Class 4: color reproduction

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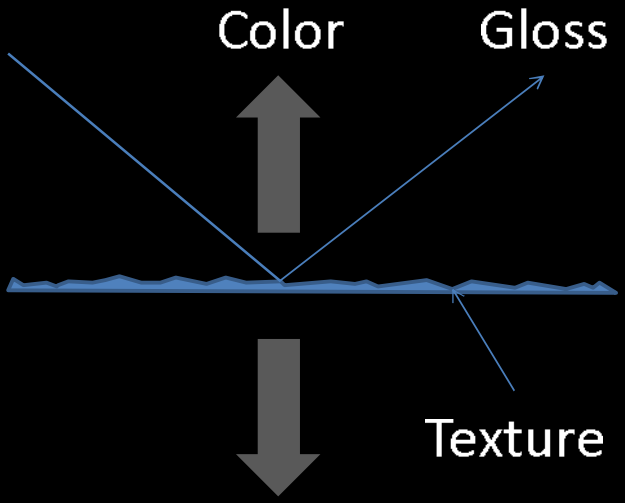
Class 4: color reproduction

1. A comment about appearance
2. A recap about color
   - Components of color experience
   - Mixing processes to produce color
   - CIE standards (illuminant and observer)
   - Trichromatic theory
3. Remember how cameras work
4. What about reproduction? Screens
5. What about reproduction? Printers
   - What is halftoning?
6. Color workflow
7. Color management
8. Closing statements

What is visual appearance?

CIE four categories to characterize visual appearance:



A recap about color

1. Light

- Visible spectrum ~400nm-700nm
- Different types of light
- 'Color' of light influences perceived color

Color can be produced by:

- Additive process (light mixing)
- Subtractive process (paint mixing)

2. Object

- Light interacts with the particles of the object (it bounces inside, goes through, bounces back...)
- Color is NOT a property of the object

3. Sensor

- HVS is composed of three sensors (cones) SML
- CIE has characterized the HVS (chromatic diagram) to obtain a 'standard observer'

HVS: human visual system

How to (re)produce color?

Additive process
(Primaries R,G,B)

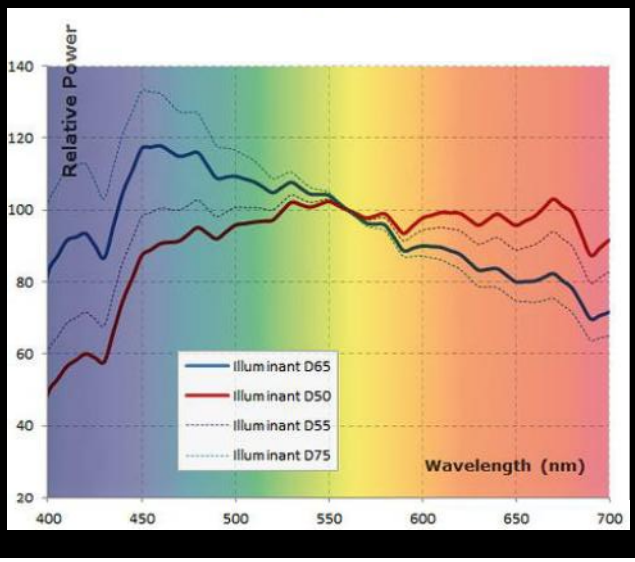
Subtractive process
(Primaries CMY)

CIE standards

CIE (Commission internationale de l'éclairage)

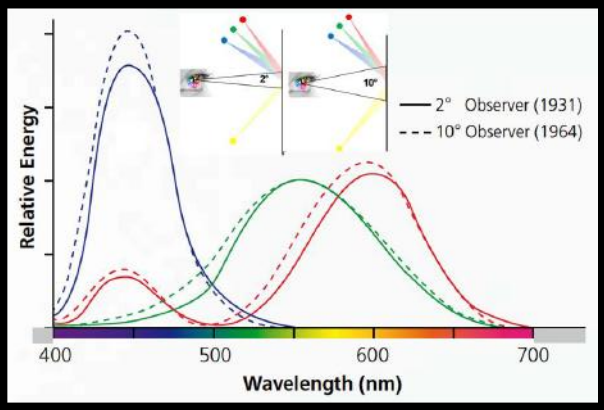
standard illuminants

definition of spectral power distributions (SPD) for some typical light sources



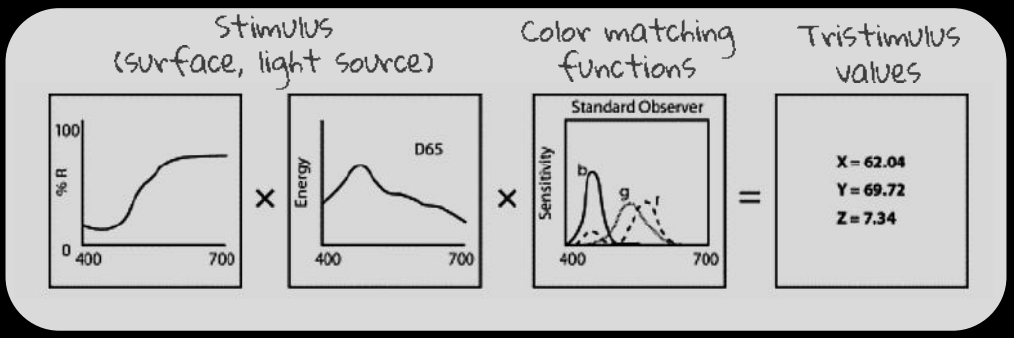
Standard observers

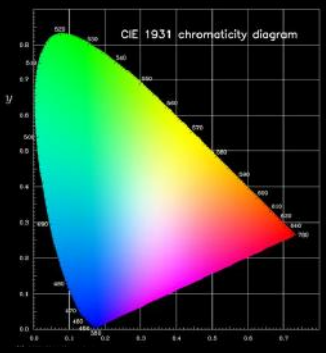
how an average person sees colors across the visible spectrum

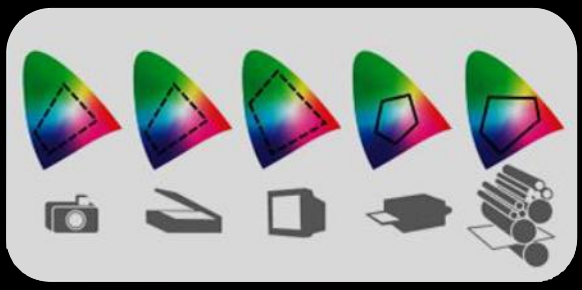


Trichromatic theory

three receptors for color perception

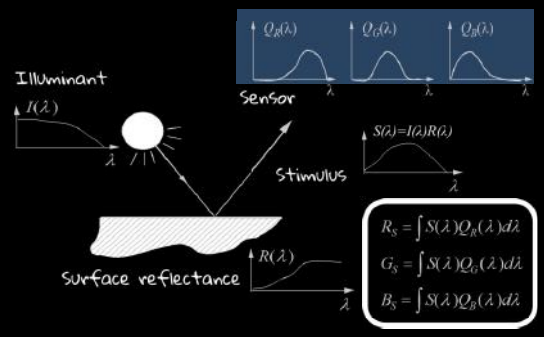


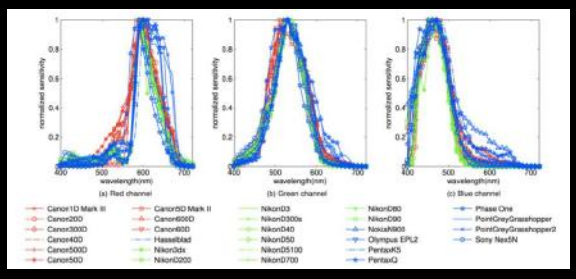




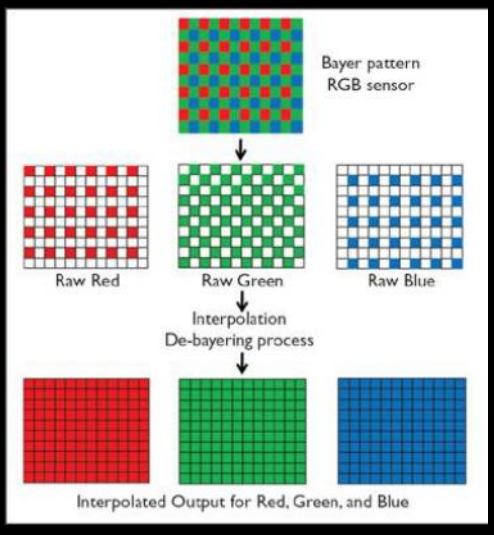
Remember how cameras work?

capturing color





Camera outputs TIF or JPEG file that contains 3 channels: RGB



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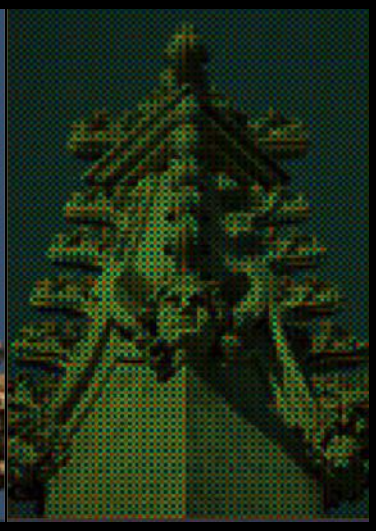
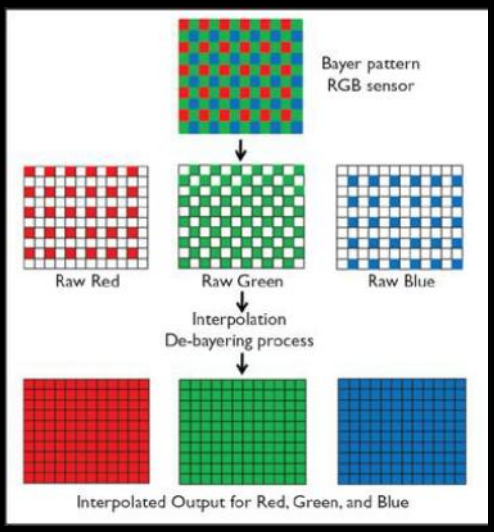
Original

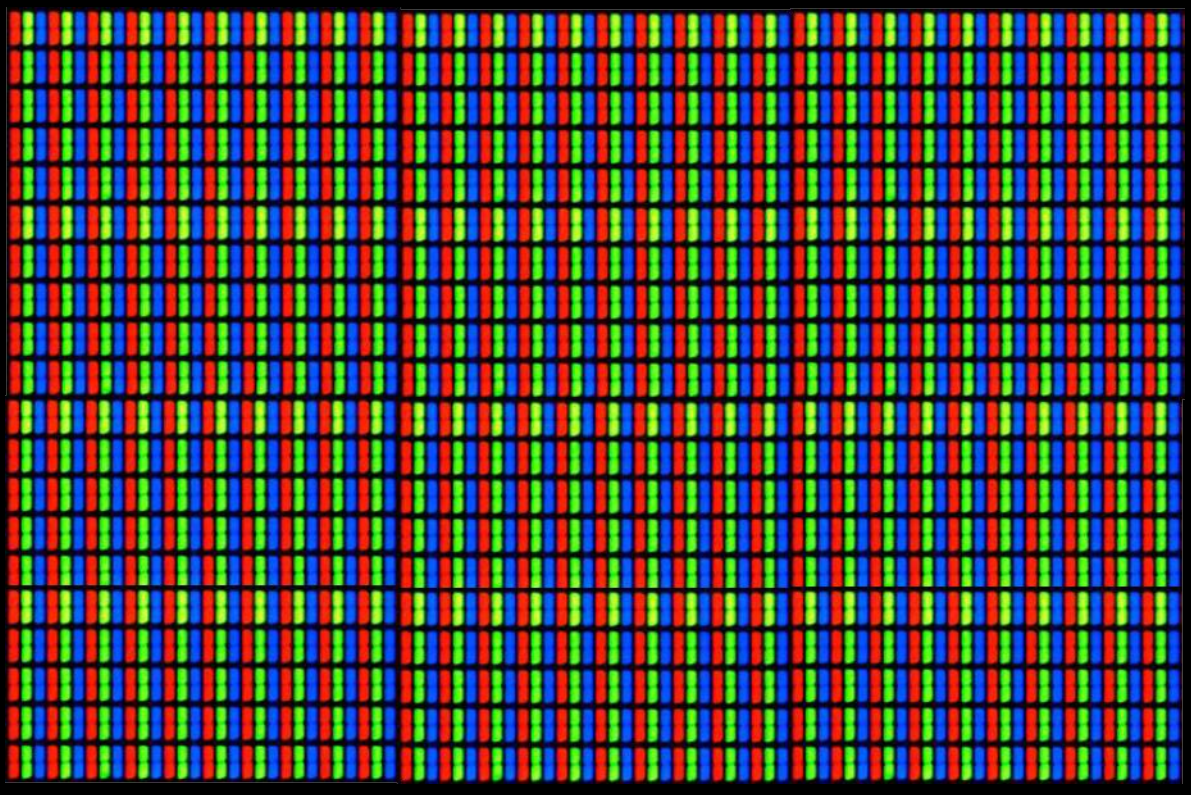


What your camera sees



And what about reproduction?

case study: screens



- Liquid crystals: state in between liquid and solid
- Each liquid crystal cell is handled by a transistor (on/off) to polarize light

- 1 pixel in LCD = 3 subpixels (RGB)
- 256 shades per subpixel
- Off: blocks light that comes from the back
- On: lets light go through

- Combining the subpixels produces a possible palette of 16.8 million colors (256 shades of red x 256 shades of green x 256 shades of blue)

- These color displays take an enormous number of transistors. For example, a typical laptop computer supports resolutions up to 1,024x768,

  If we multiply 1,024 columns by 768 rows by 3 subpixels, we get 2,359,296 transistors etched onto the glass!

And what about reproduction?

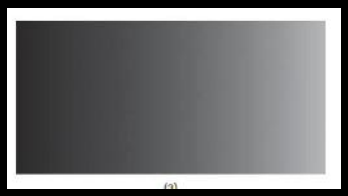
case study: printers

Image/Doc
- Color/BW
- Size
- Paper type

Driver/RIP (raster image processor)
- Device dependent parameters (economy, pro, resolution)
- Color management
- Halftone
- Translates halftoned image into voltage

Printer
- Printhead jets (or not) droplets of ink in a specific location
- Paper and/or printhead move

Continuous image
255.....127.....0



1. Color separation

2. Halftone image
1.....1 1 0.....1.....0

And what about reproduction?

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Halftone image
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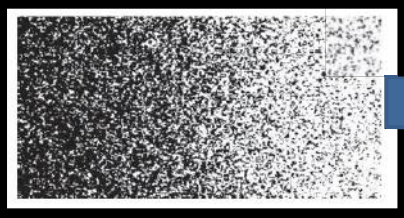
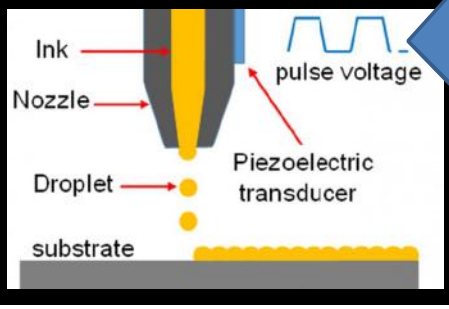
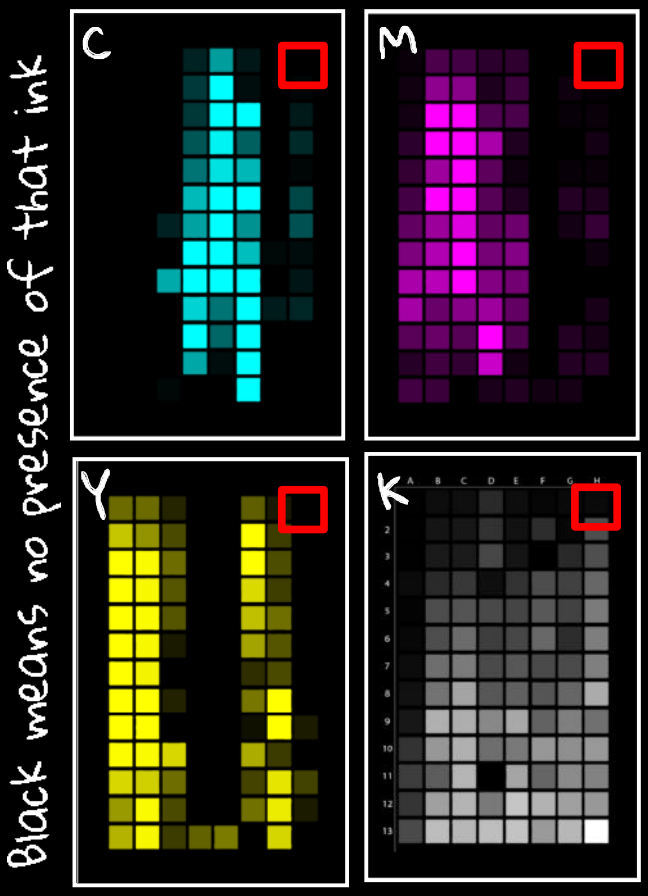




- Binary devices: print (1) or not to print (0)
- Multilevel devices: print (1), print less (3/4), print half (2/4), print even less (1/4), don't print (0)
- The same is repeated for each channel/printhead (CMYK)

1. Color separation

CMYK case



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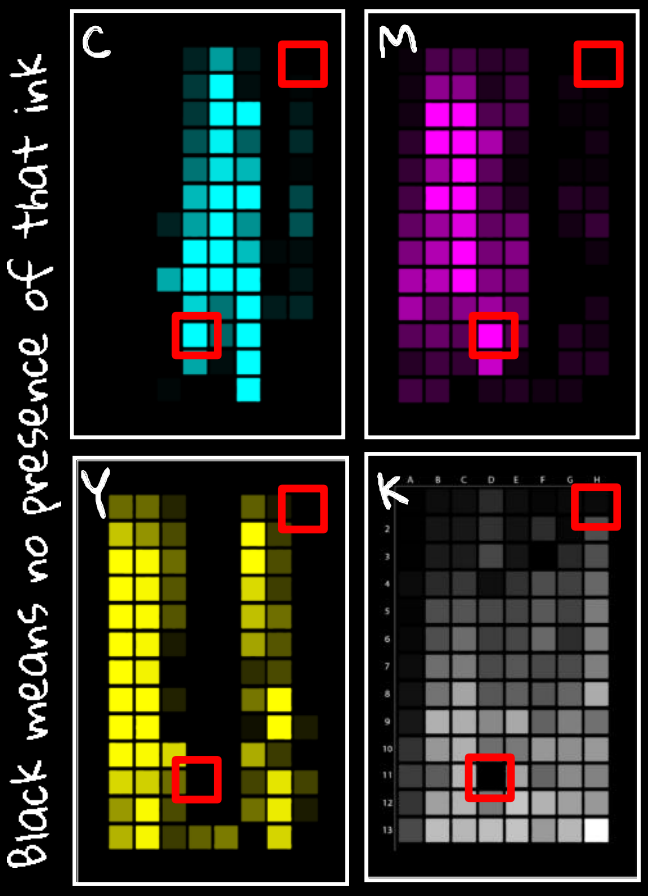
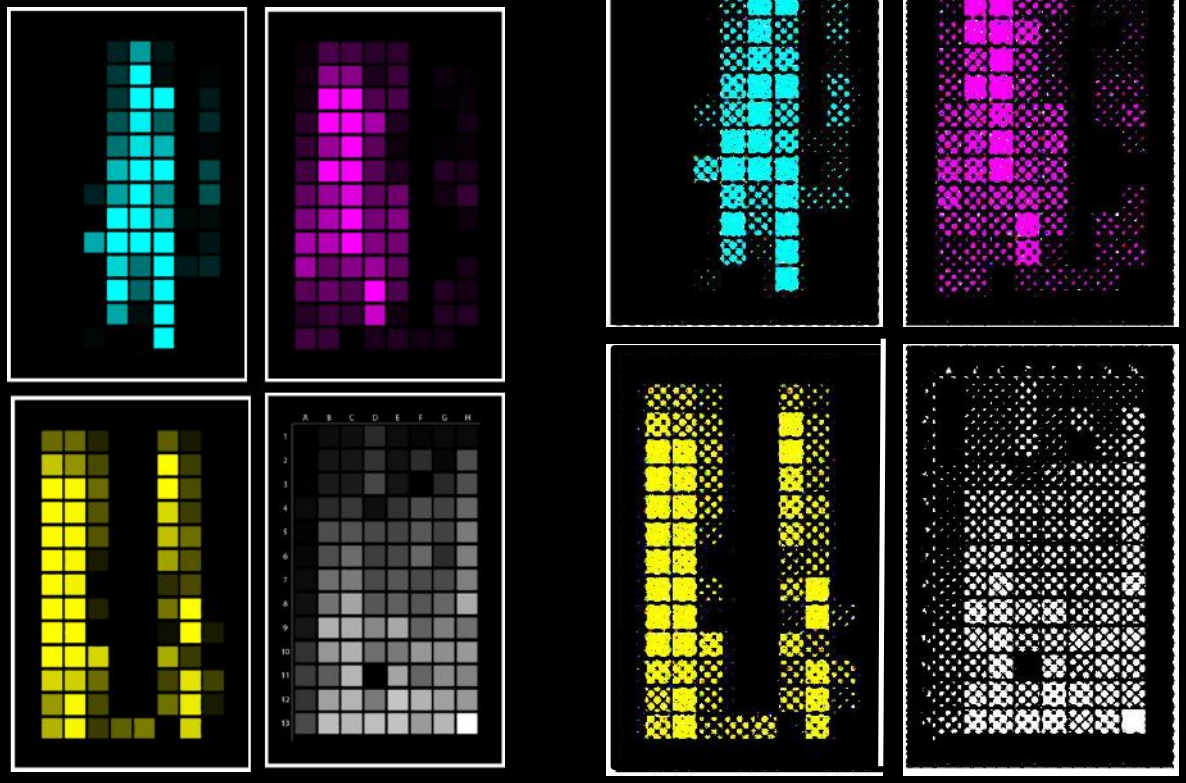
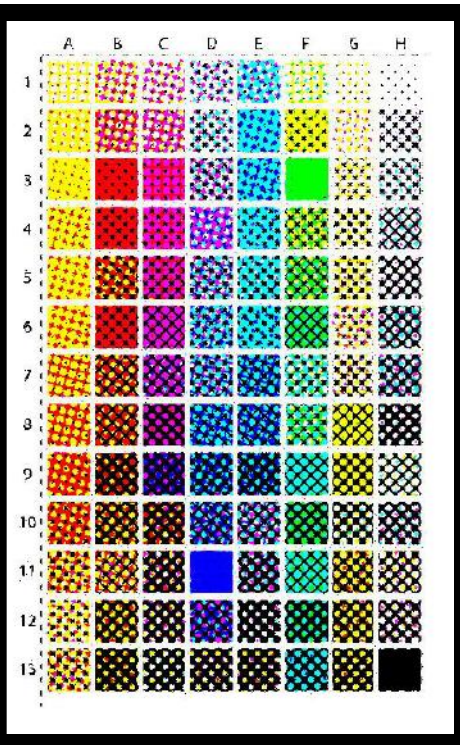


2. Halftone

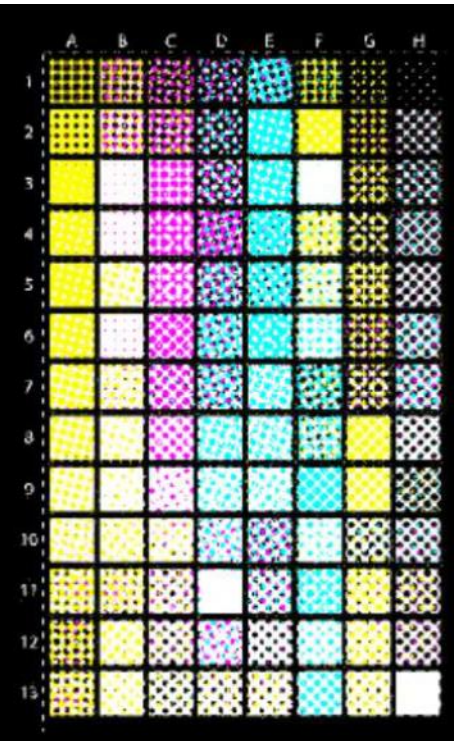
CMYK case





Why the CMYK images of the color separation and halftoning had black in "don't-print" areas and Photoshop and other show the opposite (white means no print.... look at the margins!)

Ans./ Just for visualization!



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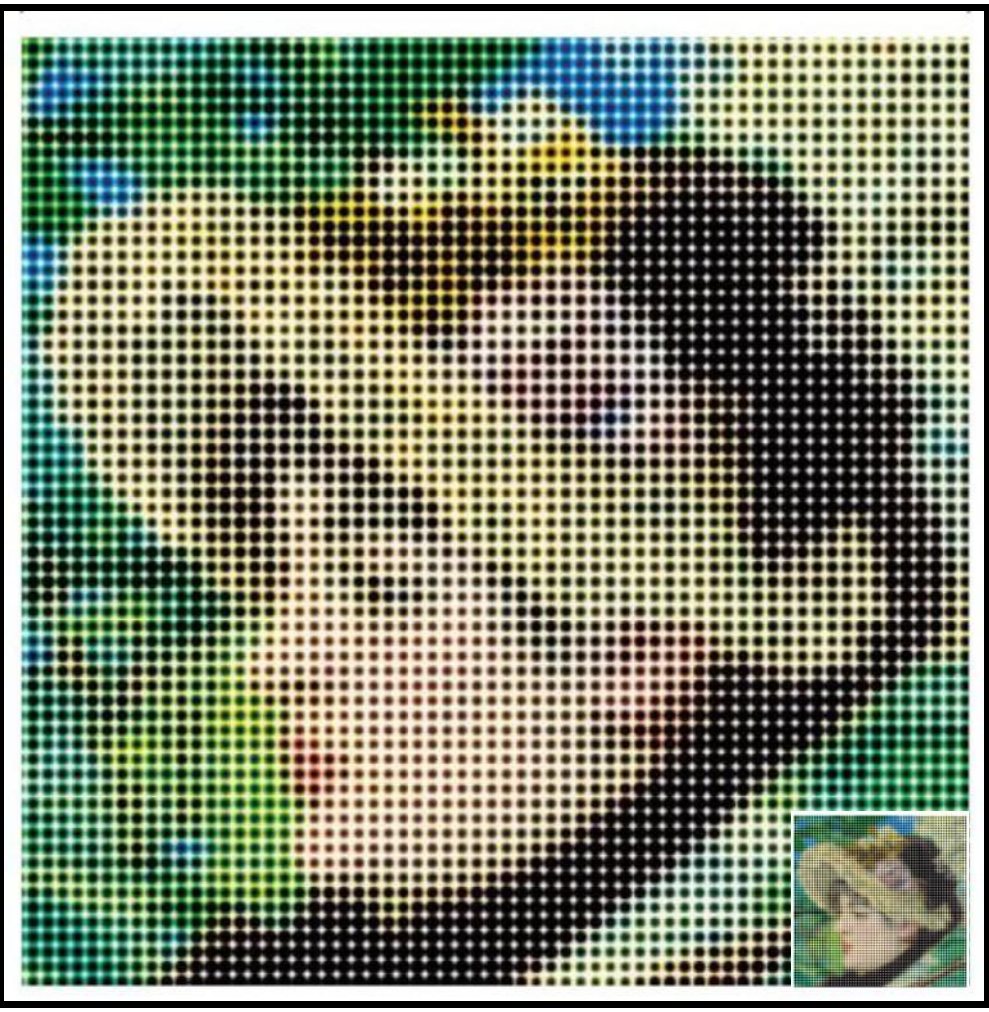
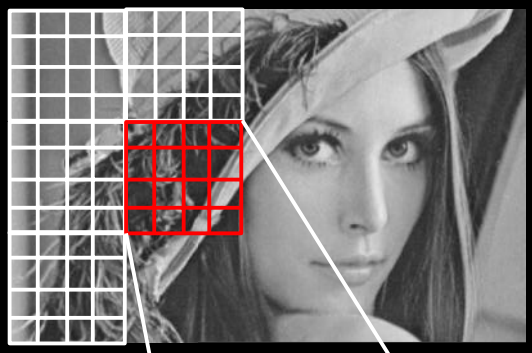


But, what is halftoning?



12	51	34	121
78	254	10	97
45	113	110	16
90	200	206	34

Input kernel

$\geq$

0	60	0	60
45	110	45	110
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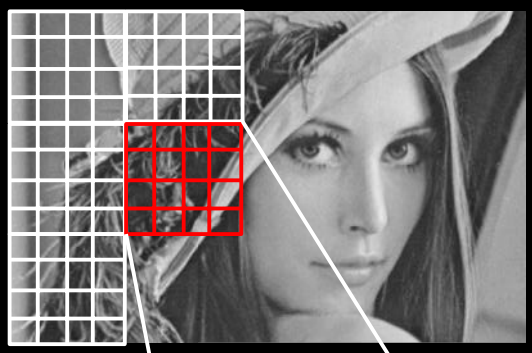
45	110	45	110

Dither matrix

$=$

Output kernel

But, what is halftoning?



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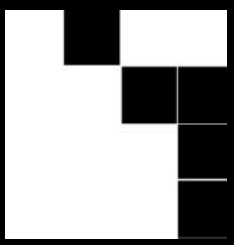

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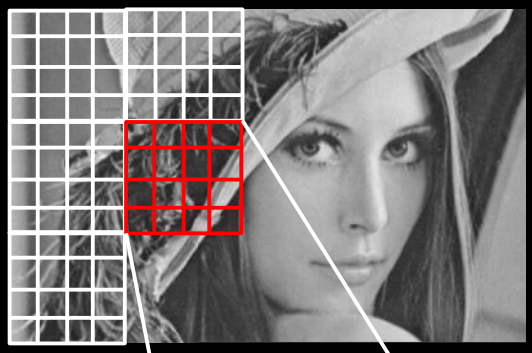

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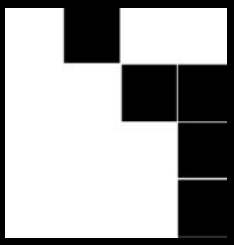
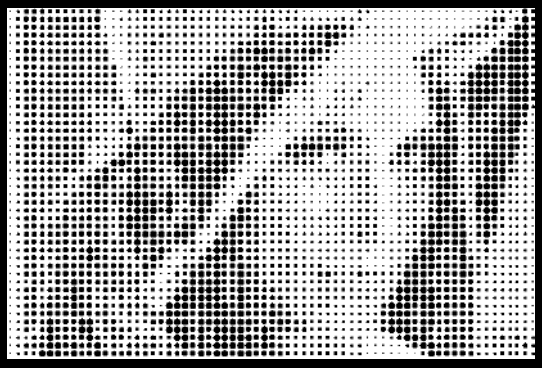


Output kernel



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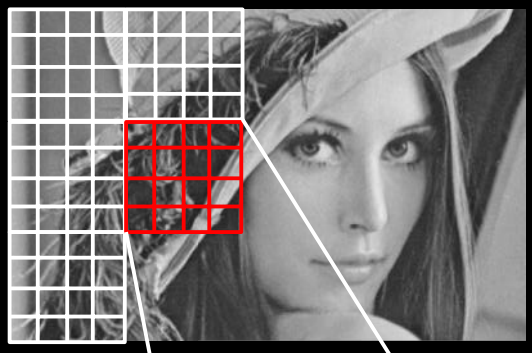

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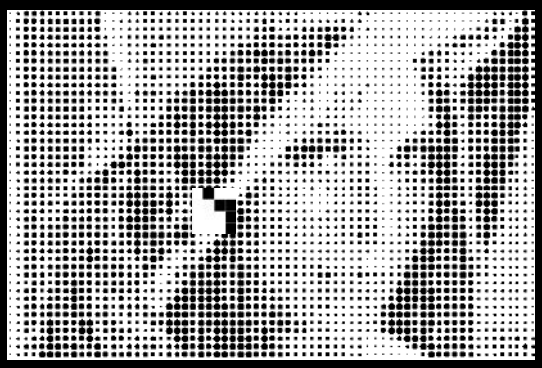
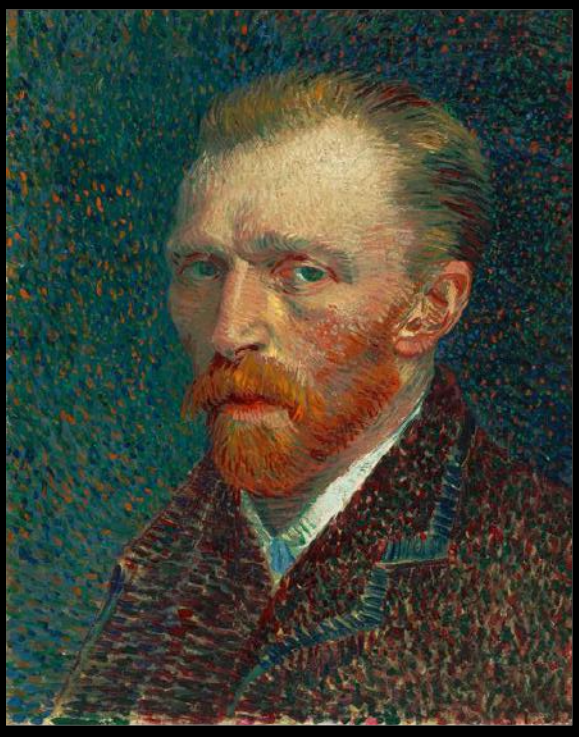
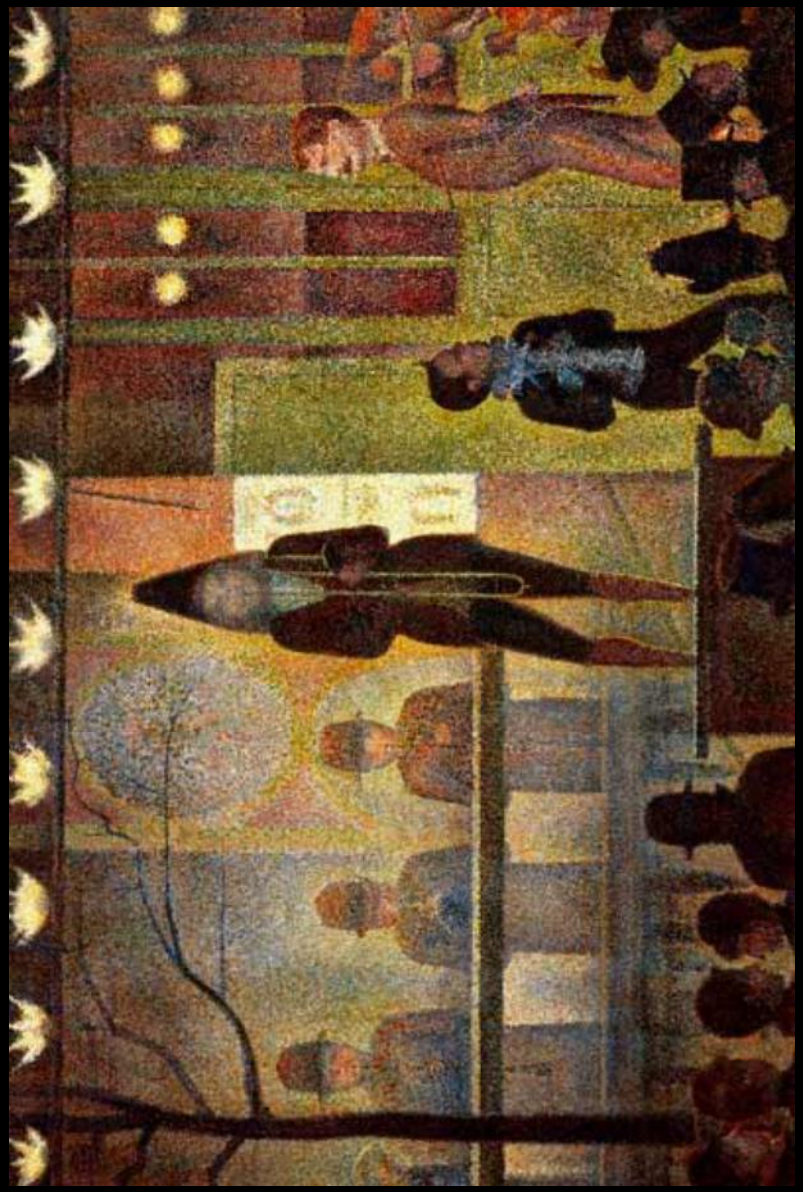
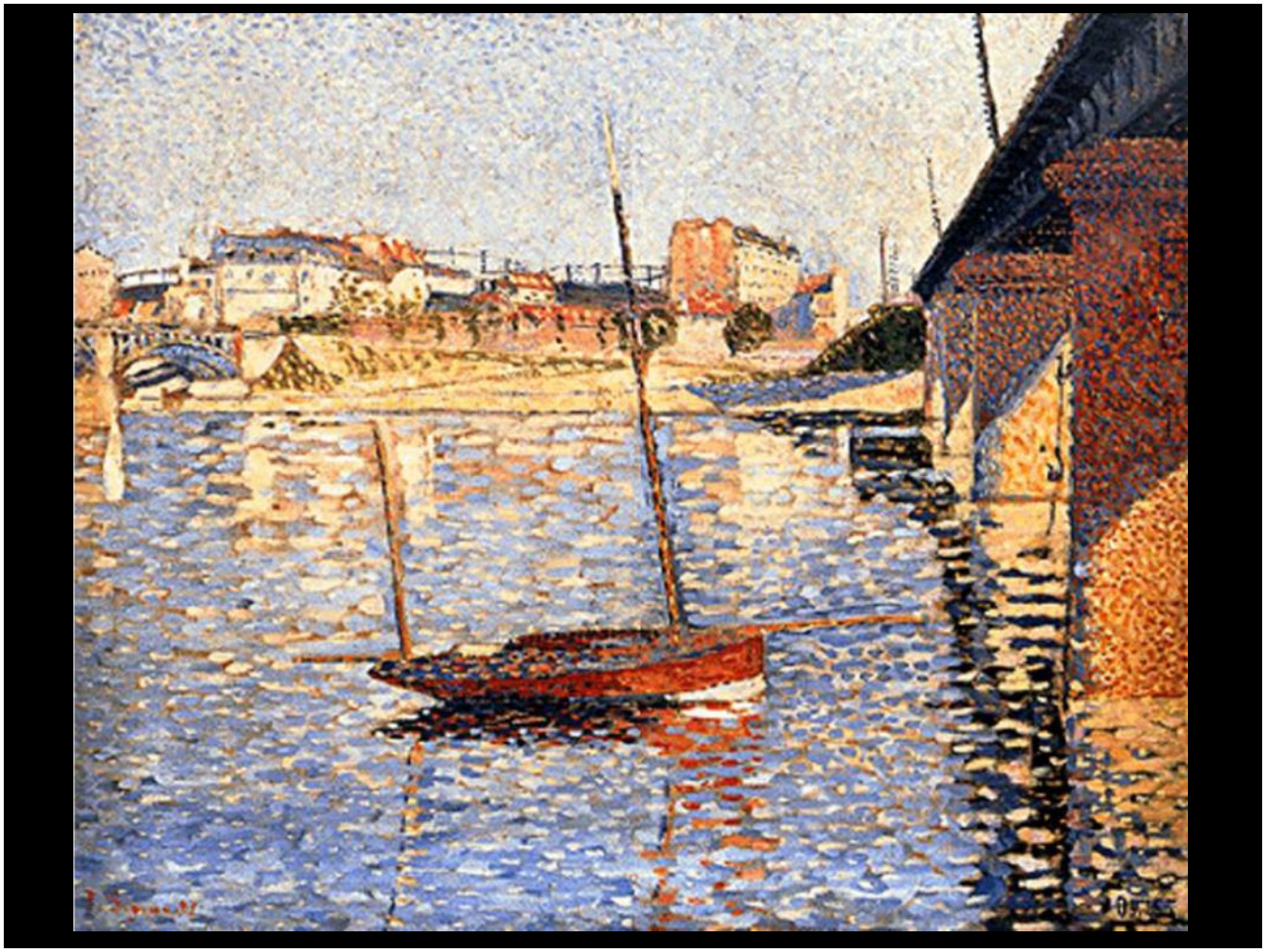
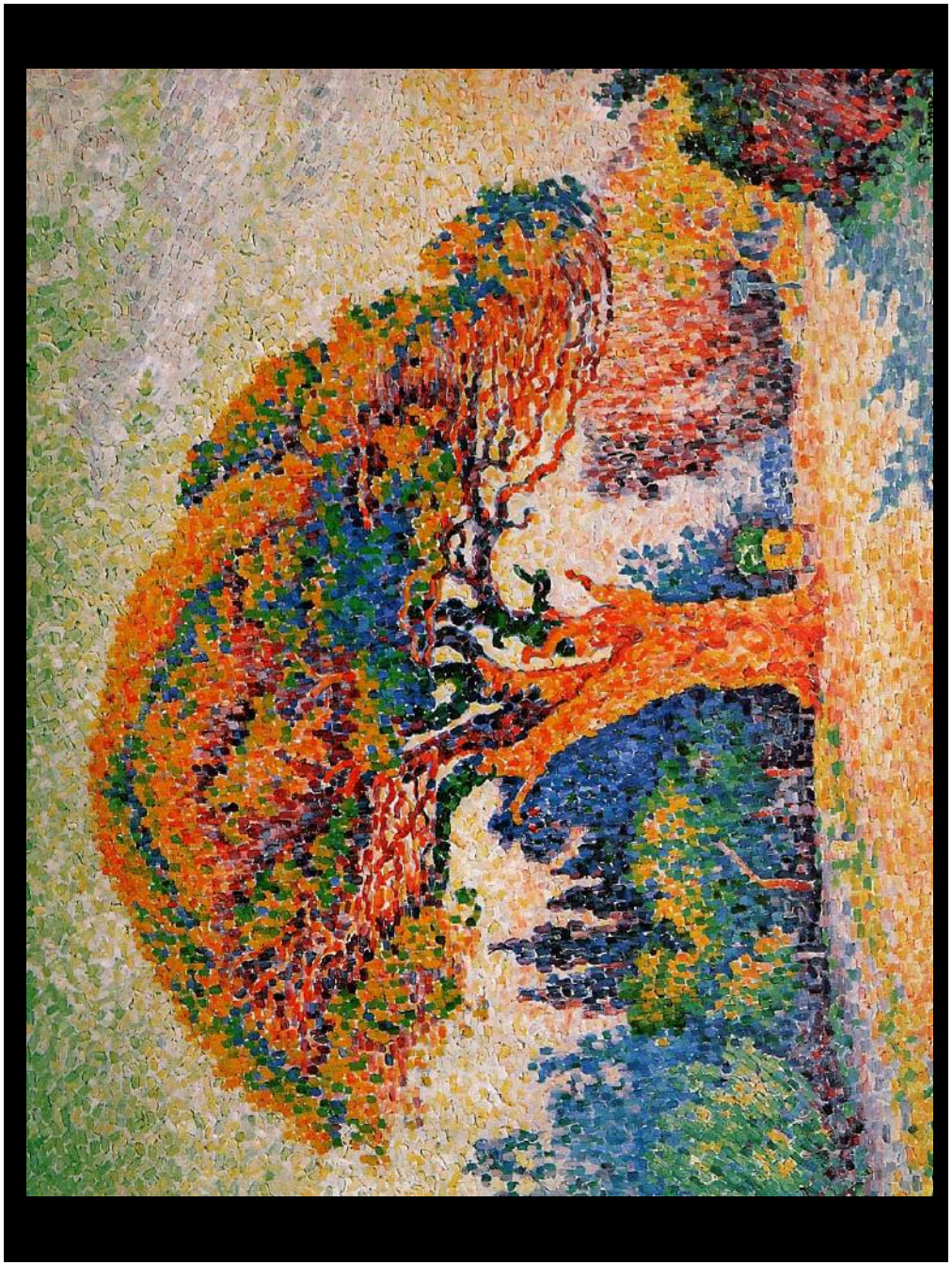


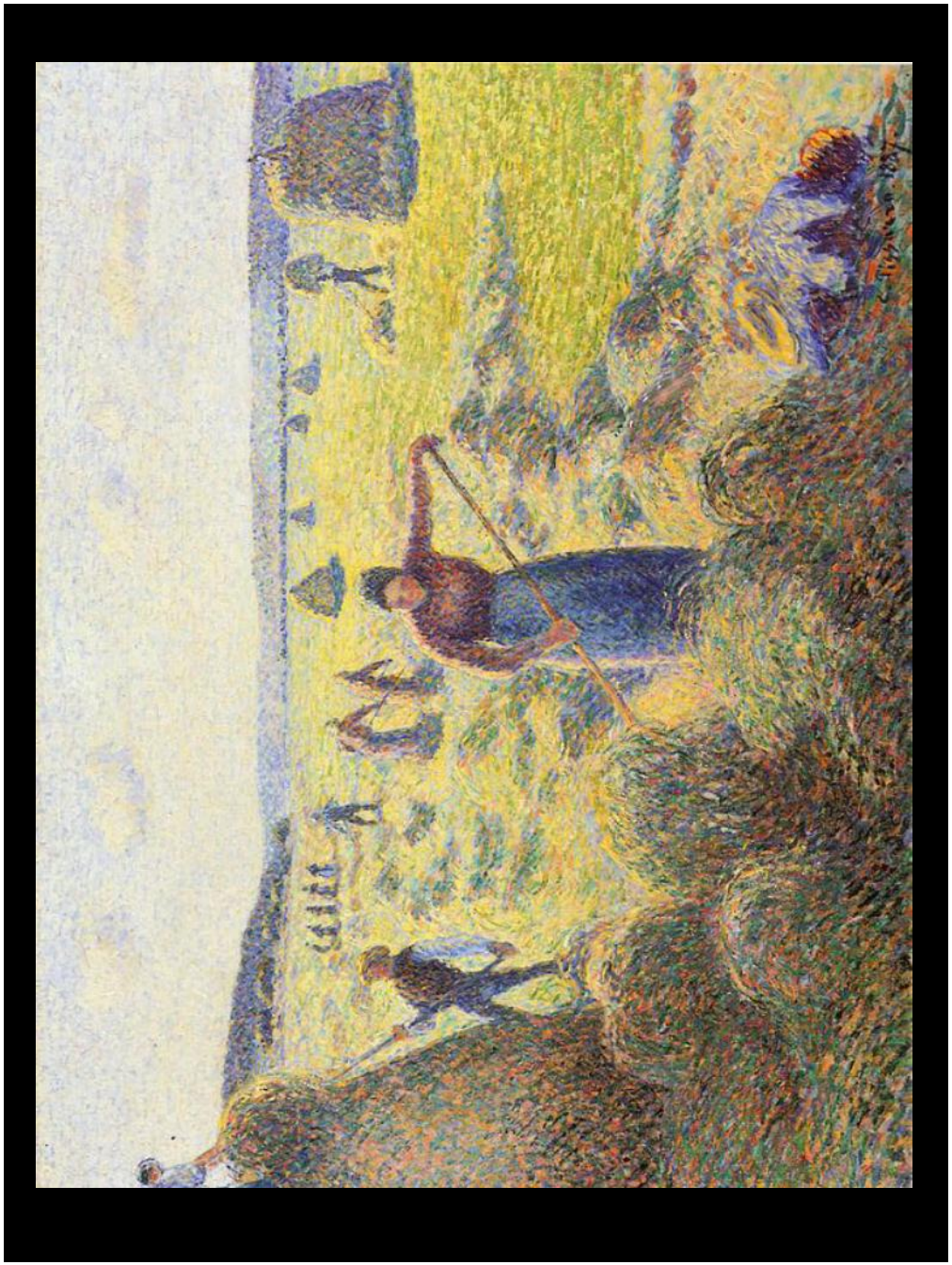
Halftoning in art









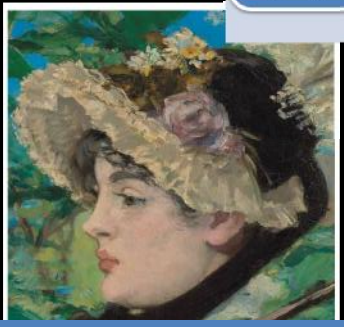


Recap about printing

Image/Doc
- Color/BW
- Size
- Paper type

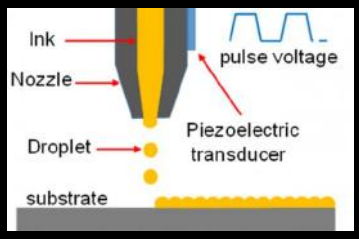
Driver/RIP (raster image processor)
- Device dependent parameters (economy, pro, resolution)
- Color management
- Halftone
- Translates halftoned image into voltage

Printer
- Printhead jets (or not) droplets of ink in a specific location
- Paper and/or printhead move



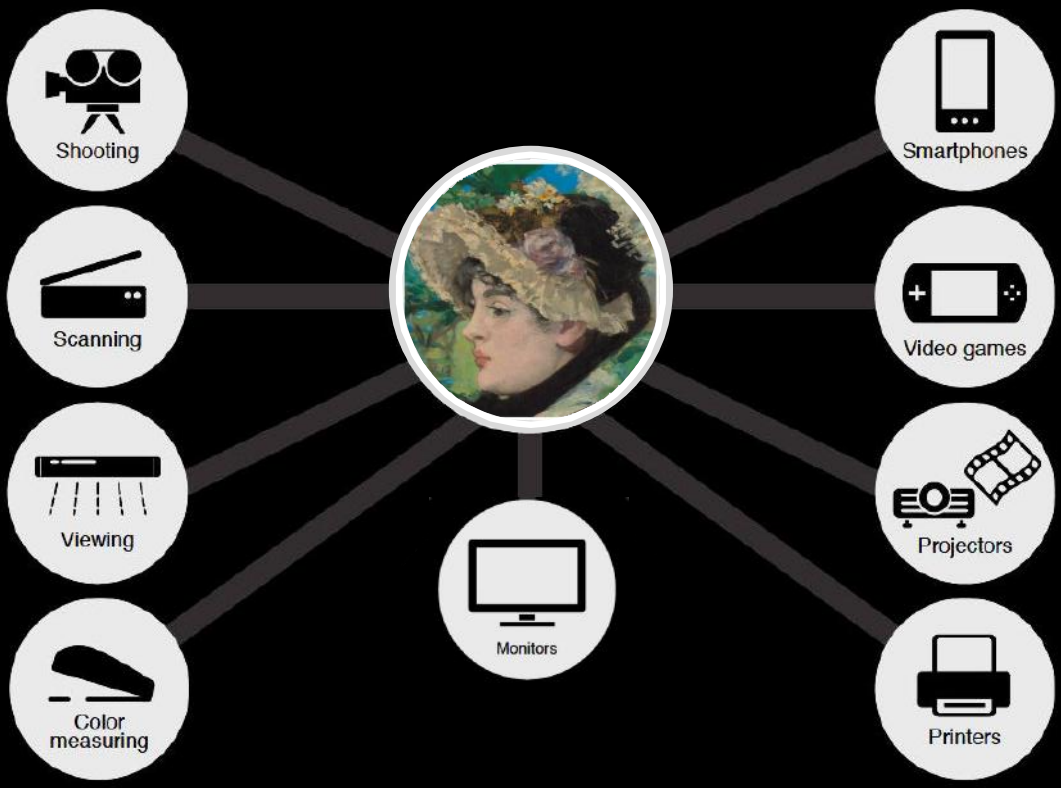
Input: raster image

1. Color separation
2. Halftoning
3. Electrical signal for printheads

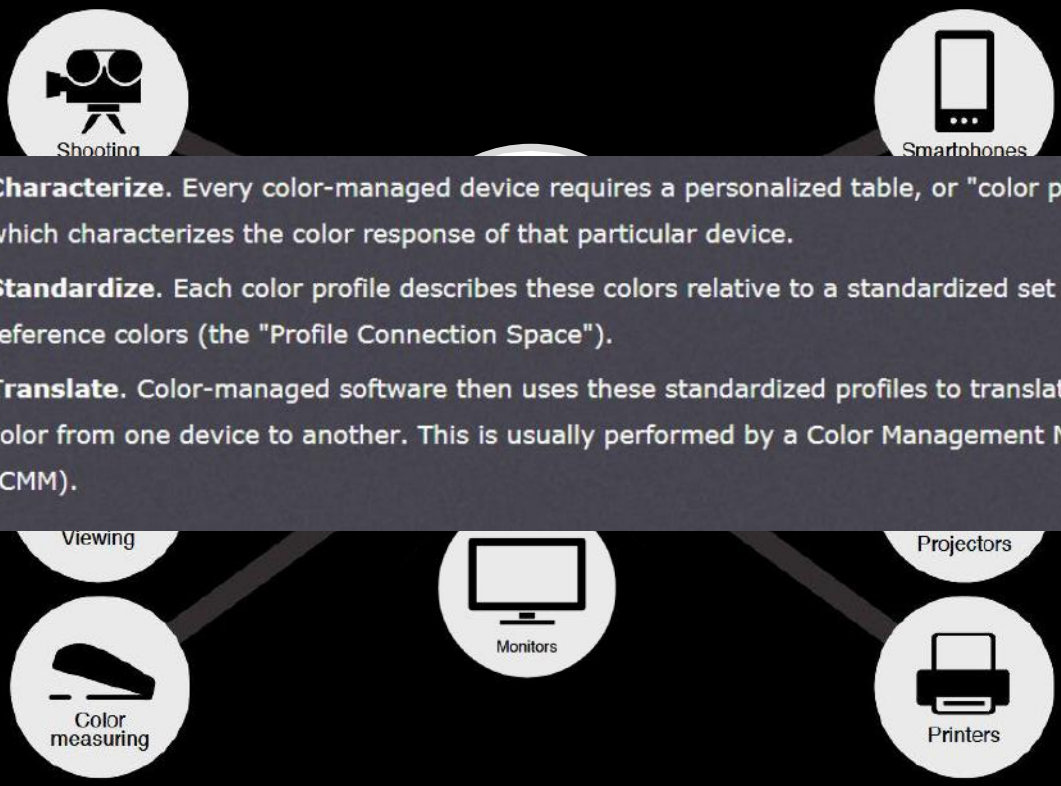


Output: printed image

Color workflow



Color workflow



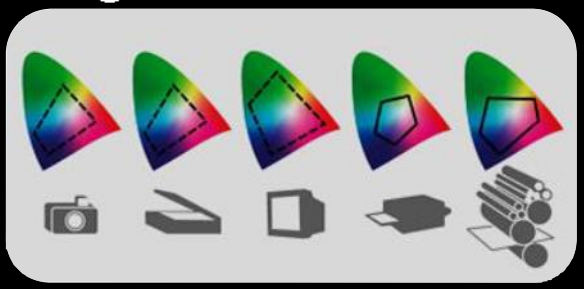
1 - **Characterize**. Every color-managed device requires a personalized table, or "color profile," which characterizes the color response of that particular device.

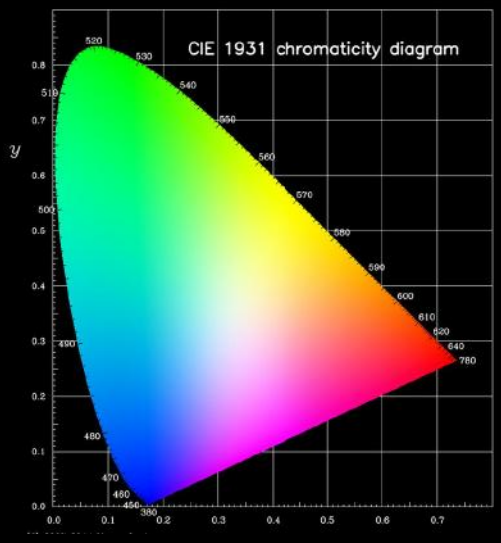
2 - **Standardize**. Each color profile describes these colors relative to a standardized set of reference colors (the "Profile Connection Space").

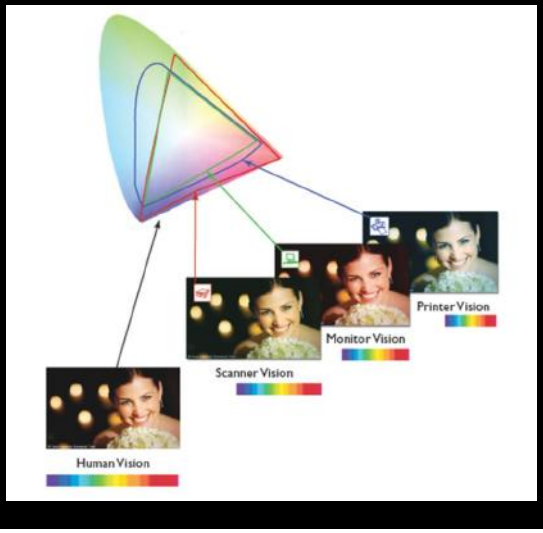
3 - **Translate**. Color-managed software then uses these standardized profiles to translate color from one device to another. This is usually performed by a Color Management Module (CMM).

Characterization: device color space

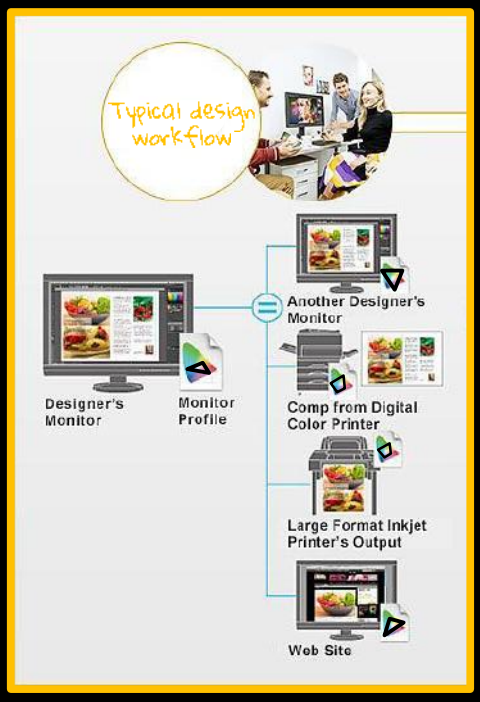
color gamut



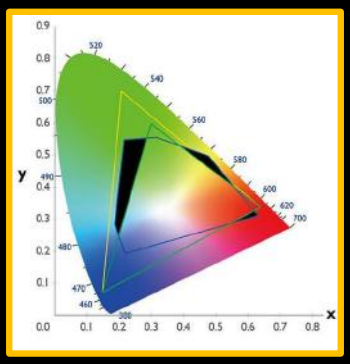




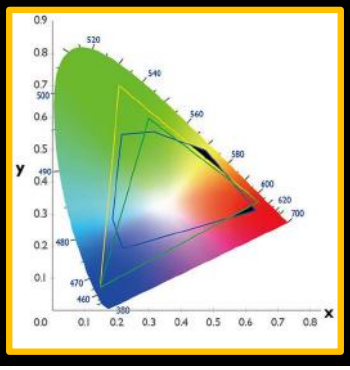
How to reproduce the same color?



sRGB vs CMYK



Adobe RGB vs CMYK



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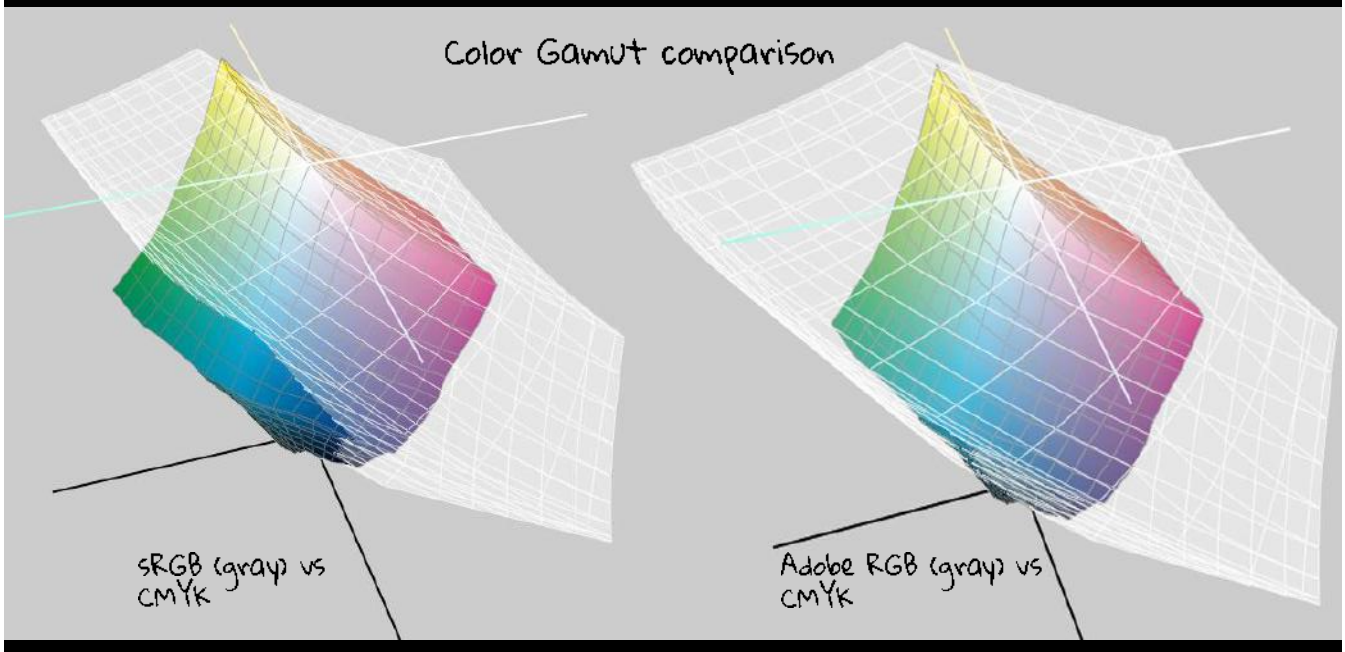
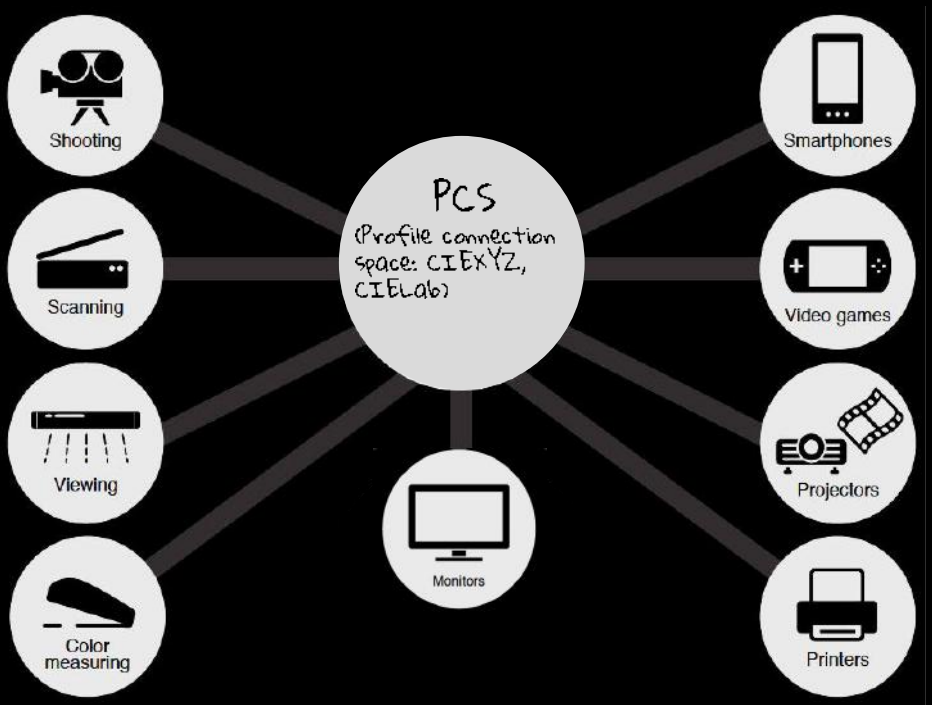


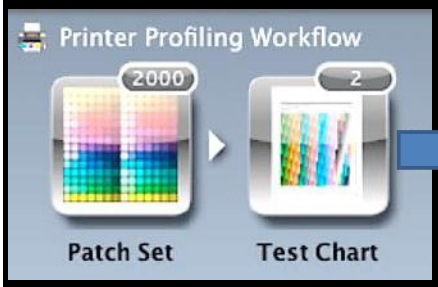
Standardize: ICC color management



Main idea: use a device-independent color space to communicate color between devices

Translation: How to do an ICC profile?

case study: printers

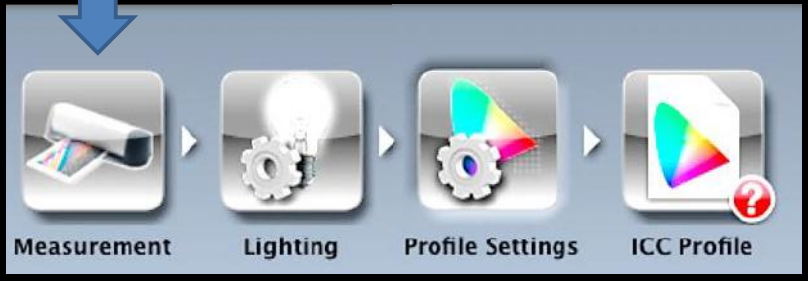


An ICC profile corresponds to a very **specific state** of the printing process:

- Printing mode
- Resolution
- Paper
- Ink batch
- Humidity/temperature
- ....

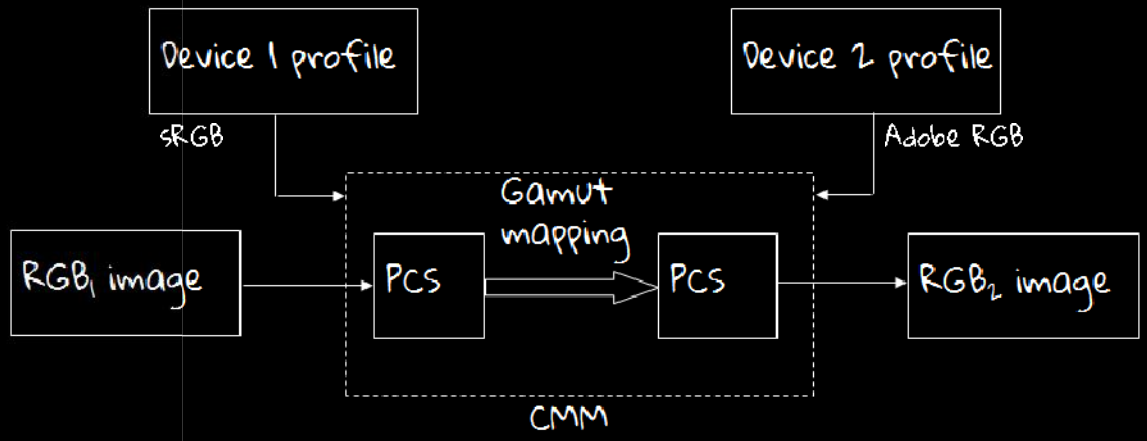
ICC profiles depend also on:

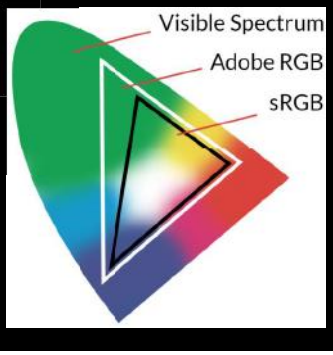
- Measuring device
- Profile settings
- Profiler software
- PC used to produce profile (OS, processor, etc)



How to use profiles?

an example

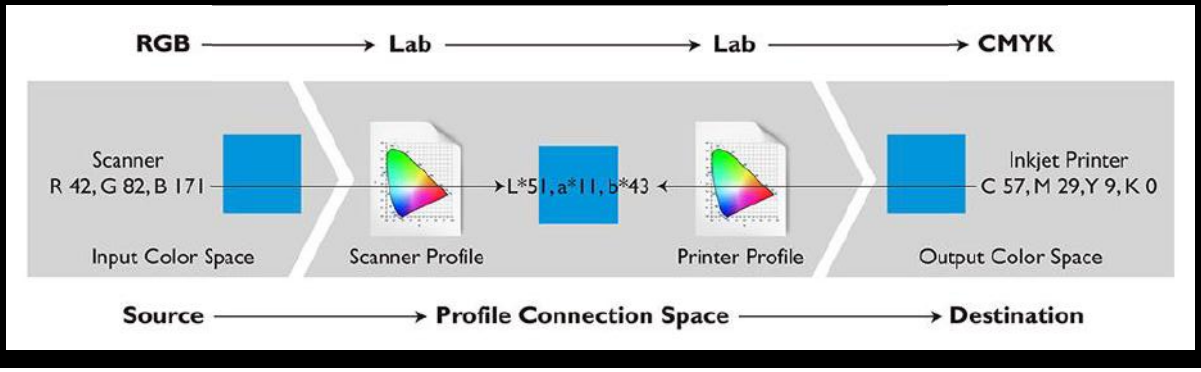




CMM (color management module): is a software algorithm that adjusts the numerical values that get sent to or received from different devices

Another example

From RGB to CMYK



A recap: color workflow

1 - **Characterize.** Every color-managed device requires a personalized table, or "color profile," which characterizes the color response of that particular device.

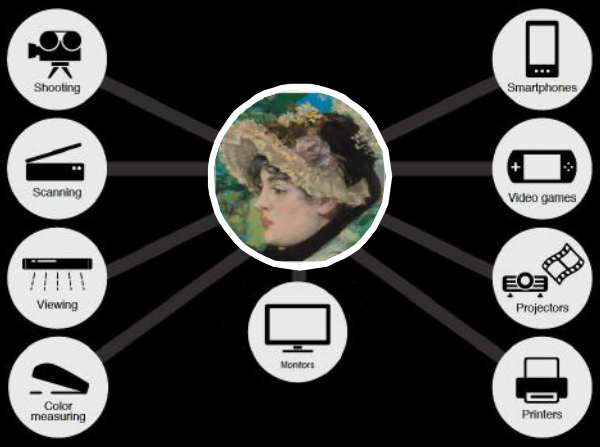
2 - **Standardize.** Each color profile describes these colors relative to a standardized set of reference colors (the "Profile Connection Space").

3 - **Translate.** Color-managed software then uses these standardized profiles to translate color from one device to another. This is usually performed by a Color Management Module (CMM).

→ Get device color space/gamut

→ Go to a device-independent color space (PCS)

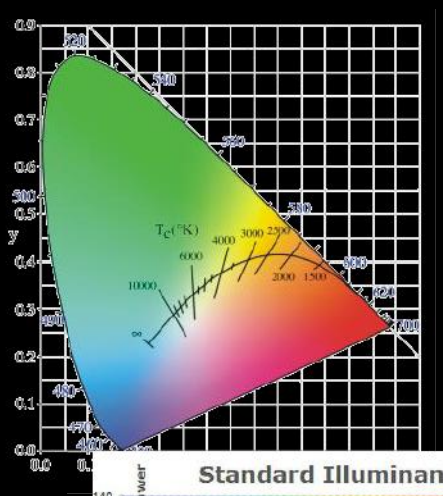
→ Apply ICC profile source-destination (CMM)

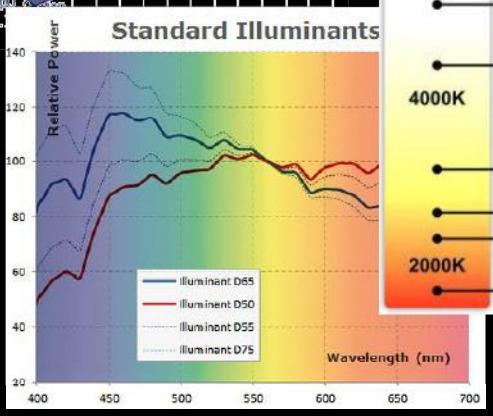


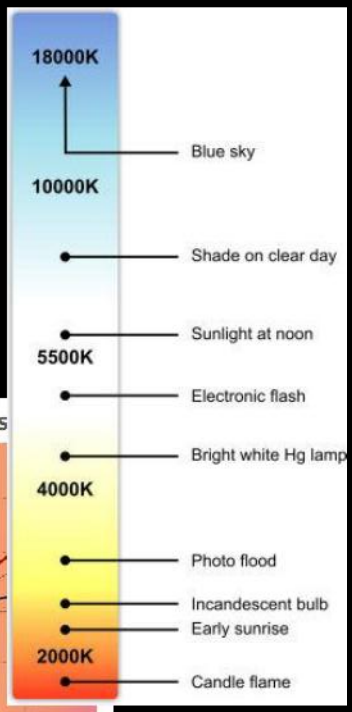
Profile (typical) settings

1. Illuminant - under what conditions we would use the profile?
2. Rendering intent - how to achieve gamut mapping?, do we want to be numerically accurate or perceptually accurate?
3. Black/white point compensation (B/WPC) - cameras, manually adjusted or automatic
4. Gray component replacement (GCR) - printers, how to generate the 4th channel

Illuminant



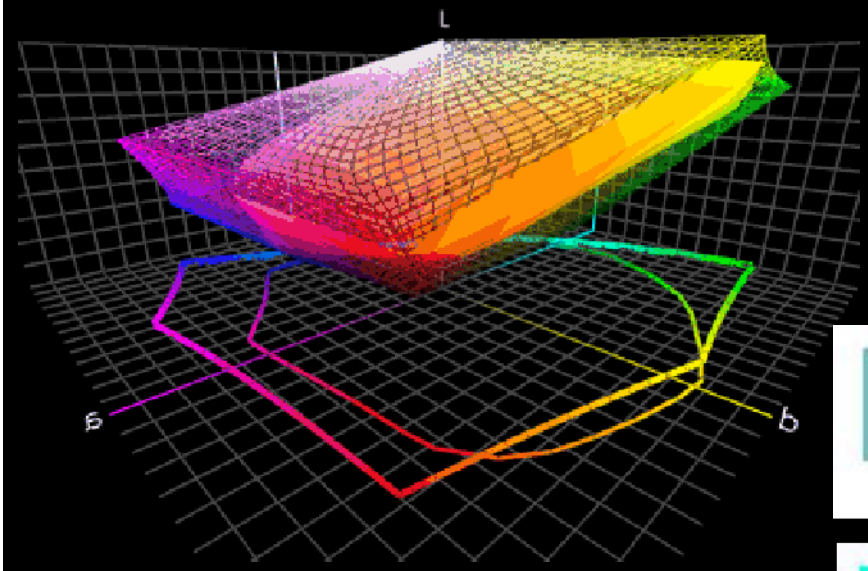


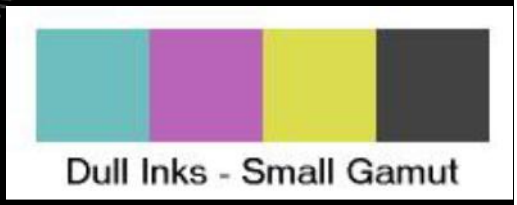


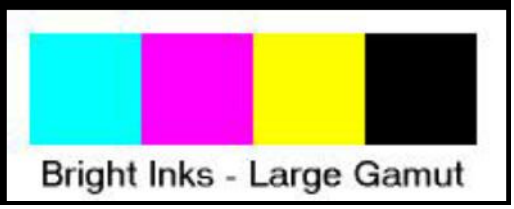
Nice, we can choose the illuminant!

Not that nice, we can't change afterwards as everything gets calculated based on that

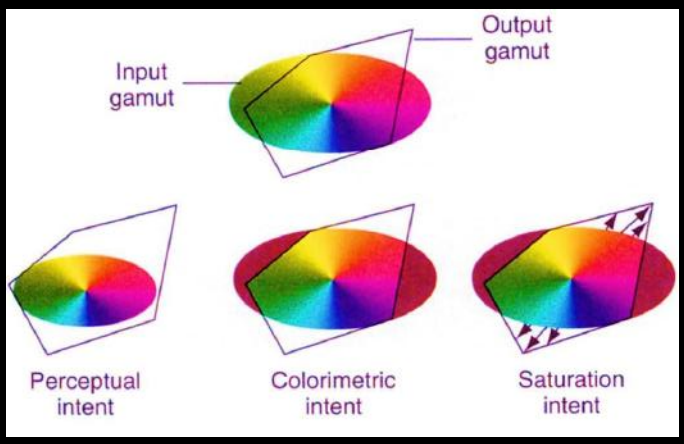
Color gamut







Rendering intent/Gamut mapping



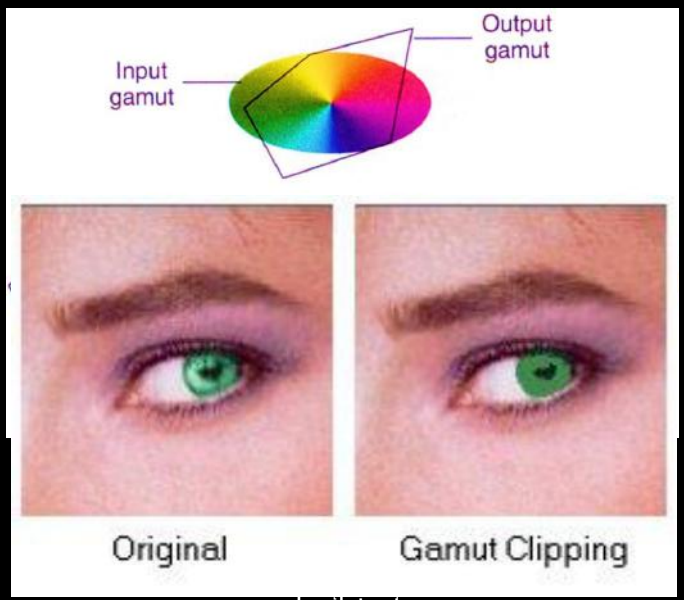
in-gamut colors shifted so the relationship between all the colors remains the same
out-of-gamut colors mapped to closest in-gamut colors

maps primary colors in the source to primary colors in the destination, neglecting differences in hue, saturation, or lightness

in-gamut colors reproduced exactly
out-of-gamut colors clipped to the nearest reproducible hue

Absolute: in-gamut colors reproduced exactly. Out-of-gamut colors are clipped to the nearest reproducible hue preserving the white point

Rendering intent/Gamut mapping



in-gamut colors shifted so the relationship between all the colors remains the same
out-of-gamut colors mapped to closest in-gamut colors

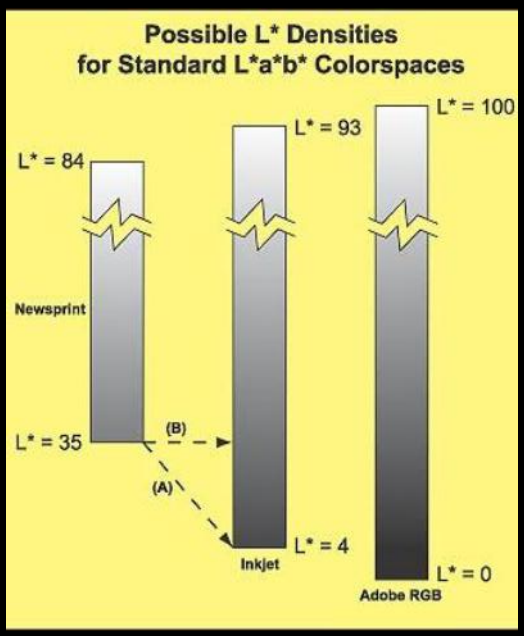
maps primary colors in the source to primary colors in the destination, neglecting differences in hue, saturation, or lightness

reproducible hue

Absolute: in-gamut colors reproduced exactly. Out-of-gamut colors are clipped to the nearest reproducible hue preserving the white point

WPC/BPC

- The white/black point of one space is rendered by the white/black point of the other, with intermediate levels mapped to produce a pleasing, smooth result.



Gray color replacement (GCR)

How 4th channel is generated in CMYK printers? GCR

- Gray level of an image when C=M=Y
- Full GCR, replace the value of C=M=Y by K
- X% of GCR, replace x% of the value C=M=Y by K

Original RGB image

Values of the image that contain C=M=Y

0 GCR

Gray color replacement (GCR)

How 4th channel is generated in CMYK printers? GCR

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- X% of GCR, replace x% of the value C=M=Y by K

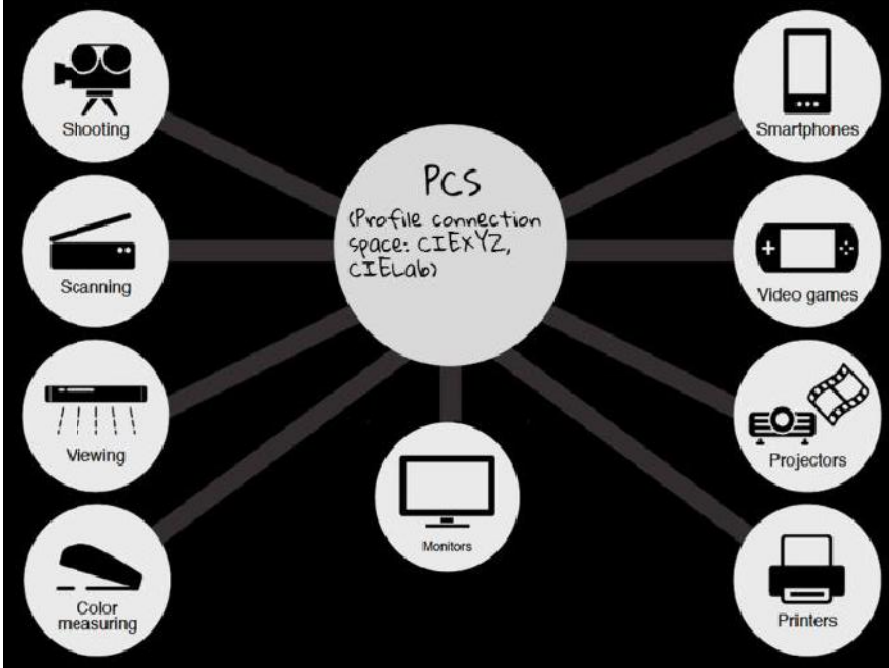
Original RGB image

Values of the image that contain C=M=Y

0 GCR

Full GCR

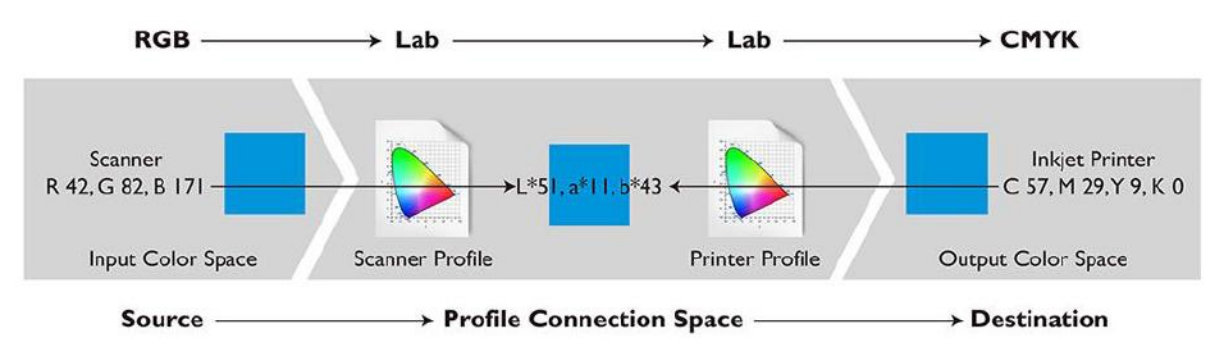
Recap why/how to use/make an ICC profile



Too many devices with different sensors, illumination and viewing/rendering conditions exist....all use color in different ways and with different purposes!

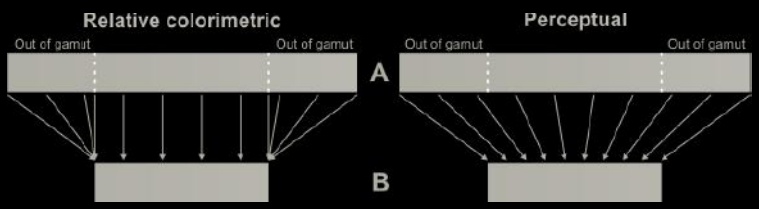
There is the need to standardize the use of color.

Recap why/how to use/make an ICC profile

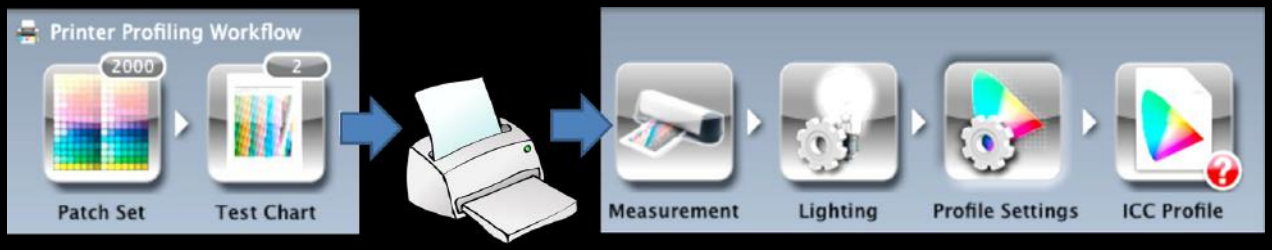


We usually have a source and a destination profile and we need to "translate" colors from one to the other.

ICC profiles do the translation in between devices



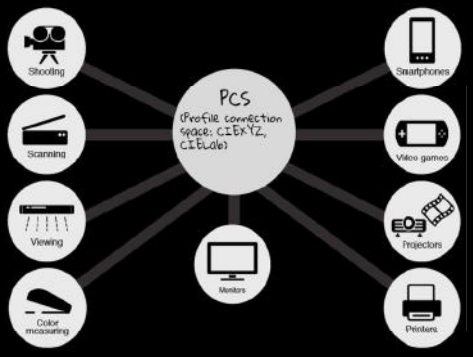
Recap why/how to use/make an ICC profile

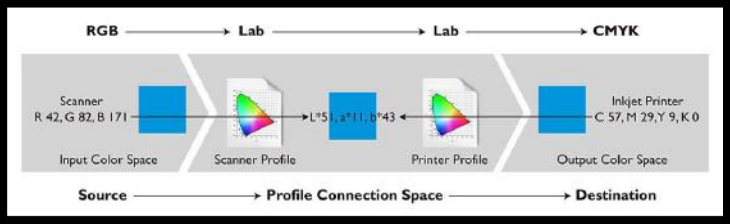


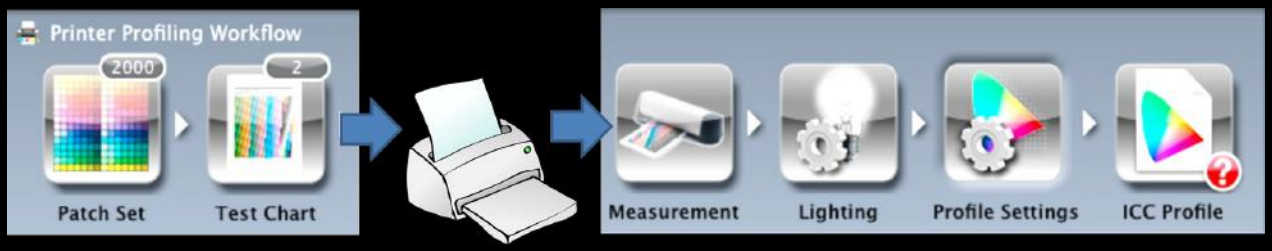
An ICC profile represents a given instance of a profiling process. It contains (intrinsically) all the internal and external parameters under which it was created

Profile software, inks, profile settings, test chart, number of patches, measuring device, lighting, standard observer, temperature, humidity.....etc etc etc

Recap why/how to use/make an ICC profile







Take home message

- Color is still very complicated
- Different devices use color, in order to communicate, there is the need to:
  - Characterize them (get their color space)
  - Go to a device-independent color space (standardize)
  - Get translation to another color space
- The translation depends on rendering intents
  - Colorimetric: clip colors
  - Perceptual: shrinks gamut
  - Saturation: keep saturation over color
  - Absolute: soft-proofing, maintain white point
- ICC profiles help but are not a guarantee of accuracy

Some areas of research

- Gamut mapping
- Gamut sampling
- Color in 3D printing
- More dynamic ICC profiles → ICCMax
- Halftoning for 3D applications (less for 2D because resolution and PC are powerful enough)
- WPC/BPC/GCR
- Device color constancy
- Inter-device color constancy
- Spectral reproductions
- Pigments/materials