CS559: Computer Graphics

Lecture 12: OpenGL - Transformation

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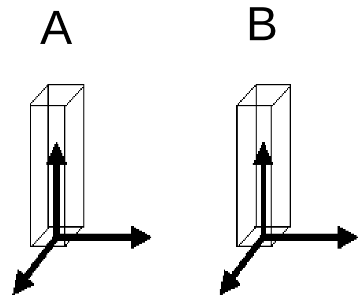
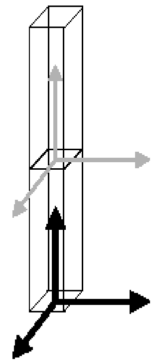
Today

- Finish transformation in OpenGL
- Lighting

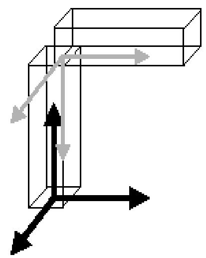
- Reading
  - Shirley, Ch 9.1, 9.2

Connecting primitives





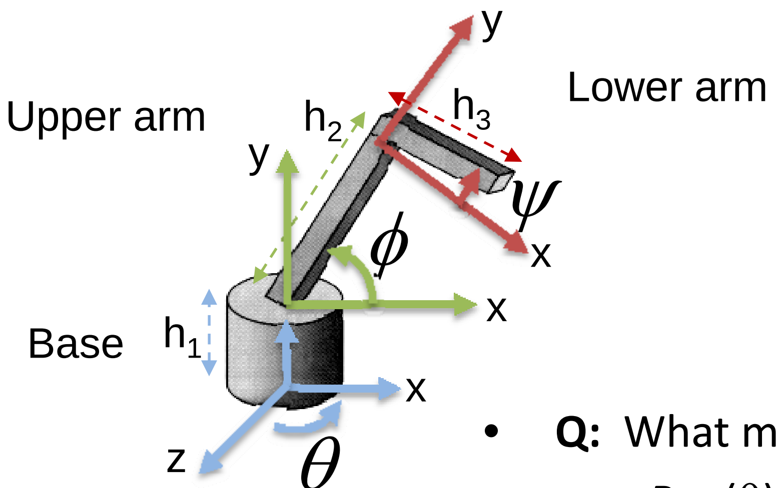
```
glLoadIdentity();
draw_block_A();
glTranslate(0, h, 0);
Draw_block_B();
```



```
glLoadIdentity();
draw_block_A();
glTranslate(0, h, 0);
glRotate(-90, 0, 0, 1);
Draw_block_B();
```

3D Example: A robot arm

- Consider this robot arm with 3 degrees of freedom:
  - Base rotates about its vertical axis by θ
  - Upper arm rotates in its *xy*-plane by ϕ
  - Lower arm rotates in its *xy*-plane by ψ



- **Q:** What matrix do we use to transform the base to the world?
  - R_y(θ)
- **Q:** What matrix for the upper arm to the base?
  - T(0,h1,0)R_z(ϕ)
- **Q:** What matrix for the lower arm to the upper arm?
  - T(0,h2,0)R_z(ψ)

Robot arm implementation

- The robot arm can be displayed by keeping a global matrix and computing it at each step:

```
Matrix M_model;
display(){
    . . .
    robot_arm();
    . . .
}
robot_arm()
{
    M_model = R_y(theta);
    base();
    M_model = R_y(theta)*T(0,h1,0)*R_z(phi);
    upper_arm();
    M_model = R_y(theta)*T(0,h1,0)*R_z(phi)*T(0,h2,0)*R_z(psi);
    lower_arm();
}
```

- **Q:** What matrix do we use to transform the base to the world?
  - R_y(θ)
- **Q:** What matrix for the upper arm to the base?
  - T(0,h1,0)R_z(ϕ)
- **Q:** What matrix for the lower arm to the upper arm?
  - T(0,h2,0)R_z(ψ)

How to translate the whole robot?

Do the matrix computations seem wasteful?

Robot arm implementation, better

- Instead of recalculating the global matrix each time, we can just update it *in place* by concatenating matrices on the right:

```
Matrix M_model;
display(){
    . . .
    M_model = identity;
    robot_arm();
    . . .
}
robot_arm()
{
    M_model *= R_y(theta);
    base();
    M_model *= T(0,h1,0)*R_z(phi);
    upper_arm();
    M_model *= T(0,h2,0)*R_z(psi);
    lower_arm();
}
```

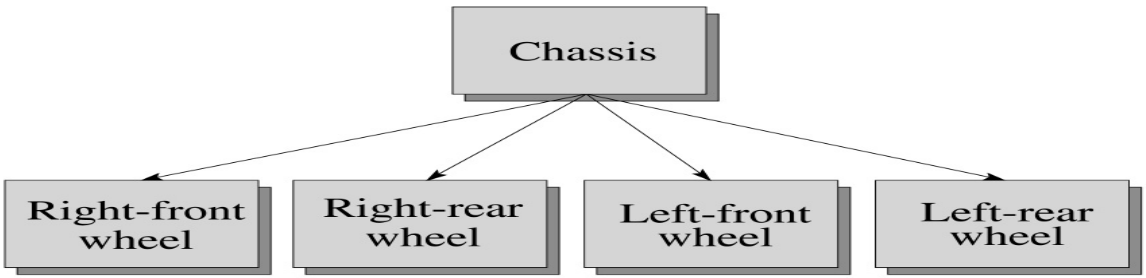
Robot arm implementation, OpenGL

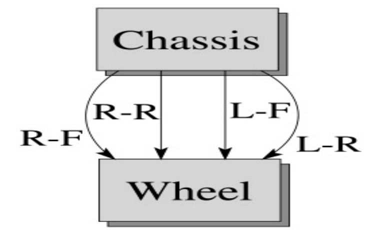
- OpenGL maintains the **model-view matrix**, as a global state variable which is updated by concatenating matrices on the ***right***.

```
display()
{
    . . .
    glMatrixMode( GL_MODELVIEW );
    glLoadIdentity();
    robot_arm();
    . . .
}
robot_arm()
{
    glRotatef( theta, 0.0, 1.0, 0.0 );
    base();
    glTranslatef( 0.0, h1, 0.0 );
    glRotatef( phi, 0.0, 0.0, 1.0 );
    lower_arm();
    glTranslatef( 0.0, h2, 0.0 );
    glRotatef( psi, 0.0, 0.0, 1.0 );
    upper_arm();
}
```

Hierarchical modeling

- Hierarchical models can be composed of instances using trees:

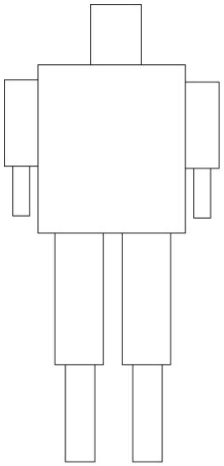


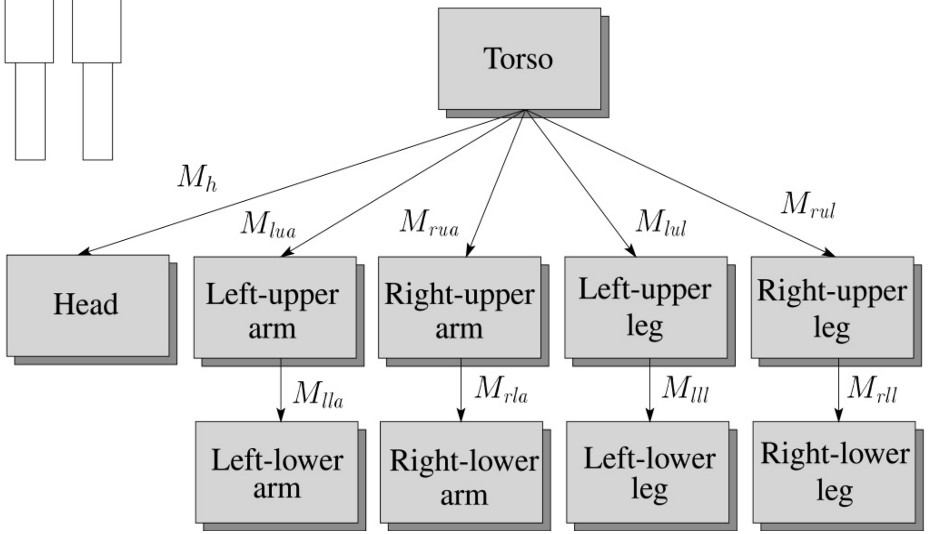


  - edges contain geometric transformations
  - nodes contain geometry (and possibly drawing attributes)

How might we draw the tree for the robot arm?

A complex example: human figure





- **Q:** What's the most sensible way to traverse this tree?

Human figure implementation, OpenGL

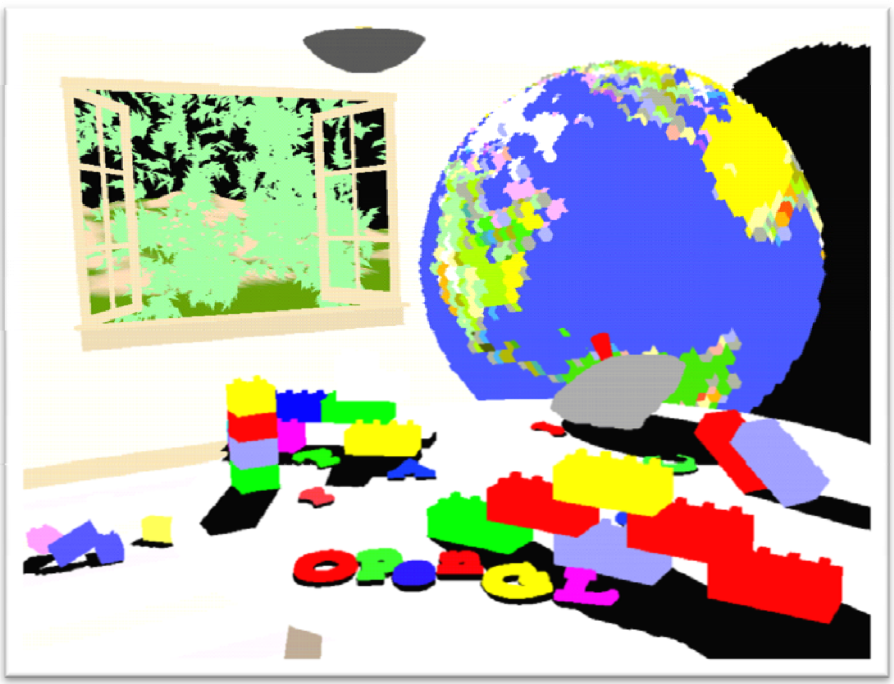
```
figure()
{
    torso();
    glPushMatrix();
        glTranslate( ... );
        glRotate( ... );
        head();
    glPopMatrix();
    glPushMatrix();
        glTranslate( ... );
        glRotate( ... );
        left_upper_arm();
        glPushMatrix();
            glTranslate( ... );
            glRotate( ... );
            left_lower_arm();
        glPopMatrix();
     glPopMatrix();
     . . .
}
```

So far…

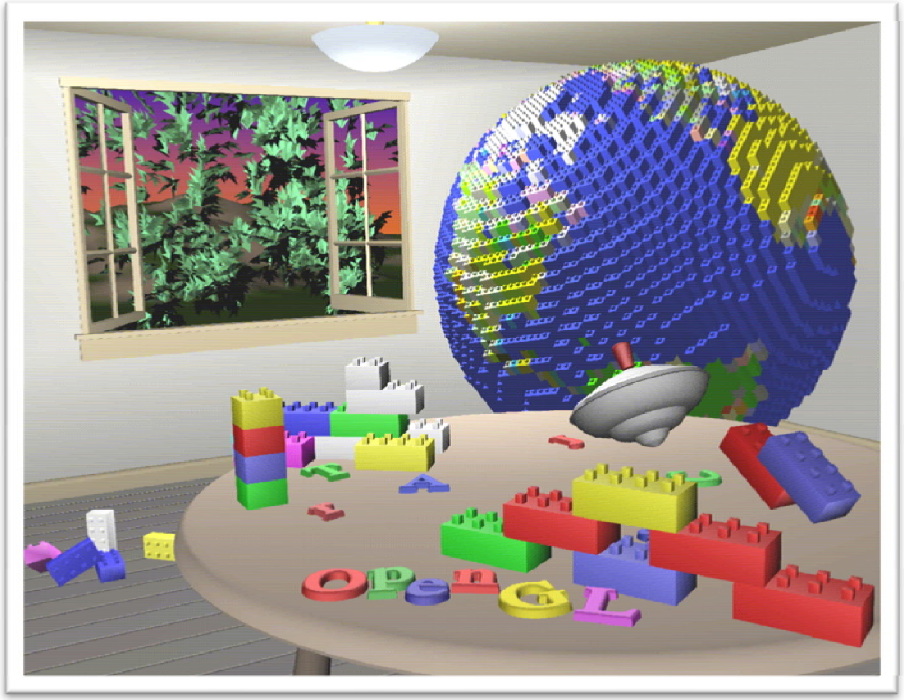
- We've talked exclusively about geometry.
  - What is the shape of an object?
    - glBegin() … glEnd()
  - How do I place it in a virtual 3D space?
    - glMatrixMode() …
  - How to change viewpoints
    - gluLookAt()
  - How do I know which pixels it covers?
    - Rasterization
  - How do I know which of the pixels I should actually draw?
    - Z-buffer, BSP

So far

```
glColor(…);
Apply_transforms();
Draw_objects();
```



Flat shaded



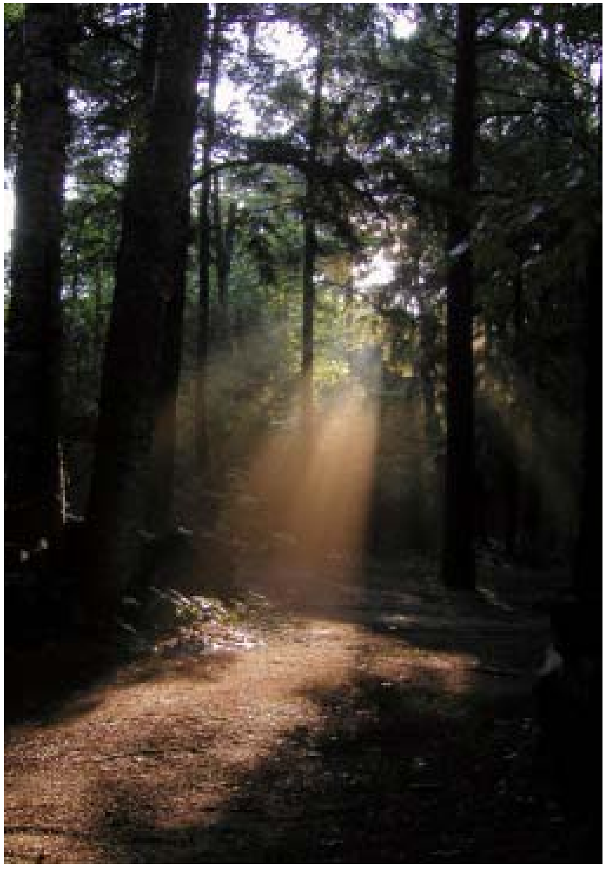
Lit surface

Next…

- Once we know geometry, we have to ask one more important question:
  - To what value do I set each pixel?
- Answering this question is the job of the **shading model**.
- Other names:
  - Lighting model
  - Light reflection model
  - Local illumination model
  - Reflectance model
  - BRDF

An abundance of photons

- Properly determining the right color is *really hard.*



Particle Scattering

An abundance of photons

- Properly determining the right color is *really hard.*

Translucency

An abundance of photons

- Properly determining the right color is *really hard.*

Refraction

An abundance of photons

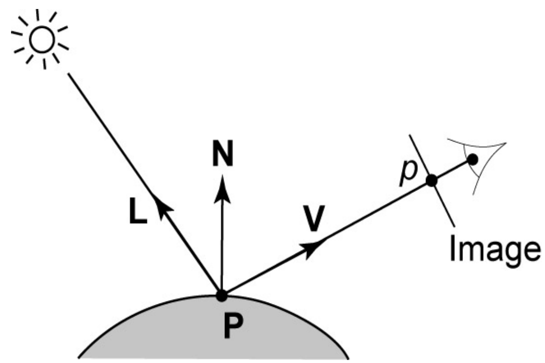
- Properly determining the right color is *really hard.*

Global Effect

Our problem

- We're going to build up to an *approximation* of reality called the **Phong illumination model**.
- It has the following characteristics:
  - *not* physically based
  - gives a "first-order" *approximation* to physical light reflection
  - very fast
  - widely used
- In addition, we will assume **local illumination**, i.e., light goes: light source -> surface -> viewer.
- No interreflections, no shadows.

Setup…



$$\|\mathbf{N}\| = \|\mathbf{L}\| = \|\mathbf{V}\| = 1$$

- Given:
  - a point **P** on a surface visible through pixel *p*
  - The normal **N** at **P**
  - The lighting direction, **L**, and intensity, *L* ,at **P**
  - The viewing direction, **V**, at **P**
  - The shading coefficients at **P**
- Compute the color, *I*, of pixel *p*.
- Assume that the direction vectors are normalized:

“Iteration zero”

- The simplest thing you can do is…
- Assign each polygon a single color:

$$I = k_e$$

- where
  - I is the resulting intensity
  - k_e is the **emissivity** or intrinsic shade associated with the object

- This has some special-purpose uses, but not really good for drawing a scene.

"Iteration one"

- Let's make the color at least dependent on the overall quantity of light available in the scene:

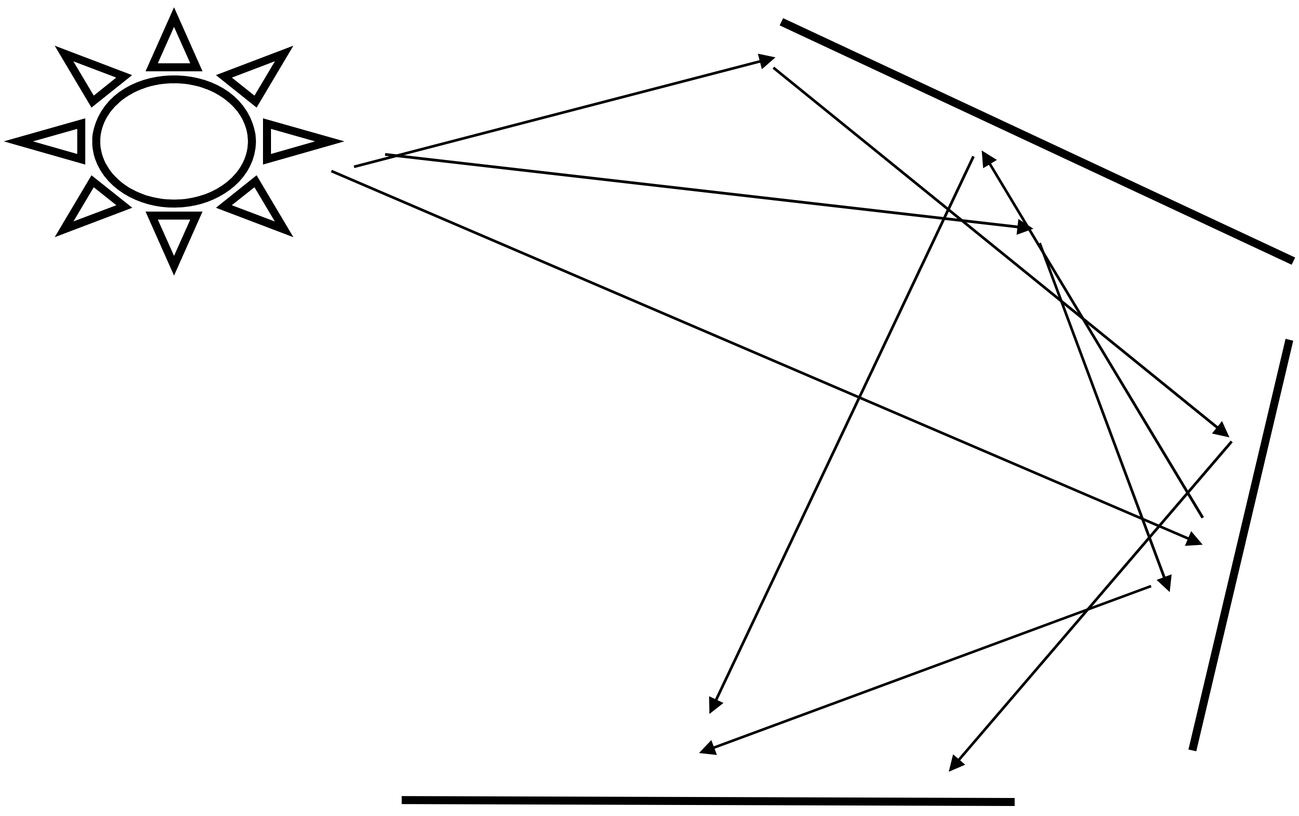
$$I = k_e + k_a L_a$$

  - k_a is the **ambient reflection coefficient**.
    - really the reflectance of ambient light
    - "ambient" light is assumed to be equal in all directions
  - L_a is the **ambient light intensity**.

- Physically, what is "ambient" light?

Ambient Term

- Hack to simulate multiple bounces, scattering of light
- Assume light equally from all directions



Slide from Ravi Ramamoorthi

Wavelength dependence

- Really, k_e, k_a, and L_a are functions over all wavelengths λ.
- Ideally, we would do the calculation on these functions. For the ambient shading equation, we would start with:

$$I(\lambda) = k_a(\lambda) L_a(\lambda)$$

- then we would find good RGB values to represent the spectrum $I(\lambda)$.
- Traditionally, though, k_a and I_a are represented as RGB triples, and the computation is performed on each color channel separately:

$$I_R = k_{a,R} L_{a,R}$$
$$I_G = k_{a,G} L_{a,G}$$
$$I_B = k_{a,B} L_{a,B}$$

Diffuse reflection

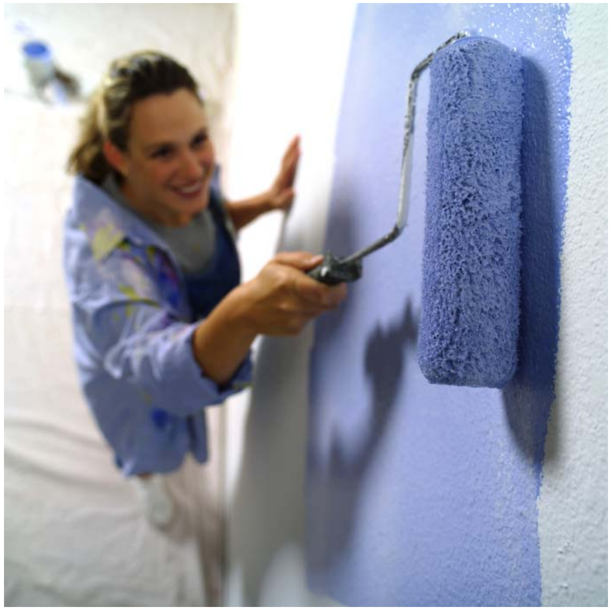
$$I = k_e + k_a L_a$$

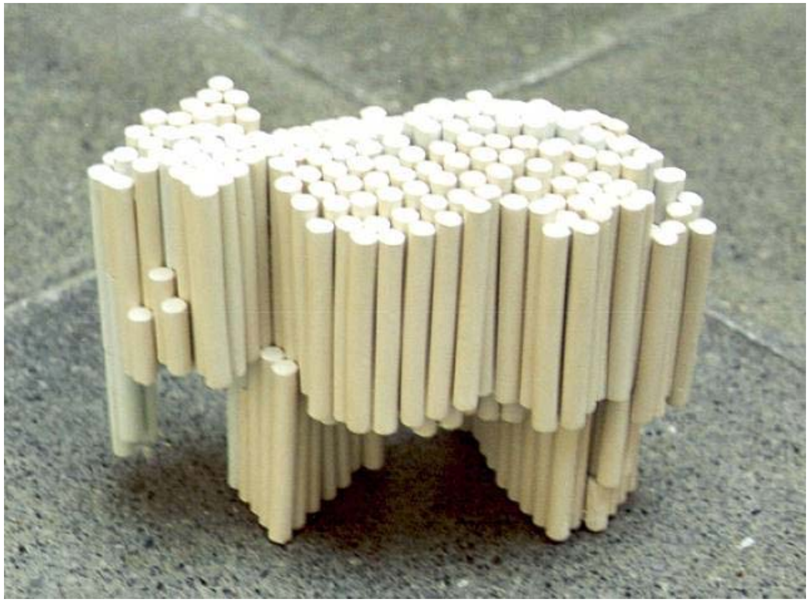
- So far, objects are uniformly lit.
  - not the way things really appear
  - in reality, light sources are localized in position or direction

- **Diffuse**, or **Lambertian** reflection will allow reflected intensity to vary with the direction of the light.

Diffuse reflectors

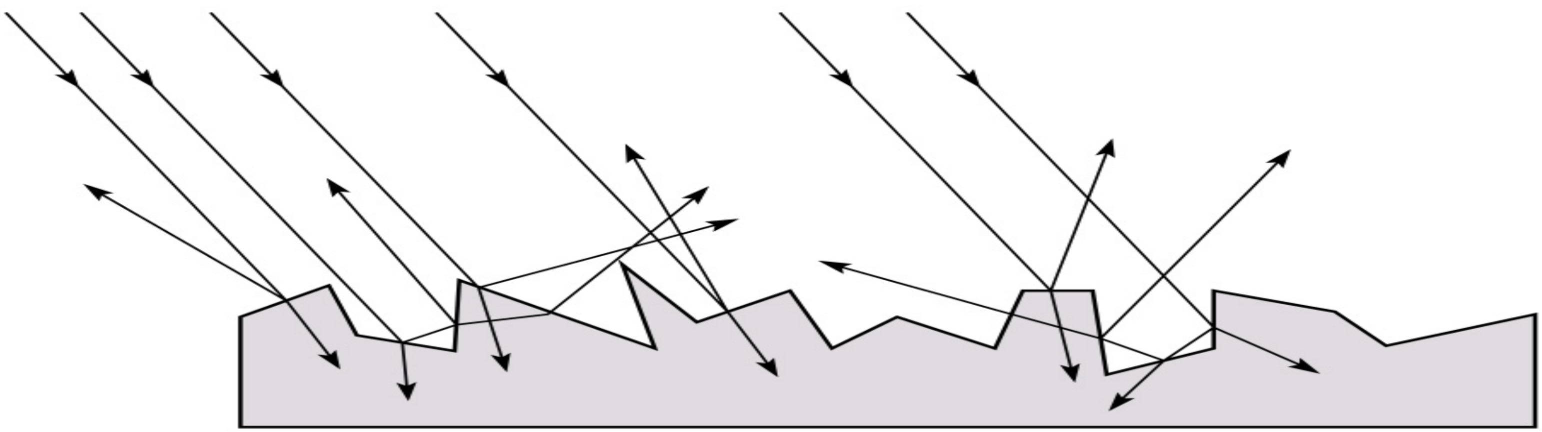
- Diffuse reflection occurs from dull, matte surfaces, like latex paint, or chalk.
- These **diffuse** or **Lambertian** reflectors reradiate light equally in all directions.





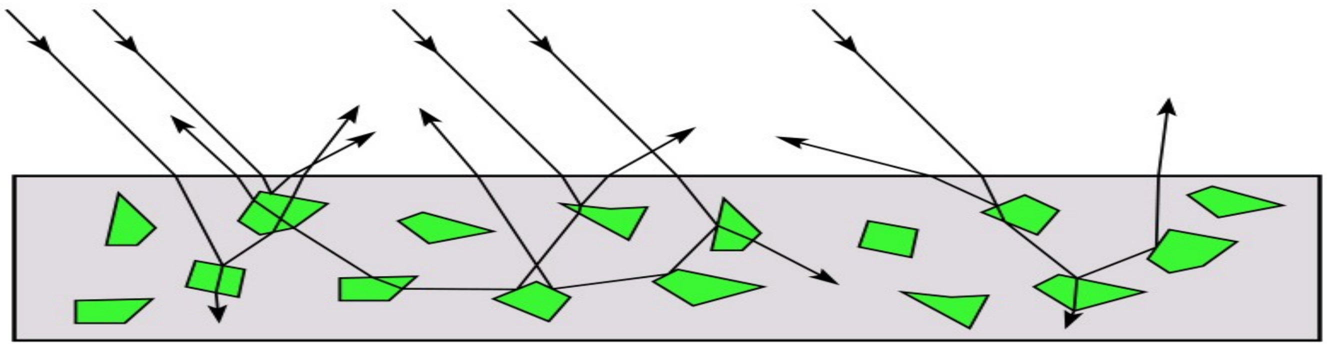
Diffuse reflectors

- Diffuse reflection occurs from dull, matte surfaces, like latex paint, or chalk.
- These **diffuse** or **Lambertian** reflectors reradiate light equally in all directions.
- Picture a rough surface with lots of tiny **microfacets**.



Diffuse reflectors

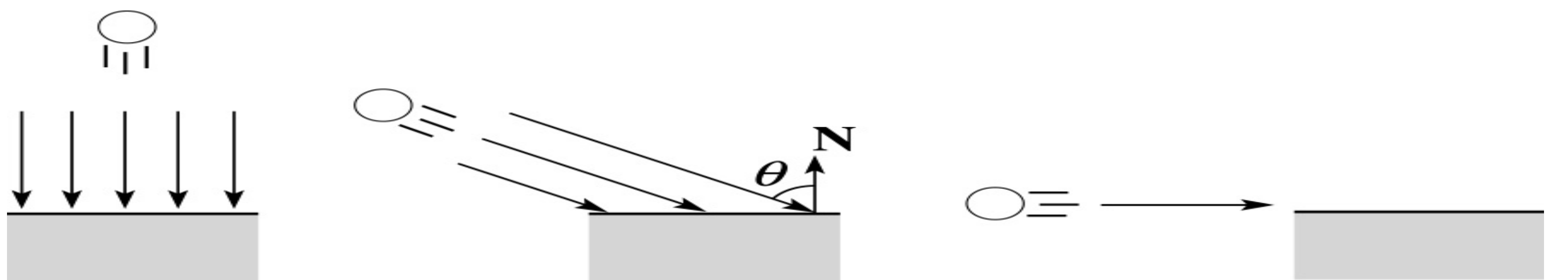
- …or picture a surface with little pigment particles embedded beneath the surface (neglect reflection at the surface for the moment):



- The microfacets and pigments distribute light rays in all directions.
- Embedded pigments are responsible for the coloration of diffusely reflected light in plastics and paints.
- Note: the figures above are intuitive, but not strictly (physically) correct.

Diffuse reflectors, cont.

- The reflected intensity from a diffuse surface does not depend on the direction of the viewer. The incoming light, though, does depend on the direction of the light source:



“Iteration two”

- The incoming energy is proportional to <u> cosθ </u>, giving the diffuse reflection equations:

$$I = k_e + k_a L_a + k_d L \cdot (\mathbf{L} \cdot \mathbf{N})$$

$$= k_e + k_a L_a + k_d L \cdot \max(0, \mathbf{L} \cdot \mathbf{N})$$

- where:
  - k_d is the **diffuse reflection coefficient**
  - L_d is the intensity of the light source
  - **N** is the normal to the surface (unit vector)
  - **L** is the direction to the light source (unit vector)