Information Visualization

W07: Shading

Graduation School of System Informatics

Department of Computational Science

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Schedule

- W01 4/11 Guidance
- W02 4/12 Setup
- W03 4/18 Introduction to Data Visualization
- W04 4/19 CG Programming
- W05 4/25 Rendering Pipeline
- W06 4/26 Coordinate Systems and Transformations
- W07 5/09 Shading
- W08 5/10 Shader Programming
- W09 5/16 Visualization Pipeline
- W10 5/17 Data Model and Transfer Function
- W11 5/23 Scalar Data Visualization 1 (Isosurface Extraction)
- W12 5/24 Implementation of Isosurface Extraction
- W13 5/30 Scalar Data Visualization 2 (Volume Rendering)
- W14 5/31 Implementation of Volume Rendering
- W15 6/06 Student Presentations

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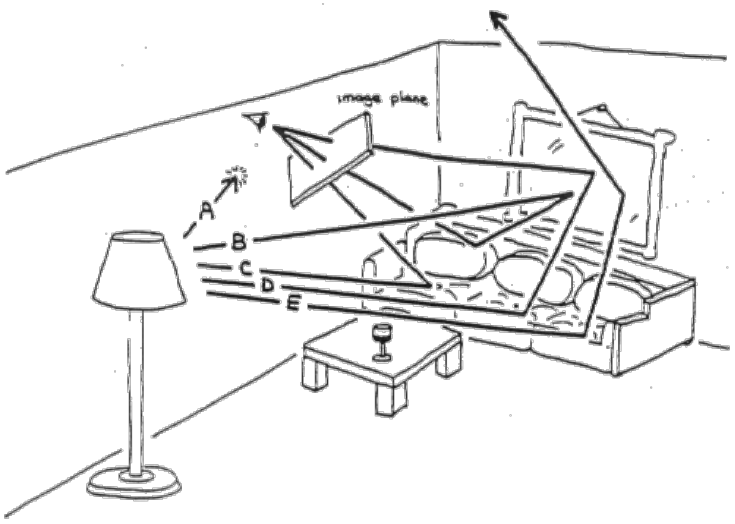
Illumination

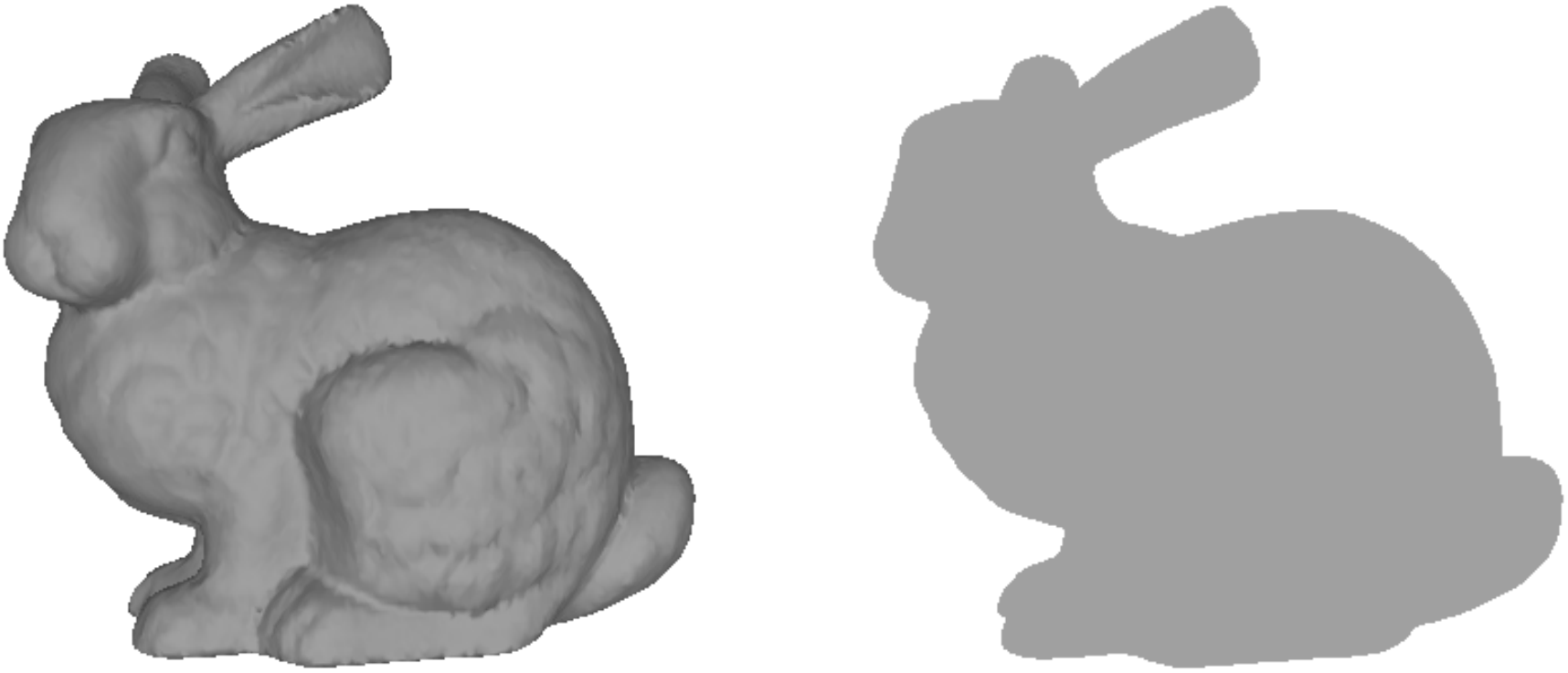
- Illumination model (Lighting)
  - From Physics we can derive models, called "illumination models", of how light reflects from surfaces and produces what we perceive as color.
  - In general, light leaves some light source, e.g. a lamp or the sun, is reflected from many surfaces and then finally reflected to our eyes, or through an image plane of a camera.



https://www.siggraph.org/education/materials/HyperGraph/illumin/illum1.htm

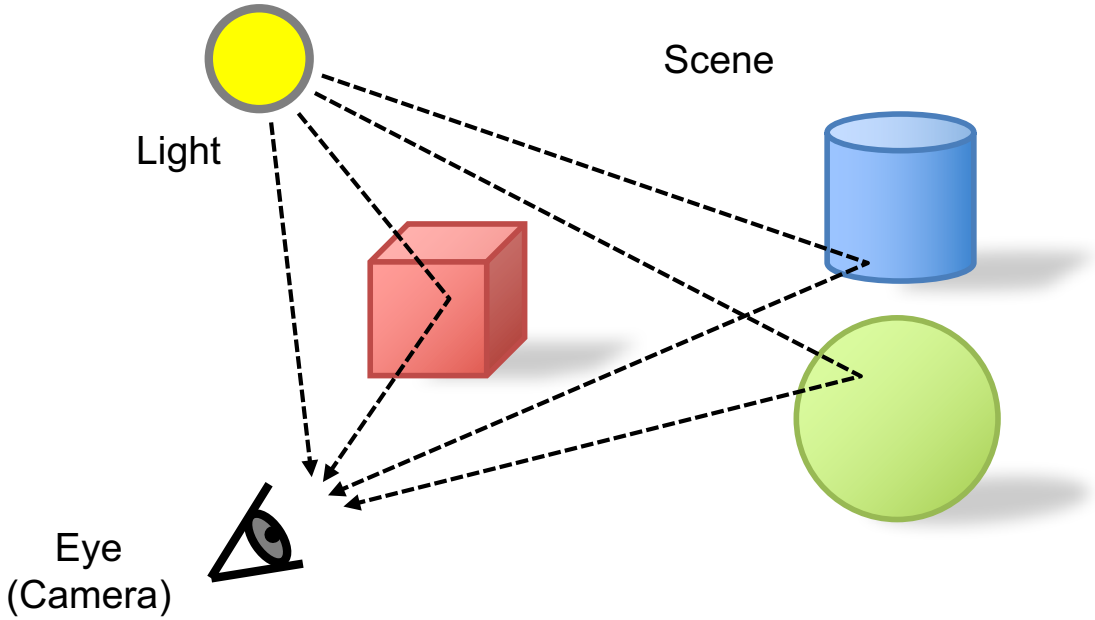
Illumination

- Lighting
  - Stanford bunny with and without lighting effects



Illumination Model

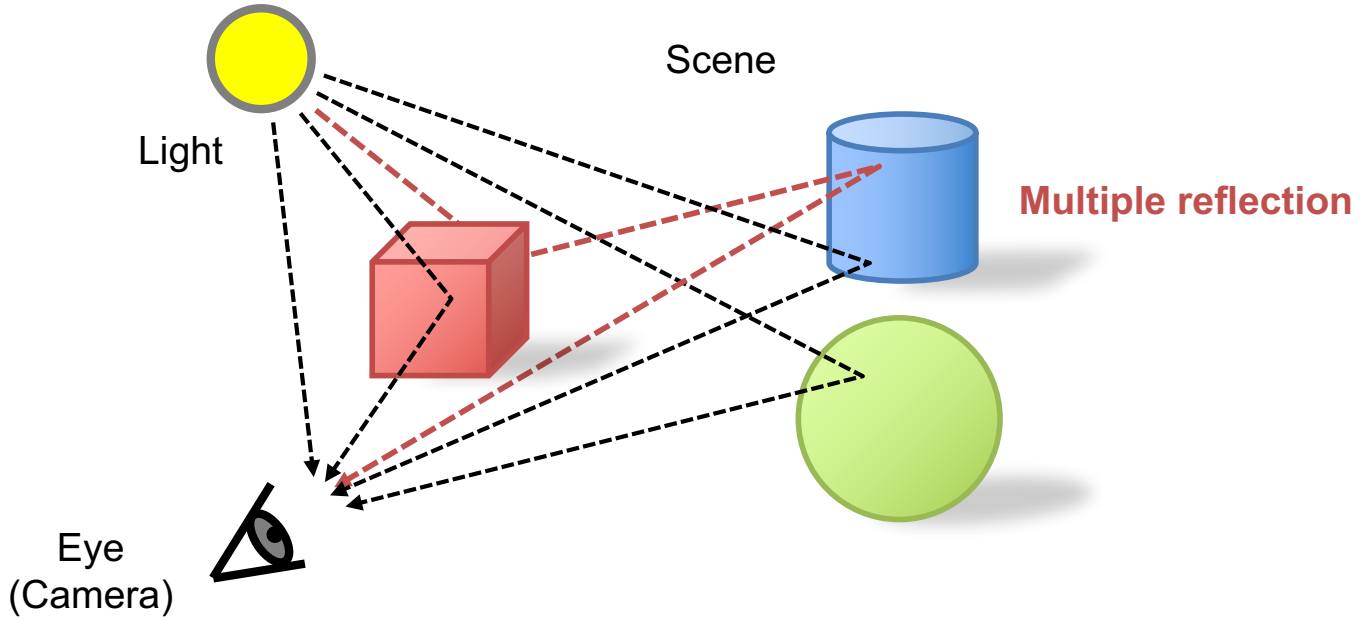
- Local Illumination Model
  - The contribution from the light that goes directly from the light source and is reflected from the surface is called a "local illumination model".



https://www.siggraph.org/education/materials/HyperGraph/illumin/illum1.htm

Illumination Model

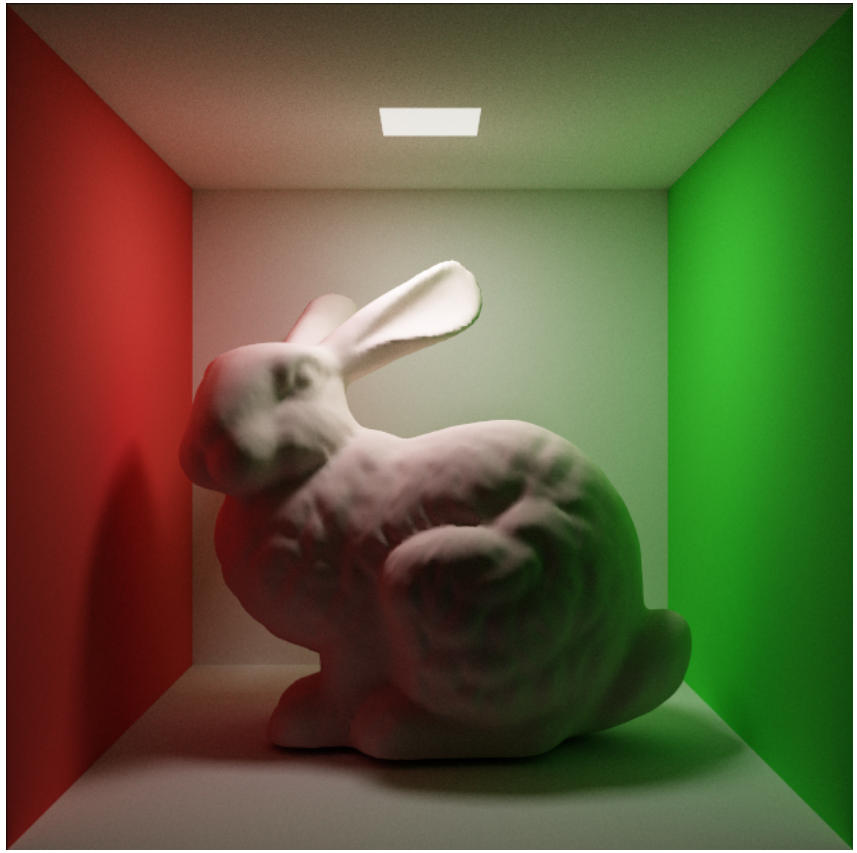
- Global Illumination Model
  - A "global illumination model" adds to the local model the light that is reflected from other surfaces to the current surface.

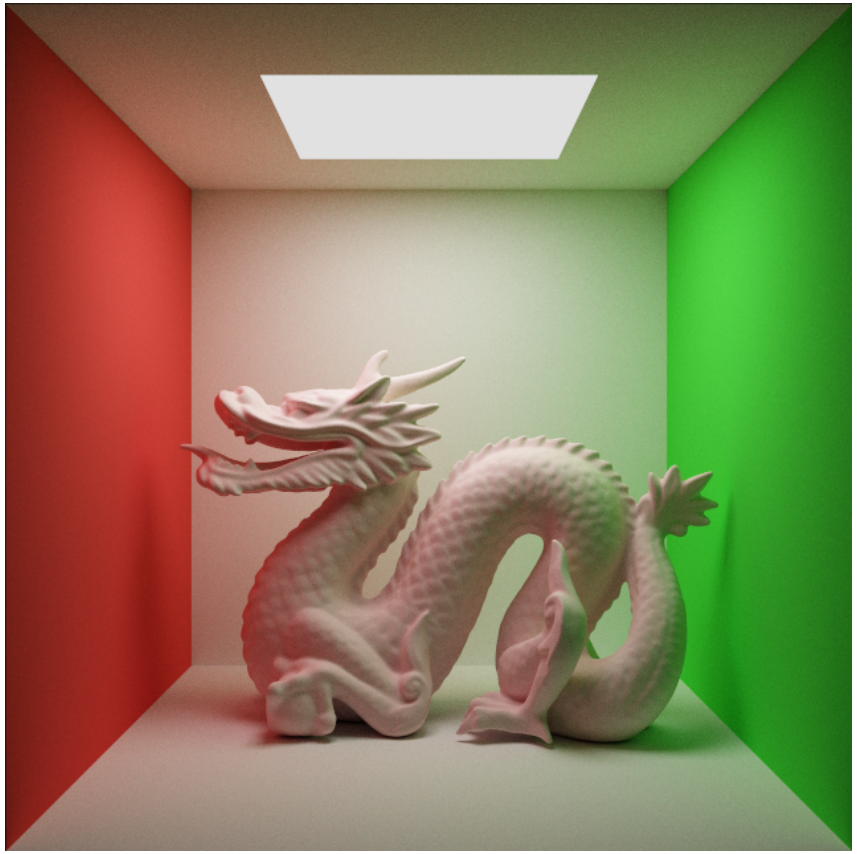


https://www.siggraph.org/education/materials/HyperGraph/illumin/illum1.htm

Illumination

- Global Illumination Model





http://srodal.net/oldray/

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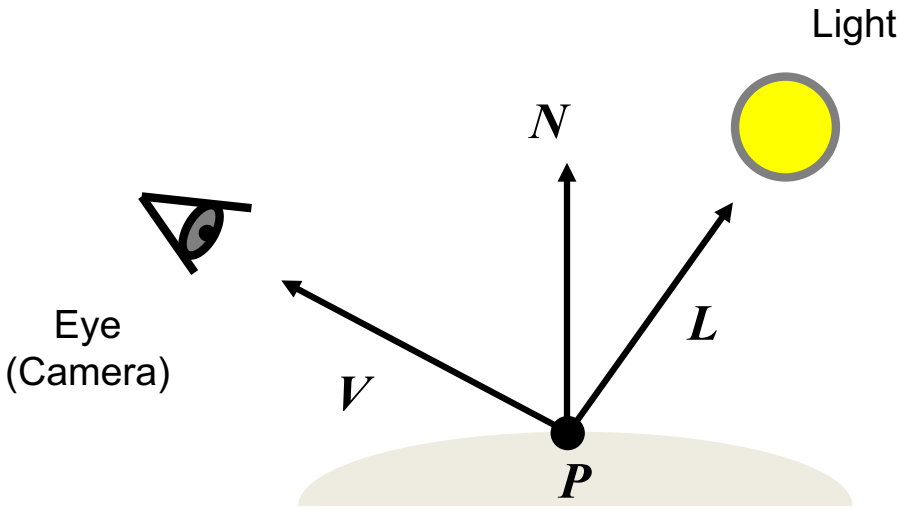
- Illumination Model
- Reflection Model
- Shading Model
- Shader Programming

Reflection

- The intensity (luminosity) of the reflected light can be calculated by the following components.
  - Ambient reflection
  - Diffuse reflection
  - Specular reflection



P	Point on a surface
N	Normal vector at P
L	Light direction at P
V	Viewing direction at P

Ambient Reflection

- Reflection of light from the environment and assumed to be equal in all directions.
  - Independent of light position, object orientation, camera position or orientation

$$I_{ambient} = I_a \, k_a$$

$I_{ambient}$	Intensity of the ambient reflection
I_a	Ambient intensity
k_a	Ambient reflection coefficient

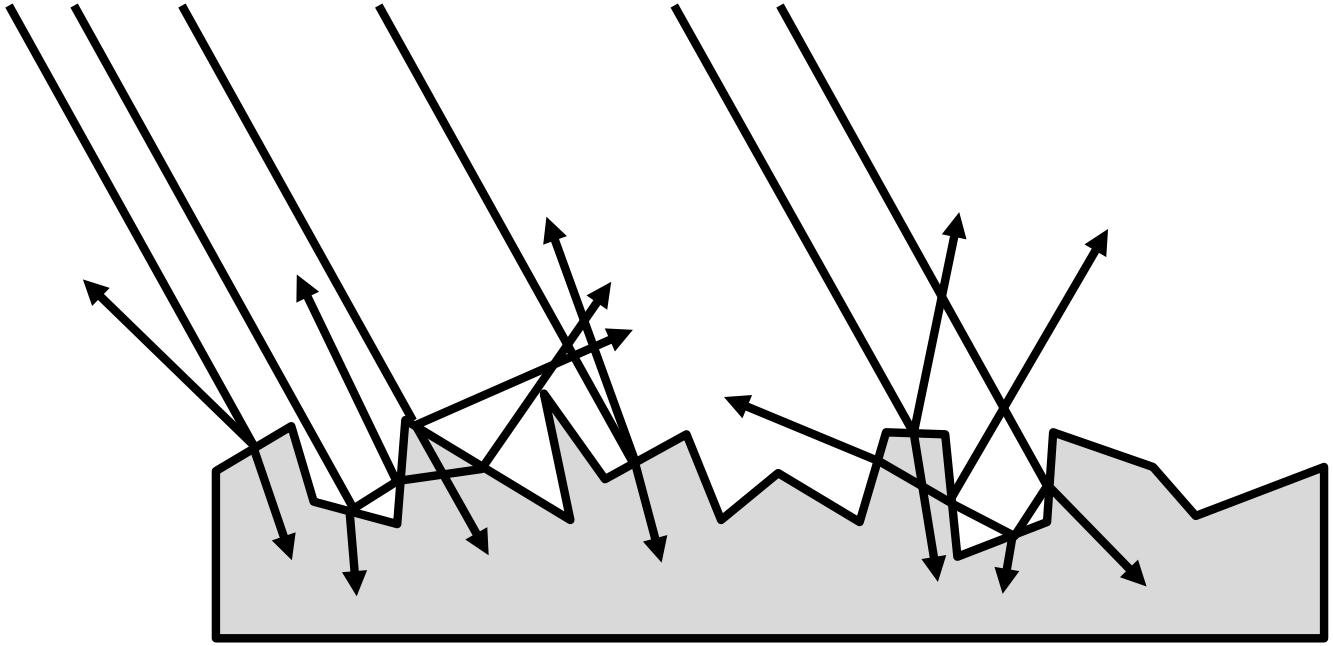
Ambient Reflection

- Effect of ambient reflection coefficient k_a

$k_a = 0.2$ $k_a = 0.6$ $k_a = 1.0$

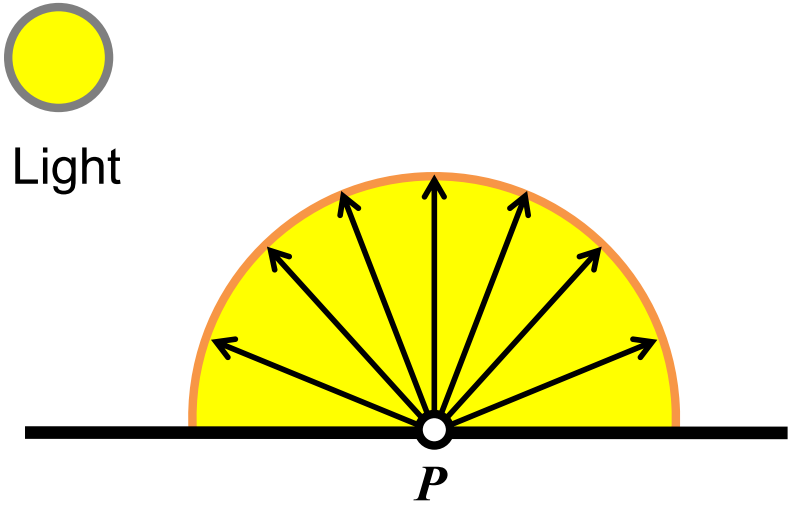
Diffuse Reflection

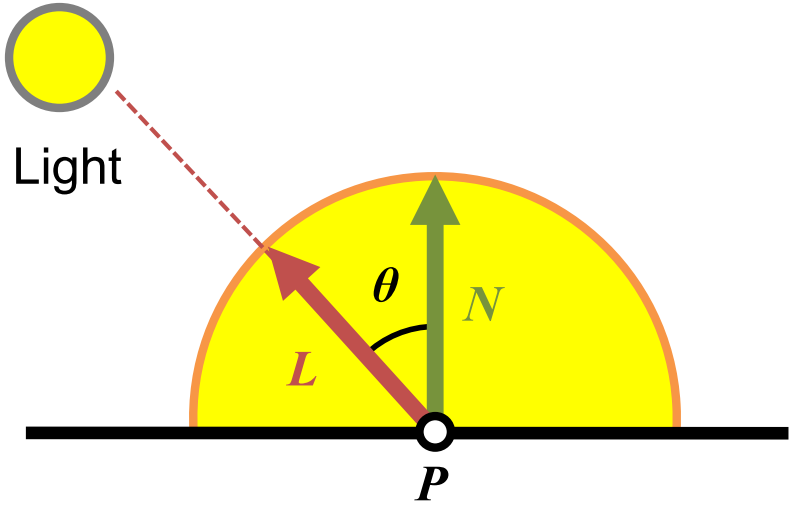
- Reflection of light from a surface such that incident light is reflected into many different directions.



Diffuse Reflection

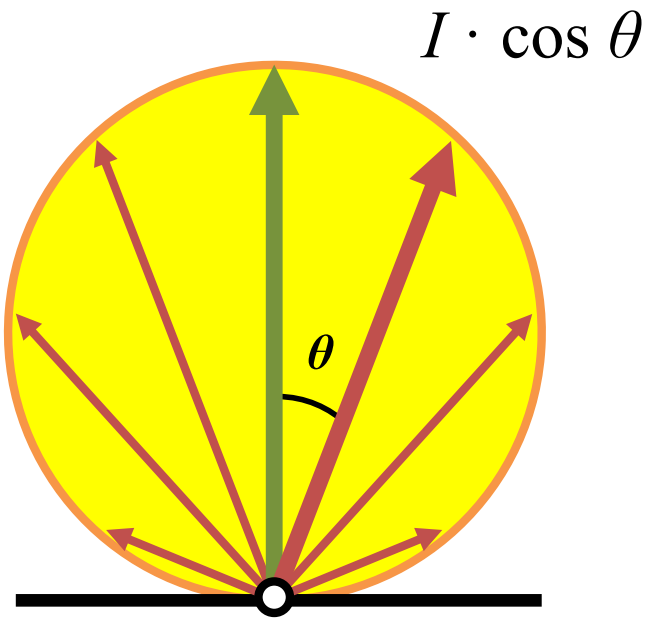
- Reflected intensity does not depend on the viewing direction.
- Incoming light depends on the light direction.





Diffuse Reflection

- Lambert's cosine law
  - Radiant intensity observed from an ideal diffusely reflecting surface is directly proportional to the cosine of the angle θ between the direction of the incident light and the surface normal.



https://en.wikipedia.org/wiki/Lambert%27s_cosine_law

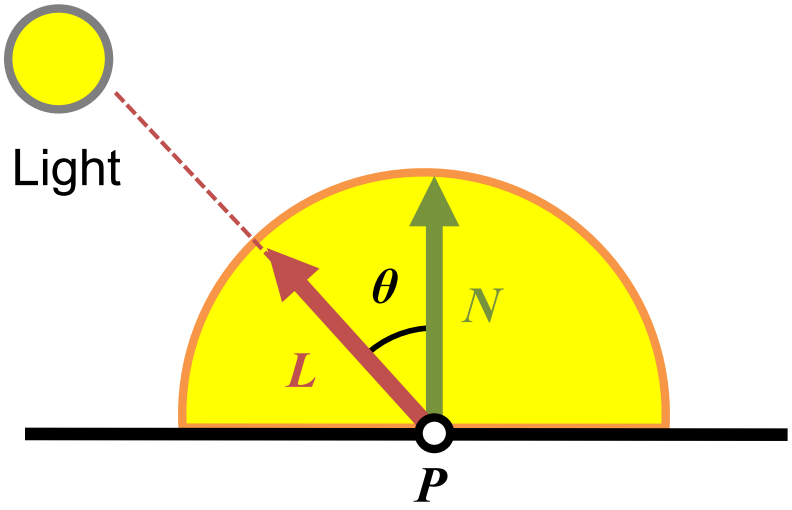
Diffuse Reflection

- Calculation of diffuse reflection

$$I_{diffuse} = I_i \, k_d \cos\theta$$

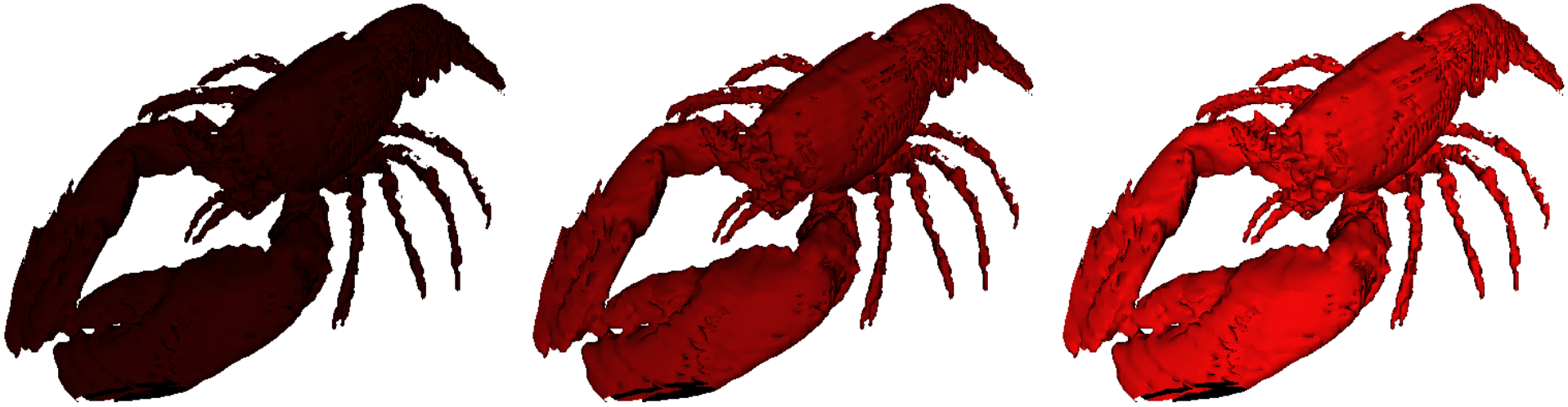
$$= I_i \, k_d \, (\boldsymbol{N} \cdot \boldsymbol{L})$$

$I_{diffuse}$	Intensity of the diffuse reflection
I_i	Intensity of the light source
k_d	Diffuse reflection coefficient
$\boldsymbol{N}$	Normal vector (unit vector)
$\boldsymbol{L}$	Light direction (unit vector)



Diffuse Reflection

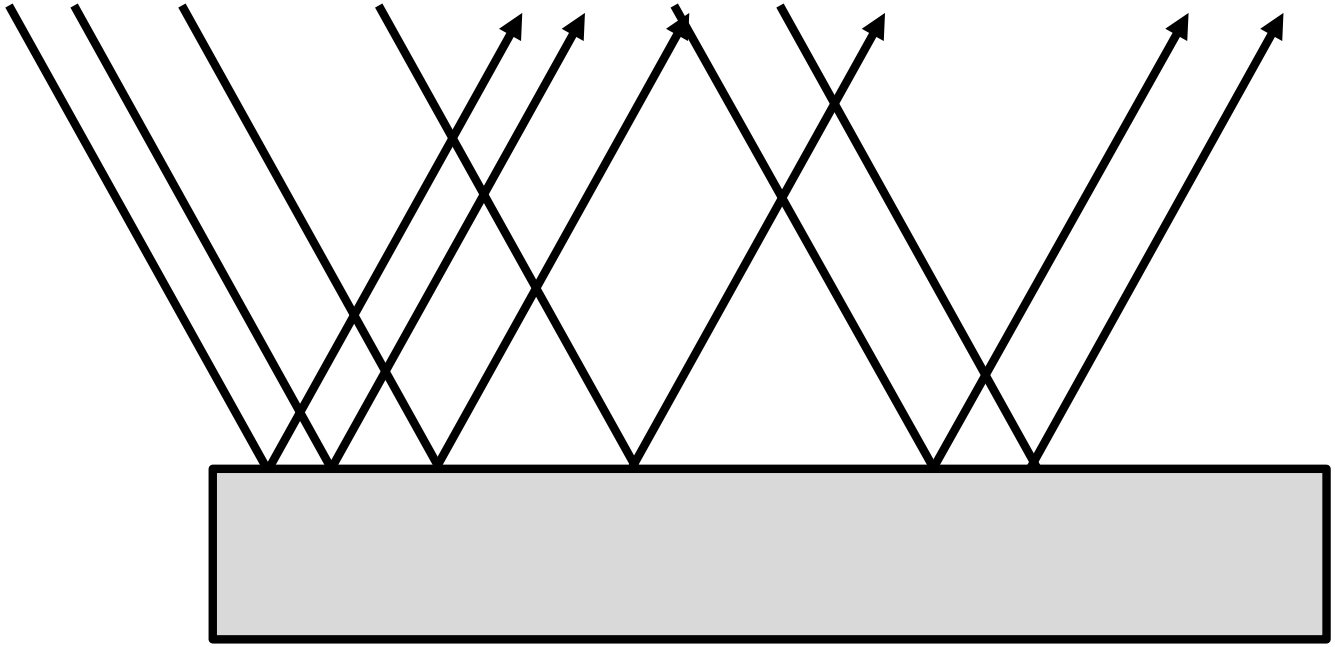
- Effect of diffuse reflection coefficient k_d



$k_d = 0.2$ $k_d = 0.6$ $k_d = 1.0$

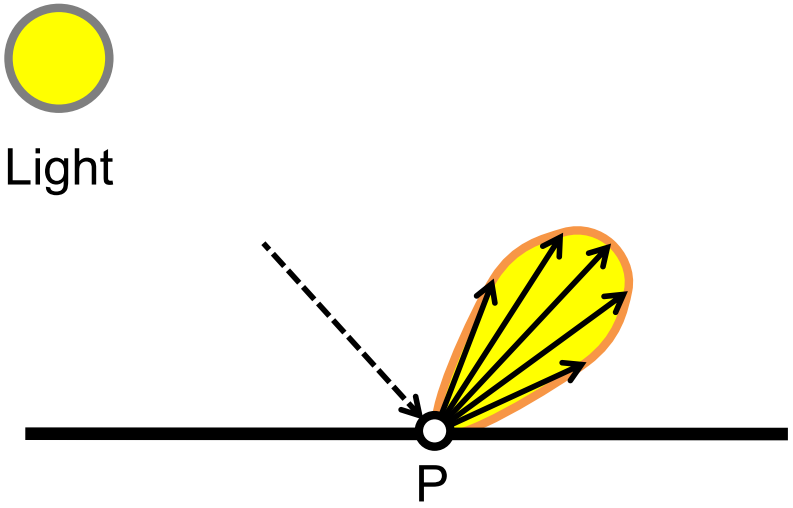
Specular Reflection

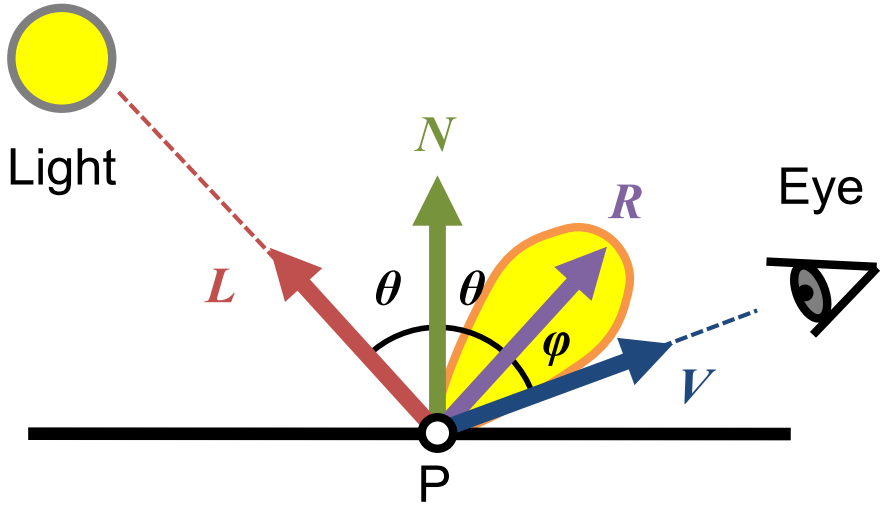
- Mirror-like reflection of light from a surface, in which light from a single incoming direction is reflected into a single outgoing direction.



Specular Reflection

- Reflected intensity does not depend on the viewing direction.
- Incoming light depends on the light direction.





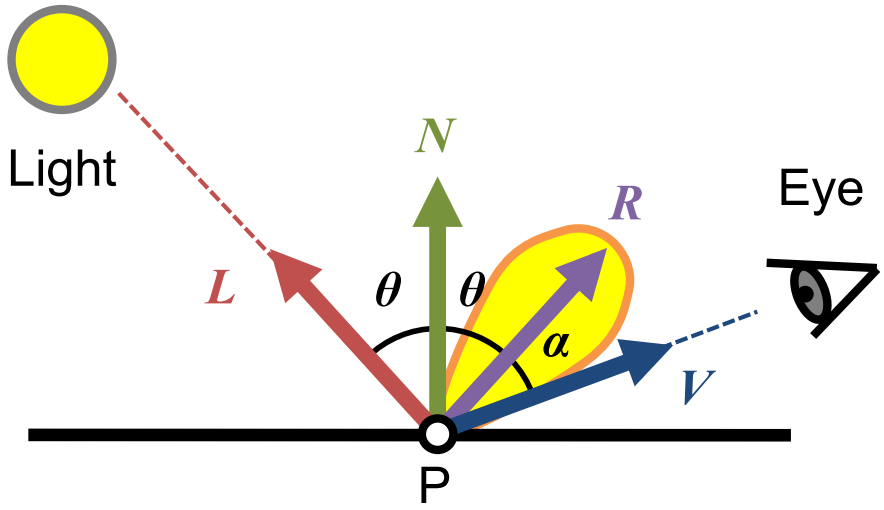
Specular Reflection

- Calculation of specular reflection

$$I_{specular} = I_i \, k_s \cos^n \alpha$$

$$= I_i \, k_s \, (\boldsymbol{V} \cdot \boldsymbol{R})^n$$

$I_{specular}$	Intensity of the specular reflection
I_i	Intensity of the light source
k_s	Specular reflection coefficient
$\boldsymbol{N}$	Normal vector (unit vector)
$\boldsymbol{L}$	Light direction (unit vector)
$\boldsymbol{V}$	Viewing direction (unit vector)
$\boldsymbol{R}$	Reflection vector of $\boldsymbol{L}$

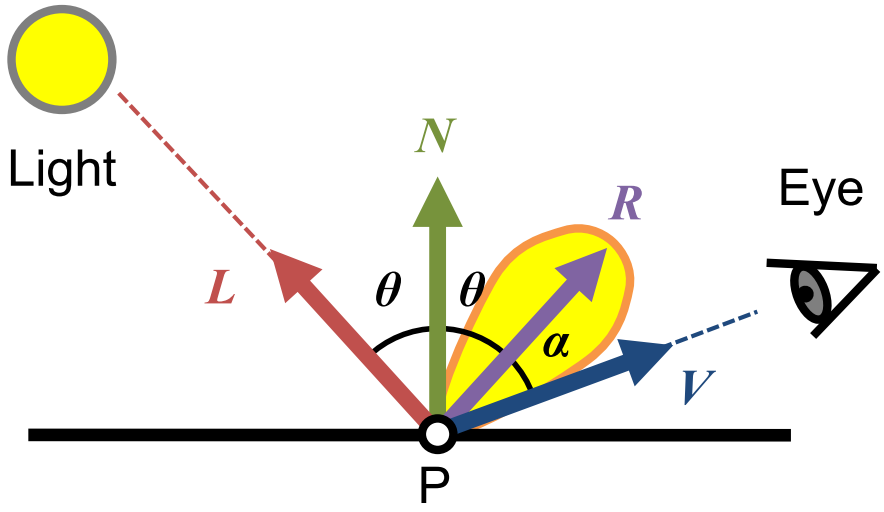


Specular Reflection

- Calculation of reflection vector $\boldsymbol{R}$

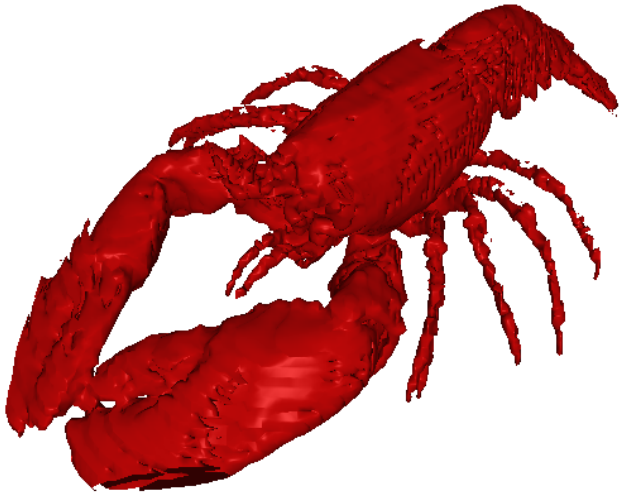
$$\boldsymbol{R} = 2\,(\boldsymbol{N} \cdot \boldsymbol{L})\,\boldsymbol{N} - \boldsymbol{L}$$

$I_{specular}$	Intensity of the specular reflection
I_i	Intensity of the light source
k_s	Specular reflection coefficient
$\boldsymbol{N}$	Normal vector (unit vector)
$\boldsymbol{L}$	Light direction (unit vector)
$\boldsymbol{V}$	Viewing direction (unit vector)
$\boldsymbol{R}$	Reflection vector of $\boldsymbol{L}$

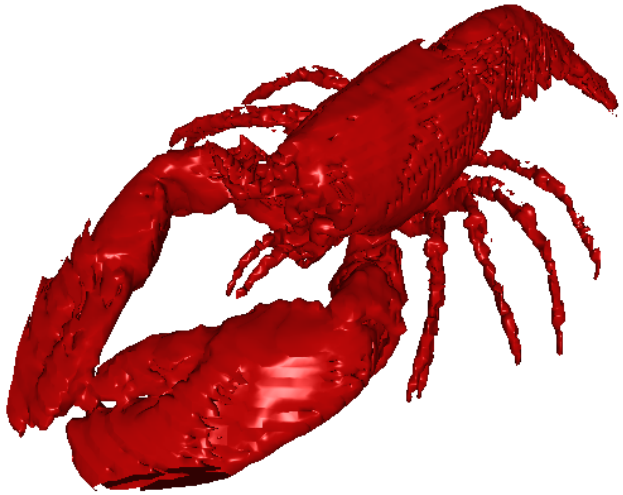


Specular Reflection

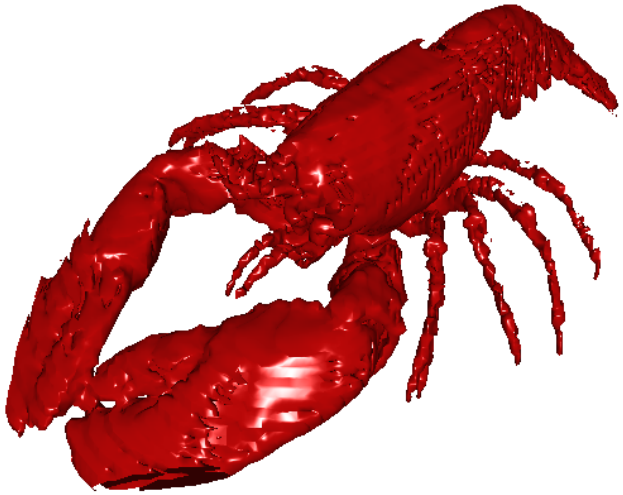
- Effect of specular reflection coefficient k_s



$k_s = 0.2$



$k_s = 0.6$

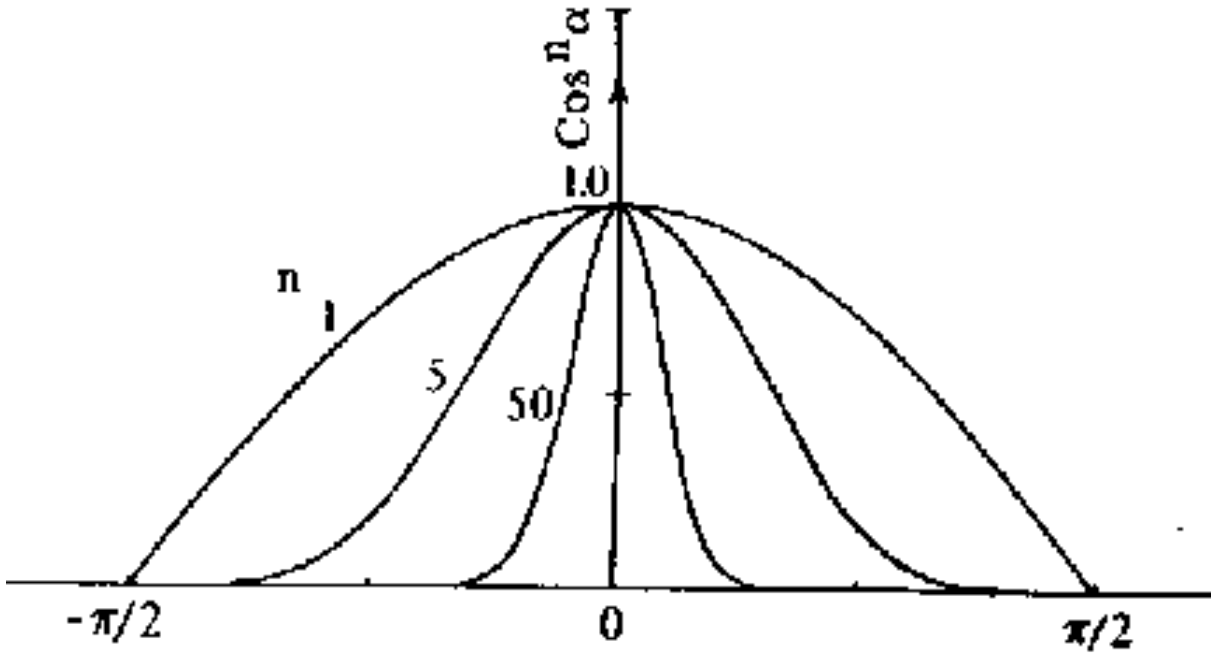


$k_s = 1.0$

Specular Reflection

- Shininess exponent n

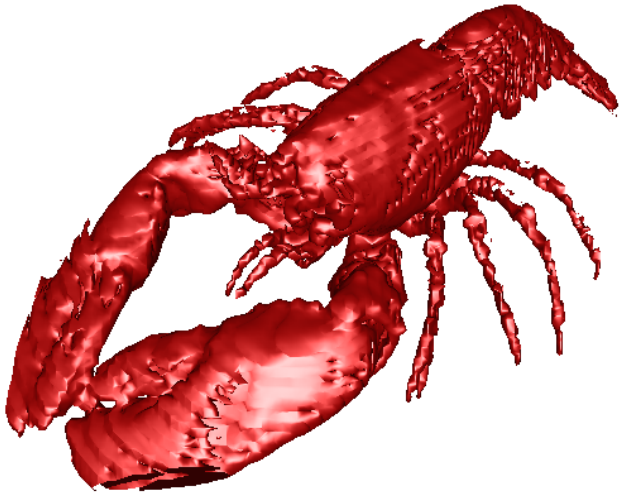
$$I_{specular} = I_i k_s \cos^n \alpha$$



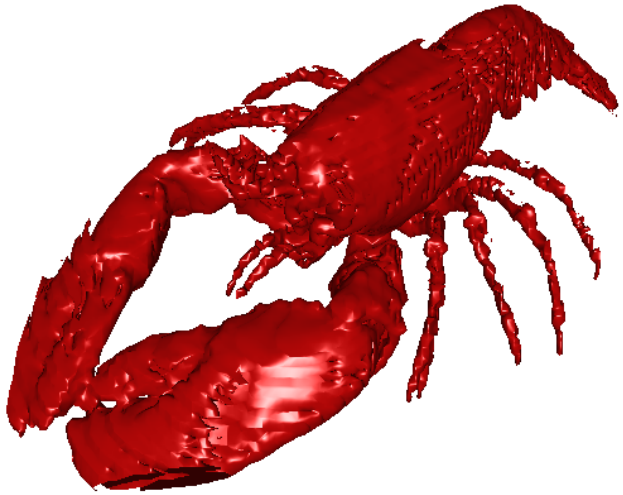
https://www.siggraph.org/education/materials/HyperGraph/illumin/specular_highlights/phong_model_specular_reflection.htm

Specular Reflection

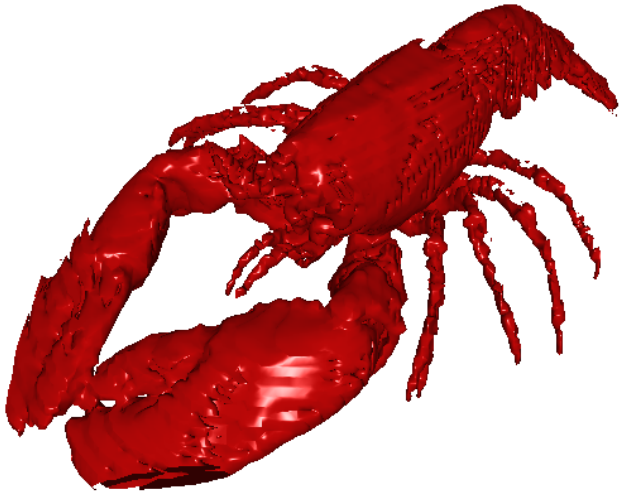
- Effect of shininess exponent n



$n = 10$



$n = 50$



$n = 150$

Reflection Model

- Lambertian reflection model

$$I = I_{ambient} + I_{diffuse}$$

$$= I_a k_a + I_i k_d (\boldsymbol{N} \cdot \boldsymbol{L})$$

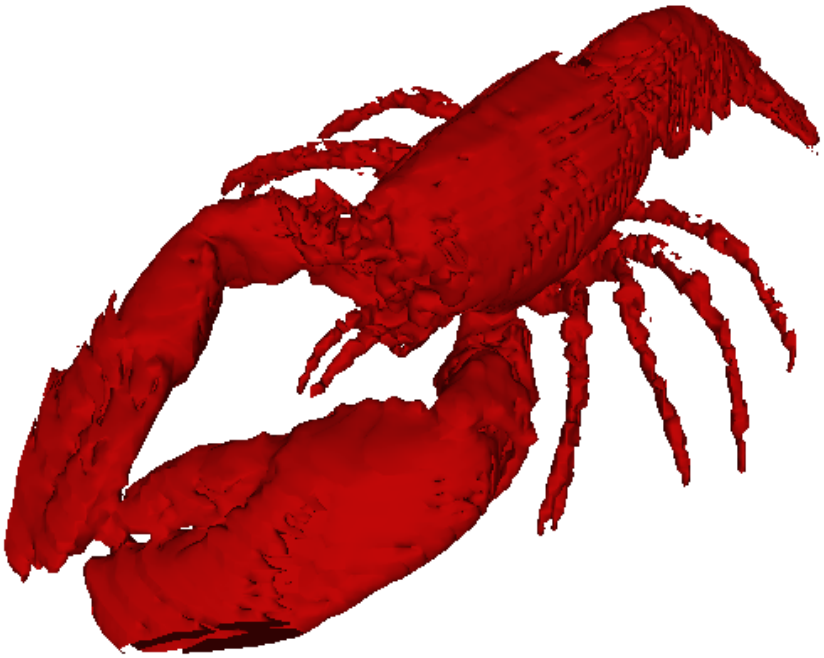
- Phong reflection model

$$I = I_{ambient} + I_{diffuse} + I_{specular}$$

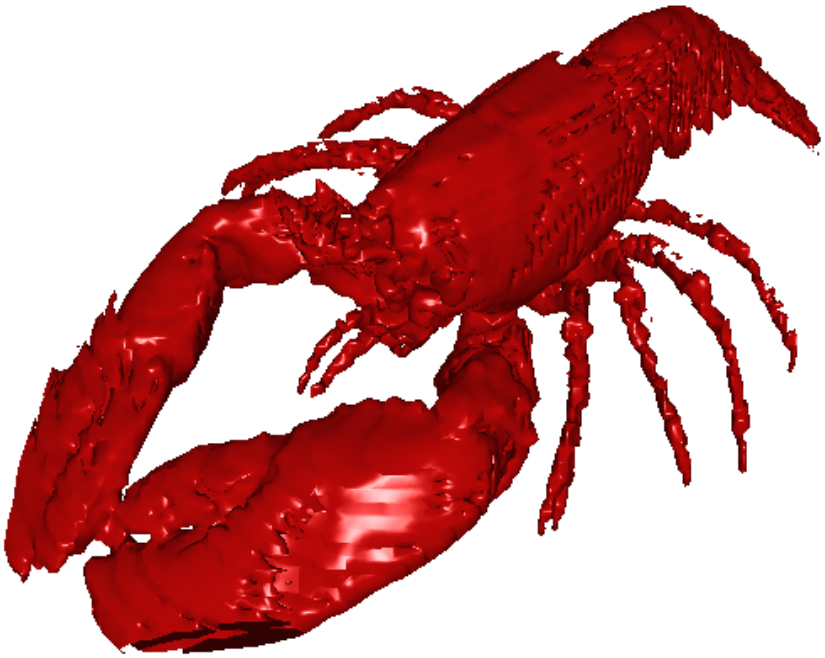
$$= I_a k_a + I_i k_d (\boldsymbol{N} \cdot \boldsymbol{L}) + I_i k_s (\boldsymbol{V} \cdot \boldsymbol{R})^n$$

Reflection Model

- Comparison with Lambertian (left) and Phong (right) reflection models



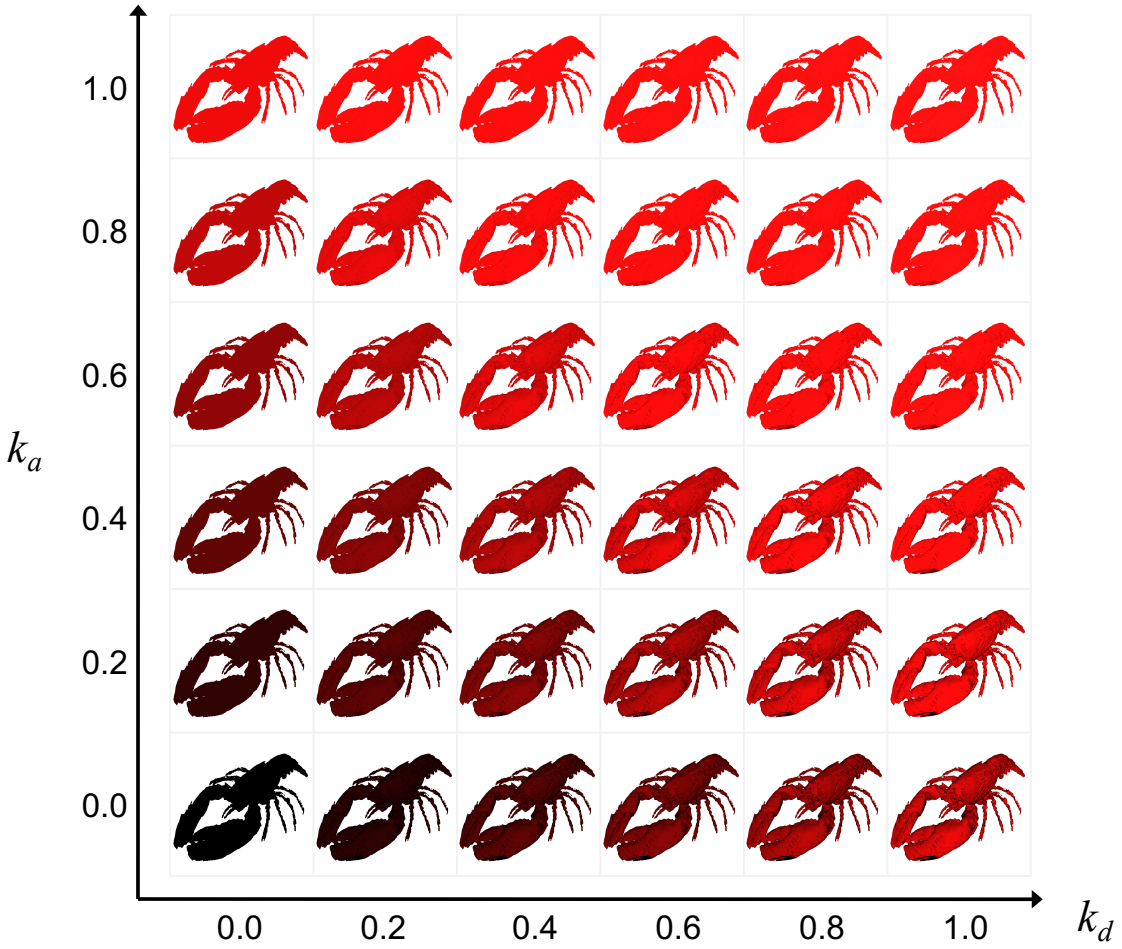
$k_a = 0.2, k_d = 0.6$



$k_a = 0.2, k_d = 0.6, k_s = 0.8, n = 100$

Lambertian Reflection Model

- Effect of k_a and k_d



Phong Reflection Model

- Effect of k_s and n

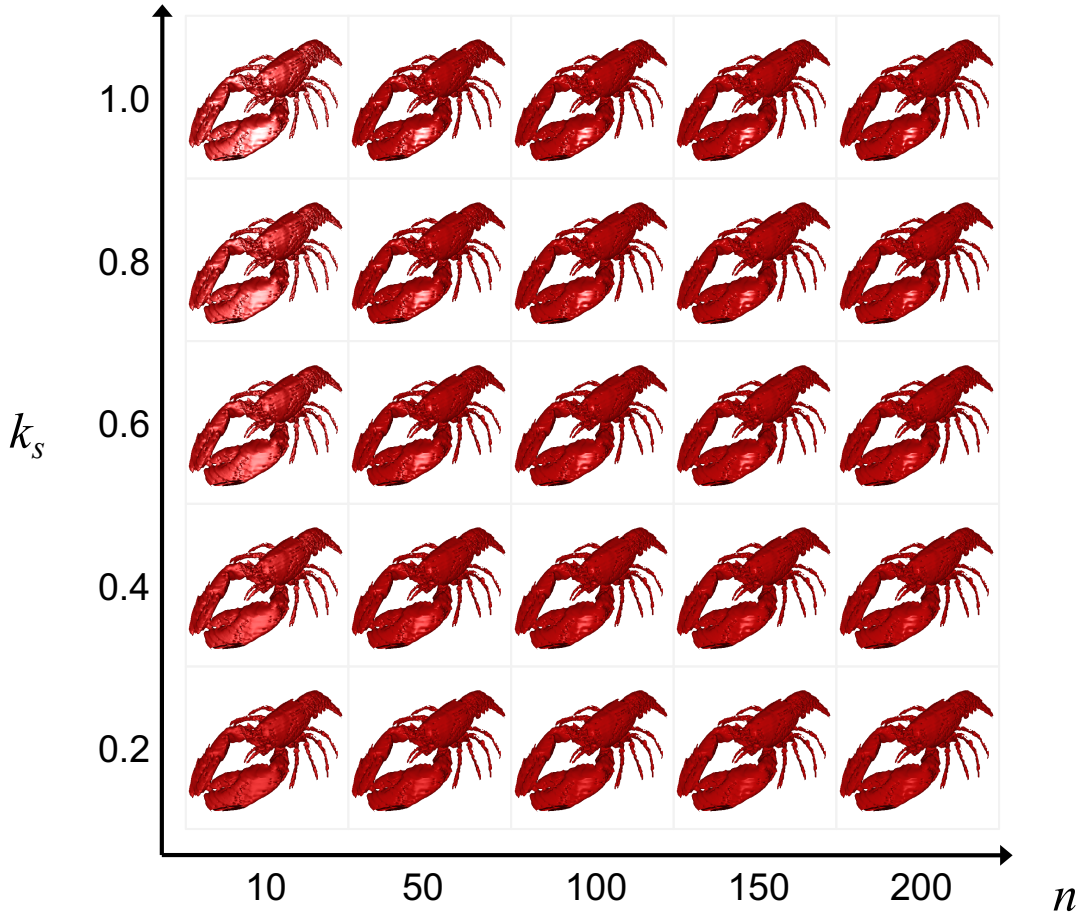


Table of Contents

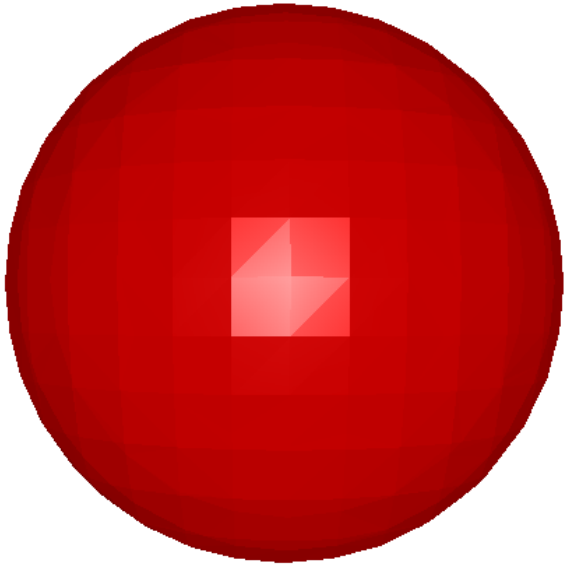
- Illumination Model
- Reflection Model
- Shading Model
- Shader Programming

Shading

- Process of determining the color of a pixel based on the reflection models
  - Flat shading
  - Smooth shading

Flat Shading

- Uses the same color for every pixel in a face
  - Less computationally expensive
  - Edges appear
  - Not suitable for smooth objects

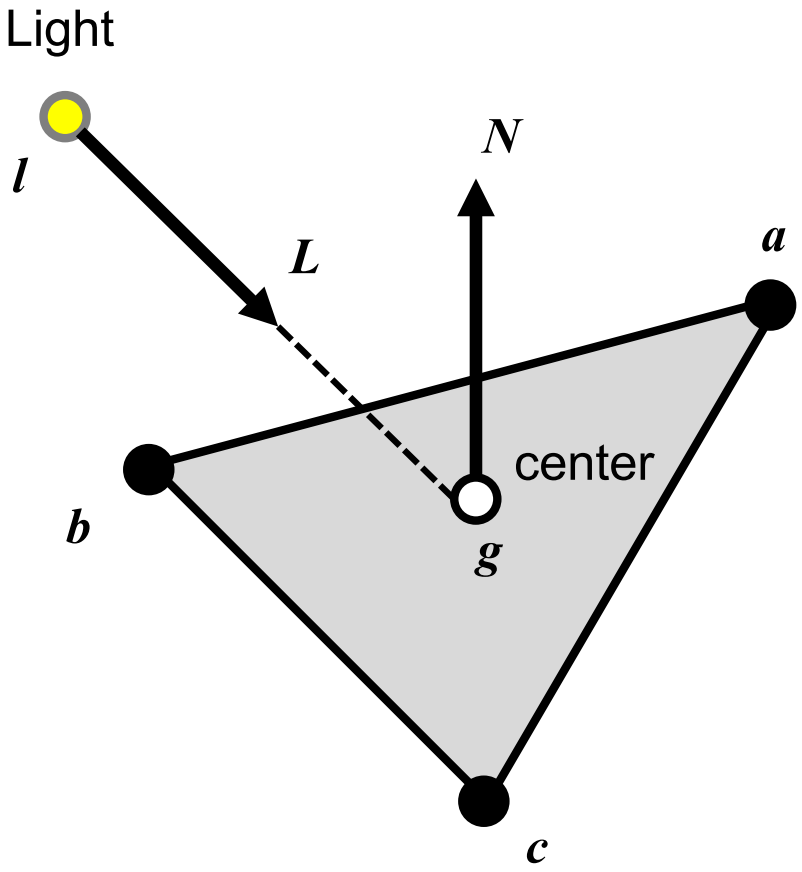


Flat Shading

- Calculation of normal vector $\boldsymbol{N}$ and light direction vector $\boldsymbol{L}$ for a face

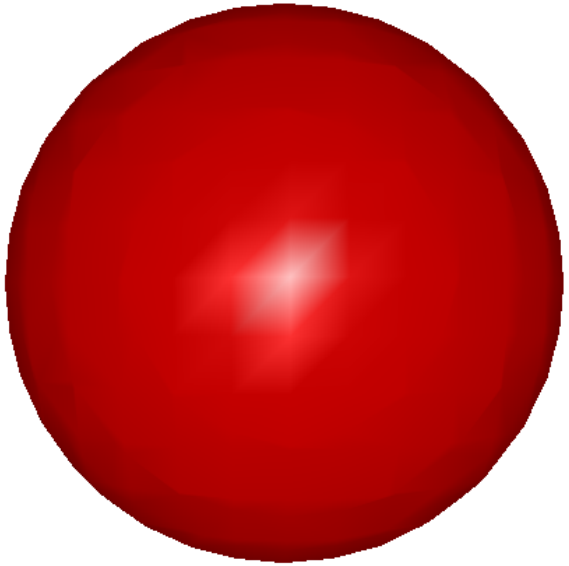
$$\vec{N} = \frac{(\vec{b}-\vec{a}) \times (\vec{c}-\vec{a})}{\left|(\vec{b}-\vec{a}) \times (\vec{c}-\vec{a})\right|}$$

$$\vec{L} = \frac{\vec{l}-\vec{g}}{\left|\vec{l}-\vec{g}\right|}$$



Smooth Shading

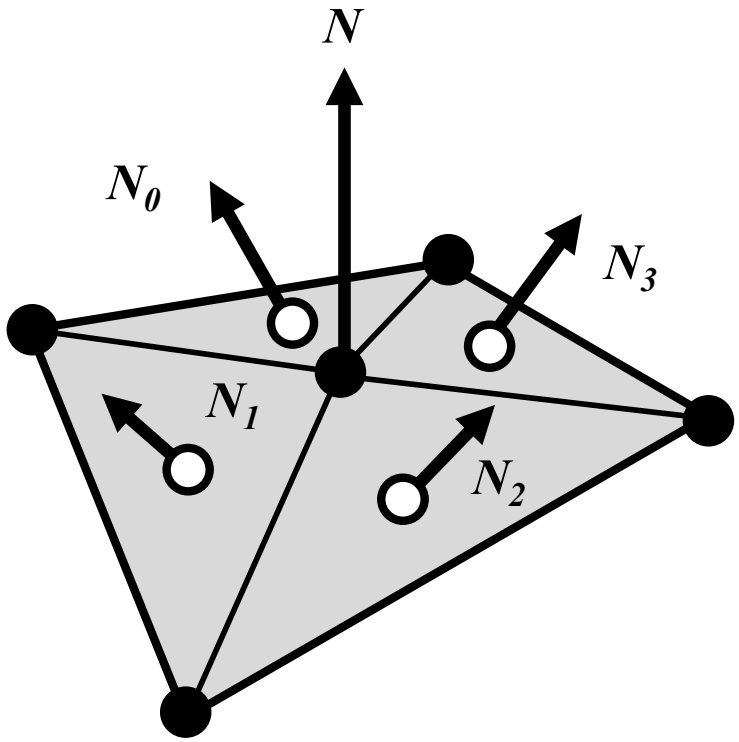
- Uses linear interpolation of colors or normal vectors between vertices
  - More computationally expensive
  - Edges disappear
  - Suitable for any objects



Smooth Shading

- Calculation of normal vector N for a vertex

$$\vec{N} = \frac{\vec{N}_0 + \vec{N}_1 + \vec{N}_2 + \vec{N}_3}{\left|\vec{N}_0 + \vec{N}_1 + \vec{N}_2 + \vec{N}_3\right|}$$

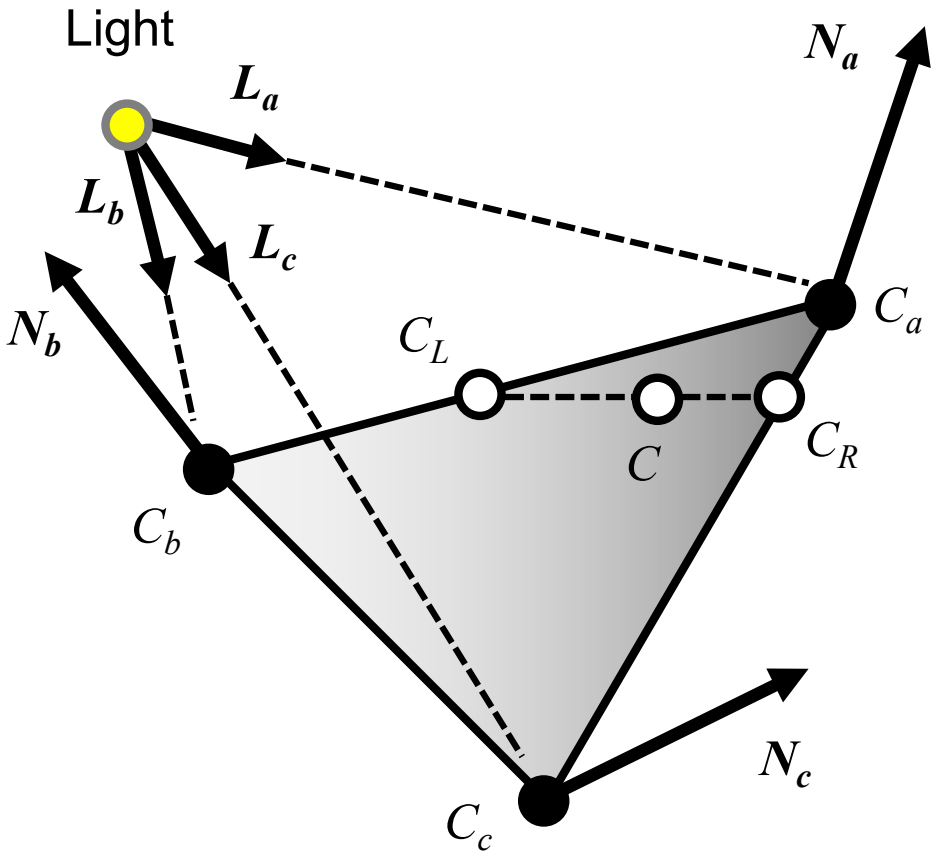


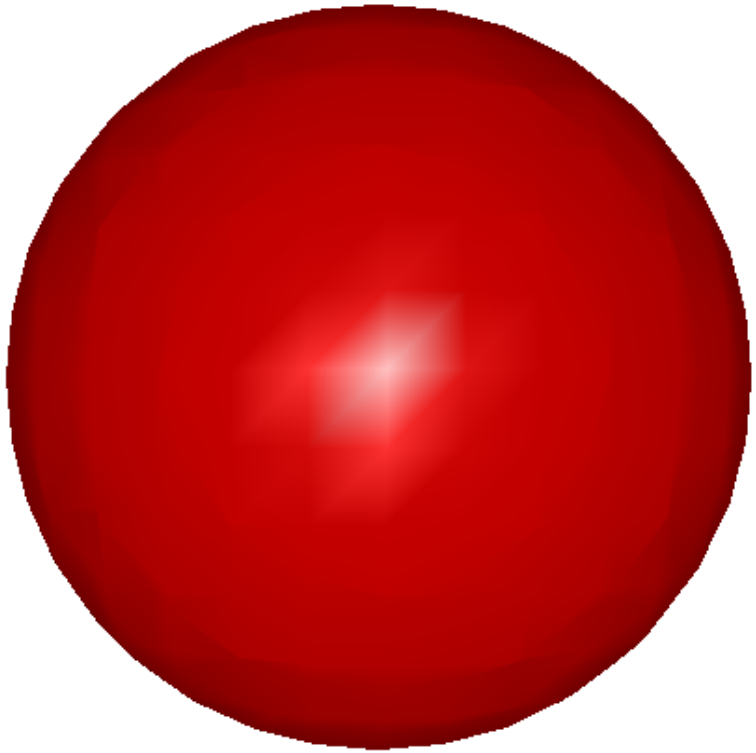
Types of Smooth Shading

- Gouraud shading
  - Color interpolation shading
- Phong shading
  - Normal interpolation shading

Gouraud Shading

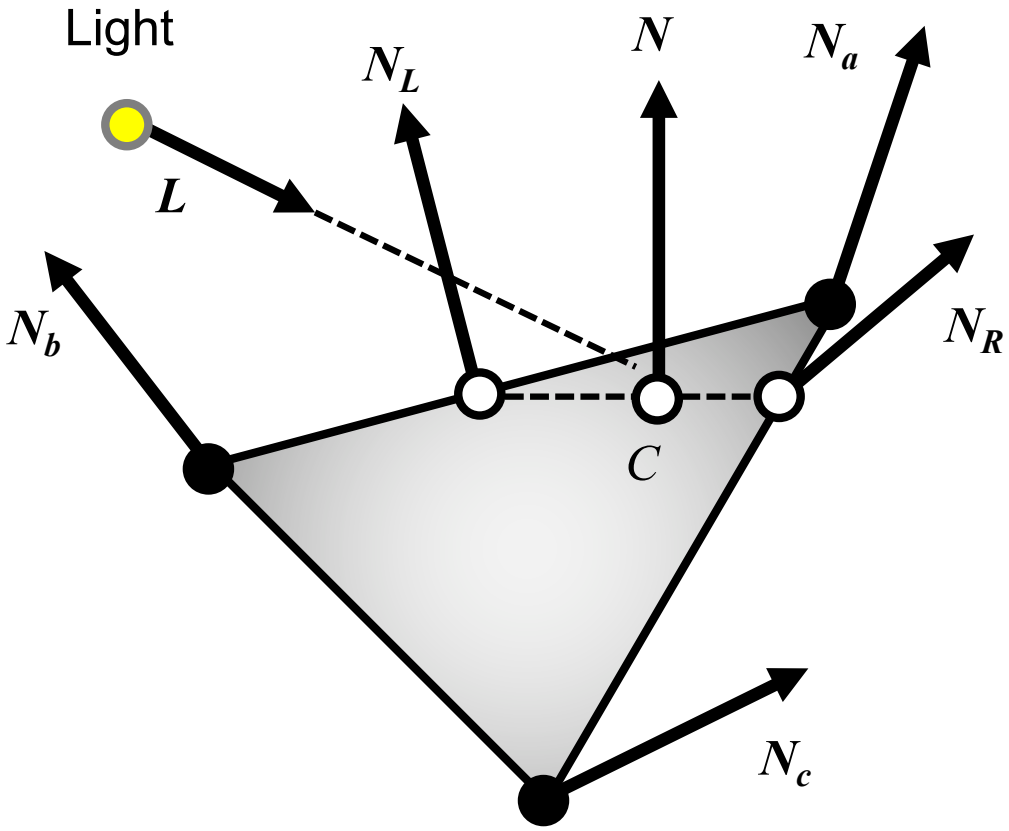
- Colors are interpolated across the face
- Reflection model used at each vertex

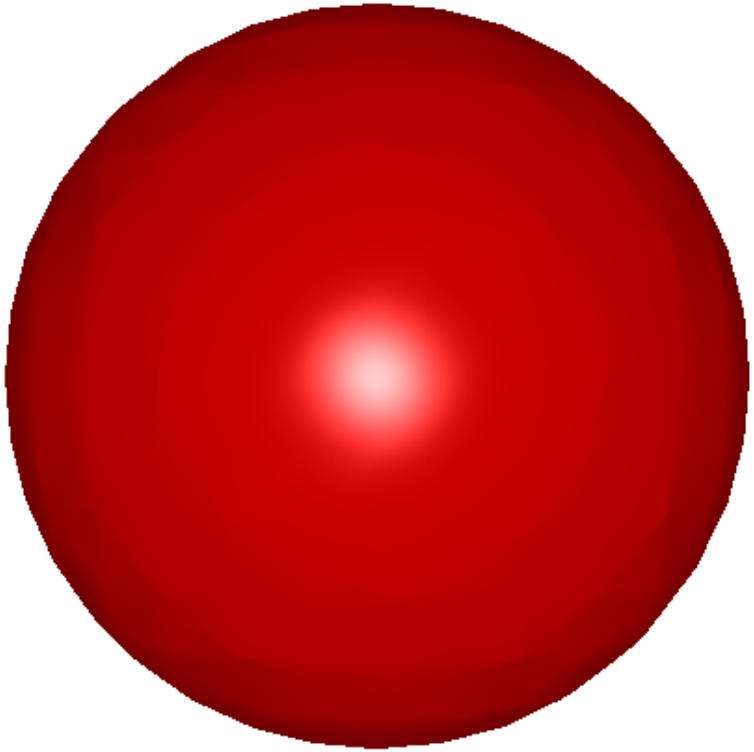




Phong Shading

- Normals are interpolated across the face
- Reflection model used at each pixel





Interpolation

- Linear interpolation

$$S = (1 - t)\, S_0 + t\, S_1$$

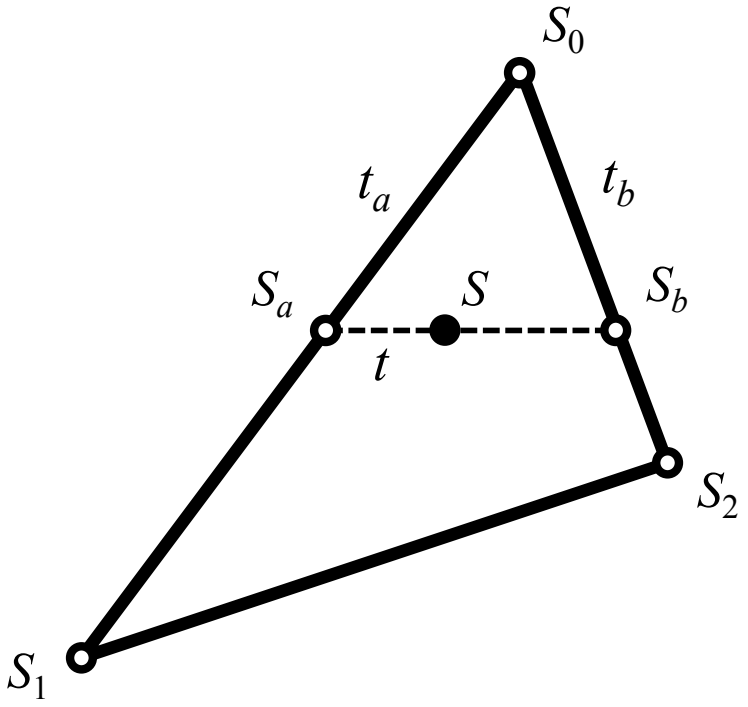
Interpolation

- Bilinear interpolation

$$S = (1 - t)\, S_{\mathrm{a}} + t\, S_{\mathrm{b}}$$

$$S_a = (1 - t_a)\, S_0 + t_a\, S_1$$

$$S_b = (1 - t_b)\, S_0 + t_b\, S_2$$



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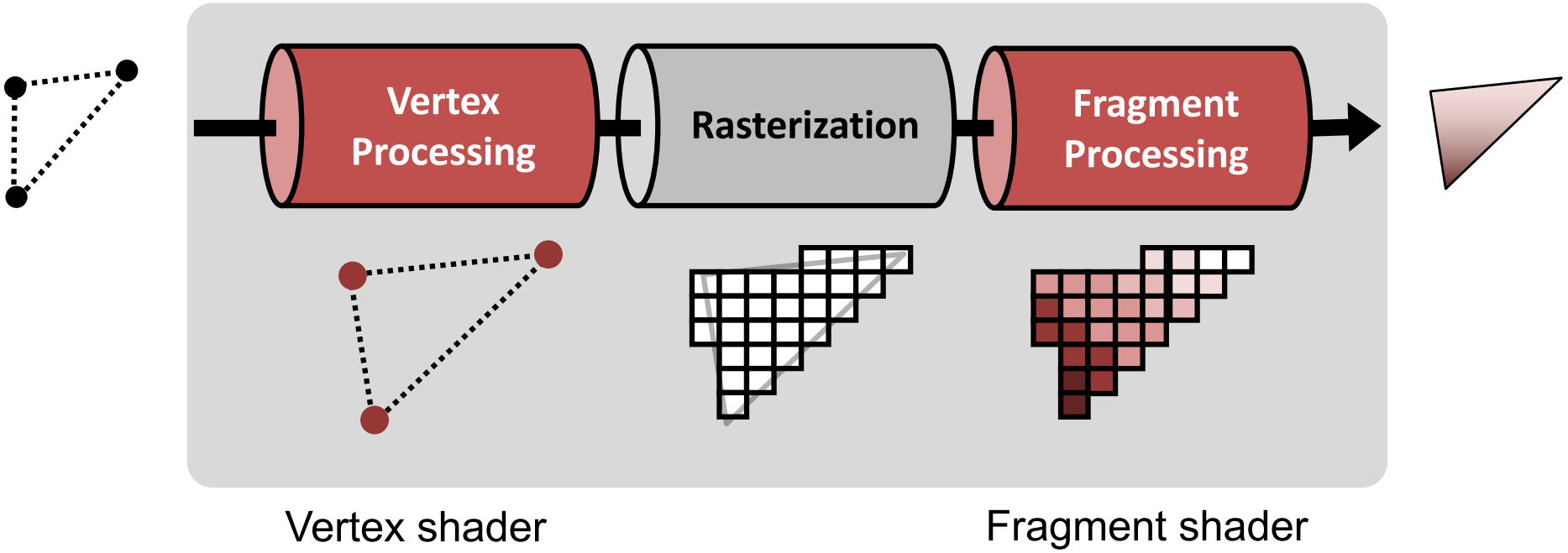
Shader

- OpenGL Shading Language (GLSL)
  - High-level shading language based on the syntax of the C programming language.
  - Created by the OpenGL ARB (OpenGL Architecture Review Board) to give developers more direct control of the graphics pipeline without having to use ARB assembly language or hardware-specific languages.

https://en.wikipedia.org/wiki/OpenGL_Shading_Language

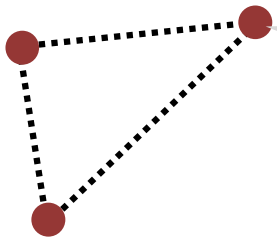
Shader Programming

- Rendering pipeline
  - Vertex shader
  - Fragment shader



Vertex Shader

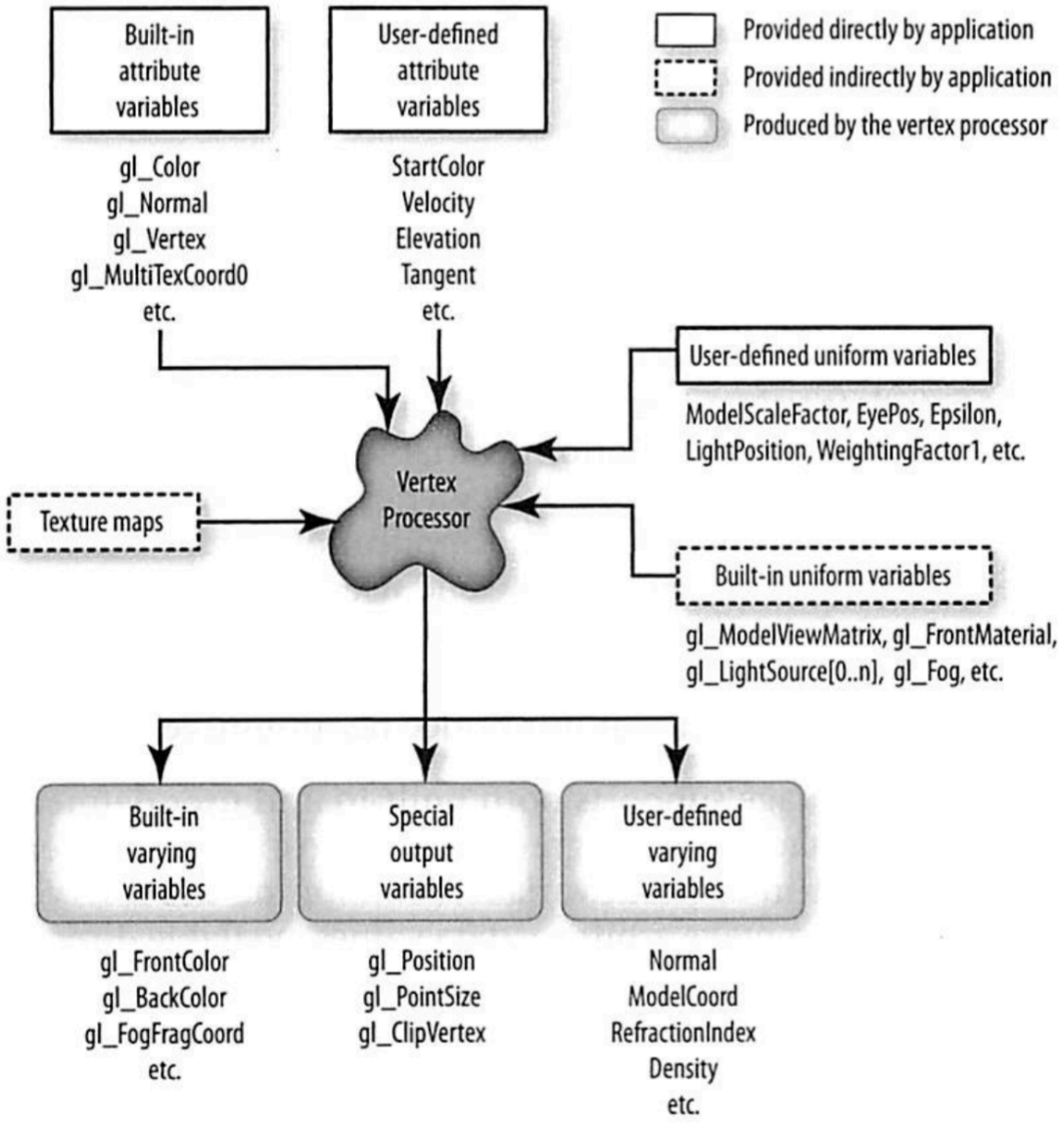
- Programmable Shader stage in the rendering pipeline that handles the processing of individual vertices.



```
void main()
{
    vec4 v = vec4( position, 1.0 );
    mat4 MV = modelViewMatrix;
    mat4 P = projectionMatrix;
    gl_Position = P * MV * v;
}
```

https://en.wikipedia.org/wiki/OpenGL_Shading_Language

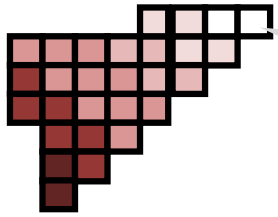
Vertex Shader Inputs and Outputs



[OpenGL Shading Language]

Fragment Shader

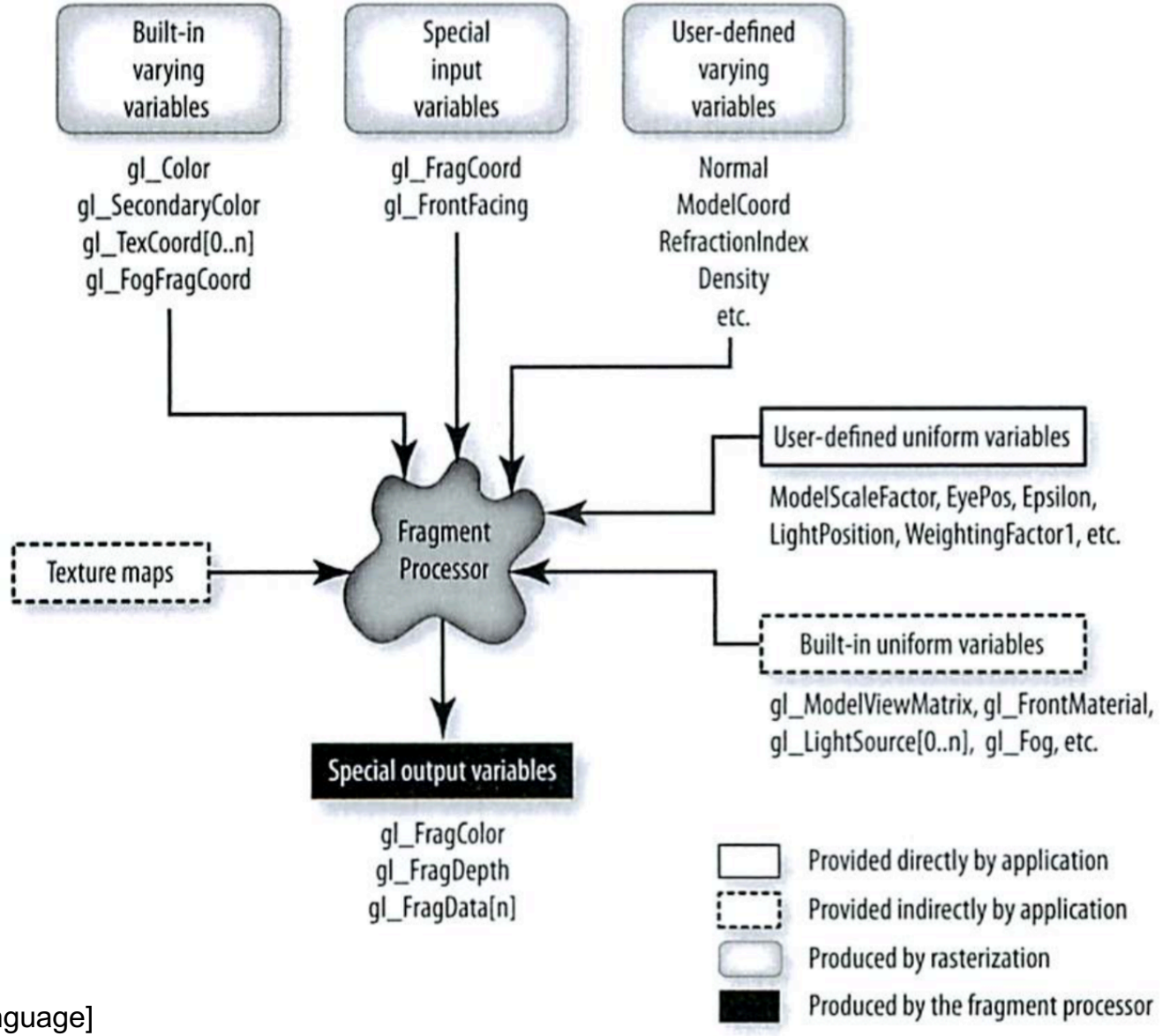
- Programmable Shader stage that will processes a Fragment generated by the Rasterization into a set of colors and a single depth value.



```
void main()
{
    vec4 C = vec4(0.8,0.1,0.1,1.0);
    gl_FragColor = C;
}
```

https://en.wikipedia.org/wiki/OpenGL_Shading_Language

Fragment Shader Inputs and Outputs



[OpenGL Shading Language]

Implementation

- Gouraud shading
  - Vertex shader

```
void main()
{
    point_position = modelViewMatrix * vec4( position, 1.0 );
    normal_vector = normalMatrix * normal;

    vec3 C = color;
    vec3 L = normalize( light_position - point_position.xyz );
    vec3 N = normalize( normal_vector );

    point_color = LambertianReflection( C, L, N );
    gl_Position = projectionMatrix * point_position;
}
```

Implementation

- Gouraud shading
  - Fragment shader

```
void main()
{
    gl_FragColor = vec4( point_color, 1.0 );
}
```

Implementation

- Phong shading
  - Vertex shader

```
void main()
{
    point_color = color;
    point_position = modelViewMatrix * vec4( position, 1.0 );
    normal_vector = normalMatrix * normal;

    gl_Position = projectionMatrix * point_position;
}
```

Implementation

- Phong shading
  - Fragment shader

```
void main()
{
    vec3 C = point_color;
    vec3 L = normalize( light_position - point_position.xyz );
    vec3 N = normalize( normal_vector );

    vec3 shaded_color = LambertianReflection( C, L, N );
    gl_FragColor = vec4( shaded_color, 1.0 );
}
```

Polling

- Take the poll
  - Student ID Number
  - Name