Lights and Lighting
Digital Lighting and Rendering
CGT 340

Lighting is 5% of light setup and 95% of revisions and adjustments.

Jeremy Birn

Lecture overview

- What is light?
- Spectrum
- Typical cases
- Metamers
- CG lights

Light

Light electromagnetic radiation between ~ 400 nm and ~ 700 nm

\( \lambda \) (nm)

- Radio waves
- Infrared
- Ultraviolet
- X-rays
- Gamma rays

Red
Orange
Yellow
Green
Blue
Indigo
Violet
Light Sources

Light source can be characterized by its emission spectrum or spectral characteristic, which is a graph of intensity of emission at different wavelengths.

- **Light source**

  • the daylight emission spectrum
  • it can be measured

  ![Graph of intensity vs. wavelength]

  - Wavelength [nm]
  - Intensity [W]

Light Sources

• **Light source**

  • Important special cases of light sources

  • Achromatic light: Usually perceived as white or gray
    • Increasing/decreasing the intensity of the achromatic light, we get brighter/darker gray
  • Monochromatic light (includes one chroma): Usually perceived as a pure color
    • The only intensity is the dominant wavelength or dominant frequency
    • Examples are a laser beam, a sodium bulb

  ![Graph of intensity vs. wavelength]

  - Wavelength [nm]
  - Intensity [W]

Light Sources

• Achromatic light
  • Lat. chroma = color

• Monochromatic light
Light Sources and Color

Will two different spectra be perceived as two different colors?

Always?

Metamers

• Two lights with different spectra that are perceived as the same color are called metamers.

• Why?
  • Convolution of the emission spectra over the eye light sensitivity for short, medium, and long cones gives the same numbers.

Color matching experiment

• change intensity of the three lights
• get the same color as of the source
• let the three lights be called A, B, and C
• they are called primaries

Light in Computer Graphics

• the three components
  • Diffuse light
  • Specular light
  • Ambient light
Light in Computer Graphics

- Diffuse ~ color
- Specular ~ reflections, highlights
- Ambient ~ indirect illumination, multiple reflections

This comes from reflections and it characterizes the material more than lights

Types of light sources

- Based on the way they shine:
  - Ambient light
  - Point light
  - Spot light
  - Directional light
  - Area light
  - Volume light

Let’s meet them personally

Phong Illumination Model

- Bui Tuong Phong (1973) University of Utah
- Empirical model of light reflection.
- Light and material have three components:

  1) Ambient light
  2) Diffuse light
  3) Specular light

Ambient Light

- Is constant in the entire scene
- An approximation of multiple reflections

\[ I_a = I_{AB} + I_{AG} + I_{AB} \]

(intensity of ambient)
Ambient Light

- Ambient light does not have a position

\[
R_a = k_a \otimes I_a = [k_{ag} * L_{ag}, k_{ab} * L_{ab}]
\]

Example:
Surface reflects color: \( \text{material} = [1,0,0] \) (red)
Illuminated with: \( \text{light} = [0,0,1] \) (blue)

\[
\text{reflected} = \text{material} \otimes \text{light} = [1x0, 0x0, 0x1] = [0,0,0]
\]
(the symbol \( \otimes \) means per-element multiplication)

Light Sources

Characterized by their diffuse and specular component

\[
I_s = [L_{sr}, L_{sg}, L_{sb}]
\]

\[
I_r = [L_{rr}, L_{rg}, L_{rb}]
\]
Material

Material is characterized by its ability to reflect:

- Specular light: \( k_s = [k_{sR}, k_{sG}, k_{sB}] \)
- Diffuse light: \( k_d = [k_{dR}, k_{dG}, k_{dB}] \)
- Ambient light: \( k_a = [k_{aR}, k_{aG}, k_{aB}] \)
- Shinniness: \( S \)

More is needed

- The eye position \( E \)
- The light position \( L \)
- The normal vector \( N \)
- The vertex position \( v \)

Diffuse Term

Depends on the position of the light and the vertex.

The Lambert's law:

\[ R_d = k_d \otimes I_d \cdot \max(N \cdot L, 0) \]

\( N \cdot L \) is the dot product of the normal vector and the direction to the light.

Lambertian or matte reflection: incoming light is spread into all directions with equal probability, corresponding to a plastic material.

- Perfect diffuse surface (Lambertian surface)
- (plastic, chalk)
- \( f_r = p_r / \pi \)
- \( p_r \) is the ratio of the reflected to the incident energy (0 \( \leq \rho_r \leq 1 \))
- \( \pi = \int \cos \theta d\omega \)
- \( \Theta \)
Diffuse Term

• Depends on the \( V, L, \) and the eye position

\[
R_S = (V \cdot R)^5 I_S \otimes M_S
\]

\( V \) is vector to the viewer,
\( R \) is the reflected ray direction, and
\( S \) is the shininess coefficient

\( L \) is vector pointing to the light,
\( N \) is the normal vector to the surface

Blinn-Phong Specular Term

\[
R_S = (\max(H \cdot N), 0)^5 I_S \otimes M_S
\]

depends on

\( H \) is so called bisector,
\( S \) is the shininess coefficient

No reflected vector is needed, so it is slightly faster

But also a bit different

Specular Term

Specular (glossy) reflection acts as a ray of light

Idealized specular surface is a mirror

Perfect specular surface (mirror)

\[
\rho_s = \rho_s \delta(\theta_m) / \cos \theta
\]

\( \rho_s \) is the ratio of the reflected to the incident energy \( (0 \leq \rho_s \leq 1) \)

the Dirac pulse is

\[
\delta(\theta_m) = \begin{cases} 1 & \theta_m = 1 \\ 0 & \text{otherwise} \end{cases}
\]
Specular Term

The Shinniness

Phong Reflection Model
Putting this all together

Reflected light is

\[ R = R_A + \sum_{i=0}^{n} (R_D^i + R_S^i) \]

i.e., ambient light for complete scene plus sum of the diffuse and specular contributions of all lights

The result is _clamped_ to \([0,1]\)
It means, if the reflection is 1
another light does not increase it!

---

Phong Reflection Model Summary

- due to the ambient light nothing can be entirely black
- mirror reflections are possible
- can be computed very fast (used in VR and games)
- very good approximation of diffuse surfaces
- physically inaccurate
- expressed in terms of vector geometry

---

Phong Reflection Model Summary

- An example of Phong Reflection Model in Ray Tracing

---

Ambient Light

- Why not to use it?
  - does not depend on any angle
  - is a flattered fill of a color
  - the best is – turn it OFF
  - but we do need the indirect illumination...
  - use fill lights, but dim them
Ambient Light – one light

Ambient Light - ambient

Ambient Light - directional

Ambient [0, 0.25, 0.5, 1.0]
Ambient Light

- Maya
- Attribute
  Ambient Shade=0 -> behaves as ambient
  Ambient Shade=1 -> behaves as point

Point Light Source

- Also called *omni, omnidirectional*
- Does *not* exist in reality
- Mathematical abstraction
- Like a light bulb in the middle of a room
- The fastest light source to calculate

Point Light Source

- Trick in Maya
  - set negative intensity
  - behaves like a “negative light”
Spot Light
- The most commonly used
- Probably the most powerful light source
- The best controlled light
- It is a point light that is aimed somewhere
- It has its: target, cone, penumbra angle, etc.

Spot Light - positioning
- Select light
- Panel-> Look through selected

Spot Light
- Reflector
- Point light with more parameters
- Positioning
  - press object pick ("T") to put and situate

Spot Light - positioning
- Aiming to an object
- Panel -> View -> Look at Selection
Spot Light- cone angle 40°

Spot Light- cone angle 70°

Spot Light- penumbra angle 20°

Spot Light- drop-off 140°
Spot Light – color as a file

Throw

- Cookies and gobos
- “cookie” – cuicoloris
- “gobo” – go-between objects between lights and the occluder
- Venetian blinds, fan on ceiling etc.
- Can be done by a model
- Easier by a light map

Spot – light mapping intensity

- $I = f(d)$
- Can be mapped manually
- The Graph Editor
- Window -> Animation Editors -> Graph editor
- Select the spotlight
- In the Light Effect option select Intensity Curves
- Use the middle key to move the points
Spot – light mapping intensity

Spot Light – making a soft shadow
- DLR 2nd edition page 22
- Aim multiple lights so they overlap
- Decrease the penumbra angle
- It is not a shadow! But it looks cool...

Directional Light
- Depends only on an angle
- Translation does not make any sense
- Represents distant light sources
- Point in infinity (vector)
- All rays are parallel
- Fast to calculate
- Can project images
Directional Light

Area Light

- **spherical light**
  - good when close to an object
  - for large distance ~ point
- **flat area**
  - disc, rectangle
  - faster to calculate
  - good for lamps, etc
- **linear light**
  - fluorescent tube

Area Light

- Rectangular (in Maya)
- The slowest to calculate
- The *only* that produces soft shadows
- Object pick ("T") to put and situate

Area Light

- The size does matter!
- The bigger the light source, the more illuminated the scene
Area Light

Volume Light

- In Maya
- 3D shape and the light direction (in, out, etc.)
- Everything inside the volume is illuminated

Volume Light

Light Linking

- Also called *selective lighting*
- Maya → Relationship Editor
- Light/Shading → Light linking
- Defines which light shines on which object
- Can *significantly increase speed of rendering*
Light Linking – two lights

Light Linking

Light Linking

Shadows

- one of the most important visual clues
- help to establish spatial relationship
Shadows

- can help to see alternate angles

Shadows

- increase contrast of a scene
- shadow color is important! intense color can be used to see what is actually lit
- can help to divide the space

Shadows

- Black shadow is not natural (always?)
Shadows

- Use fill light to brighten shadows

Shadows - algorithms

- Shadow map
  - fast and usually ugly
  - problems with transparency
- Raytraced shadows
  - excellent choice
  - slow
  - critical – shadow rays
  - higher ~ slower, better

Shadow Geometry

Light source

Can a point light produce soft shadows?

Shadows - raytraced

- Penumbra quality = f(shadow rays)
Shadows – shadow mapped

- Shadow quality = f(size of the map)

Ambient Occlusion

- Important and neat effect that darkens wrinkled parts
- Done by hemicube or hemispherical sampling

Ambient Occlusion

- Can be achieved by Global Illumination

Ambient Occlusion

- Is calculated *without* a light source
- Very soft shadows
- Very nice
- Details – later in Global Illumination
Lens Flares and Halos

- Nice and cheap effect
- Caused by multiple reflections in camera’s lenses
- In Maya associated with a light source
- Can be active/inactive

Lens Flares and Haloes

- Select light source
- Go to Light effects and select Light Glow
- Select Lens Flares
- Glow spread controls the distance the glow goes
- Ignore light will display just the effect

Qualities of light

- Soft/Hard
- Intensity
- Color
- Throw
- Animation
Soft/Hard Light

- Means in fact, soft/hard shadow
- Soft shadows can be simulated by more light sources
  - faster, easier
  - each light will have 1/n-th intensity
- Hard light – sunlight, close light bulb

Soft/Hard Light

- Hard light
  - sunlight, close light bulb
  - space scenes, inhospitable environments

- Soft lights
  - warm environments
  - distance lights

Rules of thumb

- Isolate one light to see its influence
- Start with small intensities
- Lighting is linear! (thank G-d!)
- Use flipbook to see the influences
- Area lights at the end
- Area lights may not be necessary in animations

To take home...

- Light is...
- Metamers
- Types of light sources (point, spot...)
- Why not to use ambient light
- Why a spot is the best light source
- Shadows and tricks with them
- Rules of thumb
Readings

- Andrew Glassner, Principles of Digital Image Synthesis
- Donald Hearn, M.Pauline Baker.
- F.S.Hill,
  Computer Graphics, Prentice Hall 1990, pages 564->
- Watt, Watt, 2nd edition,
  Advanced Animation and Rendering Techniques
- Cohen, Wallace,
  Radiosity and Realistic Image Synthesis