The Road So Far...

Last week

- Construct geometry
  - Define transformations
  - Assign material properties

This week

- Vertex Transformations
  - Object's local space → viewport space
  - Determine front-facing triangles
  - Determine which vertices are visible

- Culling & Clipping
  - Determine which vertices are visible

- Rasterization
  - Fill the triangle with fragments

- Fragment Shading
  - Calculate correct color values

- Visibility Tests
  - Is the fragment visible?
  - Blend together multiple fragments

- Blending
Color

• What is color?
Color

- We represent color values with 3 channels:
  - Red
  - Green
  - Blue
Color

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• The 4th (*alpha*-channel) is used for *semi-transparent* color values.
Color

- We represent color values with 3 channels:
  - Red
  - Green
  - Blue
- The 4th *(alpha-channel)* is used for *semi-transparent* color values.
- Values usually in ranges:
  - \([0, 1]\)
  - \([0, 255]\)
  - \([0, FF]\)
Color

```javascript
gl_FragColor = vec4(1.0, 0.2, 0.2, 1.0);

var color = new THREE.Color( 0xff0000 );

wuContext.fillStyle = 'rgba(255, 0, 0, 0.5)';
```
Alpha Channel

• Do you believe that these are all red triangles?
RGB
RGB

• Subset of the visible color space
RGB

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- Humans see wavelengths roughly from 390 – 700 nm.
RGB

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- Humans see wavelengths roughly from 390 – 700 nm.
- They see them using 3 types of cones with varying response rates in the eye.
RGB

- Subset of the visible color space
- Humans see wavelengths roughly from 390 – 700 nm.
- They see them using 3 types of cones with varying response rates in the eye.
- *Infinite* amount of different colors.
There are actually many ways to specify colors in the computer (HSV, YCbCr, CMYK).

RGB
RGB

- There are actually many ways to specify a color space in the computer (HSV, YCbCr, CMYK).

- Also many different RGB color spaces (sRGB, Adobe RGB, Apple RGB, CIE RGB).
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- Also many different RGB color spaces (sRGB, Adobe RGB, Apple RGB, CIE RGB).
- Mostly we use the sRGB (standard) color space in graphics.
- But there is a catch...
Gamma Correction

- Do these seem of the same shade of gray?

Vertical black-and-white bars compared to sRGB color (128, 128, 128)
Gamma Correction

• The colors that the monitor outputs have your values passed through a function:

\[ \text{outputRGB} = sRGB^{\gamma}, \quad \gamma = 2.2 \]
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- This is because the old CRT monitors had a non-linear response rate (the function above).
- Thus a correction for this function was encoded in all media and has persisted to this day.
- Also it allows more different darker grays to be represented in sRGB.
Gamma Correction

• sRGB (128, 128, 128) gray is not exactly halfway between white and black when displayed.

• Imagine a fully red cube (255, 0, 0).

• If it is lit by a white light so that only 25% reflects off, what is the response we see?
Gamma Correction and sRGB

• Questions about sRGB, alpha channel, gamma correction?

• See if your monitor is calibrated correctly: http://www.lagom.nl/lcd-test/gamma_calibration.php


• About sRGB: http://dpanswers.com/content/tech_colmgmnt01.php
Lighting Models

- There are different types of light reflection, because there are different types of materials.
Lighting Models

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• In computer graphics, basic lighting models include 3 distinct reflections / terms:
  • Ambient
  • Diffuse (Lambertian)
  • Specular (Phong, Blinn-Phong)
Lighting Models

- There are different types of light reflection, because there are different types of materials.
- In computer graphics, basic lighting models include 3 distinct reflections / terms:
  - Ambient
  - Diffuse (Lambertian)
  - Specular (Phong, Blinn-Phong)
- These describe a very basic lighting model. There exist more physically accurate ones.
Diffuse Reflection (Lambertian)

- We assume that light hitting a surface scatters in all directions equally.
Diffuse Reflection (Lambertian)

- So the amount of light reaching a viewer is independent of the viewer's position.
Diffuse Reflection (Lambertian)

- So the amount of light reaching a viewer is independent of the viewer's position.
- Which viewer sees more light from the surface?
Diffuse Reflection (Lambertian)

- So the amount of light reaching a viewer is independant of the viewer's position.
- What if we change the light's direction?
Diffuse Reflection (Lambertian)

- What about the light's direction?
- Looking closer...
Diffuse Reflection (Lambertian)

- What about the light's direction?
- Looking closer...

- Which surface looks more brighter for the viewer?
Diffuse Reflection (Lambertian)

- How much light reaches one surface unit?
Diffuse Reflection (Lambertian)

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Diffuse Reflection (Lambertian)

- Sine is difficult, can we calculate it with a cosine?
Diffuse Reflection (Lambertian)

- Sine is difficult, can we calculate it with a cosine?

\[
\sin(\alpha) = \cos(90^\circ - \alpha) = \cos(\beta)
\]
Diffuse Reflection (Lambertian)

• How to calculate $\cos(\beta)$ knowing $l$ and $n$?

$n$ – surface normal

$l$ – direction vector towards the light source
Diffuse Reflection (Lambertian)

- This is the diffuse reflection term.

\[ I = n \cdot l \]
Diffuse Reflection (Lambertian)

- This is the diffuse reflection term.
- For a colored surface, we multiply it with coefficients $M \in [0, 1]$ for each color channel.

\[ I = M \cdot n \cdot l \]
Diffuse Reflection (Lambertian)

- This is the diffuse reflection term.
- For a colored surface, we multiply it with coefficients $M \in [0, 1]$ for each color channel.
- For a colored light source we multiply it with coefficients $L \in [0, 1]$ for each color channel.

$$I = M \cdot L \cdot n \cdot l$$
Diffuse Reflection (Lambertian)

\[ I = M \cdot L \cdot n \cdot l \]
Diffuse Reflection (Lambertian)

\[ I = M \cdot L \cdot n \cdot l \]

How much light reaches the surface

\( n \) – surface normal
\( l \) – direction vector towards the light source
Diffuse Reflection (Lambertian)

\[ I = M \cdot L \cdot n \cdot l \]

How intense is that light in RGB channels

\[ M \in [0, 1] \]
Diffuse Reflection (Lambertian)

\[ I = M \cdot L \cdot n \cdot l \]

How much the material reflects light in RGB channels

\[ L \in [0, 1] \]
Ambient Light

- Describe these cubes...
Ambient Light

- Ambient light is almost always bouncing around.
**Ambient Light**

- Ambient light is almost always bouncing around.
- We add some small value of ambient light.

\[
I = M_{\text{ambient}} \cdot L_{\text{ambient}} + M_{\text{diffuse}} \cdot L_{\text{diffuse}} \cdot n \cdot l
\]
Specular Reflection

• Is there something missing?
Specular Reflection

- Some surfaces seem more shiny
- That is because they will reflect some light directly, not scatter it in all directions
Specular Reflection (Phong)

- The surface should seem more brighter, if the light is reflecting directly into viewer's eye.
Specular Reflection (Phong)

- We can take the cosine of the angle between the viewer direction $\mathbf{v}$ and the reflected light $\mathbf{r}$.

\[ \mathbf{v} \cdot \mathbf{r} \]
Specular Reflection (Phong)

- We can take the cosine of the angle between the viewer direction $v$ and the reflected light $r$.

- Because that gives a too wide highlight, we also rise it to a power of shininess.

$$\left( v \cdot r \right)^{\text{shininess}}$$
Specular Reflection (Phong)

- We can take the cosine of the angle between the viewer direction $v$ and the reflected light $r$.
- Because that gives a too wide highlight, we also raise it to a power of shininess.
- Multiply also with the $M$ and $L$.

$$M_{\text{spec}} \cdot L_{\text{spec}} \cdot (v \cdot r)^{\text{shininess}}$$

Check out CGLearn examples
Specular Reflection (Phong)

- $\text{shininess} = 0$
- $\text{shininess} = 30$
- $\text{shininess} = 300$
- $\text{shininess} = 90$
Phong's Lighting Model

• Bui Tuong Phong. (1942 – 1975)

• The model published in:
  • 1973 – PhD dissertation
  • 1975 – paper

We do not expect to be able to display the object exactly as it would appear in reality, with texture, overcast shadows, etc. We hope only to display an image that approximates the real object closely enough to provide a certain degree of realism

from Illumination for Computer Generated Pictures (Phong, 1975)
Phong's Lighting Model

- Bui Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]
Phong's Lighting Model

- Bui Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]

The ambient term

Describes the uniform indirect light all around the scene.
Phong's Lighting Model

- Bui Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]

The diffuse term

Describes the direct light that is diffusely scattered
Phong's Lighting Model

- Bui Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]

The specular term

Describes the direct light that is specularly reflected
Phong's Lighting Model

- Bui Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{shininess} \]

Material's color is usually the same for both ambient and diffuse
Phong's Lighting Model

- Bui Tuong Phong, 1975.

\[
I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{shininess}
\]

Material's specular color (tint) is usually white.
Phong's Lighting Model

- Bui Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]

**Light's color** is usually the same for diffuse and specular
Phong's Lighting Model

- Bui Tuong Phong, 1975.

\[ I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}} \]

**Ambient light's color** depends on the scene.  
*Eg* lot of red objects in the scene produce a red ambient light.
Phong's Lighting Model

- Questions about ambient, diffuse, specular light?

\[
I = M_{amb} \cdot L_{amb} + M_{dif} \cdot L_{dif} \cdot n \cdot l + M_{spec} \cdot L_{spec} \cdot (v \cdot r)^{\text{shininess}}
\]
Shading

• Where to apply the light calculation?
• What points do we have in our geometry?
Shading

- Flat – apply it \textit{per polygon}
- Gouraud – apply it \textit{per vertex}, interpolate
- Phong – apply it \textit{per fragment}

Diffuse lighting with flat, Gouraud and Phong shading models.

No specular reflection

Cube has duplicate vertices
What was awesome today?

What more would you like to know?

Next time

Textures and Sampling