Visual Perception

- **Cornea** – outer cover at front of eye
- **Iris** – opening varies in diameter to control amount of light entering eye; contains pigment
- **Pupil** – opening in iris
- **Lens** – focus an image on the retina
- **Retina** – innermost membrane; contains rods and cones

**Example**

- **Blind spot** – connection point of optic nerve
- **Fovea** – indentation 1.5 mm in diameter; highest density of cones
- **Focal length** varies from 17 mm (far vision) to 14 mm (near vision)

**Visual Perception**

- **Cones**
  - **Photopic vision** – bright light vision
  - Located mostly in fovea
  - 6-7 million
  - **Color vision**
  - **Detail vision**
- **Rods**
  - **Scotopic vision** – dim light vision
  - Distributed throughout retina
  - 75-150 million
  - **Lower resolution**
  - **Gray scale vision**

**Range of light intensity that can be perceived** approx. $10^{10}$

- **Subjective brightness** is a log function of light intensity
- Cannot perceive entire range of intensities simultaneously
- **Brightness adaptation** – see figure 2.4, page 38
- **Weber ratio**
Visual Perception

- 12-24 intensity levels can be perceived simultaneously
- Neurons in the retina do intensity differencing:
  - Mach bands – see page 41
  - Simultaneous contrast – see page 41

Light and the EM Spectrum

- Visible light wavelength
  - Energy of one photon
  - In general, more energetic processes produce more energetic, higher frequency, shorter wavelength photons
  - Wavelength must be equal to or smaller than dimensions of object observed

Light and the EM Spectrum

- Perceived color is based on reflected light
- Achromatic, monochromatic, gray level
  - White light; no color
  - Has only intensity
- Three terms
  - Radiance – total energy from light source, measured in watts (W)
  - Luminance – amount of energy perceived by observer, measured in lumens (lm)
  - Brightness – subjective measure of light

Image Acquisition

- Single sensors
- Sensor strips
- Sensor arrays
- Illumination
- Reflectance
- Transmissivity
Sampling and Quantization

- **Sampling** – digitizing coordinate values
- **Quantization** – digitizing amplitude values
- Two ways to diagram sampling:

Matrix Notation

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

- See pages 57-60 for examples
- False contouring – perceived lines in smoothly shaded areas due to gray level quantization
- Most visual information is in the edges
- Images with much detail and many edges need fewer gray levels

Aliasing

- Shannon sampling theorem:

Zooming and Shrinking

- Integer factor – fast method
  - Shrink by 2 – delete every other row and column
  - Zoom by 2 – replicate every row and column
- Integer factor – somewhat better method
  - Shrink by 2
    - Blur image to prevent aliasing
    - Delete every other row and column
  - Zoom by 2
    - Double number of rows by linearly interpolating (averaging) between adjacent rows
    - Double number of columns by linearly interpolating (averaging) between adjacent columns

Zooming and Shrinking

- Non-integer zooming and shrinking
  - Determine new pixel locations
  - Assign gray levels at new locations
- Interpolation methods
  - Nearest neighbor
  - Bilinear interpolation
  - See page 65
### Pixel Relationships

- **4-neighbors**
- **Diagonal neighbors**
- **8-neighbors**

### Adjacency

- \(p\) and \(q\) are **4-adjacent** if both have values in \(V\) and \(p \in N_4(q)\)
- \(p\) and \(q\) are **8-adjacent** if both have values in \(V\) and \(p \in N_8(q)\)
- \(p\) and \(q\) are **\(m\)-adjacent** (mixed adjacency) if both have values in \(V\) and
  - \(p \in N_4(q)\), or
  - \(p \in N_8(q)\) and \(N(p) \cap N_4(q)\) has no pixels with values in \(V\)

### Paths and Sets

- A **path** from \((x, y)\) to \((s, t)\) is a sequence of pixels \((x, y) = (x_0, y_0), (x_1, y_1), \ldots, (x_n, y_n) = (s, t)\) where \((x_i, y_i)\) and \((x_{i+1}, y_{i+1})\) are adjacent
- If \((x_0, y_0) = (x_n, y_n)\) then the path is a **closed path**
- Let \(S\) be any subset of pixels; \(p \in S\) and \(q \in S\) are **connected** in \(S\) if there exists a path between \(p\) and \(q\) in \(S\)
- For any \(p \in S\), the set of pixels that are connected to \(p\) in \(S\) is a **connected component** of \(S\)
- If \(S\) has only one component, then \(S\) is a **connected set**

### Regions and Boundaries

- A set of pixels, \(R\), is a **region** if it is a connected set
- The **boundary** of \(R\) is the set of pixels adjacent to pixels not in \(R\)
  - Include pixels along perimeter of image as necessary to complete the boundary
- A boundary is always a closed path
  - A **global phenomenon**
- An **edge** is a gray level discontinuity
  - A **local phenomenon**
  - Need not be a closed path
Distance Measures

- D is a distance measure or metric if
  - \( D(p,q) \geq 0 \)
  - \( D(p,q) = 0 \) if and only if \( p = q \)
  - \( D(p,q) = D(q,p) \)
  - \( D(p,z) \leq D(p,q) + D(q,z) \)
- \( L_p \)-norm:
  \[
  ||x||_p = \left( \sum_n |x_n|^p \right)^{\frac{1}{p}}
  \]

Image Operations

- Arithmetic operations on two images

- Arithmetic operations on a scalar and an image

Distance Measures

- Euclidean distance (uses \( L_2 \)-norm)

- D4 distance (uses \( L_1 \)-norm)

- D8 distance (uses \( L_\infty \)-norm)

Linear Operations

- Let \( f \) and \( g \) be images, signals, vectors, functions, etc...
- Let \( a \) and \( b \) be scalars
- \( H \) is a linear operator if \( H(af + bg) = aH(f) + bH(g) \)