Digital Halftoning & Error Diffusion

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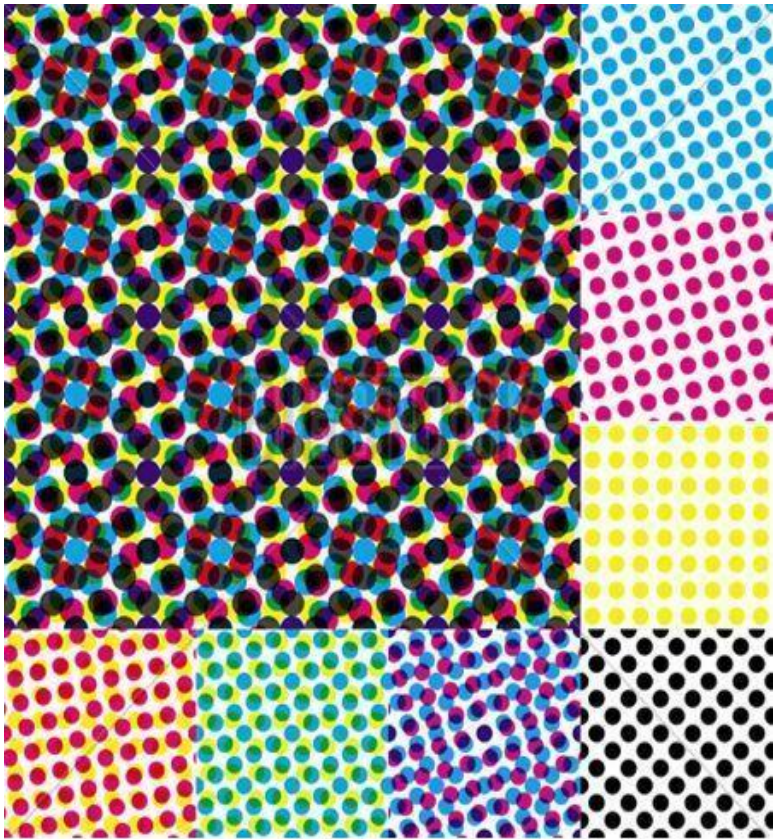
Why Discuss Halftoning?

The World’s Oldest Image Processing Algorithm?

Printed halftone photograph from 1869, published in Canadian Illustrated News. First known use of printing plate halftoning.

Physical Halftoning



Physical halftoning is achieved through layering of patterned dots. Dots of different colors are arrayed at specific offsets on dye plates, which combine together to produce repetitive patterns called Moire patterns.

Using dots of color to simulate halftones is called “dithering.”

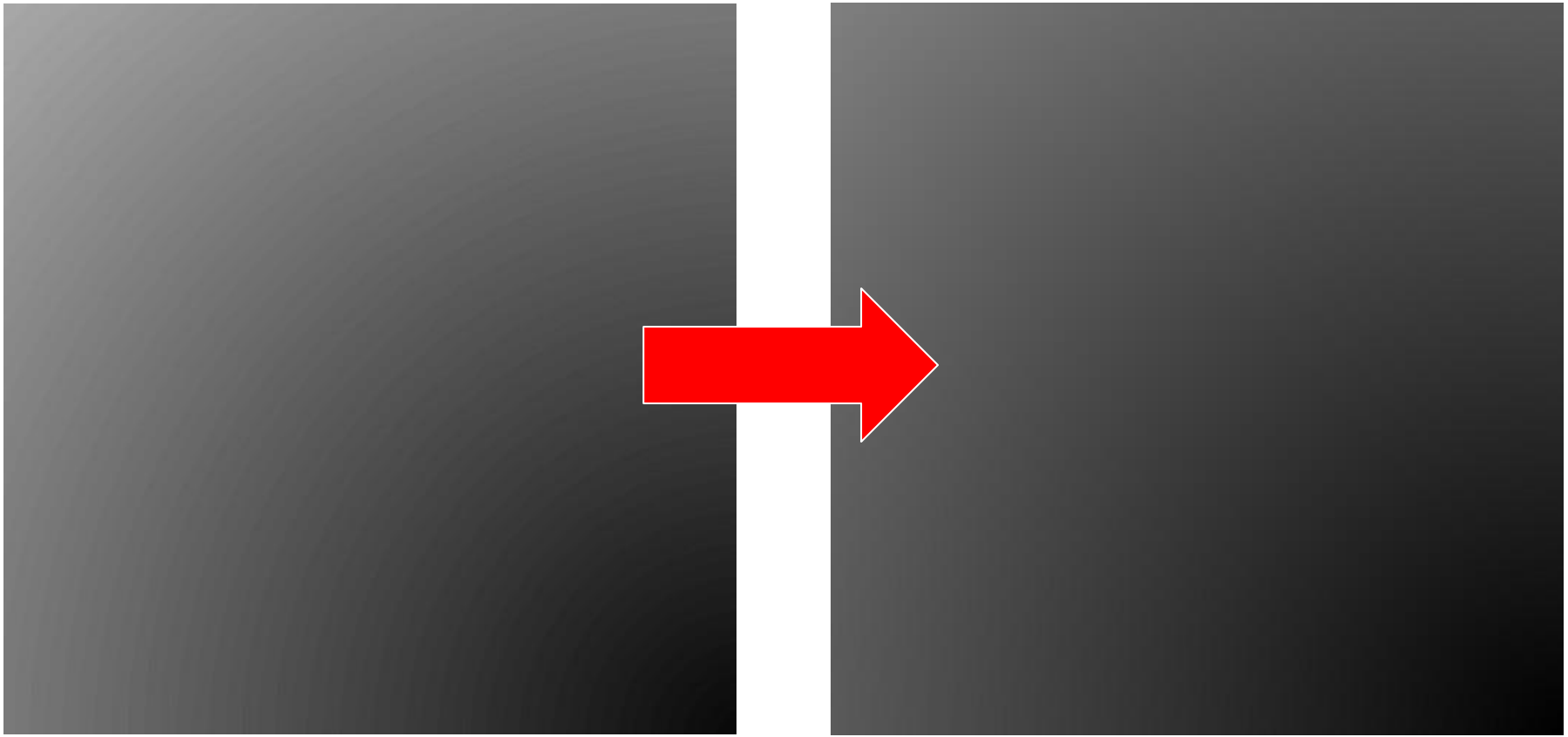
Modern Halftoning Applications

File Format Conversion

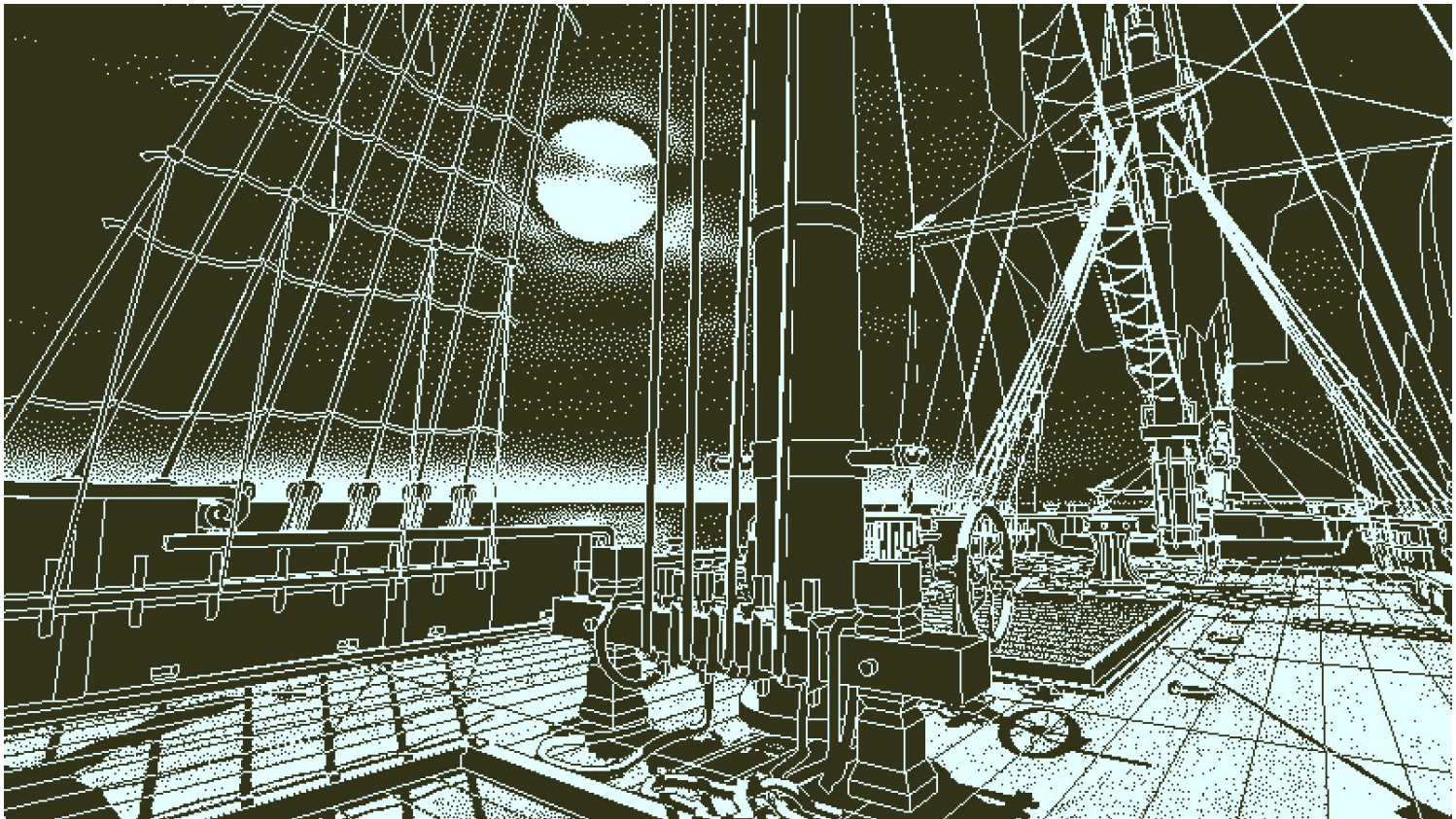
256 Color Depth (no dithering)

256 Color Depth (FS dithering)

Color Banding Reduction



Style and Aesthetics



Error Diffusion

According to the Wiki,

"Error diffusion is a type of halftoning in which the quantization residual is distributed to neighboring pixels that have not yet been processed. Its main use is to **convert a multi-level image into a binary image**, though it has other applications."

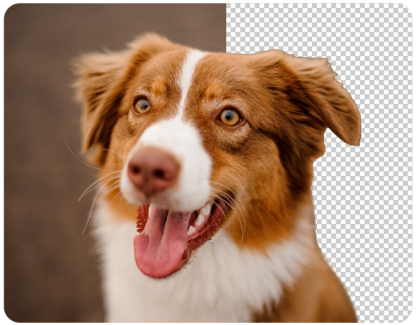
Let's say from 256(2^8) color to 2, 4, 8, 16.

Algorithm

- One-dimensional error diffusion
- Two-dimensional error diffusion
- Color error diffusion
- Error diffusion with several gray levels

One-dimensional & Two-dimensional

Half-gray value = 255/2



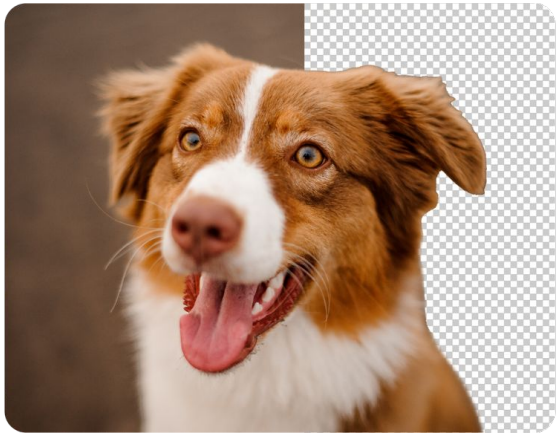
```
for i in row:
    for j in col:
        if (current value > half-gray value)
            return white
        else
            return black
```

One-dimensional

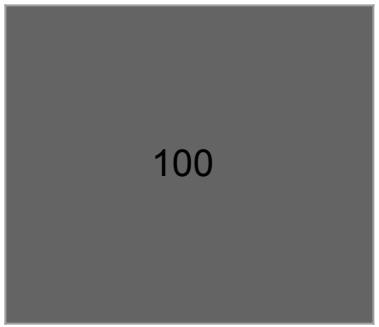
$$\frac{1}{2}\begin{bmatrix} \# & 1 \\ 1 & 0 \end{bmatrix}$$

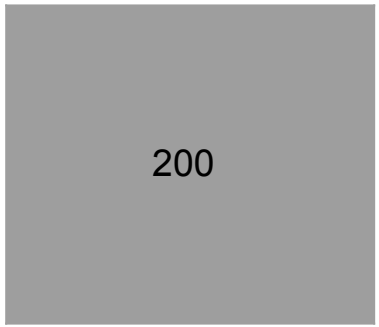
Two-dimensional

One Dimensional Example



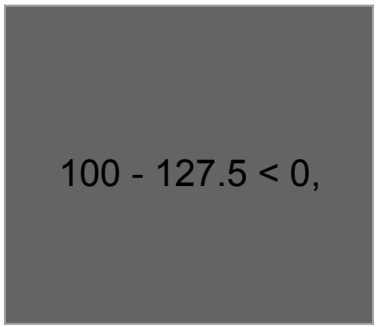
Single pixel





Single pixel

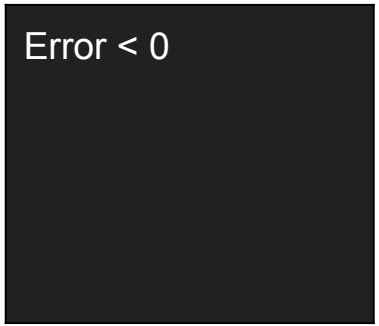
For one-dimensional,
Calculating error

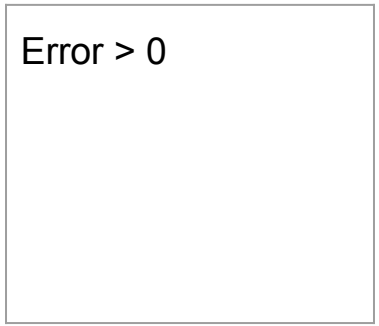


For one-dimensional,

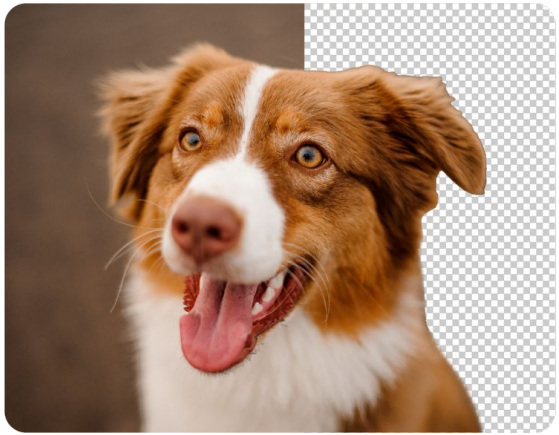
If error is negative, set pixel to black

If error is positive, set pixel to white

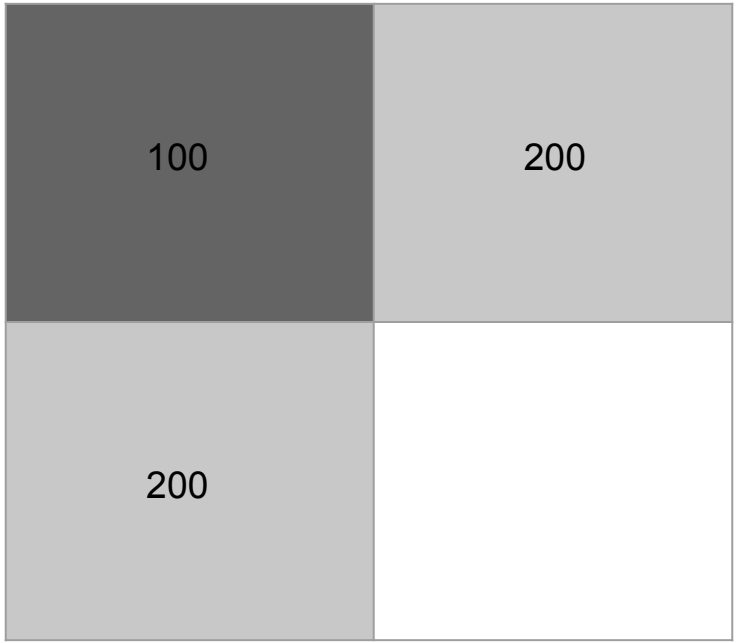




Two Dimensional Example

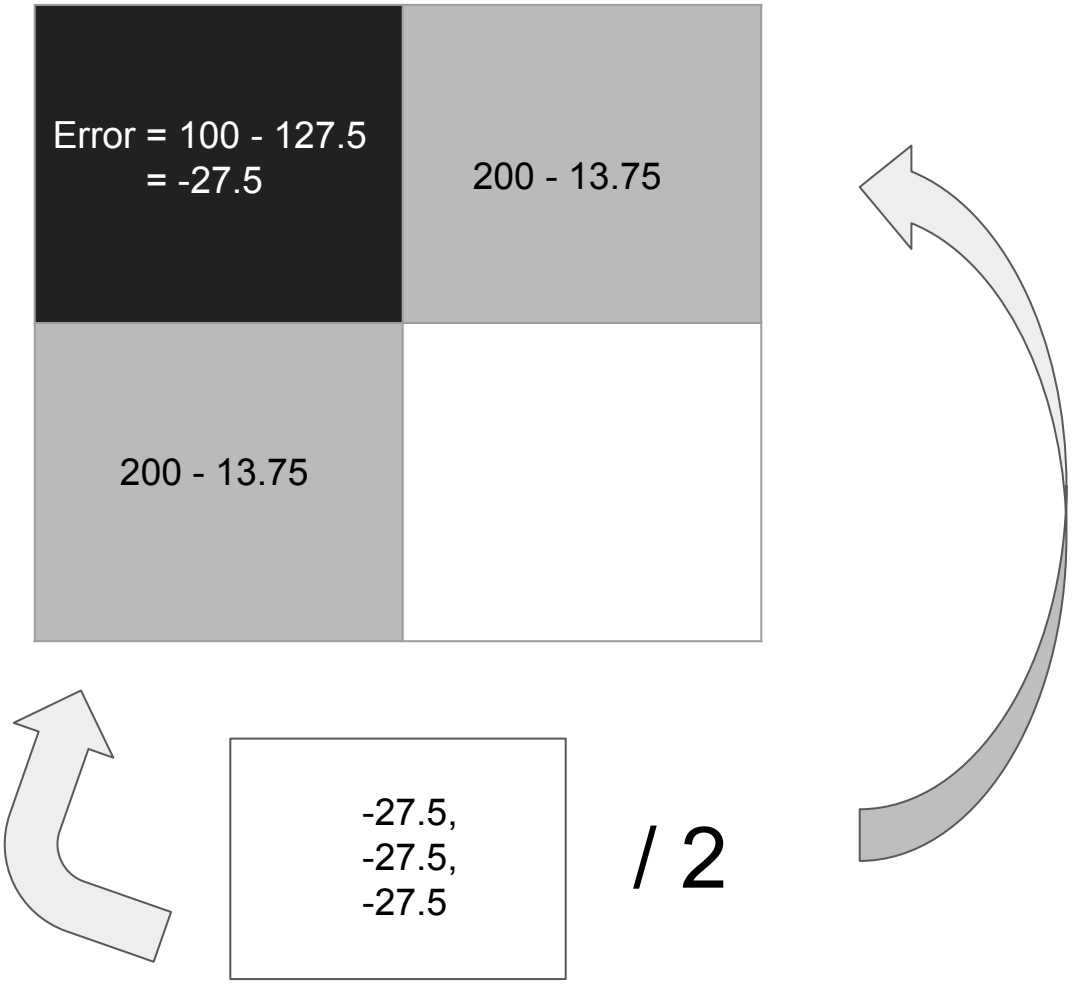


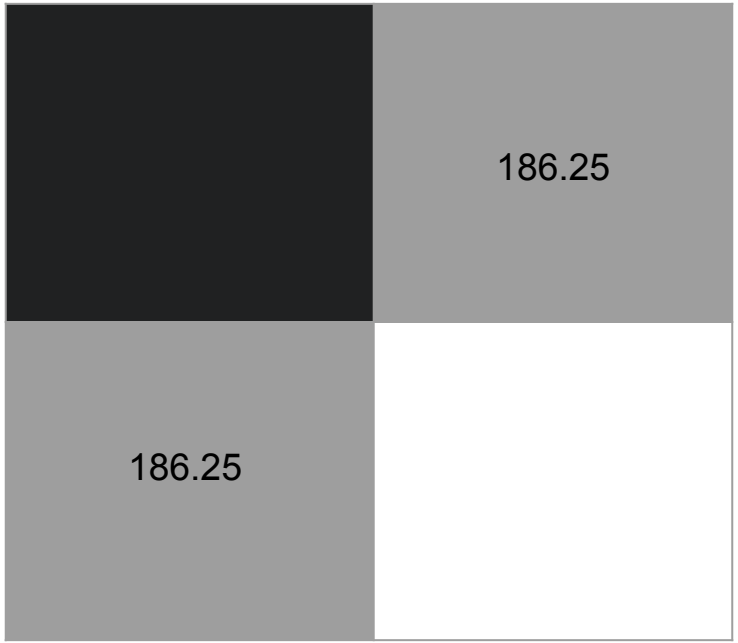
2x2 pixels

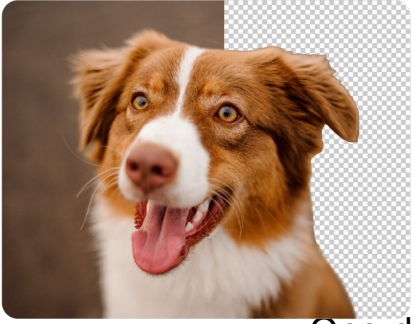


For two-dimensional,

If error is negative, set pixel to black



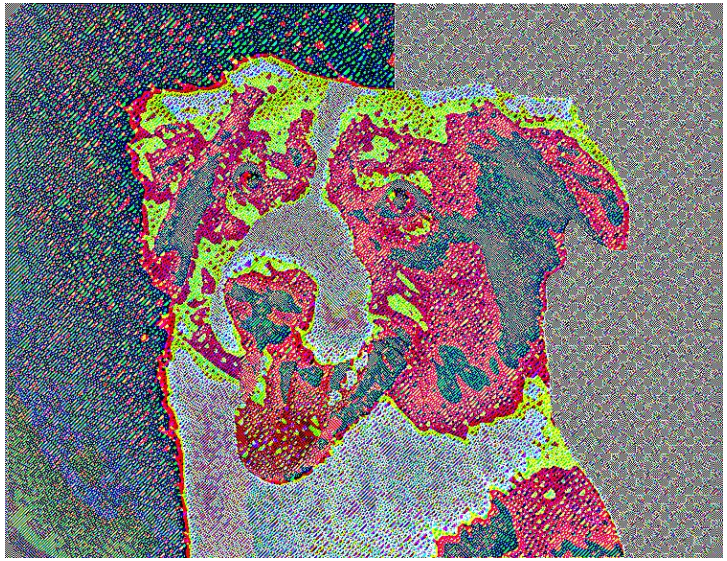

186.25
186.25



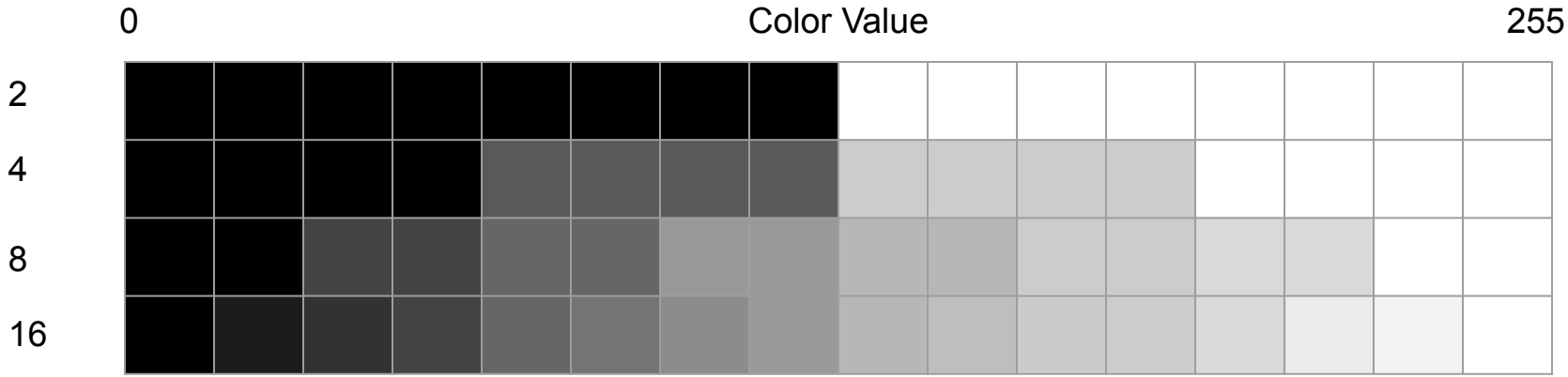
Color Error Diffusion

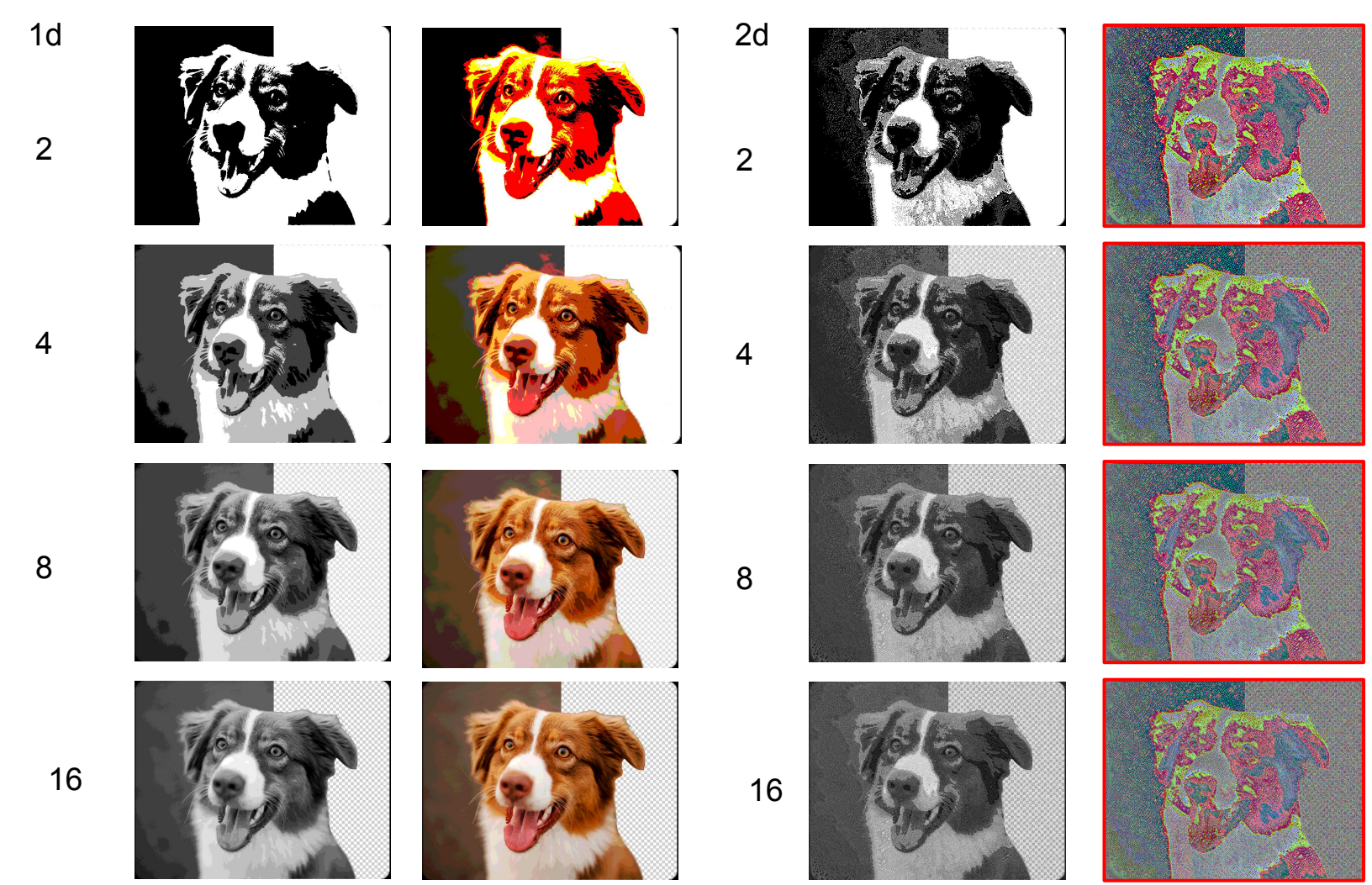
One-dimensional Color

Two-dimensional Color
(bad for human visual)



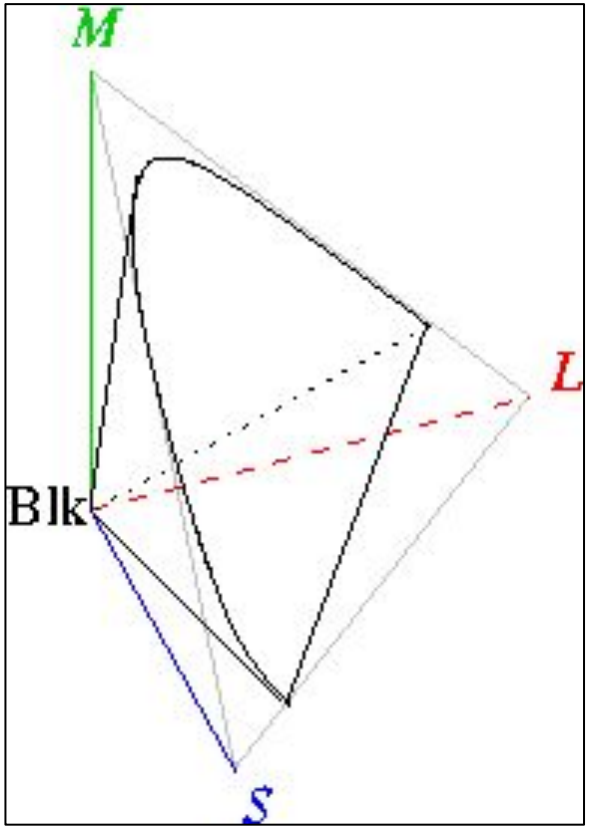
Error diffusion with several gray levels

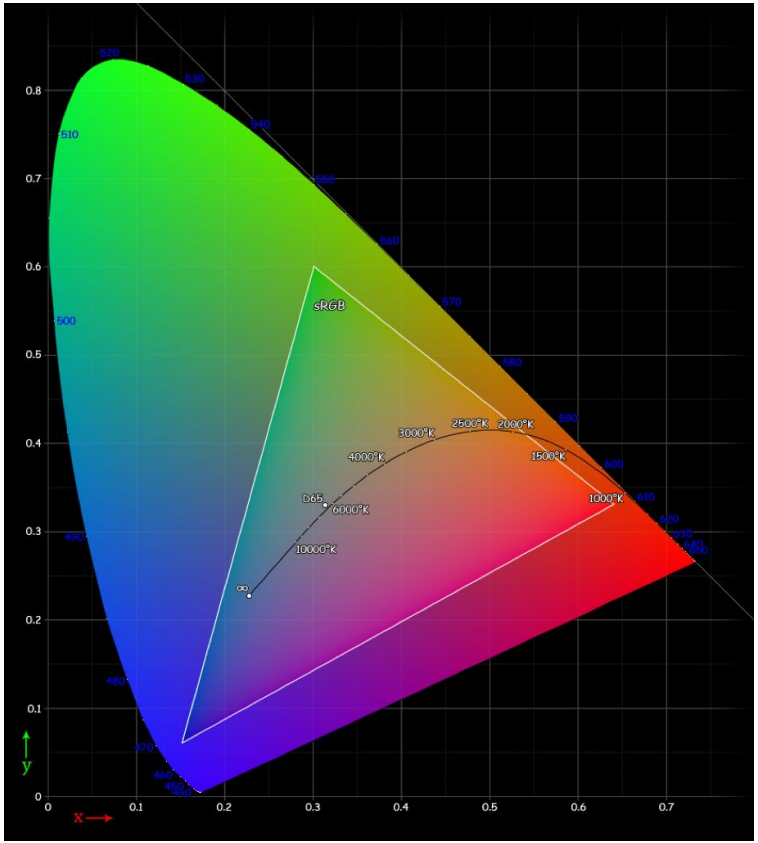




With the red borders, we are in lack of knowledge to make this part better visual for human.

RGB to lightness, hue and saturation channels.


M
L
Blk
S


sRGB
D65
2500°K
2000°K
3000°K
4000°K
1500°K
1000°K
6000°K
10000°K
∞
x
y

Human Better Color Halftoning

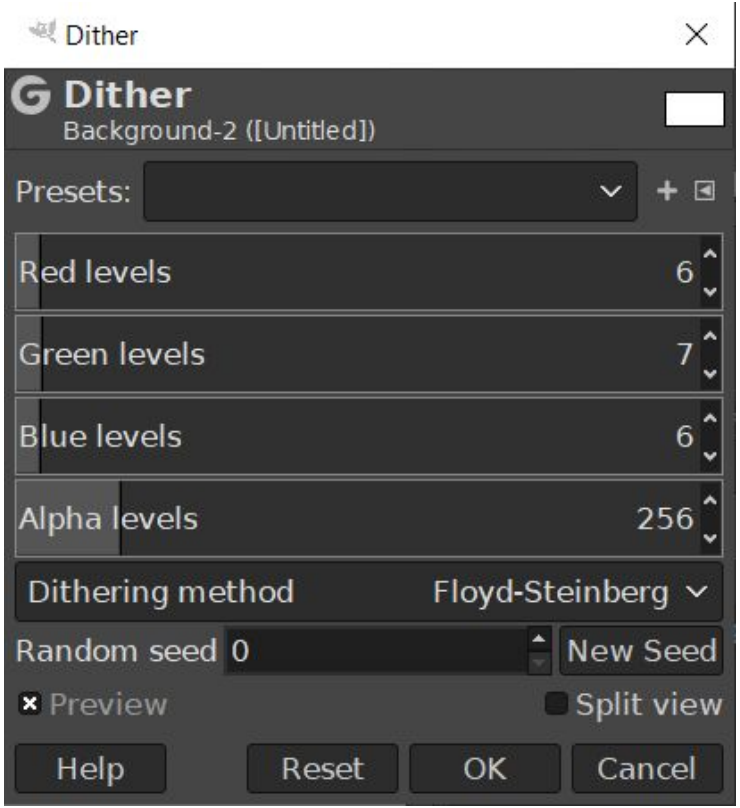
Ours

Correct for Human

Floyd-Steinberg Dithering

Image dithering algorithm published by Robert Floyd and Louis Steinberg in 1976. Floyd-Steinberg Dithering is the default dithering algorithm for most modern image processing software.

Floyd-Steinberg Dithering utilizes Error Diffusion.



Floyd-Steinberg Dithering

$$\begin{bmatrix} * & \frac{1}{2} \\ \frac{1}{2} & 0 \end{bmatrix}$$

2D Error Diffusion kernel matrix

$$\begin{bmatrix} \cdots & \cdots & * & \frac{7}{16} & \cdots \\ \cdots & \frac{3}{16} & \frac{5}{16} & \frac{1}{16} & \cdots \end{bmatrix}$$

Floyd-Steinberg Dithering kernel matrix

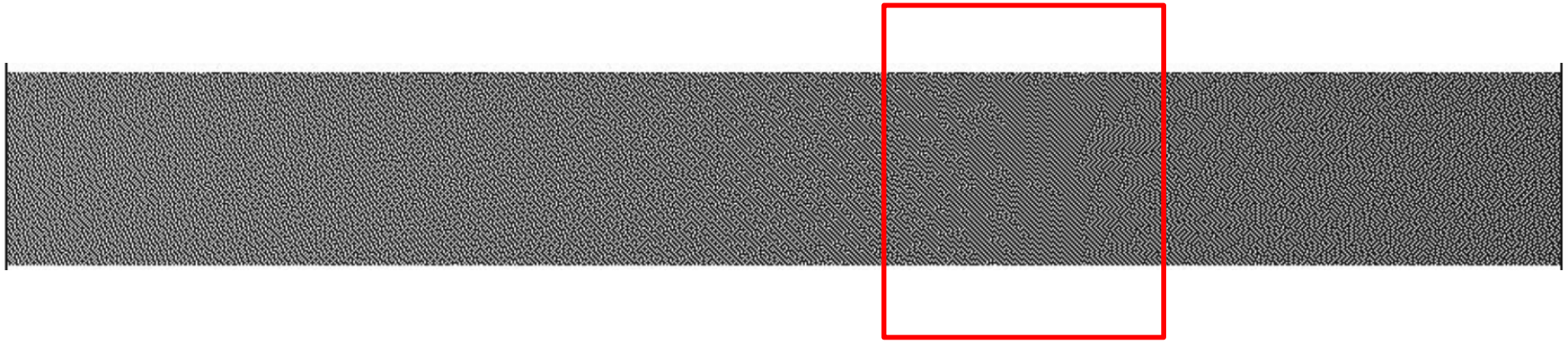
1-bit Color Depth

1 Dimensional Error Diffusion

2 Dimensional Error Diffusion

Floyd-Steinberg Dithering

What about the artifacting?



How do we address this?

Addressing Artifacting

Option 1: Use more weights!

		•	7/48	5/48
3/48	5/48	7/48	5/48	3/48
1/48	3/48	5/48	3/48	1/48

Filter proposed by Jarvis, Judice, and Ninke

Addressing Artifacting

Option 2: Adjust your weights dynamically!

Some sophisticated dithering algorithms adjust diffusion weights based on the current gray value.

Addressing Artifacting

Option 3: Scan your image in nonlinear patterns!

One component of regular artifacting is the linear order of pixel scanning. By scanning the image nonlinearly, this pattern can be reduced

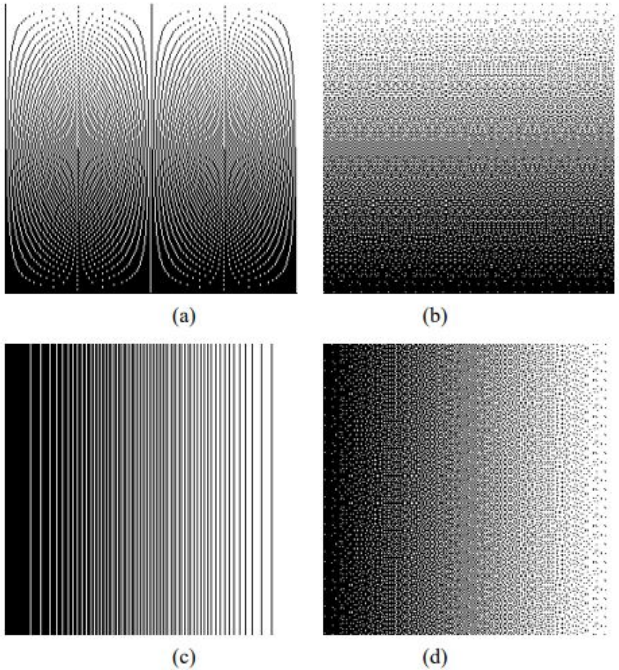
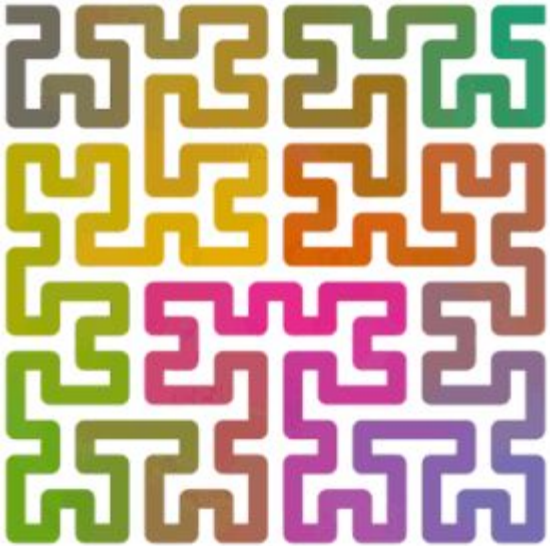


Figure 7. A comparison between the scanning orders in the IGS quantization: Results from the vertical ramp image by (a) Raster scanning and by (b) Hilbert scanning; results from the horizontal ramp image by (c) Raster scanning and by (d) Hilbert scanning. All the images are displayed at a resolution of 200 pixels per inch (PPI).

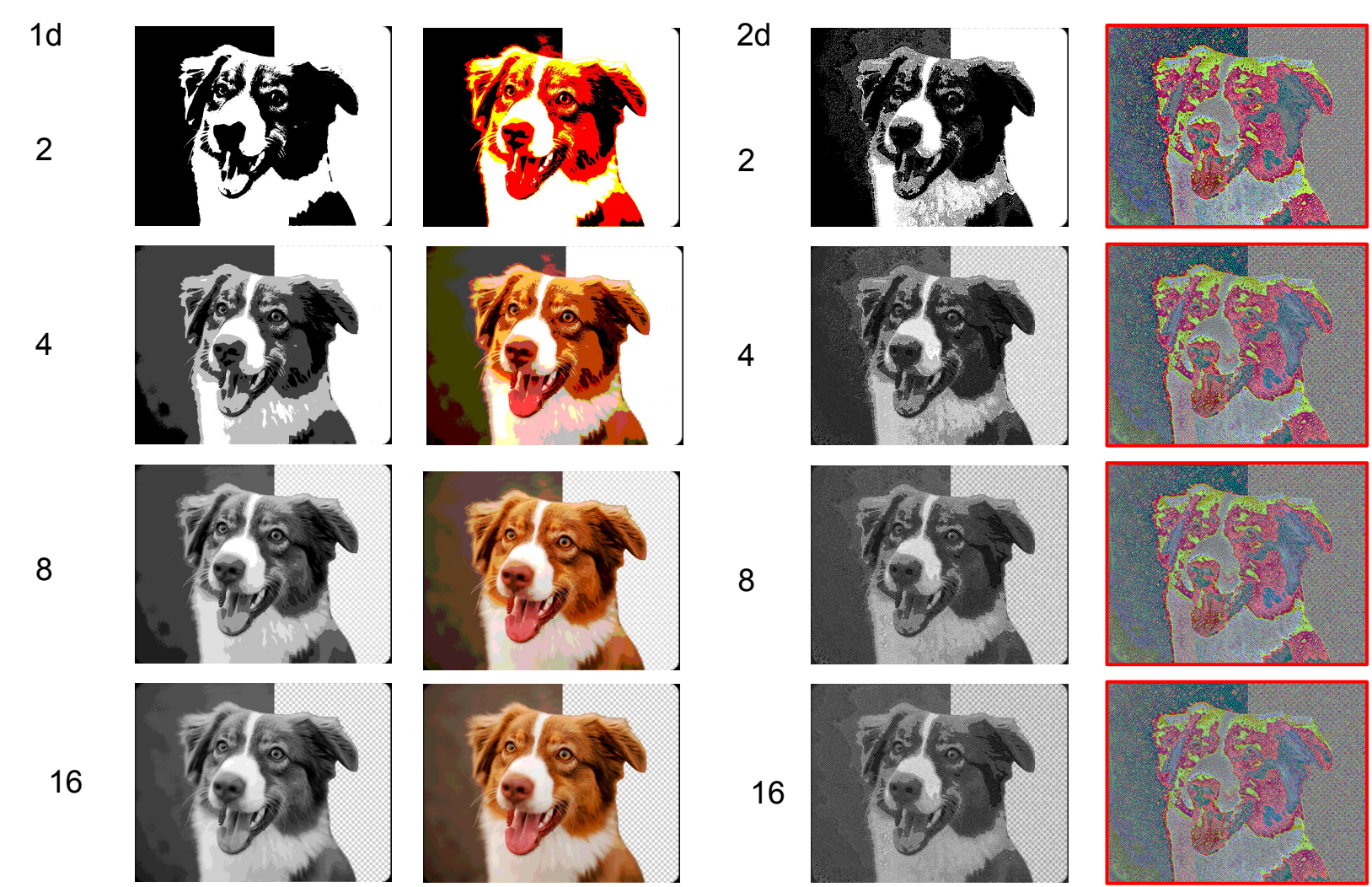


Example from Multi-Level Halftoning by IGS Quantization, T. Kimoto, 2013

Quiz

1. What is difference between one and two dimensional error diffusion?

a. Two dimensional has more detail on the lower gray level images
b. Two dimensional has more detail on the higher gray level images
c. Two dimensional has less detail on the lower gray level images
d. Two dimensional has less detail on the high gray level images



For better human visual, we convert RGB to lightness, hue and saturation channels.

We currently don’t know how.

Quiz

2.

Assuming 4-bit integer grayscale (0 to 15), what is the new value of pixel 3 after one pass of two-dimensional Error Diffusion?

a. 8
b. 15
c. 4
d. 0

1 8	2 4
3 4	4

Middle gray is 8

8 - 8 = 0

0 / 2 = 0

It depends on the implementation to decide if middle gray is rounded to black or to white.

1 15 or 0	2 4 - 0
3 4 - 0	4

Takeaways and Conclusion

Digital halftoning simulates combined color tones using pixels as dithered dots. Most dithering algorithms use Error Diffusion, the process of distributing color differences over neighboring pixels, to achieve this halftoning while decreasing the color depth of images. Different distribution weights produce different visual outputs.

Error diffusion algorithm:

One-dimensional & two-dimensional & color & gray levels.

Common dithering algorithms. From left to right: Atkinson; Burkes; Floyd–Steinberg; Jarvis, Judice & Ninke; Sierra; Stucki. Davids courtesy of Wikipedia user Gerbrant

Future Search

Implement on different area such as text, voice, etc.

Questions?
or
Thank You!

Reference

1. https://en.wikipedia.org/wiki/Halftone#/media/File:Halftoning_introduction.svg
2. https://upload.wikimedia.org/wikipedia/commons/3/33/Neighborhood_watch_bw.png
3. https://ars.els-cdn.com/content/image/3-s2.0-B9781558607873500037-f02-06-9781558607873.jpg
4. https://www.adobe.com/express/feature/image/media_16ad2258cac6171d66942b13b8cd4839f0b6be6f3.png?width=750&format=png&optimize=medium
5. https://scipython.com/blog/floyd-steinberg-dithering/
6. https://en.wikipedia.org/wiki/Color_model
7. Modern Digital Halftoning, D. Lau and G Arce. 2nd Ed.