Digital Image Processing

Lecture #6 Ming-Sui (Amy) Lee

Announcement

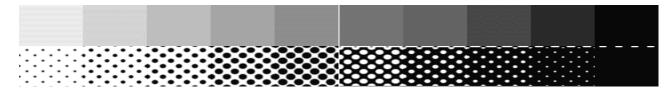
- Class Information
 - The following schedule

03/23	Lecture 5	05/11	proposal
03/30	Lecture 6	05/18	Lecture 9
04/06	Lecture 7	05/25	Lecture 10
04/13	RealSense	06/01	Lecture 11
04/20	midterm	06/08	Demo
04/27	RealSense	06/15	Demo
05/04	Lecture 8	06/22	Final Package Due



Goal

 Render the illusion of a continuous-tone image based on two-tone (half-tone) display



- Applications
 - Computer hardcopies
 - Laser printers/dot-matrix printers/color printers
 - Fax machine
- Implementation
 - Thresholding at 1/2?





Gray-level image

Half-toned images

Color Printer

Continuous Image





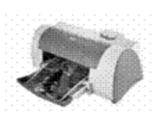
Binary Image











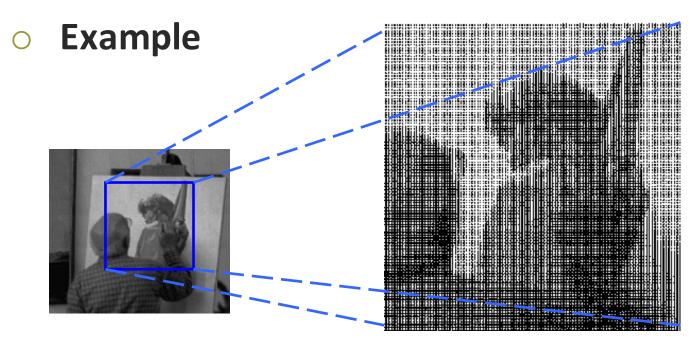


- Basic idea
 - Spatial modulation
 - Three approaches
 - Patterning
 - Dithering
 - Error Diffusion

Patterning p If p=4→ 16 binary pixels → 17 levels (0~16) → 256 gray levels → Quantization 1 Dot pattern 1 Gray-level pixel Rylander's recursive

- Patterning
 - Four steps
 - Read in the given grey-level image
 - Quantization
 - Design the patterning table
 - Map each pixel to its corresponding pattern
 - Simplest way
 - Generates image with higher spatial resolution than the source image

Patterning



Original gray-level image

Half-toned image: patterning

- Dithering
 - Create an image with the same number of dots as the number of pixels in the source image
 - Idea

$$N(j,k) \rightarrow Why??$$

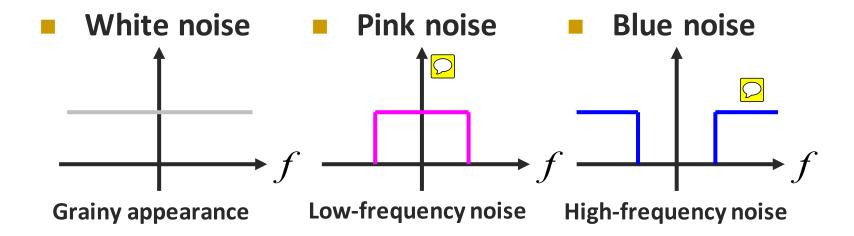
$$F(j,k) \longrightarrow H(j,k)$$
Threshold $G(j,k)$

- Dithering
 - Owner of the control of the contr
 - Under fixed thresholding → taking MSB
 - E.g. before and after adding noise

≥128 <127

- To break the monotonicity of accumulated error in the area of constant (nearly constant) gray level
- White noise, pink noise, blue noise and green noise

- Dithering
 - Noise Type
 - Power spectral density



- Robert Ulichney, "Digital Halftoning"
 - http://www.hpl.hp.com/people/u/

Dithering

- Adaptive thresholding
 - Generate a threshold matrix according to a dither matrix
 - Whenever the pixel value of the image is greater than the value in the threshold matrix, the pixel is turned on

Notes

- No randomness
- Region-to-region mapping
- Recursive definition allowed

- Dithering
 - Dither matrix

$$I_2(i,j) = \begin{bmatrix} 1 & 2 \\ 3 & 0 \end{bmatrix}; \quad I_2(i,j) = \begin{bmatrix} 3 & 1 \\ 0 & 2 \end{bmatrix}$$

- 0 → lowest threshold
- 3 → highest threshold

Dithering

- The general form of the NxN dither matrix
 - = 2x2 \rightarrow 4x4 \rightarrow 8x8 \rightarrow 16x16...

$$I_{2n}(i,j) = \begin{bmatrix} 4I_n(i,j) + 1 & 4I_n(i,j) + 2 \\ 4I_n(i,j) + 3 & 4I_n(i,j) + 0 \end{bmatrix}$$

Eg. What is
$$I_4(i,j)$$
 if $I_2(i,j) = \begin{bmatrix} 1 & 2 \\ 3 & 0 \end{bmatrix}$?

- Dithering
 - Determine the threshold matrix

$$T(i,j) = 255 \cdot \frac{I(i,j) + 0.5}{N^2}$$

Eg. N=4

Eg. N=4
$$I_4(i,j) = \begin{bmatrix} 5 & 9 & 6 & 10 \\ 13 & 1 & 14 & 2 \\ 7 & 11 & 4 & 8 \\ 15 & 3 & 12 & 0 \end{bmatrix}, \quad T_4(i,j) = ?$$

Dithering

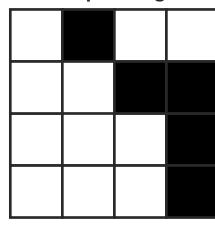
Input image

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

Repeated threshold matrix

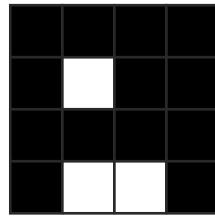
0	60	0	60
45	110	45	110
0	60	0	60
45	110	45	110

Output image



Another repeated threshold matrix

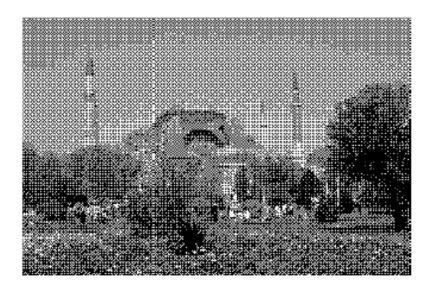
128	128	128	128
128	128	128	128
128	128	128	128
128	128	128	128



Experimental results



Original Image



Dithering

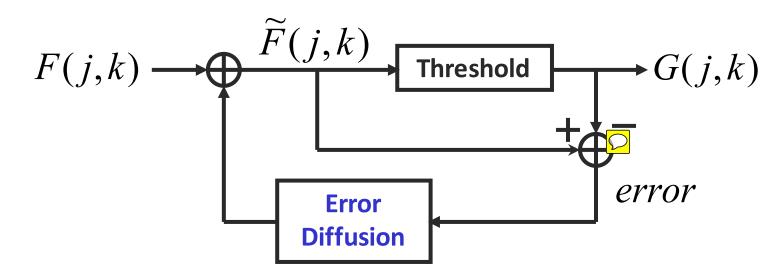
Experimental results



Original Image

Dithering

- Error diffusion
 - 1975 Floyd & Steinberg
 - A practical algorithm to implement blue noise dithering
 - Framework



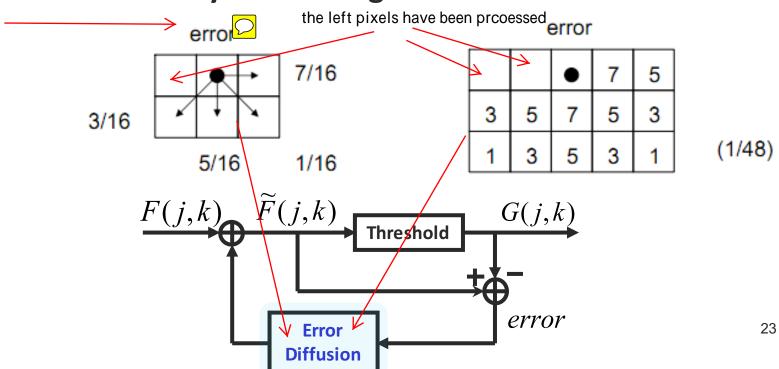
- Error diffusion
 - Normalize F(j,k) to lie between [0,1]
 - Set threshold=0.5
 - Output image: 0 or 1

$$F(j,k) \xrightarrow{\widetilde{F}(j,k)} \text{Threshold} \qquad if \quad \widetilde{F}(j,k) \geq 0.5 \quad \Rightarrow \quad G(j,k) = 1$$

$$if \quad \widetilde{F}(j,k) < 0.5 \quad \Rightarrow \quad G(j,k) = 0$$

$$Define \quad E(j,k) = \widetilde{F}(j,k) - G(j,k)$$

- Error diffusion
 - Error diffusion filter masks
 - 1975 Floyd Steinberg: 1976 Jarvis et al:



- **Error diffusion**
 - Error diffusion + serpentine scanning

$$\frac{1}{16} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 7 \\ 3 & 5 & 1 \end{pmatrix}$$

Left to Right

$$\frac{1}{16} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 7 \\ 3 & 5 & 1 \end{pmatrix} \qquad \frac{1}{16} \begin{pmatrix} 0 & 0 & 0 \\ 7 & 0 & 0 \\ 1 & 5 & 3 \end{pmatrix}$$

Right to Left

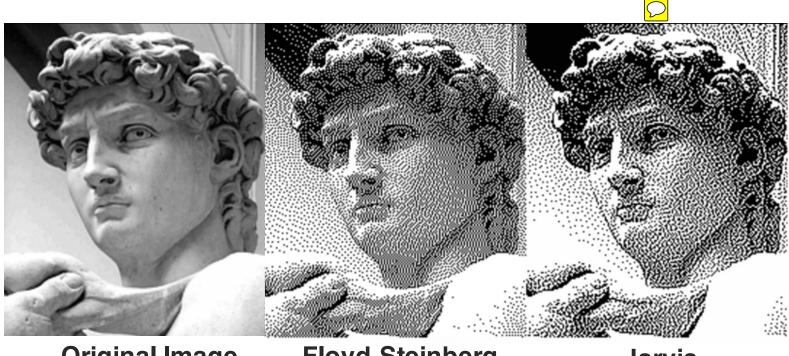
Experimental results



Original Image

Error Diffusion

Experimental results



Original Image

Floyd-Steinberg

Jarvis

- Multi-scale Error diffusion
 - Several issues
 - Region-to-region mapping
 - Multi-resolution
 - Time series/causal error diffusion process
 - Easy to implement
 - Causalit pappears to be artificial in images
 - Is non-causal error diffusion possible?
 - Quality metrics of half-toned images

Multi-scale Error diffusion

"A multiscale error diffusion technique for digital halftoning" Ioannis Katsavounidis and C. -C. Jay Kuo

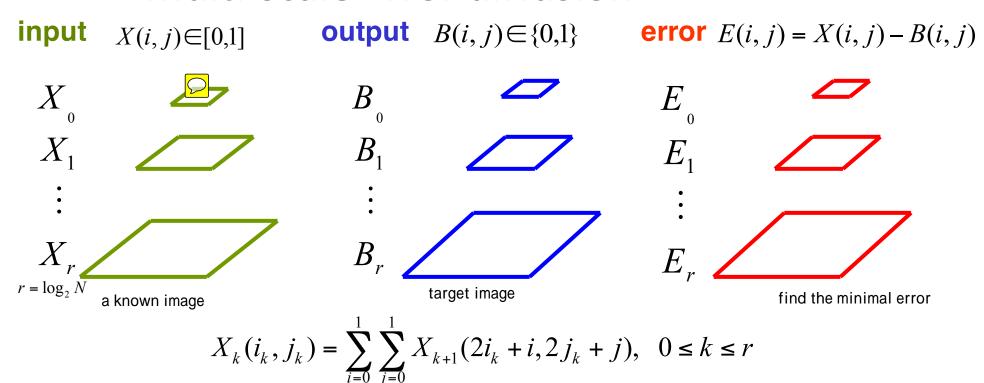
Problem set-up

- Input image $\rightarrow X(i,j) \in [0,1]$ Output image $\rightarrow B(i,j) \in \{0,1\}$
- **Error image** \rightarrow E(i, j) = X(i, j) B(i, j)
- Intermediate stage →

$$X_{k}(i_{k}, j_{k}), \quad 0 \le k \le r, \quad r = \log_{2} N$$

$$X_{k}(i_{k}, j_{k}) = \sum_{i=0}^{1} \sum_{j=0}^{1} X_{k+1}(2i_{k} + i, 2j_{k} + j)$$

Multi-scale Error diffusion



Goal: minimize the error pyramid in a certain way!

 $E_k(i_k, j_k) = X_k(i_k, j_k) - B_k(i_k, j_k), \quad 0 \le k \le r$

Multi-scale Error diffusion

- //Step 1// Initialization
 - Set the entire output image pyramid to "0"

//Step 2// Dot assignment



- Find the largest error from top to bottom level
- 1 parent node distributes its dots (integer numbers) to 4 children
- //Step 3// Error diffusion proces

error diffuse
$$\frac{1}{12} \begin{pmatrix} 1 & 2 & 1 \\ 2 & -12 & 2 \\ 1 & 2 & 1 \end{pmatrix} \qquad \frac{1}{8} \begin{pmatrix} 0 & 0 & 0 \\ 2 & -8 & 2 \\ 1 & 2 & 1 \end{pmatrix} \qquad \frac{1}{5} \begin{pmatrix} 0 & 0 & 0 \\ 0 & -5 & 2 \\ 0 & 2 & 1 \end{pmatrix}$$
center
side
corner

$$\frac{1}{8} \begin{pmatrix} 0 & 0 & 0 \\ 2 & -8 & 2 \\ 1 & 2 & 1 \end{pmatrix}$$
side

$$\frac{1}{5} \begin{pmatrix} 0 & 0 & 0 \\ 0 & -5 & 2 \\ 0 & 2 & 1 \end{pmatrix}$$

- Multi-scale Error diffusion
 - Quality management
 - MSE vector

$$MSEV = \begin{pmatrix} MSE_0 \\ MSE_1 \\ \vdots \\ MSE_r \end{pmatrix} \qquad MSE_k = \frac{1}{N^2} \sum_{i=0}^{2^k - 1} \sum_{j=0}^{2^k - 1} E_k^2(i, j)$$

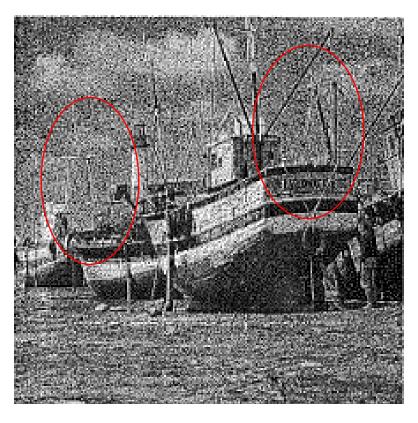
- Notes
 - Preserve contrast of the original image
 - Does not over-smooth the image

Experimental results

better detail and contrast



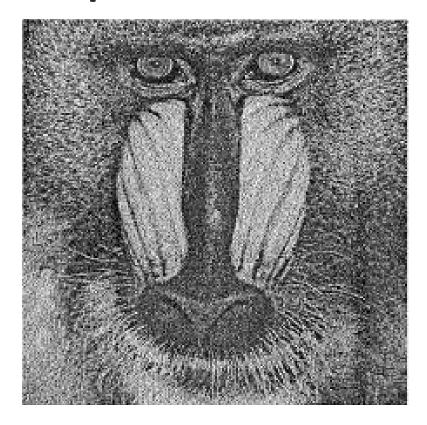
Error Diffusion

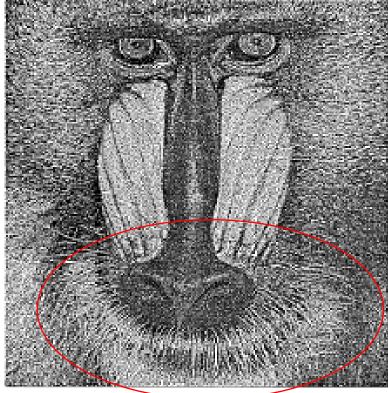


Multi-Scale Error Diffusion

Experimental results







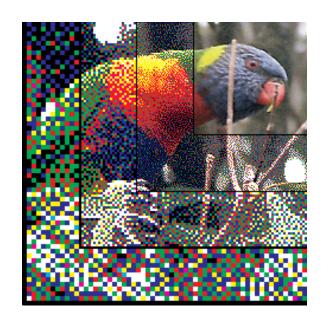
Error Diffusionworse contrast and detail

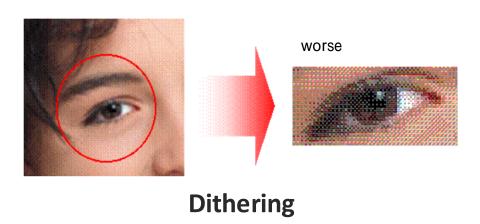
Multi-Scale Error Diffusion

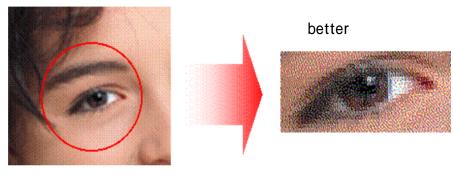
Color image R,G,B is half-tone individually and then combined again.



Examples







Error Diffusion

- Application
 - Visual cryptography

"visual cryptography based on void-and-cluster halftoning technique" E. Myodo, S. Sakazawa and Y. Takishima

