University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2010

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Lighting/Shading I

Week 6, Fri Feb 12

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2010

Correction: W2V vs. V2W

slide 38 week3.day3 (Fri Jan 22)

- M_{W2V}=TR $\quad \mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & e_x \\ 0 & 1 & 0 & e_y \\ 0 & 0 & 1 & e_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \mathbf{R} = \begin{bmatrix} u_x & v_x & w_x & 0 \\ u_y & v_y & w_y & 0 \\ u_z & v_z & w_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$
- we derived position of camera in world
  - invert for world with respect to camera
- $M_{V2W}=(M_{W2V})^{-1}=R^{-1}T^{-1}$

$$\mathbf{M}_{view2world} = \begin{bmatrix} u_x & u_y & u_z & 0 \\ v_x & v_y & v_z & 0 \\ w_x & w_y & w_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -e_x \\ 0 & 1 & 0 & -e_y \\ 0 & 0 & 1 & -e_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} u_x & u_y & u_z & -\mathbf{e} \bullet \mathbf{u} \\ v_x & v_y & v_z & -\mathbf{e} \bullet \mathbf{v} \\ w_x & w_y & w_z & -\mathbf{e} \bullet \mathbf{w} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Correction: W2V vs. V2W

- $M_{V2W}=(M_{W2V})^{-1}=R^{-1}T^{-1}$

$$\mathbf{M}_{view2world} = \begin{bmatrix} u_x & u_y & u_z & 0 \\ v_x & v_y & v_z & 0 \\ w_x & w_y & w_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -e_x \\ 0 & 1 & 0 & -e_y \\ 0 & 0 & 1 & -e_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} u_x & u_y & u_z & -\mathbf{e} \bullet \mathbf{u} \\ v_x & v_y & v_z & -\mathbf{e} \bullet \mathbf{v} \\ w_x & w_y & w_z & -\mathbf{e} \bullet \mathbf{w} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{M}_{V2W} = \begin{bmatrix} u_x & u_y & u_z & -e_x * u_x + -e_y * u_y + -e_z * u_z \\ v_x & v_y & v_z & -e_x * v_x + -e_y * v_y + -e_z * v_z \\ w_x & w_y & w_z & -e_x * w_x + -e_y * w_y + -e_z * w_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Correction: Perspective Derivation

slide 30 week4.day3 (Fri Jan 29)

z axis flip!

$$\begin{bmatrix} x' \\ y' \\ z' \\ w' \end{bmatrix} = \begin{bmatrix} E & 0 & A & 0 \\ 0 & F & B & 0 \\ 0 & 0 & C & D \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$x' = Ex + Az$$
$$y' = Fy + Bz$$
$$z' = Cz + D$$
$$w' = -z$$

$$x = left \rightarrow x'/w' = -1$$
$$x = right \rightarrow x'/w' = 1$$
$$y = top \rightarrow y'/w' = 1$$
$$y = bottom \rightarrow y'/w' = -1$$
$$z = -near \rightarrow z'/w' = 1$$
$$z = -far \rightarrow z'/w' = -1$$

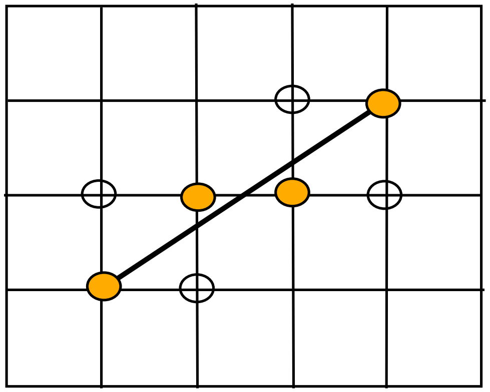
$$y' = Fy + Bz, \qquad \frac{y'}{w'} = \frac{Fy + Bz}{w'}, \qquad 1 = \frac{Fy + Bz}{w'}, \qquad 1 = \frac{Fy + Bz}{-z},$$

$$1 = F\frac{y}{-z} + B\frac{z}{-z}, \quad 1 = F\frac{y}{-z} - B, \quad 1 = F\frac{top}{-(-near)} - B,$$

$$1 = F\frac{top}{near} - B$$

News

- P2 due date extended to Tue Mar 2 5pm
  - V2W correction affects Q1 and thus cascades to Q4-Q7
  - perspective correction affects Q8
- TA office hours in lab for P2/H2 questions Fri 2-4 (Garrett)



PPT Fix: Basic Line Drawing

$$y = mx + b$$

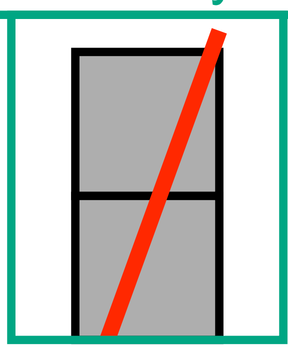
$$y = \frac{(y_1 - y_0)}{(x_1 - x_0)}(x - x_0) + y_0$$

- goals
  - integer coordinates
  - thinnest line with no gaps
- assume
  - $x_0 < x_1$, slope $0 < dy/dx < 1$
  - one octant, other cases symmetric
- how can we do this more quickly?

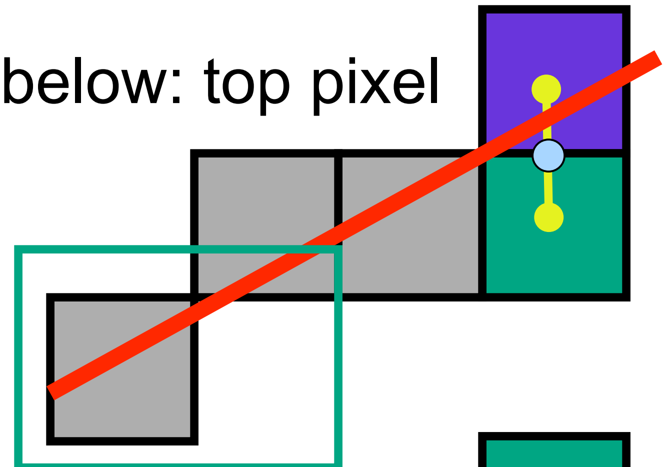
Line (x_0, y_0, x_1, y_1)
begin
float $dx, dy, x, y, slope$;
$dx \Leftarrow x_1 - x_0$;
$dy \Leftarrow y_1 - y_0$;
$slope \Leftarrow dy/dx$;
$y \Leftarrow y_0$
for x from x_0 to x_1 do
  begin
    PlotPixel (x, **Round** (y)) ;
    $y \Leftarrow y + slope$;
  end ;
end ;

Clarification/Correction II: Midpoint

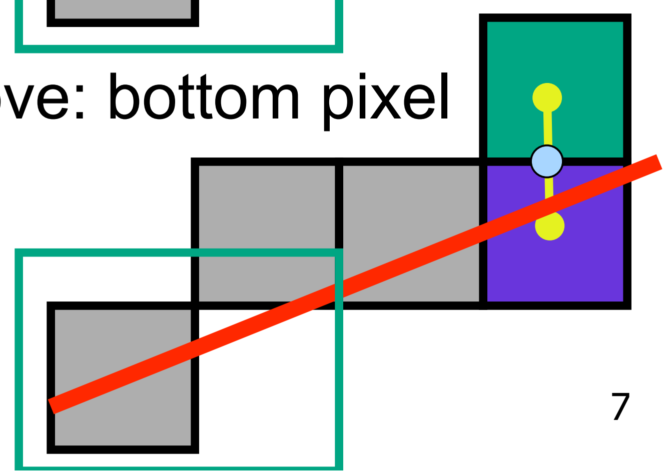
- we're moving horizontally along x direction (first octant)
  - only two choices: draw at current y value, or move up vertically to y+1?
    - check if midpoint between two possible pixel centers above or below line
  - candidates
    - top pixel: (x+1,y+1)
    - bottom pixel: (x+1, y)
  - midpoint: (x+1, y+.5)
- check if midpoint above or below line
  - below: pick top pixel
  - above: pick bottom pixel
- other octants: different tests
  - octant II: y loop, check x left/right



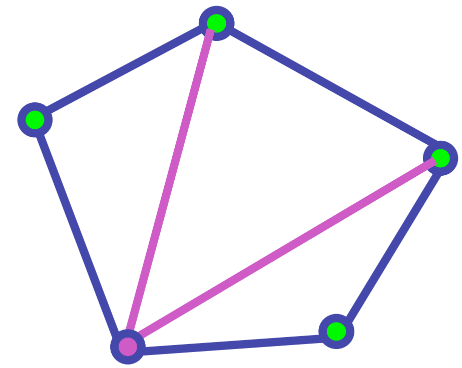
below: top pixel



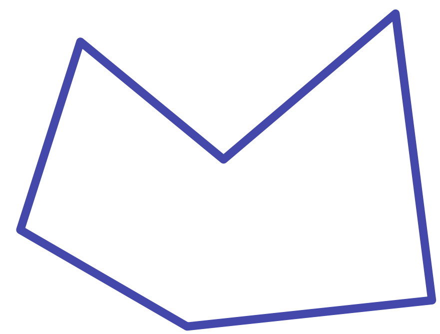
above: bottom pixel



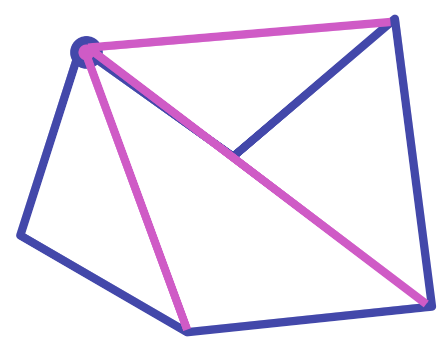
Review: Triangulating Polygons



- simple convex polygons
  - trivial to break into triangles
  - pick one vertex, draw lines to all others not immediately adjacent
  - OpenGL supports automatically
    - glBegin(GL_POLYGON) ... glEnd()

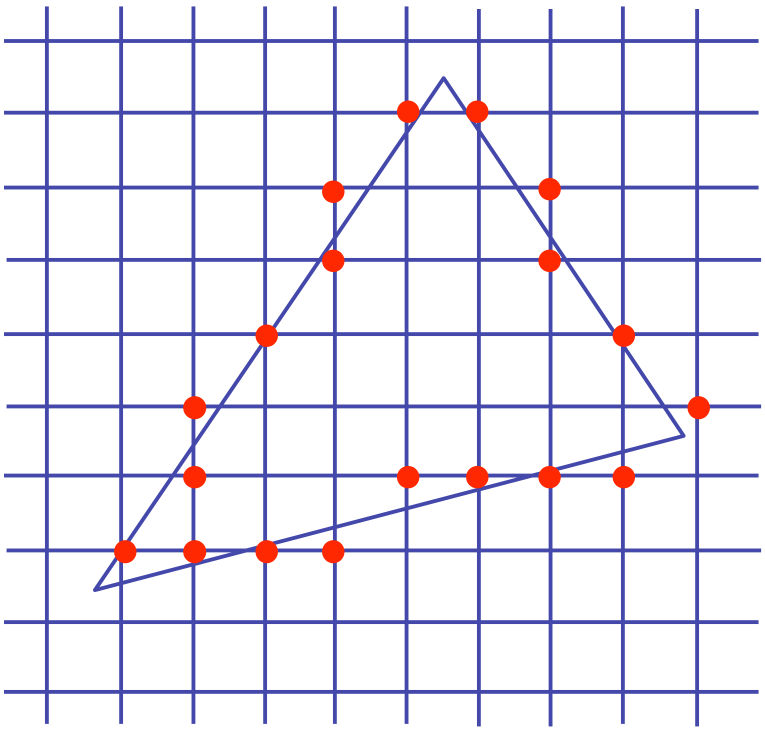


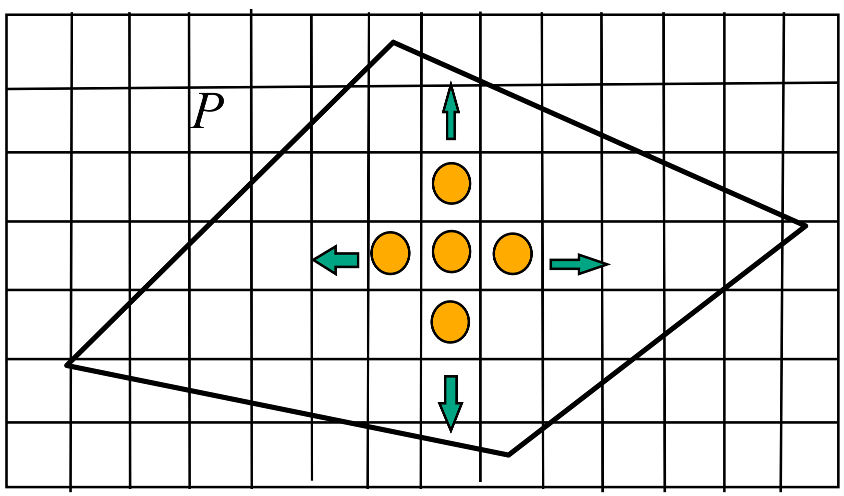
- concave or non-simple polygons
  - more effort to break into triangles
  - simple approach may not work
  - OpenGL can support at extra cost
    - gluNewTess(), gluTessCallback(), ...



Review: Flood Fill

- simple algorithm
  - draw edges of polygon
  - use flood-fill to draw interior





PPT Fix: Flood Fill

- draw edges
- run:

FloodFill(Polygon P, int x, int y, Color C)

if not (**OnBoundary**(x,y,P) or **Colored**(x,y,C))

begin

    PlotPixel(x,y,C);

    FloodFill(P,$x+1,y,C$);

    FloodFill(P,$x,y+1,C$);

    FloodFill(P,$x,y-1,C$);

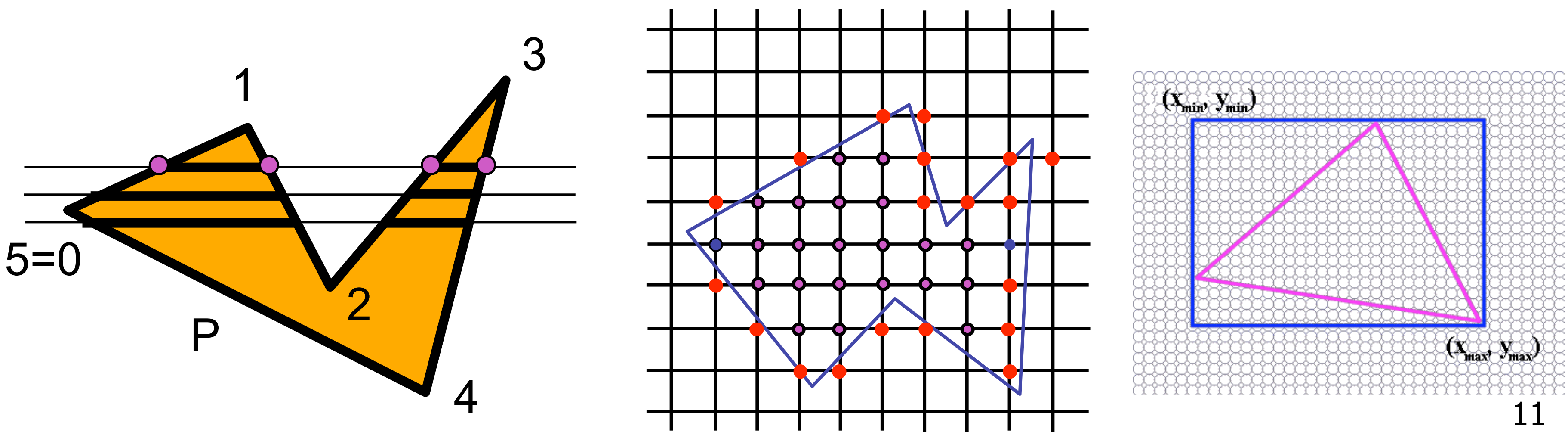
    FloodFill(P,$x-1,y,C$);

end ;

- drawbacks?

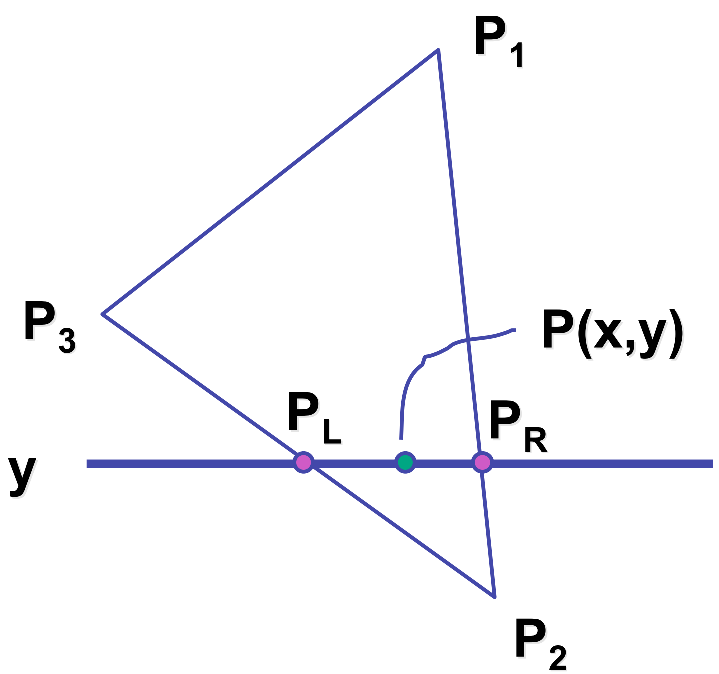
Review: Scanline Algorithms

- scanline: a line of pixels in an image
  - set pixels inside polygon boundary along horizontal lines one pixel apart vertically
    - parity test: draw pixel if edgecount is odd
    - optimization: only loop over axis-aligned bounding box of xmin/xmax, ymin/ymax



Review: Bilinear Interpolation

- interpolate quantity along L and R edges, as a function of y
  - then interpolate quantity as a function of x



Review: Barycentric Coordinates

- non-orthogonal coordinate system based on triangle itself
  - origin: P_1, basis vectors: (P_2-P_1) and (P_3-P_1)

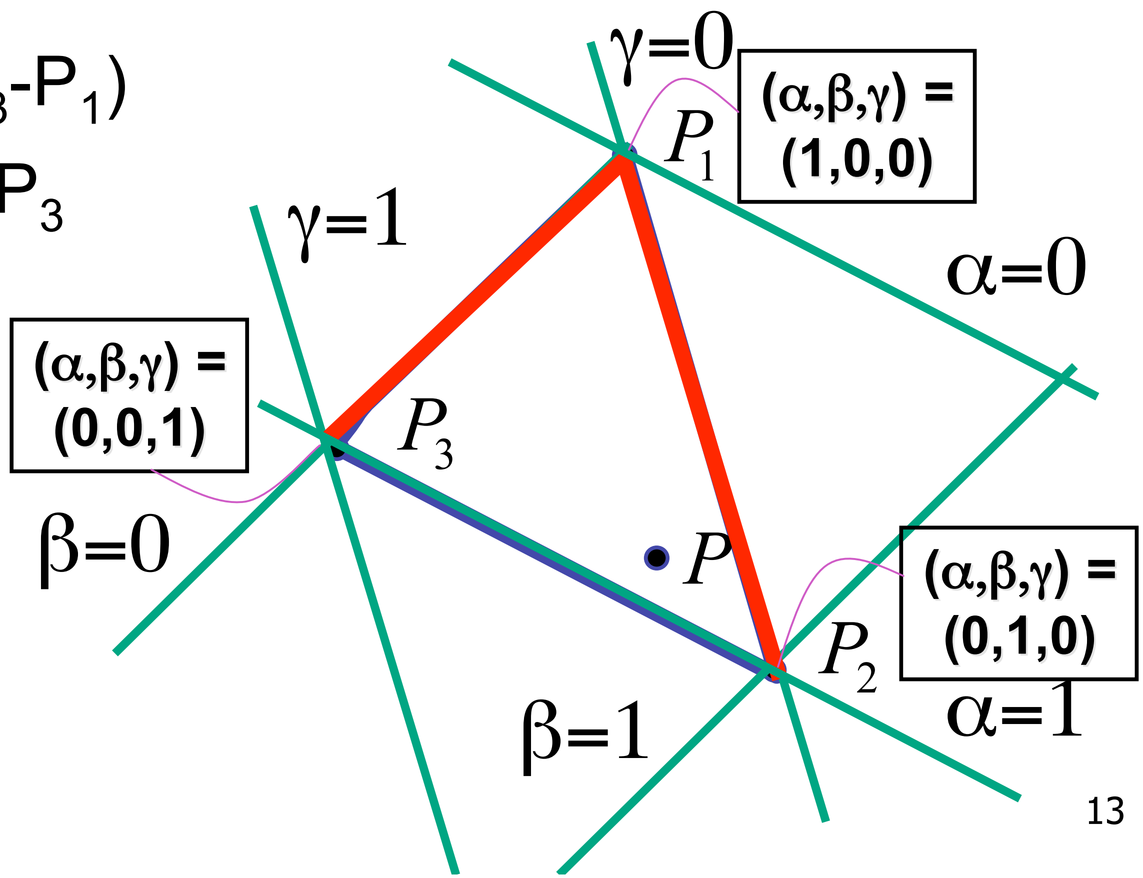
$P = P_1 + \beta(P_2-P_1)+\gamma(P_3-P_1)$

$P = (1-\beta-\gamma)P_1 + \beta P_2+\gamma P_3$

$P = \alpha P_1 + \beta P_2+\gamma P_3$

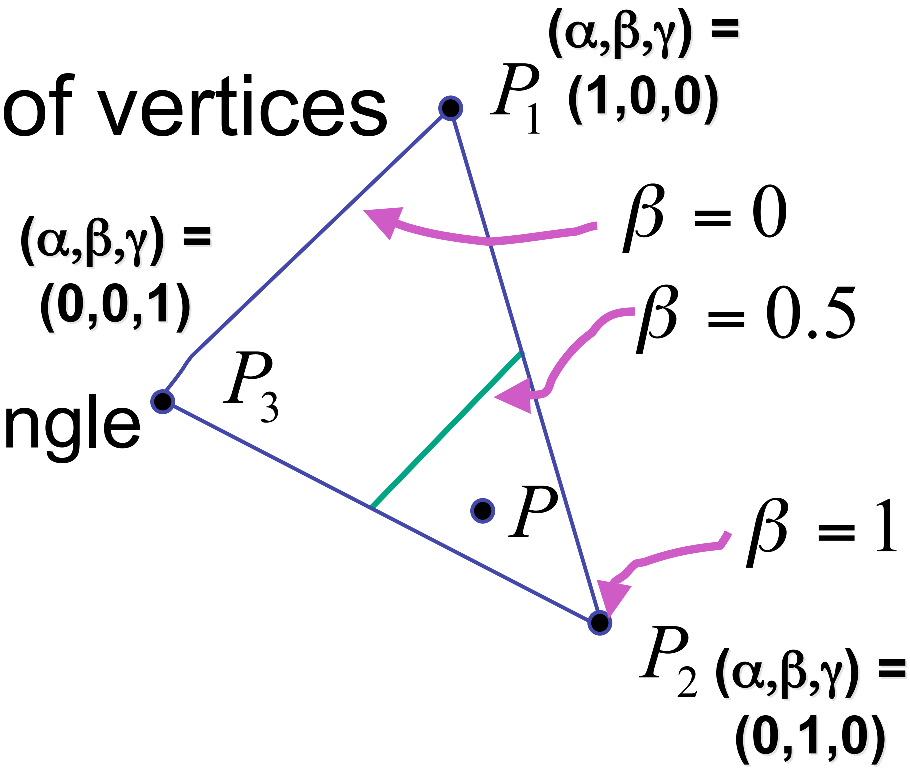
$\alpha + \beta + \gamma = 1$

$0 <= \alpha, \beta, \gamma <= 1$



Using Barycentric Coordinates

- weighted combination of vertices
  - smooth mixing
  - speedup
    - compute once per triangle



$$P = \alpha \cdot P_1 + \beta \cdot P_2 + \gamma \cdot P_3$$

$$\alpha + \beta + \gamma = 1$$

$0 \le \alpha, \beta, \gamma \le 1$ for points inside triangle

"convex combination of points"

- demo
  http://www.cut-the-knot.org/Curriculum/Geometry/Barycentric.shtml

Computing Barycentric Coordinates

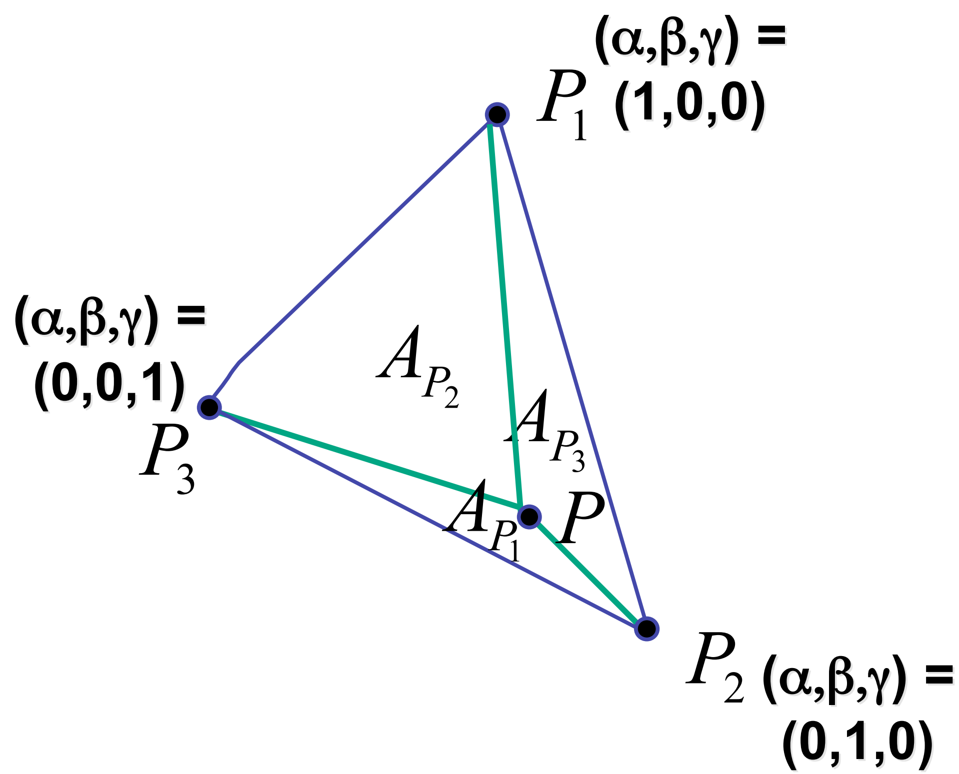
- 2D triangle area
  - half of parallelogram area
    - from cross product

$A = A_{P1} + A_{P2} + A_{P3}$

$\alpha = A_{P1} / A$

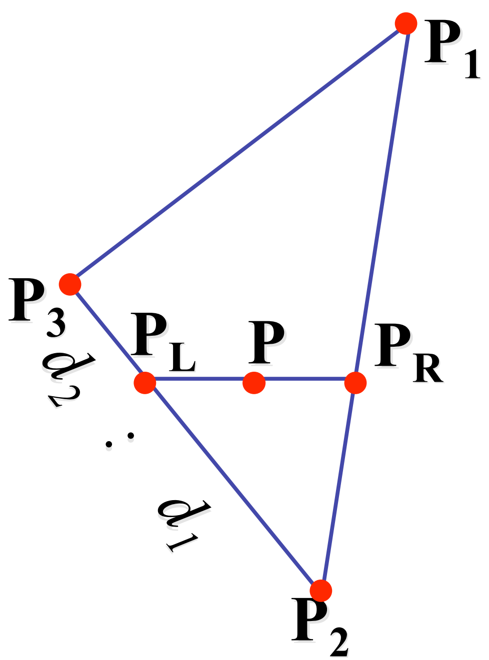
$\beta = A_{P2} / A$

$\gamma = A_{P3} / A$



Deriving Barycentric From Bilinear

- from bilinear interpolation of point P on scanline



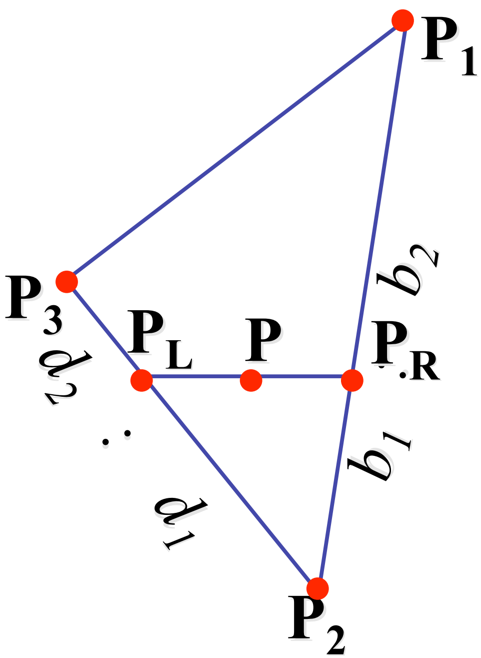
$$P_L = P_2 + \frac{d_1}{d_1 + d_2}(P_3 - P_2)$$

$$= (1 - \frac{d_1}{d_1 + d_2})P_2 + \frac{d_1}{d_1 + d_2}P_3 =$$

$$= \frac{d_2}{d_1 + d_2}P_2 + \frac{d_1}{d_1 + d_2}P_3$$

Deriving Barycentric From Bilineaer

- similarly



$$P_R = P_2 + \frac{b_1}{b_1 + b_2}(P_1 - P_2)$$

$$= (1 - \frac{b_1}{b_1 + b_2})P_2 + \frac{b_1}{b_1 + b_2}P_1 =$$

$$= \frac{b_2}{b_1 + b_2}P_2 + \frac{b_1}{b_1 + b_2}P_1$$

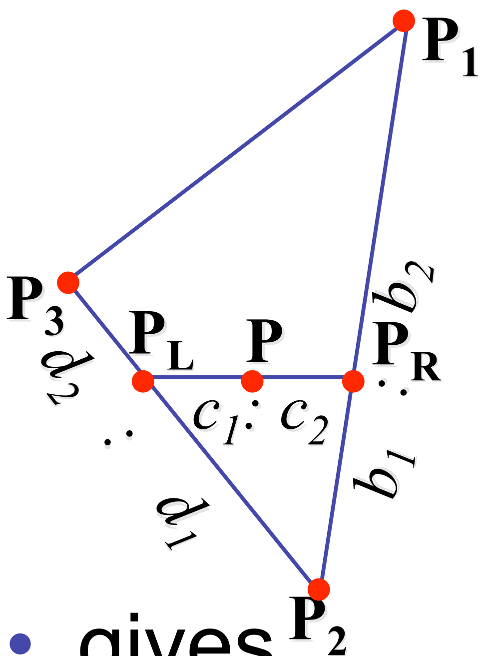
Deriving Barycentric From Bilinear

- combining

$$P = \frac{c_2}{c_1 + c_2} \cdot P_L + \frac{c_1}{c_1 + c_2} \cdot P_R$$

$$P_L = \frac{d_2}{d_1 + d_2} P_2 + \frac{d_1}{d_1 + d_2} P_3$$

$$P_R = \frac{b_2}{b_1 + b_2} P_2 + \frac{b_1}{b_1 + b_2} P_1$$



- gives

$$P = \frac{c_2}{c_1 + c_2}\left(\frac{d_2}{d_1 + d_2} P_2 + \frac{d_1}{d_1 + d_2} P_3\right) + \frac{c_1}{c_1 + c_2}\left(\frac{b_2}{b_1 + b_2} P_2 + \frac{b_1}{b_1 + b_2} P_1\right)$$

Deriving Barycentric From Bilinear

- thus $P = \alpha P_1 + \beta P_2 + \gamma P_3$ with

$$\alpha = \frac{c_1}{c_1 + c_2} \frac{b_1}{b_1 + b_2}$$

$$\beta = \frac{c_2}{c_1 + c_2} \frac{d_2}{d_1 + d_2} + \frac{c_1}{c_1 + c_2} \frac{b_2}{b_1 + b_2}$$

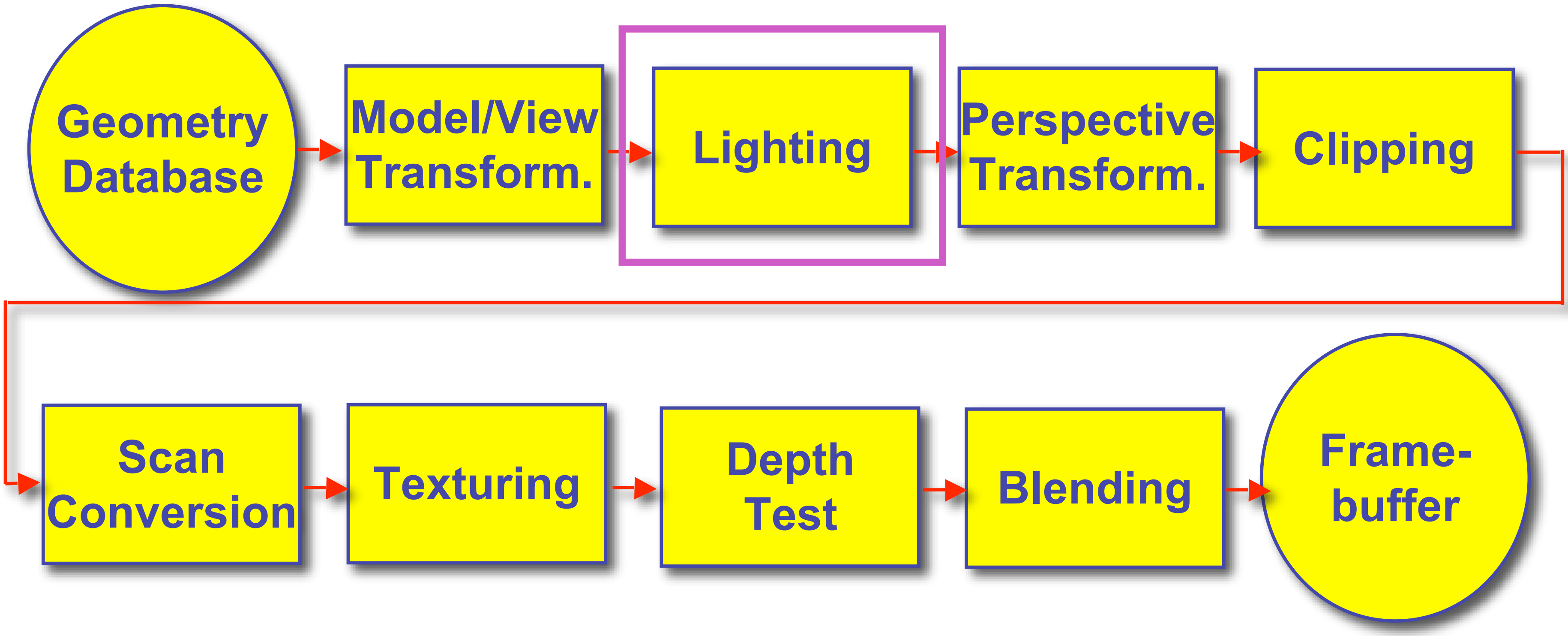
$$\gamma = \frac{c_2}{c_1 + c_2} \frac{d_1}{d_1 + d_2}$$

- can verify barycentric properties

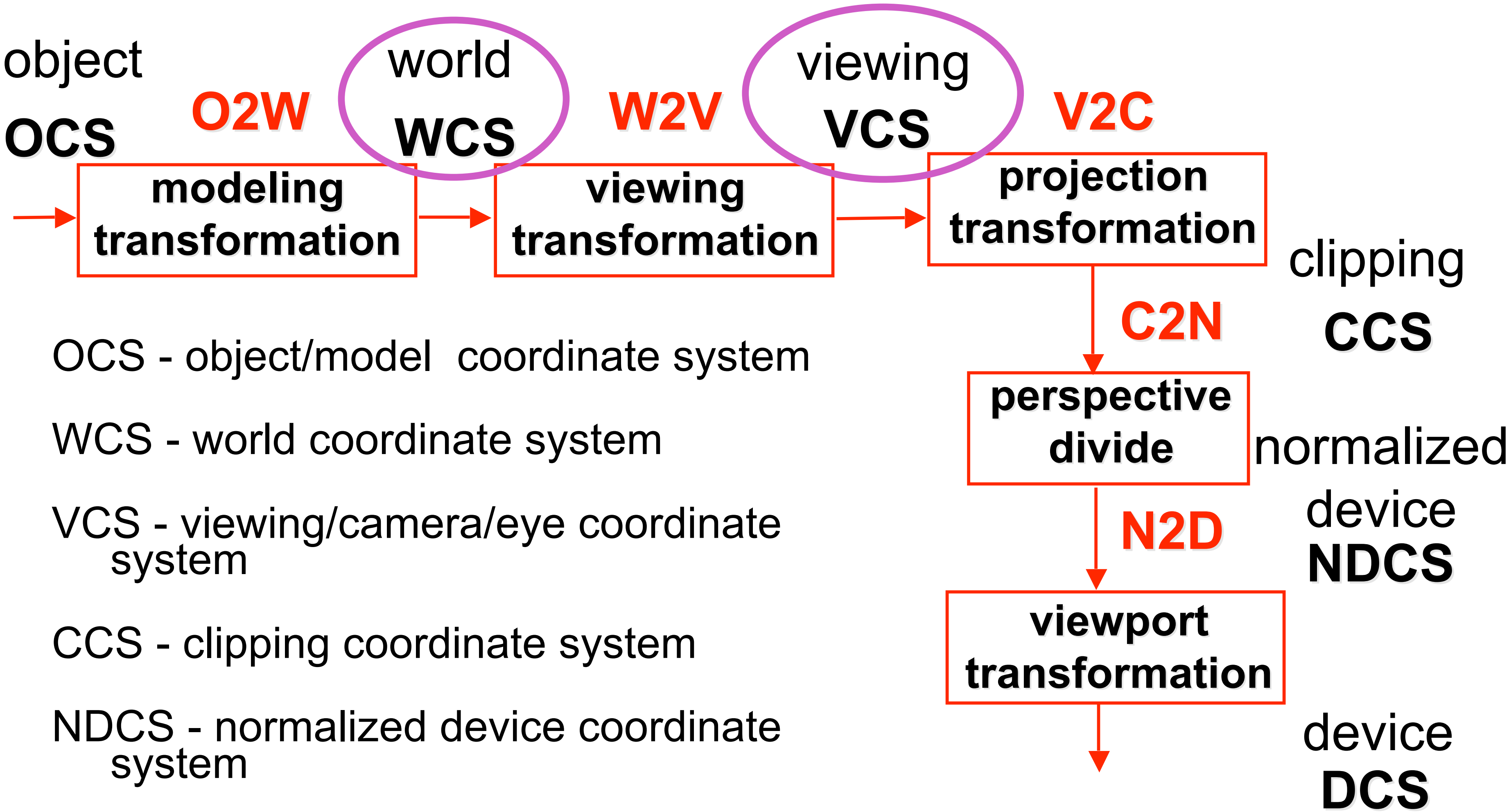
$$\alpha + \beta + \gamma = 1, \qquad 0 \leq \alpha, \beta, \gamma \leq 1$$

Lighting I

Rendering Pipeline



Projective Rendering Pipeline



OCS - object/model coordinate system

WCS - world coordinate system

VCS - viewing/camera/eye coordinate system

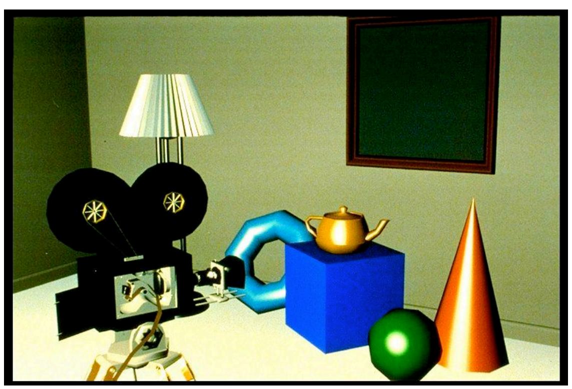
CCS - clipping coordinate system

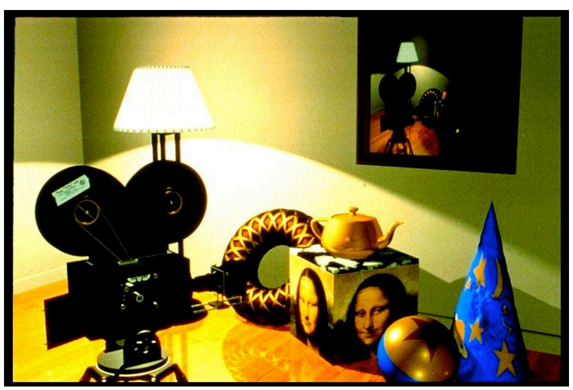
NDCS - normalized device coordinate system

DCS - device/display/screen coordinate system

Goal

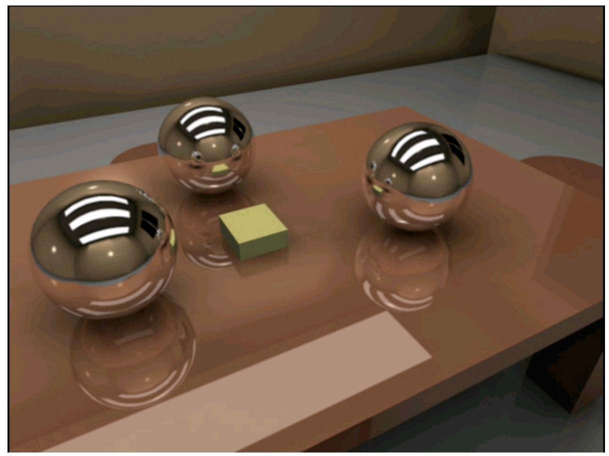
- simulate interaction of light and objects
- fast: fake it!
  - approximate the look, ignore real physics
- get the physics (more) right
  - BRDFs: Bidirectional Reflection Distribution Functions
- local model: interaction of each object with light
- global model: interaction of objects with each other



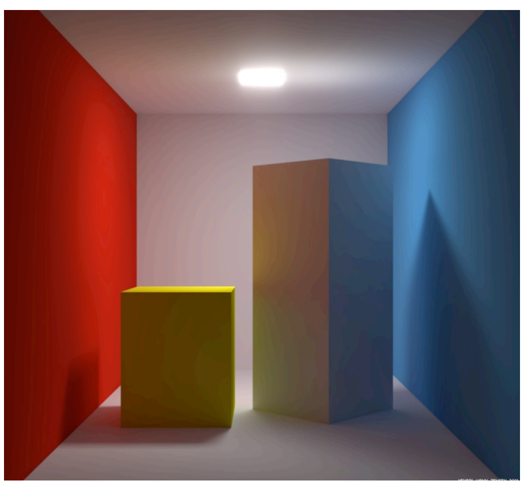


Photorealistic Illumination

- transport of energy from light sources to surfaces & points
  - global includes direct and indirect illumination – more later



[electricimage.com]



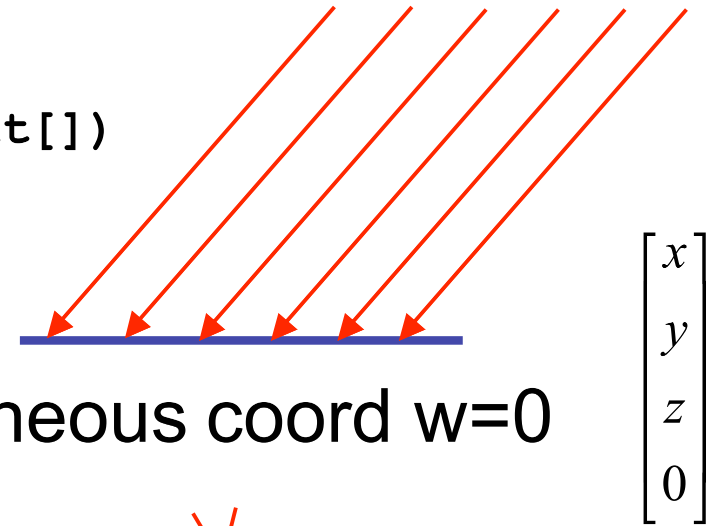
Henrik Wann Jensen

Illumination in the Pipeline

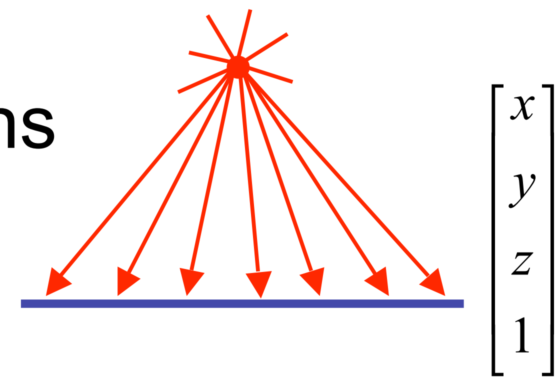
- local illumination
  - only models light arriving directly from light source
  - no interreflections or shadows
    - can be added through tricks, multiple rendering passes
- light sources
  - simple shapes
- materials
  - simple, non-physical reflection models

Light Sources

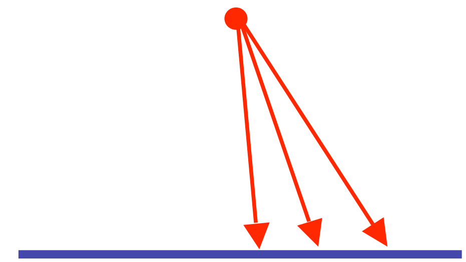
- types of light sources
  - `glLightfv(GL_LIGHT0,GL_POSITION,light[])`
  - directional/parallel lights
    - real-life example: sun
    - infinitely far source: homogeneous coord w=0



  - point lights
    - same intensity in all directions

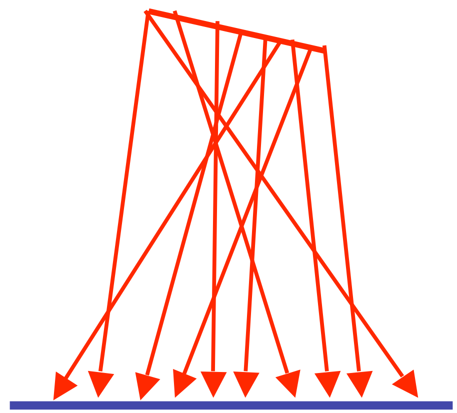


  - spot lights
    - limited set of directions:
      - point+direction+cutoff angle



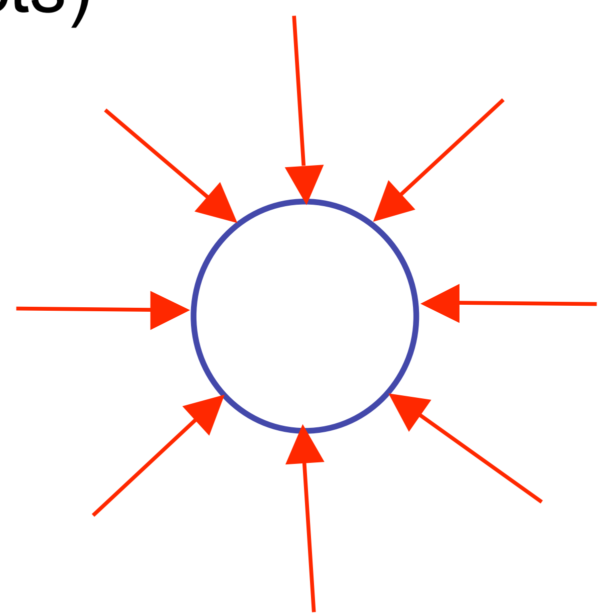
Light Sources

- area lights
  - light sources with a finite area
  - more realistic model of many light sources
  - not available with projective rendering pipeline (i.e., not available with OpenGL)



Light Sources

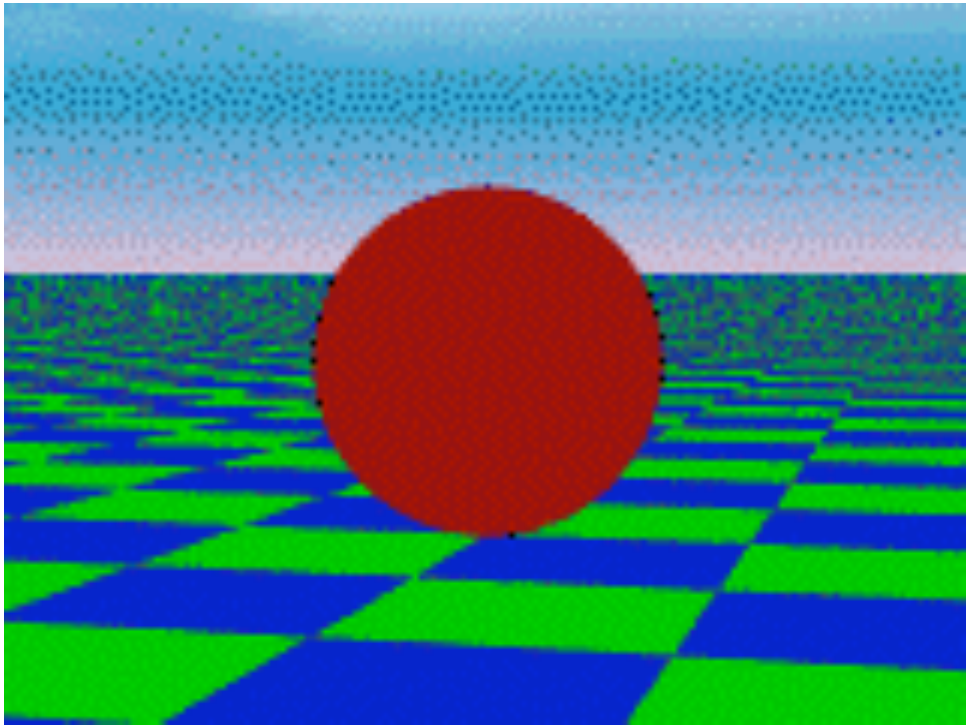
- ambient lights
  - no identifiable source or direction
  - hack for replacing true global illumination
    - (diffuse interreflection: light bouncing off from other objects)



Diffuse Interreflection

Ambient Light Sources

- scene lit only with an ambient light source



Light Position
Not Important

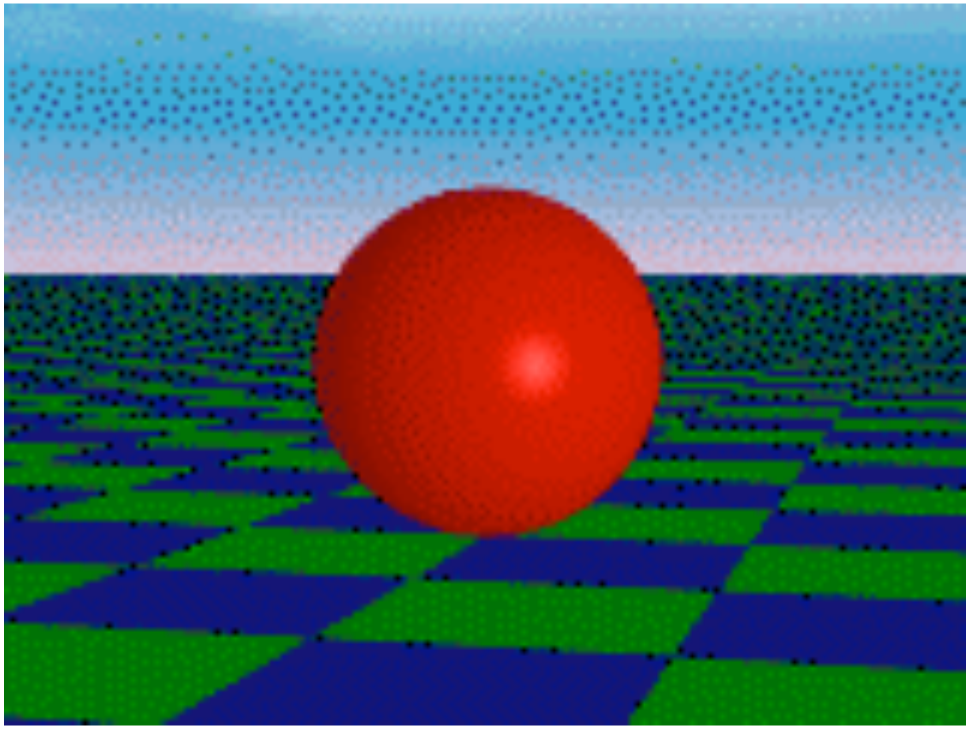
Viewer Position
Not Important

Surface Angle
Not Important

Directional Light Sources

- scene lit with directional and ambient light

Surface Angle Important



Light Position Not Important

Viewer Position Not Important

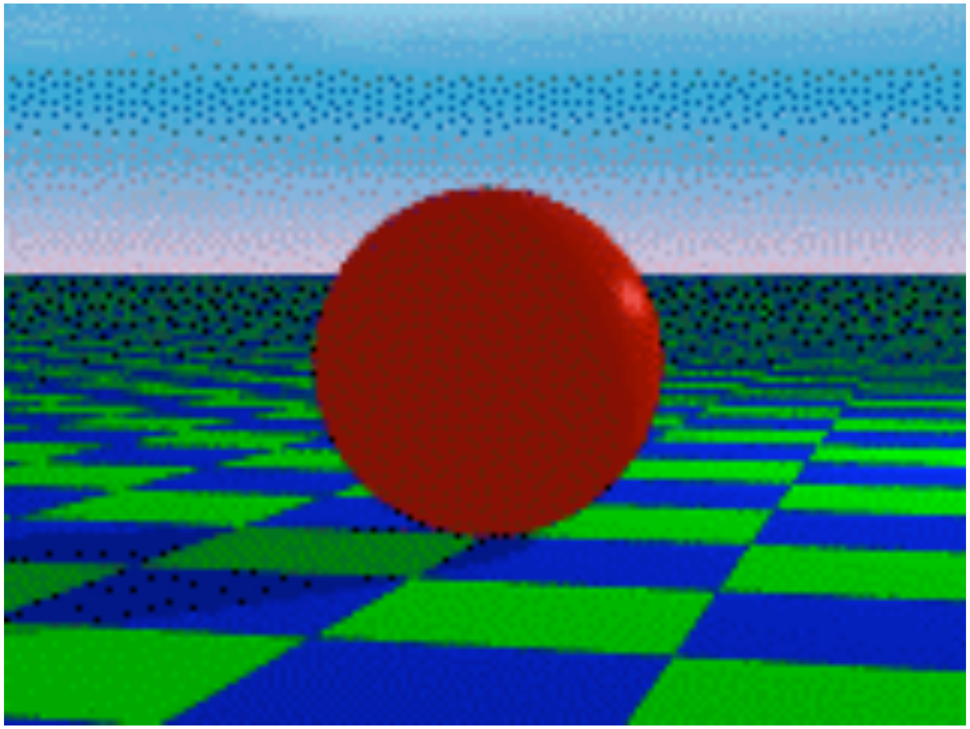
Point Light Sources

- scene lit with ambient and point light source

Light Position Important

Viewer Position Important

Surface Angle Important

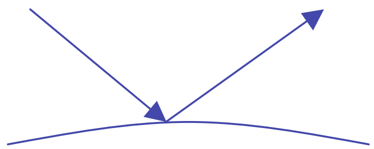


Light Sources

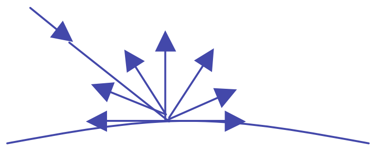
- geometry: positions and directions
  - standard: world coordinate system
    - effect: lights fixed wrt world geometry
    - demo: http://www.xmission.com/~nate/tutors.html
  - alternative: camera coordinate system
    - effect: lights attached to camera (car headlights)
  - points and directions undergo normal model/view transformation
- illumination calculations: camera coords

Types of Reflection

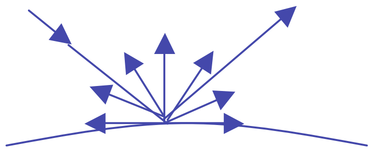
- *specular* (a.k.a. *mirror* or *regular*) reflection causes light to propagate without scattering.



- *diffuse* reflection sends light in all directions with equal energy.



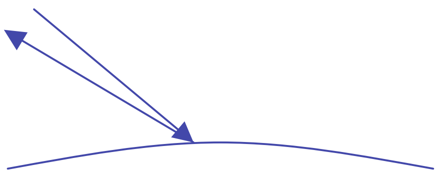
- *mixed* reflection is a weighted combination of specular and diffuse.



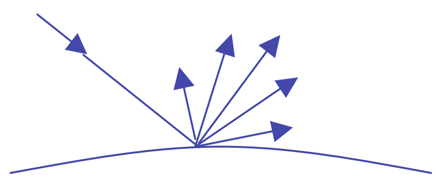
Specular Highlights

Types of Reflection

- *retro-reflection* occurs when incident energy reflects in directions close to the incident direction, for a wide range of incident directions.

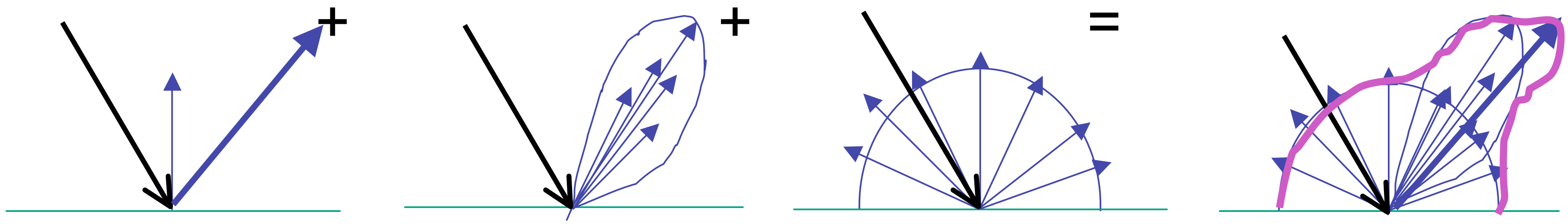


- *gloss* is the property of a material surface that involves mixed reflection and is responsible for the mirror like appearance of rough surfaces.



Reflectance Distribution Model

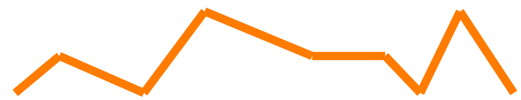
- most surfaces exhibit complex reflectances
  - vary with incident and reflected directions.
  - model with combination



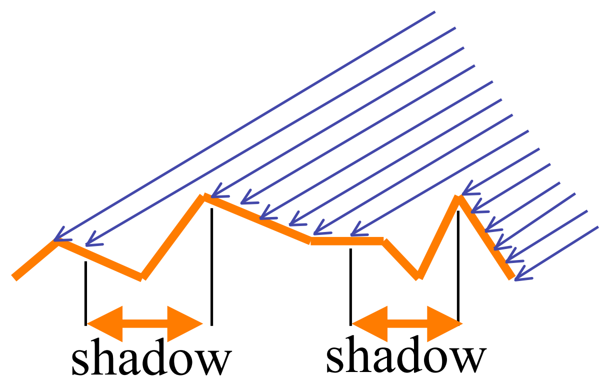
specular + glossy + diffuse =
reflectance distribution

Surface Roughness

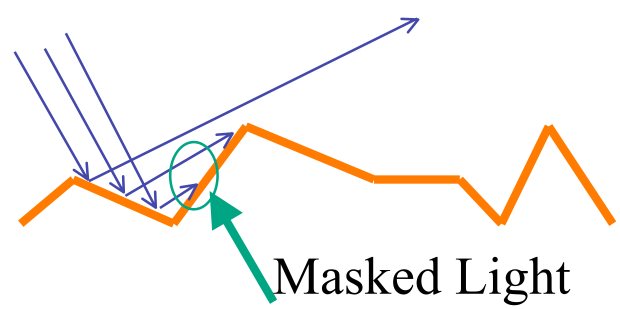
- at a microscopic scale, all real surfaces are rough



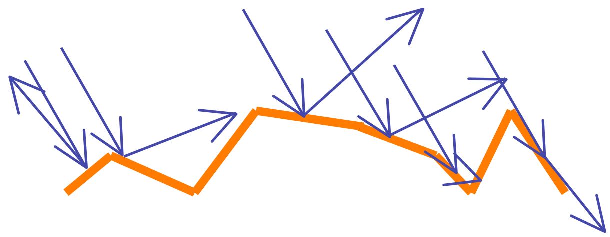
- cast shadows on themselves



- “mask” reflected light:



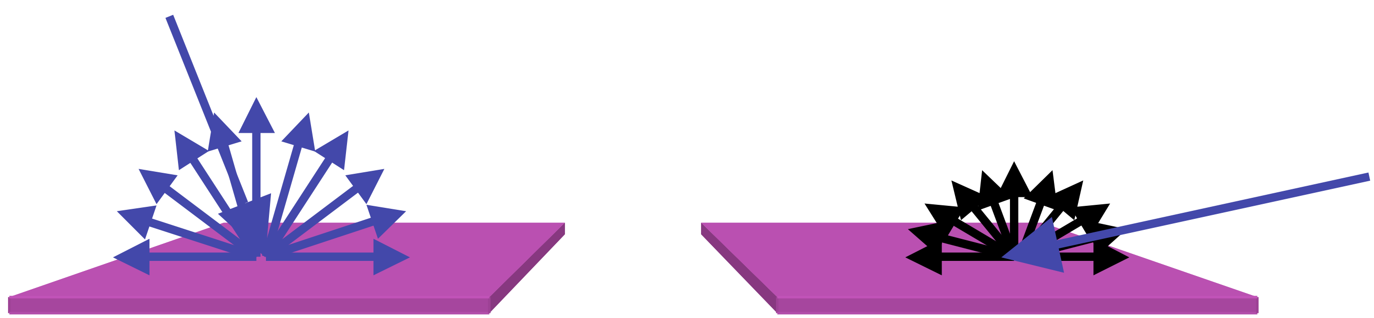
Surface Roughness



- notice another effect of roughness:
  - each "microfacet" is treated as a perfect mirror.
  - incident light reflected in different directions by different facets.
  - end result is mixed reflectance.
    - smoother surfaces are more specular or glossy.
    - random distribution of facet normals results in diffuse reflectance.

Physics of Diffuse Reflection

- ideal diffuse reflection
  - very rough surface at the microscopic level
    - real-world example: chalk
  - microscopic variations mean incoming ray of light equally likely to be reflected in any direction over the hemisphere
  - what does the reflected intensity depend on?



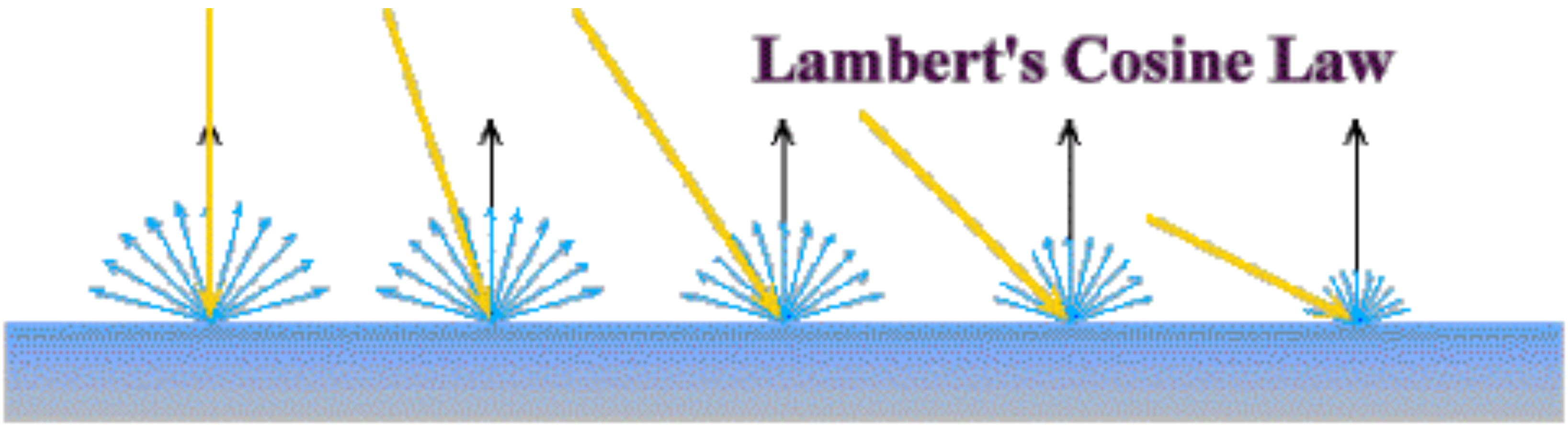
Lambert's Cosine Law

- ideal diffuse surface reflection

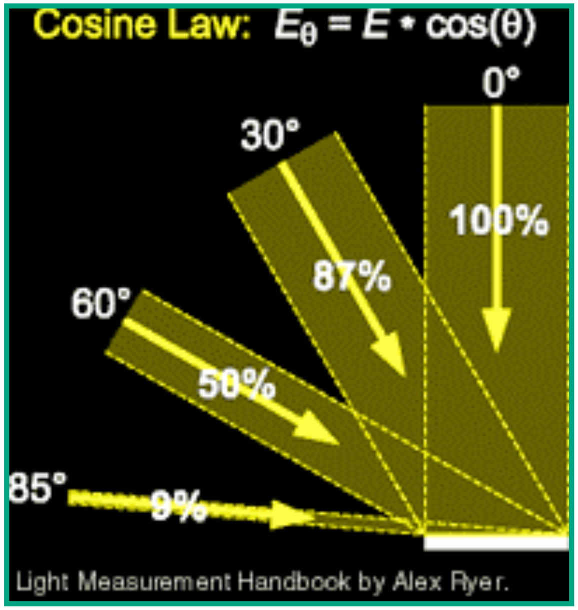
  the energy reflected by a small portion of a surface from a light source in a given direction is proportional to the cosine of the angle between that direction and the surface normal

- reflected intensity
  - independent of viewing direction
  - depends on surface orientation wrt light
- often called Lambertian surfaces

Lambert's Law

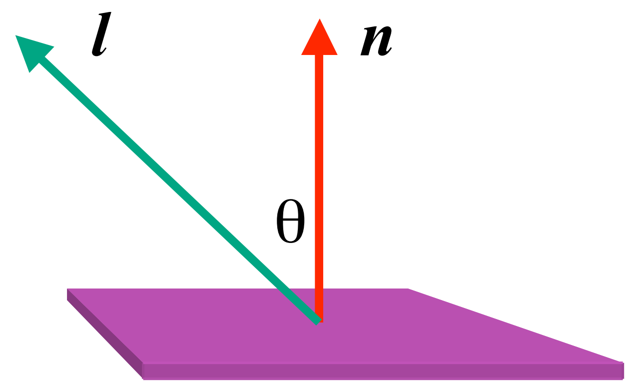


intuitively: cross-sectional area of the "beam" intersecting an element of surface area is smaller for greater angles with the normal.



Computing Diffuse Reflection

- depends on angle of incidence: angle between surface normal and incoming light
  - $I_{diffuse} = k_d I_{light} \cos \theta$
- in practice use vector arithmetic
  - $I_{diffuse} = k_d I_{light} (\mathbf{n} \bullet \mathbf{l})$



- **always normalize vectors used in lighting!!!**
  - $\mathbf{n}$, $\mathbf{l}$ should be unit vectors
- scalar (B/W intensity) or 3-tuple or 4-tuple (color)
  - k_d: diffuse coefficient, surface color
  - I_{light}: incoming light intensity
  - $I_{diffuse}$: outgoing light intensity (for diffuse reflection)

Diffuse Lighting Examples

- Lambertian sphere from several lighting angles:

- need only consider angles from 0° to 90°
  - *why?*
  - *demo: Brown exploratory on reflection*
  - http://www.cs.brown.edu/exploratories/freeSoftware/repository/edu/brown/cs/exploratories/applets/reflection2D/reflection_2d_java_browser.html