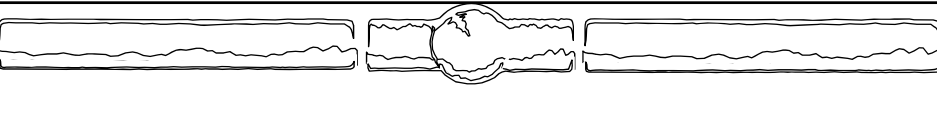


PRINCIPLES OF PHOTOGRAPHY AND IMAGING

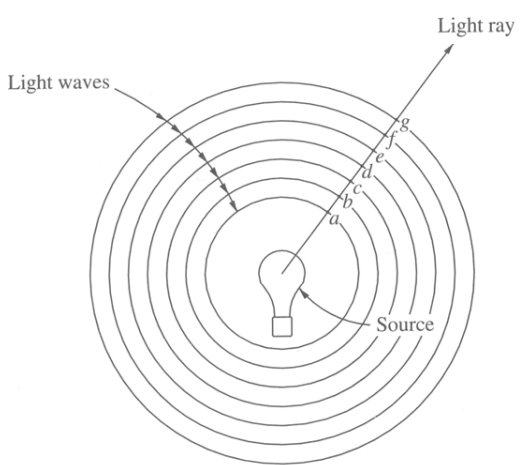
Center for Photogrammetric Training
Ferris State University

RCB




LIGHT

- ❖ Travels through medium in series of electromagnetic waves from a point

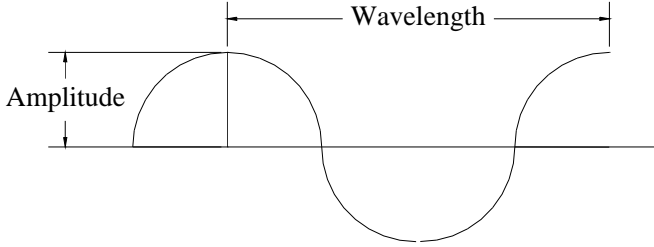


The diagram illustrates the propagation of light from a central point source. Concentric circles represent the wavefronts, labeled as 'Light waves'. A straight line with an arrow pointing away from the source is labeled 'Light ray'. The source is depicted as a light bulb and labeled 'Source'. Points 'a' through 'j' are marked along the path of the light ray, showing its intersection with the wavefronts.




LIGHT

- ❖ Frequency – No. waves passing given point in set time
- ❖ Amplitude – height of crest or depth of trough
- ❖ Wavelength – distance between 2 succeeding waves



The diagram shows a sine wave on a horizontal axis. A vertical line is drawn from the horizontal axis to the first crest. A horizontal line with arrows at both ends is drawn from the top of this vertical line to the top of the next crest. This horizontal line is labeled 'Wavelength'. A vertical line with arrows at both ends is drawn from the horizontal axis to the top of the first crest. This vertical line is labeled 'Amplitude'.



LIGHT


- ❖ Velocity

$$V = f \lambda$$

- ❖ f = frequency, cycles/second or hertz
- ❖ λ = wavelength, meters
- ❖ About 299,792,460 m/s in vacuum

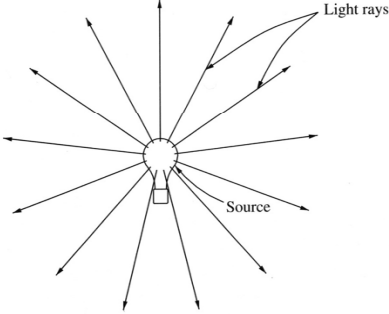
- ❖ Velocity varies –function of density of medium
- ❖ Refractive index:

$$n = \frac{c}{V}$$




LIGHT

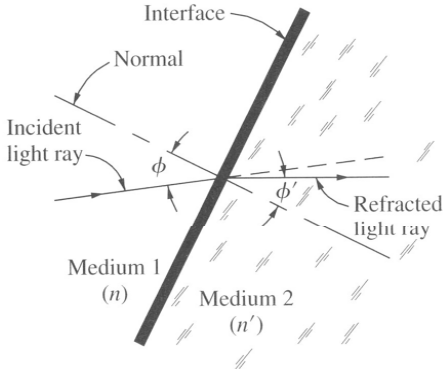
- ❖ Geometric optics
 - ❖ Travels through medium in straight lines
 - ❖ Light rays
 - ❖ Bundle of rays
 - ❖ entire group



The diagram shows a central point labeled 'Source' with a small square symbol below it. Multiple straight lines with arrows at their ends radiate outwards from this source, labeled 'Light rays'.



REFRACTION




The diagram illustrates the refraction of light at an interface between two media. A thick diagonal line represents the 'Interface'. A dashed line perpendicular to the interface is labeled 'Normal'. An 'Incident light ray' is shown in 'Medium 1 (n)' approaching the interface at an angle ϕ to the normal. A 'Refracted light ray' is shown in 'Medium 2 (n\'' bending towards the normal at an angle ϕ' .

Bending of light rays when passing from one medium to another with different refractive indices

Snell's law


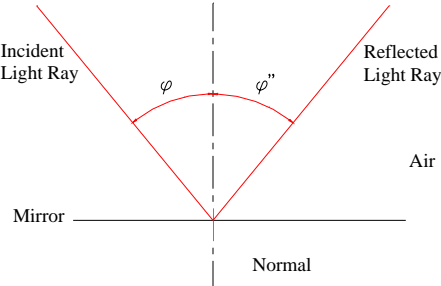
$$n \sin \phi = n' \sin \phi'$$

- ❖ ϕ - angle of incidence
- ❖ ϕ' - angle of refraction



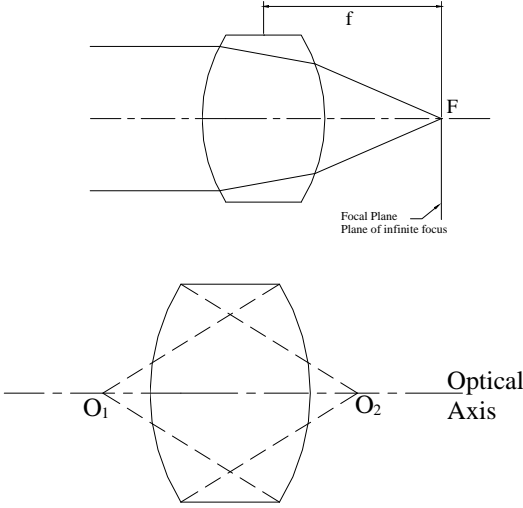
REFLECTION

- ❖ Changes direction of light ray
- ❖ Angle of reflection (ϕ'') equals angle of incidence (ϕ)
- ❖ Angles measured in common plane



LENSES

- ❖ Primary function – gather light rays from object space and bring them to focus in image plane
 - ❖ Employs principles of refraction
 - ❖ f – focal length
 - ❖ F – focal point of lens
- ❖ Optical axis
 - ❖ Line joining centers of curvature of spherical surfaces of lens



LENSES

- ❖ Example: Given the following
 - ❖ $n = 1.0003$ (air)
 - ❖ $n' = 1.52$ (glass)
 - ❖ $R = 5.00$ cm
 - ❖ Light ray parallel & 1.00 cm above optical axis
 - ❖ What is angle of incidence (ϕ) and angle of refraction (ϕ')?


LENSES

❖ Solution:

$$\sin \phi = \frac{1.00 \text{ cm}}{5.00 \text{ cm}} \Rightarrow \phi = 11.5^\circ$$

$$n \sin \phi = n' \sin \phi'$$

$$1.0003 \left(\frac{1.00 \text{ cm}}{5.00 \text{ cm}} \right) = 1.52 \sin \phi' \Rightarrow \phi' = 7.56^\circ$$



LENS FORMULA

❖ Relationship of object distance, o , and image distance, i , to focal length, f , of converging lens

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$


❖ Example: what is image distance for an object distance of 50.0 m and a focal length of 50.0 cm?

❖ Solution:

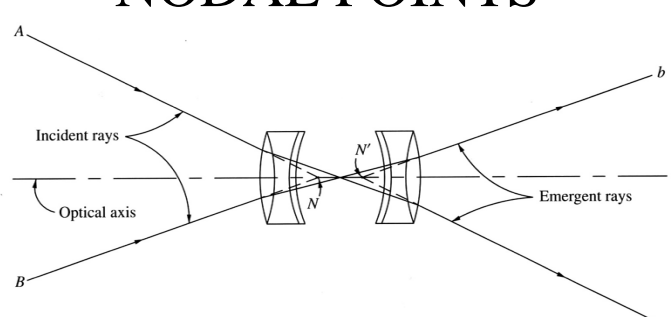
$$\frac{1}{50.0 \text{ m}} + \frac{1}{i} = \frac{1}{0.500 \text{ m}}$$

$$\frac{1}{i} = \frac{1}{0.500 \text{ m}} - \frac{1}{50.0 \text{ m}} = 2.00 - 0.0200 = 1.98$$


$i = 50.5 \text{ cm}$



NODAL POINTS





❖ Property: any ray directed towards incident nodal point passes through the lens and emerges on other side in a direction parallel to the original incident ray and directly away from the emergent nodal point




ABERRATIONS & DISTORTIONS

- ❖ Aberration
 - ❖ Degrades sharpness of image
 - ❖ Blurs image
 - ❖ Caused by faulty grinding of the lens
- ❖ Lens distortion
 - ❖ Degrades geometric quality (positional accuracy)
 - ❖ Symmetric radial – distorts along radial lines from optical axis
 - ❖ Caused by faulty grinding of lens
 - ❖ Outward +, inward –
 - ❖ Decentering – tangential & asymmetric radial components
 - ❖ Causes off-center distortion pattern
 - ❖ Caused by faulty alignment of individual lens elements





RESOLUTION & DEPTH OF FIELD

- ❖ Resolution (resolving power)
 - ❖ Ability of lens to show detail
 - ❖ Line pairs or modulation transfer function
 - ❖ Good resolution important
 - ❖ Sharp & clear for precise measurements & accurate interpretative work
- ❖ Depth of Field
 - ❖ Range in object distance accommodated by lens without introducing significant image deterioration
 - ❖ Can be increased by reducing aperture
 - ❖ Shorter focal length – greater depth of field



VIGNETTING

- ❖ Also called falloff
- ❖ Causes resultant images to appear brighter in center than around edges
- ❖ Compensate by
 - ❖ Lens design
 - ❖ Use of antivignetting filter
 - ❖ Lighting adjustment in printing process



ILLUMINANCE

- ❖ Brightness or amount of light received per unit area
- ❖ Meter-candle (1m·cd) – illumination of standard candle at 1 meter
- ❖ Proportional to amount of light passing through lens opening during exposure
 - ❖ Proportional to area of opening
 - ❖ Area of opening is $(\pi d^2)/4$ -- illuminance proportional to d^2 , the square of diameter of opening

AFFECTS OF IMAGE DISTANCE ON ILLUMINANCE


- ❖ Adheres to inverse square law
 - ❖ Amount of illumination inversely proportional to square of distance from aperture
 - ❖ At center of photo, illuminance proportional to $1/i^2$
 - ❖ As distance increases from center, distance from aperture likewise increases
 - ❖ Causes decreased illuminance
- ❖ One aspect of falloff



BRIGHTNESS FACTOR


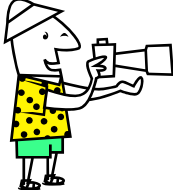
- ❖ Normally, object distances long so $1/o \Rightarrow 0$
 - ❖ Then $i = f$ and at center, illuminance proportional to $1/f^2$ and the 2 qualities may be combined so that illuminance is proportional to d^2/f^2
 - ❖ Square root called brightness factor

$$\sqrt{\frac{d^2}{f^2}} = \frac{d}{f} = \text{brightness factor}$$




f-STOP

- ❖ Inverse of brightness factor – $f\text{-stop} = f/d$
- ❖ Ratio of focal length to diameter of aperture
 - ❖ Aperture increase – f-stop number decreases and illuminance increases, requiring less exposure time
 - ❖ Used of expressing lens speed or “light gathering” power of lens



APERTURE-SHUTTER RELATIONSHIP

<ul style="list-style-type: none">❖ Exposure time set by shutter speed❖ Illuminance regulated by varying f-stop<ul style="list-style-type: none">❖ Controlled by diaphragm❖ Larger diaphragm opening<ul style="list-style-type: none">❖ Faster exposures❖ Less depth of field❖ Lens distortion more severe	<ul style="list-style-type: none">❖ Faster shutter speed<ul style="list-style-type: none">❖ Reduce image motion❖ Nominal f-stop settings<ul style="list-style-type: none">❖ 1, 1.4, 2.0, 2.8, 4.0, 5.6, 8.0, 11, 16, 22, 32❖ F-stop of 1 occurs when aperture diameter equals lens focal length❖ Each succeeding nominal f-stop halves aperture area of proceeding
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APERTURE-SHUTTER RELATIONSHIP

❖ Example: $d_1 = f$, where $d_1 =$ aperture diameter

$$\frac{f}{d_1} = 1 = f\text{-stop} \qquad A_1 = \frac{\pi d_1^2}{4}$$

❖ Aperture reduced to d_2

$$A_2 = \frac{A_1}{2} = \frac{\pi d_2^2}{4} = \frac{\pi d_1^2}{2(4)}$$

$$\therefore d_2 = \frac{d_1}{\sqrt{2}} \qquad \text{and} \qquad f\text{-stop} = \frac{f\sqrt{2}}{d_1} = 1\sqrt{2} = 1.4$$


APERTURE-SHUTTER RELATIONSHIP


Example (2-3 in text)

❖ Photographic film optimally exposed with f-stop of f-4 & shutter speed of 1/500 sec. What is correct f-stop if shutter speed changed to 1/1,000 sec?

Solution

❖ Total exposure is diaphragm area (A_i) times shutter speed (t_i)

$$A_1 t_1 = A_2 t_2 \qquad \Rightarrow \qquad A_2 = A_1 \left(\frac{t_1}{t_2} \right)$$



$A_1 = \frac{\pi d_1^2}{4}$
 $A_2 = \frac{\pi d_2^2}{4}$


$d_1 = \frac{f}{f\text{-stop}} = \frac{f}{4}$

**APERTURE-
SHUTTER
RELATIONSHIP
EXAMPLE**

(solution continued)

$$\frac{\pi d_2^2}{4} = \left[\frac{\pi f^2}{4(4^2)} \right] \left(\frac{1/500}{1/1000} \right) = \left[\frac{\pi f^2}{4(16)} \right] \left(\frac{1000}{500} \right)$$

$$\frac{f^2}{d_2^2} = \left[\frac{4(16)}{\pi} \right] \left(\frac{\pi}{4} \right) \left(\frac{500}{1000} \right)$$

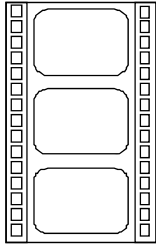
$$\frac{f}{d_2} = \sqrt{\frac{(16)(500)}{1000}} = 2.8 = f\text{-stop}$$



PHOTOGRAPHIC FILM

- ❖ 2 parts: emulsion & backing
- ❖ Emulsion contains light-sensitive silver halide crystals
 - ❖ When exposed to light, bond between silver & halide weaken
 - ❖ Emulsion has latent image
 - ❖ When latent image developed, areas of emulsion exposed to intense light turn to free silver & become black

Emulsion

Film Support






FILM DENSITY

- ❖ Degree of darkness of developed emulsion
- ❖ Greater density, darker the emulsion
- ❖ Found by comparing intensity of light upon film to that which pass through film (transmitted light)

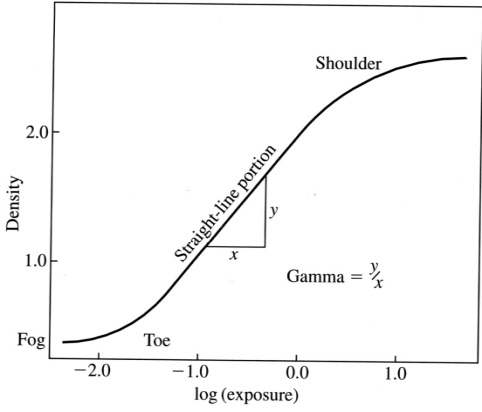
$$D = \log \left(\frac{\text{incident intensity}}{\text{transmitted intensity}} \right)$$

- ❖ Intensity of human eye non-linear \Rightarrow use base 10 logarithm so density nearly proportional to perceived brightness




CHARACTERISTIC CURVE

- ❖ D-log E curve or H- and D curve
- ❖ Plot of density versus logarithm of exposure
- ❖ Lower part, concave up
 - ❖ Toe region
- ❖ Upper part, concave down
 - ❖ Shoulder region
- ❖ Straight line in middle




The graph plots Density on the y-axis (ranging from 0 to 2.0) against log(exposure) on the x-axis (ranging from -2.0 to 1.0). The curve starts at a point labeled 'Fog' at approximately (-2.0, 0.2). It then rises through a 'Toe' region (concave up) to a 'Straight-line portion' (linear), and finally levels off in a 'Shoulder' region (concave down). A right-angled triangle is drawn on the straight-line portion with a horizontal side labeled 'x' and a vertical side labeled 'y'. The formula $\text{Gamma} = \frac{y}{x}$ is shown next to the triangle.



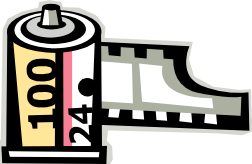
PHOTOGRAPHIC FILM

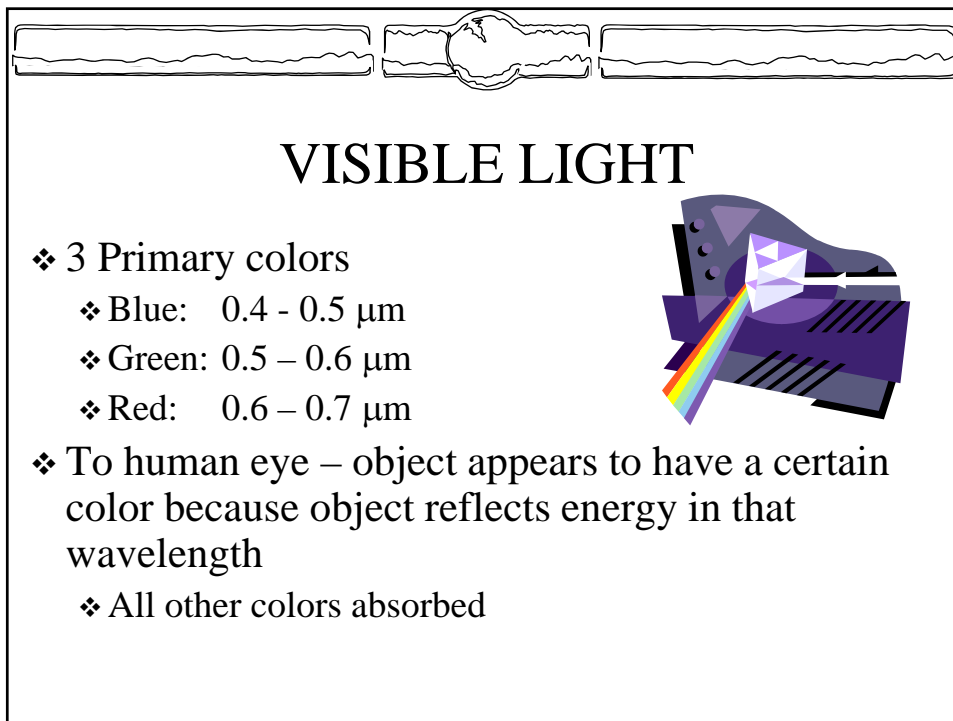
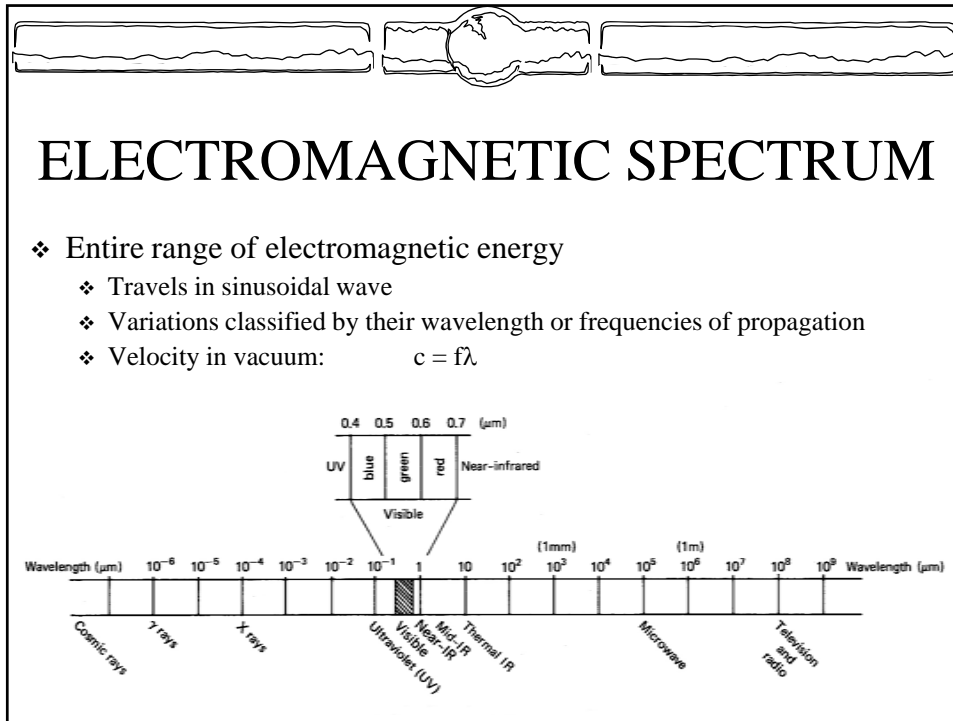
- ❖ As sensitivity & grain size increase, image becomes coarse & sharpness (resolution) reduced
- ❖ Sensitivity expressed as AFS (Aerial Film Speed)
 - ❖ Determined by point on characteristic curve where density is 0.3 unit above fog density
 - ❖ Different than ISO (International Standards Organization) number used to indicate film sensitivity or speed for regular photographic films




PHOTOGRAPHIC FILM

<ul style="list-style-type: none">❖ Negative<ul style="list-style-type: none">❖ Reversed tone and geometry from original scene❖ Positive<ul style="list-style-type: none">❖ Correct tone & geometry by using negative❖ Can use printing paper, plastic film, glass plate❖ Called diapositive in photogrammetry	<ul style="list-style-type: none">❖ Processing Black & White film<ol style="list-style-type: none">1. Developing2. Stop bath3. Fixing4. Washing5. Drying
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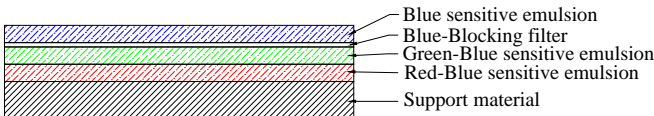
FILTERS

- ❖ Allow only certain wavelengths of energy through lens
 - ❖ Ex: haze filter blocks haze
 - ❖ Atmospheric haze \Rightarrow caused by scattering of ultraviolet and short blue wavelengths
- ❖ Protects lens
- ❖ Can be used to reduce vignetting effect




COLOR FILM

- ❖ Consists of 3 layers
- ❖ Blue-blocking filter prevents blue light from exposing bottom 2 layers
- ❖ Can be color negative or color reversal film

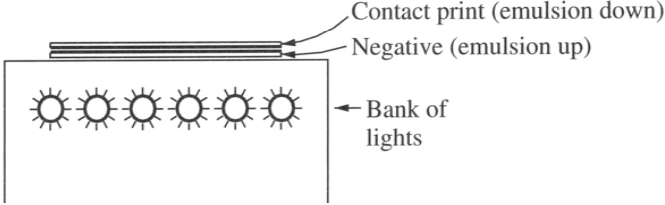


The diagram shows a cross-section of color film with five distinct layers. From top to bottom, they are: a blue-sensitive emulsion layer (blue hatching), a blue-blocking filter layer (green hatching), a green-blue sensitive emulsion layer (green hatching), a red-blue sensitive emulsion layer (red hatching), and a support material layer (diagonal hatching). Lines connect the labels to the corresponding layers.

- Blue sensitive emulsion
- Blue-Blocking filter
- Green-Blue sensitive emulsion
- Red-Blue sensitive emulsion
- Support material




CONTACT & PROJECTION PRINTING



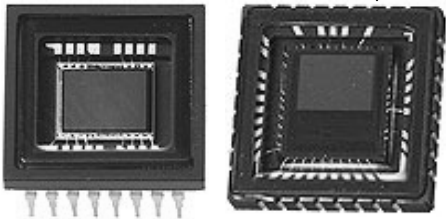
The diagram shows a contact print setup. A negative with its emulsion side up is placed on a surface. A contact print with its emulsion side down is placed on top of the negative. A bank of lights is positioned below the negative to illuminate it.

- ❖ Contact printing – direct process of making photo from negative
 - ❖ Dodging
- ❖ Projection printing – used to make positives at enlarged or reduced scale from aerial negative



CCD Versus CMOS

- ❖ CCD – Charge Coupled Device
- ❖ CMOS – Complementary Metal Oxide Semiconductor
- ❖ Both capture images digitally
- ❖ Both are pixilated metal oxide semiconductors
- ❖ Both accumulate signal charge in each pixel proportional to local illumination intensity



The image shows two square sensor chips. The left chip is a CCD sensor, and the right chip is a CMOS sensor. Arrows point from the text labels to their respective chips.

CCD Versus CMOS


❖ CCD transfers each pixel's charge packet sequentially to common output structure while CMOS does more on-chip before shipping it off-chip

CCD photon to electron conversion **CMOS**

charge to voltage conversion


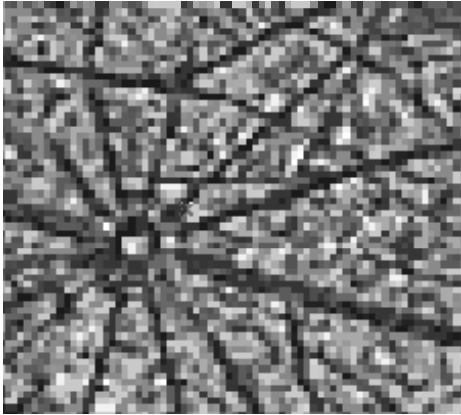
CCD Versus CMOS

- ❖ CCD are said to create higher quality and cleaner files than CMOS
- ❖ CMOS is power efficient compared to CCD Sensors.
- ❖ CMOS are cheaper to produce that's why most cameras use CMOS
- ❖ CCD technology is older and been optimized for better quality.
- ❖ CCD has advantage in Dynamic Range and Noise over the CMOS
- ❖ CMOS has the advantage over CCDs because all camera functions can be placed on the image sensor.
- ❖ CMOS has natural blooming immunity (Antiblooming, the ability to gracefully drain localized overexposure without compromising the rest of the image in the sensor) CCD requires engineering antiblooming also known as simple as over exposure
- ❖ Both image chip types are equally reliable in most consumer and industrial applications.
- ❖ CMOS image sensors are designed for a large, consumer or near-consumer application.
- ❖ CCD image sensors, on the other hand, are more general purpose.



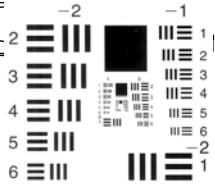
DIGITAL IMAGES


- ❖ Image divided into pixels
- ❖ Image consists of integers
 - ❖ Called digital numbers
- ❖ Numbers range from 0 – 255
 - ❖ 8-bit image = 1 byte
- ❖ Produced by discrete sampling



RESOLUTION


- ❖ Spatial (geometric)
 - ❖ Physical size of physical pixel
 - ❖ Smaller size – higher resolution
- ❖ Spectral
 - ❖ Number of bands image sensitive to
 - ❖ Higher level – more accurate representation of response
 - ❖ Affects amount of storage
- ❖ Radiometric
 - ❖ Quantization – conversion of amplitude of analog signal to number of discrete levels (digital image)
 - ❖ 8 bit quantization – 256 gray levels
 - ❖ 10 bits – 1024 gray levels
 - ❖ 12 bits – 4096 gray levels
 - ❖ Lower level quantization, large areas appears homogeneous & subtle tonal variations not detected






Newton Rings

- ❖ Interference pattern due to reflection of light between 2 surfaces that are not flat
- ❖ Appears as concentric, alternating light & dark rings centered at point of contact
- ❖ In scanning, caused by tiny air gap between 2 pieces of clear material



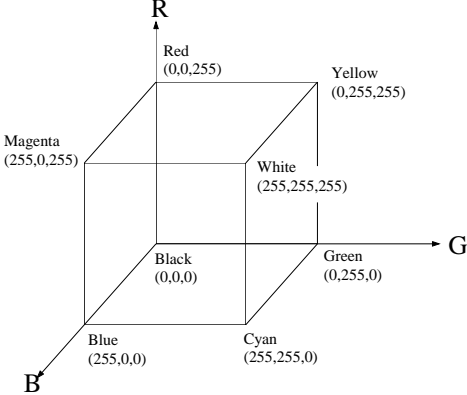


RESOLUTION

- ❖ Example (2-4)
 - ❖ 3,000 x 3,000 pixel image comprised of 3 spectral channels. Each pixel is 8-bits per channel. How many bytes of computing memory required? If transfer rate over computer network is 100,000 bytes/s, how long will it take to transfer image?
- ❖ Solution:
 - No. pixels = $(3,000)(3,000) = 9,000,000$ pixels
 - Bytes/pixel = $(3 \text{ channels})(1 \text{ byte}) = 3$ bytes
 - Image Size = $(9,000,000 \text{ pixels})(3 \text{ bytes/chan}) = 27,000,000$ bytes
 - Transferrate = $\frac{27,000,000 \text{ bytes}}{100,000 \text{ bytes/sec}} = 270 \text{ sec}$ or $4\frac{1}{2} \text{ min.}$

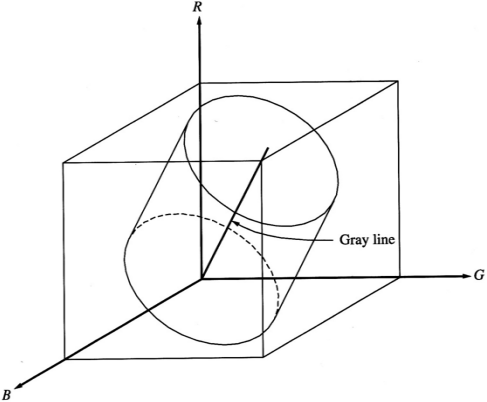
COLOR IMAGE REPRESENTATION


- ❖ RGB color cube
 - ❖ Color of pixel expressed as triplet containing blue, red, green values



COLOR IMAGE REPRESENTATION

- ❖ IHS (intensity-hue-saturation)
 - ❖ More understood by humans
 - ❖ Set of cylindrical coordinates
 - ❖ Axis of cylinder – gray line





RGB \Rightarrow IHS

- ❖ Intensity axis lined with red then rotate to gray line
- ❖ Standard Cartesian-to-cylindrical transformation
- ❖ Compute intermediate values


$$X = \frac{B - G}{\sqrt{2}} \quad Y = \frac{B + G - 2R}{\sqrt{6}}$$

- ❖ Compute intensity, hue, saturation

$$I = \frac{B + G + R}{\sqrt{3}}$$

$$H = \tan^{-1}\left(\frac{Y}{X}\right)$$

$$S = \sqrt{X^2 + Y^2}$$



IHS \Rightarrow RGB

- ❖ Process reversed
- ❖ Compute intermediate variables

$$X = S \cos H$$


$$Y = S \sin H$$


- ❖ Compute red, green, blue

$$B = \frac{X}{\sqrt{2}} + \frac{Y}{\sqrt{6}} + \frac{I}{\sqrt{3}}$$

$$G = -\frac{X}{\sqrt{2}} + \frac{Y}{\sqrt{6}} + \frac{I}{\sqrt{3}}$$

$$R = -\frac{2Y}{\sqrt{6}} + \frac{I}{\sqrt{3}}$$






IHS \leftrightarrow RGB


❖ Example (2.5): Convert B, G, R coordinates (165,57,105) to I, H, S values and back to B, G, R

❖ Solution: compute intermediate values

$$X = \frac{165 - 57}{\sqrt{2}} = 76.37$$

$$Y = \frac{165 + 57 - 2(105)}{\sqrt{6}} = 4.899$$



Compute intensity, hue, saturation



$$I = \frac{165 + 57 + 105}{\sqrt{3}} = 188.8$$

$$H = \tan^{-1}\left(\frac{4.899}{76.37}\right) = 3.670^\circ$$


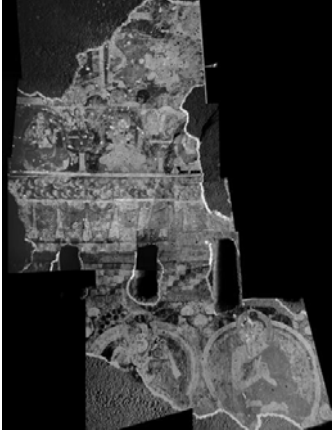
$$S = \sqrt{(76.37)^2 + (4.899)^2} = 76.52$$



Compute intermediate values


$$X = 76.52 \cos(3.670^\circ) = 76.36 \qquad Y = 76.52 \sin(3.670^\circ) = 4.899$$

Compute Blue, Green, Red values

$$B = \frac{76.36}{\sqrt{2}} + \frac{4.899}{\sqrt{6}} + \frac{188.8}{\sqrt{3}} = 165$$
$$G = -\frac{76.36}{\sqrt{2}} + \frac{4.899}{\sqrt{6}} + \frac{188.8}{\sqrt{3}} = 57$$
$$R = -\frac{2(4.899)}{\sqrt{6}} + \frac{188.8}{\sqrt{3}} = 105$$



















DIGITAL IMAGE PRINTING


- ❖ RGB system – color additive process
- ❖ Printing on paper different
 - ❖ Color subtraction process
 - ❖ Certain colors absorbed (subtracted) from white light
- ❖ Intensity difficult to control with current printer technology



DIGITAL IMAGE PRINTING


- ❖ Tonal variations – simulated by varying spatial density of various ink dots
 - ❖ One method: patterning
 - ❖ With 4 x 4 array – 17 different gray levels represented

					
0	1	2	3	4	5
					
6	7	8	9	10	11
					
12	13	14	15	16	



DIGITAL IMAGE PRINTING

- ❖ Example (2-6) A laser printer can print 600 dpi over an area of 8" x 10". Using a 4 x 4 output array, how many rows and columns can be printed? How many if a 6 x 6 output array is used?




DIGITAL IMAGE PRINTING

❖ **Solution**

❖ 4 x 4: No. of columns = $\frac{(600 \text{ dpi})(8")}{4} = 1200 \text{ columns}$
 No. of rows = $\frac{(600 \text{ dpi})(10")}{4} = 1500 \text{ rows}$

❖ 6 x 6: No. of columns = $\frac{(600 \text{ dpi})(8")}{6} = 800 \text{ columns}$
 No. of rows = $\frac{(600 \text{ dpi})(10")}{6} = 1000 \text{ rows}$



DIGITAL IMAGE PRINTING

❖ **Alternative approach – dithering & error diffusion**

- ❖ Output produced such that image pixel corresponds directly to single ink dot
- ❖ Image printed at same spatial resolution as output device
- ❖ Different radiometric levels - vary average densities of dots in localized areas corresponding to local brightness value
- ❖ Subtle loss in radiometric resolution

RCB