Introduction to Image Processing

Lecture 1
16th Sept. 2015

Guillaume Lemaître
guillaume.lemaitre@udg.edu

Université de Bourgogne

1. Human Vision
    - Human eye
    - Image formation in the eye
    - Brightness adaptation & discrimination

2. Digital Image
    - Formation
    - Sampling & quantisation

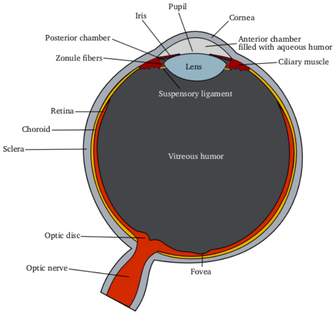
3. Pixel Relationships
    - Neighbours
    - Adjacency
    - Path
    - Subset & region
    - Distance measures

Human Vision
Human eye

From the eye to a camera

Choroid

- Composed of blood vessels serving as source of nutrition
- Avoid the entrance of external light or backscatter
- See relation with physics experiments

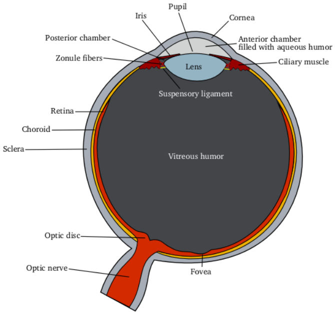


Human Vision
Human eye

From the eye to a camera

Ciliary body & iris

- Control the amount of light (2 mm to 8 mm)
- Relation with the camera aperture

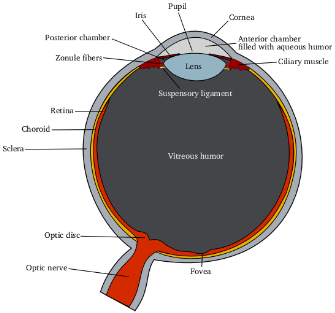


Human Vision
Human eye

From the eye to a camera

Lens

- Made of fibrous cells and attached to ciliary body
- Absorb 8 % of visible light and all the IR and UV
- Cataract diseases
- Idem to an optical lens

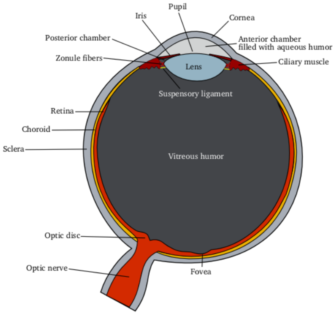


Human Vision
Human eye

From the eye to a camera

Retina

- Contains 2 types of discrete light receptors: the cones and the rods
- Myopia & hyperopia

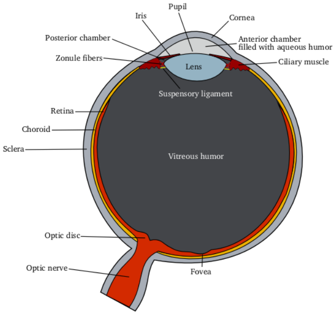


Human Vision
Human eye

From the eye to a camera

Cones

- Account for about 6 to 7 million per eye
- Are sensitive to color and details
- Each one connected to a single nerve end
- Cone vision is called *photopic* and is sensitive to high levels of illumination
- Similar to a high frequency receptor

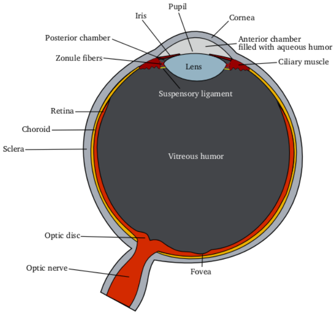


Human Vision
Human eye

From the eye to a camera

Rods

- Account for 75 to 150 millions per eye
- Not involved in color
- Give a general and overall picture of the FOV
- Several rods connected to a single nerve end
- Sensitive to low levels of illuminations: *scotopic*
- Similar to a low frequency receptor

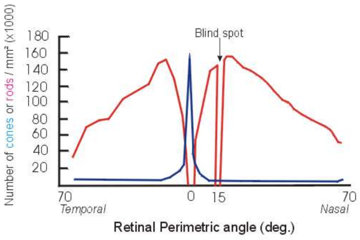


Human Vision
Human eye

From the eye to a camera

Cones & Rods

- Symmetrically distributed
- Note the presence of the blind spot



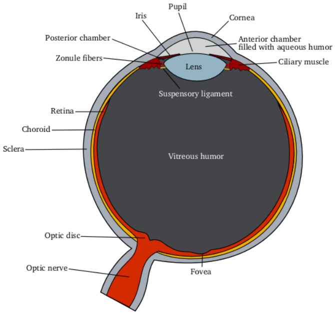
Adapted after Østerberg, 1935

Human Vision
Human eye

From the eye to a camera

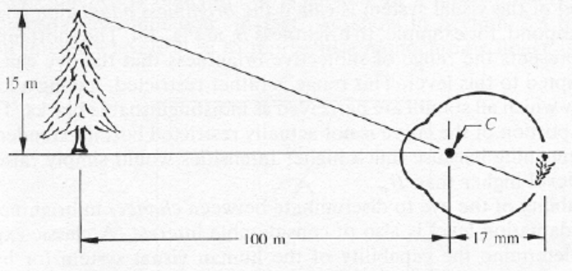
Fovea

- Localisation of the cones in this area
- 1.5 mm $\times$ 1.5 mm
- 150,000 elts/mm^2 to 337,000 elts/mm^2
- CCD imaging ship would need a 5 mm $\times$ 5 mm to achieve similar density



Human Vision
Image formation in the eye

Example

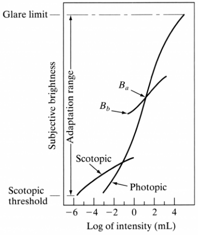


- Focal length varies from 17 mm to 14 mm
- Perception takes place by the relative excitation of light receptors.
- The receptors transform this energy to electrical impulses

Human Vision
Brightness adaptation & discrimination

Human visual system

- The human vision system (HVS) can adapt to 10^{10} light intensity levels
- Subjective brightness is a logarithmic function of the light intensity incident on the eye



- The HVS cannot operate over such a range simultaneously
- For a given set of conditions, the current sensitivity level is called *brightness adaptation level*

Human Vision
Brightness adaptation & discrimination

Human visual system

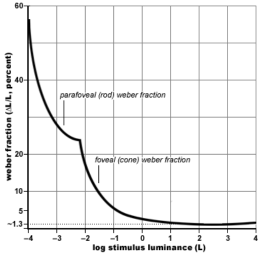
- The eye also discriminates between changes in brightness at any specific adaption level
- This is characterised by the Weber ratio

$$\frac{\Delta I_c}{I}, \tag{1}$$

where ΔI_c is the increment of illumination discriminable 50 % of the time and I is the background illumination

Human Vision
Brightness adaptation & discrimination

Human visual system



- Small values of Weber ration mean good brightness discrimination and vice versa
- At low levels of illumination brightness discrimination is poor (rods)
- It improves significantly as background illumination increases (cones)
- The typical observer can discern one to two dozen different intensity changes

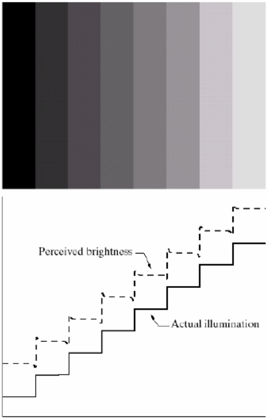
Human Vision
Brightness adaptation & discrimination

Human visual system

- Overall intensity discrimination is broad due to different set of incremental changes to be detected at each new adaptation level
- Perceived brightness is not a simple function of intensity: Mach band effect, simultaneously contrast, and optical effect

Human Vision
Brightness adaptation & discrimination

Mach band effect

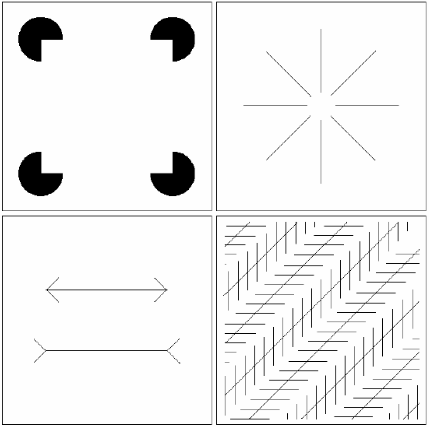


Human Vision
Brightness adaptation & discrimination

Simultaneously contrast

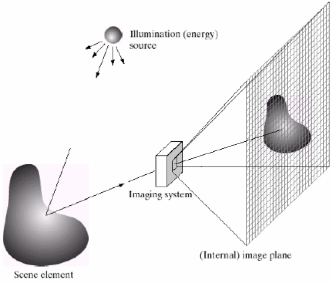
Human Vision
Brightness adaptation & discrimination

Optical effect



Digital Image

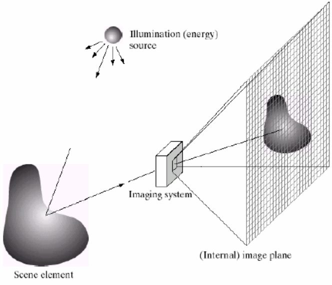
Digital image formation



- $f(x, y)$: intensity or brightness of a pixel at a position (x, y)
- $0 < f(x, y) < +\infty$

Digital Image

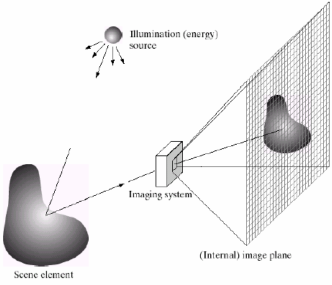
Digital image formation



- $r(x, y)$: illumination — $[0, +\infty[$

Digital Image

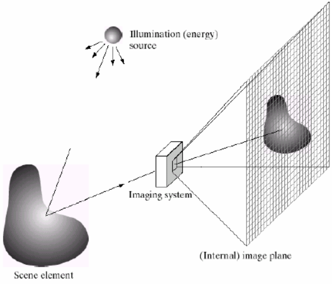
Digital image formation



- $r(x, y)$: illumination — $[0, +\infty[$
- $i(x, y)$: reflectance — $[0, 1]$

Digital Image

Digital image formation



- $r(x, y)$: illumination — $[0, +\infty[$
- $i(x, y)$: reflectance — $[0, 1]$
- $f(x, y) = r(x, y)i(x, y)$

Digital Image

Example of reflectance

- Black velvet: 0.01
- Snow: 0.93

Example of illumination

- Sunny day: 9000 foot-candles
- Cloudy day: 1000 foot-candles
- Full moon: 0.01 foot-candles

Digital Image

In practise

- $i(x,y)$ and $r(x,y)$ are bounded

$$i_{\min}(x_0,y_0)r_{\min}(x_0,y_0) < \quad f(x_0,y_0) \quad < i_{\max}(x_0,y_0)r_{\max}(x_0,y_0) \;, \tag{2}$$

$$L_{\min} < \quad f(x_0,y_0) \quad < L_{\max} \;. \tag{3}$$

- $[L_{\min}, L_{\max}] \approx [10, 1000]$ — Shifted in $[0, L-1]$

Digital Image

In practise

- $i(x, y)$ and $r(x, y)$ are bounded

$$i_{min}(x_0, y_0) r_{min}(x_0, y_0) < \quad f(x_0, y_0) \quad < i_{max}(x_0, y_0) r_{max}(x_0, y_0) \ , \tag{2}$$

$$L_{min} < \quad f(x_0, y_0) \quad < L_{max} \ . \tag{3}$$

- $[L_{min}, L_{max}] \approx [10, 1000]$ — Shifted in $[0, L-1]$

$\rightarrow$ What is the value for true white and black colors in an image?

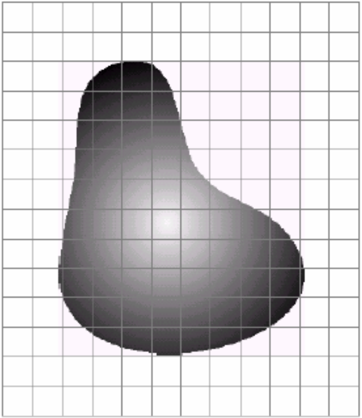
Digital Image

Conversion from continuous to digital

- $f(x, y)$ is a continuous function with regarding the coordinates and the amplitude
- Image sampling to refer to spatial coordinates
- Signal quantisation to digitise the amplitude

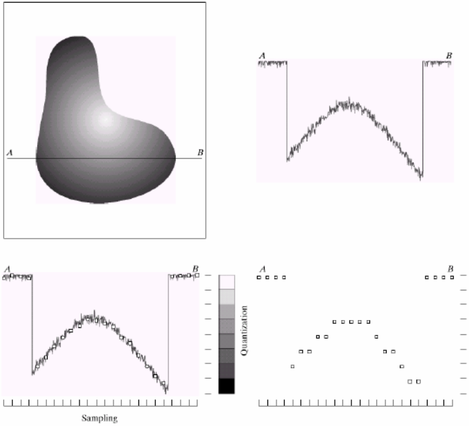
Digital Image

Sampling



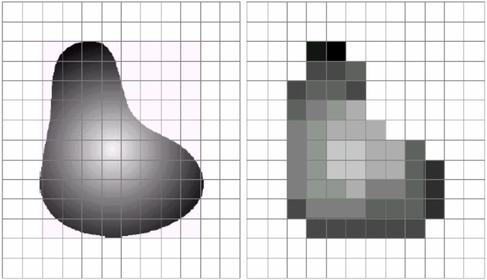
Digital Image

Quantisation



Digital Image

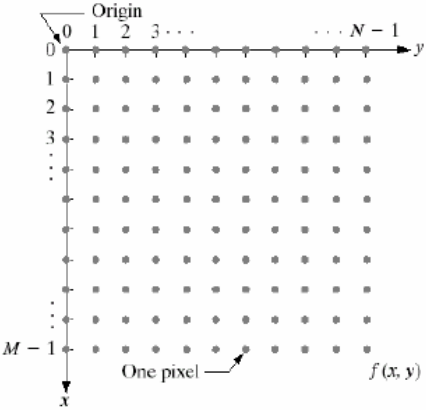
Digital image



- Check the appendix notebook

Digital Image

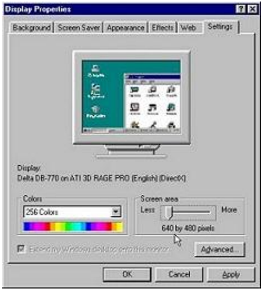
Coordinate system convention



Digital Image

Digitisation requirements

- Set an height: M
- Set an width: N
- Set an intensity level: $L = 2^k$ and equally spaced
- *Dynamic range* : $\frac{L_{\min}}{L_{\max}}$



Digital Image

Parameter variations

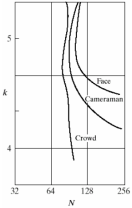
N/k	1 (L = 2)	2 (L = 4)	3 (L = 8)	4 (L = 16)	5 (L = 32)	6 (L = 64)	7 (L = 128)	8 (L = 256)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

$\rightarrow$ What is the best values regarding the resolution and dynamic range parameters?

- Larger is better ...
- ... storage and processing could be a problem

Digital Image

Isopreference curves



Digital Image

Non-uniform sampling and quantisation

Digital Image

Non-uniform sampling and quantisation

- Fine sampling in details region — coarse sampling in smooth region

Digital Image

Non-uniform sampling and quantisation

- Fine sampling in details region — coarse sampling in smooth region
- Few gray levels in details regions — more in smooth region

Pixel Relationships

Neighbours

4-neighbours — N_4-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

D-neighbours — N_D-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-neighbours — N_8-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

Pixel Relationships

Neighbours

4-neighbours — N_4-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

D-neighbours — N_D-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-neighbours — N_8-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

Pixel Relationships

Neighours

4-neighbours — N_4-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

D-neighbours — N_D-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-neighbours — N_8-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

Pixel Relationships

Neighbours

4-neighbours — N_4-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

D-neighbours — N_D-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-neighbours — N_8-p

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

Pixel Relationships

Adjacency

Let denotes $V = \{1\}$ defining the adjacency

4-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

m-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

Pixel Relationships

Adjacency

Let denotes $V = \{1\}$ defining the adjacency

4-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

m-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

Pixel Relationships

Adjacency

Let denotes $V = \{1\}$ defining the adjacency

4-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

m-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

Pixel Relationships

Adjacency

Let denotes $V = \{1\}$ defining the adjacency

4-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

m-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

$q \in N_4(p)$

Pixel Relationships

Adjacency

Let denotes $V = \{1\}$ defining the adjacency

4-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

m-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

$q \in N_D(p)$

Pixel Relationships

Adjacency

Let denotes $V = \{1\}$ defining the adjacency

4-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

m-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

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

Pixel Relationships

Adjacency

Let denotes $V = \{1\}$ defining the adjacency

4-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

8-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

m-adjacency

0	1	1	1	0
0	1	0	0	1
0	0	1	0	0
1	0	1	1	0
0	1	1	0	1

Pixel Relationships

Path

0	1	1	1	0
0	1	0	0	1
0	1	1	0	0
1	0	1	1	0
0	1	1	1	1

Pixel Relationships

Path

4-path

0	1	1	1	0
0	1	0	0	1
0	1	1	0	0
1	0	1	1	0
0	1	1	1	1

Pixel Relationships

Path

8-path

0	1	1	1	0
0	1	0	0	1
0	1	1	0	0
1	0	1	1	0
0	1	1	1	1

Pixel Relationships

Path

m-path

0	1	1	1	0
0	1	0	0	1
0	1	1	0	0
1	0	1	1	0
0	1	1	1	1

- if $(x_{\text{init}}, y_{\text{init}}) = (x_{\text{end}}, y_{\text{end}}) \rightarrow$ closed path

Pixel Relationships

Subset

- p and q are *connected* in the subset S if there is a path in with all the pixels belonging to S
- For any pixel p in S, the set of pixels in S that are connected to p is a *connected component* of S
- If S has only one connected component then S is called a *connected set*

Region

- R is a subset of pixels: R is a region if R is a connected set
- Region can be *adjacent* or *disjoint*

Pixel Relationships
Distance measures

Definition

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

- $D(p, q) \geq 0$ $(D(p, q) = 0$ iff $p = q)$
- $D(p, q) = D(q, p)$ and
- $D(p, z) \leq D(p, q) + D(q, z)$

Pixel Relationships
Distance measures

Euclidean distance

For pixels p, q, z with coordinates (x, y), (s, t), (u, v):

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

D_4 distance

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

D_8 distance

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

D_m distance

- Shortest *m*-path considering the *m*-adjacency