Electronic Voting

Ronald L. Rivest
MIT CSAIL

NSA June 3, 2004

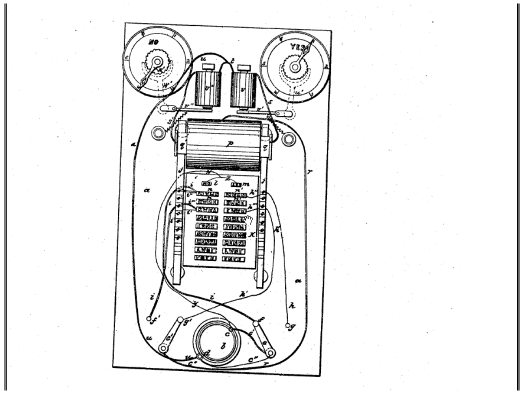
CSAIL

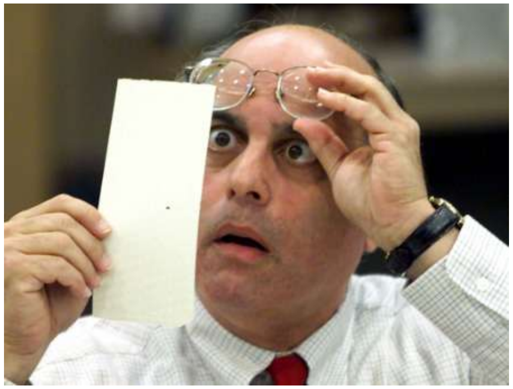
Outline

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

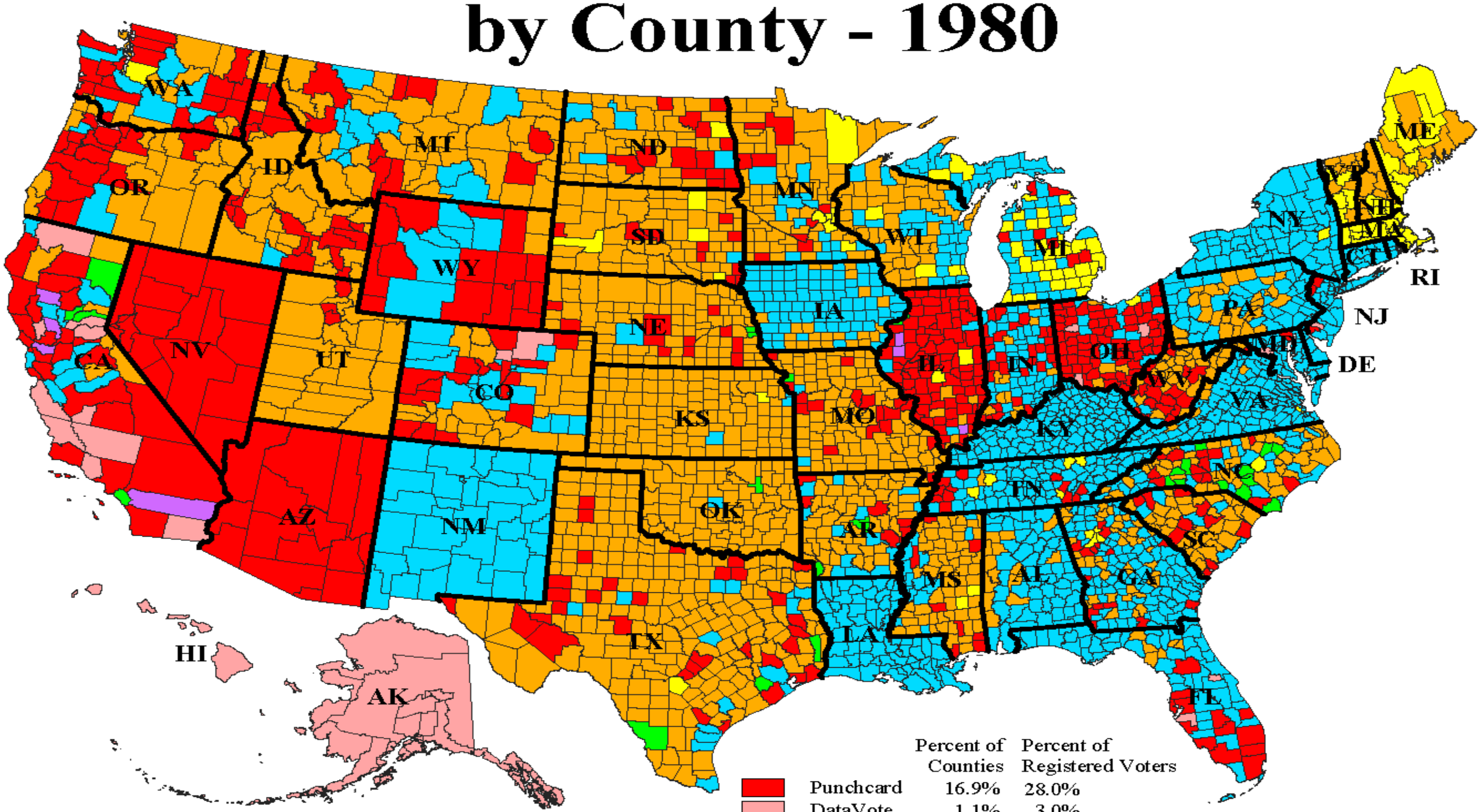
Voting tech is in transition…

- 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.

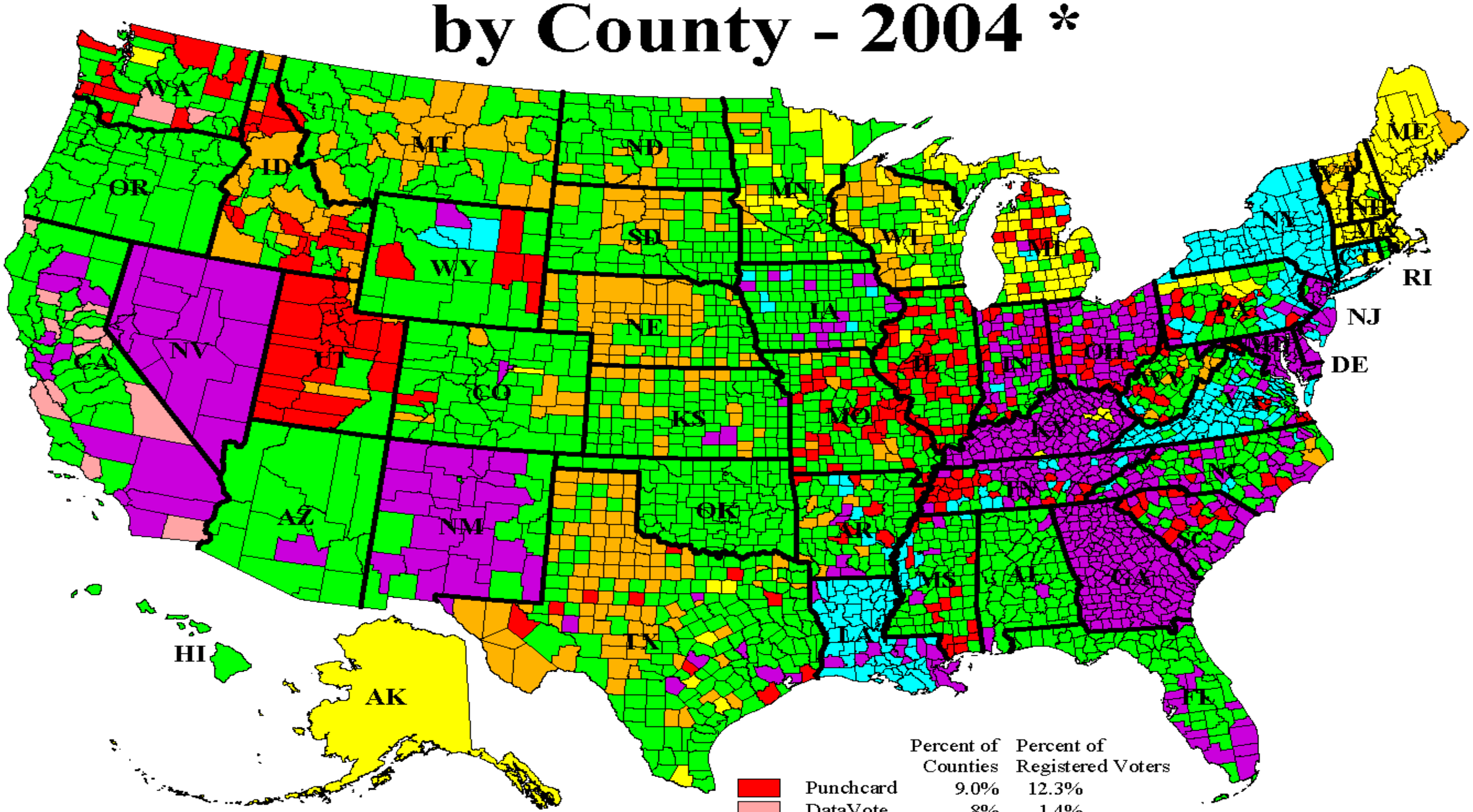
		Percent of Counties	Percent of Registered Voters
🟥	Punchcard	16.9%	28.0%
▨	DataVote	1.1%	3.0%
🟦	Lever	36.9%	42.9%
🟧	Paper	41.0%	10.8%
🟩	Optical	.8%	2.1%
🟪	Electronic	.2%	.7%
🟨	Mixed Systems	3.0%	12.5%

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.

Printed 5/4/2004.

Election Data Services
(202) 789-2004
1401 K Street NW, Suite 500
Washington, DC 20005-3417
www.ElectionDataServices.com

Type of Voting Equipment by County - 2004 *



Alaska does not have counties.
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.

Election Data Services
(202) 789-2004
1401 K Street NW, Suite 500
Washington, DC 20005-3417
www.ElectionDataServices.com

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".

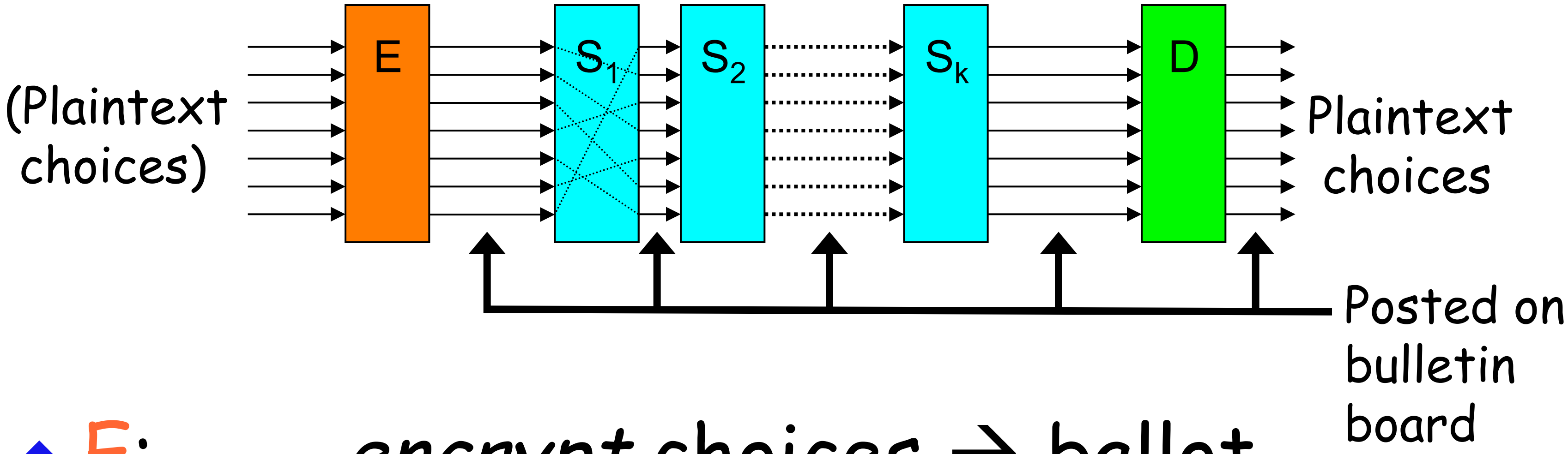
Outline

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

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.

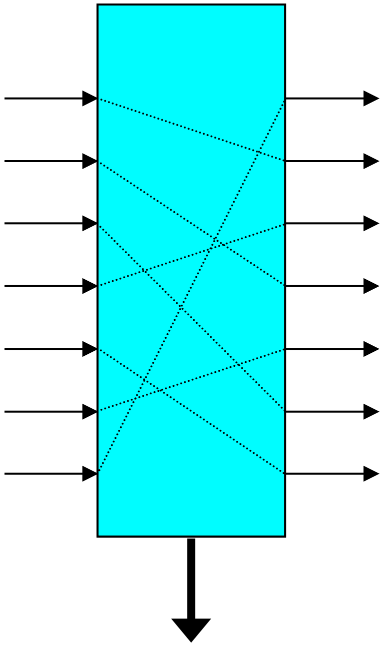
Everyone needs evidence

- 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.

Outline

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

Robust mixes



Proof or evidence

- 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!

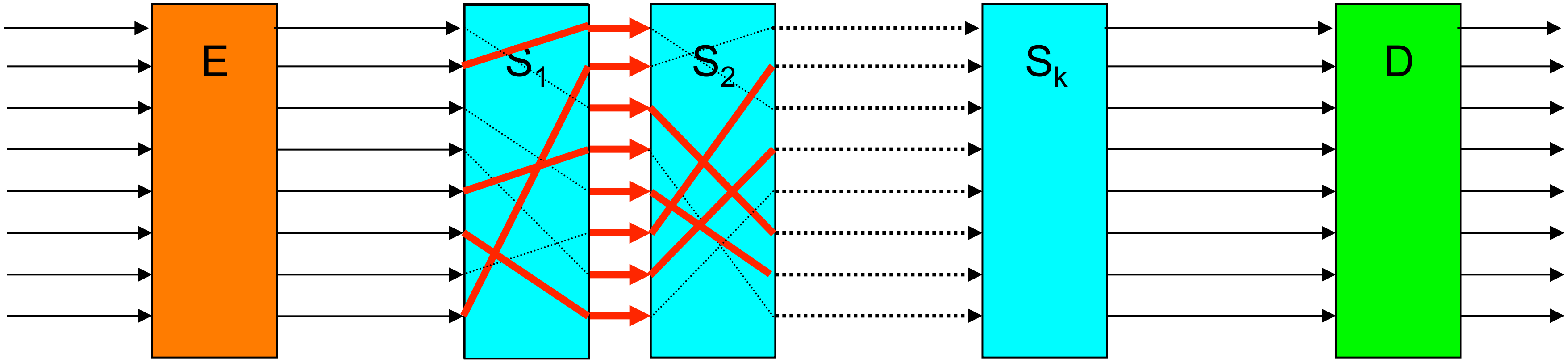
Practical Robust Mixes

- 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 ½ 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.

Outline

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

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 ½.
- Voter can check evidence on exit.
- Signed B_i's are easy to get…

Pedagogical variant (details)

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

- 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 ½.
- Voter can check evidence on exit.
- Signed B_i's are easy to get…

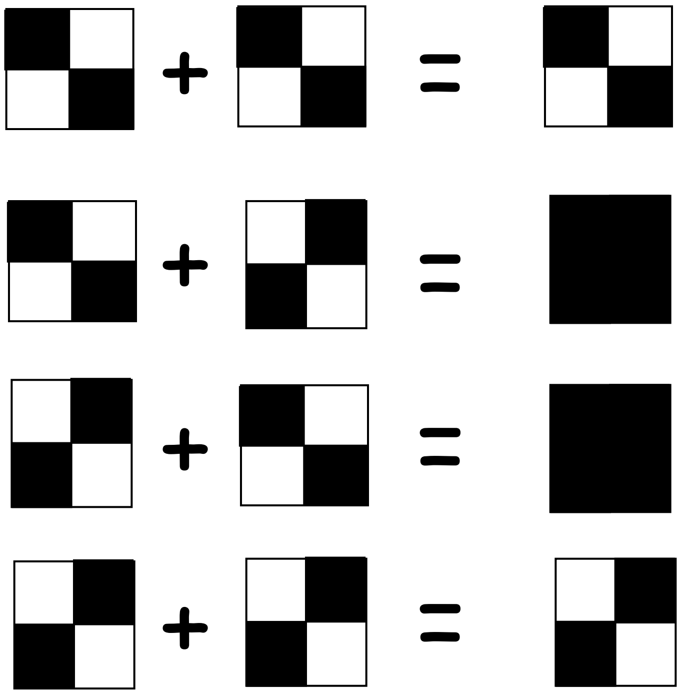
Pedagogical variant (details)

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

- El-Gamal encryption and re-encryption:
  $C_i = (g^{ri}, B_i{*}y^{ri}),\ \ D_i = (g^{ri+si}, B_i{*}y^{ri+si})$
- 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…

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

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

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

Variant with visual crypto

$$\begin{tikzcd}
B'_i \arrow[r, "r'_i"] & D'_i \\
 & D''_i
\end{tikzcd}$$

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

Variant with visual crypto

$$\begin{tikzcd}
 & D'_i \\
B''_i \arrow[r, "r''_i"] & D''_i
\end{tikzcd}$$

- 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)

Variant with visual crypto

- Any attempt by voting machine to cheat will result in detection with probability ½.

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)