Color and Shading

Shapiro and Stockman, Chapter 6

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Color

- Color is an important factor for for human perception for object and material identification, even time of day.
- Color perception depends upon both the physics of the light and complex processing by the eye-brain which integrates properties of the stimulus with experience.

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Color and Perception

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Color and Machine Vision

- With the advent of inexpensive color imagery and processing, color information can be used effectively for machine vision.
- Color provides multiple information per pixel, often enabling complex classification.

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Color and Shading

- Shading plays an important role in the perception of color information.
- The shading of an object depends not just on the color of the object and the light illuminating the object but also other factors such as roughness of surface, the angle of light hitting the surface, the distance of the surface from the light and the viewer.

Physics of Color

- Some facts
  - Sensation of color is perceived between 400 and 700 nanometers (10^{-9} meters, also referred to as millimicrons).
  - For blue light, 400×10^{-9} meters per wave means 2.5×10^{6} waves per meter or 25,000 waves per cm.
  - Vision devices can detect greater ranges of wavelengths than humans. (X-Ray, IR for eg.)

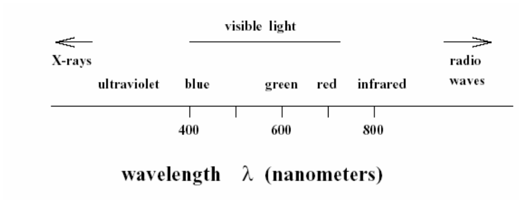
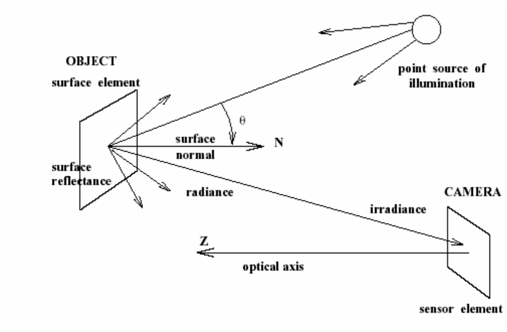


Figure 6.2: Visible part of the electromagnetic spectrum.

Sensing

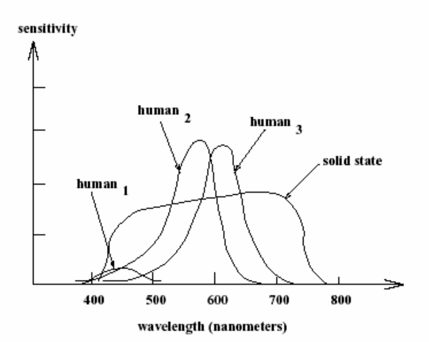


Perception of Color

- Perception of Color depends on three factors:
  - The spectrum of energy in various wavelengths illuminating the object surface,
  - The spectral reflectance of the object surface, which determines how the surface changes the received spectrum into the radiated spectrum,
  - The spectral sensitivity of the sensor irradiated by the object's surface.

- For example – An object that is *blue* has surface material that appears blue when illuminated by *white light*. (White light is composed of approximately equal energy in all wavelengths of the visible spectrum).
- The same object will appear violet if illuminated by red light.
- A blue object under intense white light (like sunlight) will become hot and radiate energy in the IR range, which cannot be seen by human eye but can be captured by an IR camera.

Sensitivity of receptors



- Actual receptors react only to some wavelengths and are more sensitive to certain wavelengths than to others.
- The three different human curves correspond to different type of cones in the human eye.
- The curve named *human₁* corresponds to a type of cone that is mildly sensitive to blue light between 400-500nm.
- The brain fuses the responses from the three types of cones to perceive color.
- Several animals have only one or two type of color receptor.
- Solid state cells usually have good sensitivity above the range of humans.

The RGB Basis

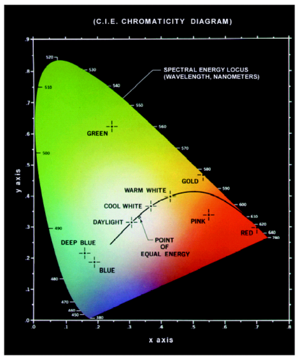
- The *trichromatic* RGB (Red-Green-Blue) encoding in graphics usually uses 3 bytes enabling $(2^8)^3$ or roughly 16 million colors.
- More precisely 16 million codes, because humans cannot perceive that many colors while the computer can.
- The 24-bit encoding uses 8-bits for each of Red, Green and Blue colors.

- Color display devices whose color resolution matches the human eye typically use 16-bits (extra bit used for larger green sensitivity).
- These bits can be combined to produce any arbitrary colors.
- It is useful to scale between 0 and 1.

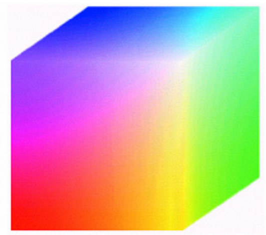
	RGB	CMY	HSI
RED	(255, 0, 0)	(0,255,255)	(0.0 , 1.0, 255)
YELLOW	(255,255, 0)	(0, 0,255)	(1.05, 1.0, 255)
	(100,100, 50)	(155,155,205)	(1.05, 0.5, 100)
GREEN	(0,255, 0)	(255, 0,255)	(2.09, 1.0, 255)
BLUE	(0, 0,255)	(255,255, 0)	(4.19, 1.0, 255)
WHITE	(255,255,255)	(0, 0, 0)	(-1.0, 0.0, 255)
GREY	(192,192,192)	(63, 63, 63)	(-1.0, 0.0, 192)
	(127,127,127)	(128,128,128)	(-1.0, 0.0, 127)
	(63, 63, 63)	(192,192,192)	(-1.0, 0.0, 63)
	...		
BLACK	(0, 0, 0)	(255,255,255)	(-1.0, 0.0, 0)

- The RGB color system starts are (0,0,0) and adds values to obtain color.
- For the purpose of interpretation by humans and computer programs, it is useful to normalize the image data (and to transform to other color systems) as given below.
  - *Intensity I* = *(R + G+ B)/3*
  - *Normalized red* = *R/(R + G + B)*
  - *Normalized green* = *G/(R + G + B)*
  - *Normalized blue* = *B/(R + G + B)*
- The normalized values will add up to 1.
- Can also use *max(R,G,B)* instead of sum.

- By scaling values between 0 and 1, the relationship of coordinate values to colors can be plotted.
- The blue-axis is perpendicular to the r-g axes and can be computed by b = 1-r-g



RGB 24-bit Cube



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Other color bases

- Several other color bases exist which have special advantages relative to devices that produce color or relative to human perception.
- Some bases are simple linear transformations while others are not.
- We will see the CMY and the HSI color systems here.

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- The CMY (Cyan-Magenta-Yellow) color system begins with white (1,1,1) and subtracts to get color unlike RGB.

	RGB	CMY	HSI
RED	(255, 0, 0)	(0,255,255)	(0.0 , 1.0, 255)
YELLOW	(255,255, 0)	(0, 0,255)	(1.05, 1.0, 255)
	(100,100, 50)	(155,155,205)	(1.05, 0.5, 100)
GREEN	(0,255, 0)	(255, 0,255)	(2.09, 1.0, 255)
BLUE	(0, 0,255)	(255,255, 0)	(4.19, 1.0, 255)
WHITE	(255,255,255)	(0, 0, 0)	(-1.0, 0.0, 255)
GREY	(192,192,192)	(63, 63, 63)	(-1.0, 0.0, 192)
	(127,127,127)	(128,128,128)	(-1.0, 0.0, 127)
	(63, 63, 63)	(192,192,192)	(-1.0, 0.0, 63)
	...		
BLACK	(0, 0, 0)	(255,255,255)	(-1.0, 0.0, 0)

Some properties of CMY

- *Cyan* absorbs red illumination, *magenta* absorbs green and yellow *absorbs* blue.
- (0,0,0) is white because no illumination is absorbed, (255,255,255) is black because all components of white are absorbed.

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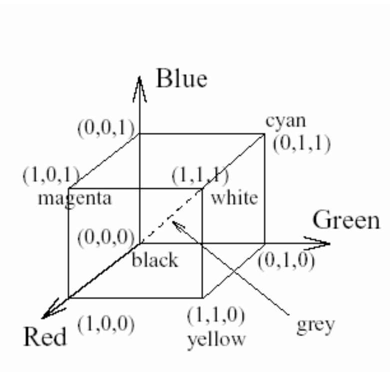
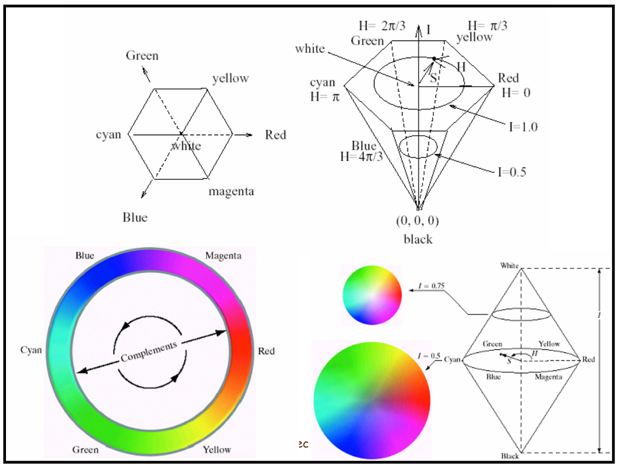
RGB vs. CMY



HSI: Hue-Saturation-Intensity

- The HSI system encode color information by separating out an overall intensity value from two values encoding *chromaticity* : hue and saturation.
- Now take the RGB space, the diagonal would represent the gray-scale values. Take this as the axis for intensity and the following two graphs result.



- This resulting hexagon would have it center as white with the six major axes as the corners.
- As the center would be with with the corner representing full values (1 or 255), as the values change, the resultant structure is a *hexacone*, with the intensity as the axis down the middle.
- Hue H is defined by an angle between 0 and 2π relative to the red-axis.
- Saturation is the third coordinate that represents the purity of the color or hue, with 1 representing completely pure and 0 modeling a completely unsaturated hue, that is some shade of gray.

Conversion of RGB encoding to HSI encoding.

```
R,G,B : input values of RGB all in range [0,1] or [0,255];
I : output value of intensity in same range as input;
S : output value of saturation in range [0,1];
H : output value of hue in range [0,2π), -1 if S is 0;
R,G,B,H,S,I are all floating point numbers;

    procedure RGB_to_HSI( in R,G,B; out H,S,I)
    {
    I := max ( R, G, B );
    min := min ( R, G, B );
    if (I ≥ 0.0) then S := (I - min )/I else S := 0.0;
    if (S ≤ 0.0) then { H := -1.0; return; }
      "compute the hue based on the relative sizes of the RGB components"
    diff := I - min;
    "is the point within +/- 60 degrees of the red axis?"
    if (r = I) then H := (π/3)*(g - b)/diff;
    "is the point within +/- 60 degrees of the green axis?"
    else if (g = I) then H := (2 * π/3) + π/3 *(b - r)/diff;
    "is the point within +/- 60 degrees of the blue axis?"
    else if (b = I) then H := (4 * π/3) + π/3 *(r - g)/diff;
    if (H ≤ 0.0) H := H + 2π;
    }
```

Algorithm 1: Conversion of RGB to HSI.

Original image, a 40% increase in Saturation and a 20% reduction In Saturation

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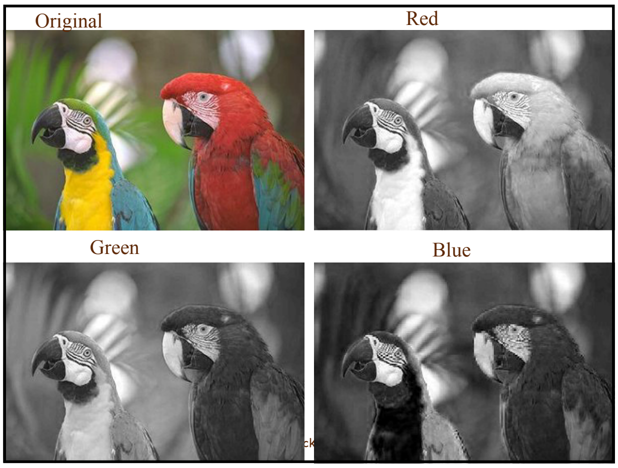

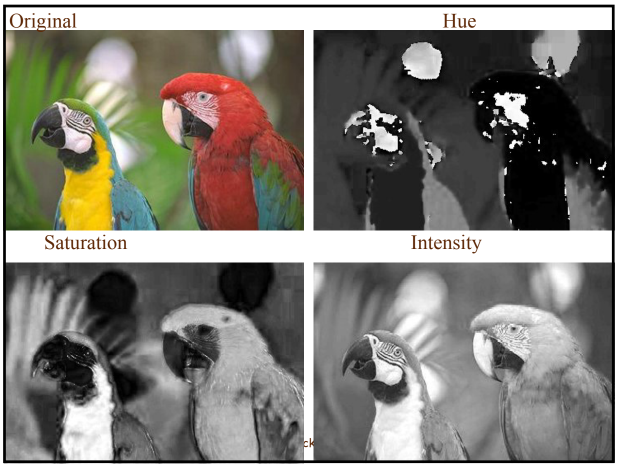

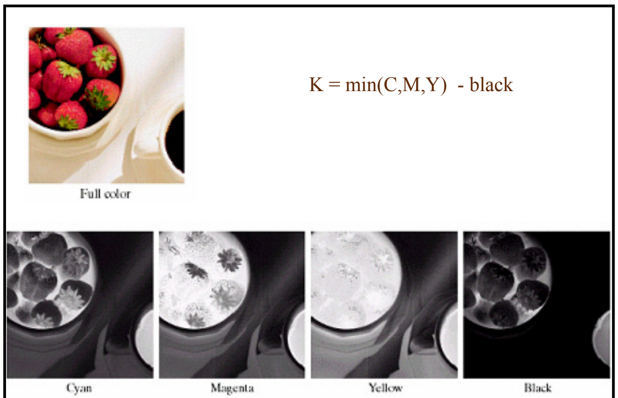

K = min(C,M,Y) - black

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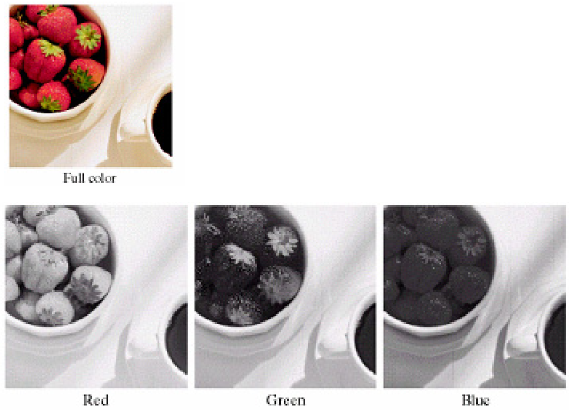

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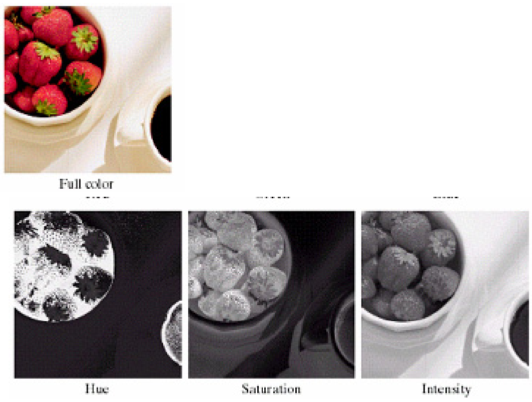

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YIQ TV Signals.

- The NTSC television standard is an encoding of one luminance Y and two chromaticity values I and Q. Only Y is used in Black and White TVs. Y is usually encoded with more bits than I and Q. Humans are more sensitive to changes in luminance than color.
- Linear transform can convert RGB to YIQ easily.

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YUV for digital video

- YUV encoding is used in some digital video products and compression algorithms such as JPEG and MPEG.
- The YIQ and YUV have better potential for compression of digital images and video than do the other color schemes. The luminance and chromaticity can be represented using different number of bits.

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Using color for classification

Color Histogram

- The histogram of a color image has been shown to be very useful for the purpose of image retrieval or object recognition.
- Color histogram can be obtained by simply concatenating the two higher order bits from each color band and forming a 64-bin histogram.
- Another approach is to concatenate the histograms of each band (after reducing the quantization).

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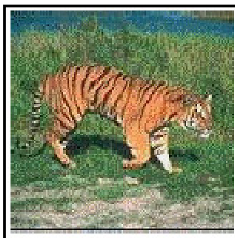

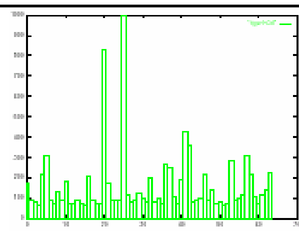

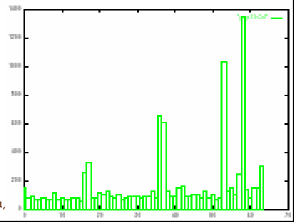

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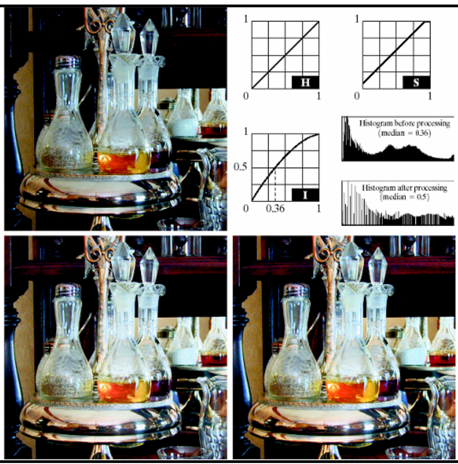

Using histogram for matching

- The intersection of image histogram and model histogram is defined as the sum of the minimum over all K corresponding bins.
- The intersection is normalized by the size of the model to get a match value.

$$intersection(h(I), h(M)) = \sum_{j=1}^{K} min\{h(I)[j], h(M)[j]\}$$

$$match(h(I), h(M)) = \frac{\sum_{j=1}^{K} min\{h(I)[j], h(M)[j]\}}{\sum_{j=1}^{K} h(M)[j]}$$

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- Other measures have included – normalizing the histogram by the size of the image and using Euclidean distance on the frequencies.
- If the image and the matching template were taken under different lighting conditions then the intensity should be factored out first (or equalized).
- Histogram matching is rotation, translation and scale invariant and will work on partially occluded objects as well.

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Color Segmentation

- Segmentation is the process of identifying based on common properties.
- These properties could include intensity, color, texture etc.
- Thresholding grayscale images can be useful for segmentation.
- Segmentation can also be accomplished using edges.

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Application

- Consider the problem of locating/segmenting faces from images using color.
- First we need to identify the range of colors that could be associated with a face.
- The lighting conditions would play a significant role.
- Even under uniform illumination, other objects could fall into that color space. In this case we could use shape information for the purpose of segmentation.

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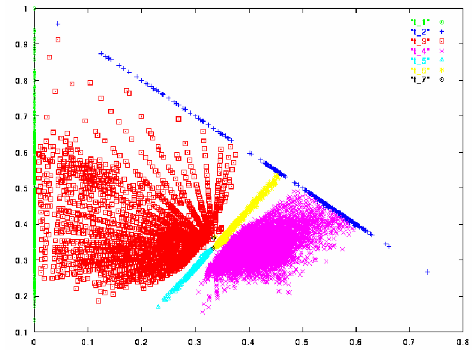
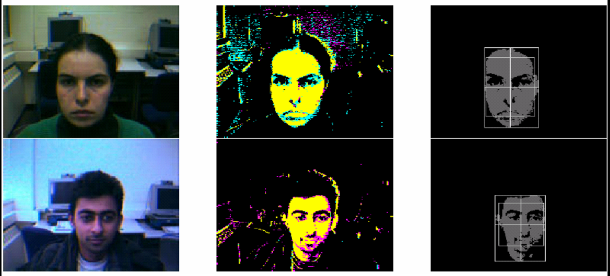
Color space analysis





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- Three major steps are involved in the face segmentation procedure
1. First we need to create a labeled image based on the training data for identifying the color space that would represent the face.
2. Connected component is used to merge regions that would be part of the face.
3. The face is identified as the largest component and areas close to the components are merged.

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Shading

- Several factors affect how am image is viewed or captures.
- Factors such as specularity of the surface, distance of the light source and the camera, angle of the light source on the object surface all play a role in the perception of an object.

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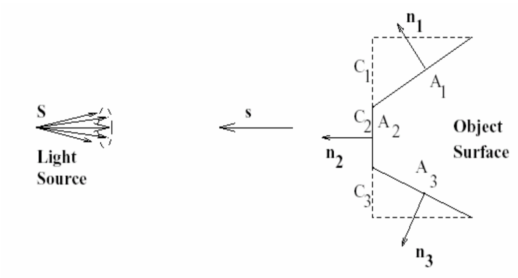
Radiation from one light source



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- Consider the case where the light source is far enough so that the direction from all surface elements of the illuminated object to the light source can be represented by a single unit vector **s**.
- The light energy per unit area (*intensity i*) that reaches the surface element A_j is proportional to the area of the surface element times the cosine of the angle that the surface element make with the illumination direction **s**.
- The radiation received is directly proportional to the power of the light source.
- The fraction of the incident radiation that the surface element reflects is called its *albedo*.

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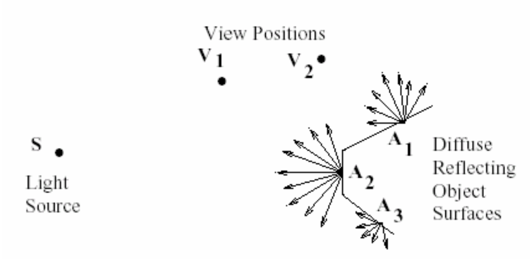
Diffuse Reflection



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- Light energy reaching a surface element is reflected evenly in all directions of the hemisphere centered at the surface element.
- Diffuse reflections occur with surfaces that are rough relative to the wavelength of the light.
- The intensity of the reflected illumination is proportional to the intensity of the received illumination and appear to have the same brightness from all viewpoints.

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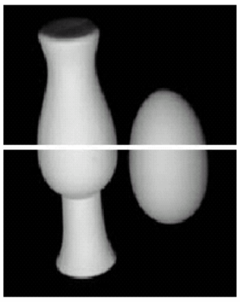

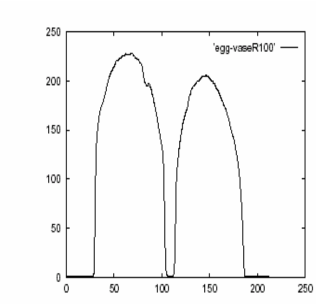

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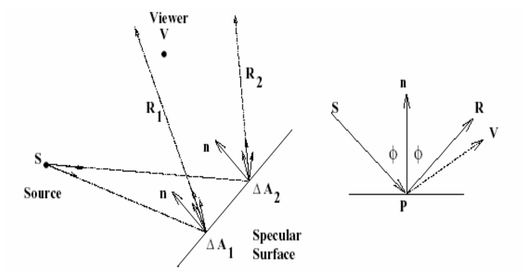
Specular Reflection



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Specular Reflection

- **Specular reflection** is mirror like reflection. Light reflected off the surface is radiated out in a tight cone about the ray of reflection. The wavelength composition of the reflected light is similar to that of the source and independent of the surface color.
- A **highlight** on an object is a bright spot caused by the Specular reflection of a light source. Highlights indicate that the object is waxy, metallic or glassy...

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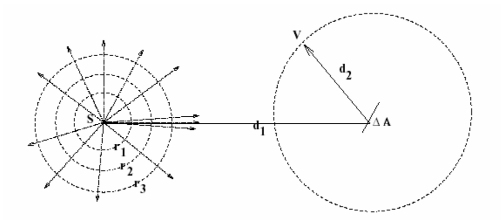
Darkening with distance



The intensity of light received by any object surface will decrease
With square of its distance from the source.