CS-184: Computer Graphics

Lecture #8: Shading

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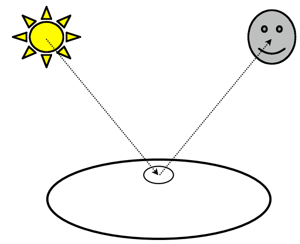
Today

- Local Illumination & Shading
  - The BRDF
  - Simple diffuse and specular approximations
  - Shading interpolation: flat, Gouraud, Phong
  - Some miscellaneous tricks
- Normal Vectors

Local Shading

- Local: consider in isolation
  - 1 light
  - 1 surface
  - The viewer
- Recall: lighting is linear
  - Almost always...



Counter example: photochromatic materials

Local Shading

- Examples of non-local phenomena
  - Shadows
  - Reflections
  - Refraction
  - Indirect lighting

The BRDF

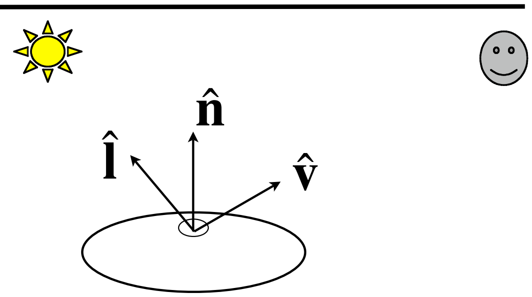
- The **B**i-directional **R**eflectance **D**istribution **F**unction
- Given
  - Surface material
  - Incoming light direction
  - Direction of viewer
  - Orientation of surface

$$\rho = \rho(\theta_V, \theta_L)$$
$$= \rho(\mathbf{v}, \mathbf{l}, \mathbf{n})$$

- Return:
  - fraction of light that reaches the viewer
- We'll worry about physical units later...

The BRDF

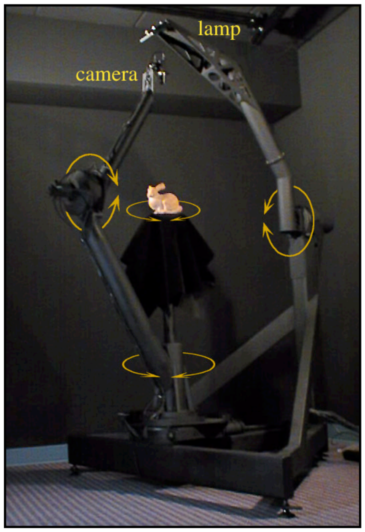
$$\rho(\mathbf{v}, \mathbf{l}, \mathbf{n})$$

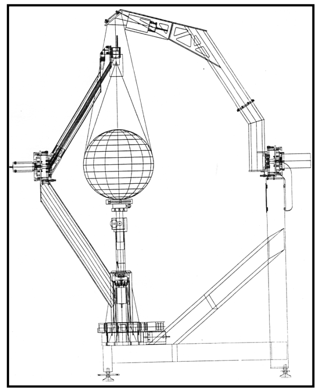


- Spatial variation capture by "the material"
- Frequency dependent
  - Typically use separate RGB functions
  - Does not work perfectly
  - Better: $\rho = \rho(\theta_V, \theta_L, \lambda_{\text{in}}, \lambda_{\text{out}})$

Obtaining BRDFs

- Measure from real materials





Images from Marc Levoy

Obtaining BRDFs

- Measure from real materials
- Computer simulation
  - Simple model + complex geometry
- Derive model by analysis
- Make something up

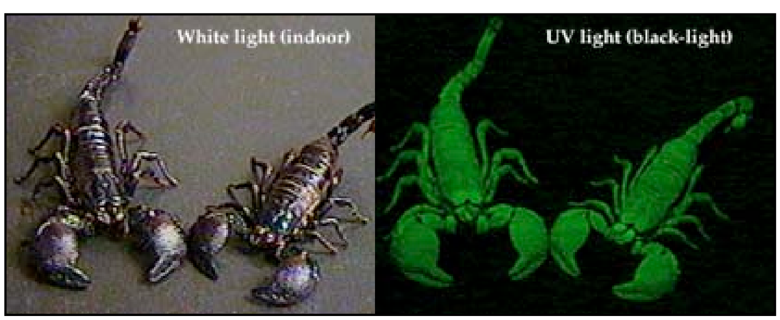
Beyond BRDFs

- The BRDF model does not capture everything
  - *e.g.* Subsurface scattering (BSSRDF)

Images from Jensen *et. al, SIGGRAPH 2001*

Beyond BRDFs

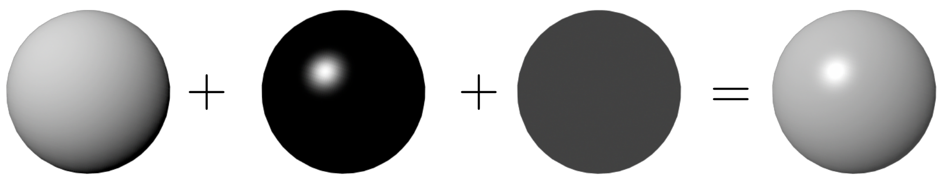
- The BRDF model does not capture everything
  - *e.g.* Inter-frequency interactions



$\rho = \rho(\theta_V, \theta_L, \lambda_{\text{in}}, \lambda_{\text{out}})$ This version would work....

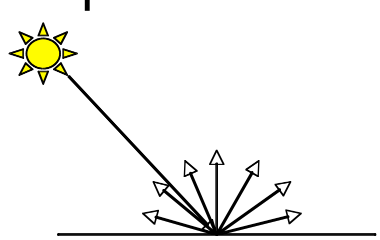
A Simple Model

- Approximate BRDF as sum of
  - A diffuse component
  - A specular component
  - A "ambient" term



Diffuse Component

- Lambert's Law
  - Intensity of reflected light proportional to cosine of angle between surface and incoming light direction
  - Applies to "diffuse," "Lambertian," or "matte" surfaces
  - Independent of viewing angle
- Use as a component of non-Lambertian surfaces

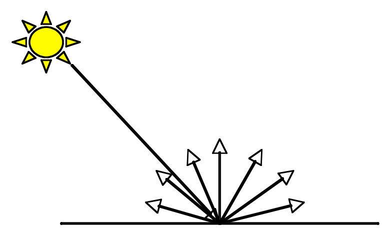


Diffuse Component

Comment about two-side lighting in text is wrong...

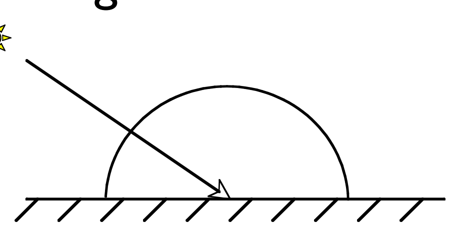
$$k_d I(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}})$$

$$\max(k_d I(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}}), 0)$$

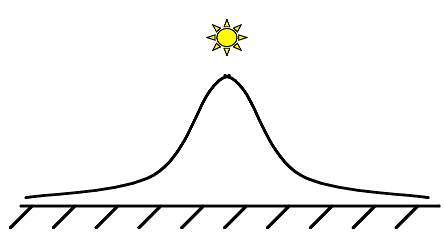


Diffuse Component

- Plot light leaving in a given direction:

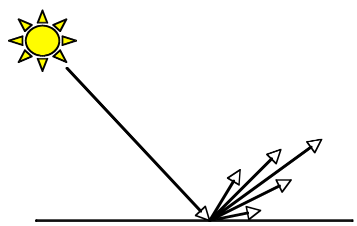


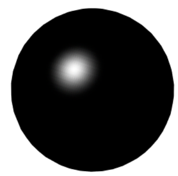
- Plot light leaving from each point on surface



Specular Component

- Specular component is a mirror-like reflection
- Phong Illumination Model
  - A reasonable approximation for some surfaces
  - Fairly cheap to compute
- Depends on view direction

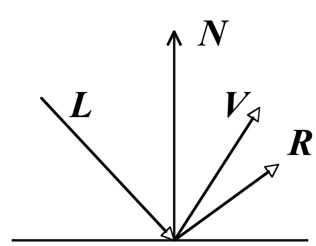


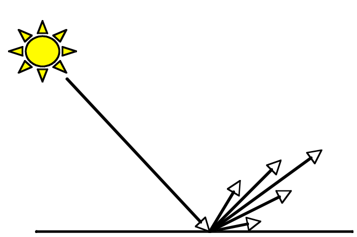


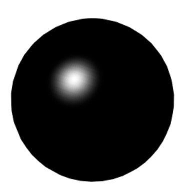
Specular Component

$$k_s I (\hat{\mathbf{r}} \cdot \hat{\mathbf{v}})^p$$

$$k_s I \max(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}}, 0)^p$$



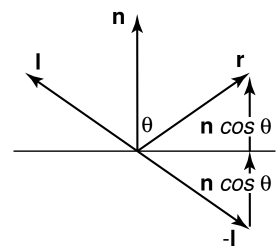




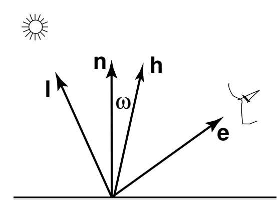
Specular Component

- Computing the reflected direction

$$\hat{\mathbf{r}} = -\hat{\mathbf{l}} + 2(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}})\hat{\mathbf{n}}$$

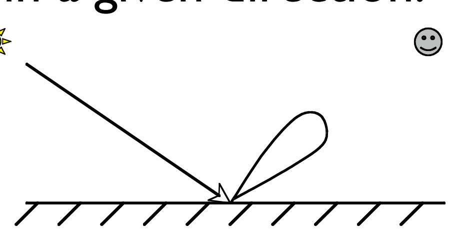


$$\hat{\mathbf{h}} = \frac{\hat{\mathbf{l}} + \hat{\mathbf{v}}}{||\hat{\mathbf{l}} + \hat{\mathbf{v}}||}$$

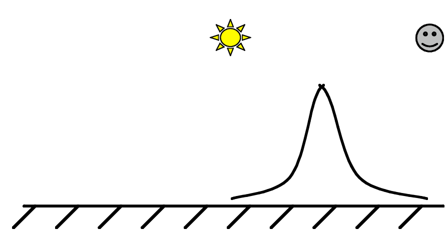


Specular Component

- Plot light leaving in a given direction:

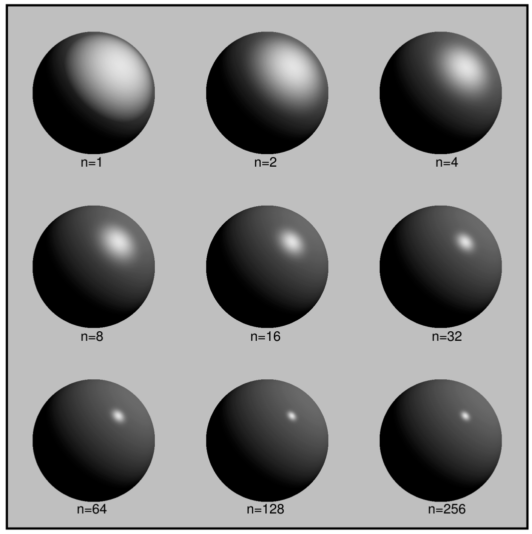


- Plot light leaving from each point on surface



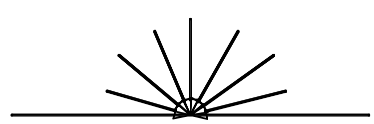
Specular Component

- Specular exponent sometimes called "roughness"



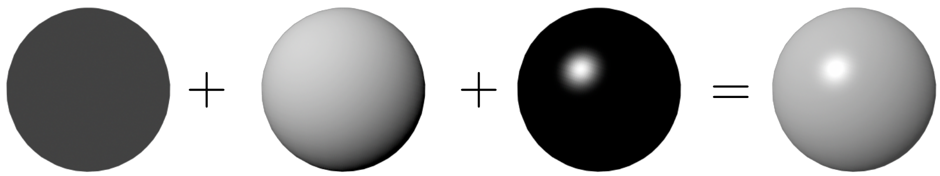
Ambient Term

- Really, its a cheap hack
- Accounts for "ambient, omnidirectional light"
- Without it everything looks like it's in space



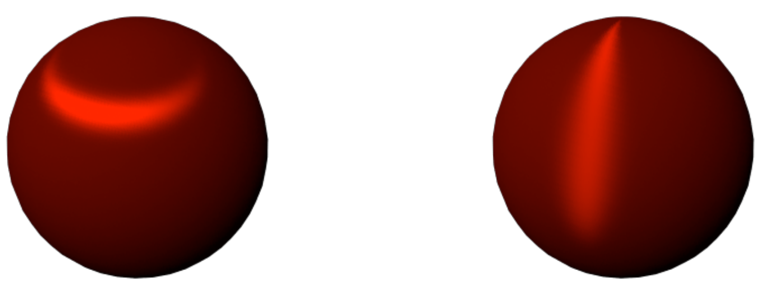
Summing the Parts

$$R = k_a I + k_d I \max(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}}, 0) + k_s I \max(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}}, 0)^p$$

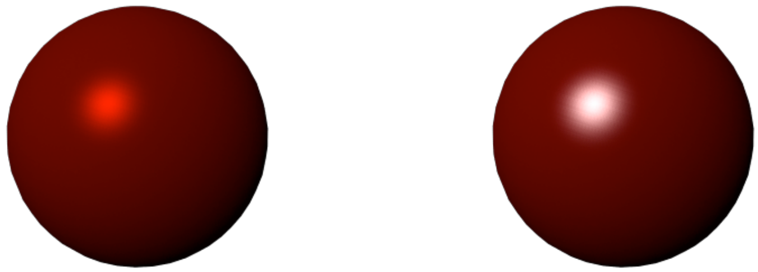


- Recall that the $k_?$ are by wavelength
  - RGB in practice
- Sum over all lights

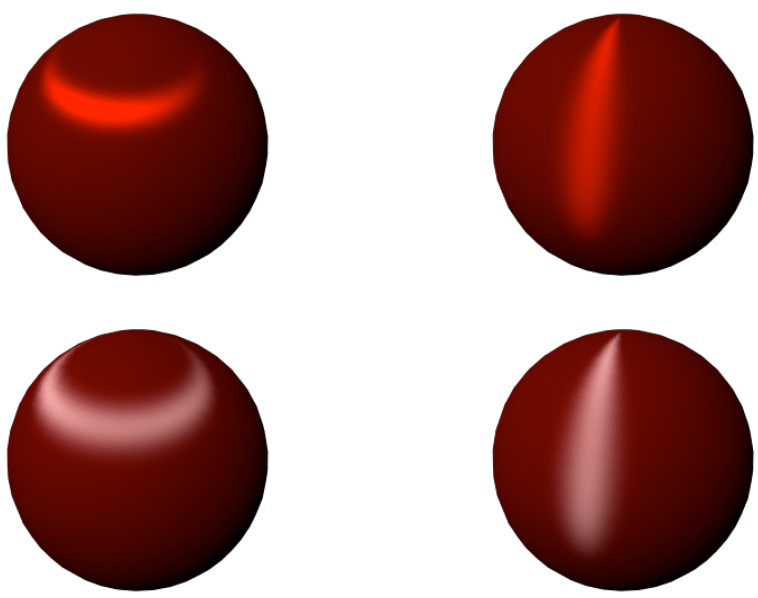
Anisotropy



Metal -vs- Plastic

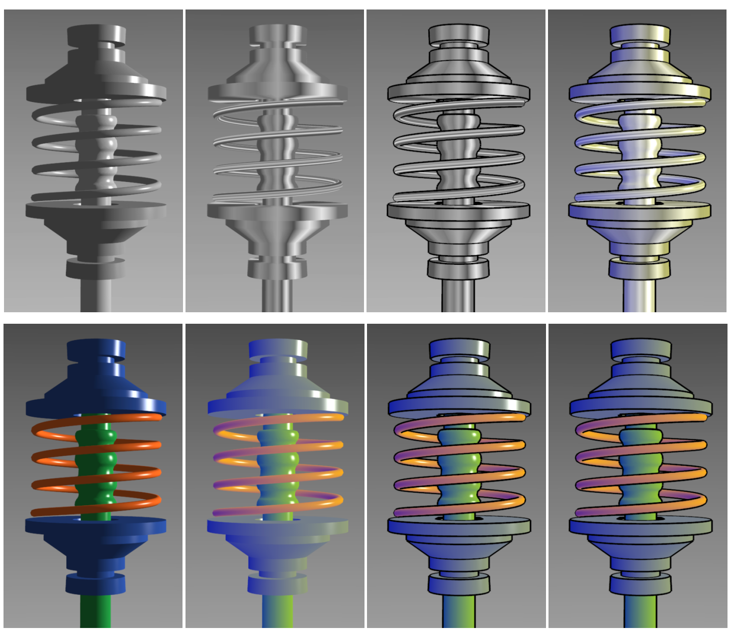


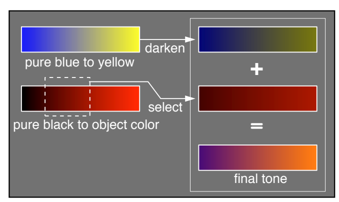
Metal -vs- Plastic



Other Color Effects

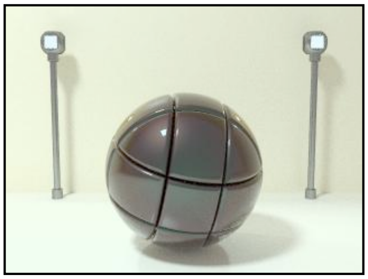
Other Color Effects

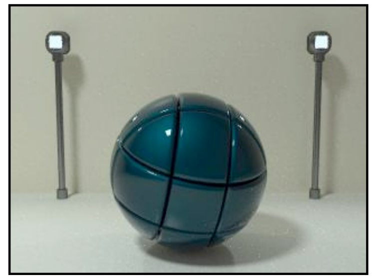




Images from Gooch *et. al*, *1998*

Measured BRDFs





BRDFs for automotive paint

Images from Cornell University Program of Computer Graphics

Measured BRDFs

BRDFs for aerosol spray paint

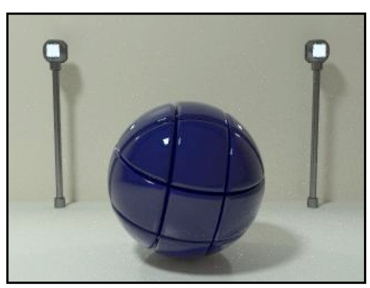
Images from Cornell University Program of Computer Graphics

Measured BRDFs

BRDFs for house paint

Images from Cornell University Program of Computer Graphics

Measured BRDFs



BRDFs for lucite sheet

Images from Cornell University Program of Computer Graphics

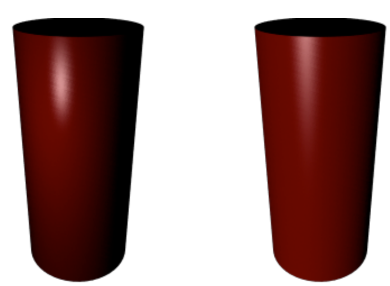
Details Beget Realism

- The "computer generated" look is often due to a lack of fine/subtle details... a lack of richness.

From bustledress.com

Direction -vs- Point Lights

- For a point light, the light direction changes over the surface
- For "distant" light, the direction is constant
- Similar for orthographic/perspective viewer

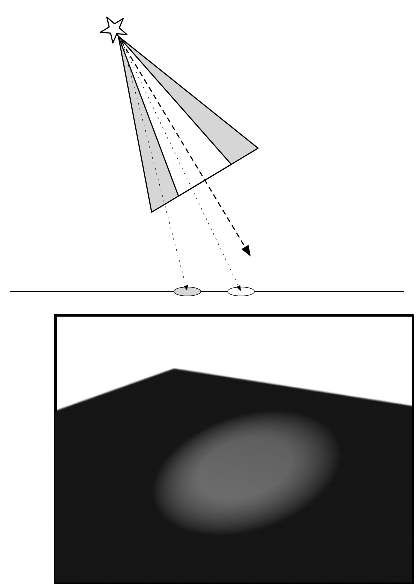


Falloff

- Physically correct: $1/r^2$ light intensify falloff
  - Tends to look bad (why?)
  - Not used in practice
- Sometimes compromise of $1/r$ used

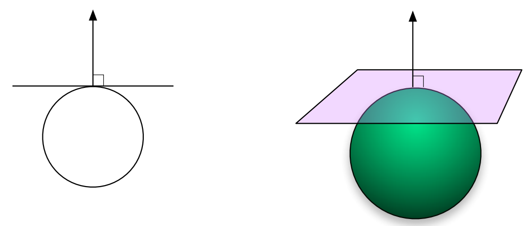
Spot and Other Lights

- Other calculations for useful effects
  - Spot light
  - Only light certain objects
  - Negative lights
  - *etc.*

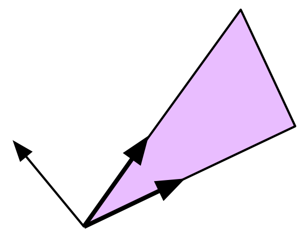


Surface Normals

- The normal vector at a point on a surface is perpendicular to all surface tangent vectors

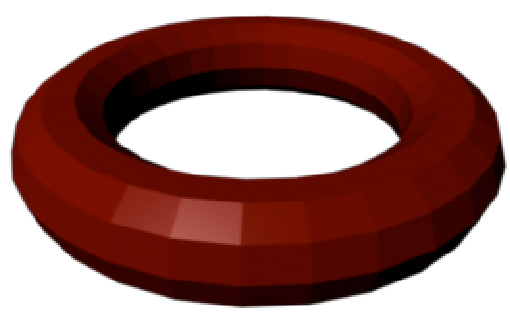


- For triangles normal given by right-handed cross product



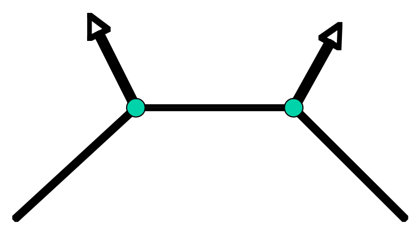
Flat Shading

- Use constant normal for each triangle (polygon)
  - Polygon objects don't look smooth
  - Faceted appearance very noticeable, especially at specular highlights
  - Recall mach bands...



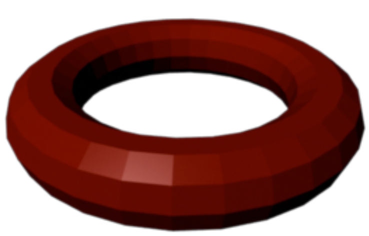
Smooth Shading

- Compute "average" normal at vertices
- Interpolate across polygons
- Use threshold for "sharp" edges
  - Vertex may have different normals for each face

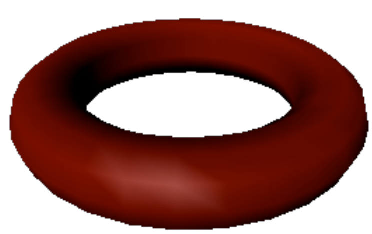


Gouraud Shading

- Compute shading at each vertex
  - Interpolate colors from vertices
  - Pros: fast and easy, looks smooth
  - Cons: terrible for specular reflections



Flat

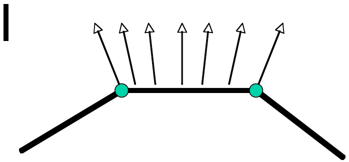


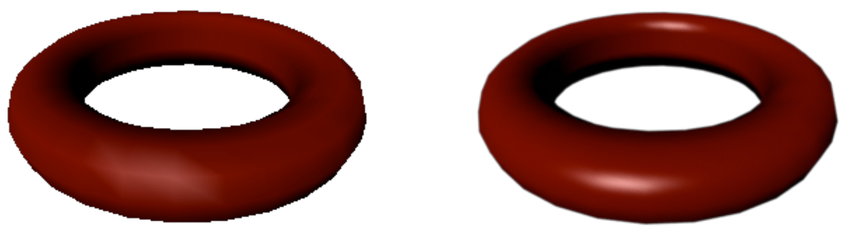
Gouraud

Note: Gouraud was hardware rendered...

Phong Shading

- Compute shading at each pixel
  - Interpolate *normals* from vertices
  - Pros: looks smooth, better speculars
  - Cons: expensive





Gouraud   Phong

Note: Gouraud was hardware rendered...

Transforming Normals

- Normals are directions
  - But they must maintain underlaying geometric property

$$\hat{\mathbf{n}} \cdot (\mathbf{a} - \mathbf{b}) = \mathbf{0}$$
$$\hat{\mathbf{n}}^{\mathsf{T}}(\mathbf{a} - \mathbf{b}) = \mathbf{0}$$

  - A bit of manipulation

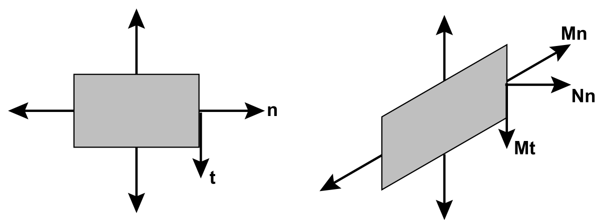
$$\hat{\mathbf{n}}_{\text{new}}^{\mathsf{T}}(\mathbf{Ta} - \mathbf{Tb}) = \mathbf{0}$$
$$\hat{\mathbf{n}}_{\text{new}}^{\mathsf{T}}\mathbf{T}(\mathbf{a} - \mathbf{b}) = \mathbf{0}$$
$$\hat{\mathbf{n}}^{\mathsf{T}}\mathbf{T}^{-1}\mathbf{T}(\mathbf{a} - \mathbf{b}) = \mathbf{0}$$
$$\boxed{\hat{\mathbf{n}}_{\text{new}} = \mathbf{T}^{-\mathsf{T}}\hat{\mathbf{n}}}$$

Transforming Normals

- Special transformation rule for normals

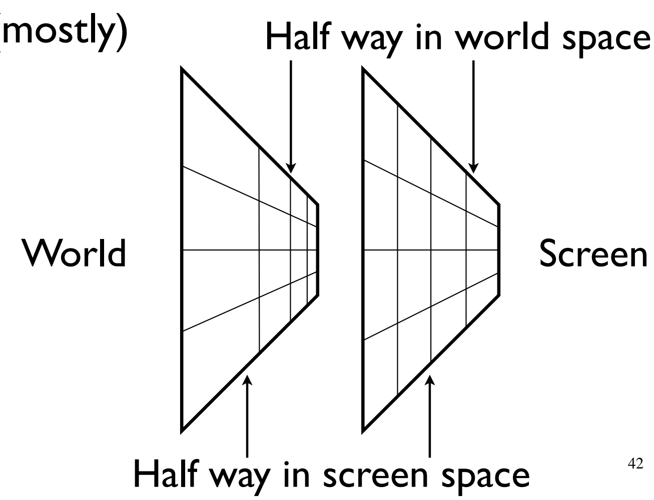
$$\hat{\mathbf{n}}_{\text{new}} = \mathbf{T}^{-\mathsf{T}}\hat{\mathbf{n}}$$

- Note: A rotation is its own inverse transpose

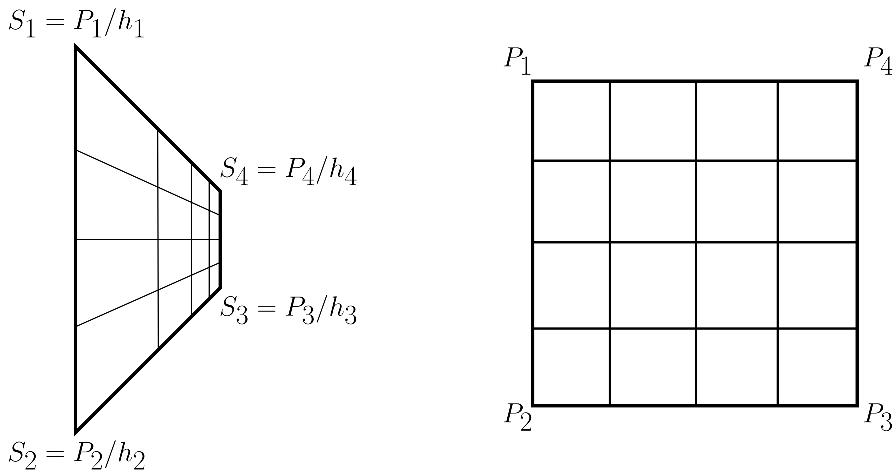


Depth Distortion

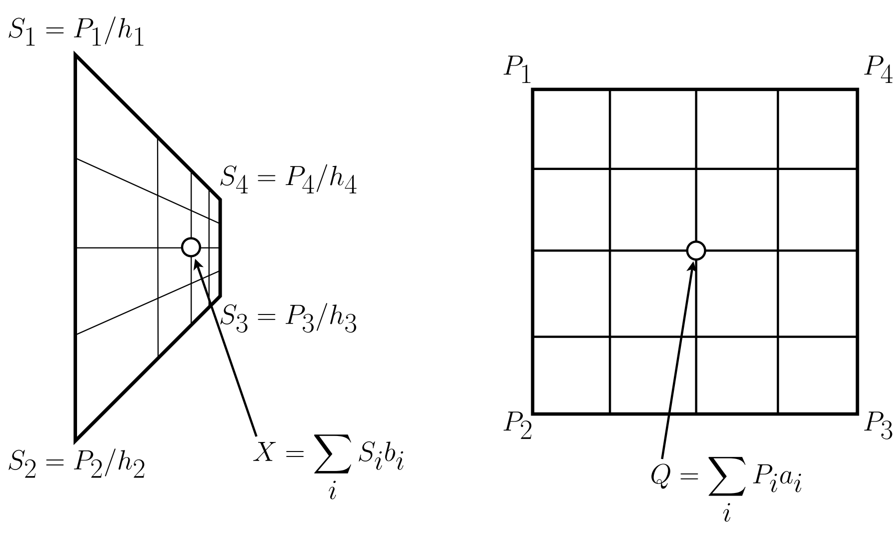
- Recall depth distortion from perspective
  - Interpolating in screen space different than in world
  - Ok, for shading (mostly)
  - Bad for texture



Depth Distortion

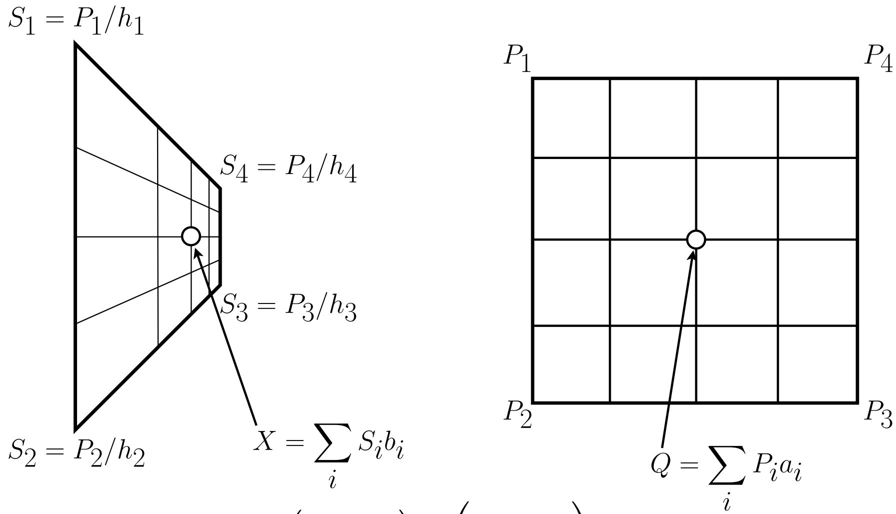


Depth Distortion



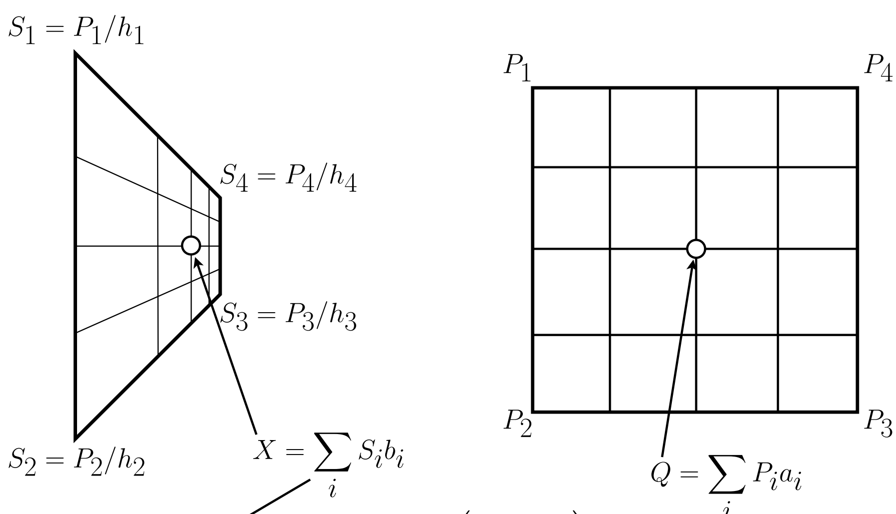
We know the S_i, P_i, and b_i, but not the a_i.

Depth Distortion



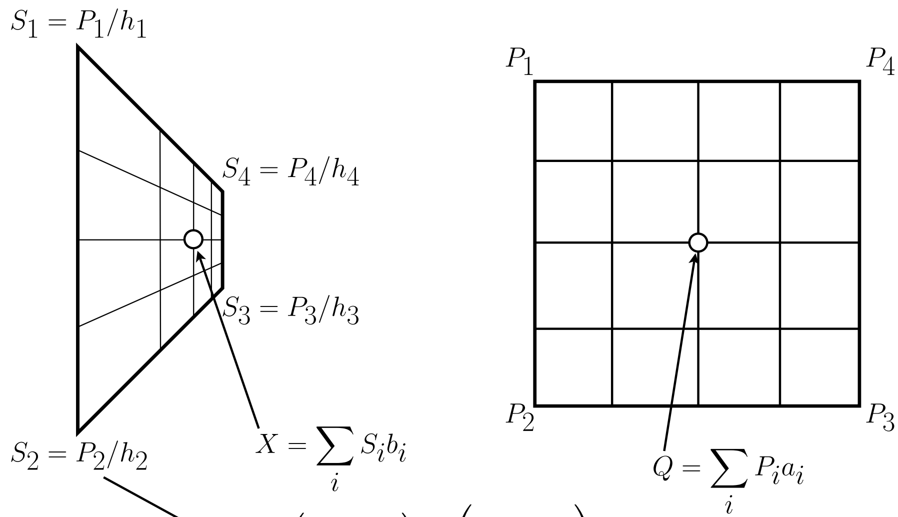
$$X = Q/h = \left(\sum_i P_i a_i \right) / \left(\sum_j h_j a_j \right)$$

Depth Distortion



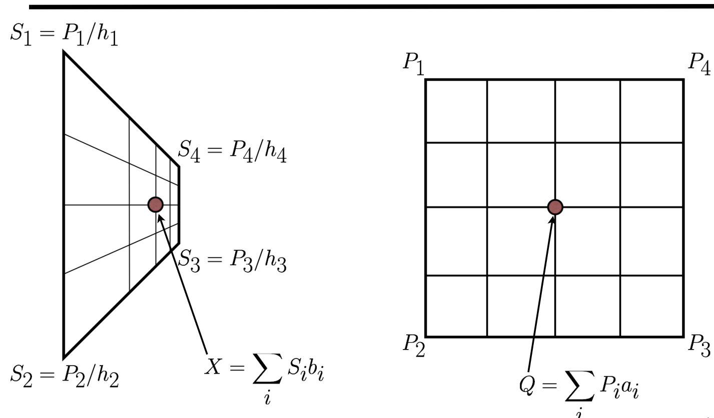
$$\sum_i S_i b_i = \left(\sum_i P_i a_i \right) / \left(\sum_j h_j a_j \right)$$

Depth Distortion



$$\sum_i P_i b_i / h_i = \left(\sum_i P_i a_i \right) / \left(\sum_j h_j a_j \right)$$

Depth Distortion

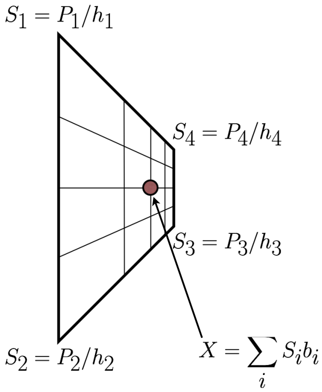


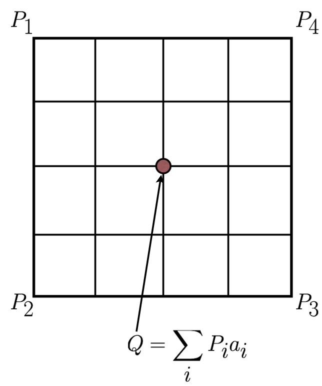
Independent of given vertex locations.

$$\sum_i P_i b_i / h_i = \left(\sum_i P_i a_i \right) / \left(\sum_j h_j a_j \right)$$

$$b_i / h_i = a_i / \left(\sum_j h_j a_j \right) \quad \forall i$$

Depth Distortion



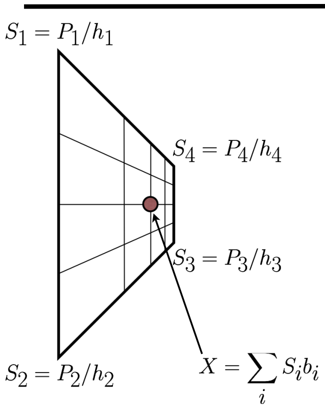


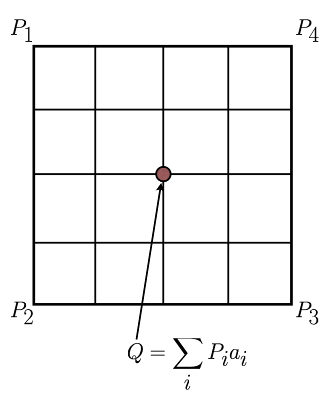
$$b_i/h_i = a_i / \left(\sum_j h_j a_j \right) \quad \forall i$$

Linear equations in the a_i .

$$\left(\sum_j h_j a_j \right) b_i/h_i - a_i = 0 \quad \forall i$$

Depth Distortion





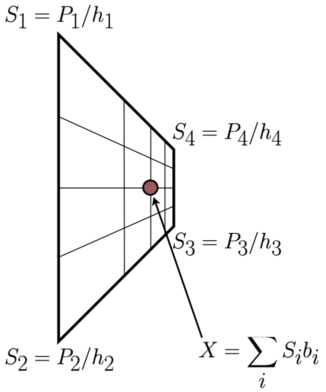
Linear equations in the a_i .

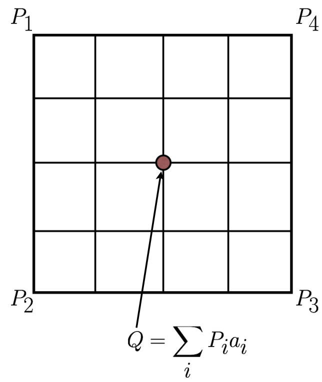
$$\left(\sum_j h_j a_j \right) b_i/h_i - a_i = 0 \quad \forall i$$

Not invertible so add some extra constraints.

$$\sum_i a_i = \sum_i b_i = 1$$

Depth Distortion





For a line: $a_1 = h_2 b_i / (b_1 h_2 + h_1 b_2)$

For a triangle: $a_1 = h_2 h_3 b_1 / (h_2 h_3 b_1 + h_1 h_3 b_2 + h_1 h_2 b_3)$

Obvious Permutations for other coefficients.