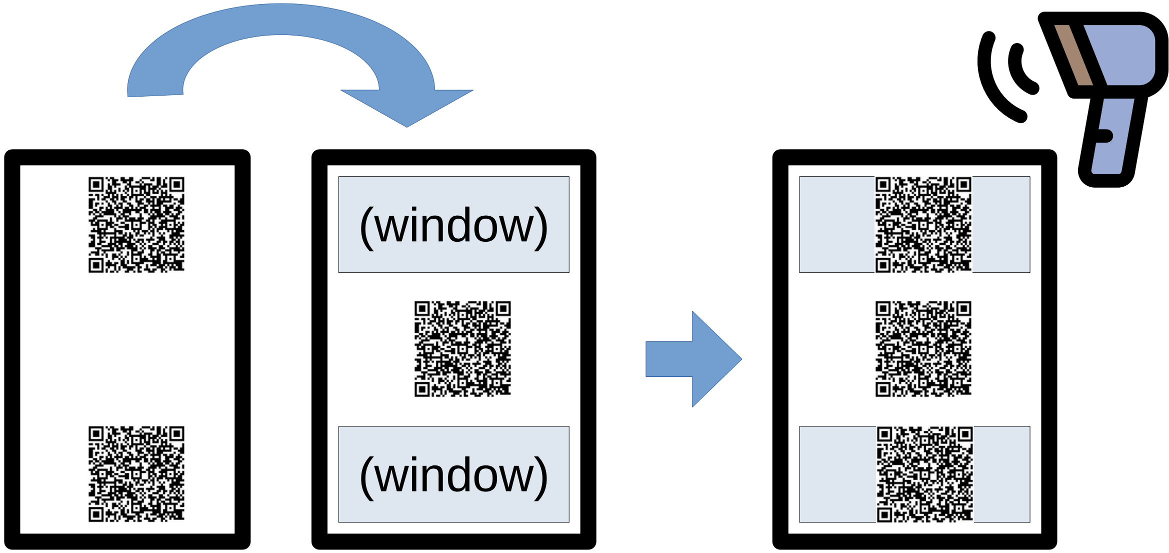
Check-out and subsequent voting

Voter presents *any* credential (e.g., coercer’s) at check-out desk for official to scan

- Activates *all* credentials, real and fake

At leisure, voter scans credential(s) with device(s)

- **Any** device can check validity
- **Associated** device can cast votes, read prior votes



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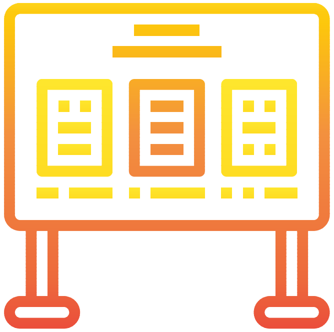
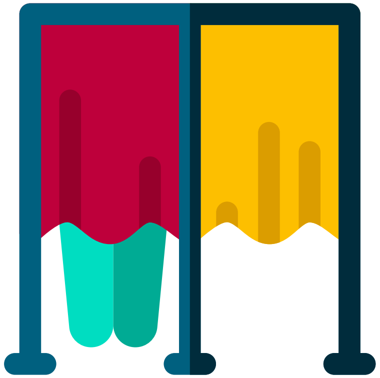
Votegral system components



Electronic bulletin board
(e.g., public blockchain)

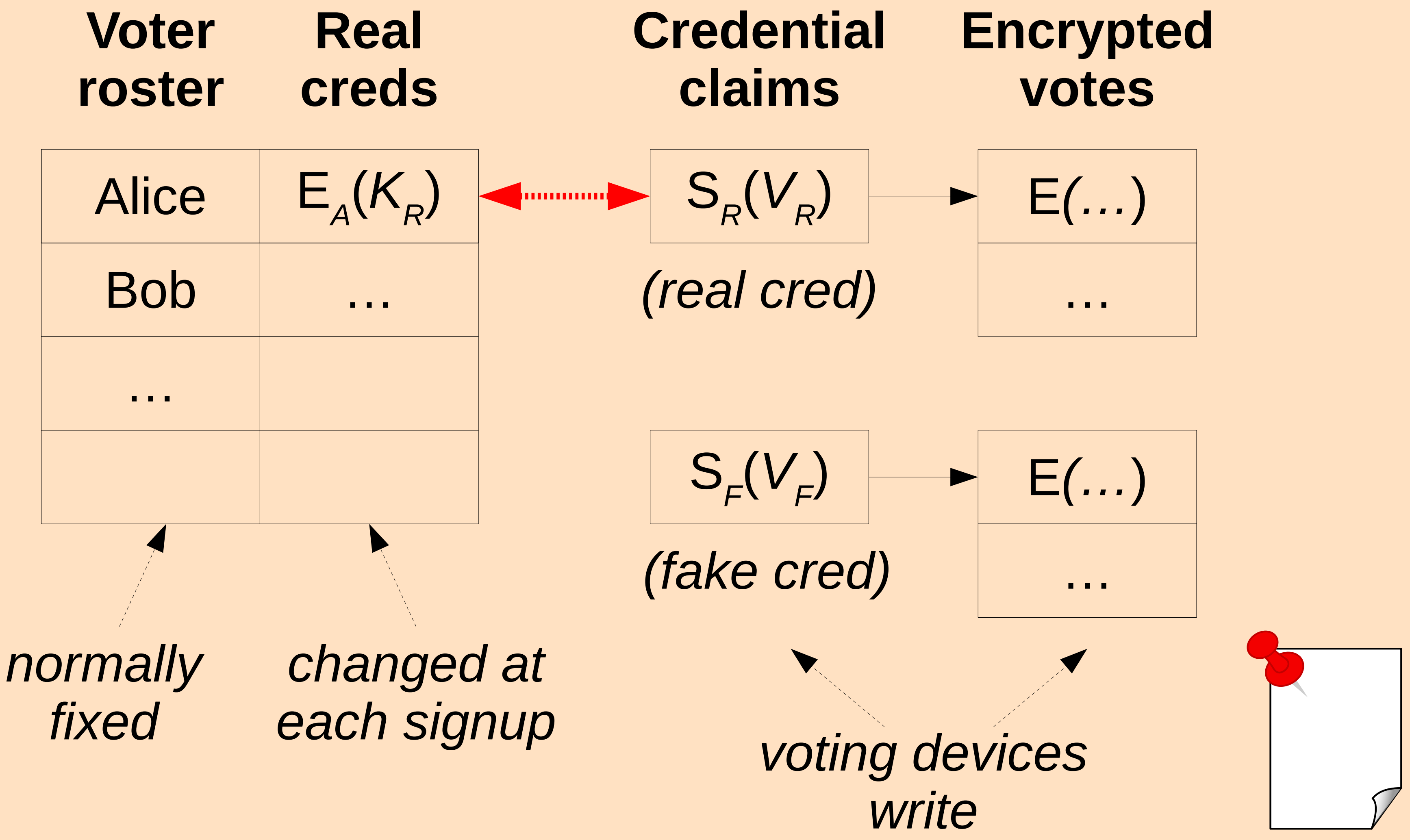
Authority/tally servers



Physical office/booth
with signup terminal

Voter’s personal device(s)

What’s on the bulletin board?



Voter roster	Real creds
Alice	$E_A(K_R)$
Bob	…
…	

Credential claims

$S_R(V_R)$

(real cred)

$S_F(V_F)$

(fake cred)

Encrypted votes

E(…)

…

E(…)

…

normally fixed

changed at each signup

voting devices write

What does signup device do?

Signup device trusted **only** for coercion resistance

- Air-gapped, sees no private info about voters, holds no secrets that can cast or decrypt votes

Signup produces 2 encryptions + interactive ZKP

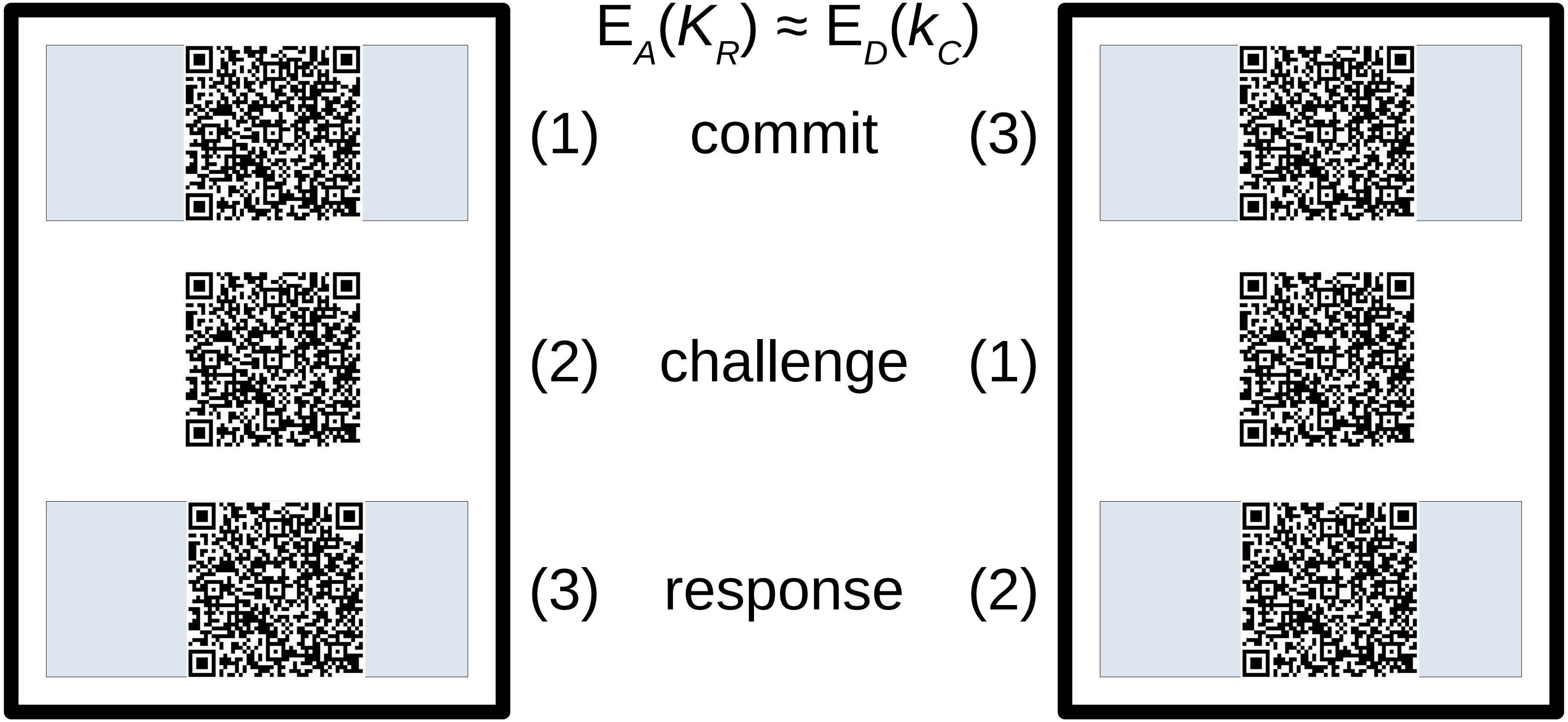
- $E_A(K_R)$: **Real** cred’s public key, Enc → **Authority**
  - Written to **voter roster entry** on BB at check-out
- $E_D(k_c)$: **This** cred’s private key, Enc → **Device**
  - Device can use **once** to create voting profile on BB
- ZKP: **Real** or **fake** interactive ZKP that $K_C = K_R$

Credentials have interactive ZKPs

Real or **fake** proofs that credential matches roster

- Distinguishable only via **order of generation**

$E_A(K_R) \approx E_D(k_C)$



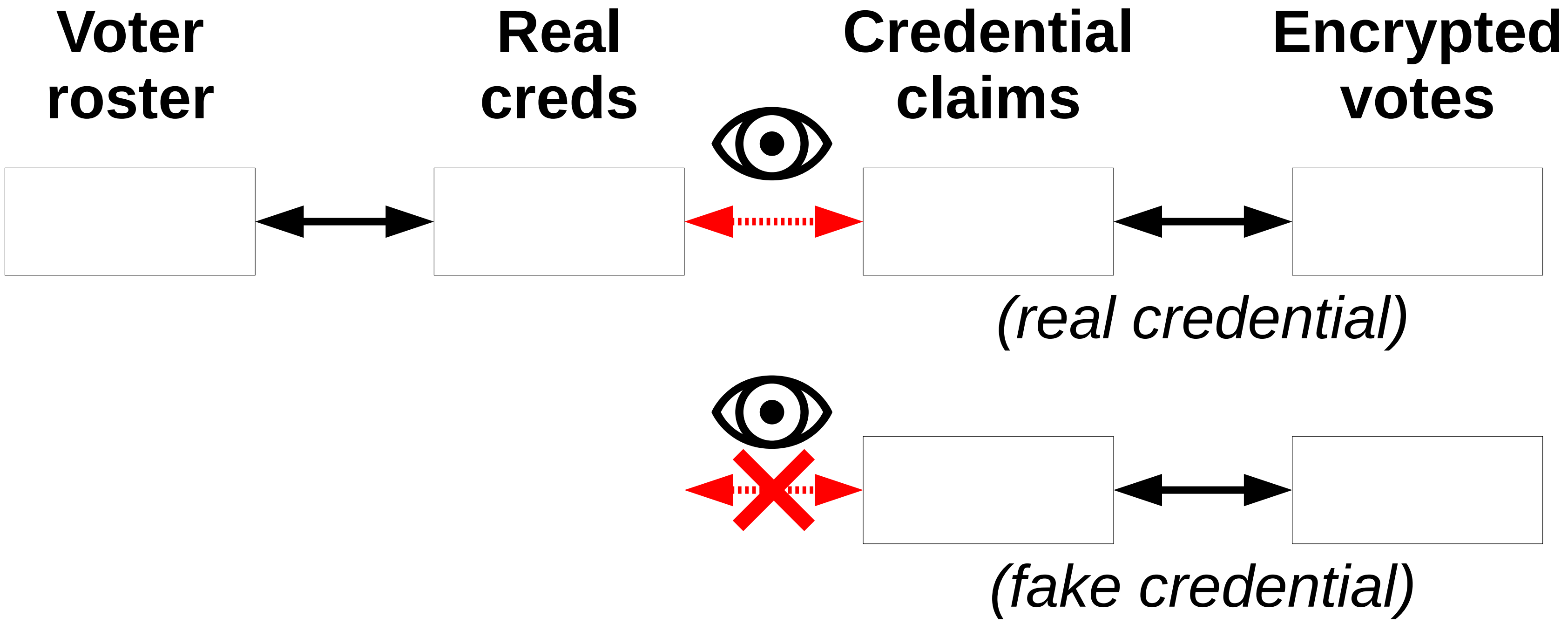
(1)	commit	(3)
(2)	challenge	(1)
(3)	response	(2)

Real credential **Fake credential**

End-to-end vote verification

Every step in signup + voting process is verifiable

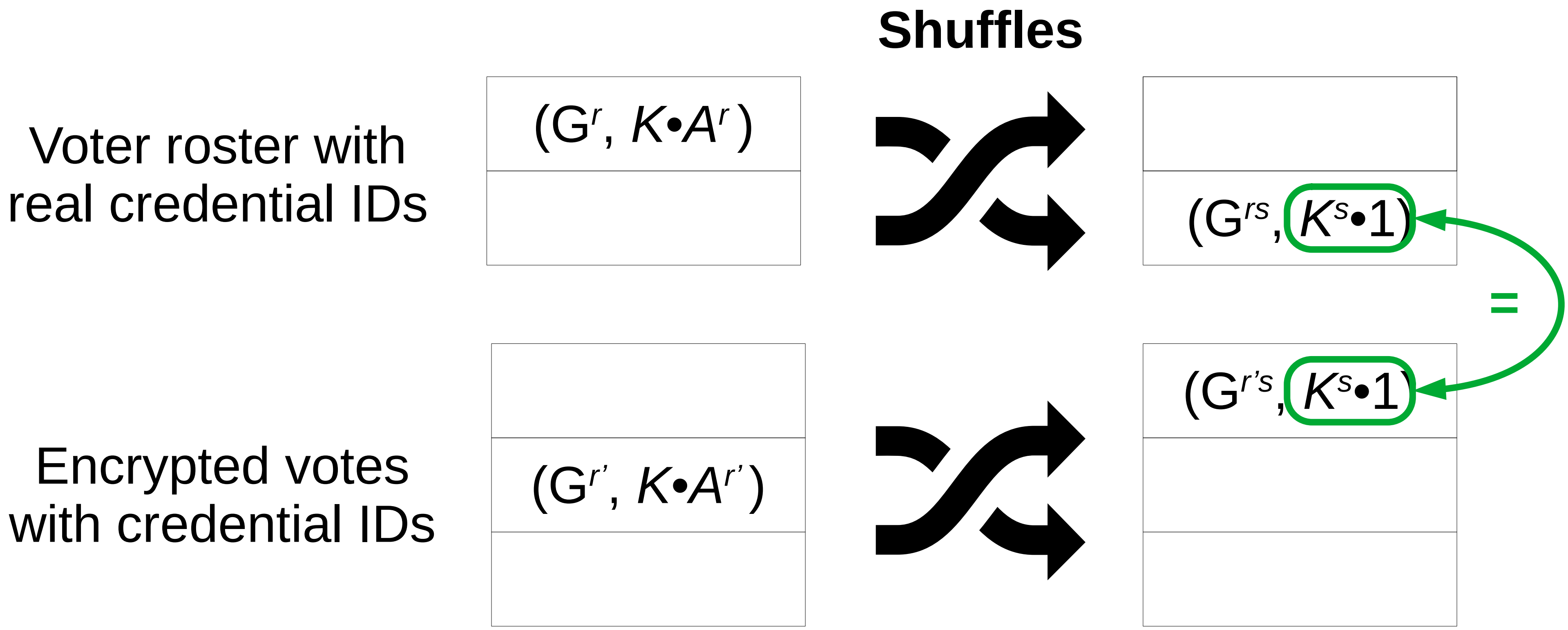
- But “critical link” of **voter roster** ↔ **cred claim** is verifiable only *interactively* by voter in private



Vote tallying process

Uses distributed rewriting of randomized ElGamal ciphertexts into convergent Pohlig-Hellman

- Fully verifiable, splittable, used in PSI protocols



Shuffles

Voter roster with real credential IDs

$(G^{r}, K \bullet A^{r})$

$(G^{rs}, K^{s} \bullet 1)$

=

Encrypted votes with credential IDs

$(G^{r'}, K \bullet A^{r'})$

$(G^{r's}, K^{s} \bullet 1)$

Vote tallying process

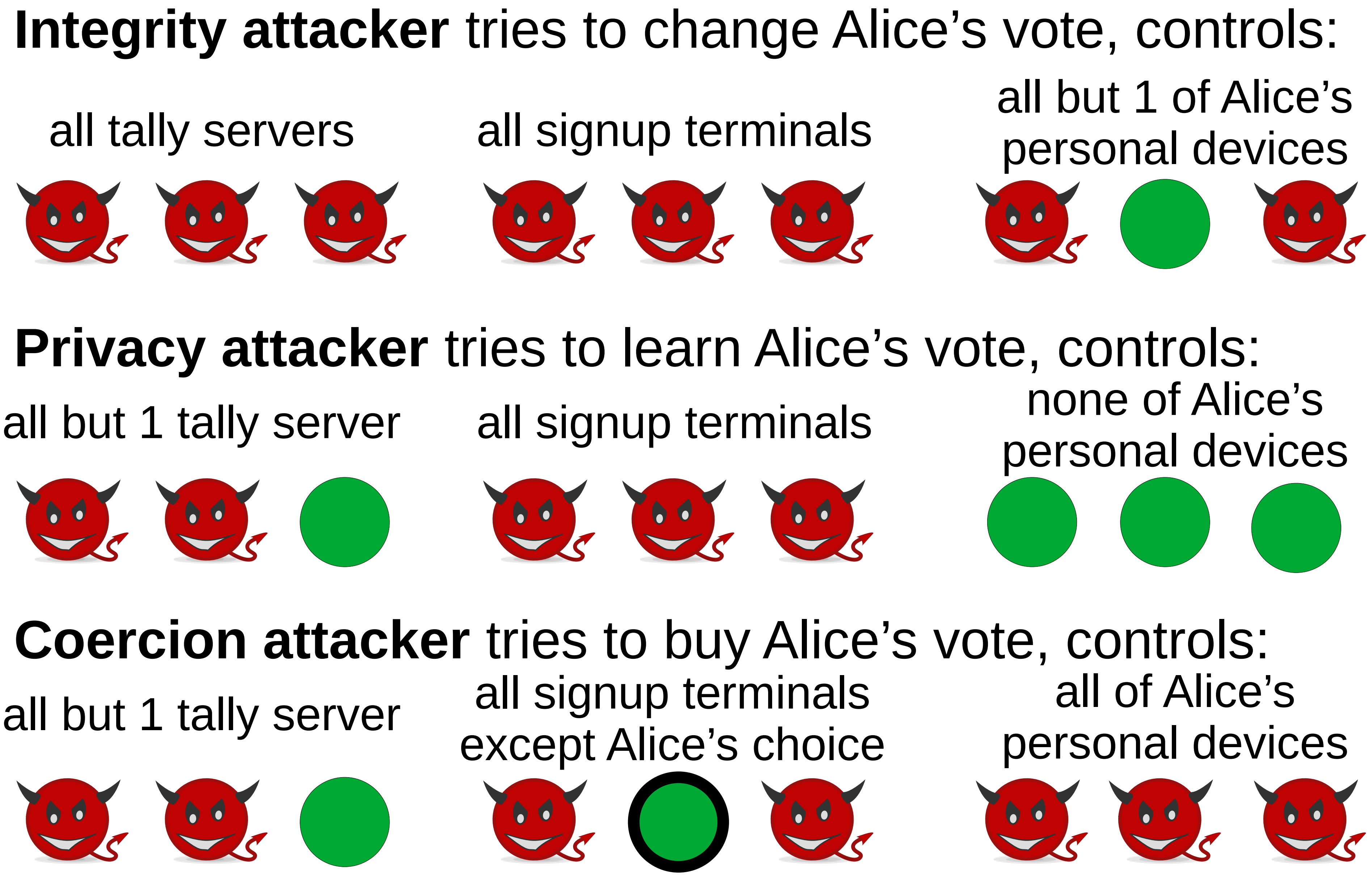
Uses distributed rewriting of randomized ElGamal ciphertexts into convergent Pohlig-Hellman

- Fully verifiable, splittable, used in PSI protocols

Useful properties:

- Naturally linear-time: just match output cred IDs
- Doesn’t leak whether a given voter cast a vote
- Supports well-known keys, e.g., party-line votes

Threat model summary



Integrity attacker tries to change Alice’s vote, controls:

all tally servers: 😈 😈 😈

all signup terminals: 😈 😈 😈

all but 1 of Alice’s personal devices: 😈 🟢 😈

Privacy attacker tries to learn Alice’s vote, controls:

all but 1 tally server: 😈 😈 🟢

all signup terminals: 😈 😈 😈

none of Alice’s personal devices: 🟢 🟢 🟢

Coercion attacker tries to buy Alice’s vote, controls:

all but 1 tally server: 😈 😈 🟢

all signup terminals except Alice’s choice: 😈 🟢 😈

all of Alice’s personal devices: 😈 😈 😈

Summary of relevant features

- End-to-end **verifiability**, minimize required trust
- Coercion-resistant signup via **interactive ZKPs**
- Signup devices **untrusted** for integrity, privacy
- Credentials have **no toxic waste**: discardable
- Linear-time tallying with **last-minute roster**
- Limited credentials per user → **no BB flooding**
- If anything goes wrong, just **signup again**

Votegral: Conclusion

Adapts in-person voting-like process for signup: make coercion-resistant *choice of voting channel*

- Supports governmental or decentralized voting
- Voters get real and fake credentials at signup
  - Learn which is which only **interactively** in private
- Use to vote in multiple subsequent elections
  - Fully-dematerialized voting, check on other devices
- End-to-end verifiability, minimally trusted signup

We **can** make coercion resistance secure, usable!