Gernot Hoffmann

Color Rendering
Printing
Scanning
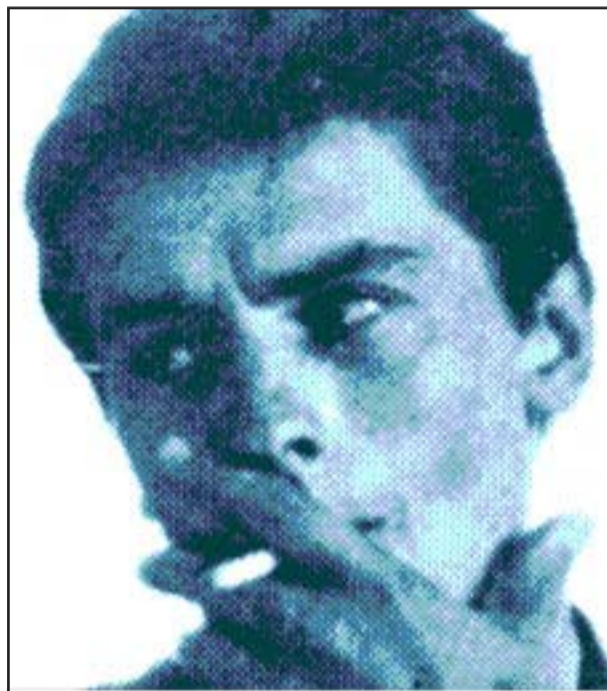
Contents

1. Introduction

Physical colors are defined by spectra: waves with varying intensity for the wavelength. Eye and brain condense this information to only three values which we may call Red, Green, Blue, though this is a little simplified.

At least we need only three informations to describe a color. A color projector could be made by three lasers with red, green and blue monochromatic rays. The arbitrary mixture of these rays with intensities from zero to one delivers a set of available colors – the gamut of the device. Monitors do not use monochromatic sources but three spectral distributions of waves, but these are characterized by equivalent monochromatic red, green and blue sources R,G,B. Obviously, the result of the mixture depends on the real color of the 'primaries' R,G,B. These are described in absolute physical coordinates CIE XYZ, based on the CIE(1931) color matching theory. CIE xyY (next page) is a perspective transform of the human gamut in XYZ onto a plane x,y. The luminance is left out, the content of the horseshoe shows colors *symbolically*. An image contains for each pixel a set of three numbers R,G,B, one byte or two bytes per channel. Equal values R,G,B mean gray, everything from black to white. A gray can be red-ish or blue-ish, therefore a white point W has to be defined in addition the primaries R,G,B.

These informations are carried in an ICC profile, either a working space profile like sRGB or Adobe RGB(98) or a monitor profile or a scanner profile. The gamut of such a tristimulus system appears in xyY as a triangle. In XYZ it is an affine distorted cube.

Printing is done by inks Cyan, Magenta, Yellow and additionally Black (K). Printed inks interact with the light source color by reflectance. C absorbes R, M absorbes G and Y absorbes B.

For printing, the file image can be mapped virtually onto the paper. This is here called source RGB image on the next pages. The source image pixels are not printed directly, they have to be interpreted.

Offset and laser printers use raster cells to simulate the image. The ink or toner is clustered by ordered dithering. Inkjets use stochastic dithering or diffusion by small drops. Both techniques have a very limited set of a few inks, CMYK and eventually some extra inks like spot colors (offset inks) or light magenta, light cyan, orange, green (inkjets, hexachrome).

Characteristics of printers are defined by ICC profiles as well. Therefore it is possible to convert a source image color R,G,B into a physical color X,Y,Z and then into amounts of ink, which creates the correct impression for at least one specified light source.

Altogether we have plenty conversions:

■ Interpretation of the source RGB image by physical colors.
■ Mapping of source RGB pixels to real or fictitious raster cells.
■ Conversion to CMYK colors with the same appearance on the paper.
■ Generation of appropriate patterns of clusters or single dots.

The conversion from a well defined RGB space into a well defined CMYK space is done for offset printing in advance, e.g. by Photoshop. For desktop printers the conversion is done by the printer driver or the printer itself.
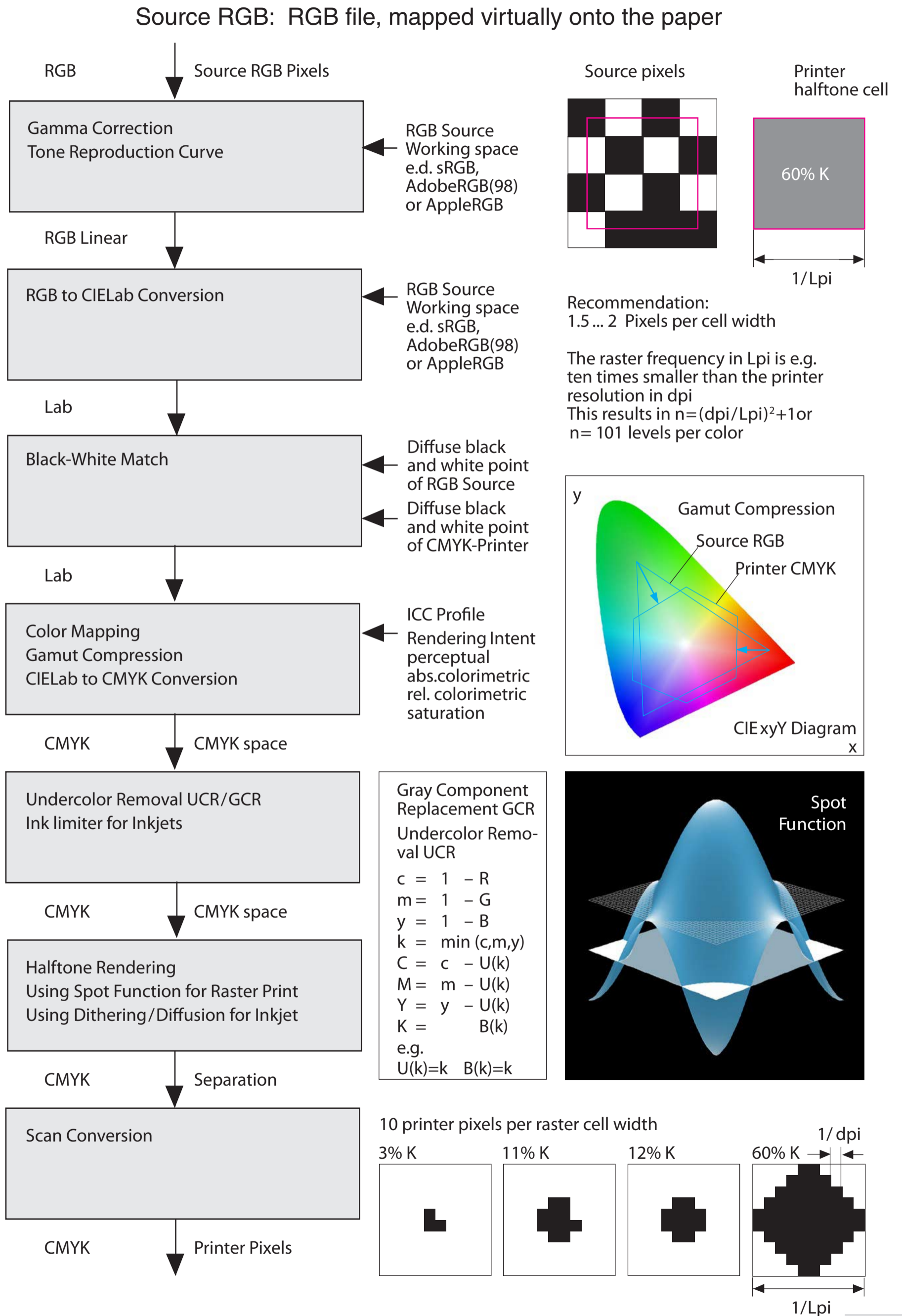

Settings for Acrobat

Edit / Preferences / General / Page Display (since version 6)
Custom Resolution 72 dpi / View by zoom 100% or 200%

Edit / Preferences / General / Color Management (full version only)
sRGB
Euroscale Coated or ISO Coated or SWOP
Gray Gamma 2.2

2.1 Color Rendering / Source RGB to Printer CMYK

Source RGB: RGB file, mapped virtually onto the paper

RGB | Source RGB Pixels

Gamma Correction
Tone Reproduction Curve

← RGB Source Working space e.d. sRGB, AdobeRGB(98) or AppleRGB

RGB Linear

RGB to CIELab Conversion

← RGB Source Working space e.d. sRGB, AdobeRGB(98) or AppleRGB

Lab

Black-White Match

← Diffuse black and white point of RGB Source

← Diffuse black and white point of CMYK-Printer

Lab

Color Mapping
Gamut Compression
CIELab to CMYK Conversion

← ICC Profile

Rendering Intent perceptual abs.colorimetric rel. colorimetric saturation

CMYK | CMYK space

Undercolor Removal UCR/GCR
Ink limiter for Inkjets

CMYK | CMYK space

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

CMYK | Separation

Scan Conversion

CMYK | Printer Pixels

Source pixels

Printer halftone cell

60% K

1/Lpi

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

Gamut Compression
Source RGB
Printer CMYK

y

x

CIE xyY Diagram

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.
$U(k)=k \quad B(k)=k$

Spot Function

10 printer pixels per raster cell width

1/dpi

3% K | 11% K | 12% K | 60% K

1/dpi

1/Lpi

3

2.2 Color Rendering / Raster Cells

The explanations on the previous page were simplified for tutorial purposes: actually the content of a raster cell is *not* an averaged version of the underlying source image. The values for the printer pixels are taken directly from the mapped source image, using a so-called threshold array (which is not explained here). This retains sharp edges. The clusters in the halftone cell may look fuzzy for low Lpi to dpi ratios.

The illustration shows halftoning by the author's implementation for round spots.
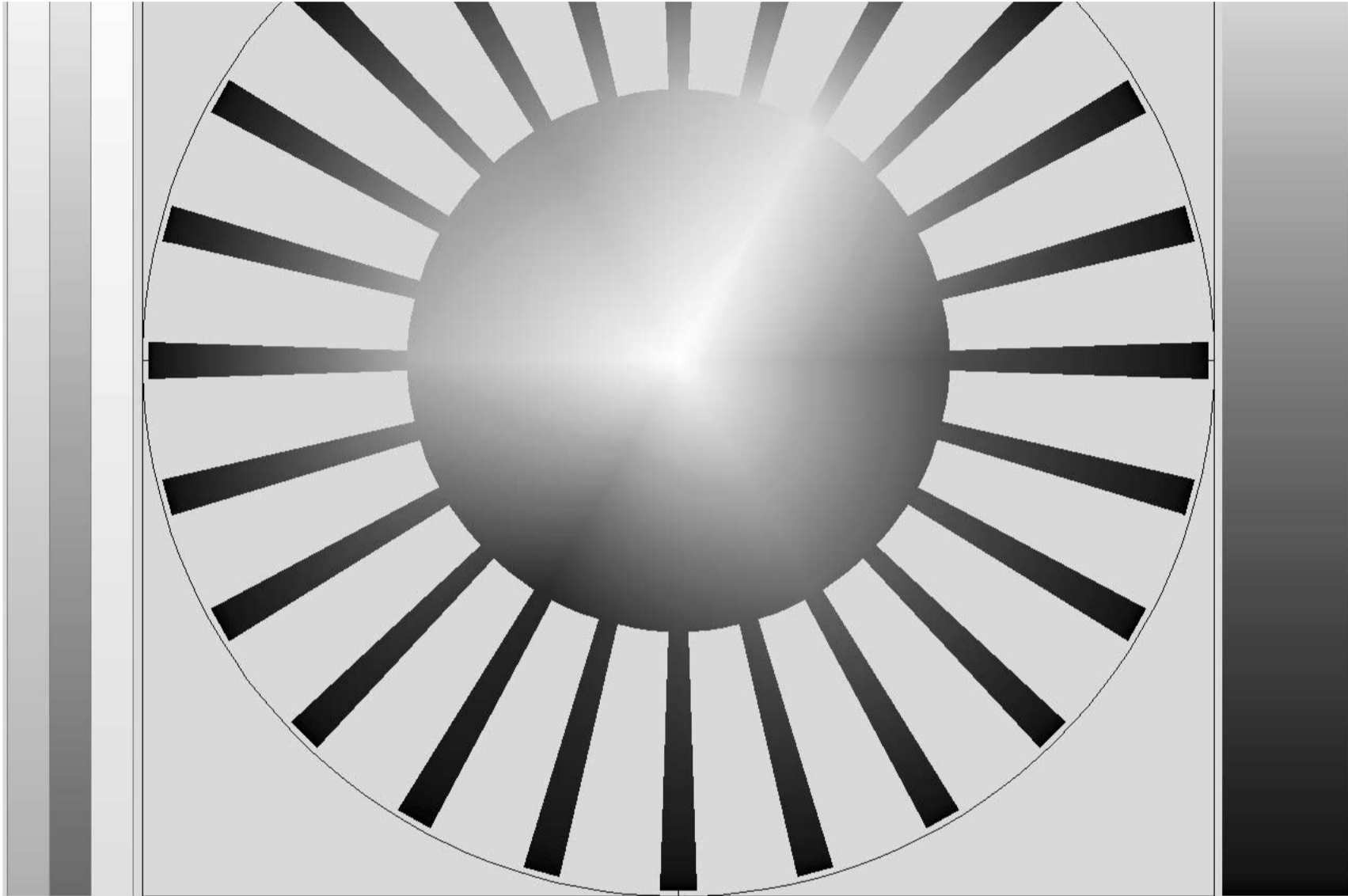
Best view zoom 200%
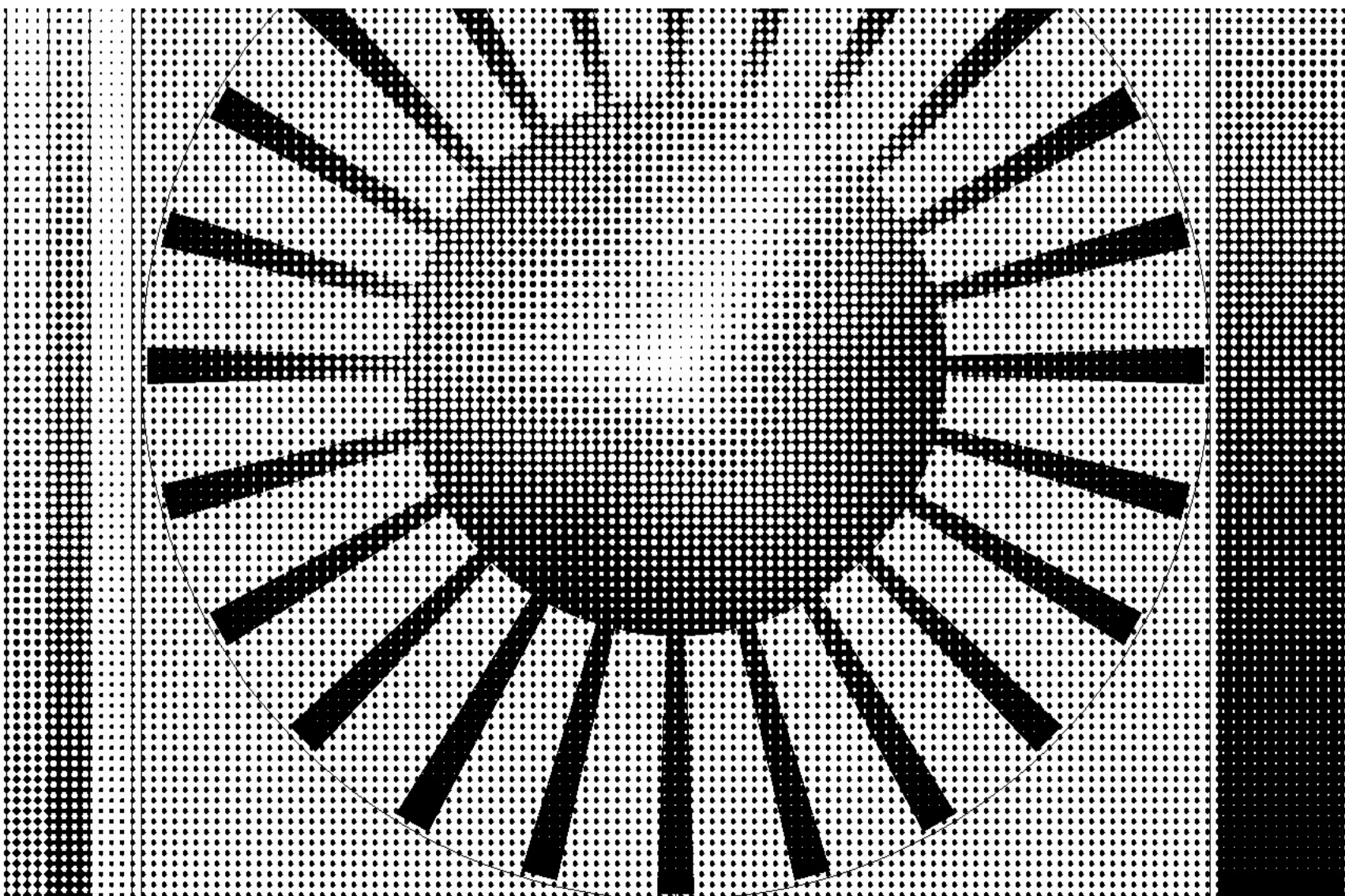
2.3 Spot Function for PostScript Round Dot

A raster spot is generated by the intersection of the spot function $z(x,y) = 0.5\,[\cos(\pi x) + \cos(\pi y)]$ and a plane. The spot function defines the area, but the spot has to be created by a spiral scan, starting in the middle. Fuzzy single dot lines should be avoided.

05%K

15%K

40%K

50%K

60%K

85%K

95%K

100%K
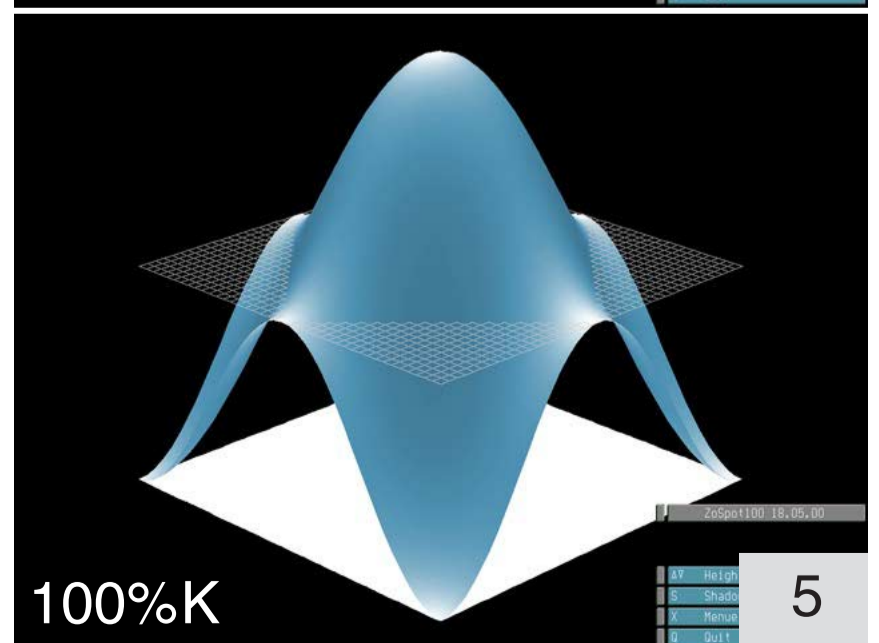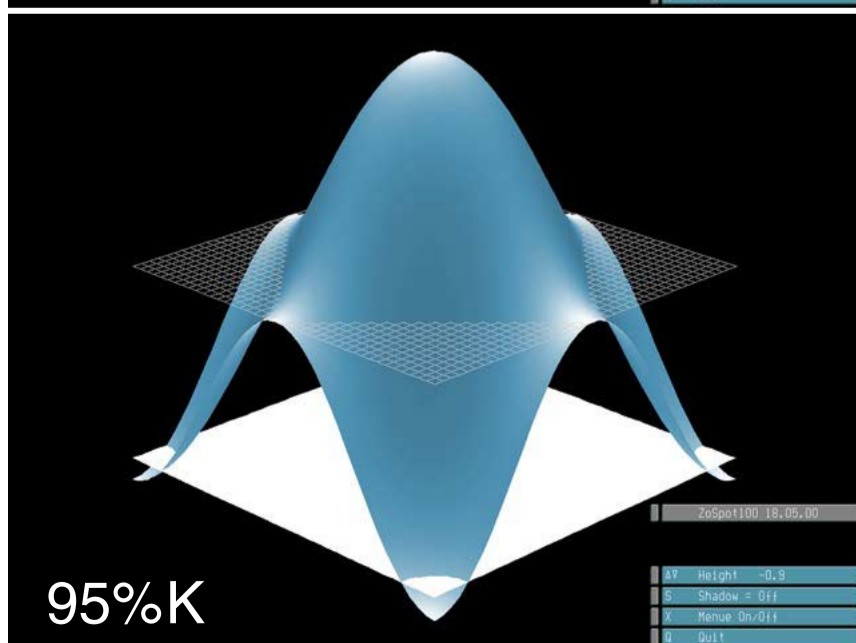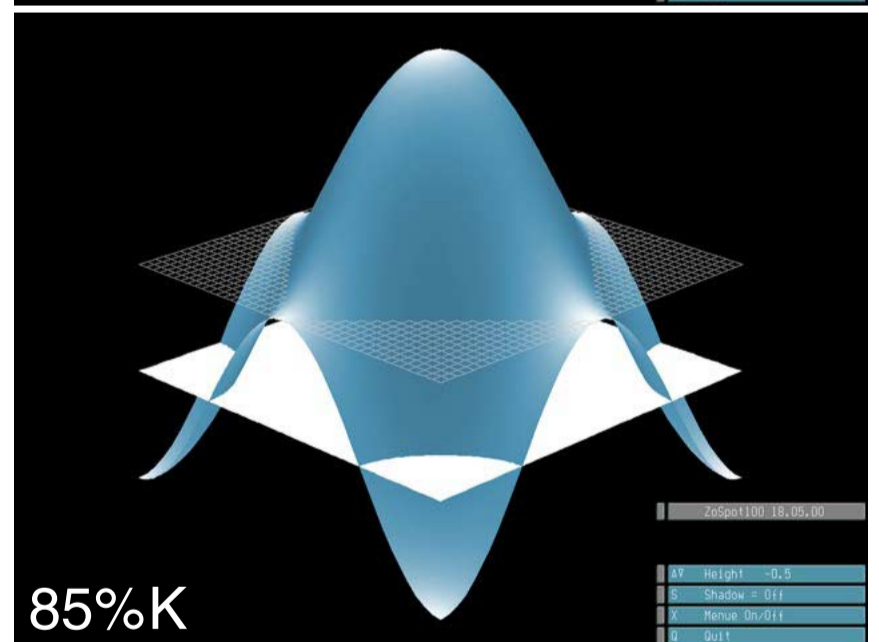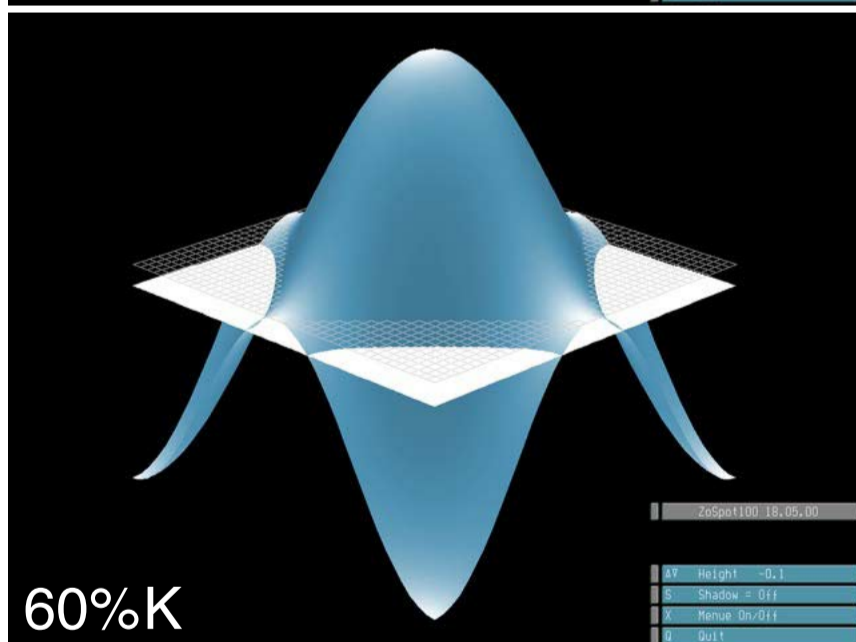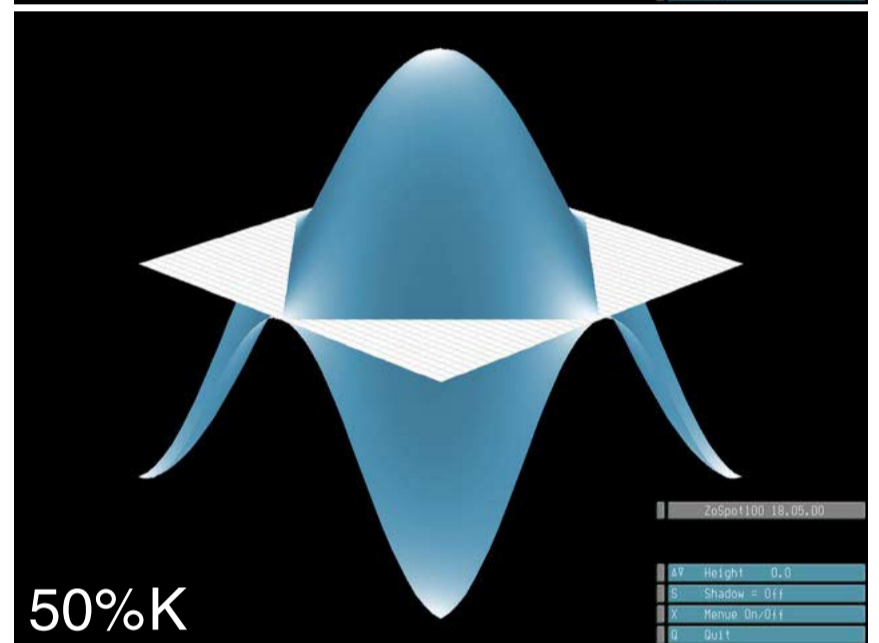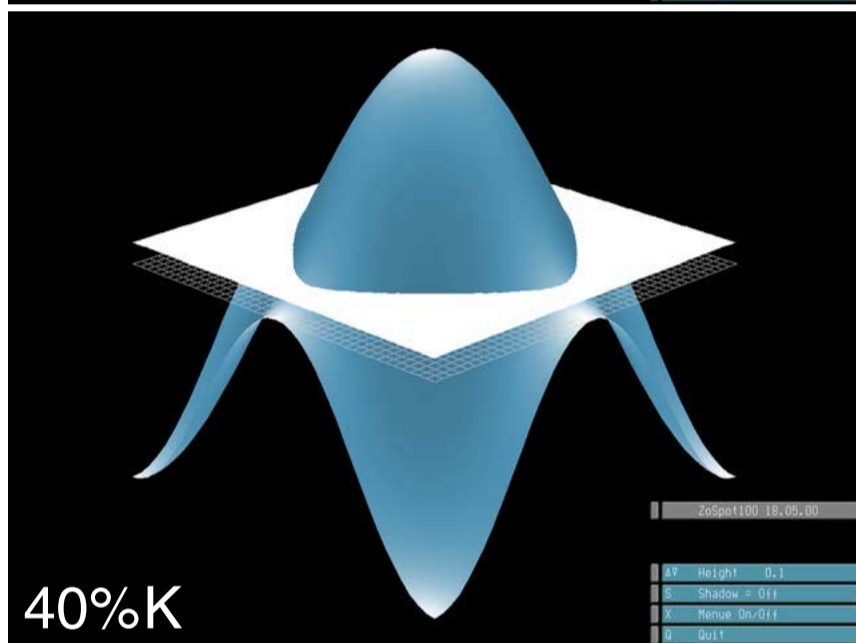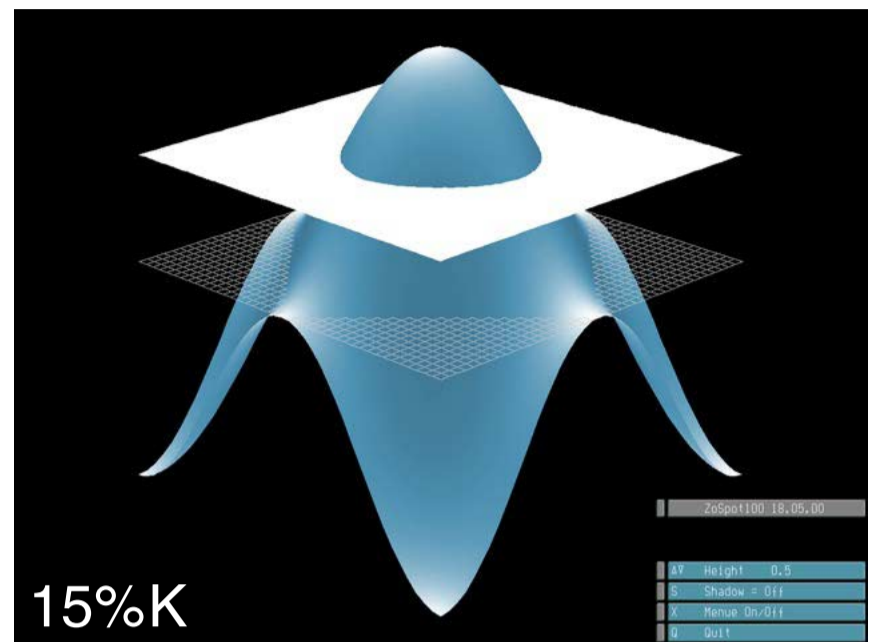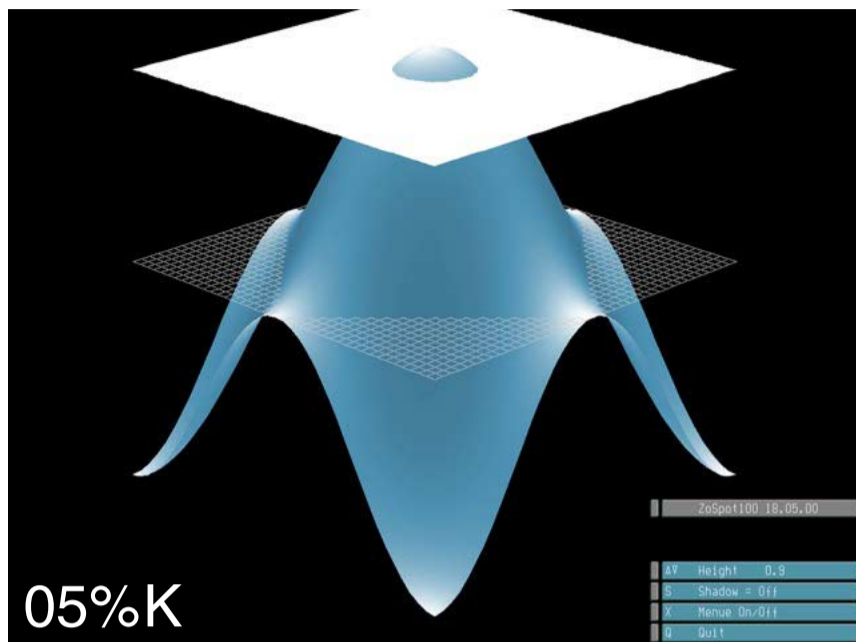
3. Laser and Offset Printing

CMYK and K-only

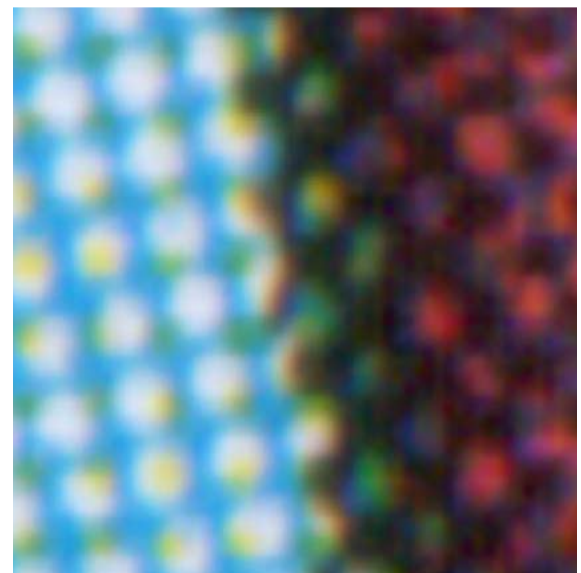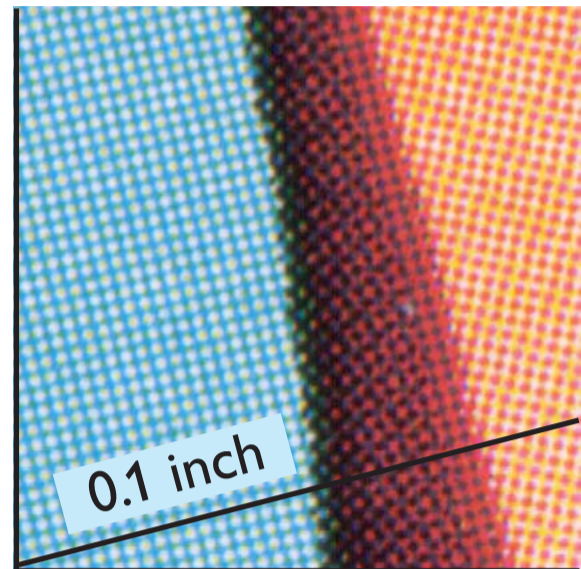Raster frequency   150 Lpi
Resolution about   2400   dpi
Angle   C   75°
Angle   M   15°
Angle   Y   0°
Angle   K   45°

Scan resolution   1200 dpi

Zoomfactor   5

Zoom by interpolation

75°

0.1 inch

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 counterclockwise, beginning at the horizontal.

4.1 How many Pixels for Raster Printing ?

It´s obvious from the previous chapters that we need at least one source pixel per raster cell. The recommendation below, Factor (1.5..2), is based on practical experiences.
Too many source pixels per raster cell might make the dots fuzzy, but this could not be proved by laser printing with 1200 dpi / 106 Lpi.

$px = (1.5...2.0) \cdot Lpi \cdot wx$	px	pixel number in width direction
	Lpi	raster frequency in Lines per inch
	wx	width of image in inch on print

$ppi = (1.5...2.0) \cdot Lpi$	ppi	pixels per inch for the source image, mapped virtually onto the paper

What happens if the ppi-value is too high, too many source image pixels ? It is common knowledge that this can spoil the print.
This issue was further investigated in September 2005, printing by a new color laser printer 1200dpi / 120 Lpi (next pages). This can be considered as a simulation for offset printing.

The guidelines as above are still valid, but modern rasterizes do not spoil the print if the source image is too large by pixels.

In the tests on the next pages the source image has always 120 x 120 pixels, but each one is shown scaled by a different size on the paper. This scaling means: the original source image is sent always as it is to printer, accompanied by PostScript commands 'bottom left corner at x,y' and 'edge lengths a,b on the paper'.
Neither PageMaker nor InDesign manipulate images (with the exception of cropping for printing to PostScript).

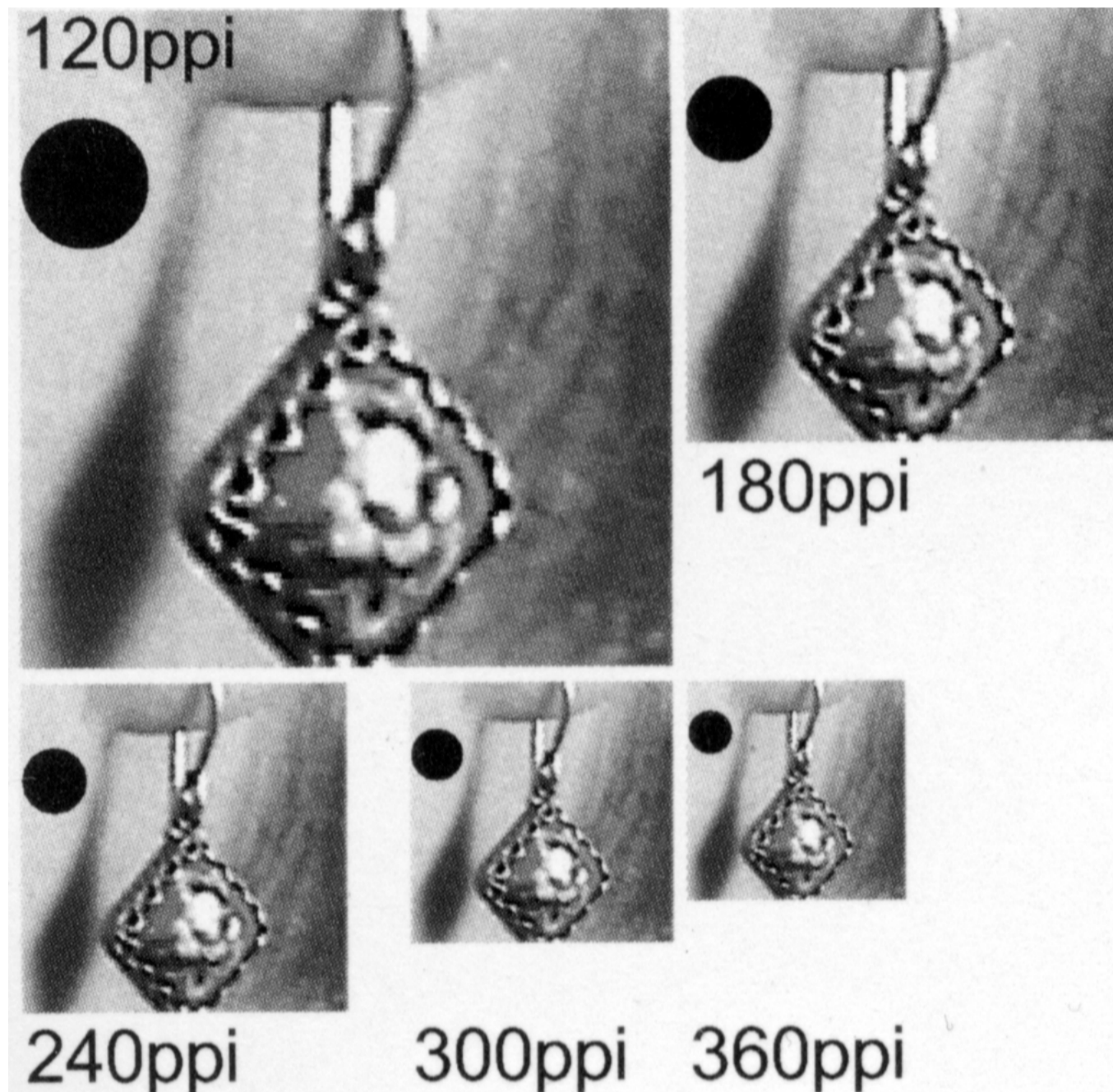# 4.2 How many Pixels for Raster Printing ?
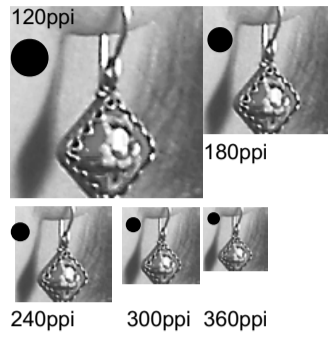
The image is always the same, a photo 120x120 pixels, and a circle as vector graphic. Scaled by PageMaker.
The page was printed by a laser printer 120Lpi/1200dpi.
RGB gray was printed as rich black CMYK.

The print was scanned as RGB/1200dpi, downsampled for 600dpi and converted to RGB gray (below).

120ppi = Factor 1.0
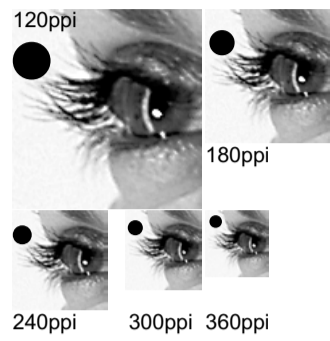180ppi = Factor 1.5
240ppi = Factor 2.0
300ppi = Factor 2.5
360ppi = Factor 3.0

Which version is the best ?
Is the quality really different ?
Use Acrobat resolution 72dpi and zoom 100% / 200% / 300% / 400%
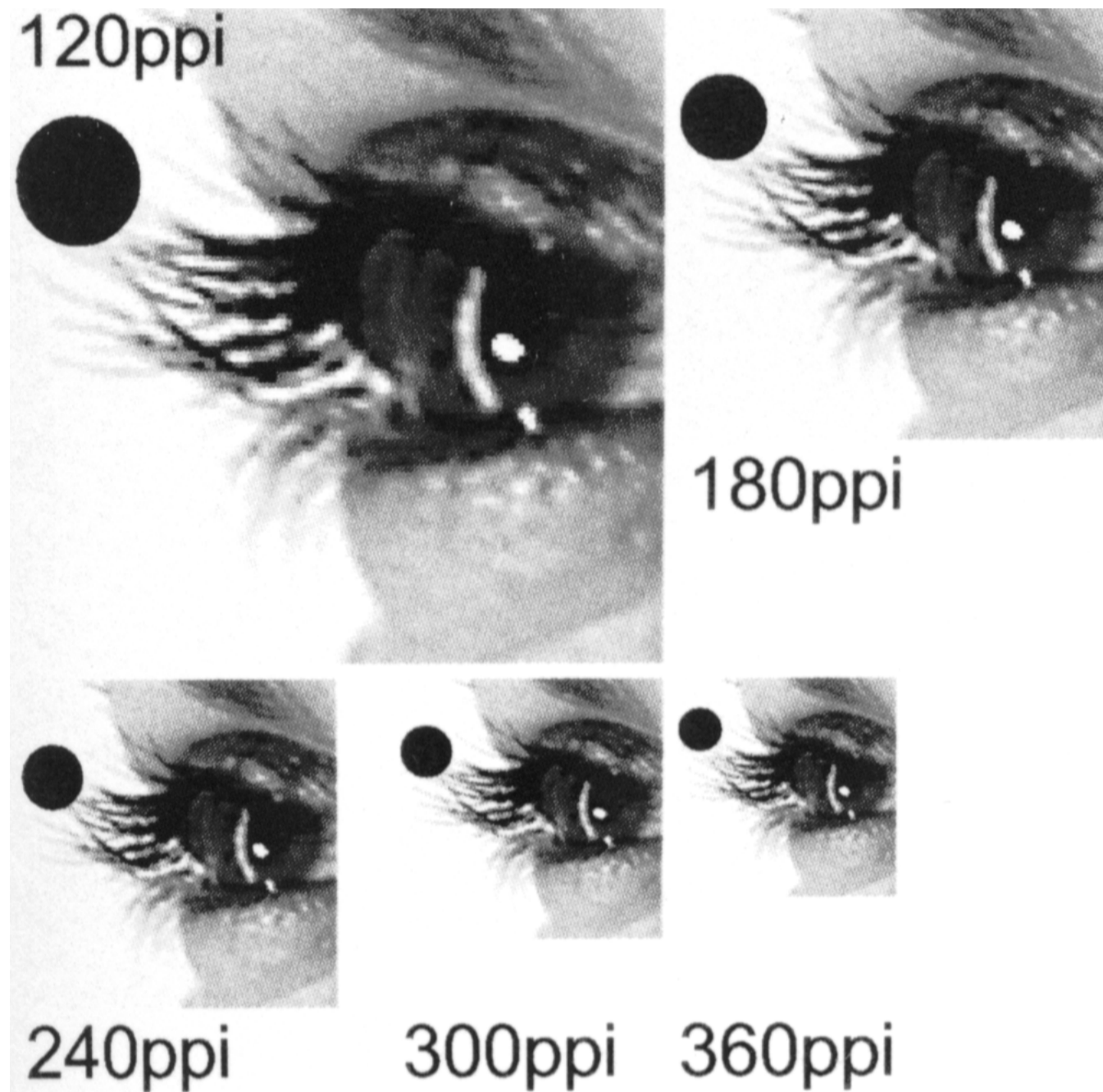
4.3 How many Pixels for Raster Printing ?

The image is always the same, a photo 120x120 pixels, and a circle as vector graphic. Scaled by PageMaker.
The page was printed by a laser printer 120Lpi/1200dpi.
RGB gray was printed as rich black CMYK.

The print was scanned as RGB / 1200dpi,
downsampled for 600dpi and converted to RGB gray (below)

120ppi = Factor 1.0
180ppi = Factor 1.5
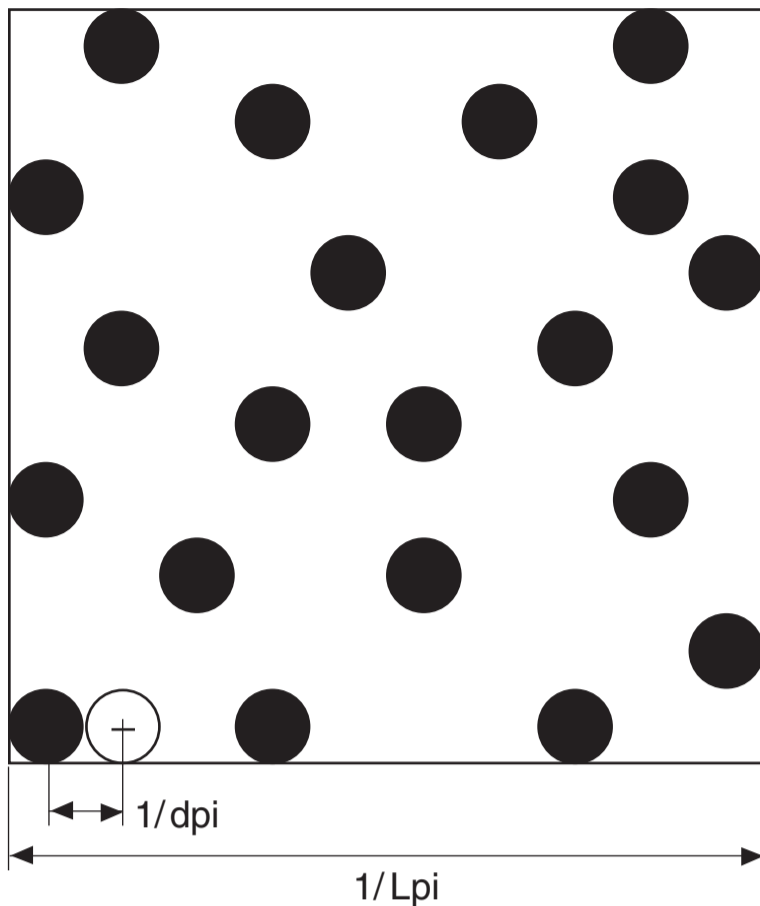240ppi = Factor 2.0
300ppi = Factor 2.5
360ppi = Factor 3.0

Which version is the best ?
Is the quality really different ?
Use Acrobat resolution 72dpi and zoom 100% / 200% / 300% / 400%

5.1 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$=10$

Inkjet users cannot choose the cell size Lpi value.
A reasonable assumption: Lpi$=$dpi/10.
This allows the application of the same rules as for raster printing (previous pages).
The 'reasonable assumption' is based on information per area.
The dots are in reality slightly larger than in the drawing, e.g.by a factor 1.4. 100 drops should cover the cell width without gaps.

Inkjet printers try to simulate color patterns by clouds of ink dots without creating artifacts. It is helpful to assume a fictitious raster cell, though the calculation 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 for raster printers. Assuming a fictitious Lpi value, the number of necessary pixels can be calculated, at least a reasonable guess.

This is a test image: two patches 10x10mm, left 80%K, right 100%K.
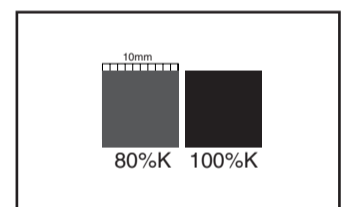
A view through the microscope for the 80%K image:
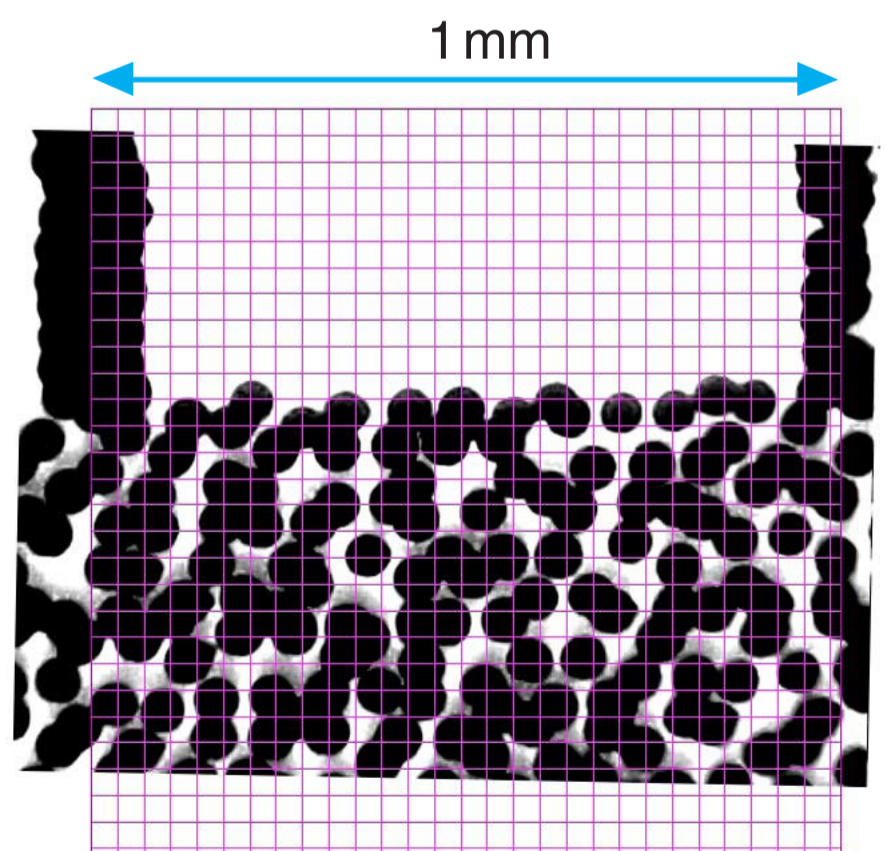Please view by zoom 200%

Mutoh 6100, 720dpi.
The millimeter scale was estimated by two available lines.
Theoretically we have 720/25.4=28.35 dots per millimeter. The grid width is 1/720 inch. The dots look randomly distributed.
This uneven spacing may be a result of inaccurate positioning or timing for the nozzle control system.
Density D=0.97, visual dot area 86%.

1 mm

5.2 How many Pixels for Inkjet Printing ?

An example: an inkjet prints with 720 dpi. The fictitious raster cell width is defined by 72 Lpi. This delivers 101 levels. The source image should have $(1.5...2) \cdot 72$ pixels per inch, which means 108...144 ppi. More source pixels do no harm, this was proved by many experiments.

For more levels we will need larger fictitious raster cells. These need less source pixels. Gray images need 256 levels. For color images without weak monochrome gradients the number of necessary levels is somewhere between 120 and 180.

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 (bottom image on previous page).

Offset ink cannot be printed easily by FM because of the high viscosity. It can be handled better by clusters. In the last years the technical problems could be solved. FM seems to be the standard in future.

Some desktop inkjets use a few different drop sizes, but the precision is limited. Large format printers use always 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 distance of magenta and cyan dots can be reduced - the same effect as produced by smaller dots.

6. 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 is 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.

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

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

Example

$$px = (1.5...2) \cdot 150 \cdot 5 = (1.5...2) \cdot 750 = 1125...1500$$

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

The scan resolution is $sr = (1125...1500)/3 = 375...500$ scan dots per inch (dpi). Practically the image can be scanned by 600 dpi as well, if the file size is accepted.

The scanner scans anyway by optical resolution 600dpi or 1200dpi, or what is 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 is not necessary to know the scale.
We do not have any fixed or accurate relation between Scanner-dpi and Imagesetter-dpi.

Example images are on the next page.

7. Example for Scanning

Printed width	5	inch
Line screen	150	Lpi
Factor	2	
Image	300	ppi
Pixel number	1500	
Scanned width	3	inch
Scan resolution	500	dpi

5 inch
Printed image

3 inch
Scanned image

This doc:
http://docs-hoffmann.de/colrend290800.pdf