

Elections, Computer Security, and Electronic Voting

CS 334
Thanks to
David Wagner,
UC Berkeley
for providing these
slides.

Some History

- One early method, dating back to the Romans, involved each voter casting a colored ball into an urn. The color represented the vote. The Masons used this to vote on new members - white meant accept, black meant to refuse membership - hence the term "blackball".
- In Italian, they were called ballota - literally, "little balls" - which is where the word "ballot" comes from.
- The painting on the following slide shows an election held in Missouri in 1846. The person in the red shirt is a voter taking the oath; he will state who he is voting for out loud, and the clerk records his vote. The person tipping his hat is a candidate for office - notice that he is soliciting votes right at the polling place.



Some History

- The painting on the following slide shows an election held in Missouri in 1846. The person in the red shirt is a voter taking the oath; he will state who he is voting for out loud, and the clerk records his vote. The person tipping his hat is a candidate for office - notice that he is soliciting votes right at the polling place.
- Some obvious drawbacks:
 - No privacy for the voter - everyone, including the candidates, heard how you voted.
 - The lack of privacy created serious problems of bribery and intimidation, and soon led to a consensus for systems that keep the voter's vote secret.

Some History

- In the mid-1880s, many states gravitated towards paper ballots, where the voter writes down who they want to vote for on a slip of paper and drop it into a ballot box.
- Voters had to provide their own slip of paper, and writing out all candidate names was somewhat inconvenient for voters.
- So...The slip of paper on the following slide was probably torn from a newspaper ad paid for by Francis Gehon (a candidate in the 1839 Iowa election), printed as a convenience to voters who wanted to vote for him.

For Delegate to Congress.
FRANCIS GEHON.
For Representatives.

John Priestow
S. S. Lathrop

For County Commissioners.

Abner Walcott
John Mayford

For Treasurer.

John Higgins

For Surveyor.

Cyrus Sanders

For Assessor.

L. B. Mulholland

For Coroner.

John Hawthorn

For Constable.

John Royal
Dorise Lippert
Shirley
A. D. Stephen

Some History

- The practice of candidates and parties pre-printing ballots proved effective and soon became very widespread.
- On the following slide, two tickets pre-printed by the Republican party for an election (the left is from an 1880 Iowa election). The party handed these out and printed them in newspapers, hoping that voters would take them and vote as is.
- Note that these are not merely fliers or advertisements - voters were expected to take these and cast them directly into the ballot box.
- Voters were free to scratch out any names they didn't like, and write in some other candidate

REPUBLICAN TICKET.

For Mayor,
M. F. FAIRCHILD.

For City Solicitor,
J. P. DOLLIVER.

For City Assessor,
L. G. SPRING.

For City Treasurer,
BETH VINCENT.

For Councilman—4th Ward,
A. H. JOHNSON.

REPUBLICAN TICKET.

STATE TICKET.

For Governor,
WILLIAM LARRABEE,
Of Fayette County.
For Lieutenant Governor,
JOHN A. T. HULL,
Of Polk County.
For Judge of the Supreme Court,
GIFFORD S. ROBINSON,
Of Buena Vista County.
For Superintendent of Public Instruction,
HENRY SABIN,
Of Clinton County.

County Ticket

For Senator Thirty-sixth District,
J. P. PATRICK.
For Representative Seventieth District,
W. W. GOODWIN.
For Auditor,
JULIUS H. BUHLMAN.
For Treasurer,

For Sheriff,
WILLIAM WELLMAN.
For County Superintendent,
JAMES W. WYATT.

For Supervisor,
PATRICK COSTIGAN.

For Coroner,
L. L. RENSHAW.

For Surveyor,
SANFORD L. PECK.

Township Ticket.

For Trustee,

For Constable,

For Road Supervisor District No.

Some History

- Over time, parties learned tricks to make deviating from the party ticket as inconvenient as possible for voters.
 - So note that the right ticket was apparently deliberately formatted to be hard to read, leaving little white space to write in some other candidate.
 - These schemes proved effective at getting voters to toe the party line and greatly reduced the rate of defection in down-ticket races.

Some History

Following slide: A ticket pre-printed by the Union party in 1851. On the left, the front of the pre-printed ticket; on the right, the back side. As you might expect, printing in color and on two sides is more expensive than printing in black-and-white on one side. Why do you suppose the Union party leaders chose to spend their money this way?

10th District.

ADMINISTRATION UNION TICKET

For Mayor.
CALEB T. FAY

For County Judge.
THOS. W. FREELON

For District Attorney.
CHARLES H. PARKER

For County Clerk.
JOHN A. MONROE

For Sheriff.
THOMAS J. POULTERER

*For Recorder, to fill the vacancy for the unexpired
term of G. W. Beck, resigned.*

GEORGE B. REEVE

For County Recorder.
GEORGE B. REEVE

For City and County Treasurer.
ASA T. LAWTON

For City and County Assessor.
THOS. D. MATHEWSON

For City and County Surveyor.
REED BIGLER

For Coroner.
DR. B. A. SHELDON

For Harbor Master.
CAPT. N. PROCTOR SMITH

For Superintendent of Common Schools.
JOHN H. BREWER

*For Supervisor.....*STEPHEN C. STORY
*For School Director.....*J. M. BUTTINGTON
*Inspector of Election.....*J. B. F. DAVIS
*Judge of Election.....*J. M. KEARNEY

Fifth Township.
*Justice of the Peace.....*GEO. T. BOULDEN
*Constable.....*PHINEAS HOWARD, JR.

"Subscription of Three Hundred Thousand
Dollars, to the San Francisco and San Jose Rail-
road Company." YES.

Polls—Brick Building westerly side of Third,
between Folsom and Harrison streets.

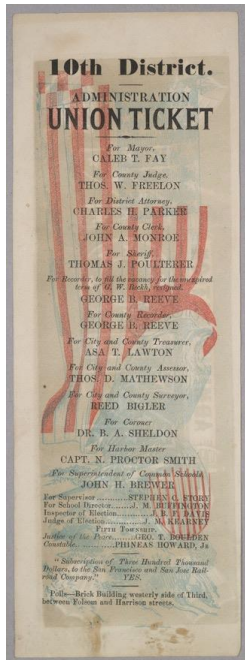


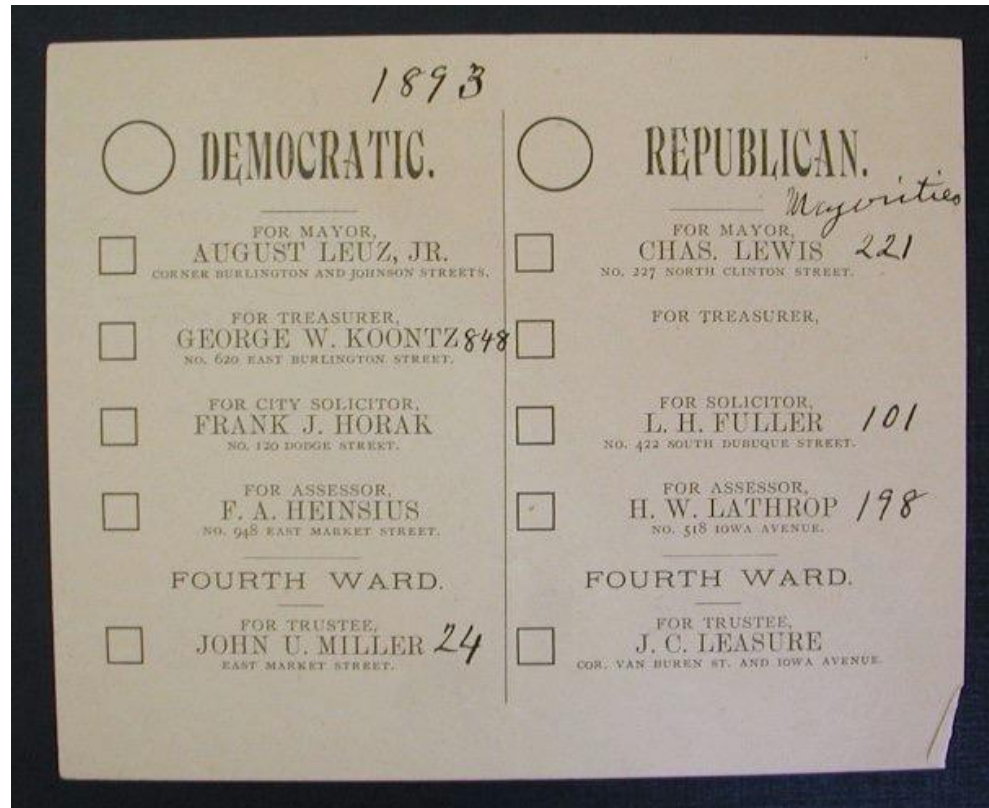
Some History

- Why do you suppose the Union party leaders chose to spend their money this way?
- The most likely answer is that this design would make it very easy to tell when voters cast the Union party ticket into the ballot box.
 - This allowed vote-buying, coercion, and intimidation of voters - sometimes subtle, sometimes not. Over time, parties learned how to exploit this weakness in the system to good effect.
- The security problem with the system: voters were able to prove how they voted, and this opened them up to intimidation and coercion.
 - Indeed, if there was any method of voting (even one not used in the ordinary course of voting) that would let a voter demonstrate how they have voted, then a coercer would pressure the voter to use that method, and the voter might not feel free to resist. It thus became clear that the only workable defense would be to have a system where it is impossible for a voter to **prove** to anyone else how they voted. This is a critical security requirement for an election system.

Security Goals for an Election

- Integrity: No election fraud
- Transparency: Everyone must be able to verify that the election was conducted appropriately
 - Who is more likely to complain about the results of an election?
- Privacy: No one learns how the voter has voted
- Secret ballot: Voter cannot prove how she voted

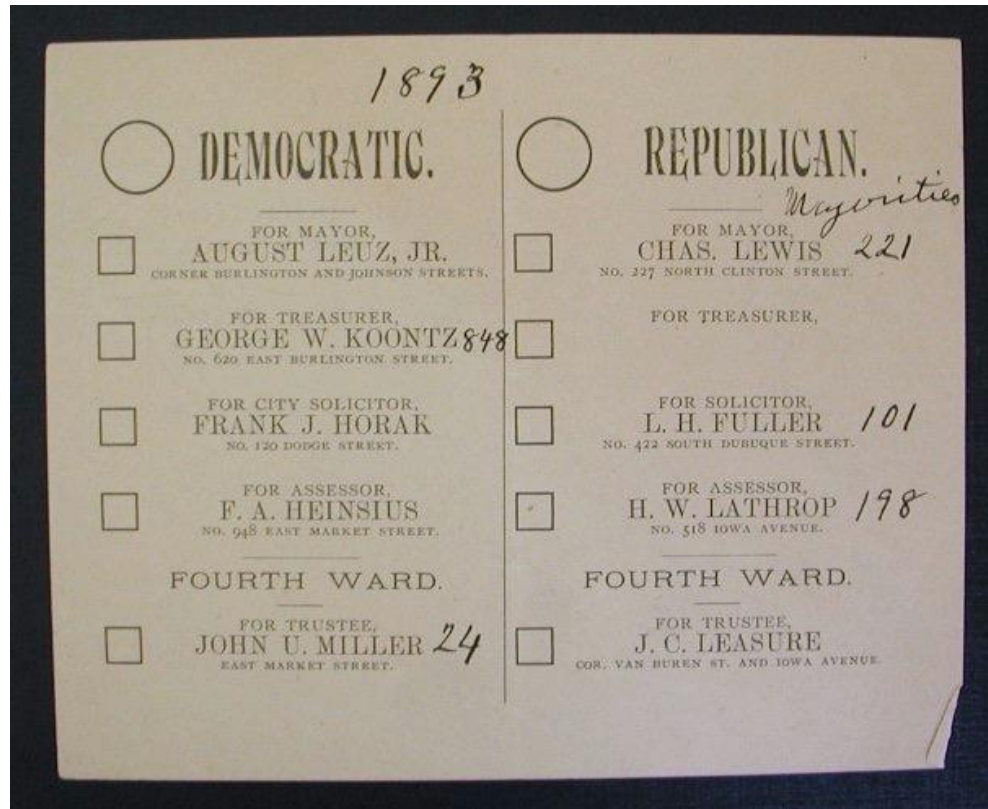




Breakthrough! — the Australian secret ballot.

Ballot printed by govt. Ballot boxes monitored by observers. Ballots counted, by hand, in public. Competing interests keep each other honest.

Key principle: two-person control! (a.k.a. separation of responsibilities)



Breakthrough! — the Australian secret ballot.

Ballot printed by govt. Ballot boxes monitored by observers. Ballots counted, by hand, in public. Competing interests keep each other honest.

Can you think of a practical issue with this?



COLLECTING BOX
RETURN TO OFFICE
Please Return Here

OFFICES

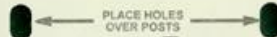
- A
- B
- C
- D
- E
- F
- G

 **HANDICAPPED
ACCESS MACHINE**
ASK AN INSPECTOR FOR
ASSISTANCE IN LOWERING
THE VOTING PANEL
FOR EASIER ACCESS

AMERICAN
Voting Equipment
Manufacturing

 **Browns County
Board of Elections**

ABSENT VOTER BALLOT
STUB A No. 7720



INSERT CARD

THIS SIDE UP

STUB B No. 7720
ABSENT VOTER BALLOT

**IMPORTANT
DO NOT
DETACH STUB**

.	.	39	58	.	115	134	.	191	210
1	20	40	77	96	116	153	172	192	211
.	.	59	78	97	117	135	154	173	193
2	21	41	60	79	98	118	136	155	174
.	.	61	80	99	119	137	156	175	194
3	22	42	62	81	100	120	139	158	177
.	.	63	82	101	121	140	159	178	198
4	23	43	64	83	102	122	141	160	179
.	.	65	84	103	123	142	161	180	199
5	24	44	66	85	104	124	143	162	181
.	.	67	86	105	125	144	163	182	200
6	25	45	68	87	106	126	145	164	183
.	.	69	88	107	127	146	165	184	201
7	26	46	70	89	108	128	147	166	185
.	.	71	90	109	129	148	167	186	202
8	27	47	72	91	110	130	149	168	187
.	.	73	92	111	131	150	169	188	203
9	28	48	74	93	112	132	151	170	189
.	.	75	94	113	133	152	171	190	210
10	29	49	76	95	114	134	153	172	191
.	.	77	96	115	135	154	173	192	211
11	30	50	78	97	116	136	155	174	193
.	.	51	79	98	117	137	156	175	194
12	31	52	80	99	118	138	157	176	195
.	.	53	81	100	119	139	158	177	196
13	32	54	82	101	120	140	159	178	197
.	.	55	83	102	121	141	160	179	198
14	33	56	84	103	122	142	161	180	199
.	.	57	85	104	123	143	162	181	200
15	34	58	86	105	124	144	163	182	201
.	.	59	87	106	125	145	164	183	202
16	35	60	88	107	126	146	165	184	203
.	.	61	89	108	127	147	166	185	204
17	36	62	90	109	128	148	167	186	205
.	.	63	91	110	129	149	168	187	206
18	37	64	92	111	130	150	169	188	207
.	.	65	93	112	131	151	170	189	208
19	38	66	94	113	132	152	171	190	209
.	.	67	95	114	133	153	172	191	210

TO BE FILLED IN BY ELECTION BOARD ONLY
PRECINCT NO. WRITE-IN NO.



INSERT
CARD
HERE



SPECIAL BALLOT
GENERAL ELECTION
NOVEMBER 7, 2000

OFFICIAL BALLOT
GENERAL ELECTION
NOVEMBER 7, 2000

FOR PRESIDENT AND VICE PRESIDENT
OF THE UNITED STATES
(Write in one group)

FEDERAL

GEORGE W. BUSH - PRESIDENT DICK CHENEY - VICE PRESIDENT	(REPUBLICAN)	3→
AL GORE - PRESIDENT JOE LIEBERMAN - VICE PRESIDENT	(DEMOCRATIC)	5→
HARRY BROWNE - PRESIDENT ART OLIVER - VICE PRESIDENT	(LIBERTARIAN)	7→
RALPH NADER - PRESIDENT WINONA LADUKE - VICE PRESIDENT	(GREEN)	9→
JAMES HARRIS - PRESIDENT MARGARET TROWE - VICE PRESIDENT	(SOCIALIST WORKERS)	11→
JOHN HAGELIN - PRESIDENT NAT. GOLDBERGER - VICE PRESIDENT	(NATURAL LAW)	13→

PAT BUCHANAN - PRESIDENT EZOLA FOSTER - VICE PRESIDENT	(REFORM)	4→
DAVID McREYNOLDS - PRESIDENT MARY CAL HOLLIS - VICE PRESIDENT	(SOCIALIST)	6→
HOWARD PHILLIPS - PRESIDENT J. CURTIS FRAZIER - VICE PRESIDENT	(CONSTITUTION)	8→
MUNICA MOOREHEAD - PRESIDENT GLORIA LA RIVA - VICE PRESIDENT	(WORKERS WORLD)	10→

WRITE IN CANDIDATE

To vote for a write in candidate, follow the
directions on the long stub of your ballot card

g turn back
page

"Butterfly Ballot"

CES

VOTOMATIC

Confusion at Palm Beach County polls

Some Al Gore supporters may have mistakenly voted for Pat Buchanan because of the ballot's design.

Although the Democrats are listed second in the column on the left, they are the third hole on the ballot.

Punching the second hole casts a vote for the Reform party.

ELECTORS FOR PRESIDENT AND VICE PRESIDENT (A vote for the candidates will actually be a vote for their electors.) (Vote for Group)	(REPUBLICAN)	3 ➡		
	GEORGE W. BUSH - PRESIDENT DICK CHENEY - VICE PRESIDENT			
	(DEMOCRATIC)	5 ➡		
	AL GORE - PRESIDENT JOE LIEBERMAN - VICE PRESIDENT			
	(LIBERTARIAN)	7 ➡		
	HARRY BROWNE - PRESIDENT ART OLIVIER - VICE PRESIDENT			
	(GREEN)	9 ➡		
	RALPH NADER - PRESIDENT WINONA LaDUKE - VICE PRESIDENT			
	(SOCIALIST WORKERS)	11 ➡		
	JAMES HARRIS - PRESIDENT MARGARET TROWE - VICE PRESIDENT			
(NATURAL LAW)	13 ➡			
JOHN HAGELIN - PRESIDENT NAT GOLDHABER - VICE PRESIDENT				
	(REFORM)	4 ➡		
	PAT BUCHANAN - PRESIDENT EZOLA FOSTER - VICE PRESIDENT			
	(SOCIALIST)	6 ➡		
	DAVID McREYNOLDS - PRESIDENT MARY CAL HOLLIS - VICE PRESIDENT			
	(CONSTITUTION)	8 ➡		
	HOWARD PHILLIPS - PRESIDENT J. CURTIS FRAZIER - VICE PRESIDENT			
	(WORKERS WORLD)	10 ➡		
	MONICA MOOREHEAD - PRESIDENT GLORIA La RIVA - VICE PRESIDENT			
	WRITE-IN CANDIDATE To vote for a write-in candidate, follow the directions on the long stub of your ballot card.			

Another anomaly during the 2000 election

From: Lana Hires

Subject: 2000 November Election

I need some answers! Our department is being audited by the County.

I have been waiting for someone to give me an explanation as to why Precinct 216 gave Al Gore a minus 16022 when it was uploaded. Will someone please explain this so that I have the information to give the auditor instead of standing here "looking dumb".

A Diebold
(now
Premier
Election
Solutions)
DRE



A DRE is a
computer
with a
simple
graphical
interface.
Votes are
recorded
in
electronic
form.



These are Sequoia DREs. They work the same.



This is a DRE built by Election Software Solutions (ES&S)

VOTE

Voting on an iVotronic is as easy as 1, 2, 3

1 Make your selections

Touch the candidate on the screen to make your selection.

☐	
☒	
☐	

Use the Next and Back buttons to view the ballot pages.



2 Review your selections

Touch the contest or the candidate on screen to make changes.

☒	
☒	

3 Cast your ballot

Press the Vote button at the top of the voting machine when it begins to flash OR press the "Cast your ballot now" when it appears on screen.

VOTE



View Ballot



COUNTY NAME, STATE
ELECTION DATE

COUNTY CLERK

BALLOT STYLE

Best Automobile Manufacturer
Vote For ONE

☐	BMW
☐	MERCEDES
☐	GENERAL MOTORS
☒	HONDA
☐	FERRARI
☐	JAGUAR
☐	FORD
☐	VOLVO
☐	Write-In

Best Vocal Artist
(Vote for Not More Than TWO)

☐	FRANK SINATRA
☐	ELVIS
☐	PATSY CLINE
☐	JANIS JOPLIN
☐	BUDDY HOLLY
☒	BARRY WHITE
☐	BILLIE HOLIDAY
☐	STEVIE RAY VAUGHAN
☐	"MAMA" CASS ELLIOT
☒	FA
☐	Write-In

01 / 02



Next



Summary Ballot Instructions

Press the candidate name or contest title to return to a contest.

Vote button will light up when you may cast your ballot.

Press here to cast your ballot now

Best Automobile Manufacturer Vote For ONE



FORD

Best Vocal Artist (Vote for Not More Than TWO)



FA

No selection made.

Best Ice-Cream Flavor Vote For ONE

No selection made.

Proposition 1

No selection made.

Proposition 2

No selection made.



Back

01 / 01



So, Why DREs?

- DREs are flexible
 - They can support multiple languages
 - They make election administration a lot easier, because most tasks are automated
 - Most machines come with an audio interface, so they can be used by blind voters and are accessible to disabled voters
 - This is a big deal. E.g., It means blind voters can vote independently and secretly

Question: How do election security goals apply to touchscreen (DRE) electronic voting machines?

1. Machine must allow each authorized voter to vote exactly once; must prevent tampering with votes after they are cast.
2. Machine should be verifiably trustworthy.
3. Machine must randomize the order in which votes were cast.
4. Machine must not give voter a "receipt".



Security Goals for an Election:
Integrity, Transparency, Privacy, Secret ballot

Nov 4, 2002:

State of Georgia votes on Diebold DREs.

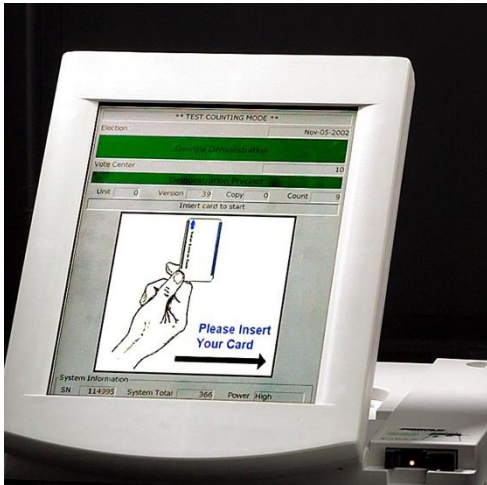
March 18, 2003:

Diebold source code leaks. (It had been accidentally placed on an open FTP site by Diebold, and writer/activist Bev Harris noticed and grabbed a copy.)

July 23, 2003:

Tadayoshi Kohno, Adam Stubblefield, Avi Rubin, Dan Wallach, "Analysis of an Electronic Voting System".

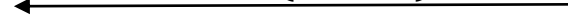
The voter authorization protocol



QueryStatus



ACTIVE (0x01)



(record vote)

smartcard

SetStatus CANCELED (0x08)

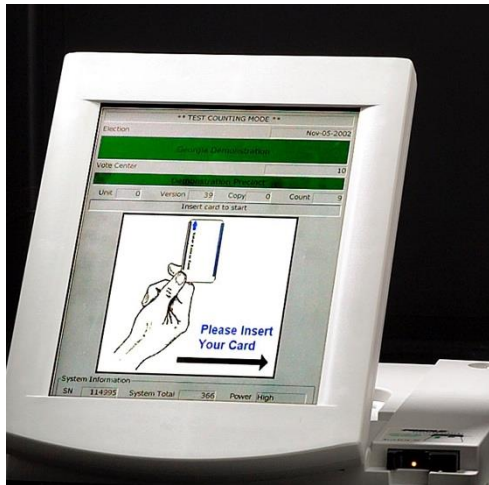


Status = CANCELED

Succeeded



The voter authorization protocol



QueryStatus [Are you a valid card?]

← ACTIVE (0x01) [Yup.]

(record vote)

smartcard

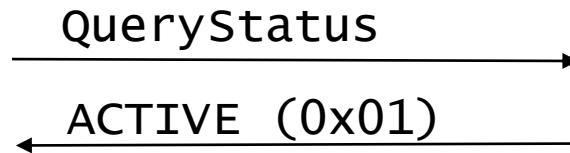
[Please cancel yourself.]

SetStatus CANCELED (0x08)

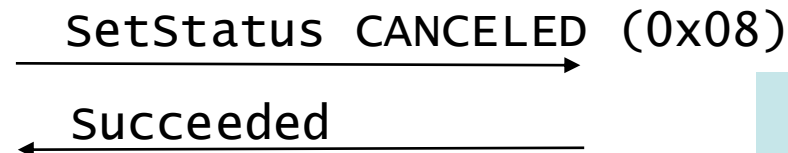
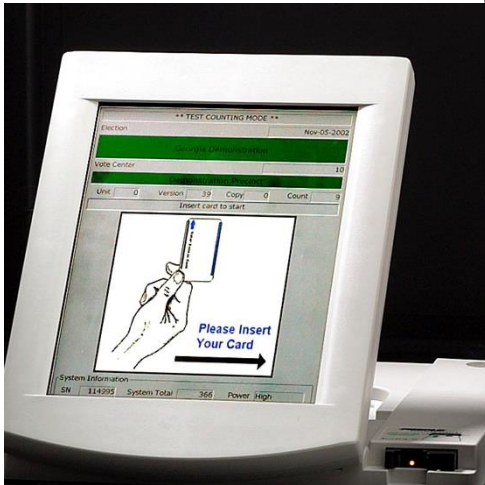
Status = CANCELED

← Succeeded [Ok.]

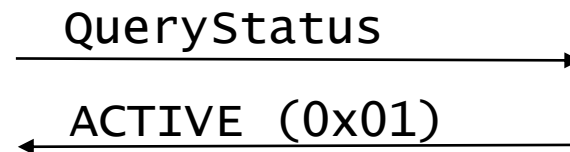
Attack!



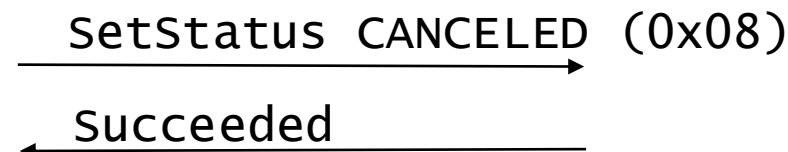
(record vote)



malicious
smartcard



(record another vote)



Authenticating election officials

What kind of card are you?

An administrator card.

smartcard

What's the secret PIN?

2301



What's the secret PIN?

2301

Ok, you have admin access.



Source code excerpts: code to encrypt electronic vote files and audit logs

```
#define DESKEY ((des_key*)"F2654hD4")
```

```
DESCBCEncrypt((des_c_block*)tmp,  
(des_c_block*)record.m_Data, totalSize,  
DESKEY, NULL, DES_ENCRYPT);
```

This parameter is the initialization vector (IV) for "cipher block chaining". It is set to zero. That is a confidentiality flaw. How would you fix this confidentiality flaw?

Source code excerpts

```
// LCG - Linear Congruential Generator -  
// used to generate ballot serial numbers  
// A psuedo-random-sequence generator  
// (per Applied Cryptography, Bruce Schneier)  
  
int lcgGenerator(int lastSN) {  
    return ((lastSN*1366) + 150889)%714025;  
}
```

“Unfortunately, linear congruential
generators cannot be used for cryptography.”
— Applied Cryptography, p.369

Interesting Facts

- So, what was the PRNG used for? For reordering the votes when they were loaded on the tabulator
- Prior to that point, when the votes were recorded and stored in the voting machine, they were stored in the order they were cast
- Thoughts?

Vendor reactions



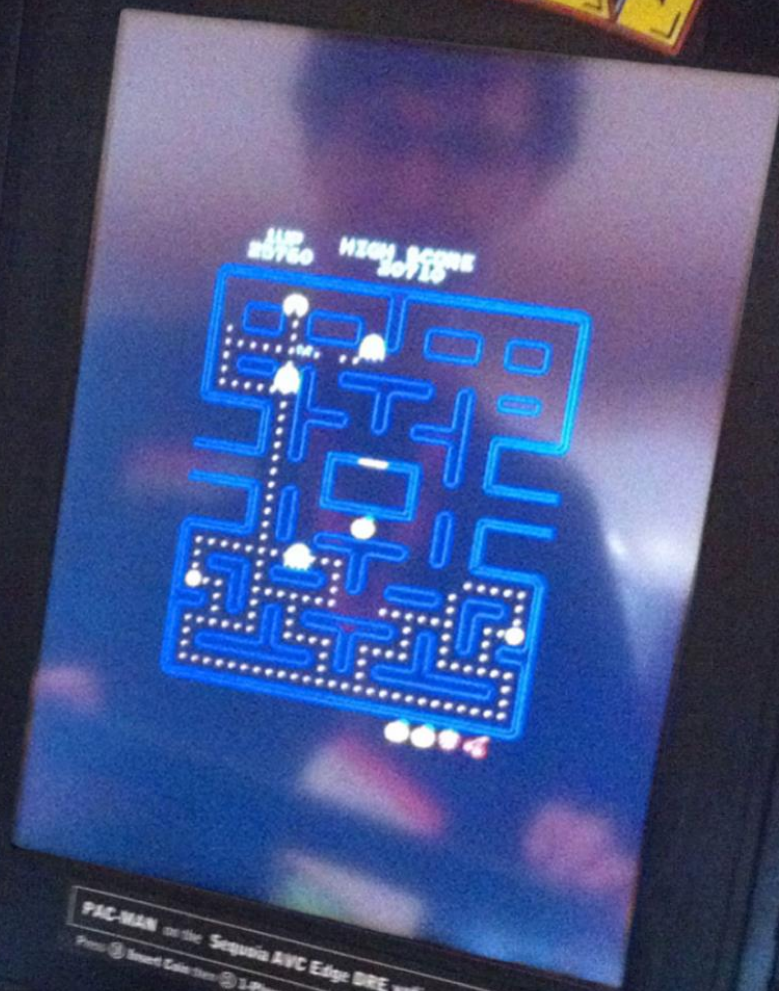
`Not a computer,
can't be hacked.'



Yes it can!



PAC-MAN



PAC-MAN on the Sequoia AVC Edge BIRE voting machine
Press Insert Coin(s) 1-Player or 2-Player. Use to Move.

TOUCH

YOU MAY CHANGE

your vote by touching the same selective again. The candidate is unselected and all circles for the correct appear again.

Press to Move.

WRITE-IN

the name of a qualified candidate by touching a on the candidate list. When the appears, key in the candidate's name. Then touch . The write-in candidate's name now appears on the list of candidates.

Press to Write-In.

CONTINUE

on the following page by touching at the bottom right of the screen. To return to the previous page, touch at the bottom left of the screen.

REVIEW

a summary of all on the page. To make a change, touch the or to return to the ballot page for that race.

COMPLETE

by touching the yellow at the bottom.

MR. BALLOT IS NOW CAST!



When they found these problems, the Hopkins folks published a paper. They also went to election officials and testified before lawmakers.



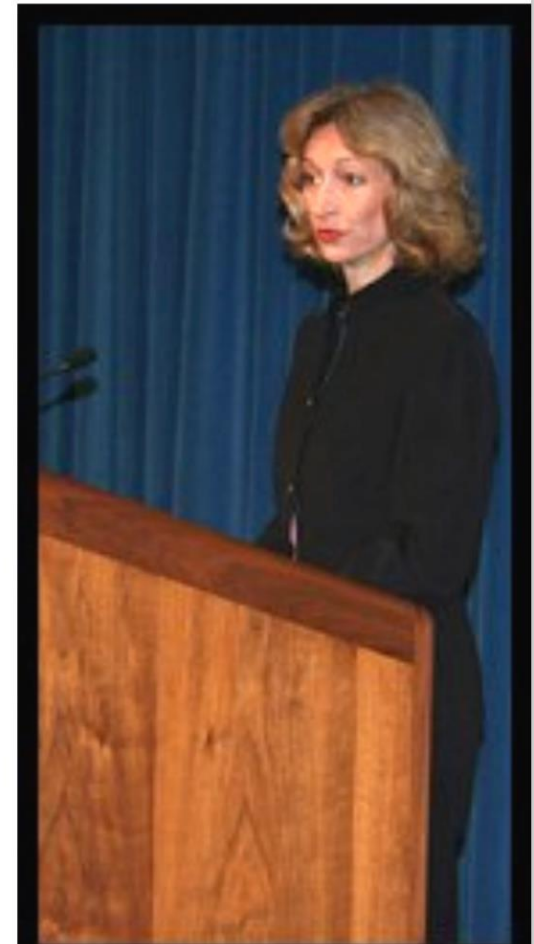
Public reaction to the revelation of these flaws was intense. People had been trusting the vendors to do the right thing - and when they actually got the chance to look under the hood, they were disappointed by what they found. Here you can see people protesting in Colorado.

Princeton E-vote Demo Video

California Top-to-Bottom Review

In 2007, California Secretary of State Debra Bowen commissions a review of California's voting systems.

43 experts (led by David Wagner & Matt Bishop) examine voting systems used nationally.



THE SECRETARY
Bowen opens the public
hearing in Sacramento.

Technical findings of the CA TTBR

All voting systems examined have serious security problems:

- None followed sound engineering principles expected of security-critical systems.
- All were vulnerable to viral attacks: one outsider could subvert all voting machines countywide

Example flaw (Diebold/Premier system)

Bug: The code that reads data off the memory card has buffer overrun vulnerabilities.

Attack:

1. Attacker writes malicious code onto 1 card
2. When central PC reads votes off card on election night, it gets infected
3. Infected PC writes malicious code onto all cards used in the next election, infecting entire county

Quotes from the reports

“We found pervasive security weaknesses throughout the Sequoia software. Virtually every important software security mechanism is vulnerable to circumvention.”

“Our study of the Diebold source code found that the system does not meet the requirements for a security-critical system. It is built upon an inherently fragile design and suffers from implementation flaws that can expose the entire voting system to attacks.”

“The Hart software and devices appear to be susceptible to a variety of attacks which would allow an attacker to gain control of some or all of the systems in a county. [...] Many of these attacks can be mounted in a manner that makes them extremely hard to detect and correct. We expect that many of them could be carried out in the field by a single individual, without extensive effort, and without long-term access to the equipment.”

Outcome of the CA TTBR

Bowen decertifies most
touchscreen e-voting machines
and imposes strict new
procedural protections.

Result: Most Californians now vote on paper ballots.

No longer true: 80% use vote by mail

OFFICIAL BALLOT **ALAMEDA COUNTY, CALIFORNIA** **NOVEMBER 4, 2008 GENERAL ELECTION**

INSTRUCTIONS TO VOTERS: USE SLACK OR BLUE BALLPOINT PEN ONLY. To vote for a candidate of your choice, complete the arrow  to the right of the candidate's name. To vote for a qualified voter candidate, **INITIAL** the person's name in the blank space provided and complete the arrow. To vote on any measure, complete the arrow after the word **YES** or **NO**.

PRESIDENT OF THE UNITED STATES	CITY OF BERKELEY	MEASURES SUBMITTED TO THE VOTER
PRESIDENT AND VICE PRESIDENT	CITY CLERK JANIS HAY JANIS HAY	STATE
  	  	  
 	 	 
 	 	 
 	 	 
 	 	 
 	 	 
 	 	 
 	 	 
 	 	 
 	 	 
 	 	 
 	 	 
 	 	 
 	 	

Of course, all of the flaws we've seen so far were pretty easy to fix, and Diebold did so quickly. The risk of unintentional security holes like this is scary. But even if we ignore the possibility of inadvertent mistakes, there is an even more devastating risk: the possibility of malicious code that has been deliberately introduced into the system, e.g., by an insider.

Trojan Horses and the Insider Threat



Ronald Dale Harris

Employee, Gaming Control Board, 1983-1995

Arrested, Jan 15, 1995

Convicted, Sept 23, 1997, for rigging slot machines

Ron Harris, an example of an attacker who had insider access. He was a computer engineer at the Nevada regulatory board that oversees casinos. From 1993-1995, he used his inside access to cheat casinos. As a tester for the Nevada Gaming Control Board, he had access to the internals of slot machines. He made a few EPROMs containing a variant of the software that was programmed to detect a special sequence of coin insertions (the "secret knock on the door"), and issue a big payoff when that sequence occurred. He used this to rig at least 20 machines, and walked away with thousands of dollars.

On Jan 14, 1995, he got greedy and tried to grab a \$100,000 jackpot in Atlantic City. His conspirator behaved oddly, the casino got suspicious, and they caught Harris. He pled guilty and was sentenced 7 years in jail. It was only because he got greedy and sloppy that he was eventually caught.

What if an insider introduced malicious logic into a voting machine that waited for a "secret knock" and then recorded bogus votes?

Attempted Trojan Horse in Linux Kernel

```
...  
    schedule();  
    goto repeat;  
}  
if ((options == (__WCLONE|__WALL)) && current->uid = 0))  
    retval = -EINVAL;  
retval = -ECHILD;  
end_wait4:  
current->state = TASK_RUNNING;  
...
```



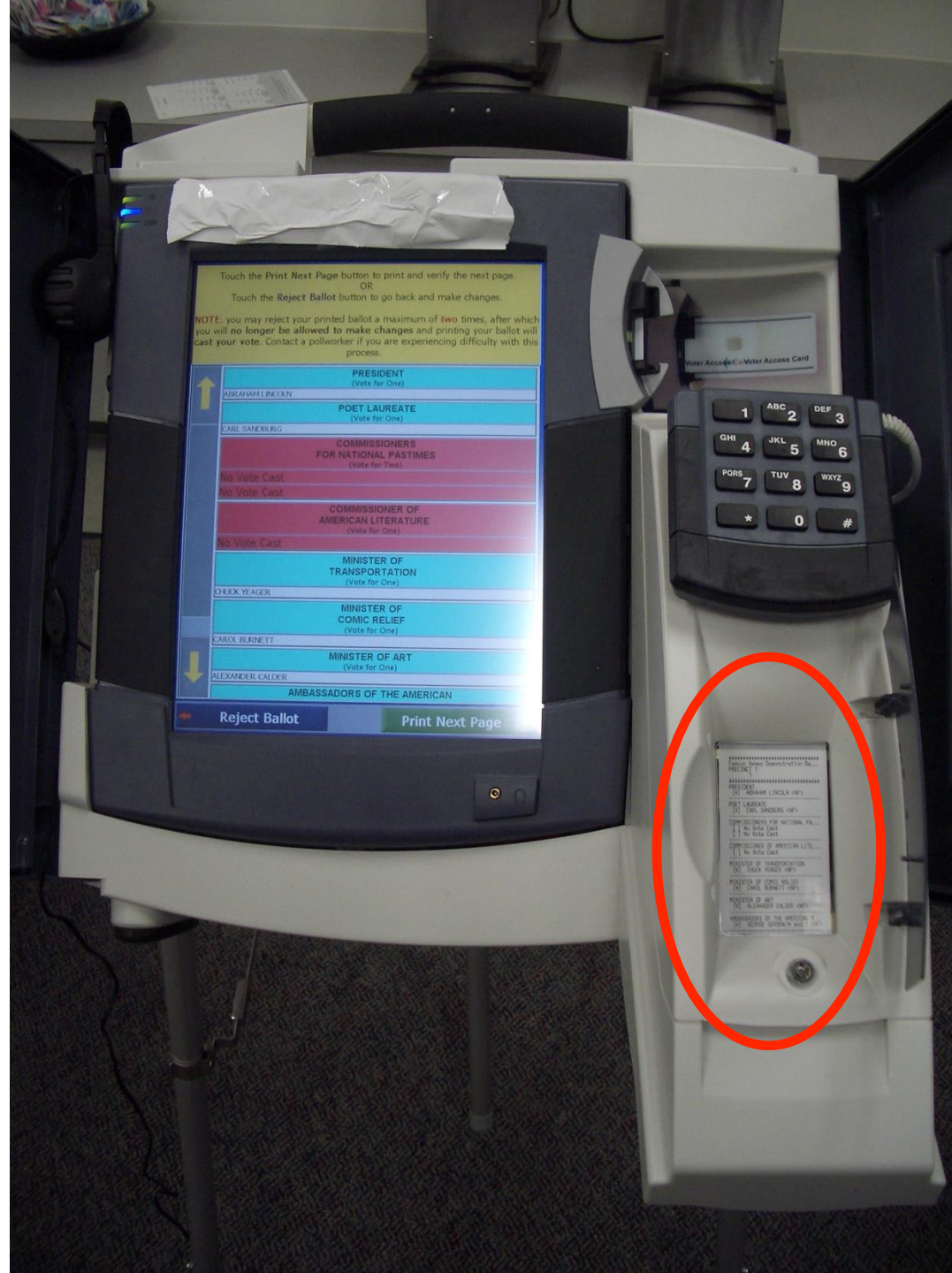
Trojan Horses and Voting Machines

Malicious logic hidden by an insider might, e.g., record votes incorrectly to favor one candidate. Extremely difficult to prevent or detect.

Potential solutions:

- Verify that the software is free of Trojans. (beyond the state of the art)
- Verify that output of the sw is correct.
 - Voter-verified paper audit trail, 1% audits
 - Optical scan (paper ballots)
 - Ballot marking devices (paper ballots)





Here is a DRE that has been retrofitted with a printer attachment (circled).

Printer Attachment Be...
PRELIM 1

PRESIDENT (Vote for One)
ABRAHAM LINCOLN
POET LAUREATE (Vote for One)
CARL SANDBURG
COMMISSIONERS FOR NATIONAL PASTIMES (Vote for Two)
No Vote Cast
No Vote Cast
COMMISSIONER OF AMERICAN LITERATURE (Vote for One)
No Vote Cast
MINISTER OF TRANSPORTATION (Vote for One)
CHUCK YAGER
MINISTER OF COMIC RELIEF (Vote for One)
CAROL BURNETT
MINISTER OF ART (Vote for One)
ALEXANDER CALDER
AMBASSADORS OF THE AMERICAN

**COMMISSIONERS
FOR NATIONAL PASTIMES**
(Vote for Two)

- ☐ JIM THORPE
- ☐ BILL RUSSELL
- ☒ JOE DIMAGGIO
- ☐ PEGGY FLEMING
- ☐ Write-in
- ☐ Write-in

**COMMISSIONER OF
AMERICAN LITERATURE**
(Vote for One)

- ☐ ERNEST HEMINGWAY
- ☐ WILLIAM FAULKNER
- ☐ JOHN STEINBECK
- ☐ SINCLAIR LEWIS
- ☐ Write-in

A paper copy of your ballot, which may be used for recount or auditing purposes, will be printed before your vote is cast.

Touch the **Print Ballot** button to print and verify your ballot.

OR

Touch the **Back** button or one of the races on this screen to go back and make changes.

PRESIDENT
(Vote for One)

ABRAHAM LINCOLN

POET LAUREATE
(Vote for One)

CARL SANDBURG

**COMMISSIONERS
FOR NATIONAL
PASTIMES**
(Vote for Two)

No Vote Cast

No Vote Cast

**COMMISSIONER OF
AMERICAN
LITERATURE**
(Vote for One)

No Vote Cast

**MINISTER OF
TRANSPORTATION**
(Vote for One)

CHUCK YEAGER

**MINISTER OF
COMIC RELIEF**
(Vote for One)

CAROL BURNETT

MINISTER OF ART
(Vote for One)

ALEXANDER CALDER

**AMBASSADORS OF
THE AMERICAN
MUSICAL COMEDY**
(Vote for One pair)

GEORGE GERSHWIN and
IRA GERSHWIN

QUESTION

Do you favor a National
Lottery Administered by the
Federal Government?

No Vote Cast

QUESTION

Shall the City of Anytown,
USA issue and sell its
General Obligation Bonds
not to exceed \$150,000,000;
YES

Back

Instructions

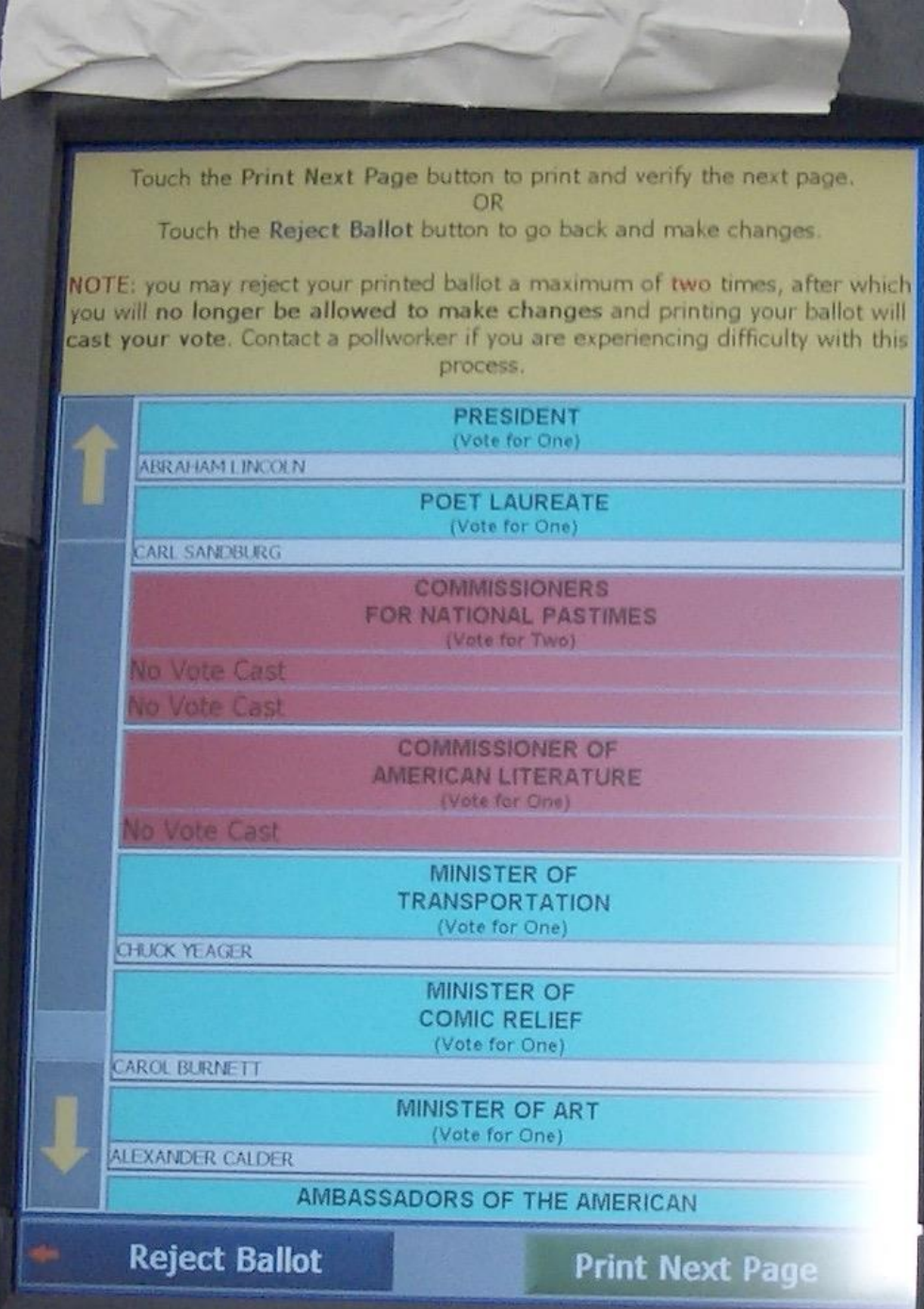
Page
2 of 4

Summary

Next

Back

Print Ballot



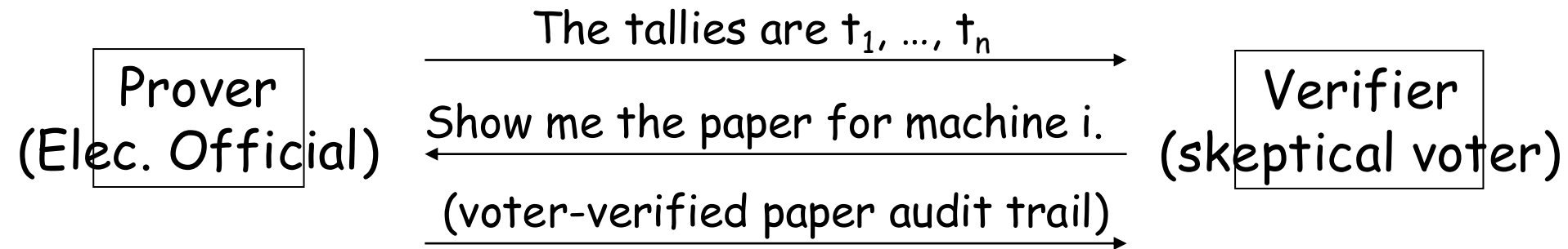
Before the voter casts their vote, a paper record is printed. If the voter accepts what has been printed, they can cast their ballot. Otherwise, they can void the paper record and make changes.

Note that with DRE, the naked eye. In contrast, voters have no way of verifying whether what was electronically recorded matches their intent.



Statistical audit

- After election, randomly choose 1% of machines and manually recount the paper records on those machines. If paper count $\neq$ electronic count, there was fraud.
- If $\gg 100$ machines cheat, detection is likely. Consequently: If paper count = electronic count, then no more than ~ 100 machines cheated.



Another
solution is
to use
optically
scanned
paper
ballots.

SAMPLE BALLOT

N.C. STATE SENATE DISTRICT 25 You may vote for ONE ☐ WILLIAM R. (BILL) PURCELL DEM ☐ _____	DISTRICT COURT JUDGE DISTRICT 20 You may vote for ONE ☐ HUNT GWYN	AMENDMENT II Constitutional amendment to provide that the General Assembly may place the clear proceeds of civil penalties, civil forfeitures, and civil fines collected by a State agency in a State fund to be used exclusively for maintaining free public schools. ☐ FOR ☐ AGAINST
N.C. STATE HOUSE DISTRICT 69 You may vote for ONE ☐ PRYOR GIBSON DEM ☐ HILDA L. MORTON REP	DISTRICT COURT JUDGE DISTRICT 20 You may vote for ONE ☐ LISA BLUE THACKER	
REGISTER OF DEEDS You may vote for ONE ☐ JOANNE S. HUNTLEY DEM	DISTRICT COURT JUDGE DISTRICT 20 You may vote for ONE ☐ TANYA WALLACE	AMENDMENT III Constitutional amendment to provide for the first term of office for magistrates of the General Court of Justice to be two years and for subsequent terms to be four years. ☐ FOR ☐ AGAINST
NON PARTISAN OFFICES Non partisan offices are not included in Straight Party voting and must be voted separately to be counted.	DISTRICT COURT JUDGE DISTRICT 20 You may vote for ONE ☐ W. DAVID McSHEEHAN ☐ JOSEPH J. WILLIAMS	
ASSOCIATE JUSTICE OF SUPREME COURT You may vote for ONE ☐ SARAH PARKER ☐ JOHN M. TYSON	NON PARTISAN OFFICES Additional instructions to Voter If you wish to write in a name for any of the following offices, write the name in the blank space provided and completely fill in the oval to the left of the name in order for your vote to count.	
ASSOCIATE JUSTICE OF SUPREME COURT You may vote for ONE ☐ RONNIE ANSLEY ☐ RACHEL LEA HUNTER ☐ HOWARD E. MANNING, JR. ☐ BETSY McCRODDEN ☐ FRED MORRISON, JR. ☐ PAUL MARTIN NEWBY ☐ MARVIN SCHILLER ☐ JAMES A. WYNN, JR.	BROWN CREEK SOIL AND WATER CONSERVATION DISTRICT SUPERVISOR You may vote for ONE ☐ JOHN C. SPRINGER ☐ _____	
JUDGE, COURT OF APPEALS You may vote for ONE ☐ LINDA McGEE ☐ BILL PARKER	STATE OF NORTH CAROLINA CONSTITUTIONAL AMENDMENTS	
JUDGE, COURT OF APPEALS You may vote for ONE ☐ WANDA G. BRYANT ☐ ALICE C. STUBBS	AMENDMENT I Constitutional amendment to promote local economic and community development projects by (i) permitting the General Assembly to enact general laws giving counties, cities, and towns the power to finance public improvements associated with qualified private economic and community improvements within development districts, as long as the financing is secured by the additional tax revenues resulting from the enhanced property value within the development district and is not secured by a pledge of the local government's faith and credit or general taxing authority, which financing is not subject to a referendum; and (ii) permitting the owners of property in the development district to agree to a minimum tax value for their property, which is binding on future owners as long as the development district is in existence. ☐ FOR ☐ AGAINST	
JUDGE, COURT OF APPEALS You may vote for ONE ☐ BARBARA JACKSON ☐ ALAN THORNBURG		
DISTRICT COURT JUDGE DISTRICT 20 You may vote for ONE ☐ CHRIS BRAGG	TURN OVER TO CONTINUE VOTING	



Statewide Special Election Orange County, California October 07, 2003		OFFICIAL BALLOT Precinct: 7601	
Instruction Note: HOW TO VOTE: To vote, fill in and BLACKEN completely the rectangle to the left of any candidate or to the left of the word "YES" or "NO". Vote for only ONE of the 135 candidates, OR enter a write-in candidate in the space provided. Use only the special marking device provided. (Absent voters should use a dark pen or a #2 pencil.)	☐ BOB LYNN EDWARDS Democratic - Attorney	☐ MICHAEL JACKSON Republican - Satellite Project Manager	MEASURES SUBMITTED TO THE VOTERS
	☐ ERIC KOREVAAR Democratic - Scientist/Businessman	☐ JOHN "JACK" MORTENSEN Democratic - Contractor/Businessman	
Shall GRAY DAVIS be recalled (removed) from the office of Governor?	☐ STEPHEN L. KNAPP Republican - Engineer	☐ DARRYL L. MOBLEY Independent - Businessman/Entrepreneur	STATE
	☐ KELLY P. KIMBALL Democratic - Business Executive	☐ JEFFREY L. MOCK Republican - Business Owner	Proposition 53
Candidates to succeed GRAY DAVIS as Governor if he is recalled:	☐ D.E. KESSINGER Democratic - Paralegal/Property Manager	☐ BRUCE MARGOLIN Democratic - Marijuana Legalization Attorney	FUNDS DEDICATED FOR STATE AND LOCAL INFRASTRUCTURE. LEGISLATIVE CONSTITUTIONAL AMENDMENT.
	☐ EDWARD "ED" KENNEDY Democratic - Businessman/Educator	☐ GINO MARTORANA Republican - Restaurant Owner	Generally dedicates up to 3% of General Fund revenues annually to fund state and local (excluding school and community college) infrastructure projects. Fiscal Impact: Dedication of General Fund revenues for state and local infrastructure. Potential transfers of \$50 million in 2006-07, increasing to several billions of dollars in future years, under specified conditions.
Vote for One	☐ TREV THUNDER KELLY Independent - Business Executive/Artist	☐ PAUL MARIANO Democratic - Attorney	☐ YES ☐ NO
	☐ JERRY KUNZMAN Independent - Chief Executive Officer	☐ ROBERT C. MANNHEIM Democratic - Retired Businessperson	Proposition 54
☐ CRUZ M. BUSTAMANTE Democratic - Lieutenant Governor	☐ PETER V. WEBEROTH Republican - Businessman/Olympics Advisor	☐ FRANK A. MACALUSO, JR. Democratic - Physician/Medical Doctor	CLASSIFICATION BY RACE, ETHNICITY, COLOR, OR NATIONAL ORIGIN. INITIATIVE CONSTITUTIONAL AMENDMENT.
☐ CHERYL BLY-CHESTER Republican - Businesswoman/Environmental Engineer	☐ BILL PRADY Democratic - Television Writer/Producer	☐ PAUL "CHIP" MAILANDER Democratic - Golf Professional	Prohibits state and local governments from classifying any person by race, ethnicity, color, or national origin. Various exemptions apply. Fiscal Impact: The measure would not result in a significant fiscal impact on state and local governments.
☐ B.E. SMITH Independent - Lecturer	☐ DARIN PRICE Natural Law University Chemistry Instructor	☐ DENNIS DUGGAN MCMAHON Republican - Barber	☐ YES ☐ NO
☐ DAVID RONALD SAMS Republican - Businessman/Producer/Writer	☐ GREGORY J. PAWLK Republican - Realtor/Businessman	☐ MIKE MCNEILLY Republican - Artist	Sample Ballot
☐ JAMIE ROSEMARY SAFFORD Republican - Business Owner	☐ LEONARD PADILLA Independent - Law School President	☐ MIKE P. MCCARTHY Independent - Used Car Dealer	
☐ LAWRENCE STEVEN STRAUSS Democratic - Lawyer/Businessman/Student	☐ RONALD JASON PALMIERI Democratic - Gay Rights Attorney	☐ BOB MCCLAIN Independent - Civil Engineer	Sample Ballot
☐ ARNOLD SCHWARZENEGGER Republican - Actor/Businessman	☐ CHARLES "CHUCK" PINEDA JR. Democratic - State Hearing Officer	☐ TOM MCCLINTOCK Republican - State Senator	
☐ GEORGE B. SCHWARTZMAN Independent - Businessman	☐ HEATHER PETERS Republican - Mediator	☐ JONATHAN MILLER Democratic - Small Business Owner	Sample Ballot
☐ MIKE SCHMER Democratic - Attorney	☐ ROBERT "BUTCH" DOLE Republican - Small Business Owner	☐ CARL A. MEHR Republican - Businessman	
☐ DARRIN H. SCHEIDLE Democratic - Businessman/Entrepreneur	☐ SCOTT DAVIS Independent - Business Owner	☐ SCOTT A. MEDNICK Democratic - Business Executive	Sample Ballot
☐ BILL SIMON Republican - Businessman	☐ RONALD J. FRIEDMAN Independent - Physician	☐ DORENE MUSILLI Republican - Parent/Educator/Businesswoman	
☐ RICHARD J. SIMMONS Independent - Attorney/Businessperson	☐ GENE FORTE Republican - Executive Recruiter/Entrepreneur	☐ IVAN VO Republican - Radio Producer/Businessman	Sample Ballot
☐ CHRISTOPHER SPROUL Democratic - Environmental Attorney	☐ DIANA FOSS Democratic	☐ PAUL W. VANN Republican - Financial Planner	
☐ RANDALL D. SPRAGUE Republican - Discrimination Complaint Investigator	☐ LOHRAINE (ABNER ZURD) FONTANES Democratic - Film Maker	☐ JAMES M. VANDEVENTER, JR. Republican - Salesman/Businessman	Sample Ballot
☐ TIM SYLVESTER Democratic - Entrepreneur	☐ WARREN FARRELL Democratic - Father's Issues Author	☐ BILL VAUGHN Democratic - Structural Engineer	
☐ JACK LOYD GRISHAM Independent - Musician/Laborer	☐ DAN FEINSTEIN Democratic	☐ MARC VALDEZ Democratic - Air Pollution Scientist	Sample Ballot
☐ JAMES H. GREEN Democratic - Firefighter/Paramedic/Nurse	☐ LARRY FLYNT Democratic - Publisher	☐ MOHAMMAD ARIF Independent - Businessman	
☐ GARRETT GRUENER Democratic - High-Tech Entrepreneur	☐ CALVIN V. LOUIE Democratic - CPA	☐ ANGEL YNE Independent - Entertainer	Sample Ballot
☐ GEROLD LEE GORMAN Democratic - Engineer	☐ DICK LANE Democratic - Educator	☐ DOUGLAS ANDERSON Republican - Mortgage Broker	
☐ RICH GOSSE Republican - Educator	☐ TODD RICHARD LEWIS Independent - Businessman	☐ IRIS ADAM Natural Law - Business Analyst	Sample Ballot
☐ LEO GALLAGHER Independent - Comedian	☐ GARY LEONARD Democratic - Photographer/Author	☐ BROCKE ADAMS Independent - Business Executive	
☐ JOE GUZZARDI Democratic - Teacher/Journalist	☐ DAVID LAUGHING HORSE Democratic - Tribal Chairman	☐ ALEX-ST. JAMES Republican - Public Policy Strategist	Sample Ballot
☐ JON W. ZELHOEFER Republican - Energy Consultant/Entrepreneur	☐ NED ROSCOE Libertarian - Concrete Retailer	☐ JIM HOFFMANN Republican - Teacher	
☐ PAUL NAVE Democratic - Businessman/Prizefighter/Father	☐ DANIEL C. "DANNY" RAMIREZ Democratic - Businessman/Entrepreneur/Father	☐ KEN HAMIDI Libertarian - State Tax Officer	Sample Ballot
☐ ROBERT C. NEWMAN II Republican - Physiologist/Farmer	☐ CHRISTOPHER RANKEN Democratic - Planning Commissioner	☐ SARA ANN HANLON Independent - Businesswoman	
☐ BRIAN TRACY Independent - Businessman/Consultant	☐ JEFF RAINFORTH Independent - Marketing Coordinator	☐ IVAN A. HALL Green - Custom Denture Manufacturer	Sample Ballot
☐ A. LAVAR TAYLOR Democratic - Tax Attorney	☐ KURT E. "TACHIKAZE" RIGHTMYER Independent - Middleweight Sumo Wrestler	☐ JOHN J. "JACK" HICKEY Libertarian - Healthcare District Director	
☐ WILLIAM TSANGARES Republican - Businessperson	☐ DANIEL W. RICHARDS Republican - Businessman	☐ RALPH A. HERNANDEZ Democratic - District Attorney Inspector	Sample Ballot
☐ PATRICIA G. TILLEY Independent - Attorney	☐ KEVIN RICHTER Republican - Information Technology Manager	☐ C. STEPHEN HENDERSON Independent - Teacher	
☐ DIANE BEALL TEMPLIN American Independent - Attorney/Realtor/Businesswoman	☐ REVA RENEE RENZ Republican - Small Business Owner	☐ ARIANNA HUFFINGTON Independent - Author/Columnist/Mother	Sample Ballot
☐ MARY "MARY CAREY" COOK Independent - Adult Film Actress	☐ SHARON RUSHFORD Independent - Businesswoman	☐ ART BROWN Democratic - Film Writer/Director	
☐ GARY COLEMAN Independent - Actor	☐ GEORGY RUSSELL Democratic - Software Engineer	☐ JOEL BRITTON Independent - Retired Meat Packer	Sample Ballot
☐ TODD CARSON Republican - Real Estate Developer	☐ MICHAEL J. WOZNIAK Democratic - Retired Police Officer	☐ AUDIE BOCK Democratic - Educator/Small Businesswoman	
☐ PETER MIGUEL CAMEJO Green - Financial Investment Advisor	☐ DANIEL WATTS Green - College Student	☐ VIK S. BAJWA Democratic - Businessman/Father/Entrepreneur	Sample Ballot
☐ WILLIAM "BILL" S. CHAMBERS Republican - Retired Swiftperson/Businessman	☐ NATHAN WHITECLOUD WALTON Independent - Student	☐ BADI BADIOZAMANI Independent - Entrepreneur/Author/Executive	
☐ MICHAEL CHELI Independent - Businessman	☐ MAURICE WALKER Green - Real Estate Appraiser	☐ VIP BHOLA Republican - Attorney/Businessowner	Sample Ballot
☐ ROBERT CULLENBINE Democratic - Retired Businessman	☐ CHUCK WALKER Republican - Business Intelligence Analyst	☐ JOHN W. BEARD Republican - Businessman	
☐ D. (LOGAN DARROW) CLEMENTS Republican - Businessman	☐ LINGEL H. WINTERS Democratic - Consumer Business Analyst	☐ ED BEYER Republican - Chief Operations Officer	Sample Ballot
☐ S. ISSA Republican - Engineer	☐ C.T. WEBER Peace and Freedom - Labor Official/Analyst	☐ JOHN CHRISTOPHER BURTON Independent - Civil Rights Lawyer	
	☐ JIM WEIR Democratic - Community College Teacher	☐ Write-In	
	☐ BRYAN QUINN Republican - Businessman		

Sample Ballot

Sample Ballot

FAMOUS NAMES DEMONSTRATION BALLOT

Darken in the oval ☐ provided to the left of the candidate indicating the way you desire to vote.

PRESIDENT (Vote for One)

THOMAS JEFFERSON ☐

ABRAHAM LINCOLN ☐

JOHN F. KENNEDY ☐

DWIGHT D. EISENHOWER ☐

FRANKLIN D. ROOSEVELT ☐

_____ ☐

COMMISSIONER OF AMERICAN LITERATURE (Vote for One)

ERNEST HEMINGWAY ☐

WILLIAM FAULKNER ☐

JOHN STEINBECK ☐

SINCLAIR LEWIS ☐

_____ ☐

MINISTER OF COMMERCE (Vote for One)

LUCILLE BALL ☐

BURT REYNOLDS ☐

CAROL BURNETT ☐

LILY TOMLIN ☐

_____ ☐

POET LAUREATE (Vote for One)

MARIANNE MOORE ☐

ROBERT FROST ☐

CARL SANDBURG ☐

T.S. ELIOT ☐

EZRA POUND ☐

_____ ☐

COMMISSIONERS FOR NATIONAL PASTIMES (Vote for Two)

JIM THORPE ☐

BILL RUSSELL ☐

JOE DIMAGGIO ☐

PEGGY FLEMING ☐

_____ ☐

_____ ☐

MINISTER OF TRANSPORTATION (Vote for One)

AMELIA EARHART ☐

CHUCK YEAGER ☐

ORVILLE WRIGHT ☐

NEIL ARMSTRONG ☐

_____ ☐

MINISTER OF ART (Vote for One)

ANDREW WYETH ☐

ALEXANDER CALDER ☐

_____ ☐

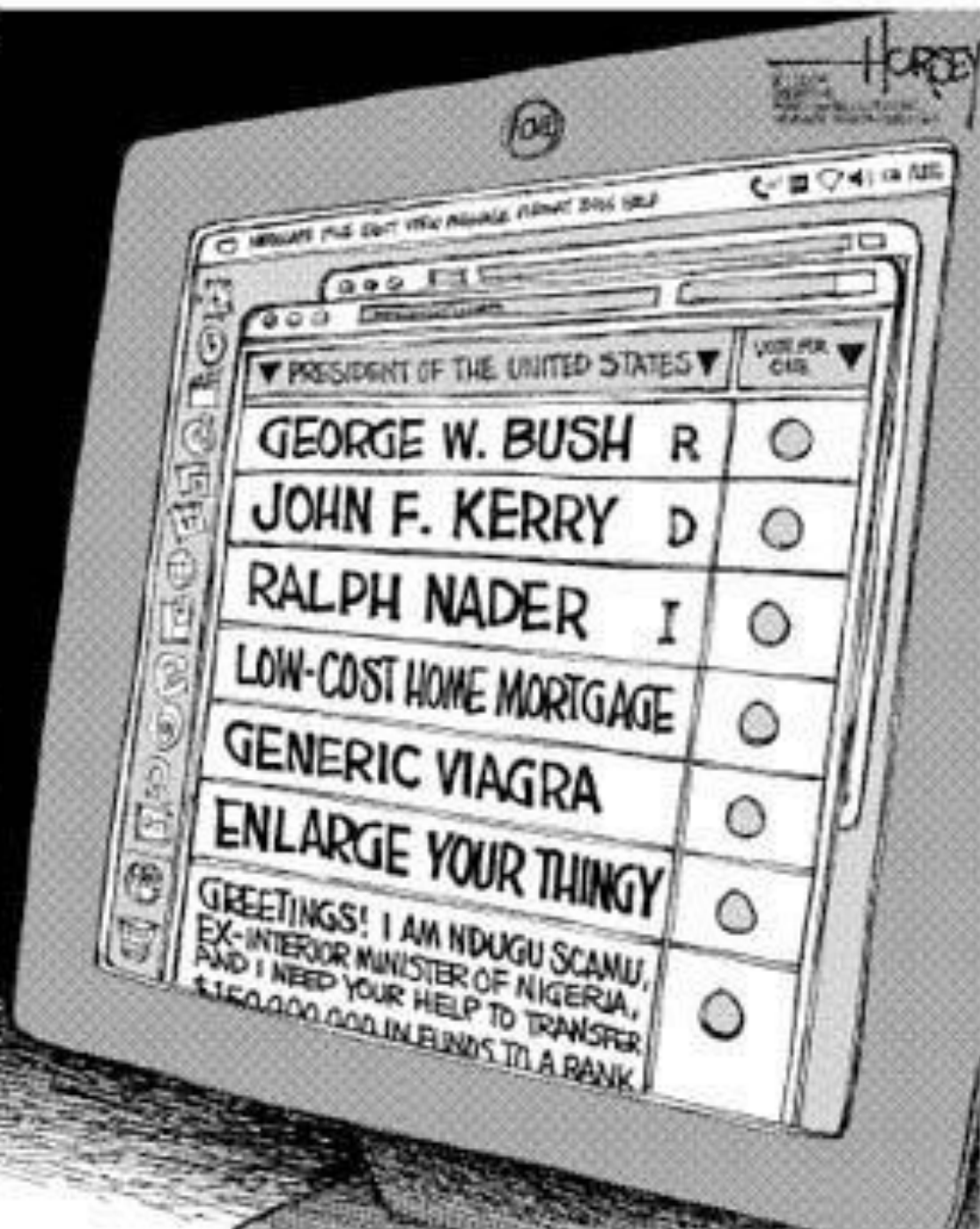
VOTE BOTH SIDES



Conclusions

- E-voting security is hard, because computers aren't transparent.
- All known solutions use paper. Secure paperless voting is an open research problem.
- Computer science is deeply relevant to democracy.
- Technical principles:
 - Two-person control, separation of duties
 - Statistical audit
 - Security against malicious insiders
 - Security through obscurity

THE HAZARDS OF ONLINE VOTING...



ONE CONTEST HAS TOO MANY VOTES
SECOND CHOICE, CA ATTRACTION PRECINCT 1
ACCEPT



DEMOCRATIC BALLOT
CITY AND COUNTY OF SAN FRANCISCO
DISTRICT 1, 2000

INSTRUCTIONS TO VOTERS: Fill in the oval to the left of your choice. If you are voting by mail, you must also fill in the oval to the right of your choice. If you are voting by mail, you must also fill in the oval to the right of your choice.

FAVORITE FLOWER
1 In the ballot box only to
YES/NO
NO/YES

FAVORITE WEATHER
2 Are the instructions
YES/NO
NO/YES

FAVORITE STYLE OF MUSIC
3 In the voting system
YES/NO
NO/YES

4 How is easy to select
YES/NO
NO/YES

5 Would you like to use
YES/NO
NO/YES

More than 4,500 North Carolina votes lost because of mistake in voting machine capacity

JACKSONVILLE, N.C. (AP) — More than 4,500 votes have been lost in one North Carolina county because officials believed a computer that stored ballots electronically could hold more data than it did. Scattered other problems may change results in races around the state.

Officials said UniLect Corp., the maker of the county's electronic voting system, told them that each storage unit could handle 10,500 votes, but the limit was actually 3,005 votes.

Machine error gives Bush 3,893 extra votes in Ohio

By John McCarthy, Associated Press

COLUMBUS, Ohio — An error with an electronic voting system gave President Bush 3,893 extra votes in suburban Columbus, elections officials said.

Franklin County's unofficial results had Bush receiving 4,258 votes to Democrat John Kerry's 260 votes in a precinct in Gahanna. Records show only 638 voters cast ballots in that precinct. Bush's total should have been recorded as 365.

Fall 2003, Ohio

"I am committed to helping Ohio deliver its electoral votes to the president."

-- Wally O'Dell



CEO of Diebold

Broward Vote-Counting Blunder Changes Amendment Result

POSTED: 1:34 pm EST November 4, 2004

BROWARD COUNTY, Fla. -- The Broward County Elections Department has egg on its face today after a computer glitch misreported a key amendment race, according to WPLG-TV in Miami.

Amendment 4, which would allow Miami-Dade and Broward counties to hold a future election to decide if slot machines should be allowed at racetracks, was thought to be tied. But now that a computer glitch for machines counting absentee ballots has been exposed, it turns out the amendment passed.

"The software is not geared to count more than 32,000 votes in a precinct. So what happens when it gets to 32,000 is the software starts counting backward," said Broward County Mayor Ilene Lieberman.

That means that Amendment 4 passed in Broward County by more than 240,000 votes rather than the 166,000-vote margin reported Wednesday night. That increase changes the overall statewide results in what had been a neck-and-neck race, one for which recounts had been going on today. But with news of Broward's error, it's clear amendment 4 passed.



Broward County Mayor Ilene Lieberman says voting counting error is an "embarrassing mistake."



November 8, 2004

George Gilbert
Director of Elections
Guilford County Board of Elections
Greensboro, NC

Dear George,

As you know, Tuesday's election drew an unprecedented number of voters to the polls. This unanticipated level of voter participation was a challenge that we believe was managed very well in Guilford County.

On behalf of the team at Election Systems & Software, I would like to congratulate you and your staff on running a very successful election. And, all of us at ES&S want to thank you for the opportunity to partner with you to carry out our important roles in the democratic process. The success of this election was the result of a tremendous amount of hard work from everyone involved. Where challenges did arise, we worked together to address them quickly and effectively so the election process continued uninterrupted. The countless hours of preparation paid off, and all in all, it was a very good day.

One challenge we did face was the incorrect information contained in preliminary and unofficial returns for certain contests in the Guilford County "One Stop" precinct used to collect totals for early voting. As you know, this occurred because exceptional voter participation generated a number of ballots and votes cast that exceeded the capacity of single precinct vote counters accepting this amount of data in the Election Reporting Manager results reporting software.

This limitation in the results reporting software was previously documented and known to ES&S. To clarify further, the limitation has nothing to do with the Votronic tabulation systems. No votes were lost. All ballot data and vote counts were correctly captured and reported by the Votronic touch screen tabulation systems.

We regret any confusion the discrepancy in early vote totals has caused.

We would like to explain in further technical detail what caused this issue, should you or others at the county have questions. The 32,767 capacity limitation at a single precinct level is a function of the design and definition of the results database used by ERM. The data storage element used to record votes at the precinct level is a two byte binary field. 32,767 is 2 to the 15th power, which is the maximum number held by a two byte word (16 bits) in memory, where the most significant bit is reserved as the sign bit (a plus or minus indicator). Additionally, ERM precinct

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PHONE: (402) 593-0101 ■ Toll Free: 1 (800) 247-8683 ■ FAX: (402) 593-8107
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www.essvote.com

count level data is stored in a binary computer format known as two's complement. Data on ERM results reports are printed as the absolute value of the two's complement of the associated data in the ERM database. This means that once the 32,767 limitation is reached, additional incremental tallies of vote results would not be printed correctly (32,768 through 65,536 would actually be represented as 65,536 to 32,768).

While this value, 32,767 is certainly higher than any practical value that could be tabulated in a single election day precinct, the consideration of reporting all absentee ballots or early voting into a single absentee or "One Stop" precinct does hold the possibility of yielding much higher totals than what may be possible in single election day precincts.

While the discrepancy in preliminary vote totals did cause some early confusion, it is very important to note that the final results reported to the state were accurate and complete. Final counts based on the Votronic systems and paper tapes were fully accurate and correct.

To avoid this limitation in elections where the One Stop early voting totals may exceed the 32,767 limitation, ES&S would recommend one of the following:

1. Using the Unity EDM software, code multiple precincts to support the larger counts. Create a split for each ballot style for each precinct. Configure early voting terminals and follow vote collection procedures that would ensure no individual precinct totals would approach the 32,767 limitation.
2. Collect early voting "One Stop" and other absentee votes into Election Day precincts.
3. Upgrade systems and software to the Unity 2.5 or Unity 3.0 versions, when available in North Carolina. The ERM database has been expanded in these versions to accommodate vote totals in excess of millions of votes in any individual precinct.

Heretofore, in previous elections, Guilford County had configured, collected and distributed the early voting results into multiple separately defined precincts (as suggested above, avoiding this limitation). ES&S was not aware that this practice had changed. Had we been aware of this change, we would have advised Guilford County of this limitation and suggested one of the other configuration options.

ES&S shares Guilford County's commitment to making sure every vote cast is counted accurately. We are absolutely confident in the accuracy of the final results that were reported. If you have additional questions on this issue, please do not hesitate to contact me.

Sincerely,

Ken Carbullido
Senior Vice President, Product and Software Development
Election Systems & Software Inc.

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We would like to explain in further technical detail what caused this issue, should you or others at the county have questions. The 32,767 capacity limitation at a single precinct level is a function of the design and definition of the results database used by ERM. The data storage element used to record votes at the precinct level is a two byte binary field. 32,767 is 2 to the 15th power, which is the maximum number held by a two byte word (16 bits) in memory, where the most significant bit is reserved as the sign bit (a plus or minus indicator). Additionally, ERM precinct count level data is stored in a binary computer format known as two's complement. Data on ERM results reports are printed as the absolute value of the two's complement of the associated data in the ERM database. This means that once the 32,767 limitation is reached, additional incremental tallies of vote results would not be printed correctly (32,768 through 65, 536 would actually be represented as 65,536 to 32,768).