CPE409 Image Processing

Part 2
Acquiring and Digitalization of Image

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When something can be read without effort, great effort has gone into its writing. ~E. J. Poncela

Outline

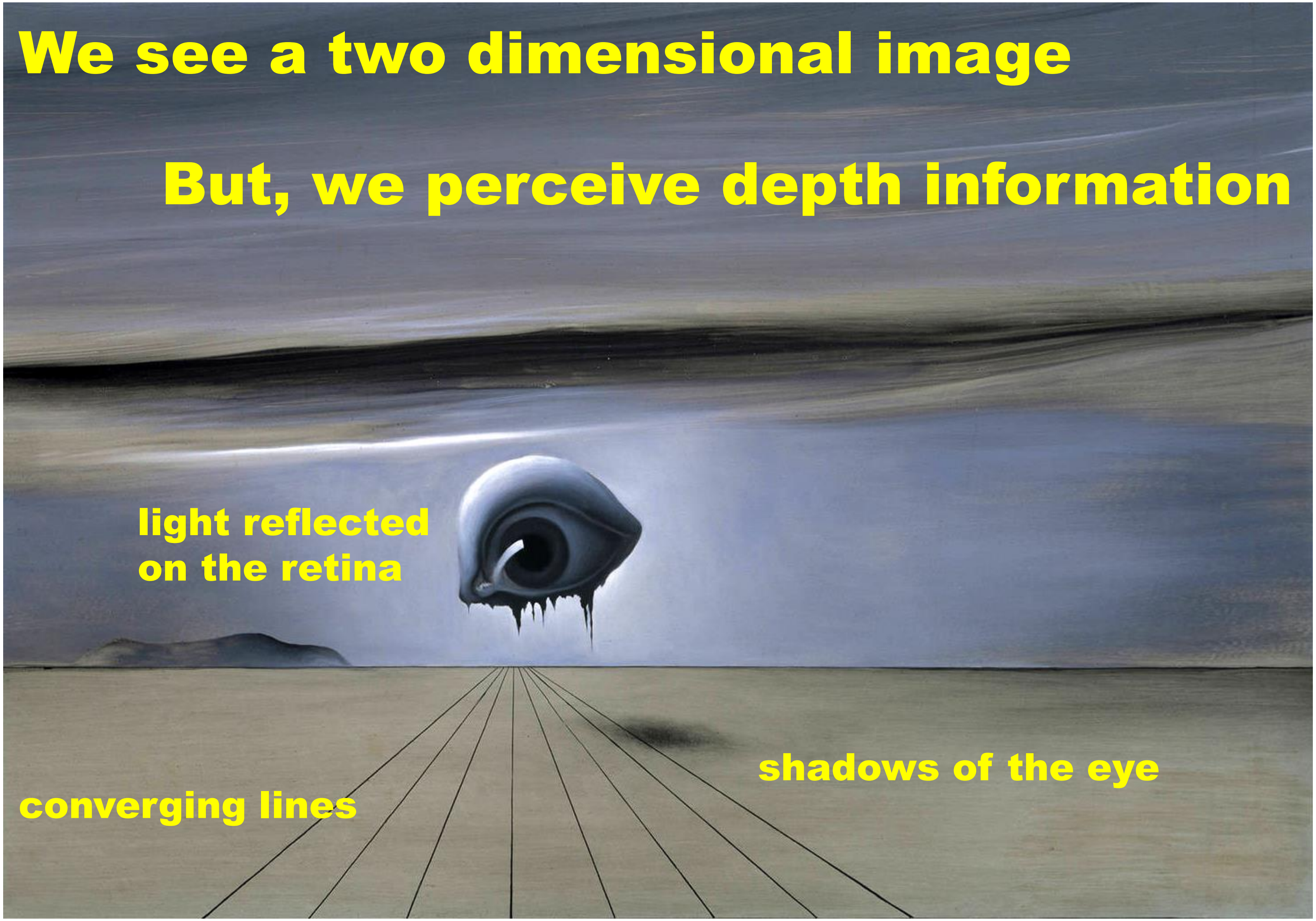
2. Digital Image Fundamentals
   - Elements of Visual Perception
   - Light and the Electromagnetic Spectrum
   - Image Sensing and Acquisition
   - Image Sampling and Quantization
   - Introduction to the MATLAB
   - Some Basic Relationships between Pixels
   - An Introduction to the Mathematical Tools Used in Digital Image Processing

What does it mean, to see?

- “The plain man’s answer (and Aristotle’s, too) would be, to know what is where by looking. In other words, vision is the process of discovering from images what is present in the world, and where it is.” David Marr, Vision, 1982

- Our brain is able to use an image as an input, and interpret it in terms of objects and scene structures.

What does Salvador Dali's Study for the Dream Sequence in Spellbound (1945) say about our visual perception?



Elements of Visual Perception

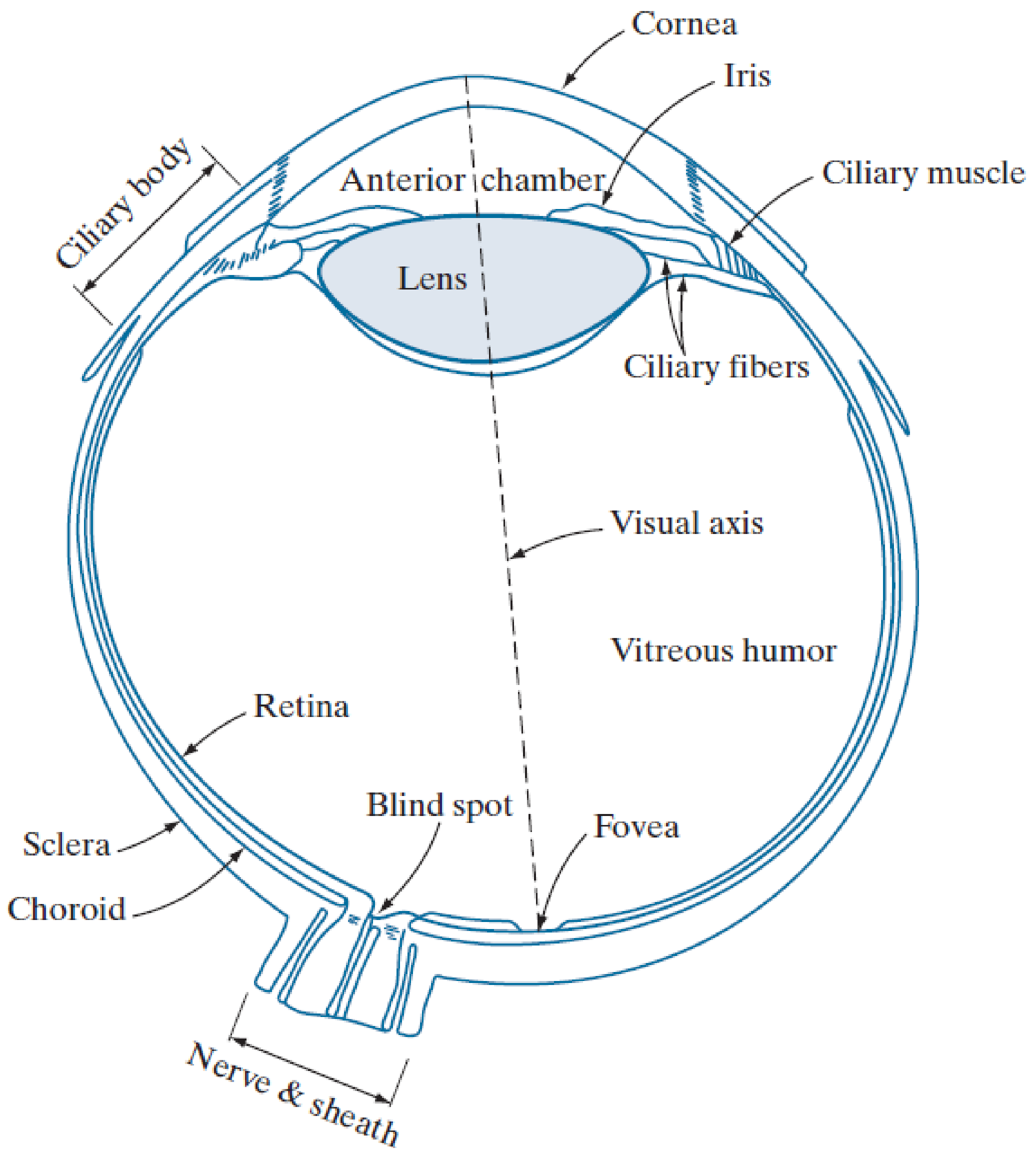


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Elements of Visual Perception

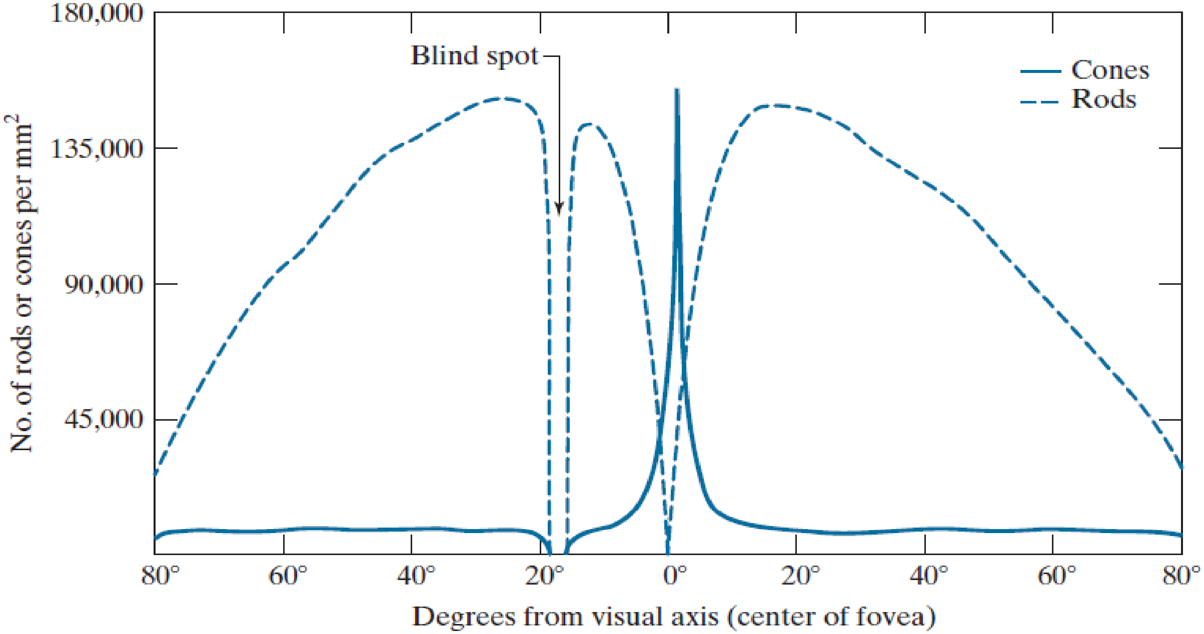


FIGURE 2.2 Distribution of rods and cones in the retina.

Rods

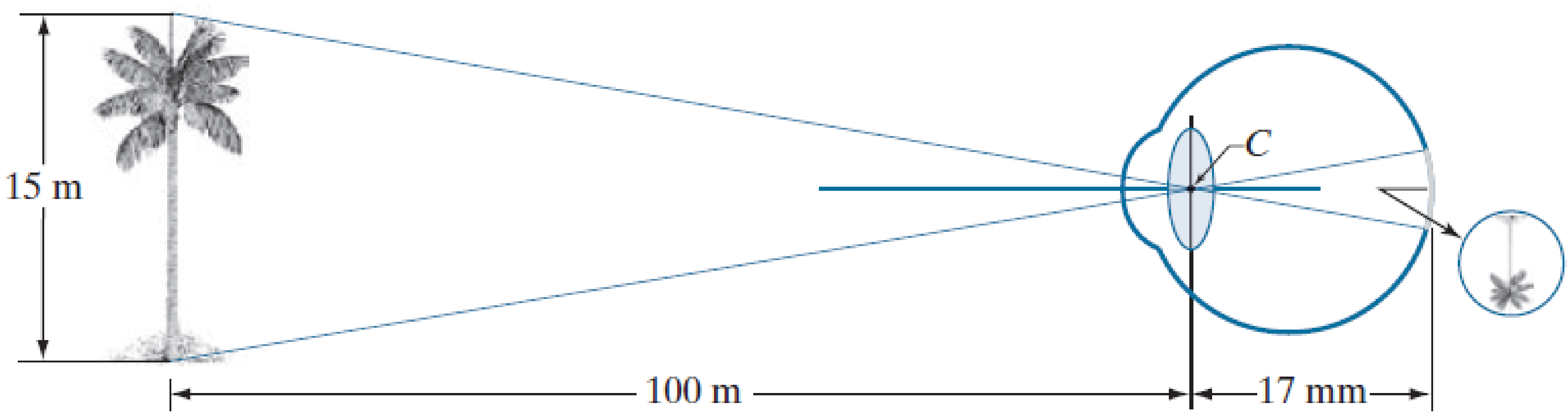
They perceive changes in intensity of light independently of color.
They perceive objects in black, white and gray tones.
When people have low light in the darkness of the night, they can still see the surroundings as black and white thanks to these rods. But they can not see color.

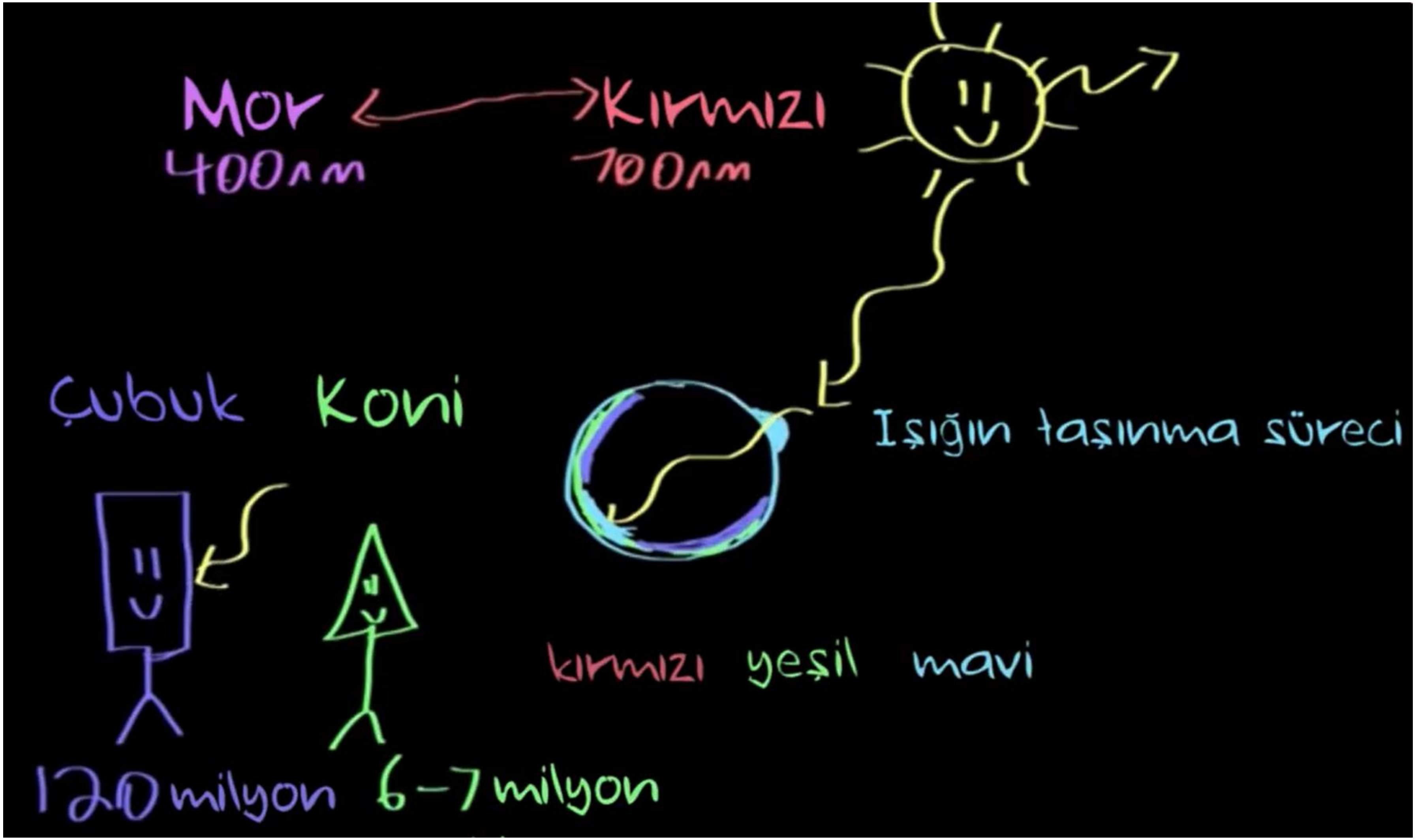
Cones

Responsible for color matters.
But they need more light than rods to see.
There are three different cone cells. These are: L type, M type and S type.

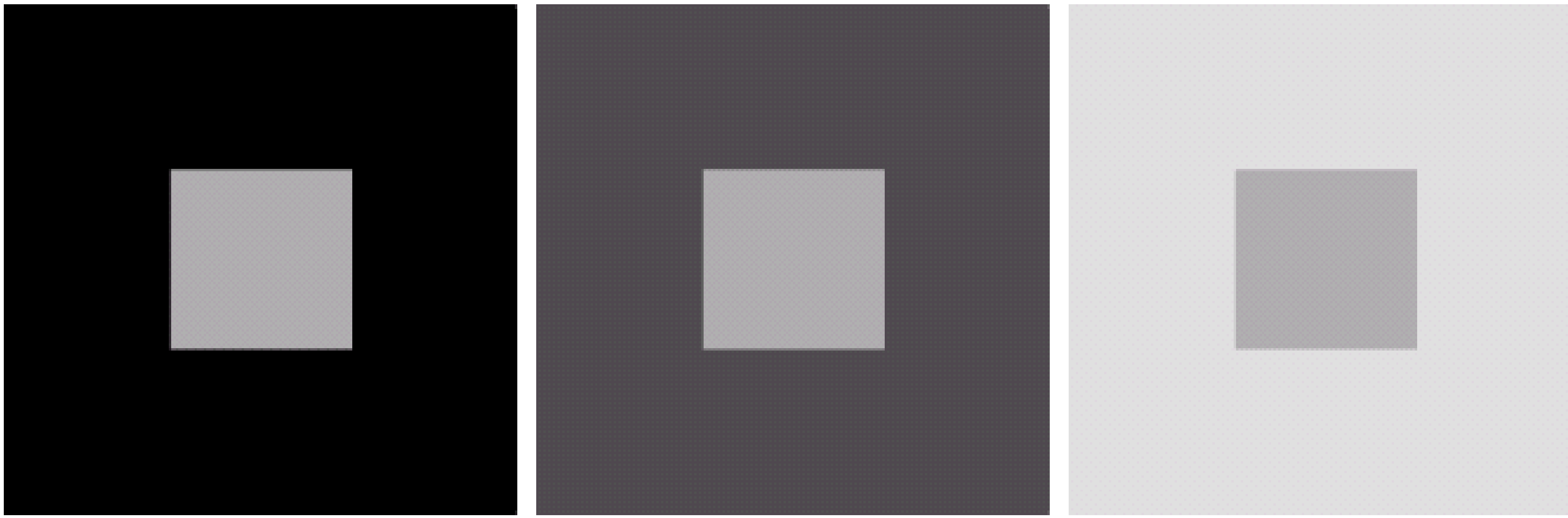
Elements of Visual Perception

FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the focal center of the lens.




Mor
400nm
Kırmızı
700nm
Çubuk
Koni
Işığın taşınma süreci
kırmızı yeşil mavi
120 milyon
6-7 milyon

Elements of Visual Perception



a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

Elements of Visual Perception

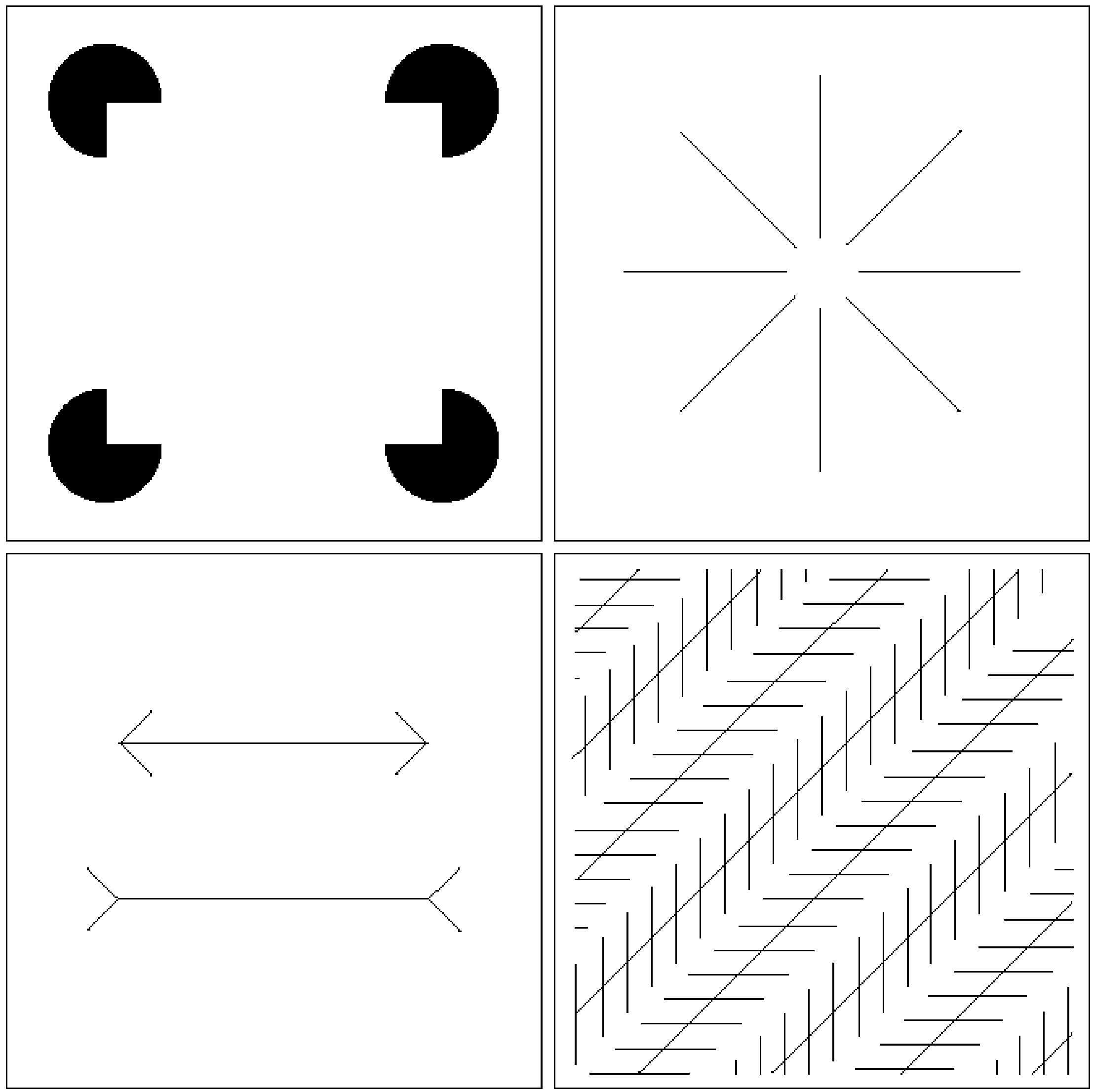
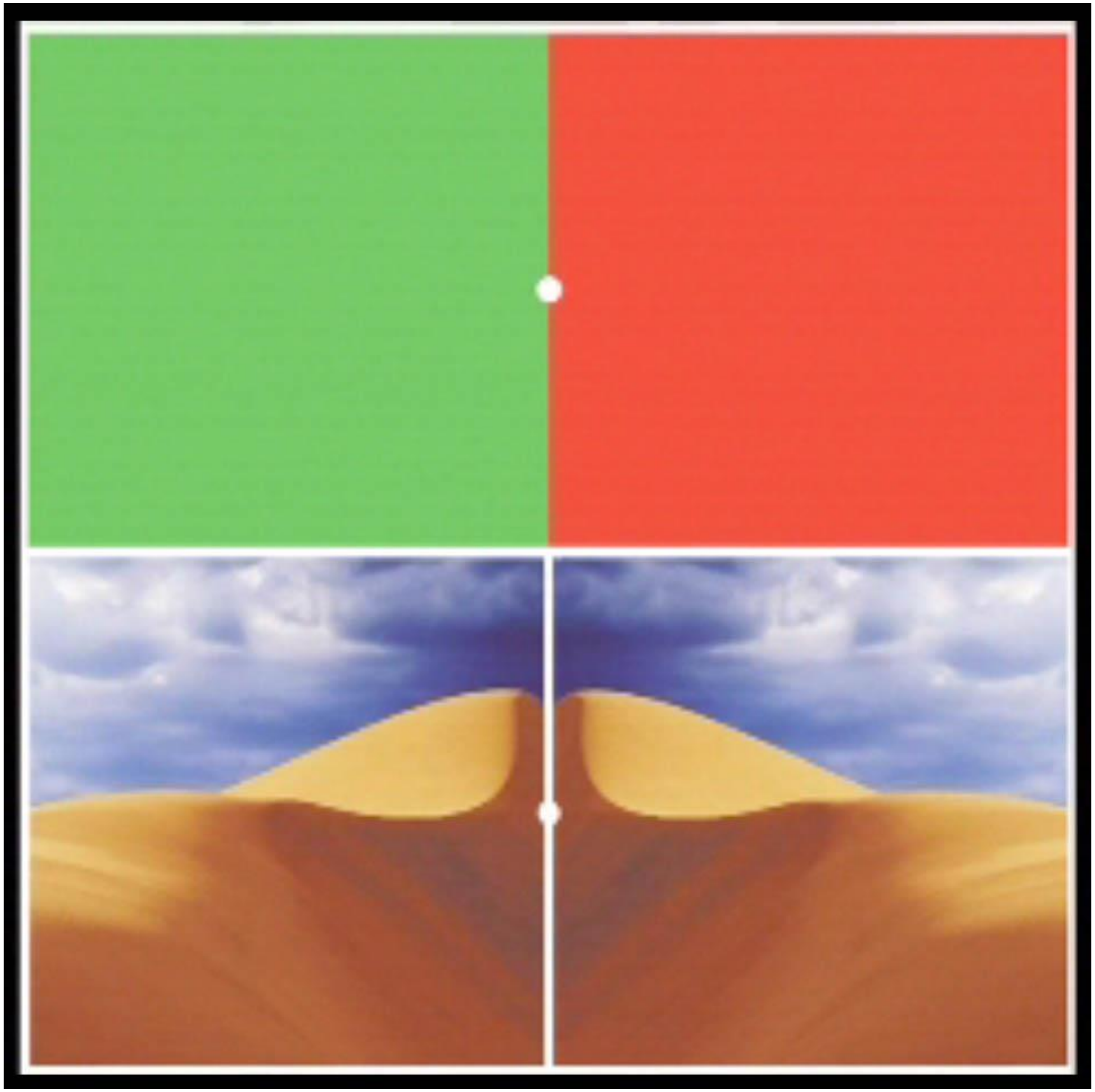


FIGURE 2.9 Some well-known optical illusions.

Görsel Algının Unsurları



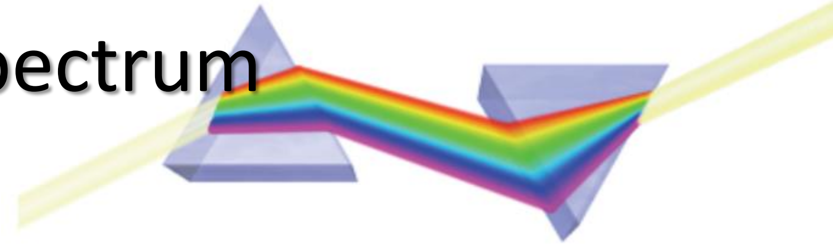
Görsel Algının Unsurları

- Watch Beau Lotto’s TED talk on “Optical illusions show how we see”.

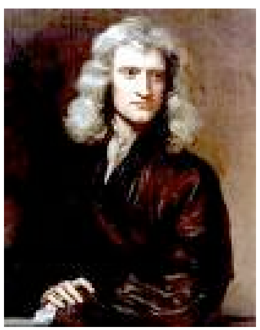
TED Ideas worth spreading

Video Link: https://www.ted.com/talks/beau_lotto_optical_illusions_show_how_we_see?language=tr#t-395398

Light and Electromagnetic Spectrum

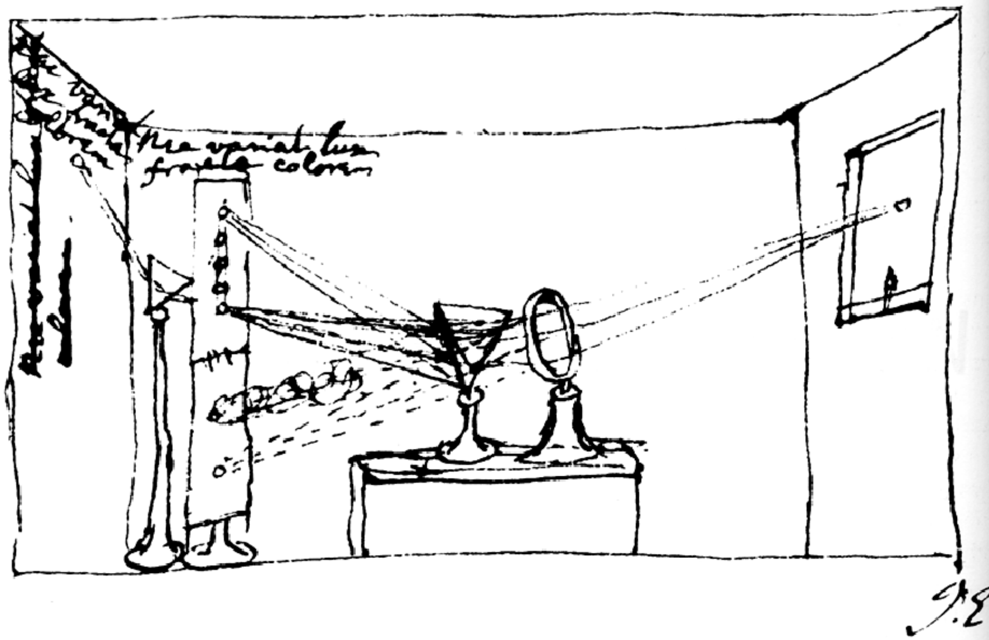


- White light: composed of about equal energy in all wavelengths of the visible Spectrum.



Newton 1666

Color



4.1 NEWTON'S SUMMARY DRAWING of his experiments with light. Using a point source of light and a prism, Newton separated sunlight into its fundamental components. By reconverging the rays, he also showed that the decomposition is reversible.

From Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Video Link: https://www.youtube.com/watch?v=GaDxFvMdi0Q

Slide credit: B. Freeman, A. Torralba, K. Grauman

Light and Electromagnetic Spectrum

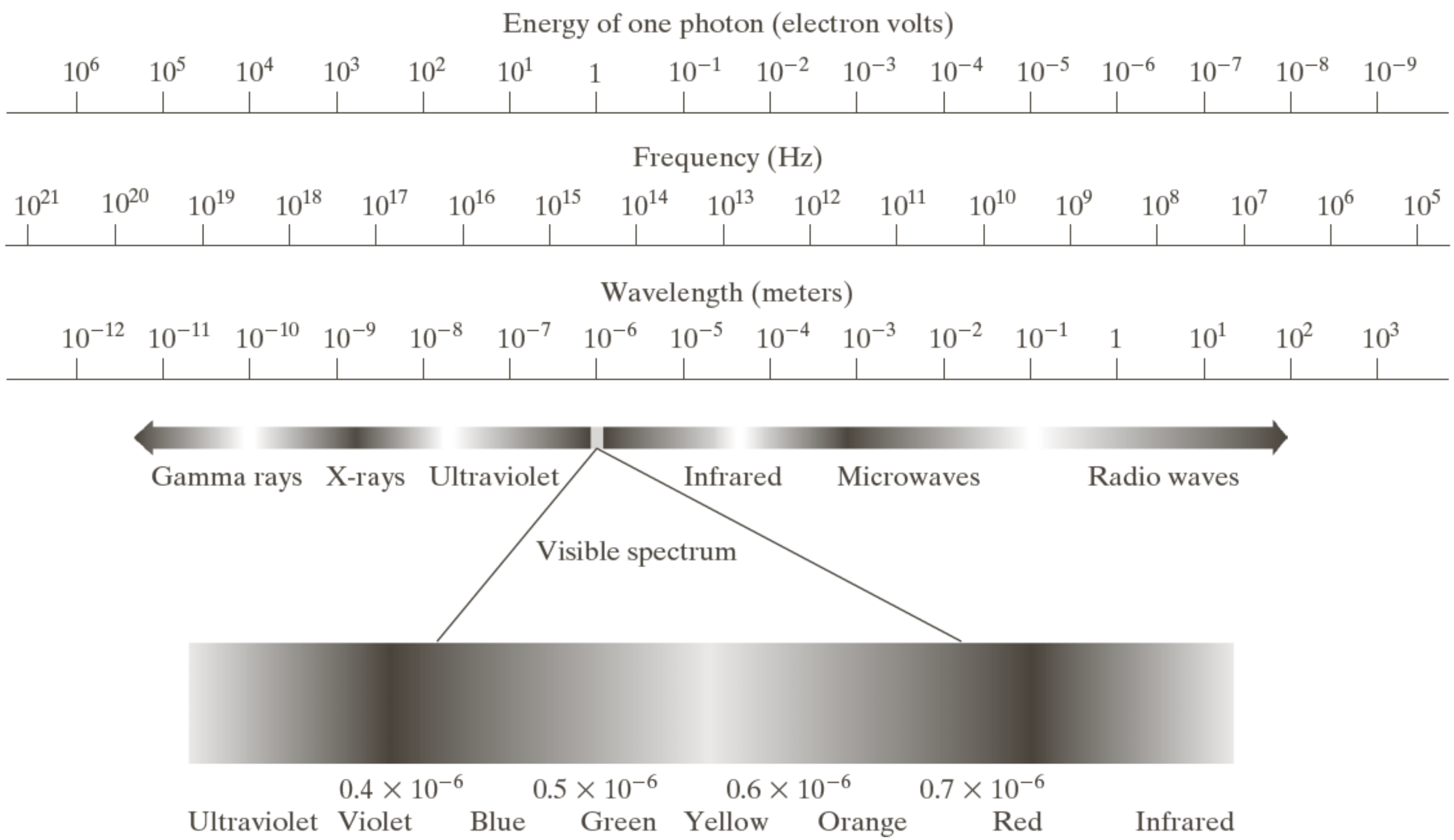
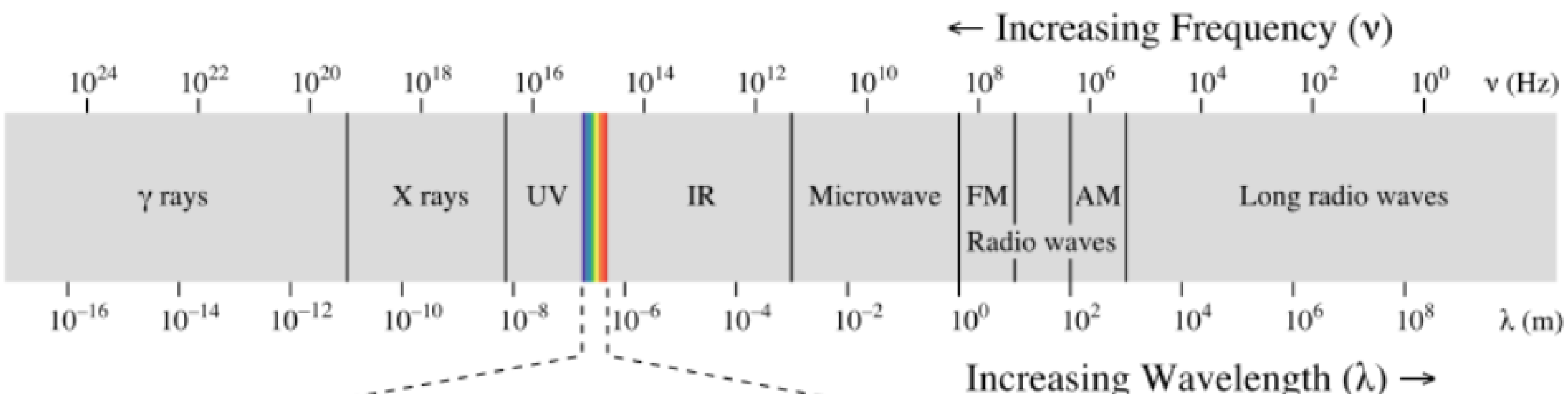


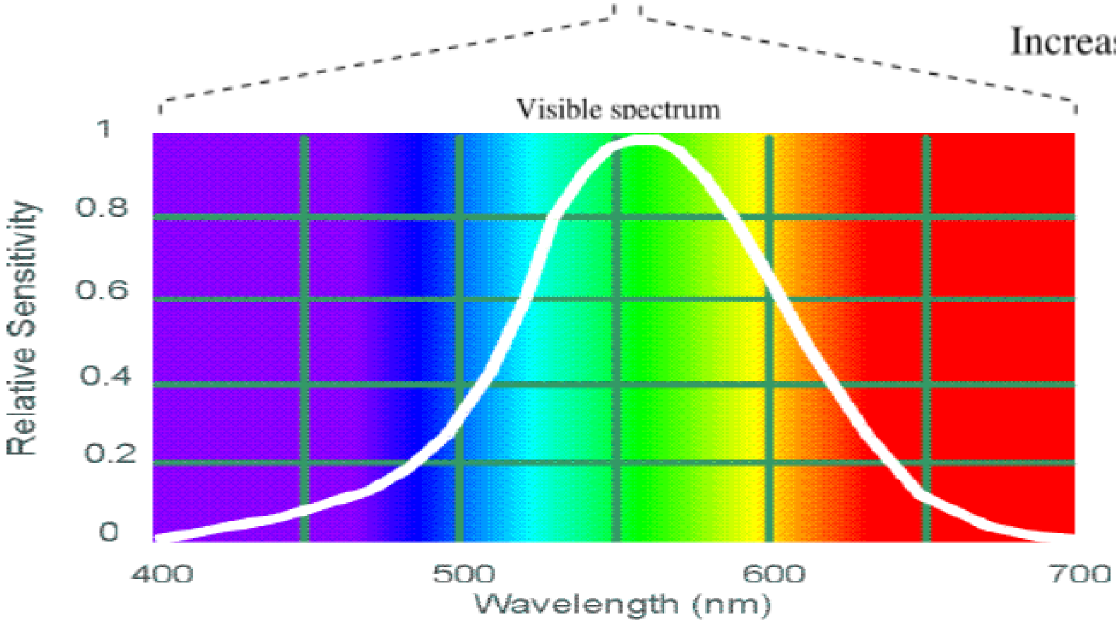
FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

$\lambda = c / v$ $E = hv$ h: Planck's katsayısı

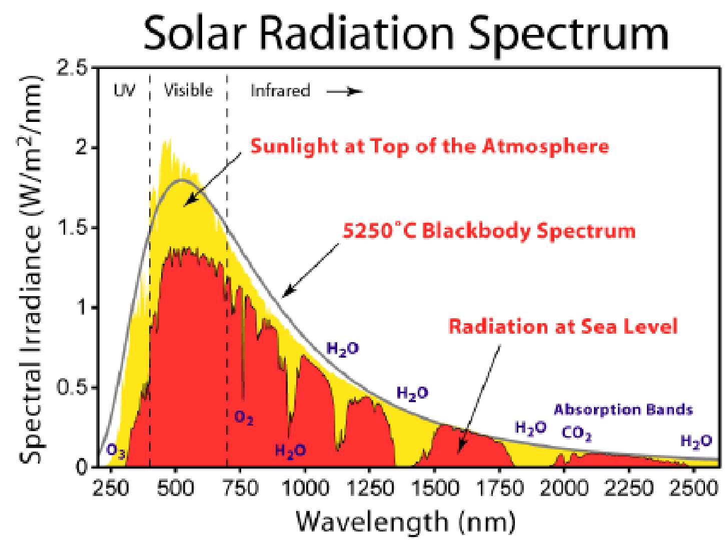
Video Link: https://www.youtube.com/watch?v=iyz6W6aJ_jA https://www.youtube.com/watch?v=HUT1BPYUQQ8

Işık ve Elektromanyetik Spektrum





Human Luminance Sensitivity Function

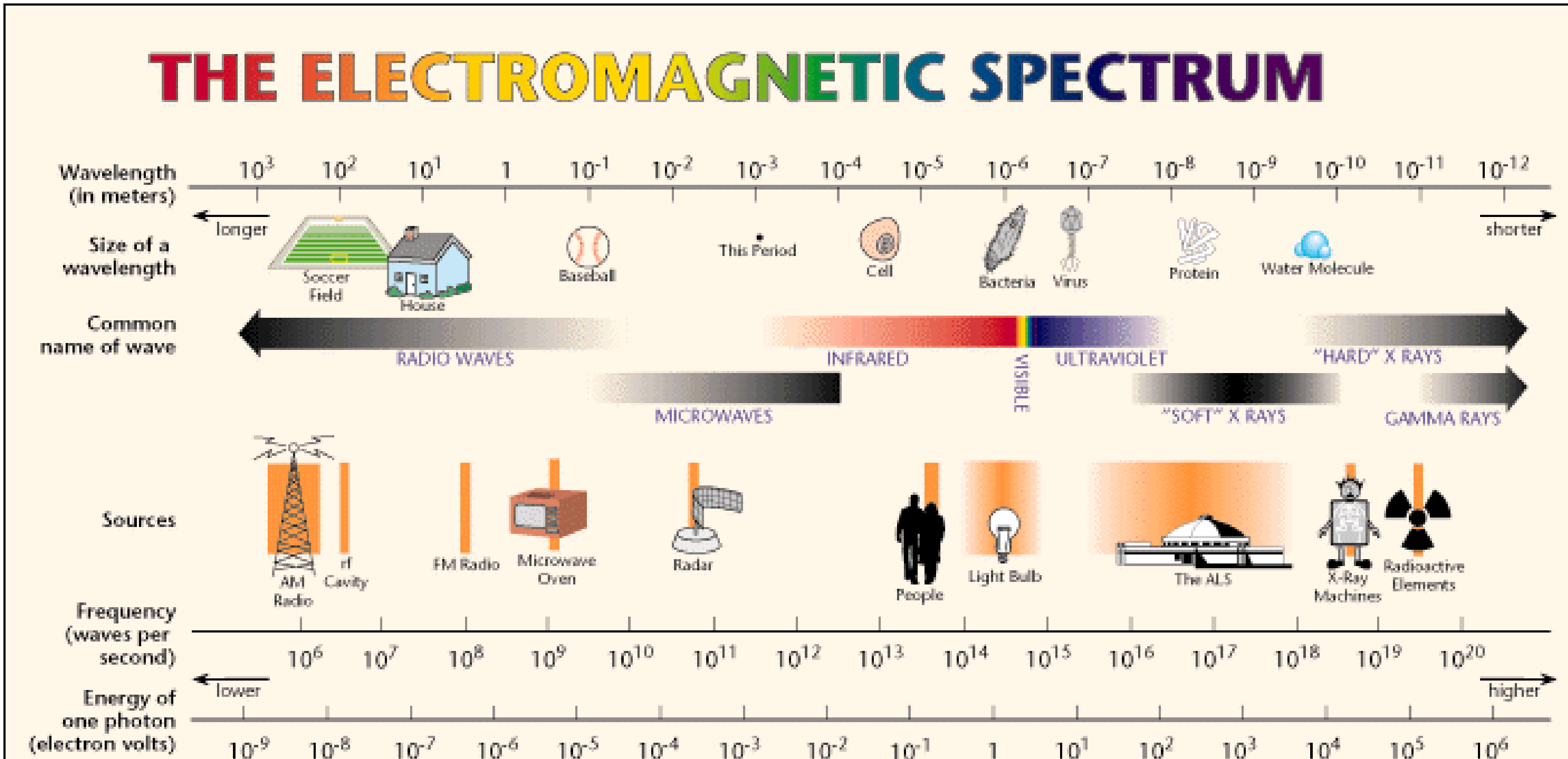


Slide credit: A. Efros

Video Link: https://www.youtube.com/watch?v=m4t7gTmBK3g

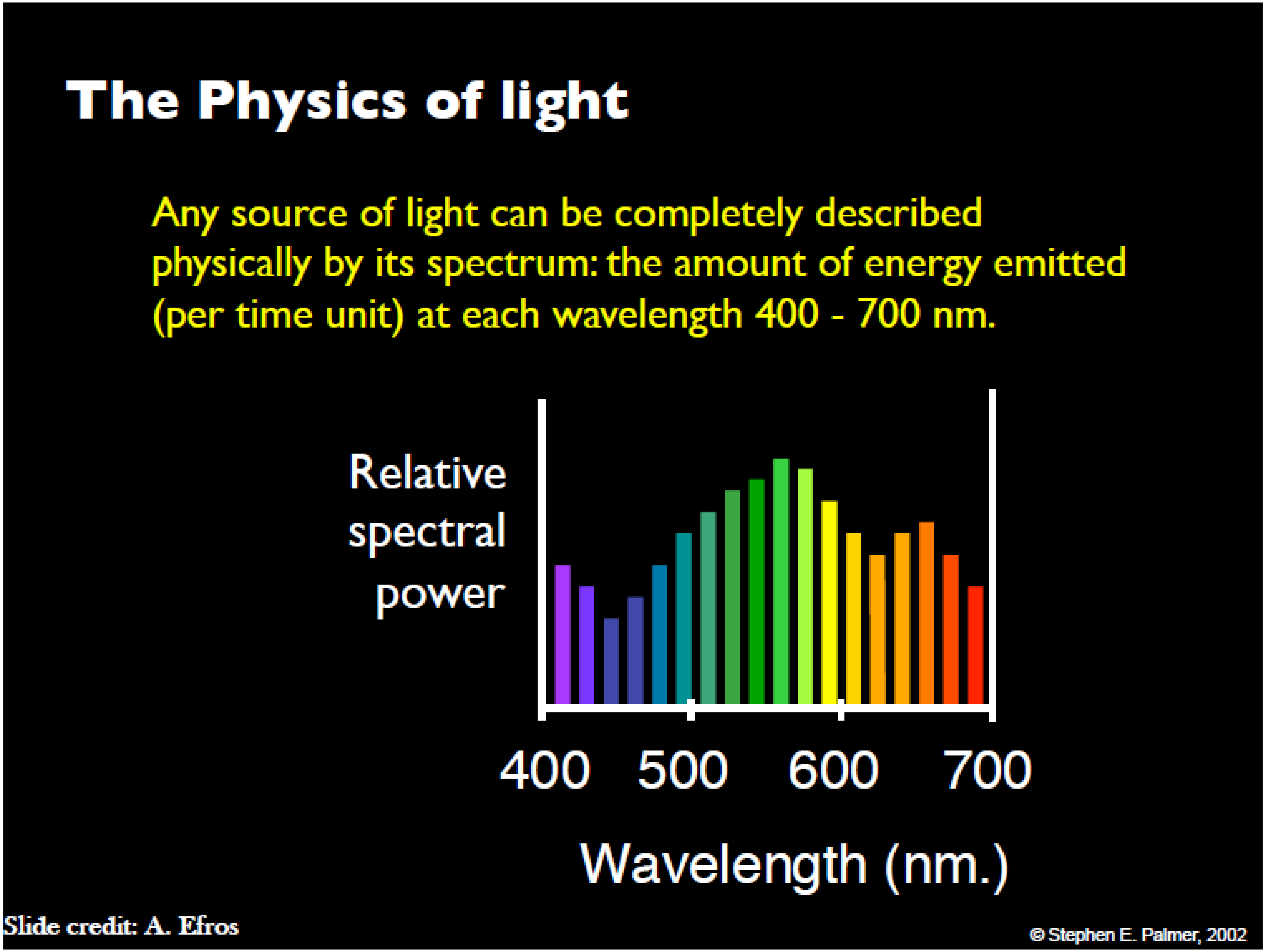
Işık ve Elektromanyetik Spektrum

- The wavelength of an EM wave required to “see” an object must be of the same size as or smaller than the object.

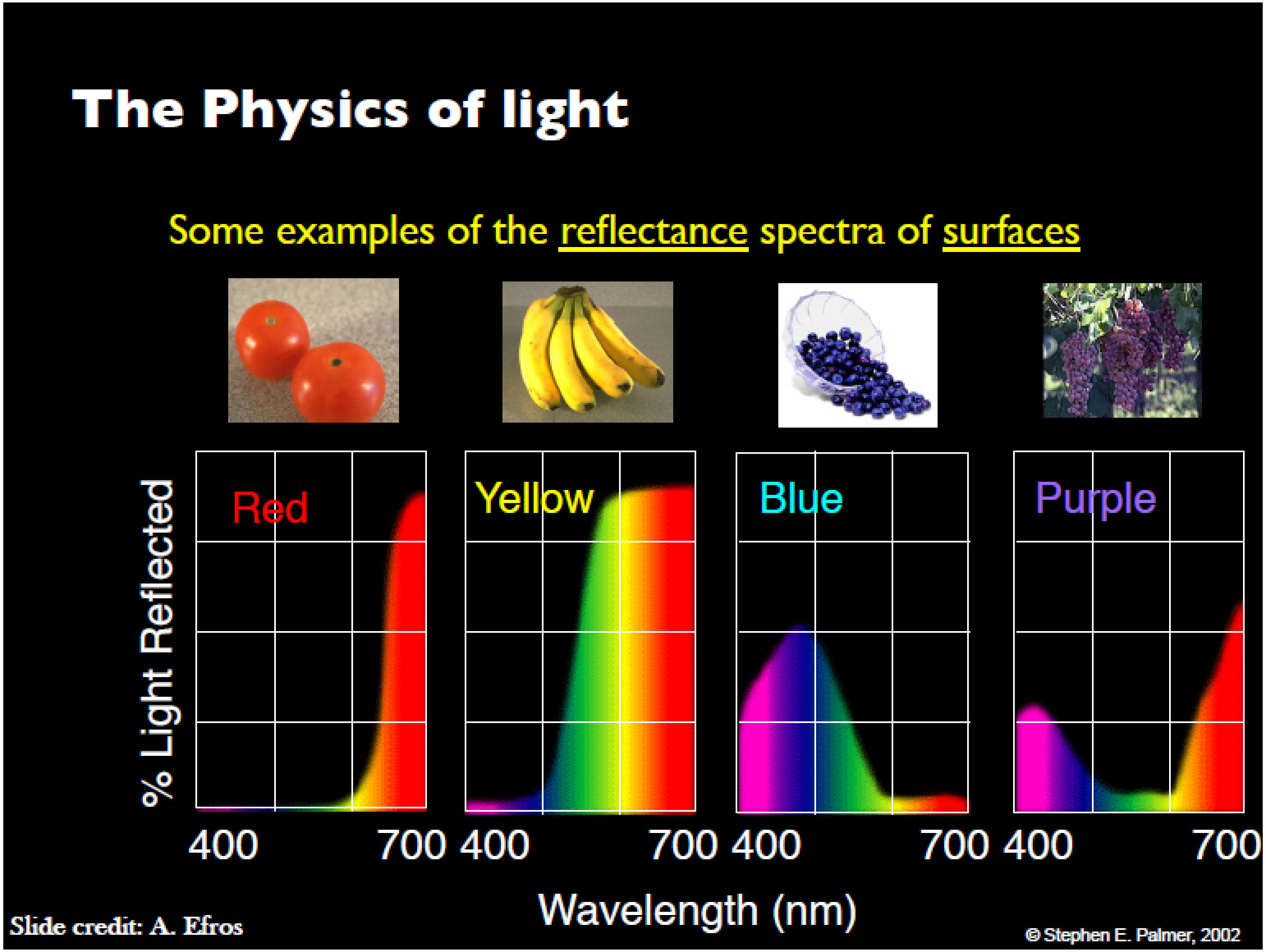


Video Link: https://www.youtube.com/watch?v=cfXzwh3KadE

Işık ve Elektromanyetik Spektrum

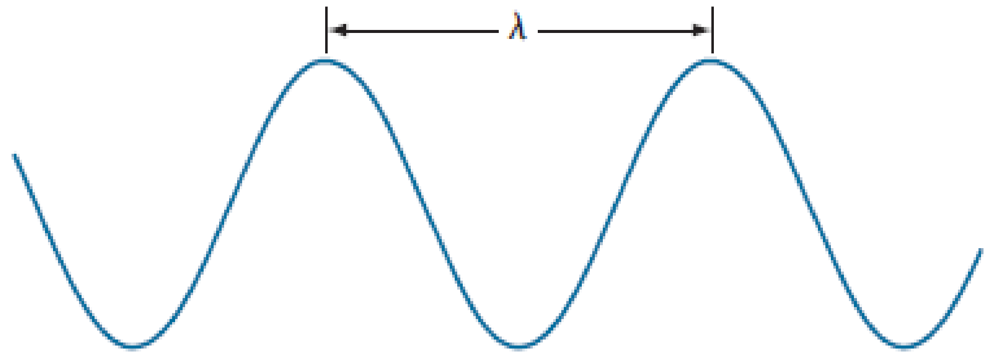


Işık ve Elektromanyetik Spektrum



Light and Electromagnetic Spectrum

FIGURE 2.11
Graphical representation of one wavelength.



- Electromagnetic waves can be visualized as sinusoidal waves advancing with lambda wavelength.

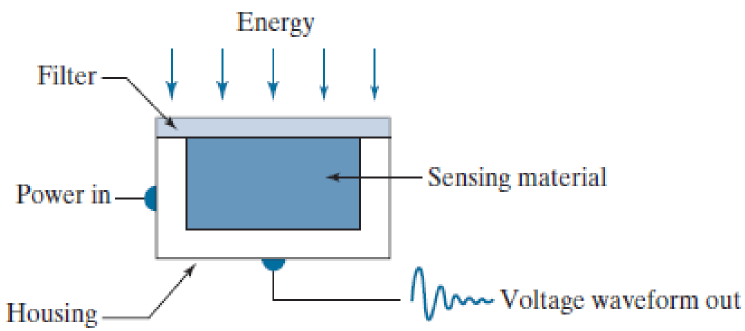
- The colors that humans perceive in an object are determined by the nature of the light reflected from the object.

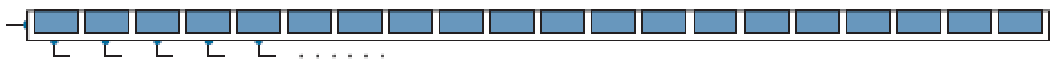
    e.g. green objects reflect light with wavelengths primarily in the 500 to 570 nm range while absorbing most of the energy at other wavelength

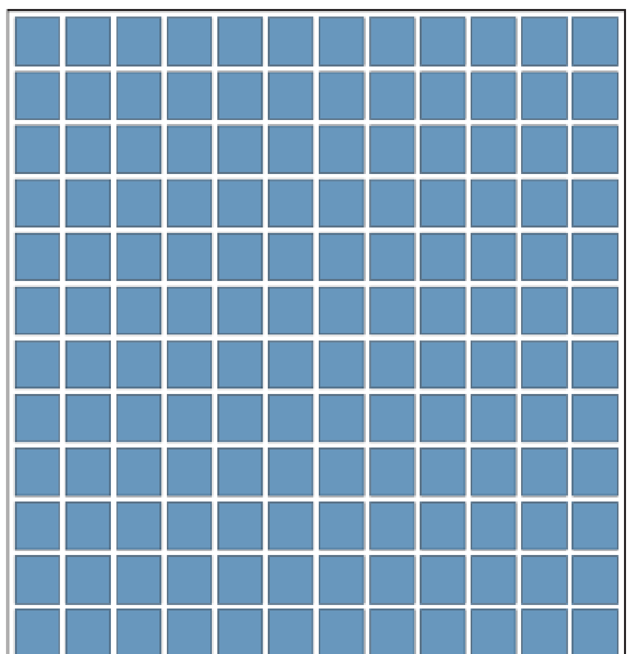
Light and Electromagnetic Spectrum

- Monochromatic light: void of color
  - **Intensity** is the only attribute, from black to white
  - Monochromatic images are referred to as gray-scale images
- Chromatic light bands: 0.43 to 0.79 um
  - The quality of a chromatic light source:
  - **Radiance:** total amount of energy (measured as watt)
  - **Luminance (lm):** the amount of energy an observer perceives from a light source (measured as lumen)
  - **Brightness:** a subjective descriptor of light perception that is impossible to measure. It embodies the achromatic notion of intensity and one of the key factors in describing color sensation.

Image Sensing and Acquisition







Transform illumination energy into digital images

a
b
c

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

Image Acquisition Process

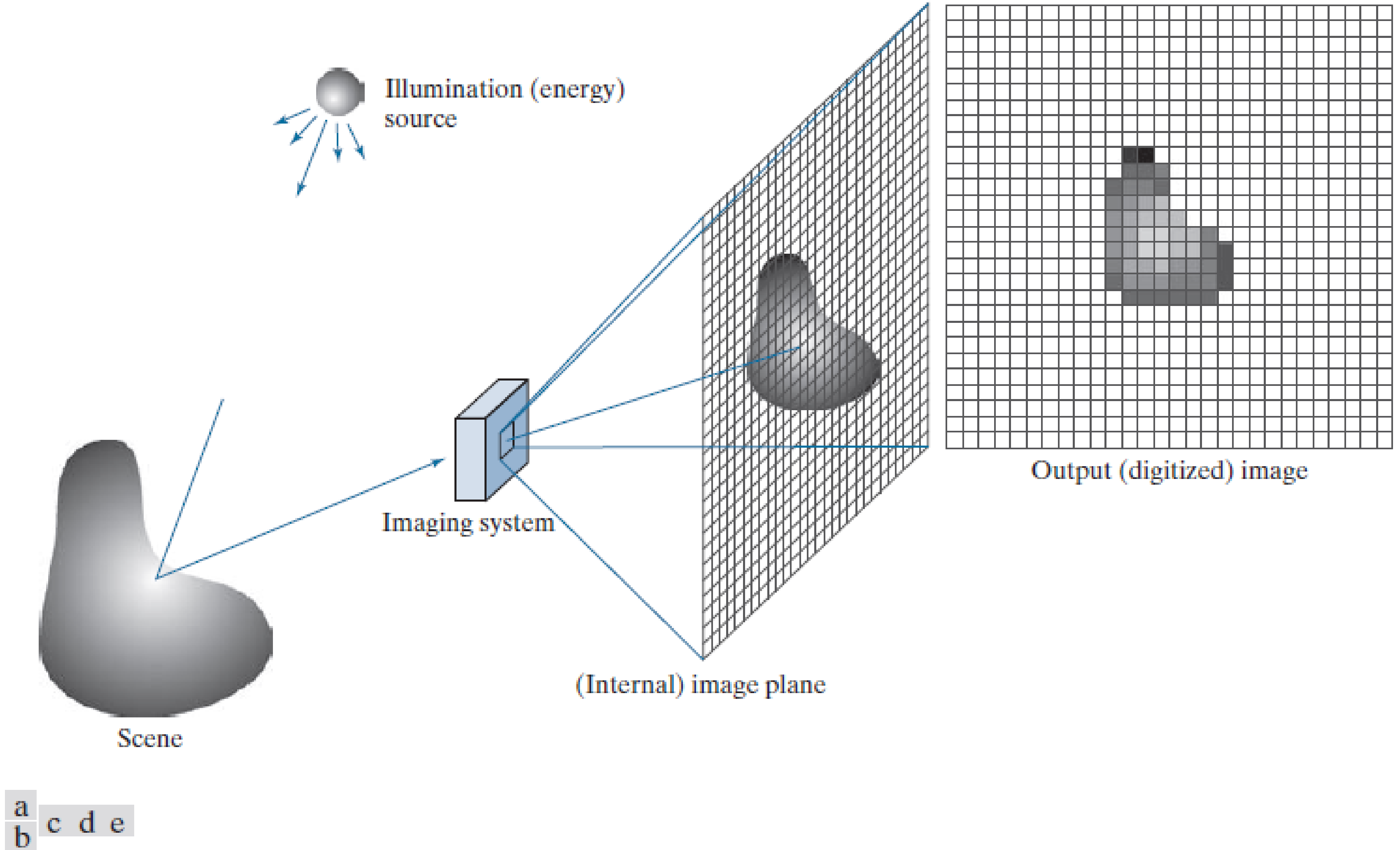


FIGURE 2.15 An example of digital image acquisition. (a) Illumination (energy) source. (b) A scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

A Simple Image Formation Model

f(x,y) is nonzero and finite;

$$f(x,y) = i(x,y)\, r(x,y)$$

$f(x, y)$: intensity at the point (x, y)

$i(x, y)$: illumination at the point (x, y)

(the amount of source illumination incident on the scene)

$r(x, y)$: reflectance/transmissivity at the point (x, y)

(the amount of illumination reflected/transmitted by the object)

where $0 < i(x, y) < \infty$ and $0 < r(x, y) < 1$

Some Typical Ranges of Illumination

- Illumination

  Lumen — A unit of light flow or luminous flux

  Lumen per square meter (lm/m^2) — The metric unit of measure for illuminance of a surface

  - On a clear day, the sun may produce in excess of 90,000 lm/m^2 of illumination on the surface of the Earth
  - On a cloudy day, the sun may produce less than 10,000 lm/m^2 of illumination on the surface of the Earth
  - On a clear evening, the moon yields about 0.1 lm/m^2 of illumination
  - The typical illumination level in a commercial office is about 1000 lm/m^2

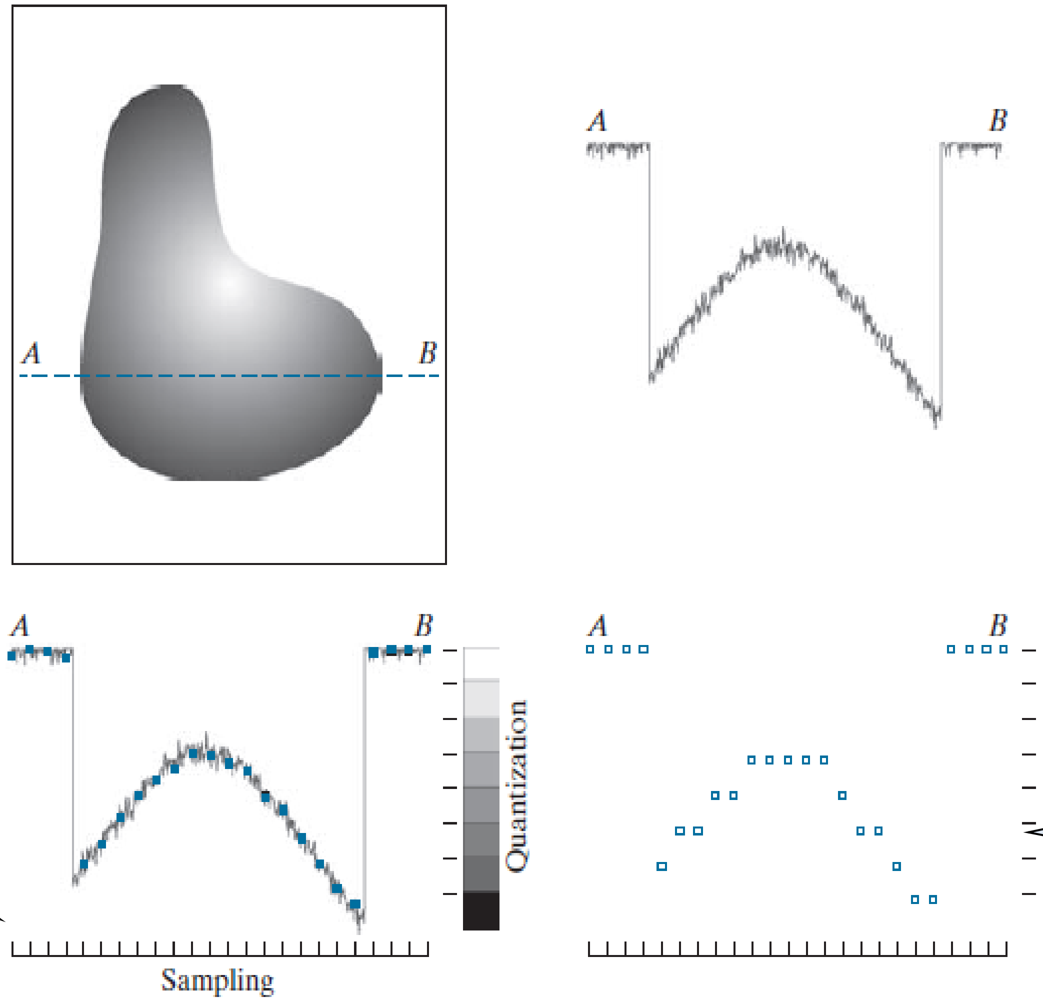
Some Typical Ranges of Reflectance

- Reflectance
  - 0.01 for black velvet
  - 0.65 for stainless steel
  - 0.80 for flat-white wall paint
  - 0.90 for silver-plated metal
  - 0.93 for snow

Image Sampling and Quantization

a b
c d

FIGURE 2.16
(a) Continuous image. (b) A scan line showing intensity variations along line AB in the continuous image. (c) Sampling and quantization. (d) Digital scan line. (The black border in (a) is included for clarity. It is not part of the image).



Digitizing the coordinate values

Digitizing the amplitude values

Image Sampling and Quantization

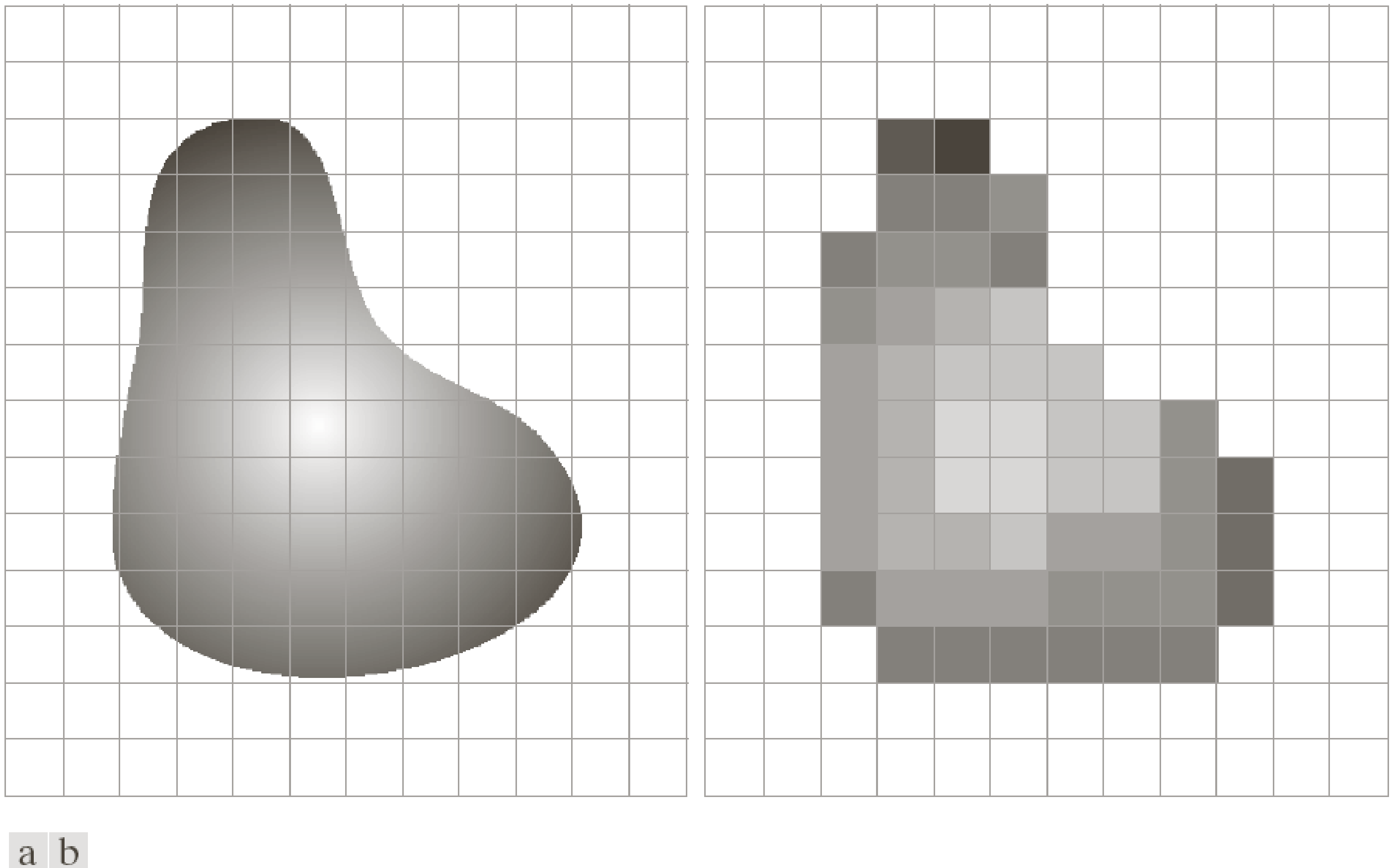
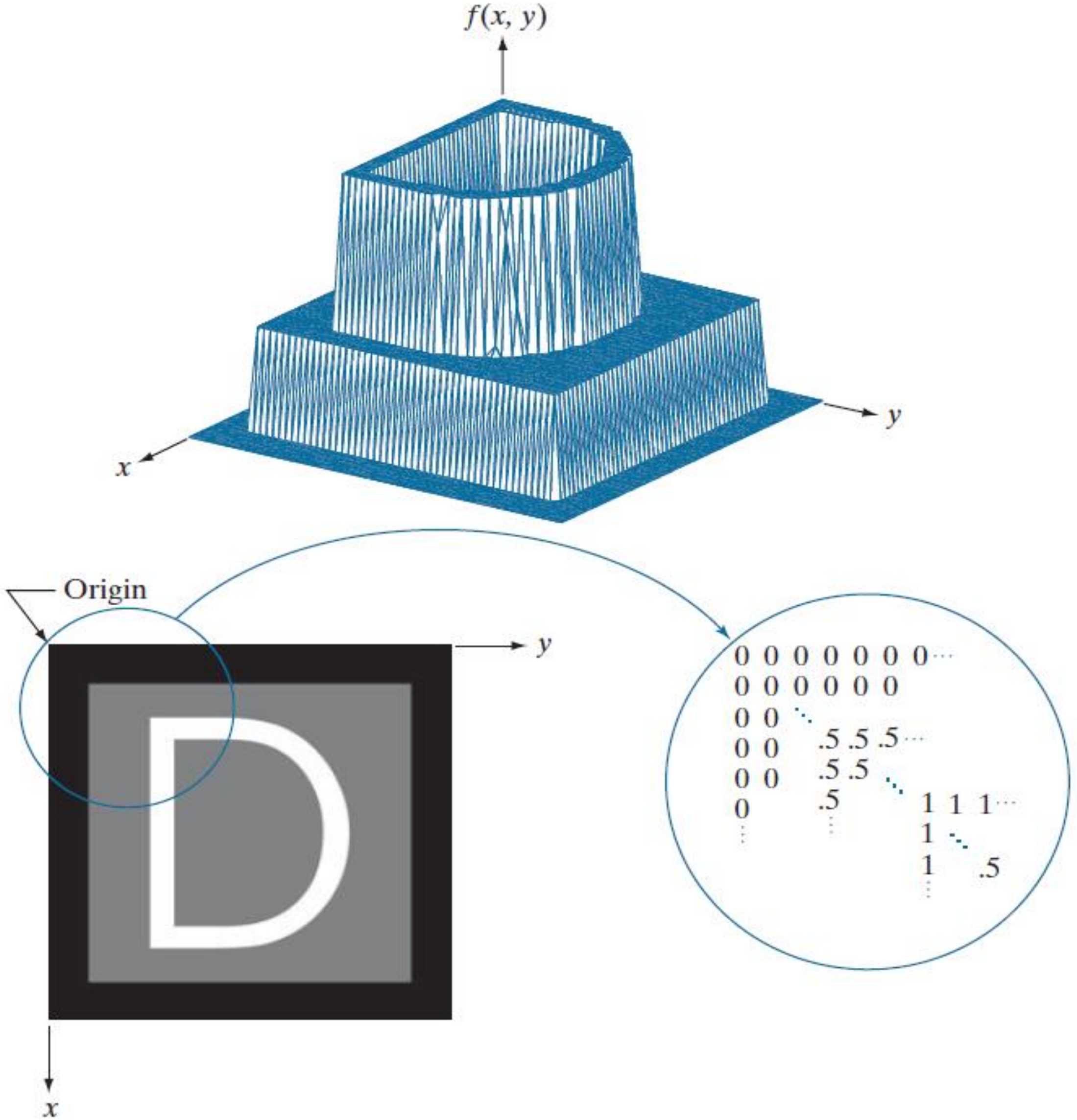


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Representing Digital Images

a
b c

FIGURE 2.18
(a) Image plotted as a surface. (b) Image displayed as a visual intensity array. (c) Image shown as a 2-D numerical array. (The numbers 0, .5, and 1 represent black, gray, and white, respectively.)



Representing Digital Images

- The representation of an M×N numerical array as

$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & \dots & f(1,N-1) \\ \dots & \dots & \dots & \dots \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix}$$

Representing Digital Images

- The representation of an M×N numerical array as

$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \cdots & \cdots & \cdots & \cdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

Representing Digital Images

- Discrete intensity interval [0, L-1], $L=2^k$

- The number b of bits required to store a $M \times N$ digitized image

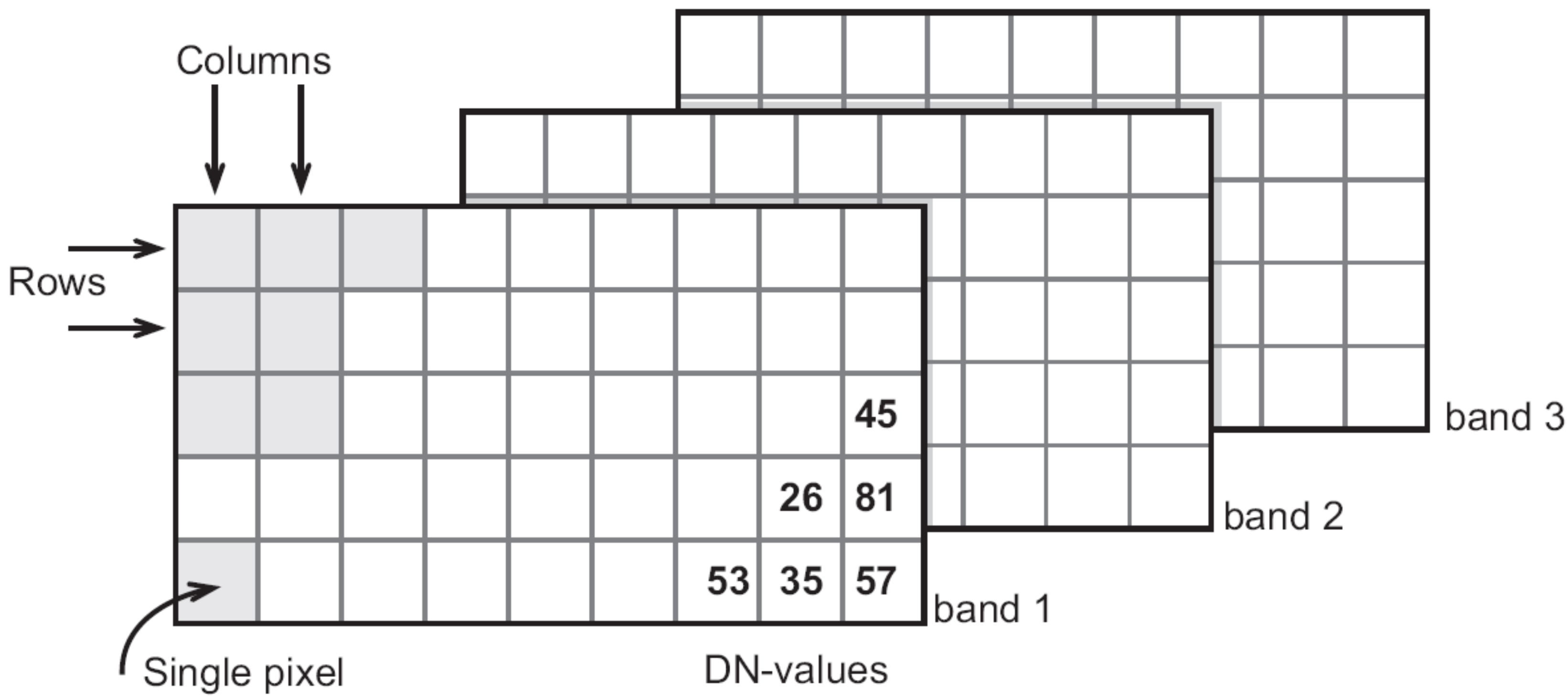
$$b = M \times N \times k$$

Representing Digital Images

TABLE 2.1
Number of storage bits for various values of N and k.

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

Representing Digital Images



Representing Digital Images

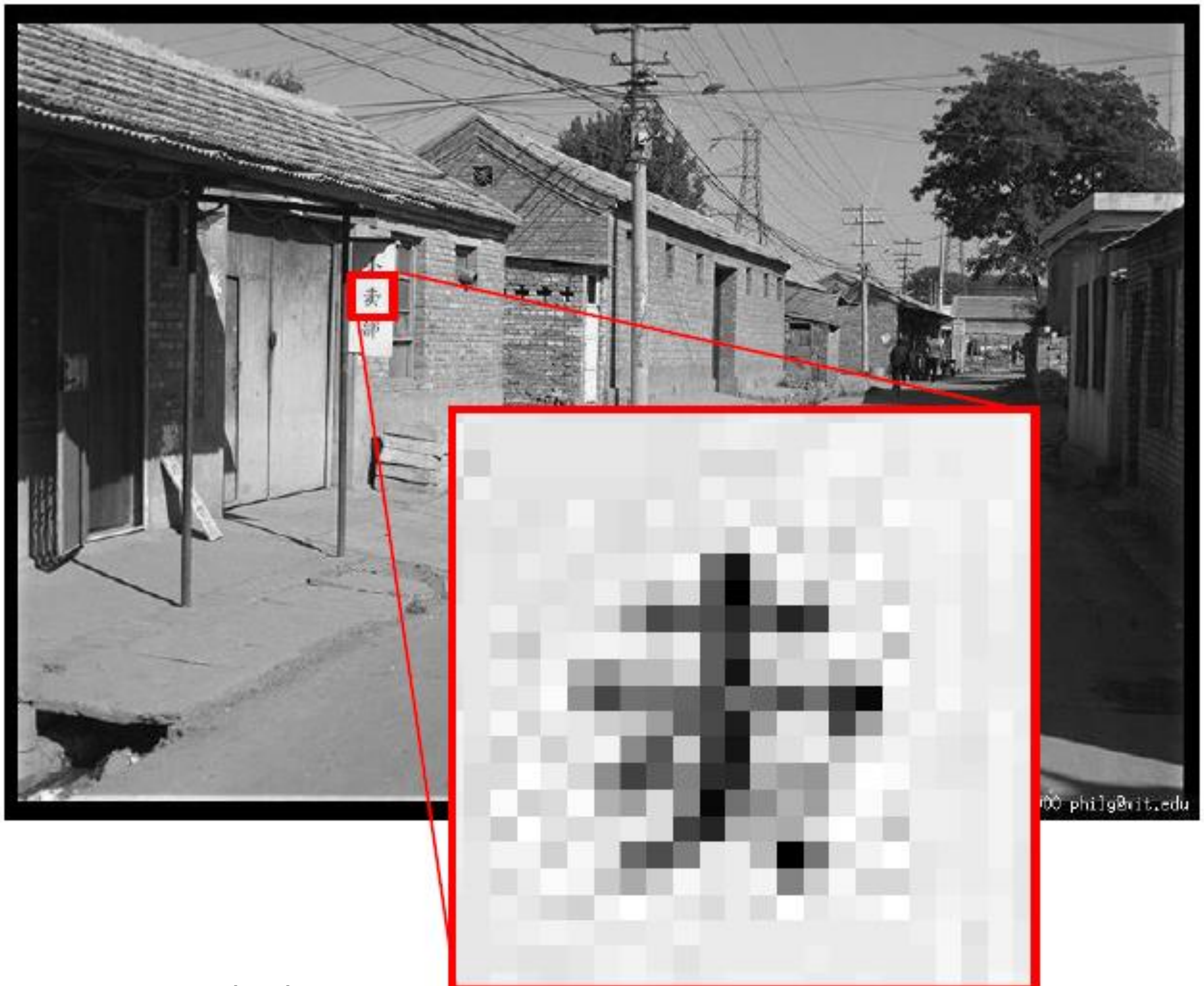


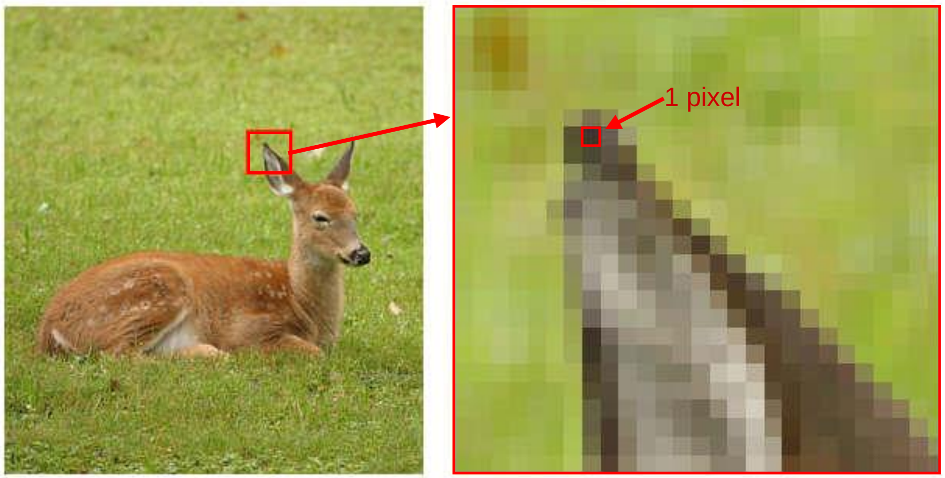
Figure: M. J. Black

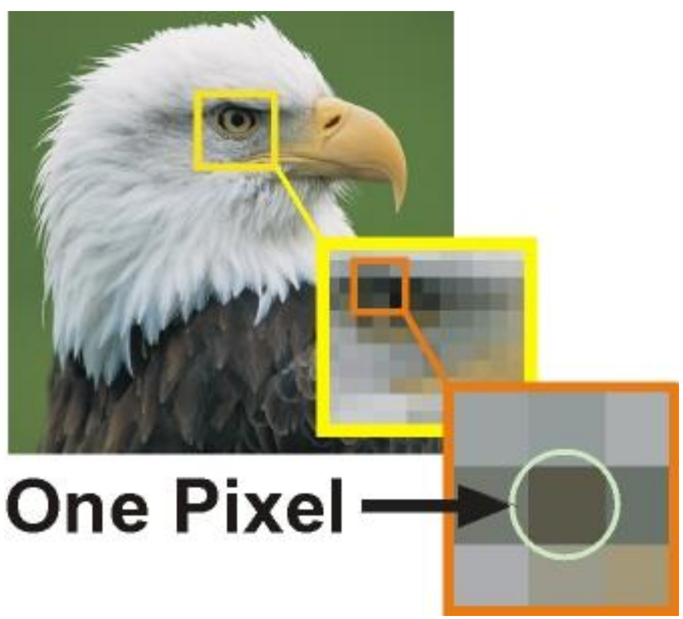
Representing Digital Images

0.92	0.93	0.94	0.97	0.62	0.37	0.85	0.97	0.93	0.92	0.99
0.95	0.89	0.82	0.89	0.56	0.31	0.75	0.92	0.81	0.95	0.91
0.89	0.72	0.51	0.55	0.51	0.42	0.57	0.41	0.49	0.91	0.92
0.96	0.95	0.88	0.94	0.56	0.46	0.91	0.87	0.90	0.97	0.95
0.71	0.81	0.81	0.87	0.57	0.37	0.80	0.88	0.89	0.79	0.85
0.49	0.62	0.60	0.58	0.50	0.60	0.58	0.50	0.61	0.45	0.33
0.86	0.84	0.74	0.58	0.51	0.39	0.73	0.92	0.91	0.49	0.74
0.96	0.67	0.54	0.85	0.48	0.37	0.88	0.90	0.94	0.82	0.93
0.69	0.49	0.56	0.66	0.43	0.42	0.77	0.73	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93

Figure: M. J. Black

Representing Digital Images





135	100	160
85	**65**	78
141	98	92

How are these numbers formed?

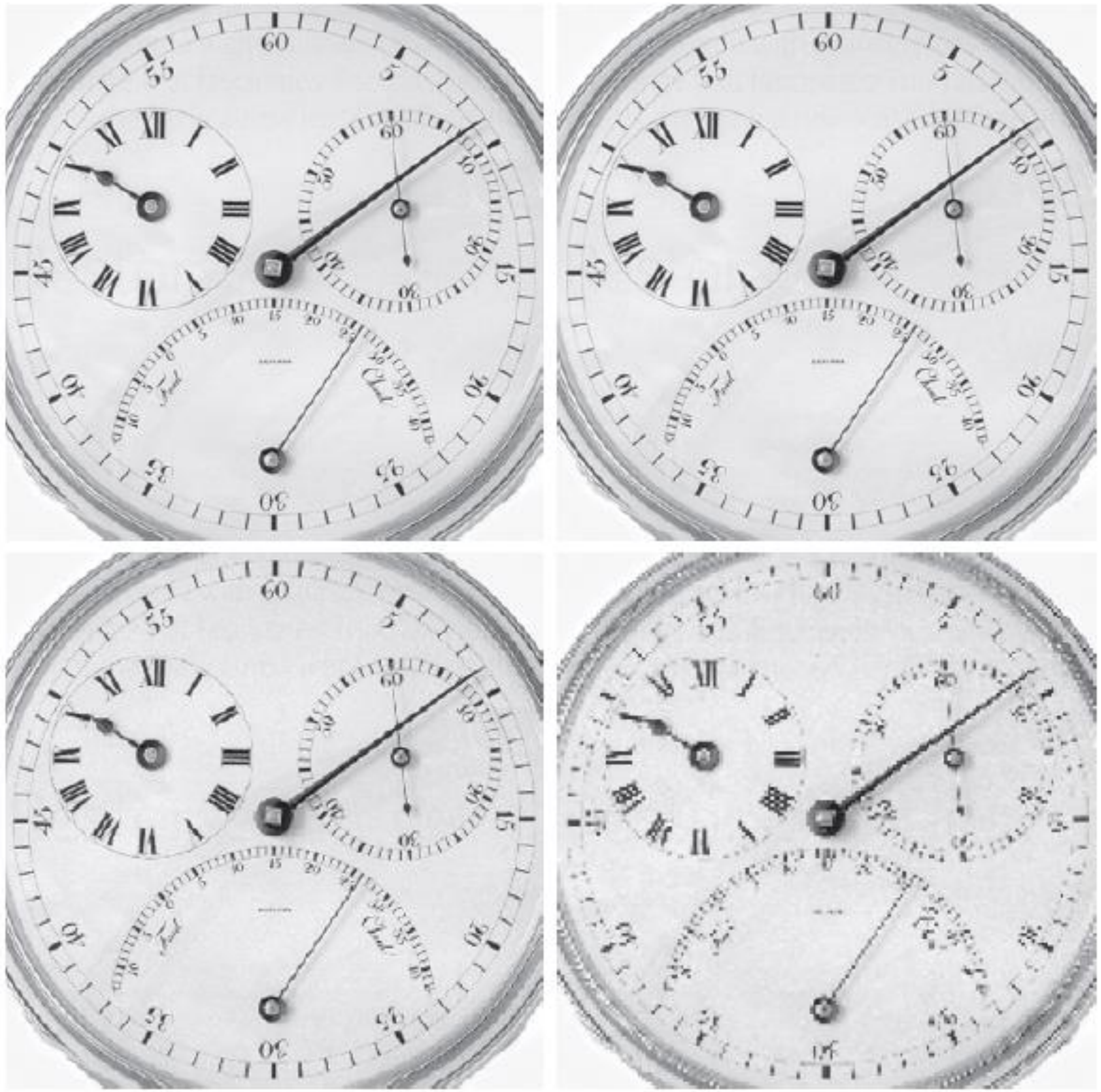
Source: http://www.comp.dit.ie/bmacnamee/gaip.htm

Spatial and Intensity Resolution

- Spatial resolution
  — A measure of the smallest discernible detail in an image
  — stated with line pairs per unit distance, dots (pixels) per unit distance, dots per inch (dpi)

- Intensity resolution
  — The smallest discernible change in intensity level
  — stated with 8 bits, 12 bits, 16 bits, etc.

Spatial and Intensity Resolution



a b
c d

FIGURE 2.23 Effects of reducing spatial resolution. The images shown are at:
(a) 930 dpi,
(b) 300 dpi,
(c) 150 dpi, and
(d) 72 dpi.

Spatial and Intensity Resolution

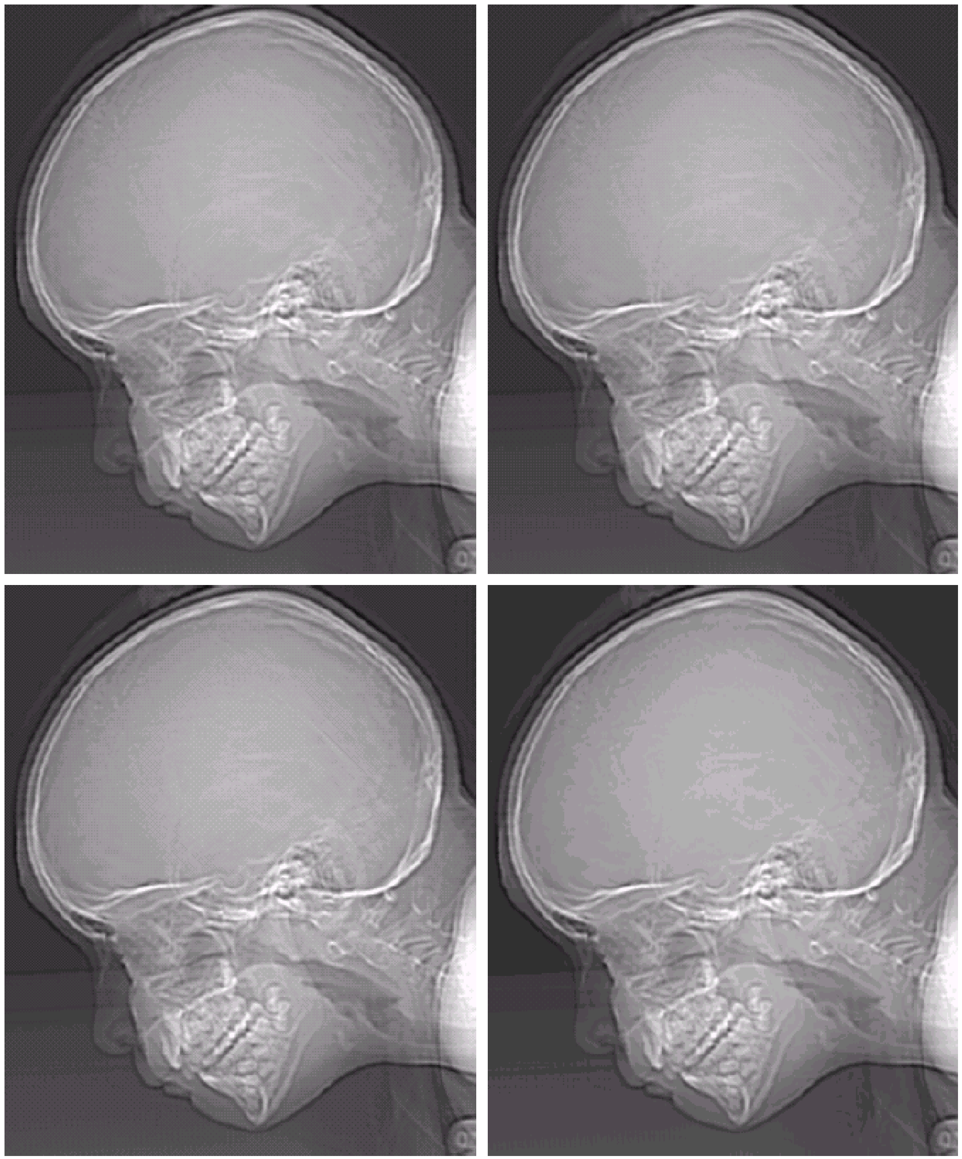
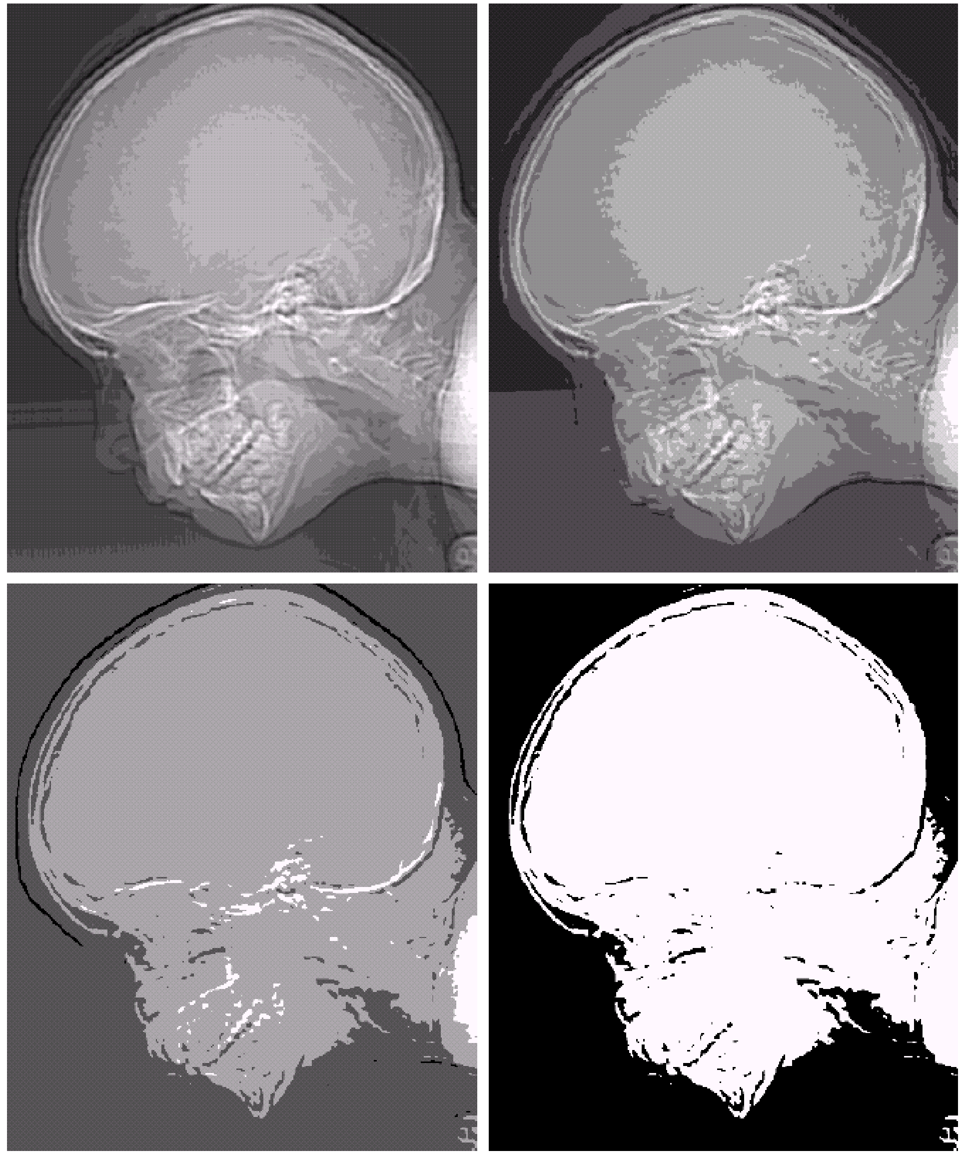


FIGURE 2.21
(a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

Spatial and Intensity Resolution



e f
g h

FIGURE 2.21 *(Continued)* (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

Spatial and Intensity Resolution

a b c

FIGURE 2.22 (a) Image with a low level of detail. (b) Image with a medium level of detail. (c) Image with a relatively large amount of detail. (Image (b) courtesy of the Massachusetts Institute of Technology.)

Introduction to Python

- Python was founded by Guido van Rossum as the heir to a language called ABC.
- Python is a platform-independent, full-featured, object-oriented programming language that has gained popularity due to its versatility and clear syntax.
- The most important feature of Python; finds a small number of lines of code sufficient to perform a large number of tasks.

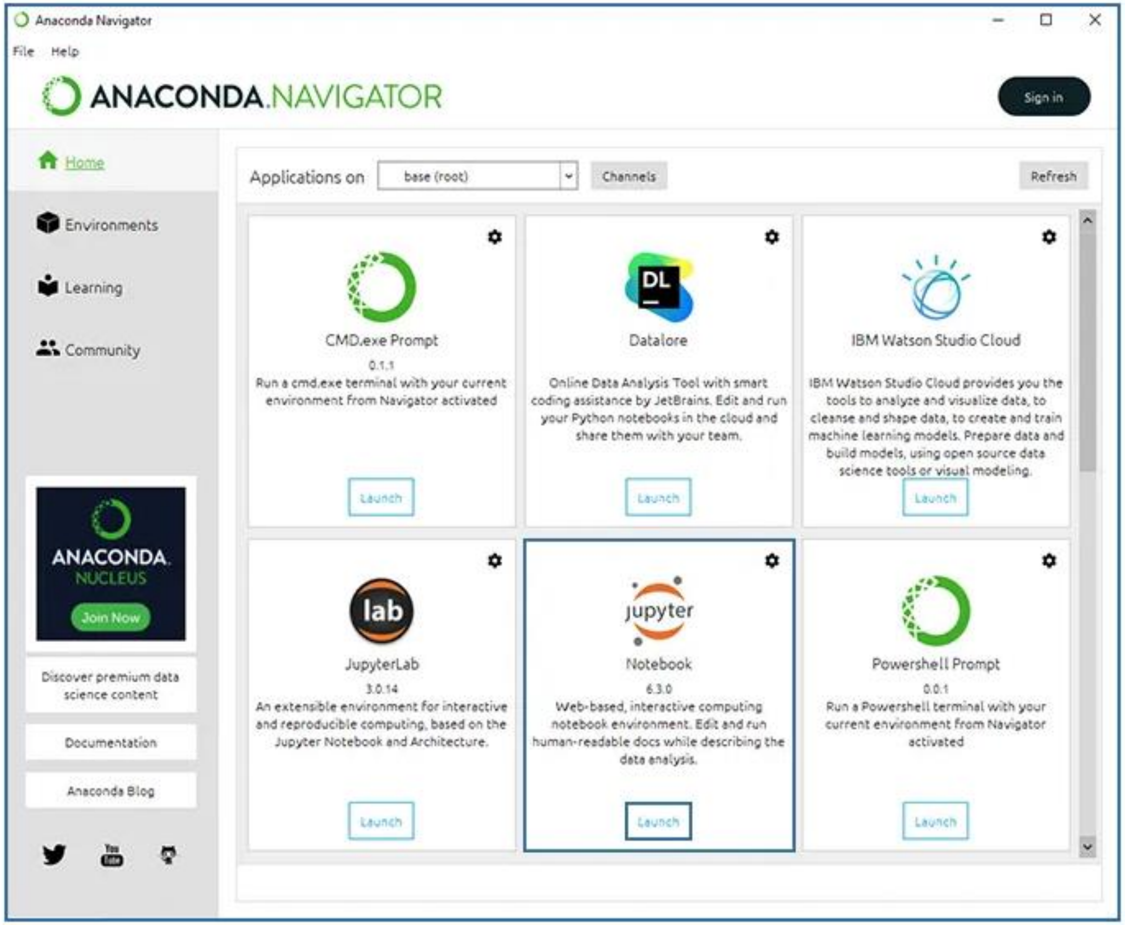
Introduction to Python

- In universities, Python is preferred because of its easy-to-learn structure and the fact that the operations you want to perform with the one suitable for your purpose from the libraries it contains can be carried out in a simple way thanks to the methods provided.
- Python consists of libraries that offer results specific to applications in certain domains.
- Numpy, OpenCV, Matplotlib, Pillow, Scipy, Scikit-Image libraries are generally used for image processing in the Python programming language.

Introduction to Python

- Studies will be carried out on Jupyter notebook.
- Access to this notebook will be done through Anaconda.
- Anaconda is an integrated Python distribution with many package programs for those who want to use Python to prepare data science and similar scientific applications.

Introduction to Python



Python Anaconda Navigator Arayüzü

Install Anaconda program by clicking on the link https://www.anaconda.com/products/distribution.

Introduction to Python

- After the installation, type 'Anaconda prompt (anaconda3)' in the search field.
- Now let's create an environment where we can run our project. This environment is called 'Environment'. The line of code we will write for this operation:

  - ***conda create - n <enviroment_name> python=3.6.4***

Introduction to Python

- Required line of code to activate the environment we have installed:

  >> conda activate environment_name

- Then, let's install a few necessary libraries and Jupyter Notebooks that we use often. Required lines of code for these operations:

  >> pip install numpy

  >> pip install matplotlib

  >> pip install jupyter notebook

Introduction to Python

- Required line of code to check the Python version you have installed:

  >> Python –version

```
(ocv) C:\Users\raziy>python --version
Python 3.6.4 :: Anaconda, Inc.
```

Introduction to Python

- https://sourceforge.net/projects/opencvlibrary/
- Install OpenCV from the link and then write the following code on the command line:

  >> conda install -c conda-forge opencv

Introduction to Python

- To check whether the installation was successful, we enter the command line again and run the codes below:

  >> python

  >> import cv2

  >> cv2.__version__

```
(ocv) C:\Users\raziy>python
Python 3.6.4 |Anaconda, Inc.| (default, Mar 12 2018, 20:20:50) [MSC v.1900 64 bit (AMD64)] on win32
Type "help", "copyright", "credits" or "license" for more information.
>>> import cv2
>>> cv2.__version__
'4.5.3'
```

Introduction to Python

- Now we can open jupyter notebook. For this process, after reaching the required directory with the 'cd' command on the Anaconda prompt screen, type the following command:

    >> Jupyter notebook

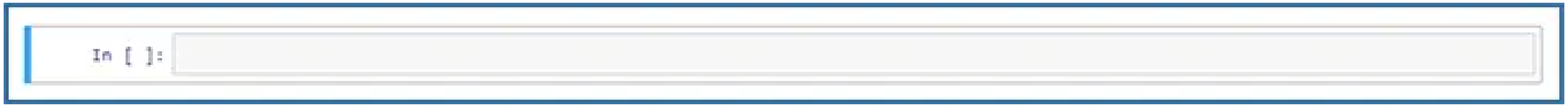
Introduction to Python

- Let's click the **"New"** button on the web page that comes up and select the **"Python 3"** section to create a Python project.

Python Anaconda Proje Oluşturma

Introduction to Python

- We can perform operations on the line of code that appears.



Python Anaconda Kod Satırı

Introduction to Python

- Matrices in Python

  A = [[1,4,5],

  [-5,8,9]]

A 2x3 matrix named A was created.

- The array() method in the numpy library can also be used to create a matrix.
  - Import numpy as np
  - A = np.array([[1,2,3],[3,4,5]])

Introduction to Python

- There are also auxiliary methods in the formation of matrices of the desired size, whose contents are filled with values of 0 or 1.
  - import numpy as np
  - array =np.zeros((2,3))
  - print(array)
  - Output: [[0. 0. 0.]
    [0. 0. 0.]]

Introduction to Python

  - import numpy as np
  - array =np.ones((1,5))
  - print(array)
  - Output: [[1 1 1 1 1]]
- And some other methods :
  - Numpy.eye(), numpy.random.randn(), numpy.random.rand(), numpy.matrix()

Introduction to Python

- Here are some operators and methods that can be used to perform matrix operations in Python:
  - ✓ +, -, *, /, **, math.cos(), math.sin(), sqrt(), dot(), T, transpose(), multiply(), matmul(), add(), subtract(), divide(), shape(), linalg.inv(), linalg.matrix_power(), size()

Introduction to Python

- Rules for Python variables:
  - ✓ The variable name must begin with a letter or underscore character.
  - ✓ Variable name cannot start with a number.
  - ✓ The variable name can contain only alphanumeric characters and underscores (A-z, 0-9 and _).
  - ✓ Variable names are case sensitive (age, Age, and AGE are three different variables).
  - ✓ There is no limit on the length of the variable name.

Introduction to Python

- Python Arithmetic Operators

Operator	Name	Example
+	Addition	x + y
-	Subtraction	x - y
*	Multiplication	x * y
/	Division	x / y
%	Modulus	x % y
**	Exponentiation	x ** y
//	Floor division	x // y

Introduction to Python

▶ Python Assignment Operators

<table>
<tr><th>Operator</th><th>Example</th><th>Same As</th></tr>
<tr><td>=</td><td>x = 5</td><td>x = 5</td></tr>
<tr><td>+=</td><td>x += 3</td><td>x = x + 3</td></tr>
<tr><td>-=</td><td>x -= 3</td><td>x = x - 3</td></tr>
<tr><td>*=</td><td>x *= 3</td><td>x = x * 3</td></tr>
<tr><td>/=</td><td>x /= 3</td><td>x = x / 3</td></tr>
<tr><td>%=</td><td>x %= 3</td><td>x = x % 3</td></tr>
<tr><td>//=</td><td>x //= 3</td><td>x = x // 3</td></tr>
<tr><td>**=</td><td>x **= 3</td><td>x = x ** 3</td></tr>
<tr><td>&=</td><td>x &= 3</td><td>x = x & 3</td></tr>
<tr><td>|=</td><td>x |= 3</td><td>x = x | 3</td></tr>
<tr><td>^=</td><td>x ^= 3</td><td>x = x ^ 3</td></tr>
<tr><td>>>=</td><td>x >>= 3</td><td>x = x >> 3</td></tr>
<tr><td><<=</td><td>x <<= 3</td><td>x = x << 3</td></tr>
</table>

Introduction to Python

- Python Comparison Operators

Operator	Name	Example
==	Equal	x == y
!=	Not equal	x != y
>	Greater than	x > y
<	Less than	x < y
>=	Greater than or equal to	x >= y
<=	Less than or equal to	x <= y

Introduction to Python

▶ Python Logical Operators

Operator	Description	Example
and	Returns True if both statements are true	x < 5 and x < 10
or	Returns True if one of the statements is true	x < 5 or x < 4
not	Reverse the result, returns False if the result is true	not(x < 5 and x < 10)

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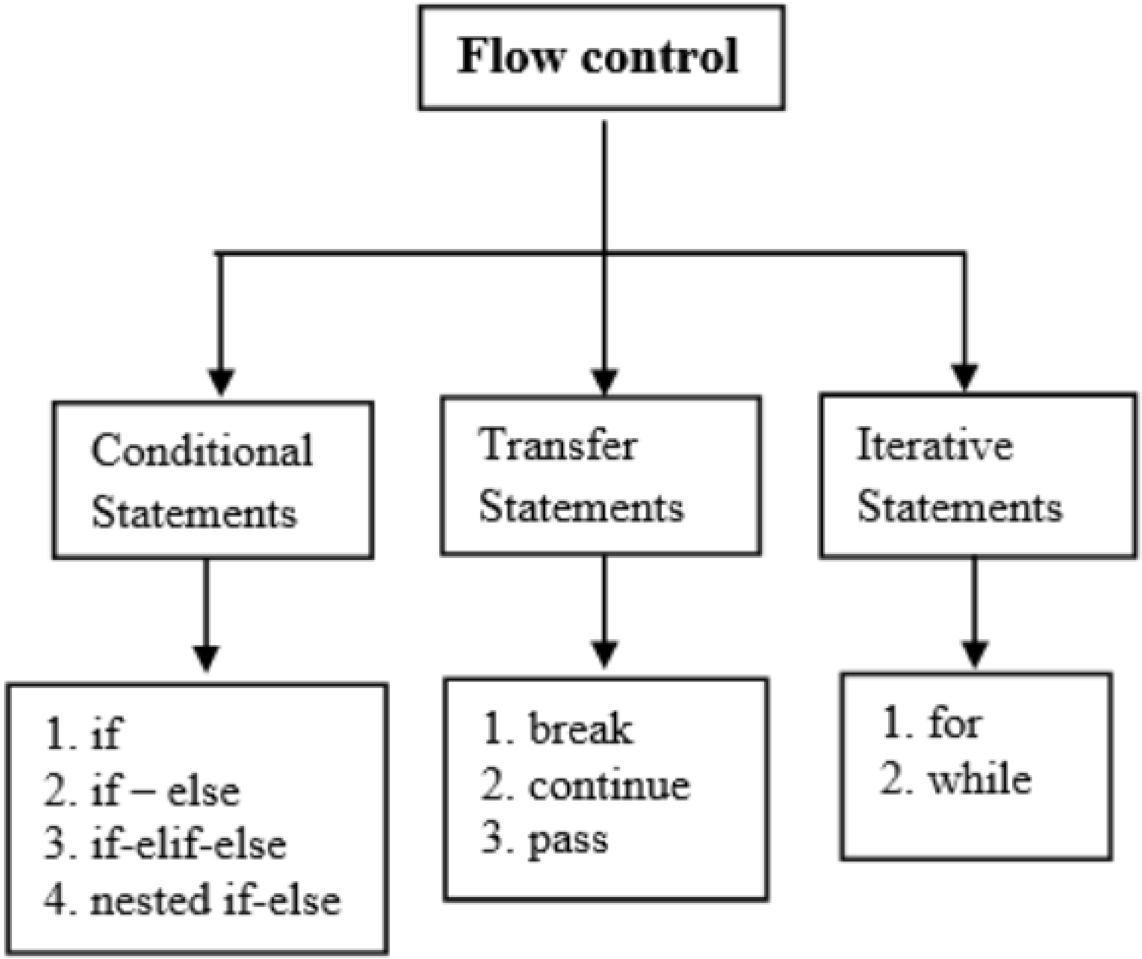
- Python Bitwise Operators

Operator	Name	Description
&	AND	Sets each bit to 1 if both bits are 1
|	OR	Sets each bit to 1 if one of two bits is 1
^	XOR	Sets each bit to 1 if only one of two bits is 1
~	NOT	Inverts all the bits
<<	Zero fill left shift	Shift left by pushing zeros in from the right and let the leftmost bits fall off
>>	Signed right shift	Shift right by pushing copies of the leftmost bit in from the left, and let the rightmost bits fall off

Introduction to Python



Introduction to Python

- IF STATEMENT CONDITION

  The general form of the IF statement is

```
if condition-1:
      statement 1
elif condition-2:
      stetement 2
elif condition-3:
      stetement 3
      ...
else:
      statement
```

Introduction to Python

- FOR STATEMENT CONDITION

  The general form of the FOR statement is

```
for element in sequence:
    body of for loop
```

Introduction to Python

- WHILE STATEMENT CONDITION

    The general form of the WHILE statement is

```
while condition :
    body of while loop
```

Introduction to Python

- Functions
  - When we need to use a certain piece of code in a few places in a python application we have written, creating a function makes our work easier.
  - In such cases, we can enclose the lines of code that we will use constantly and call and run them whenever we want.

```
def functionname( parameters ):
   "function_docstring"
   function_suite
   return [expression]
```

Introduction to Python

- Example: The code in which the elements taken from the user are added to the list as much as the number entered by the user and the average of the values in the list is calculated.

```python

n=int(input("Kaç Adet Sayı Girilecek: "))
a=[]
for i in range(0,n):
    elem=int(input("Sayıyı Girin: "))
    a.append(elem)
avg=sum(a)/n
print("Girilen Sayıların Ortalaması : ",round(avg,2))

```

References

- Sayısal Görüntü İşleme, Palme Publishing, Third Press Trans. (*Orj: R.C. Gonzalez and R.E. Woods: "Digital Image Processing", Prentice Hall, 3rd edition, 2008*).
- "Digital Image Processing Using Matlab", Gonzalez & Richard E. Woods, Steven L. Eddins, Gatesmark Publishing, 2009
- Lecture Notes, CS589-04 Digital Image Processing, Frank (Qingzhong) Liu, http://www.cs.nmt.edu/~ip
- Lecture Notes, BIL717-Image Processing, Erkut Erdem
- Lecture Notes, EBM537-Image Processing, F.Karabiber
- https://docs.opencv.org/
- Bekir Aksoy, Python ile İmgeden Veriye Görüntü İşleme ve Uygulamaları, Nobel Akademik Yayıncılık