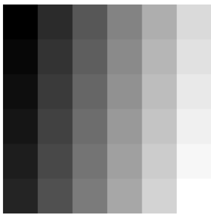
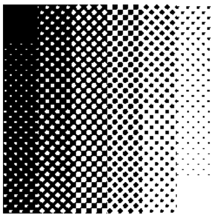
Lecture 11

Halftoning

- Cluster Dot Dithering
- Disperse Dot Dithering
- Error Diffusion
- Color Halftoning
- Color Screening



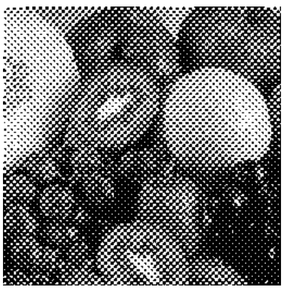


Monochrome Printing

GrayScale

Threshold

Halftoning (Screening)



Halftoning

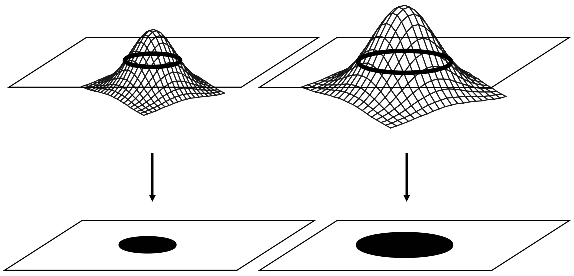
GrayScale

Threshold

Halftone

Local average gray in halftone image $\cong$ Local average gray in grayscale image

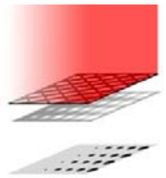
Physical Screening



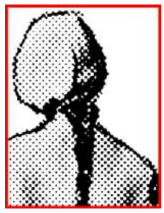
Larger hole in screen -> more ink goes through

See demo:
http://www.ted.photographer.org.uk/photoscience_halftones.htm

Physical Screening

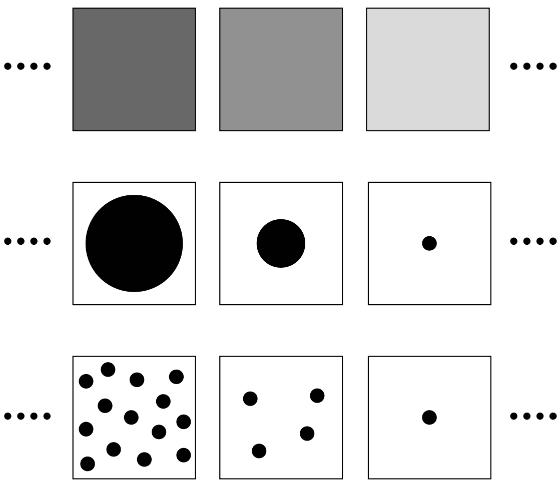


Larger hole in screen -> more light goes through



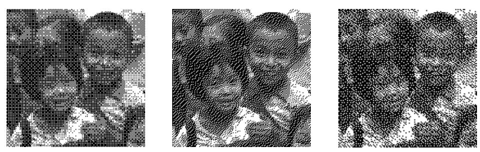
Halftoning

Percentage of ink coverage of a region determines the grayscale:



Halftoning Methods

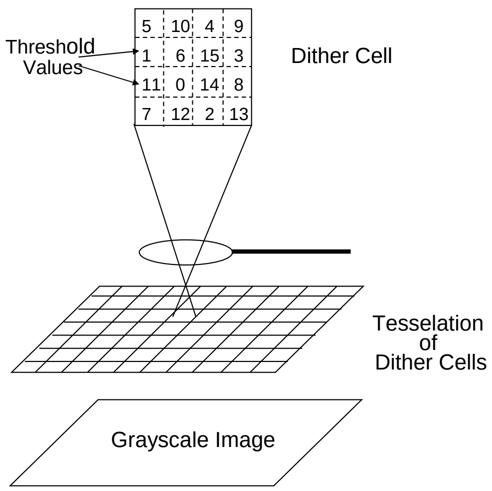
1) Dithering
2) Error diffusion
3) Direct Binary Search
   (Iterative - error minimization)



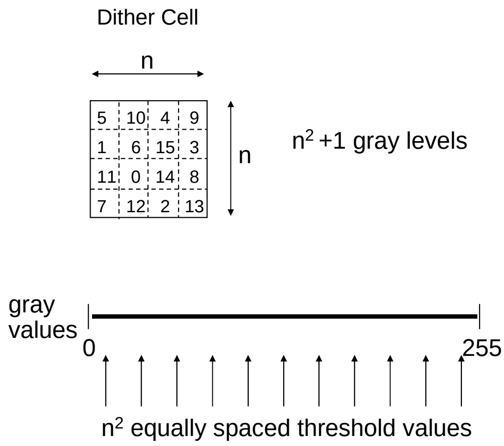
Proportion of local ink coverage in halftone image	$\cong$	Local average gray in grayscale image

Dithering

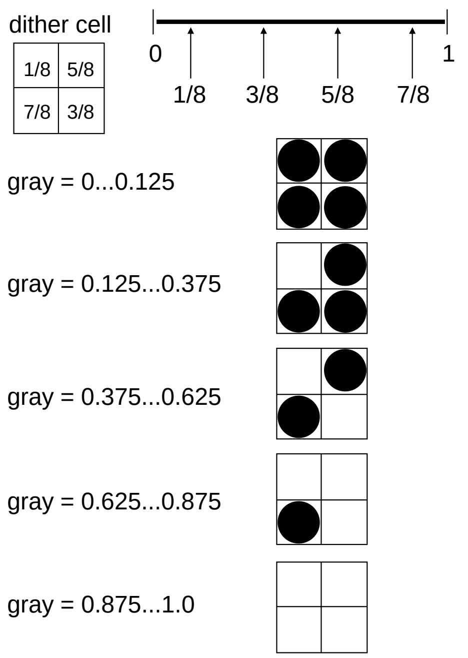
Every pixel in a region is thresholded using a different threshold value.



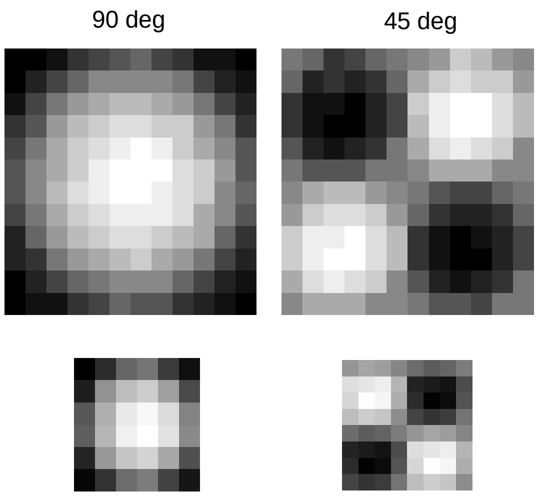
Threshold Values in Dither Cell



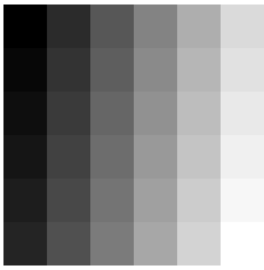
Example:



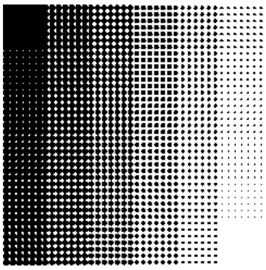
Cluster Dot Dither Cells



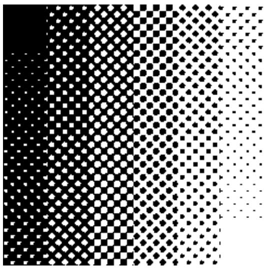
Cluster Dot Dither Cells



Grayscale



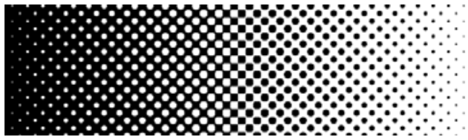
C_6 90 deg



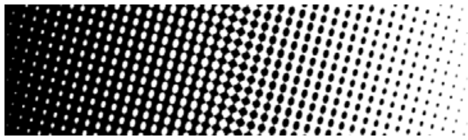
C_{12} 45 deg

Cluster Dot Dithering

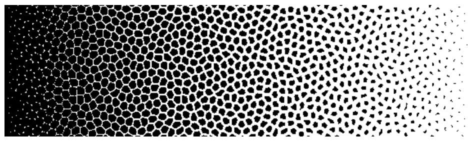
Clustered Dot Postscript Screens



Rotated Elliptical



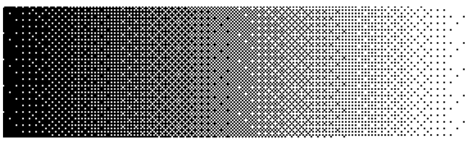
Hybrid FM Clustered Dot



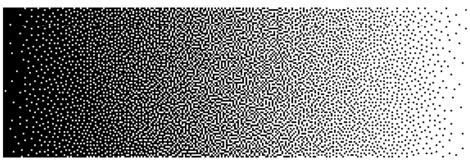
Dispersed Dot Dithering

True Random

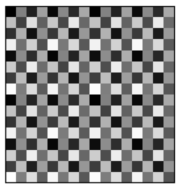
Bayer = perfectly smooth



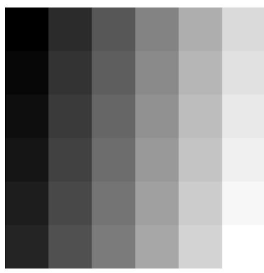
Blue Noise



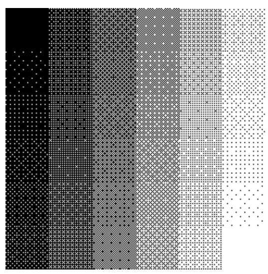
Bayer Dithering



Bayer Dither Cell



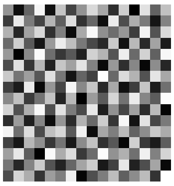
Grayscale



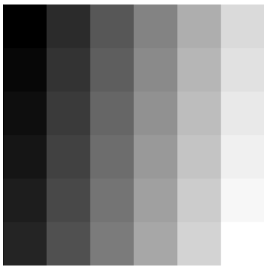
Bayer Dither

(Bayer, 1973)

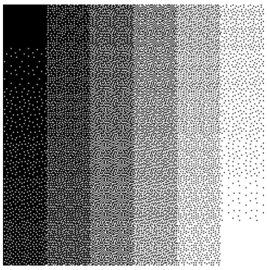
Void and Cluster Dithering



Void & Cluster Dither Cell



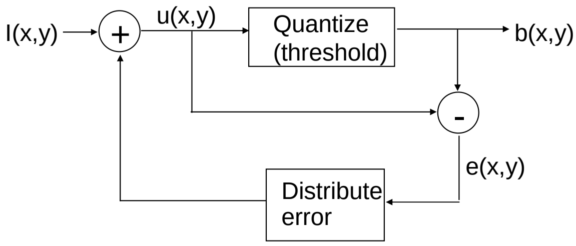
Grayscale



Void & Cluster Dither

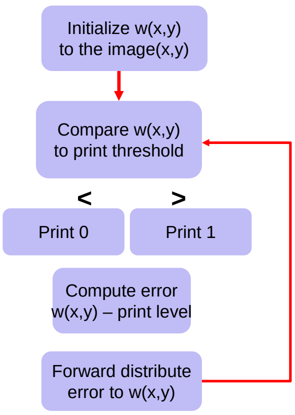
(Ulichney 1993)

Error Diffusion (Floyd Steinberg)



(Floyd and Steinberg 1976)

Error Diffusion (Floyd Steinberg)



- Decide for each image point whether to print or not
- Take error between the desired output at that position and the printed level.
- Distribute that error forward to pixels yet-to-be printed

Example: 1D error diffusion

I =

0.7	0.7	0.3	0.5	0.1	0.1	0.1

I(1) = u(1) = 0.7 → threshold at 0.5 → b(1) = 1

e(1) = b(1) - u(1) = 0.3

Since pixel I(1) was over represented, compensate by subtracting error from next pixel I(2)

u(2) = I(2) - e(1) = 0.4

u(2) = 0.4 → threshold at 0.5 → b(1) = 0

e(2) = b(2) - u(2) = -0.4

u(3) = I(3) - e(2) = 0.7

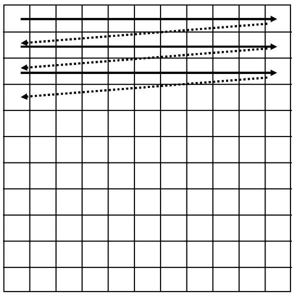
and so on....

b =

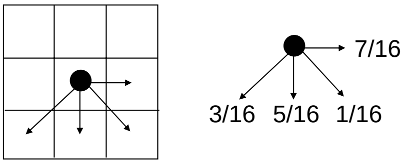
1	0	1	0	0	0	1

Error Diffusion in 2D

Scan Image:



error diffusion

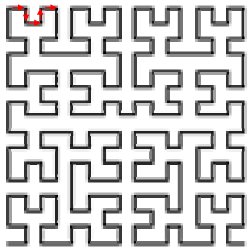


Error Diffusion - Variations

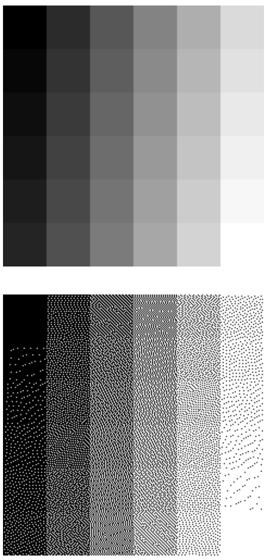
Jarvis Judice and Ninke (1976)
Error diffused differently

		*	7	5
3	5	7	5	3
1	3	5	3	1

Terada, Tamura, and Saito
Use Peano scan (Space filling curve)



Error Diffusion



Error Diffusion

Direct Binary Search (DBS)

Given an error metric:

$d(I(x,y),b(x,y))$

example: $d(I,b) = \Sigma((I(x,y)-b(x,y))^2)$

Initialize binary image $b(x,y)$ (example - choose random binary image).

Randomly chose a pixel (x_0,y_0) in $b(x,y)$

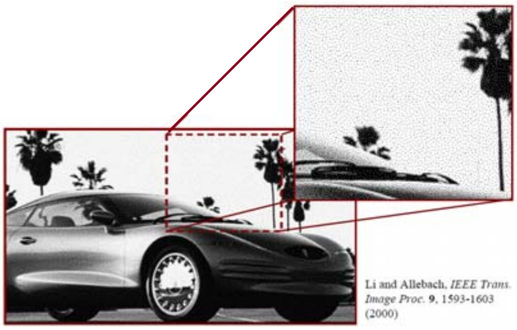
if $d(I,\tilde{b}) < d(I,b)$ then assign $b = \tilde{b}$

where $\tilde{b}$ is b except for $\tilde{b}(x_0,y_0) = 1-b(x_0,y_0)$

Repeat last step until $|d(I,\tilde{b}) - d(I,b)|$ is "small".

Error metric can be "smart" for example based on Human Visual System.

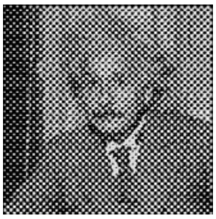
Direct Binary Search (DBS)



Li and Allebach, *IEEE Trans. Image Proc.* **9**, 1593-1603 (2000)

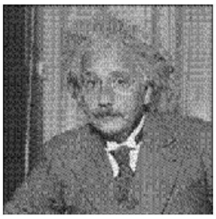
Halftoning - Comparison

Cluster Dot

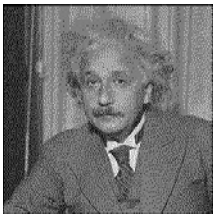


Bayer

Void and Cluster

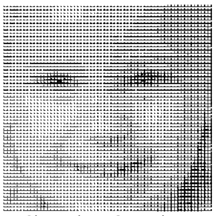


Error diffusion

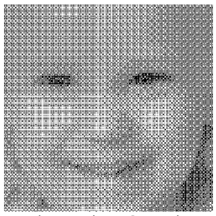


Comparison of various halftoning:
http://www.cs.indiana.edu/~dmiguse/Halftone/

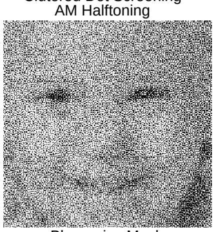
Halftoning - Comparison



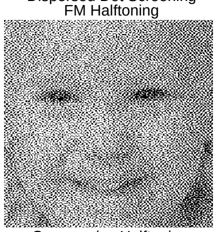
Clutered Dot Screening
AM Halftoning



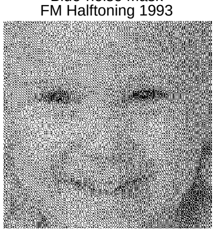
Dispersed Dot Screening
FM Halftoning



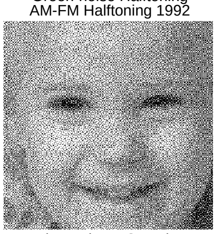
Blue-noise Mask
FM Halftoning 1993



Green-noise Halftoning
AM-FM Halftoning 1992

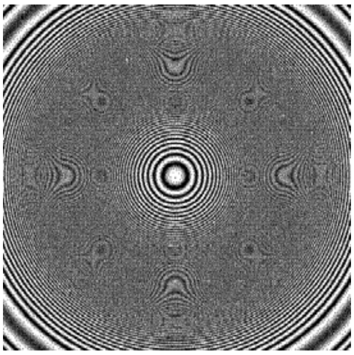


Error Diffusion
FM Halftoning 1975



Direct Binary Search
FM Halftoning 1992

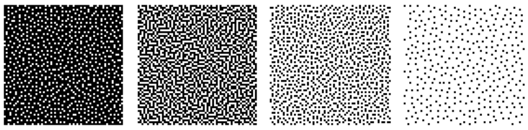
Aliasing - Moire



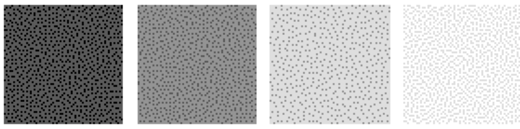
Aliasing due to dot overlap (DBS method)

Variable Dot Size

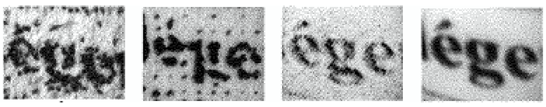
Fixed Dot Halftoning (On or Off)



Variable Dot Halftoning (4 different dot sizes)



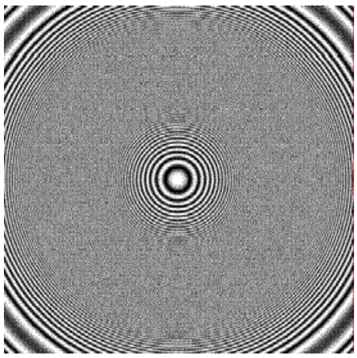
Variable Dot Size



Ink Jet | Thermal transfer | Variable dot Thermal transfer | Dye diffusion

(Moroney and Viggiani 1994)

Aliasing Removed

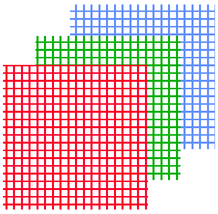


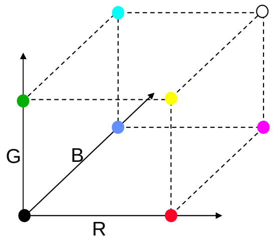
Aliasing Removed using variable dot size
(dot overlap model).

(Baquai, Taylor and Allebach 1996)

Color Halftoning

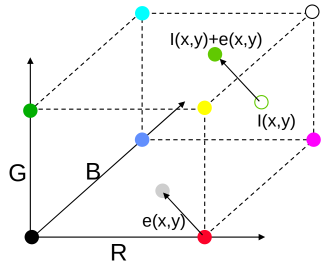
1) Perform halftoning in each plane (R,G,B) separately.
2) Perform halftoning in color space





Error Diffusion in RGB Space

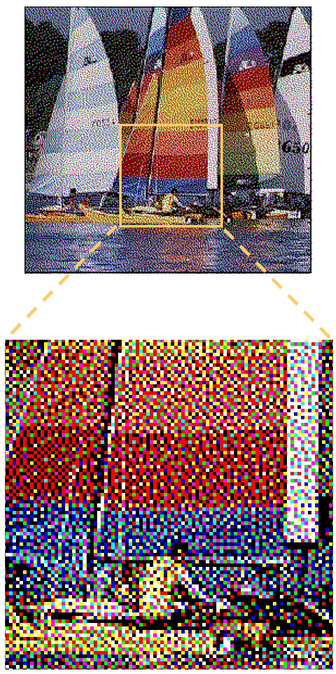
The error e(x,y) - is a vector



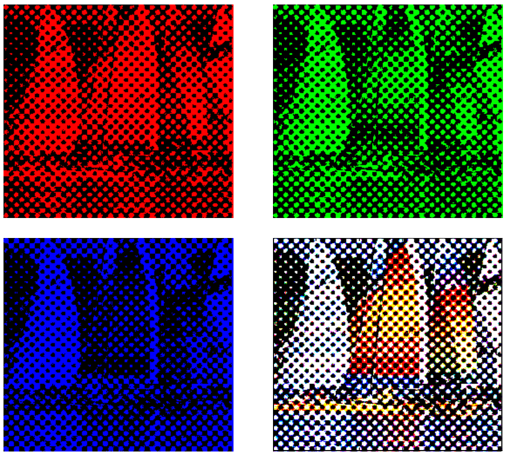
Adding and subtracting is in 3D vector space.

Error Diffusion in Color Images

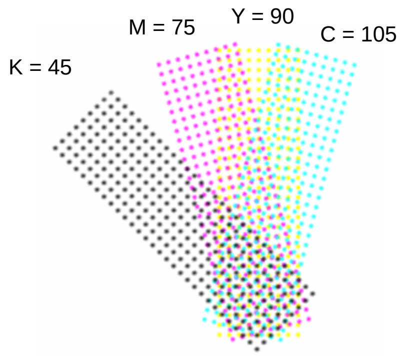
Error Diffusion in Color Images



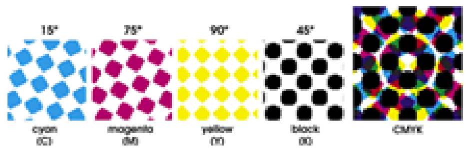
Cluster Dot Dithering in Color Images



Color Screen Angles

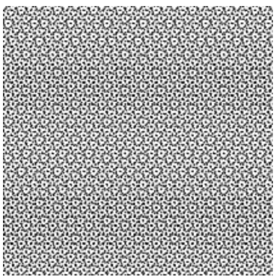


- Every screen at a different angle.
- Optimally 30° apart.
- Since there are 4 screens and not 3:
  Y (color of least contrast) is set at 15° between 2 others.
- K (colour of most contrast) is set at the visually ideal angle of 45 degrees.

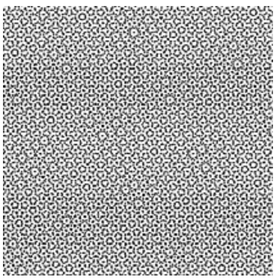


Color Screening

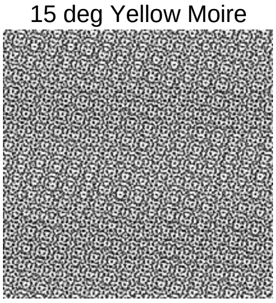
CMK Rosetes



Failed CMK Rosettes



15 deg Yellow Moire



Final Print