Chapter II

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Chapter 2: Imaging Fundamentals

- **Human visual system**
  - For efficient design of imaging systems it is beneficial to have understanding of the mechanism of human vision.
  - Such knowledge can be utilized to develop conceptual models of the human visual process.
  - Models are vital in the construction of measures of image fidelity and intelligibility.

- **Color representation**
  - Understanding of color perception is fundamental to develop image acquisition and display systems.
  - Adequate color spaces in which distances model color mismatches.
Light: Radiant energy which, by its action on the organs of vision, enables them to perform their function of sight

**Observed light**

- **Fundamental limit:**
  - To see an object the EM wavelength must be no bigger than the object
  - To image molecules far ultraviolet or soft x-ray waves must be used
Light Perception (I)

Refraction

Three common perceptual descriptors of light:
- Brightness
- Hue
- Saturation
Light Perception (II)

Perceptual representation of light: Munsell system
Eye Physiology

- Enclosing membranes
  - Outer-cornea, sclera

- Iris opening (2-8mm)

- Retina light receptors
  - Cones in fovea
    - 6-7 millions
    - Color sensitive
    - Photopic (bright-light) vision
  - Rods
    - 75-150 million
    - Not color sensitive
    - Scotopic (low-light) vision
Human Visual System

- Light entering the eye is refracted as it passes through the cornea and passes through the pupil (controlled by the iris).
- It is then refracted by the lens and cornea acting together as a compound lens to project an inverted image onto the retina.
The retina is a light-sensitive tissue lining the inner surface of the eye.

Events trigger nerve impulses that are sent to centers of the brain through the fibers of the optic nerve.

Retina is a layered structure of neurons interconnected by synapses. Neurons that are sensitive to light are the photoreceptor cells. These are of two types: the rods and cones.
Fovea

- Size: approximately 1.5mm × 1.5mm
- Cone density: approximately 150,000 elements per mm²
The photoreceptor mosaic on the retina

(a) In the fovea, the cones are densely packed on a hexagonal sampling array. (b) In the periphery, their size and separation grows, and rods fill in the spaces. Each image shows an area of $35 \times 25 \mu m^2$. ©1990 John Wiley & Sons.
Point spread function of the human eye as a function of visual angle
Variation of the modulation transfer function of a human eye model with wavelength. (cpd) cycles per degree
Sinusoidal grating with contrast of $C_M = 0.6$ and its luminance profile.

$$C_M = \frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}} + L_{\text{min}}}$$
Approximations of achromatic and chromatic contrast sensitivity functions.
Brightness of a uniform disk varied sinusoidally at a particular frequency until the changes in intensity could just be seen.
Rod cells respond to a single photon of light (100 times more sensitive than cones). Rods are cylindrical shape and are concentrated at the outer edges of the retina providing peripheral vision.

Rod cells are almost entirely responsible for night vision (scotopic vision).

Multiple rod cells converge on a single interneuron (amplifies but decreases resolution).

Cone cells require tens to hundreds of photons to become activated.
Convergence of rod cells tends to make peripheral vision very sensitive to movement.

Rods are most sensitive to wavelengths around 498 nm (green-blue). As intensity dims at twilight, the rods take over, and before color disappears completely, peak sensitivity of vision shifts towards the rods’ peak sensitivity (blue-green).
Cone cells are responsible for color vision. Function best in bright light.
Cone cells are densely packed in the fovea, but gradually become sparser towards the periphery of the retina.
About 4.5 million cone cells and 90 million rod cells in the human retina.
Cones perceive finer detail and more rapid changes in images, because their response times to stimuli are faster than those of rods.
Humans have three kinds of cones. With peak wavelengths near 564-580 nm, 534-545 nm, and 420-440 nm.

Cone cells are shorter than rods, but wider and tapered, and are much less numerous than rods, but greatly outnumber rods in the fovea.
Color Blindness

Normal

Deuteranomaly

Protanomaly

Tritanomaly
Visual Phenomena

Brightness adaptation and discrimination

- Light sensitivity range: $10^{10}$
- Subjective (perceived) brightness is logarithmic
- Entire range cannot be perceived simultaneously
  - Brightness adaptation
- Photopic (cone) range is greater than scotopic (rod) range
Brightness perception is not strictly a function of intensity.
The visual system introduces under shoot and over shoot at boundaries.
Mach Band Effect

Vertical lines are an illusion created by nonlinear response of the visual system to spatial frequency.
Simultaneous Contrast

The perceived brightness depends on the background

**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.
FIGURE 2.9 Some well-known optical illusions.
Visual Perception

Although both the blue area and white area are in our visual field, we cannot see figure and ground simultaneously.
Look at this arrangement and try to separate the figure from ground.
Again if you do not know what you are looking for the task is difficult.
Illusion. Where is the dot located?
The background in an image cannot be discovered from the foreground.

Question: Are the red horizontal lines parallel or bowed outward?
Change the background and you change the foreground. Now the red lines look bowed inward.
Subjective contours are related to the idea of closure.
Retina: Cons (Color) and Rods (Movement, Low brightness)

“GRAIN” of the human retina is made up of cones and rods (dots at far right). Semicircle indicates fovea.
Are the two small rings the same physical color.
The color in the red and blue bars changes as dark and light patterns are superimposed.
Simultaneous contrast
The color patches used in the upper image are exactly the same as those used in the lower image. The only difference is their arrangement.
THE PUPIL OF THE EYE EXPANDS AS MUCH AS 45 PERCENT WHEN A PERSON LOOKS AT SOMETHING PLEASING.
electric motor
Design: H.J. Verwaal - exio - the Netherlands
The rotor seems to rotate clockwise
As your vision moves back and forth the center area seems to be moving toward the center (contracting).