
# Electronic Voting

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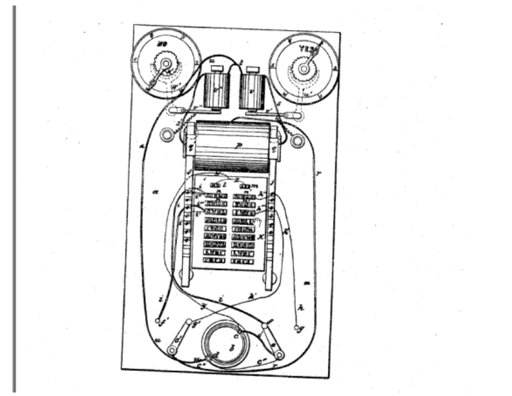
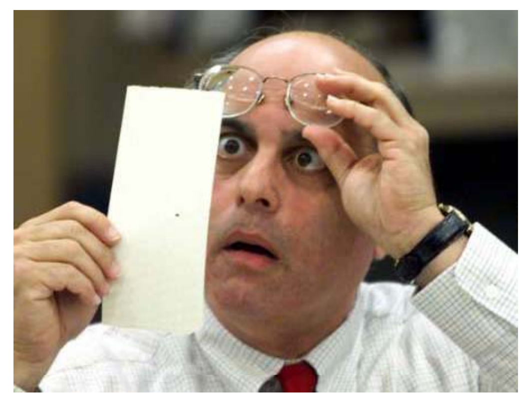
# Outline

- Introduction / Voting
- Voting using mix-nets
- Randomized Partial Checking (Jakobsson/Juels/Rivest USENIX '02)
- Pedagogic variant of Chaum's proposal

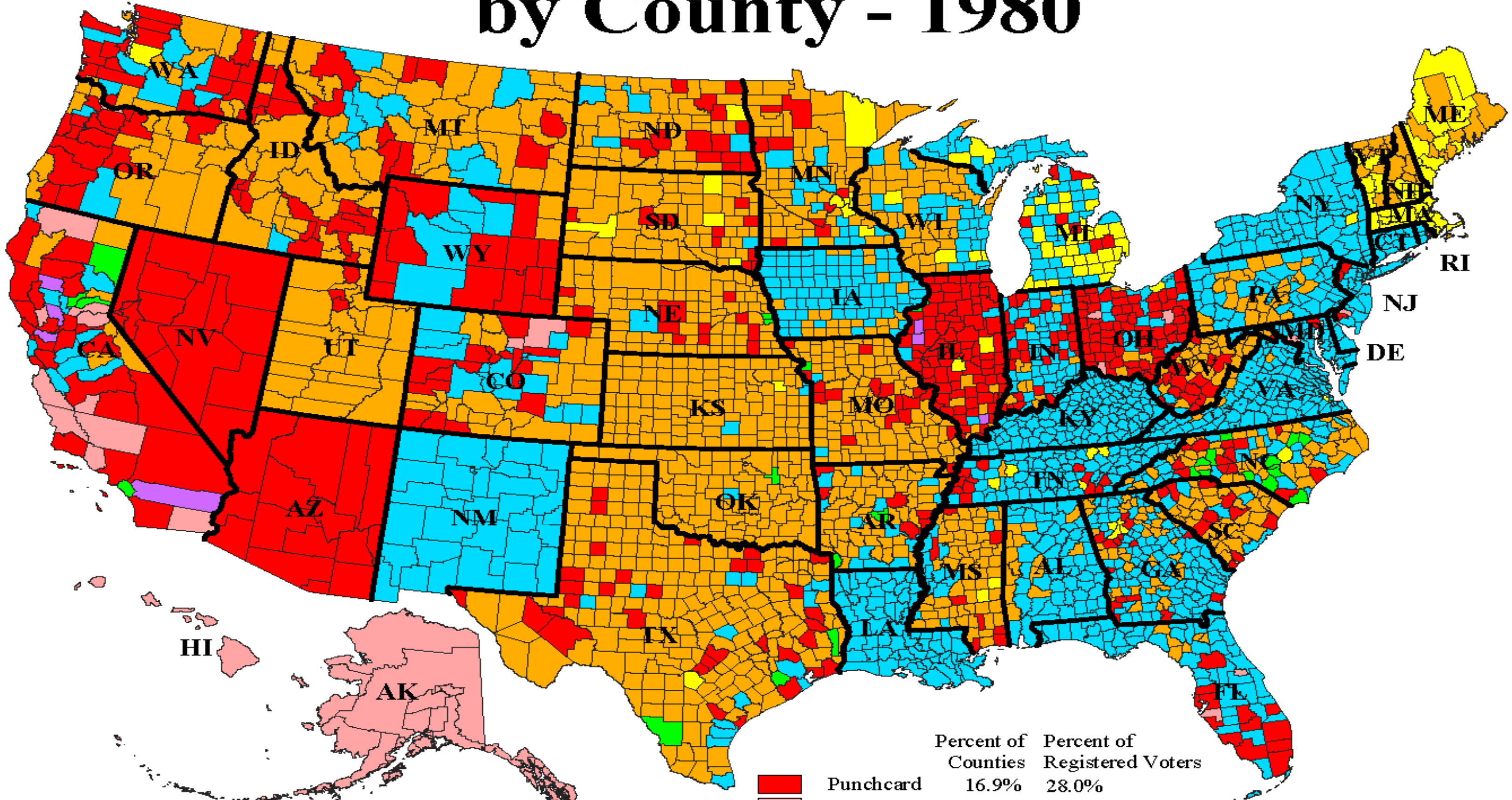
# Voting tech is in transition…

- Voting tech follows technology:
  Stones → Paper → Levers →
  Punch cards → Op-scan →
  Computers(??)
- Punch cards "out" after Nov. '00
- DRE's (touch-screen) require VVPAT (voter-verified paper audit trail) in Cal.
- Is technology ready for electronic (paperless) voting?





# Type of Voting Equipment by County - 1980




Alaska does not have counties.
Datavote system is used statewide
except for a few paper ballot precincts.

| | Percent of Counties | Percent of Registered Voters |
|---|---|---|
| Punchcard | 16.9% | 28.0% |
| DataVote | 1.1% | 3.0% |
| Lever | 36.9% | 42.9% |
| Paper | 41.0% | 10.8% |
| Optical | .8% | 2.1% |
| Electronic | .2% | .7% |
| Mixed Systems | 3.0% | 12.5% |

Equipment used in the November 1980 election as reported by state election officials. The map shows equipment used at polling places, not necessarily absentee balloting.



Election Data Services
(202) 789-2004
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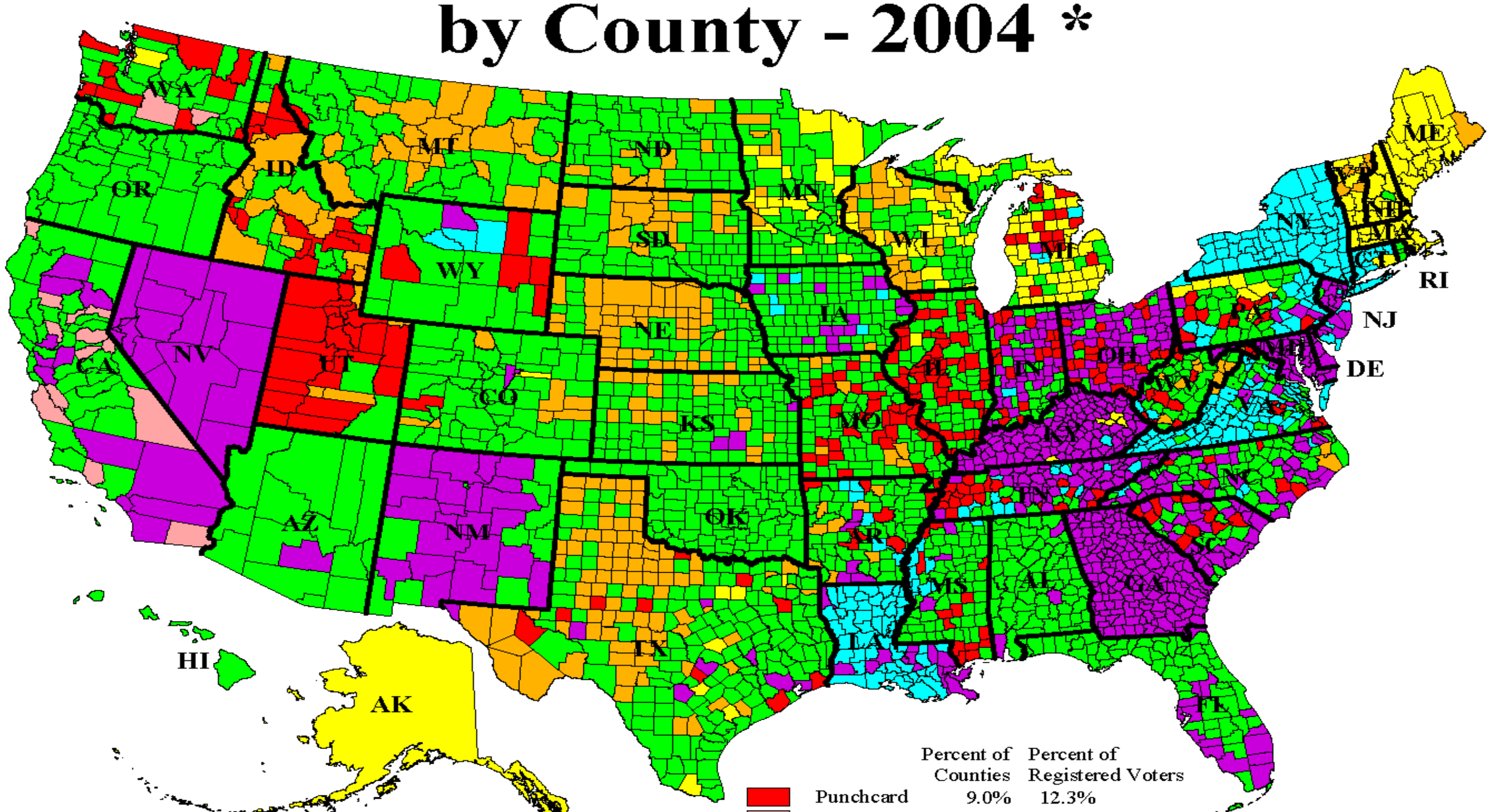
# Type of Voting Equipment by County - 2004 *

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Accuvote system is used statewide
except for a few paper ballot precincts.

| | Percent of Counties | Percent of Registered Voters |
|---|---|---|
| Punchcard | 9.0% | 12.3% |
| DataVote | .8% | 1.4% |
| Lever | 8.6% | 13.9% |
| Paper | 9.6% | .7% |
| Optical | 45.4% | 33.7% |
| Electronic | 21.7% | 30.8% |
| Mixed Systems | 4.8% | 7.2% |

* Equipment expected to be used in the November 2004 election as reported by state election officials. The map shows equipment used at polling places, not necessarily absentee balloting.


*Printed with information available as of 5/3/2004.

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# Voting is a hard problem

- **Voter Registration** - each eligible voter votes at most once
- **Voter Privacy** – no one can tell how any voter voted, even if voter wants it; no "receipt" for voter
- **Integrity** – votes can't be changed, added, or deleted; tally is accurate.
- **Availability** – voting system is available for use when needed
- **Ease of Use** – esp. for disabled

# Voting is important

- Cornerstone of our (any!) democracy
- *Voting security is clearly an aspect of national security.*
- "Those who vote determine nothing; those who count the votes determine everything." -- *Joseph Stalin*

# Are DRE's trustworthy?

- Diebold fiascoes..??
- Intrinsic difficulty of designing and securing complex systems


- Many units (100,000's) in field, used occasionally, and managed by the semi-trained
- Certification process is "riddled with problems" (NYT editorial 5/30/04)

# Voter-Verified Paper Audit Trails?

- Rebecca Mercuri: Voting machine should produce "paper audit trail" that voter can inspect and approve.
- VVPAT is "official ballot" in case of dispute or recounts.
- David Dill (Stanford CS Prof.) initiated on-line petition that ultimately resulted in California requiring VVPAT's on many DRE's.

# VVPAT's controversial…

- Still need to guard printed ballots.
- Two-step voting procedure may be awkward for some voters (e.g. disabled).
- Doesn't catch all problems (e.g. candidate missing from slate)
- Malicious voters can cause DOS by casting suspicion on voting machine
- Not *"end-to-end"* security:
  - Helps ensure votes "cast as intended"
  - Doesn't help ensure votes "counted as cast".

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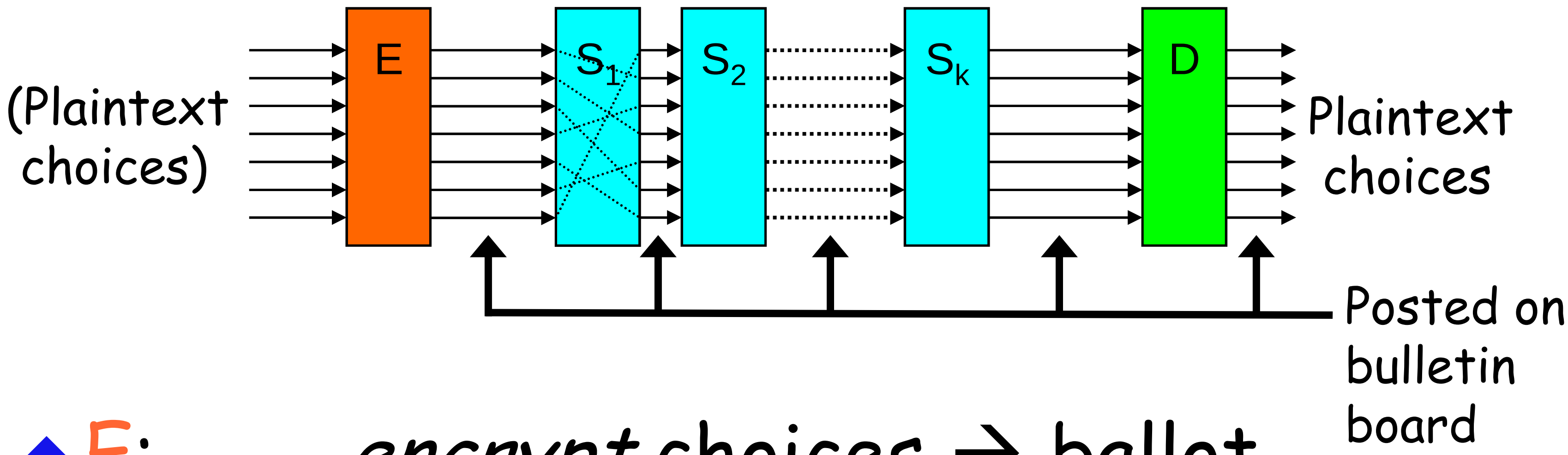
# Can *cryptography* help?

- Yes – using "mix-nets" (Chaum) and "voter-verified secret ballots" (Chaum; Neff)
- Official ballot is *electronic* not paper.
- Ballot is *encrypted* version of choices.
- Ballots posted on public *bulletin board*.
- Voter gets paper "receipt" so she can:
  - Ensure that her ballot is properly posted
  - Detect voting machine error or fraud

# Voting using mix-nets




- E: *encrypt* choices → ballot
(done at each voting machine)
- $S_1 \ldots S_k$: *mix-servers* provide anonymity
(secretly permute and re-encrypt)
- D: *decrypt* ballots
(trustees threshold decrypt)

# Voter needs evidence

- That her vote is "cast as intended":
- That her ballot is indeed encryption of her choices, and what her ballot is.
  - This is extremely challenging, since
    - She can't compute much herself
    - She can't take away anything that would allow her to prove how she voted
- So: she takes away *evidence* that allows her (as she exits polling site) to detect whether cheating occurred, and *receipt* to prove what her ballot is.

# Everyone needs evidence

- That votes are "counted as cast":
- That mix-servers ("mixes") properly permute and re-encrypt ballots.
  - This is challenging, since
    - Mixes can not reveal the permutation they applied to ballots
- That trustees properly decrypt the permuted ballots
  - This is relatively straightforward, using known techniques.

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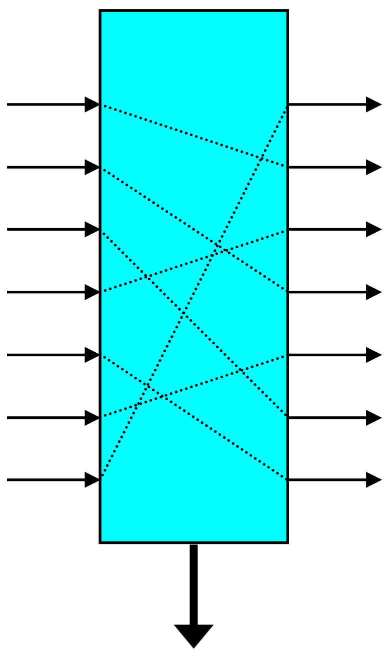
# *Robust* mixes




- Provide *proof* (or at least *strong evidence*) of their correct operation.
- *Anyone* can check proof.
- Even if all mixes are corrupt and collude, it is infeasible for them to produce such proof (*universally verifiable*).
- Proof does not reveal input / output correspondence!

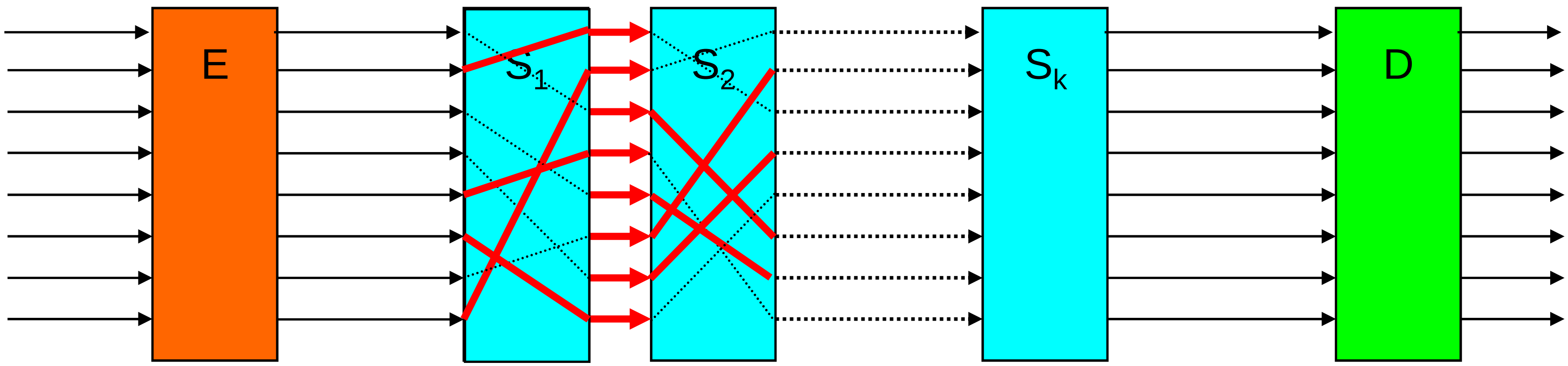
# Practical Robust Mixes

- Jakobsson "Flash Mix" (PODC '99)
- Mitomo and Kurosawa (Asiacrypt '00)
- Desmedt and Kurosawa (EC '00)
- Neff (ACM CCS '01)
- Furukawa-Sako (Crypto '01)
- Golle (ACM CCS '02)
- Golle, Zhong, Boneh, Jakobsson, Juels (Asiacrypt '02)
- …

# "Randomized Partial Checking Mix

- Conceptually very simple
- Very efficient
- Works with any cryptosystem
- Aimed at voting
- Force each mix to reveal and prove *half* of its input-output correspondences
- No complete path from input to output revealed; voter's anonymity preserved within set of at least $\frac{1}{2}$ the voters.

# RPC illustrated




- Mixes are *paired* ($S_1$,$S_2$), ($S_3$,$S_4$), etc.
- For each ballot B between elements of a pair (e.g. ($S_1$,$S_2$)), produce "challenge bit" *b* from hash of all bulletin board contents
- If *b* = 0, first server must reveal where B came from and prove it by revealing keys/randomness.
- If *b* = 1, second server must reveal where B goes and prove it by revealing keys/randomness.

# Security theorem

- An adversary who queries random oracle (≈ hash function) at most $q$ times will have a chance of at most $q\,2^{-t}$ of producing a bulletin board transcript that passes public verification yet where the vote count has been altered by $t$ votes.

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# A pedagogical variant of Chaum's voting proposal

- Used in my class this spring as introductory example, before going into details of Chaum's and Neff's schemes.
- Captures many significant features, but not all; some problems/concerns not well handled.
- Intended to be simpler to explain and understand than full versions.
- Related to Jakobsson/Juels/Rivest RPC mix-net scheme.
- Main ideas (e.g. cut and choose) already present in Chaum's scheme.

# Pedagogical variant (overview)

- Voting machine produces ballot that is *encryption* of voter's choices.
- Ballot is posted on bulletin board as "official cast ballot" (electronic).
- Voter given *receipt copy* of ballot.
- Voter given *evidence* that ballot correctly encodes his intended choices.
- Ciphertexts "mixed" for anonymity.
- Ciphertexts decrypted and counted (threshold decryption by trustees).

# Pedagogical variant (details)

- Voter $V_i$ prepares choices $B_i$
- Machine prints and signs $B_i$, $C_i$, $D_i$, $r_i$, $s_i$ and gives them to voter.
  $C_i$ is encryption of $B_i$ (randomization $r_i$)
  $D_i$ is re-encryption of $C_i$ (randomization $s_i$)
- If voter doesn't like $B_i$ , she starts over.
- Voter destroys either $r_i$ or $s_i$ , and keeps the other information as *evidence* (paper).
- Voting machine signs and posts ($V_i$, $D_i$,"final"), and gives (paper) *receipt copy* to voter.
- Final $D_i$'s mixed up (mixnet), decrypted, and counted.

# Pedagogical variant (details)

$$B_i \xrightarrow{r_i} C_i \xrightarrow{s_i} D_i$$

- El-Gamal encryption and re-encryption:
  $C_i = (g^{r_i}, B_i{*}y^{r_i}),\ \ D_i = (g^{r_i+s_i}, B_i{*}y^{r_i+s_i})$
- Voter keeps only one link as evidence (similar to Jakobsson/Juels/Rivest, or Chaum)
- Any attempt by voting machine to cheat will be detected with probability $\frac{1}{2}$.
- Voter can check evidence on exit.
- Signed $B_i$'s are easy to get…

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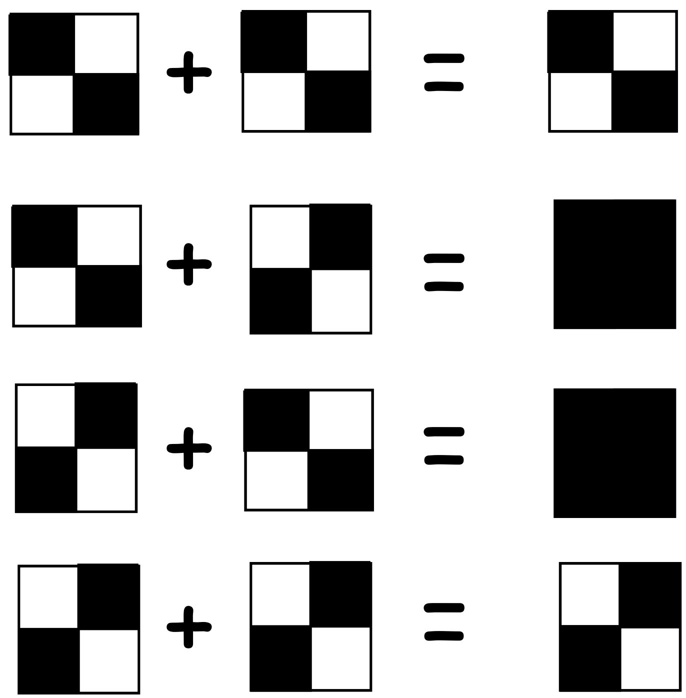
# Variant with “visual crypto”

- Naor/Shamir: can do “xor” visually:



0 + 0 = 0

0 + 1 = 1

1 + 0 = 1

1 + 1 = 0

# Variant with visual crypto

$$
\begin{array}{rl}
 & B'_i \xrightarrow{r'_i} D'_i \\
+ & B''_i \xrightarrow{r''_i} D''_i \\
\hline
 & B_i
\end{array}
$$

- Print $B_i'$ and $B_i''$ on transparencies
- Visually verify $B_i' + B_i'' = B_i$
- Keeps $D'_i$, $D''_i$, and <u>either</u> $(B'_i, r'_i)$ <u>or</u> $(B''_i, r''_i)$

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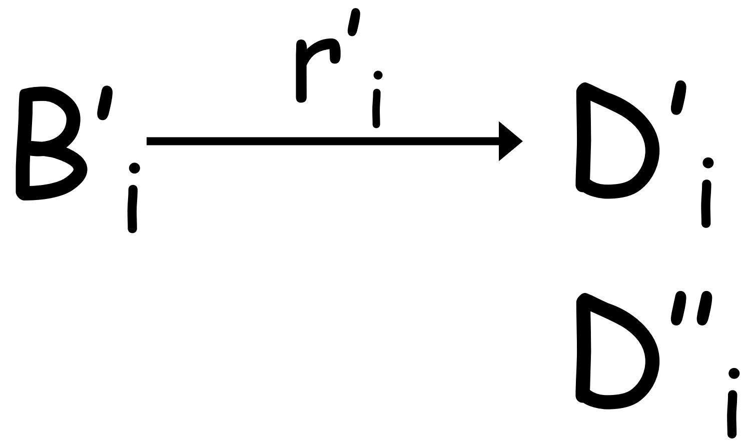


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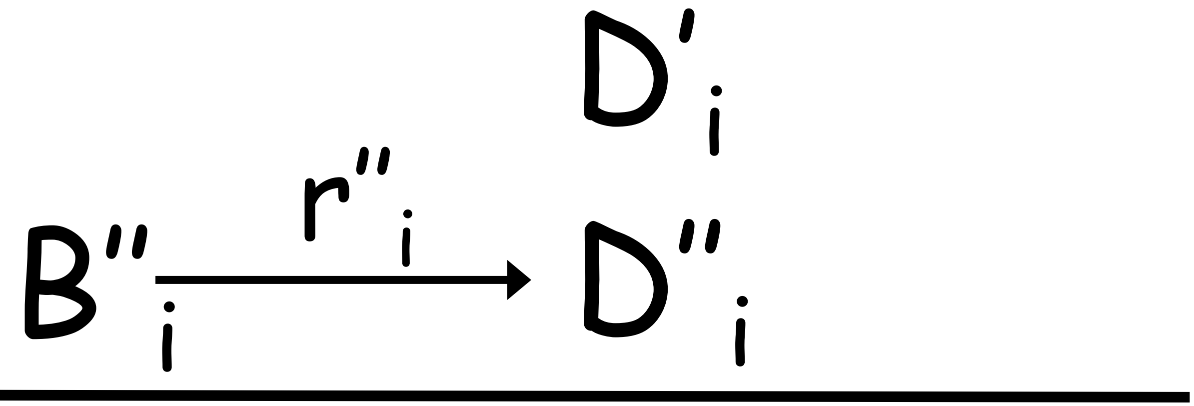


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# Variant with visual crypto

- Any attempt by voting machine to cheat will result in detection with probability $\frac{1}{2}$.

# Pedagogical variant (summary)

- Schemes such as these (Chaum / Neff) provide an interesting degree of *"end-to-end"* security: from *voter's intentions* to *final tally.*
- Paper is used, but not to record official ballots or for recounts, but as *commitments* so fraud and error can be detected.

# Conclusions

- Voting technology is in a state of transition to electronics.
- It seems possible to have electronic voting without:
  - trusting machines for integrity
  - using paper ballots for recounts
  - revealing how any voter votes
- How can we do all of this *well*?

(The End)