Halftone (II)

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Halftone Methods

- Threshold Dithering
- Random Modulation
- Ordered Dithering [1, Bayer, 1973]
  - Cluster dot screen
  - Disperse dot screen
- Error Diffusion [2, Floyd and Steinberg, 1975]

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Ordered Dithering [1]

- Ordered dithering is *a point process* that produces output by comparing a single continuous-tone input value to a deterministic **periodic array of thresholds** (**dither matrix**) [4].
- For example, a 2×2 dither matrix D_2:

$$D_2 = \begin{bmatrix} 0 & 2 \\ 3 & 1 \end{bmatrix}$$

- The dither matrix can be converted to a "*threshold matrix*" or "screen" using the following operation.

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

- The ordered dithering algorithm is applied via thresholding. X is an original grayscale image.

$$b(i,j) = \begin{cases} 255 & \text{if } X(i,j) > T(i,j) \\ 0 & \text{otherwise} \end{cases}$$

Example for Ordered Dithering

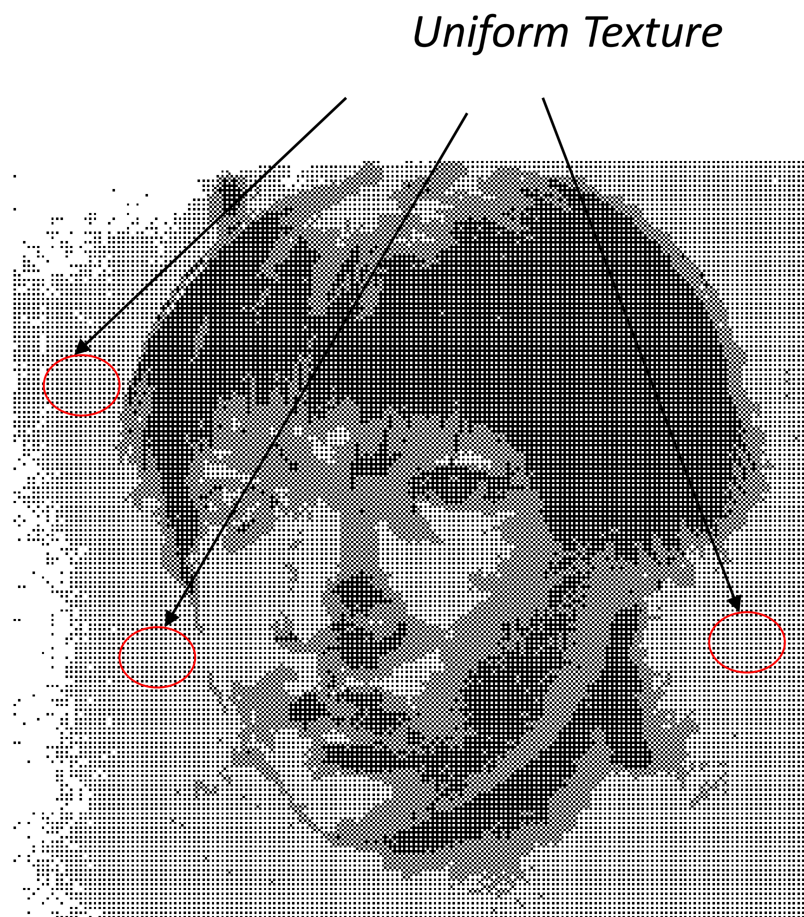

Fig.1 (a) Original grayscale image (b) Halftone image dithered with D_2

Dither Matrix

- The size of the matrix and the arrangement of the values have an important effect on the dither process.
- Two common dither matrix patterns: **clustered** pattern and **dispersed** pattern.
  - **Clustered** pattern: if the consecutive thresholds are located in spatial proximity, then it is called a “clustered pattern”.
  - **Dispersed** pattern: the thresholds are uniformly distributed in the matrix.

Two 8×8 Dither Matrix Patterns

62	57	48	36	37	49	58	63
56	47	35	21	22	38	50	59
46	34	20	10	11	23	39	51
33	19	9	3	0	4	12	24
32	18	8	2	1	5	13	25
45	31	17	7	6	14	26	40
55	44	30	16	15	27	41	52
61	54	43	29	28	42	53	60

(a)

0	32	8	40	2	34	10	42
48	16	56	24	50	18	58	26
12	44	4	36	14	46	6	38
60	28	52	20	62	30	54	22
3	35	11	43	1	33	9	41
51	19	59	27	49	17	57	25
15	47	7	39	13	45	5	37
63	31	55	23	61	29	53	21

(b)

Fig.2 Examples for two dither matrix patterns (a) **Clustered** pattern (b) **Dispersed** pattern

Properties of Clustered Pattern

- Relatively visible texture
- Relatively poor detail rendition
- Uniform texture across entire grayscale.
- Robust performance with non-ideal output devices

Dispersed Dithering

- *Bayer's optimal dither matrix* [1, Bayer, 1973]

$$D_{2n} = \begin{bmatrix} 4\times D_n(i,j) & 4\times D_n(i,j)+2 \\ 4\times D_n(i,j)+3 & 4\times D_n(i,j)+1 \end{bmatrix}$$

- 4×4 and 8×8 *Bayer's optimal dither matrixes*

0	8	2	10
12	4	14	6
3	11	1	9
15	7	13	5

0	32	8	40	2	34	10	42
48	16	56	24	50	18	58	26
12	44	4	36	14	46	6	38
60	28	52	20	62	30	54	22
3	35	11	43	1	33	9	41
51	19	59	27	49	17	57	25
15	47	7	39	13	45	5	37
63	31	55	23	61	29	53	21

Fig.3 Bayer' optimal dither matrix

Example for Dispersed Dithering with 8×8 *Bayer's Optimal Dither Matrix*

(a)

(b)

Fig. 4(a) Original grayscale image (b) Halftone image dithered with 8×8 *Bayer's optimal dither matrix*

Properties of Dispersed Dithering

- Within any region containing K dots, the K thresholds should be distributed as uniformly as possible.
- Textures used to represent individual gray levels have low visibility.
- Improved detail rendition.
- Transitions between textures corresponding to different gray levels may be more visible.
- Not robust to non-ideal output devices

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Error Diffusion Halftoning [2]

- Quantizes each pixel using a **neighborhood** operation, rather than a simple pointwise operation.
- Moves through image in a scan curve, quantizing the result, and "***pushing***" the error forward.
- Can produce better quality images than is possible with screens.

- Variations: which neighbor pixels are affected?

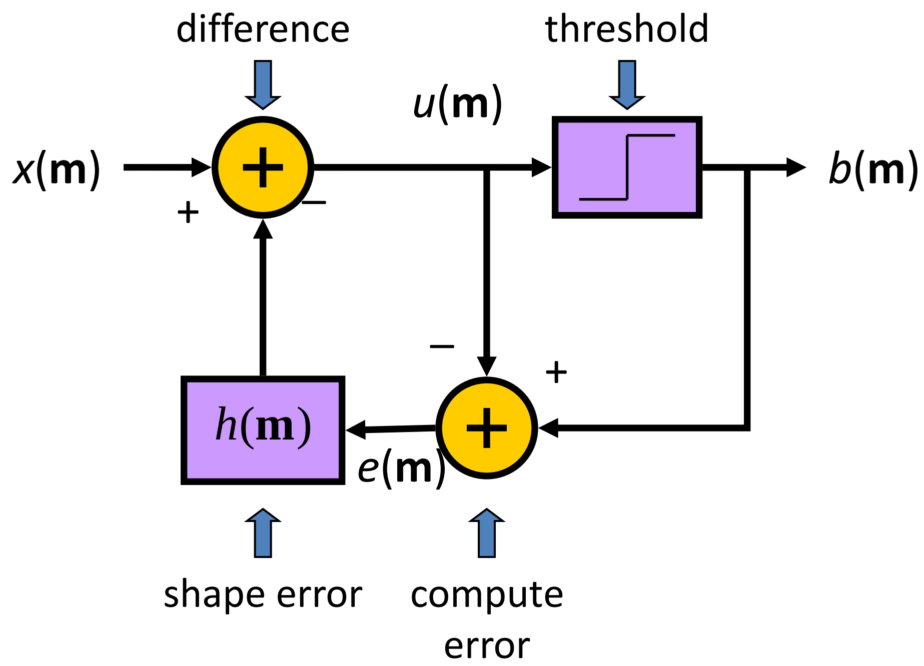
Filter View of Error Diffusion

Equations:

$$u_{m,n} = x_{m,n} - \sum_{(k,l)\in R} h_{k,l} e_{m-k,n-l}$$

$$b_{m,n} = Q(u_{m,n}) = \begin{cases} \lambda & u_{m,n} \geq \lambda / 2 \\ 0 & u_{m,n} < \lambda / 2 \end{cases}$$

$$e_{m,n} = b_{m,n} - u_{m,n} = Q(u_{m,n}) - u_{m,n}$$



Parameters:

♠ Threshold is typically $\lambda/2 = 127$.

♠ $h_{k,\,l}$ are typically chosen to be positive and sum to 1.

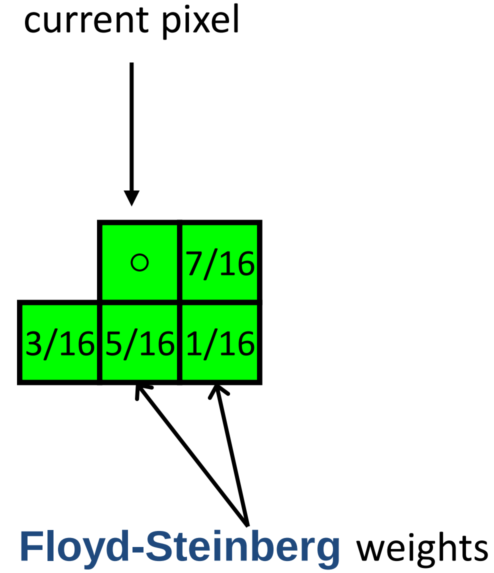
Error Diffusion Algorithm

- 1.Initialize $u_{m,n}$ with $x_{m,n}$, $e_{m,n}$ and $b_{m,n}$ with zeros.
- 2.For each pixel in the image (in scan curve)

  (a) Compute

$$b_{m,n} = Q(u_{m,n}) = \begin{cases} \lambda & u_{m,n} \geq \lambda / 2 \\ 0 & u_{m,n} < \lambda / 2 \end{cases}$$

  (b) **Diffuse** $e_{m,n}$ forward, such as the following scheme (Floyd-Steinberg filter)



- 3.Display the binary image $b_{m,n}$.

Variation: Filter

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

(a)

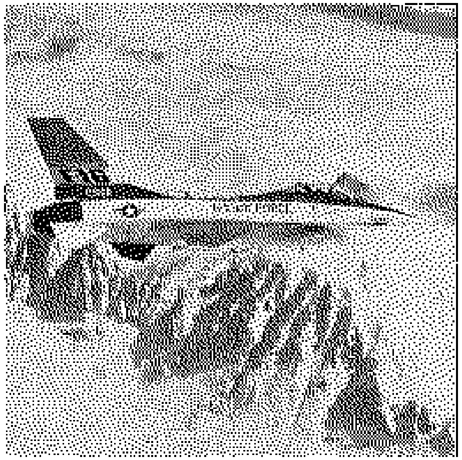
		*	*8*	*4*
2	*4*	*8*	*4*	*2*
1	*2*	*4*	*2*	*1*

(b)

Fig.5 Variation: filter (a) Jarvis filter (48) (b) Stucki filter (42)

Examples for Different Error Diffusion Filters

(a)



(b)

(c)

(d)

Fig.6 (a) Original grayscale image “Plane” (b) (c) (d) halftone images generated by Floyd-Steinberg, Jarvis and Stucki filters.

References

- [1] B. E. Bayer, “An optimum method for two-level rendition of continuous-tone pictures,” in Proceedings of the IEEE International Conference on Communication, pp. 11-26, 1973.
- [2] R. Floyd and L. Steinberg, “An adaptive algorithm for spatial grey scale,” Society for Information Display Symposium, Digest of Technical Papers, pp.36-37, 1975.

Thank You!

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