

Lecture 2

Human visual system, perception & pixel

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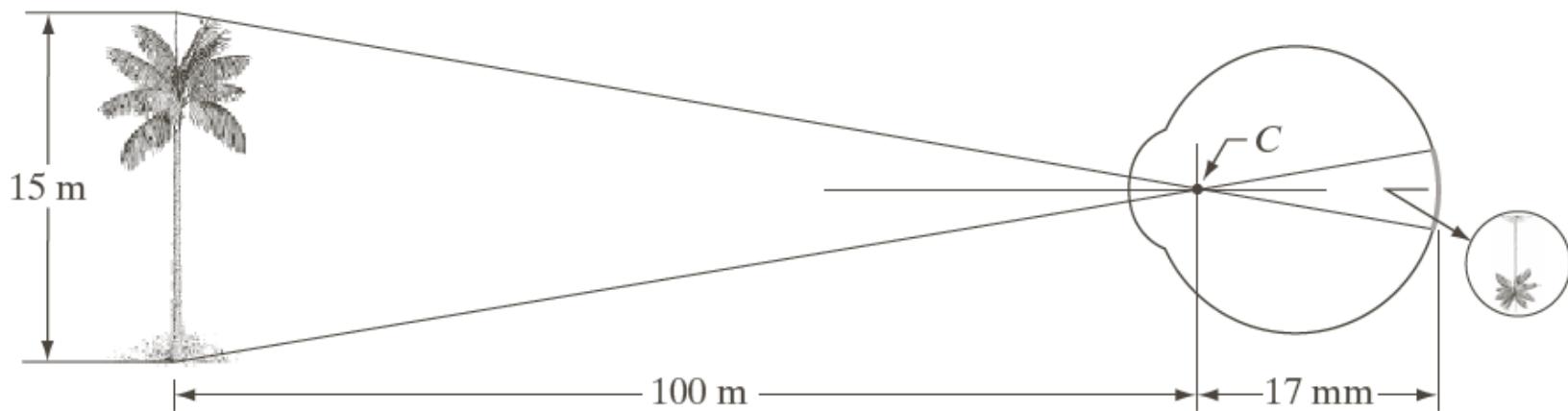
Outline

- Anatomical structure of eye ball
- Image formation and brightness adaptation in the eyes
- Visual illusions
- Pixel
- Basic operation of DIP

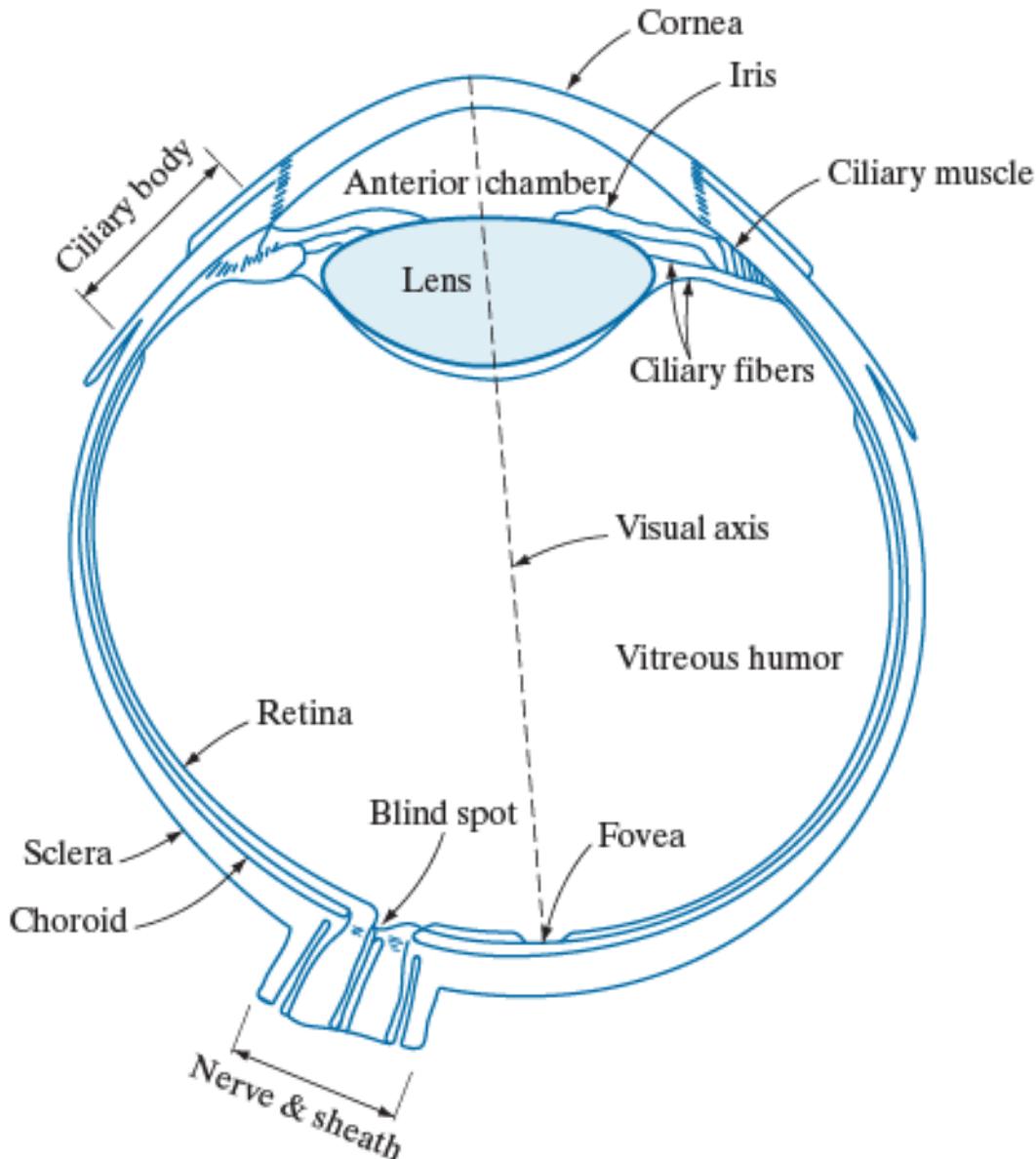


Graphical representation of human eye

- Objects captured as focused images on the image plane at retinas
- Perspective projection based on pinhole model geometry,
- Image size depends on distance of object
- In practice, optical devices with lens



Human Eye



Fovea: 中央凹

Retina: 视网膜 感光

Iris: 虹膜 透光量

Pupil: the opening of the iris (2-8 mm) 瞳孔

Lens: 晶状体

Blind spot: 盲点

Receptors:

Rod: 杆状体

(scotopic or dim-light vision)

Cone: 锥状体

(photopic or bright-light vision)

Human Visual Perception

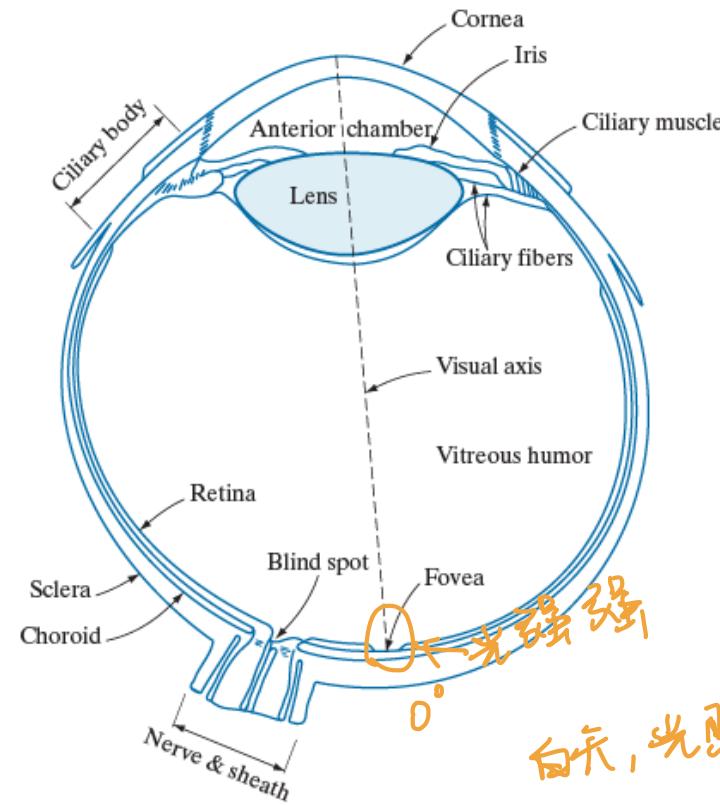


Figure 2.1: Sagittal Eye ball anatomy

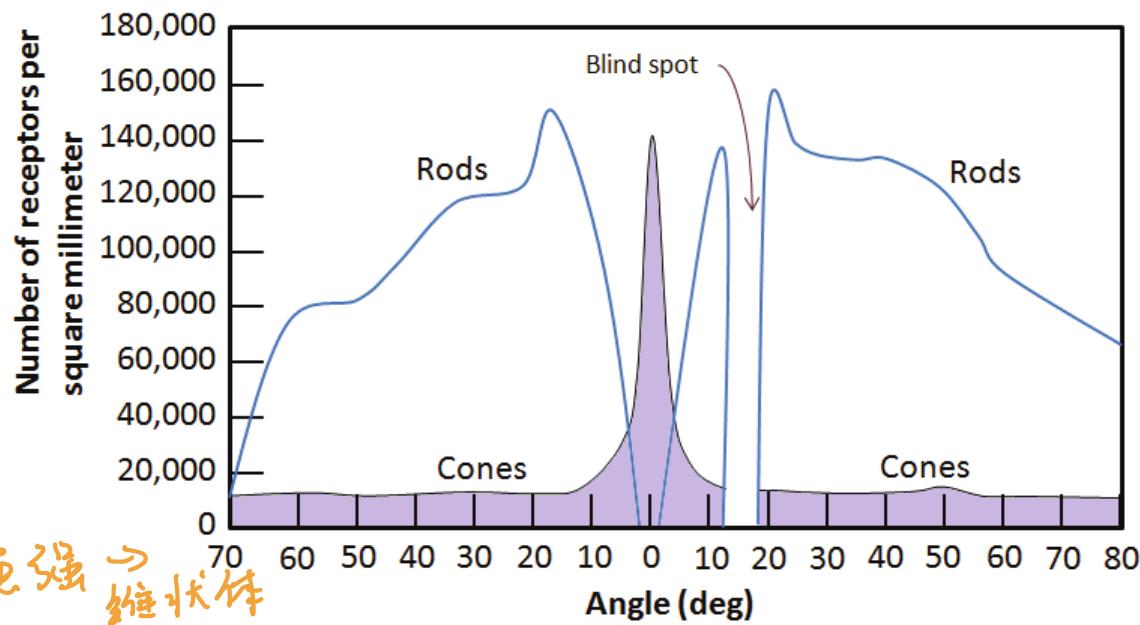


Figure 2.2: Distribution of rods and cones in the retina

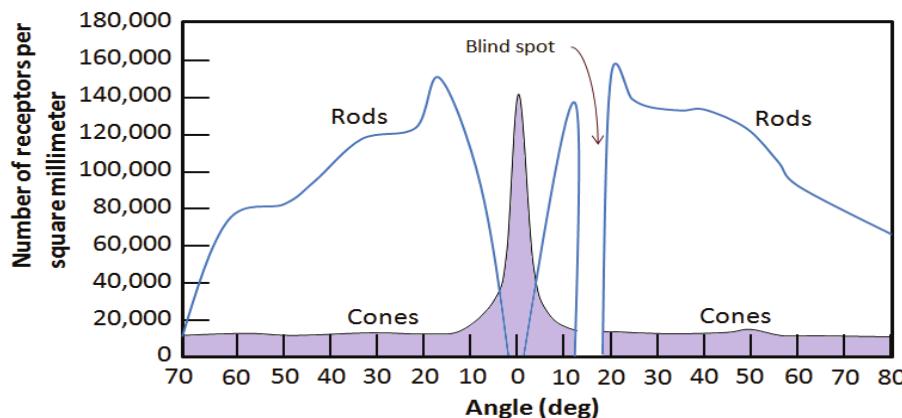
Human visual system perception elements

□ Rods:

- Sensitive to light intensity
- Night “scotopic” vision
- Achromatic 消色 [xiāo sè] color 敏感不强
- Low acuity (many per nerve end)
- Peripheric vision
- Slow response
- 75-150 Million/Retina

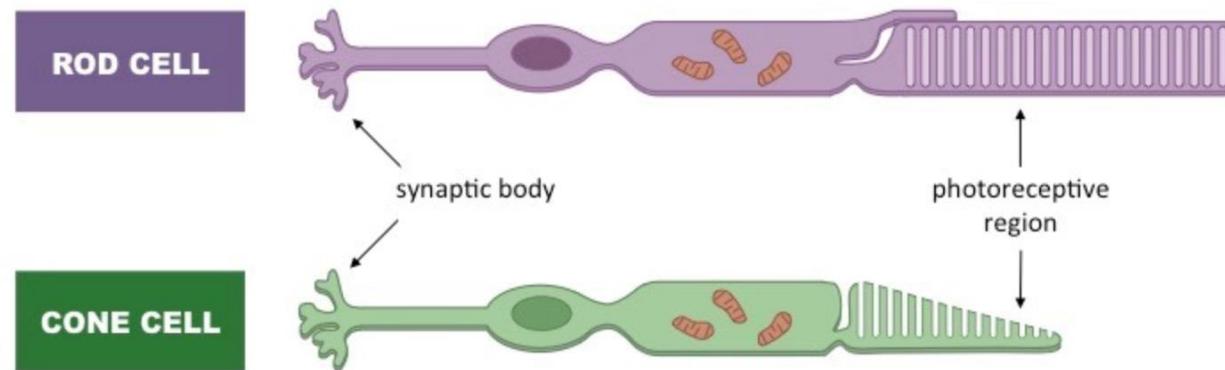
□ Cones:

- Only direct to direct light
- “Photopic” vision
- Chromatic (3 “colors”)
- Concentrated in fovea (1 per nerve end)
- High visual acuity, spatial resolution.
- Fast response
- 6-7 Million/Retina



Rods and cones

Types of Photoreceptors (Rods and Cones)

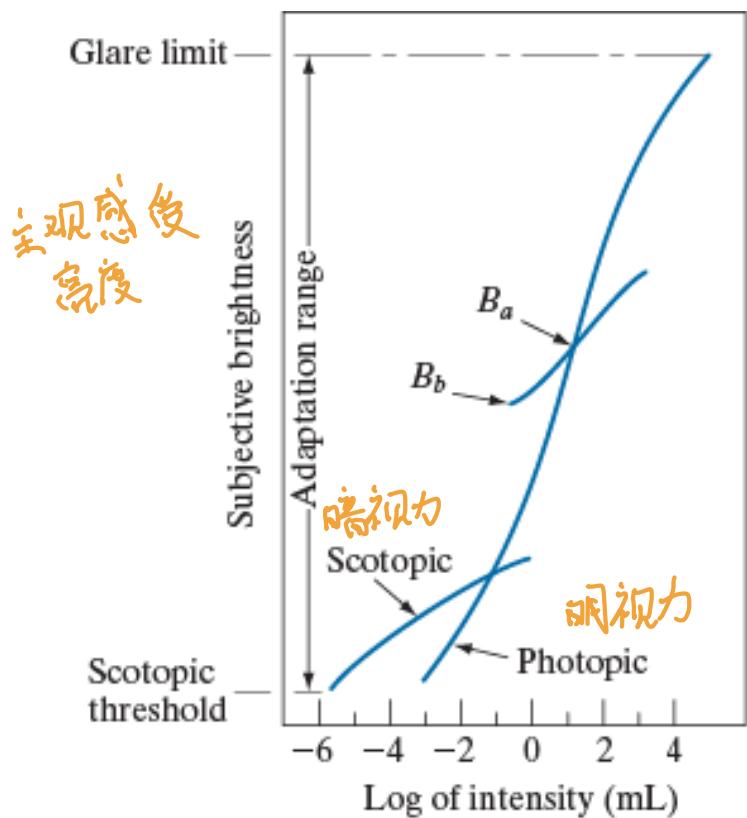


	Rod Cells	Cone Cells
Location in retina	Found around periphery	Found around centre (fovea)
Optimal light conditions	Dim light ('night' vision)	Bright light ('day' vision)
Visual acuity	Low resolution (many rods : one bipolar cell)	High resolution (one cone : one bipolar cell)
Colour sensitivity	All wavelengths	Certain wavelengths (red, green, blue)
Type of vision	Achromatic (black and white)	Colour
Number of types	One (all contain rhodopsin)	Three different iodopsin pigments
Relative abundance	Many	Fewer

Characteristics of Human Visual System

- ❑ Brightness adaption
- ❑ Simultaneous contrast

- ❑ Mach band effect
- ❑ Optical illusion



- Impressive total dynamic range ;)
- But, **cannot** operate over a long range simultaneously ;(
- Brightness adaption level (B_a)
- Below B_b is **black!**



Characteristics of Human Visual System

- Brightness adaption
- Simultaneous contrast

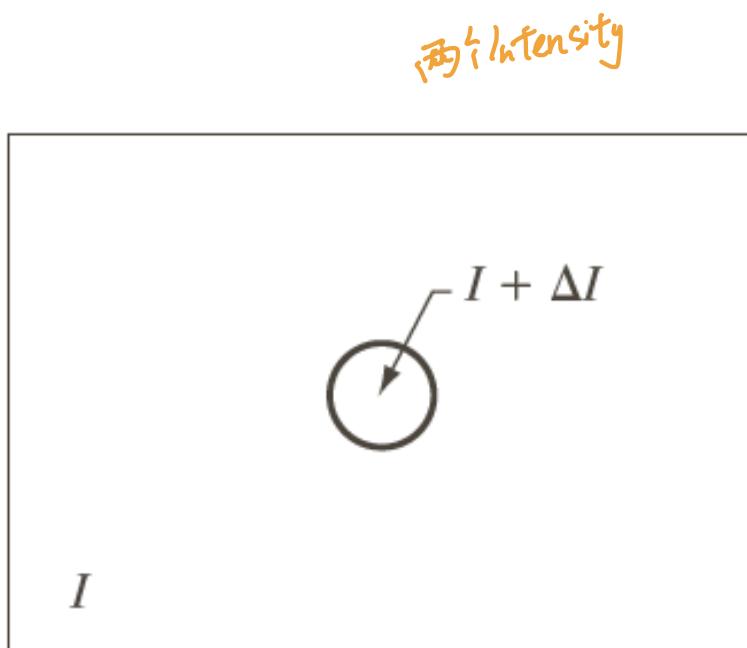
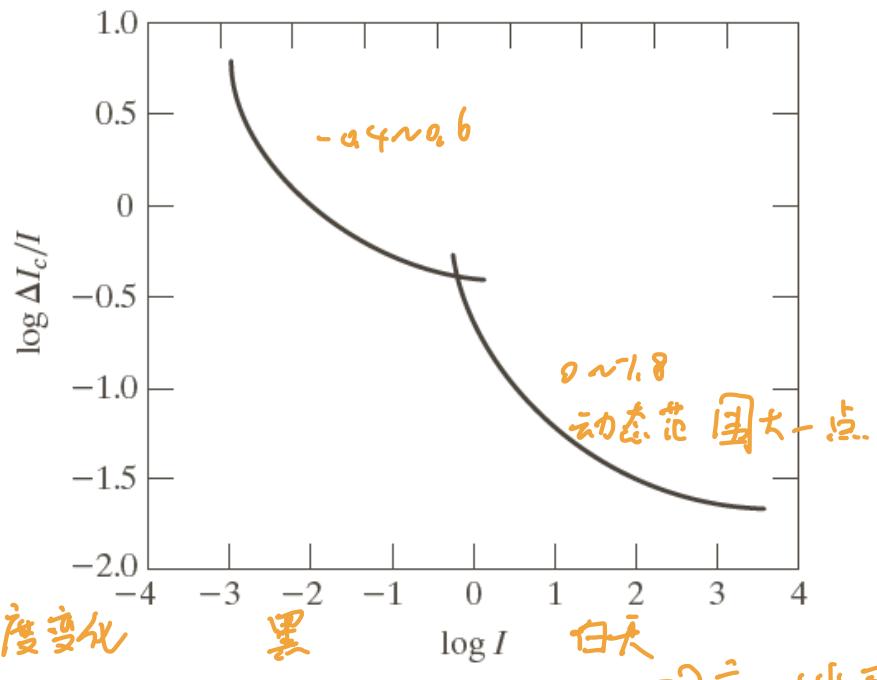


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

- Mach band effect
- Optical illusion



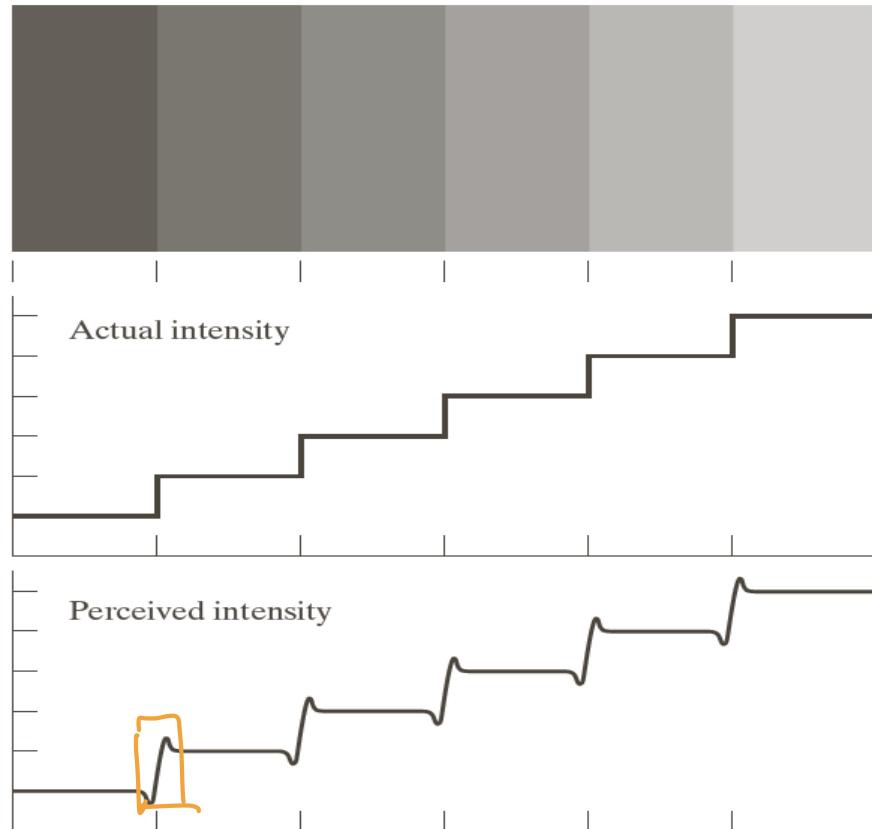
多视者看有无亮度变化

FIGURE 2.6 明亮对光变化感受能力强一些
Typical Weber ratio as a function of intensity.

Characteristics of Human Visual System

- ❑ Brightness adaption
- ❑ Simultaneous contrast

- ❑ Mach band effect
- ❑ Optical illusion

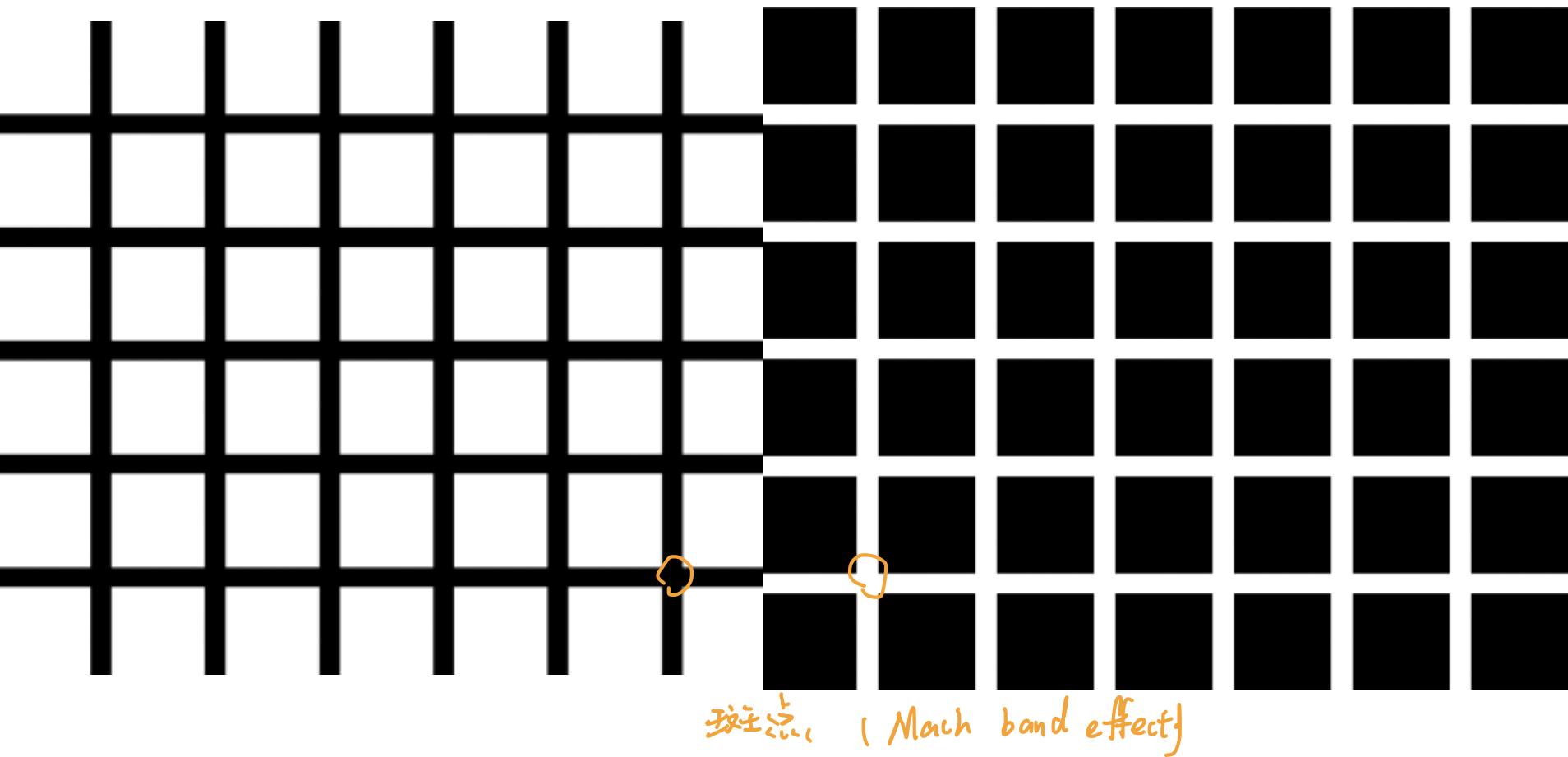


视觉感受和 real 有一定差异

Figure 2.7: Perceived intensity is not a simple function of actual intensity



Characteristics of Human Visual System

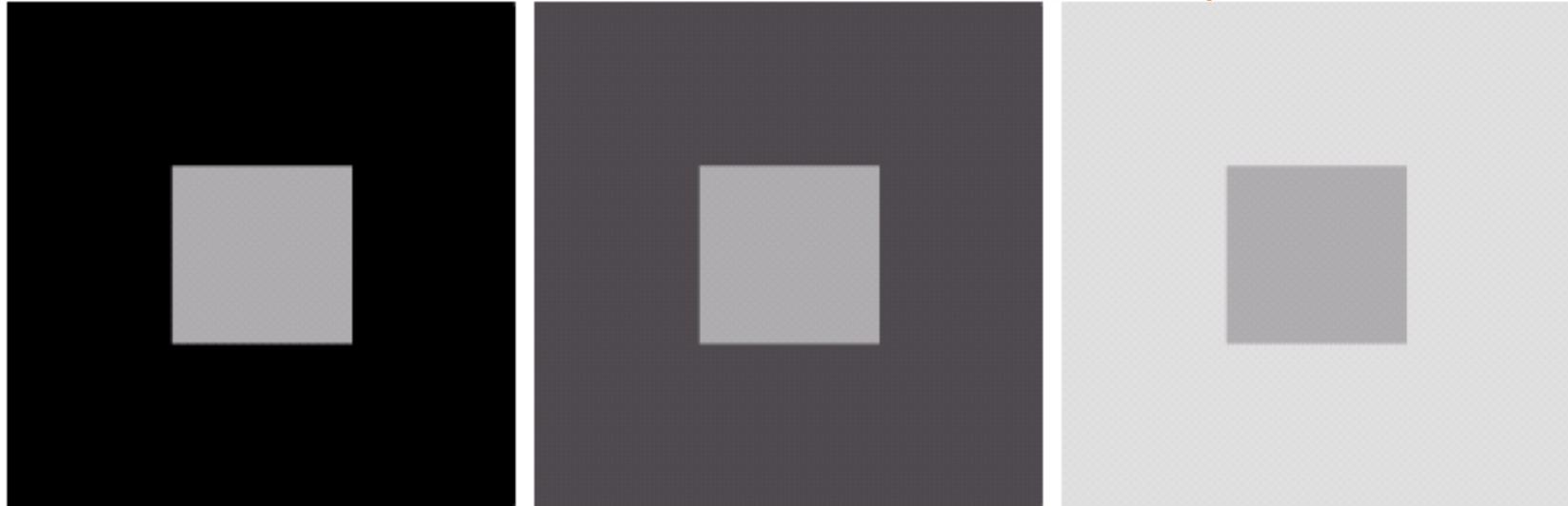


Characteristics of Human Visual System

- Brightness adaption
- Simultaneous contrast 同视对比

- Mach band effect
- Optical illusion

感受的color不仅与本身还与背景有关

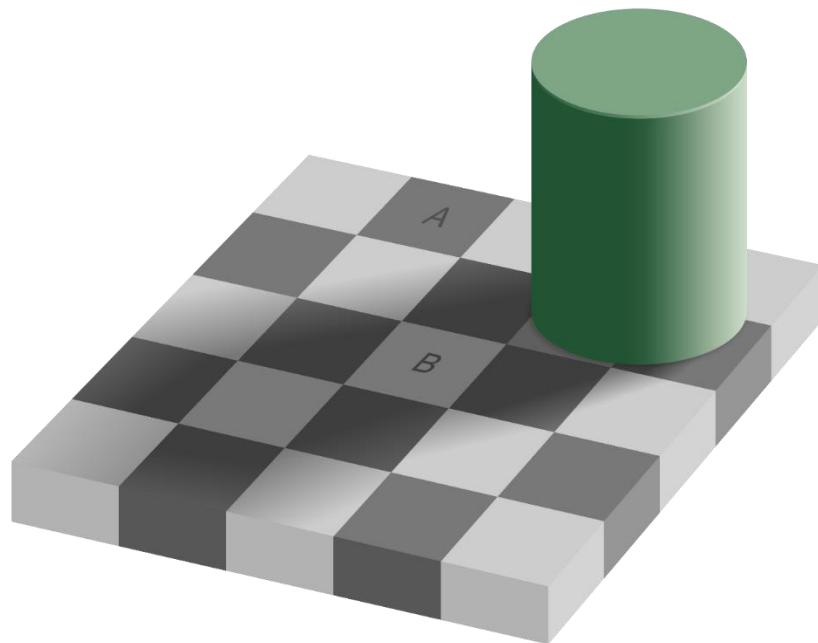


All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter



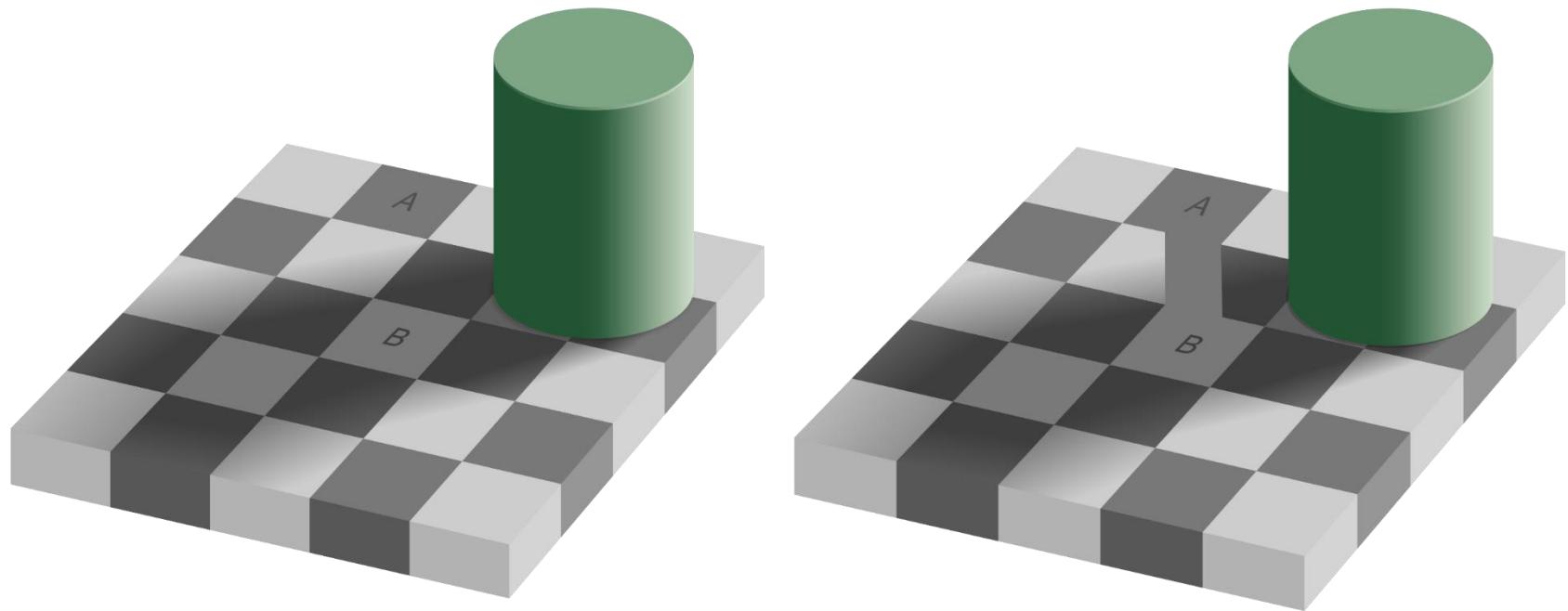
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Checker shadow illusion



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Checker shadow illusion



Cube

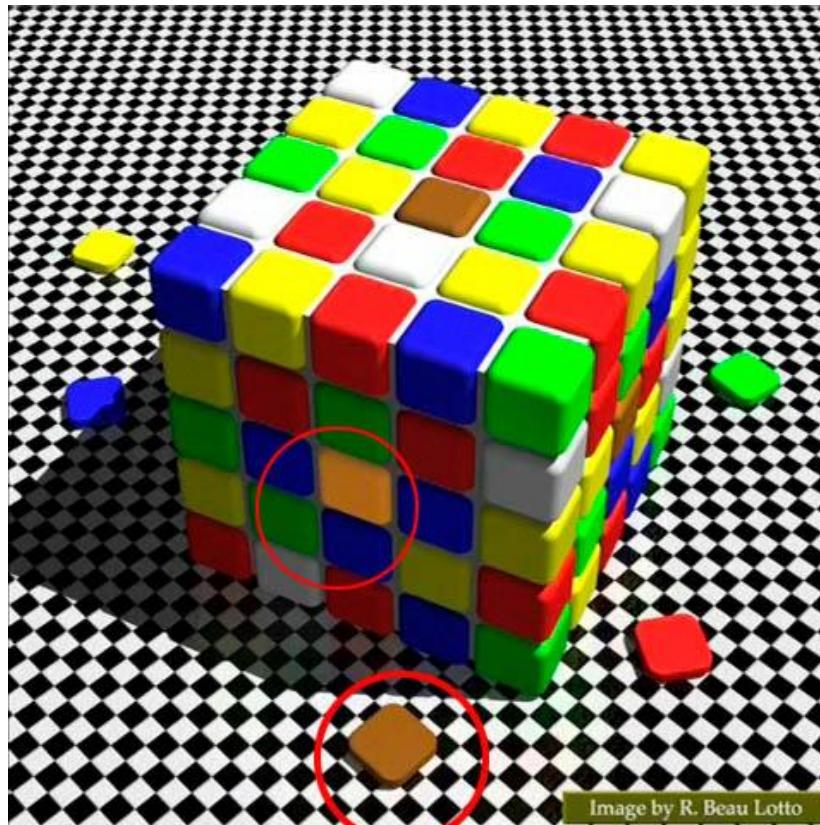
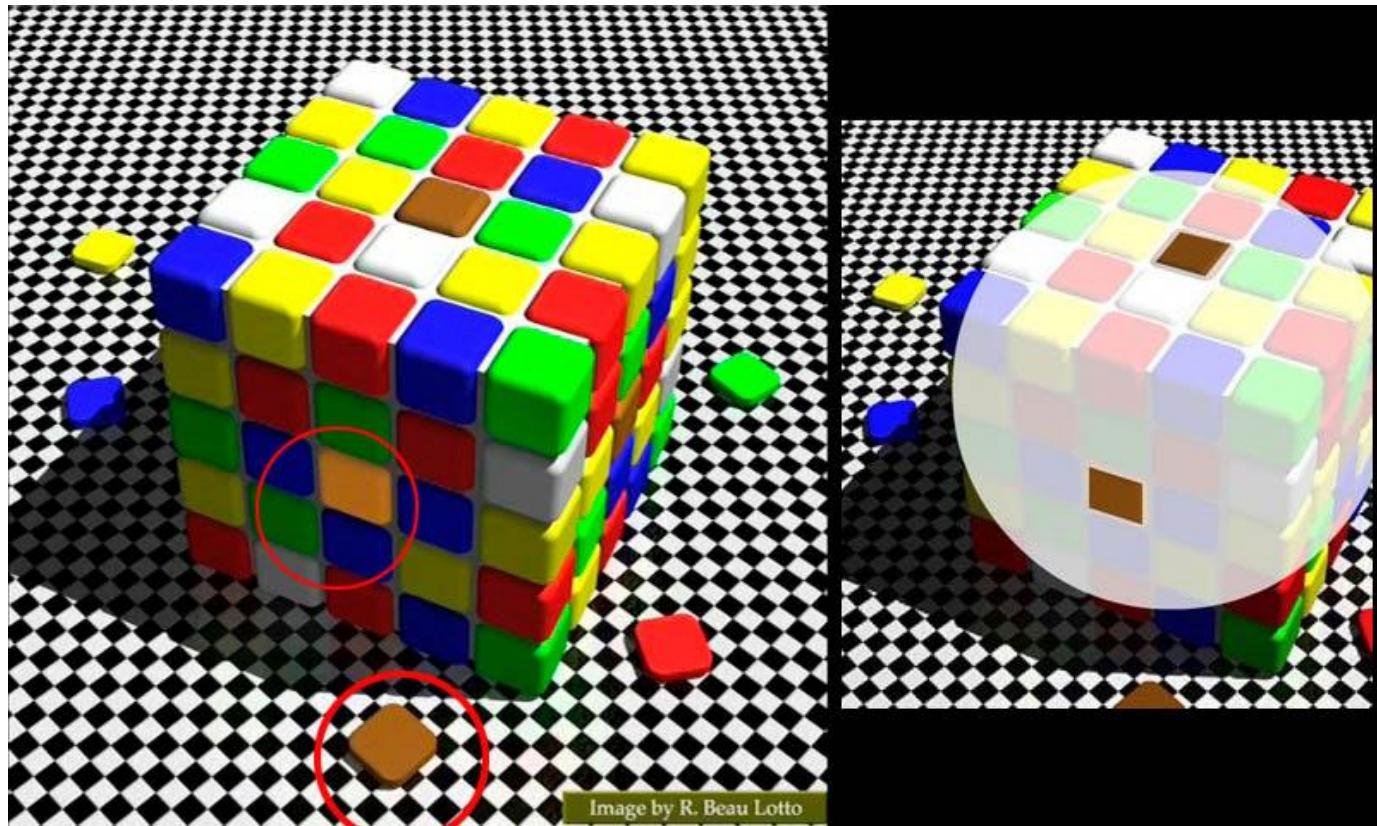


Image by R. Beau Lotto



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Cube



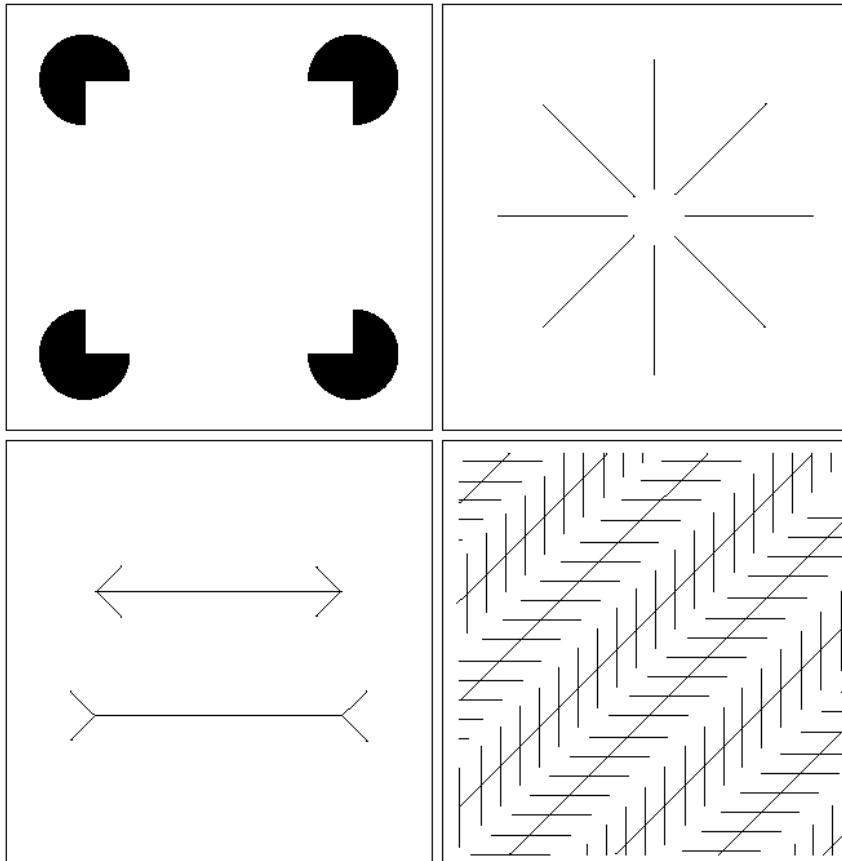
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Characteristics of Human Visual System

- Brightness adaption
- Simultaneous contrast

- Mach band effect
- Optical illusion

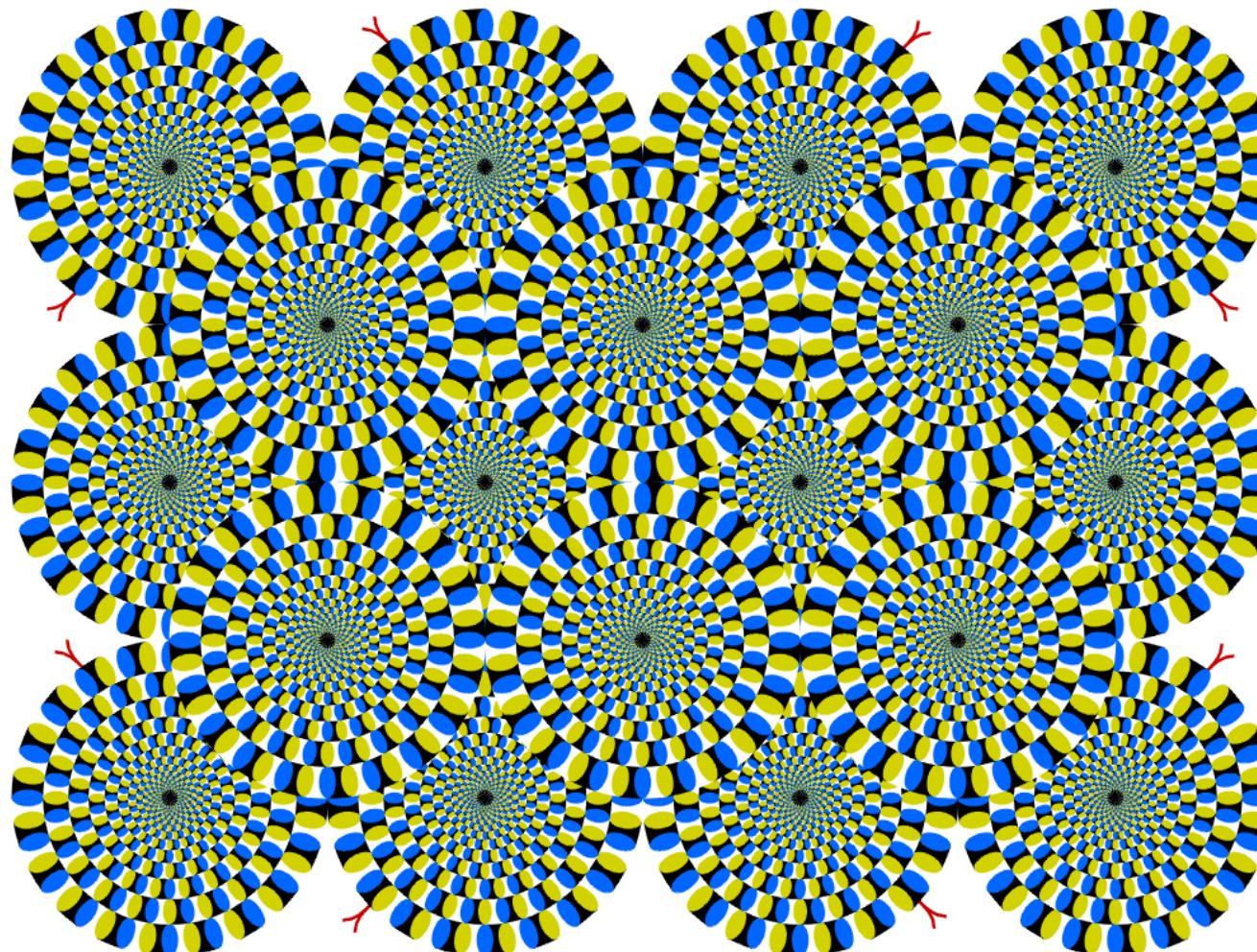
错觉感知如何特点
脑补不存在形状



中间穿过的线 seems
不平行

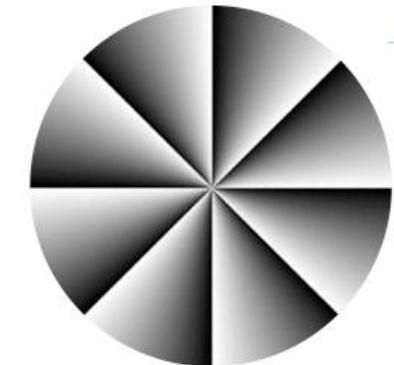
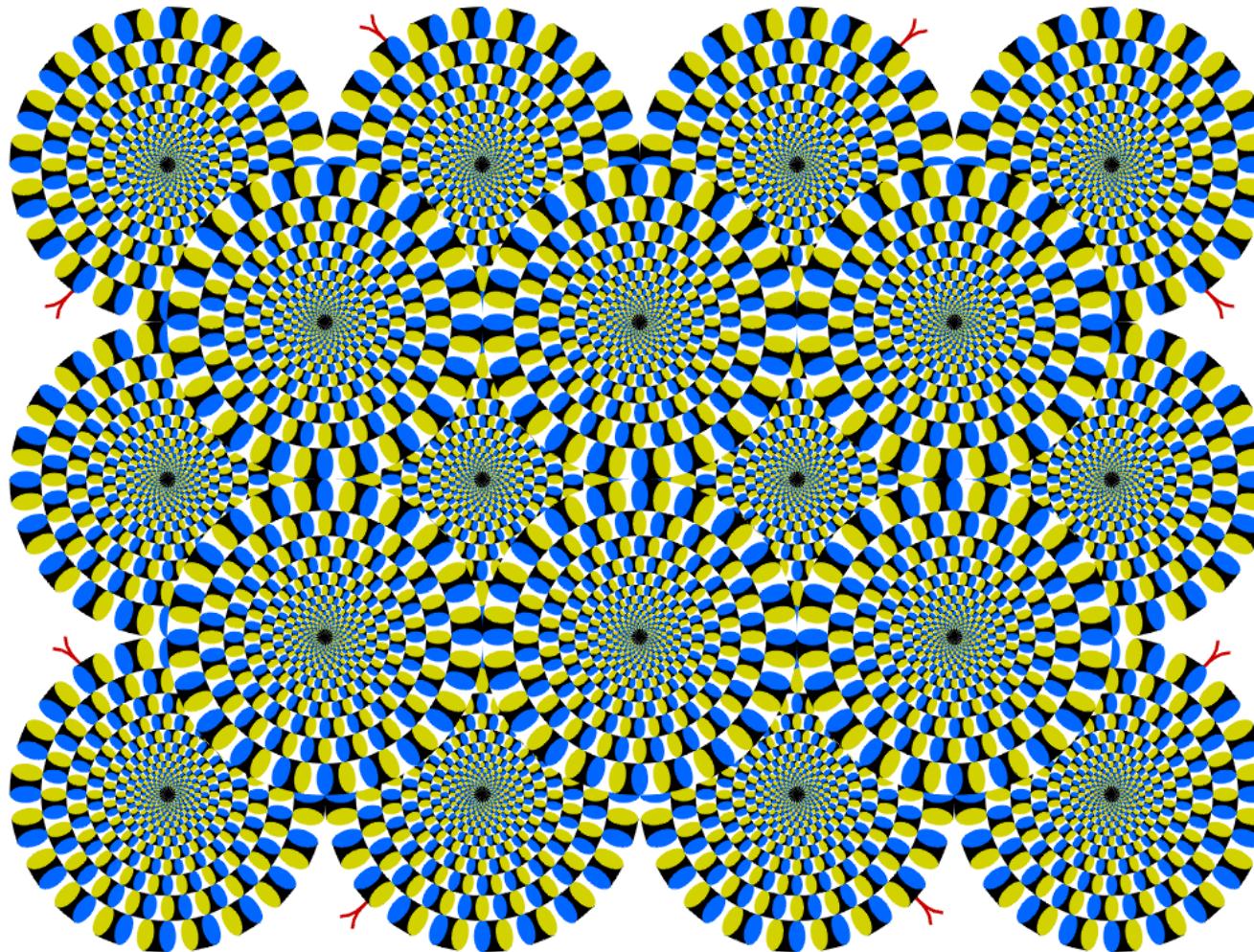
Characteristics of Human Visual System

固 迪 漂 移 错 觉

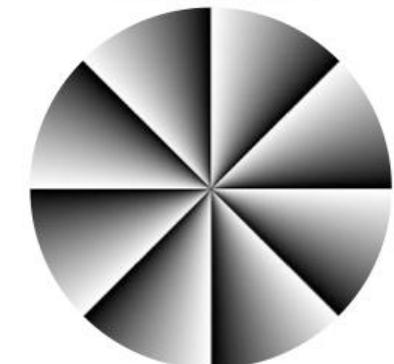


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Characteristics of Human Visual System



What do you see when you read this?
Do you see motion in the images above and below?
(If not try blinking rapidly while fixating here - - -)
If so, do they move in the same direction?
Is the motion consistent with the luminance profile?



<http://www.ritsumei.ac.jp/~akitaoka/index-e.html>

Gender illusion

同一个调整肤色



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Your eyes can do more than you think...

- McGurk effect 发音一样，但不同口型，感受到声音改变
- <https://www.youtube.com/watch?v=G-lN8vWm3m0>
- <https://www.youtube.com/watch?v=jtsfidRq2tw>

- Rubber hand illusion
- <https://www.youtube.com/watch?v=DphlhmtGRqI>



Take home message



- Be careful of your brain,
it might be alien...



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Pixel basics

- Neighbors of Pixel
- Relationship between Pixels 像素性质
 - Adjacency
 - Connectivity
 - Regions
 - Boundaries
- Distance measures
 - Euclidean distance
 - City-block distance
 - Chessboard distance

Neighbors of Pixel

If a pixel p at coordinate (x, y)

➤ $N_4(p)$

➤ $N_D(p)$

➤ $N_8(p)$



Neighbors of Pixel

If a pixel p at coordinate (x, y)

➤ $N_4(p)$

$(x+1, y), (x-1, y), (x, y+1), (x, y-1)$

➤ $N_D(p)$

➤ $N_8(p)$

	q_1	
q_2	p	q_3
	q_4	



Neighbors of Pixel

If a pixel p at coordinate (x, y)

➤ $N_4(p)$

$(x+1, y), (x-1, y), (x, y+1), (x, y-1)$

➤ $N_D(p)$ 对角线

$(x+1, y+1), (x+1, y-1), (x-1, y+1), (x-1, y-1)$

➤ $N_8(p)$

r_1		r_2
	p	
r_3		r_4



Neighbors of Pixel

If a pixel p at coordinate (x, y)

➤ $N_4(p)$

$(x+1, y), (x-1, y), (x, y+1), (x, y-1)$

➤ $N_D(p)$

$(x+1, y+1), (x+1, y-1), (x-1, y+1), (x-1, y-1)$

➤ $N_8(p): N_4(p) \cup N_D(p)$

r_1	q_1	r_2
q_2	p	q_3
r_3	q_4	r_4



Adjacency

□ To define adjacency (邻接性) of pixels, we need identify

□ Type of Neighbor

- $N_4(p), N_D(p), N_8(p)$

□ The set of intensity values V

只有0/1

- Binary image: $V = \{1\}$
- Gray-scale image: $V = [L_{min}, L_{max}]$

e.g. $V = [10, 15]$, which pixels are adjacent?

Why adjacency? (E.g. Used for edge detection)

q_1	p	q_2

0	0	0
0	1	1
0	0	0

Adjacency in a binary image

	q_1	
q_2	p	q_3

0	39	0
11	13	16
0	0	0

Adjacency in a gray-scale image

$$V = [10, 15]$$

Adjacency

Types of Adjacency:

- 4-adjacency
- 8-adjacency
- M-adjacency (mixed adjacency)



Adjacency

Types of Adjacency:

- 4-adjacency
 - $p, q \in V$
 - $q \in N_4(p)$
- 8-adjacency
- M-adjacency (mixed adjacency)

4-adjacency

r_{11}	r_{12}	r_{13}
r_{21}	r_{22}	r_{23}
r_{31}	r_{32}	r_{33}

0	1	1
0	1	0
0	0	1



Adjacency

Types of Adjacency:

- ❑ 4-adjacency
- ❑ 8-adjacency
 - ❑ $p, q \in V$
 - ❑ $q \in N_8(p)$
- ❑ M-adjacency (mixed adjacency)

8-adjacency

r_{11}	r_{12}	r_{13}
r_{21}	r_{22}	r_{23}
r_{31}	r_{32}	r_{33}

0	1	1
0	1	0
0	0	1



Adjacency

Types of Adjacency:

- 4-adjacency
- 8-adjacency
- M-adjacency (mixed adjacency)

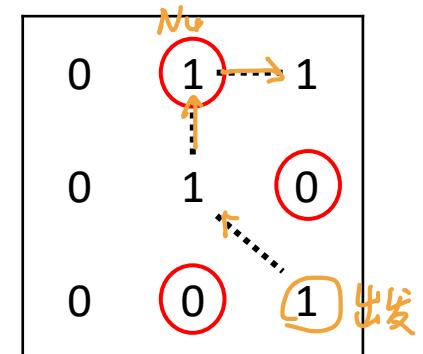
➤ $p, q \in V$

➤ $q \in N_4(p)$ or

➤ $q \in N_D(p)$ and $N_4(p) \cap N_4(q) \notin V$

如果有 N_4 优先连，
没 N_4 连对角线

r_{11}	r_{12}	r_{13}
r_{21}	r_{22}	r_{23}
r_{31}	r_{32}	r_{33}



M-adjacency is a modification of 8-adjacency, to eliminate the **ambiguities** that may result from using 8-adjacency



Connectivity

- Important concept used in establishing boundaries of objects and components of regions in an image (连通性)

- Path
- Connected
- Connected component
- Connected set

r_{11}	r_{12}	r_{13}
r_{21}	r_{22}	r_{23}
r_{31}	r_{32}	r_{33}

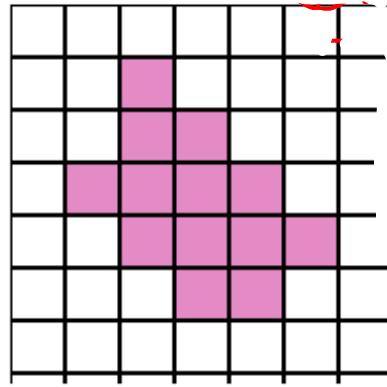
0	1	1
0	1	0
0	0	1

0	1	1
0	1	0
0	0	1

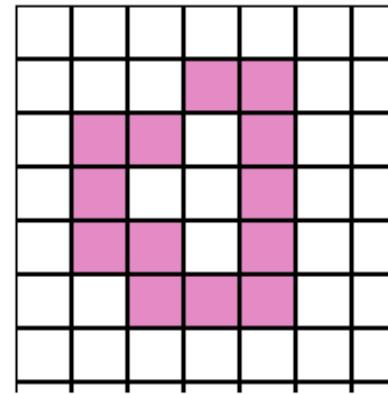
4-adjacency : ①②

8-adjacency : ①②③

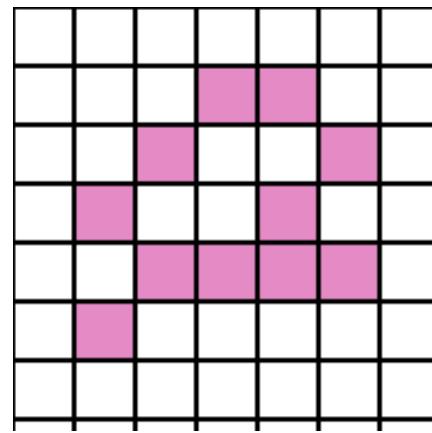
①



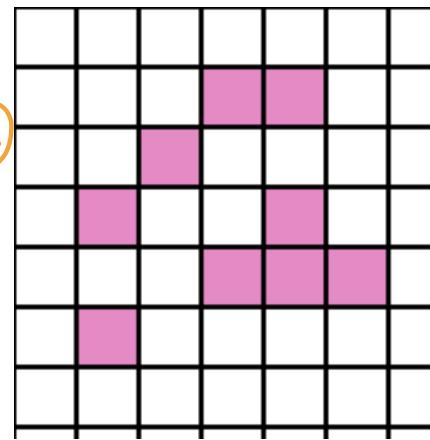
②



③

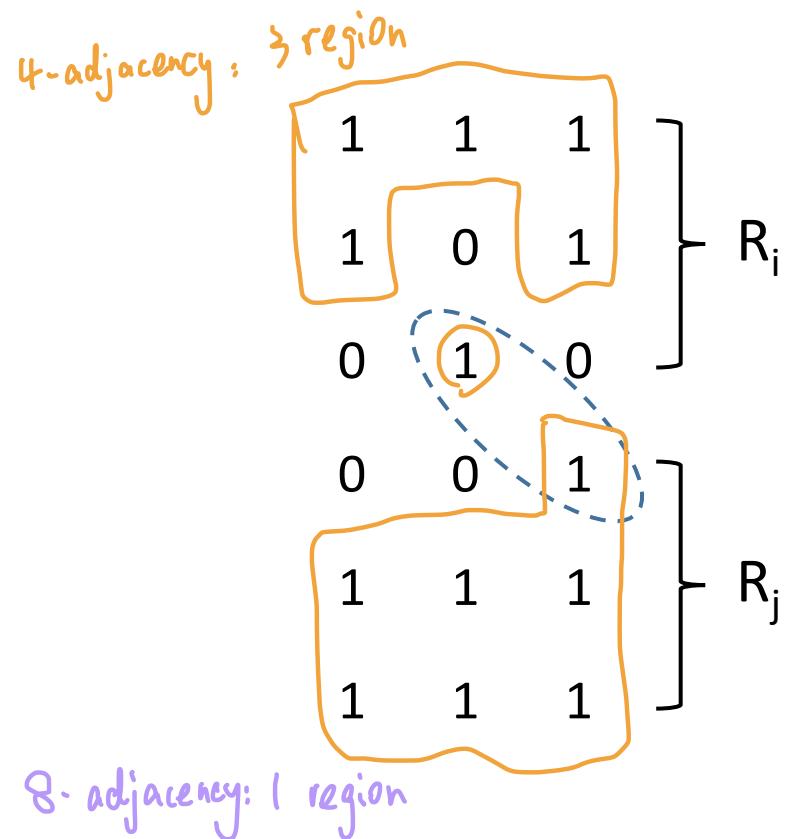


④



Region

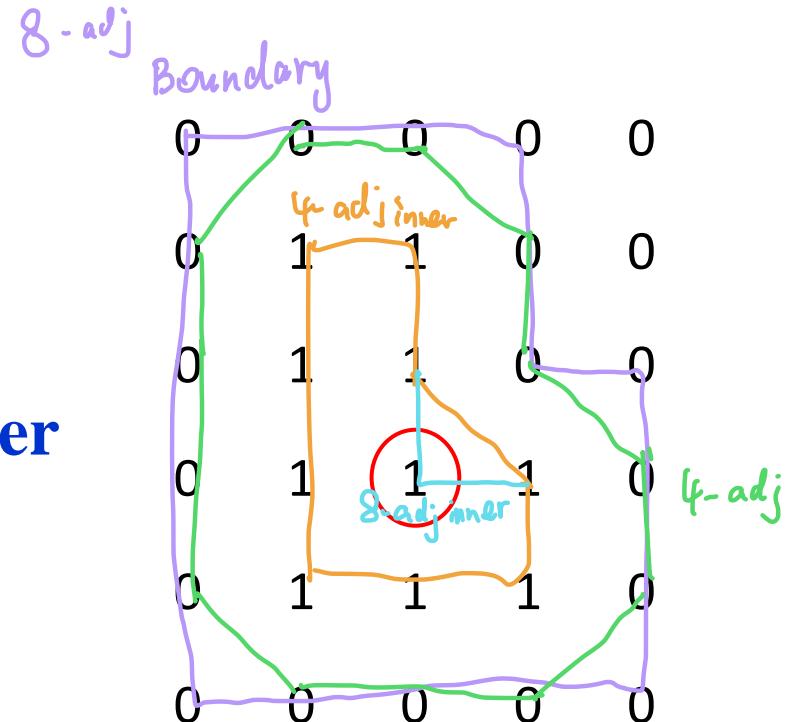
- R : a subset of an image which is also a connected set
- Adjacent region
- Disjoint region



Boundary

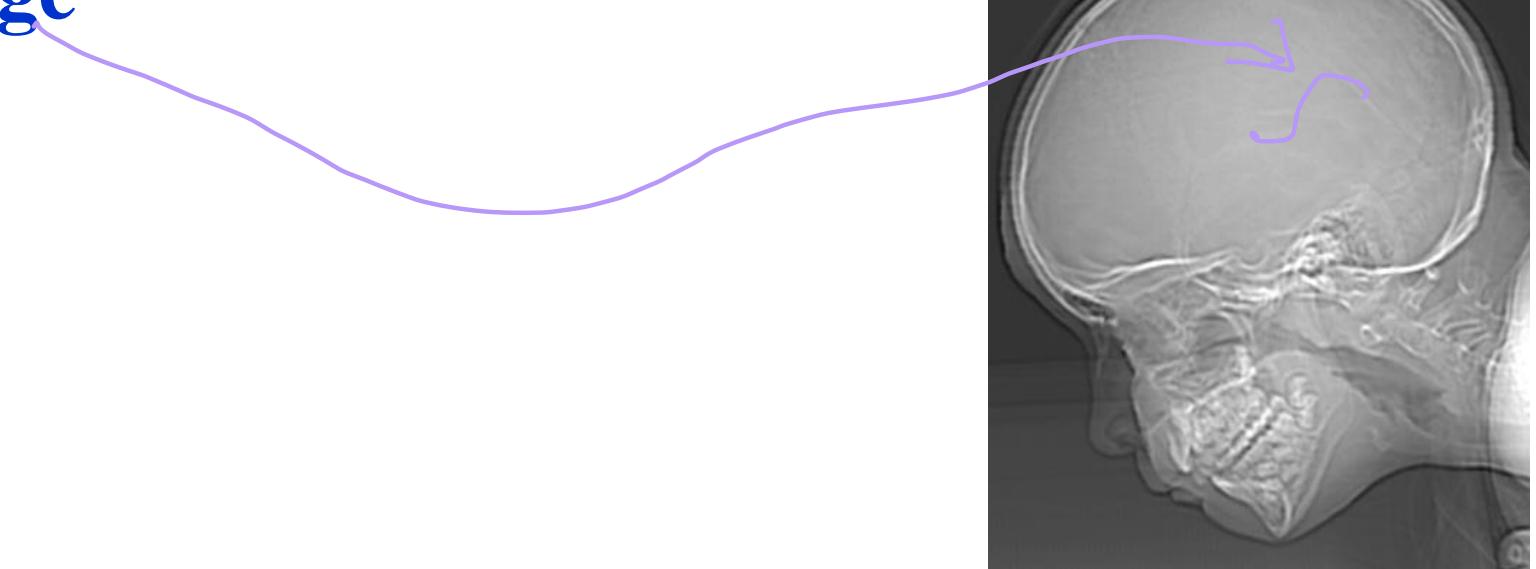
A set of pixels that are adjacent to pixels in the complement of R .

- Inner border and outer border
- Image border
- Edge 不一定闭合, 可能只是一条线



Boundary

- ❑ A set of pixels that are adjacent to pixels in the complement of R .
- ❑ Inner border and outer border
- ❑ Image border
- ❑ Edge



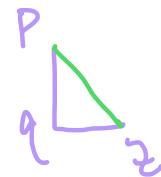
Pixel basics

- Neighbors of Pixel
- Relationship between Pixels
 - Adjacency
 - Connectivity
 - Regions
 - Boundaries
- Distance measures
 - Euclidean distance
 - City-block distance
 - Chessboard distance

Distance Measures

- For pixels p, q and z, with coordinates (x, y), (s, t) and (v, w), D is a distance function or metric if

- $D(p, q) \geq 0$ ($D(p, q) = 0$ only if $p = q$)
- $D(p, q) = D(q, p)$
- $D(p, z) \leq D(p, q) + D(q, z)$



Distance Measures

Intensity → $f(x,y)$
Location

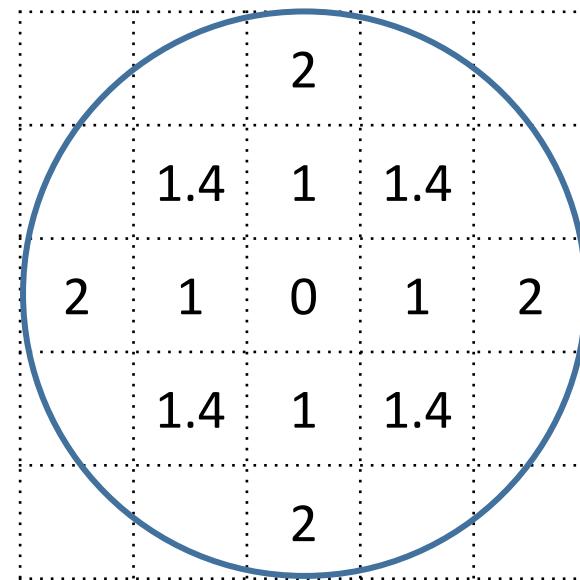
- Euclidean distance:

$$D_e(p, q) = \sqrt{(x-s)^2 + (y-t)^2}$$

像素点位置差异

- City-block distance:

- Chessboard distance



Distance Measures

➤ Euclidean distance:

$$D_e(p, q) = \sqrt{(x-s)^2 + (y-t)^2}$$

2	1	2		
2	1	0	1	2
2	1	2		

➤ City-block distance:

$$D_4(p, q) = |x-s| + |y-t|$$

➤ Chessboard distance



Distance Measures

➤ Euclidean distance:

$$D_e(p, q) = [(x-s)^2 + (y-t)^2]^{1/2}$$

2	2	2	2	2
2	1	1	1	2

➤ City-block distance:

$$D_4(p, q) = |x-s| + |y-t|$$

2	1	0	1	2
2	1	1	1	2

➤ Chessboard distance

$$D_8(p, q) = \max(|x-s|, |y-t|)$$

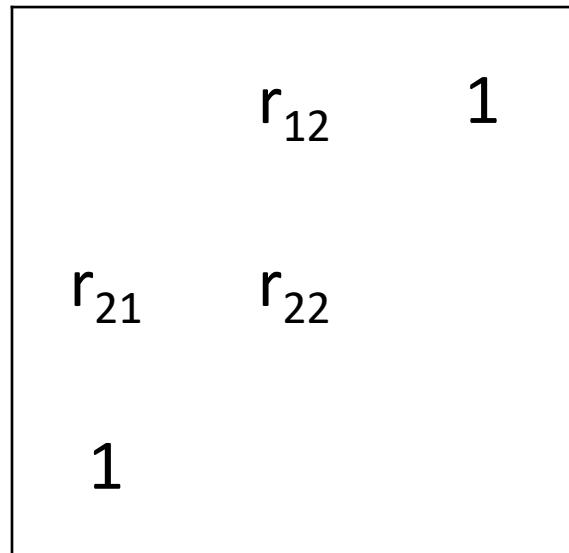
2	2	2	2	2
2	2	2	2	2



Distance Measures

- D_m distance is defined as the shortest m-path between the point

根据 m-adj 矩阵路径

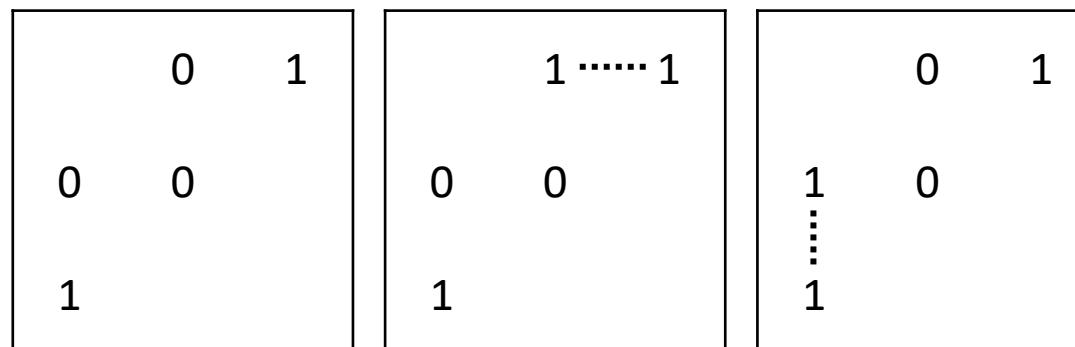


$$D_m = ?$$



Distance Measures

- No m-path between the point

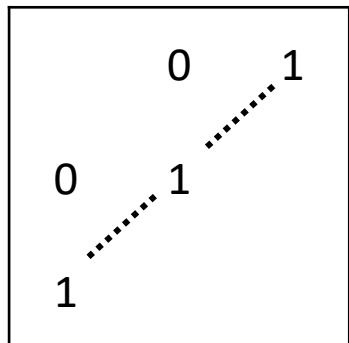


Distance Measures

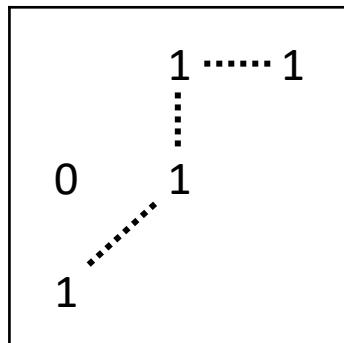
- D_m distance is different by the values of r_{12} , r_{21} and r_{22}

起几步

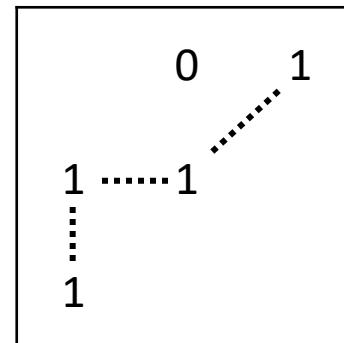
优先N₄再N₈



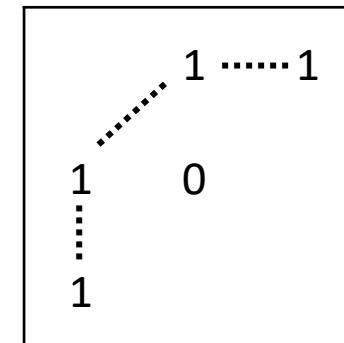
$$D_m = 2$$



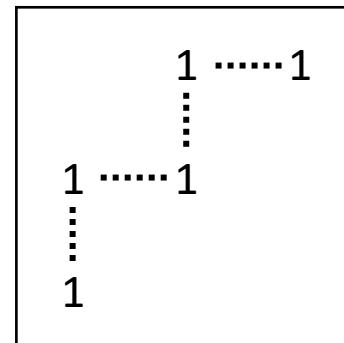
$$D_m = 3$$



$$D_m = 3$$



$$D_m = 3$$



$$D_m = 4$$



Arithmetic Operation

➤ **Addition**

$$s(x, y) = f(x, y) + g(x, y)$$

➤ **Subtraction**

$$d(x, y) = f(x, y) - g(x, y)$$

➤ **Multiplication**

$$p(x, y) = f(x, y) \times g(x, y)$$

➤ **Division**

$$v(x, y) = f(x, y) \div g(x, y)$$



Array and Matrix Operation

Consider two 2×2 image

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \text{ and } \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

➤ Array product *Hadamard product* 哈达玛积

(维度及尺寸一致)

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} = \begin{bmatrix} a_{11}b_{11} & a_{12}b_{11} \\ a_{21}b_{21} & a_{22}b_{22} \end{bmatrix}$$

➤ Matrix product

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} = \begin{bmatrix} a_{11}b_{11} + a_{12}b_{21} & a_{11}b_{12} + a_{12}b_{22} \\ a_{21}b_{11} + a_{22}b_{21} & a_{21}b_{12} + a_{22}b_{22} \end{bmatrix}$$



Image Addition

降 Gaussian 白噪声
→ 多条集平均

对比度差

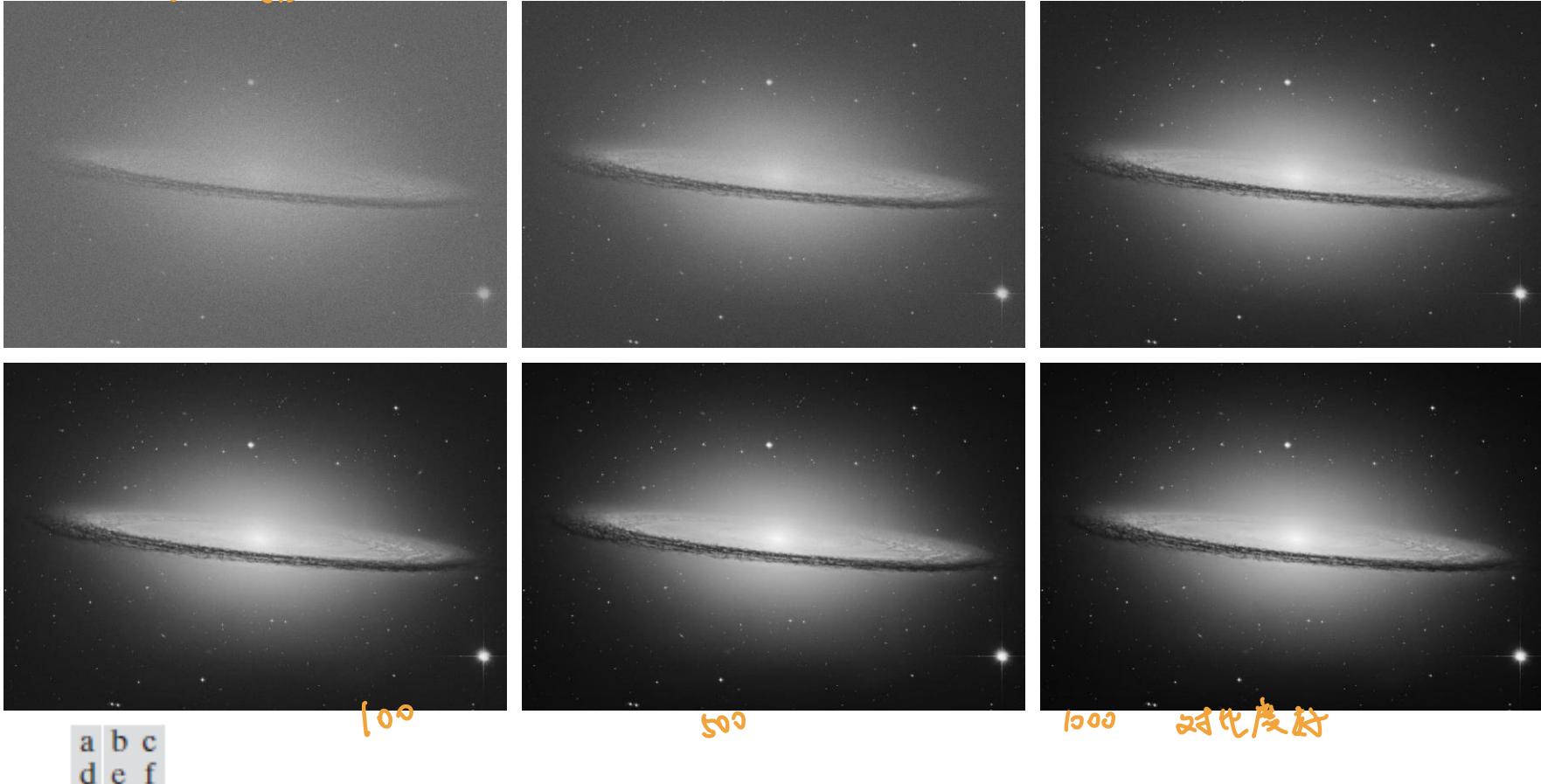
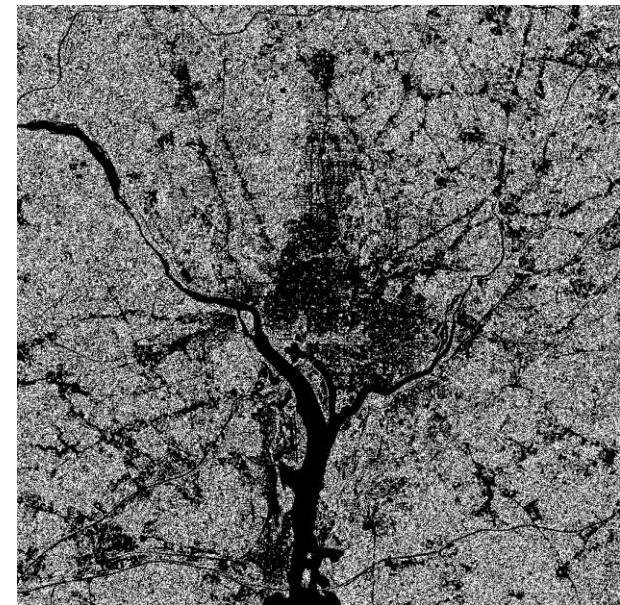
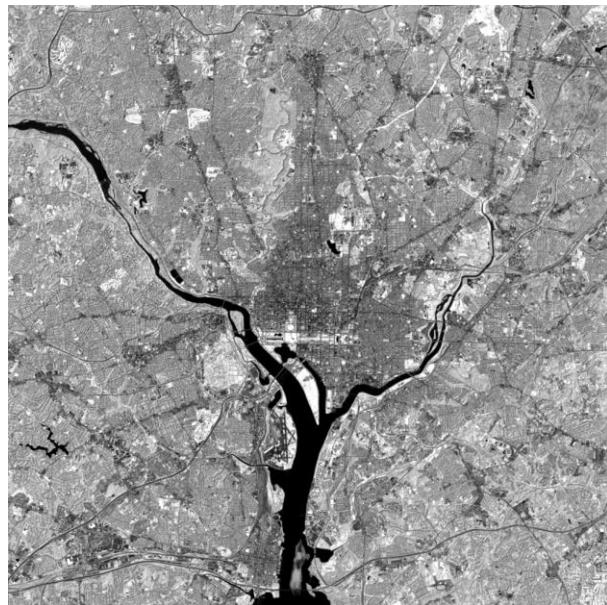


FIGURE 2.29 (a) Sample noisy image of the Sombrero Galaxy. (b)-(f) Result of averaging 10, 50, 100, 500, and 1,000 noisy images, respectively. All images are of size 1548×2238 pixels, and all were scaled so that their intensities would span the full $[0, 255]$ intensity scale. (Discovered in 1767, the Sombrero Galaxy is 28 light years from Earth. Original image courtesy of NASA.)

Image Subtraction

体现差异



a b c

FIGURE 2.30 (a) Infrared image of the Washington, D.C. area. (b) Image resulting from setting to zero the least significant bit of every pixel in (a). (c) Difference of the two images, scaled to the range [0, 255] for clarity. (Original image courtesy of NASA.)

Image Subtraction



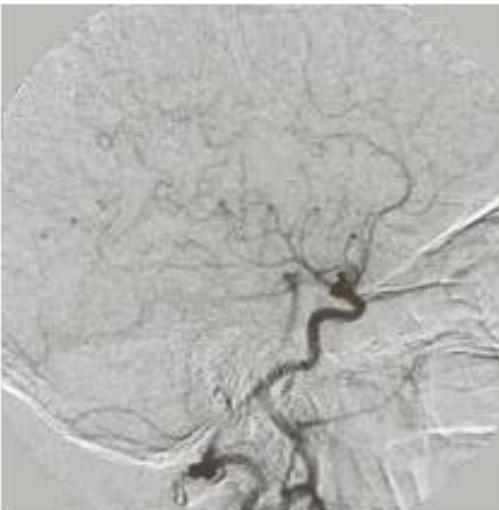
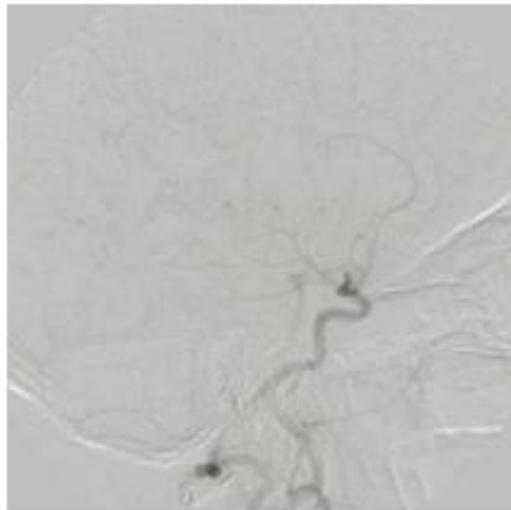
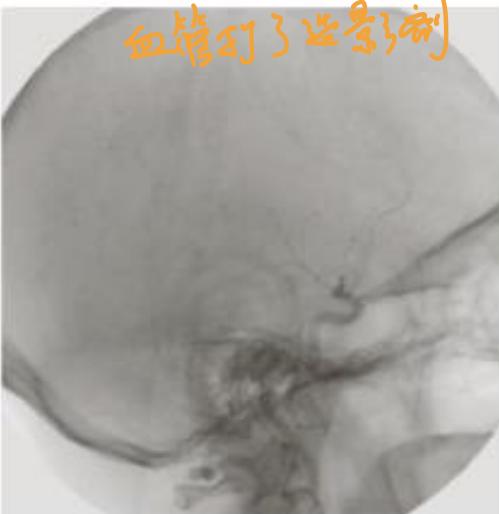
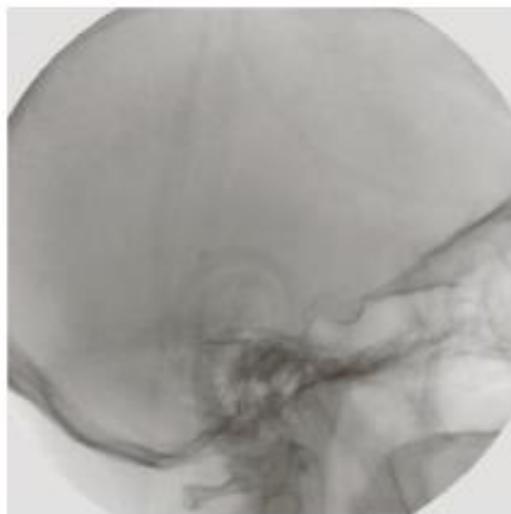
a b c

FIGURE 2.31 (a) Difference between the 930 dpi and 72 dpi images in Fig. 2.23. (b) Difference between the 930 dpi and 150 dpi images. (c) Difference between the 930 dpi and 300 dpi images.



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Image Subtraction



a b
c d

FIGURE 2.32
Digital subtraction angiography.
(a) Mask image.
(b) A live image.
(c) Difference between (a) and (b). (d) Enhanced difference image.
(Figures (a) and (b) courtesy of the Image Sciences Institute, University Medical Center, Utrecht, The Netherlands.)



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Image Subtraction

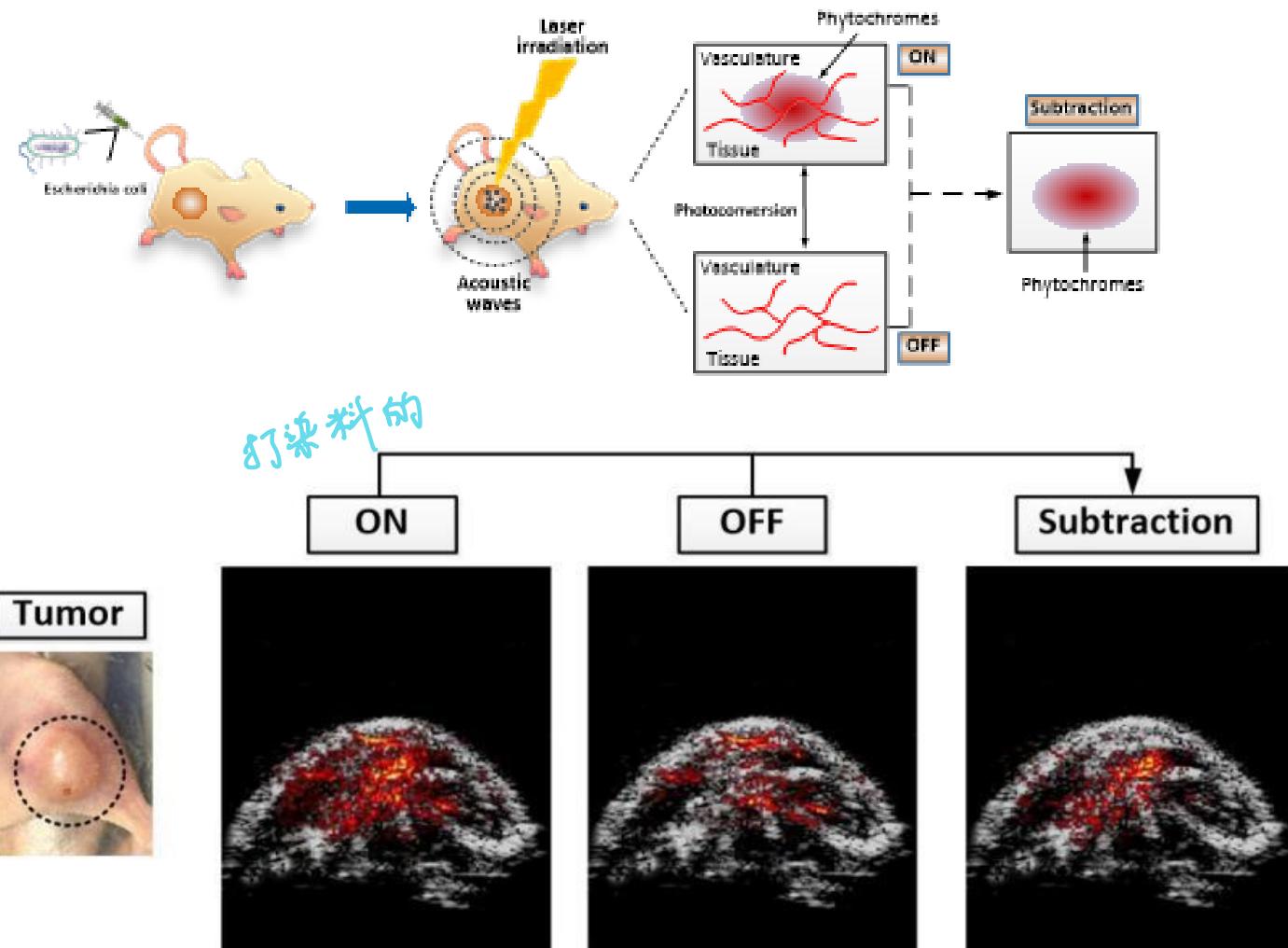


Image Multiplication



$$p(x, y) = f(x, y) \times g(x, y)$$

Image Division

光照信息除掉



$$g(x, y) = f(x, y) h(x, y)$$

$$h(x, y)$$

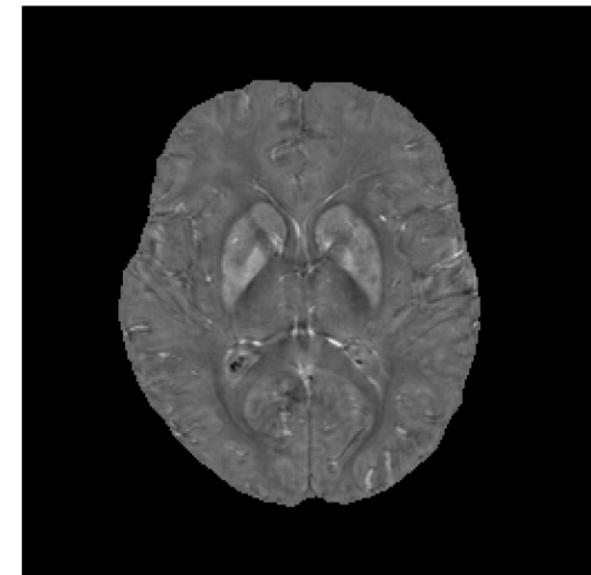
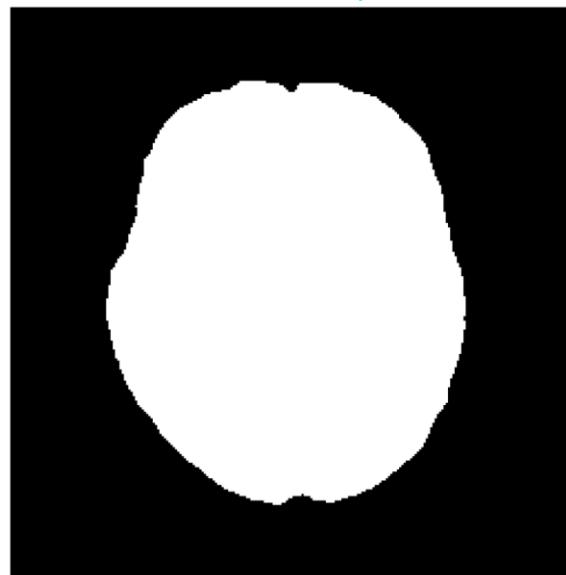
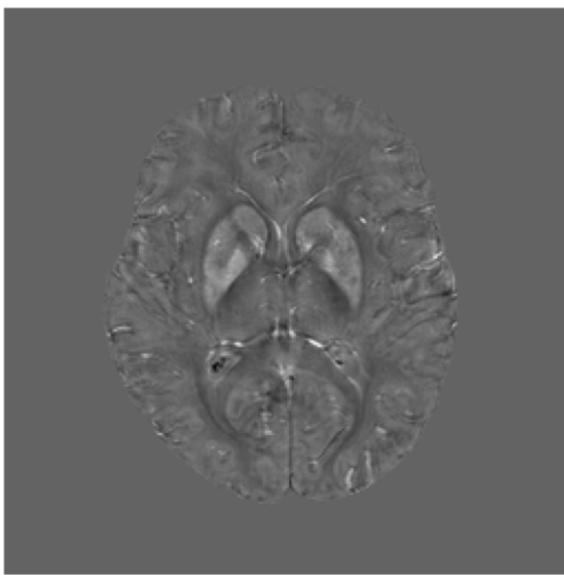
$$f(x, y)$$

$$f(x, y) = g(x, y) / h(x, y)$$



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Background removal



The negative

$$255 - 240 = 15$$

取反

归一化使更好分布

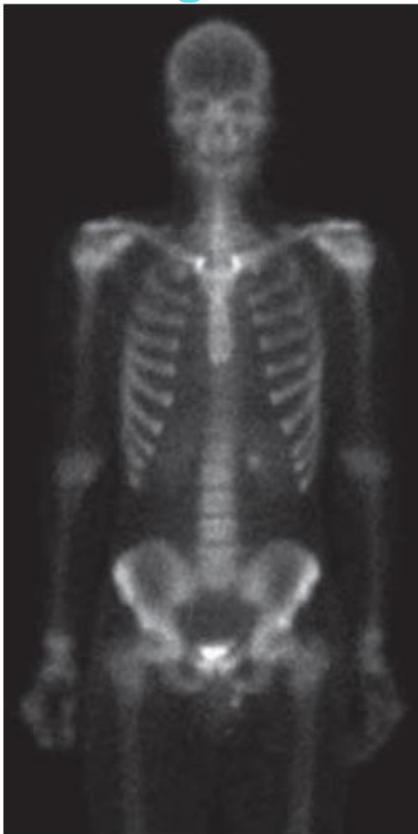
b

255 - z

a b c

FIGURE 2.36

Set operations involving grayscale images. (a) Original image. (b) Image negative obtained using grayscale set complementation. (c) The union of image (a) and a constant image. (Original image courtesy of G.E. Medical Systems.)



Affine transformation

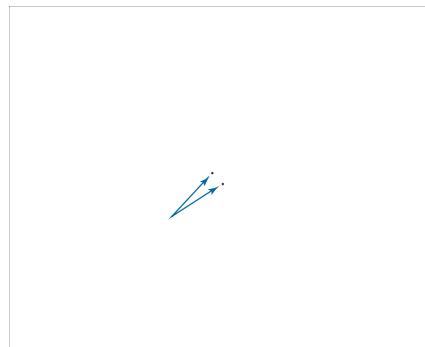
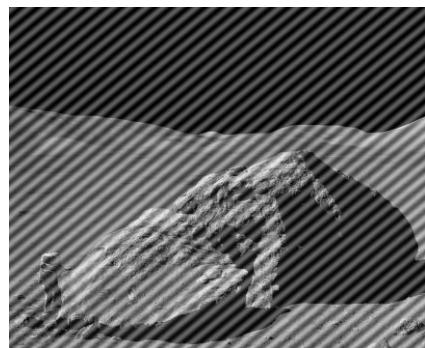
TABLE 2.3

Affine transformations based on Eq. (2-45).

Transformation Name	Affine Matrix, A	Coordinate Equations	Example
Identity	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x$ $y' = y$	
Scaling/Reflection (For reflection, set one scaling factor to -1 and the other to 0)	$\begin{bmatrix} c_x & 0 & 0 \\ 0 & c_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = c_x x$ $y' = c_y y$	
Rotation (about the origin)	$\begin{bmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x \cos \theta - y \sin \theta$ $y' = x \sin \theta + y \cos \theta$	
Translation	$\begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x + t_x$ $y' = y + t_y$	
Shear (vertical) <i>垂直剪切 (非刚性)</i>	$\begin{bmatrix} 1 & s_v & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x + s_v y$ $y' = y$	
Shear (horizontal)	$\begin{bmatrix} 1 & 0 & 0 \\ s_h & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x$ $y' = s_h x + y$	



Transform domain



a
b
c
d

FIGURE 2.45
(a) Image corrupted by sinusoidal interference.
(b) Magnitude of the Fourier transform showing the bursts of energy caused by the interference (the bursts were enlarged for display purposes).
(c) Mask used to eliminate the energy bursts.
(d) Result of computing the inverse of the modified Fourier transform.
(Original image courtesy of NASA.)

