# VoTeR Center

## UConn Voting Technology Research Center

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# Pre-Election Audit of Memory Cards
# for the November 2008 Presidential Elections

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**Summary**

The UConn VoTeR Center performed a pre-election audit of the memory cards for the Accu-Vote Optical Scan tabulators that are to be used in the November 2008 Elections in Connecticut. The cards are programmed by LHS Associates of Methuen, Massachusetts, and shipped to Connecticut districts for use in the elections. For the pre-election audit the VoTeR Center received and examined 620 memory cards as of November 3, 2008. These cards correspond to 620 distinct districts in Connecticut. About 2/3 of these memory cards were randomly chosen by the VoTeR Center personnel during the visits to LHS and before the cards were packed and shipped to the towns. Another 1/3 of the memory cards came from the towns directly, where the cards were randomly chosen for pre-election audit (this procedure applied to the town for which the cards were not selected at LHS). The towns that shipped the cards to be audited were not asked to perform the local pre-election testing before shipping, thus the majority of the cards received from the towns did not contain the pre-election testing events in their audit logs.

This document reports on the findings obtained during the audit. Among the 620 cards received and tested as of this writing, 564 cards (91%) were found to have been properly programmed for election. These cards contained valid ballot data and the executable code on these cards was the expected code, with no extraneous data or code.

Among the remaining cards, 1 card (0.16%) was not programmed and 55 cards (or 8.9%) were found to contain "junk" data, that is, they contained apparently random data. Such cards are easily detected as during the pre-election testing by the tabulators, and they cannot be used in any election. However, this constitutes a high percentage of faulty cards.

During this audit more memory cards were examined than in any previous audit in Connecticut, with 620 cards representing over 70% of the districts. As the audit progressed, several verbal reports were given to the Office of the Secretary of the State (SOTS) before November 4, 2008. The VoTeR Center staff discussed the preliminary reports with SOTS staff, with no issues surfacing that would necessitate either contracting or broadening the scope of the audit.

The audit was performed on request of the Office of the Secretary of the State.

# 1   Preface

The Voting Technology Research (VoTeR) Center at the University of Connecticut at Storrs conducted a pre-election audit of the memory cards to be used in the AccuVote Optical Scan (AV-OS) tabulators in the November 2008 elections in the State of Connecticut. The audit was performed on request of the Office of the Secretary of the State of the State of Connecticut.

The memory cards were programmed for the November 2008 election by LHS Associates of Methuen, Massachusetts, and provided by LHS to the districts in Connecticut. The audit was performed on a set of memory cards that were either randomly chosen by the VoTeR Center personnel during the visits to LHS and before the cards were packed and shipped to the towns, or that were delivered to the VoTeR Center from the towns directly, where the cards were randomly chosen for pre-election testing.

The memory cards were subject to several integrity tests (an earlier report presents a comprehensive overview of the procedures followed by the VoTeR Center personnel in conducting such audits[1]). We do not repeat here the description of the engineering that was performed to enable the audit and the technical setup used in the tests.

In this report, we present the objectives of the pre-election audit and the audit results. The audit process included testing, comparison, and analysis of the data collected during the audit. There were a series of safekeeping steps taken in dealing with the memory cards after receiving them from LHS or the districts. These include a strict chain of custody policy with regard to handling the cards, maintaining a log of all transactions and activities, and safekeeping (both physical and electro-magnetic) of the memory cards.

We conclude the report with several observations based on what was learned during the pre-election audit process. We believe that technological audits are crucial in providing valuable feedback and maintaining the integrity of the electoral process.

This report is a high-level, non-technical presentation of the audit results and it omits all technical details. We also note that we had no access to, and we did not use any vendor documentation regarding the design and the internals of the AV-OS terminal.

## About the UConn VoTeR Center

Following our participation in the Connecticut Voting Technology Standards Board in 2005, the Voting Technology Research (VoTeR) Center was established in 2006 to advise state government in the use of voting technologies, to research, investigate and evaluate voting technology and voting equipment, and to develop and recommend safe use procedures for the computerized voting technology in elections. The personnel of the Center includes several faculty members, graduate students, and technical and administrative staff of the Computer Science and Engineering Department at the University Of Connecticut.

The work of VoTeR Center in the State of Connecticut is funded by the Office of the Connecticut Secretary of the State (SOTS), and we function in close contact with the SOTS Office personnel. We offer the State an independent, objective analysis of the voting technologies offered by several vendors, we advise the State on selecting and administering the voting equipment for its election needs, and we are not associated with any of the voting technology vendors. The evaluations of the voting technology are performed at the VoTeR Center Lab at the University of Connecticut. These include hands-on evaluations, exploration of possible attack vectors, physical integrity checks of the terminals and memory cards, and mitigation strategies. The VoTeR Center is not involved in establishing State's policies for procuring the voting technology, but limited to providing technical

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[1] Pre-Election Audit of Memory Cards for the November 2007 Connecticut Elections. UConn VoTeR Center, Version 1.0, January 24, 2008. Available online at http://voter.engr.uconn.edu/voter/Reports.html.

expertise on, and evaluating these technologies before deployment and during the use by the State. In this sense the VoTeR Center is a third party independent technical consulting resource for the State of Connecticut.

VoTeR Center personnel assisted the State in developing safe use procedures for the Optical Scan terminals. The procedures in place for the elections include strict physical custody policy, tamper-resistant protection of the equipment, and audits.

## 2    Introduction

We start by overviewing the AV-OS (AccuVote Optical Scan) based election system used in Connecticut, the goals of the post-election memory card audit, and a preview of the audit results.

### 2.1    Brief Description of the AV-OS

The AV-OS election system consists of two components: the AccuVote Optical Scan voting terminal (AV-OS terminal) and the ballot design and central tabulation system, GEMS, for Global Election Management System. See our reports at URL http://voter.engr.uconn.edu/voter/Reports.html for other information on this election system. We point out the following characteristics of these components:

- The AV-OS systems currently in use in the State of Connecticut contains the firmware version 1.96.6. It is equipped with an optical scanner, a paper-tape dot-matrix printer, a LCD display, a serial communication port, and telephone jacks leading to a built-in modem.

- The GEMS software is installed on a conventional PC (or a laptop). It includes a ballot design system and a tabulation system.

- Once the election data is entered into the GEMS system, the specifications of the election are downloaded into a memory card via an AV-OS system connected to GEMS by a serial line cable.

  In the State of Connecticut, GEMS is *not* used for central tabulation of election results.

- The memory cards are the 40-pin 128KB Epson cards. The memory card is installed into to the 40-pin card slot (J40 connector) of the AV-OS. It is worth mentioning that Epson has discontinued this memory card some time ago, and reader/writers for this memory card are not readily available.

For election deployment the system is secured within a ballot box so that no sensitive controls or connectors are exposed to the voter. Each memory card contains executable code that is used for printing the reports and the results. The code is written in a proprietary symbolic language. Such executable files are identified as *.abo (AccuBasic Object) bytecode. The installation of the GEMS software on the PC contains several databases as well as the bytecode for AV-OS. The databases are updated for each specific election to include the data and ballot layouts corresponding to the districts of the State of Connecticut.

### 2.2    Goals of the Pre-Election Memory Card Audit

The VoTeR Center implements memory card audits as a part of its relationship with the Connecticut SOTS Office. The primary goal of the pre-election audit was to perform an integrity check of the contents of the memory cards.

The memory cards used in the AV-OS terminals contain the data and the ballot layout for the elections. The memory cards also store the tally of the ballots cast and report the results of the election. In this sense the memory cards are the electronic analogue of a physical ballot box.

The data, layout and the functionality on memory cards are loaded from the GEMS database to the memory cards using the AV-OS terminal. The GEMS database to be used as the baseline for the election data was provided by LHS Associates prior to the election.

For the pre-election audit the VoTeR Center received and examined 620 memory cards as of November 3, 2008. These cards correspond to 620 distinct districts in Connecticut. About 2/3 of these memory cards were randomly chosen by the VoTeR Center personnel during the visits to LHS and before the cards were packed and shipped to the towns. Another 1/3 of the memory cards came from the towns directly, where the cards were randomly chosen for pre-election testing. This procedure applied to the towns for which the cards were not selected at LHS (the towns were not instructed to test the cards before shipping).

The contents of the cards were extracted at the VoTeR Center and compared with the intended contents using the GEMS database as the reference. The audit process was automated to the extent possible. Any discrepancies or deviations from the baseline were then logged and analyzed. Specifically, the memory cards were audited for any deviations in the ballot data/layout, bytecode, and the state of the counters.

During this pre-election audit, we also targeted for examination the audit logs that are stored in memory cards and that contain significant events in the life of a card since its last format.

## 2.3   Preview of the Audit Results

A total of 620 cards, were received and examined by the VoTeR Center as of this writing.

Among the 620 cards, 564 cards (91%) were properly programmed.

In more detail, 541 cards (87.2%) were found to have been properly programmed for election. These cards contained valid ballot data and the executable code on these cards was the expected code, with no extraneous data or code.

23 cards (3.8%) contained a few bytes of noise (or "specks") in the apparently unused part of the memory. The specs apparently do not interfere with electoral process; these cards were otherwise properly programmed and contained the correct executable code.

55 cards (8.9%) were found were found to contain "junk" data, that is, they contained apparently random data. These cards are easily detected by the tabulators as such during the pre-election testing at districts, and they could not have been used in the election. However, this is a high percentage of faulty cards.

Additionally, 1 card (0.16%) was formatted but not programmed. This is also easily detected by the tabulators. Thus, among the cards readable by the tabulators, all but one were properly programmed (564 out of 565).

Finally we note that the towns that shipped the cards to the VoTeR Center for this audit were not asked to perform the local pre-election testing before shipping. Thus the majority of the cards received from the towns did not contain the pre-election testing events in their audit logs.

# 3   Audit Results

We now present the results of the pre-election audit in greater detail. For the November 2008 elections we received and examined 620 cards that represent 620 distinct districts in Connecticut. These cards were programmed for this election by LHS Associates. About 2/3 of these cards were collected by as at LHS headquarters, and the remaining 1/3 of the cards were sent to us by the individual districts.

### 3.1   Memory Card Data Audit Results

Table 1 shows the frequency of various states observed on the audited memory cards for the 620 cards examined. The data is presented in four parts.

**(a) Card Format:**

541 cards (87.3%) were properly formatted and contained good data.

24 cards (3.9%) contained a few bytes of noise (or "specks"). Among these, 22 of the cards, the presence of specks correlated to card duplication (these cards were either the master cards in a duplication process, or the resulting cards). That is, out of 24 cards that contained "specks", 22 cards indicated that these cards were involved in card duplication, serving as either master cards or being programmed through duplication. Thus it is possible that "specks" are introduced as the result of card duplication.

One card with S/N 0002975 for MONTVILLE DISTRICT 4 had some differences in the naming of a race relative to the baseline we received. The audited card is identified as "STATE REP DIST 39", while the base file has the string "STATE REP. DIST 139".

55 cards (8.9%) contained "junk" data, that is the card format is unrecognizable and appears to contain arbitrary noise. Such cards are not readable by AV-OS and they are readily detected through pre-election testing by poll workers, thus they could not have been used in the election.

One card (0.16%) was properly formatted (blank), but not programmed.

In the rest of the analysis the percentages are computed for the 565 cards (91.1%) that were properly formatted, i.e., the cards that did not contain junk data.

**(b) Card Status:**

This refers to the current state of the memory card, such as blank (not programmed), loaded with an election, set for election, running an election, or closed election, and others.

558 cards or 98.8% were in "Not Set for Election" state. This is the intended state for cards that were selected for the audit by VoTeR Center personnel at LHS, and for cards that did not undergo pre-election testing at the towns. (The towns that shipped the cards to be audited were not asked to perform the local pre-election testing before shipping, thus the majority of the cards received from the towns did not go through pre-election testing.) If those cards were to be used in the election, they would eventually be "set for election" by the districts, which would result in the counters of the card being set to zero, and the state changed to "Set For Election".

One blank/unprogrammed but properly formatted card was found. From the log of the card we conclude that the card was formatted at its district. This could have happened either by accident, or if the card contained junk data and the precinct personnel decided to format it.

Six cards (1.1%) we found in "Set for Election" state. This is the intended state for pre-election cards that went through pre-election testing at the districts. Thus most cards were shipped by the districts to the VoTeR Center before the pre-election testing.

No cards with Results Print Aborted were found. No cards with Election Closed were found. No cards with uploaded results were found. No cards with audit report printed were found. These are the expected results.

**(c) Card & Counter Status:**

508 cards (89.9%) were in "Not Set" state with non-Zero counters. This is the expected state for cards coming from LHS and not yet tested. This indicates that districts shipped their cards to the VoTeR Center, before completing their pre-election testing progress.

Six cards (1.1%) were in "Set For Election" state and had Zero counters. This is the intended state for memory cards that underwent pre-election testing at the districts.

50 cards (8.8%) were in "Not Set" for election state with Zero counters. It implies that at some point of the testing, counters were reset, or that no testing was performed. This is not an expected state, although this is not problematic.

One card (0.18%) was not programmed with zero counters. This is unexpected. From the log of the card we conclude that the card was formatted at its precinct. This could have happened either by accident, or the card contained junk data and the precinct personnel decided to format it.

| | All Cards | |
|---|---|---|
| | Number | % Total |
| **(a) Card Format** | | |
| Good Data, Clean Card | 541 | 87.3% |
| Good Data, Some "Specks" | 24 | 3.9% |
| Not Programmed | 1 | 0.2% |
| Unusable Cards, "Junk Data" | 55 | 8.9% |
| Totals: | 620 | 100% |
| **(b) Card Status** | | |
| Not Programmed (Blank) | 1 | 0.2% |
| Not Set for Election | 558 | 98.8% |
| Set for Election | 6 | 1.1% |
| Results Print Aborted | 0 | 0.0% |
| Election Closed | 0 | 0.0% |
| Results Sent/Uploaded | 0 | 0.0% |
| Audit Report Printed | 0 | 0.0% |
| Totals: | 565 | 100% |
| **(c) Card &Counter Status** | | |
| Not Programmed, Zero Counters | 1 | 0.2% |
| Not Set for Election, Non-Zero Counters | 508 | 89.9% |
| Not Set for Election, Zero Counters | 50 | 8.8% |
| Set for Election, Zero Counters | 6 | 1.1% |
| Results Print aborted, Non-Zero Counters | 0 | 0.0% |
| Election Closed, Non-Zero Counters | 0 | 0.0% |
| Election Closed, Zero Counters | 0 | 0.0% |
| Totals: | 565 | 100% |

Table 1: Memory card analysis summary for all cards: (a) card format, (b) card status, (c) card & counter status.

## 3.2   Memory Card Audit Log Analysis

During the pre-election audit, we also examined the logs stored on the memory cards against a set of rules that defined a proper state of the log for a pre-election card. In this section we summarize our findings.

In 532 cards (94.2%) of the 565 cards that properly formatted (we exclude the unreadable cards), the log had the expected actions.

33 cards (or 5.8%) had unexpected events in their logs.

- The logs in 24 cards (4.2%) had events indicating card duplication.

- In 7 cards (1.2%) the test elections were aborted by turning off the machine, instead of using an ender card.

- In 2 cards (0.4%) the order of the events ENDER CARD and BAL TEST START was reversed. One card had the event MEM CARD RESET event after it was set for election.

Finally we found 56 cards (about 10%) that were programmed according to the log on the dates from "00-07-00" to "00-12-00". We concluded that one of the machines used by LHS to program the cards had not a proper date set, and this machine was used to program these 56 cards.

The above does not reveal any malice, but the observations still indicate that procedures are not always followed to the letter.

## 3.3   Bytecode Analysis Result

We have analyzed the Accu-Basic bytecode that is loaded into each programmed memory card. Based on the analysis we conclude that the bytecode provided by LHS Associates for the elections is safe to use. The bytecode performs the expected reporting functions. Note that it is not possible to overwrite the contents of the card with the Accu-Basic bytecode.

# 4   Discussion and Recommendations

Having performed and completed both the pre-election and post-election audits, we believe that technological audits of voting equipment, and specifically memory card audits, are important in providing valuable and timely information and monitoring necessary to ensure the integrity of our electoral system. This section contains the conclusions we draw from the audit process, and some recommendations on safe-use procedures.

1. Larger than acceptable number of cards contained what we describe as "junk" data.

   By saying that the card contains "junk data" we understand that the card contains arbitrary data and it does not contain proper programming. When one puts the card containing the "junk" data into the AV-OS terminal it issues a prompt requesting to format the card. Among the audited cards 8.9% of the cards contained junk data. This percentage is high and this issue has to be resolved in the future.

   We are pursuing an investigation to determine the cause of junk data on cards. Since the last election we examined several conjectures, but with no conclusive results to report is of this writing. For example, we investigated the conjecture (formulated by Mr. H. Busey) that junk data is caused by "hot starting" the cards and that "cold starting" (i.e., inserting the cards into the tabulator that is turned off) would eliminate the junk data problem. Our tests did not show a difference between "hot" and "cold" starting the cards. It was also conjectured that

the cards may become damaged during shipping. To test this conjecture, VoTeR personnel traveled to LHS to select cards for audit and to transport the cards directly to UCONN. No statistically significant difference was observed in the rate of junk cards that were transported in person (9.1% out of 427 cards) vs. the cards that were shipped (8.3% out of 193 cards). Thus shipping can be ruled out as the source of this problem.

To address this issue, new documentation requirements were put in place to better monitor quality assurance (QA) efforts at LHS. In particular, work sheets now accompany cards to towns that show exactly who QA was done at LHS.

2. Memory card duplication: Among the cards examined we found 23 duplicated cards.

   We assume that the cards were duplicated at the districts or at LHS, apparently to repair bad/unusable/junk data on the cards. Our recommendation is that all card duplication events must be logged and brought to the attention of the SOTS Office. There should be no undocumented duplication of the cards at the districts.

   The current SOTS procedure is not to duplicate cards, but this is now being reconsidered, with one possibility being to allow duplication at the districts and to document and report all such occurrences. The amplified procedure is being considered with SOTS with the goal of formalizing it before the election.

3. No detected ballot data or bytecode corruption.

   During the data analysis we have not detected any corruption of the ballot data or the bytecode. The ballot layout of the audit cards were identical to the ballot layout of the corresponding baseline data.

4. Pre-election audit of memory cards vs. pre-election testing at districts.

   In future pre-election audits, if it is desirable for the results of the audit to cover the pre-election handling of the memory cards at the districts, it will be beneficial to select cards for pre-election testing after the districts conclude their pre-election testing.

[End]