Digital Image Processing

Lecture Two
Fundamentals of DIP

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2018

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This Lecture Includes:

Outline

- The human visual system
- Light and electromagnetic spectrum
- Image representation
- Image sensing and acquisition
- Sampling, quantisation and resolution

Human Visual System

- The best vision model we have! Knowledge of how images form in the eye can help us with processing digital images.
  We will take just a whirlwind tour of the human visual system.

Structure of The Human Eye

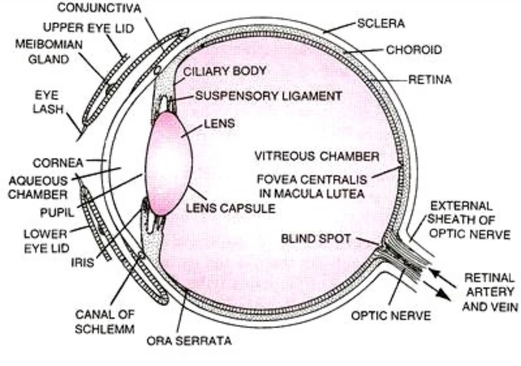


Fig. 21.24. V. S. Human Eye.

Structure of The Human Eye

- The lens focuses light from objects onto the retina
- The retina is covered with light receptors called cones (6-7 million) and rods (75-150 million)
- Cones are concentrated around the fovea and are very sensitive to colour
- Rods are more spread out and are sensitive to low levels of illumination

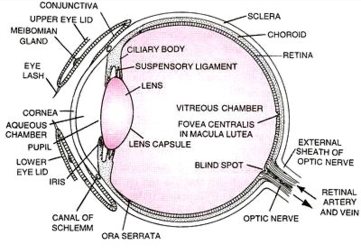
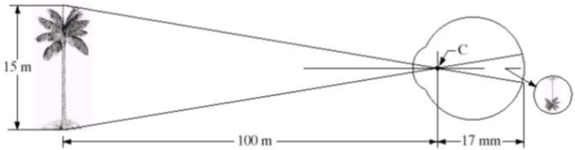


Fig. 21.24. V. S. Human Eye.

Image Formation In The Eye

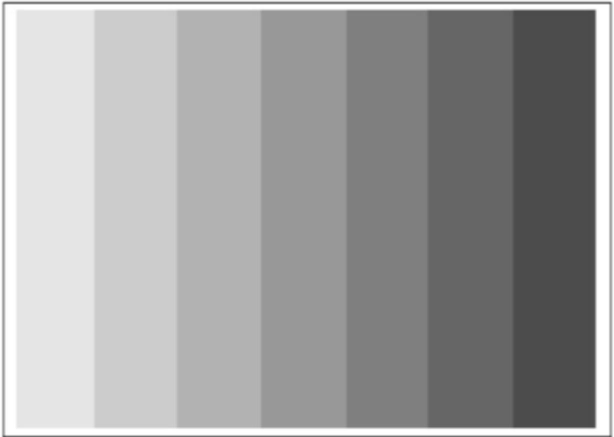
- Muscles (Iris) within the eye can be used to change the shape of the lens allowing us focus on objects that are near or far away
- An image is focused onto the retina causing rods and cones to become excited which ultimately send signals to the brain



Brightness Adaptation & Discrimination

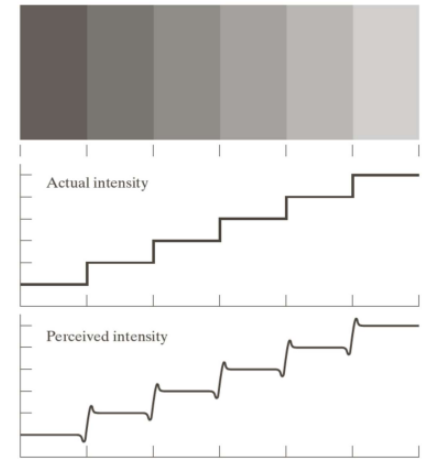
- The human visual system can perceive approximately 1010 different light intensity levels
- However, at any one time we can only discriminate between a much smaller number brightness adaptation
- Similarly, the perceived intensity of a region is related to the light intensities of the regions surrounding it

Brightness Adaptation & Discrimination

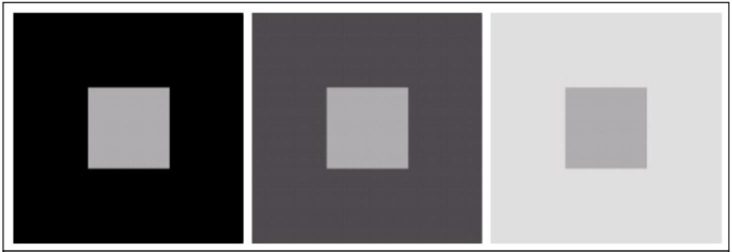


An example of Mach bands

Brightness Adaptation & Discrimination

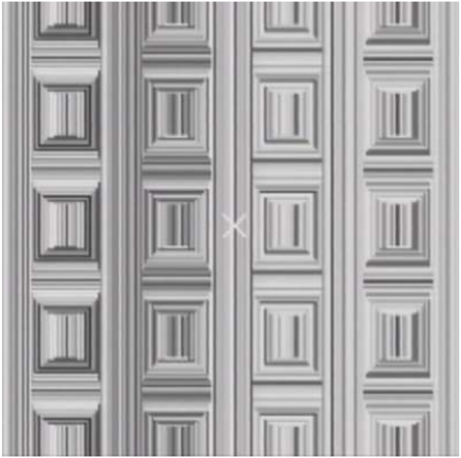


Brightness Adaptation & Discrimination



An example of *simultaneous contrast*

Optical Illusion



Do at home illusion

Stare at the cross in the middle of the image and think circles

Light & Electromagnetic Spectrum

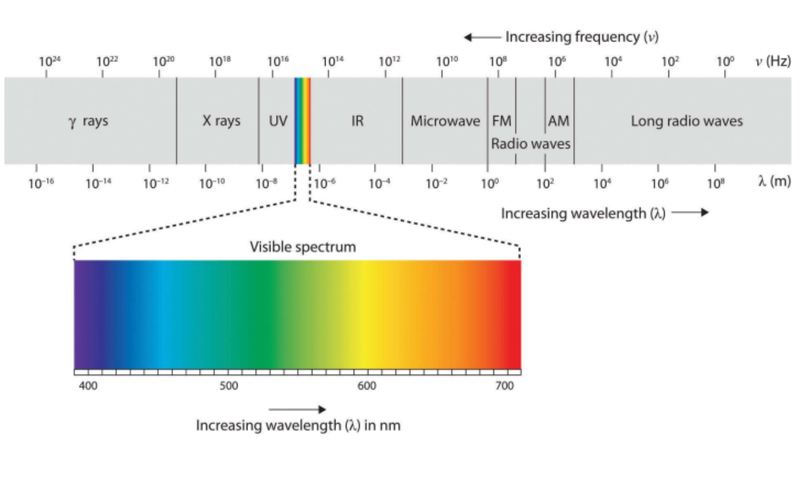
In 1666 Sir Isaac Newton discovered that **light passed through a prism splits into a continuous spectrum** of colour.

Many image applications **use electromagnetic radiation** that is far outside the visual spectrum – x-ray images, infra-red images etc.

Light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye.

The electromagnetic spectrum is split up according to the wavelengths of different forms of energy.

Electromagnetic Spectrum



The colours that we perceive are determined by the nature of the light reflected from an object

For example, if white light is shone onto a green object most wavelengths are absorbed, while green light is reflected from the object

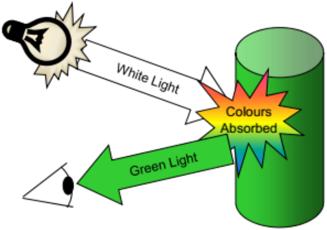


Image Formation

Amplitude values:

$$f(x,y) = i(x,y)*r(x,y)+n(x,y)$$

$0<f(x,y)<\infty$	Intensity – proportional to energy radiated by a physical source
$0<i(x,y)<\infty$	**illumination**
$0<r(x,y)<1$	**reflectance**
$n(x,y)$	**noise**

Image Generation

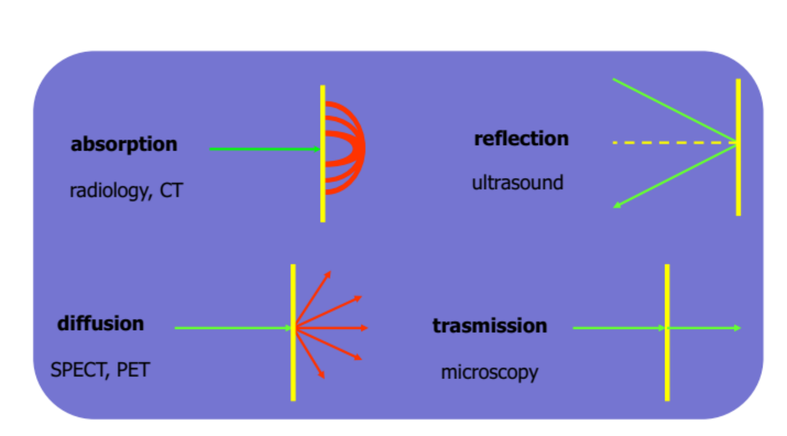


Image Quantisation And Resolution

In the following slides we will consider what is involved in capturing a digital image of a real-world scene:

1. **Image sensing and representation**
2. **Sampling and quantisation**
3. **Resolution**

Image Representation

Before we discuss image acquisition recall that a digital image is composed of M rows and N columns of pixels each storing a value.

Pixel values are most often grey levels in the range 0-255(black-white).

We will see later on that images can easily be represented as matrices

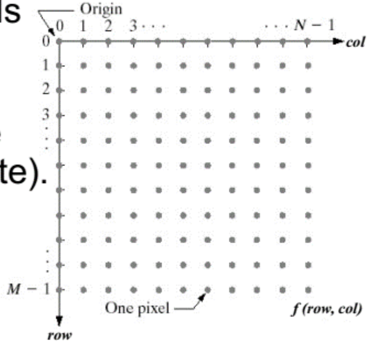
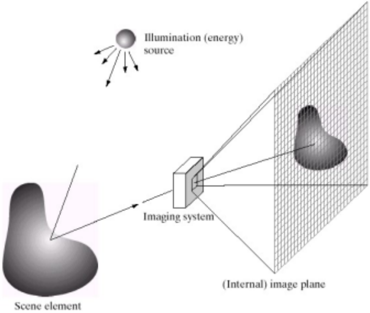


Image Acquisition

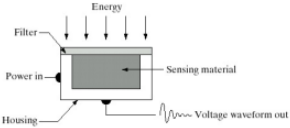
Images are typically generated by *illuminating* a *scene* and absorbing the energy reflected by the objects in that scene



– Typical notions of illumination and scene can be way off:
  - X-rays of a skeleton
  - Ultrasound of an unborn baby
  - Electro-microscopic images of molecules

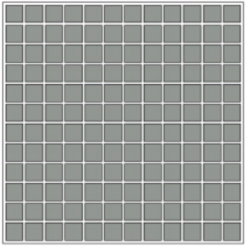
Incoming energy lands on a sensor material responsive to that type of energy and this generates a voltage

Collections of sensors are arranged to capture images



Imaging Sensor

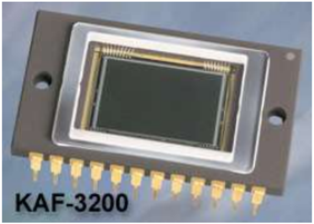
Line of Image Sensors



Array of Image Sensors

Image Sensing

Charge-Coupled Device (CCD)



CCD KAF-3200E from Kodak.
(2184 x 1472 pixels,
Pixel size 6.8 **microns²**)
(1 micron= 10^{-6}m)

- Used to convert a continuous image into a digital image
- Contains an array of light sensors
- Converts photon into electric charges accumulated in each sensor unit

E = h * f

Plank's Constant h = 6.62606957 × 10^{-34}

Image Sampling and Quantisation

A digital sensor can only measure a limited number of **samples** at a **discrete** set of energy levels

Sampling & Quantisation are the processes of converting a continuous **analogue** signal into a digital representation of this signal

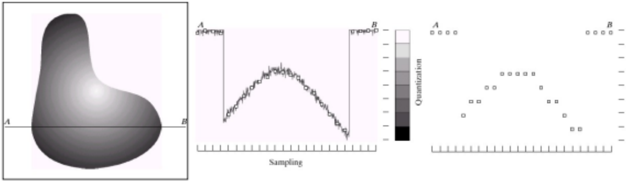


Image Sampling and Quantisation

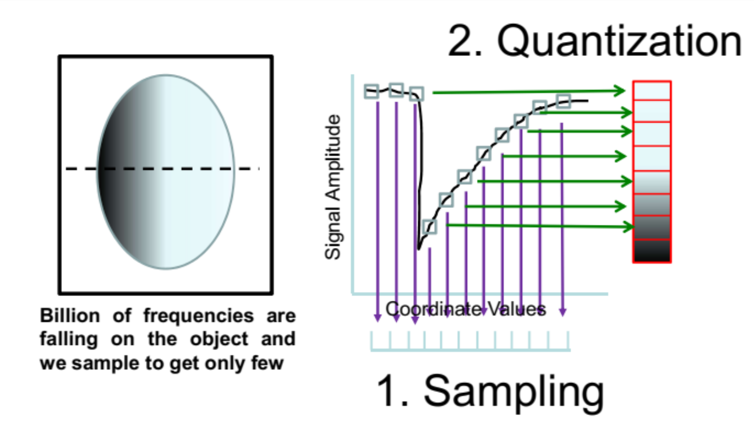


Image Sampling and Quantisation

An image may be continuous with respect to the x- and y-coordinates, and also in amplitude. To convert it to digital form, we have to sample the function in both coordinates and in amplitude. Digitizing the coordinate values is called ***sampling***. Digitizing the amplitude values is called ***quantization***.

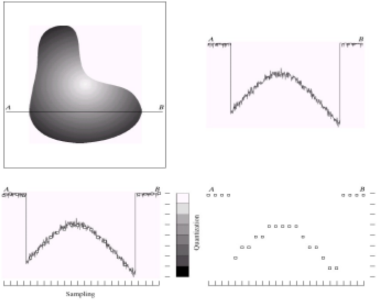


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Image Sampling and Quantisation

Remember that a digital image is always only an **approximation** of a real world scene

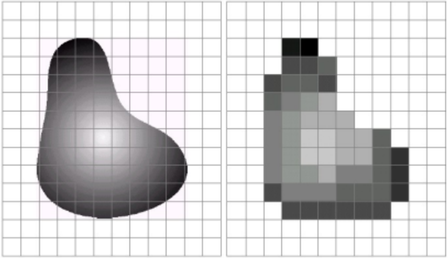
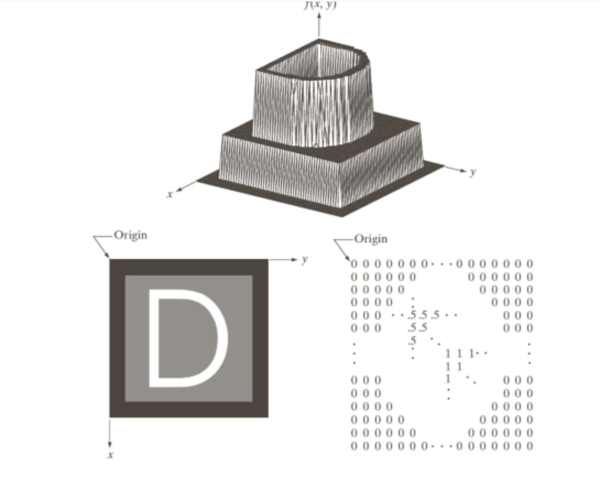


Image Representation



Spatial Resolution

The ***spatial resolution*** of an image is determined by how sampling was carried out.

Spatial resolution simply refers to the smallest discernable detail in an image

- Vision specialists will often talk about pixel size
- Graphic designers will talk about *dots per inch* (DPI)

Spatial Resolution

Spatial Resolution

Resolution:
1024x1024

Spatial Resolution

Resolution:
128x128

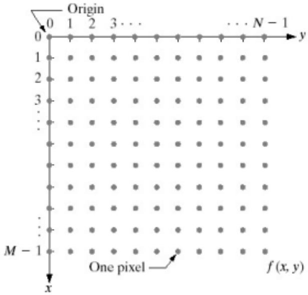
Spatial Resolution

Resolution:
32x32

<u>Intensity level resolution</u> refers to the number of intensity levels used to represent the image

- The more intensity levels used, the **finer the level of detail discernable** in an image
- Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

Number of Bits	Number of Intensity Levels	Examples
1	2	0, 1
2	4	00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	1010101010101010



Digital image

M $\times$ ***N*** array

\# bits to store : ***b* = *M*** $\times$ ***N*** $\times$ ***k bits***

L discrete intensities – power of 2

L* = 2*ᵏ

Integers in the interval [**0, *L* - 1**]

Dynamic range is the range of tonal difference between the lightest and darkest light of an image.

If low: image has a dull, washed-out gray look.

Contrast: difference between highest and lowest intensity

If high: Images are visually appealing.

Image Representation

The histogram of an image shows us the distribution of grey levels in the image

Massively useful in image processing, especially in segmentation

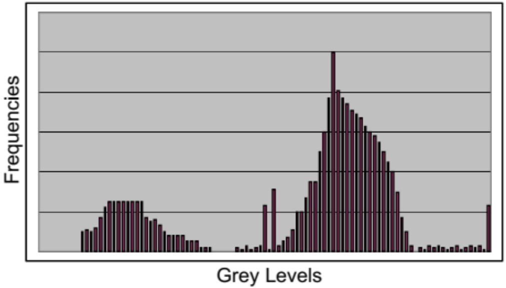


Image Representation

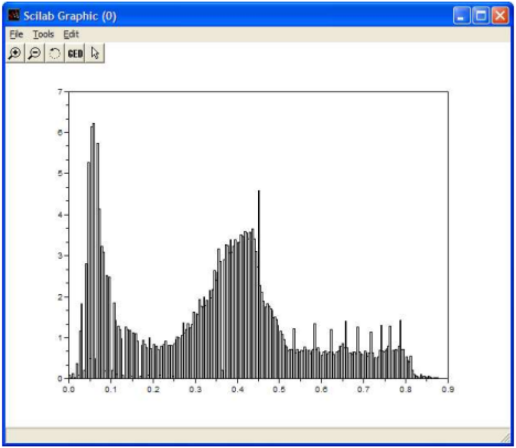
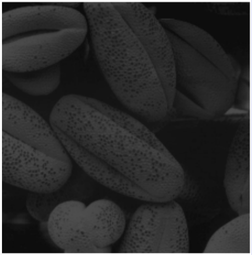


Image Representation



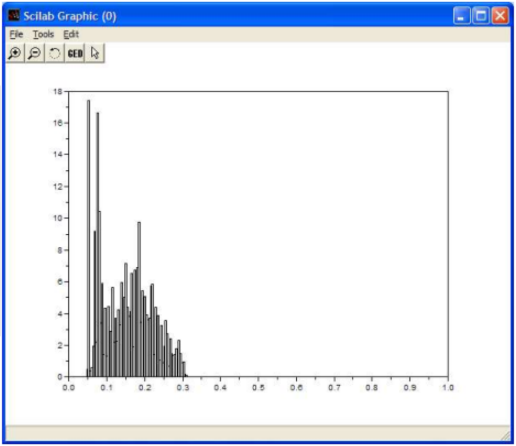
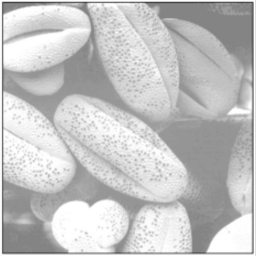


Image Representation



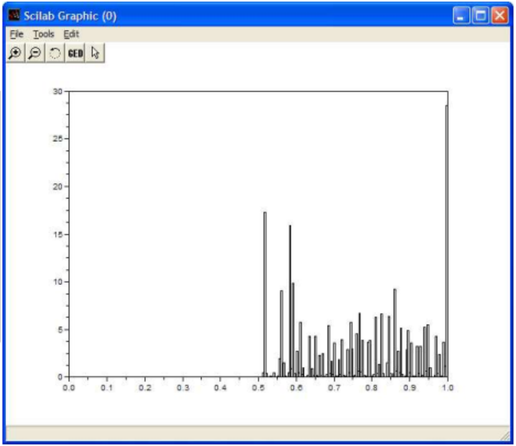


Image Representation

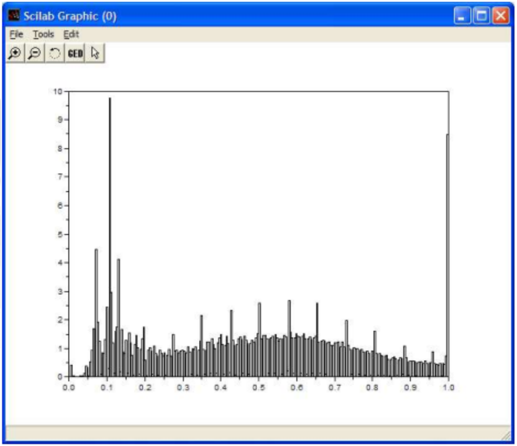


Image Representation

A selection of images and their histograms

Notice the relationships between the images and their histograms

Note that the **high contrast image** has the most **evenly spaced histogram**

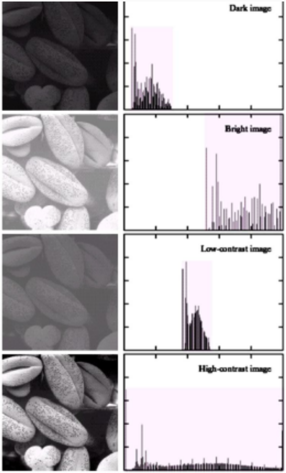
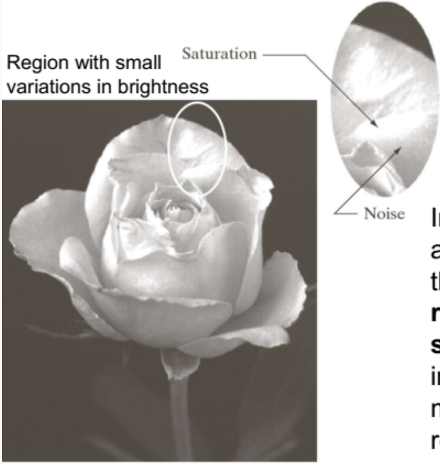


Image Representation



Noise is an unwanted signal that exists in electronic systems

In imaging, **saturation** is a type of distortion where the **recorded image (or region) is limited to some maximum value**, interfering with the measurement of bright regions of the scene.

Brightness and Contrast

Brightness is a relative term. It depends on your visual perception. Brightness comes into picture when we try to compare with a reference.

Contrast is the **variation in intensity levels** of an image. When the **Dynamic range** of an image **covers all available range** of the imaging system then the image exhibits **high contrast**.

$$Brightness(B) = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1} f(i,j)$$

$$Contrast = \sqrt{\frac{1}{MN}(f(i,j) - B)^2}$$

Entropy

Entropy is a measure of the amount of disorder or randomness in a system.

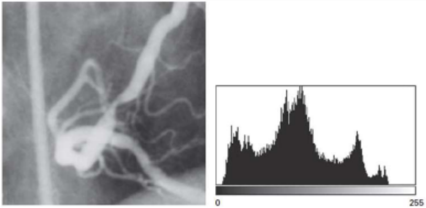
For images entropy measures the average global information content of the image in bits per pixel.

In information theory the **information content** of a single message state in units of information is given by:

$$I(E) = \log(1/P(E)) = -\log P(E)$$

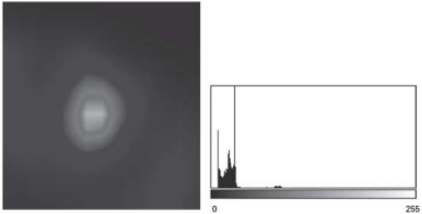
Where $P(E)$ is the prior probability of the occurrence of a message and $I(E)$ is the amount of information in the message.

Entropy Example



(i)

High Contrast and High Entropy



(ii)

Low Contrast and Low Entropy

Resolution is how much enough?

The picture on the right is fine for counting the number of cars, but not for reading the number plate

Intensity Level 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.)

Huang Experiment [1965] attempt to quantify experimentally the effects on image quality produced by varying *N* and *k* simultaneously.

Intensity Level Resolution

Isopreference curves tend to become more vertical as the detail in the image increase.

As the detail in the image decrease the perceived quality remained the same in some intervals in which the spatial resolution was increased, but the number of gray levels actually decreased.

A possible explanation is that a decrease in *k* tends to increase the apparent *contrast* of an image, a visual effect that human often perceive as improved quality in an image.