



# Ranked Choice Voting

Document Version 1.2  
April 2008  
Confidential Information

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## 1. Conventions

Unless otherwise specified, the word “candidate” in this document shall mean qualified candidate (or qualified write-in candidate). For example, without further clarification, a vote for an unqualified write-in should not be treated as a vote for a candidate.

An Undervote is defined as an empty contest vote. Without looking into how many rankings or seats are being used or elected, and undervote is an empty ballot image for any given contest.

## 2. Vote Images

A “vote image” is a collection of choices at each ranking for a single RCV contest. For example, “(1) Charles, (2) Anne, (3) Bob” is a vote images.

Vote images are used to encode in their most raw and unprocessed form the RCV marks on a ballot card or DRE’s ballots.

### 2.1. Ballot interpretation

In certain situations, the same marks on a given ballot card can give rise to different vote images at different stages of an election — depending on how the card is being read. For instance, optical scanners interpret voter intent differently from the human eye.

Voting equipment limitations are generally the cause of these differences. To illustrate, say a voter uses the wrong type of pen to mark his or her ballot, or else marks the ballot incorrectly in some other way. Assume this causes an Insight scanner or central scanner to interpret all of those marks as “BLANK.” Manual inspection may reveal that the voter intended many of those marks to be marks for candidates. This would cause the vote images to change.

As another example, say a voter writes in “Darnell” at some ranking on an optical scan ballot. Initially, an Insight scanner interprets that mark as “WRITE-IN” with no accompanying name. Later on, hand inspection can read the name and reinterpret that mark as for “Darnell” or “UNQUALIFIED WRITE-IN,” depending on whether or not Darnell is a qualified candidate. This can also change the vote images.

In this way, vote images interpretations can undergo refinement or correction during the canvas.

### 2.2. Capture and storage

The system captures and stores vote images for votes cast in an RCV contest.

In other words, the system reads and stores all marks at all rankings for each RCV contest. Rankings with no choice marked (a “blank” ranking) should be stored as such and they will be treated as an undervote.

The system provides, for ballots that cannot be processed fully by machine, a way for the vote images data to be input or corrected in the system by hand.

#### 2.2.1. Voter anonymity

The order in which vote images were cast on a machine at a polling location is not recoverable from the electronic information stored on that machine. The order

in which voters vote at polling places is publicly observable. By ensuring that the vote images order cannot be recovered from the machine, this measure ensures that vote images cannot be tied to the voters that cast them. Consequently, this measure strengthens voter secrecy.

### 2.2.2.Descriptive tags

Every vote images is associated with a collection of “tags” or descriptors. The collection includes a tag for each of the following characteristics:

- (a) Precinct number
- (b) Cast at a polling place or not
- (c) Cast provisionally or not
- (d) Cast absentee or not
- (e) Cast at an Early Voting station or not
- (f) Origin ( refers to the conceptual bin it was tallied in)
- (g) Cast using what type of machine, if any (e.g. a touch-screen machine)
- (h) Possibly reviewed vote images.

These tags relate to the sections on reporting and the public manual audit, in particular to the sections on reports.

The main reasons for having these descriptor tags in the vote images report are:

*First*, it allows for greater flexibility in the conduct manual tally for audits and confirmations.

Associating tags to the vote images data allows certain categories of ballots to be verified separately, if keeping them physically separate is desired. These tags also make it easier to track the source of errors.

*Second*, it allows research into where improvement is needed, say, in RCV voter education materials, the ballot instructions and/or the ballot interface. For example, an observation that absentee voters mark RCV ballots incorrectly at higher rates may indicate that absentee voter education materials need to improve. Similarly, an observation that touch-screen machine users rank significantly fewer candidates may lead to a change in procedures for touch-screen machine voters.

## 2.3. Irregular patterns

In this section we define six kinds of vote images patterns that we call “irregular” vote images patterns. They are listed below in order of “irregularity,” with the most irregular listed first.

### 2.3.1.Over voted ranking

A ranking that contains marks for two distinct candidates is an over voted ranking.

### 2.3.2.Inconsistent ordering

A vote images with some candidate A ranked both above and below some other candidate B has an inconsistent ordering, e.g. “(1) Emile, (2) Fatima, (3) Emile.” Observe that some candidate must be given at least two rankings for this to occur (i.e. the image must match the “duplicated candidate” pattern below).

### 2.3.3. Skipped ranking

A ranking with no candidate marked followed by a later ranking with a candidate marked is a skipped ranking, e.g. “(1) BLANK, (2) BLANK, (3) Geri.” In this example, both the first and second rankings are skipped rankings.

### 2.3.4. Duplicated candidate

A candidate that has been marked at more than one ranking is a duplicated candidate, e.g. “(1) Henry, (2) Henry, (3) Henry.”

### 2.3.5. Undervote

An undervote is a vote images with no candidates marked at any ranking.

### 2.3.6. Unused ranking

A vote images with no candidate marked at some ranking has unmarked rankings.

Some of these irregular patterns are stronger than, or imply, others. We list those relationships here. In each case, the more irregular of the two patterns implies ( $\Rightarrow$ ) the less irregular: (Inconsistent ordering)  $\Rightarrow$  (Duplicated candidate), (Skipped ranking)  $\Rightarrow$  (Unused ranking), and (Undervote)  $\Rightarrow$  (Unused ranking).

For the purposes of this document, an “irregular vote images” is a vote images that fits an irregular pattern. It is possible for a vote images to fit more than one irregular pattern. For example, “(1) Grace, (2) BLANK, (3) Han, (4) Grace, Irene” fits five of the six irregular patterns. A “regular vote images” is a vote images that is not irregular.

Here are some examples to illustrate the application of this convention. Say a voter both marks “Jade” and writes in “Jade” at the first ranking. Before inspection, even though the two markings will later be found to represent the same qualified candidate, the ballot is considered an overvote. Until found otherwise, we assume the write-in mark represents a qualified candidate different from Jade.

The irregularity concept is used several times below. For instance, it can be used at polling places to determine whether ballot cards have “errors” serious enough to give voters a chance to correct. This scenario is what drove the thinking behind which patterns should be considered more irregular than others.

To determine the ordering of which patterns are more irregular than others, we imagined teaching someone how to vote in an RCV contest. What errors would you want to teach the person to correct first? For example, one would rather a voter not overvote than order candidates inconsistently. As another, one would rather a voter not order inconsistently the candidates he or she does rank than skip rankings. And so on.

## 3. Sequoia Insight

This section outlines Insight scanner requirements. These requirements relate to stopping certain ballots before final deposit into the bin (i.e. “second-chance voting”), setting aside certain ballots in a secondary bin for later inspection, and printing the results tape.

### **3.1. Second-chance voting**

Insight scanners have the advantage of being able to scan ballots on submission and give voters a second chance to correct possible “mistakes” that have been detected.

#### **3.1.1. Advance configuration**

The requirements in this section allow one to customize, before the election takes place, which patterns should be considered mistakes in each case. The mistake patterns can be customized election wide.

##### **3.1.1.1. Pattern activation**

The system permits any combination of the six irregular patterns to be “activated” on the Insight scanners on any given election, further developments will allow switch configuration per contest or race.

The severity of the various patterns along with their past and expected frequency can help election administrators decide which irregular patterns to activate for the election.

##### **3.1.1.2. Messages**

The Insight scanners communicate a message to the voter if a submitted ballot card contains an activated irregular pattern.

#### **3.1.2. Election Day behavior**

##### **3.1.2.1. Returning ballot card**

The Insight scanners give voters the opportunity to correct any ballot card that contains a vote images matching an irregular pattern activated for that election.

##### **3.1.2.2. Message to voter**

When an Insight scanner gives a voter the opportunity to correct a ballot card, the scanner communicates to the voter the message corresponding to the most irregular activated pattern that occurs on the card. The message includes the name of the contest corresponding to the most irregular activated pattern on that card.

### **3.2. Set-asides into secondary bin**

Insight scanners can be configured to set potential “problem ballots” aside for later manual review. For example, ballots with write-ins need to be reviewed manually.

### **3.3. Results tape.**

Currently, when a polling place closes, each Sequoia Insight prints out a “results tape” — a roll of paper containing the vote totals recorded by that machine for all contests. This practice provides redundancy. It is an additional safeguard against ballot tampering. It can even protect against the loss of the originally scanned ballots.

The Insight scanners prints on the results tape, for each RCV contest on the ballot, a list of how many votes in each rank for each candidate.

Also a detail report is available; this report prints a list of the vote images scanned by that machine and the number of times each image occurred. The images appear in an order unrelated to the order in which the images were scanned.

## **4. Edge II /Edge II Plus DRE Touch Screen**

### **4.1. Allowable images**

The touch-screen machines do not permit the creation of vote images that fit any of the following four irregular patterns: over voted ranking, inconsistent ordering, skipped ranking, and duplicated candidate.

### **4.2. Unused rankings**

#### **4.2.1. Advance configuration**

##### **4.2.1.1. Contest selection**

The system permits an “unused ranking” warning to be activated on touch-screen machines.

##### **4.2.1.2. Warning text**

The system permits the customization of the “unused ranking” warning displayed to voters by the touch-screen machines.

##### **4.2.1.3. Election Day behavior**

The touch-screen machines displays the “unused ranking” warning to the voter each time the voter does not use all of his or her rankings on a contest.

The warning is displayed when the voter attempts to submit all votes.

### **4.3. Voter-verifiable paper audit trail (VVPAT)**

The VVPAT allows ballots cast on touch-screen machines to be audited. A VVPAT allows voters to confirm that their votes have been correctly registered in the machine.

The VVPAT achieves this by displaying to voters their ballot selections before the selections have been submitted.

The Edge II / Edge II Plus displays on the VVPAT the vote images selected by the voter for each RCV contest on the ballot. The names of any selected write-ins are also displayed.

### **4.4. Results tape.**

Currently, when a polling place closes, each Sequoia Edge II / Edge II Plus prints out a “results tape” — a roll of paper containing the vote totals recorded by that machine for all contests. This practice provides redundancy. It is an additional safeguard against ballot tampering.

The Edge II /Edge II Plus prints on the results tape, for each RCV contest on the ballot, a list of how many votes in each rank for each candidate.

Also a detail report is available; this report prints a list of the vote images recorded by that machine. The images appear in an order unrelated to the order in which the votes were cast.

## 5. 400 C Central Scanner

400 C Central scanners are bulk scanners not operated in the presence of the voter. They scan many ballots cast on or before Election Day. Such ballots can include absentee ballots, provisional ballots, ballots cast at Early Voting stations, remade ballots, and ballots with write-ins.

### 5.1. Descriptive tags

The 400 C central scanners permit vote images to be scanned and stored with the values of their descriptor tag variables described in the section on vote images.

In many election departments, centrally scanned ballots are unsorted and/or kept separate from the polling place ballots. For that reason, it helps to have a way of auditing the centrally scanned ballots independent of auditing the ballots scanned at polling places.

### 5.2. Set-asides

Just as Insight scanners have the ability to set aside “problem ballots” for later hand-inspection, so the 400 C central scanners. This allows central scanners to be configured and operated the same way as Insight scanners.

## 6. Tabulation

This section specifies requirements related to the tabulation of RCV contests. This includes the base RCV algorithm as well as all “options” the system makes available.

We have also included requirements for the tabulation of RCV contests with more than one winner. While the first implementation of our system only allows RCV races on single seat contest, future developments efforts will include multiple seat contests. The requirements for multiple-winner RCV are largely the same. Only in this section the requirements differ.

### 6.1. Preliminaries

#### 6.1.1. Candidates

In each round of RCV tabulation, every candidate is exactly one of the following types: continuing, eliminated, or elected. Ordinarily, all candidates start out continuing. However, in the rare situation that some candidate is ruled ineligible to participate in the tabulation, that candidate should start out eliminated (see the subsection on “candidate disqualification” under “configurable options”).

#### 6.1.2. Votes

Every ballot cast by a voter eligible to vote in an RCV contest gives rise to one vote.

In multiple-winner elections, that single vote may break into several “vote portions” that sum to one. Henceforth, “vote” will mean vote or vote portion. In

each round, every vote is exactly one of the following types: undervote, overvote, continuing, or exhausted. A continuing vote is a vote contributing towards the vote total of some candidate.

### **6.1.3. Advancement**

All votes begin at the first ranking and advance to later rankings as needed. An advancing vote shall always advance to the next ranking that either indicates a continuing candidate or is an over voted ranking. In particular, advancing votes shall always skip over skipped rankings. A vote advancing to a ranking that indicates one continuing candidate and no other candidates shall count towards that candidate. A vote advancing to an over voted ranking shall become an overvote. An advancing vote that is not an undervote and can neither become an overvote nor count towards some candidate shall become exhausted. Loosely speaking, an exhausted vote is a non-undervote that “runs out of rankings.”

## **6.2. Algorithm**

The system tabulates RCV contests according to the algorithm described in this subsection. The steps below are subject to the preliminaries above.

### **6.2.1. (Step 1) First-round count**

Begin round one, and count all the votes. Count the number of undervotes, and count every other ballot according to the choice(s) marked at the first ranking.

#### **6.2.1.1. Notes**

As in all rounds, “first ranking” is interpreted subject to the advancement rules. For example, if the first ranking is a skipped ranking, the vote is advanced before is counted. The number of undervotes does not change after the first round. Unless some candidate is ruled ineligible to participate in the tabulation (see “candidate disqualification”), the number of exhausted ballots is zero in the first round.

### **6.2.2. (Step 2) Calculate winning threshold**

Determine the number of votes a candidate needs to win in this round. This is called the “winning threshold.” Calculate the winning threshold as follows.

#### **6.2.2.1. 1 seat election**

The winning threshold is the smallest integer strictly bigger than the total number of continuing ballots in that round divided by two.

#### **6.2.2.2. 2 or more seat election**

The winning threshold is the smallest integer strictly bigger than the total number of first-round continuing ballots divided by one more than the number of seats. This is also called the “Droop threshold.”

#### **6.2.2.3. Observation**

Observe that the winning threshold almost always changes from round to round in the case of a one-seat election but stays the same from round to round for elections for two or more seats. This is to ensure that, with the possible exception of candidates elected last, all candidates in multiple-winner elections will be elected with the same threshold of votes.

### **6.2.3.(Step 3) Check for winners**

Declare elected any candidate that meets or exceeds the winning threshold. Moreover, if the number of continuing candidates is less than or equal to the number of seats that remain to be filled, declare elected all continuing candidates

### **6.2.4.(Step 4) End tabulation or begin new round**

If all seats are filled or no continuing candidates remain, the tabulation is over. Otherwise, start a new round and continue below.

### **6.2.5.(Step 5 – only for two or more seats) Transfer surplus**

Skip this step if the election is for one seat. If some candidate has more than the winning threshold, transfer surplus from the candidate elected in the earliest round and, if there is more than one such candidate, the biggest vote total among those. Recount all the votes, and go to Step 2.

#### **6.2.5.1. Details**

The “surplus” of a candidate is the vote total of the candidate minus the winning threshold. For each vote counting towards that candidate, create a new vote, advance it to the next ranking, and transfer it at the following value: the value of the old vote times the surplus of the candidate divided by the winning threshold.

#### **6.2.5.2. Ties.**

If two or more candidates are tied, for the criterion to decide the candidate from which to transfer, transfer surplus from all those tied candidates simultaneously in the same round.

### **6.2.6.(Step 6) Eliminate last place candidate**

Eliminate the last place candidate, and transfer those votes. Recount all the votes, and go to Step 2.

#### **6.2.6.1. Details**

For each vote counting towards that candidate, advance it to the next ranking and transfer it at its current value.

#### **6.2.6.2. Ties**

If two or more candidates tie for last place, resolve the tie according to whichever tie-breaking method below was selected in the configuration.

#### **6.2.6.3. Exception**

If the “simultaneous elimination” option described below is enabled, more than one candidate can be eliminated and transferred from in a single round.

## **6.3. Configurable options**

This subsection describes what tabulation options can be configured. All of the options are configurable prior to the tabulation on a contest-by-contest basis.

### **6.3.1.Number of seats**

The system permits the number of seats to be designated for each contest.

### 6.3.2.Candidate disqualification

For each contest, the system permits any subset of candidates to be designated eliminated at the beginning of the tabulation.

This option is only necessary if it is ruled that some candidate cannot legally participate in the election count. For the purposes of the tabulation, such candidates shall be considered “eliminated” in the first round as opposed to “not qualified.”

### 6.3.3.Tie-breaking options

Occasionally, ties for last place may need to be broken in the elimination stage of the tabulation (Step 6 above). The system permits the tie-breaking mechanism to be chosen from among the following three options: computer random selection, manual intervention, and predetermined order. These three methods are described in detail below. In each case, the chosen candidate is the candidate eliminated.

#### 6.3.3.1. Computer random selection

With this method, ties are broken automatically by random computer selection. Note that ties will not necessarily resolve the same way with this method if the tabulation is run multiple times.

#### 6.3.3.2. Manual intervention

With this method, the system stops the tabulation and allows the user to specify which of the tied candidates should be eliminated; this candidate will be selected according to local rules and guidelines, coin toss, paper draw, etc.

#### 6.3.3.3. Predetermined order

With this method, the system accepts as input an ordered list of the candidates in advance of the tabulation. If a tie occurs, the candidate appearing lowest on the list is eliminated.

### 6.3.4.Simultaneous elimination

With this method, certain candidates mathematically certain to be eliminated in a later round are eliminated in one round. The method is a shortcut that simplifies reporting, auditing, and, in some cases, avoids ties. It doesn't affect the outcome.

The method works as follows. During the elimination stage of any round, if some candidate has a vote total that strictly exceeds the sum of the vote totals of all candidates with a strictly smaller vote total, then all those candidates with a smaller vote total shall be eliminated in that round. The maximum number of such candidates shall always be eliminated, provided that at least two candidates remain after the elimination.

For example, assume the candidate vote totals are as follows in some round.

10, 20, 25, 80, 90, 2000, 2100, 3000

Then the sum of the vote totals of the bottom three candidates (55) is strictly less than the vote total of the next candidate (80), and the sum of the vote totals of the bottom five candidates (225) is strictly less than the vote total of the next candidate (2000). Under simultaneous elimination, then, the bottom five candidates are eliminated in this round (the larger of the two possibilities).

## 7. Reporting

This section describes the reporting requirements after an RCV election. Three types of reports go into the reporting we will discuss here: preliminary report, rounds chart reports, and vote images reports.

### 7.1. Preliminary reports

The preliminary report provides a snapshot of the first round before running any RCV algorithm or reduction. It is the simplest post-election report, only the first rank votes for every candidates will be showed in this report, in case one of the candidates has more votes than the current (not final) winning threshold it will tagged as unofficial winner.

#### 7.1.1.Frequency and time of release

The first RCV Preliminary reports should be released to the public on election night at the same time the first preliminary results for non-RCV contests are announced. The election night RCV preliminary reports should be updated throughout the night as more precincts and ballots are processed, just as the results for non-RCV contests are updated regularly throughout the night. Note that, just as the winner(s) of a non-RCV contest can change as more ballots come in, so can the winner(s) of an RCV contest.

After election night, this report is not available any more.

#### 7.1.2.Mode of release

Preliminary reports should be posted on the web as they are produced. They should also be made available on paper in cases where non-RCV results are made available on paper (e.g. on election night).

### 7.2. RCV Chart reports

The chart report provides a round-by-round snapshot of the tabulation of an RCV election. It is the simplest post-election report and the report that members of the public and political observers will look at most.

#### 7.2.1.Frequency and time of release

The first RCV chart reports should be released to the public on election night after all the precinct ballots are read into the system.

After election night, the preliminary RCV chart reports should continue to be updated as more ballots are processed. These reports can be updated on the same schedule that reports for non-RCV races are updated (e.g. daily).

#### 7.2.2.Mode of release

Preliminary chart reports should be posted on the web as they are produced. They should also be made available on paper in cases where non-RCV results are made available on paper (e.g. on election night).

#### 7.2.3.Format

An RCV chart report is a grid with rows corresponding to candidates (and various other subtotals) and columns corresponding to the rounds. We first describe the format for the rows and then the format for the columns.

**7.2.3.1. Rows**

The rows of an RCV chart report divide naturally into “candidate” rows and “subtotal” rows. The candidate rows are listed first and the subtotal rows second.

The candidate rows are ordered as follows. The winning candidate(s) should be listed first. In the case of RCV elections with more than one winner, the winning candidates are listed in order of election, with the first-elected candidates listed first. Candidates winning election in the same round are listed in order of vote total in the round in which they won election. In those situations, the candidates with the highest vote totals are listed first. This agrees with the order in which candidates have their surplus transferred.

The rest of the candidates (the non-winning candidates) are listed in reverse order of elimination, so that the first-eliminated candidates appear last.

Candidates eliminated in the same round (because of simultaneous elimination) are listed in order of vote total in the round in which they were eliminated. In those situations, the candidates with the highest vote totals are listed first.

The subtotal rows are as follows. The first subtotal row is the “continuing” vote row. The continuing row is a total of all the candidate rows appearing above that row, or equivalently, the total number of continuing votes. In order, the next subtotal rows are the “exhausted” vote row, the “overvote” row, and the “undervote” row. Finally, the last row is the “total” row. Summing the continuing, exhausted, overvote, and undervote rows yields the total row.

**7.2.3.2. Columns**

The columns of an RCV chart report are grouped in pairs, with each pair corresponding to one round of the RCV tabulation. For each round, the left column of the pair is the “transfer” column, and the right column of the pair is the “total” column. The “total” column for each round simply gives the vote totals in that round for each candidate or subtotal.

“Transfer” columns display the change in votes that begin a round. The transfer columns allow the reader to understand the tabulation process more easily. A value in a transfer column can be either positive (e.g. in the case of a candidate receiving votes) or negative (e.g. in the case of a candidate being eliminated). The transfer column for round one is always identical to the total column for round one (because all candidates always start out with zero votes), and for that reason the transfer column for round one can safely be omitted. For all other rounds, the value in the transfer column can be obtained by subtracting the total value immediately to the left from the total value immediately to the right. Note that the value in the total row of a transfer column should always be zero (because the net transfer of votes is always zero).

**7.2.3.3. Decimal places**

For single-winner elections, the values in the chart report are always integers (positive or negative). For multiple-winner elections, the values

can become fractions once a candidate acquires a surplus. For that reason, values should be reported using decimals in multiple-winner elections (e.g. to three places beyond the decimal point).

#### **7.2.3.4. Displaying the report**

If the tabulation of an RCV contest has many rounds, the chart report as described above will be very wide and not easily fit on one page or on a web site without horizontal scrolling. For that reason, the chart report can be split into several pages or spread across several sub-reports. For example, chart reports can be broken into several grids, each showing, say, four rounds at a time. Successive grids should begin with the right-most column of the previous grid (a "total" column) to make the reports easier to read. In other words, the last column of totals should always be repeated on the next grid to enhance continuity.

### **7.3. Vote Image reports**

The system is able to produce vote images reports that conform to the characteristics described in this section. A vote images report is a report listing all the stored vote images for an RCV contest. Appropriately formatted and released, vote images reports allow members of the public to check the tabulation of an RCV contest from the vote images. Vote image reports also allow the public to evaluate things like how well voters used their available rankings and where increased voter education is needed most.

#### **7.3.1. Contents**

##### **7.3.1.1. Choices**

Each vote images is displayed in full. In particular, over voted rankings wont appear as so, only a mark showing that rank as an overvote ( to avoid vote tracking using complex over voting sequences), and rankings with no choices should be noted.

##### **7.3.1.2. Write-ins**

Vote images reports distinguishes between marks for qualified candidates, write-in marks for qualified candidates, write-in marks not yet inspected, and write-in marks for unqualified candidates. In particular, the system can distinguish between a mark for a ballot-qualified candidate and a write-in mark for that same candidate.

#### **7.3.2. Descriptive tags**

Vote image reports displays the descriptive tags associated to each vote images in any combination. The possible descriptive tags are listed in the section on vote images.

#### **7.3.3. Format**

Just like for the comprehensive report, the vote images reports for an RCV contest or contests consists of one or more text files in a consistent and easily described CSV format. The reasons are the same.

#### **7.3.4. Time and mode of release**

Just like for the chart report, the first vote images reports should be posted on the web on election night and updated regularly as more ballots are processed.

After election night, the vote images reports can be updated regularly as other races are updated (e.g. daily).

## 8. Bibliography

Jerdonek, Chris Ranked Choice Voting System Requirements Specification V 1.2  
12/15/2006