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Color Rendering
Printing
Scanning

Traditionally, TrueColor bitmap images are defined by one byte R,G,B per color channel. This is called a tristimulus system.
The RGB values don´t give a complete information about physical colors. The reference to physical colors is created by defining the CIE xyY values of the Primaries and the White Point. RGB is a color order system, CIE is a color space. The Primaries are the corners of a gamut triangle in the CIE xyY diagram in the wellknown horseshoe contour.
Calculations are done in a Working Space. This is represented by an RGB triangle as above. Standard Working Spaces are sRGB or Adobe RGB(98).

So we can assume, that file data refer to a tristimulus system which is either defined explicitely or embedded in the file as a so called Tagged Profile. Without this information it´s not possible to print correctly or to show the data correctly on a monitor, which has its own Profile.
For printing, the file image can be mapped virtually onto the paper. This is called Source RGB Image on the next pages. The source image pixels are not printed directly, they are interpreted.
Offset and Laser printers use raster cells to simulate the image. Here the ink or toner is clustered. Inkjets use dithering or diffusion by small drops. Both techniques have a very limited set of a few inks C,M,Y,K and eventually some extra inks like spot colors (offset inks) or light Magenta, light Cyan, Orange, Green (inkjets).

So we have a lot of conversions:
a) Interpretation of the Source RGB Image as physical colors.
b) Mapping of Source RGB pixels to real or fictitious raster cells.
c) Conversion to CMYK colors with the same appearance on the paper.
d) Generation of appropriate patterns of clusters or single dots.

Further informations in this documentt concern the necessary number of pixels for scanning, which is related to the printing process.

Color Rendering from Source RGB to Printer CMYK

Source RGB: RGB file, mapped virtually to the paper

RGB — Source RGB Pixels

Mean Value Computation or Interpolation

RGB — Color Halftone Cell

Gamma Correction
RGB to CIE Conversion

← RGB Source
sRGB, Trinitron
AppleRGB or
Working Space
e.g. Adobe 98

XYZ — Color CIE

Black-White Match

← Diffuse Black and White Point of RGB Source

← Diffuse Black and White Point of CMYK-Printer

XYZ — Color CIE

Color Mapping
Gamut Compression
CIE to CMYK Conversion

← ICC Profile
Rendering Intent
perceptual
abs.colorimetric
rel. colorimetric
saturation

CMYK — Color CMYK

Undercolor Removal
Ink limiter for Inkjets

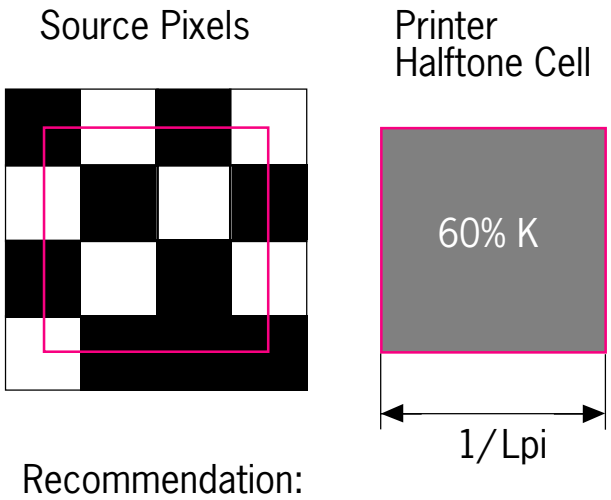
CMYK — Color CMYK-Printer

Halftone Rendering
Using Spot Function for Raster Print
Using Dithering/Diffusion for Inkjet

CMYK — Color CMYK-Printer

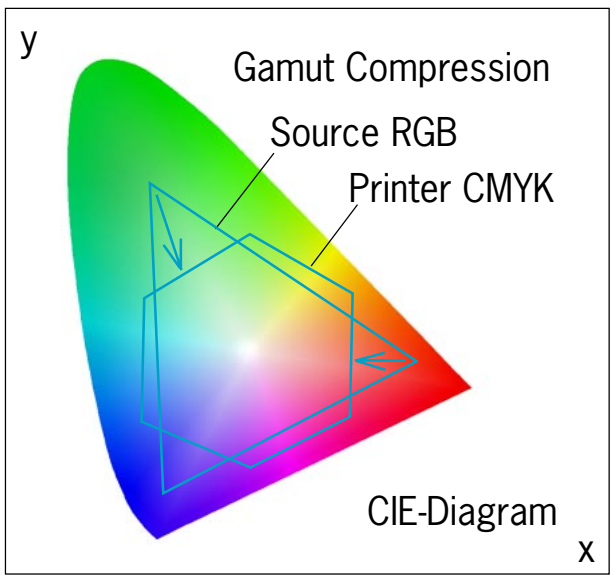
Scan Conversion

CMYK — Printer Pixels



Recommendation:
1.5 ... 2 Pixels per cell width

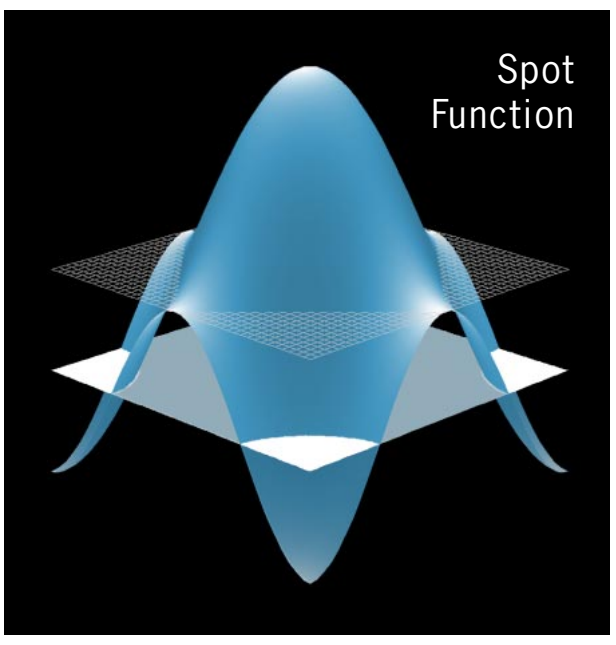
The Raster Frequency in Lpi is e.g. ten times smaller than the Printer Resolution in dpi
This results in $n = (dpi/Lpi)^2 + 1$
or $n = 101$ levels per color



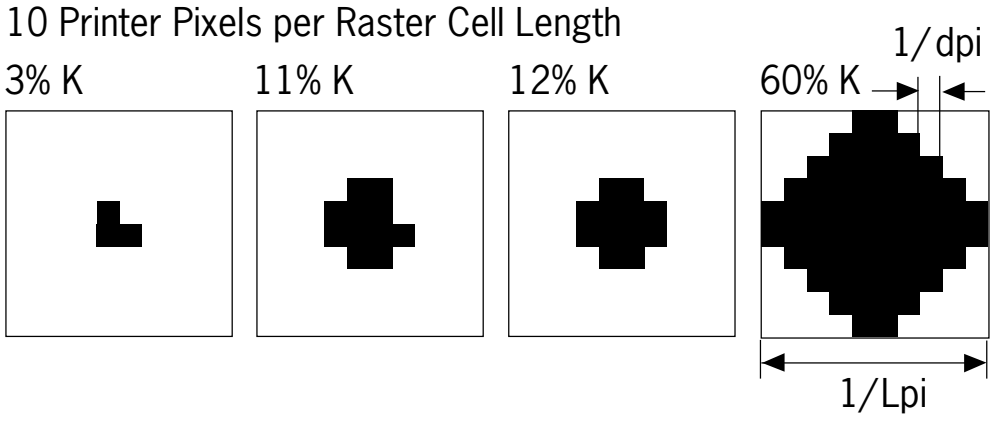
Gray Component Replacement GCR

Undercolor Removal UCR

c = 1 – R
m = 1 – G
y = 1 – B
k = min (c,m,y)
C = c – U(k)
M = m – U(k)
Y = y – U(k)
K = B(k)
e.g.
U(k)=k B(k)=k

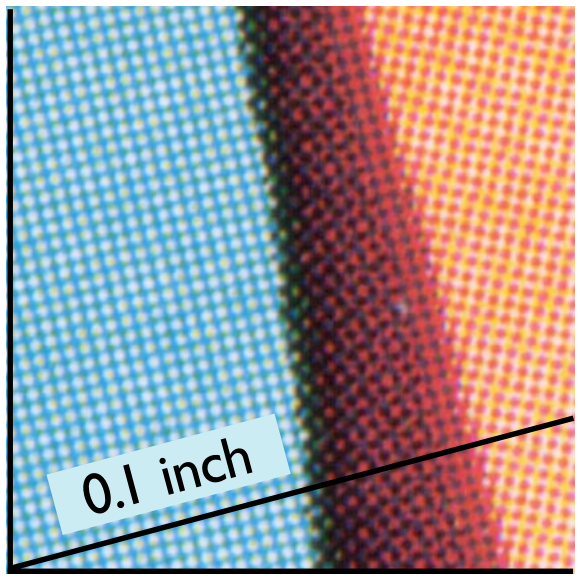


10 Printer Pixels per Raster Cell Length



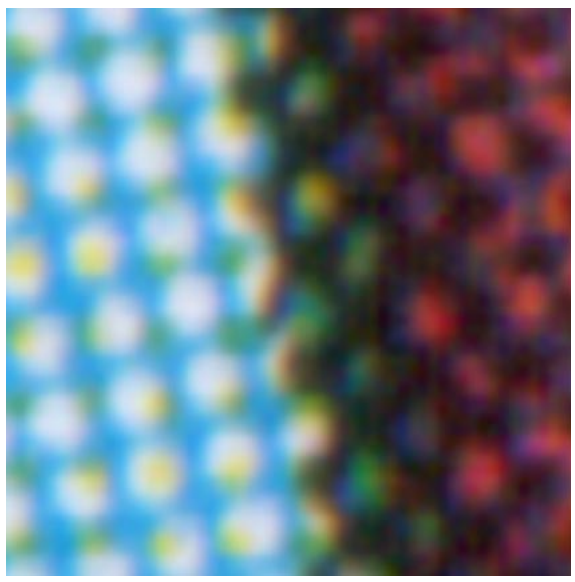
Laser and Offset Printing
CMYK and K only

Raster frequency	150	Lpi
Resolution about	2400	dpi
Angle C	75°	
Angle M	15°	
Angle Y	0°	
Angle K	45°	
Scan resolution	1200	dpi



Zoomfactor	5	

Zoom
by interpolation

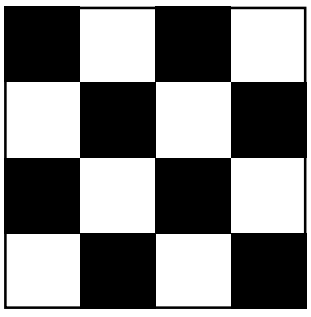


Raster frequency	175	Lpi
Resolution about	2400	dpi
Angle K	45°	
Scan resolution	1200	dpi

Angles are measured in German standards clockwise, beginning at the vertical. In other standards they are measured counter-clockwise, beginning at the horizontal.

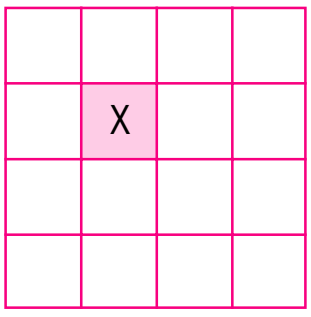
How many Pixels for Raster Printing ?

The left figures show images, virtually mapped on the paper. 8 white and 8 black pixels. The right figures show 16 (resp. 4) raster cells in Lines per inch divisions (Lpi). Fig. B : one image pixel per raster cell is correctly reproduced. Fig. C: the relative position is shifted. The raster dots are different, but the appearance is also medium gray. Attention: normally, pixels are not aligned to cells. Refer to figure page 1, top right.

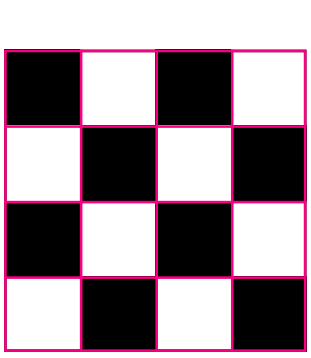


Left: A chess board pixel pattern, virtually mapped on the paper.

Right: Grid of raster cells in Lpi divisions. The gray value of a cell X is computed by averaging the inside pixel values

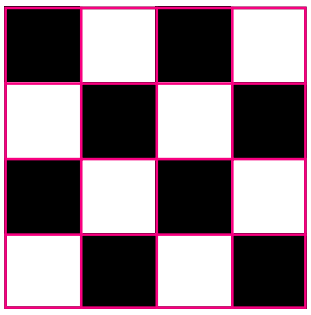


A

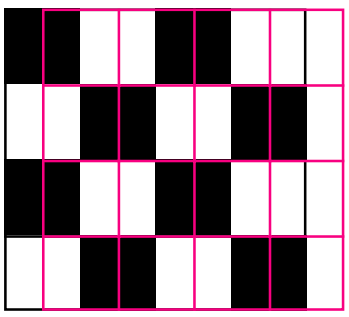


Left: Exactly one pixel per raster cell. Pixel pattern and raster grid are aligned.

Right: Precise reproduction of the content. This is not perceived as a chess board but as 50% gray.

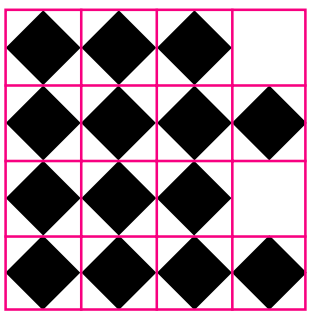


B

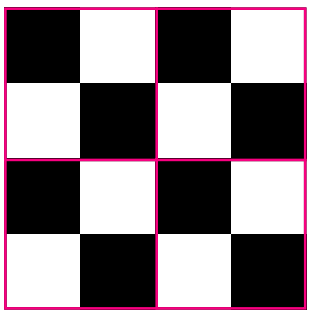


Left: Exactly one pixel per raster cell. Pixel pattern and raster grid are not aligned.

Right: Reproduction of the average in each cell by 50% K dots.
This is also perceived as 50 % gray.

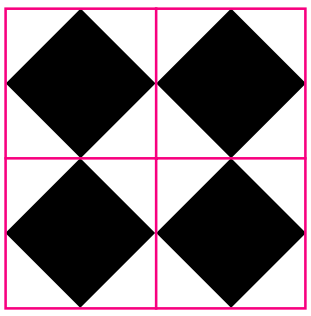


C



Left: Exactly two pixel per cell length. Pixel pattern and raster grid are aligned.

Right: Reproduction of the average in each cell by large 50% K dots.
Appearance again 50 % gray.



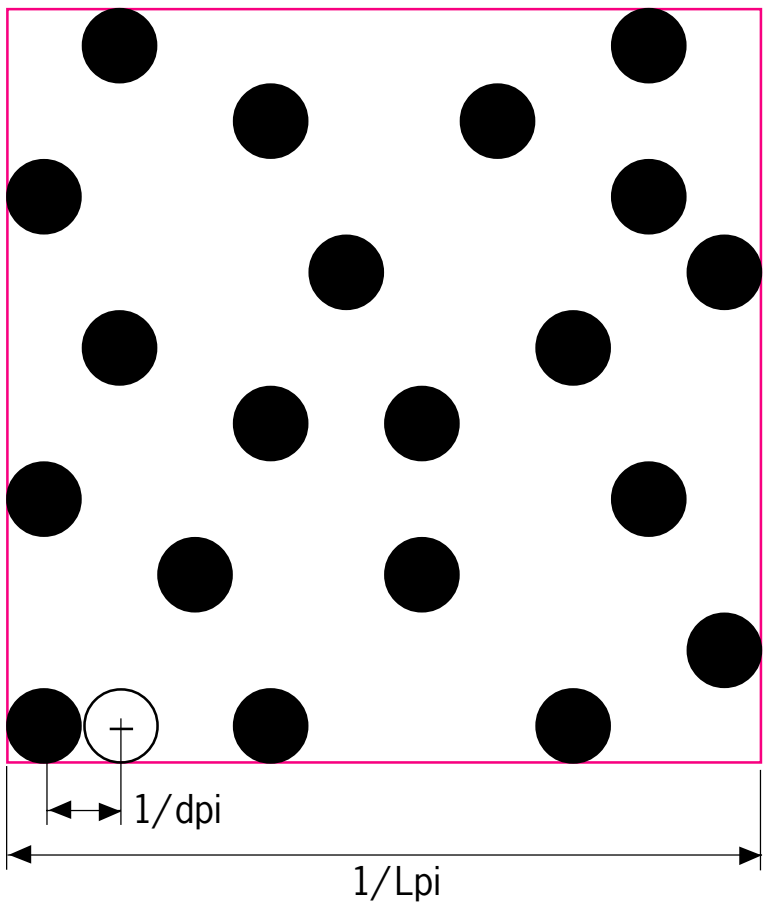
D

Fig. D: half the Lpi value, means two pixels per raster cell width. The appearance is again medium gray. Each raster cell is an averager. This should not be considered as sampling. Therefore the Nyquist-Shannon Sampling Theorem - at least two samples per wavelength, here 2 pixels - is not directly applicable.
By Nyquist- Shannon, only version B would be correct. The theoretical minimum is one pixel per raster cell length.
To avoid aliasing (fuzzy edges), 1.5 to 2 pixels per cell width are usually recommended.

$$px = (1.5 \ldots 2) \cdot Lpi \cdot wx$$

px	pixel number in width direction
Lpi	raster frequency in Lines per inch
wx	width of image in inch on print

How many Pixels for Inkjet Printing ?



This fictitious raster cell represents one or more source pixels with an average of 20% gray.

The number of gray levels in one cell is defined by $n = (dpi/Lpi)^2 + 1$

Here we have $n = 101$ for $dpi/Lpi = 10$

The relation of dpi/Lpi in the printer settings is therefore very important for the number of levels per color, though the cells are not visible. The cell size defines directly the area in which the virtual image pixels are averaged.

In fact the dots are slightly larger, because 100 drops should cover the cell completely.

Inkjet printers try to simulate color patterns by clouds of ink dots without creating artifacts. It´s helpful to assume a fictitious raster cell, though the computation of dot clouds is distributed over the whole image (error diffusion, dithering).
A large cell can represent many levels per color (here gray), a small cell shows the geometry of the pixel image more accurately, but the number of color levels is smaller. Thus we have exactly the same situation as with raster printers. Depending on the fictitious Lpi setting, the number of necessary pixels has to be computed.

The printer software offers usually a default value for the raster frequency in Lpi. This may mean the Lpi setting for vector elements, which are not printed by dithering, e.g. text, lines and boxes. Then it´s not relevant for raster images (Lexmark 4079plus).
Raster printing is called AM or Amplitude Modulation. The size of the printed cluster dot is varied.
Diffusion printing is called FM or Frequency Modulation. The distance and the number of drops with equal size is varied.
Offset ink cannot be printed easily by FM, because of the high viscosity. This can be handled only by clusters.
Some desktop inkjets use a few different dropsizes, but the precision is limited. Large Scale printers use the same size, but eventually two additional colors, either orange and green (better gamut) or light magenta and light cyan. With these light colors, the dis-tance of magenta and cyan dots can be reduced - the same effect as smaller dots.

How many Pixels for Scanning ?

Scanning images should be considered as a process which has primarily nothing to do with printing - scan for image banks, apply image processing and save for any application. Nevertheless, sometimes it´s necessary to scan directly for a printable page. Again, we have to gather enough pixels. Therefore define the minimum scan size in pixels. Start with optical resolution. If the file is too large then reduce the resolution.

px = (1.5...2) · Lpi · wx

px	pixel number in width direction
Lpi	raster frequency in lines per inch
wx	width of image in inch on print
ws	width of image in inch on source
sc	scale sc = wx / ws
sr	scan resolution sr = px / ws

Example

px = (1.5...2) · 150 · 5 = (1.5...2) · 750 = 1125...1500

Lpi	150
wx	5
ws	3
sc	1.67
sr	375...500

The scan resolution is sr=(1125...1500)/3 = 375...500 scan dots per inch (dpi). Practically the image can be scanned also by 600 dpi, if the file size is accepted.
The scanner scans anyway by optical resolution (600dpi or 1200dpi, if available).
Scanning by any virtual resolution , e.g. 500 dpi, is performed by optical scanning and interpolation in advance to the file generation.
Starting with the printed size, it´s not necessary to know the scale.
We don´t have the least relation between Scanner-dpi and Imagesetter-dpi! It´s not useful to talk about dpi for an image. Only the pixel number px is essential.

Images on next page

Example for Scanning

Printed width	wx	=	5 inch
Scanned width	ws	=	3 inch
Pixel number	px	=	1500
Scan resolution	sr	=	500 dpi

Printed image

Scanned image

Everything about Color and Computers
http://www.efg2.com

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Website