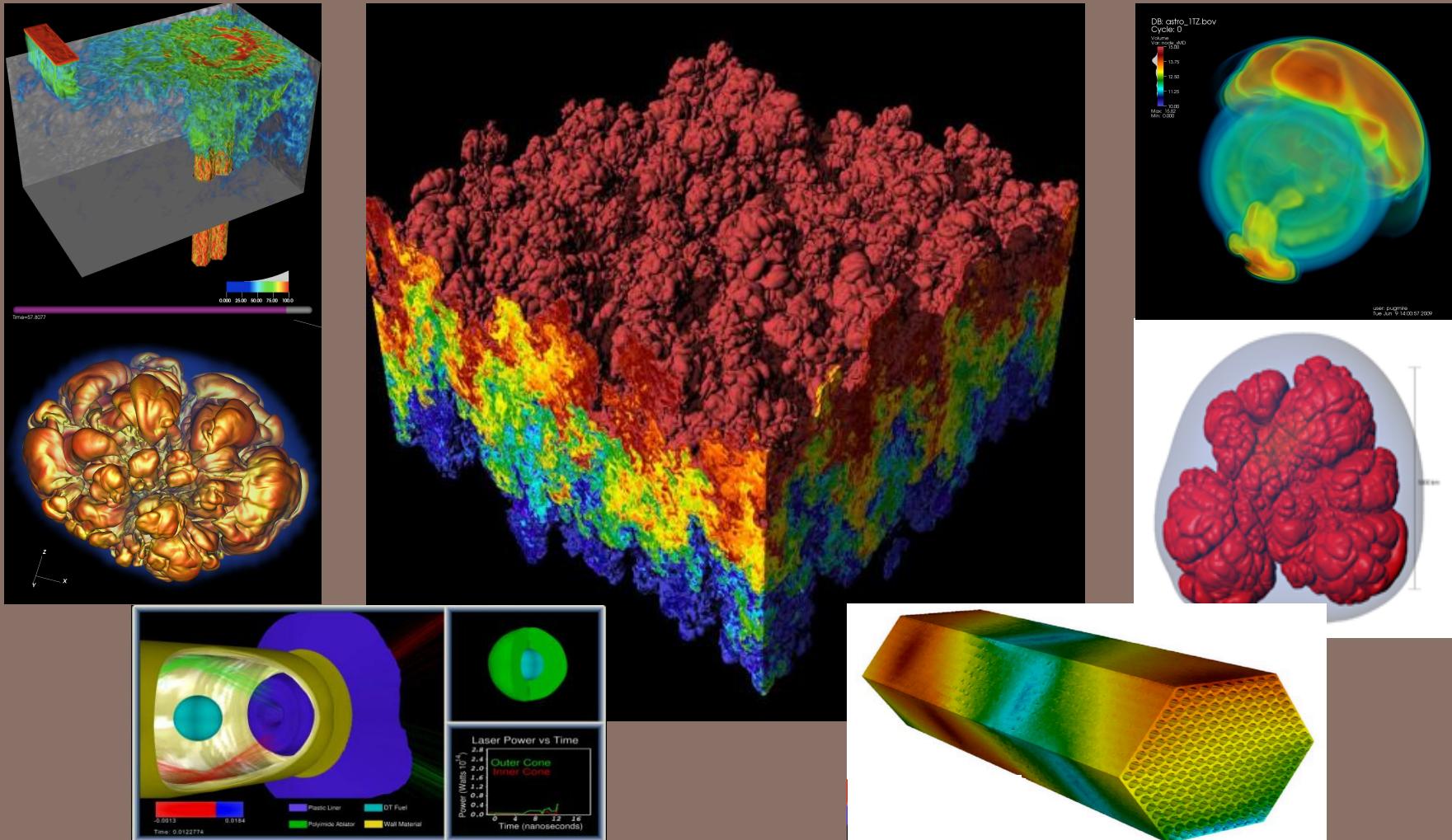


CIS 441/541: Introduction to Computer Graphics

Lecture 8: Math Basics, Lighting Introduction & Phong Lighting



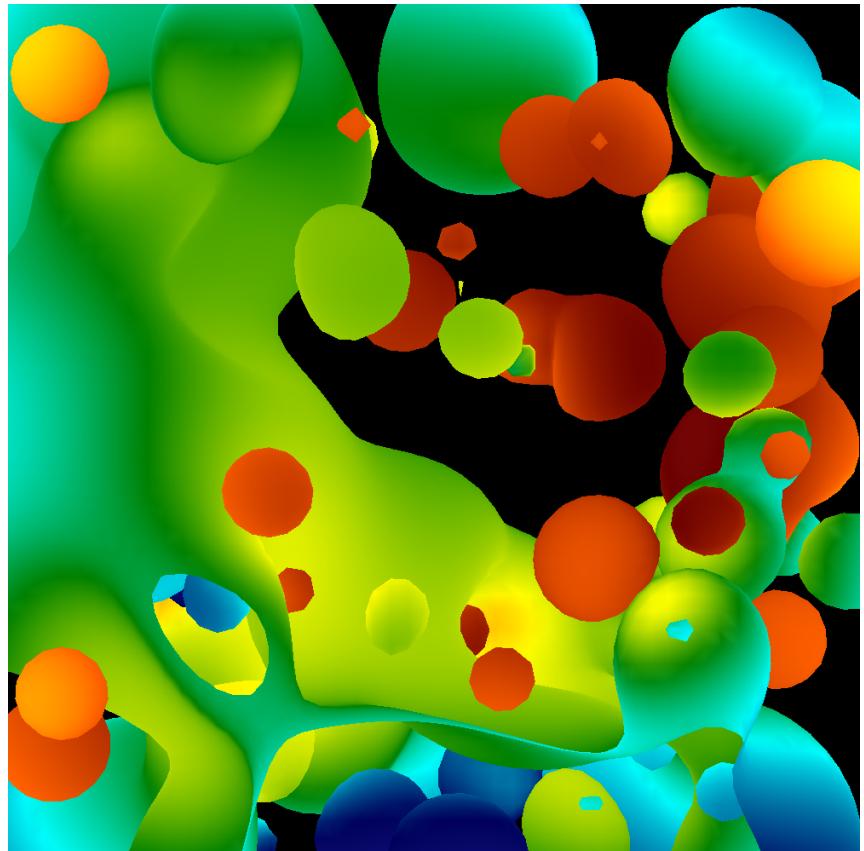
Oct. 11th, 2016

Hank Childs, University of Oregon

Project #1D (5%), Due Tues 10/18



- Goal: interpolation of color and zbuffer
- Extend your project1C code
- File proj1d_geometry.vtk available on web (1.4MB)
- File “reader1d.cxx” has code to read triangles from file.
- No Cmake, project1d.cxx





Color is now floating-point

- We will be interpolating colors, so please use floating point ($0 \rightarrow 1$)
- Keep colors in floating point until you assign them to a pixel
- Fractional colors? \rightarrow use ceil441...



Changes to data structures

```
class Triangle  
{  
public:  
    double X[3], Y[3], Z[3];  
    double colors[3][3];  
};
```

→ reader1d.cxx will not compile until you make these changes



Project 1D

- Everyone understand what to do?
- Reference:

WORKING ON TRIANGLE 2

- FLAT BOTTOM PART –
PRINTING THE TRIANGLE:

(551.02, 877.551, -0.953298)/(0.117997, 0.117997, 0.569589), (551.02, 864.703, -0.938775)/(0.100532, 0.100532, 0.538104), (567.985, 864.703, -0.941226)/(0.103373, 0.103373, 0.543226)

Scanline 865 with left intercept at 551.02, depth -0.939111, and color 0.100936/0.100936/0.538833, right intercept at 567.592, depth -0.941505, and color 0.103712/0.103712/0.543836

Assigning pixel (552, 865) with color 25, 25, 137 and depth -0.939253

Assigning pixel (553, 865) with color 25, 25, 137 and depth -0.939397

Assigning pixel (554, 865) with color 25, 25, 137 and depth -0.939542

Assigning pixel (555, 865) with color 25, 25, 137 and depth -0.939686

Assigning pixel (556, 865) with color 25, 25, 137 and depth -0.939831

Assigning pixel (557, 865) with color 25, 25, 137 and depth -0.939975

Assigning pixel (558, 865) with color 26, 26, 137 and depth -0.94012

Assigning pixel (559, 865) with color 26, 26, 138 and depth -0.940264

Assigning pixel (560, 865) with color 26, 26, 138 and depth -0.940409

Assigning pixel (561, 865) with color 26, 26, 138 and depth -0.940553

Assigning pixel (562, 865) with color 26, 26, 138 and depth -0.940698

Assigning pixel (563, 865) with color 26, 26, 138 and depth -0.940842

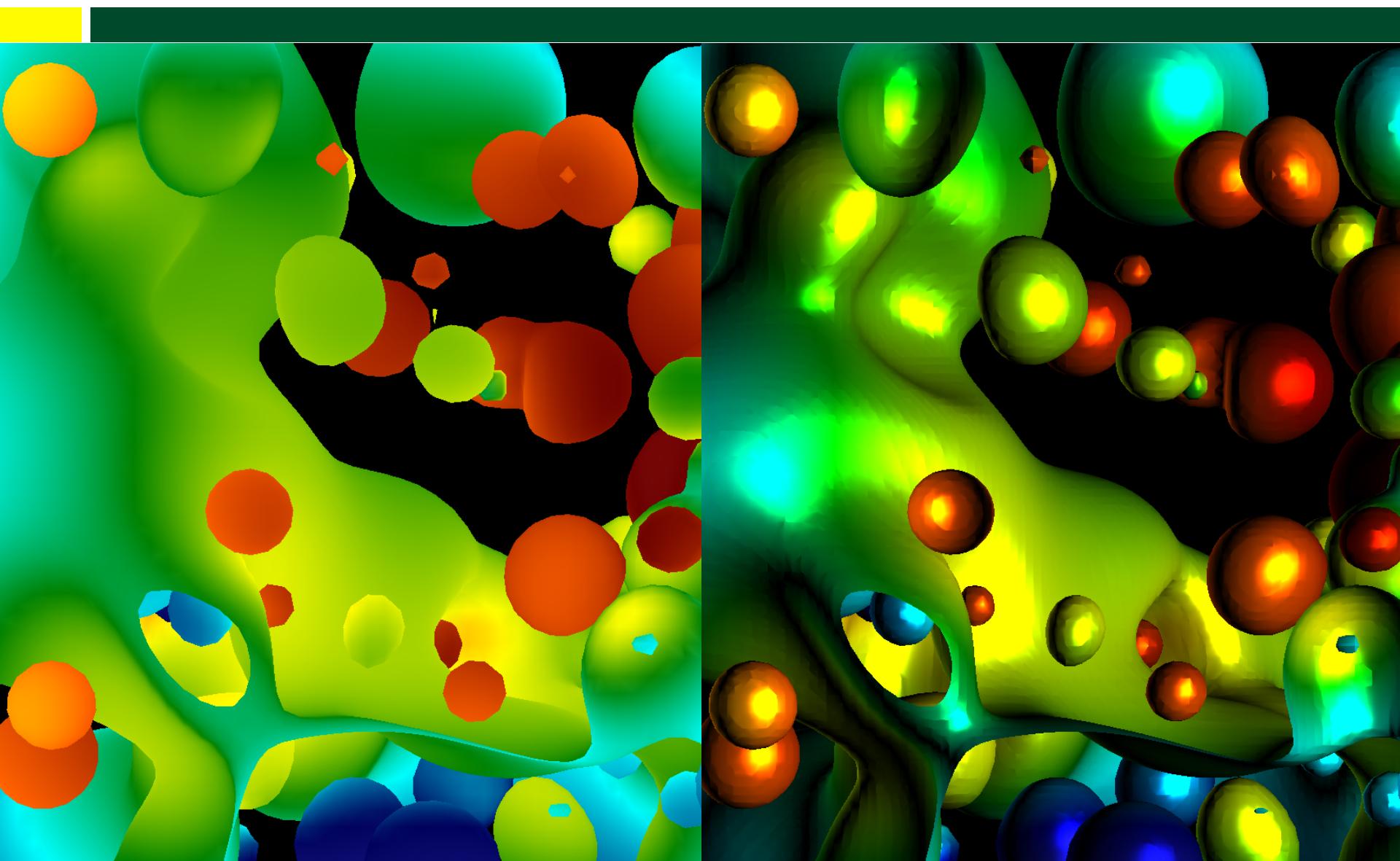
Assigning pixel (564, 865) with color 26, 26, 138 and depth -0.940986

Assigning pixel (565, 865) with color 26, 26, 138 and depth -0.941131

Assigning pixel (566, 865) with color 26, 26, 138 and depth -0.941275

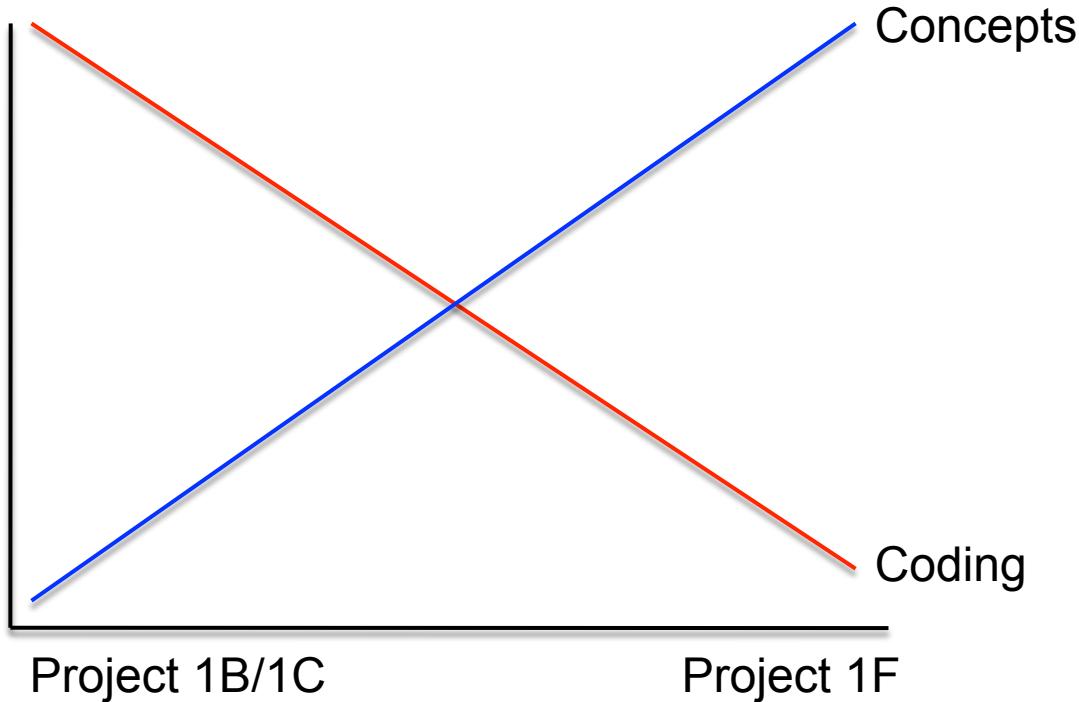
```
unsigned char rgb[3];
rgb[0] = (unsigned char) ceil441(255.0*(leftRGB[0] + proportion*
(rightRGB[0]-leftRGB[0])));
rgb[1] = (unsigned char) ceil441(255.0*(leftRGB[1] + proportion*
(rightRGB[1]-leftRGB[1])));
rgb[2] = (unsigned char) ceil441(255.0*(leftRGB[2] + proportion*
(rightRGB[2]-leftRGB[2])));
double z = leftZ + proportion*(rightZ-leftZ);
Assign(j, i, rgb, z);
```

Our goal with 1E: add shading





My belief about Project #1 X





Outline

- Math Basics
- Lighting Basics
- The Phong Model



Outline

- Math Basics
- Lighting Basics
- The Phong Model



What is the norm of a vector?

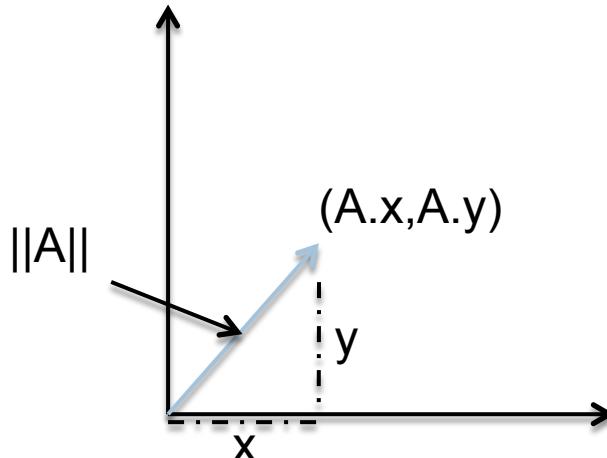
- The norm of a vector is its length

- Denoted with $\|\cdot\|$

- For a vector $A = (A.x, A.y)$,

$$\|A\| = \sqrt{A.x^*A.x + A.y^*A.y}$$

- Physical interpretation:



- For 3D, $\|A\| = \sqrt{A.x^*A.x + A.y^*A.y + A.z^*A.z}$

What does it means for a vector to be normalized?



- The vector A is normalized if $\|A\| = 1$.
 - This is also called a unit vector.
- To obtain a normalized vector, take $A/\|A\|$
- Many of the operations we will discuss today will only work correctly with normalized vectors.



What is the normal of a triangle?

- A triangle coincides with a flat plane.
- A triangle's normal is the vector perpendicular to that plane.
- If a triangle is on plane $= Ax+By+Cz = D$,
then the triangle's normal is (A, B, C)

Norm, Normal, Normalize, Oh My!

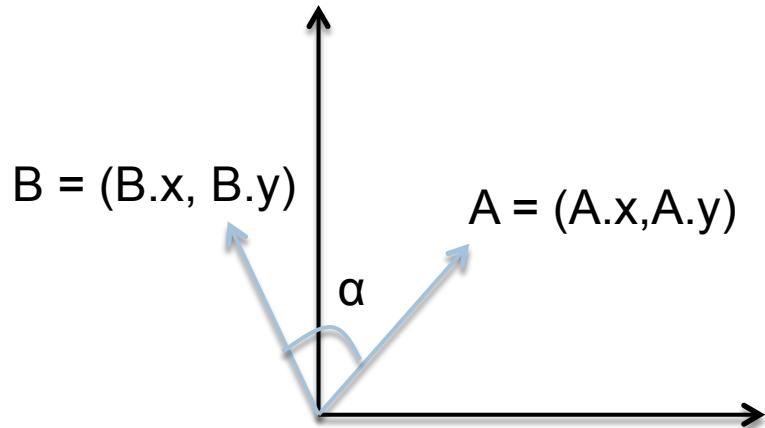


- Norm: the length of a vector ($\|A\|$)
- Normal: a perpendicular vector to a plane coincident with geometry
- Normalize: the operation to create a vector with length 1 ($A/\|A\|$)
- All 3 are important for today's lecture



What is a dot product?

- $A \cdot B = A.x * B.x + A.y * B.y$
 - (or $A.x * B.x + A.y * B.y + A.z * B.z$)
- Physical interpretation:
- $A \cdot B = \cos(\alpha) * (| |A| | * | |B| |)$





What is the cross product?

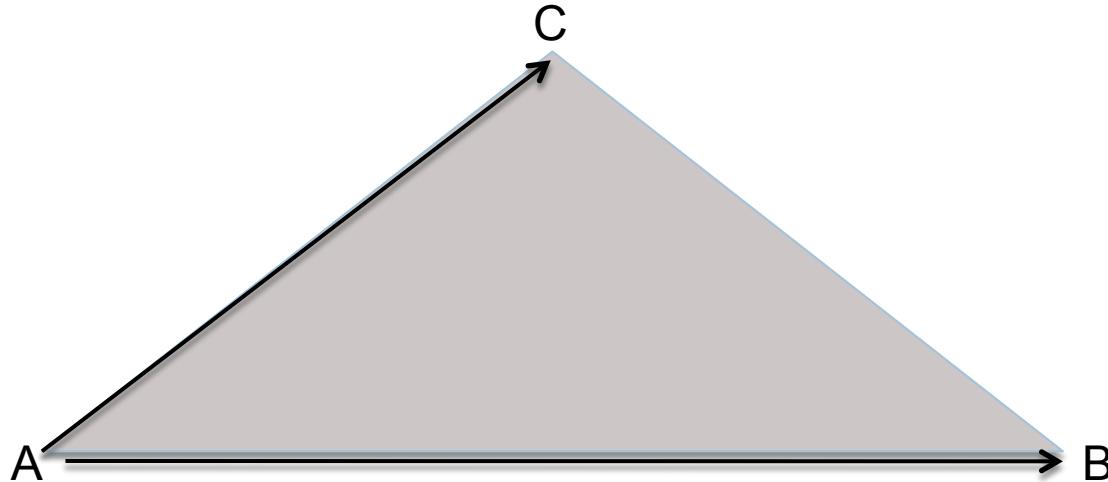
- $A \times B = (A.y^*B.z - A.z^*B.y,$
 $B.x^*A.z - A.x^*B.z,$
 $A.x^*B.y - A.y^*B.x)$

- What is the physical interpretation of a cross product?
 - Finds a vector perpendicular to both A and B.

Easy Way to Calculate Normal For a Triangle



- $\text{Normal} = (\mathbf{C}-\mathbf{A}) \times (\mathbf{B}-\mathbf{A})$



Important:

$$(\mathbf{C}-\mathbf{A}) \times (\mathbf{B}-\mathbf{A}) \neq (\mathbf{B}-\mathbf{A}) \times (\mathbf{C}-\mathbf{A})$$

... we'll worry about this later



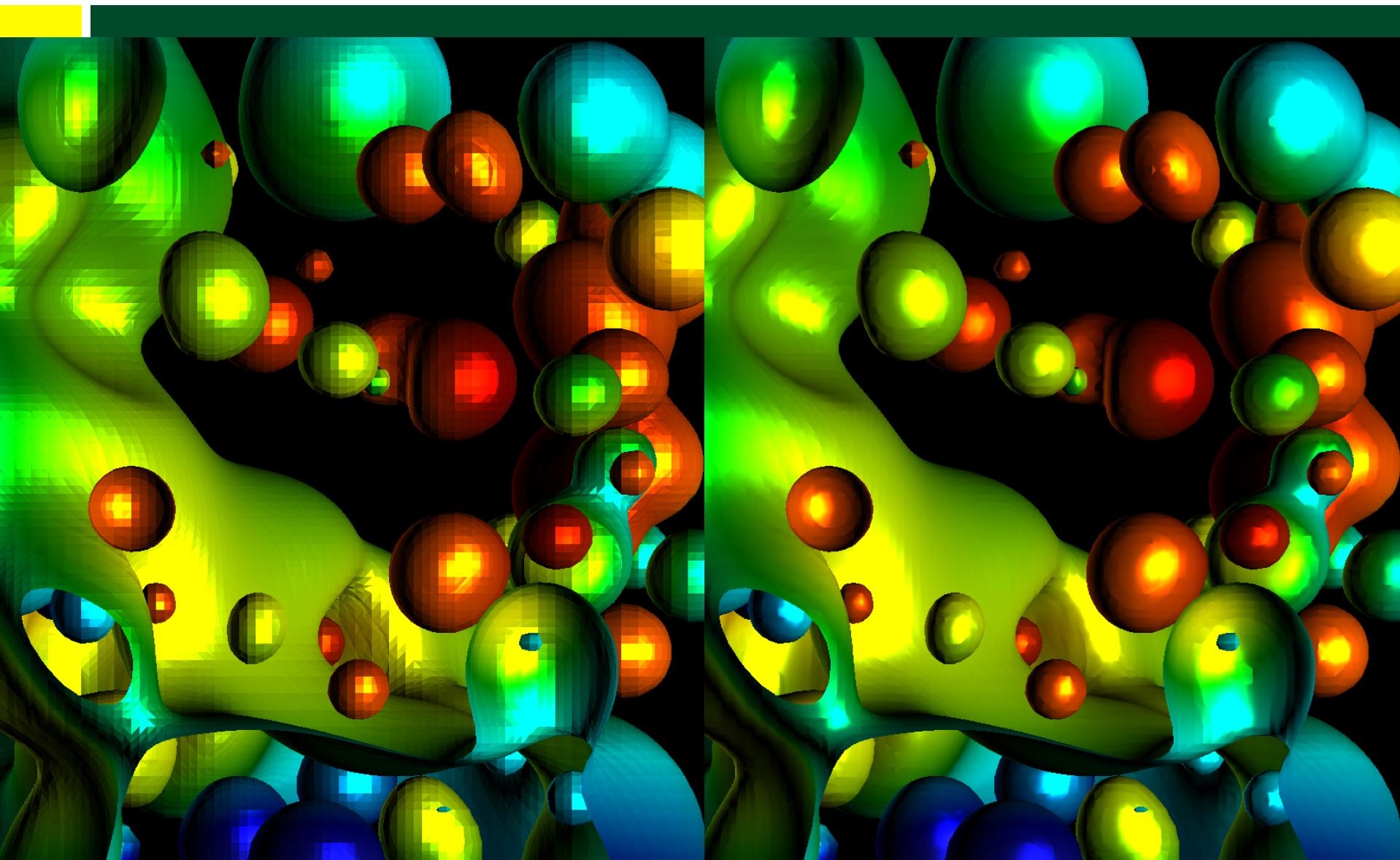
Lighting and Normals

- Two ways to treat normals:
 - Constant over a triangle
 - Varying over a triangle

- Constant over a triangle \leftrightarrow flat shading
- Varying over a triangle \leftrightarrow smooth shading



Flat vs Smooth Shading





Lighting and Normals

- Two ways to treat normals:
 - Constant over a triangle
 - Varying over a triangle

- Constant over a triangle \leftrightarrow flat shading
 - Take $(C-A) \times (B-A)$ as normal over whole triangle

- Varying over a triangle \leftrightarrow smooth shading
 - Calculate normal at vertex, then use linear interpolation
 - How do you calculate normal at a vertex?
 - How do you linearly interpolate normals?

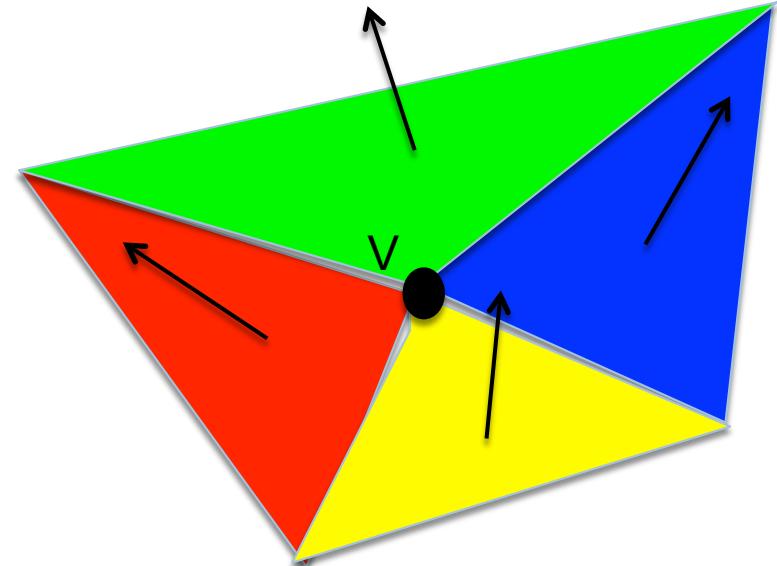


Vertex Normals

□ Algorithm:

□ For vertex V ,

- Find all triangles T_i incident to V
- $\text{Normal}(V) = \{0,0,0\}$
- $\text{NumIncident} = 0$
- For each T_i ,
 - calculate $\text{Normal}(T_i)$
 - $\text{Normal}(V) += \text{Normal}(T_i)$
 - $\text{NumIncident}++$
- $\text{Normal}(V) /= \text{NumIncident}$



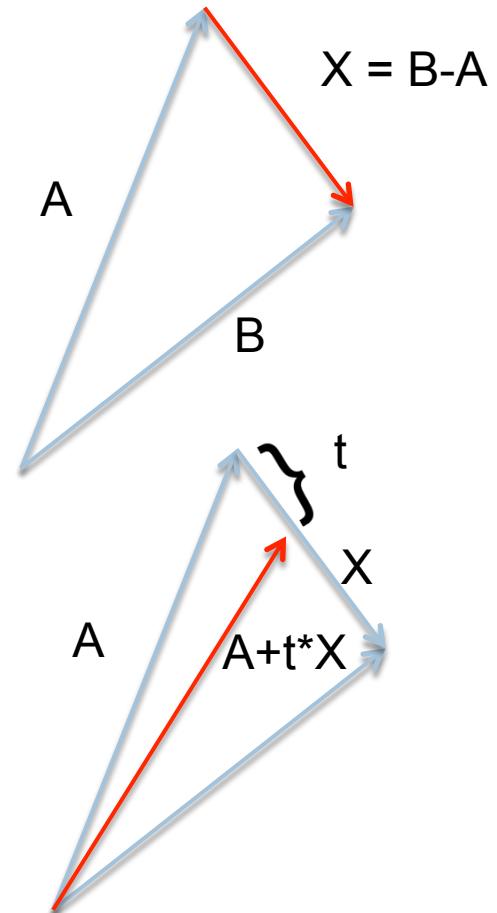
$$\text{N}(V) = (N(T1)+N(T2)+N(T3)+N(T4)) / 4$$

- Note: our data structures don't allow for "Find all triangles T_i incident to V " very easily.
- Vertex normals are precalculated for 1E



LERPing vectors

- LERP = Linear Interpolate
- Goal: interpolate vector between A and B.
- Consider vector X , where $X = B-A$
- Back to normal LERP:
 - $A + t*(B-A) = A+t*X$
- You will need to LERP vectors for 1E





Outline

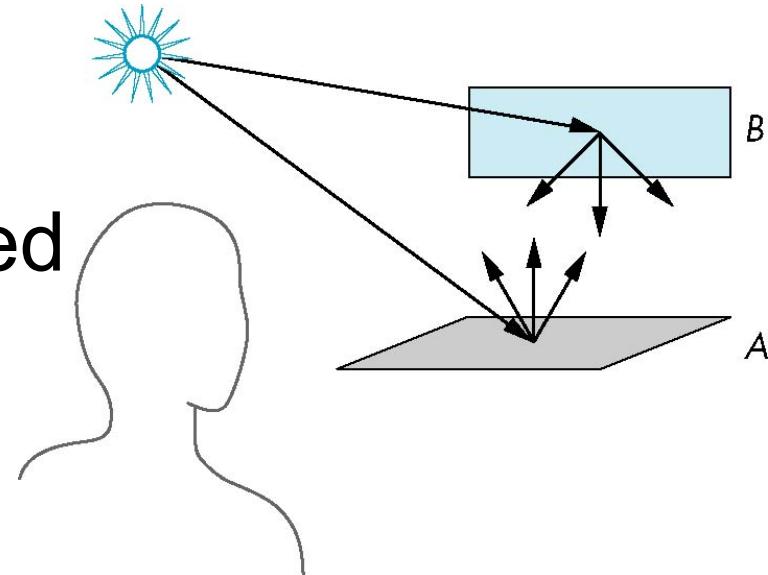
- Math Basics
- Lighting Basics
- The Phong Model



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Scattering

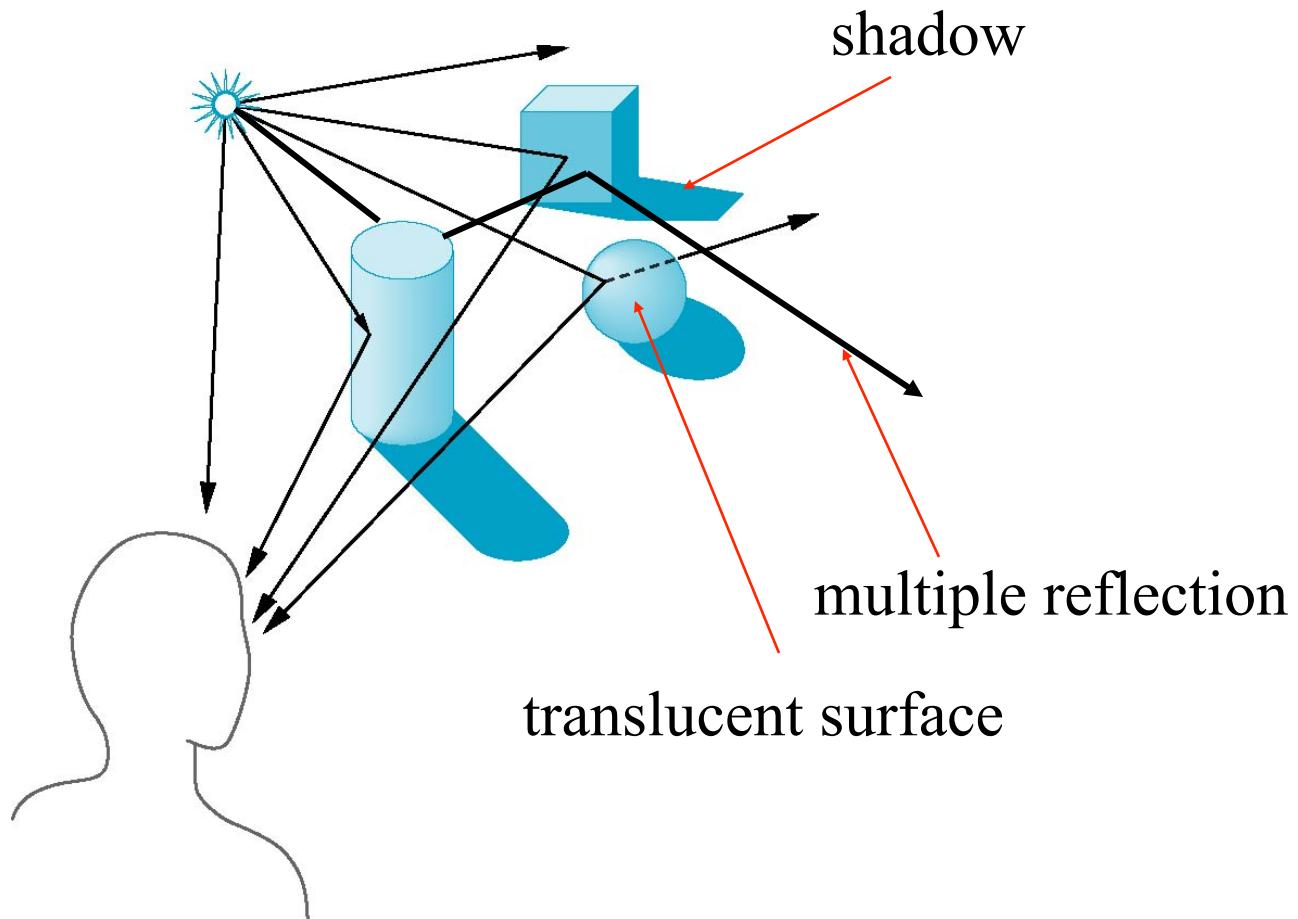
- Light strikes A
 - Some scattered
 - Some absorbed
- Some of scattered light strikes B
 - Some scattered
 - Some absorbed
- Some of this scattered light strikes A and so on





The University of New Mexico

Global Effects





Local vs Global Rendering

- Correct shading requires a global calculation involving all objects and light sources
 - Incompatible with model which shades each polygon independently (local rendering)
- However, in computer graphics, especially real time graphics, we are happy if things “look right”
 - Many techniques exist for approximating global effects



The University of New Mexico

Light-Material Interaction

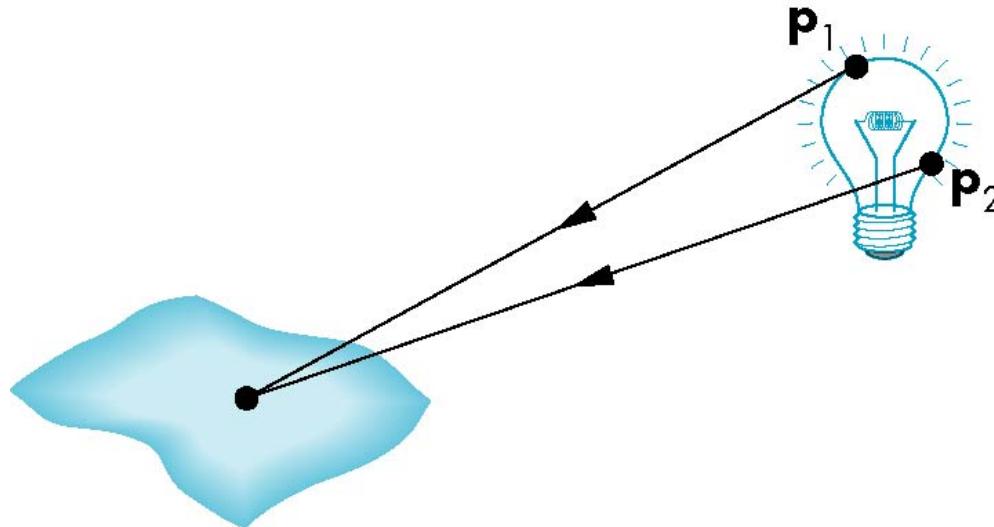
- Light that strikes an object is partially absorbed and partially scattered (reflected)
- The amount reflected determines the color and brightness of the object
 - A surface appears red under white light because the red component of the light is reflected and the rest is absorbed
- The reflected light is scattered in a manner that depends on the smoothness and orientation of the surface



The University of New Mexico

Light Sources

General light sources are difficult to work with because we must integrate light coming from all points on the source





The University of New Mexico

Simple Light Sources

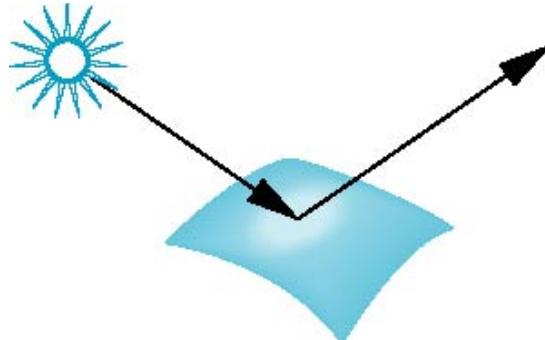
- Point source
 - Model with position and color
 - Distant source = infinite distance away (parallel)
- Spotlight
 - Restrict light from ideal point source
- (We will do point sources for 1E ... and this class)



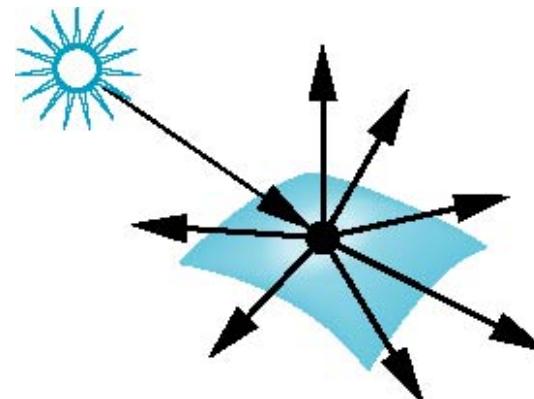
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Surface Types

- The smoother a surface, the more reflected light is concentrated in the direction a perfect mirror would reflect the light
- A very rough surface scatters light in all directions



smooth surface



rough surface

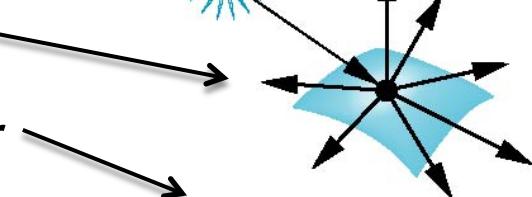


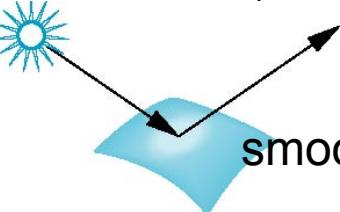
Shading

- Our goal:
 - For each pixel, calculate a shading factor
 - Shading factor typically between 0 and 1, but sometimes > 1
 - Shading > 1 makes a surface more white

- 3 types of lighting to consider:

- Ambient 
 - Light everywhere

- Diffuse 

- Specular 

rough surface

smooth surface

Our game plan:
Calculate all 3
and combine
them.

How to handle shading values greater than 1?



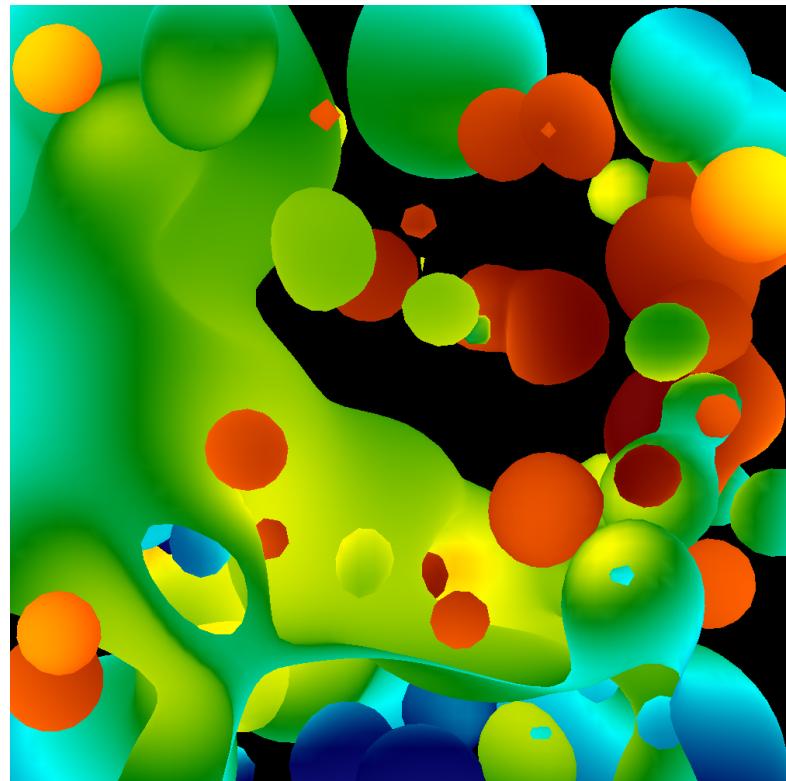
- Color at pixel = (1.0, 0.4, 0.8)
- Shading value = 0.5
 - Easy!
 - Color = (0.5, 0.2, 0.4) → (128, 52, 103)
- Shading value = 2.0
 - Color = (1.0, 0.8, 1.0) → (255, 204, 255)
- $\text{Color_R} = 255 * \min(1, R * \text{shading_value})$
- This is how bright lights makes things whiter and whiter.
 - But it won't put in colors that aren't there.



Ambient Lighting

- Ambient light
 - Same amount of light everywhere in scene
 - Can model contribution of many sources and reflecting surfaces

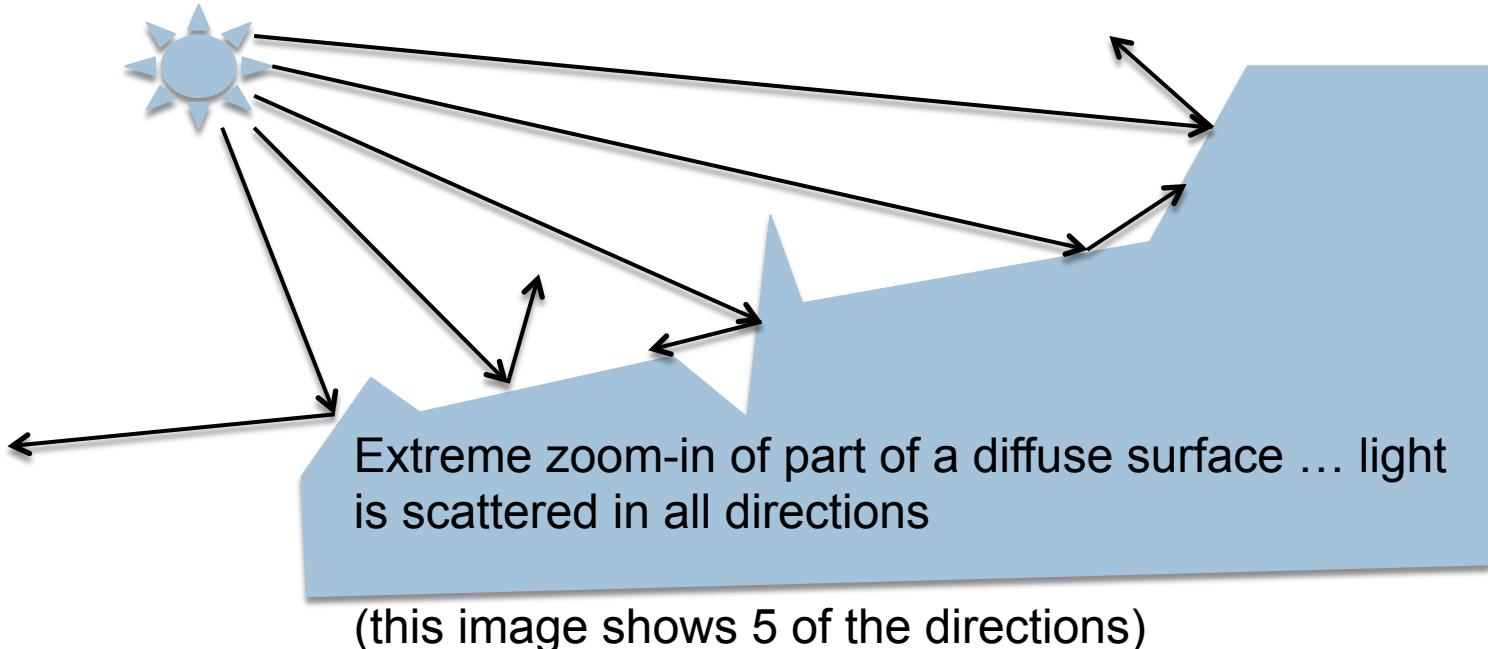
Surface lit with
ambient lighting
only





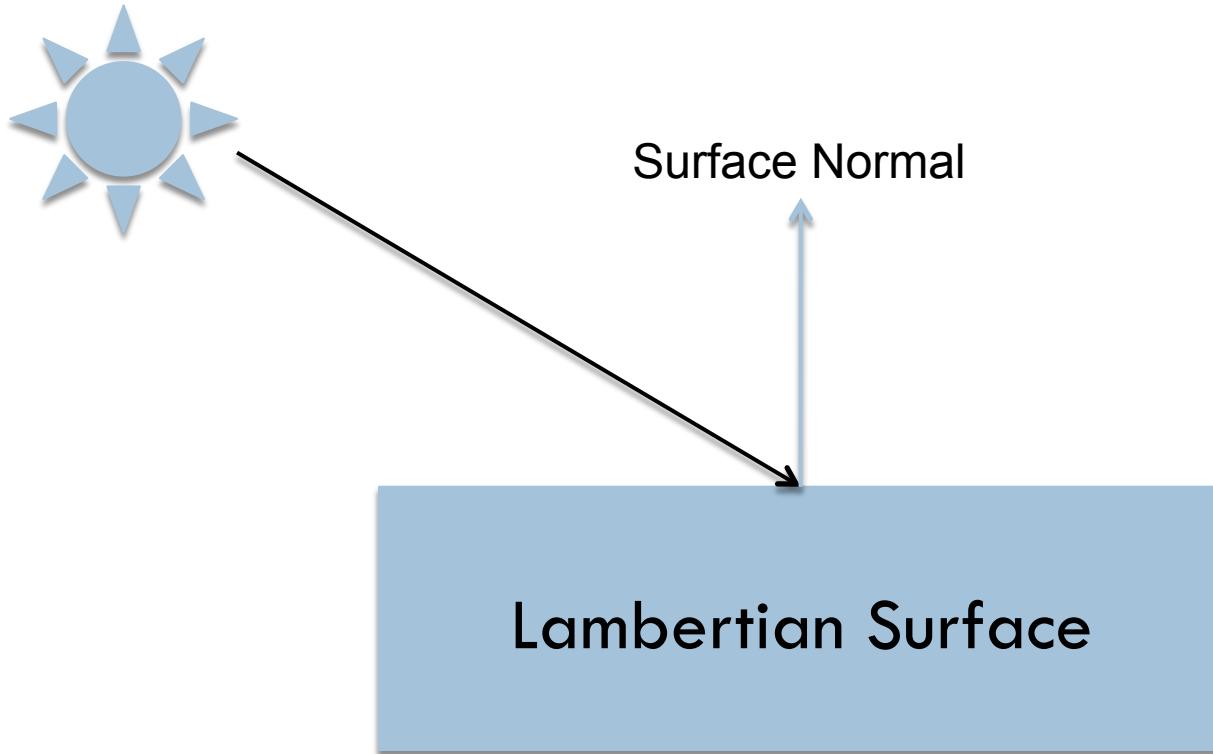
Lambertian Surface

- Perfectly diffuse reflector
- Light scattered equally in all directions



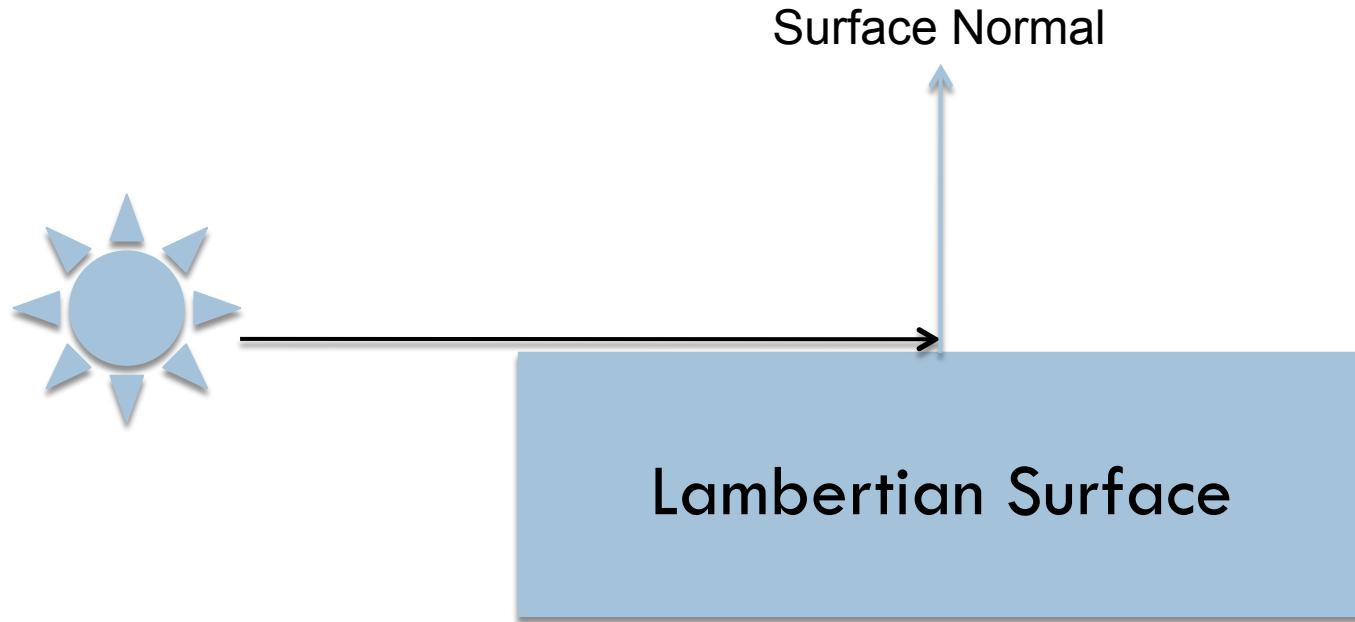


Diffuse Lighting





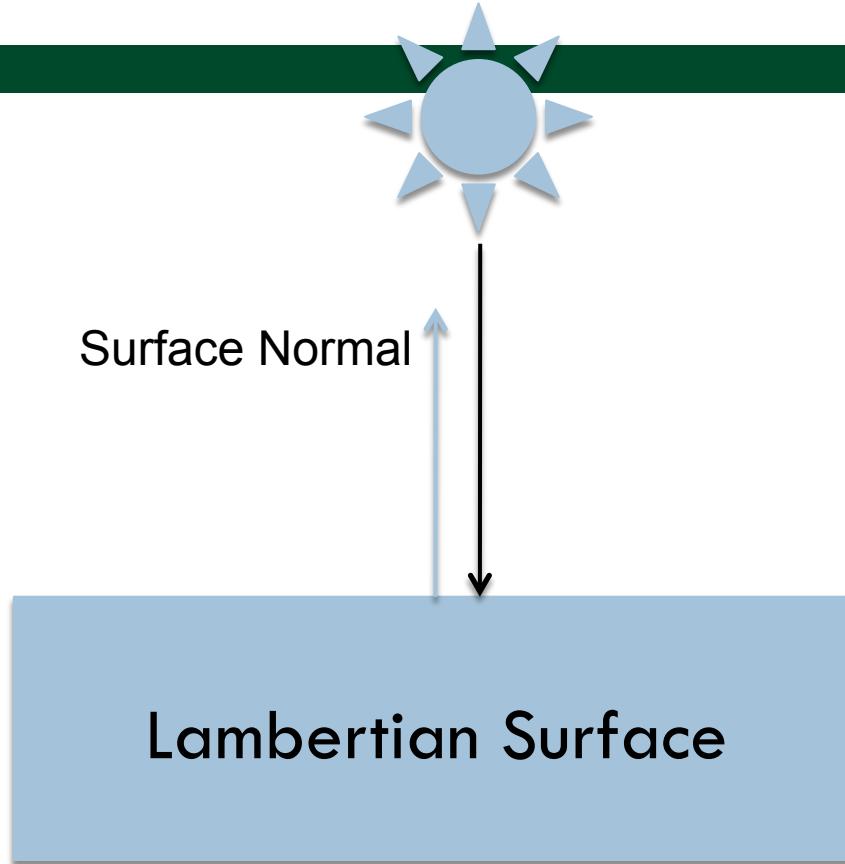
Diffuse Lighting



No light reflects off the (top) surface
(Light direction and surface normal are perpendicular)



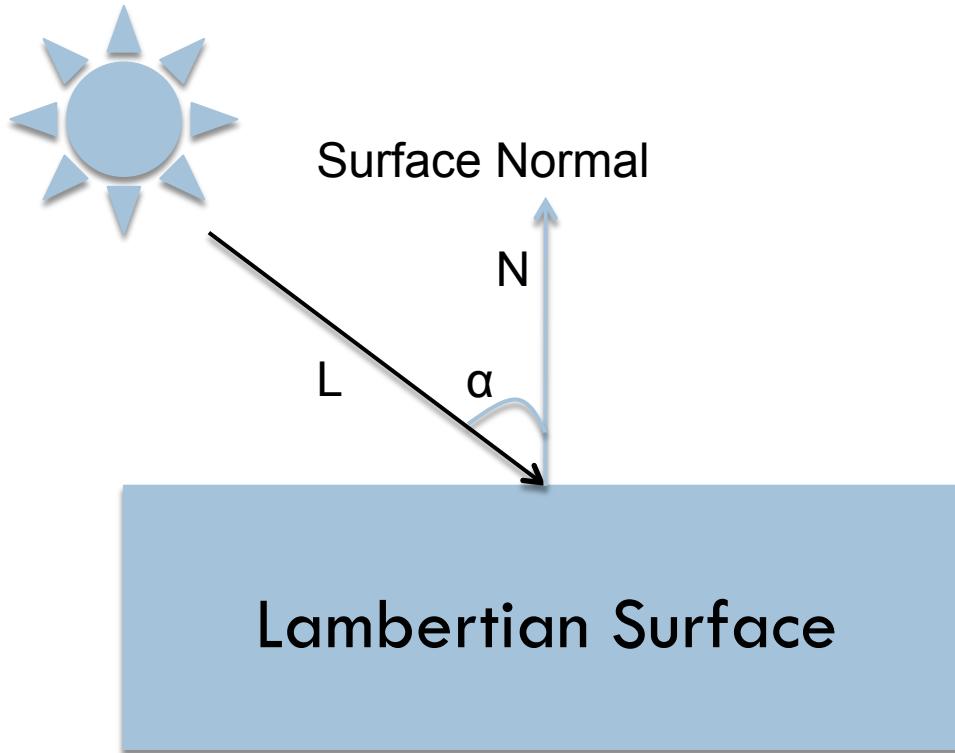
Diffuse Lighting



When the light squarely hits the surface, then
that's when the most light is reflected



Diffuse Lighting



How much light should be reflected in this case?

$$\underline{A: \cos(\alpha)}$$

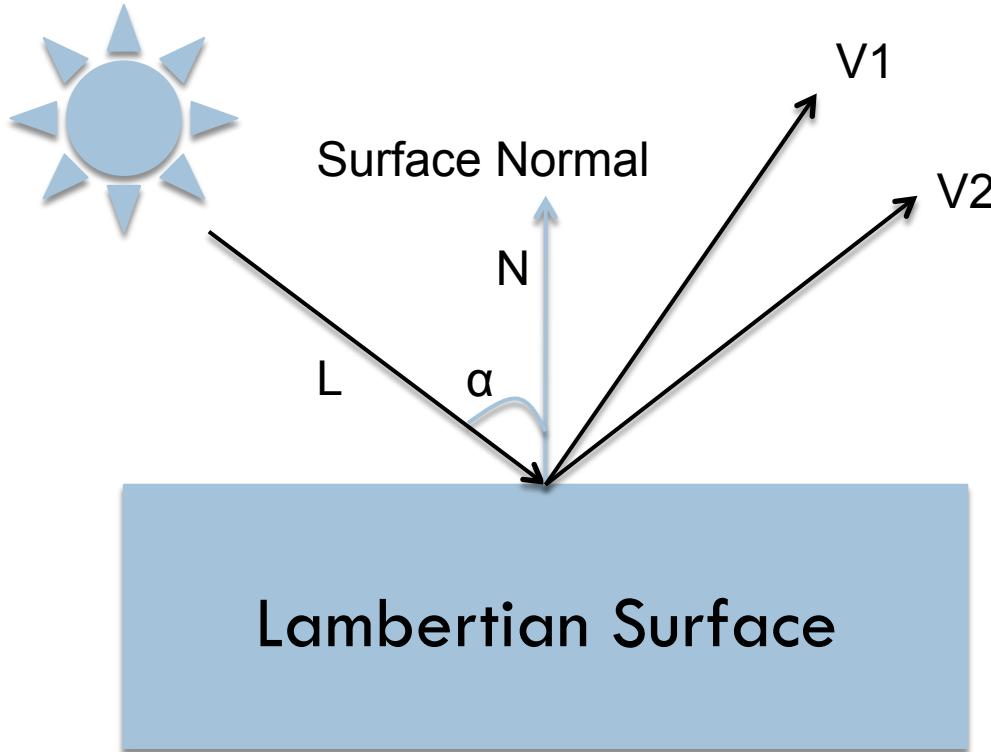
And note that:

$$\cos(0) = 1$$

$$\cos(90) = 0$$



Diffuse Lighting



How much light makes it to viewer V1? Viewer V2?

A: $\cos(\alpha)$ for both

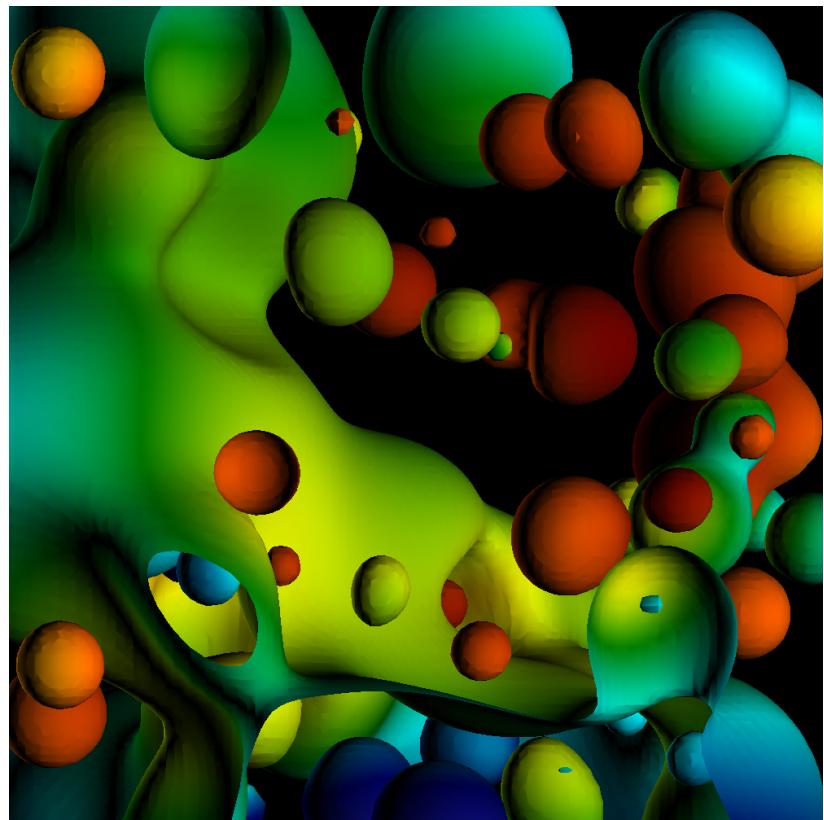
Lambertian surfaces reflect light equally in all directions



Diffuse Lighting

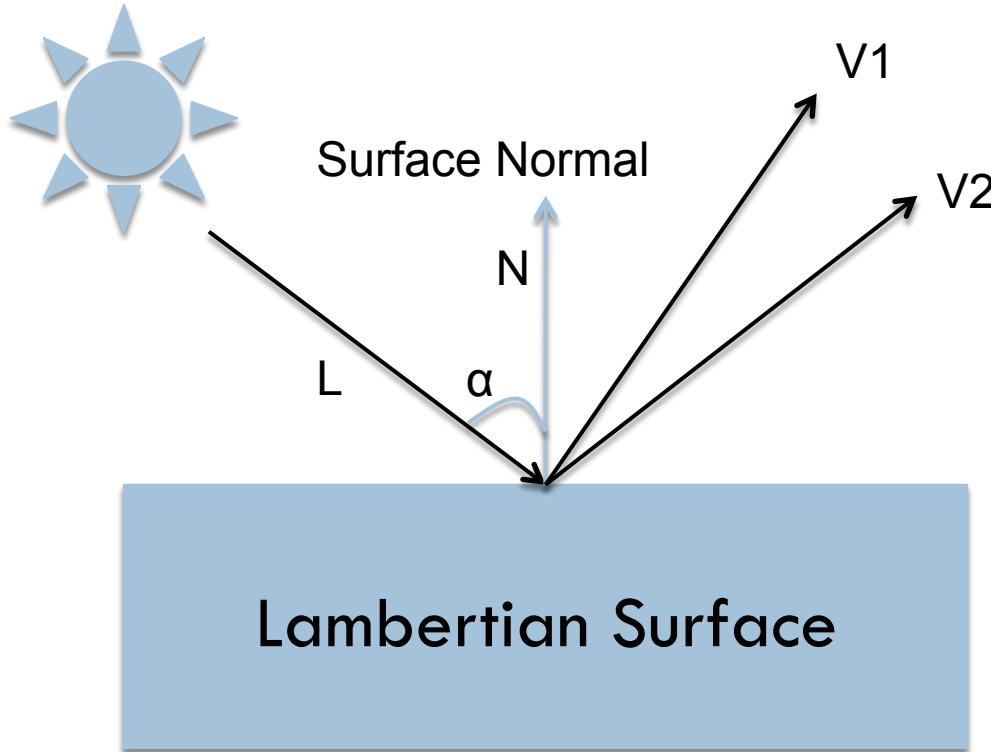
- Diffuse light
 - Light distributed evenly in all directions, but amount of light depends on orientation of triangles with respect to light source.
 - Different for each triangle

Surface lit with
diffuse lighting only





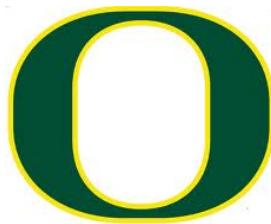
SLIDE REPEAT: Diffuse Lighting



How much light makes it to viewer V1? Viewer V2?

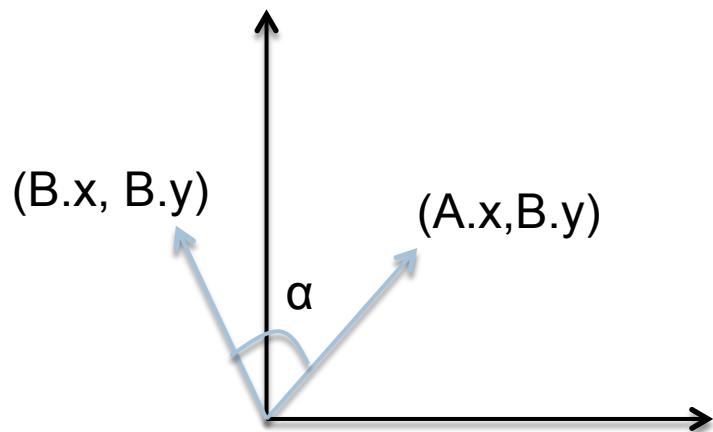
A: $\cos(\alpha)$ for both

Lambertian surfaces reflect light equally in all directions



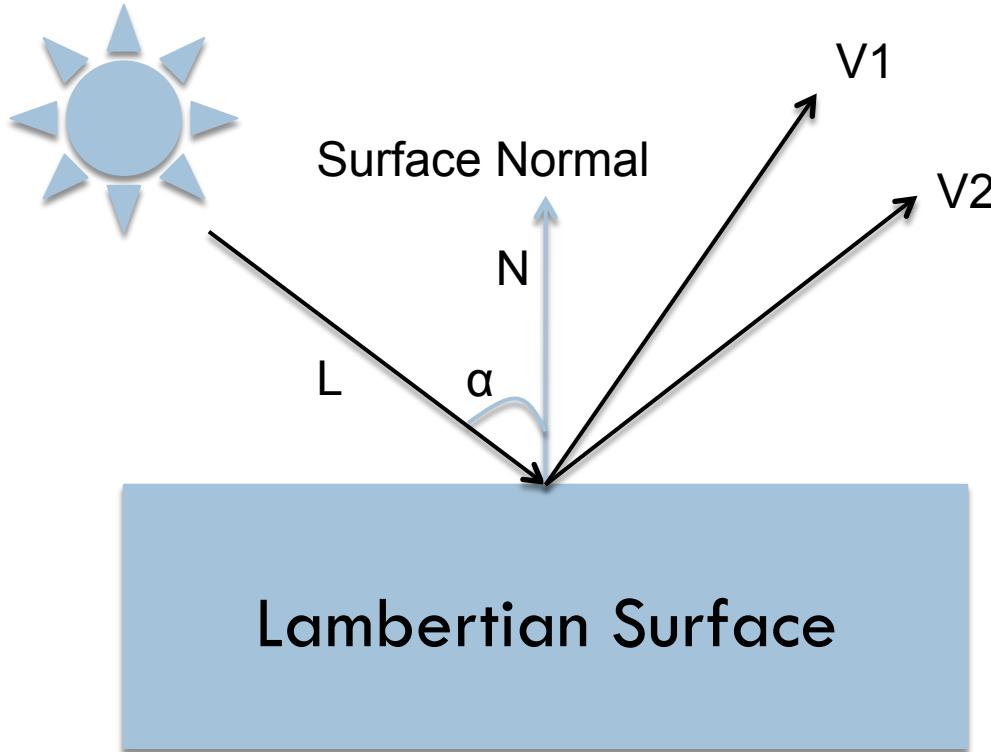
What is a dot product?

- $A \cdot B = A.x * B.x + A.y * B.y$
- Physical interpretation:
 - $A \cdot B = \cos(\alpha) / (\|A\| * \|B\|)$





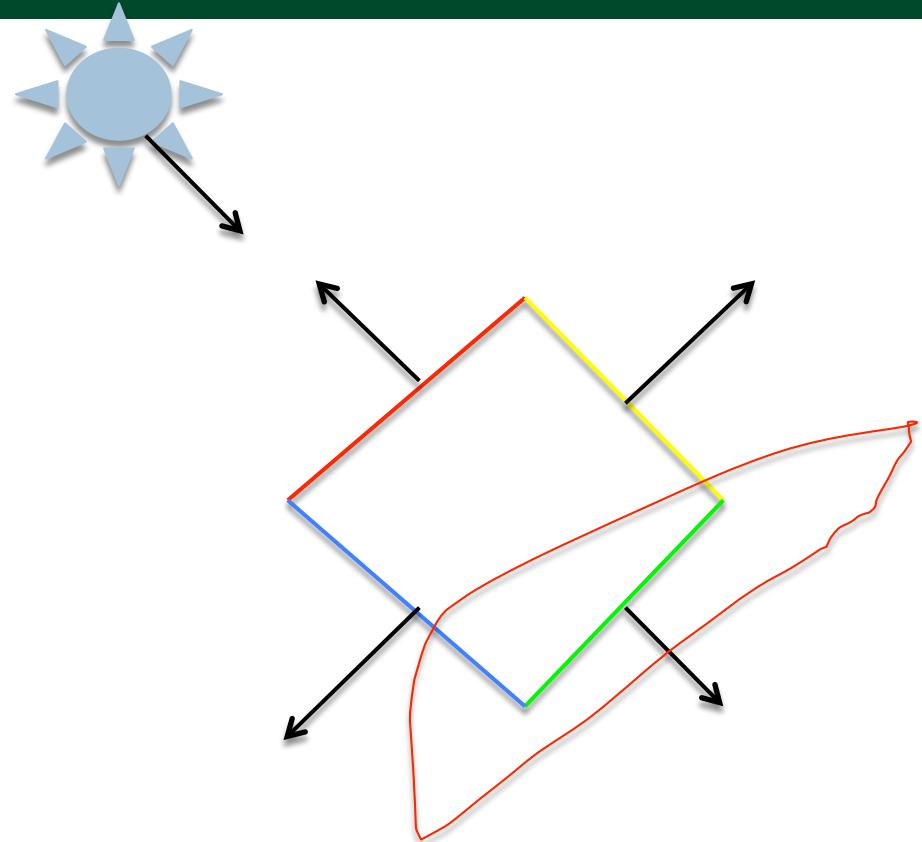
Diffuse Lighting



You can calculate the diffuse contribution by taking
the dot product of L and N,
Since $L \cdot N = \cos(\alpha)$
(assuming L and N are normalized)

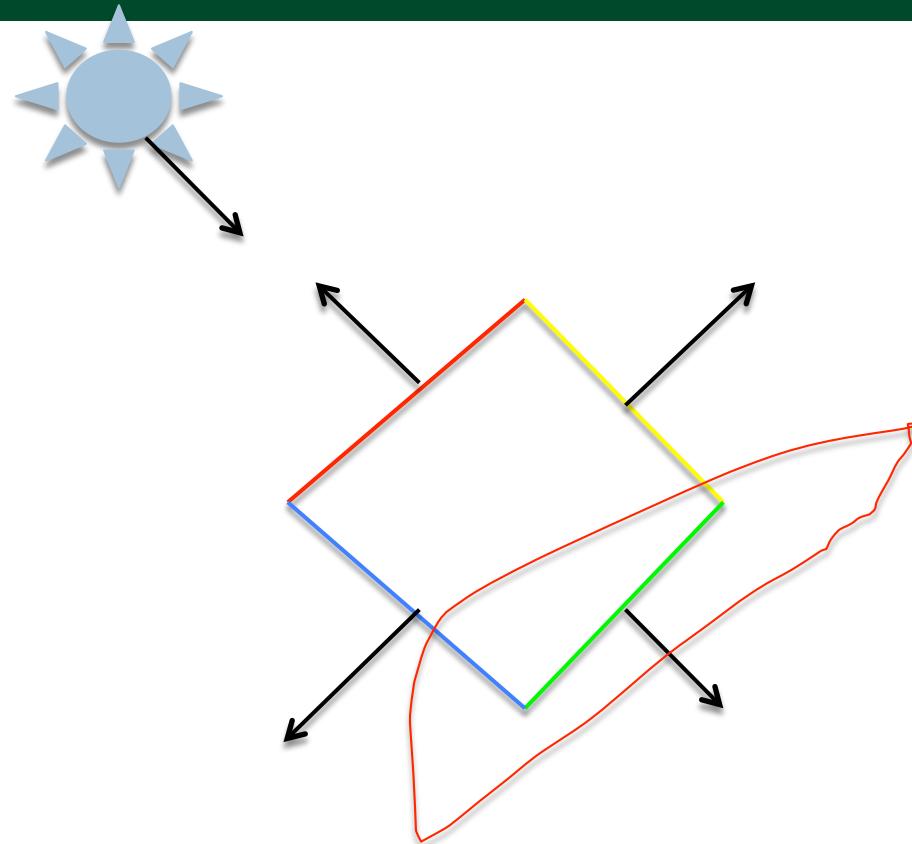


What about cases where $L \cdot N < 0$?





What about cases where $L \cdot N < 0$?



$$L \cdot N = -1$$

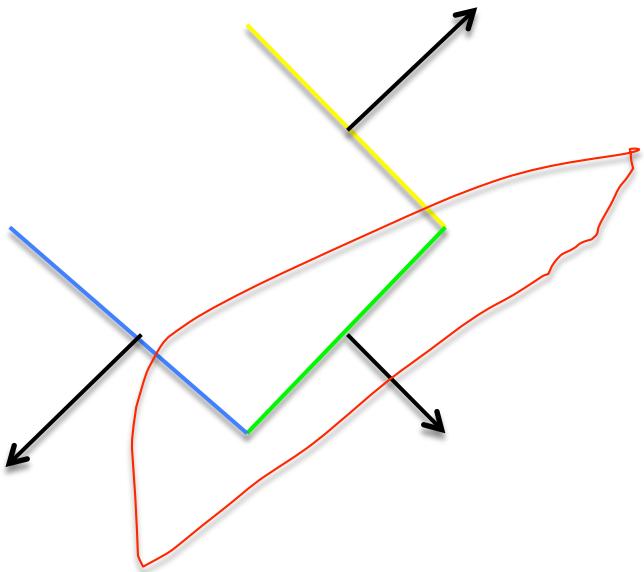
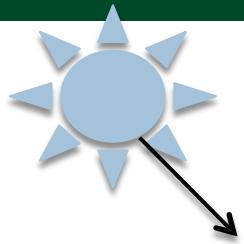
Non-sensical ... takes away light?

Common solution:

$$\text{Diffuse light} = \max(0, L \cdot N)$$



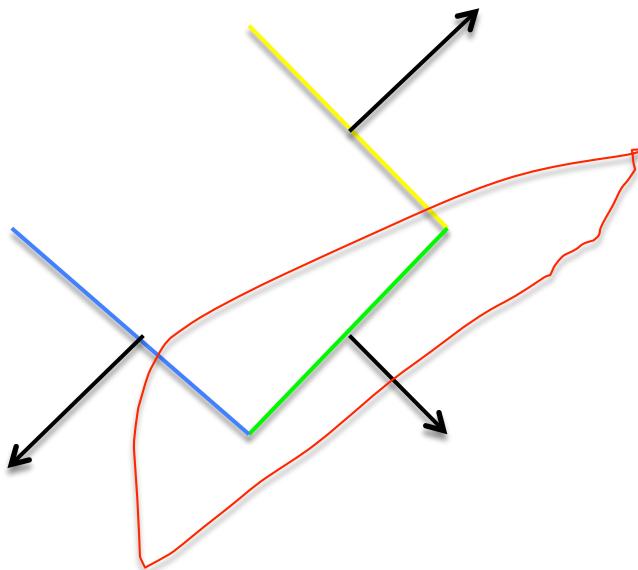
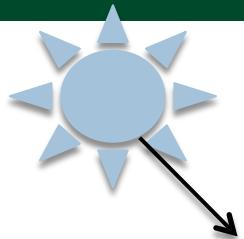
But wait...



If you have an open surface, then there is a “back face”. The back face has the opposite normal.



But wait...

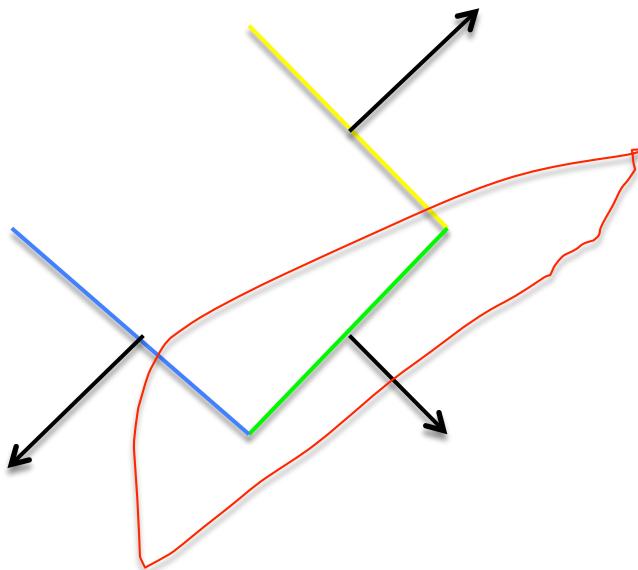
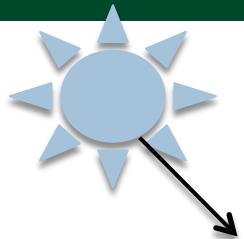


If you have an open surface, then there is a “back face”. The back face has the opposite normal.

How can we deal with this case?



But wait...



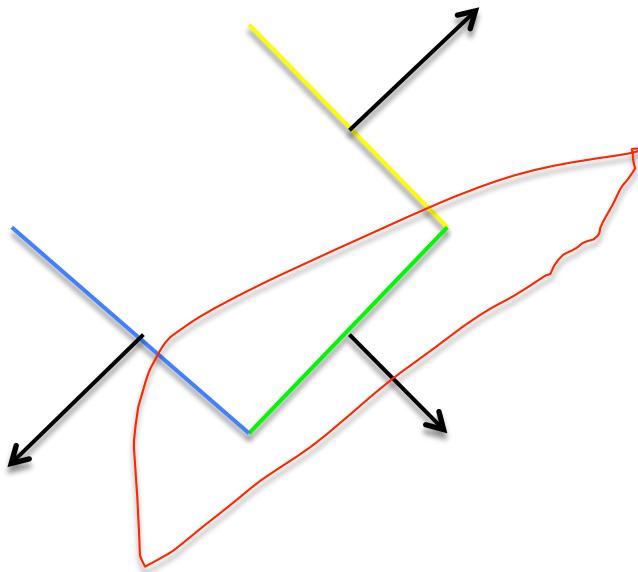
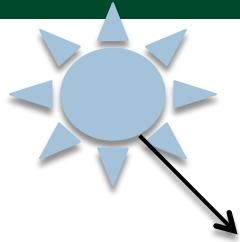
If you have an open surface, then there is a “back face”. The back face has the opposite normal.

How can we deal with this case?

- Idea #1: encode all triangles twice, with different normals
- Idea #2: modify diffuse lighting model



But wait...



This is called two-sided lighting

If you have an open surface, then there is a “back face”. The back face has the opposite normal.

How can we deal with this case?

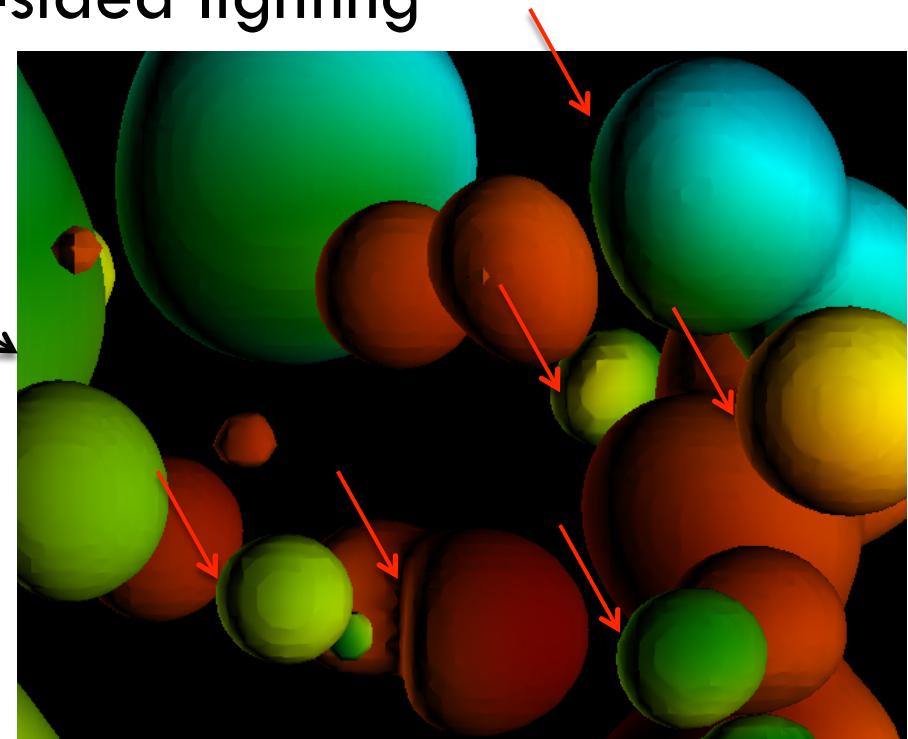
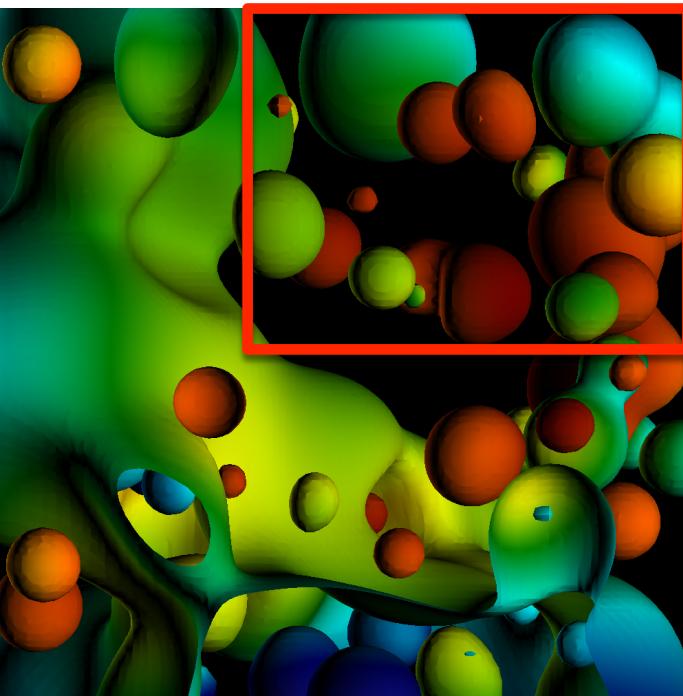
Idea #1: encode all triangles twice, with different normals
Idea #2: modify diffuse lighting model

$$\text{Diffuse light} = \text{abs}(\mathbf{L} \cdot \mathbf{N})$$

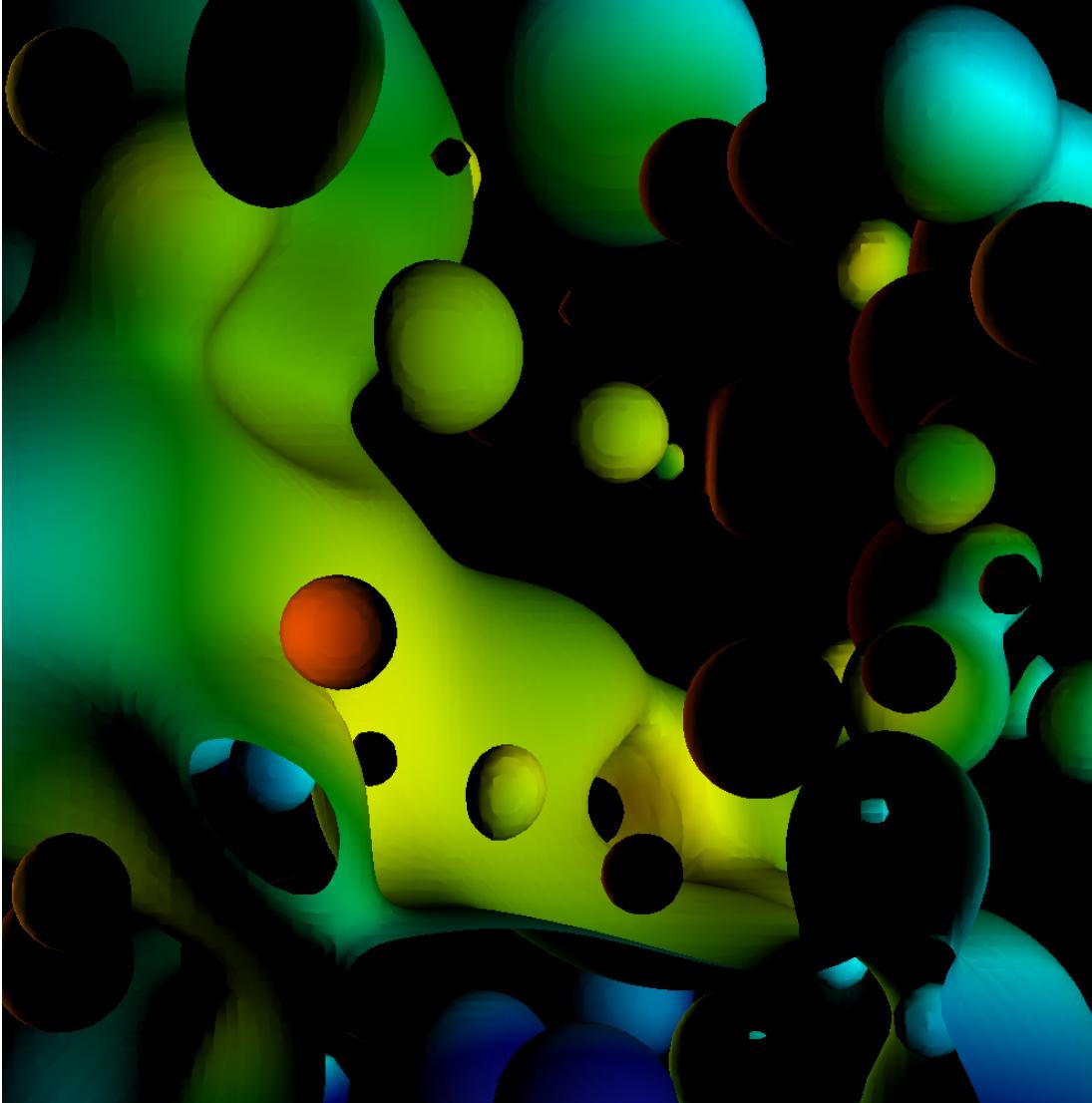


Two-sided lighting

- We will use two-sided lighting for project 1E, since we have open surfaces
- Note that Ed Angel book assumes closed surfaces and recommends one-sided lighting



One-sided lighting with open surfaces is disappointing



The most valuable thing I learned in Freshman Physics



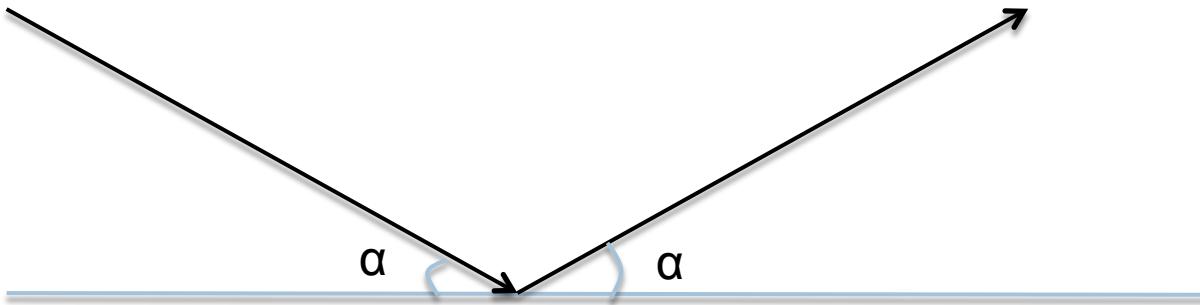
- “angle in = angle out”



The most valuable thing I learned in Freshman Physics

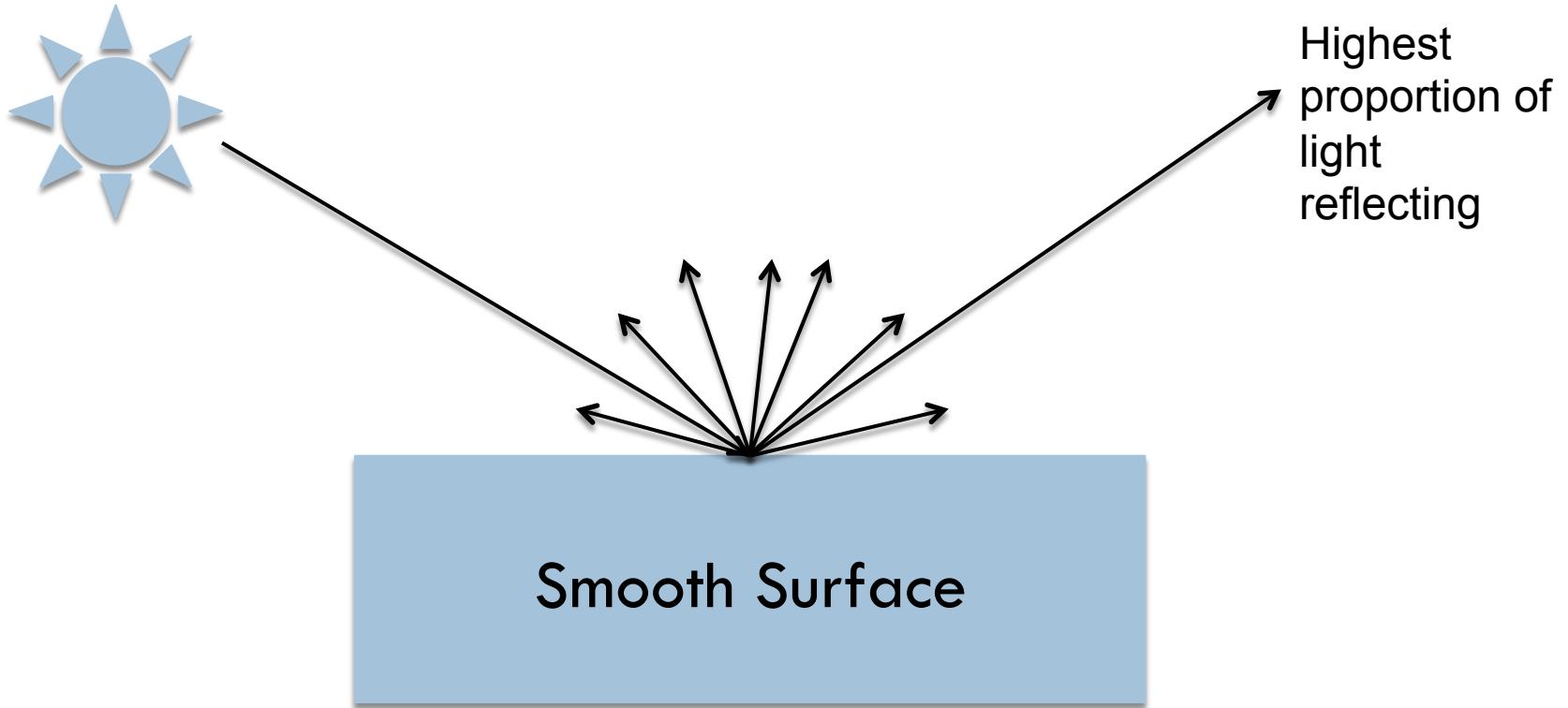


- “angle in = angle out”



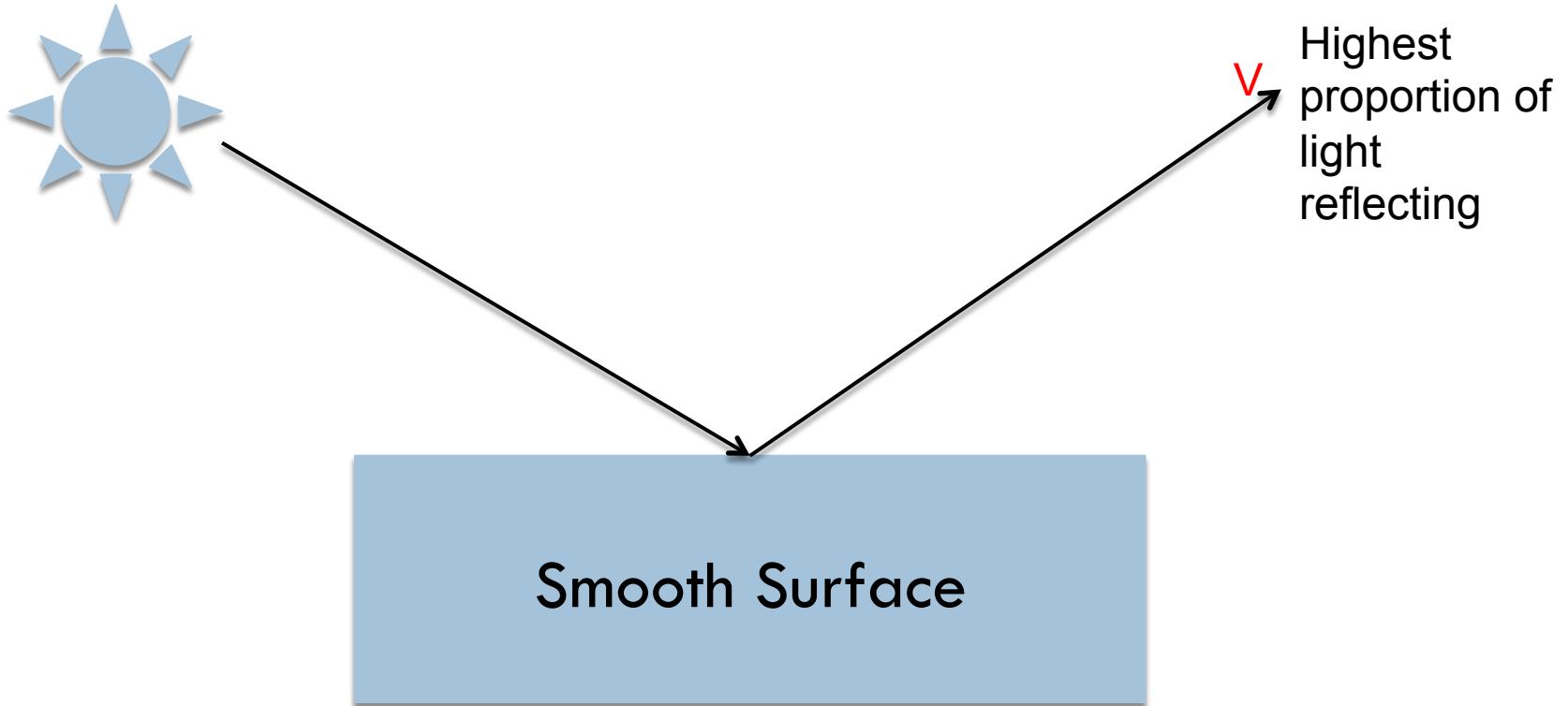


Specular Lighting



Light reflects in all directions.
But the surface is smooth, not Lambertian, so amount of reflected light varies.
So how much light??

How much light reflects with specular lighting?

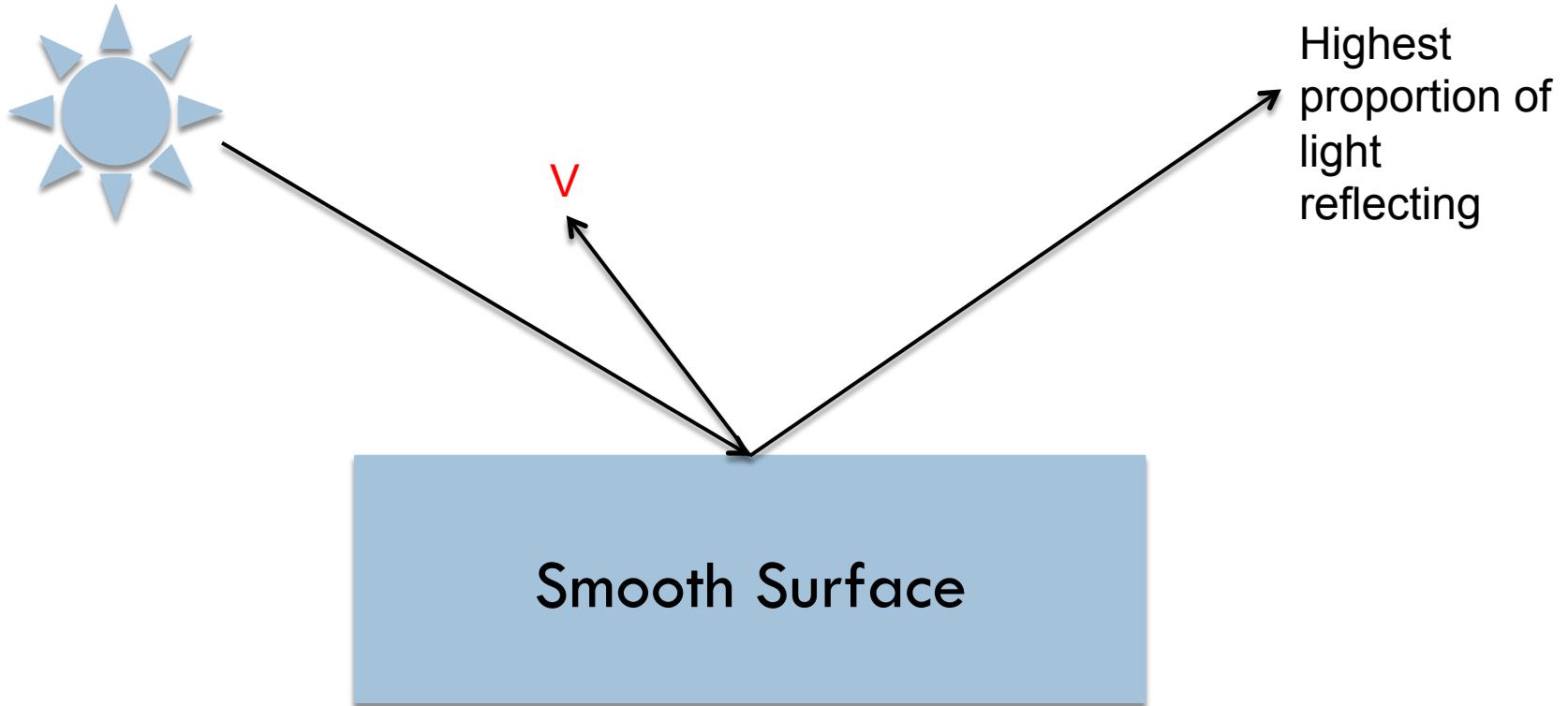


Consider V located along reflection ray.

Answer: most possible

Call this “1”

How much light reflects with specular lighting?

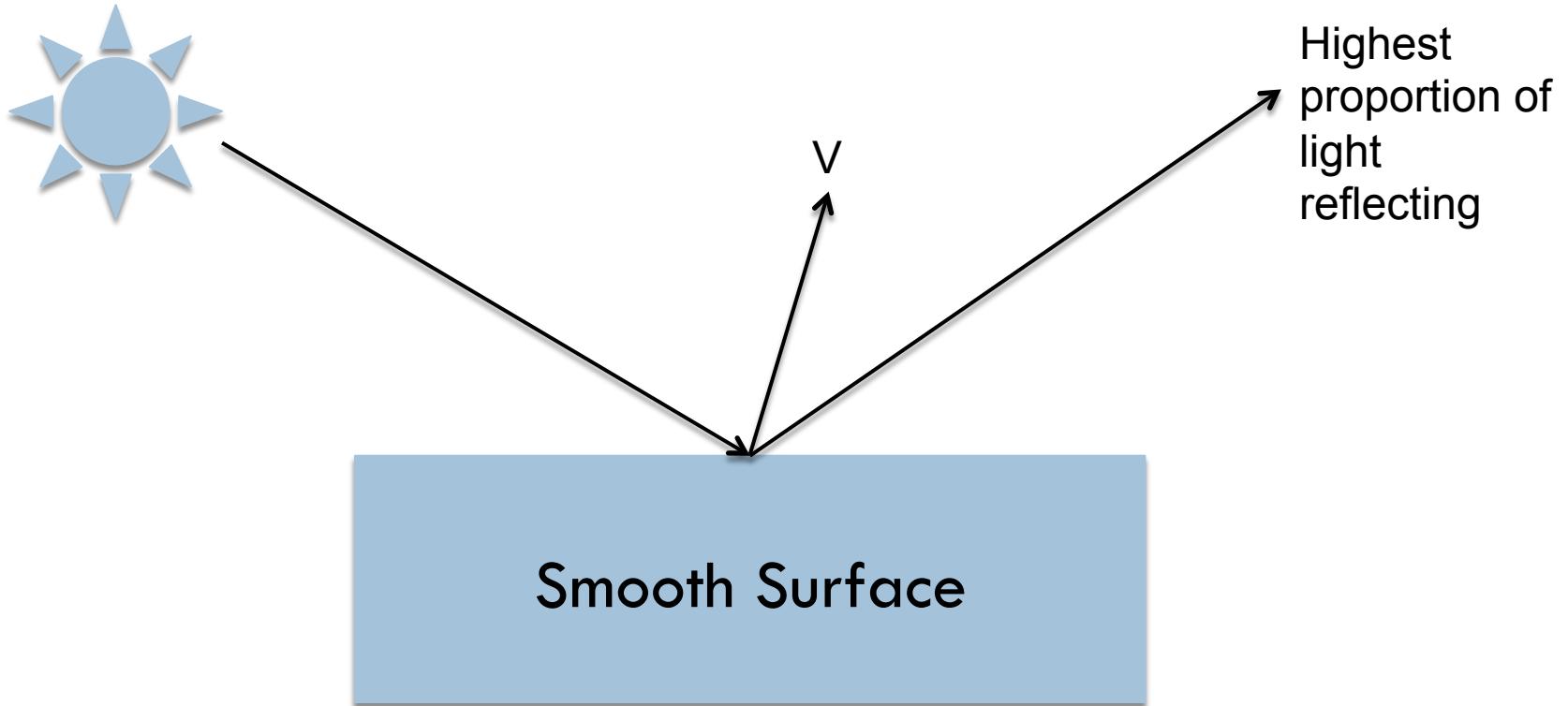


Consider V located along perpendicular ray.

Answer: none of it

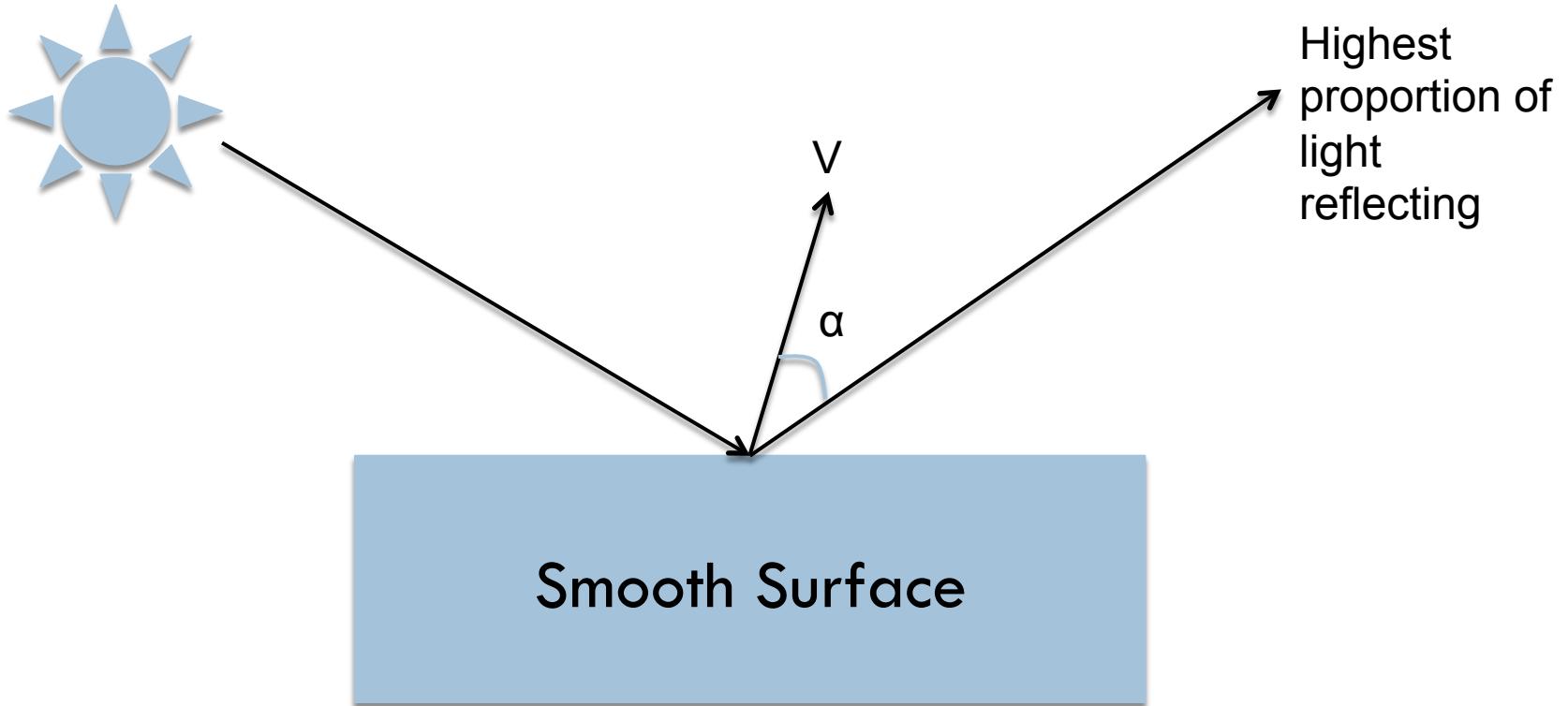
Call this “0”

How much light reflects with specular lighting?



How much light gets to point V?

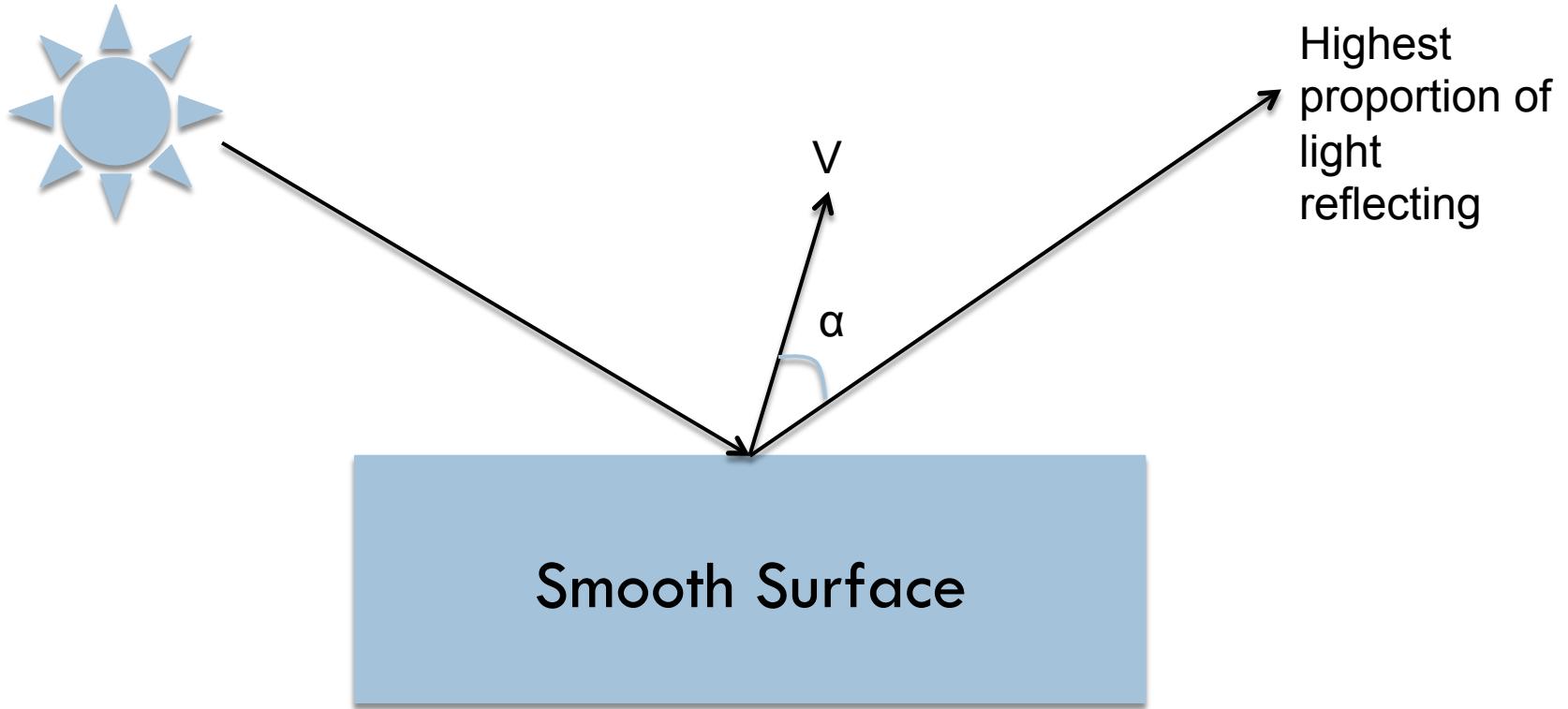
How much light reflects with specular lighting?



How much light gets to point V?

A: proportional to $\cos(\alpha)$

How much light reflects with specular lighting?



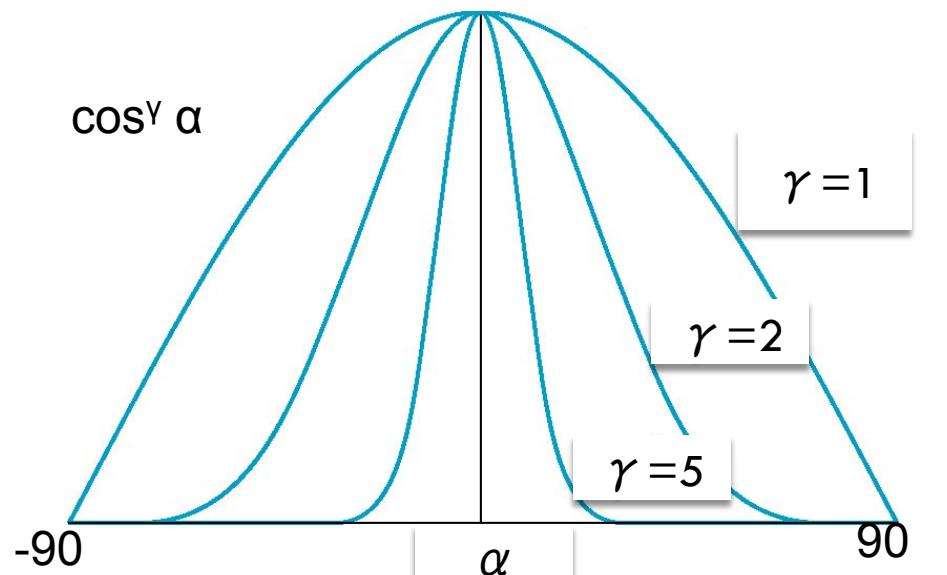
How much light gets to point V?

A: proportional to $\cos(\alpha)$
(Shininess strength) * $\cos(\alpha)^{\text{shininess coefficient}}$

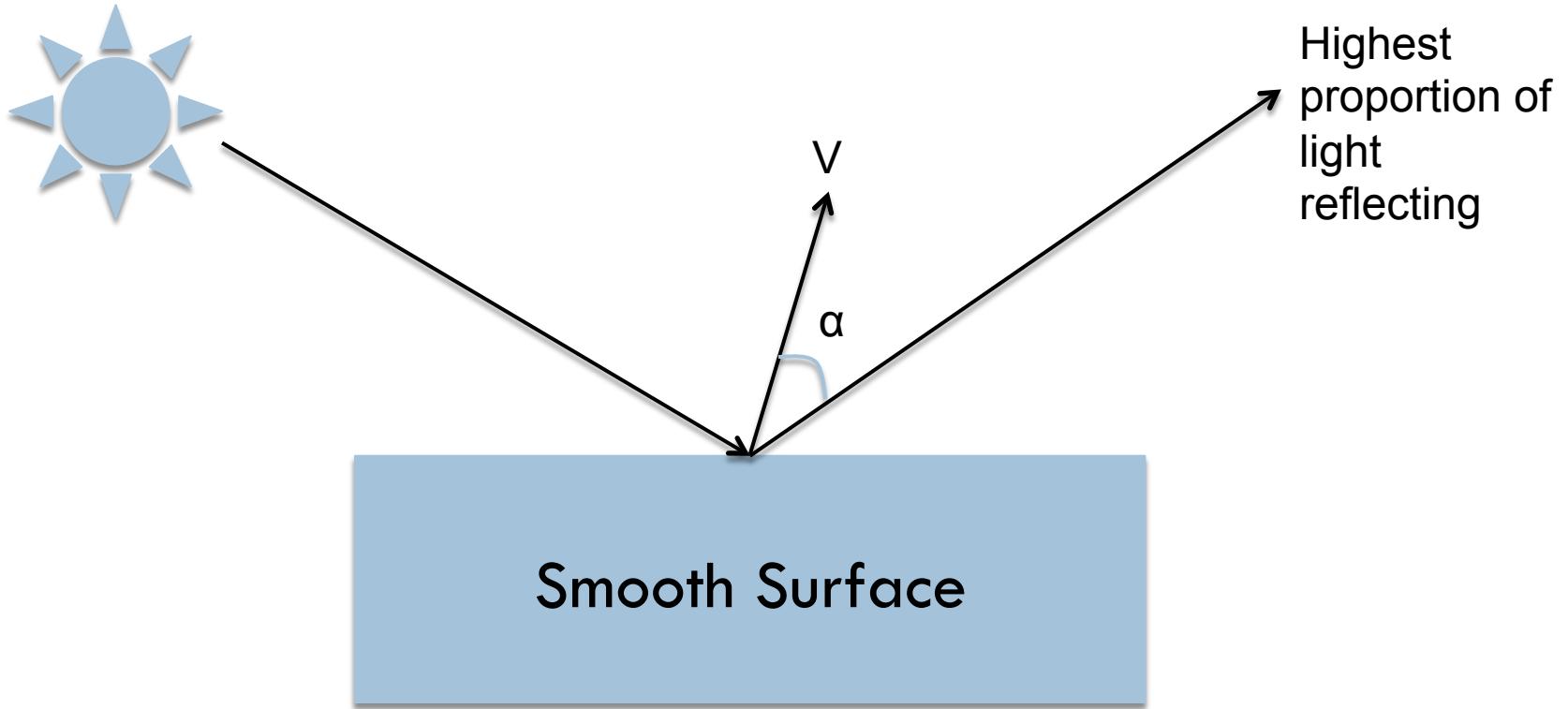


γ : The Shininess Coefficient

- Values of γ between 100 and 200 correspond to metals
- Values between 5 and 10 give surface that look like plastic



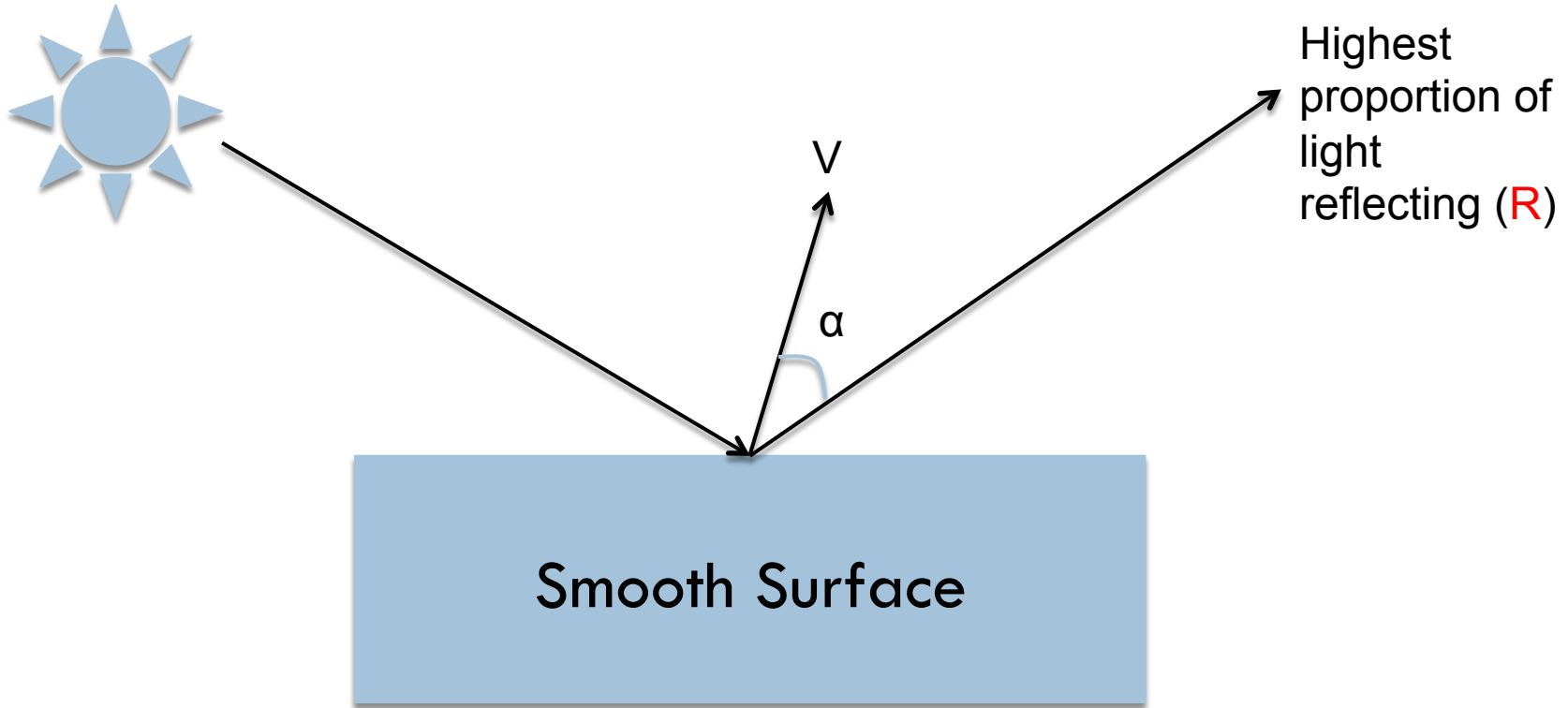
How much light reflects with specular lighting?



How much light gets to point V?

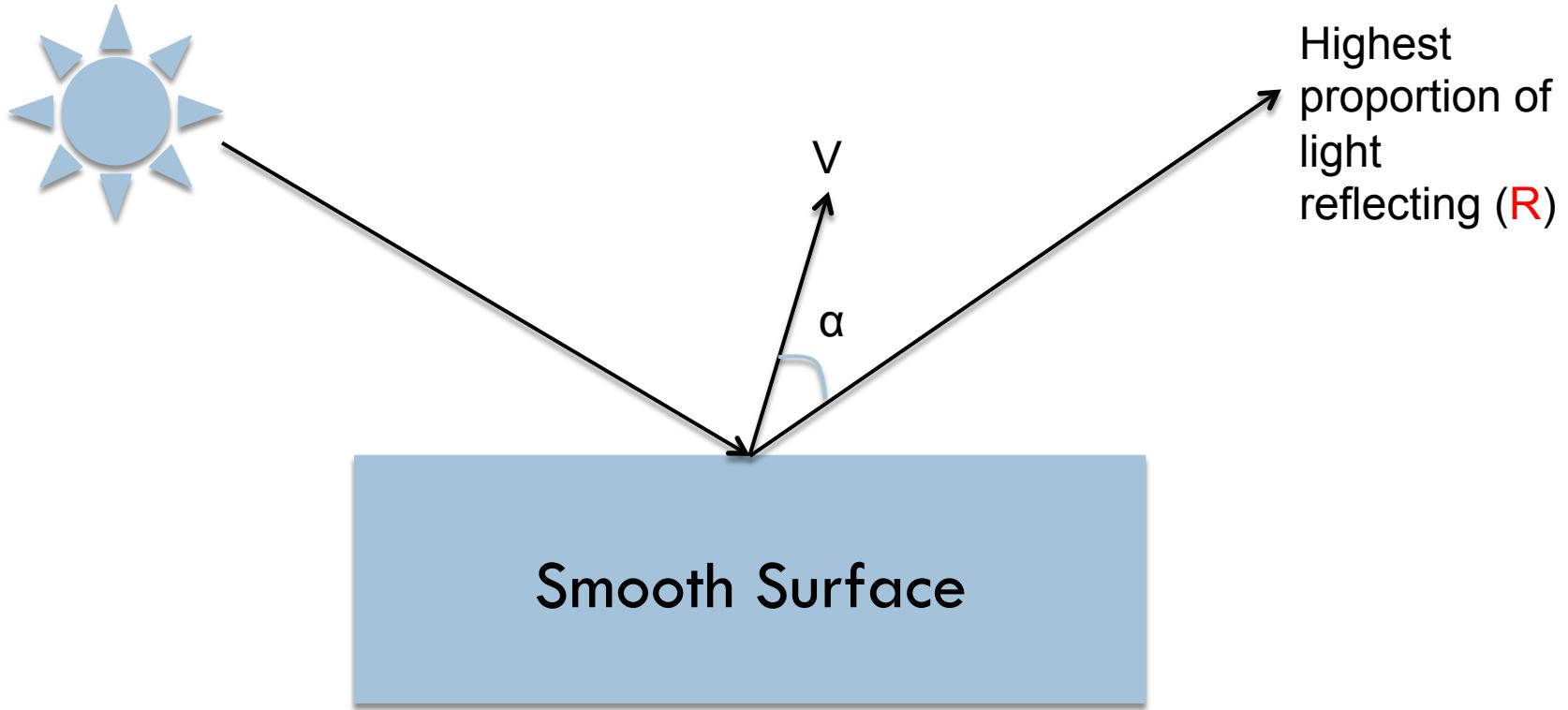
A: proportional to $\cos(\alpha)$
(Shininess strength) * $\cos(\alpha)^{\text{shininess coefficient}}$

How much light reflects with specular lighting?

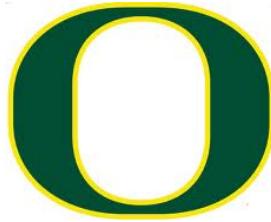


Great!
We know that $\cos(\alpha)$ is $V \cdot R$.

How much light reflects with specular lighting?



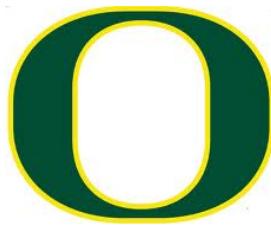
Great!
We know that $\cos(\alpha)$ is $V \cdot R$.
But what is R ?
It is a formula: $R = 2 * (L \cdot N) * N - L$



Two-sided lighting

- For specular lighting, we will use one-sided lighting for project 1E
 - It just looks better

- Diffuse: $\text{abs}(\mathbf{L} \cdot \mathbf{N})$
- Specular: $\max(0, S^*(\mathbf{R} \cdot \mathbf{V})^\gamma)$



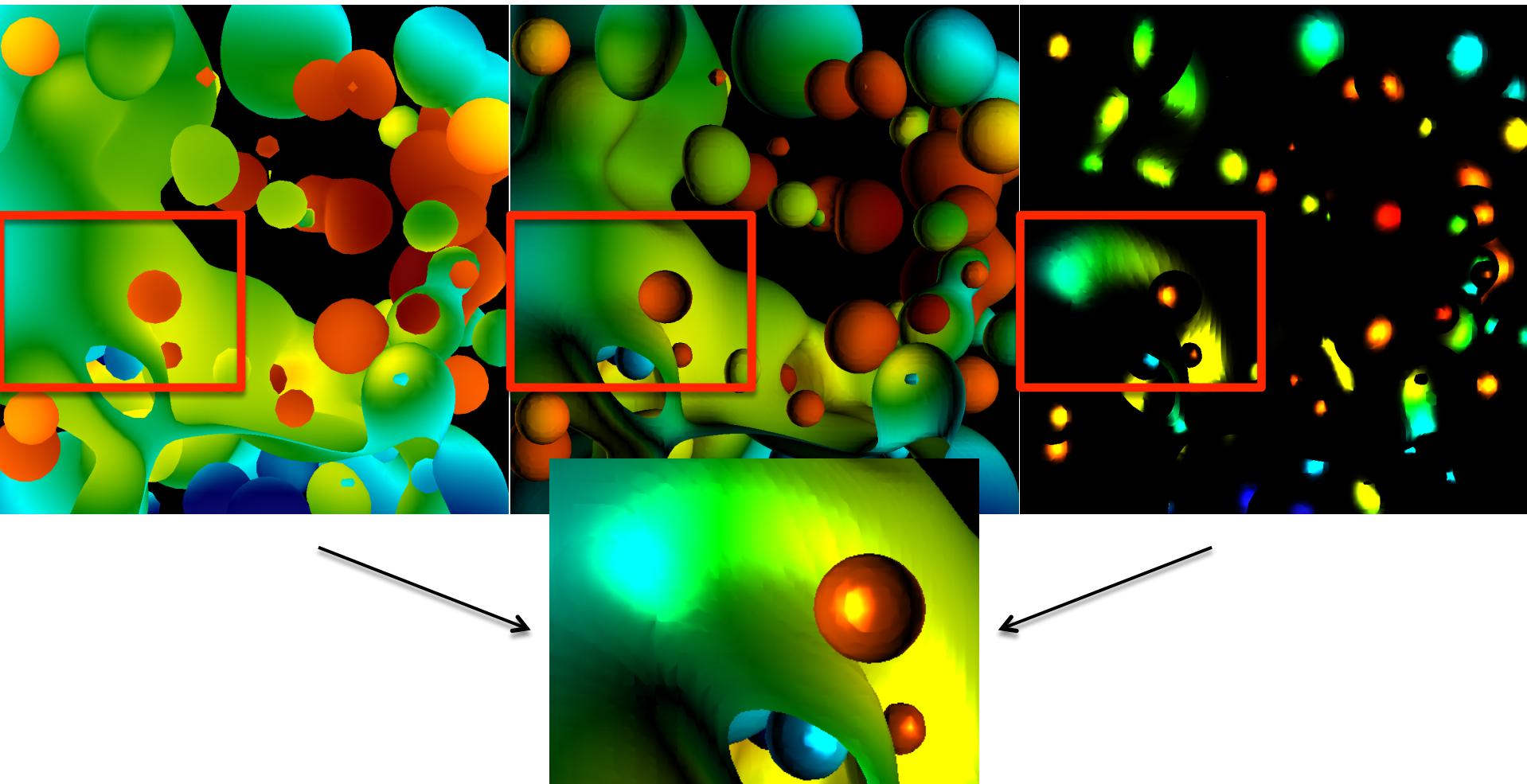
Outline

- Math Basics
- Lighting Basics
- The Phong Model



Phong Model

- Combine three lighting effects: ambient, diffuse, specular





Phong Model

- Simple version: 1 light, with “full intensity” (i.e., don’t add an intensity term)
- Phong model
 - $\text{Shading_Amount} = K_a + K_d * \text{Diffuse} + K_s * \text{Specular}$
- Signature:
 - `double CalculatePhongShading(LightingParameters &, double *viewDirection, double *normal)`
 - For us, `viewDirection = (0,0, +1)`



Lighting parameters

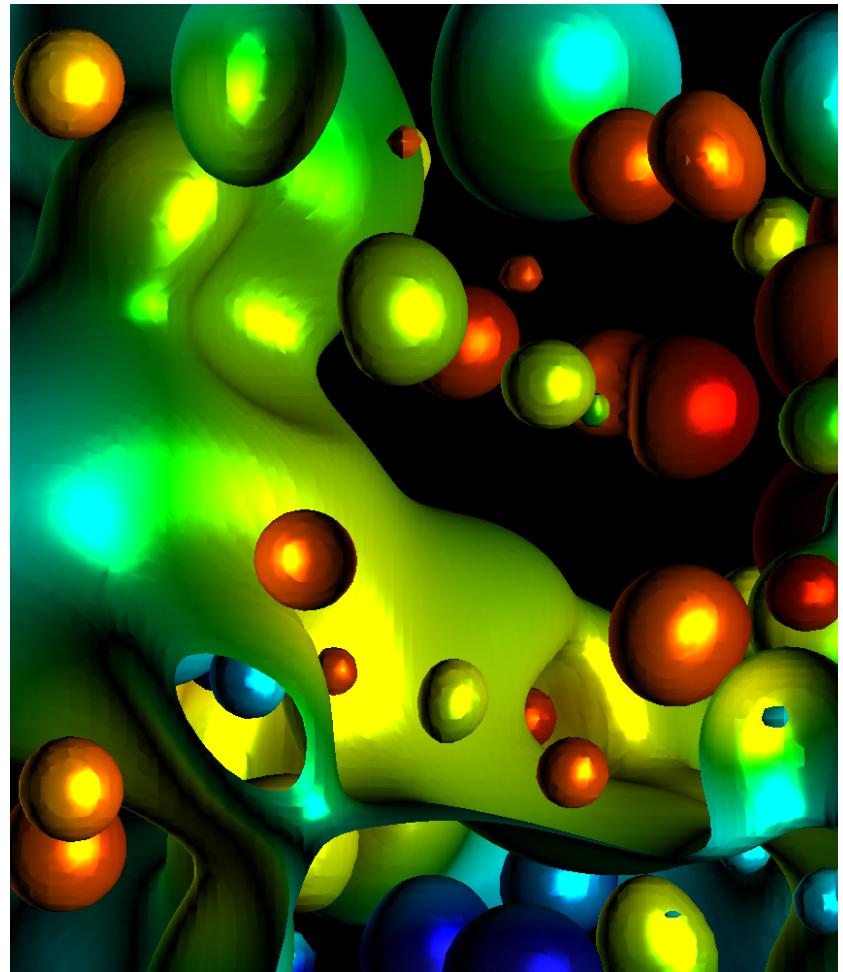
```
struct LightingParameters
{
    LightingParameters(void)
    {
        lightDir[0] = -0.6;
        lightDir[1] = 0;
        lightDir[2] = -0.8;
        Ka = 0.3;
        Kd = 0.7;
        Ks = 5.3;
        alpha = 7.5
    };

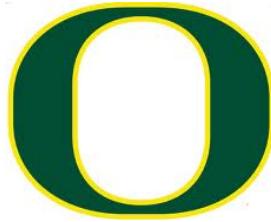
    double lightDir[3]; // The direction of the light source
    double Ka;          // The coefficient for ambient lighting.
    double Kd;          // The coefficient for diffuse lighting.
    double Ks;          // The coefficient for specular lighting.
    double alpha;        // The exponent term for specular lighting.
};
```



Project #1E (7%) (soon)

- Goal: add Phong shading
- Extend your project1D code
- File proj1e_geometry.vtk available on web (9MB)
- File “reader1e.cxx” has code to read triangles from file.
- No Cmake, project1e.cxx





Changes to data structures

```
class Triangle
{
public:
    double X[3], Y[3], Z[3];
    double colors[3][3];
    double normals[3][3];
};
```

→ reader1e.cxx will not compile until you make these changes

→ reader1e.cxx will initialize normals at each vertex



More comments

- New: more data to help debug
 - I will make the shading value for each pixel available.
 - I will also make it available for ambient, diffuse, specular.
- Don't forget to do two-sided lighting
- This project in a nutshell:
 - LERP normal to a pixel
 - You all are great at this now!!
 - Add method called “CalculateShading”.
 - My version of CalculateShading is about ten lines of code.
 - Modify RGB calculation to use shading.

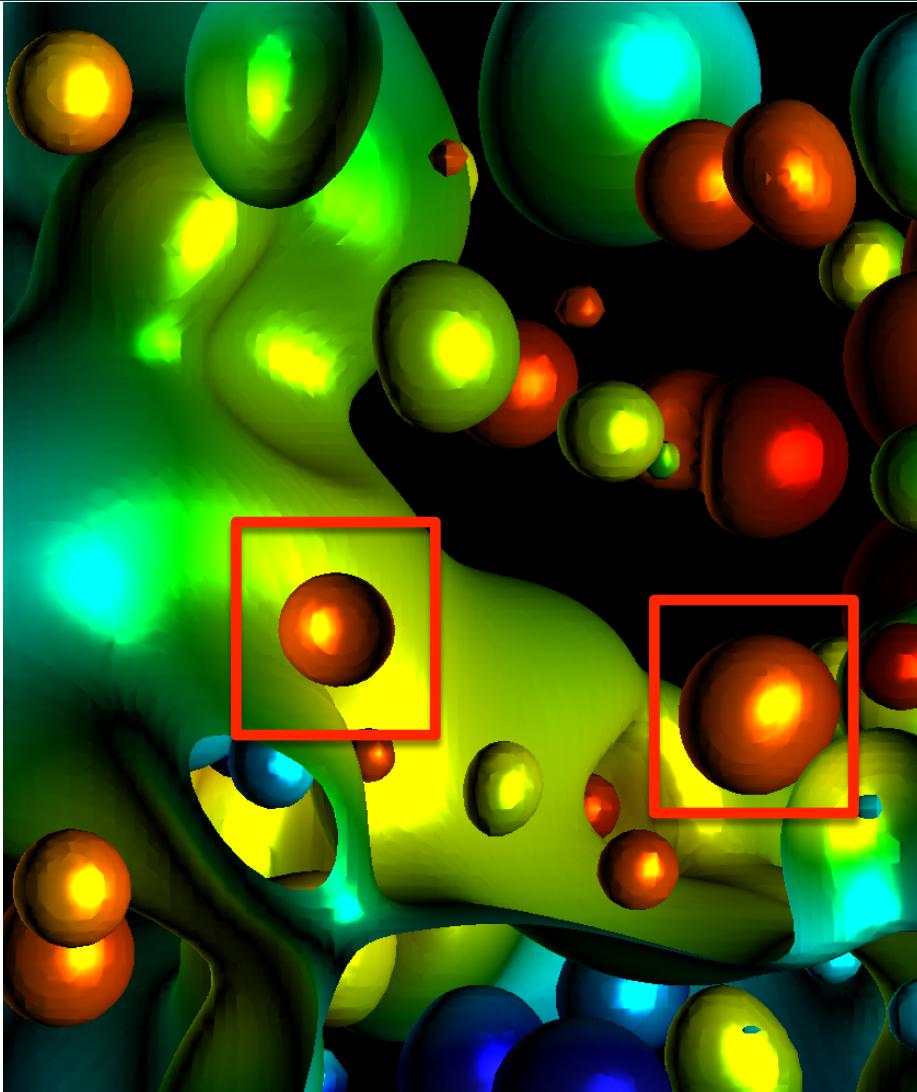
Where Hank spent his debugging time...



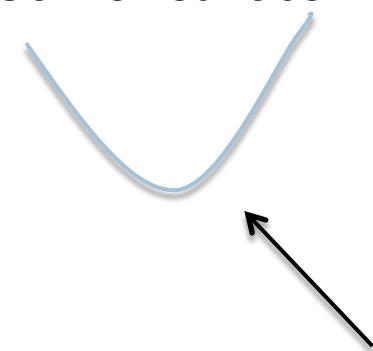
Concave surface



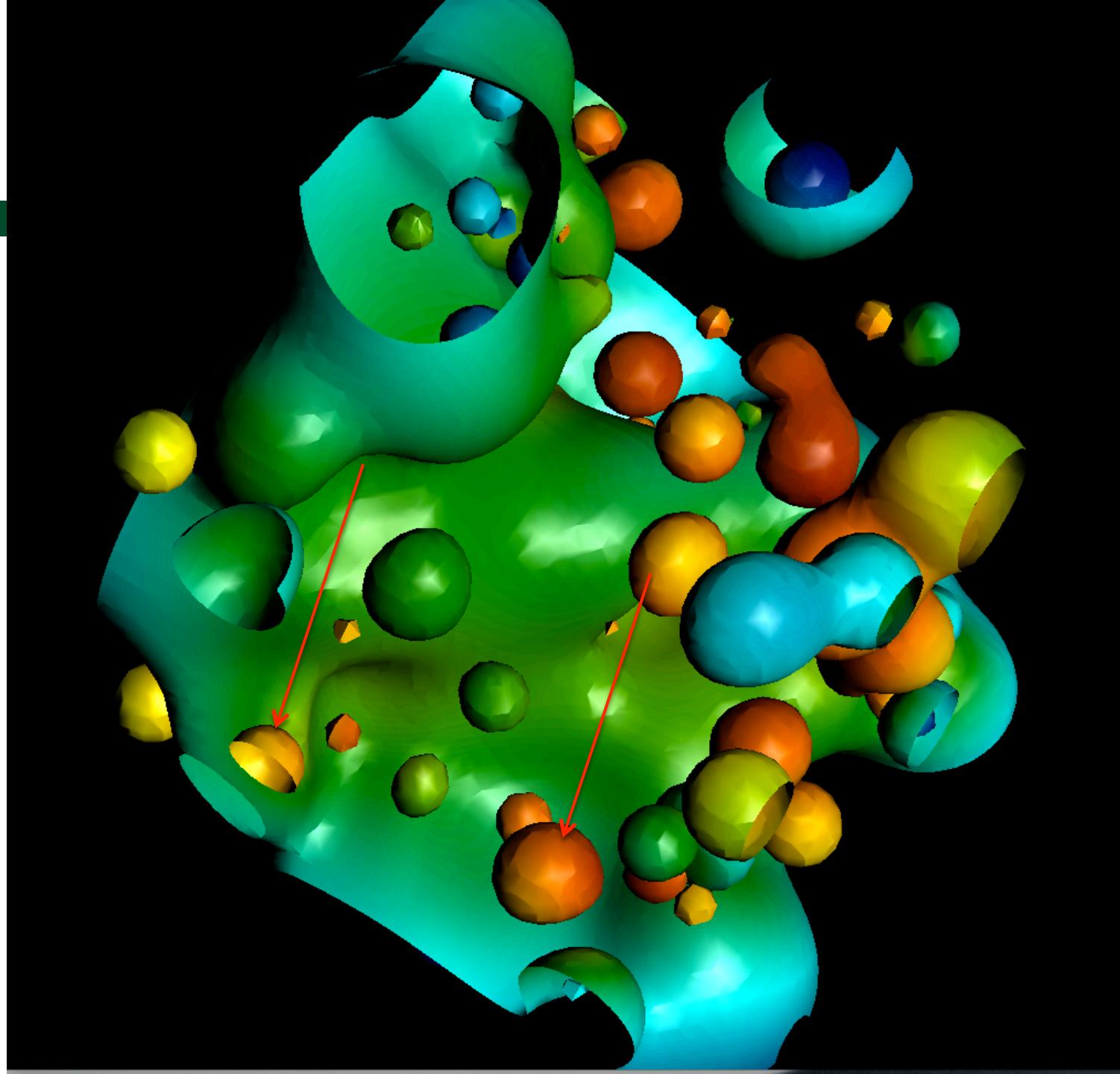
Lighting
direction



Convex surface



Lighting
direction



D