On Subliminal Channels in Encrypt-on-Cast Voting Systems

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Ballot Secrecy

Essential

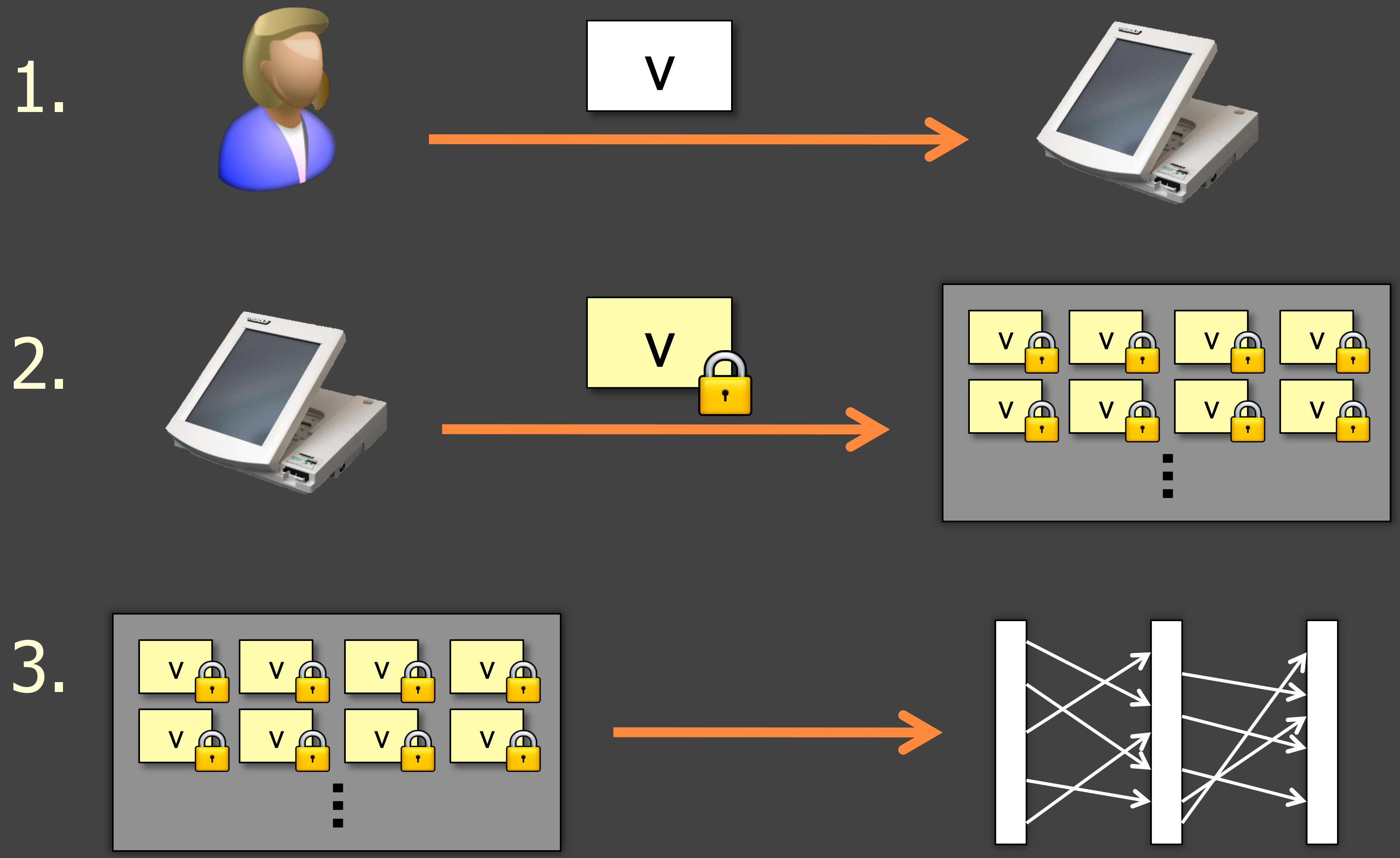
- Potential coercion
- Even possibility of disclosure might affect behavior

Hard

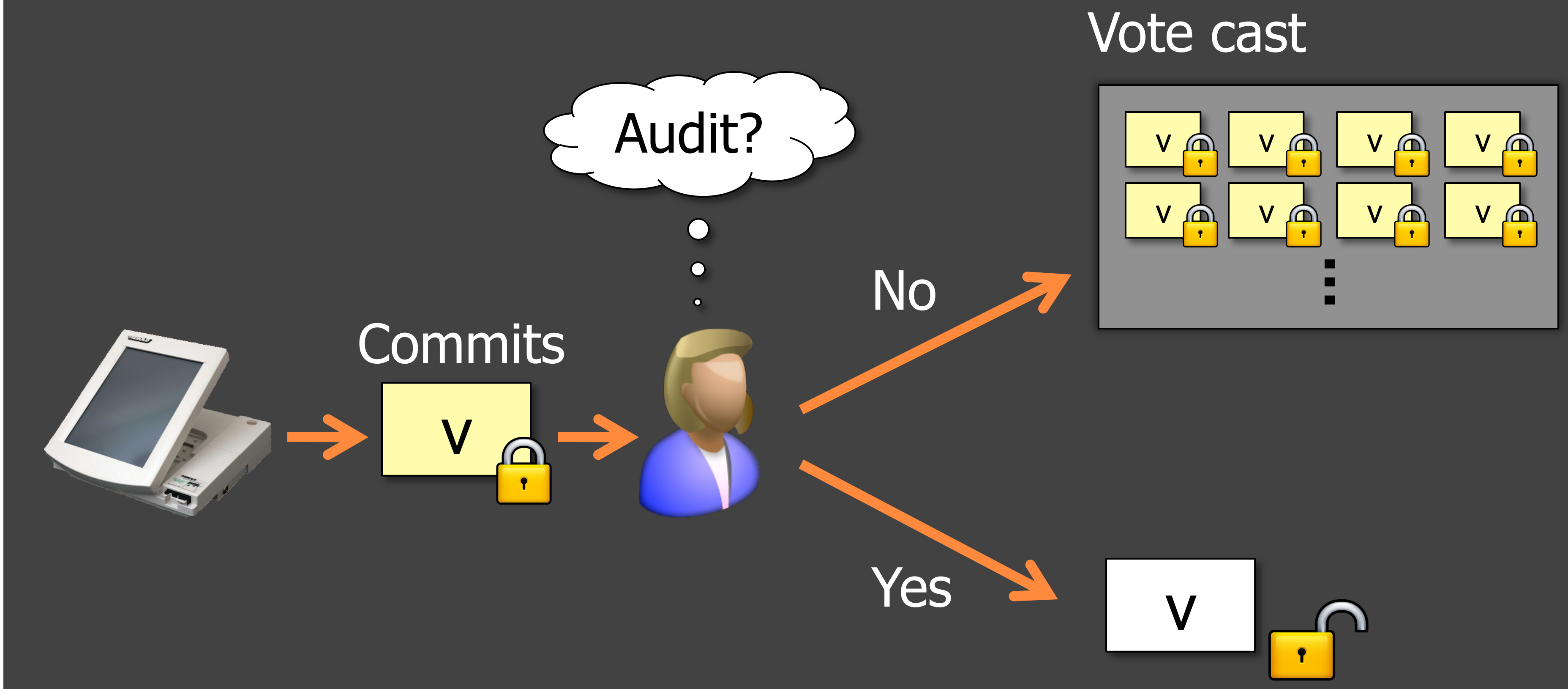
- Cell phone cameras
- Leaks to poll workers
- Distinguishing marks

Cryptographic voting has unique problems

Encrypt-on-Cast (e.g. Benaloh, VoteBox)



Voter-initiated Audits



- Verifiably decrypted
- Vote doesn’t count

Talk Outline

Subliminal Channel Problem

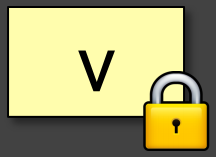
Good News

Bad News

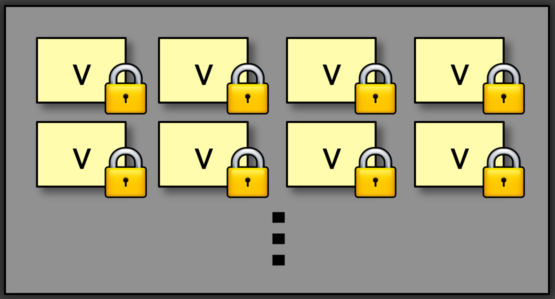
Conclusion

Subliminal Channel Problem

Leaky Bulletin Board [KSW05]



$= E_{pk}(v, r)$



Want to leak: 011001

$E_{pk}(v, r_1) = \ldots 110101$

$E_{pk}(v, r_2) = \ldots 111001$

⋮

$E_{pk}(v, r_n) = \ldots 011001$

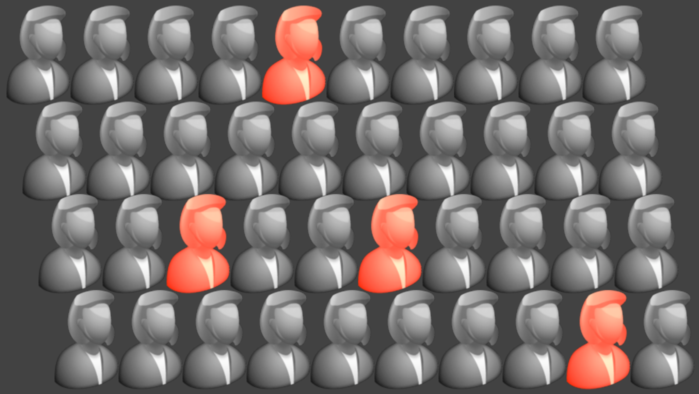
Leak t bits in expected $O(2^t)$ work

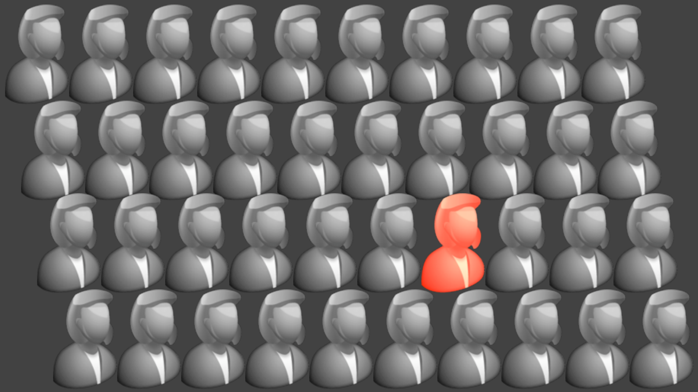
Only Need to Leak a Few Bits

Don’t need to compromise every voter’s vote

(e.g. 1000 voters)

Reveal how 10% voted with 100 bits





Single out a non-compliant voter with 10 bits

Can Audits Solve This? [GGR09]

Set of k trustees generate all randomness

For each vote,

- Trustees generate: $\pi_1, \ldots, \pi_k$
- V $= E_{pk}(v, r')$ where $r' = f(\pi_1, \ldots, \pi_k)$

If vote audited,

V

- Machine reveals r' and $\pi_1, \ldots, \pi_k$
- Can verify $\pi_1, \ldots, \pi_k$ with trustees' public keys

Only for audited votes

Audits Aren’t Enough

Can’t assume a high audit rate —

Auditing is cumbersome

Suppose 5% audit

(95% chance of altering 1 ballot without detection)

Steal 1 vote

OR

Leak 100 bits

10 bits/race with $O(2^{10})$ work, assuming 10 races

Coercion requires corrupting fewer ballots

Good News

Overview

1. Voting machines don't generate randomness
2. Set of k trustees generate all randomness
3. Anyone can check the randomness on every ballot

El Gamal Encryption

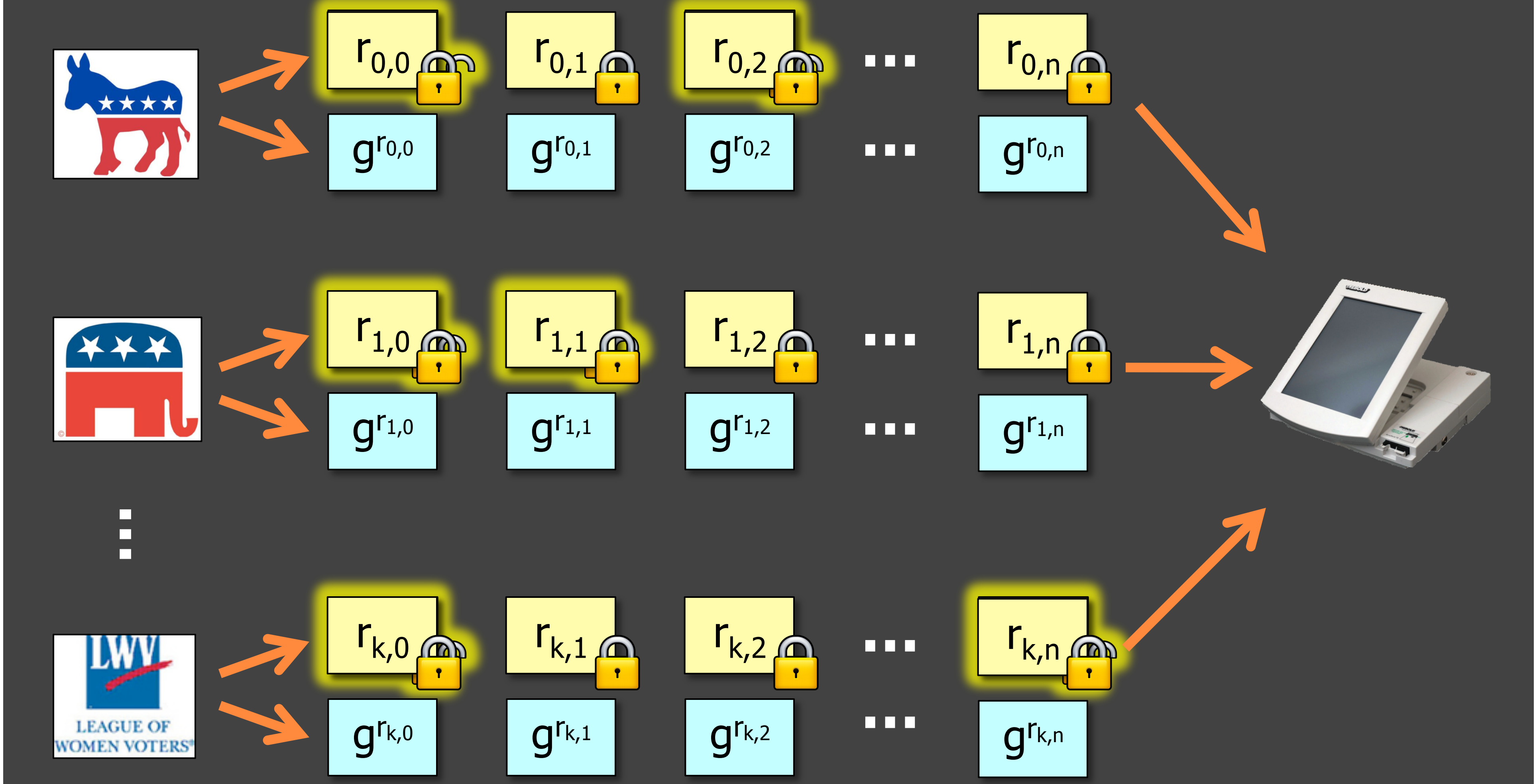
To encrypt,

- Choose random r
- $\boxed{v}$🔒 $= (\alpha, \beta) = (g^r, y^r \bullet v)$

(generator g, public key y)

Before the Election

For each voting machine,



$r_{0,0}$	$r_{0,1}$	$r_{0,2}$	…	$r_{0,n}$
$g^{r_{0,0}}$	$g^{r_{0,1}}$	$g^{r_{0,2}}$	…	$g^{r_{0,n}}$
$r_{1,0}$	$r_{1,1}$	$r_{1,2}$	…	$r_{1,n}$
$g^{r_{1,0}}$	$g^{r_{1,1}}$	$g^{r_{1,2}}$	…	$g^{r_{1,n}}$
⋮				
$r_{k,0}$	$r_{k,1}$	$r_{k,2}$	…	$r_{k,n}$
$g^{r_{k,0}}$	$g^{r_{k,1}}$	$g^{r_{k,2}}$	…	$g^{r_{k,n}}$

During the Election

To encrypt vote $v_{i,}$

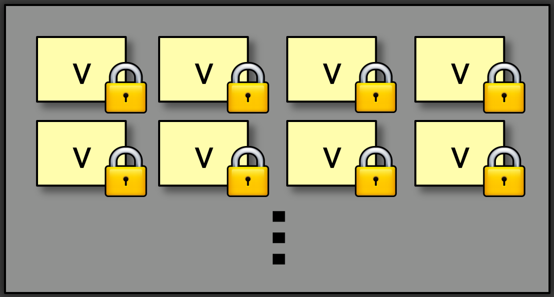
- $\alpha_i = g^{r_{0,i}} \bullet g^{r_{1,i}} \bullet \ldots \bullet g^{r_{k,i}}$
- $\beta_i = y^{r_{0,i}+r_{1,i}+\ldots+r_{k,i}} \bullet v_i$

$\boxed{v_i}$ 🔒 $= (\alpha_i, \beta_i)$

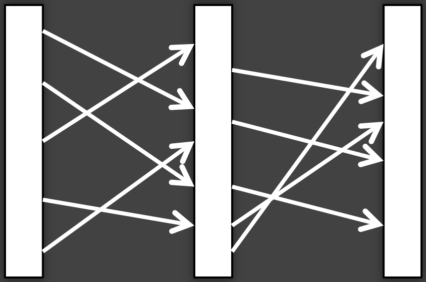
Combine trustees' random values

Must use the i^{th} values

After the Election



1. For encrypted vote (α_i, β_i), check that $\alpha_i = g^{r_{0,i}} \bullet g^{r_{1,i}} \bullet \ldots \bullet g^{r_{k,i}}$



2. Rencryption mixnet + decryption

3. To verify β_i, check that it decrypts to a valid vote

Why Does This Work?

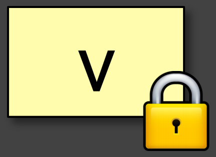
Corrupted encrypted vote (α_i, β_i')

Then, $\beta_i' = y^{r_{0,i}+r_{1,i}+\ldots+r_{k,i}} \bullet v_i'$

- If v_i' is invalid, coercer will be caught
- If v_i' is valid, it's equivalent to vote-flipping

Bad News

Vote-flipping Can Leak



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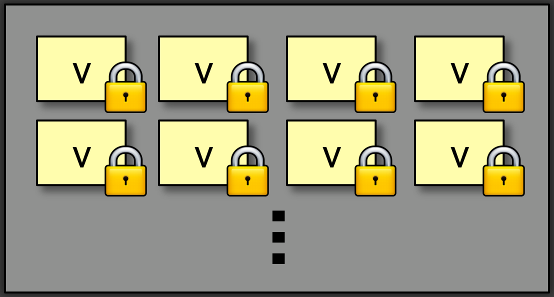

Want to leak: 011001

$E_{pk}(v_1, r) = \ldots 110101$

$E_{pk}(v_2, r) = \ldots 111001$

$\vdots$

$E_{pk}(v_n, r) = \ldots 011001$

George Washington

Abraham Lincoln

⋮

Adlai Stevenson

Vote-flipping Can Leak (cont.)

Low bandwidth — can fail to leak desired bits

Coercer can deal with this

- Only leak bits in races with enough candidates
- Use an error-correcting code

Previous mitigation strategy won’t work

Conclusion

Conclusion

Subliminal channels are a particular threat to encrypt-on-cast voting systems

Coercion requires corrupting fewer ballots than vote-stealing (auditing may not catch it)

Verifying the randomness used to encrypt every vote is a partial mitigation

Vote-flipping itself is a subliminal channel

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