

A Document Analysis System for Supporting Electronic Voting Research

Daniel Lopresti

Computer Science & Engineering
Lehigh University
Bethlehem, PA, USA

George Nagy

Electrical, Computer, and Systems Engineering
Rensselaer Polytechnic Institute
Troy, NY, USA

Elisa Barney Smith

Electrical and Computer Engineering
Boise State University
Boise, ID, USA

Overview

- Background: the push toward paper-based voting
- Issues in processing scanned ballots
- Opportunities for document analysis research
- Overview of our ongoing work*
- Summary

* Ideas and a prototype system, but no experimental results yet.



E-voting in the news

Electronic Voting Systems: the Good, the Bad, and the Stupid

Security Analysis of the Diebold AccuVote-TS Voting Machine

SECURITY ALERT: July 4, 2005

Critical Security Issues with Diebold Optical Scan Design

Security Assessment of the Diebold Optical Scan Voting Terminal

Pennsylvania voters: trust but verify

Poll finds most want ballot verification

Electronic Voting System Usability Issues

THE MACHINERY OF DEMOCRACY:

PROTECTING ELECTIONS

IN AN ELECTRONIC WORLD

Hack-a-Vote: Security Issues with Electronic Voting Systems

Analysis of an Electronic Voting System

Privacy Issues in an Electronic Voting Machine



HBO DOCUMENTARY

Candidate A Candidate B

-0005 +0005

HACKING DEMOCRACY
An HBO Documentary Film
9 pm Thursday

"The bottom line is if we don't have the ability to authenticate our own elections as citizens, we don't live in a democracy."

HBO Documentary Films presents [Hacking Democracy](#), Thursday at 9 pm.

[VIDEO ▶ Preview Hacking Democracy](#)

SECURITY ALERT: May 11, 2006

Critical Security Issues with Diebold TSx

Trusted Agent Report
Diebold AccuVote-TS Voting System

What are the problems?

Recent transition to e-voting in U.S. has been rocky at best:

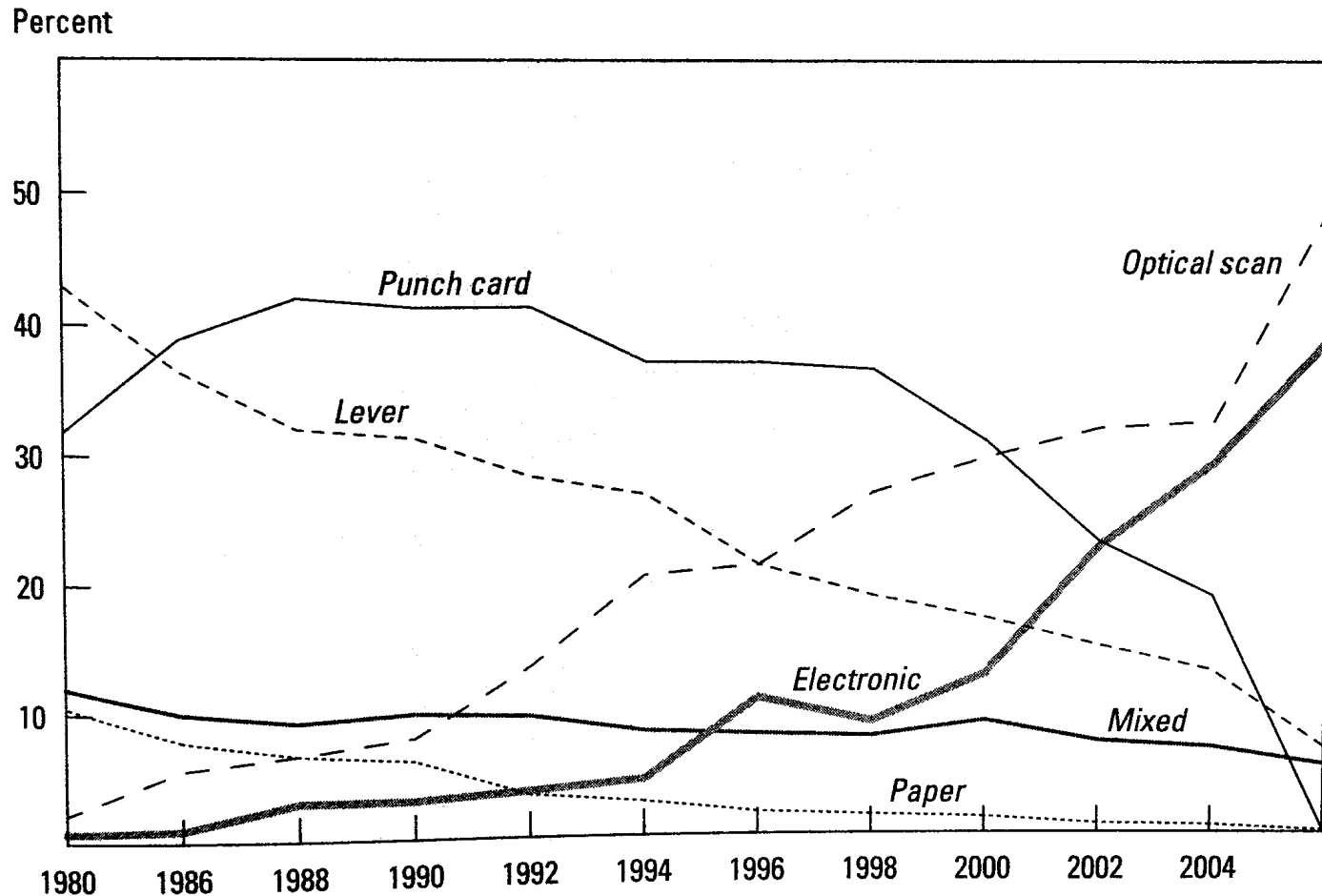
- Well-publicized “attacks” by computer security researchers who have obtained examples of such systems.
- Votes lost in real elections due to software / hardware failures ...
- ... and due to under-trained workers, bad user interface designs.

*No matter the vendor, one truth holds:
all computer systems of this complexity have bugs.*

Situation exacerbated by:

- Closed (proprietary) systems, no independent audit trail.
- Result is loss of voter trust, lawsuits, flurry of new legislation.

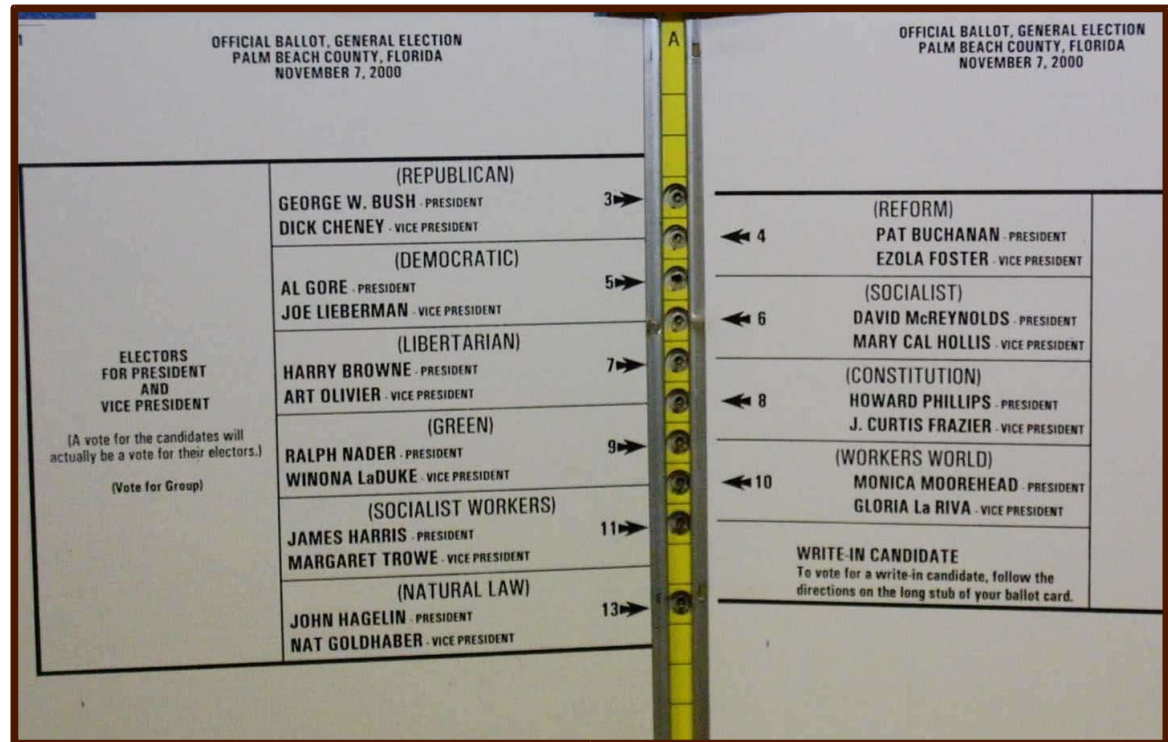
Voting system use in the U.S.



From *Voting Technology: The Not-So-Simple Act of Casting a Ballot*, by Paul S. Herrnson, et al, Brookings Institution Press, 2008.

How did we get where we are?

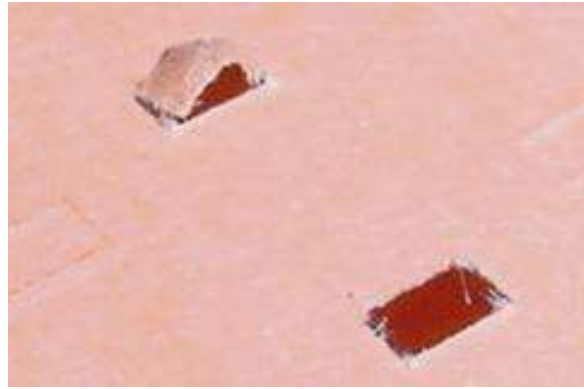
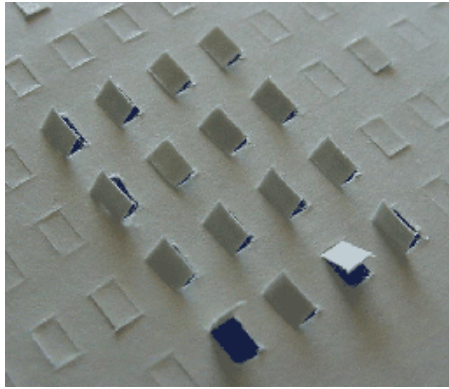
The infamous butterfly ballot from the 2000 U.S. Presidential election:



The Florida ballot is a classic example of bad user interface design. (Computer software can suffer from such problems just as easily.)

http://www2.indystar.com/library/factfiles/gov/politics/election2000/img/prezrace/butterfly_large.jpg

Hanging chads & voter intent



Votomatic technology used in Florida was prone to paper jams. This led to hanging and dimpled chads, making it hard to determine *voter intent*, which provides the legal standard.

<http://www.cs.uiowa.edu/~jones/cards/chad.html>

<http://www.pushback.com/justice/votefraud/DimpledChadPictures.html>

Counting votes may not be easy

OFFICIAL BALLOT
 Judge _____
 Judge _____

STATE GENERAL ELECTION BALLOT
 COUNTY NAME _____
 NOVEMBER 7, 2006

INSTRUCTIONS TO VOTERS
 To vote, completely fill in the oval(s) next to your choice(s) like this:

FEDERAL OFFICES	STATE OFFICES	COUNTY OFFICES
UNITED STATES SENATOR VOTE FOR ONE	SECRETARY OF STATE VOTE FOR ONE	COUNTY TROOPMASTER VOTE FOR ONE
<input type="radio"/> CANDIDATE INDEPENDENCE	<input type="radio"/> CANDIDATE INDEPENDENCE	<input type="radio"/> CANDIDATE
<input checked="" type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE REPUBLICAN	<input checked="" type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE DEMOCRATIC/FARMER-LABOR	<input type="radio"/> CANDIDATE DEMOCRATIC/FARMER-LABOR	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE Party of Principle	<input type="radio"/> CANDIDATE	COUNTY TREASURER VOTE FOR ONE
<input type="radio"/> CANDIDATE	STATE AUDITOR VOTE FOR ONE	<input type="radio"/> CANDIDATE
UNITED STATES REPRESENTATIVE DISTRICT (NUMBER) _____ VOTE FOR ONE	<input type="radio"/> CANDIDATE INDEPENDENCE	<input checked="" type="radio"/> CANDIDATE
<input checked="" type="radio"/> CANDIDATE INDEPENDENCE	<input checked="" type="radio"/> CANDIDATE REPUBLICAN	COUNTY RECORDER VOTE FOR ONE
<input type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE DEMOCRATIC/FARMER-LABOR	<input checked="" type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE DEMOCRATIC/FARMER-LABOR	<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	ATTORNEY GENERAL VOTE FOR ONE	<input type="radio"/> CANDIDATE
STATE OFFICES	<input type="radio"/> CANDIDATE INDEPENDENCE	COUNTY SHERIFF VOTE FOR ONE
STATE SENATOR DISTRICT (NUMBER) _____ VOTE FOR ONE	<input type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE
<input checked="" type="radio"/> CANDIDATE INDEPENDENCE	<input checked="" type="radio"/> CANDIDATE DEMOCRATIC/FARMER-LABOR	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE	COUNTY ATTORNEY VOTE FOR ONE
<input type="radio"/> CANDIDATE DEMOCRATIC/FARMER-LABOR	CONSTITUTIONAL AMENDMENT	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	Provide 1, vote on a constitutional amendment, will have the same effect as voting on it if it is approved.	<input type="radio"/> CANDIDATE
STATE REPRESENTATIVE DISTRICT (NUMBER) _____ VOTE FOR ONE	To vote for a proposed constitutional amendment, completely fill in the oval next to the word "YES" for that question. To vote against a proposed constitutional amendment, completely fill in the oval next to the word "NO" for that question.	COUNTY SURVEYOR VOTE FOR ONE
<input checked="" type="radio"/> CANDIDATE INDEPENDENCE	CONSTITUTIONAL AMENDMENT TITLE	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE REPUBLICAN	(Body of question is related to question on reverse side of ballot)	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE DEMOCRATIC/FARMER-LABOR	YES	<input checked="" type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	NO	<input type="radio"/> CANDIDATE
GOVERNOR AND LIEUTENANT GOVERNOR VOTE FOR ONE TEAM	<input checked="" type="radio"/> NO	CITY OFFICES [CITY NAME OPTIONAL] VOTE FOR UP TO TWO
<input type="radio"/> CANDIDATE AND CANDIDATE INDEPENDENCE	COUNTY OFFICES	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE AND CANDIDATE REPUBLICAN	COUNTY COMMISSIONER DISTRICT (NUMBER) _____ VOTE FOR ONE	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE AND CANDIDATE DEMOCRATIC/FARMER-LABOR	<input checked="" type="radio"/> CANDIDATE	<input checked="" type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE

VOTE FRONT AND BACK OF BALLOT

INSTRUCTIONS TO VOTERS
 To vote, completely fill in the oval(s) next to your choice(s) like this:



Is this a legal vote?

- Courts would probably say so ...
- ... but op-scan readers might not count it.

Increasing demands that machine's interpretation match a human's.

Evaluating election technologies

Some general system-level goals for trustworthy elections:

- Need accurate determination of voter intent.
- Must preserve voter anonymity.
- Accessibility for disabled voters and non-native speakers.
- If possible, prevent overvoting (invalidates voter's ballot).
- If possible, prevent unintentional undervoting (voter confusion?).
- Easy to administer, even by under-trained poll workers.
- Transparently fair.



Lingering concerns about paper

Draft report on Voluntary Voting Systems Guidelines by the Security and Transparency Subcommittee for the Technical Guidelines Development Committee of the National Institute of Standards and Technology (NIST):

“The widespread adoption of voting systems incorporating paper did not seem to cause any widespread problems in the November 2006 elections. But, the use of paper in elections places more stress on (1) the capabilities of voting system technology, (2) of voters to verify their accuracy, and (3) of election workers to securely handle the ballots and accurately count them. Clearly, the needs of voters and election officials need to be addressed with improved and new technology. The STS believes that current paper-based approaches can be improved to be significantly more usable to voters and election officials ...”

W. Burr, J. Kelsey, R. Peralta, and J. Wack. Requiring software independence in VVSG 2007: STS recommendations for the TGDC. Technical report, National Institute of Standards and Technology, November 2006. <http://vote.nist.gov/DraftWhitePaperOnSIinVVSG2007-20061120.pdf>.

Research questions

Issues that arise from using paper ballots in elections:

- Accurate interpretation of marginal markings.
- Human cost, error rate, and bias in performing manual recounts.
- Failure modes in ballot imaging (e.g., paper jams).
- Systematic errors due to ballot layout (one candidate may be disadvantaged over another based on physical location on page).

Also keep in mind:

- U.S. Elections can be complex (10's to 100's of choices).
- Impact of “voter error” (e.g., improper markings, erasures).
- Potential for traditional ballot-box stuffing.
- Computer hackers attempting to manipulate the vote.

Connection to forms processing

Similarities to forms processing, but also some key differences:

- Much broader range of users (education level, literacy, etc.) than for traditional forms applications.
- Ballots must preserve a voter's anonymity.
- Demand to count votes and report results quickly.
- Elections are held infrequently, so voting equipment sits unused for long periods in storage.
- Poll workers often lack technical expertise.
- Maintaining chain-of-custody is a critical security requirement.
- No *financial* interest in making sure votes are counted accurately, but there is tremendous *public* interest.



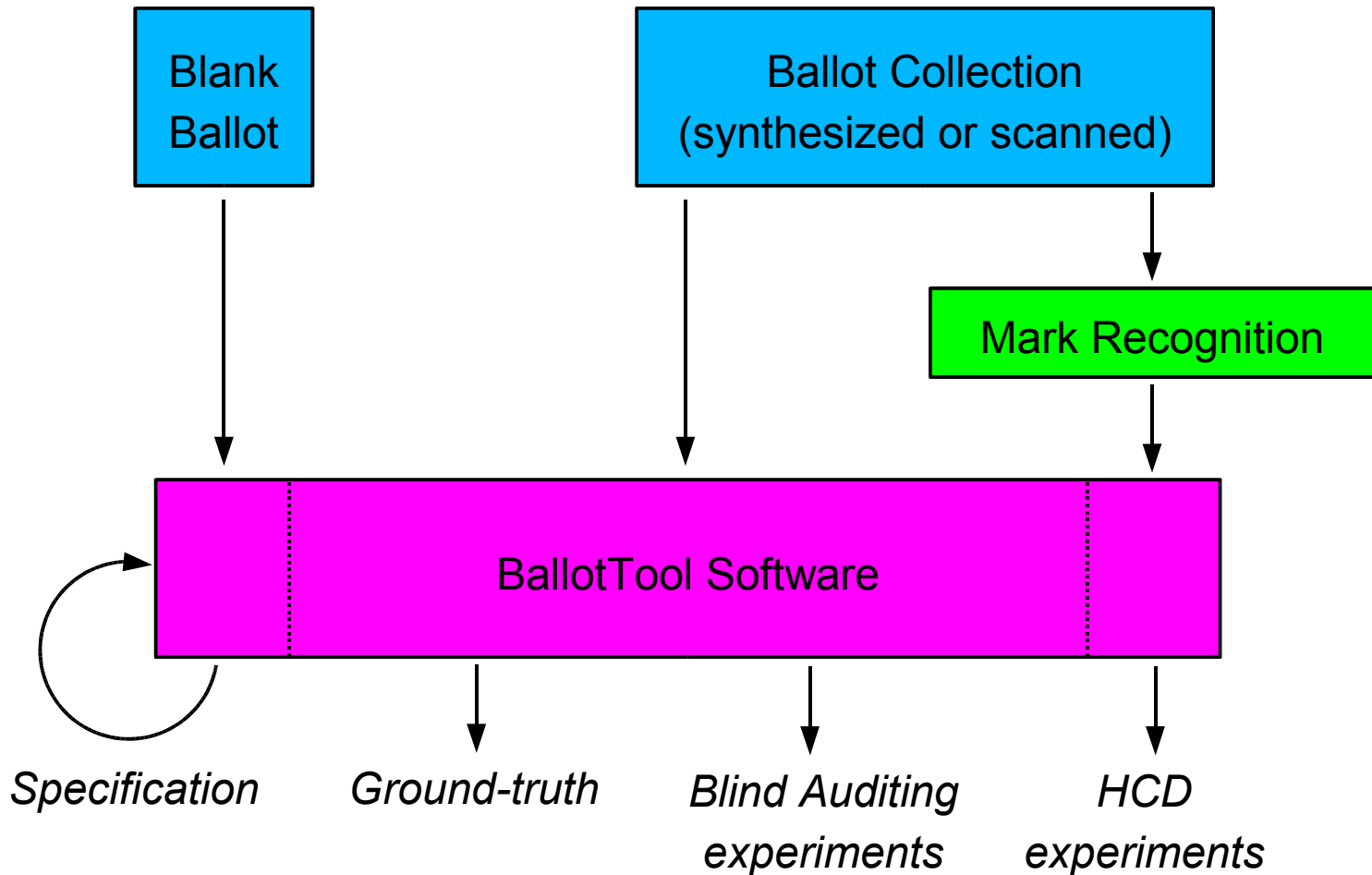
BallotToolkit

Software components written in Tcl/Tk and runnable under both MS Windows and Linux. GUI logs user interactions (all events time-stamped) to facilitate user studies. Data interchange via XML-like file formats.

Provides support for:

- Ballot specification (locating targets, defining races and elections).
- Ballot ground-truthing (human interpretation of ballot markings).
- Synthesizing collections of marked ballots.
- Investigating “blind” auditing to eliminate human bias.
- Investigating homogeneous class display to facilitate recounts.

BallotTool software



BallotTool GUI

The image displays the BallotTool GUI, which is used for defining and rendering electronic ballots. It consists of two main windows:

- LM_survey1b (x0.25):** The main survey form window. It contains the following content:
 - Header: Lehigh University / Muhlenberg College, 2008 Presidential Election, NATIONAL SURVEY
 - Instructions: "Please choose only one answer for each question. Fill in the oval for the answer that you select for each question." and "In determining your vote for president in the 2008 election please indicate how important the following issues will be:"
 - Response options: Very Important, Somewhat Important, Not Too Important, Not At All Important.
 - Issues: The War in Iraq, Global Warming, The Economy, Terrorism, Taxes, Education, Health Care, Crime. (Note: 'The War in Iraq' and 'Global Warming' are highlighted in green in the original image.)
 - Candidate section: "Please identify your views on the following candidates for president:" with options: Very Favorable, Somewhat Favorable, Not Too Favorable, Not At All Favorable. Candidates listed: John McCain, Hillary Clinton, Barack Obama, Mitt Romney, Mike Huckabee.
 - Additional questions: "If the 2008 presidential election was being held today and the candidates were Democrat Hillary Clinton and Republican John McCain, who would you vote for?" and "If the 2008 presidential election was being held today and the candidates were Democrat Barack Obama and Republican John McCain, who would you vote for?"
- Ballot Definition:** A configuration window for defining the ballot's structure and appearance. It includes:
 - Election:** Lehigh-Muhlenberg. **Bounding Box:** x1: 10, y1: 10, x2: 2542, y2: 3290.
 - Race:** The War in Iraq. **VoteFor:** 1. **Bounding Box:** x1: 350, y1: 1050, x2: 800, y2: 1105.
 - Candidate:** Very Important. **Label Bounding Box:** x1: 830, y1: 890, x2: 1060, y2: 1020. **Target Bounding Box:** x1: 900, y1: 1050, x2: 990, y2: 1105.
 - Candidate:** Somewhat Important. **Label Bounding Box:** x1: 1130, y1: 890, x2: 1360, y2: 1020. **Target Bounding Box:** x1: 1200, y1: 1050, x2: 1290, y2: 1105.
 - Candidate:** Not Too Important. **Label Bounding Box:** x1: 1430, y1: 890, x2: 1660, y2: 1020. **Target Bounding Box:** x1: 1500, y1: 1050, x2: 1590, y2: 1105.
 - Candidate:** Not At All Important. **Label Bounding Box:** x1: 1730, y1: 890, x2: 1960, y2: 1020. **Target Bounding Box:** x1: 1800, y1: 1050, x2: 1890, y2: 1105.
 - Race:** Global Warming. **VoteFor:** 1. **Bounding Box:** x1: 350, y1: 1110, x2: 800, y2: 1165.
 - Candidate:** Very Important. **Label Bounding Box:** x1: 830, y1: 890, x2: 1060, y2: 1020. **Target Bounding Box:** x1: 900, y1: 1110, x2: 990, y2: 1165.
 - Candidate:** Somewhat Important. **Label Bounding Box:** x1: 1130, y1: 890, x2: 1360, y2: 1020. **Target Bounding Box:** x1: 1200, y1: 1110, x2: 1290, y2: 1165.
 - Candidate:** Not Too Important. **Label Bounding Box:** x1: 1430, y1: 890, x2: 1660, y2: 1020. **Target Bounding Box:** x1: 1500, y1: 1110, x2: 1590, y2: 1165.
 - Candidate:** Not At All Important. **Label Bounding Box:** x1: 1730, y1: 890, x2: 1960, y2: 1020. **Target Bounding Box:** x1: 1800, y1: 1110, x2: 1890, y2: 1165.

File format for specifying ballots

Blank ballot

Lehigh University / Muhlenberg College
2007 Presidential Election
NATIONAL SURVEY

Please choose only one answer for each question. Fill in the oval for the answer that you select for each question.

In determining your vote for president in the 2008 election please indicate how important the following issues will be:

	Very Important	Somewhat Important	Not Too Important	Not At All Important
The War in Iraq	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Global Warming	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The Economy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Terrorism	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Taxes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Education	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Health Care	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Crime	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Please identify your views on the following candidates for president:

	Very Favorable	Somewhat Favorable	Not Too Favorable	Not At All Favorable
Rudi Giuliani	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Hillary Clinton	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Barack Obama	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mitt Romney	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
John McCain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

If the 2008 presidential election was being held today and the candidates were Democrat Hillary Clinton and Republican Rudy Giuliani, who would you vote for?

Hillary Clinton
Rudi Giuliani

If the 2008 presidential election was being held today and the candidates were Democrat Barack Obama and Republican Rudy Giuliani, who would you vote for?

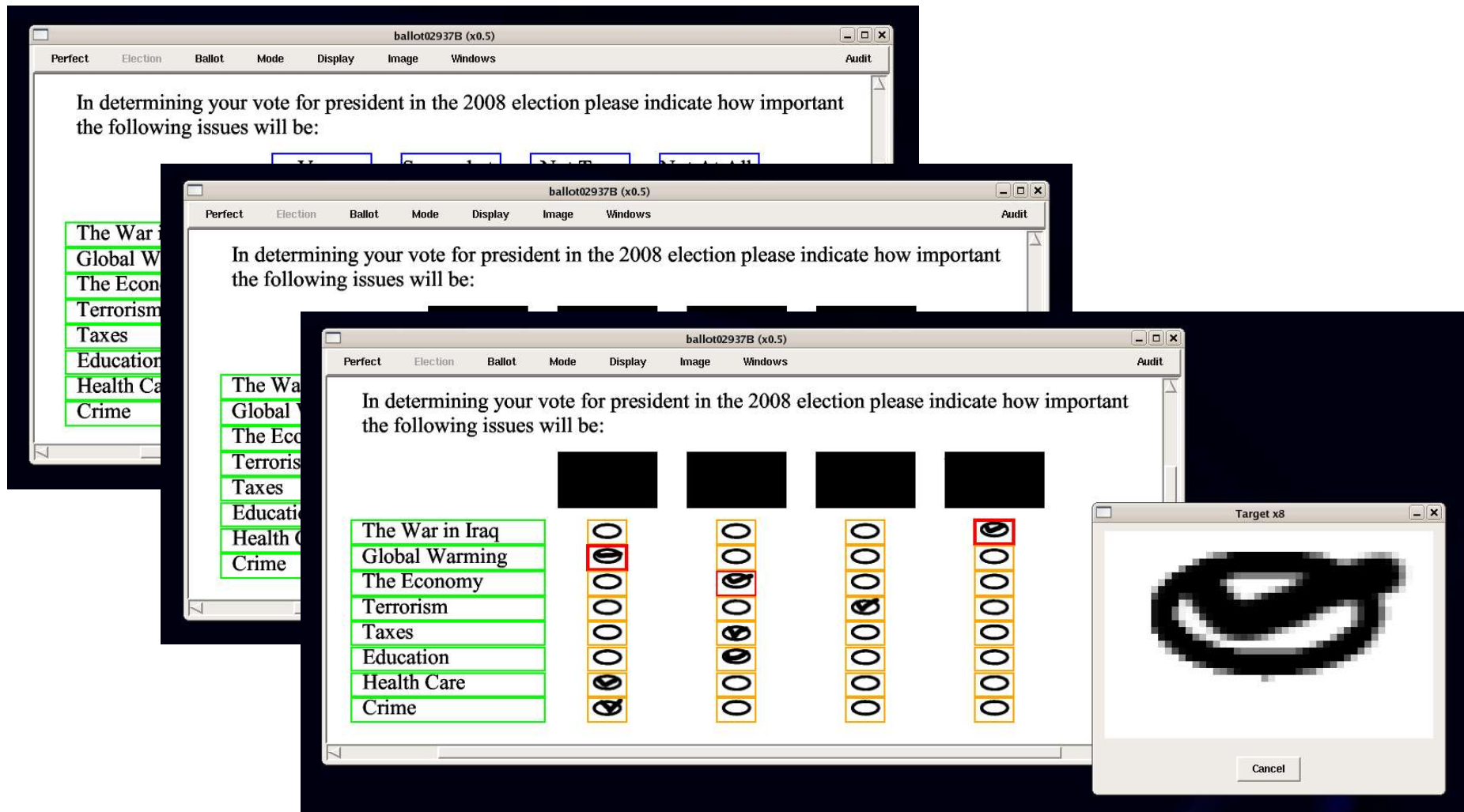
Barack Obama
Rudi Giuliani

Associated specification

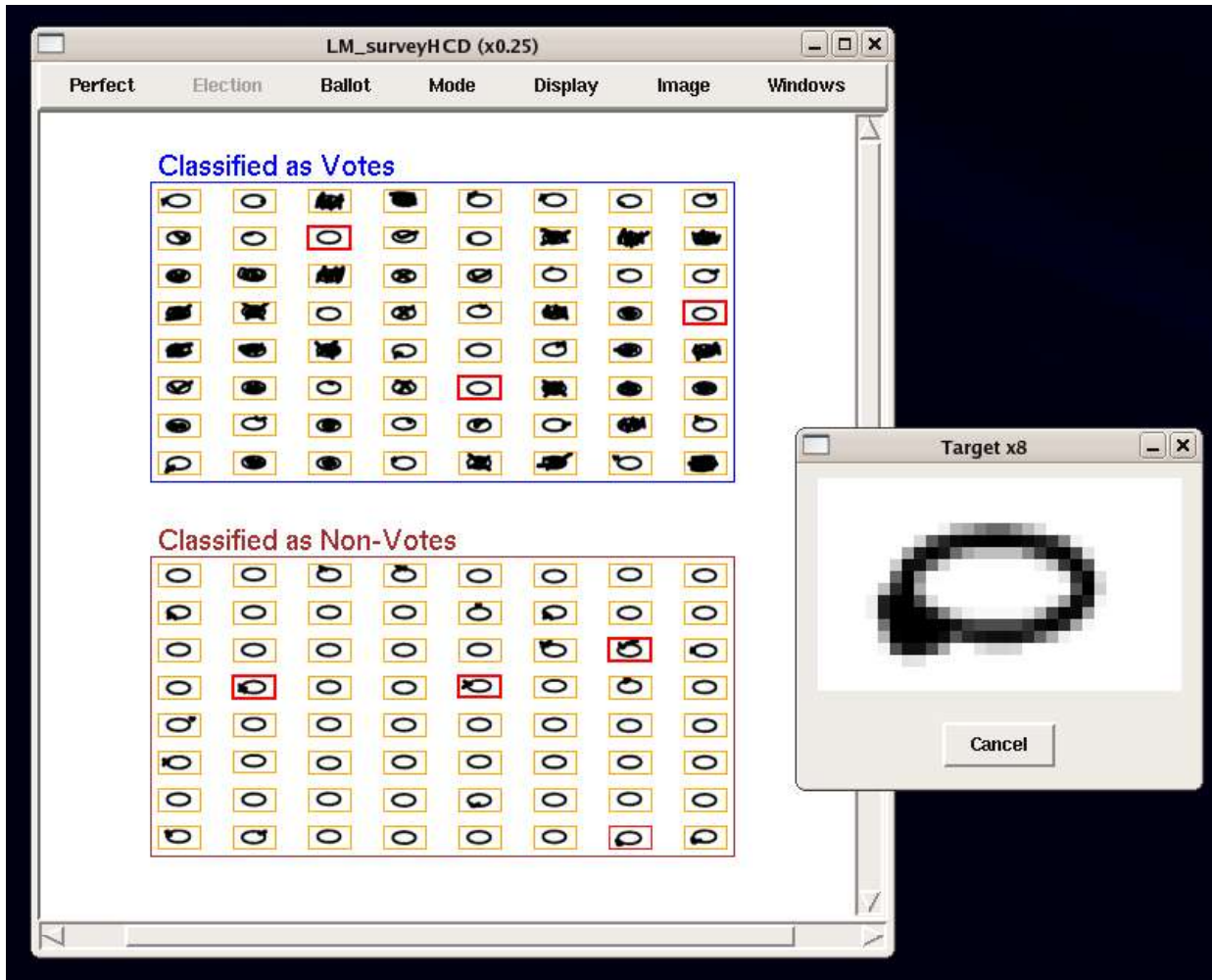
```
<election ID="election001" Election="Lehigh-Muhlenberg Survey"
  bb_x1="10" bb_y1="10" bb_x2="2542" bb_y2="3290">
<race ID="race001" Race="The War in Iraq" VoteFor="1"
  bb_x1="350" bb_y1="1050" bb_x2="800" bb_y2="1105">
<candidate ID="cand001" Candidate="Very Important"
  bbl_x1="830" bbl_y1="890" bbl_x2="1060" bbl_y2="1020"
  bbt_x1="900" bbt_y1="1050" bbt_x2="990" bbt_y2="1105">
<candidate ID="cand002" Candidate="Somewhat Important"
  bbl_x1="1130" bbl_y1="890" bbl_x2="1360" bbl_y2="1020"
  bbt_x1="1200" bbt_y1="1050" bbt_x2="1290" bbt_y2="1105">
<candidate ID="cand003" Candidate="Not Too Important"
  bbl_x1="1430" bbl_y1="890" bbl_x2="1660" bbl_y2="1020"
  bbt_x1="1500" bbt_y1="1050" bbt_x2="1590" bbt_y2="1105">
<candidate ID="cand004" Candidate="Not At All Important"
  bbl_x1="1730" bbl_y1="890" bbl_x2="1960" bbl_y2="1020"
  bbt_x1="1800" bbt_y1="1050" bbt_x2="1890" bbt_y2="1105">
</race>
<race ID="race002" Race="Global Warming" VoteFor="1"
  bb_x1="350" bb_y1="1110" bb_x2="800" bb_y2="1165">
<candidate ID="cand001" Candidate="Very Important"
  bbl_x1="830" bbl_y1="890" bbl_x2="1060" bbl_y2="1020"
  bbt_x1="900" bbt_y1="1110" bbt_x2="990" bbt_y2="1165">
```

...

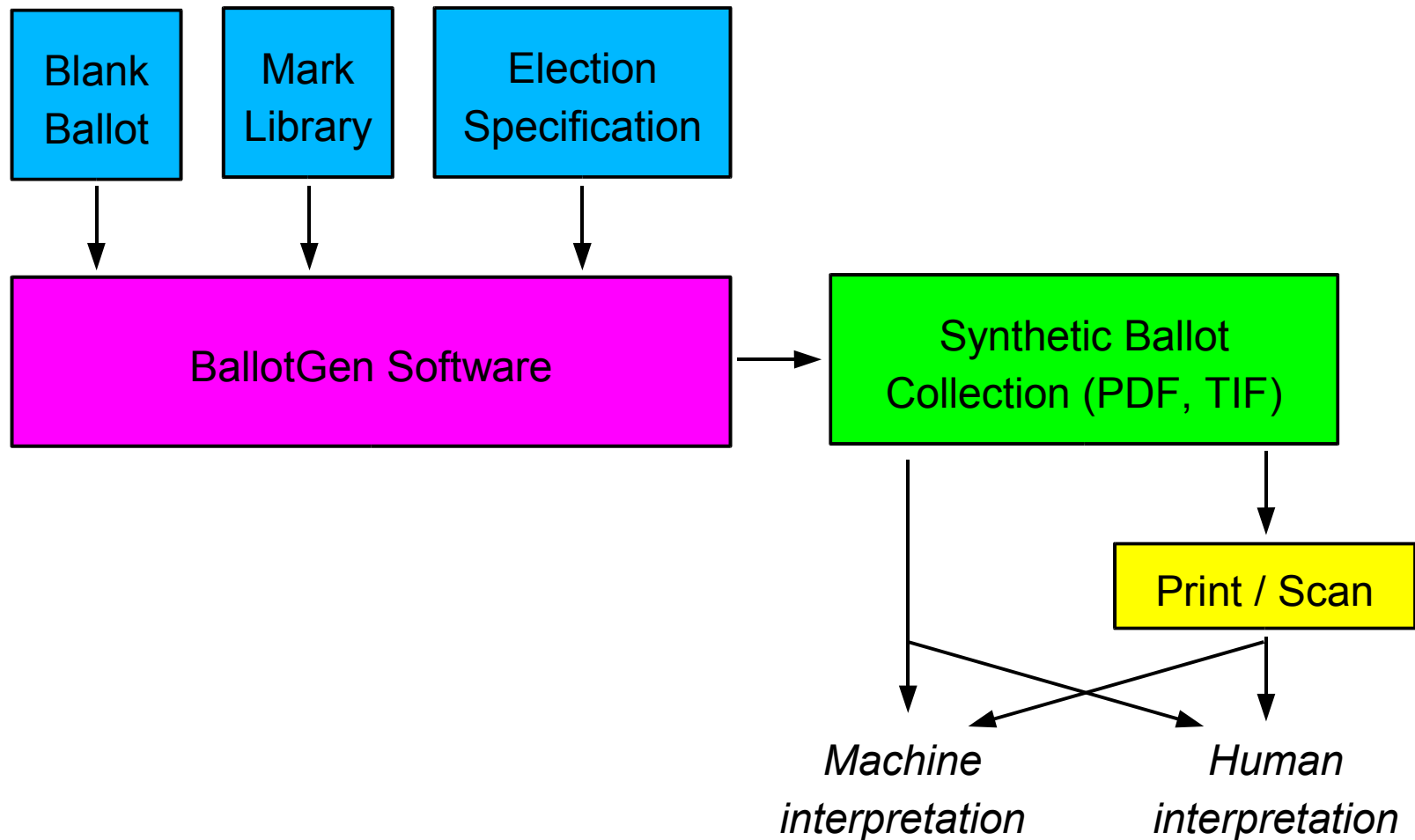
BallotTool GUI for blind auditing



BallotTool GUI for HCD



BallotGen software



Synthesizing ballots

Two paradigms for injecting marks on blank ballot substrate:

- Extract and place pre-marked targets on image.
- Transform and overlay marks with transparent backgrounds.

In latter case, we can:

- Adjust x- and y-displacement from target center.
- Scale x- and y-dimensions independently.
- Rotate mark by a random amount.
- Re-map grayscale or color of mark.

Pre-marked targets

	Very Important	Somewhat Important
The War in Iraq	<input checked="" type="radio"/>	<input checked="" type="radio"/>
Global Warming	<input checked="" type="radio"/>	<input checked="" type="radio"/>

	Very Important	Somewhat Important
The War in Iraq	<input checked="" type="radio"/>	<input checked="" type="radio"/>
Global Warming	<input checked="" type="radio"/>	<input checked="" type="radio"/>

	Very Important	Somewhat Important
The War in Iraq	<input type="radio"/>	<input type="radio"/>
Global Warming	<input type="radio"/>	<input type="radio"/>

	Very Important	Somewhat Important
The War in Iraq	<input type="radio"/>	<input type="radio"/>
Global Warming	<input type="radio"/>	<input type="radio"/>

	Very Important	Somewhat Important
The War in Iraq	<input checked="" type="radio"/>	<input checked="" type="radio"/>
Global Warming	<input checked="" type="radio"/>	<input checked="" type="radio"/>

	Very Important	Somewhat Important
The War in Iraq	<input checked="" type="radio"/>	<input checked="" type="radio"/>
Global Warming	<input checked="" type="radio"/>	<input checked="" type="radio"/>

	Very Important	Somewhat Important
The War in Iraq	<input type="radio"/>	<input type="radio"/>
Global Warming	<input type="radio"/>	<input type="radio"/>

Synthesizing ballots

Lehigh University / Muhlenberg College
2008 Presidential Election
NATIONAL SURVEY

Please chose only one answer for each question. Fill in the oval for the answer that you select for each question.

In determining your vote for president in the 2008 election please indicate how important the following issues will be:

	Very Important	Somewhat Important	Not Too Important	Not At All Important
The War in Iraq	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
Global Warming	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The Economy	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
Terrorism	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Taxes	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Education	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Health Care	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Crime	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>

Please identify your views on the following candidates for president:

	Very Favorable	Somewhat Favorable	Not Too Favorable	Not At All Favorable
John McCain	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
Hillary Clinton	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Barack Obama	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
Mitt Romney	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mike Huckabee	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>

If the 2008 presidential election was being held today and the candidates were Democrat Hillary Clinton and Republican John McCain, who would you vote for?

Hillary Clinton

John McCain

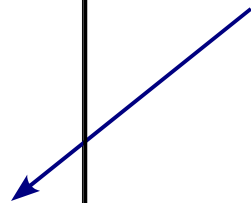
If the 2008 presidential election was being held today and the candidates were Democrat Barack Obama and Republican John McCain, who would you vote for?

Barack Obama

John McCain

39705-B

Simulated Lehigh-Muhlenberg 2008 Presidential Election survey. Synthesized using marks that are randomly chosen and placed (some intentionally “marginal”).



Transformed and overlaid marks

OFFICIAL BALLOT

STATE GENERAL ELECTION BALLOT

Judge _____
 Judge _____

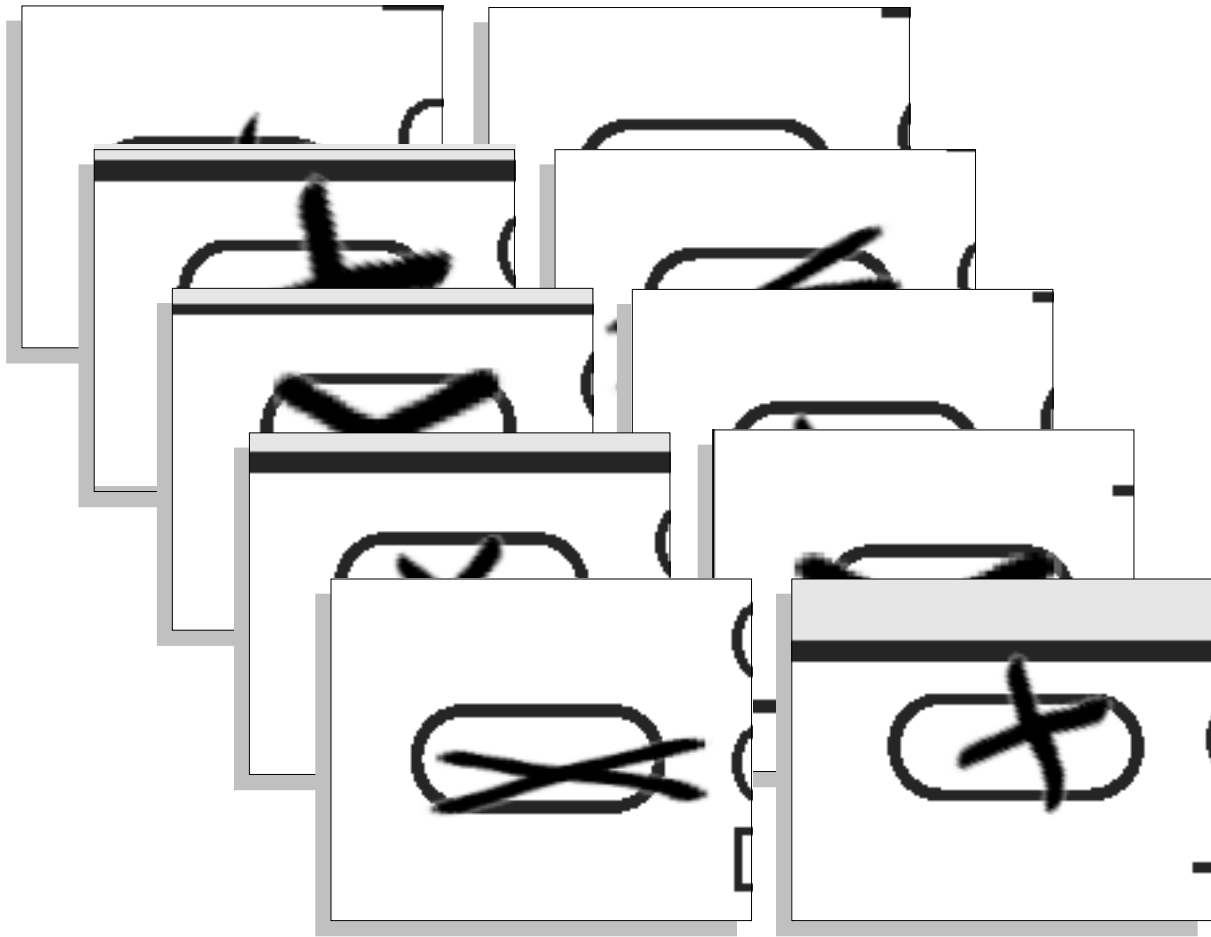
COUNTY NAME _____
 NOVEMBER 7, 2006

INSTRUCTIONS TO VOTERS
 To vote, completely fill in the oval(s) next to your choice(s) like this:

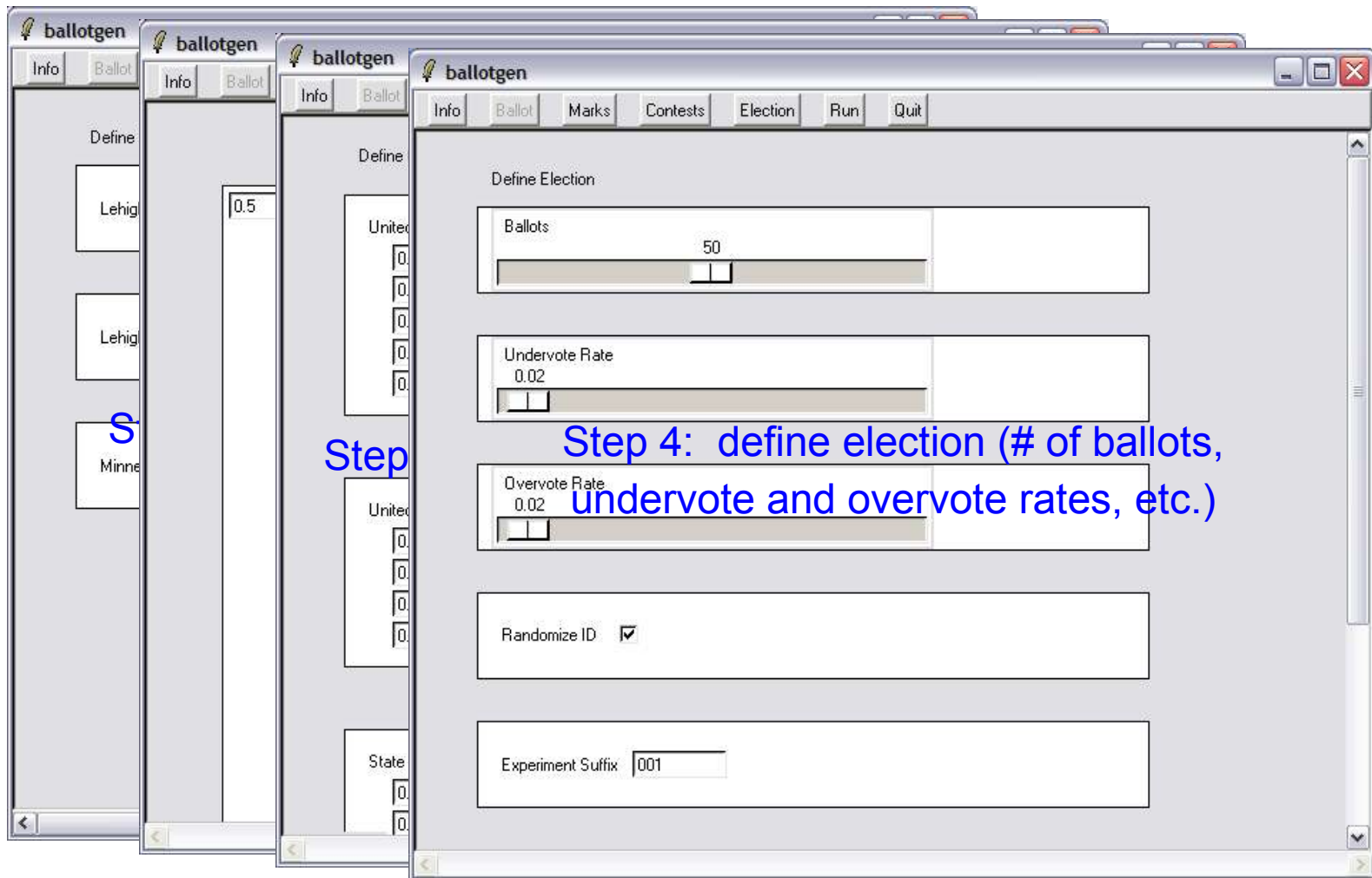
FEDERAL OFFICES	STATE OFFICES	COUNTY OFFICES
UNITED STATES SENATOR VOTE FOR ONE	SECRETARY OF STATE VOTE FOR ONE	COUNTY AUDITOR VOTE FOR ONE
<input type="radio"/> CANDIDATE INDEPENDENCE	<input type="radio"/> CANDIDATE INDEPENDENCE	<input type="radio"/> CANDIDATE
<input checked="" type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE REPUBLICAN	<input checked="" type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE DEMOCRATIC-FARMER-LABOR	<input type="radio"/> CANDIDATE DEMOCRATIC-FARMER-LABOR	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE Party of Progress	<input type="radio"/> CANDIDATE	COUNTY TREASURER VOTE FOR ONE
<input type="radio"/> CANDIDATE	STATE AUDITOR VOTE FOR ONE	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	<input checked="" type="radio"/> CANDIDATE REPUBLICAN	<input checked="" type="radio"/> CANDIDATE
UNITED STATES REPRESENTATIVE DISTRICT (NUMBER) VOTE FOR ONE	<input type="radio"/> CANDIDATE INDEPENDENCE	<input type="radio"/> CANDIDATE
<input checked="" type="radio"/> CANDIDATE INDEPENDENCE	<input checked="" type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE DEMOCRATIC-FARMER-LABOR	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE DEMOCRATIC-FARMER-LABOR	<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	ATTORNEY GENERAL VOTE FOR ONE	COUNTY SHERIFF VOTE FOR ONE
STATE OFFICES	<input type="radio"/> CANDIDATE INDEPENDENCE	<input type="radio"/> CANDIDATE
STATE SENATOR DISTRICT (NUMBER) VOTE FOR ONE	<input type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE
<input checked="" type="radio"/> CANDIDATE INDEPENDENCE	<input checked="" type="radio"/> CANDIDATE DEMOCRATIC-FARMER-LABOR	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE	COUNTY ATTORNEY VOTE FOR ONE
<input type="radio"/> CANDIDATE DEMOCRATIC-FARMER-LABOR	CONSTITUTIONAL AMENDMENT	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	Provide 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000	<input type="radio"/> CANDIDATE
STATE REPRESENTATIVE DISTRICT (NUMBER) VOTE FOR ONE	<input type="radio"/> CANDIDATE INDEPENDENCE	COUNTY SURVEYOR VOTE FOR ONE
<input checked="" type="radio"/> CANDIDATE INDEPENDENCE	<input type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE REPUBLICAN	<input type="radio"/> CANDIDATE DEMOCRATIC-FARMER-LABOR	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE DEMOCRATIC-FARMER-LABOR	CONSTITUTIONAL AMENDMENT TITLE	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	[Body of question related to proposed constitutional amendment]	<input type="radio"/> CANDIDATE
GOVERNOR AND LIEUTENANT GOVERNOR VOTE FOR ONE TEAM	<input type="radio"/> YES	CITY OFFICES [CITY NAME OPTIONAL]
<input type="radio"/> CANDIDATE AND CANDIDATE INDEPENDENCE	<input checked="" type="radio"/> NO	COUNCIL MEMBER VOTE FOR UP TO TWO
<input type="radio"/> CANDIDATE AND CANDIDATE REPUBLICAN	COUNTY OFFICES	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE AND CANDIDATE REPUBLICAN	COUNTY COMMISSIONER DISTRICT (NUMBER) VOTE FOR ONE	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE AND CANDIDATE DEMOCRATIC-FARMER-LABOR	<input checked="" type="radio"/> CANDIDATE	<input checked="" type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE
<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE	<input type="radio"/> CANDIDATE

VOTE FRONT AND BACK OF BALLOT

© 2006-001



Synthesizing ballot collections



Summary

Status:

- Prototype nearly complete – blind auditing and HCD experiments will commence soon in collaboration with social scientist colleagues. Results to be presented in future papers.

Conclusions:

- Paper ballot processing provides an opportunity to apply document analysis research to a timely and important problem.
- Upon reflection, a number of other ideas will come to mind. E.g., style-based recognition for interpreting marginal markings.

Whole-ballot recognition

Stray mark?

Valid vote?

BASEBALL HALL OF FAME
(vote for no more than 5)

- Ty Cobb
- Rogers Hornsby
- Walter Johnson
- Nap Lajoie
- Christy Mathewson
- Babe Ruth
- Tris Speaker
- Honus Wagner
- Cy Young

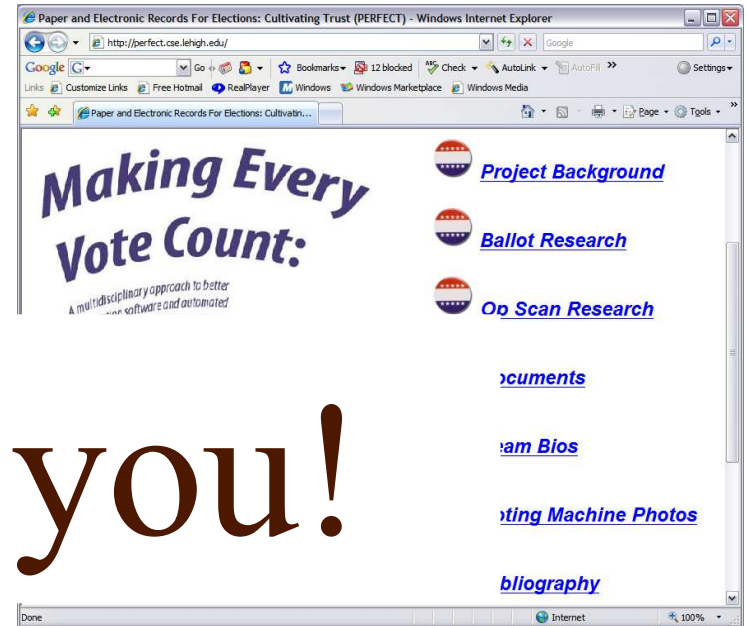
BASEBALL HALL OF FAME
(vote for no more than 5)

- Ty Cobb
- Rogers Hornsby
- Walter Johnson
- Nap Lajoie
- Christy Mathewson
- Babe Ruth
- Tris Speaker
- Honus Wagner
- Cy Young

⇒ Capture voter intent via style-based techniques.

http://perfect.cse.lehigh.edu/

Paper and Electronic Records
for Elections: Cultivating Trust



Thank you!

This work was supported in part by the National Science Foundation under award numbers NSF-0716368, NSF-0716393, NSF-0716647, and NSF-0716543. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the National Science Foundation.