Ray tracing

- cast ray through pixel into scene
- find intersection point (if any) that is closest to eye
- compute color at intersection

Color

The color of a point on a surface depends on:
- lights in scene
- material properties of surface
- geometry of scene

For each channel, we’ll approximate the color at the intersection point as the sum of four terms:
- emission
- ambient reflection
- diffuse reflection
- specular reflection

We’ll describe the terms for the red channel.

Red emission term

*erm* the material red emission

Note: terms shown in red are input parameters
red = mer + ...

color

for each channel we'll approximate the color at the intersection point as the sum of four terms
- emission
- ambient reflection
- diffuse reflection
- specular reflection

ambient light

The red ambient term is \( ar \times mar \) where
- \( ar \) is the red intensity of the ambient light
- \( mar \) is the response of the surface to red ambient light

red ambient term

red = mer + ar \times mar + ...

color

for each channel we'll approximate the color at the intersection point as the sum of four terms
- emission
- ambient reflection
- diffuse reflection
- specular reflection
diffuse reflections

rough/matte surface:
light reflects uniformly
in all directions

diffuse reflections provide the
surface "color"

red diffuse term

the red diffuse reflection term is $\sum R_{L, D}$ where
- the summation is taken over all lights $L$
- $R_{L, D}$ is the intensity of the red, diffuse
reflection of light $L$ at the intersection point

Note: terms in green are explained in
subsequent slides

$R_{L, D}$

depends on
- type of light
- geometry of scene
- material properties of surface

types of lights

- directional light
- point light
- spot light

directional light

- light positioned at
  "infinity": intensity
  and incident angle
  are constant for all
  points in scene
- specification
  - direction
  - red, green, and blue
  intensity

$R_{L, D}$ for directional light $L$

$R_{L, D} = 0$ if $L$ is occluded
$R_{L, D} = \text{mdr} \cdot \text{lr} \cdot \max(0, (n \cdot -ld))$
otherwise
- mdr is the diffuse response of the surface
  material to red light
- lr is the red intensity of light $L$
- $n$ is the unit normal of the surface at the point
  of intersection
- ld is a unit vector in direction the light falls

Note: you need to compute terms in blue
normal

normal in direction of intersecting ray

reflection decreases as θ increases. If |θ| > 90°, the light falls on the other side of the surface and is not reflected

point light

• light emanates uniformly in all directions
• specification
  - location in world coordinates
  - red, green, and blue intensity
  - how the light drops off with distance

\[
R_{L,D} = 0 \text{ if } L \text{ is occluded}
\]
\[
R_{L,D} = A \cdot mdr \cdot lr \cdot \max(0, n \cdot -ld)
\]
otherwise

• mdr, lr, and n are as previously defined
• ld is the unit vector from the light position PL to the intersection point
• \( A = \frac{1}{(ca + la \cdot d + qa \cdot d^2)} \) is the attenuation term, d is the distance between the light and the surface point

spot light

• light emanates in a cone
• specifications
  - location in world coordinates
  - red, green, and blue intensity
  - how the light drops off with distance
  - how light drops with angle from center
  - light orientation vector lo
  - cutoff angle CO
  - drop off exponent DO

\[
R_{L,D} = 0 \text{ if } L \text{ is occluded}
\]
\[
R_{L,D} = A \cdot SP \cdot mdr \cdot lr \cdot \max(0, (n \cdot -ld))
\]
where

• A, mdr, lr, and ld are as previously defined
• SP is the "spot light effect"
  - SP=0 if angle between lo and ld is greater than CO
  - \( SP = \max(0, ld \cdot lo)^{\frac{-128}{DO}} \) otherwise

where does the 128 come from? what should you do about it?
Diffuse reflection term for each light L

\[ R_{L,D} = 0 \text{ if } L \text{ is occluded} \]

\[ R_{L,D} = A \cdot SP \cdot mdr \cdot lr \cdot \max(0, (\mathbf{n} \cdot -\mathbf{ld})) \]

- \( \mathbf{n} \cdot \mathbf{ld} \) indicates the dot product of the normal vector at the intersection point and the light direction vector.
- \( A \) represents positional/spot light attenuation (1 for directional light).
- \( SP \) is the spot light effect (1 for directional and point lights).

\[
\text{red} = \text{mer} + ar \cdot mar + \sum L R_{L,D} + \ldots
\]

**color**

For each channel, we'll approximate the color at the intersection point as the sum of four terms:
- emission
- ambient reflection
- diffuse reflection
- specular reflection

**specular reflections**

- \( \sum L R_{L,S} \) where
  - the summation is taken over all lights L
  - \( R_{L,S} \) is the intensity of the red, specular reflection of light L at the intersection point (details to follow shortly)

**red specular**

- The red specular reflection term is \( \sum L R_{L,S} \) where
  - the summation is taken over all lights L
  - \( R_{L,S} \) is the intensity of the red, specular reflection of light L at the intersection point (details to follow shortly)

**directional light**

- Light positioned at infinity; intensity and incident angle are constant for all surface points in scene
**R\_L,S for directional light L**

\[ R_{L,S} = 0 \text{ if light is occluded} \]

\[ R_{L,S} = m_{sr} \cdot l_r \cdot \max(0, (-v \cdot dr)) \cdot 128 \cdot k_{spec} \]

otherwise

- \( m_{sr} \) is the specular response of the surface material to red light
- \( l_r \) is as previously defined
- \( v \) is the direction of the incoming ray
- \( dr \) is a unit vector in the direction of reflection
- \( k_{spec} \) is the shininess constant

*where does the 128 come from? what should you do about it?*

---

**vector of reflection**

\[ \text{compute } dr \text{ given } n \text{ and } ld \]

(all unit vectors)

---

**R\_L,S**

depends on

- type of light
- geometry of scene
- material properties of surface

---

**vector of reflection**

\[ (-ld \cdot n) + ld \]

since \( n \) is a unit vector

---

**vector of reflection**

\[ 2((-ld \cdot n) + ld) \]
vector of reflection

\[ \mathbf{dr} = -\mathbf{l}_d + 2(-\mathbf{l}_d \cdot \mathbf{n})\mathbf{n} = \mathbf{l}_d + 2(-\mathbf{l}_d \cdot \mathbf{n})\mathbf{n} \]

point light

- light emanates uniformly in all directions
- specification
  - location in world coordinates
  - red, green, and blue intensity
  - how the light drops off with distance

\[ R_{L,S} \text{ for point light } L \]

\[ R_{L,S} = 0 \text{ if light is occluded} \]

\[ R_{L,S} = A \cdot \mathbf{msr} \cdot \frac{1}{r} \cdot \max(0, (\mathbf{v} \cdot \mathbf{dr}))^{128\times k_{\text{spec}}} \]  
  otherwise

all terms are as previously defined

spot light

- light emanates in a cone
- specifications
  - location in world coordinates
  - red, green, and blue intensity
  - how the light drops off with distance
  - how light drops with angle from center

Specular reflection term for each light L

\[ R_{L,S} = 0 \text{ if } L \text{ is occluded} \]

\[ R_{L,S} = A \cdot SP \cdot \mathbf{msr} \cdot \frac{1}{r} \cdot \max(0, (\mathbf{v} \cdot \mathbf{dr}))^{128\times k_{\text{spec}}} \]
  otherwise

spot light effect (SP=1 for directional and point lights)

positional/spot light attenuation (A=1 for directional lights)

\[ R_{L,S} \text{ for spot light } L \]

\[ R_{L,S} = 0 \text{ if } L \text{ is occluded} \]

\[ R_{L,S} = A \cdot SP \cdot \mathbf{msr} \cdot \frac{1}{r} \cdot \max(0, (\mathbf{v} \cdot \mathbf{dr}))^{128\times k_{\text{spec}}} \]  
  otherwise

all terms are as previously described
red

red = mer + ar*mar + \( \Sigma L (R_{L,D} + R_{L,S}) \)

occlusion

what about occlusions? (i.e. shadows)

ray tracing

- simple ray casting
- recursive ray tracing
- cheap tricks
- optimizations

global effects

- shadows
- indirect specular reflection
- indirect specular transmission

color: ray tracing

for each channel we'll approximate the color at the intersection point as the sum of five terms
- emission
- ambient reflection
- diffuse reflection (check for occlusion)
- specular reflection (check for occlusion)
- recursive term
**recursive rays**

- cast ray
- indirect specular reflection
- shadow
- indirect specular transmission

**occlusion (shadows)**

- normal in direction of incoming ray
- intersection point P
- light L is occluded if the ray \( R' = (P, -ld) \) intersects some object in the scene

**occlusion: implementation**

- offset \( R' \) slightly so it doesn't intersect at P
- intersection point P
- L is occluded if the ray \( (P, -ld) \) intersects some object in the scene

**global effects**

- shadows
- indirect specular reflection
- indirect specular transmission

next time