A Voting System with a Modular Voting Architecture and an Electronic Audit Trail[1]

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Abstract

We present a design for a voting system with a modular voting architecture and an electronic audit trail. The voting system consists of am electronic ballot printer, a PC with a visual or auditory interface that prints a paper ballot and mtaintains an electronic audit trail, a ballot verification station that reads a paper ballot and either displays or "speaks" the ballot's selections and undervotes, and a ballot tabulation and reconciliation station that reads the ballots and tabulates the votes and reconciles them against the electronic audit trail. A prototype of this system has been built and demonstrated.

1. Introduction

Voting is the foundation of a democratic system of government, whether the system uses direct or representative governance. The heart of voting is trust that each vote is recorded and tallied with accuracy and impartiality. There is no shortage of historical examples of attempts to undermine the integrity of electoral systems. The paper and mechanical systems we use today, although far from perfect, are built upon literally hundreds of years of actual experience.

There is immense pressure to replace our "dated" paper and mechanical systems with computerized systems. There are many reasons why such systems are attractive. These reasons include, cost, speed of voting and tabulation, elimination of ambiguity from things like "hanging chads," and a belated recognition that many of our traditional systems are not well suited for use by citizens with physical impairments.

However, electronic voting brings a new set of risks and drawbacks as well as advantages. In response to the problems and opportunities of electronic voting, the Open Voting Consortium was established.

The Open Voting Consortium (OVC) is creating an open source, trustworthy, cost effective, voter verifiable voting system using open source software components on industry standard computers. A primary element of this Open Voting system is the use of software through which the voter creates a *printed paper ballot* containing his or her choices. Before casting his or her ballot the voter may use other, independently programmed, computers to verify that the ballot properly reflects the voter's choices. The voter may also visually inspect the text printed on the paper ballot. The paper ballot is cast by placing it into a ballot box. Once cast, that paper ballot is the authoritative record of the voter's choices for the election and for any recount of that election. Open Voting ballots are machine-readable and may be tabulated (and re-tabulated in the case of a recount) either by computer or by hand.

Open Voting systems can be engineered to accommodate the special needs of those who have physical impairments, or limited reading ability.

Many of us today have come to trust many of our financial transactions to ATMs (automatic teller machines). The push for electronic voting machines has benefited from that faith in ATMs. However, we are starting to learn that that faith is unwarranted.

First, ATM machines do fail and are often attacked. Those who operate ATMs usually consider the loss rate to be a proprietary secret. Banks are well versed in the actuarial arts and they build into their financial plans various means to cover the losses that do occur. In more crude terms, it's only money.

Second, voting machines carry a more precious burden — there is no way to buy insurance or to set aside a contingency fund to replace a broken or tampered election.

There are several areas of concern regarding the new generation of computerized voting machines:

- No means for the voter to verify that his or her votes have been tallied properly.
- No means outside of the memories of the voting machines themselves to audit or recount the votes.
- Lack of ability to audit the quality of the software. Fortunately the widespread belief

that "computers are always right" is fading. Our individual experiences with error-ridden software on personal computers and consumer products (e.g., the BMW 745i[2]), software errors by even the best-of-the-best (e.g., NASA and the loss of the Mars Climate Orbiter[3]), and the possibility that intentional software bugs can be hidden so deeply as to be virtually invisible (Ken Thompson's famous 1984 paper — Reflections on Trusting Trust[4]) have all combined to teach us that we should not trust software until that trust has been well earned. And even then, we ought not to be surprised if unsuspected flaws arise.

- Vulnerability of the machines or of their supporting infrastructures to intentional attack or inadvertent errors.

The Help America Vote Act of 2002[5] was passed into law to modernize voting equipment as a result of the 2000 US Presidential election and the problems observed in Florida.[6] The Federal Election Commission (FEC) has issued a set of Voting System Standards (VSS)[7] that serve as a model of functional requirements that elections systems must meet before they can be certified for use in an election. The next section discusses the existing voting machines that meet those standards. Section 3 considers the rationale for an accessible voter-verifiable paper ballot. Section 4 is a description of the Open Voting Consortium architecture for the polling place. Section 5 mentions the current state of the system and next steps for its development. Conclusion, acknowledgements, and references follow.

2. OVC System Description

The OVC system design is very much like a traditional system in which the voter enters the polling place, marks his or her choices onto a paper ballot, and inserts the ballot into a ballot box. Our design applies computer technology to that traditional system. However, unlike some of the other computerized voting systems that change the basic nature of the traditional system, our design applies computer technology only in a limited and conservative way.

The OVC design preserves the paper ballot. However, under the OVC design the voter "marks" the ballot using a computerized voting station rather than a pencil or colored marker. The ballot is printed in plain text that the voter can read. Voters have the opportunity to inspect the ballot to ensure that it properly reflects their choices.

The OVC design preserves the ballot box. Voters must insert their paper ballots into the ballot box. The OVC ballots may contain a barcode in addition to the plain text. This barcode makes it easy for the poll workers to count the ballots[8] when the ballot box is opened.

The OVC design is for a voter-verified voting system. The core difference between this design and other systems, such as DRE equipped with printers, is that in the OVC design the paper ballot is the actual ballot will the text of the selections made; information that might be recorded in computer memories or on computer media is used only for security, error-detection, fraud detection/prevention, and auditing.

3. Existing Electronic Voting Machines

Existing DRE (Direct Recording Electronic) voting machines have come under increasing scrutiny with widespread reports of malfunctions, omissions and user interface problems during elections.

3.1 Diebold AccuVote TS and TS-X

A group led by Avi Rubin and Dan Wallach analyzed the Diebold AccuVote TS DRE voting machine and found numerous flaws.[9] SAIC was commissioned by the state of Maryland to analyze the Diebold voting system and found "[t]he system, as implemented in policy, procedure, and technology, is at high risk of compromise."[10] Based on these reports, the California Secretary of State's office established security procedures for DRE voting machines.[11] Diebold was then found to have used uncertified software in 17 counties in California.[12] The California Secretary of State then decertified the Diebold and all other DREs on April 30, 2004.[13] The appointed California Secretary of State conditionally certified the Diebold TSX on February 17, 2006.[14] Yet serious flaws were found in this system by Harri Hursti.[15]

3.2 Electronic Systems and Software iVotronic

ES&S iVotronic is a poll-worker-activated, multilingual touch screen system that records votes on internal flash memory. A poll worker uses a cartridge-like device called a Personal Electronic Ballot (PEB) to turn the machine on and enable voting. Voters first choose their ballot language and then make their selections via a touch screen. When the polls close, poll workers

read summary data from each machine onto the PEB via infrared. The PEBs are then transported to election headquarters or their contents transmitted via a computer network.

In September 2002 in Florida, a spot check of iVotronic machines revealed several precincts where hundreds of voters had only one or even no selections chosen the their ballots cast on Election Day and vote totals produced by the main and backup system did not agree.[16] In October 2002 in Texas, several people reported that their votes registered for a different candidate on screen and, in fact, some votes cast for Republicans were counted for Democrats.[17] In November 2002, two early-voting locations in Wake County, North Carolina (Raleigh) failed to record 436 ballots due to a problem in the iVotronics' firmware.[18]

3.3 Hart InterCivic eSlate

Hart's eSlate is a voter-activated multilingual voting system where the voter turns a selector wheel and set of buttons to indicate their votes. The eSlate terminals are connected via daisy-chained serial cable to a central controller, the Judges' Booth Controller (JBC), which provides power, vote activation, and vote storage for up to twelve eSlate terminals. A poll worker issues a 4-digit PIN to the voter using the JBC. The voter enters this PIN on an eSlate and votes using its selector wheel and buttons. Once the vote is cast, the vote is transmitted via a cable to the JBC and stored in flash memory on the JBC's Mobile Ballot Box (MBB). The MBB is then either physically transported to election headquarters or its contents transmitted via computer network.

In November 2003, poll workers in Harris County, Texas, confused by the system's complexity, could not get the machines to work properly and had been assigning the wrong ballots to voters using the JBC.[19] In February 2004 in Virginia, voters had to cast paper ballots when the JBC used at one precinct "fried," rendering all the eSlate machines unusable.[20] In March 2004 in Orange County, California, hundreds of voters were turned away when one eSlate machine broke down.[21] At the same time in California, poll workers incorrectly assigned ballots from different precincts to their voters and approximately 7000 voters cast ballots for the incorrect precinct.[22]

3.4 Sequoia Voting Systems AVC Edge

The Sequoia AVC Edge is a voter-activated multilingual touch screen system that records votes on flash memory. Its operation is very similar to the Diebold AccuVote-TS described above.

In March 2002 in Palm Beach County, Florida, the Edge machines froze up when voters selected their ballot language and other reports indicate votes counted for the wrong candidate.[23] As well, 15 PCMCIA cards were temporarily lost and the central system would not report the results and in a very close race many ballots were blank.[24] In April 2002, in Hillsborough County, Florida, one precinct could not transfer data on 24 out of 26 PCMCIA cards; results were faxed and entered in by hand.[25] In March 2003, a similar problem plagued PCMCIA cards.[26] In November 2002, in Bernalillo County, New Mexico, 48,000 people voted early, but no race showed more than 36,000 votes due to a software bug.[27] In June 2004, in Morris County New Jersey, the central tabulation system read only zeros from the PCMCIA cards.[28]

3.5 Voter-Verified Paper Audit Trail

DRE vendors are adding printers to their DREs.[29] In 2004, California enacted Senate Bill 1438 requiring voter verified paper trails for elections in 2006 and beyond. These will be in use for the primary election on June 6, 2006, in which one of our authors is serving as a precinct inspector. One concern with paper audit trails and voting system security measures in general is that some longtime poll workers do not see the need for these measures and may be hostile to the extra work incurred.[30]

AccuPoll has an Electronic Voting System with a voter-verified paper audit trail[31] and Sequoia Voting Systems is marketing optional voter-verified paper record printers for their DREs.[32] The state of Nevada used these VeriVote printers in the 2004 primary and presidential elections.[33] Although some predicted that the printers would fail or cause long lines, "[t]he primary election was free of serious problems that have embarrassed registrars in Florida, California, Maryland and other states with touchscreen machines."[34] The Avante Vote-Trakker is a DRE with a voter-verified paper audit trail.[35]

3.6 Paper Ballots with Optical Scan Machines

There are several problems with the use of paper ballots that are optically scanned with mark/sense-type tabulation systems. The paper ballot is not accessible to the visually impaired or reading impaired. And the paper ballot must be available in multiple languages as required by the jurisdiction. The use of paper does enable

recounts, but potentially suffers from the problems of overvotes, undervotes, and improper changes to ballots (including extraneous marks, which would void the ballot). Note that overvotes would not be a problem if approval voting were adopted.[36] In fact, under approval voting, the overvotes on the butterfly ballot in Florida would have gone to *both* Buchanan *and* Gore, a change that would have affected the election outcome.

3.6.1 AutoMark

The AutoMark[37] system is an Electronic Ballot Marker (EBM) that addresses accessibility problems by using an interface comparable to a Direct Recording Electronic voting machine. Similarly, it can provide support for multiple languages and limit overvotes and undervotes through its user interface. AutoMark uses ballots identical to those also used for manually-marked optical-scan systems. AutoMark effectively replaces the pen in such systems with a marking device that supports multiple languages and detects overvotes and undervotes. So there is the question of whether the printed ballots are in each required language, so that a non-English-speaking voter can still verify his or her ballot. It is possible to have a device with accessible output modes that reads the voter's marked choices (like that of OVC system described in Section 5.1.7), so that the voter may verify that the ballot is marked correctly, but that is not currently part of the AutoMark system. A key benefit of the AutoMark system is that the same optical scan tabulation system can be used for ballots cast in polling places, absentee ballots, and provisional ballots. But they neither maintain an electronic audit trail nor use digital signatures to detect ballot stuffing.

However, the optical scan tabulating systems are also potential sources of error. They must be calibrated to properly distinguish the ballot markings. For example, during the March 2004 primary election in Napa County, California, "optical scan machines from Sequoia Voting Systems failed to record voters' ballot marks on the paper copy…. Apparently, the optical scan machines can read carbon-based ink but not gel pens."[38] There is also the potential that the vote tabulation software could have errors or have been fraudulently modified.

3.6.2 Populex

The Populex[39] system is an Electronic Ballot Printer (EBP) that also addresses accessibility by using an interface comparable to a Direct Recording Electronic Voting Machine. The output is a small printed ballot with a barcode that contains the voter's ballot selections. Numbers are printed on the bottom of the ballot so that the voter can read the choices, but these numbers must be matched to a chart (e.g., on the wall) in the precinct. Because the ballots are paper, a provisional ballot could be placed in an envelope for subsequently determining whether the ballot should be counted. However, absentee ballots must be counted using a different technology, unless the absentee voter uses a Populex system.

3.7 DREs used internationally

Various countries around the world have chosen to use DRE systems. The Dutch-based NEDAP[40] system is used in the Netherlands, France, Germany, the United Kingdom and Ireland but has been criticized for its flaws.[41] The voting machine developed and used recently in India[42] is very simple and lacks features like disabled and multilingual access. Venezuela chose VVPAT-enabled Smartmatic[43] DREs on which to conduct its recent referendum on the President; there were allegations of fraud, but the "audit concluded the voting machines did accurately reflect the intent of the voters, as evidenced by a recount of the paper ballots in a sample of the machines."[44]

4. Why an Accessible Voter-Verifiable Paper Ballot

Many computer and other experts have joined VerifiedVoting.org's call for "the use of voter-verified paper ballots (VVPBs) for all elections in the United States, so voters can inspect individual permanent records of their ballots before they are cast and so meaningful recounts may be conducted. We also insist that electronic voting equipment and software be open to public scrutiny and that random, surprise recounts be conducted on a regular basis to audit election equipment."[45]

4.1 Paper Receipts vs. Paper Ballots

We speak of OVC creating a paper *ballot*, not a receipt, nor simply a "paper trail." That is, for OVC machines, the printout from a voting station is the primary and official record of votes cast by a voter. Electronic records may be used for generating preliminary results more rapidly or for auditing purposes, but the paper ballot is the actual official vote document counted.[46]

Some writers discuss producing a paper receipt, which a voter might carry home with them, as they do an ATM receipt. There are two

significant problems with this approach. In the first place, if we suppose that a voting station might have been tampered with and/or simply contain a programming error, it is not a great jump to imagine that it may print out a record that differs from what it records electronically. A receipt is a "feel good" approach that fails to correct the underlying flaws of DREs.

But the second problem with receipts is even more fundamental. A voting receipt that can be carried away by a voter enables vote buying and vote coercion. An interested third party—even someone as seemingly innocuous as an overbearing family member—could demand to see a receipt for voting in a manner desired. With OVC systems, ballots must be placed into a sealed ballot box to count as votes. If a voter leaves with an uncast ballot, even if she went through the motions of printing it at a vote station, that simply does not represent a vote that may be "proven" to a third party.

What some vendors refer to as a paper trail suffers from a weakness similar to the first problem paper receipts suffer. Under some such models, a DRE voting station might print out a summary of votes cast at the end of the day (or at some other interval). But such a printout is also just a "feel good" measure. If a machine software or hardware can be flawed out of malice or error, it can very well print a tally that fails to accurately reflect the votes cast on it. It is not *paper* that is crucial, but *voter-verifiability*.

4.2 Paper Audit Trail Under Glass vs. Paper Ballot

While "paper audit trail under glass" does indeed do a pretty good job of preventing ballot box stuffing with forged physical ballots, this approach is not the only—nor even the best—technique to accomplish this goal. We plan for OVC systems to incorporate cryptographic signatures and precinct-level customization of ballots that can convincingly prove a ballot is produced on authorized machines, at the polling place, rather than forged elsewhere. For example, a simple customization of ballots is a variation of the page position of our ballot watermarks in a manner that a tamperer cannot produce in advance. Surprisingly much information can be subtly coded by moving two background images a few millimeters in various directions. Another option is to encode a cryptographic signature within the barcode on a ballot—in a manner that can be mathematically proven not to disclose anything about the individual voter who cast that vote, but simultaneously that cannot be forged without knowledge of a secret key, which is known only to that electronic voting machine.

There are several narrowly technical problems with “paper audit trail under glass” systems. A “paper audit trail under glass” system has some extra mechanical problems with allowing rejection of incorrect paper record; some sort of mechanism for identifying the paper record as spoiled, perhaps through an ink mark. This approach increases the potential of physical failure, such as paper jams.

A more significant issue for "paper audit trail under glass" systems is their failure to provide the quality of accessibility to vision- or reading-impaired voters that OVC's design does. Sighted voters who happen to need reading glasses, or who can read only large print or closely held print, are likely to find “paper audit trail under glass” systems more difficult to check than printed ballots they can physically hold. Even if these machines add provisions for audio feedback on final ballots, users are dependent on the very same machine to provide such audio feedback. Potentially, a tampered-with machine could bias votes, but only for blind voters (still perhaps enough to change close elections). In contrast, OVC positively encourages third parties to develop software to assure the barcode encoding of votes matches the visibly printed votes—every voter is treated equally, and all can verify ballots.

From a more sophisticated cryptology perspective, “paper audit trail under glass” systems are likely to compromise voter anonymity in subtle ways. One of the issues is the possibility that sequential or time-stamp information on ballots could be correlated with the activity of individual voters. Even covert videotaping of the order in which voters enter a polling place might be used for such a compromise. This problem is more serious in those systems in which the voter-verified paper audit trail is maintained on a continuous paper tape fed onto a take-up spool. However, on systems that cut the audit trail into pieces, one for each voter, that ballots that fell to the bottom of the glass bin may be visible to subsequent voters. Such potential visibility also compromises anonymity.

A far more serious problem with a voter-verified paper audit trail is the difficulty of automated tabulation of the audit trail. This problem is especially acute when the voter-verified paper audit trail is cut into pieces, one for each voter. The glass bin is likely to be a mass of

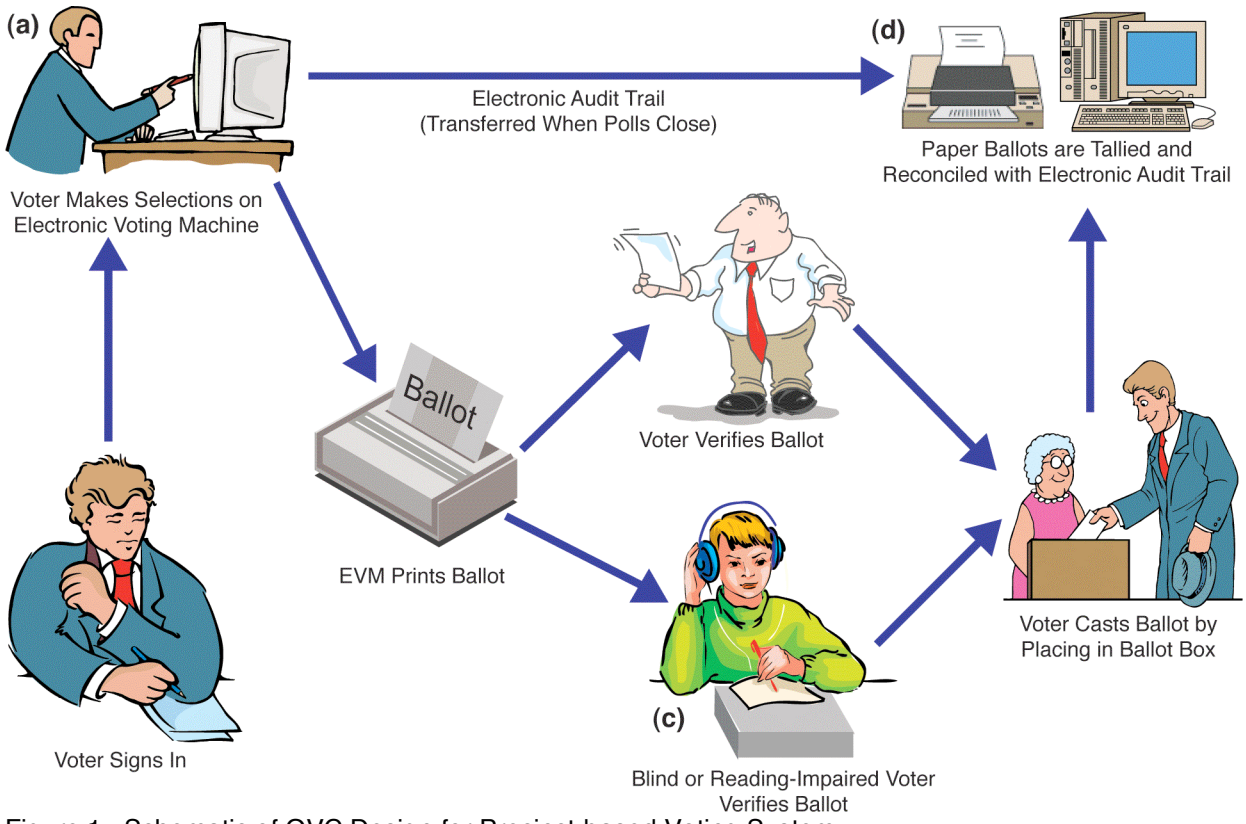

Figure 1. Schematic of OVC Design for Precinct-based Voting System.
(a) Electronic Voting Station.
(b) Electronic Voting Station with Reading-Impaired Interface (not shown).
(c) Ballot Verification Station.
(d) Ballot Reconciliation Station.

coiled paper strips. While the continuous spool approach to the paper audit trail is neater, it suffers from an anonymity problem as identified above. When the paper audit trail can only be used in a manual tabulation process, there will be enormous pressure to minimize its use, thereby reducing its effectiveness. In contrast, the OVC design facilitates automated tabulation of the paper ballots while enabling manual counting and voter-verification also. However, even when there is an automated tabulation process of the paper ballots, it is critical for a random sample of precincts to be manually tabulated, as a further check on the system.

4.3 Accessible Voting

One of the key benefits of electronic voting machines is to allow disabled voters to vote unassisted.[47] However, as the movement for a voter-verifiable paper audit trail grows,[48] there is a need for the paper audit trail to be accessible as well.[49] The Open Voting Consortium's voting system is designed to be accessible for both entering the votes and verifying the paper ballot produced.

5. OVC System Overview

The Open Voting Consortium (OVC) is developing a PC-based open source voting machine with an accessible voter-verified paper ballot. A prototype of this system exists, but for the purposes of this workshop, we present the more complete design instead. We use an open source operating system for the PC, such as Knoppix, a variant of Linux that boots off of a CD. The polling place system consists of a Voter Sign-in Station, an Electronic Voting Station, an Electronic Voting Station with a Reading-Impaired Interface, a Ballot Verification Station, and a Ballot Reconciliation Station. See Figure 1. In addition, there are components at the county canvassing site that are discussed only briefly in this paper.

5.1 Precinct/Polling Place Element

The OVC Precinct/Polling Place Element is intended to provide all of the systems and

procedures required for a polling place except for voter rolls, sign-in books and the like. The OVC system design is flexible and adaptable to applicable laws as well as local preferences.

The OVC design accommodates polling places in which different classes of voters, for example voters of different parties, may be accommodated with ballots appropriate for that particular voter.

Overall design and operation of the OVC system is simplified because the paper ballot produced by it will be the legal ballot. For example, in the OVC design, equipment failures are not to be handled at the polling place except to the extent necessary to disconnect the failed unit, seal it, and deploy a backup unit.

The OVC design is based on the requirement that voters with physical disabilities and limited reading ability are accommodated. The OVC design supports variations of the Voting Station and Ballot Verification Station that will be designed with user interfaces tailored to the needs of voters with certain types of physical impairments.

The OVC design will not require substantial changes to the workflow of a typical polling place; voters and poll workers will find that procedures are comparable to those used in existing American polling places.

5.1.1 Voter Sign-in Station

The Voter Sign-In Station is used by the poll worker when the voter signs in and involves giving the voter a "token." It is a requirement that each voter cast only one vote and that the vote cast be of the right precinct and party for the voter. The "token" authorizes the voter to cast a ballot using one of these techniques.

- Pre-printed ballot stock
  - Option for scanning ballot type by EVM
- Poll worker activation
- Per-voter PIN (including party/precinct identifier)
- Per-party/precinct token
- Smart cards

The token is then used by the Electronic Voting Station and the Electronic Voting Station with the Reading Impaired Interface to ensure that each voter votes only once and only using the correct ballot type.

If the voter spoils a ballot, the ballot is marked spoiled and kept for reconciliation at the Ballot Reconciliation Station, and the voter is given a new token for voting.

In the case of a per-voter PINs or smart cards, it is imperative that these do not personally identify the voter.

5.1.2 Electronic Voting Station

The Voting Station is the voter's primary point of contact with the OVC system. After the voter signs-in, a poll worker will direct the voter to a Voting Station.

The physical appearance of the voting station will be that of a lightweight booth with privacy curtains or walls. There will be an integrated device—an Electronic Voting Station—containing computer, printer, battery, and flat screen display. The display will allow touch-screen use and will be mounted so that it may be adapted for use by voters who stand and voters who are in wheel chairs.

The Voting Station should be tamperproof and be engineered to endure physical abuse during shipping, deployment, and use. The Voting Station should be sealed against unauthorized access with locks and lead/wire seals.

Procedures are required to that ensure that the correct certified software is operating on the voting machines. We suggest the use of techniques like booting from a CD rather than the hard drive, verifying checksums and hardware configurations.

The Electronic Voting Station consists of these components:

- A computer, preferably stock commodity hardware, with these features:
  - A monitor, preferably LCD, possibly 15" or 17" touch-screen measured diagonally.
  - One or more input devices, such as:
    - Touch-screen interface on LCD screen
    - Mouse
    - Keyboard
    - Buttons surrounding the screen, like on an ATM
    - Numeric keypad
    - Symbolic keypad
  - Possibly a smart card reader/writer
- A CD-R drive. The CD-R will contain:
  - The operating system, e.g., a Linux system without unnecessary components
  - The EVM software
  - Ballot Definition files and public keys of various external components
  - Optionally, sound files for the ballot (included for the Electronic Voting Station with the Reading Impaired Interface)

- Personalization, potentially including public/private key pairs[50] for this voting station
- Startup record, possibly including generated public key of this voting station
- Electronic Ballot Images (EBIs), in XML format (and possibly in Postscript format), written at end of day in ascending order by (randomly generated) ballot ID
- The CD-R is used subsequently by the Ballot Reconciliation System and possibly during county canvassing.
- A printer with these specifications:
- Inkjet or laser
- Preferably output page is obscured from view (either by appearing face down, or by a cover)
- Feedback to the user (auditory or visual) that the ballot is printing and will come out soon
- Prints a test document at the start of a voting day that includes records of the public keys for the EVM for this day.
- Depending on voter "token," EVM takes blank ballot stock given to voter upon sign-in; alternatively, EVM includes storage for blank ballot stock for printing. Blank ballot stock may be specially printed paper, possibly pre-printed on reverse side (with "please turn over" message).
- Prints ballot in printed ballot format potentially using special printed ballot stock.
- The ballot can be read by the Ballot Verification Station and includes text in OCR format, plus a barcode for more foolproof reading.
- A persistent EBI storage device, such as a USB memory dongle (i.e., a USB flash memory device) for persistently storing the EBIs until the end of the day, when the EBIs are transferred onto the CD-R. The USB memory dongle is kept for audit purposes.
- Device should be large enough not to be easily lost
- Device should be lockable and tamper proof when locked
- Potentially, device could lock in the open position onto cabinet and PC and lock in the closed position sealed and ready for removal. Device could be set to be open only once, and on subsequent openings the device would be read only.
- May also have hardware private key for digitally signing the ballot.
- Security enclosure that prevents tinkering with the device

5.1.3 Electronic Voting Station with Reading Impaired Interface

The Electronic Voting Station with Reading Impaired Interface is a computer similar to the Electronic Voting Station described above that includes auditory output of the ballot choices and selections made and also includes additional modes of making selections suitable for the blind or reading impaired. Whether these features are integrated to a common voting machine with all functionality, or whether there is a separate configuration for the disabled, is an open question. For example, additional modes of input may be useful for those who can read printed materials, but have physical limitations. The ideal is a universal design that accommodates all voters.

The electronic voting station for the reading impaired produces a printed ballot that can be processed by the Ballot Verification Station.

5.1.4 Paper Ballot

The paper ballot is generated by the Electronic Voting Station or the Electronic Voting Station with Reading Impaired Interface. It is the paper on which the voter's choices are recorded. It must be "cast" in order to be tallied during canvassing, testing, or a manual recount.

The paper ballot can easily be read by the voter so that the voter may verify that his or her choices have been properly marked. It also contains security markings and a barcode. The barcode encodes the user's choices, as expressed in the human readable portion of the ballot. The human readable text should be in an OCR-friendly font so it is computer-readable as well. The voter may use the Ballot Verification Station to verify that the barcode accurately reflects their choices. The Ballot Verification Station not only assists sight-impaired and reading-impaired voters in verifying their ballots, but also to give any voter the assurance that the barcode on the ballot properly mirrors their choices, as represented in the human-readable text on the ballot. Ideally, the Ballot Reconciliation System reads the OCR text of the ballot was well, not just the barcode.

The barcode consists of several things:

- Identifiers, such as the date (but *not* time), election, precinct, type of ballot, polling machine, and random ballot ID for reconciliation against the electronic record made by the Electronic Voting Station or the Electronic Voting Station with Reading Impaired Interface. No information that can identify the voter is included on the ballot.
- The selections made by the voter.
- Checksums to detect processing errors.
- Additional padding data to obscure the barcode so that poll workers, who will be able to see the barcode (but not the textual part of the ballot) will not be readily able to ascertain by eye what selections the voter made.
- The barcode is designed so that none of the information in the barcode can be used to identify any voter personally.

Spoiled paper ballots are kept by the Ballot Reconciliation System to be reconciled against Electronic Ballot Images (EBIs) produced by the Electronic Voting Station or the Electronic Voting Station with Reading Impaired Interface.

5.1.5 Privacy Folder

The paper ballot contains the voter's choices in two forms: a form that can be read by people and a barcode that expresses those choices in a machine-readable form.

Poll workers may come in contact with the ballot should they be asked to assist a voter or to cast the ballot into the ballot box. In order to protect voter privacy it is desirable to minimize the chance that a poll worker might observe the voter's ballot choices.

A privacy folder is just a standard file folder with an edge trimmed back so that it reveals only the barcode part of a ballot. The voter is expected to take his/her ballot from the printer of the Electronic Voting Station or the Electronic Voting Station with Reading Impaired Interface and place it into a privacy folder before leaving the voting booth.

The privacy folder is designed so that the voter may place the ballot still in its folder against the scanning station of Ballot Verification Station to hear the voter's ballot's choices spoken.

When handed the ballot by the voter, the poll worker casts the ballot by turning the privacy folder so the ballot is face down, and then sliding the paper ballot into the ballot box.

5.1.6 Ballot Box

This is a physically secure container, into which voters have their paper ballots placed, in order to "cast" their votes. The mechanical aspects of the voting box will vary from jurisdiction to jurisdiction, depending on local laws and customs.

5.1.7 Ballot Verification Station

The Ballot Verification Station reads the ballot produced by the Electronic Voting Station or the Electronic Voting Station with Reading Impaired Interface and speaks (auditorily) the selections on the voter's ballot. A count is kept of usage, including counts of consecutive usage for the same ballot, but no permanent record is kept of which ballots are verified.

The computer boots off the CD-R, which includes the following:

- The operating system
- The BVS software
- Ballot Definition files and public keys of various Electronic Voting Stations
- Sound files for the ballot
- Personalization
- Startup record
- Non-ballot identifying statistics on usage

It is possible for the Ballot Verification Station to have a screen and to display the selections on the screen at the voter's option. Such an option (enabled by the voter upon her request) would enable a voter who can read to verify that her ballot will be read correctly for automated tallying.

The Ballot Verification Station reads the same portion of the paper ballot read by the Ballot Reconciliation Station, including the barcode and, ideally, the text via OCR.

5.1.8 Ballot Reconciliation Station

The Ballot Reconciliation Station reads the paper ballots and reconciles them against the Electronic Ballot Images (EBIs) on the CD-Rs from the Electronic Voting Station or the Electronic Voting Station with Reading Impaired Interface. The purpose of reconciling the paper ballots with the electronic ballot images is to prevent ballot stuffing as well as an audit check on the canvassing process. The process also produces the vote totals for that precinct.

The Ballot Reconciliation Station includes the following components:

- Scanner, preferably page fed
- PC
- Monitor

- Input devices: keyboard, mouse
- Printer
  - Prints vote totals for posting
- CD-R
  - Like the other CD-R; includes cumulative copy of EBIs as well as vote totals by precinct.
- CD drive (not writeable)
  - For loading the CD-R's from the Voting Stations.

The Ballot Reconciliation System runs the Ballot Reconciliation Procedure, which is beyond the scope of this paper.

5.1.9 Box for Spoiled Ballots

When a voter spoils a ballot, perhaps because the ballot does not accurately reflect her preferences, the ballot is marked spoiled and placed in a box for spoiled ballots for later reconciliation.

5.1.10 Box for Provisional Ballots

When a voter shows up at a polling place and does not appear on the voting roll or the voting roll shows that the voter was sent an absentee ballot, then the voter is allowed to vote by being given a "token" for a provisional ballot. A distinctive smart card or a provisional "blank" ballot or even a distinctive privacy folder is given to the voter. When the voter has printed the provisional ballot and hands it to the poll worker, the poll worker seals the provisional ballot in an envelope along with the details necessary to determine whether the ballot should be counted and places the provisional ballot in a box for provisional ballots for later reconciliation.

5.2 Absentee Ballots and Manual Polling-Place Ballots

Paper optical-scan ballots will be used for absentee ballots and also for the manually cast polling-place ballots.

5.2.1 Format and Marking

The format and marking of the absentee ballots will be similar to those of existing optical scan ballot systems.

5.2.2 Acceptance at Polling Place

When an absentee ballot is received at a polling place, a poll worker checks the identification of the person delivering it, places on the envelope a sticker from the absentee ballot audit sheet, and places it in the absentee ballot box.

Manual polling-place ballots are placed in the manual ballot box.

5.2.3 Acceptance by Mail or In-Person at County

When an absentee ballot is received by mail, a county poll worker places on the envelope a sticker from the absentee ballot audit sheet, and places it in the absentee ballot box. When an absentee ballot is hand delivered at the county canvassing site, a county poll worker checks the identification of the person delivering it, places on the envelope a sticker from the absentee ballot audit sheet, and places it in the absentee ballot box.

5.2.4 Validation

The process for validating absentee ballots is comparable to the current process, with the notable exception that the sticker must be present on the envelope. The database record for the voter needs to be marked to indicate an absentee ballot was cast. When a voter casts an absentee ballot also casts a provisional ballot, the provisional ballot will not be counted. The ballot is separated from the envelope for canvassing.

5.2.5 Canvassing

A canvassing system for absentee and provisional ballots will be developed that reads in each optically scanned ballot to create an electronic ballot image. These electronic ballot images are aggregated with the scanned or reconciled versions of the electronic voting machine-printed paper ballots.

5.2.6 Reporting

Reports are made available by precinct for the vote totals for the combination of absentee and provisional ballots. The number of absentee and of provisional ballots is also made available by precinct.

6. Conclusions

The Open Voting Consortium has demonstrated a voting system based on a PC-based electronic voting machine with voter-verifiable accessible paper ballot. We have described the design for the production system we propose to build, based on the prototype we have built and the lessons learned in the process. In the development of this system, we expect to enhance the state of the art in building reliable and trustworthy computerized systems. However, it is

not merely the software and hardware components that are of concern; the voting processes and procedures are also key to the development of a reliable, secure, trustworthy and accessible system.

7. Acknowledgements

We acknowledge the efforts of the volunteers of the Open Voting Consortium who contributed to the design we describe. In particular, Alan Dechert developed much of the design and Doug Jones provided significant insights into voting issues. Arthur Keller organized the development of the software and arranged for the demonstrations. The demonstration software was largely developed by Jan Kärrman, John-Paul Gignac, Anand Pillai, Eron Lloyd, David Mertz, Laird Popkin, and Fred McLain. Karl Auerbach wrote an FAQ on which parts of this paper is based. Amy Pearl also contributed to the system description. Joseph Lorenzo Hall contributed useful background and was a coauthor on an earlier version. Ron Crane gave useful feedback.

Our work was inspired by Curtis Gans, Roy Saltman, Henry Brady, Ronnie Dugger, Irwin Mann, and others who have spoken out on the need for auditable, consistent, secure and open election administration. In the last two years, David Dill and Bev Harris have been especially helpful. David Dill referred several people to the OVC, and he and Bev Harris have helped the public recognize the need for a voter-verified paper audit trail.

9. References

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[50] Each ballot's barcode will be digitally signed. We use the private key for signing each ballot and the public key verifying the signature. The key pair could be generated by the voting machine, with the public key recorded on the CD-R and on the "test sheet" printed at the start of a voting day and the private key never released outside the voting machine itself.