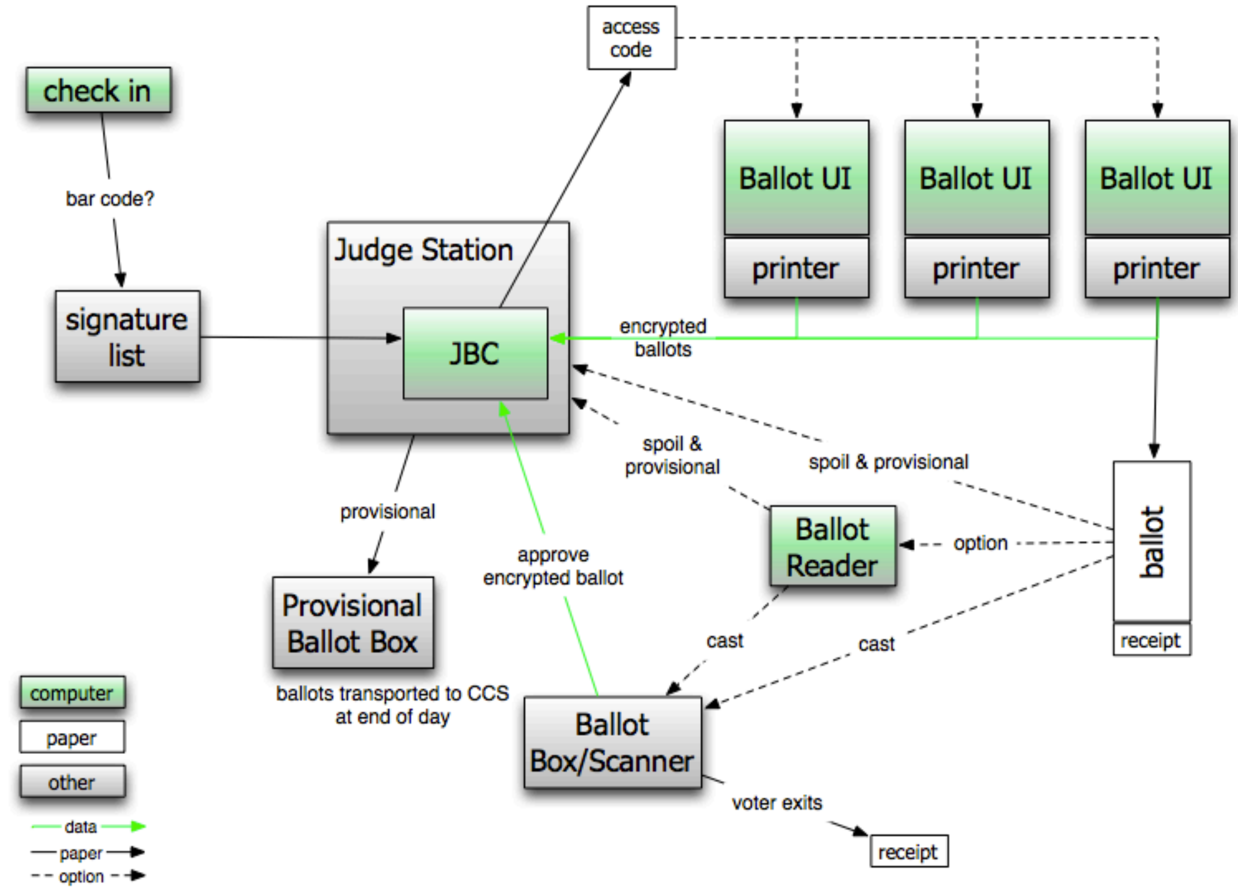

Figure XX. The design of the STAR-Vote system. Green objects are computers, white objects are paper records, and other objects are shaded gray. Arrows display the flow of information; green for digital information, black for paper, and dashed lines indicate that the flow is contingent on voter choice.

2.1 Voter Flow

Figure XX shows how STAR-Vote works from the perspective of a voter going through the system.

1. Check-in (pollbook)

The first step for the voter is to check-in with a poll worker. This is where voter registration is verified and the voter's precinct is identified so that the appropriate ballot style can be generated. The voter also signs a signature list. The voter will receive something to take with them to the JBC that identifies their ballot style; probably a piece of paper with a bar code on it. If the voter registration cannot be verified then this will identify them as requiring a provisional ballot.

2. Receive token

The voter takes the ballot style identifier to a poll worker at the Judge Booth Controller (JBC) which issues a token, again probably a piece of paper with a 5-digit code on it. (There will probably need to be a special alternative for ADA compliance as not all voters can see/handle paper.) This token authorizes the voter at a voting station and identifies his/her ballot style to the station. The token will also be flagged as provisional if that applies. The token has a limited life, so that the 5 digit sequence can be reused.

3. Select machine

The voter possibly queues at this point, and then selects from one of the available voting stations.

4. Enter token

The first thing the voter does at the voting station is enter the information on their token. This causes the JBC to send the appropriate ballot style to the voting station and consumes the token.

5. Make selections

The voter makes selections on the GUI (for sighted voters) or auditory UI (for non-sighted voters). There is a review screen (or the auditory equivalent) so that the voter can confirm their selections before producing a paper record.

6. Print

When the voter has finished making selections, s/he tells the UI to print a paper record of their selections. This cryptographically commits the choices and sends their encrypted ballot to the JBC as well as printing a paper record, which includes not only a human-readable summary of the voter's selections but the encrypted ballot (as a bar code or something similar) and a human-readable crypto receipt (essentially a ballot ID number).

7. Review printed record

The voter may then review the printed record to confirm their selections. There will be at least one station available that can OCR the paper record and read it back to the voter for those who cannot read the paper record.

8. Option: Cast, or challenge/spoil

After review, the voter has two choices: either cast this ballot or spoil it. Spoiling the ballot may be because of an error (or change of heart) or because the voter wishes to challenge the crypto. The two procedures are described below. Note also that there is a special procedure for provisional ballots.

8a. Cast Ballot

If the voter wants to cast the ballot, s/he takes the paper record to the ballot box/scanner. The voter optionally removes the receipt and drops it into the box, where the bar code on the record is scanned. This is scan is communicated to the JBC, which then marks the vote as recorded (meaning it will be counted).

8b. Spoil Ballot

If the paper record is to be spoiled, the voter returns to a poll worker at a JBC. The record will be placed in a special sleeve so that the poll worker cannot see the selections. The bar code on the record is scanned so that the JBC can record that the ballot is to be spoiled, which means that the decryption of the ballot will be published. The ballot will be stamped to indicate that it is a spoiled ballot. The voter may retain the paper record to check that the decryption matches the selections shown on the paper record. After the spoiled ballot is processed, then the voter is issued a new token.

8c. Provisional ballot

In the case of a provisional ballot, the voter does not have the cast vs. spoil option, and must return the ballot to a poll worker, who places it into a provisional ballot box. The voter may retain the receipt to see if the ballot ends up being counted.

9. Optional: Voter checks crypto

Using the receipt, after leaving the polling place, the ballots will be published. Cast votes are published in encrypted format, so the voter can check to make sure his/her vote is present and will be counted. In addition, any voter can check the tally of the cast votes. Spoiled votes are decrypted before publication so that the crypto can be challenged.

<< sections 2.2 and 3 should go in here somewhere >>

4. USABILITY

4.1 Design Considerations

In designing this reference voting system it was important to maximize the usability of the system within the framework of enhanced security and administrative expediency. The overall design of the system was strongly influenced by usability concerns. For example, a proposal was put forth to have *all* voters electronically review the paper record on a second station; this was rejected on usability grounds.

ISO 9241 Part 11 (ISO, 1998) specifies the three metrics of usability as effectiveness, efficiency and satisfaction, and these are the parameters we attempt to maximize in this design. Effectiveness of the system means that users should be able to reliably accomplish their task, as they see it. In voting, this means completing a ballot that correctly records the candidate selections of their choice, whether that be though individual candidate selection by race, straight party voting or candidate write–ins. Efficiency measures the ability of a voter to complete the task with a minimum of effort, as measured through time on task or number of discrete operations required to complete a task. Efficiency is important because users want to complete the voting task in the minimum amount of time and voting officials are concerned about voter throughput. Reduced efficiency means longer lines for waiting voters, more time in the polling booth and more equipment costs for election officials. Satisfaction describes a user's subjective assessment of the overall experience. While satisfaction does not directly impact a voter's ability to cast a vote in the current election, it can have direct impact on their willingness to engage in the process of voting at all, so low satisfaction might disenfranchise voters even if they can cast their ballots effectively and efficiently.

How does this design seek to maximize these usability metrics? For voting systems, the system must generally be assumed to be walk-up-and-use. Voting is an infrequent activity for most, so the system must be intuitive enough that little to no instruction is required to use. The system should minimize the cognitive load on the voter, so that they can focus on making candidate selections and not on system navigation or operation. The system should also mitigate the kinds of error that humans are known to make, and support the easy identification and simple correction of those errors before the ballot is cast.

Why not paper?

Paper ballots (bubble ballots in particular) exhibit many positive characteristics that make them highly usable (Everett, Byrne & Greene, 2006; Byrne, Greene & Everett, 2007). Users are familiar with paper, and most have had some experience with bubble-type item selection schemes. Voting for write-in candidates is simple and intuitive. Unlike electric voting machines, paper is nearly 100% reliable and is immune from issues of power interruption. Further, paper leaves an auditable trail, and wholesale tampering is extremely difficult.

For all these benefits, paper is not the perfect solution. Voters actually show higher satisfaction with electronic voting methods than they do with paper

(Everett, Greene, Byrne, Wallach, Derr, Sandler, & Torous, 2008) and paper still has some significant weaknesses that computers can overcome more easily. First, voting by individuals with disabilities can be more easily accommodated using electronic voting methods (e.g., screen readers, jelly switches). Second, electronic voting can significantly aid in the reduction of error (e.g. undervotes, overvotes, stray marks) by the user in the voting process. Third, electronic voting can more easily support users whose first language is not English, since additional ballots for every possible language request do not have to be printed, distributed and maintained at every polling location. This advantage is also evident in early voting and vote center administration—rather than having to print, transport, secure and administer every possible ballot for every precinct, the correct ballot can simply be displayed for each voter. The use of computers also allows for the inclusion of sophisticated security and cryptography measures that are more difficult to implement in a pure paper format. Finally, administration of the ballots can be easier with electronic formats, since vote counting and transportation of the results are more efficient.

We have taken a hybrid approach in this design, by using both paper and electronic voting methods in order to create a voting system that retains the benefits of each medium while minimizing their weaknesses.

Usability vs Security

Usability and security are often at odds with each other. Password design is a perfect example of these opposing forces. A system that requires a user have a 32 character password with upper and lower case letters, numbers and symbols with no identifiable words imbedded might be highly secure, but it would have significant usability issues. Further, security might actually be compromised as users would be likely to write the password down and leave it in an insecure location (like the computer monitor). In voting we must strive for maximum usability while not sacrificing the security of the system (our security colleagues might argue that we need to maximize security while not sacrificing usability). In our implementation, many of the security mechanisms are invisible to the user. Those that are not invisible are designed in such a way that only those users who *choose* to exercise the enhanced security/verifiability of the voting process are required to navigate additional tasks (e.g., ballot challenge, post-voting verification).

Error reduction

The use of computers in combination with paper is anticipated to reduce errors committed by voters. Because voters will fill out the ballot on the electronic device, certain classes of errors are completely eliminated. For example, it will be impossible to over vote or make stray ballot marks, as the interface will preclude the selection of more than a single candidate per race. Under voting will be minimized by employing sequential race presentation, forcing the voter to make a conscious choice to skip a race (Greene, 2008). Undervotes will also be highlighted in color on the review screen, providing further opportunity for users to reduce undervotes. This review screen will also employ a novel party identification marker (described below) that will allow a voter to easily discern the party for which they cast a vote in each race. The use of the paper ballot (printed when the voter signals completion) provides the voter with a final additional chance to review his/her choices before casting the final ballot.

4.2 User Interface Design Specification

The basic design for the UI is a standard touchscreen DRE with auditory interface for visually impaired voters and support for voter-supplied hardware controls for physical impairments (e.g., jelly switches).

The VVSG

The starting point for UI specifications is the 2007 version of the Voluntary Voting System Guidelines (VVSG). These guidelines specify many of the critical properties required for a high-quality voting system user interface, from simple visual properties such as font size and display contrast to more subtle properties such as ballot layout. They also require that interfaces meet certain usability benchmarks in terms of error rates and ballot completion time. We believe that no extant commercial voting UI meets these requirements, and that any new system that could meet them would be a marked improvement in terms of usability. That said, there are some additional requirements that we believe should be met.

Accessibility

While the VVSG includes many guidelines regarding accessibility, more recent research aimed at meeting the needs of visually-impaired voters (Piner & Byrne, 2011) has produced some additional recommendations that should be followed. These include:

* The system should include an auditory interface than can be used either alone or in conjunction with the visual interface.
* Speech rate (as well as volume) should be adjustable by the voter.
* In order to maximize intelligibility, a synthesized male voice should be used so that speed can be altered without changing pitch.
* Navigation should allow users to skip through sections of speech that are not important to them as well as allowing them to replay any parts they may have missed or not comprehended the first time.
* At the end of the voting process, a review of the ballot must be included, but should not be required for the voter.

Review Screens

Another area where the VVSG can be augmented concerns review screens. Voter detection of errors (or possible malfeasance) on review screens is poor (Everett, 2007), but there is some evidence that UI manipulations can improve detection in some cases (Campbell & Byrne, 2009b). Thus, STAR-Vote requires the following in addition to the requirements listed in the VVSG:

* Full names of contests and candidates should be displayed on the review screen; that is, names should be text-wrapped rather than cut off. Party affiliation should also be displayed.
* Undervotes should be highlighted using an orange-colored background.
* Activating (that is, touching on the visual screen or selecting the relevant option in the auditory interface) should return the voter to the full UI for the selected contest.
* In addition to party affiliation in text form, graphic markings should be used to indicate the state of each race: voted Republican, voted Democratic, voted third-party, and not voted. These graphic markings should be highly distinguishable from each other so that a rapid visual scan quickly reveals the state of each race. An example symbol set appears in Figure XX.

Figure XX. Symbol set for review screen and paper record, indicating from left to right: Republican, Democrat, third-party, and undervote.

Paper Record

The VVSG has few recommendations for the paper record. For usability, the paper record should meet the VVSG guidelines for font size and should contain full names for office and candidate. To enable scanner based recounts (if necessary), the font used should be OCR-friendly. Contest names should be left-justified while candidate names should be right-justified to a margin that allows for printing of the same graphic symbols used in the review screen to facilitate rapid scanning of ballots for anomalies. Candidate names should not be placed on the same line of text as the contest name and a thin horizontal dividing line should appear between each office and the next in order to minimize possible visual confusion.

4.3 Issues that still need to be addressed

There are still several issues that need to be addressed in order to make the system have the highest usability. The first of these is straight party voting (SPV). SPV can be quite difficult for a voter to understand and accomplish without error, particularly if voters intend to cross-vote in one or more races (Campbell & Byrne, 2009). Both paper and electronic methods suffer from these difficulties, and the optimum method of implementation will require additional research. Races in which voters are required to select more than one candidate (k of n races) also create some unique user difficulties, and solutions to those problems are not yet well understood.

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