Dithering:

(including Error Diffusion Dithering/ Floyd-Steinberg methods)

and **Halftoning:**

(including Pattern and Ordered Dither)

Reducing dynamic range

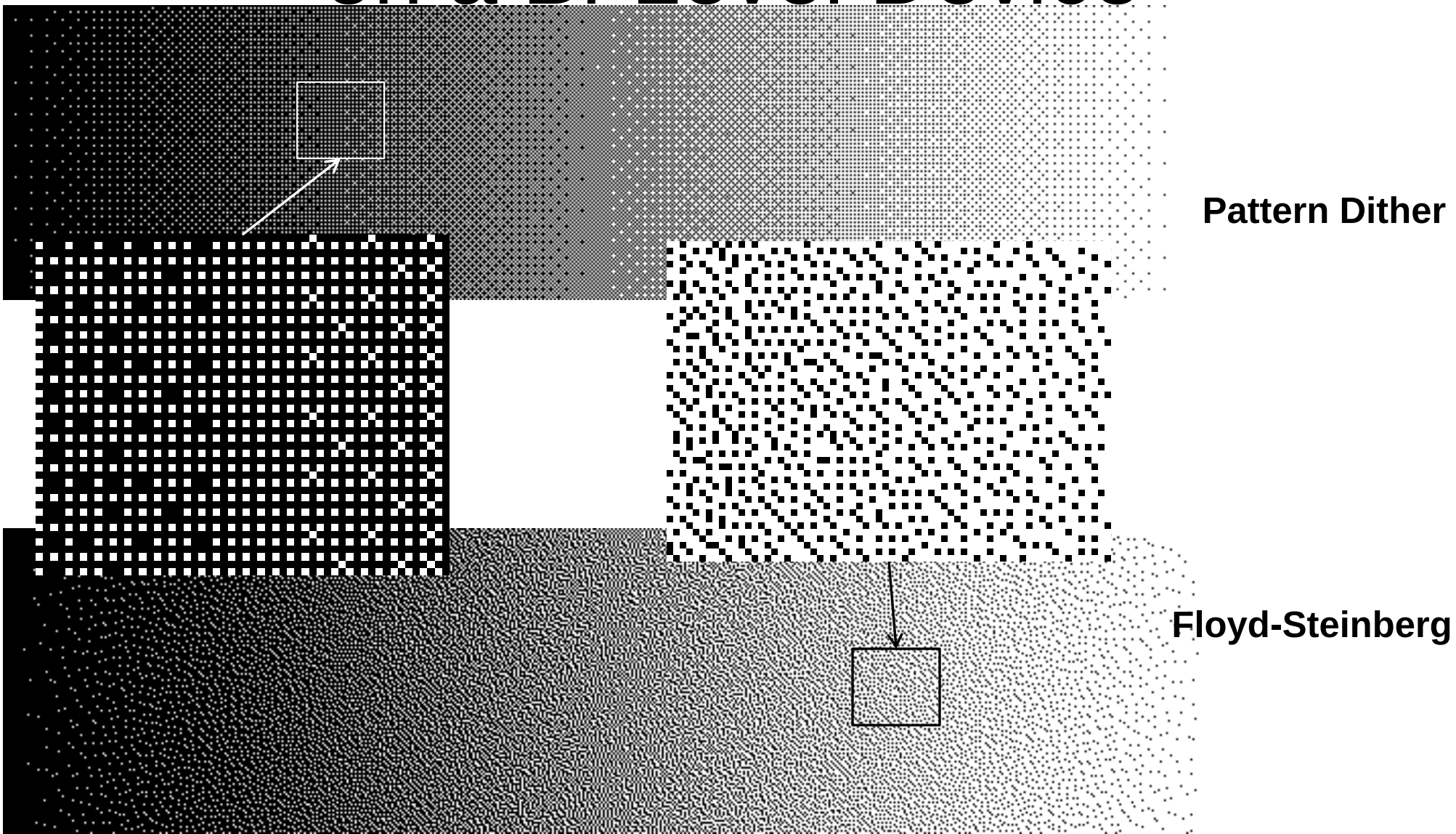
p585-591 of Hearn & Baker (3rd)

Displaying Grey-Scale on a Bi-Level Device

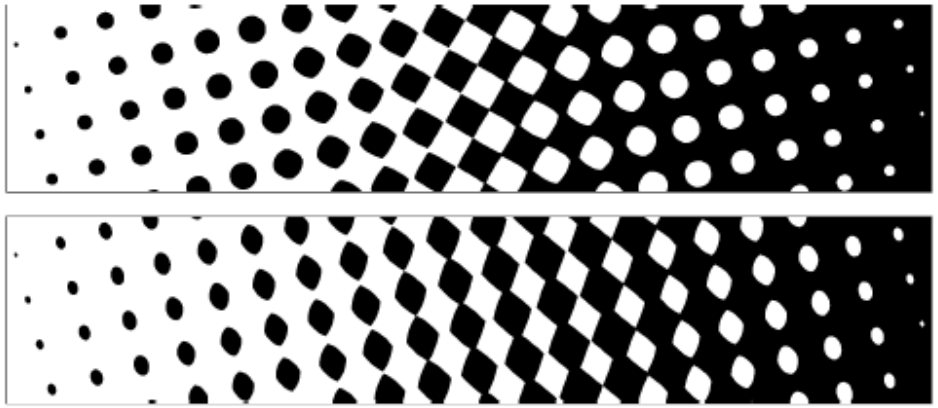
256 Greys

Thresholding

Displaying Grey-Scale on a Bi-Level Device



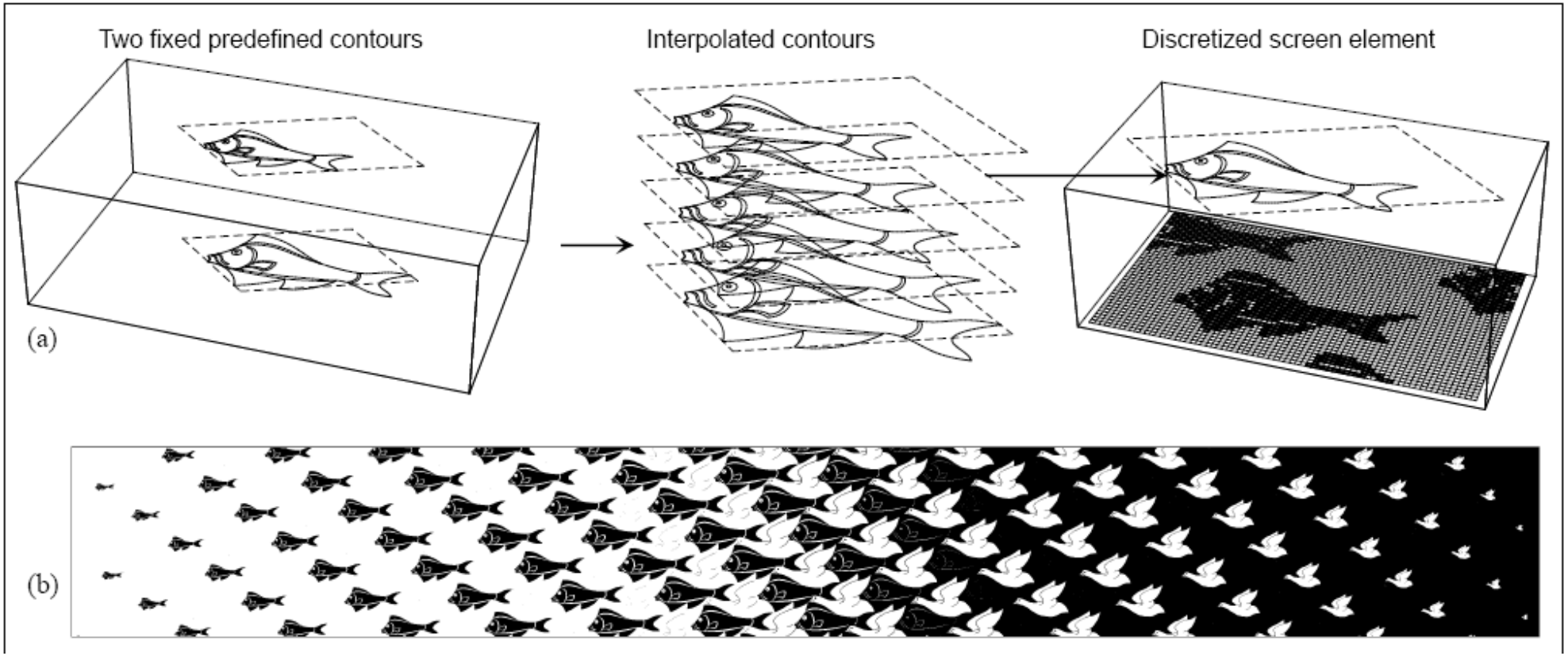
Other Grey Scales



- (Top) Print industry
- (Bottom) Computer generated

Victor Ostromoukhov and Roger D. Hersch, Artistic screening, Siggraph, 219 - 228, 1995

Escher Inspired



Victor Ostromoukhov and Roger D. Hersch, Artistic screening, Siggraph, 219 - 228, 1995

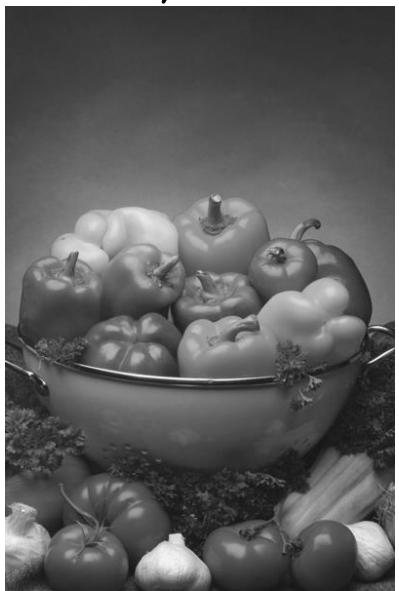
image->adjustments->posterise and threshold

Thresholding

Code:

```
threshold=128;
for j=1 to height
  for i=1 to width
     if (grey[j][i]<threshold) bw[j][i]=0
     else bw[j][i]=255;
```

grey=$\frac{(r+g+b)}{3}$



threshold

Calculating Error

original grey image (0-255)

100	100	120	140
110	110	130	150
120	150	170	200
140	170	200	250

Total intensity=
100+100+120+…+250=2360
Average=
2360/16=147.5

threshold image

0	0	0	255
0	0	255	255
0	255	255	255
255	255	255	255

Total intensity=
0+0+0+255+…+255=2550
Average=
2550/16=159.375
Error (Total)=190 (Average)=11.875

Pathological Case

original grey image (0-255)

127	127	127	127
127	127	127	127
127	127	127	127
127	127	127	127

Total intensity=
127+127+127+…+127=2032
Average=
2032/16=127

threshold image

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

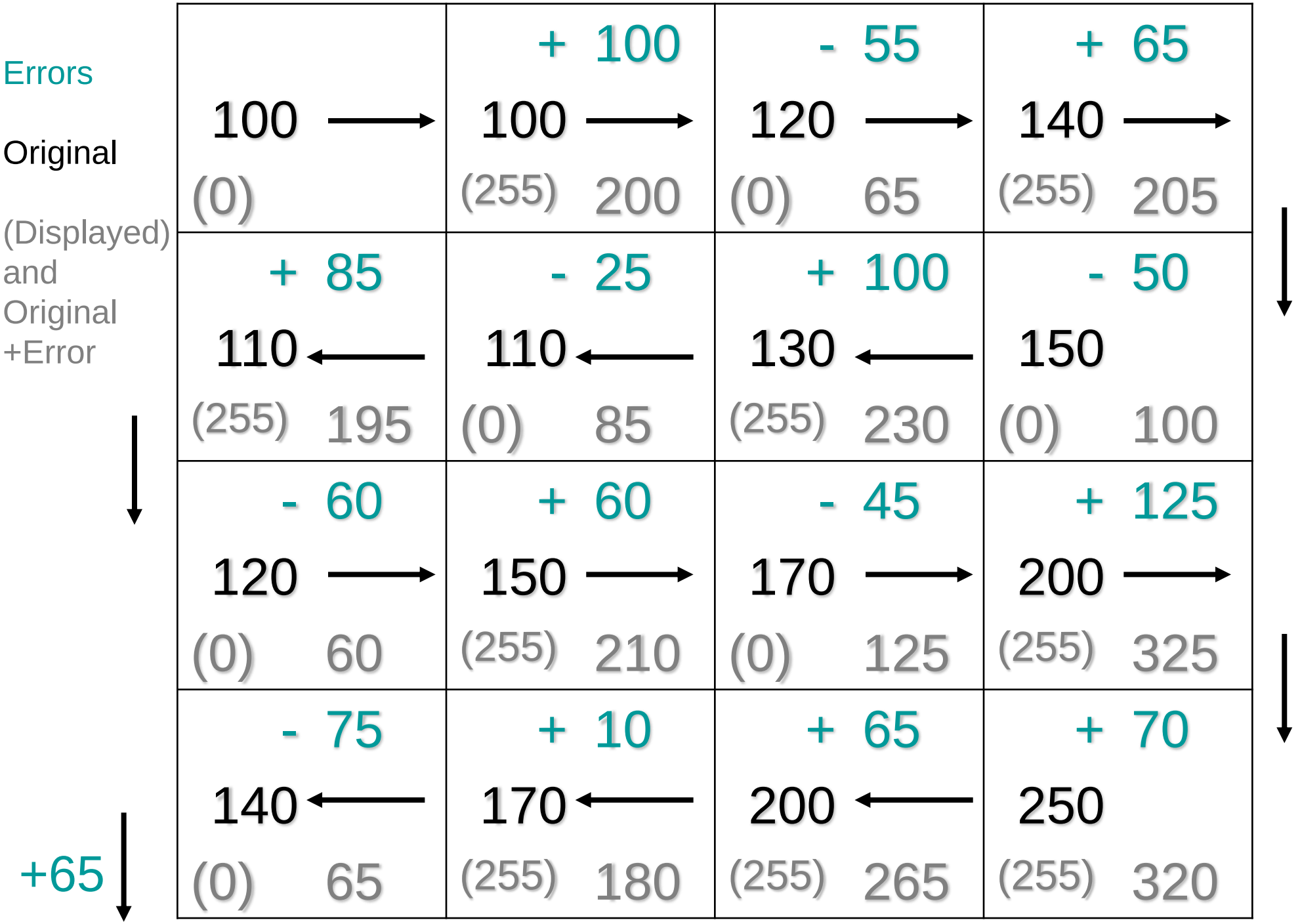
Total intensity=
0+0+0+…+0=0
Average=
0/16=0
Error (Total)=-2032 (Average)=-127

Error Diffusion Dithering

```
threshold=128;
max_intensity=255;
Code at each pixel:
grey[j][i]=grey[j][i]+error
if (grey[j][i]<threshold) {
        bw[j][i]=0
        error=grey[j][i]
}
else {
        bw[j][i]=max_intensity
        error=grey[j][i]-max_intensity
}
```

Error=0

100	100	120	140
110	110	130	150
120	150	170	200
140	170	200	250


Errors
Original
(Displayed) and Original +Error
100
(0)
+ 100
100
(255) 200
- 55
120
(0) 65
+ 65
140
(255) 205
+ 85
110
(255) 195
- 25
110
(0) 85
+ 100
130
(255) 230
- 50
150
(0) 100
- 60
120
(0) 60
+ 60
150
(255) 210
- 45
170
(0) 125
+ 125
200
(255) 325
- 75
140
(0) 65
+ 10
170
(255) 180
+ 65
200
(255) 265
+ 70
250
(255) 320
+65

Calculating Error

original grey image (0-255)

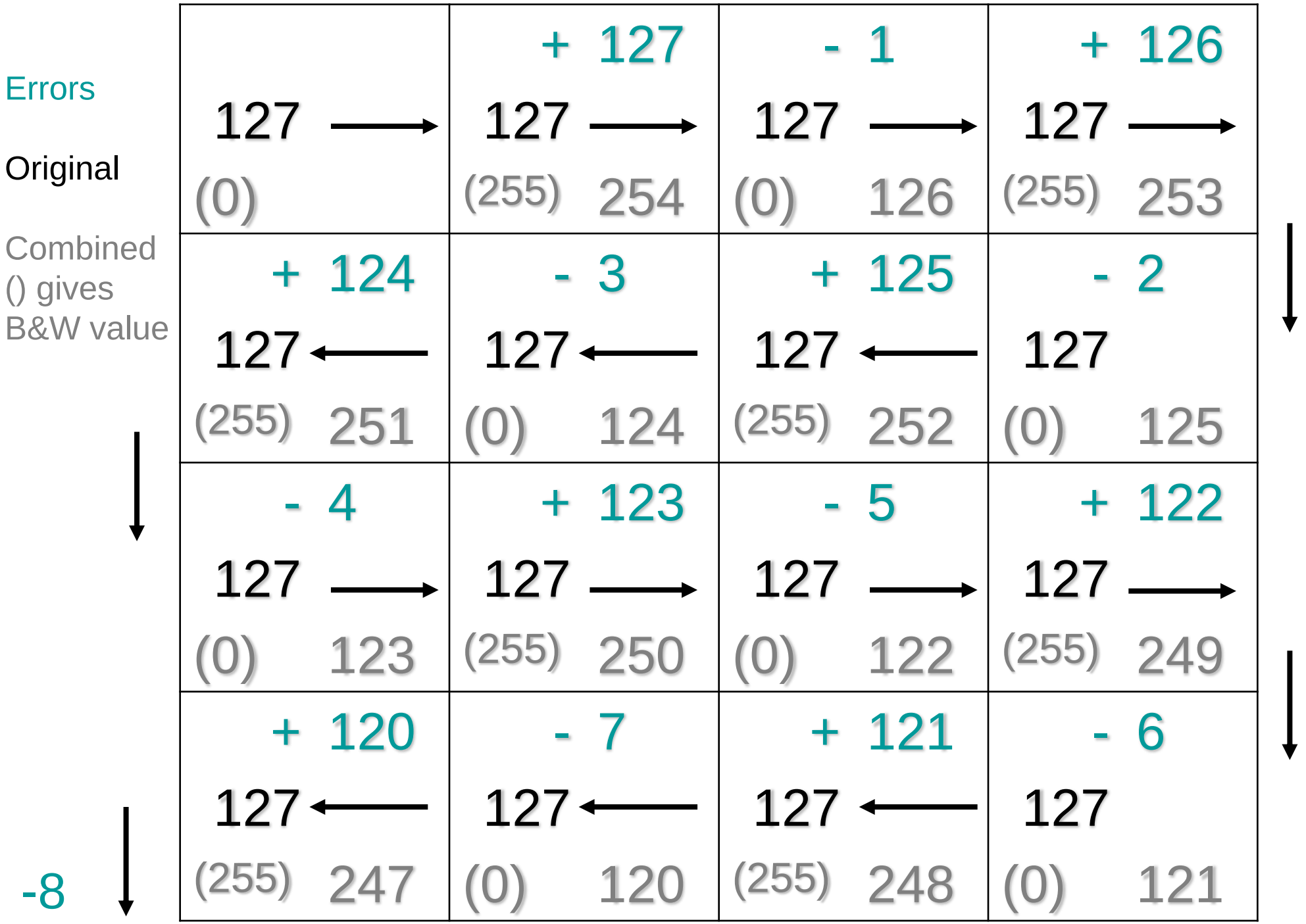
100	100	120	140
110	110	130	150
120	150	170	200
140	170	200	250

Total intensity=
100+100+120+…+250=2360
Average=
2360/16=147.5

error diffusion image

0	255	0	255
255	0	255	0
0	255	0	255
0	255	255	255

Total intensity=
0+255+0+255+…+255=2295
Average=
2295/16=143.4375
Error (Total)=-65 (Average)=-4.0625


Errors
Original
Combined
() gives
B&W value
127
(0)
+ 127
127
(255) 254
- 1
127
(0) 126
+ 126
127
(255) 253
+ 124
127
(255) 251
- 3
127
(0) 124
+ 125
127
(255) 252
- 2
127
(0) 125
- 4
127
(0) 123
+ 123
127
(255) 250
- 5
127
(0) 122
+ 122
127
(255) 249
+ 120
127
(255) 247
- 7
127
(0) 120
+ 121
127
(255) 248
- 6
127
(0) 121
-8

Pathological Case

original grey image (0-255)

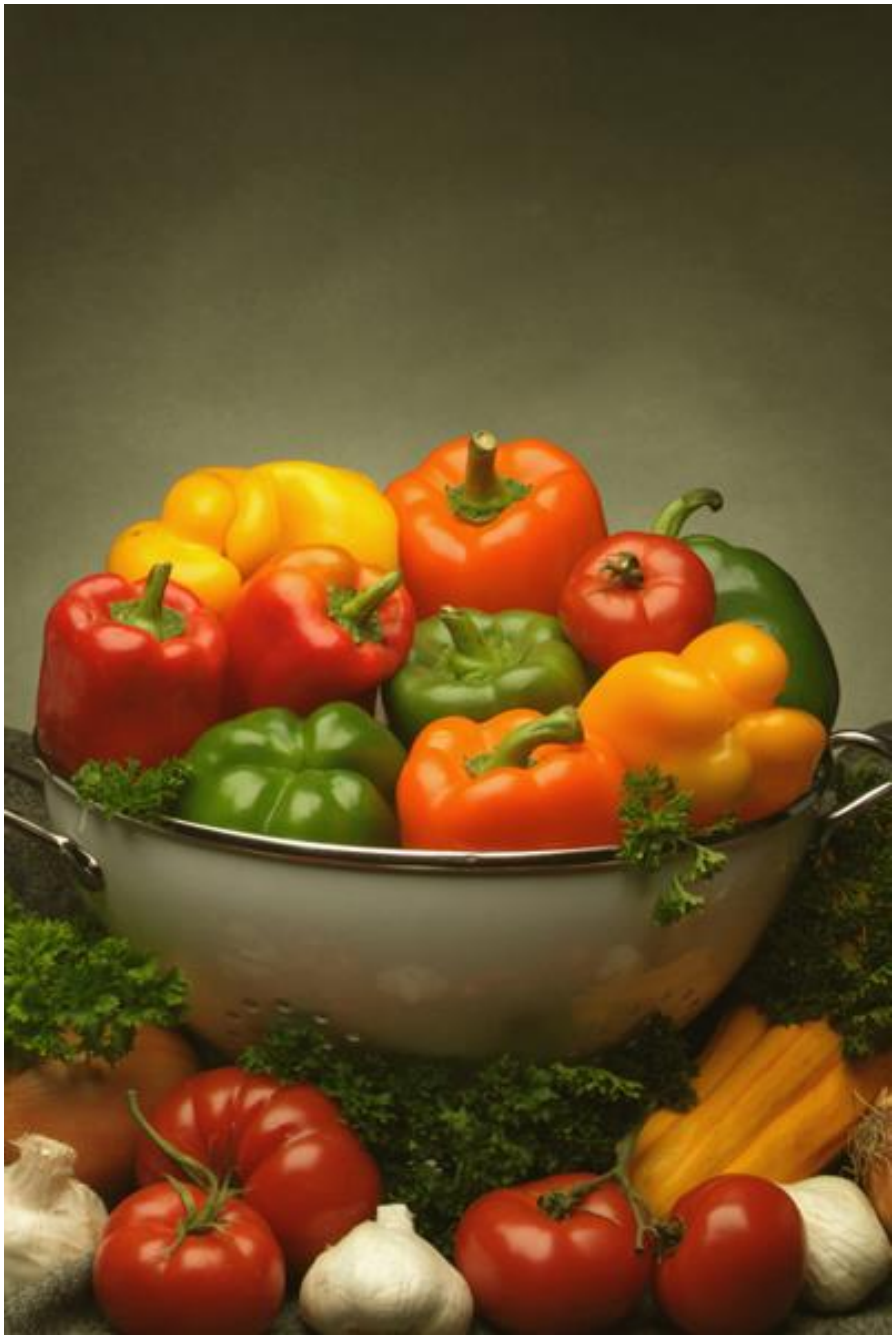
127	127	127	127
127	127	127	127
127	127	127	127
127	127	127	127

Total intensity=
127+127+127+…+127=2032
Average=
2032/16=127

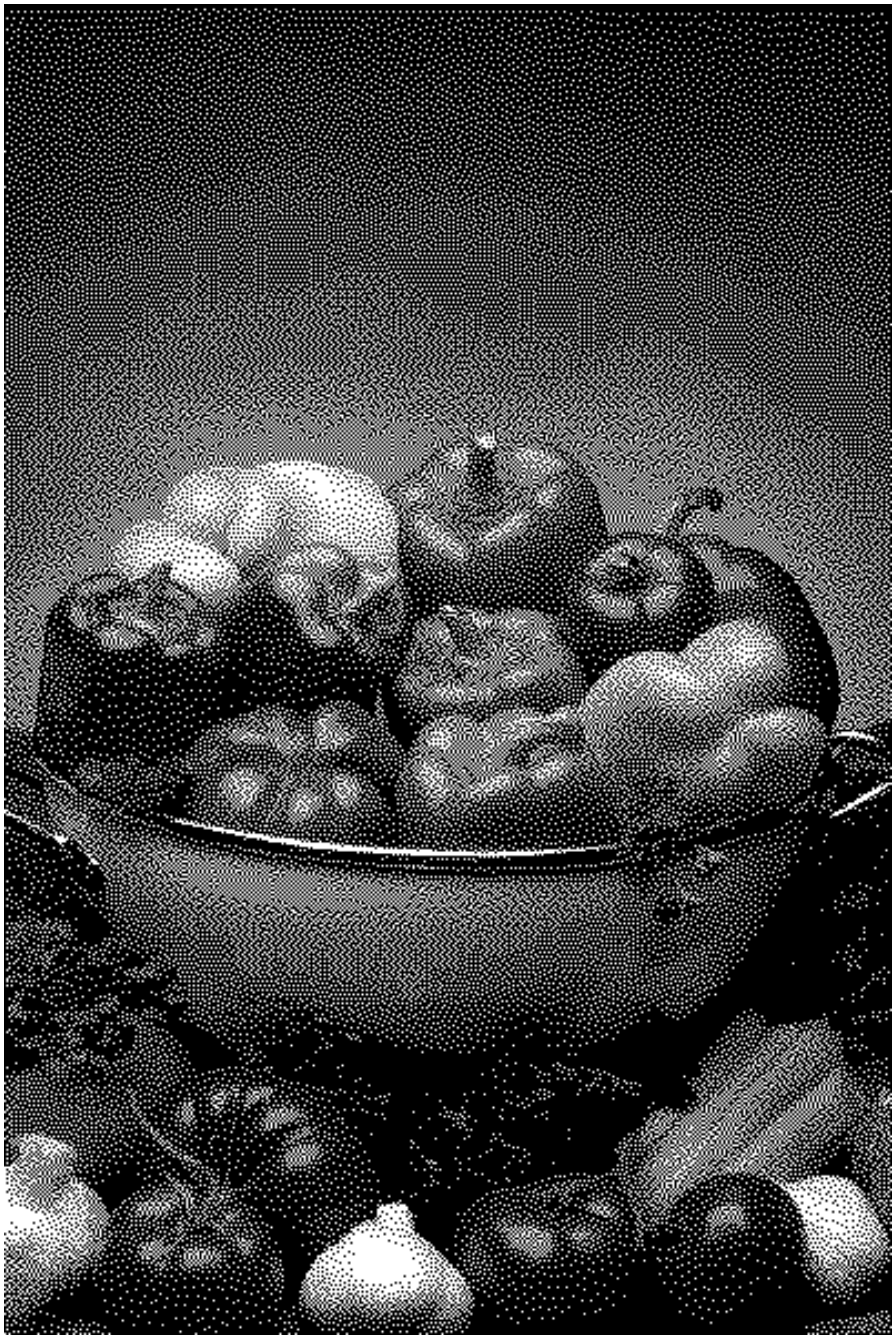
error diffusion image

0	255	0	255
255	0	255	0
0	255	0	255
255	0	255	0

Total intensity=
0+255+0+…+0=2040
Average=
2040/16=127.5
Error (Total)=8 (Average)=0.5



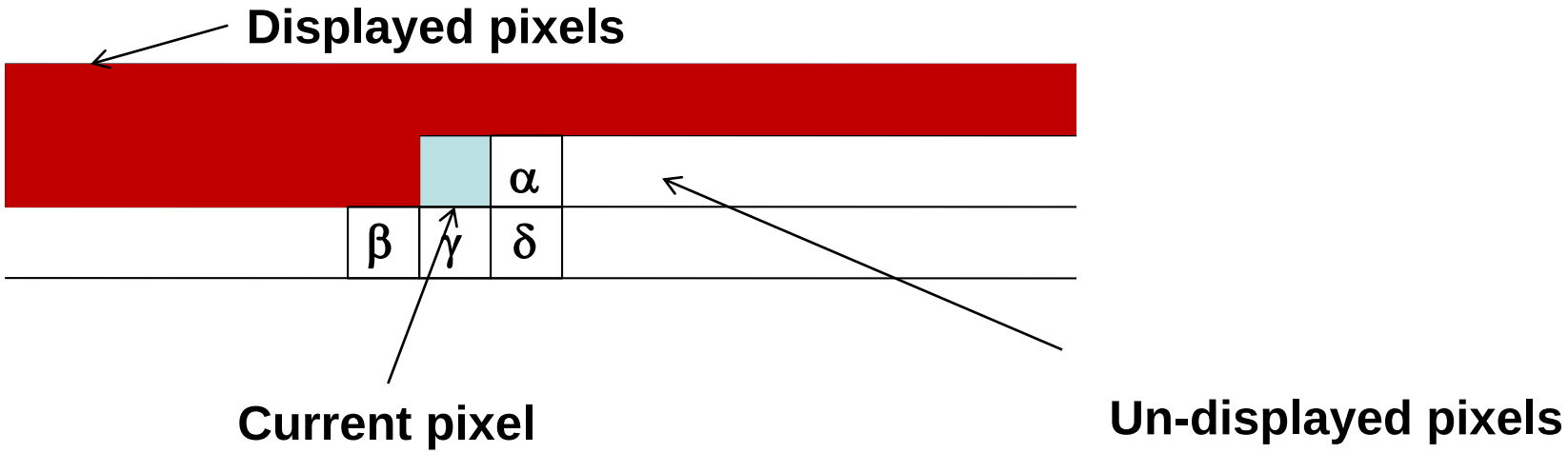
True colour



2 colour (B&W)

Floyd-Steinberg Error Diffusion Dithering

- Instead of passing 100% of the error to the next pixel, distribute it to the 4 “un-displayed” neighbours of the current pixel.
- $\alpha+\beta+\gamma+\delta=1$, e.g. $(\alpha,\beta,\gamma,\delta)=({}^{7}/_{16}, {}^{3}/_{16}, {}^{5}/_{16}, {}^{1}/_{16})$



Floyd-Steinberg Error Diffusion Dithering

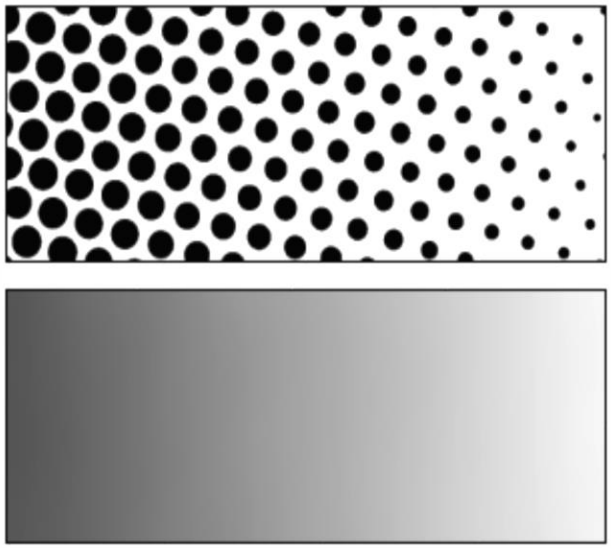
Code at each pixel:

```
if (grey[j][i]<128) {
        bw[j][i]=0
        error=grey[j][i]
}
else {
        bw[j][i]=255
        error=grey[j][i]-255
}
grey[j+1][i-1]=grey[j+1][i-1]+error*β;
grey[j+1][i]=grey[j+1][i]+error*γ;
grey[j+1][i+1]=grey[j+1][i+1]+error*δ;
grey[j][i+1]=grey[j][i+1]+error*α;
```

- Passing error
- Assumes grey[j][i] corresponds to pixel (i,j)
- Care must be taken at edges
- Grey must be type integer

Halftoning (Print industry)

- B&W images produced using differently sized black circles
- Diameter proportional to darkness of region
- Colour halftones use dots of different sizes in each colour channel (usually CMY=Cyan, Magenta, Yellow)
- Reduces dynamic range (use fewer colours, but still give the impression of continuous tone)



Halftoning (Computer Graphics)

- Use halftone approximation patterns (halftone patterns)
- These are example templates that produce the patterns that shall be used in the following sections (3x3, 4x4, 5x5):

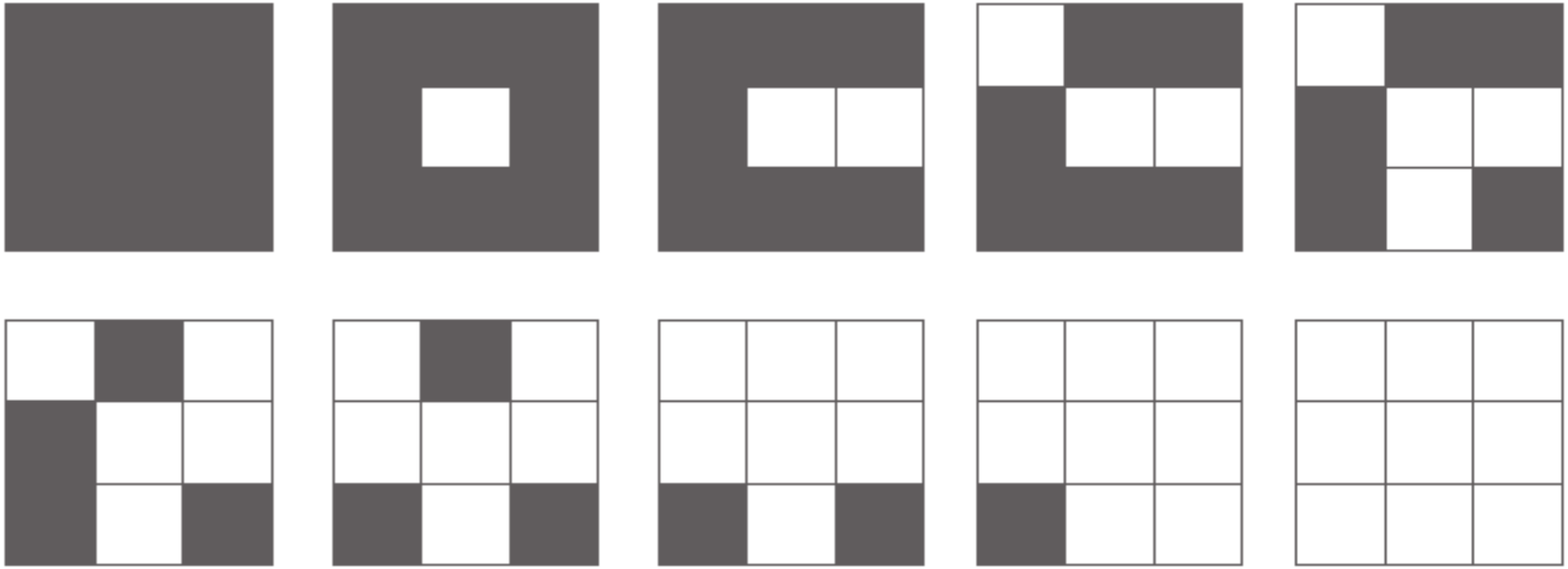
3	7	5
6	1	2
9	4	8

1	9	3	11
13	5	15	7
4	12	2	10
16	8	14	6

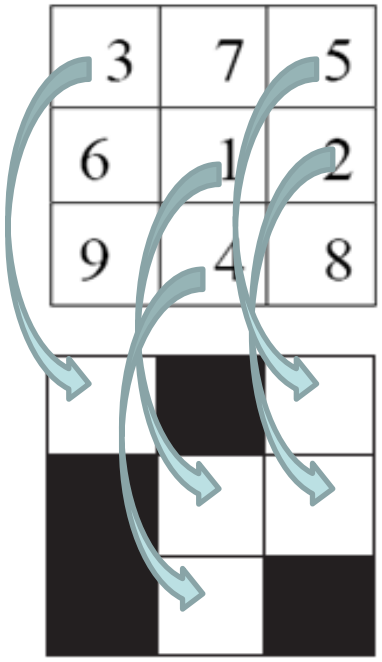
22	11	18	15	24
16	3	7	5	10
21	6	1	2	19
13	9	4	8	14
25	17	20	12	23

Halftoning

- nxn pixels can represent n^2+1 intensity levels (on a bi-level display)
- 3x3 displays 10 intensity levels distributed from black to white – halftone patterns:



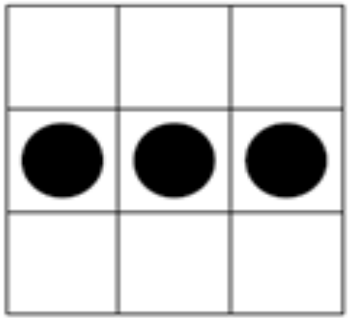
Halftoning



- e.g. intensity level 5, all pixels up to and including 5 are set to white
- Given original intensity $I \in [0,1]$ and an nxn halftone template, intensity I is represented by pattern p, where
- $p=\min(\text{floor}(I*(n^2+1)), n^2)$
- (Intensity levels are labelled $0..n^2$ e.g. 0..9 in case of 3x3)

Halftoning Patterns

- The patterns must form a growth sequence so that any pixel on for intensity level j is also on for all levels k>*j. (Avoids some visual effects)*
- Avoid single pixels (i.e. try to set neighbouring pixels). *(Avoids problems with inaccurate printers)*
- Avoid patterns developing, e.g. this 3x3 dither pattern for intensity level 3 would result in stripes appearing for large regions of this intensity



e.g. 4x4 template

1	9	3	11
13	5	15	7
4	12	2	10
16	8	14	6

Pattern Dither

100	100	120	140
110	110	130	150
120	150	170	200
140	170	200	250

Process – get total scaled intensity=0.578
Find pattern template to use (p=9)
Compare with 4x4 template
Set pixel white if p >= template number

1	9	3	
	5		7
4		2	
	8		6

- $p=\min(\text{floor}(I*(n^2+1)), n^2)$
- To get total scaled intensity $I \in [0,1]$:
- Total intensity=100+100+120+…+250=2360
- Average intensity=Total intensity/number of pixels: 2360/16=147.5
- Total Scaled intensity=average intensity/255: 147.5/255=0.578
- 4x4 Pattern $p=\min(\text{floor}(0.578*(4^2+1)), 4^2)=9$

Ordered Dither

e.g. 4x4 template

1	9	3	11
13	5	15	7
4	12	2	10
16	8	14	6

100	100	120	140
110	110	130	150
120	150	170	200
140	170	200	250

Process – get pattern number for each pixel.

6	6	8	9
7	7	8	10
8	10	11	13
9	11	13	16

- **$p=\min(\text{floor}(I*(n^2+1)), n^2)$**
- **To get scaled intensity $I \in [0,1]$:**
- **Top left pixel=100**
- **Scaled intensity=intensity/255: 100/255=0.39**
- **4x4 Pattern $p=\min(\text{floor}(0.39*(4^2+1)), 4^2)=6$**
- **For 110, p=7, for 120, p=8, for 130, p=8, for 140, p=9, for 150, p=10, for 170, p=11, for 200, p=13, for 250, p=16**

Ordered Dither

e.g. 4x4 template

1	9	3	11
13	5	15	7
4	12	2	10
16	8	14	6

6	6	8	9
7	7	8	10
8	10	11	13
9	11	13	16

Now compare pattern number with template. If pattern number is >= template number, set pixel to white

6	6	8	9
7	7	8	10
8	10	11	13
9	11	13	16

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Question 3

(a) Using the image below, show what the results would be if we tried to display it on a bi-level device using *thresholding*. Calculate the error between the original and the bi-level images. What are the advantages and disadvantages of using such a method?

90	100	100	110	125
95	110	120	130	140

Demonstrate the results of using the *standard error-diffusion* method. Calculate the error between the original and the new image. What are the advantages and disadvantages of this method, and what extension exists that improves upon it? What feature of the standard error-diffusion process retains error in the local area? (In all cases assume a 0-255 grey-level image).

[10 marks]

Question 1

(a) Given the following pattern dithering matrix:

3	7	5
6	1	2
9	4	8

and the following 6x3 grey-level image (with levels from 0 to 255):

100	100	110	120	120	140
110	110	120	120	140	150
120	140	150	150	180	180

demonstrate all of the stages of the two processes of dithering and halftoning to obtain a bi-level image. Also create a bi-level image using the thresholding algorithm. Compare the total error resulting from using the thresholding algorithm with the dithering and halftoning algorithms.

Using the same 6x3 grey-level image given above, also perform standard error diffusion on the first *two* rows of the image. Again compare the total error from the thresholding result for the first two rows with the total error resulting from using the standard error diffusion algorithm.

You should include a description of each method as part of your answer, along with the advantages and disadvantages of each method.

[20 marks]