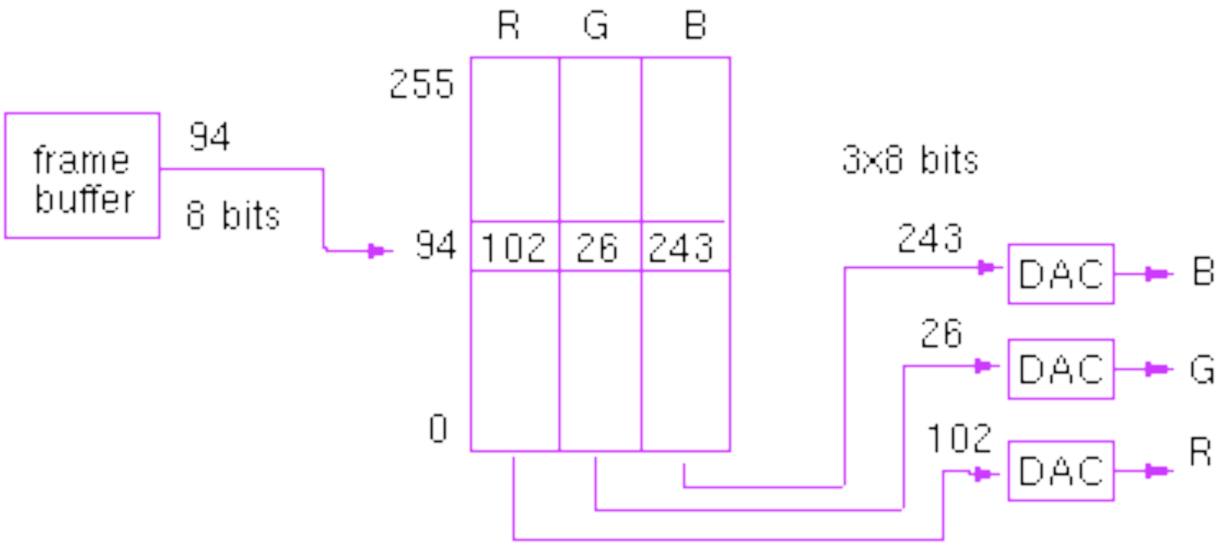
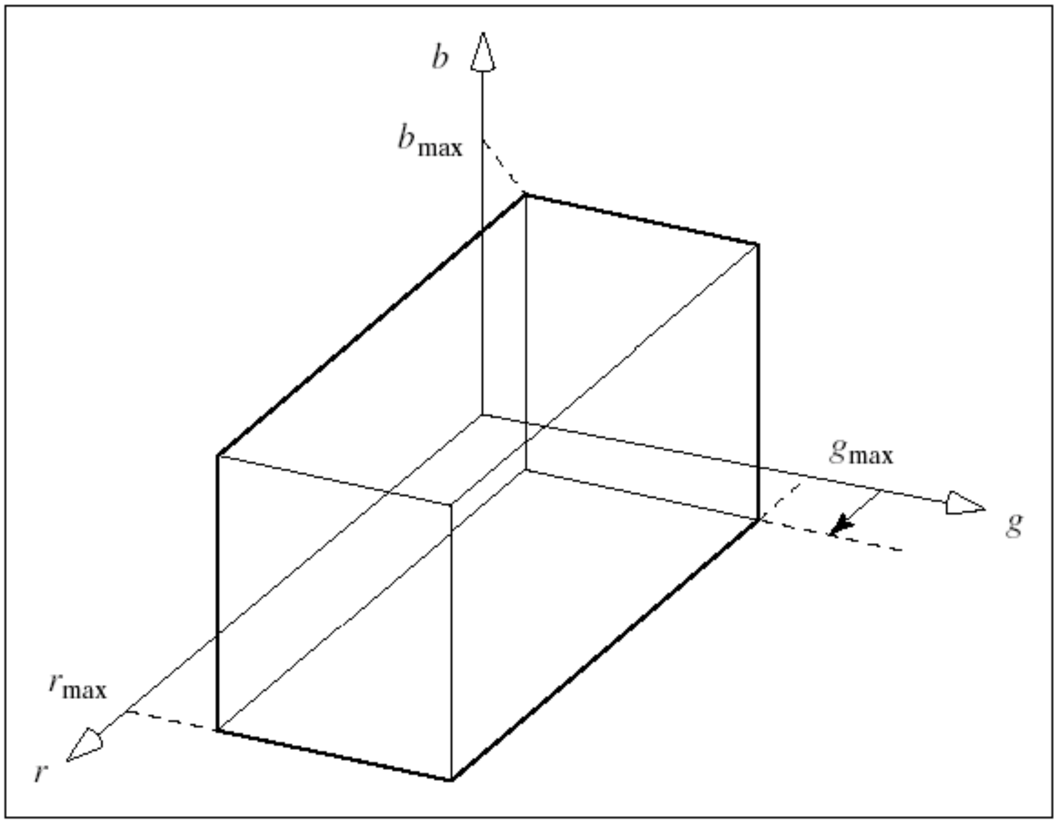
Color maps (Hill, 688-697)

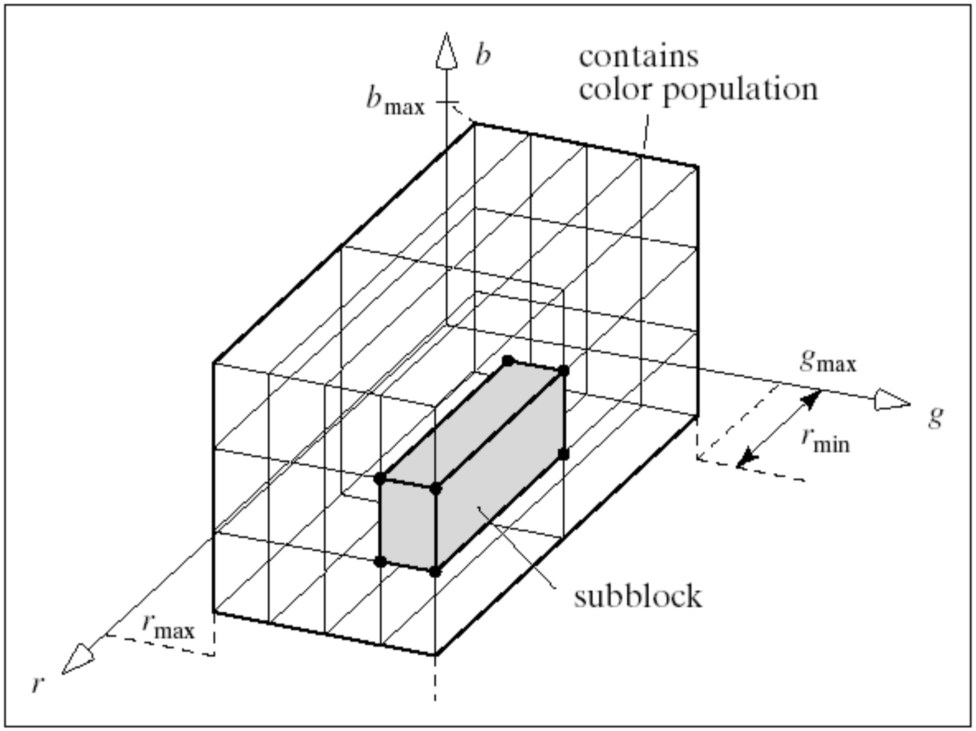
Reduced size (web)



Which colors do we keep?



Uniform

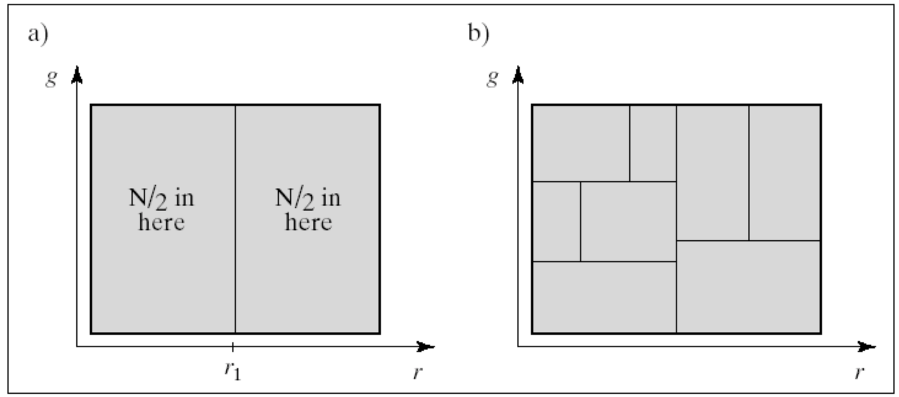


b
b_{max}
contains
color population
g_{max}
g
r_{min}
subblock
r_{max}
r

Popularity algorithm (Heckbert 1982)

- Find the popularity of all colors
- Sort them according to popularity
- Scan the file and replace each color with the closest one from the k-most popular colors.
  - *Find i for which $(rd - r[i])^2 + (grn - g[i])^2 + (blue - b[I])^2$ is minimum.*

Median Cut (Heckbert 1982)



Subdivide into 2 blocks at the median (each block same number of colors).

Slice along the longest dimension at the median until K blocks.

The representative for each block with the center color.

Rescan the file and substitute the colors with the center color of the block they fall into.

Digital Halftoning (Hill 587-596)

Bilevel displays

How can we create the illusion of different intensities?

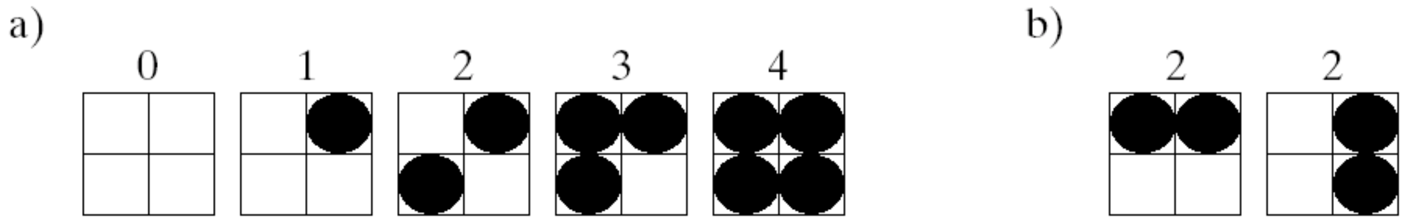
- Continuous media: vary the size of dots.
- Digital media: use patterns to approximate the variable size of dots.

Example

Halftoning with 2x2 patters

Origin image 100x100 with 256 shades new image 200x200 bilevel

Four shades with 2x2 patterns

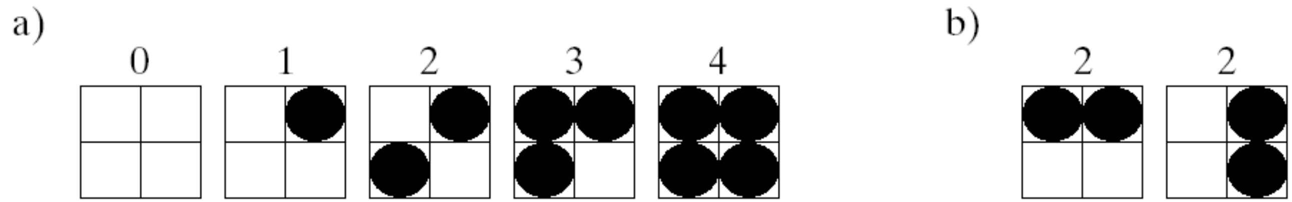


Avoid artifacts by irregular patterns

Patterns

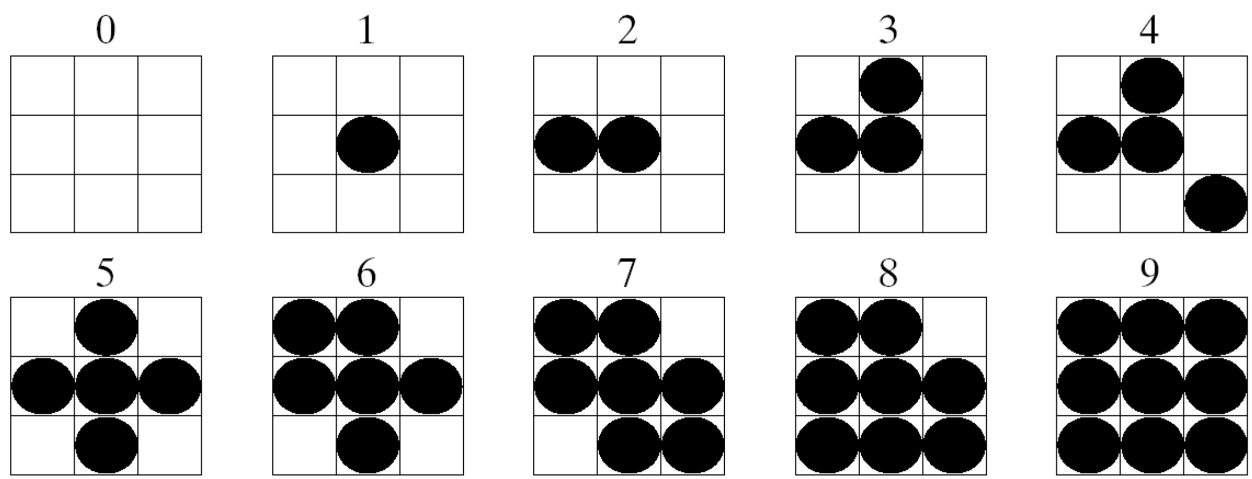
2x2

Four levels



3x3

Nine levels



Growth sequence [Foley]

Avoid artifacts (contouring, islands)

1. If pixel i on at level j then on at every level > j.
2. Grow outwards.
3. Grow in a circle.

Halftoning with same dimensions

Original image 100x100 with n shades of gray

New image 100x100 bilevel

Easy way: Thresholding

- If(p[x][y] > t[x][y]) then p[x][y] = 1 else p[x][y] = 0,
- If T[x][y] is the same for every pixel then we get contours and islands of constant color.

Ordered dithering

Vary the threshold from pixel to pixel

- Array of thresholds (dither pattern).

Example: Original image 16 gray shades.

- Shades: 0-15
- Dither pattern 2x2: $D=\begin{pmatrix} 3 & 9 \\ 12 & 6 \end{pmatrix}$
- Thresholding: t[x][y] = D[x % 2][y % 2]

What is the effect ?

More perceived gray levels

$$\begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$

0, 0.25, 0.5, 0.75, 1

Areas of constant intensity

Intensity 8 becomes:

$$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Whose average is 0.5

Thresholding an image with ordered dithering

2x2

original image

8	8	8	8	8					
8	8	8	8	8					
7	8	8	8	8					
7	7	8	8	8					
6	6	6	5	4					

dither pattern

3	9	3	9	3	9	3	9	3	9
12	6	12	6	12	6	12	6	12	6
3	9	3	9	3	9	3	9	3	9
12	6	12	6	12	6	12	6	12	6
3	9	3	9	3	9	3	9	3	9
12	6	12	6	12	6	12	6	12	6
3	9	3	9	3	9	3	9	3	9
12	6	12	6	12	6	12	6	12	6
3	9	3	9	3	9	3	9	3	9
12	6	12	6	12	6	12	6	12	6

$>$

displayed pixel values

1	0	1	0	1	0	1	0	1	0
0	1	0	1	0	0	0	0	0	0
1	0	1	0	1	0	1	0	1	0
0	1	0	1	0	0	0	0	0	0
1	0	1	0	1	0	1	0	1	0
0	0	0	?	?	?	?	?	?	?
1	0	1	0	?	?	?	?	?	?
0	0	0	0	?	?	?	?	?	?
1	0	1	0	?	?	?	?	?	?
0	0	0	0	?	?	?	?	?	?

What values appear here?

General case

Original image has m gray levels.

New image bilevel with a nxn dither pattern.

- Chose n^2 equispaced thresholds $m/(n^2+1)$
- Arrange then in nxn array using a growth pattern

Trade off between spatial resolution and shade (color) resolution

Multi-level dithering

Example: Original image 256 levels of gray, new image 8 levels

Simple thresholding

- 0,…,255 → 0,…,7 that means we have to map 256 / 8 = 32 original shades to each of the 8 available levels.
- D = (int) (P/32) ;   // find the lower bound
  if(P – 32*D) >= 16) // if P greater than lb+16 then closer to D++
  D++ ;   // essentially we round to the closest level

Better approach: Dithering

Pattern 2x2

- D = (int) (P/32) ;
  if(P – 32*D >= M[x %2][y % 2])
  then D++ ;

  where M = $\begin{pmatrix} 0 & 16 \\ 24 & 8 \end{pmatrix}$

What is the effect ?

Effect: more perceived gray levels

Reminder: 0,…,255 → 0,…,7

Consider an area of constant intensity

- P = 178 lies between 5x32 = 160 and 6x32 = 192.

$$\begin{pmatrix} 178 & 178 \\ 178 & 178 \end{pmatrix} < P - 5 * 32 > \rightarrow \begin{pmatrix} 18 & 18 \\ 18 & 18 \end{pmatrix}$$

- Aver $< threshold > \begin{pmatrix} 0 & 16 \\ 24 & 8 \end{pmatrix} \rightarrow \begin{pmatrix} 6 & 6 \\ 5 & 6 \end{pmatrix}$ o
178/ en 5 and 6.
- Original levels 160 and 192 ,184 is ¾ between 160 and 192 which is not far from 178.

Dithering of color images

Dither each color channel separetely.

Error diffusion

Back to Bilevel images: 0,…,255 → 0,1

Pure thresholding:

- if(P < 128) P’=0 else P’=1

Errror?

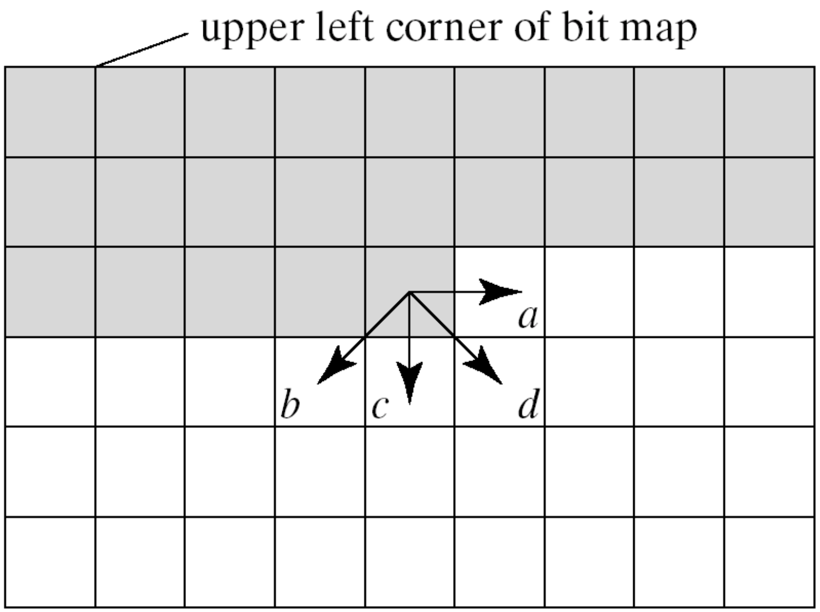
- If P = 42 → E = 42 – 0 = 42
  If P = 167 → E = 255-167 = 88
- That is if P < 128 → P’=0 → E = P
  if P ¸ 128 → P’ = 255 →E = 255 - P

Fix: Diffuse the error to the neighbors.

Error diffusion

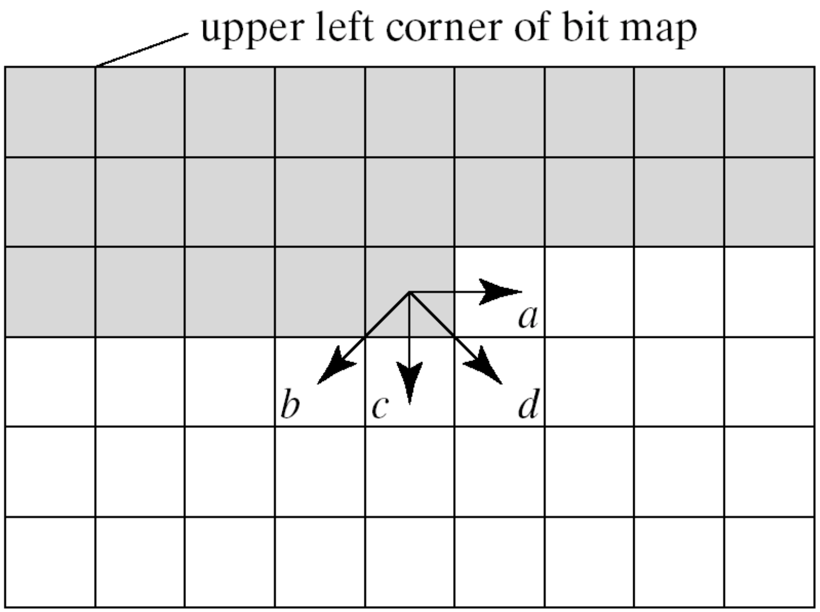
Diffuse the error to the neighbors.

- 0,…,255 → 0,1
- Pure thesholding
  if(P > 128) P'=1 else P'=0
- If P = 42 → E = 0 – 42=-42
  If P = 167 → E = 255-167
  E = 88



Error diffusion

- $E = -P$ or $255 - P$
- $a = a - f_aE$
  $b = b - f_bE$
  $c = c - f_cE$
  $d = d - f_dE$
- $(f_a, f_b, f_c, f_d) = (7/16, 3/16, 5/16, 1/16)$ sum to unity.
- Serpentine pattern



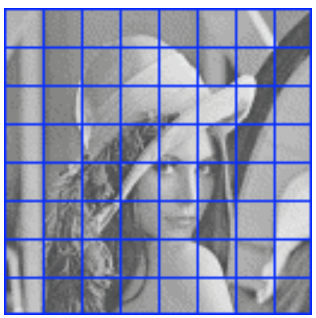
Example: Error diffusion

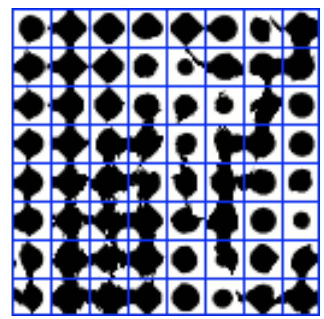
Advanced concept: Clustered dot ordered dither

Images (c) 1998 Austin Donnelly <Austin_Donnelly@yahoo.co.uk>

Syperimpose a grid

Example (too coarse) 16x16



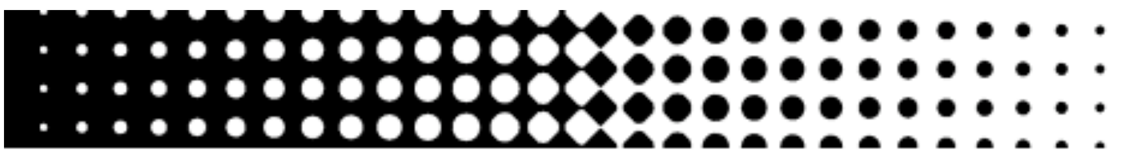


- Shape start as circles and grow according to a spot function (threshold)

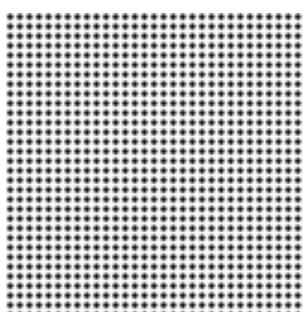
Clustered dot ordered dither (cont'd)

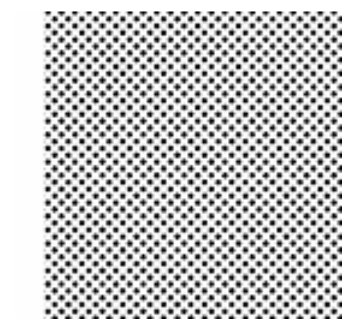
Reference gradient

Images (c) 1998 Austin Donnelly <Austin_Donnelly@yahoo.co.uk>

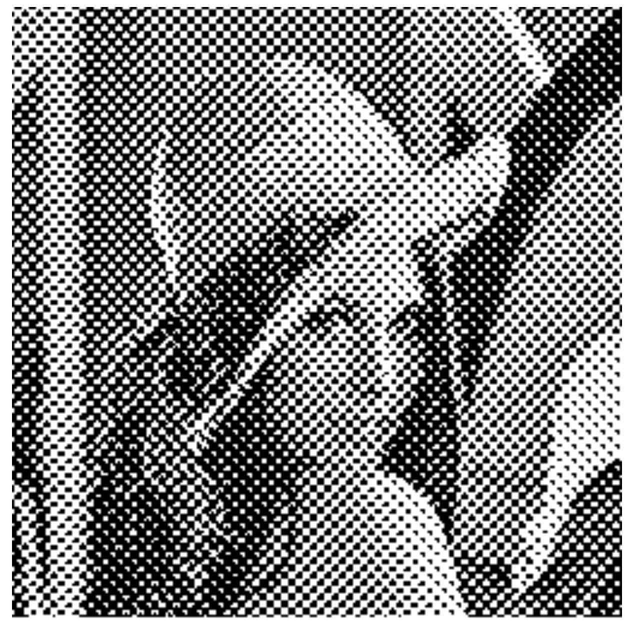


Angle: 0 degrees 45 degrees





Example: Clustered dot Ordered Dither



Example: Dispersed Ordered Dither

Example: White noise dither

Example: Screen to printer

Banding

Error diffusion

Advanced concepts

Combination of dithering and error diffusion [Knuth87]

Stochastic approaches