Light as Electromagnetic Wave.

$C(x, y, t, \lambda) = \text{energy density of electromagnetic wave.}$

- Location
- Time
- Wavelength

$C(\lambda)$

- Energy per (Area $\times$ Time $\times$ Wavelength)
- Joules/m$^2$/s

![Graph showing energy distribution with wavelength (\lambda) on the x-axis and intensity on the y-axis.](image-url)
Perceptual Domains: Brigham

 hue: red, green, blue

 color: [sunlight, windmill]

 very appropriate

 Physical Domain: cell d

 physical domain

 SCA?
Additive/subtractive color system

Additive: Two \( c_1(d) \) and \( c_2(d) \) combine.

\[ C(d) = c_1(d) + c_2(d) . \]

Additive system: Add light at different wavelengths to get a new color.
Ex additive sys → TV.

Red + Cyan → Green
Blue + Green → Cyan
Green + Yellow → White

3 primary colors → Red, Green, Blue
Subtractive Color cycle.
Spring colors of subtraction eye

cyan
green
yellow
blue
black
red
magenta
Human Visual System

Light → \text{Peripheral neural signal} → \text{Central level} → \text{Vision}

Central level → not well understood.
Peripheral level → Better understood.

1. Physiological studies
2. Psychophysical studies
One simple model for Reipheal level.

$H(r_x, r_y) \leq 1$

Fig 7.23 J. Lin

Freq. Respon. $H(r_x, r_y)$

\[ \text{JND} = \text{just noticeable difference} \]
\[ \frac{\Delta I}{I} \approx \text{constant} \]

\[ \frac{dI}{I} \approx \text{constant} = a (\log I) \]
Adaptation Experiment

\[ I \quad I+\Delta I \]

left  
right

I₀
Sensitivity to intensity is high if \( \frac{dI}{dI} \text{ is low} \). Near the level that the observer is adapted to.
Spatial Frequency Response

\[ I(x, y) = I_0(y) \cos(\omega(x)x) + \text{constant} \]

\text{constant} \rightarrow \text{ensure } I \text{ is always positive.}

plot \rightarrow 7.22.
Image Sensing Acquisition

All Maladies

Illumination source
- infrared
- X-ray
- radar
- visible light

Reflect in absorption or transmission

Plaques in plaque
Image formation

Characterized by 3 components:

(a) amount of source illumination incident on scene.

(b) amount that is reflected.

\[ f(x,y) = i(x,y) \cdot r(x,y) \]

Sensed imaging.

\[ 0 < i(x,y) < \infty \]

Sunny clear day 90,000 \( \text{lm/m}^2 \)
Clear evening 0.1 \( \text{lm/m}^2 \)
\( 0 < r(x,y) < 1 \)

- 0.01 black velvet
- 0.15 stainless steel
- 0.80 flat white wall
- 0.9 silver plated metal
- 0.95 snow
Empirical observations

Exploited in Image Processing System

1. Sharper image looks better.

2. Some noise in uniform background region is more visible than noise in text.

3. Same noise in dark areas are more noticeable than in bright area.

4. Same amount of noise hides a lot more than natural noise.

5. Jumps with unnatural aspects catch viewer's attention.
Figure 7.1 Spectral contents of the sun's radiation, above the earth's atmosphere (solid line) and on the ground at noon in Washington (dotted line). After [Hardy].
Figure 7.2 Different types of electromagnetic waves as a function of the wavelength $\lambda$. 
Figure 7.3 C.I.E. relative luminous efficiency function. After [Hardy].
Figure 7.4 White light split into a succession of monochromatic lights by a prism.
Figure 7.5 Primary colors of the additive color system.
Figure 7.6 Primary colors of the subtractive color system.
Figure 7.7 Example of spectral characteristics of red, green, and blue color sensors.
Figure 7.8 Red, green, and blue components of a color image. (a) Red component; (b) green component; (c) blue component; (d) color image of $512 \times 512$ pixels.
Figure 7.9  $Y$, $I$, and $Q$ components of the color image in Figure 7.8(d). (a) $Y$ component; (b) $I$ component; (c) $Q$ component.
Figure 7.10 Horizontal cross section of a right human eye, seen from above.
Figure 7.11 Distribution of rods (dotted line) and cones (solid line) on the retina. After [Pirenne].
Figure 7.12 Layers in the retina. Note that light has to travel through several layers before it reaches light-sensitive cells.
Figure 7.13 Path that neural signals travel from the retina to the visual cortex.
Figure 7.14 Human visual system as a cascade of two systems. The first system represents the peripheral level of the visual system and converts light to neural signals. The second system represents the central level and processes neural signals to extract necessary information.
Figure 7.15 Simple model of peripheral level of human visual system.
Figure 7.16 Two stimuli used in an intensity discrimination experiment. Each trial consists of showing one of the two stimuli to an observer and asking the observer to make a forced choice of which between $I_{in}$ and $I_{out}$ appears brighter. The stimulus used in a trial is chosen randomly from the two stimuli. Results of this experiment can be used to measure the just noticeable difference $\Delta I$ as a function of $I$. 
Figure 7.17 Plot of $\Delta I/I$ as a function of $I$. Incremental intensity $\Delta I$ is the just noticeable difference. Over a wide range of $I$, $\Delta I/I$ is approximately constant. This relationship is called Weber's law.
Figure 7.18 Image of $512 \times 512$ pixels degraded by zero-mean white noise with a uniform probability density function. Same level of noise is more visible in a dark region relative to a bright region. Same level of noise is more visible in a uniform background region than in a region with edges.
Figure 7.19  Two stimuli used in studying the effect of adaptation on the intensity sensitivity. Each trial consists of showing one of the two stimuli to an observer and asking the observer to make a forced choice of which between $I_R$ or $I_L$ appears brighter. The stimulus used in a trial is chosen randomly from the two stimuli. Results of this experiment can be used to measure the just noticeable difference $\Delta I$ as a function of $I$ and $I_0$. 
Figure 7.20  Plot of $\Delta I/I$ as a function of $I$ and $I_0$. When $I_0$ equals $I$, $\Delta I/I$ is the same as that in Figure 7.17 (dotted line in this figure). When $I_0$ is different from $I$, $\Delta I/I$ increases relative to the case $I_0 = I$. This means that the observer's sensitivity to intensity decreases.
Figure 7.21 Illustration of Mach band effect.
Figure 7.22  Modulated sinewave grating that illustrates the bandpass character of the peripheral level of the human visual system.
Figure 7.23 Frequency response $H(\Omega_x, \Omega_y)$ in the model in Figure 7.15. After [Davidson].