NPAC FM color halftoning for the Indigo press: Challenges and solutions

Jiayin Liu[1], Tal Frank[2], Yotam Ben-Shoshan[2], Robert Ulichney[3], and Jan Allebach[1];

[1]Purdue University (United States), [2]HP Inc. (Israel), and [3]HP Labs, HP Inc. (United States)

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PURDUE UNIVERSITY

Big Picture

- FM (Frequency modulation) halftoning (aperiodic and dispersed dots) is increasingly popular with traditional analog offset lithographic printing.
- There is a desire from customers in the commercial market to use this capability with high-end digital presses based on electrophotographic printing (EP) technologies.
- However, the inherent instability of the EP process challenges the achievement of satisfactory print quality with dispersed-dot, aperiodic halftoning.
- The direct binary search (DBS) algorithm is widely considered to represent the gold standard of dispersed-dot, aperiodic halftone image quality.
- We continue our previous efforts to adapt DBS to use with the Indigo liquid EP printing technology.

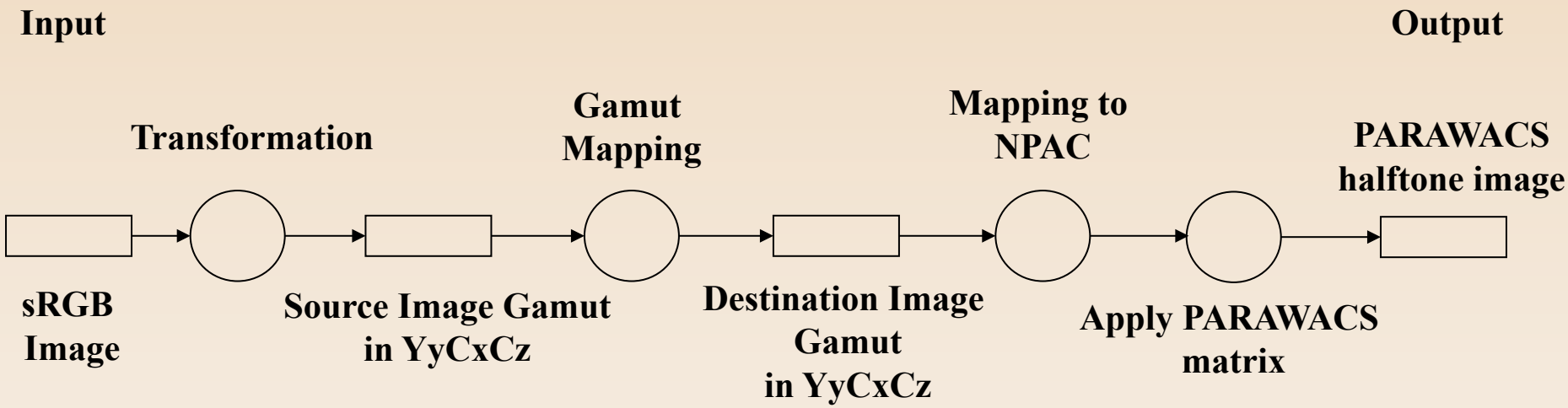
Background

- W. Xi, T. Frank, Y. Ben-Shoshan, R. Ulichney and J. P. Allebach, ”Color CLU- DBS halftoning based on neugebauer primary area coverage: Improving the breed” Electronic Imaging, 2018
- W. Jiang, W. Xi, U. Sarkar, R. Ulichney, and J. P. Allebach, Color halftoning based on Neugebauer Primary Area Coverage, Electronic Imaging, 2017
- J. Morovic, P. Morovic, M. G. Encrenaz, J. Lammens and Y. Richard, Color separation into neugebauer primary area coverage vectors U.S. Patent 8,213,055 B2, 2012.
- J. Morovic, P. Morovic and J. Arnabat ”HANS: Controlling ink-jet print at- tributes via neugebauer primary area coverages” IEEE Transations on Image Processing, VOL. 21, NO. 2, 2012 pp.688-696
- P. Morovic, J. Morovic, J. Gondek, M. Gaubatz, and R. Ulichney, PARAWACS Color halftoning with a single selector matrix Color and Imaging Conference vol. 2016, no.1 Society for Imaging Science and Technology, 2016 pp.41-46.
- P. Morovic, J. Morovic, J. Gondek, M. Gaubatz, and R. Ulichney, ”Direct Pattern Control Halftoning of Neugebauer Primaries” IEEE Transations on Image Processing, VOL. 26, NO. 9, 2017

What we will specifically talk about today?

- Inverse Mapping based on actual prints.
- PARAWACS Halftoning.

Block Diagram

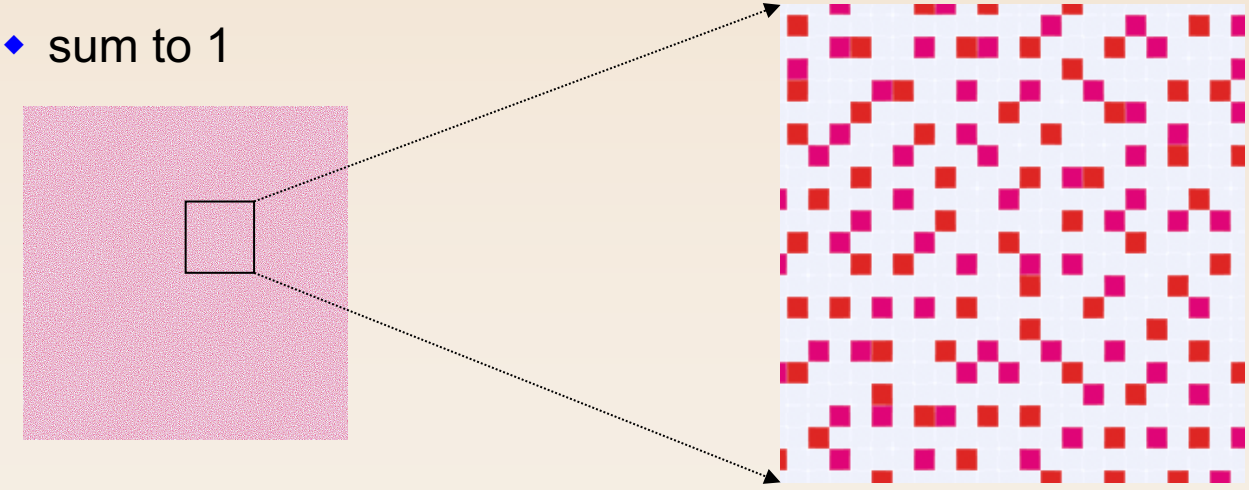


HP Indigo's Enhanced Productivity Mode (EPM)

- EPM can provide faster throughput and achieve a productivity boost by eliminating black ink from the production process: using only three colorants rather than four colorants, Cyan (C), Magenta (M) and Yellow (Y).
- This mode makes total of 8 colors in the printing process, including
  - White (W), Cyan (C), Magenta (M) and Yellow (Y), Blue (CM), Red (MY), Green(CY) and Black (CMY).
  - Each color above is a Neugebauer Primary (NP).

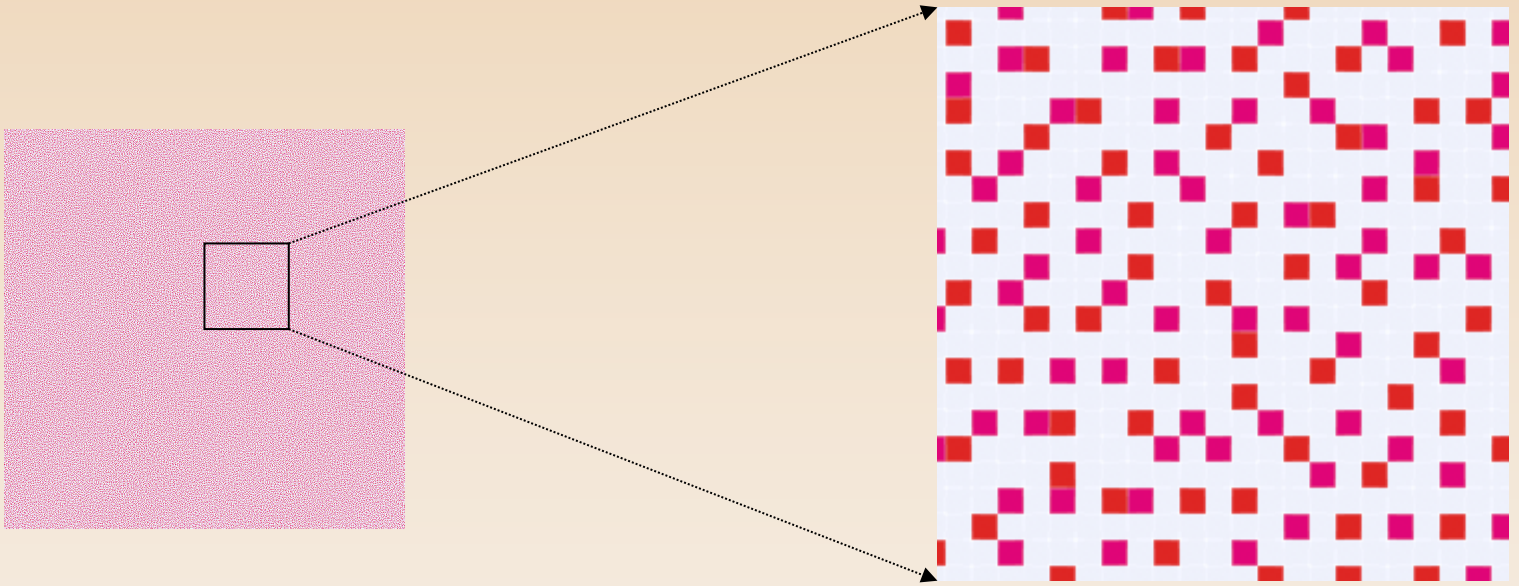
NPAC

- NPAC stands for Neugebauer Primary area coverage.
- A vector: relative area coverages of NPs over some unit area / probability of encountering given NPs.
- For example, [W, M, MY, CMY]=[0.75, 0.125, 0.125, 0]
  - 75% of some local area left black
  - 12.5% covered by the magenta colorant
  - 12.5% contain combination of magenta and yellow
  - 0% contain combination of cyan, magenta and yellow
  - sum to 1



Reference: P. Morovic, J. Morovic, J. Gondek, M. Gaubatz, and R. Ulichney, PARAWACS Color halftoning with a single selector matrix Color and Imaging Conference vol. 2016, no.1 Society for Imaging Science and Technology, 2016 pp.41-46.

The relation between NPAC and YyCxCz color space



Every NP shown here has a related YyCxCz value,
the average YyCxCz value over the whole patch is this patch's ideal YyCxCz value.
Ideally, when printed it will yield the desired YyCxCz value.

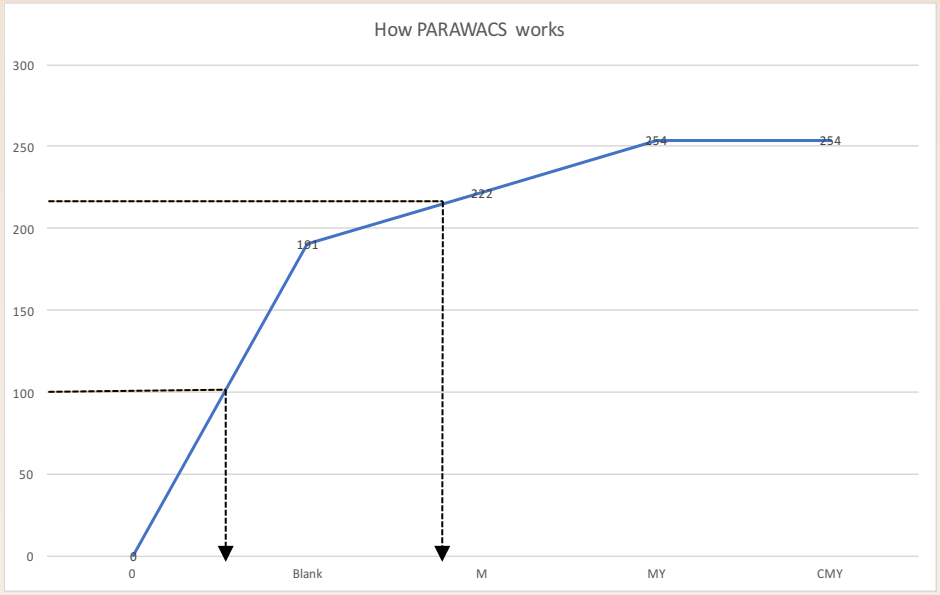
Parallel Random Weighted Area Coverage Selection (PARAWACS) Matrix

- It is a level by level designed matrix using monochrome DBS, each level tries to achieve homogeneous and uniform texture due to the virtue of DBS.
- In the selection matrix, each element is assigned a natural number ranging from 0 to the maximum level L= 254.

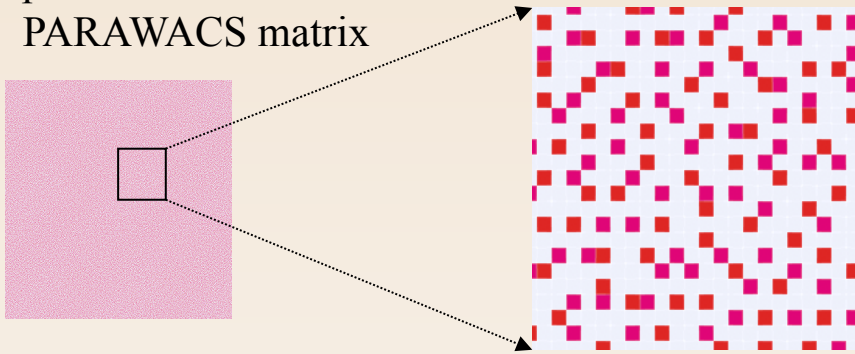
Reference: P. Morovic, J. Morovic, J. Gondek, M. Gaubatz, and R. Ulichney, PARAWACS Color halftoning with a single selector matrix Color and Imaging Conference vol. 2016, no.1 Society for Imaging Science and Technology, 2016 pp.41-46.
W. Jiang, W. Xi, U. Sarkar, R. Ulichney, and J. P. Allebach, Color halftoning based on Neugebauer Primary Area Coverage, Electronic Imaging,2017

How does PARAWACS matrix work with NPAC

- For any NPAC, find accumulated NPAC
  - [W, M, MY, CMY]=[0.75, 0.125, 0.125, 0]
  - Accumulated NPAC is [0.75, 0.875, 1,1]
  - Multiply accumulated NPAC by 254, [191, 222, 254, 254]



This patch was rendered from PARAWACS matrix



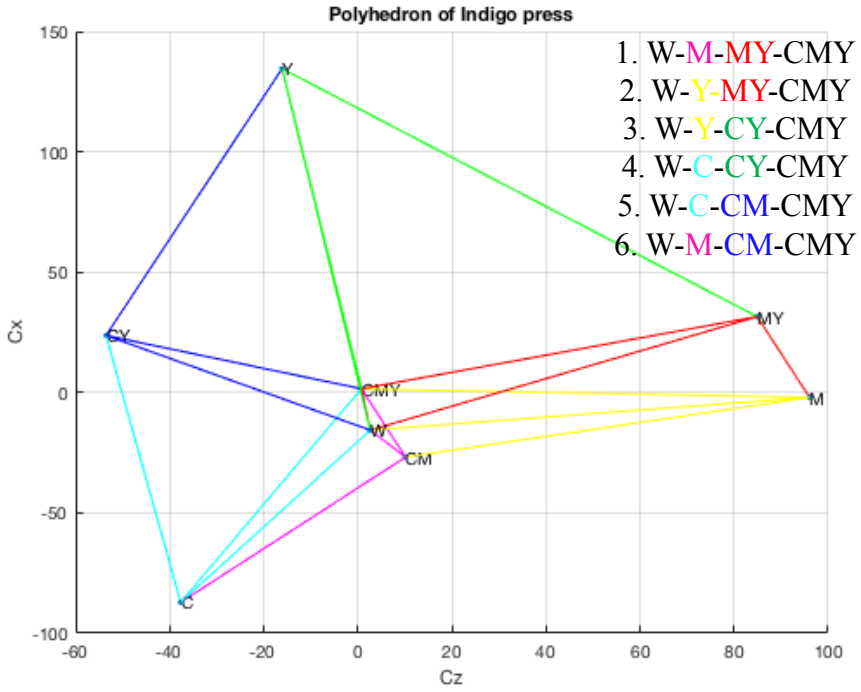
Reference: P. Morovic, J. Morovic, J. Gondek, M. Gaubatz, and R. Ulichney, PARAWACS Color halftoning with a single selector matrix Color and Imaging Conference vol. 2016, no.1 Society for Imaging Science and Technology, 2016 pp.41-46.

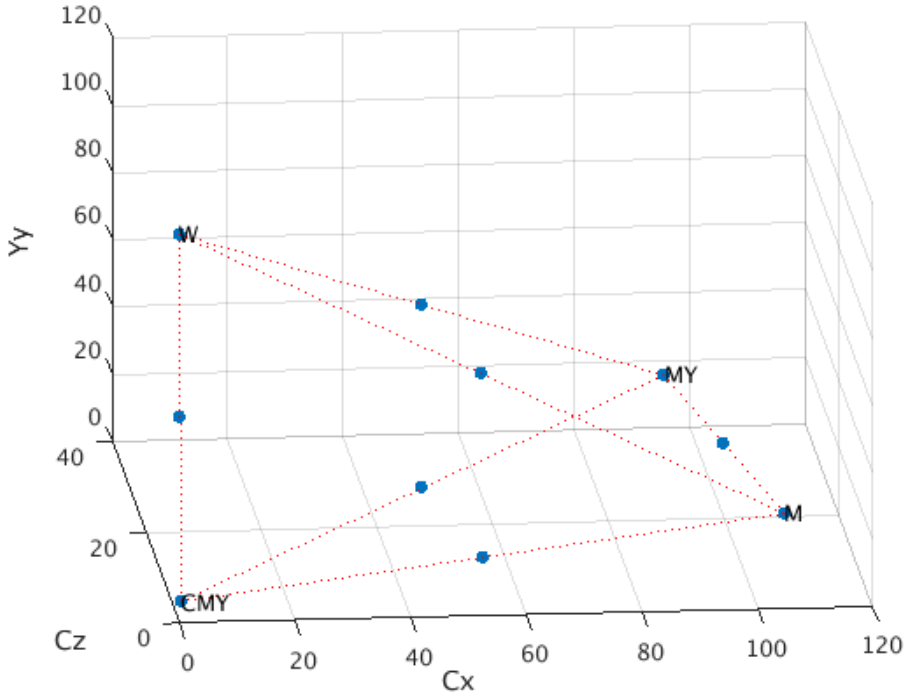
Inverse Mapping

- To develop the color management framework, we want to generate a mapping that given a YyCxCz value, will yield its NPAC value that when printed will yield the desired YyCxCz value.
- We generate inverse mapping by doing forward mapping first, which is given a particular NPAC, generate the halftone patch associated with it, measure its YyCxCz value and store it in the inverse mapping.
  - Forward Mapping
    - » Given an NPAC, find its YyCxCz value.
  - Inverse Mapping
    - » Given a YyCxCz value, calculate its predicted NPAC.

Inverse Mapping

- Tessellate YyCxCz color gamut in to six tetrahedra.
  - Treat W-CMY as neutral axis and it is included in every tetrahedron.
- Uniformly sample in every tetrahedron in the YyCxCz color space.
- The example shown on the right is $3\times3\times3$.

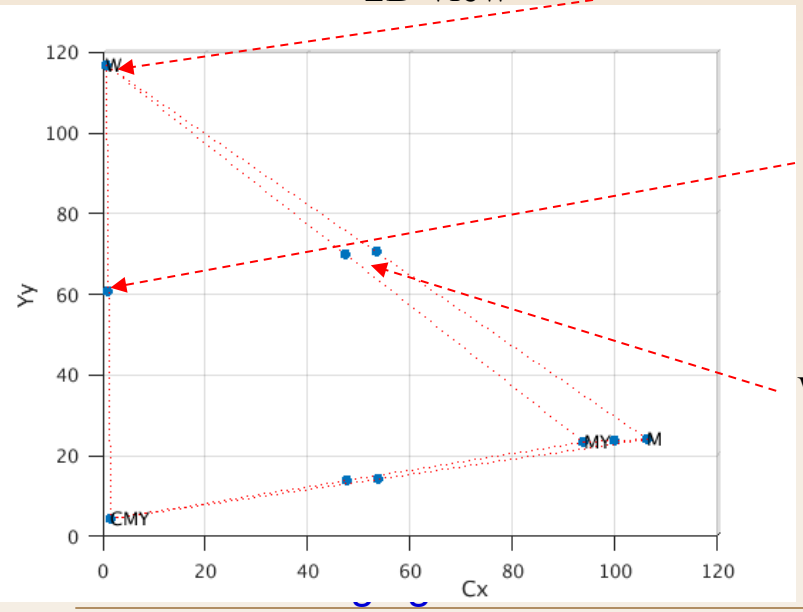




Inverse Mapping

- For any point that is inside printer gamut, use tetrahedral interpolation to find this point's NPAC from its four nearest neighbors (only three points shown below for 2D view) where each neighbor has an NPAC associated with it.

Uniformly sampled in W-M-MY-CMY tetrahedron 2D view

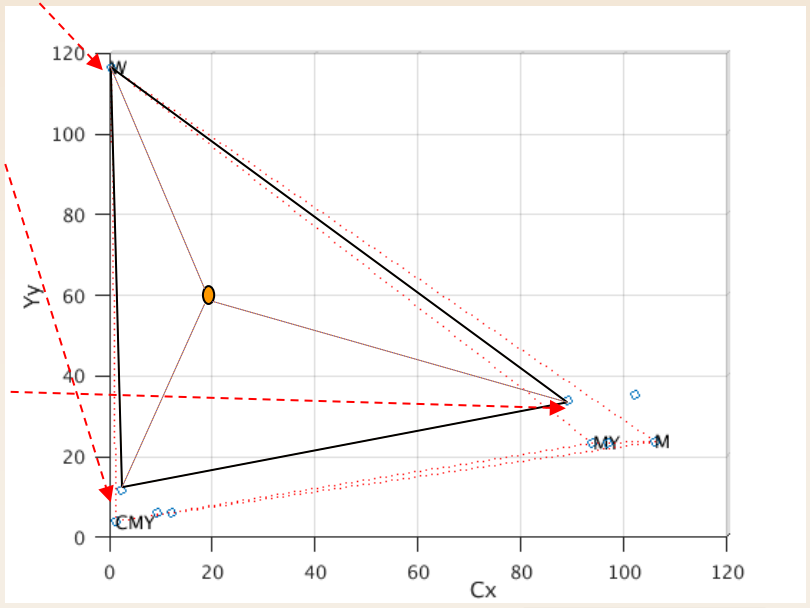


NPAC: W-M-MY-CMY: [1, 0, 0, 0]

NPAC: W-M-MY-CMY: [0.5, 0, 0, 0.5]

NPAC: W-M-MY-CMY: [0.5, 0, 0.5, 0]

Actual YyCxCz value plotted 2D view

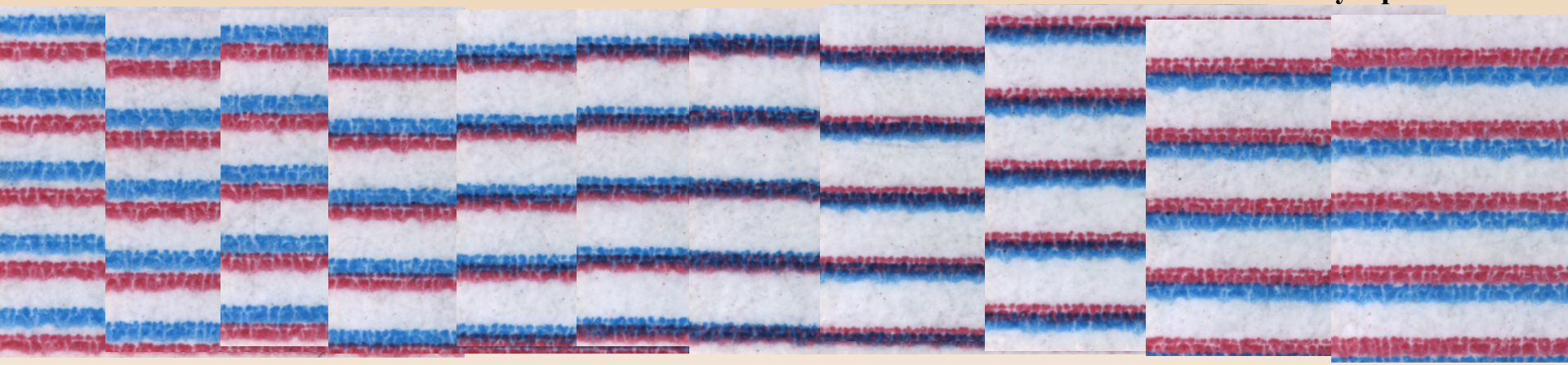


Print: Design Testpage

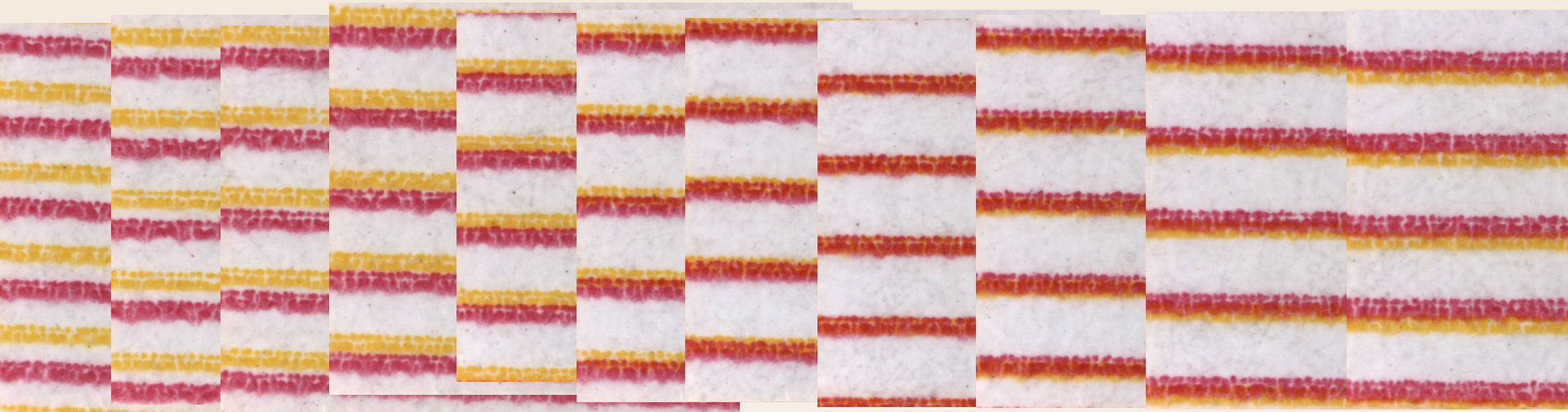
- Due to misregistration of the prints, we want to find how much a color plane is displaced.
- Add a series of test units, that each unit contains several horizontal lines. Except middle one, all others are shifted by various number of pixels from -5 to +5 pixels.
- Repeat for vertical misregistration.

Reference:W. Jang, M. Chen, J. Allebach and G. Chiu, Print Quality Test Page. Journal of imaging science and technology 2004

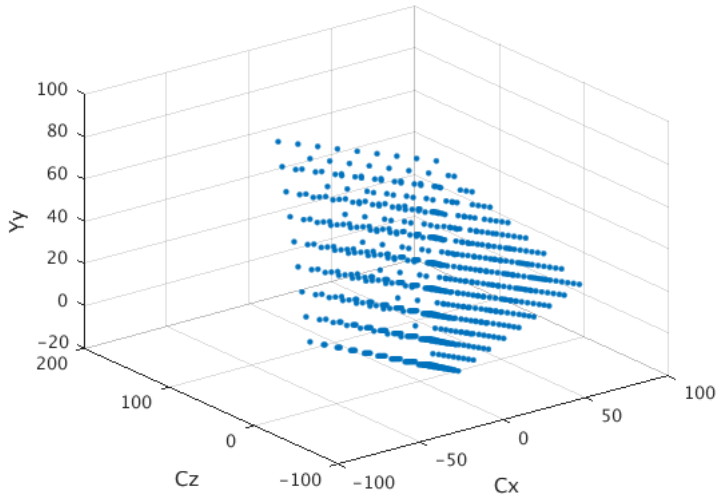
Cyan shifted down by 1.5 pixels
Yellow shifted down by 2 pixels

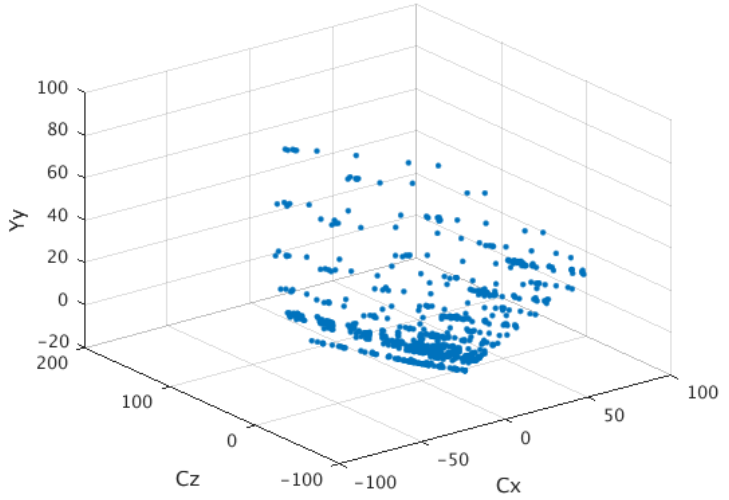


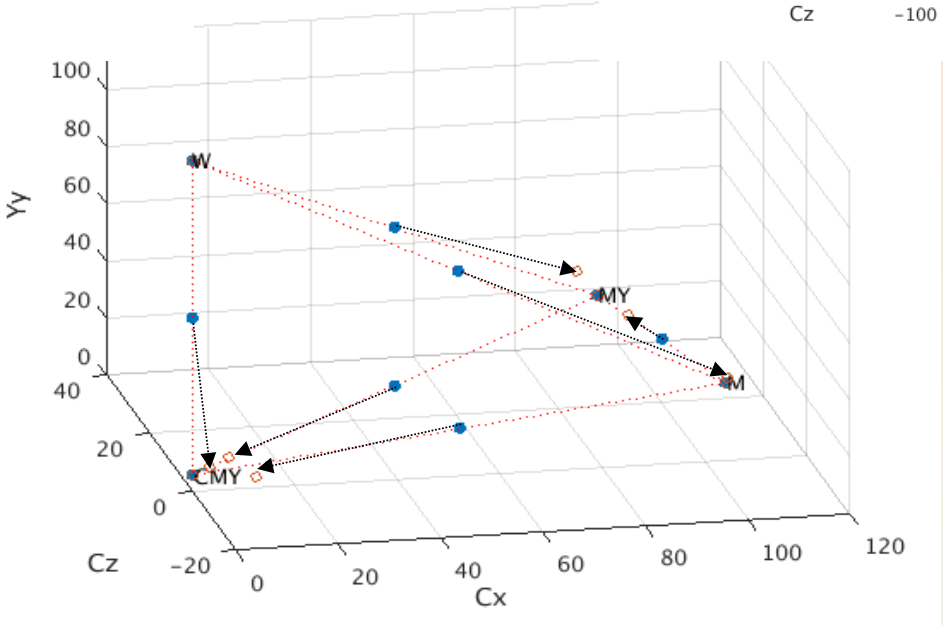
-5 -4 -3 -2 -1 0 1 2 3 4 5



Ideal and actual printer gamut







YyCxCz value are shifted due to color planes shift

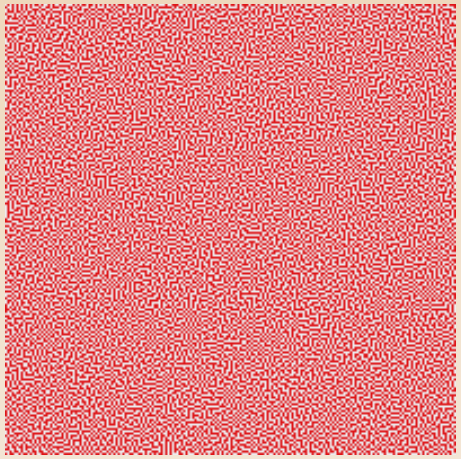
Target digital halftone image and Captured printed halftone image

100%W

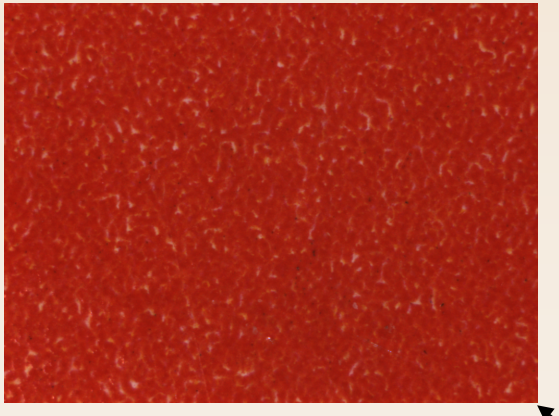
Target YyCxCz value
(116, 0, 0)

Measured YyCxCz value:
(116, 0, 0)

50%W 50%MY

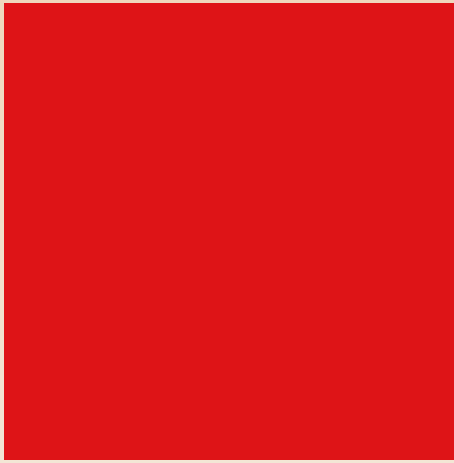


Target YyCxCz value
(69.61, 46.90, 17.32)



Measured YyCxCz value:
(33.71, 89.06, 33.26)

100%R

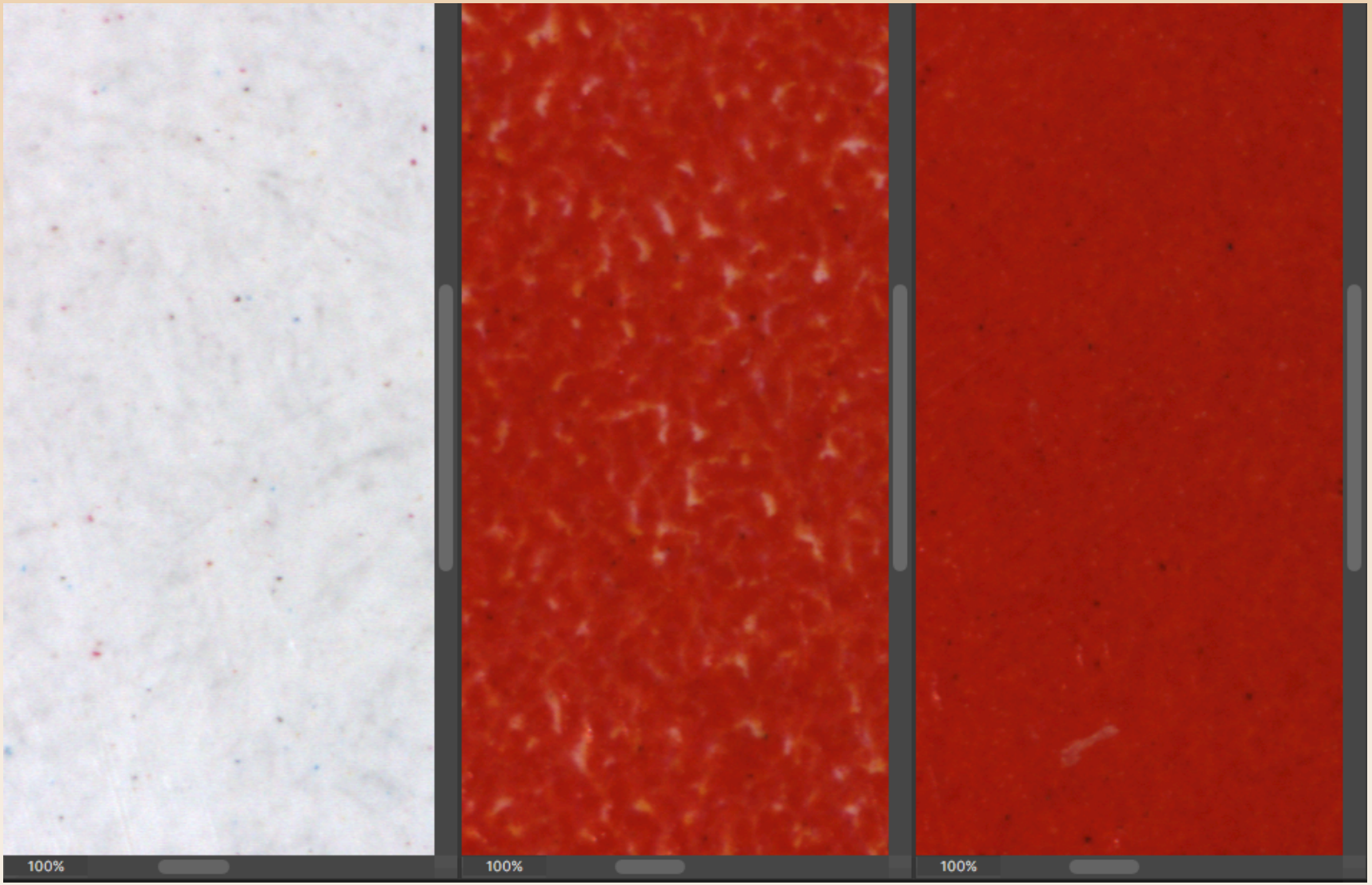


Target YyCxCz value
(23.22, 93.80, 34.65)

Measured YyCxCz value:
(23.22, 93.80, 34.65)

It should be 50% white pixels

From Photoshop

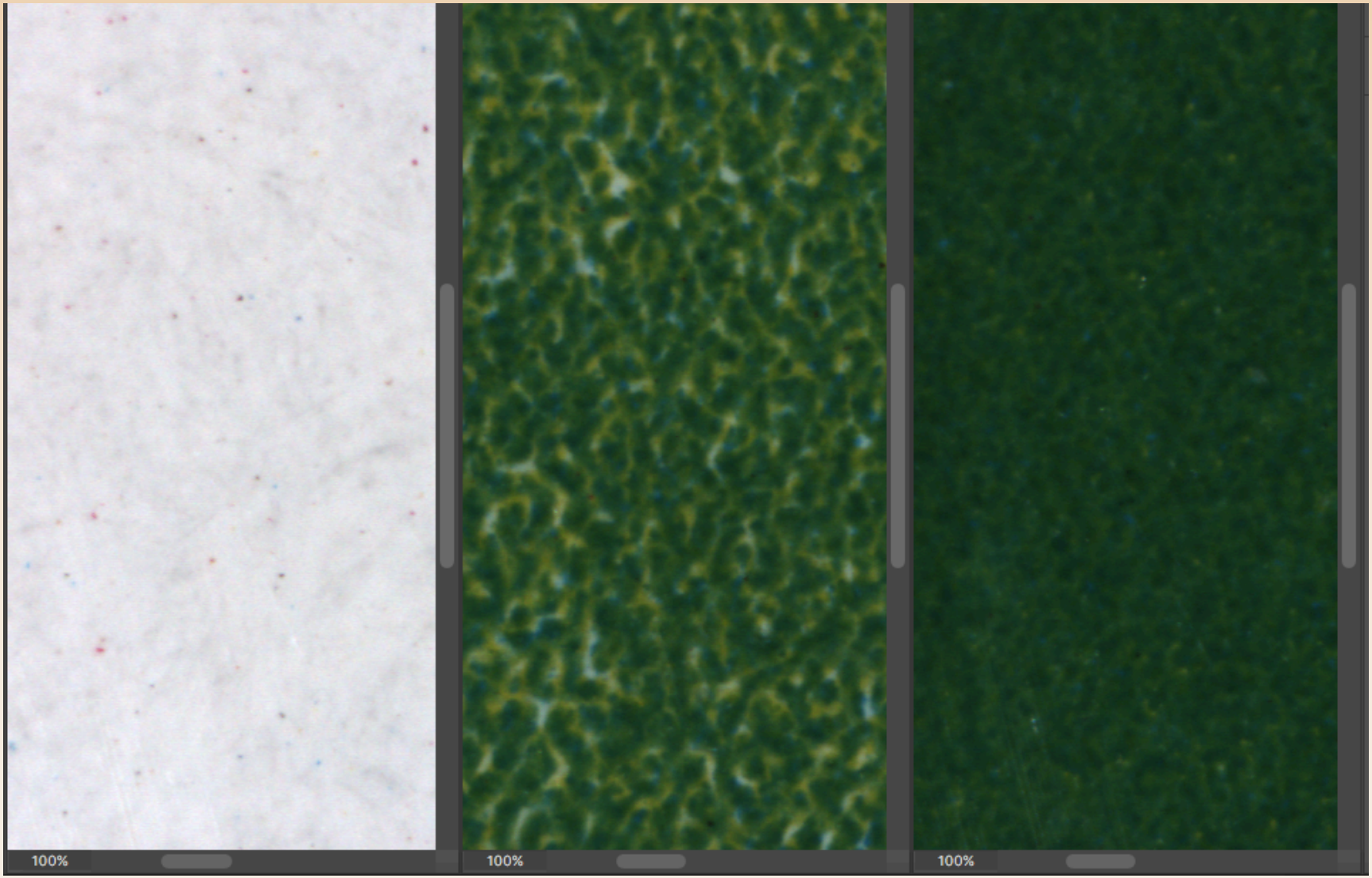


100% White

50% White and 50% Red

100% Red

From Photoshop

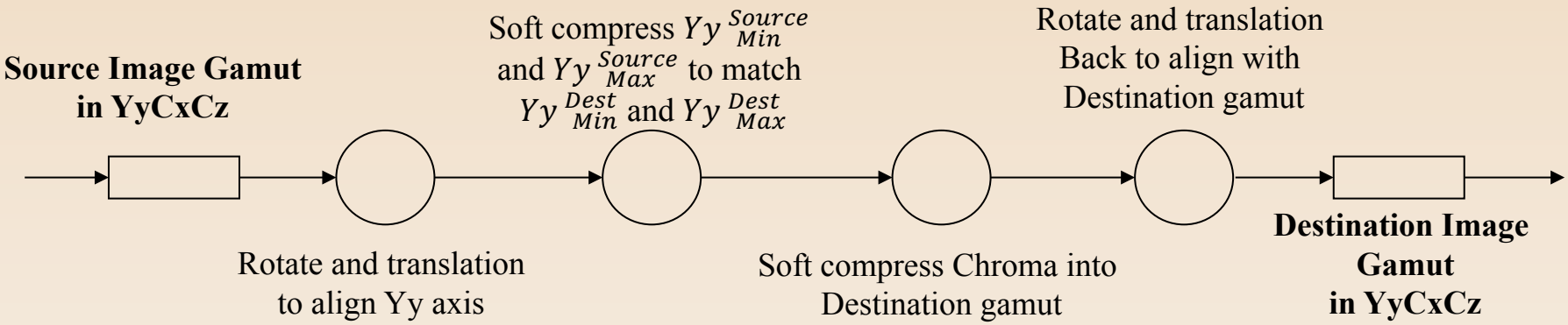


100% White

50% White
and 50% Green

100% Green

Gamut Mapping



Reference: R. S. Gentile, E. Walowit, and J. P. Allebach, "A Comparison of Techniques for Color Gamut Mismatch Compensation", Journal of Imaging Technology Volume 16, Number 5, October 1990

M. Wolski, J. P. Allebach and C. A. Bouman, "Gamut Mapping Squeezing the Most out of Your Color System", IS&T and SID's 2nd Color Imaging Conference: Color Science, System and Application (1994)-89

J. Morovic, Color Gamut Mapping Wiley, 2008.

W. Xi, T. Frank, Y. Ben-Shoshan, R. Ulichney and J. P. Allebach, "Color CLU- DBS halftoning based on neugebauer primary area coverage: Improving the breed" Electronic Imaging, 2018

Original Image

Image displayed only with
printer realizable pixels

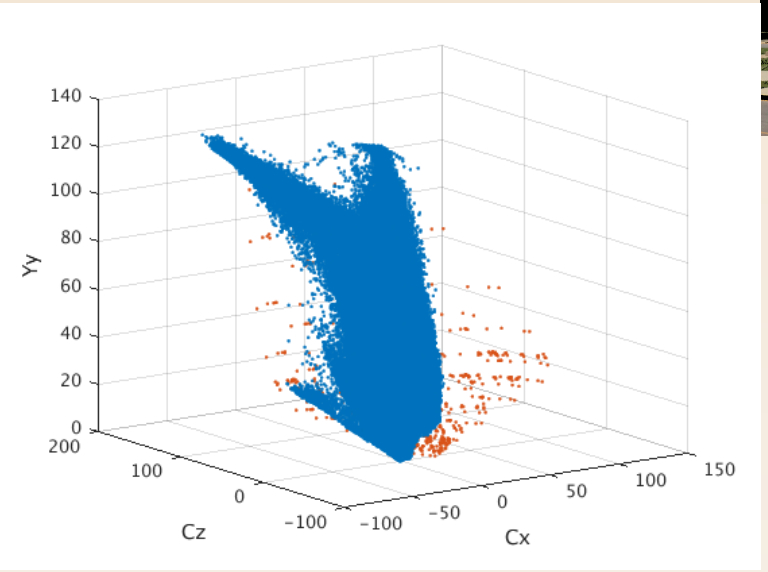


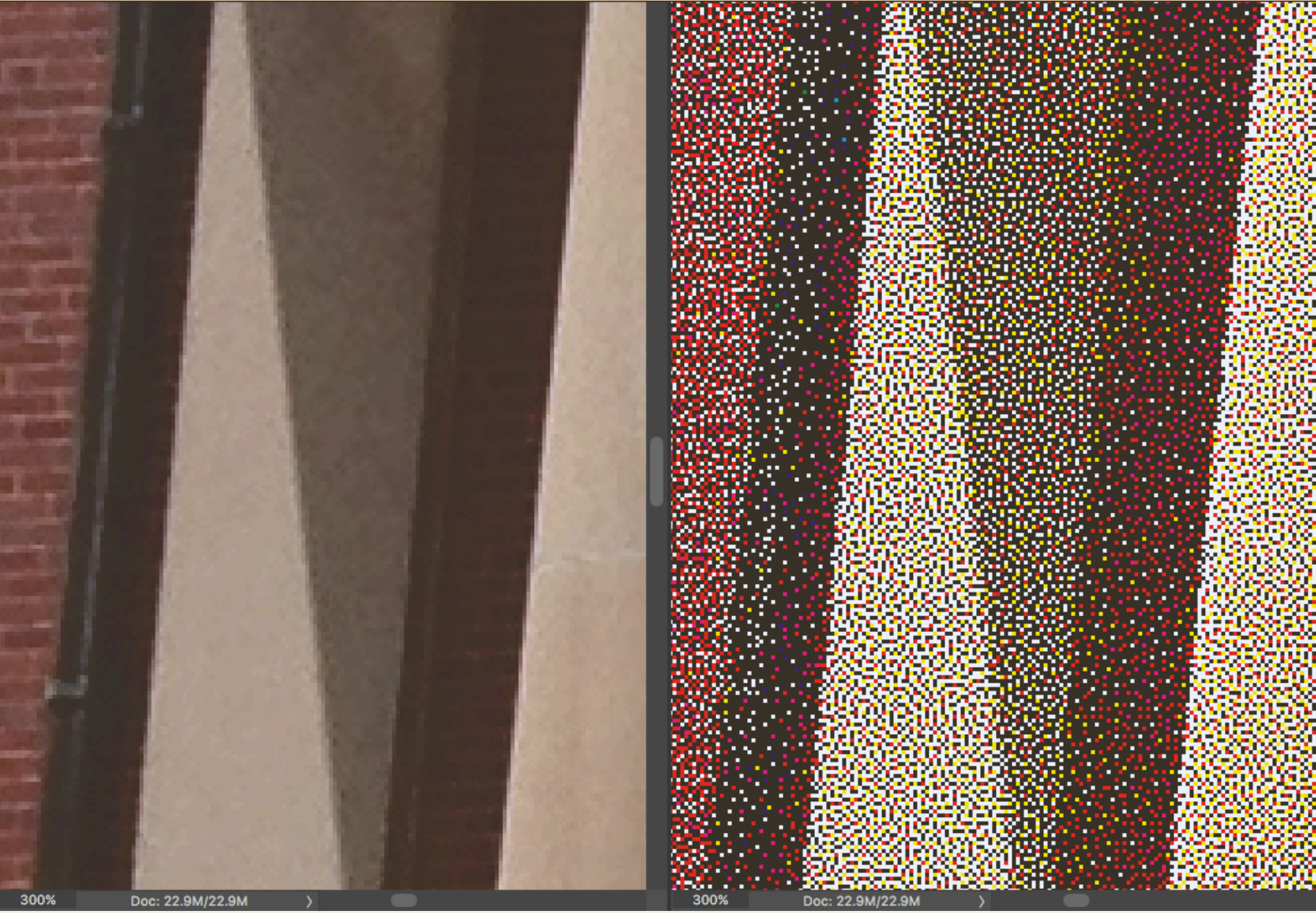
Image After Gamut Mapping

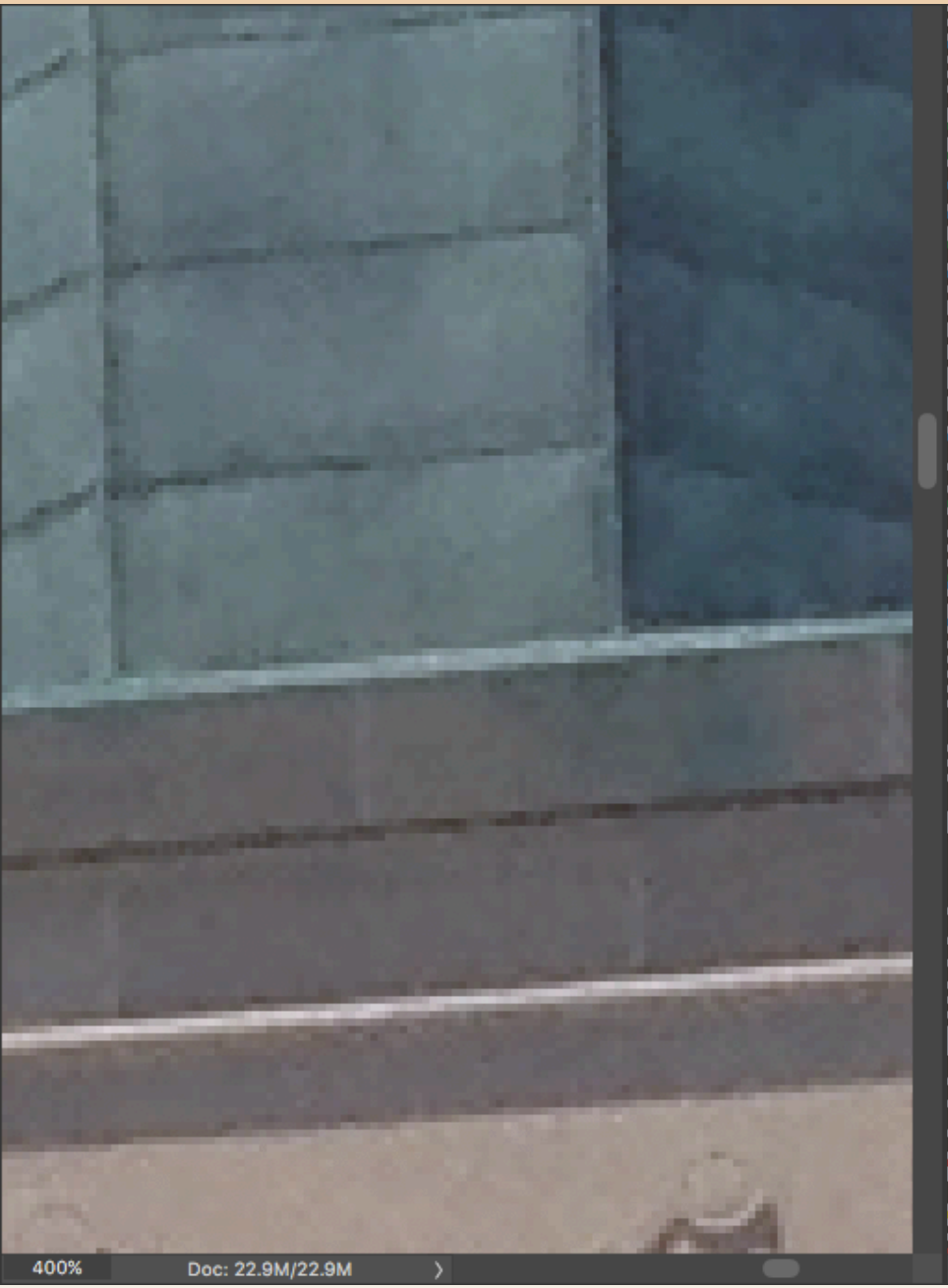
PARAWACS Halftone

- For every pixel in the image after gamut mapping, find four nearest neighbors in the inverse mapping and use tetrahedral interpolation and volume ratio to get its NPAC.
- Apply the PARAWACS selection matrix.

Continuous-tone Image after Gamut mapping

PARAWACS Halftone


300%
Doc: 22.9M/22.9M
300%
Doc: 22.9M/22.9M


400%
Doc: 22.9M/22.9M


400%
Doc: 22.9M/22.9M

Conclusions and Future Work

- Aperiodic, dispersed-dot (FM) halftoning is of growing interest in the commercial print sector.
- The PARAWACS method, which is based on a single selection matrix has been shown to yield excellent quality halftone images.
- The Direct Binary Search (DBS) algorithm provides a very effective means of designing the PARAWACS selection matrix.
- In this paper, we have introduced a complete imaging pipeline for rendering and printing images using PARAWACS for the Indigo press.
- The next step is to halftone and print images of natural scenes using the target Indigo press, and then assess print quality.

THANK YOU!