

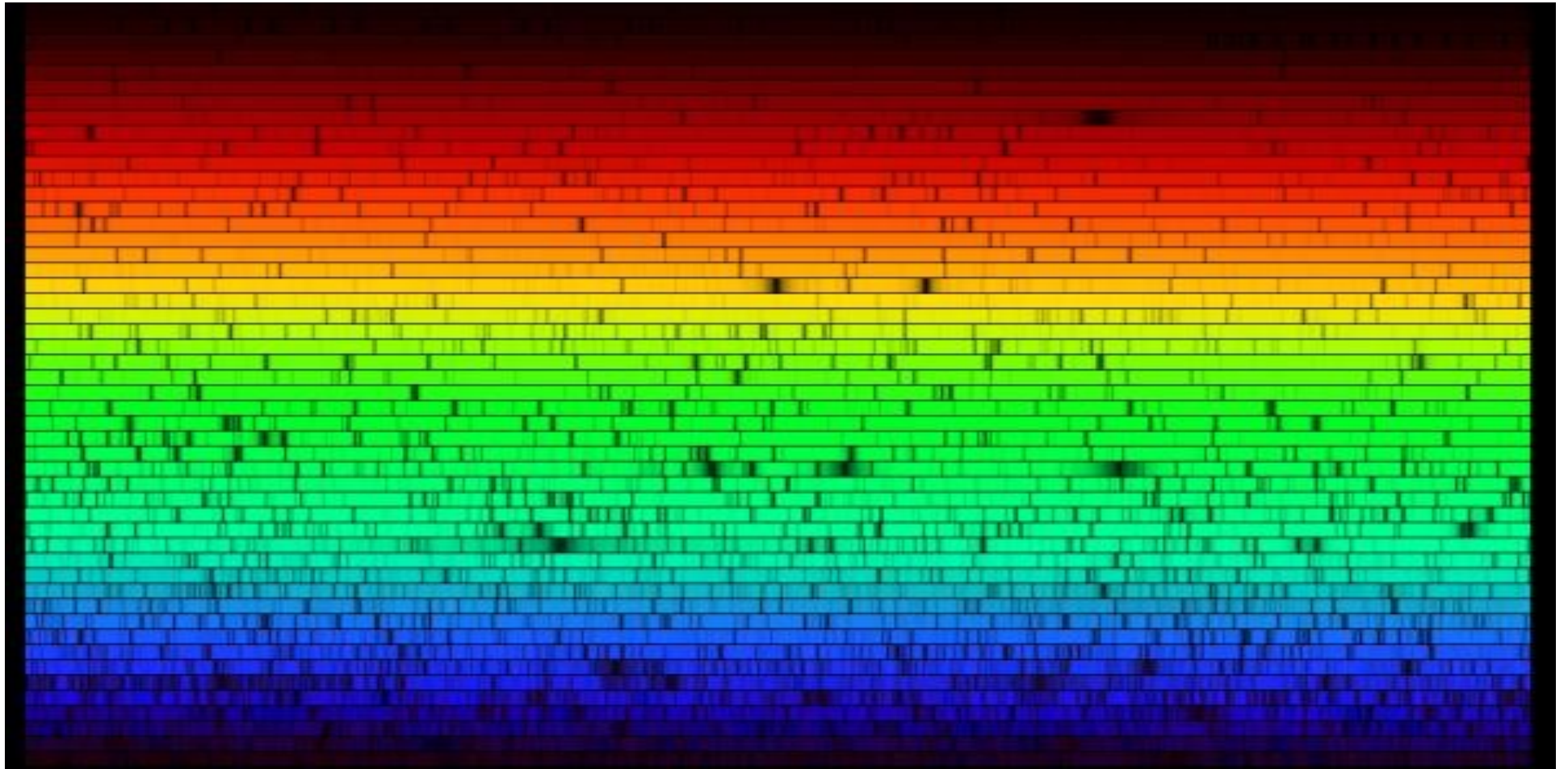
Color and Light

CSCI 4229/5229

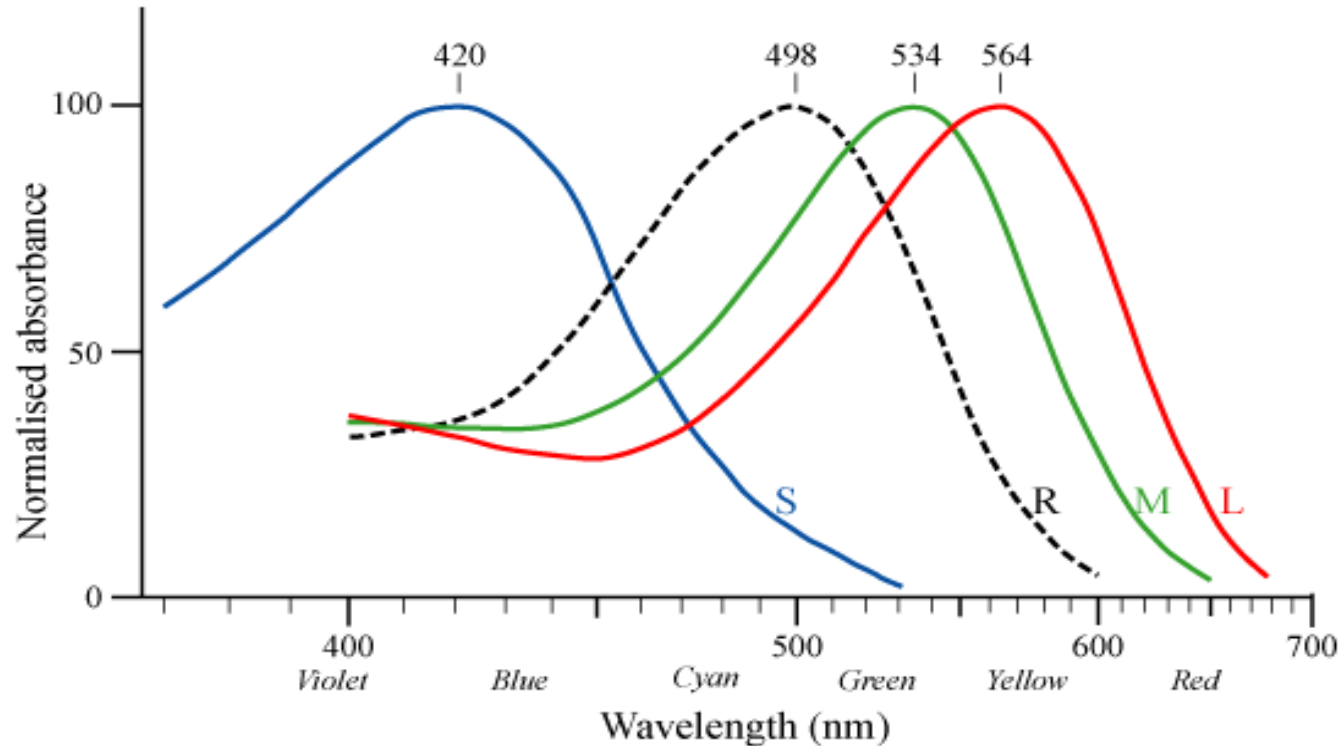
Computer Graphics

Summer 2026

Solar Spectrum



Human Trichromatic Color Perception

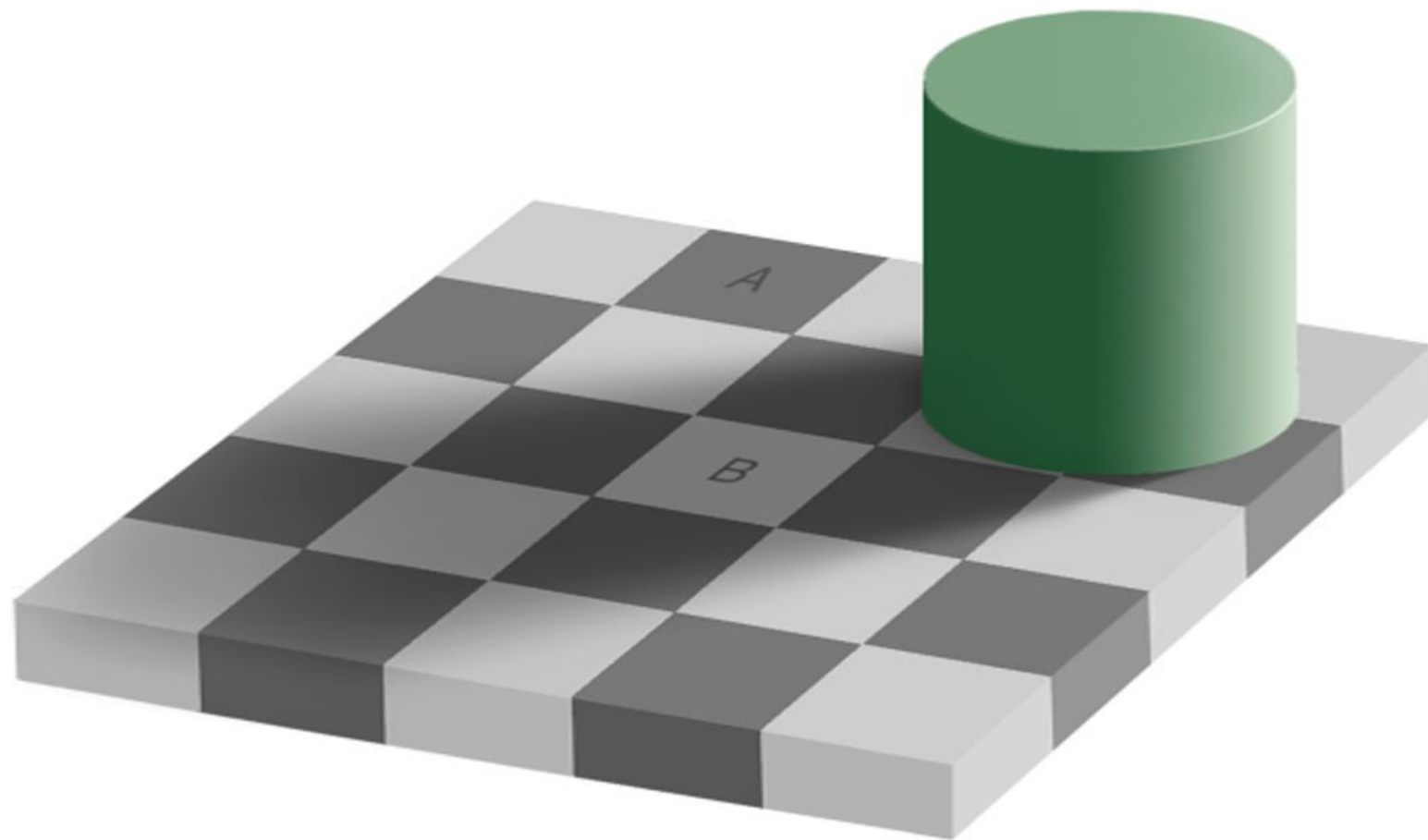


Color Blindness

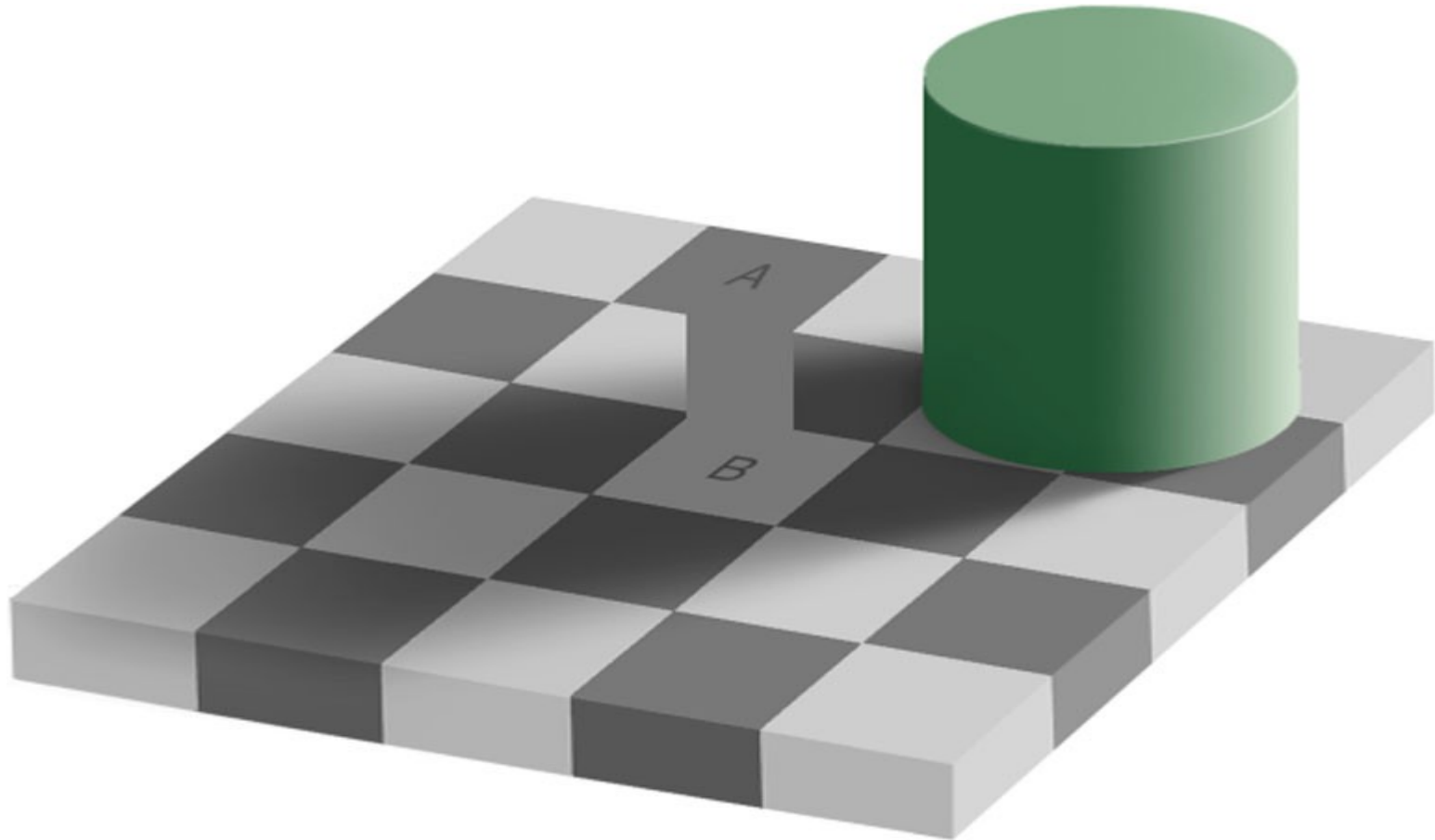
- Present to some degree in 8% of males and about 0.5% of females due to mutation of the X chromosome
- Example of severe red-green color blindness caused by absence of green cone photo receptors



Are A and B the same?



Color perception is relative



Transmission, Absorption & Reflection

- Light source generates radiation with specific energy-frequency spectrum
- Opaque objects absorb some frequencies and reflect others
- Translucent objects absorb some frequencies and transmit others
- Apparent color depends on the spectrum that remains when it reaches the eye

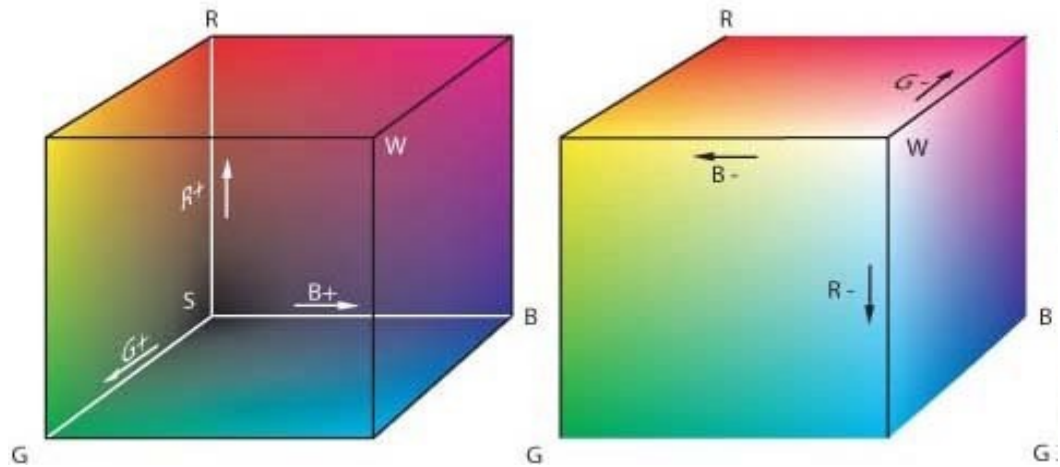
Color Examples

- White source -> red glass -> white paper = red
- White source -> white paper -> red glass = red
- Red source -> white paper = red
- White source -> red glass -> green paper = dark
- Red source -> green glass = dark

RGB Color

- Approximates how humans see
- Additive color
 - Red+Green = Yellow
 - Green+Blue = Cyan
 - Red+Blue = Magenta

Red+Green+Blue = White
No emission = Black

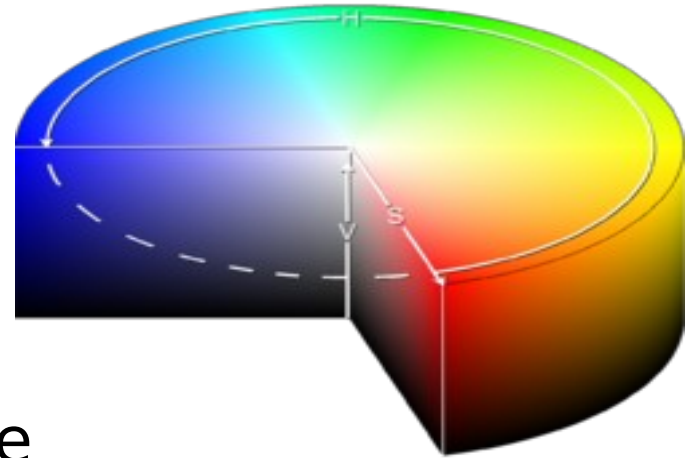


CMY/CMYK Color

- Printing color
- Subtractive Color
 - Yellow+Magenta = Red
 - Yellow+Cyan = Green
 - Cyan+Magenta = Blue
 - Yellow+Cyan+Magenta = Black
 - No ink = White
 - Black helps make darker colors and true black

HSV Color

- Color Progression model
 - Hue (color)
 - Saturation (intensity)
 - Value (brightness)
- Useful in translating values to range of colors



Color in the Real World

- Sunlight is essentially white
 - Incandescent light is yellowish
 - Fluorescent light is mostly blue-green
- Reflected light depends on the surroundings
 - Wall, ceiling and floor color
 - Large objects
 - Filtered light
- Light is often bounced off multiple objects before it reaches the eye

Local vs. Global Lighting

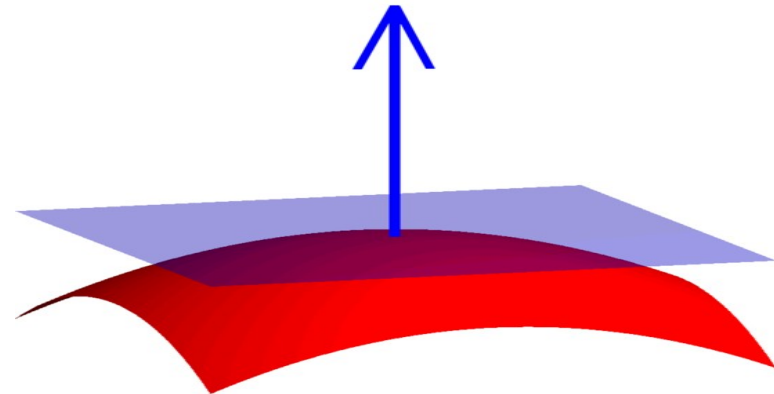
- Global lighting
 - Traces how light bounces off successive objects
 - Recursive Ray tracing and Radiosity
 - Not currently practical for real time graphics
- Local lighting
 - Separates light sources into direct and ambient
 - Calculates intensity based only on vectors
 - Many possible simplifications
 - Requires special action to generate shadows

Color and Materials

- Mirrors reflect (almost) all light
 - Highly directional
- Metals, glazed ceramics, calm water, ...
 - Mostly directional, some diffuse
- Plastics, unglazed ceramics, turbulent water, ...
 - Some directional, mostly diffuse
- Natural materials (leaves, leather, skin, ...)
 - Predominantly diffuse

Surface Normals

- How light interacts with a surface depends on the angle between the light rays and the surface
- The vector perpendicular to the surface is called the **surface normal** or just **normal** vector
- For a flat surface the normal is the same for all points on the surface
- For a curved surface the normal is potentially different at every point



Determining Surface Normals

- By inspection
 - Cube (parallel to axes)
 - Sphere (radially out)
 - Cone (singularity at top, radially out and up)
 - Torus (radially out from central axis)
- Cross product of tangential vectors
 - Polygons (difference between vertexes)
 - Analytical derivatives
- Use normals of actual surface, not polygons used to approximate the surface (see Gouraud shading)

Lighting for Real Time Graphics

- Add different “types” of light
 - Ambient: Scattered light from diffuse sources
 - Diffuse: Scattered light from point sources
 - Specular: Directional light from point sources
 - Emission: Light from object itself
- Local calculations: Light interacts with objects
- Lighting calculations by component (RGB)
- Lighting done by vertex
 - Use must specify an appropriate normal

Emission Light

- Object radiates light in all directions
- Color and intensity independent of incident light
- Typically used to represent internally lit objects
- Intensity M_E (which is a property of the material)
- *If calculations are LOCAL the light from internally lit objects does not light up the scene*
 - *This is what OpenGL does*

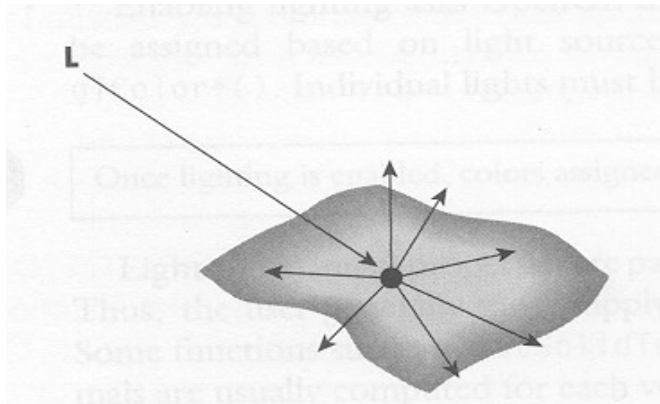
Ambient Light

- Light comes from all directions and is reflected in all directions
- The color and intensity of ambient light represents the net result of multiple reflections
 - Color of walls illuminated by white light
 - Color of canopy in forest
- Intensity MC_A



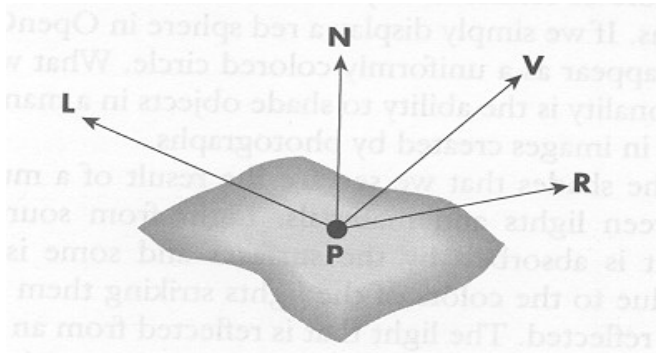
Diffuse Reflections

- Lambertian Reflection
- Diffuse light scatters in all directions
- Intensity depends on cosine of the angle of incidence
- Intensity $(N \cdot L)MC_D$



Specular Reflection

- Light is reflected in a preferred direction
- Responsible for bright spot on spheres
- Direction of reflection is $R = 2(L \cdot N)N - L$
- Intensity does not change along R
 - Gets dimmer away from R



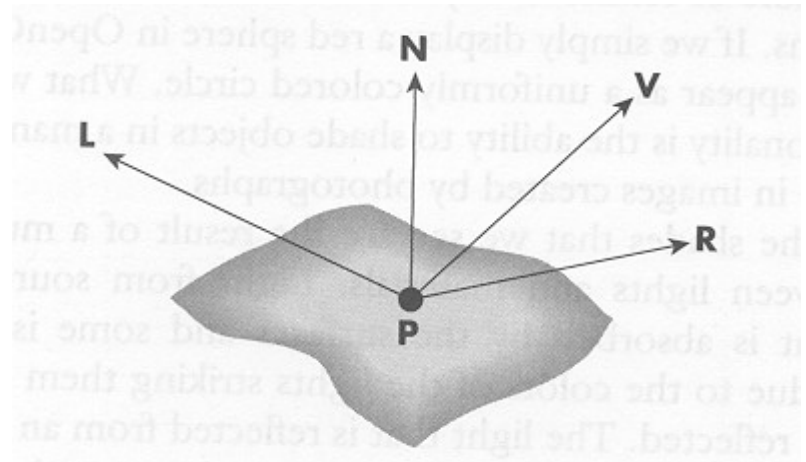
Phong Reflection Model

Bui Tuong Phong, University of Utah, 1973

- L light source
- N normal vector for surface
- R reflected light

$$R = 2(L \cdot N)N - L$$

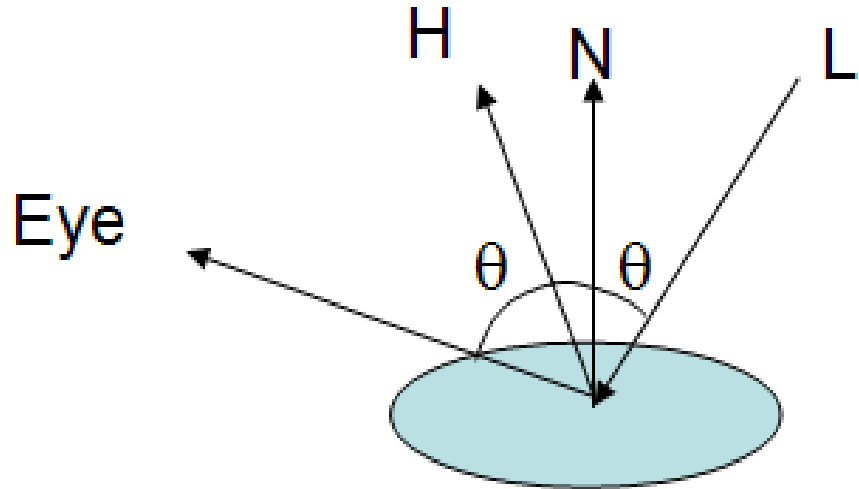
- V viewer (eye)
- Intensity $(V \cdot R)^S MC$
 - S shininess
 - M material reflection coefficient
 - C color if light source
- Calculated independently for R,G,B



Blinn-Phong Reflection Model

Jim Blinn, University of Utah, 1978

- Also called modified Phong or Fast Phong
- Half angle $H = L+V$ (renormalize)
- Simpler and faster
 - Often $V = (0,0,1)$
 - L constant if far
- Intensity $(N \cdot H)^{SMC}$



Gouraud Shading

Henri Gouraud, University of Utah, 1971

- Calculate lighting effects only at vertices
 - True Gouraud shading calculates vertex normal as the average of the normals of adjoining polygons
- Interpolate lighting effects (colors) across the surface of the polygon
- Potentially significant computational savings over calculating lighting effects for each pixel

Local Light Calculations

- Light is additive
 - Color intensity is the sum of all light sources and types (ambient, specular, ...)
 - Colors are added by component (R,G,B separately)
 - Color intensity varies with the cosine of angles
 - Color hue changes as relative component intensities change
- Light behaves algebraically
 - Intensity varies essentially linear
 - Shadows can be made by subtracting light

OpenGL Light Types

- Global Ambient
 - Ambient light not from any specific light source
- Ambient
 - Light from all directions associated with source
- Diffuse
 - Light reflecting in all directions
- Specular
 - Light reflecting in preferred direction
- Emission
 - Light emanating from each object

Combined OpenGL Lighting

- $\text{Color} = M_E + M_A C_A + (N \cdot L) M_D C_D + (N \cdot H)^S M_S C_S$
- Calculated for each light, vertex, RGB
- Requires normalized (0-1) values
- User must specify
 - Light color and position
 - Object color and normal

Physics of Non-directional Light

- Point source light
 - Radiates in all directions
 - Intensity decays inversely proportional to r^2
 - Absorption could attenuate light faster
- Diffuse surface reflection
 - Radiates in normal hemisphere
 - Reflected from rough (matte) surface
 - Also absorbed and re-emitted light

Hints on Using Lights

- Stick to a single light
- Use white lights ($R=G=B=\alpha=1$)
- Specify one ambient light (global or primary)
 - Intensity should be in the 0.1 to 0.3 range.
- Diffuse (soft) light should always be present.
- Specular (hard) light creates highlights, sparkles, etc.

Hints on Using Materials

- Changing color on materials is simpler than changing the color of light
- Use the same color for ambient and diffuse
- Materials are typically one of
 - matte, high diffuse color and low specular
 - plastic, with high diffuse color and white specular
 - metal, with low diffuse and high specular color
- Color is determined by specular for metals, diffuse for other materials

Hints on Surface Normals

- Surface normals are required for lighting
 - glu and glut objects calculate these
- Normals are perpendicular to polygons
- Normals are transformed with vertices
- Normals must be unit length (watch scaling)
 - glEnable(GL_NORMALIZE) enforces this

OpenGL Lighting Controls

- Enable Lighting
- Light Sources
 - glLight*
- Material types
 - glMaterial*
- Normals
 - glNormal*