U.S. Voting Systems: Issues and Opinions

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About me

Academic

- Teach Computer Science at Carnegie Mellon University
  - Operating Systems, Computer Networks

Elections

- “Judge of Elections” since 1997
  - Oversee operations at one polling place (~800 voters)
  - Supervise 4 poll workers and 1 deputy constable

VoteAllegheny

- Non-partisan volunteer election-integrity organization
- Observe elections according to state law
- Report to public and make suggestions to officials
- VoteAllegheny.org

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Disclaimer

Today: "Talking about voting equipment"

- **Machines, processes, threats, solutions**

Not really: "talking about voting approaches"

- **Rules for candidates, parties, winning conditions, ...**
- **Different for each country, state, city, ...**

Not: "talking politics"

- ***My*** **politics are unusual –would take too long to explain!**

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Outline

What is voting?

Why is voting hard?

System criteria

Deployed systems

“What could possibly go wrong?”

Ingredients for voter trust

Conclusions

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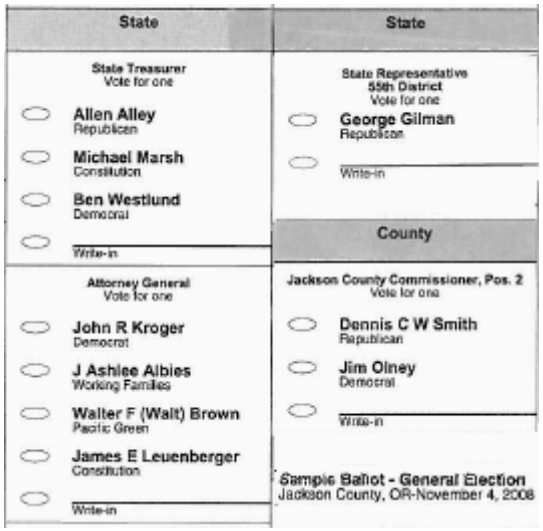
What is Voting?

“Ostrakon” (Ancient Greece)

“Town meeting”

“Australian ballot”

Image credit: Roger Dunkle, Brooklyn College
http://depthome.brooklyn.cuny.edu



State	State
State Treasurer Vote for one Allen Alley, Republican Michael Marsh, Constitution Ben Westlund, Democrat Write-in	State Representative 55th District Vote for one George Gilman, Republican Write-in
Attorney General Vote for one John R Kroger, Democrat J Ashlee Albies, Working Families Walter F (Walt) Brown, Pacific Green James E Leuenberger, Constitution Write-in	County Jackson County Commissioner, Pos. 2 Vote for one Dennis C W Smith, Republican Jim Olney, Democrat Write-in

Sample Ballot - General Election
Jackson County, OR-November 4, 2008

Image credit: Town of Chebeague Island
http://www.chebeague.org

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Why is voting hard?

“How hard is 'plus one'?”

- **Each vote is inherently digital (yes/no)**
- **Votes are combined by addition (a simple operation!)**

Surely this is simple to automate?

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Example: U.S.

Primary election vs. general election?

- Primary: each party internally chooses a candidate for each office
  - 2008 Democrats: Obama, Clinton, Edwards, ...
  - 2008 Republicans: McCain, Huckabee, Romney, ...
- General election: officeholder chosen from among parties

"Choose N" races

- School board: "select no more than 4"

"At large" races

- 13 County Council members chosen by region
- 2 more members chosen by all voters in the county

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Example: Pittsburgh, PA

Ballots have many races

- U.S.: President, House Representative, Senator
- State: Governor, Attorney General, Treasurer, State Representative, State Senator, Judge
- County: Council member, Executive, Sheriff, Judge
- School board: 9 members (5/4, 4 years)
- City: Mayor, Council member
- Polling place: Judge of Elections, Inspector

"Party lever", "Write-in voting", "Split district", ...

- Presenting ballots to voters is somewhat complicated!
- Tallying votes is harder than "+1"!

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System Criteria

Usability

Accurate recording

Durable recording

Anonymous voting

Fair ballots

Authorized voters only

Voter trust

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System Criteria

Usability

- "Voters select the candidates they intend to select"
- Not easy!
  - Elderly voters fear computers
    - » "Young man, I have never used an ATM or a VCR!"
  - Directions may be confusing
  - Multiple-language support may be necessary
- "Accessibility"
  - Blind voters
  - Voters who can't use their hands

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System Criteria

Accurate recording

- Sensing (touch screen or paper scanner)
- Tallying (adding this voter's choices to others)

Durable recording

- Votes must not be lost (in transport, bad memory card, flood, ...)

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System Criteria

Anonymous voting

- Protect the voter
  - Company boss doesn't know how you voted
  - Union leader doesn't know how you voted
  - Your father doesn't know how you voted
- Restrict the voter (protect all *other* voters)
  - Impossible to sell your vote (exchange proof for money)

Fair ballots

- Candidates at top of ballot often get more votes
- "Ballot rotation": candidate order different at each polling place

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System Criteria

Authorized voters only

- During election: poll workers must be honest
- Before/during/after: extra votes must not enter the system
  - Locks and/or tamper detection

Voter trust ☺

- Goal: my vote is secret from others
- Goal: others' votes are secret from me
- Goal: we all believe the final total
  - No lost/extra/tampered votes
  - No counting errors
- This is hard!

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System Ingredients and Sources

"Cognitive psychology" / CHI / HCI

- Usability

"Security"

- Confidentiality
- Authorization
- Durability
- Integrity ("tamper-proof")
- Randomness

"Code verification"

- Accuracy

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Deployed systems

Hand-written paper ballots

Candidate-printed paper ballots

“Australian ballot”

“Lever” machines

Punched cards

Optically-scanned paper ballots

DRE (“Direct Recording Electronic”)

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Deployed systems

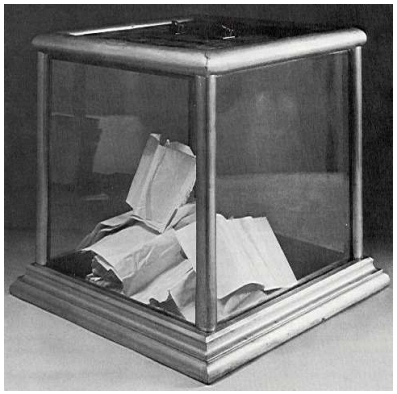

Image credit: Maryland State Archive
http://www.msa.md.gov

Hand-written paper ballots

- Voter writes names on paper, deposits paper in box
- Counted by hand

Candidate-printed paper ballots

- Candidates “helpfully” pre-print ballots for voters to use
  - Especially “helpful”: colored paper makes votes public!
- Many ballots are printed... maybe many are “stuffed” into the ballot box...

“Australian ballot”

- Government-printed ballots, uniform for anonymity
- Quantity is limited and tracked (no “stuffing” –we hope!)

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Deployed systems

"Lever" machines (1892!!)

- Automatically reject overvotes
- Machine locks after each vote
- Tallying is automatic
- System is "open" (to any mechanic)
- Safety system stops voter from casting vote unless at least one lever is flipped
  - This requires a global "OR gate" for the whole machine!
- But: gears can jam, or be jammed

Image credit: Prendergast Library
http://www.prendergastlibrary.org/jamestown/avm.htm

Image credit: Prendergast Library
http://www.prendergastlibrary.org/jamestown/avm.htm

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Deployed systems

Punched cards (~1960)

- Adaptation of IBM computer cards
- Voting station aligns holes with pages of a “book”
- Each page exposes one column and labels each candidate's hole
- Voter punches out paper “chad” from card
- Cards processed by a high-speed scanner at election HQ

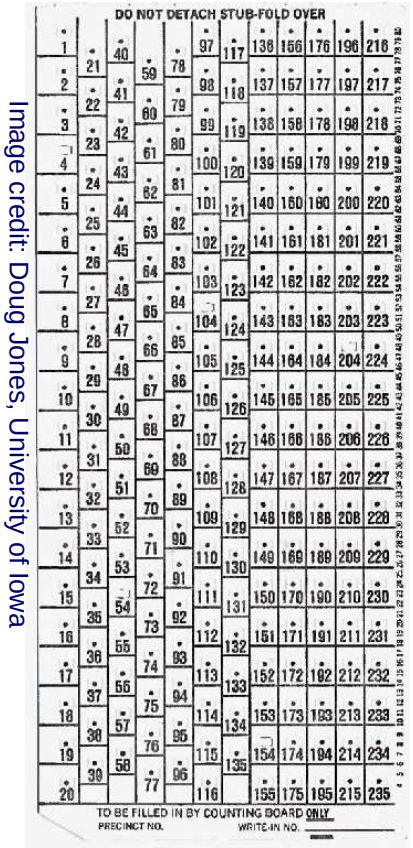

Image credit: Doug Jones, University of Iowa
http://www.cs.uiowa.edu/~jones

Image credit: State of Michigan
http://www.michigan.gov/mikids

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Deployed systems

Optically-scanned paper ballots

- Voter uses a pen to draw a line or fill in a bubble
- A “ballot marker” machine makes marks for blind voters, voters who can't hold a pen
- Ballot scanning
  - “central count” - ballot boxes taken to high-speed scanner at election HQ
  - “precinct count” - small scanner at each polling place, prints totals at end of election

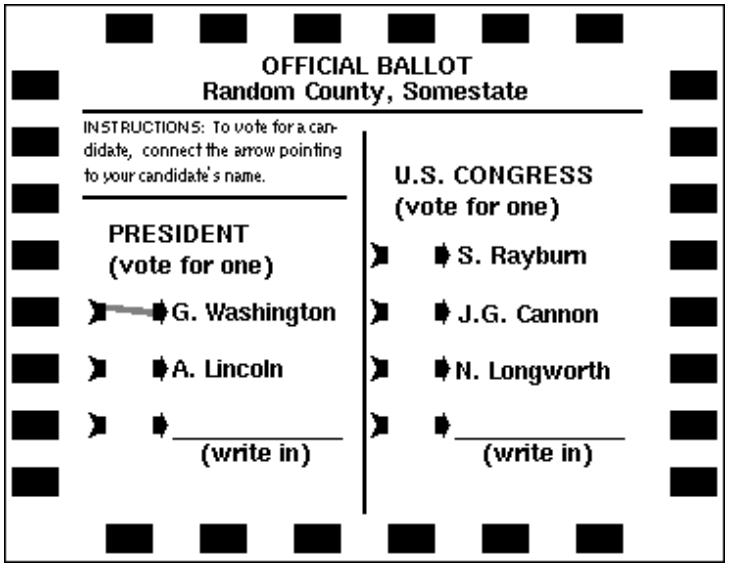

Image credit: Doug Jones, University of Iowa
http://www.cs.uiowa.edu/~jones

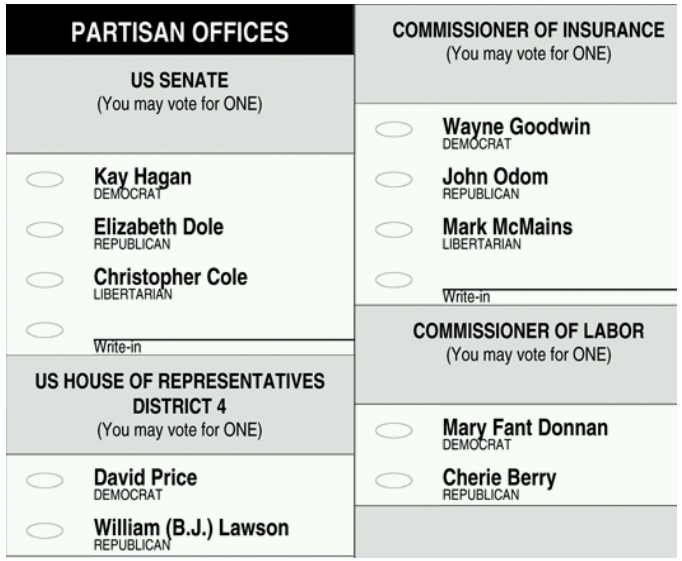

Image credit: Brennan Center for Justice
http://www.brennancenter.org

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Deployed systems

DRE ("Direct Recording Electronic")

- Voter uses touch screen, button matrix, or wheel to indicate choices
- System rejects overvotes, warns of undervotes
- Accessibility
  - "Audio ballot" for blind voters
  - Multiple ballot languages possible
- Tallying is automatic
- Results returned to HQ on memory cards, plus paper print-out

Image credit: Election Systems & Software
http://www.essvote.com

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Procurement

Nationwide standards for accuracy and security

- Tested by certified testing companies

State-level testing for state rules and needs

- Some states speak one language, others don't

County-level purchasing from a state list of systems

- Some counties have many people per polling place, some have few...

Deployed systems have received trust from three levels of government

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How well do they work?

System Criteria

- Usability
- Accurate recording
- Durable recording
- Anonymous voting
- Fair ballots
- Authorized voters only
- Voter trust

"What could possibly go wrong?"

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Usability

Criterion

- "Voters select the candidates they intend to select"

2000 presidential election

- Palm Beach County, Florida
- It seems very likely that thousands of people mis-voted for president because of bad ballot layout
  - Maybe 4,000 people punched the wrong presidential hole
  - 19,000 people punched two presidential holes
  - The state was won by ~500 votes
    - » There was other noise in the Florida election system, but this one issue was very significant
- The same mistake happened in Palm Beach in 1996 (in the opposite direction)

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Usability - “Butterfly Ballot”

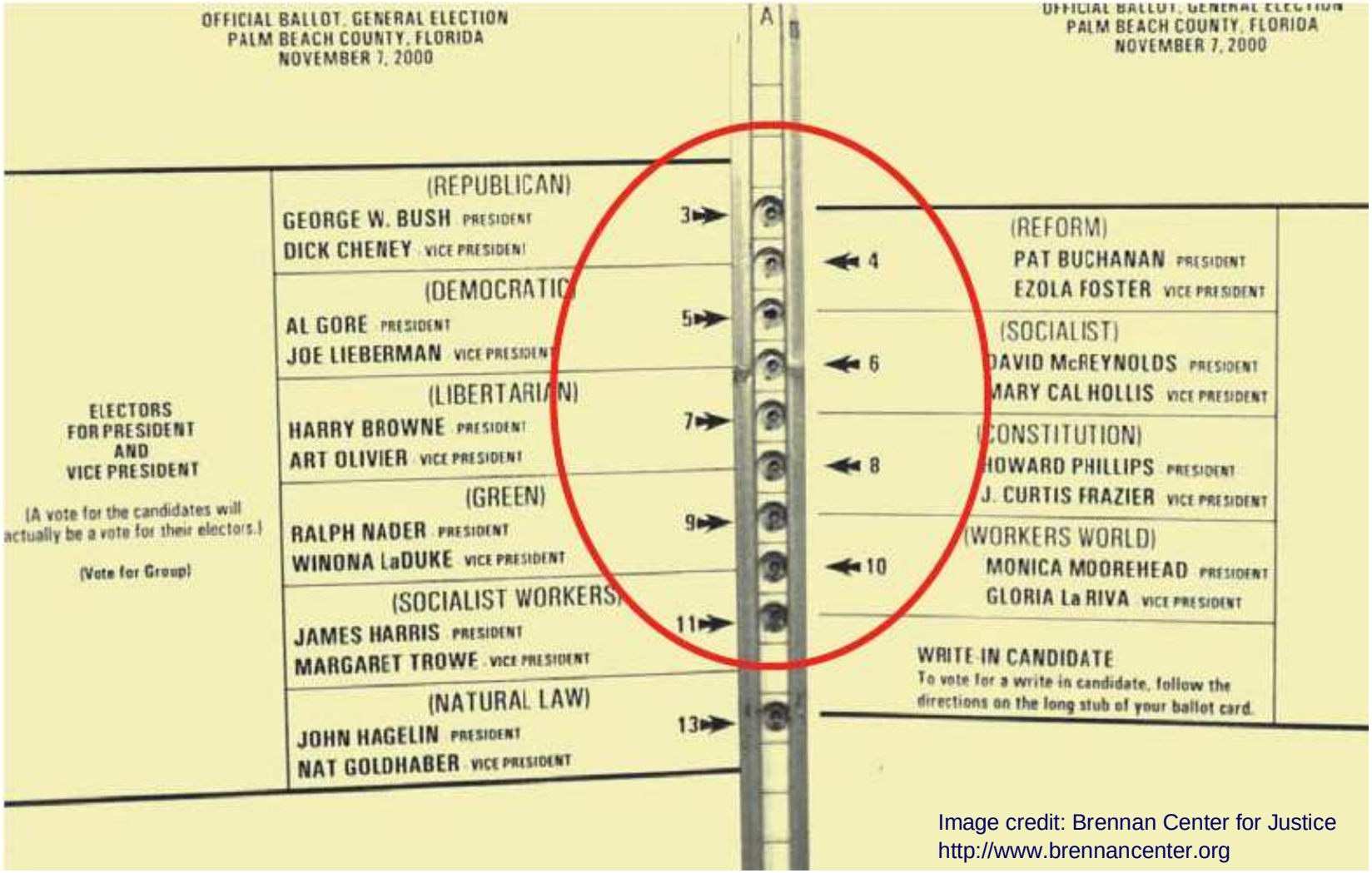

Image credit: Brennan Center for Justice
http://www.brennancenter.org

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Usability

Criterion

- "Voters select the candidates they intend to select"

2006 election for U.S. House Representative, FL-13

- Sarasota County
- Apparently, thousands of people who voted for smaller races "forgot" to cast a vote for U.S. House Representative
  - Unlikely (it was a "hot" race)
  - "Undervote" rate of ~13% (2% is "normal")
- Leading theory: bad ballot layout on an iVotronic touch-screen voting machine

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Screen 1

“Junk”

U.S. Senator

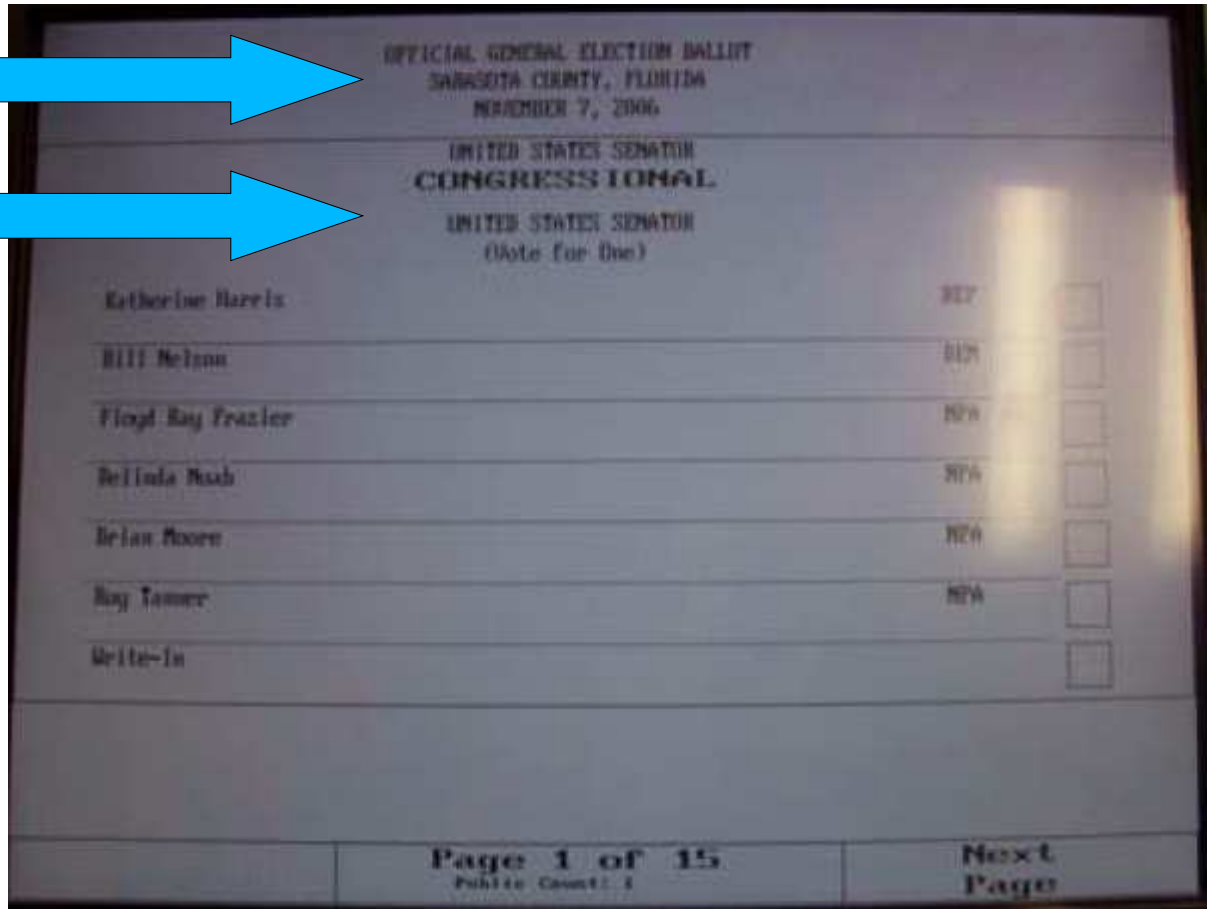

Image credit: SAIT Report

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Screen 2

“Junk”??

Governor

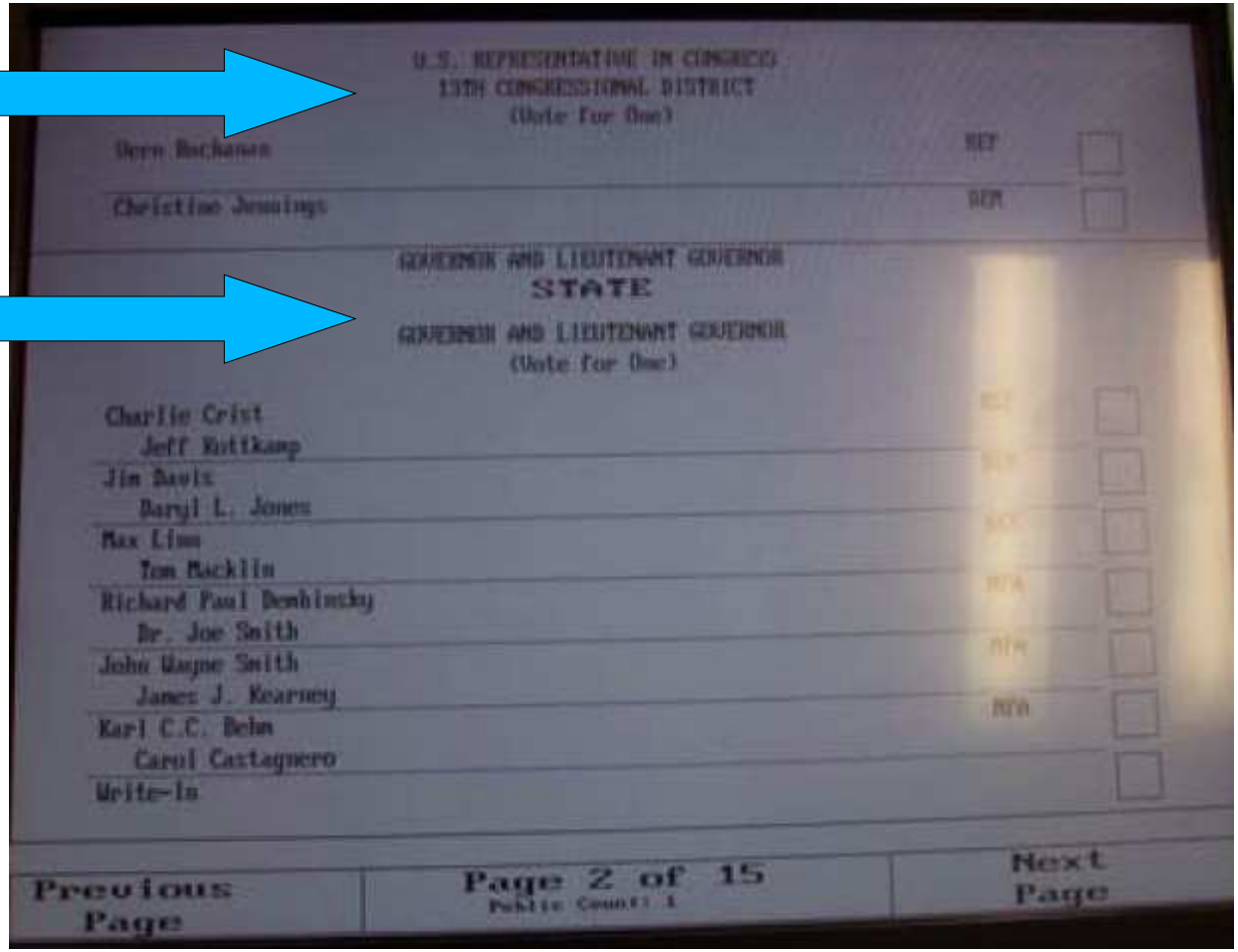

Image credit: SAIT Report

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Accurate recording

Do optical scanners scan accurately?

- We hope so!
  - (But we don't usually check.)

Do voters check touch-screen machine selections?

- "Entire races can be added or removed from ballots and [voters'] candidate selections can be flipped *and the majority of users do not notice*" –Everett Ph.D. dissertation

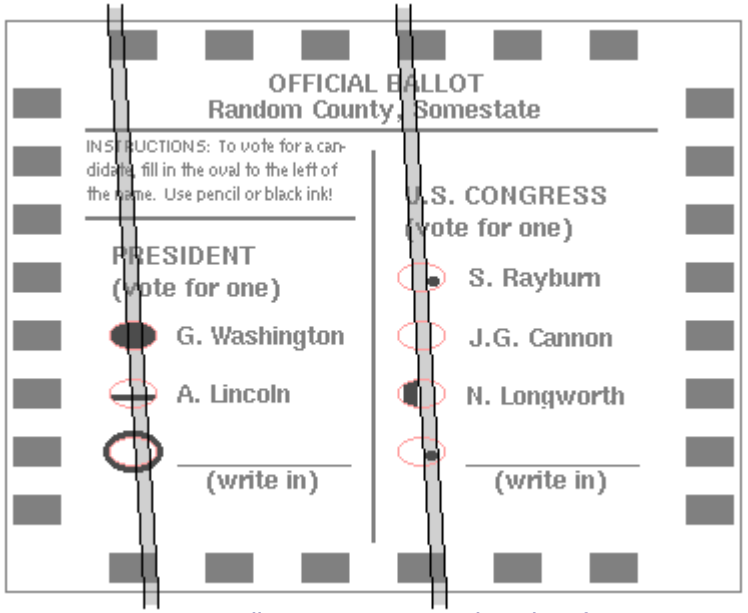

Image credit: Doug Jones, University of Iowa
http://www.cs.uiowa.edu/~jones

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Durable recording

Criterion

- "Votes must not be lost ..."

2004 election for Commissioner of Agriculture in North Carolina

- Election was "won" by a margin of 1,412 votes
- One Unilect Patriot voting machine, in Carteret County, lost 4,438 votes
  - The machine was programmed to store 3,005 votes
  - The machine was *not* programmed to stop "accepting" votes when it was full!
- After months of arguing in court, one candidate withdrew

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Anonymous voting

Criterion

- Nobody knows a voter's choices

But...

- In 2006 in the Netherlands, citizens discovered that Nedap ES3B voting machines leak radio signals indicating which choices a voter makes!

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Fair ballots

Criterion

- No candidate is “at the top of the ballot” in all polling places

Approach

- “Ballot rotation” –rearrangement of candidates in each polling place
- Voting machines internally record votes per ***ballot position***, not actual names. Names are associated later.

But...

- 2006, Pottawattamie County, Iowa: a tabulation programming error mis-assigned votes, requiring a hand count of paper ballots

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Authorized voters only

One vote per voter, please!

- Since the days of lever machines (1890's), voting machines “lock” after each voter
- Poll worker activates machine for next voter
- Sequoia “Edge II” machine activated by a smart card

But...

- Edge II *also* had a yellow “manual activation” button on the back... within reach of voters!

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Authorized voters only

No pre-election/post-election tampering, please!

- When a voting machine is not in use, it should remain locked and accept no votes
- It should also not accept “delete all votes”, “upload new firmware”, etc.

But...

- ES&S iVotronic can be controlled by a “factory-test” key
  - Useful for resetting lost passwords, etc.
- Unfortunately, this “factory-test” key is not hard to simulate...

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iVotronic password reset

Figure 7.1: A PEB emulator running on a Palm Pilot simulates an initialization PEB during an open election, resetting all terminal passwords to “EVEREST”.

Photo and caption drawn from “EVEREST: Evaluation and Validation of Election-Related Equipment, Standards, and Testing,” retrieved from http://www.sos.state.oh.us/SOS/upload/everest/14-AcademicFinalEVERESTReport.pdf

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Authorized voters only

Diebold AccuVote-TS had "some password problems"

- **Machines had 4-character passwords**
- **Actually, every character was a digit (0-9)**
- **Actually, all machines in the country had *the same* password!**
- **The global master password was easy to guess**
- **1111**
- **Actually, you didn't need the password to compromise the machine...**

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Authorized voters only

Diebold AccuVote-TS had "some access problems"

- Machine controlled by code on a memory card
- Memory card door locked with a key
- Actually, CS graduate students were able to pick the lock very quickly
- Actually, most TS-x machines sold used *exactly the same* key
- Actually, the Diebold web site showed a picture of the key
- Actually, somebody printed out the picture and made a working key
- Actually, the key is *exactly the same* as many hotel mini-bar refrigerators use...maybe you already have one!

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Voting-machine tampering

Many problems have been found in many machines

Buffer overflow

Short passwords

Nationwide passwords

Nationwide encryption keys

"Access logs" that forget security events

Back doors

Viral propagation between machines

Encryption without signatures

"Output format code" which can steal votes

Do we think we've found *all* of these problems?

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Voter trust

Can we trust our voting system?

- **Wrong question!**

***What kind* of trust can we have?**

- **"The system never breaks"**
  - **This is a *very difficult* thing to believe**
- **"When the system breaks, we will probably catch it"**
  - **This is more achievable**
  - **But it requires more work**

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Ingredients for voter trust

Ideally the voter can *see* that the vote is recorded

- **Voters can't see transistors**
- **Voters *can* see ink on paper**
- **If "the numbers are wrong", paper is a reliable indicator:**
  - **Ballot layout problem?**
  - **Scanning/counting error?**
  - **Even some tampering is detectable**
- **Should a machine help voters mark the paper?**

Totals should be generated and publicized close to the voter

- **"Precinct count" scanners better than "central count"**

Multi-party cross-checks (*automatic* hand counts)

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Conclusions

Voting is a hard problem after all!

Opportunities for Computer Science

- **Be careful! Don't break an election and shame CS!**
- **Threat model (system view)**
- **HCI –what works for real voters?**
- **Auditing protocols**
- **Provable code –could we *prove* a tabulation system or a voting machine correct?**
- **Cryptographic "your vote was counted" proofs?**
  - **Can voters really believe this?**
  - **Will they really run the protocol?**

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Further reading

Tracy Campbell, Deliver the Vote

"EVEREST report"

- **"EVEREST: Evaluation and Validation of Election-Related Equipment, Standards, and Testing",**
  http://www.sos.state.oh.us/SOS/upload/everest/14-AcademicFinalEVERESTReport.pdf

"SAIT report"

- **Yasinsac et al., Software Review and Security Analysis of the ES&S iVotronic 8.0.1.2 Voting Machine Firmware**

Sarah P. Everett

- **The Usability of Electronic Voting Machines and How Votes Can Be Changed Without Detection**

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Further reading

Doug Jones, "Voting and Elections"

- **http://www.cs.uiowa.edu/~jones/**

David Morrill, "Unilect vote device causes uproar"

- **Oakland Tribune, 24 November 2004**

Chris Bagley, "Vote machine buttons ignite controversy"

- **North County Times - Californian, 3 November 2006**

Security Analysis of the Diebold AccuVote-TS Voting Machine

- **Ariel Feldman, J. Alex Halderman, and Edward W. Felten**

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Further reading

Diebold Shows How to Make Your Own Voting Machine Key

- **J. Alex Halderman**

"Hotel Minibar" Keys Open Diebold Voting Machines

- **Ed Felten**

EDRI.org, "European e-voting machines cracked by Dutch group"

"Voting computer tempest attack" (YouTube)

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“Vote by mail”?

Usability	✔
Accurate	✔
Durable	**?**
Anonymous	**X**
Fair ballots	✔
Authorized	**?**
Voter trust	**??**

Overvote protection?

Lost in mail?

Did somebody “help”?

Who filled it out?

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“Internet voting”?

Usability	**?**
Accurate	**?**
Durable	**?**
Anonymous	**X**
Fair ballots	**✔**
Authorized	**?**
Voter trust	**???**

(browser formatting?)

(client cracked?)

(server cracked?)

Did somebody “help”?

Who filled it out?

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