A Versatile Comparison of Stamps by High Resolution Image Differencing

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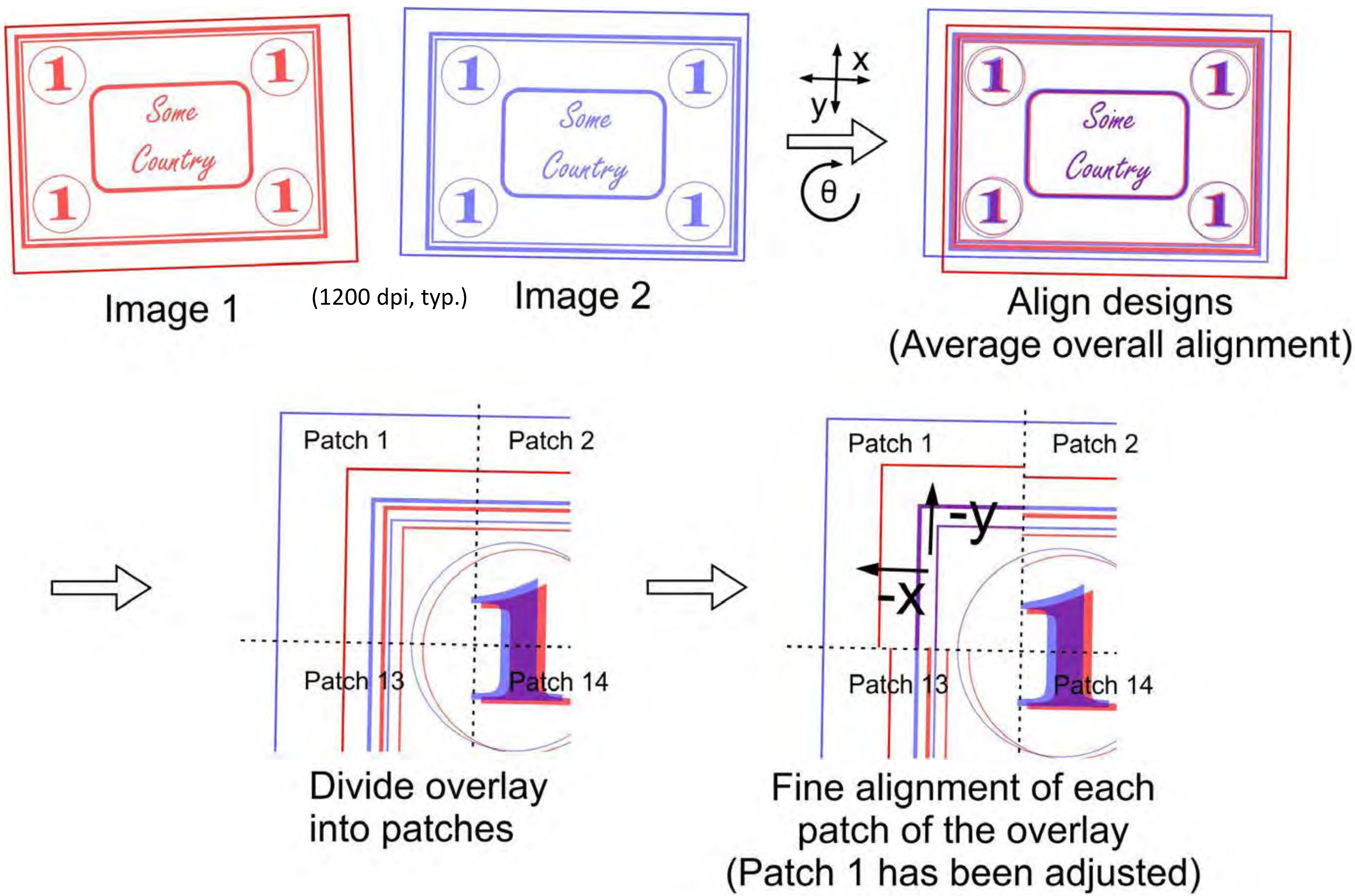
Past Research

- Previous research demonstrated the ability to digitally subtract high resolution philatelic images, pixel-by-pixel, from each other, correcting for paper shrinkage
- For the special case of blocks from the same sheet, differences between the plate impressions can be measured

Present Objective

- Broaden the versatility of the image comparison method so that differences in the plate impressions can be measured using any two stamps of the same issue, regardless of sheet and without requiring multiples
- Make the subtraction method correct for shrinkage differences between stamps rather than requiring a block of stamps that share the same shrinkage

Previous Subtraction Method (Mustacich, 2016)



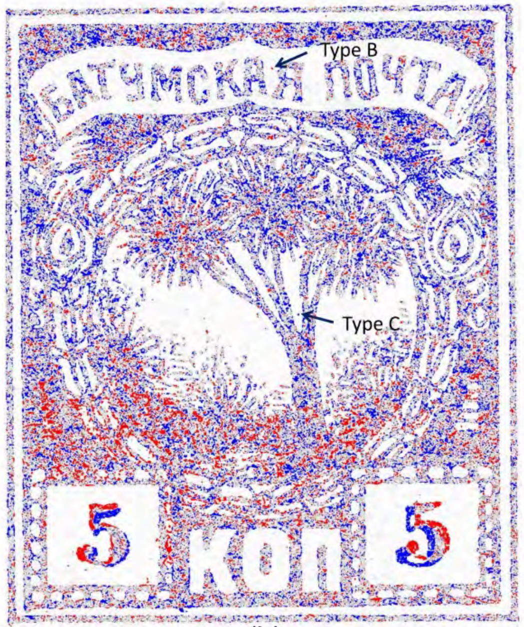
Circa 2016 Subtraction Method in Action

```
// may need 2 rows for fine mesh so that estimate reaches out enough patches to get a good local estimate

i = fopen_s(&stream, "sub.txt", "rt");  //get name list of files for block
if (i == 0)
{
    num_f = 0;
    while (fgets(fname[num_f++], 80, stream) != 0);
}
else
{
    wsprintf(Buffer, _T("File open error %i"), i); //output error number
    MessageBox(hWnd, Buffer, _T("wat"), MB_OK);
}
fclose(stream);
num_f--;   // strip null char and add ".tif" to file names:
for (i = 0; i < num_f; i++) if (strcspn(fname[i], "\n") > 0) strncpy_s(fname[i], fname[i], strcspn(fname[i], "\n"));
strncpy_s(fname[2], fname[0], strlen(fname[0]));
strcat_s(fname[2], "-");
strcat_s(fname[2], fname[1]);
for (i = 0; i < num_f + 1; i++) strcat_s(fname[i], ".tif");

for (i = 0; i < image_width; i++)  for (j = 0; j < image_length; j++)  { z[i][j].r = 255;  z[i][j].g = 255;  z[i][j].b = 255; }
i = rd_Tif(fname[0]);  //open tif file #1 and stuff array z
if (i != 0)
{
    wsprintf(Buffer, _T("File open error %i"), i); //output error number
    MessageBox(hWnd, Buffer, _T("wat"), MB_OK);
}

GetClientRect(hWnd, &rc);  // Obtain the size of the drawing area and draw a rectangle referencing this
original = SelectObject(ps.hdc, GetStockObject(DC_PEN)); // Select the pen.
SelectObject(ps.hdc, blackPen);

count[0] = 0;
for (j = 0; j < image_length; j++)  for (i = 0; i < image_width; i++)  SetPixel(ps.hdc, rc.left + 10 + i, rc.top + 10 + j, RGB(z[i][j].r, z[i][j].g, z[i]
for (j = 0; j * 2 < image_length - 40; j++)  // scan image for frame edges
{
    ival = find_edge_vt(0, 1, 1, 0, j, 0);  //Left upper
    SetPixel(ps.hdc, rc.left + 10 + ival, rc.top + 10 + j * 2, RGB(0, 0, 0));
    lines1[j][0][0] = ival; lines1[j][1][0] = 10 + j * 2;
```

Previously Demonstrated Applications

Viewing Plate Cracks on a First Issue U.S. Revenue Stamp

(a)



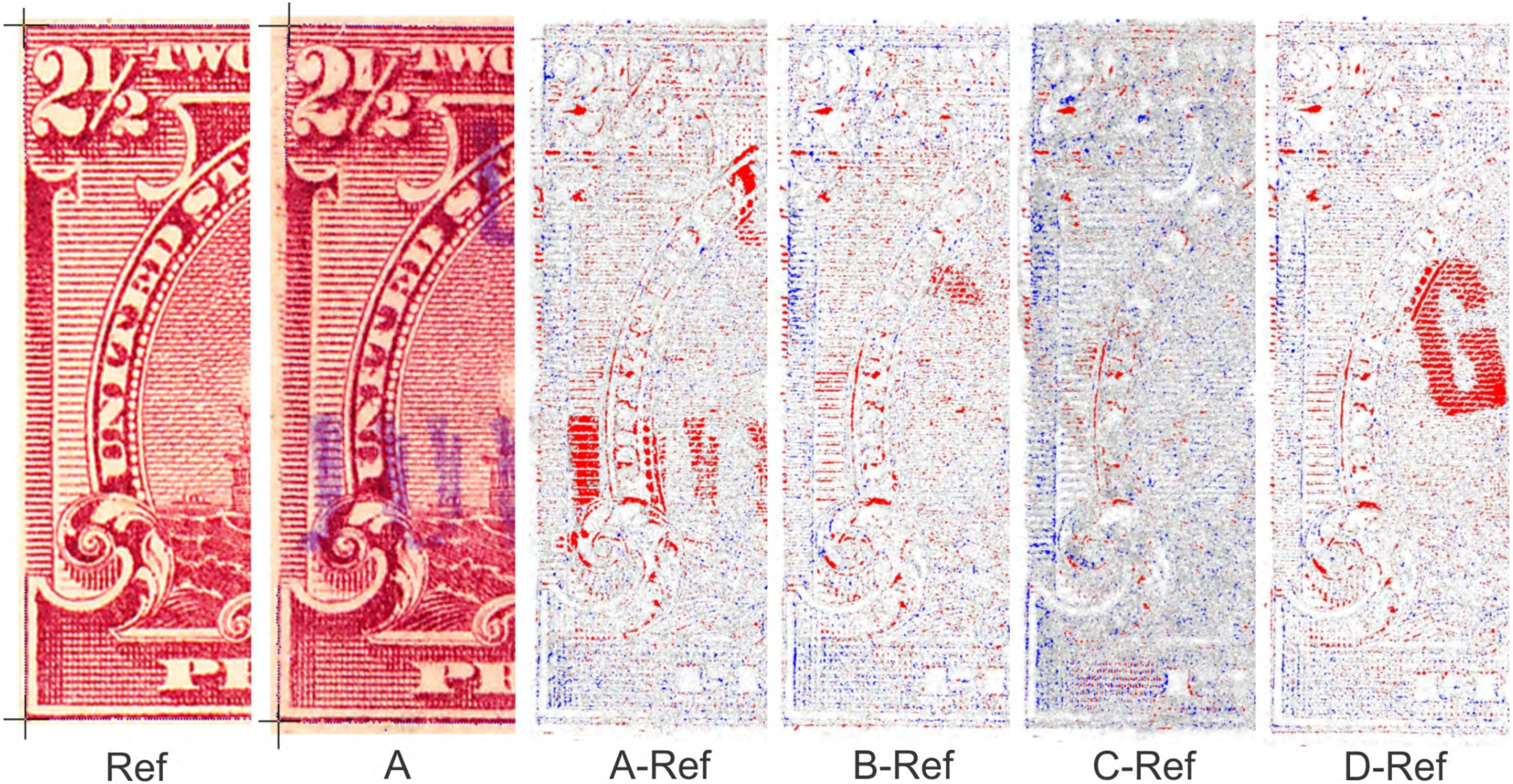
(b)

(c)

(d)

Comparing Genuine Stamps and Forgeries for Batum #1

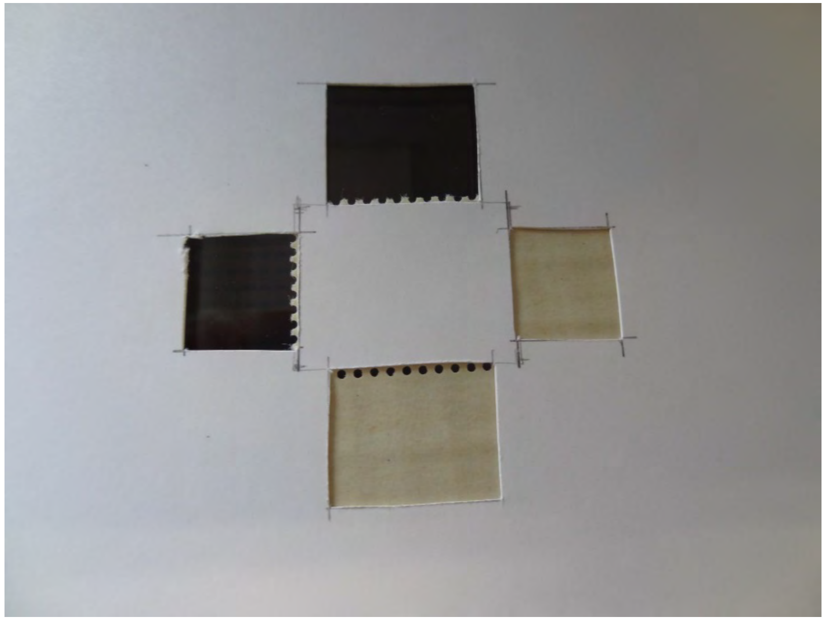
(a) Genuine type B
(b) Subtraction with genuine type C
(c) Subtraction of type I and type II forgeries
(d) Subtraction of type II forgery with genuine type B

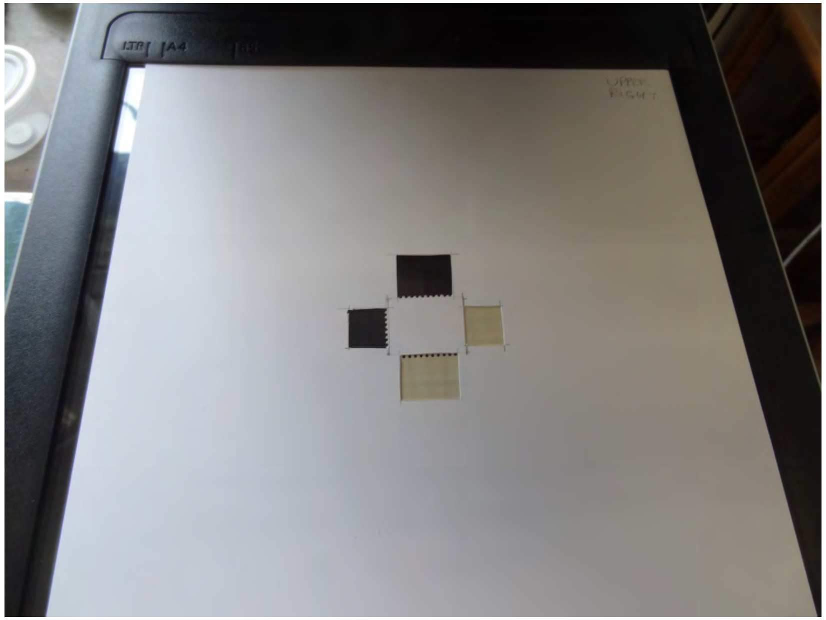


Details of Re-entry Features on U.S. Proprietary Revenue of 1898

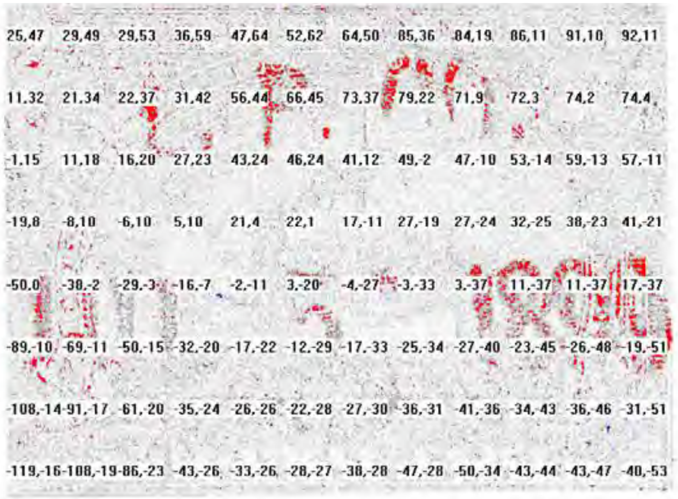
Scanner Issues and Technique

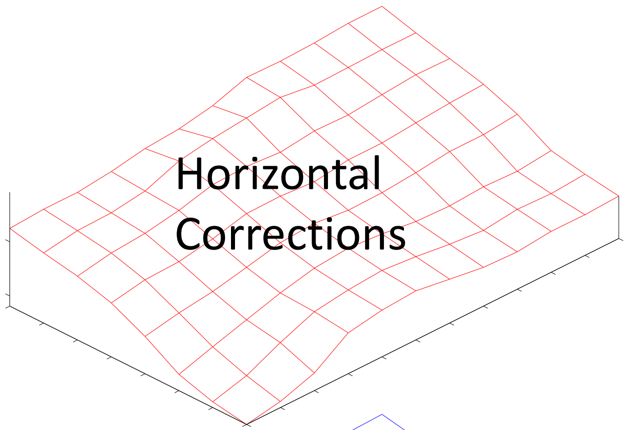
- Typical scanner variability
  - Vertical variability includes mechanical drive (gear and belt) irregularities
  - Horizontal variability more dependent on the optics and less on the drive mechanics
- Differencing tests show substantial variability in comparing the same stamp image scanned at different locations on the platen
- Can achieve a very reproducible scanning result by repeatedly using the same position on the scanner
  - Use a mask for precise and repeatable positioning for scanning
  - K1.5 mm horizontally results in average local shift < 0.03 pixels (.0.6 :m)

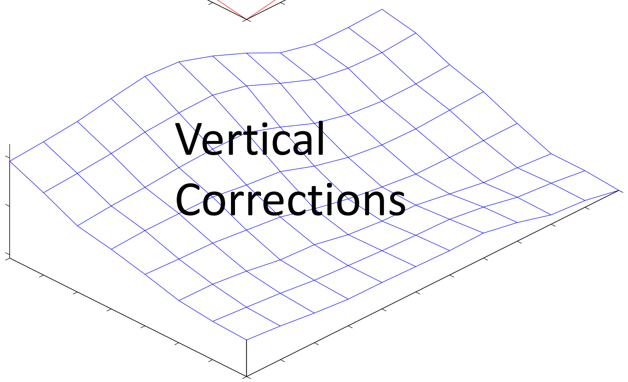


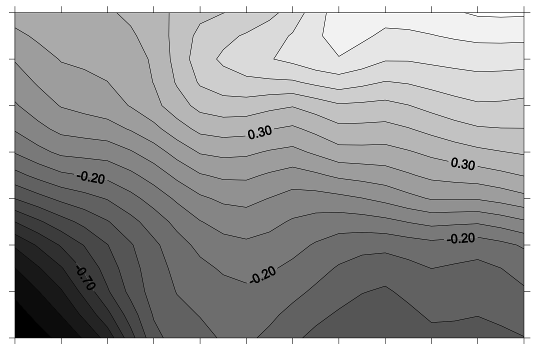


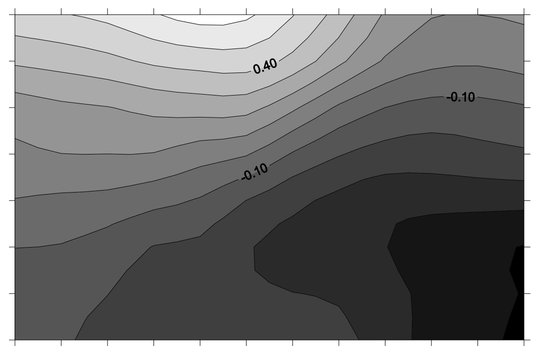
Two-Dimensional Array of Image Corrections Can be Viewed as Surfaces and Topographical Maps







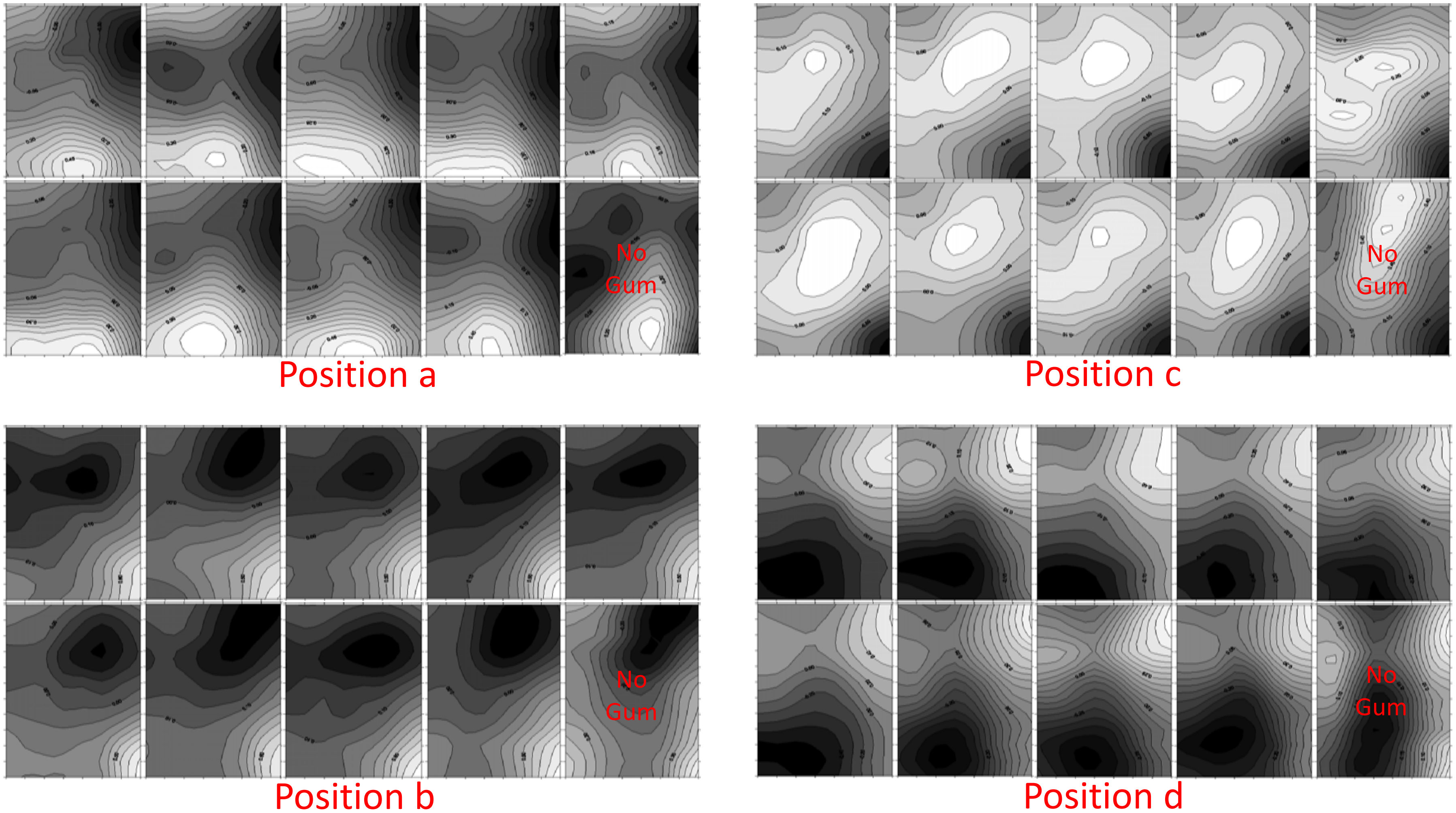




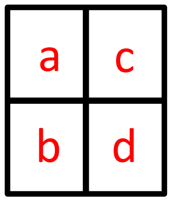
Much easier to visualize

Subtraction of “A” – “Ref” from the 1898 U.S. Proprietary Revenue Example Shown Previously

Horizontal Corrections for 10 Different, Same Plate Number Blocks Grouped by Position



US#1030 LR25981



Linear combinations of differences used to determine contours

MNH Blocks with the exception of the last which had no gum

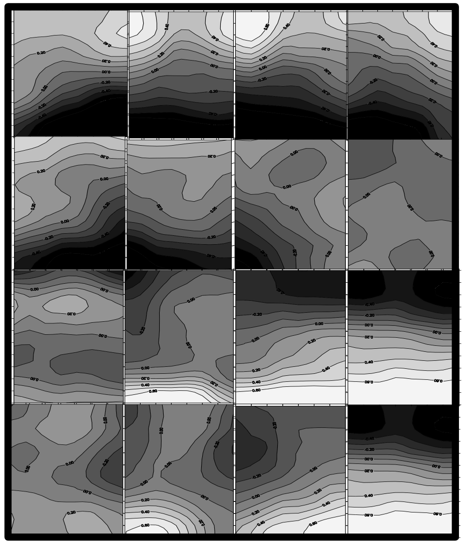
Replicates are very similar to each other, with small differences in the block without gum

Very similar result for the vertical correction patterns

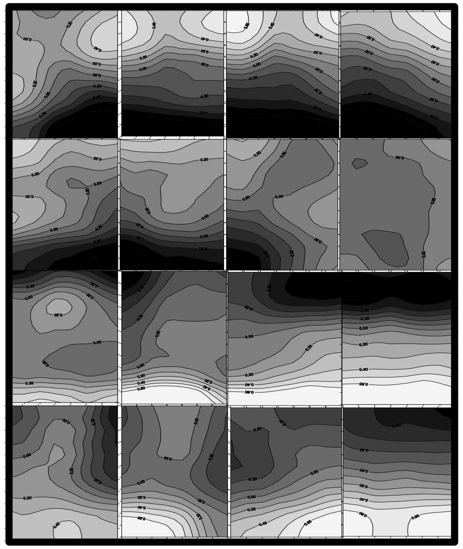
These patterns are the relative differences between the impressions.

U.S. 1953 Franklin ½ c. PL#26003: Same Patterns on Both Sheets

Block of 16 used in calculations



Sheet 1 (x)



Sheet 2 (x)

Each printing plate position has its own distortion patterns
– a consequence of small differences in the ‘plastic’ flow of the soft steel when rocking in each impression

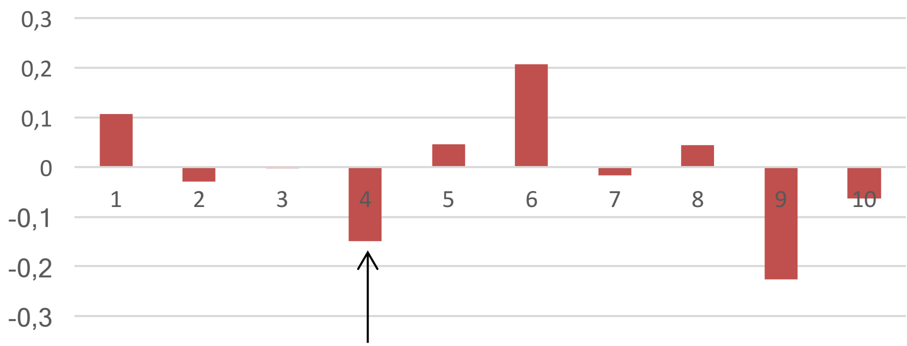
Similar results were obtained comparing sheets from other plates.

How Bad is the Problem Subtracting Two Random Stamps of the Same Issue?

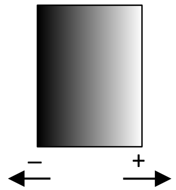
Try subtracting all positions of the 10, same plate number blocks with a single reference stamp of average size, and compare the results for each of the four positions –

- Are the results comparable for each position, or are they instead dependent on the stamp sizes?
- How large are the second-order corrections?

Width Difference of Blocks (%)

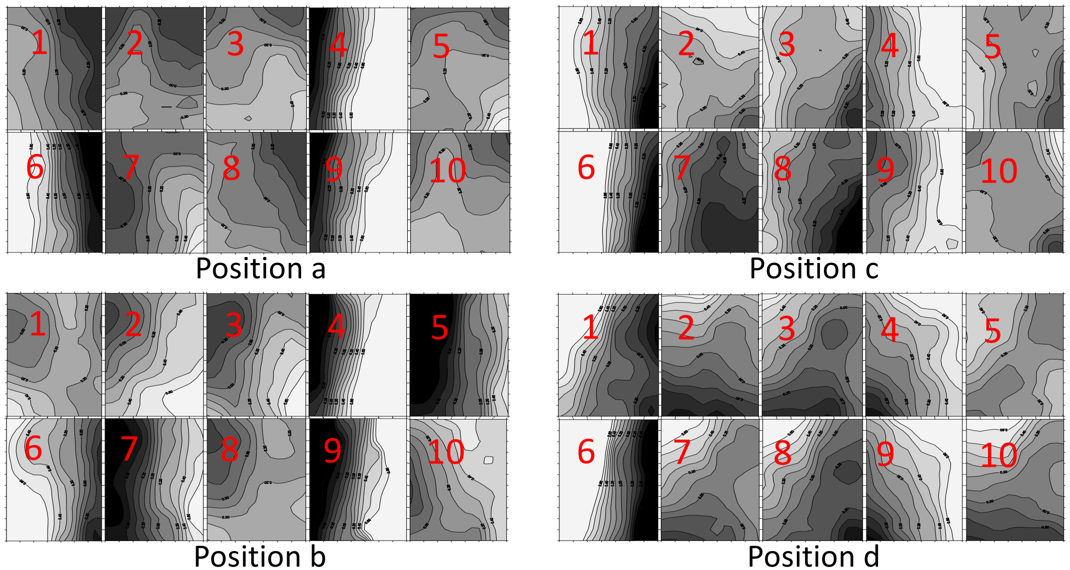


#4 undersized → need array of expansive corrections



Actual Results for the 10 Blocks by Position

Positions in a block of 4



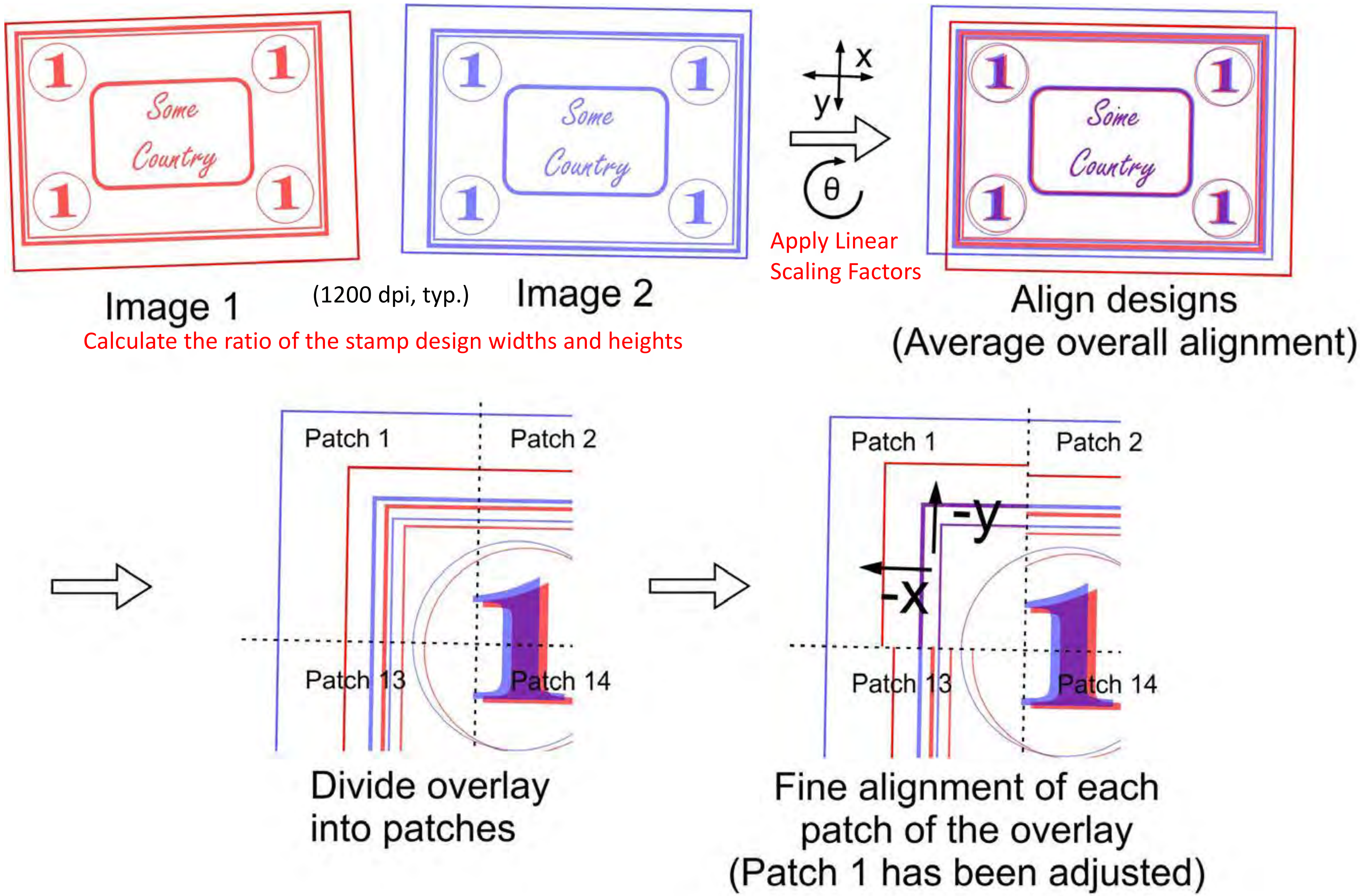
Horrible Looking Results!

Stamps in blocks 4, 6, and 9 show large distortions due to size differences!

Some Ways To Possibly Correct for Large Size Differences between Stamps

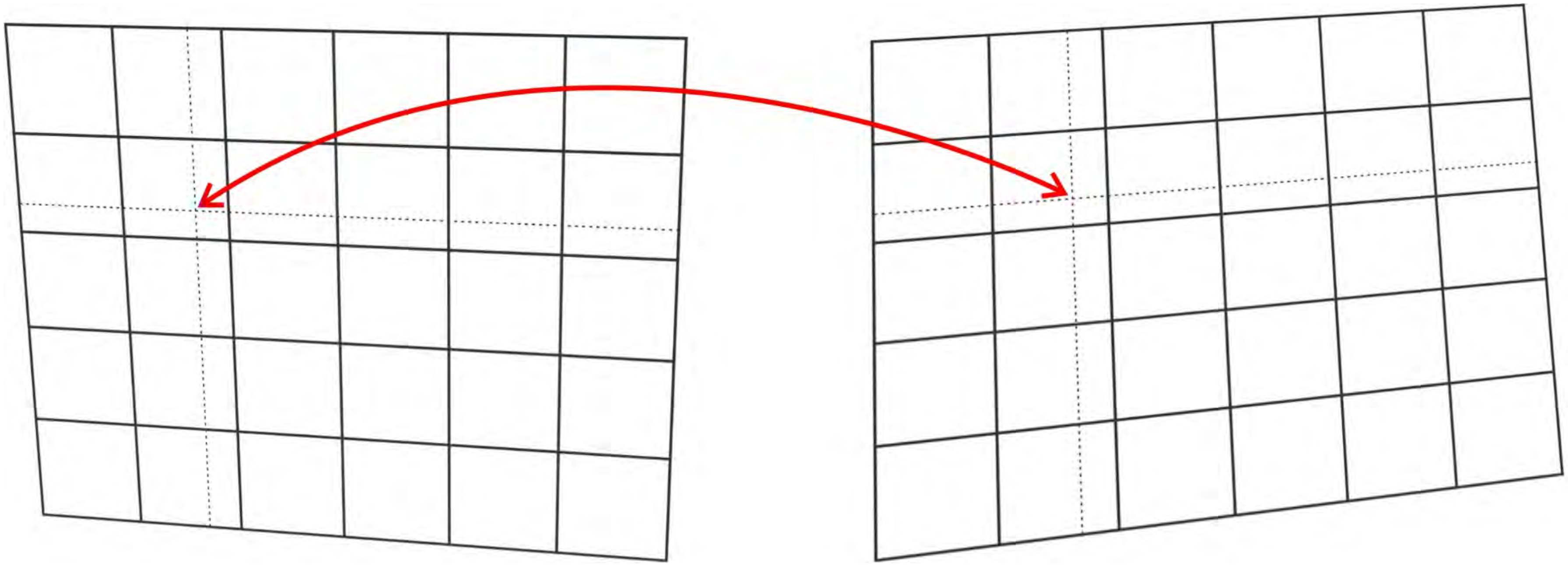
- Linear scaling
  - Use ratios of average widths and heights to correct for shrinkage
    - Should preserve genuine deviations from a rectangle
    - Only accounts for shrinkage which is uniform over the entire stamp
- Direct mapping
  - Bilinear
    - A mapping that is proportional along the boundaries that can resemble shrinkage
    - Expected to overcompensate and remove uniform deviations from rectangular shape that are genuine
    - Sensitive to the accuracy of the 4 corner locations
  - Warp and Perspective
    - Small changes to create “perspective” introduce very large distortions of an image that do not resemble shrinkage

“Linear Scaling” Method



Bilinear Mapping between Two Quadrilaterals

(differences exaggerated for clarity)

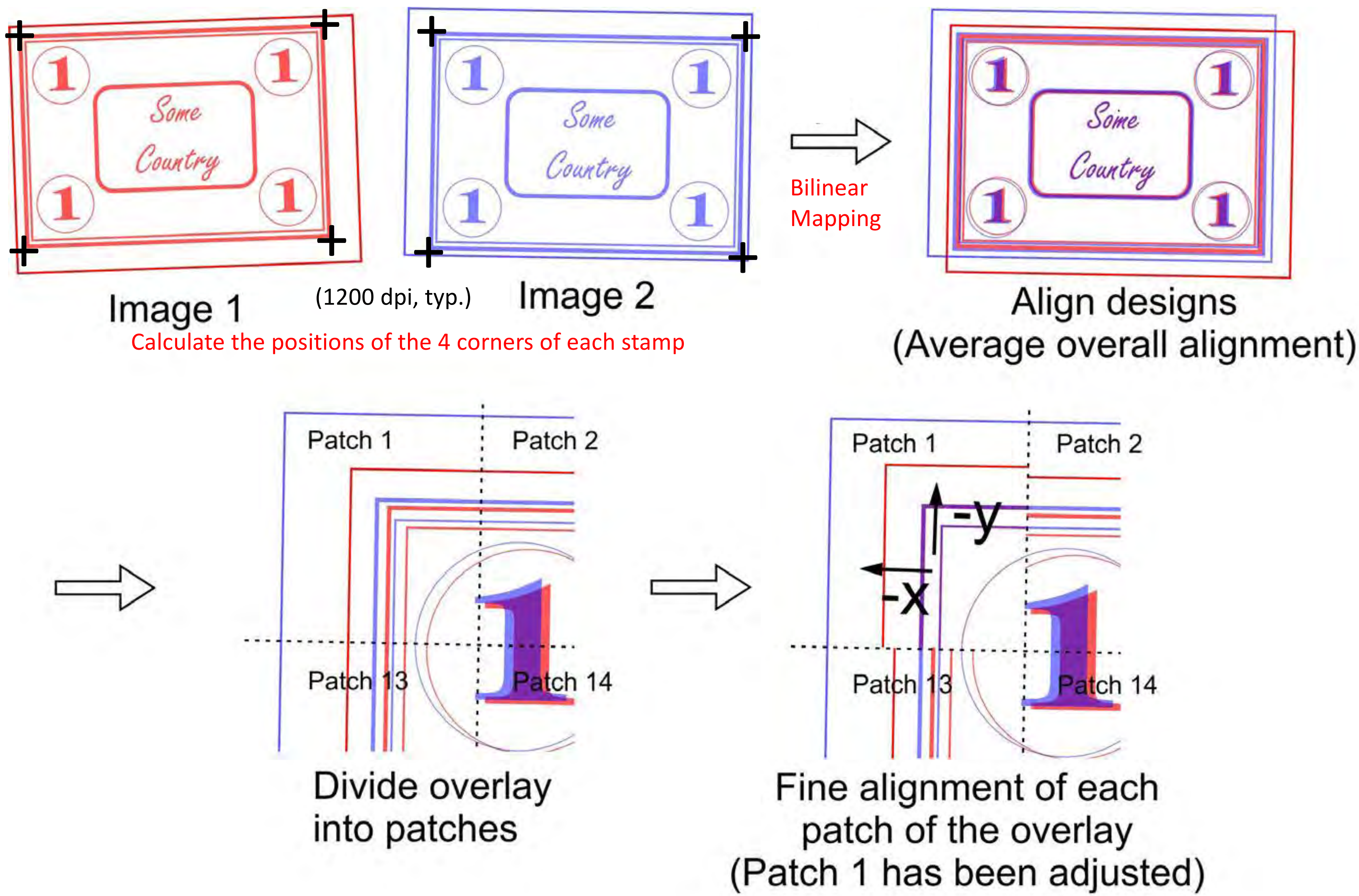


Grid mesh is evenly spaced along each (linear) edge.

Distortion is in the plane and should be similar to shrinkage distortions.

Results are very dependent on the precision of the measurement of the 4 corners.

“Bilinear” Method



“Bilinear-4Corner” Method

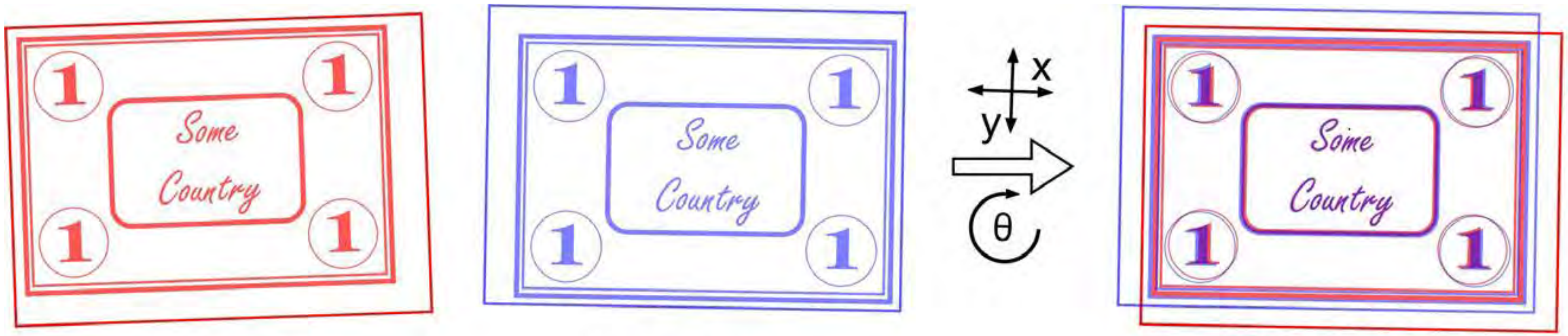
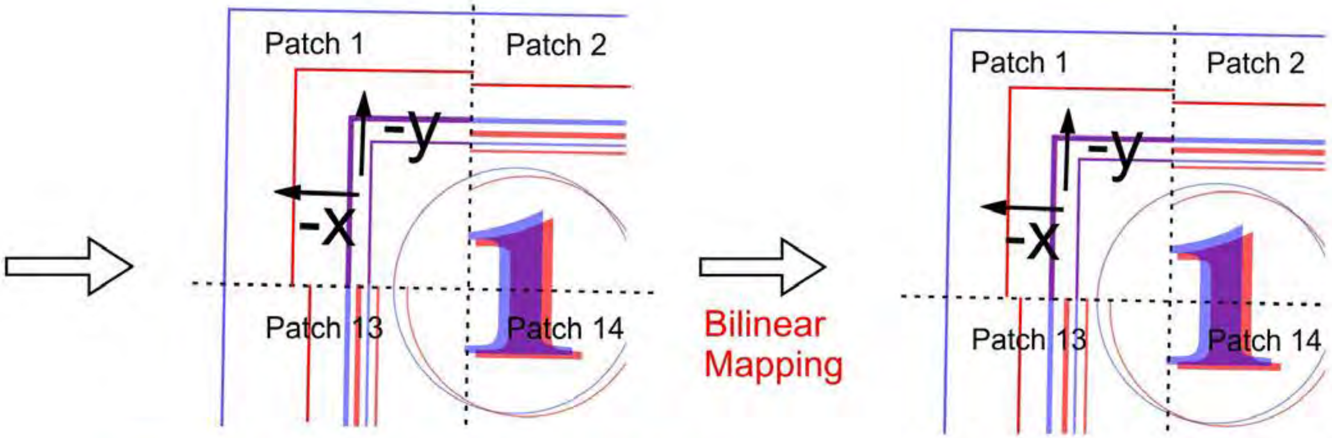


Image 1

Image 2

Align designs
(Average overall alignment)



Fine alignment of the 4 corner patches in the overlay for more precision in the bilinear mapping (Patch 1 is shown adjusted)

Fine alignment of each patch of the overlay (Patch 1 is shown adjusted)

Bilinear-4 Corner Method in Action

```
                        TextOut(hdc, rc.left + 12 + patch_x, rc.top + 25 + patch_y, Buffer, _tcslen(Buffer));
                    }
                    else patch_matrix[h][g] = current;
                }
            }
            corner[0][0].x = patches[0][0].x;  corner[0][0].y = patches[0][0].y;
            corner[0][1].x = patches[0][hz_patches-1].x;  corner[0][1].y = patches[0][hz_patches - 1].y;
            corner[1][0].x = patches[vt_patches-1][0].x;  corner[1][0].y = patches[vt_patches - 1][0].y;
            corner[1][1].x = patches[vt_patches - 1][hz_patches - 1].x;  corner[1][1].y = patches[vt_patches - 1][hz_patches - 1].y;

/* ... */
            wsprintf(Buffer, _T("Bilinear Patch Interpolations using 4 corners"));
            MessageBox(hWnd, Buffer, _T("wat"), MB_OK);

            for (i = 0; i < image_width + 30; i++)  for (j = 0; j < image_length + 30; j++) { zR1[i][j].r = 255;  zR1[i][j].g = 255;  zR1[i][j].b = 255; }
            patch_width = (int)(IW / hz_patches);  patch_length = (int)(IL / vt_patches);  //global for func_patch_sub
//          for (j = 0; j < IL; j++)  for (i = 0; i < IW; i++)
            for (j = 0; j < IL; j++)  for (i = 0; i < IW; i++)
                {
                xy_corrn = patch_interp_4corners(i, j);
                xR = image_middle_x + cos_theta*((float)i - image_middle_x) - sin_theta*((float)j - image_middle_y) - x_shift_est;
                yR = image_middle_y + sin_theta*((float)i - image_middle_x) + cos_theta*((float)j - image_middle_y) - y_shift_est;
                new_x = (int)floor(xR + xy_corrn.x);  new_y = (int)floor(yR + xy_corrn.y);
                delta_x = xR + xy_corrn.x - new_x;  delta_y = yR + xy_corrn.y - new_y;
                if ((new_x >= 1) && (new_x <= IW - 2) && (new_y >= 1) && (new_y <= IL - 2))
                {
                    k = bicubicInterpolate(new_x, new_y, (float)delta_x, (float)delta_y);   //bicubic result interp.rgb
                    temp = (int)zR[i][j] - (int)interp;   //interp is global
                    if (temp > thresh)  //color red
                    {
                        zR1[i][j].r = 255;
                        zR1[i][j].g = 0;
                        zR1[i][j].b = 0;
                    }
                    else if (temp < -thresh)  //color blue
                    {
                        zR1[i][j].r = 0;
                        zR1[i][j].g = 0;
                        zR1[i][j].b = 255;
                    }
```

“Scaled-4Corner” Method

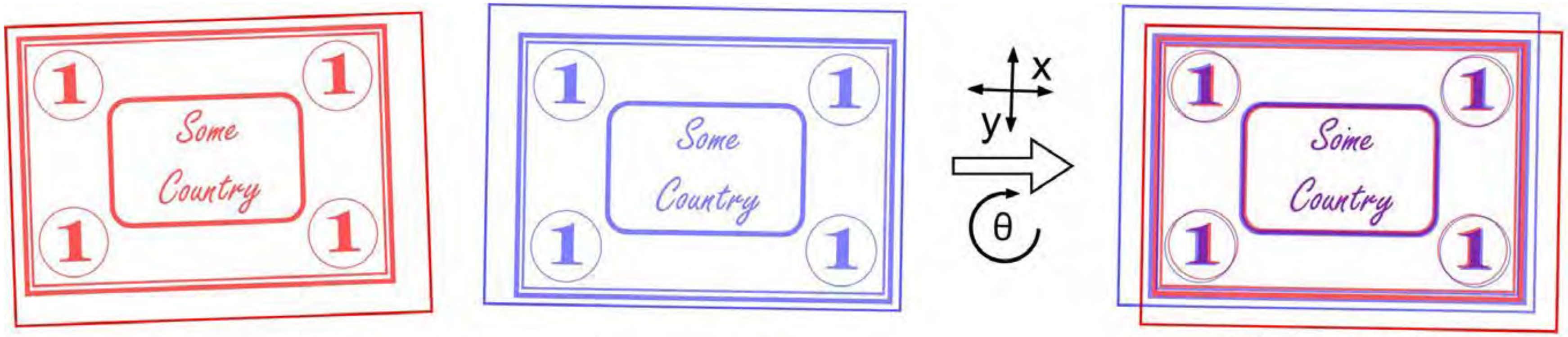
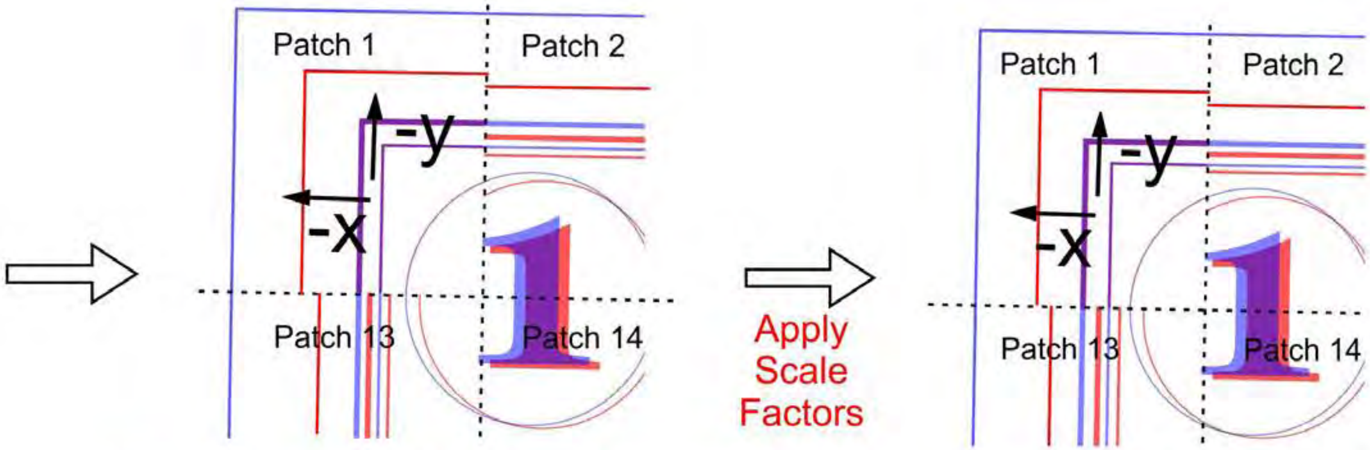


Image 1

Image 2

Align designs
(Average overall alignment)



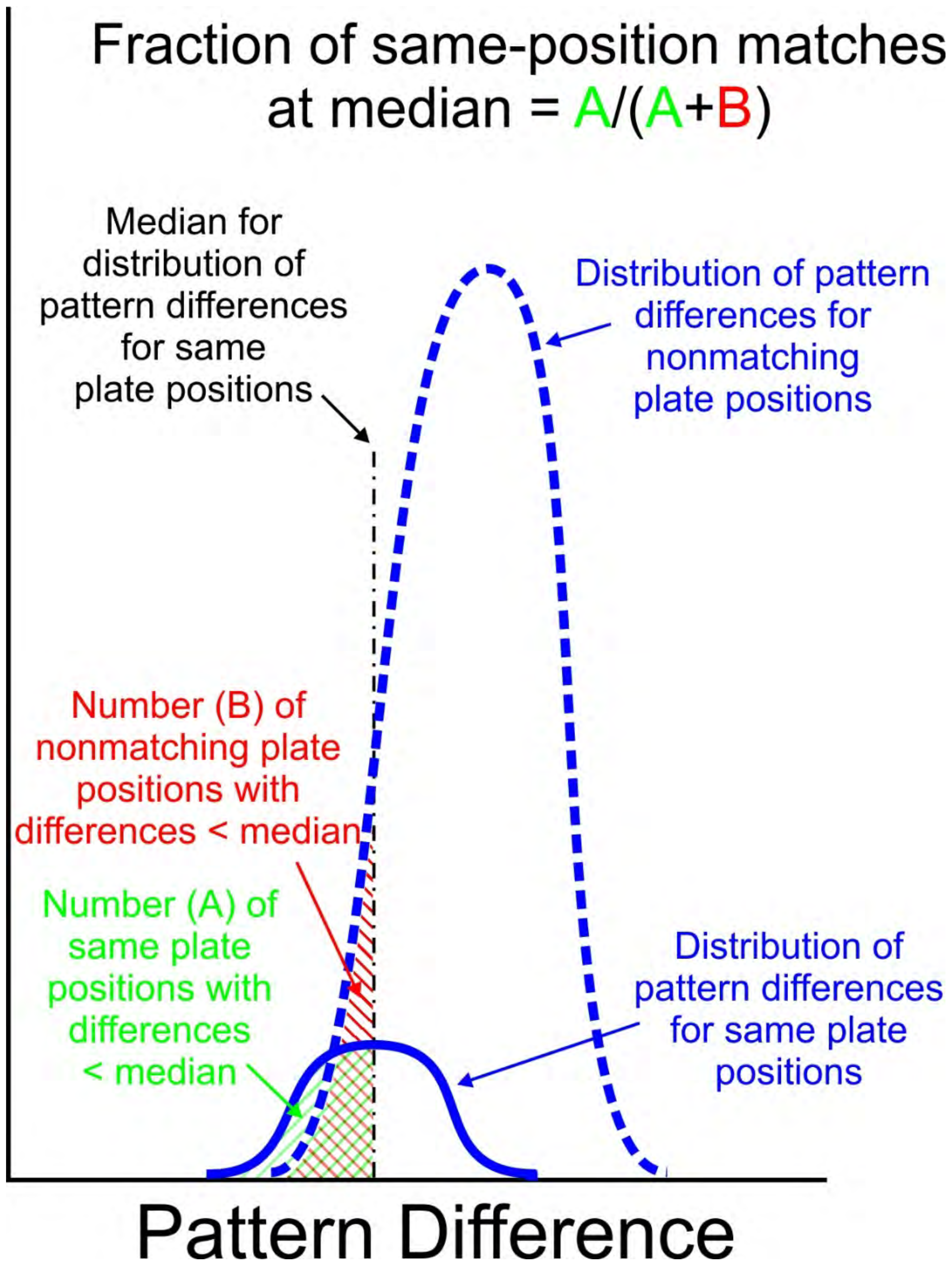
Fine alignment of the 4 corner patches in the overlay for scaling factors based on corner positions (Patch 1 is shown adjusted)

Fine alignment of each patch of the overlay (Patch 1 is shown adjusted)

(is fitting to the corners really better than fits to the sides?)

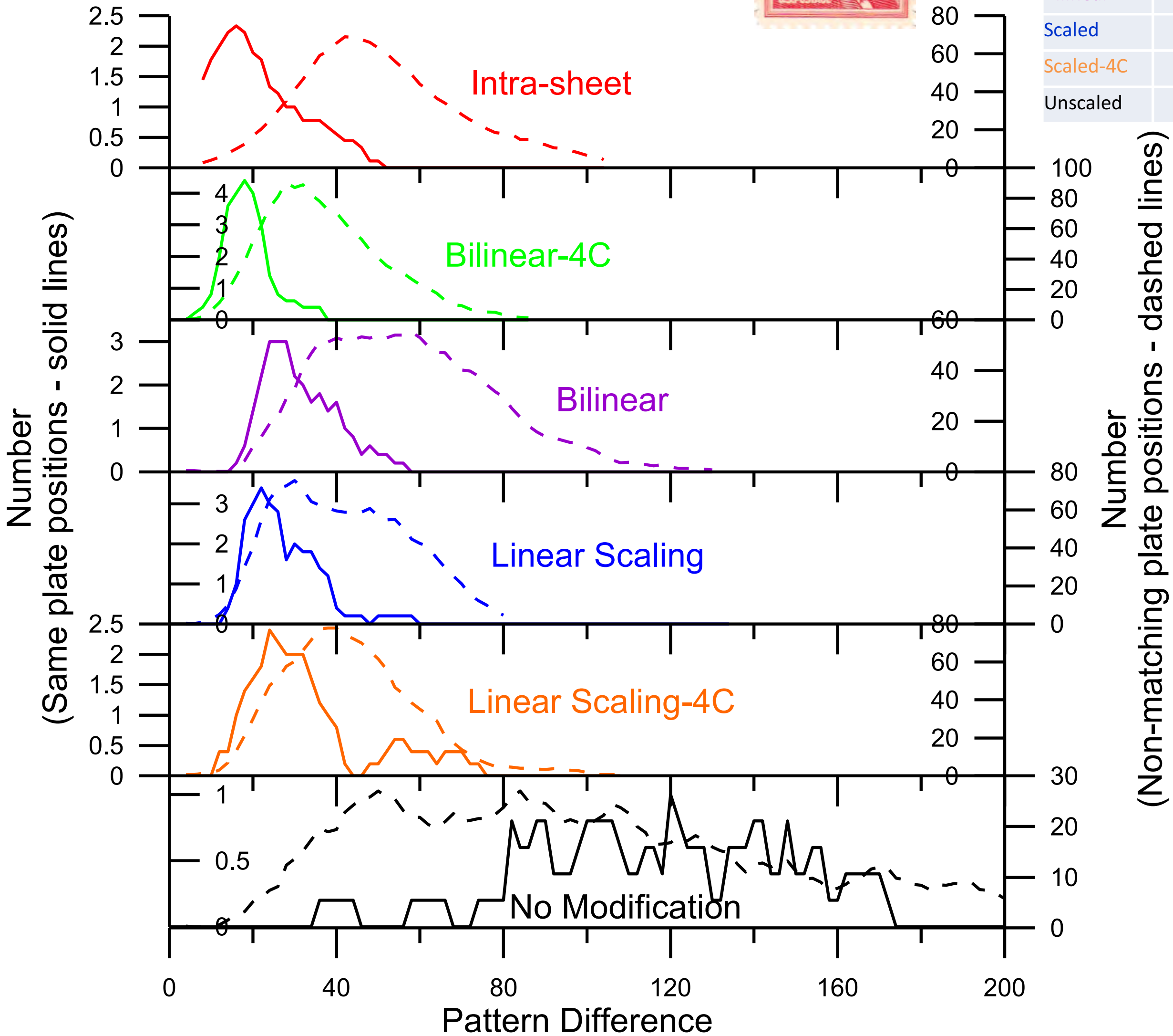
Comparing Performance

- Use sets of stamp images from the same plate positions
- Calculate how closely all of the distortion patterns match each other regardless of plate position
  - Measure the matching “error” (smaller = less difference = better)
- Compare the distributions of matching errors for matching plate positions with non-matching plate positions
  - *Ideally, the matching plate positions will have small matching errors*
- **Best performance will be small errors for matching positions and larger errors for non-matching positions**


Fraction of same-position matches
at median = A/(A+B)
Median for
distribution of
pattern differences
for same
plate positions
Distribution of pattern
differences for
nonmatching
plate positions
Number (B) of
nonmatching plate
positions with
differences < median
Number (A) of
same plate
positions with
differences
< median
Distribution of
pattern differences
for same plate
positions
Pattern Difference

1953 U.S. ½ c. Franklin
Plate UL26003, Dry printed

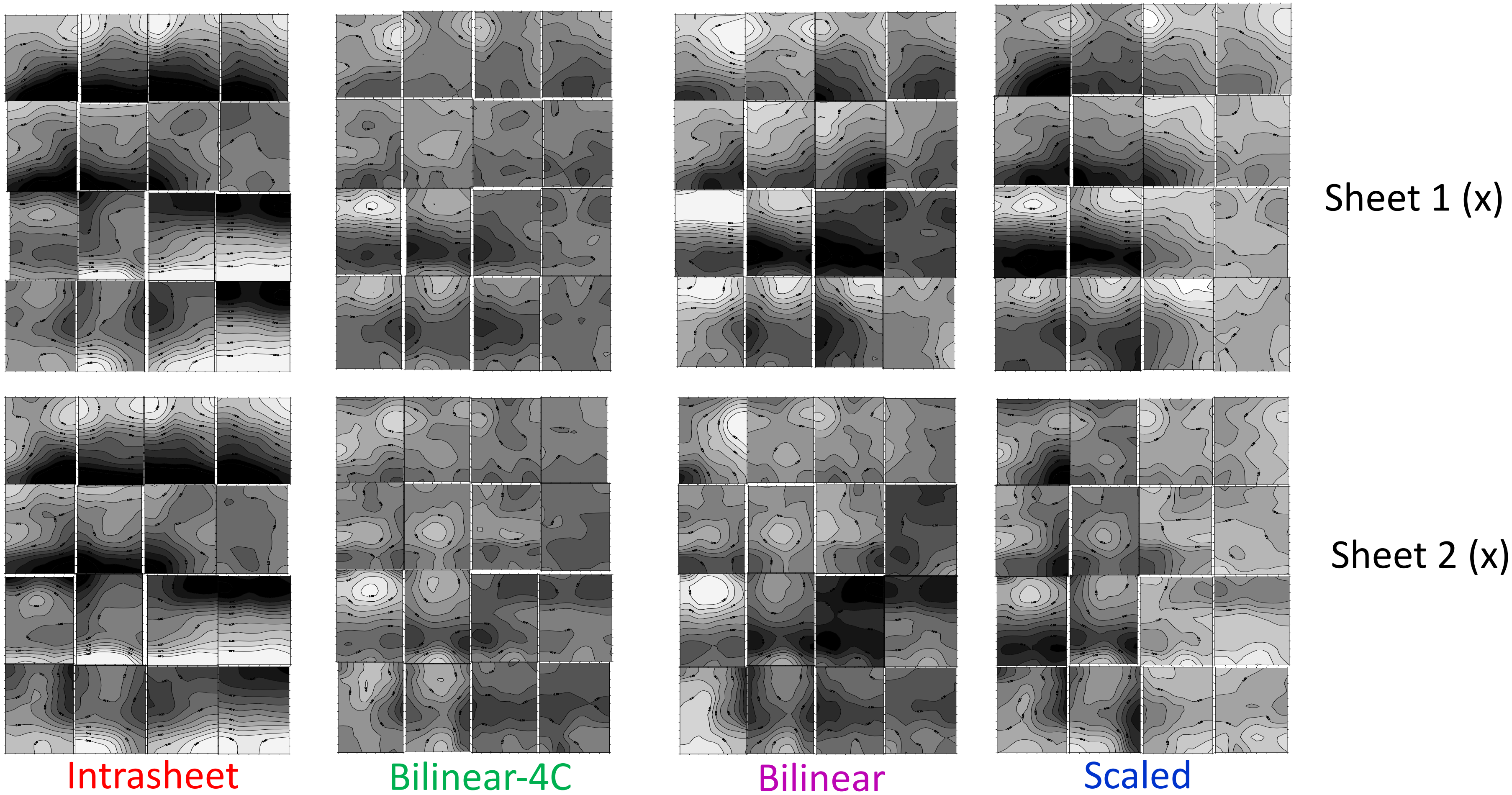
	Median Same Position	Range (10%-90%)	% Matching A/(A+B)	Median Nonmatching
Intrasheet	17	27	34.4	49
Bilinear-4C	17	13	15.5	35
Bilinear	28	20	13.3	54
Scaled	23	16	7.4	40
Scaled-4C	28	29	4.8	41
Unscaled	116	74	1.4	92



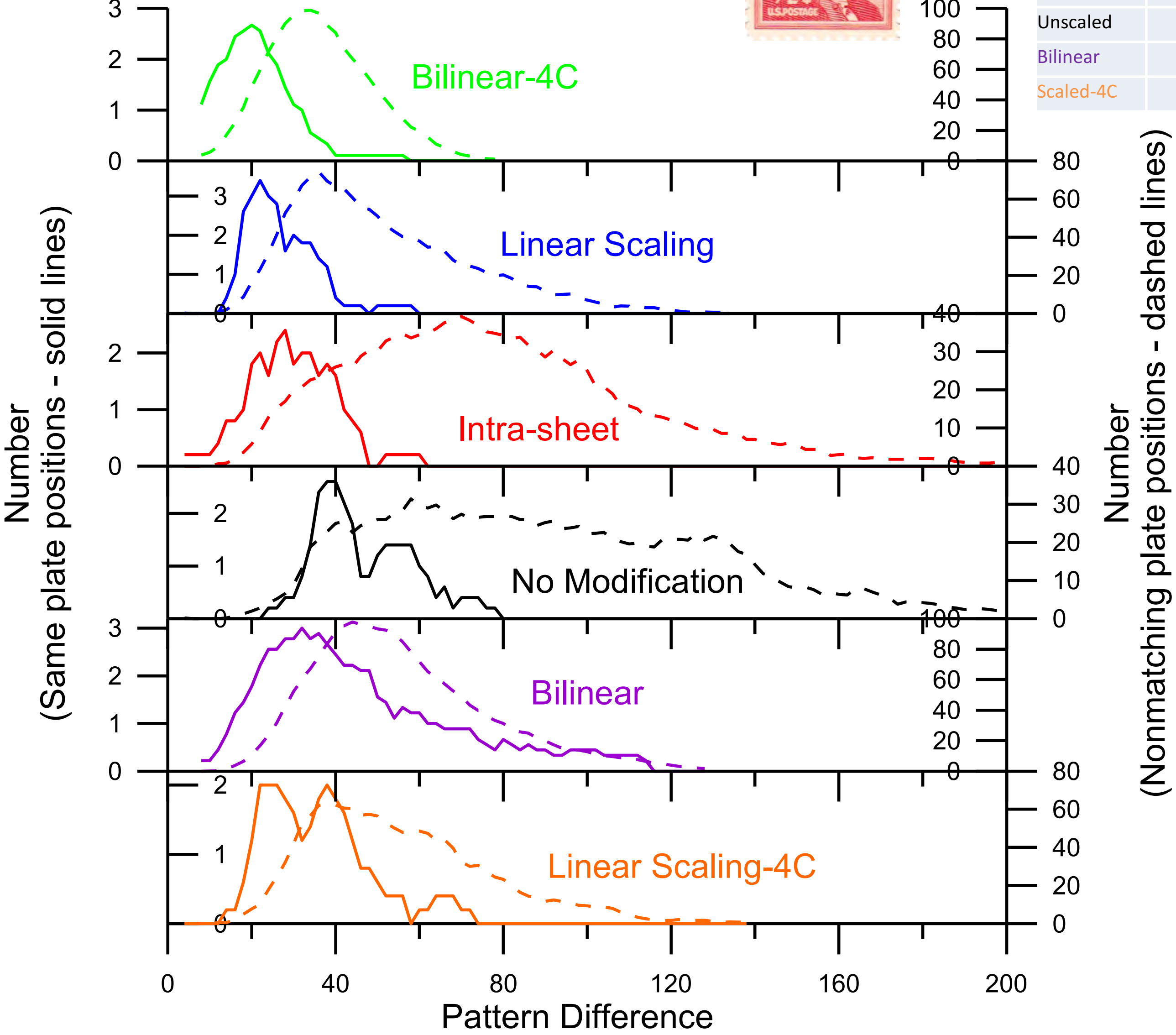
Bilinear methods only half as good as Intra-sheet comparison!

1953 U.S. ½ c. Franklin
Plate UL26003, Dry printed

	Median Matching	Range (10%-80%)	% Matching	Median Nonmatching
Intrasheet	17	27	34.4	49
Bilinear-4C	17	13	15.5	35
Bilinear	28	20	13.3	54
Scaled	23	16	7.4	40
Scaled-4C	28	29	4.8	41
Unscaled	116	74	1.4	92



1953 U.S. ½ c. Franklin
Plate LL25263, Wet printed

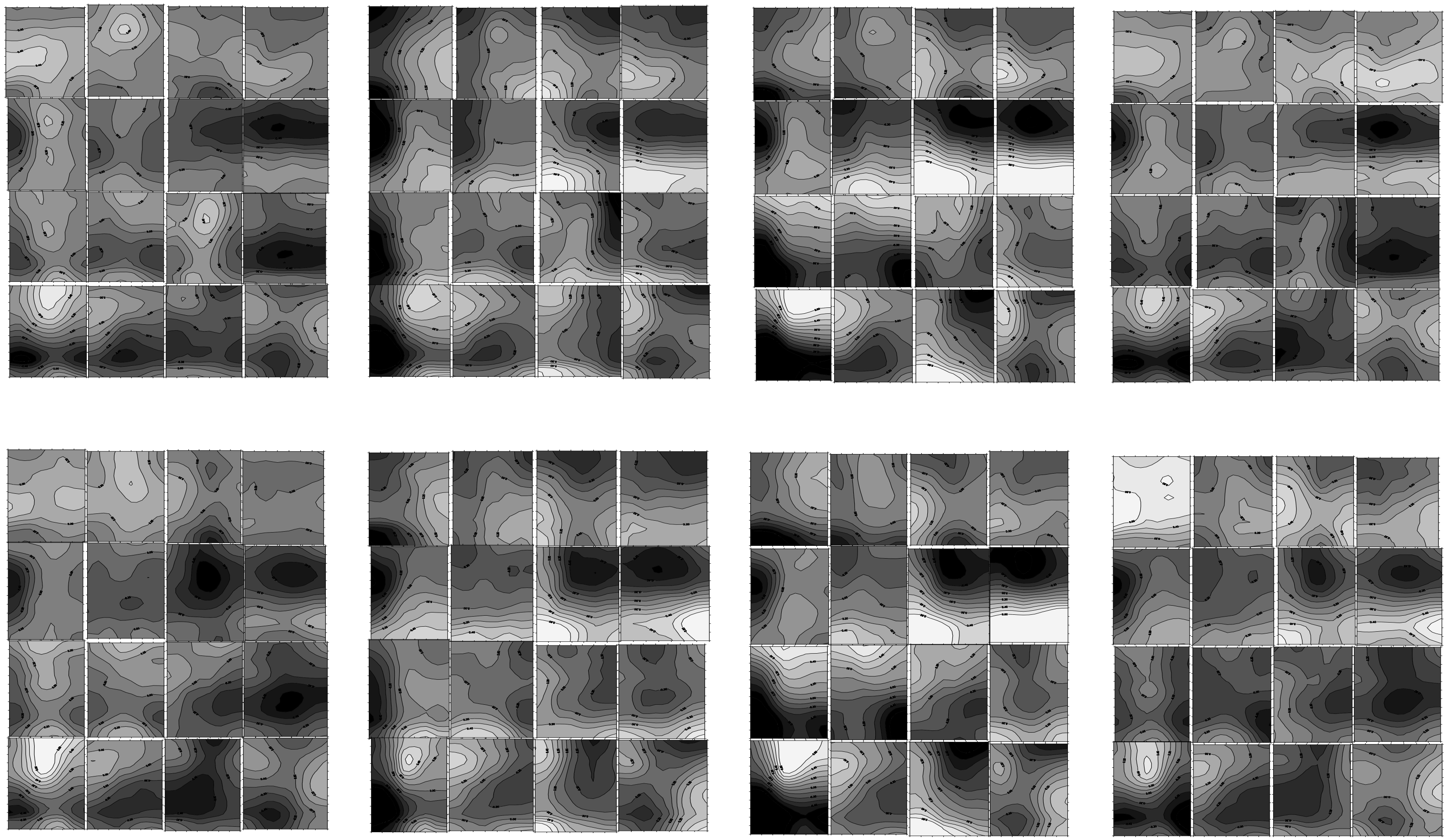


	Median Same Position	Range (10%-90%)	% Matching A/(A+B)	Median Nonmatching
Bilinear-4C	18	16	21.9	34
Scaled	23	14	17.9	45
Intrasheet	29	23	16	73
Unscaled	41	26	8.9	87
Bilinear	39	60	5.8	43
Scaled-4C	34	29	5.3	51

Bilinear-4C and Scaled both do better than Intra-sheet comparison!

1953 U.S. ½ c. Franklin
Plate LL25263, Wet printed

	Median Matching	Range (10%-90%)	% Matching	Median Nonmatching
Bilinear-4C	18	16	21.9	34
Scaled	23	14	17.9	45
Intrasheet	29	23	16	73
Unscaled	41	26	8.9	87
Bilinear	39	60	5.8	43
Scaled-4C	34	29	5.3	51



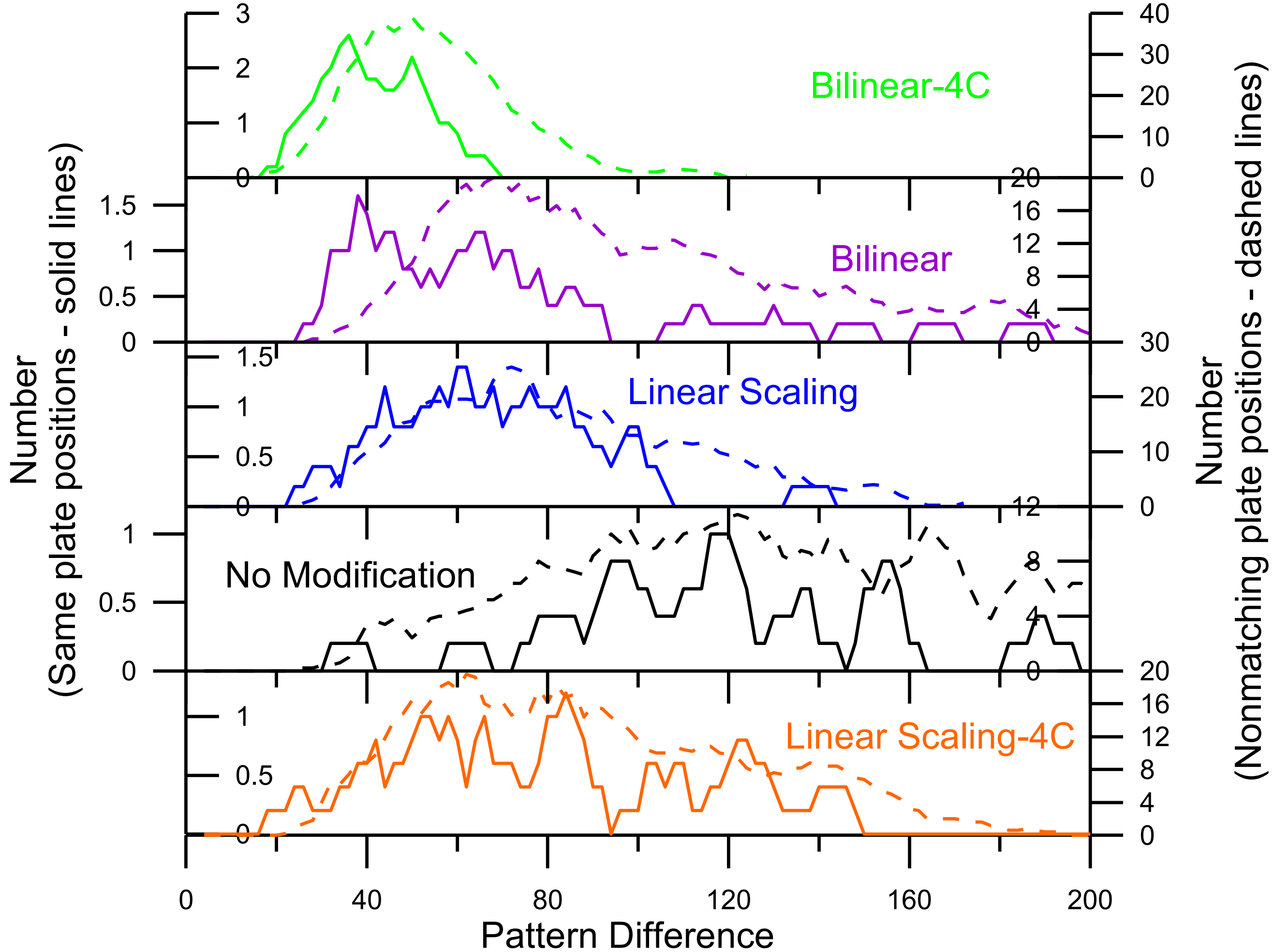
Sheet 1 (x)

Sheet 2 (x)

Bilinear-4C Scaled Intra-sheet Bilinear

US Proprietary revenue 1/8 c. of 1898 P/N 7972 (P/N singles, strips, and blocks)

	Median Same Position	Range (10%-90%)	% Matching A/(A+B)	Median Nonmatching
Bilinear-4C	38	29	11.1	52
Bilinear	62	99	10.6	134
Scaled	64	56	6.7	77
Unscaled	124	180	5.2	142
Scaled-4C	78	106	4.7	83



Bilinear methods perform best

Application: Matching Minor Re-Entries

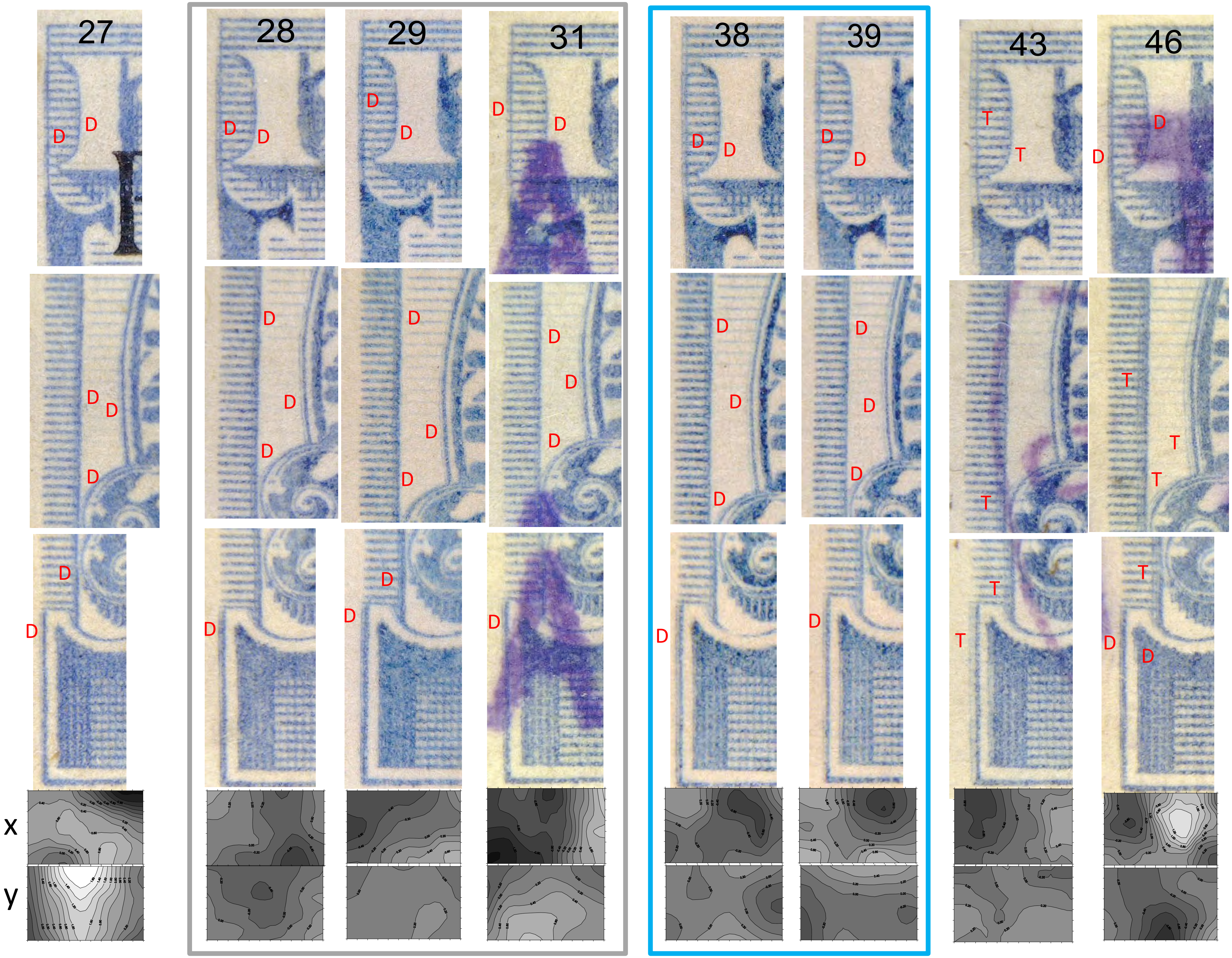
- There can be many minor re-entries in plate impressions that are very similar and a challenge to match
- Minor re-entries were first grouped according to similarities based on visual inspection by an expert for a large set of re-entries for the 1-7/8 cent U.S. Proprietary revenue stamp of 1898
- The Bilinear-4C analysis was used to profile the relative distortion patterns for this set of stamps
- All possible matches were scored, and low error scores were used to challenge the initial sorting
- More than half of the original sorting was revised after further study

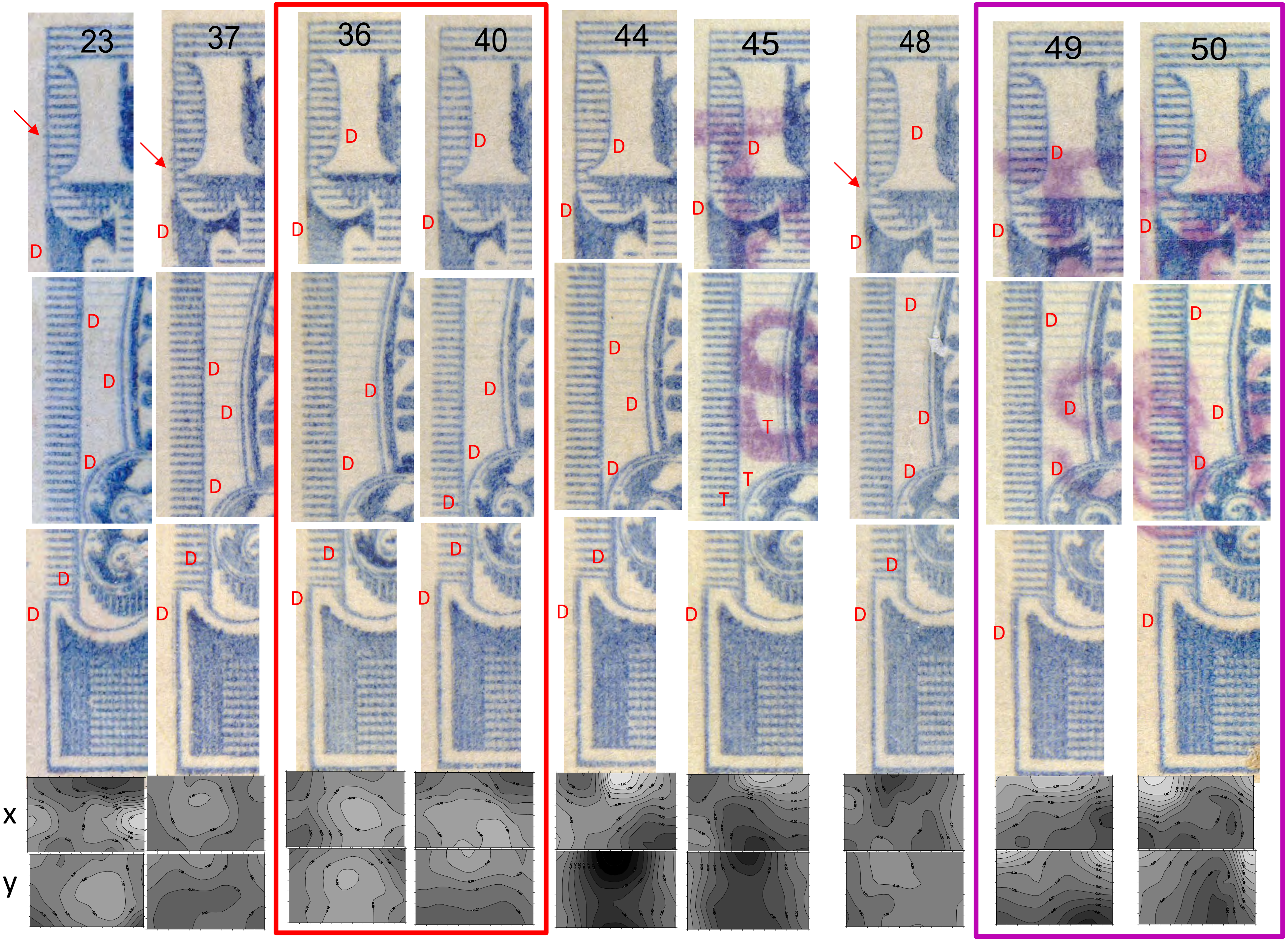
Matching Error Scores for All Possible Combinations

(stamps in the set numbered from #23-50)

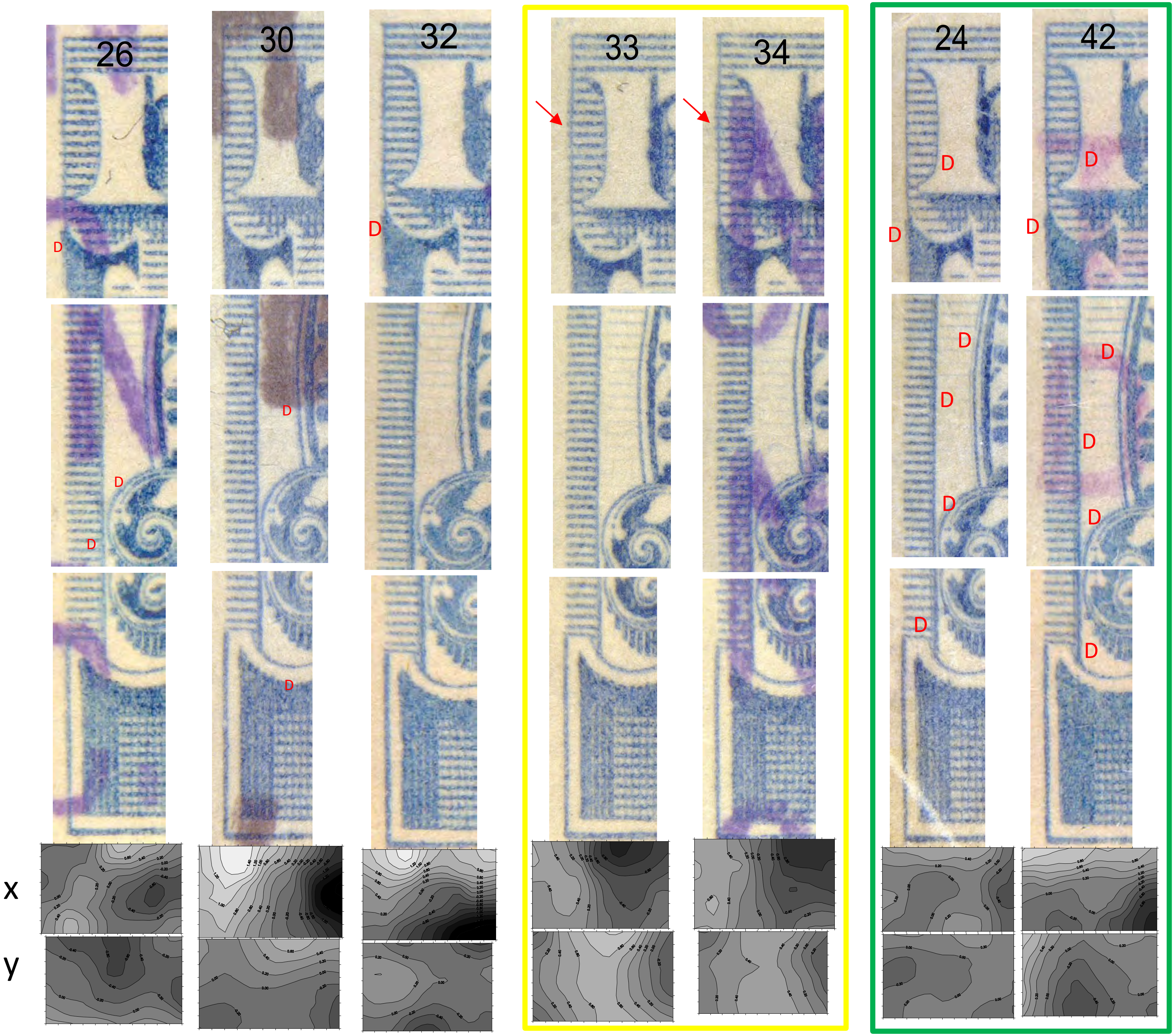
	23	24	26	27	28	29	30	31	32	33	34	36	37	38	39	40	42	43	44	45	46	48	49	50
23	0	67	99	82	88	62	114	91	81	76	71	61	68	69	65	59	90	72	133	125	102	55	88	113
24	67	0	60	110	58	60	86	113	57	86	75	69	40	50	49	63	60	68	100	85	73	53	48	88
26	99	60	0	149	59	80	107	121	68	98	86	92	61	65	70	89	68	79	81	67	81	77	46	78
27	82	110	149	0	141	117	141	143	127	84	93	82	112	120	115	84	146	132	187	185	154	115	139	177
28	88	58	59	141	0	73	108	117	49	95	87	98	51	55	62	79	60	79	80	59	77	59	58	67
29	62	60	80	117	73	0	131	64	61	93	87	61	67	55	47	72	57	34	132	105	83	41	57	78
30	114	86	107	141	108	131	0	181	111	103	87	130	84	101	106	90	131	140	130	137	138	109	121	155
31	91	113	121	143	117	64	181	0	90	113	113	85	117	92	87	129	107	57	177	132	126	80	98	104
32	81	57	68	127	49	61	111	90	0	86	78	66	58	56	65	84	71	54	104	79	85	51	59	84
33	76	86	98	84	95	93	103	113	86	0	29	84	90	60	69	87	127	102	152	142	140	78	112	138
34	71	75	86	93	87	87	87	113	78	29	0	80	84	54	66	84	119	96	141	134	133	76	103	135
36	61	69	92	82	98	61	130	85	66	84	80	0	67	79	78	63	82	61	135	124	88	67	74	114
37	68	40	61	112	51	67	84	117	58	90	84	67	0	54	53	49	53	71	87	80	73	52	53	81
38	69	50	65	120	55	55	101	92	56	60	54	79	54	0	28	82	79	62	123	94	102	46	62	88
39	65	49	70	115	62	47	106	87	65	69	66	78	53	28	0	68	71	61	127	95	94	42	56	82
40	59	63	89	84	79	72	90	129	84	87	84	63	49	82	68	0	76	91	115	112	87	65	85	108
42	90	60	68	146	60	57	131	107	71	127	119	82	53	79	71	76	0	62	87	60	56	70	45	55
43	72	68	79	132	79	34	140	57	54	102	96	61	71	62	61	91	62	0	130	97	81	48	54	72
44	133	100	81	187	80	132	130	177	104	152	141	135	87	123	127	115	87	130	0	54	88	117	87	90
45	125	85	67	185	59	105	137	132	79	142	134	124	80	94	95	112	60	97	54	0	77	93	64	64
46	102	73	81	154	77	83	138	126	85	140	133	88	73	102	94	87	56	81	88	77	0	87	71	77
48	55	53	77	115	59	41	109	80	51	78	76	67	52	46	42	65	70	48	117	93	87	0	60	75
49	88	48	46	139	58	57	121	98	59	112	103	74	53	62	56	85	45	54	87	64	71	60	0	55
50	113	88	78	177	67	78	155	104	84	138	135	114	81	88	82	108	55	72	90	64	77	75	55	0

Stamps with visually matching re-entry features were color-coded.


27
28
29
31
38
39
43
46
x
y



23
37
36
40
44
45
48
49
50
D
T
x
y


26
30
32
33
34
24
42
D
x
y

Summary

- The measurement of relative distortions between plate impressions can be extended to include stamps from arbitrary plates, plate positions, and individual stamps
- Bilinear and Scaled methods can provide results equivalent to or better than Intra-sheet image comparison
- The Bilinear-4C method using a preliminary step of image fitting of the 4 corners of the design appears to provide the best results
- The method successfully screened a large set of minor re-entries to revise the analyses based on visual examination
- Potential tool to aid in distinguishing and determining plate positions