# Development of Appropriate Test Markings for Optical Scan Voting Machines

Phase 2: Analysis of Ballot Markings NIST Contract SB1341-10-SE-0745 Revision of January 11, 2012, 7:00 AM *by Mitch Trachtenberg* 

### **<u>1. OVERVIEW</u>**

The National Institute of Standards and Technology has been asked to develop a standard set of reference markings representative of the types of marks that voters make on each common type of optical scan / marksense ballot.

As the first step in that development process, during September and December 2010, I scanned over 300 000 ballots at three elections offices. In this second step, I have analyzed the markings on these ballots, primarily the markings at vote targets, but also additional marks which were entered on the ballots after they were printed.

Each of the elections offices used a different type of printed vote target area.

Vancouver, WA used Hart \* ballots, which use a heavily marked rectangular box to designate the vote target. The voter is asked to fully fill the box.

Everett, WA used Dominion/Sequoia ballots, which use a "broken arrow" to designate the vote target. The voter is asked to draw a line connecting the two halves of the broken arrow.

Champaign, IL used ES&S ballots, which use an oval to designate the vote target. The voter is asked to fill the oval.

<sup>\*</sup>Certain commercial equipment, instruments, or materials are identified in this paper in order to specify procedures and data sources adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.



Figure 1: Hart ballot style



Figure 2: Dominion/Sequoia ballot style



Figure 3: ES&S ballot style

# **<u>2. ISOLATION</u>**

Vote targets were cropped out of each ballot and initially categorized as voted or nonvoted. Most subsequent attention was devoted to the voted category, though we checked to ensure that non-voted targets were indeed uniformly blank.

Ballots were also grouped by layout, aligned, and overlaid, such that for every pixel location of the ballots of a set, an individual image could be built using the darkest pixel value of that location. The effect is equivalent to taking a set of overhead transparencies, laying them one over another, and viewing them with a white backing underneath. The resulting image shows the material printed on the ballots together with any marks entered by voters on any ballot of the set.

## **3. APPROACH TO ANALYZING THE VOTE TARGETS**

In each mark, we determined the average red, green, and blue intensities of the pixels in and around the target areas. We also determined the maximum vertical and horizontal extents of the darkened areas. For the oval and rectangular targets, we also measured the number of light to dark transitions in each of several single-pixel horizontal stripes and several singlepixel vertical stripes. By combining the patterns from these passes with vertical and horizontal span information, we are able to locate scribbled markings of various types, as well as x's extending beyond the vote target.

Due to dust accumulating on the scanner glass, some of the images of the vote targets contain streaking. We discuss the impact of this streaking, which is not believed to affect the statistics generated.

A question arose as to whether any colors were dropped out by the Kodak i4200 scanners we used. Logically, this should not be possible, as the scanners are designed to reproduce color images faithfully. We confirmed with Kodak that no color is dropped out on the i4200. We have not checked with the vendors of ballot-specific equipment to determine whether their scanning devices drop out certain colors.

# 4. VANCOUVER / BOXES

### 4.1 Procedure

Black rectangular vote targets were isolated from approximately 90 000 ballots which had been scanned at 300 dots per inch, and placed in cropped images 66 pixels tall by 117 pixels wide. Within these crops, printed vote targets were 52 pixels tall by 99 pixels wide, with an interior approximately 32 pixels tall by 73 pixels wide.

The crops were initially divided into voted, nonvoted, and ambiguous groups. Two criteria were used: intensity of the cropped image including the printed target itself and a surrounding margin, and total number of pixels darkened below half intensity. Both these tests were performed on intensity values averaged over the red, green, and blue individual intensities.

Using an intensity scale of 0 to 255, a crop was considered possibly voted if the average intensity over all pixels in the crop was below 155, or if the number of pixels with intensity beneath 128 exceeded 3300. If both conditions were satisfied, the crop was considered to represent a voted mark.

Using these tests, 1 794 942 targets were considered possibly voted. These were further characterized.

513 000 of the targets which did not pass either test for "possibly voted" were searched for any interior pixel in a  $50 \times 15$  pixel central region with combined red, green, and blue intensity values averaging below 192. 940 such targets were discovered, and are addressed in a later section.

The possibly voted crops were filtered based on the pixel offset into the crop at which the printed target box appeared, 1 066 092 were selected for further characterization as their starting x offsets and starting y offsets each fell between 4 and 10 pixels into their crop. (Basic results were confirmed to not vary substantially between the larger set and the smaller set.)

Of these, 14 112 (1.3 %) were found to have no pixels in the lower two average intensity quartiles and were inspected and removed to a separate table; none were found to have votes. The image groups are provided on a supporting disk; the following image is one of seventy and shows the first 200 such images.

07308_1640_3637, V. AD11406_1659_2675, V. AD20109_1661_3731, V. AD23332, 1662_3596, V. AD23142_0186_3476, V. A	
	18524, 0191, 0131, VA18180, 0191, 0164, VA18022, 0201, 0344, VA191441, 0201, 0391, VA196392, 0211, 0383, VA
197394_0207_0595_V_A004606_1660_3734_V_A004681_1663_1417_V_A004722_1650_3550_V_A013151_1451_1419_V_A	014616_0188_3562_V_A051344_1665_3561_V_A052178_1649_0738_V_A062397_1663_0857_V_A152614_0208_1576_V_A
259070_0197_0589_V_A168658_0283_0593_V_A177725_0193_0590_V_A180724_0169_0595_V_A183711_0211_107_V_A	184247_0211_0594_V_A192942_0206_1104_V_A193044_0207_0594_V_A194593_0207_0595_V_A004483_1467_0785_V_A
004687_1668_0745_V_A086691_1653_2939_V_A013364_1847_0859_V_A027859_1657_0793_V_A053780_1861_3437_V_A	053780_1643_1654_V_A053877_1673_0992_V_A053954_1680_1000_V_A053971_1679_0874_V_A058781_1661_2660_V_A
	147327_0206_0599_V_A167365_0210_0598_V_A167107_0195_0593_V_A176129_0217_0725_V_A176863_0206_0592_V_A
191291_0199_0566_V_A112271_016_0517_V_A169039_0192_0591_V_A190690_0169_0532_V_A12995_0207_0595_V_A	192166_0272_0401_V_A195362_0198_0951_V_A196364_0200_0972_V_A006815_1257_0055_V_A0068124_1560_0742_V_A
010107_1663_2555_V,A013135_1658_3084_V,A019755_1665_0745_V,A020197_1647_3376_V,A020247_1660_0860_V,A	036239_0187_3417_V_A052789_1665_23551_V_A052784_1668_0741;_V_A052821_1646_16313_V_A051928_1665_0780_V_A
033981_1668_2945_V_A058758_1631_0853_V_A163074_1672_2172_V_A168280_0214_0724_V_A178705_0203_0594_V_A	182404_0187_0291_V_AL8383_0201_0392_V_AL84380_0203_0384_V_AL88374_0204_3374_V_AL88869_0204_0193_V_A
131590_0208_0603_V_A131983_0201_0712_V_A192769_0206_3583_V_A004708_1661_0746_V_A807279_1659_0743_V_A	013143_1451_2674_V_A024041_1463_1412_V_A051871_1451_1379_V_A052802_1450_3770_V_A052815_1465_2043_V_A
098742_1659_0736_V_AD78030_0194_3166_V_A186291_0205_176_V_A151595_02029_1816_V_A159455_0208_357_V_A	160744_0222_0600_V_A184004_0191_0589_V_A184375_0208_0595_V_A187053_0208_0595_V_A187213_0214_1103_V_A
147330_0202_0591_V_A100771_0201_0597_V_A112140_0201_0591_V_A107130_0200_0400_V_A259822_0157_0401_V_A	196600_0222_0595_V_A1971912_0100_000_V_A198721_0139_0725_V_A000720_1000_201_V_A0131312_1059_0107_V_A
D20110_1640_3720_V_A032179_1648_0888_V_A032793_1655_0852_V_A032803_1647_0881_V_A052829_1645_2430_V_A	054588_0191_0540_V_A051973_1644_37137_V_A073333_1651_0742_V_A103329_0213_3430_V_A104224_0193_3563_V_A
136144_0940_1271_V_A144076_0263_3500_V_A144947_0205_0994_V_A172950_0196_0591_V_A175926_0268_1352_V_A	176337_0205_0592_V_A179917_0211_0596_V_A180448_0199_0394_V_A186684_0202_0588_V_A184855_0196_0394_V_A
186039_0201_0594_V_A188081_02266_0719_V_A190371_0211_0594_V_A195240_0194_0588_V_A195627_0214_0590_V_A	197966_0201_1229_V_A006668_1644_0741_V_A011394_1454_0078_V_A011403_1650_2668_V_A013422_1447_2671_V_A
	06001_0191_1676_V_A012999_1661_075_V_A16932_0210_097_V_A170299_0209_1761_V_A184128_0205_0591_V_A
106396_0131_0594_V_A140770_0203_0590_V_A14636_0207_0597_V_A156475_0201_5697_V_A606480_14565_0507_V_A	COT700_1450_0777_V_AD11391_1462_1411_V_AD11394_1456_0187_V_AD20179_1455_1416_V_AD20187_1456_03724_V_A
03939_1654_3166_V_A051342_1663_0984_V_A052827_1667_1655_V_A0624684_1652_0896_V_A017812_1654_3715_V_A	103464_0200_2253_V_A152362_1663_0975_V_A159881_0206_0394_V_A164941_0205_0594_V_A164934_0205_0594_V_A
178644_0208_0593_V_A183555_0206_0597_V_A186320_0198_0596_V_A187724_0190_0595_V_A182614_0205_0591_V_A	192854_0210_0599_V_A593158_0205_0555_V_A595214_0189_0593_V_A604849_1649_1555_V_A6046491_1655_1970_V_A

Figure 4: Artifacts

This left 1 051 980 marks in the voted and well-centered group. The primary reason for the 14 112 ambiguous marks was that scanner streaking had lowered their average intensities into the potentially voted range, which had intentionally been set high to avoid missing any potentially voted marks.

### 4.2 Pixel counts within intensity quartiles

A  $29 \times 70$  interior rectangle of each voted target was examined. More than half (592 024) of the voted targets had zero interior pixels in the highest intensity quartile; three quarters (757 122) had fewer than ten pixels remaining in that quartile; more than 9/10 had fewer than 100 pixels in that quartile.

Two different sets of graphs are provided. The second set removes the extremes so that the mid-range is highlighted.



Figure 5: Pixel counts within intensity quartiles



Figure 6: Pixel counts within intensity quartiles, expanded y axis

Over the range where 200 to 1 200 pixels have been darkened into the lowest two quartiles, the mark count is roughly flat (equal numbers of ballots have 200 darkened pixels as have 500 darkened pixels, or 1 000). As the total number of darkened pixels rises within this range, pixels tend to leave the second quartile and move to the darkest quartile



Figure 7: Pixel shift between quartiles

#### 4.3 Color and Tint

Red, green, and blue average values were collected for horizontal lines across the center of each mark. To report tint statistics, these were converted to equivalent values in the HSV (hue, saturation, value) color space. Red intensity peaks somewhat higher than blue and green intensity.

The following graphs indicate distributions of marks based on hue, saturation, and value, followed by red, green, and blue mean intensities. The hue graph shows a small peak representing blue marks at a hue value of 0.65. This hue graph also shows a small peak at a hue value of approximately 0.22. Following these graphs are examples of marks at hue values of 0 to 0.01, 0.2 to 0.25, and 0.65 to 0.67.



Figure 8: HSV values



Figure 9: RGB values

111690_1676_1589_V_a169330_0933_1665_V_a166390_0218_4265_V_a146640_0935_1267_V_a025500_0926_1271_V_a	193310_01912_2293,U_0A071540_1635_2037_U_0A077120_11081_1084_U_0A182070_0201_1826_U_0A182080_1681_1350_U_0A
068950_1631_3364_v_a16620_0964_164_v_a1712300_0935_0640_v_a136680_1677_2000_v_a1262070_0928_23975_v_a	009970_001_1961_V_a112200_1091_2042_V_a154020_0941_3031_V_a146920_1601_2040_V_a172809_1644_2171_V_a
121610_0194_2622_V_a169330_1661_0791_V_a19760_0204_1827_V_a966868_1650_2017_V_a971856_1655_2629_V_a	199720_0210_0977_V_a002040_1698_3040_V_a165690_0930_1694_V_a199330_0396_3976_V_a126990_0205_2632_V_a
176640_0322_1223_V_s1697370_0933_2025_V_s.s17396_1468_0565_V_s379010_0208_0997_V_s183600_1663_0789_V_s	145860_1479_2550_V_m077520_6928_1191_V_m184420_0944_0777_U_m172890_0213_1100_V_m147390_1647_1413_V_m
13159_1666_2019_V_a12099_0919_1672_V_a086590_1666_0919_V_a180566_0210_1106V_a695590_0464_1672_V_a	19960_1146_2461_V_013617_1469_2687_V_01(7000_1657_2591_V_0171360_0106_1145_V_047660_1665_482,V_04
11550_019,116_V_a680350_013_2019_V_a12680_0201_3463_V_a10560_1552_0157_V_a01010_0117_170_V_a	
162310_0223_3575_V_a121690_1676_2623_V_a06698_0208_2256_V_a166738_0207_1617_V_a079050_0205_1751_V_a	171340_0191_22246_V_a114240_1466_3045_V_a161140_1467_3437_V_a079050_0205_2245_V_a110320_1469_0462_V_a
10559, 165, 1514, V_4123503, 1665, 2724, V_4175500, 0205, 1373, V_4114240, 0200, 1361, V_4120340, 1670, 1473, V_4	121070_0128_1246.0461(1950_0188_2946, v_4076500_1651_2950_y_4020510_0918_2027, v_4076500_1651_1913.y_4
M. 22 S	
17660,0222,2288, y.a66038,0396,2576, y.a7978392,160,1522, y.a776392,153,1522, y.a786420,0225,3790, y.a	
112075_0122_1447_7_4174425_1441_2431_7_418046_0716_2308_7_4104466_0212_3432_7_4123146_0443_11945_7_4	14420_0115_2176_9_455859_0175_2555_9_4177900_5755_1197_9_4120300_0210_2433_9_4105600_1676_363_9_4
B13550_01161_1159_V_L0531360_1664_2619_V_L01663250_1666_26619_V_L0166738_0934_1_1660_V_L0176420_1640_2065_V_L0	
	120360_1660_2034(_V_4076650_0052_166(_V_4150110_0641_1164_V_4137310_0211_1224(_V_4174100_0931_1651_V_4)
	10560_1670_074(v_a)10660_019(3460_v_a)07550_0205_3572_v_a)05660_1676_660_v_a)11110_0522_0660_v_a
162180_0214_2251_V_a136170_1670_2420_V_a197370_1663_0795_V_a004080_0207_3578_V_a1846620_0216_0597_V_a	161160_1668_2548_V_a144840_1665_0735_V_a110670_1653_1409_V_a131070_0943_1678_V_a120360_1675_1538_V_a

Figure 10: Marks with hue value near zero

111520_167_3424_V_461999_0797_3407_V_4101660_164_3423_V_4164770_1972_6444_V_4609270_9716_4764_V_4	
194340, 0217, 1127, V, A076460, 1677, 3757, V, A079460, 0194, 0388, V, A083490, 1641, 5757, V, A076460, 1677, 3752, V, A	177310_019_1294_V_a106080_0197_1827_V_a035780_1642_3049_V_a180810_0792_9411_V_a602896_1654_2921_V_a
194350_0199_1221_V_a139060_0284_3416_V_a127330_1657_2342_V_a035700_1642_1919_V_a083960_0935_0468_V_a	151660_020_1100_V_807660_0901_1951_V_814320_0190_1460_V_81950_092_1404_V_8137700_0209_1494_V_8
031510, 0932, 1854, V, J072400, 0932, 1932, V, J122440, 1851, 0954, V, J194230, 0974, 1341, V, J159420, 0190, 1464, V, J	161330,0205_1104_V_a067830_1449_3423_U_4815990_0520_1040_V_a084660_0201_1822_V_a8177310_0315_2075_V_a
883810_9934_9644_V_s174590_0192_0713_V_s181540_9938_0659_V_s176590_9921_06444_V_s104720_0192_3370_V_s	177310_0919_1345_U_a161330_0930_1467_U_a076660_0212_3413_U_a052020_0206_3694_U_a002399_0926_1469_U_a
076450_1072_3927_V_a111320_0214_2545_V_a033700_0935_1139_V_a073270_0522_1139_V_a125460_0031_855_V_a	177700_0359_1852_V_s185810_1460_0793_V_s137710_1467_0586_V_s127320_0193_N17_V_s137310_0192_1714_V_s
071279_16(4_1232)_V_06026200_0092_23931_V_119430_03914_0931_V_111320_0211_1941_V_1041640_2022_2494_V_4	161310_0202_125_V_4876660_1071_979_V_4055550_1403_3547_V_410700_022_3433_V_400577_0191_0465_V_4
037800_0922_1666_V_a108120_0134_1097 V_a101610_0202_1095_V_a086660_0926_2593_V_a1154390_0227_2343_V_a	196330_0924_2028_V_4815598_0920_1460_V_4812210_018(_2311_V_48(11310_002)_1200_V_488468_0201_011(_V_4
194720,8192,2399,V,a174990,0919,2019,V,a019910,0204,1792,V,a145359,1668,2039,V,a107100,0953,1686,V,a	125660_1661_2113_V_1156180_0217_1101_V_4052020_0139_1301_V_4052050_1661_2114_V_4174590_0139_1303_V_4
12/12/14/14/14/14/14/14/14/14/14/14/14/14/14/	012070_0111_0592_V_4106080_0137_2174_V_4101310_0203_3644_V_4055986_013_2547_V_4123426_1152_1538_V_4
107200_161_3065_V_#033700_0208_3612_V_#035250_1661_3921_V_#156360_0065_1900_V_#059230_0936_199_V_#	127330_1637_1939_V_412000_0205_1469_V_4076840_0113_2429_V_4177110_0919_1409_V_4120460_1469_2925_V_4
101310_0204_0375_V_a015986_0154_0045_1461_V_a	1 CESSO (929, 1155, V, 416090, 926, 9119, V, 4012070, 0184, 1571, V, 4067830, 1659, 1613, V, 4012150, 1654, 2932, V, 4
191390, 1925, 2931, "Lander Sec. 019, 1751, "Lander", 1919, "L	023940_0207_1945_V_4420000_0157_397_V_4139800_0255_2360_V_4002655_0021_1145_V_4021250_0244_1197_V_4
16699_924_524_924_9465_939_1631_1330_9_4692809_1631_2334_9_419810_0205_0349_9_416660_935_0466_9_4	055250_1460_055_V_4174590_0145_1091_V_4127330_0200_2431_V_41771310_0919_0449_V_400577_0191_1091_V_4
123420_0922_1444_V_a101440_1454_1431_V_a141330_0930_1964_V_a144070_0926_1444_V_a012070_0141_12221_V_a	052020_0928_0772_V_4835700_1442_0422_V_4093270_0915_1464_U_4083810_0913_1339_V_4083910_0207_1392_V_4
177310_019_157_07_419230_0709_1099_7_4151460_1657_0792_7_485269_0195_0593_7_4137760_0393_1249_7_4	154340_0214_1547_V_4804440_0201_1222_V_48133280_033_0653_V_4154640_045_3397_V_116440_0201_182_V_4
01990_0194_1214_V_a021250_0199_3422_V_a101440_0924_1473_V_a125440_0920_1849_V_a005270_0199_13460_V_a	174590_011#_1340_V_4111520_1441_13921_V_4094660_0330_1901_V_1141330_0204_2374_V_4174590_1444_0854_V_4
107100_1452_1932_V_1132300_0333_1931_V_1132300_0332_1101_V_1132300_0332_1101_V_11323200_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113230_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_113330_0333_1932_V_11333_10332_0333_1033_1033_1033_1033_10	141310_0930_0771_V_4612408_0194_194%_V_4101460_1054_0739_V_1144464_0200_1103_V_4055526_0934_1844_V_4.
107100_168_3447_V.4032020_092_3404_V.418648_2027_2772_V.4146480_0924_397_V.4136600_0934_397_V.4136600_0934_3197_V	1212420_1453_0354_V_4894664_0927_0647_V_4154766_0217_2944_V_4053505_1462_1592_V_1101646_0194_2431_V_4
076840_1672_2422_V_a168640_1664_0860_V_a021230_1655_2547_V_a015980_0920_3339_V_a083980_0207_0593_V_a	071910_0199_1098_V_s145350_0215_3424_V_s125460_1650_1530_V_s168640_0935_2662_V_s015980_0920_2017_V_s

Figure 11: Marks with hue between 0.2 and 0.25

001310_9924_1399; V_4422400_0933_2970; V_4179500_0937_1990; V_4477400_0195_0703_V_46010910_9030_2030_V_4	13540,0210,3117,V,400069,022,2016,V401,019,132,V,4139900,020,2415,V,400239,152,3540,V,4
013180_9932_2973_V_a099940_0204_2202_V_a109590_0214_0724_V_a195578_0220_1224_V_a12440_0194_2344_V_a Exertio_1442_0190_V_a097210_0144_5474_V_a179590_0214_1105_V_a165240_0346_0646_V_a070040_0918_1464_V_a	192440_0331_0232_V_A011300_031_1341_V_A19300_0414_022_V_A019700_0914_022_V_A019720_0914_040_V_A01720_0413_021_V_A 10440_1495_1404_V_A1913790_1409_0742_V_A154700_0940_1479_V_A184110_0913_1341_V_A194640_0204_2359_V_A
	Second State Sta
	D75140_0189_0793_V_4575460_0206_03519_V_4071660_0207_2242_V_4071660_0793_0775_V_4071670_1464_2353_V_4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1999 999, 1992, 1992, 2993, 2995, 2995, 2995, 2995, 2995, 2997, 2002, 1997, 2, 4895, 2002, 2997, 2010,	175510_0193_0393_V_452540_0306_537_V_437160_027_226_V_4371600_0312_077_V_42670700_1416_2353_V_4 17560_1462_0393_V_45260_030_011_2370_V_422460_0393_0414_V_451760_0316_1265_V_451260_0312_077_V_4 17660_1462_0416_V_440040_0312_1260_0312_0410_V_412460_0316_1260_V_451240_0316_1260_V_451260_V_451260_V_451240_V_451260_V_4500_V_4000V_4000V_4000V_400V_4
	17540_0199_0391_V_4592440_0206_1375_V_4071606_0207_226_V_4071606_0951_077_V_0407070_1444_3151_V_4 17140_1442_1444_V_4450050_011_575_V_4124440_0939_1444_V_4137440_0914_1245_V_4112470_01144_1245_V_41124
	1       1
	1       1

Figure 12: Marks with hue between 0.65 and 0.67

A small number of red marks were detected by searching using two different tests. First, a search was made for any marks with a red mean intensity greater than 152 and also greater than the average of green and blue intensity by at least 30. (Different values were tried until a set that excluded most darker brown marks was found.) The result, containing fewer than 200 marks, follows:

067793_0196_2237_V_m133093_0932_0642_V_m068955_0189_1744_V_m068055_0190_2997_V_m133093_0930_3395_V_m	D07087_0921_1193_V_a>68387_1670_1654_V_a116171_0934_5749_V_a185083_8201_3579_V_a037363_8199_5712_V_a
🖂 🧱 🎆 🔤 📖	:=: 💹 📕 🔀 📖
	🜉 📾 🔜 🖂
173088_0202_3889_V_4066379_0322_1895_V_4066379_0132_2579_V_4010770_037_0688_V_4125399_1059_3532_V_4	007961_001_901_9_11073_0000_1107_0000171_0202_0900_9_1339803_000_1001_9100_9_0001001_900_0701_9_0
	173861,1460,2007,20,468361,0207,1225,9,4622519,019,059,974,4175990,0207,0399,974,664391,0197,0595,774
97772-0722-077-4-000-000-000-000-000-000-000-000-0	11412.010.2002.02002.000.2002.000.2002.000.2002.000.2002.000.2002.000.2002.000.2002.000.2002.000.2002.000.2002
1998 IIII III III III	
	13101,140,2012,46(7115,240,0112,4,64171,2015,0912,411092,410,2915,4,411716),0195,1215,4,4
	1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - North Carlos and Car
14(777_166_0787_V_A11080_0830_1187_V_A8(7793_0196_121(_V_A8(7795_092)_1182_V_A8(1892_011_071_V_A	011891_017_2775_V_067887_1649_3841_V_067795_0821_2777_V_087795_0355_0365_V_066042_1645_2649_V_0
217343_0194_3549_V_a173409_0204_1097_V_a010975_0192_0775_V_a046299_0926_1995_V_a067087_1449_442_V_a	0077795_0921_3390_V_a143993_0205_3433_V_a1438093_1442_13930_V_a067772_0197_2556_V_a048747_0927_2579_V_a
🧫 📖 📖 💢 🚝	Si 🦉 🐖 🐼
110000, 0100, 010, 0, 4060395, 0010, 2100, V, 4120970, 0101, 1101, V, 4120970, 0101, 1221, V, 4129970, 0010, 2010, V, 4	133993_0003_9366_W_a617973_1649_3677_W_a617383_0922_0446_W_a6087873_0922_0710_W_a819933_0933_1649_W_a
133033_031_3461_V_a164737_0332_0445_V_a067342_0139_1340_V_a0640555_0514_2014_V_a064289_0519_2345_V_a	067087_0922_1468_V_#046299_0196_1096_V_#133093_02264_3239_V_#0468059_0189_23592_V_#046294_0919_3392_V_#

Figure 13: Marks with red hue and light intensity \*

<sup>\*</sup>Note that the yellow highlighter visible over an inked "x" in Figure 13 was added by a voter, and pink highlighter was used as the sole marking implement by one voter.

A test using HSV values was also run and turned up fewer results.

Although it may appear from the graphs that certain hues never occur, when the marks are filtered for saturation or "value" values greater than 0.2 and then divided by hue into 100 groups, every group is represented. The ratio between the most common hue (0.01 to 0.02) and the least common (0.39 to 0.40 for value > 0.2, 0.47 to 0.48 for saturation > 0.2) is greater than 3 000 to 1.

### 4.4 Transitions

To provide an additional dimension by which marks can be grouped, the marks were examined for light to dark intensity transitions along three horizontal and five vertical "cut lines."

These intensity transitions were defined as a drop to an intensity of 184 or below following an intensity that had been above 208, and serve as a proxy for individual well separated strokes.

Generally, when a transition count of 1 or 2 occurs at both a vertical and a horizontal "cut line," the voted target contains one or two sharp strokes as in a check or an X. Higher transition counts generally indicated scribbling which consisted of lines separated from one another by sufficient space to allow intervening pixels to return to a very light shade.

The following series of graphs shows how the transition count pattern varies with the number of pixels in the lightest quartiles, pointing to a higher likelihood that particular intensities represent scribbles as opposed to X marks and check marks.



Figure 14: Transition counts, 1500 to 2000 white pixels



Figure 15: Transition counts, 1000 to 1500 white pixels



Figure 16: Transition counts, 500 to 1000 white pixels



Figure 17: Transition counts, 300 to 500 white pixels



Figure 18: Transition counts, 100 to 300 white pixels



Figure 19: Transition counts, < 100 white pixels

The following pages present samples of marks with differing transition counts along a horizontal line centered vertically on the mark.

2 🗖 🔊 🖉 🖂	
001101_0110_1210_V_a070215_0203_3557_V_a012100_0101_0130_V_a10002_0201_1223_V_a10005_0314_1305_V	17459_0205_1752_V_A10561_0351_1305_V_A106600_040_2038_V_A066702_0131_181.6_V_A06804_0146_0716_V_A
<b>Z</b> 🗔 🛛 🖾 🖉 🖉	
BKEĘD	$\boxtimes \boxtimes \boxtimes \boxtimes \boxtimes \boxtimes$
😂 🔂 드 🖾 📨	
11664 09D, 119, Y, AD1110, 019, 011, Y, AD300L 013, 296, Y, A1226G, 002, 166, Y, A04662, 022, 319, Y,	16528_015_1757_V_4018075_0926_1200_V_4060256_1666_2500_V_007227_0912_0013_V_106562_013_1767_V_4
	04532_093_3471_V_417075_1460_0764_V_407556_0255_1455_V_4083582_0193_1322_V_412309_087_1398_V_4
172135_0210_2246_V_s131274_1438_5531_V_s027111_0190_2347_V_s064331_0937_1200_V_s172074_0931_2592_V_s	19376_0206_1220_V_4136001_1656_1268_V_A010716_0206_3054_V_418(607_0874_1410_V_417130_0207_1224_V_4

Figure 20: Transition count 0



Figure 21: Transition count 1



Figure 22: Transition count 2

Reading and a second se	

Figure 23: Transition count > 2

Transition counts along various lines can be combined in queries to isolate particular patterns. For example, here is the result of requiring zero transition counts at the top, bottom, left and right, while requiring nonzero transition counts at the center.





Figure 24: Vertical, horizontal transition counts used to isolate marks

# 4.5 Stroke style

To get a sense of stroke form and direction, a sample of marks was taken from among those with 1600 to 1610 pixels in the darkest two quartiles. This sample was taken in the hope that these are filled out with similar stroking to the far more commonplace marks which have greater coverage.

An examination of these marks shows that about three quarters can reasonably be characterized as having a particular orientation: vertical strokes, horizontal strokes, forward leaning strokes, backward leaning strokes, and circular strokes. Categories blend, as many strokes are actually elliptical curlicues oriented strongly in a direction. Where there was no strong "winning direction," the mark was categorized as random.

The following sampling gives the approximate percentages of each category noted in a manual examination.

- Vertical 60 (20 %)
- Horizontal 88 (30 %)
- Forward leaning 50 (15%)
- Backward leaning 5 (1 %)
- Circular 11 (3 %)
- Even 6 (1 %)
- Random 97 (30 %)
- Total categorized: 317

Horizontal strokes are the most common, with vertical and forward leaning strokes somewhat less common. Other stroke types are rare.

## 4.6 Lightest marks

The initial pass captured all marks with an average intensity below 155.

Those with no pixels whose average intensity fell in the lower two quartiles were removed. (For unknown reasons, 13 remain. Nine are uniform gray and four uniform pink.)



Approximately 14 000 images were pulled from the main set because they did not have pixels in the darker two quartiles. These marks were generally thought to contain streaking and, indeed, between half and a third did have substantial streaking. These 14 000 marks are on 70 mosaics that will be provided on a supporting disk.

The artifact marks were individually examined for votes and 53 possible votes were found on 39 different ballot sides. These possible votes represent 0.4 % of the artifacts and only 0.006 % of the initially screened, centered targets. A reasonable conclusion is that it is extremely rare for targets with overall intensity in the normally voted range to contain no interior pixels in the darkest two quadrants.

The possible votes follow:



Figure 25: Possible votes containing no pixels darkened to bottom half of intensity range

The "closest" marks to those in the artifacts collection are the 59 which contain fewer than 10 pixels in the darkest two quadrants, while having registered initial crop intensities between 152 and 155. At least nine of these can reasonably be interpreted as having been voted, 13 have been contacted by a vote mark placed elsewhere, 16 have specks which can reasonably be characterized as hesitation marks, one has a red dirt pattern, and somewhere between five and ten look like erasures which turned into smudges and/or roughened the paper, causing some darkened pixels.

### 4.7 Marks not Captured in the `Possibly Voted' Set

After the "possibly voted" marks were identified, 513 000 of the targets which did not pass either test for "possibly voted" were searched for any interior pixel in a  $50 \times 15$  pixel central region with combined red, green, and blue intensity values averaging below 192. 940 such targets were discovered, about 40 % of which had an overall intensity of less than 158.3, and 60 % of which had overall intensity of 158.3 and above. For the targets with lower overall intensity, approximately 30 % had marks which could be construed as votes, giving roughly 110 votes. For the targets in the higher intensity range, at most 3 % (20) could be construed as votes. Of the 513 000 targets examined, these 130 represent 0.025 %. The actual frequency will be above 0.05 % as the tested area covered less than half of the interior of the vote targets. Furthermore, there are likely to be more "unvoted" targets in the typical ballot than "possibly voted" targets, and other frequencies are specified for targets in the "possibly voted" set.

00239_0222_2371, v. A00314_0331_3467, v. A00422_0201_243, v. A00472_0312_2459, v. A00394_0322_1371, v. A	000000_0954_2011_v_a0001991_1666_2101_v_a001191_1658_2659_v_a001194_1652_1164_v_a001194_0209_1200_v_a
011530_02846_0832_v_a001674_0282_1893_v_a001704_0193_1882_v_a001732_0933_1582_v_a001854_0284_1333_v_a	012000_01999_12557_V_a0022122_0933_1578_V_a0021354_09240_0185_V_a0022250_0232_3075_V_a0022612_0924_2465_V_a
012422_0752_1578_v_002240_0730_2430_v4002474_0730_24002474_0730_0730_0730_0730_0730_0730_0730_0	012718, 0732,213 (, v.a.07217), 1673, 1673, 1674, v.a.002910, 1671, 2019, v.a.002010, 1679, 2019, v.a.003332, 1680, 1679, v.a.0
00(176_0)332_003212_0133_2033_v_a000244_1050_2144_v_a000332_0032_10462_v_a0003484_0377_0081_v_a	025512_0921_2480_v_0064992_1453_2730_v_006494_1460_1917_v_0064192_0214_2651_v_0066446_0202_1746_v_0
0.07160_0131_1164_v_007178_07178_0716_1176_v_007792_0701_2212_v_0077962_0713_11575_v_0077964_0714_15564_v_0	004234_0200_1239_v_a004272_0201_0590_v_a004284_0311_1200_v_a004264_0222_1347_v_a004464_030_2034_v_a
001544_1447_0578_v_40018824_0529_1574_v_4001833_0525_11344_v_4001835_0527_1142_v_4001835_0527_1142_v_40018452_1450_1457_v_40	009144_1693_2152_v0094666_0200_2572_v6809824_0202_1101_v_6010072_0208_18946_v_6010200_0100_2477_v_6
0.1124_0.114_0.000_0.001171_1004_0.015_0.001100_1000_1004_0.00104_0.00140_0.0014_0.0014_0.0014_0.0014_0.0014_0.0014_0.0014_0.0014_0.0014_0.0014_0.0014_0.0014_0.0014_0.0014_0.00140_0.0010000000000	513794_4155_2161_v_001397_40397_1165_v_0413972_0930_1397_v_001397_0934_1561_v_0013974_0934_1561_v_0
011330_0199_1333_v_001184_0934_2832_v_0014241_0184_2419_v_0014254_0919_2233_v_0014422_0934_2933_v_0	014668_1655_3550_v_a016568_0724_3257_v_a016604_0721_3259_v_a016716_0132_1895_v_a016736_0915_0764_v_a
مر - 1912 - 1913 - 1917 - 1917 - 1917 - 1918 - 1918 - 1918 - 1918 - 1918 - 1918 - 1918 - 1918 - 1918 - 1918 - 1	01710_100_001_00_01710_01710_0170_01700_0191_0170_01010_011_010_0_011000_0101_0100_0100_0100_0100_0000_0000
018270_0199_1700_v_0018294_0199_1865_v_0101864_1948_1970_v_0018544_2464_2464_v_0018454_0933_2862_v_0	018704_0937_1139_v_0018770_14446_0785_v_0418782_0191_2200_v_0018844_0912_1340_v_0018922_1441_3725_v_04
022204_1441_1052_v/a022311_109/_0306_v/a0223141_0924_1103_v/a022312_1068_V924_1031_v/a022312_1068_0104_201_004_004_004_004_004_004_004_004_004_0	02264, 0191, 057, v. 4022112, 0201, 077, v. 4021131, 0915, 146, v. 4021142, 0912, 102, v. 4022320, 0942, 1174, v. 4

Figure 26: Targets with intensities above 158.3 having individual interior pixel intensities beneath 192.

	ð 0
	17732_092_2015_v_a017162_0936_1505_v_a017302_0932_3465_v_a017212_0935_2656_v_a017240_0209_1111_v_a
D1422, 022, 292,	124794_0312_2127_v_4024132_0344_0451_v_40247176_0344_1475_v_40248144_0344_1444_v_40248132_0149_1423_v_4
DARDE_DIRE_202_v_AD26052_037_0468_v_AD2655_0188_2372_v_AD2655_0515_1902_v_AD2668_103_0791_v_A	
	<u>127666, 1191, 1097, 1</u> , 627102, <u>1221, 1</u> 22, <sub>1</sub> , 617102, <u>1222, 1730, 1, 627102, 1230, 1, 637102, 1230, 1, 637102, 1230, 1, 6</u>
87162_001_305_v_A07162_004_301_v_A07162_004_325_v_A07160_005_201_v_A07161_004	027900_0194_094_v_A028030_0195_0110_v_A028030_0912_9471_v_A028044_0914_1578_v_A0280346_0195_0712_v_A
laying bying baying bying bi	

Figure 27: Targets with intensities above 155 and below 158.3 having individual interior pixel intensities beneath 192.

### 4.8 Identifying borderline votes

The existence of some apparent votes mixed into the intensity range which primarily contains specks, hesitation marks, and unmarked targets indicates that measurement of overall target intensity, while sufficient for capturing more than 99.9 % of votes, will leave some votes behind. It may only be possible to distinguish the remaining votes from the background noise of hesitation marks by analyzing the location and shape of the mark within the target.

It is possible that the scanners actually used in vote counting may become dirty in the same way ours did as we scanned. In our target collection, streaks can be identified by observing similar patterns of pixel darkening above and below the target (and, in an unvoted target, in the interior of the target). It may be worth investigating the impact of the streak-filter feature in altering the generated images, to determine the impact of streak removal on borderline voted regions.

In some of the artifact images, it is difficult to determine from the target image alone whether the mark represents a vote. It can be useful to compare the area immediately outside the target with the area within, to determine whether slight darkening represents a voter's lightly shading the target or just a darkened ballot background. However, comparison against the entire ballot and the other marks of the ballot would be useful.

About 5 % of the images in the artifacts group had marks touching or very near to an unvoted mark. A few such images are listed here:

013013_1651_0856_V_a	
186795_0212_1824_V_A	
136144_0940_1271_V_A	
169678_0196_3429_V_A	
068755_0914_1897_V_A	
019113_0929_3473_V_A	
002000_0925_1265_V_A	
013013_1651_0856_V_a	
185811_0196_1824_V_A	(missed highlighter)
164733_1664_0791_V_a	

Some of the images in the artifacts group are difficult to characterize; among other things, they may represent roughness caused by erasures. A list of some unusually marked artifacts follows:

054588\_0191\_0590\_V\_A 077812\_1654\_3715\_V\_A (rough?) 065564 1649 3548 V A 196999\_0211\_0589\_V\_A 152614\_0208\_3576\_V\_A 016318\_0920\_2034\_V\_A 124271\_0941\_3085\_V\_A 164083\_0935\_1273\_V\_A 187781\_0208\_0591\_V\_A (footprint?) 067782 0915 2959 V A 194127\_0927\_2667\_V\_A (drip?) 075885 1661 2923 V A (mottled red stain?) 160645\_0206\_3574\_V\_A (footprint?) 168298\_0184\_0587\_V\_A 068580\_0934\_2584\_V\_A (vertical line not streak) 103145\_0194\_0713\_V\_A (pinkish cast) (rough) 193325\_0209\_0591\_V\_A 172950\_0199\_3570\_V\_A (rough) 055407\_0932\_3034\_V\_A (rough? marked?) 184353\_0199\_0591\_V\_A (rough?) (rough? marked?) 183950 0204 0592 V A 175308\_0192\_0831\_V\_A light fingerprint 194675 0203 3693 V A vlg (erasure?) vlg (erasure?) 028505\_0197\_0590\_V\_A red arc 075005 1660 2034 V A 159587\_0201\_0592\_V\_A footprint? 151971 0194 0591 V A speck 169121\_0204\_0596\_V\_A footprint? 067782\_0915\_2010\_V\_A (bluish pattern) 065861\_0191\_0586\_V\_A footprint?) 173397\_0198\_2495\_V\_A (bluish) 182634\_1653\_0856\_V\_A (light droplet) (bluish mark) 020199\_1649\_3730\_V\_A erasure? 174747\_0202\_1099\_V\_A 173687\_1652\_2164\_V\_A light drops 174662 0190 2494 V A erasure? 057670\_1648\_0854\_V\_A haze? 06741 0193 2625 V A 089278\_0918\_1343\_V\_A 174245 0193 0836 V A bluish wide stroked vee 067776\_0198\_2555\_V\_A

as vote

186977_1655_0789_V_A	erased X
067782_0915_2575_V_A	blue pattern
135811_0198_3486_V_a	highlighter, nonvote treated as vo
198852_1652_1658_V_A	brown wash lightening target ???
186473_0200_1756_V_A	

### 4.9 Marks in non-target regions

Composite images were generated from 10 000 ballot sides to examine ballot marks not associated with vote targets. Separate composites were generated for each different bar code found on the ballots. These composite images are provided on disk and an example follows:



Figure 28: Composite showing marks in non-target regions

Essentially all composites show write-in entries. Write-ins may be well above the write-in line and are sometimes level with the words "write-in" but rarely go above the words "write-in." Some voters include their preferred candidate's party affiliation with their write-ins.

Almost all composites show some crossout over vote targets. Crossouts may be single strokes or thick scribbles. Crossouts are generally drawn through the vote target but are sometimes drawn through the name of the candidate.

Most composites show some bleed through where marks made on the opposite side appear on the observed side; the ballots are all laid out such that the bleed through does not interfere with the vote target columns.

A summary of items found on examined composites follows. When a particular item was found on several composites, it was only noted the first several times. The numbers are those of the bar codes on the upper left of the ballots going into a composite image:

10000100100009	writeins, X through name
10000010200021	writeins, X through votes, single stroke through name, circled vote op
10000010100014	writeins, X through votes
10000020100035	circle around measure description, writeins, x's through voteops
10000020200042	X through votes, erasure name crossout single stroke
10000030100056	X through votes
10000030200063	X through votes, single stroke name crossout
10000040100077	spill in instructions, X through votes, horiz stroke crossout
10000040200084	stray line at top left
10000050100098	redo stamp long multivote crossouts
10000050200008	bleed through, write ins, x's through votes
10000070100043	blue outside vote box
10000070200050	scribbles through contests and near vote areas
10000080100064	x's through vote areas
10000080200071	x's through vote areas, heavy candidate crossout
10000090100085	valid ballot stamp,
10000090200092	x's through vote areas, arrows trail into candidates
10000100100009	candidate crossout
10000100200016	heavy stray marks in third column
10000110100030	scribbles in governor area
10000110200037	heavy x crossout over omplete contests
10000120100051	valid ballot stamp, circled initial, write in into margin
10000120200058	

January 11, 2012, 7:00 AM

10000130200079	scribble at top
10000140200003	blue bleed through, candidate line out
10000150200024	
10000160200045	question mark in candidate area, lines to side of candidates,
	heavy crossout of candidate
10000170200066	heavy crossout in writein area
10000180200087	
10000190200011	slashes across candidate areas, cut out in margin
10000200100025	signed at top, stamped at bottom, wine stain?
10000200200032	heavy crossout in writein, circled digit 2
10000210200053	
10000220200074	
10000230200095	long tails on check marks from vote boxes
10000240200019	
10000250200040	
10000260200061	
10000270200082	
10000280200006	
10000290200027	
10000300100041	note NO written in with oval
10000300200048	heavy cross out through both vote box and writein,
	x's through unmarked writeins
10000310200069	
10000320200090	
10000330200014	
10000340200035	
10000350200056	
10000360200077	
10000370200098	large check tail extends out of contest
10000380200022	
10000390200043	brown speck in third column
10000400200064	arrow pointing to candidate, second column
10000410200085	
10000420200009	street address third column
10000430100023	NOTE signed upper left with address and ssn
10000430200030	
10000440200051	cross out into margin impacting digits of bar code
10000450200072	horizontal line into left lower margin near bar code
10000460200093	ok initials, question mark
10000470200017	
----------------	---
10000480200038	
10000490200059	
10000500200080	brown stains right margin
10000510200004	(picked up pink sheet over ballot)
10000520200025	scribble in third column beneath valid area
10000530200046	large explanation below contest, x's between vote marks
10000540200067	vote target crossout into right column
10000550200088	
10000560200012	magic markered question mark
10000570200033	
10000580200054	bleed through into numbers of left margin
10000590200075	
10000600200096	
10000610200020	cross out through vote target and candidate text,
	candidate circled
10000620200041	
10000630200062	
10000640200083	write in into left margin
10000650200007	
10000660200028	bleed through or crossout near top second column
10000670200049	contests lightly xd out
10000680200070	
10000690200091	
10000700200015	
10000720200057	slashes through some contests
10000730200078	
10000750200023	high write in
10000760200044	
10000770200065	
10000780100079	Note blue stain
10000780200086	
10000790200010	
10000800200031	
10000810200052	
10000820200073	blue ink in write margin, writing in contest and blank part
10000830200094	squiggle cross out, high write in, low write in
10000840200018	blue ink in right margin near numbers
10000850200039	crossout into left margin by lower numbers

10000860200060	
10000870200081	
10000880200005	light ink blotches in columns 1 and 2, (NO) as correction
10000890200026	
10000900200047	dark mark left column at bar code
10000910200068	contests x'd
10000920200089	water/tea/coffee stains
10000930200012	initials in column 1, dark scribbled crossout
10000940200034	slashes exit columns into right margin
10000950200055	chevron in magic marker right first column?
10000960200076	torn and folded-over left margin
10000970200097	mark into left margin near bar code
	(note two high writeins of same name in same handscript)
10000980200021	tall slashes through multiple contests
10000990200042	
10001000200063	
10001010200084	
10001020200008	
10001030200029	write in into left margin
10001040200050	slight mark into lower left margin
10001050200071	marks into lower left margin
10001060200092	
10001070200016	
10001080200037	
10001090200058	squiggle crossout of check mark
10001100200079	
10001110200003	
10001120200024	initials first column
10001130200045	
10001140200066	
10001150200087	initials in left column
10001160200011	
10001170200032	
10001180200053	
10001190100067	note signed second column, stamped
10001190200074	
10001200200095	
10001210200019	
10001220200040	marks into lower left column

10001220200061	slash top laft
10001230200001	stash top left
10001240200082	crossout into left column
10001250200006	
10001260200027	extremely heavy crossout
10001270200048	fold on top right, issue at bottom,
	note purple streak through third column vote ops.

One issue that becomes apparent on examination of the Champaign composite images is the entry of "judge's initials" into an area which may be tested by optical scan equipment to determine vote columns. Examples are in the images below:



#### 4.10 Scanner streaking

In order to get a sense of the impact of scanner streaking, unvoted marks from 1000 ballot sides were examined using the same technique as that used on all voted and ambiguous marks. None appeared human marked.

Within the unvoted mark interiors, a region of  $29 \times 70$  was examined. Of 22 844 marks, 22 334 had 0 pixels in the center two intensity quartiles and 510 had one or more pixel in those quartiles. 318 had more than 30 pixels in those quartiles. 247 had more than 60 pixels in those quartiles, 34 had more than 80.

For unambiguous nonvotes, then, fewer than 1 % of the marks were impacted to the extent of having a 1 pixel wide vertical streak down the interior, and an additional 1 % were impacted to the extent of having streaking of two or more pixels in width. The largest impact of this streaking was to move pixels from the highest intensity quartile to the second intensity quartile. In the affected marks, the difference in intensity would have consisted of fewer than 70 of 2 030 pixels being darkened, generally by no more than half intensity.

Approximately 2 % of marks may have had up to 4 % of their interior pixels darkened by anywhere from 1/4 to 1/2. Streaking might lower average interior intensity of a typical affected mark by 2 % in the worst case scenario, where the box is otherwise white along the streak. Because the vast majority of marks have more than 80 % coverage, the actual impact on the typical affected mark is likely to be no more than 0.4 % darkening, and this occurs on no more than 2 % of the marks.

# 5. EVERETT / BROKEN ARROWS

Everett's Sequoia/Dominion ballots ask the voters to indicate their choices by connecting two halves of a "broken arrow" with a line. This results in much less range for variability then in the oval and rectangle targets.

The following analysis is still based on an incomplete subset of the vote database.

More than 5.1 million arrow targets were captured from the ballot sample, of which more than 1 500 000 were marked by the voter.

We measured the line heights, tilts, and colors of the marks, and isolated marks where the lines did not go all the way to the printed target. The targets remain divided into separate sets for the ballot fronts and ballot backs. There are no significant variations in statistics between the two sets; the graphs present the back data unless otherwise specified.

# 5.1 Line Heights

The heights of marks was tested at a series of locations across the break in the arrow. Location "b" is near the beginning of the break, location "l" near the end, and locations "e" and "h" were nearer the center. No significant difference was noticed in the heights at the differing locations.

The most common heights were 6 pixels and 7 pixels, approximately 0.5 mm to 0.6 mm, making up 21 % and 20 % of all marks, respectively. Only 3 % of lines spanned 4 or fewer pixels, 10 % contained 15 pixels or more, 1 % contained 29 or more, 0.1 % spanned 39 or more. were greater than 27 pixels, and only 0.01 % of heights contained 36 pixels.



Line thickness at 25 pixels from gap start (in pixels of 0.085 mm) (back set)

Figure 31: Distribution of line heights



Figure 32: Distribution of line heights, 10 pixels and greater



Figure 33: Marked lines spanning two pixels, 25 pixels into gap



Figure 34: Marked lines spanning six pixels, 25 pixels into gap



Figure 35: Marked lines spanning 11 pixels, 25 pixels into gap



Figure 36: Marked lines spanning 31 pixels, 25 pixels into gap



# Figure 37: Marked lines spanning 51 or more pixels, 25 pixels into gap

## 5.2 Line tilt

Lines showed a tendency to move very slightly downwards, by about a single pixel, moving from left to right. Very few lines showed more than 5 pixel (0.4 mm or 1/60 inch) of tilt.



Figure 38: Distribution of line tilts across arrow gap



Figure 39: Distribution of line tilts across left half of arrow gap



Figure 40: Distribution of line tilts across right half of arrow gap

### 5.3 Line extent

Of 777 727 arrow targets marked at the center, 952 (0.12 %) were found to be unmarked at 5 pixels from the gap start, 738 (0.09 %) were found to be unmarked at 10 pixels from the gap start, and 649 (0.08 %) were found to be unmarked at 15 pixels from the gap start. 2 125 marks (0.27 %) failed to reach within 5 pixels of the gap end, 1 049 (0.13 %) failed to reach within 10, 708 (0.09 %) failed to reach within 15.



Figure 41: Lines failing to reach left edge of arrow gap



Figure 42: Lines failing to reach right edge of arrow gap

# 5.4 Line intensity and color

The lines red, green and blue intensities were measured across vertical test stripes, from the first darkened pixel to the last. These intensities were also used to calculate hue, saturation and value in the HSV color model.



Figure 43: Distribution of red, green and blue mean intensity



Figure 44: HSV 'hue' distribution



Figure 45: HSV 'saturation' distribution



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Figure 46: Lines with hues of varying color.

#### 5.5 Marks away from broken arrows

Composite images were generated from 30 000 ballot sides. The composite images were generated by overlaying sets of scans from ballots with the same layout codes, taking for each pixel location the darkest pixel of any ballot image in the set.

The images were aligned at an upper left corner landmark and derotated to roughly align throughout the image.

Because write-ins were not present in the scanned set of ballots, the composite images are remarkably clear of stray marks.

The voters' marks connecting the arrow halves stay well within the arrow boundaries, almost entirely within the vertical range defined by the shaft of each arrow rather than the head.

The most serious potential problem appears to be from the folding and unfolding of the ballots, resulting in cut lines just above the entry for Brad Owen in the Lieutenant Governor race. Cut lines are also visible elsewhere along the folds.

Several voters appeared to place preliminary marks to the left of the arrows, prior to filling in the arrows.

A typical composite image follows.



Figure 47: Composite of Everett ballots

Excursions outside the arrow and other unusual marks as noted are visible on the following:

mg.	
F4	c2, Treas, Auditor
F7	c2, LG
F9	c1, 1000
F12	c1, 985, c2, Rep
F13	c1, 1000
F14	c1 mark right of column, explanation points within
F15	c2, Gov
F17	c2, US Rep line
F19	c1, 985, c2, state, c2 LG
F21	c1, Pres
F22	c2, SoS
F25	marks to left of choices
F26	c2, US Rep
F27	c2, SoS
F28	c1, 985, c2, US Rep
F36	c2, USRep crossout
F37	c1, Pres, c2, Auditor
F41	c1, 1029, c2, Auditor
F47	c2, SoS, c2, Auditor
F48	c2, Auditor
F53	c2, clipped upper right
F60	c1, torn upper left
F61	c2, clipped upper right
F62	c2, Gov/LG boundary
F63	c1, right margin
F68	c2, stray mark by Treasurer
F72	c2, US Rep
F77	c2, US Rep
F78	c2, US Rep
F79	c2, SoS, Auditor
F81	c2, above USRep
F82	c1, footprint?, c2, checkmark at SoS
F83	c2, line USRep
F84	c1, 1029 crossout No
F85	c1, 1000 circle yes
F89	c2, cut at LG
F91	c1, 1000 stray mark in arrow column, misc in c2

F97	c1, brown stain left margin
F114	c1, lines, c2, lines
F119	c1, 985 checkmark, c2, brown stain in arrow tail channel
F123	c2, brown speck Gov
F124	c1, line
F132	c1, arrows, c2 arrows
F139	c2, LG
F146	c2, Gov crossout
F147	c1, 1000, c2, SoS
F155	c2, stray line LG
F157	c1, cutline, c2, USRep, blueline
F161	c1, circlesx2, c2, Gov
F162	c1, arrows, c2, arrows
F163	c2, USRep
F164	c1, 985 water damage and scribble, c2, USRep scribble, top damage
F166	c1, Pres w-i stray mark, c2, stray line
F170	c1, 985 x
F172	c2, Treas stray mark
F173	c2, brown stains
F174	c1, cutmark, c2, cutmark
F176	c1, crossout x 3
F178	c2, Gov
F181	c1, lines x 3
F183	c1, margin comment
F186	c1, smudge near top of arrow channel
F186	c2, crossed-out write-in, no write-in arrow
F190	c1, 1000 explanatory correction text
F197	c2, cutline
F200	c1, light asterisk
F201	c2, cut line at Auditor
F203	c2, cut line at LG (stopping note of this)
F207	c2, cut line at LG, stray marks beneath
F208	c1, 1000 below arrow
F213	c2, cut line at LG (noted because severe)
F219	c1, "sorry" in arrow column at Pres
F221	c2, low line at Treas
F229	c1, crossouts
F232	c1, 1029 low lines

F241 c1, c2, bluegreen dashes

F255	c2, State vertical line
F260	c2, blue and red marks
F265	c2, speck at Treas
F268	c2, USRep
F272	c2, stain at Gov
F276	c1, dashes to left of options, dash above 1000 arrow
F292	c1, scribble near top, stain, arc in many, low line in 985
F310	c1, 985 no
F318	c2, blob at halftone
F322	c1, dashes, c2, dashes
F328	c1, blue tail beneath 1029
F353	c1, 985 yes
F354	c1, tear at top, red in margin
F356	c2, curve near top touches barcode
F359	c2, Treas stray mark, Auditor low line
F360	c1, left margin stray mark
F367	c2, crossout USRep
F370	c2, several crossouts
F372	c1, tear, c2 Gov lowline, Auditor lowline
F373	c1, 985 low line
F374	c1, c2, dashes
F375	c2, dash SoS
F377	c2, Gov
F384	c1, dash and crossout, c2, Treas stain
F386	c2, torn at top
F387	c1, purple spread
F390	c2, dash
F394	c1, stray mark arrow yes 985
F395	c1, zigzag arrow 985, c2, stray mark SoS, Auditor
F398	c1, stray blue line, c2, torn at top
B8	c1, tear upper left
B9	c1, CPL line above arrow
B11	c1, SPI smudge above arrows
B13	c2, zigzag at arrow
B14	c1, right margin stray mark
B15	c1, blue line beneath arrow

B17 c1, AG Ladenburg arrow IC Adams arrow, c2, scribble near bottom

# 6. CHAMPAIGN / OVALS

Two sets of Champaign County ballots were examined in order to reach a sample size of 100 000 ballots. Approximately 20 000 ballots from the February 2008 election were examined separately from more than 80 000 ballots from the November 2008 election.

More than 3.9 million vote ovals were captured from the November ballot sample, of which more than 1.4 million were marked by the voter. An additional 800 000 ovals were captured from the February ballot sample.

Votes were examined by cropping regions of  $87 \times 60$  (5220) pixels, with the printed vote target bounded by a rectangle of  $72 \times 30$  (2160) pixels, or approximately 40 % of the crop region. Cropped regions not containing a centered vote oval have been almost entirely removed from the data, but several hundred such regions may remain in the more than 1 125 000 ovals studied. Because these represent fewer than 0.1 % of the ovals they are not believed to represent a problem to the analysis.

With a cropped region's pixels grouped into four intensity quartiles, the typical nonvote had in the vicinity of 4800 to 4900 pixels in the highest of the four intensity ranges, with another 150 to 200 pixels in each of the next two quartiles and fewer than 30 pixels in the lowest quartile.

The typical vote removed 1500 pixels from the top intensity quartile and increased the pixel count in the low two intensity ranges to between 1500 and 1600. For the red channel, only about 200 pixels were darkened to the lowest quartile, but for the green and blue channels approximately 1000 pixels were darkened to the lowest quartile.

The following charts show the change in distribution of pixel counts as ovals are voted, first in the November ballot set and then in the February ballot set.



Figure 48: Distribution of pixel counts by intensity quartile, all, November



Figure 49: Distribution of pixel counts by intensity quartile, all, February

The following charts show the distribution of pixel counts by quartile in only the voted ovals, first in the November ballot set and then in the February ballot set.



Figure 50: Distribution of pixel counts by intensity quartile, voted, November



Figure 51: Distribution of pixel counts by intensity quartile, voted, February

The average intensity of the cropped regions drops from above 240 to approximately 190. The average intensity of voted ovals is shown both compared with nonvoted ovals and on an

expanded y axis. In addition, the average intensity of the marked area along the vertical centerline of an oval is shown. Because this picks up only the marked pixels, it shows a lower intensity than the cropped rectangle as a whole, peaking at approximately 80 rather than 190.



Figure 52: Distribution by average intensity, November



Figure 53: Distribution by average intensity, February



Figure 54: Distribution by average intensity, November



Figure 55: Distribution by average intensity, February



Figure 56: Distribution by average intensity, November



Figure 57: Distribution by average intensity, February

Using the crop area's average intensity, fewer than 1 % of votes have average intensity less than 163/255, approximately 10 % of votes have average intensity less than 179/255. Half of

voted ovals have an intensity across the cropped region of between 184 and 195, and fewer than 1 % of voted ovals have an intensity across the cropped region of 213 or above.

Using the vertical centerline, fewer than 1 % of votes have average intensity less than 47/255, approximately 10 % of votes have average intensity less than 60/255. Half of voted ovals have an intensity along their vertical centerline of between 68 and 94, and fewer than 1 % of voted ovals have an intensity along their vertical centerline of 146 or above.

The characteristics of the marks, as expected, change as the cropped regions' average intensity changes. The darkest cropped regions contain marks that were filled well outside of the printed target. The following marks have cropped region intensities below 120/255:



Figure 58: Marks in darkest group

The following marks have cropped region intensities from 120 through 149; keep in mind that these represent less than 0.2 % of voted marks:





Marks in the darkest 10 % (excluding those in the darkest 0.2 %) show nearly full coverage in the target area and some excess as well. Automark printed marks show up in this set, at the right of the eighth row:



Figure 60: Marks in dark/normal group

Marks in crops with the average intensity tend to be neatly filled in. However, some crops with this intensity contain marks with less than complete coverage, with marking outside the target contributing to the intensity drop.

As the following montage represents the most typical marks, it can serve as a useful place to point out characteristics which can usefully be used to distinguish marks. (The image is divided into 8 blocks, each of which contains a  $5 \times 5$  grid of marks. The blocks will be referred to as A to D down the left, then E to H down the right; rows and columns within a block will be designated r1 to 5 and c1 to 5. The mark at Er2c5 has a loop above the target.)



Figure 61: Marks in typical intensity group

In addition to hue, brightness, "transition count," and writing implement used, marks can be characterized by the presence and location of substantial voids and the manner in which the voter filled the target. Most of the marks in this typical set show that voters attempted to follow the target outline, probably starting at the perimeter and moving inward in an elliptical motion (the interior is often left slightly lighter than the rest).

Unusual strokes: Cr2c4 shows diagonal lines rather than elliptical curves, and Dr2c2 shows vertical lines. Dr5c3 shows a random pattern. Gr2c4 and c5 show a compromise between following the ellipse and drawing diagonal lines. tend to be neatly filled in with ink. Marks with typical average intensities are still filled neatly, with lighter ink or pencil.

Voids: Ar1c5 shows a void at upper left; in addition, the entire mark is shifted right and down from the arget. Br2c1 shows this to a lesser degree. Er2c1 and Er3c2 show minor voids but no shift of the mark with respect to the target.

Out of bounds: Gr5c5 shows a mark going substantially out of bounds to the left, and Ar1c5 goes substantially out of bounds to the right. Er2c5 goes out of bounds above the target. Gr2c4 and c5 both go out of bounds beneath the target.

As intensities rise, marks are incompletely filled in, and "x" marks, check marks, hollows, and miscellaneous variants appear.

The following three montages show, first, marks typical of those in the lightest 1.5 %, and then marks in the last 0.4 % and the last 0.1 %.

R 🕙 (M) (M) (M)	
113568_5186_2766 114570_3854_2481 114038_5185_5663 114928_51867_1666 114038_5184_1867	114928_1088_10948 114920_0870_3573 114928_0869_3368 114928_1564_1576 116988_0176_5688
	$\bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc$
116968_0175_1462 117130_0174_0662 117300_0100_0773 117300_0063_1474 117010_0168_0660	117815_D165_1466 117810_0164_1865 123088_D851_0968 123550_0171_1858 125638_D174_1058
	I I I I I I I I I I I I I I I I I I I
126114_0149_1092_126310_0149_1463_126114_0149_11651_126310_0162_22555_126513_0652_1053	120110_0851_2851 12011_1501_0869 120010_0170_1205 129510_0177_1558 1296010_0176_1869
129030_0065_1066_125030_0063_2067_129200_0177_2255_130050_1560_3161_132600_0153_0770	120815_0152_1456 127360_0461_1269 144169_0175_0682 144160_0175_1469 144169_0175_1689
3 5 9 6 6	
144148_0849_1049 144140_0842_0172 144149_0840_0149 144140_1552_1472 147059_887_0342	149999_0149_1542 149430_0170_4650 149439_0149_1141 149430_0149_1243 192499_0215_1441
	<b>O O O O O</b>
151178_0158_2759 153170_1534_1668 155388_0174_2768 155380_0870_1068 155388_0865_2669	156955_0167_1452 155570_0866_0958 157205_0176_0557 157250_0176_1859 157259_0174_1469
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117255_0865_0941 157250_8662_2466 162180_8864_2655 164560_0177_2384 164503_0201_1862	165248_0205_1872 165240_0202_2275 166430_0955_0955 166430_0860_2570 166433_0861_0369
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170346_0936_0939 170340_0963_1572 170510_0152_1571 171700_0177_2456 172386_09663_3059	175619_0164_1056_175780_0168_1464_175780_0859_1066_175550_0162_2772_175959_0851_2674
175990_0851_3169 177140_0160_0763 180710_0165_1454 180710_0165_1955 180710_0891_1557	180718_0849_2259 180710_08497_0856 180710_1539_1548 181730_0171_0451 181730_0178_1053
101730_0109_1435 101730_0106_0201 101730_0006_0004 101730_0005_0405 000340_0735_4004	00010_10012_001 001010_1072_2300 00010_1075_3330 00010_1757_1004 093576_1754_2750
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Figure 62: Marks in lightest 1.5 % of targets passing vote tests
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110216_0202_0764 110216_0156_1166 110216_0104_1566 110216_0106_1467 110216_0106_2368	110382_0146_1062_110282_0164_1463_110282_0162_1864_111034_0169_0663_111034_0167_1465
$\bigcirc \bigcirc $	
111408_0188_1041 111408_0179_1545 111408_0178_1048 111582_0142_0447 111582_0142_044	111992_0102_1070_111092_0101_2272_111749_0100_1077_111010_0100_0000_111010_0109_1000
111834_0174_0678 111884_0172_1071 111814_0175_1478 111884_0176_1872 111834_0174_0674	112618_0178_0658 112610_0176_2658 112848_0187_1065 112840_0185_1466 113038_0175_2665
<b>V N N N N N N N N N N</b>	
115556_0102_0060 115556_0177_1060 115642_0174_0650 115642_0173_1450 115644_0101_1594	116454_0176_0674 116454_0170_1080 316454_0179_1477 116562_0170_1470 117348_0190_0765
117712_0168_0662 117712_0168_0865 117712_0167_0466 117712_0166_1966 117712_0165_2767	110114_0104_1046 110946_0172_0470 110154_0179_0464 110192_0102_0458 110192_0109_1060
in the	$\bigcirc \bigcirc $
119192_0187_1443 119392_0364_1864 119828_0168_0653 119856_0176_1455 119858_0175_1856	119848_0189_1084 119868_0184_1445 119848_0184_1865 119868_0182_2266 123046_0169_1555
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123046_0166_2357 123524_0172_1866 123524_6176_1867 123722_0177_0771 123723_6176_1072	123722 0175 1474 123722_0179_1974 123722_0181_2775 123836_0170_1887 124018_0168_0667
<b>E E E E E</b>	
124018_0159_1048 124018_0161_1871 124164_0161_2744 124264_0177_1866 124264_0175_1466	124526_0184_0682_124908_0162_0761_124938_0180_1161_124988_0178_1564_124998_0176_1965
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Image: A marked of the state of the sta	

Figure 63: Marks in lightest 0.4 % of targets passing vote tests



Figure 64: Marks in lightest 0.1 % of targets passing vote tests

## 6.1 Spoiled Ballots

Ballots in the 178 000 range were spoiled by the voter. These have been included, because they are a rich sample of problematic marks. However, when an election official wrote "SPOILED" across them, the result generates artifacts where the marks appear to go across the cropped regions without any connection with the target. These marks are distinguishable from voter made marks, and are concentrated in the range with average red intensity above 230.

## 6.2 Hesitation Marks

It is important that vote counting equipment be able to distinguish the marks by which a voter typically indicates their choice from the marks which probably occur when a voter touches their marking implement to their ballot without intending to register a vote.

Vote ovals in the previous montages represent only ovals which passed either a general intensity test (below 720 for red, green, and blue intensity values combined; each on a scale of 0 to 255) or a number of darkened pixels test (more than 300 pixels in the lowest half of intensity values).

Ovals which failed both of the above tests but were between 720 ( $240 \times 3$ ) and 735 ( $245 \times 3$ ) in combined red, green, and blue average intensity were further checked for small marks. Each pixel in a central  $41 \times 14$  region (of the  $72 \times 30$  ovals, whose interiors' maximum width and height were 67 and 25 respectively), and the presence of any pixel darkened by at least 1/4 was considered a mark. This generated 2 860 marked ovals from a set of approx 2 500 000 "unmarked" targets, or approximately 0.1 % of the set initially thought to be"unmarked".

A subsample of 65 171 ovals at combined intensity of exactly 729.0 was taken for further testing. This subsample returned 73 hits in the central rectangles, which were 574 pixels in size. Per pixel, this is a hit frequency of 0.13. Then this subsample was searched more thoroughly for low intensity pixels by masking off an approximately 10 pixel wide ring around the oval, there were 83 hits over a region including 1 451 pixels, giving only 10 additional hits in 877 additional pixels, or a per pixel hit rate outside the central rectangle of 0.01. This suggests that more than 90 % of specks were in the central rectangle contained within the printed oval.

The distribution of specks shows a high rate in the small number of ovals with average intensity 240.0 to 242.0, then drops to approximately 0.05 % of all unvoted ovals. (Note that this figure includes many specks which are barely visible.)

720	158	54	35 %	avgintensity240.0
721	341	57	17 %	
722	1090	69	6 %	
723	3589	104	3 %	avgintensity241.0
724	9830	153	2 %	
725	22140	257	1 %	
726	49378	399	1 %	avgintensity242.0
727	151905	509	0.3 %	
728	438310	539	0.1 %	
729	750478	386	0.05 %	avgintensity243.0
730	606402	156	0.03 %	
731	183340	65	0.04 %	
732	67864	56	0.08 %	avgintensity244.0
733	72957	39	0.05 %	
734	57238	17	0.03 %	

The specks vary substantially in size depending upon the exact intensity at which they were found:

(Marks with numbers beginning 178887 and 178947, the "full slashes," are actually artifacts from spoiled ballots. There are no apparent voter slashes showing up in the speck intensity ranges.)



Figure 65 Specks, intensity 240 to 241

$\bigcirc \bigcirc $	$Q \bigcirc \bigcirc$
131446_0886_0970_152793_1000_1460_167369_1169_169_169_169_169_169_169_169_169_	
172271_116_2463 D1444_0164_0164_468 D20500_0167_1197 D2514_0468_2474 D2153_017_0789 019170_1032_2663 D00544_1770_2464 D03512_0173_22(0103593_0150_0668 D34234,1746_1561	00032_035_2740 10037_107_107_1072_1020_1100_1101 2007_1005_1101 20004_0055_1055_1055_12057_2776
$\bigcirc \bigcirc $	
000000_0060_0060_0000_000_000_0000_000	
	124239_1076_14/2 07324_0756_14/2 03249_0756 07459_14/17_1452 04468_04/35_0556 04469_1556_0565 124239_1476_1464 130712_0646_0775 07459_1546_1474 018159_1558_0774 031363_0142_0766
$\bigcirc \bigcirc $	
	001939_1766_1983 014318_10453_4644 04541_0873_0973 082466_1350_2007 132143_1776_3342
13376_0874_1001 141150_0870 0897 150346_0851_1075 159369_1757_1366 160746_0159_1489	
	$\bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc$
031851 0849 1066 000437 0181 2376 007260 0369 3156 013739 0168 1865 042153 0871 1072	
$\bigcirc \bigcirc $	

Figure 66 Specks, intensity 241 to 242



Figure 67 Specks, intensity above 242

## 6.3 Color and Tint

The following graphs summarize the red, green, and blue intensities found in the cropped rectangles and across the horizontal span of the contained ovals. Blue and green are consistently at lower intensity than red:



Figure 68 Red, green and blue intensities of crop, November



Figure 69 Red, green and blue intensities of crop, February



Figure 70 Red, green and blue centerline mark intensities, November



Figure 71 Red, green and blue centerline mark intensities, February

The predominating hue is slightly reddish. Following a graph in which the predominating hue swamps all other data, a second graph is presented with an expanded y axis to show the small number of marks with differing hues.

The graphs are followed by montages of marks at different H values in the HSV color system.



Figure 72 Hue distribution



Figure 73 Hue distribution, expanded y axis

<b>A A A A A</b>	
131108_0179_1040 132572_0456_2440 134374_0049_0461 134847_1070_3468 134197_1049_2956	137731_0186_1863 138132_3853_1354 162436_0171_3267 142666_3171_1855 142811_1853_3855
143441_1365_2466 147616_3169_1158 144169_5855_5959 144874_3175_1672 144854_1585_7897	145844_0195_1086 145850_0862_1570 147492_0870_1555 147880_0170_14660 145641_1768_2555
153842_0155_1061 153816_0171_0460 154040_0151_1455 154056_0852_0361 156140_0874_1069	
163265_1762_3661 165176_0207_0378 166433_1733_3683 168285_0361_1459 168341_1051_054	169830_0176_2751 178133_0359_1464 172047_1061_2045 174596_0150_1057 178145_1066_2661
	$\circ$ $\circ$ $\circ$ $\circ$ $\circ$ $\circ$
178335_0376_3157 179822_0859_2374 181246_0197_1468 008482_1856_3647 010098_1051_1458	010427_0184_1045 012084_1056_2954 012119_0184_1042 012433_0187_1443 012759_1741_2848
	$\langle 0 \rangle \circ \circ \circ \circ \circ \circ$
012095_0182_1855 013320_1754_2054 033420_1057_1958 013769_3651_2208 013803_0855_3059	813842_1745_1858 014146_1746_2163 014448_1745_1965 014968_0356_3151 016728_1055_0055
$\bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc$	
018409_0180_1064 018201_0165_1467 019665_1057_03169 019744_1047_24556 020882_1741_3552	821042_1043_2954 021504_1446 023474_1049_2745 024414_1740_2280 025615_1543_1466
825892_1745_3053 025836_1876_3166 027089_1748_3156 027102_1867_1866 027228_1747_2157	827248_1741_2155 827787_1559_1866 828184_1059_1961 828544_0376_1868 828821_0180_0772
020972_1757_1447 030552_1754_1068 030230_1744_3151 033833_0176_14468 031438_2049_2056	032046_0376_0352 032260_1740_2853 032535_1541_1078 032625_0200_0450 033336_1066_2854
834288_1055_1153 034336_1745_2556 834424_1735_1854 036330_1070_2563 837458_1066_3154	837514_1044_3158 838970_1869_2858 839443_0134_1862 041466_0389_3159 841522_1775_3252
842019_0174_1043 842204_1744_1059 843136_1056_3744 843236_1064_1055 843818_1065_2044	044051_0179_1858 044510_0375_1845 044822_1072_5250 044528_1741_0355 044952_1088_2084
847133_0178_1041 047230_0346_1850 047032_1755_3646 048048_1740_2754 048188_1049_1650	548231_0144_1867 048350_1551_2458 049494_1761_1868 049434_1878_2361 050724_1090_1981
551149_0977_1069 052339_1745_1858 852378_1065_3248 053526_0270_1861 852058_0367_2131	853254_1742_1482 D34530_3867_3366 855069_1039_2353 D56836_1050_1553 857033_1744_1556
SECOND DITE SILMS DALING 1987 JTND SCHAIT DITE 1985 DELITAN SITE 1981 SCHOTA 1744 1862	360336 1048 1947 087444 1767 1470 367474 1073 1945 069361 9174 1868 070914 1746 2157
	10110_101_101_1011 011101_1012_1012_1011_10101_1001_1001_1001_1001_1001_1001_1001_1001_1001_1001_1000_000_1000_000_10000_10000_10000_10000_10000_10000_10000_10000_10000_10000_1000000
191411_1942_3951 189332_3164_8660 185114_6179_6661 185124_3059_1046 187387_1744_3351	100001_1070_2003 111432_0072_3003 113034_0100_1003 113207_1735_1002 113206_1004_2000
$\bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc$	

Figure 74 Hue approximately 0.95

				6			0		
131333_1074_1547	131333_1872_2867	131333_1064_2962	101024_0081_3470	131338_0174_0669	131355_1067_2064	101055_1066_2561	131355_1046_2859	131355_1066_3257	131355_1066_3655
								0	-
101355_1065_3655	101355_1755_1465	131355_1755_1866	131305_1754_2164	131355_1764_3059	131356_0173_1061	131356_3176_1863	131356_0862_1037	101056_0867_2560	131356_0070_3359
C.C.B.									
131354_1551_1553	111397_1071_1464	131397_1073_1963	131397_1759_1563	131397_1765_3098	131567_0388_3361	101567_1068_1362	121567_1070_2061	131567_1979_3355	131567_1768_3549
101000-1001-1000	10082.005.2572	133383_1081_2976	11000.1077.000	137383_1073_3765	121383_1784_1582	133383_1781_1883	1000_100_2004	11061.1767.3275	123383_1761_3674
133384_0874_1085	133364_0000_2388	103705_1032_2841	133705_1329_3259	133705_1027_3658	133746_0887_2588	133766_0183_0666	133766_0183_1067	133766_0184_2775	134857_1091_1672
	-								
$\bigcirc$		0							-
234857_1088_1979	194857_1060_2945	134857_1073_3762	135216_3374_1462	135215_1764_3648	135216,0179,0682	135236_0178_1964	135216_0177_1465	135216_0175_2368	135554_0195_0455
C		Color and	Contraction of the second			0	-	$\bigcirc$	
135558_0184_1868	137569_0375_1858	137549_0378_3182	137569_1366_2454	137569_1069_3398	137565_1075_3747	137569_1753_1456	137569_1756_2752	137569_1758_3349	137569_1759_3648
-	9	-			-				
138412_0848_0941	131612_0101_3157	142847_0371_1485	142847_0377_0154	142847_1081_1584	142847_1063_1964	142847_1758_1459	142847_1751_1862	142847_1752_1963	142847_1757_3554
630									
142848_0142_0630	142848_0162_1052	142848_0182_1447	142848_0162_1354	142048_0852_1053	142848_0852_1552	142848_0851_2255	142848_0851_3052	143167_1070_1563	143167_1078_2063
_	-		-				-		
		$\bigcirc$				$\bigcirc$	$\bigcirc$	-	
143167_1069_2961	143167_1068_2352	143167_1067_3353	143167_1167_3755	143167_1759_1965	143167_1753_1866	143167_1757_2861	143167_1756_3396	143177_0375_3159	143177_1067_1467
					$\bigcirc$	$\bigcirc$			
							and the last	144767_1070_1346	144783_1087_1861
144787_1058_3240	144787_11845_3458	144787_1762_1463	194767_1756_3167	144787_1754_3663	145272_0200_0664	145272_0197_1045	145272_0103_2766	145476_0162_0567	146476_0164_1470
147003_1079_1458	147003_1001_2459	147003_1082_2856	147003_1082_1256	147003_1083_3650	147032_0857_2666	147161_1057_3240	147161_1740_1846	147101_1070_3245	147271_1082_2854
Card no								0	
147337_1054_1457	147337_1059_3210	147337_1743_1453	147330_3851_2250	147338_3538_3554	147377_1043_1944	147381_1060_1565	147381_1087_1965	147301_1070_2563	107381_1072_2940
-	9					-		9	
247382_1076_3756	147382_0006_2364	147382_1014_1544	147507_1765_2050	147528_0178_0752	147534_1541_1673	147101_1700_3343	147797_0372_1455	147367_0173_3155	147567_1754_3352
141621_1058_1546	141121_1119_1141	148821_1001_2544	141121_1112_1241	148821_1747_1447	148821_1748_1948	141121_1710_2142	148821_1751_3348	141122_0101_004	141122_1032_2255
(Jugo)	20								
140422_0852_3054	148822_1340_1554	149238_0169_2675	199355_1074_1978	150355_1075_2567	150353_1076_2064	190355_1076_3363	150355_1077_3762	150359_1763_1470	150303_1704_1070
	0					0			0
150355_1765_3244	193359_1766_3662	151241_0381_1864	151241_1070_1564	181241_1073_3844	151241_1073_2555	191241_1875_2958	151241_1076_3357	131241_1077_3755	151241_1759_1564
	0	0					0		
151241_1765_1864	151201_1763_2750	151241_1764_3257	191241_1766_3654	151423_1076_2469	101423_1079_3268	151423_1760_1469	151423_1762_1872	151423_1766_2868	161423_1769_3364

Figure 75 Hue 0.22 to 0.27



Figure 76 Hue 0.62 to 0.67

# 6.4 Horizontal Spans, Voted Ovals



Figure 77 Horizontal spans, November set



Figure 78 Horizontal spans, February set

## 6.5 Vertical Spans, Voted Ovals



Figure 79 Vertical spans, November set



Figure 80 Vertical spans, February set

## 6.6 Transition Counts

The transition count represents the number of light to dark transitions encountered following the first dark pixel encountered (typically the left edge of the printed oval). Higher transition counts represent traversal of light regions prior to encountering dark regions; typical examples would be "x" marks, check marks, zigzags, and hollow marks not in contact with the printed target.

The following graphs show the distribution of transition counts as measured at the horizontal centerline of voted marks. The second graph uses an expanded y axis.



Figure 81 Transition counts



Figure 82 Transition counts, expanded y axis

The following montages compare typical marks with a transition count of 0 with marks with a transition count of 4. Although the difference between these two sets of marks is apparent, it is not clear that the transition count as calculated can be used to give much detail with regard to "degree of scribbledness."

029401_0140_1007 010561_0175_2270 001094_1042_3251 001082_1055_1055_001542_1045_1046	\$75185_8585_2746 \$73181_8867_1871 \$74232_1794_8448 \$84478_1755_3468 \$34679_0147_1463
STALING ENGL THE THE STATE STATE STATE STATE STATE STATE STATE STATE	ENTERN LOAD DATE DITTEL DATE LOAD LITTE DITEL DATE DATED LITTE 2007 STRATE LOAD TANK
\$394935_D191_D644 041612_1742_1476 740699_1765_2234 042594_1742_1564 042481_0182_D646	842756_1755_1644 R45059_3072_3870 847059_1754_3544 047342_10468_1652 8477514_1072_1456
947379_0367_1144 047955_0865_1367 346019_0856_3067 044376_0366_3161 948309_0366_3148	848946_1087_2444 049832_8372_1457 849248_1065_1954 058167_9856_0956 850838_0195_1066
	$\bigcirc \bigcirc $
€ 851798_1869_2563 053326_1863_1968 053774_1866_3259 054655_0166_1466 055286_0361_1449	855414_0367_3150_055689_0161_3564_067773_0184_1869_057919_3854_0265_0588358_1064_3252
859334_0774_1468 069807_0960_0960 060879_0889_2556 061784_1776_3564 061992_1754_3557	\$62074_0869_2071 062214_1061_2455 062412_1754_2854 062862_0162_2370 \$43259_1055_2845
863442_1757_3348 063569_8150_1963 843647_8863_2558 064349_3658_2568 84483_0138_3063	264931_0854_2594
\$67558_1075_1565 067718_0367_1855 867786_1065_2260 D68879_1539_1869 869419_6175_2767	265562_0371_3134 265632_0373_1460 269967_0857_2367 070155_3163_1460 270718_1078_3751
871158 1745 1454 071381 1555 1576 071492 5372 3355 072308 1076 3269 072392 1749 1541	172413_0129_1841 072708_1741_319 372444_083_2473 072523_0242_9445 073073_1075_2442
Alerrineeire (2000/1007/1002/1002/1002/1002/1002/1002/	<pre>strest_ntat_nest serset_nest_serst serset_ntations netest_ntations seriestentations</pre>
וארינגרישוו אריחריאניוו איריגריסטון אריטריאניוו וווישראלאניו	14214_1514_161 341374_1777_177 14007_1844_2372 34045_0152_167 131313_1877_2444
Ородов	
инглигани инслиган инглигани ингалтини ингалтини Соборов Соборов инглигани ингалтини Соборов Соборов ингалтини Соборов Соборов ингалтини Соборов Соборов ингалтини Соборов Соборов и соборов и Соборов Соборов и соборов и Соборов Соборов Соборов и Соборов Соборов и Соборов Соборов Соборов и Соборов Соборов Соборов и Соборов Соборов Соборов и Соборов Соборов Соборов Соборов Соборов и Соборов Соборов Соборов Соборов Соборов И Соборов Соборов Соб	инглигии инглигиии инглагиии инглигии мари ингигиии инглигиии ингигиии мари ингигиии ингигиии мари ингигии мари ингигии мари ингигиии мари ингигиии мари ингигиии мари ингигиии мари и ингигиии мари и ингигиии мари и ингигиии мари и ингигиии мари и ингигиии мари и и и и и и и и и и и и и и и и и и

Figure 83 Transition count 0

029475_0103_1464	029608_1761_3353	030045_0100_1072	031453_0167_1565	031550_1054_3251	037426_1051_2458	034031_0168_1865	334399_0367_1861	034380_1958_3054	334417_1558_1578
				(P)				(MA)	
\$77324_1753_1865	037927_0162_9651	338040_1067_2956	036951_0162_1862	039136_1762_1562	039598_1768_7641	039741_0178_1466	240336_1064_3651	041321_0871_2468	041482_1068_2060
				O		(P)			
841787_0178_1868	041857_0197_2267	842149_0359_1455	042569_0375_3270	842965_0171_2366	143057_0857_2666	nas382_1079_3751	145708_1763_3261	045517_0167_1063	045944_1073_2459
		Ø	C				allo		
846016_1763_1855	047587_0155_1066	847688_1748_3258	048736_1741_2853	849127_8847_1051	851287_0H54_2572	051938_1898_1472	852028_1753_3364	b52475_0161_2369	852954_8371_1857
	Ø	Æ	O						Cano
055491_0170_0761	055509_0161_1066	355558_1052_3253	057716_1753_1444	050169_1053_2853	050197,0177,0659	058649_0853_1567	059256_1065_2859	059480_1049_3598	868175_1537_1672
	COLO PA		CORNA .		(MA)			and Street	
	ALAP		5000						
\$60228_1737_1458	061595_0870_2875	361659_1771_3561	061859_0869_2976	961916_1071_1969	062612_1062_1962	063062_1079_3655	063165_0161_1065	D63480_1749_3559	063866_1063_2064
	O		0	Ô				O	
064855_0165_0669	065022_1741_3149	366128_1059_2458	066182_1066_2061	167278_1071_2461	267753_0141_2863	170156_1761_2763	071387_0849_0972	072325_0176_1466	072556_1743_3058
							40	S	
872966_1074_2462	078258_1721_3355	081249_0873_1067	083059_1545_1862	083826_1061_2957	884095_8178_1071	084262_1743_3152	084732_1735_3351	085859_0848_1057	386403_5175_3184
		Level and the second se		0		0	0	C	
186414_0393_3160	086716_1079_2862	180254_0177_1957	100548_0175_1856	100814_0875_2868	103765_1756_2152	104003_1056_2459	184058_1561_1568	104885_1052_1965	184308_0105_1459
a				a					GMA
104747_1746_1456	105859_1747_3353	107013_1756_5563	109108_0177_2464	110207_0402_3179	110373_1078_2067	112130_1553_0#67	112255_0371_5154	113355_0388_3159	114801_1067_3553
		Ath				(A)		Q	
115404_0171_2240	114513_1754_1871	117233_0383_1888	119137_1059_2754	119840_0855_2764	123275_1043_2558	123525_1169_2367	123778_0848_2547	124526_0179_1850	124852_0184_0651
(1)							THE DAY	<b>E</b>	
125049_1064_3356	127928_0193_1455	128139_1754_3164	128396_0173_1455	129248_0855_0958	128417_1749_2854	129491_1758_9257	130123_1739_3882	130172_0171_2455	230484_0204_0655
			CALIND						
131643_1077_3253	131909_1780_3261	132618_0062_0993	132433_1148_2142	132817_1767_3656	133153_0347_1878	133563_1751_3650	133673_1076_2861	133746_0203_0678	133941_1749_1565
(CTIN)								(MAR)	
130123_1036_2476	135155_1949_3742	125149_1755_1458	135170_0852_0867	135257_1084_3755	126243_1746_2161	137627_1063_2918	117741_1064_2069	138189_1760_3449	138904_0177_0765
		6							$\bigcirc$
142069_0375_1865	145838_0196_1455	146244_0852_0508	141917_1102_110	148959_1754_1461	149959_1073_1087	100203_1070_0360	151234_0036_2358	153497_1765_3659	153801_1077_3160
		0							
154236_0155_1062	154470_0164_1960	114901_1019_2059	155542_0170_1448	155127_1078_5258	155432_5179_3759	156384_8177_1453	156991_1001_3261	157045_1070_2083	108132_0108_1462
(101.50)		$\bigcirc$					0		
158201_1053_2054	158202_0168_1454	156555_1077_3359	164718_0186_1051	164972_0850_2860	165934_0183_2758	148788_0190_1055	167312_0197_1054	147855_1062_3758	167995_1063_2262
	O	C				O	O	Ø	
169318_0177_0754	169790_0064_1964	170242_0854_2457	171551_7356_1463	171747_0368_3165	171012_0307_010	172548_0177_2655	173086_0168_2264	174260_0174_1456	174375_0141_1567
		P			X			Ø	CUD
175423_1758_3056	175852_3863_3358	176517_1067_9354	177135_1869_2866	177176_0174_0654	178069_1061_3655	174876_8173_1853	178136_0177_1865	174223_1758_2243	178308_0059_0953
C				$\bigcirc$	D				
178310_1544_8861	178355_1750_1461	178457_1764_2446	178486_0165_0258	178603_8383_1872	278765_1068_2864	180677_1186_2363	181135_1056_3661	181213_1726_2771	181641_1735_3256

Figure 84 Transition count 4

# 7. POSSIBLE MARK TAXONOMY AND NOTATION

Marks placed on oval and rectangular targets can be characterized by the intensity of the cropped region surrounding the target and/or by the intensity of the pixels across a span (for example, the centerline of the mark, from first darkened pixel to last). In addition, the hue of the mark can be used to characterize it, as can the marking implement used (when this can be discerned). The horizontal and vertical spans of the marks can be used as well, as can the number of transitions along a particular line.

Should additional characteristics be necessary, the nature of the stroking and coverage can provide additional dimensions. It is unclear whether a test set really needs to take these variations into account, but a relatively compact notation for the stroking could be as follows. The first part is based on compass direction notation:

W	out of bounds to left (west)
E	out of bounds to right (east)
Ν	out of bounds beyond top (north)
S	out of bounds beyond bottom (south)
NW,NE,etc	out of bounds at top left, top right, etc
W	void at interior left
e	void at interior right
n	void at interior top
S	void at interior bottom
0	void at center
nw,ne,etc	void at top left, void at top right, etc
V	vertical strokes
Н	horizontal strokes
Т	strokes conforming to target ellipse
t	strokes conforming to target ellipse, not extending to printed target
F	diagonal strokes leaning forward
В	diagonal strokes leaning backward
Х	an X nor check mark (voids would be assumed)
С	a surrounding circle (though this is extremely rare)
D	an interior dot or dash
G	uniform light coverage, no strokes evident
R	random or not otherwise defined stroke pattern
!	modifier suffix indicating the prior pattern is major
r	modifier suffix indicating strokes are rounded (curlicues)
[09]	alternate modifiers indicating degree to which prior pattern exists

Using this notation, mark Ar1c5 of the montage at page 68 could be described as "SE nw T". This notation could be extended to incorporate the other mentioned characteristics: intensity, writing implement used, predominating color, etc...

# **8. NEXT STEPS**

Following completion of the mark databases and mark characterization, procedures will be developed and documented for producing a set of reference marks on typical ballots using each of the three vote target types analyzed.

-END-