University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2007

Tamara Munzner

Lighting/Shading I

Week 6, Wed Feb 14

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2007

News

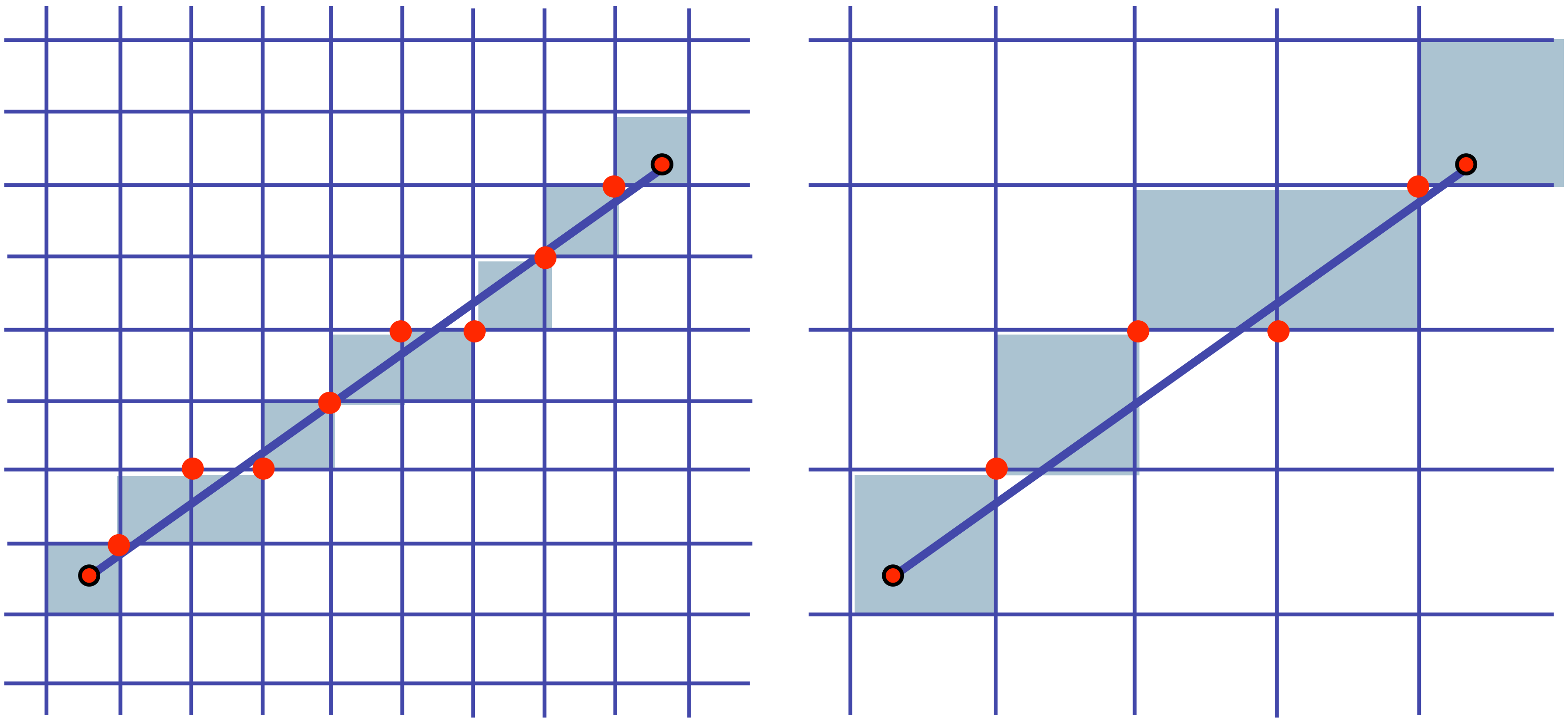
- Homework 2 out today
- Project 2 out Friday
    - due Mon Feb 26 instead of Fri Feb 23

Reading for Today & Next 2 Lectures

- FCG Chap 9 Surface Shading
- RB Chap Lighting

Review: Scan Conversion

- convert continuous rendering primitives into discrete fragments/pixels
  - given vertices in DCS, fill in the pixels
- display coordinates required to provide scale for discretization



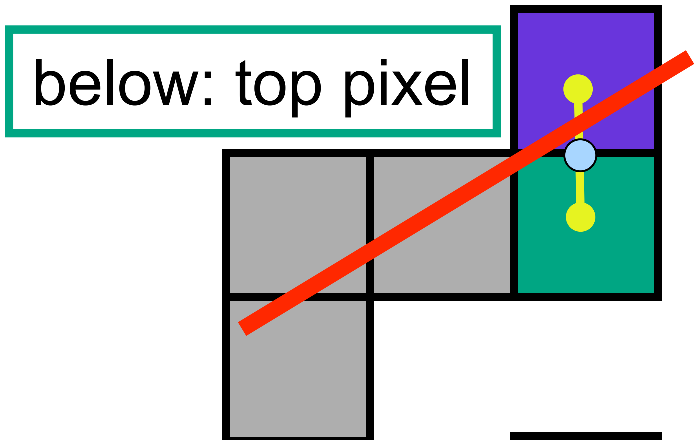
Correction: Making It Fast: Reuse Computation

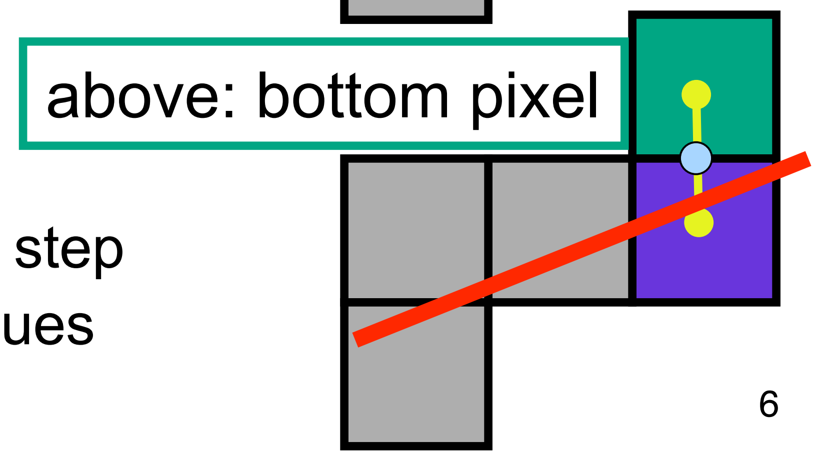
- midpoint: if f(x+1, y+.5) < 0 then y = y+1
- on previous step evaluated f(x-1, y-.5) or f(x-1, y+$\boxed{.5)}$
- $f(x+1, y) = f(x,y) + (y_0-y_1)$
- $f(x+1, y+1) = f(x,y) + (y_0- y_1) + (x_1- x_0)$

```
y=y0
d = f(x0+1, y0+.5)
for (x=x0; x <= x1; x++) {
  draw(x,y);
  if (d<0) then {
   y = y + 1;
   d = d + (x1 - x0) + (y0 - y1)
  } else {
   d = d + (y0 - y1)
}
```

Review/Correction: Midpoint Algorithm

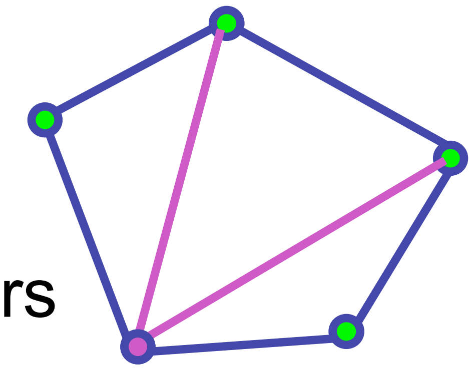
- we're moving horizontally along x direction (first octant)
  - only two choices: draw at current y value, or move up vertically to y+1?
    - check if midpoint between two possible pixel centers above or below line
  - candidates
    - top pixel: (x+1,y+1)
    - bottom pixel: (x+1, y)
  - midpoint: (x+1, y+.5)
- check if midpoint above or below line
  - below: pick top pixel
  - above: pick bottom pixel
- key idea behind Bresenham
  - reuse computation from previous step
  - integer arithmetic by doubling values



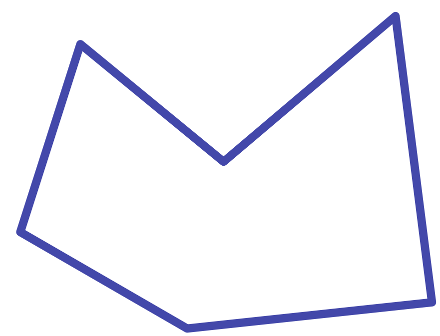


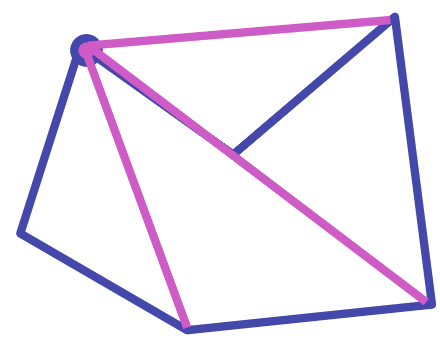
Review: Triangulating Polygons

- 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()



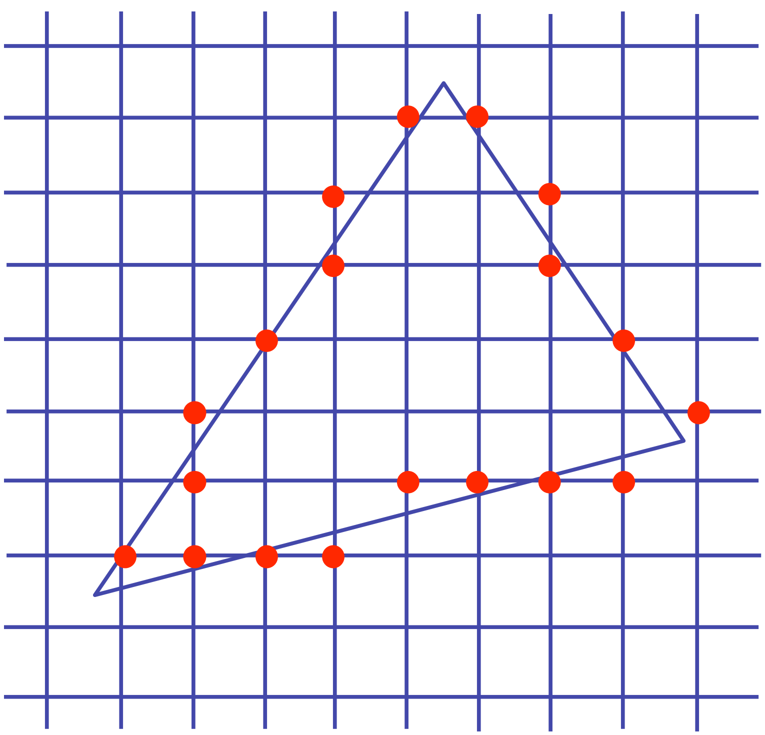
- concave or non-simple polygons
  - more effort to break into triangles
  - simple approach may not work
  - OpenGL can support at extra cost
    - gluNewTess(), gluTessCallback(), ...

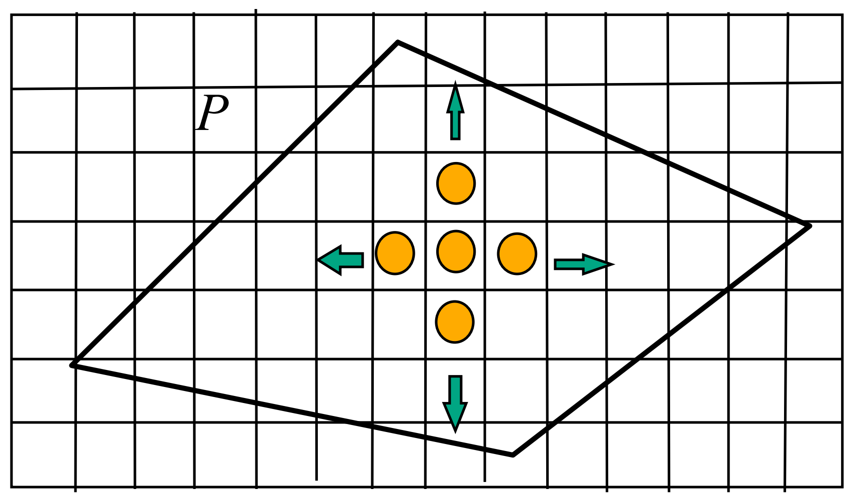




Review: Flood Fill

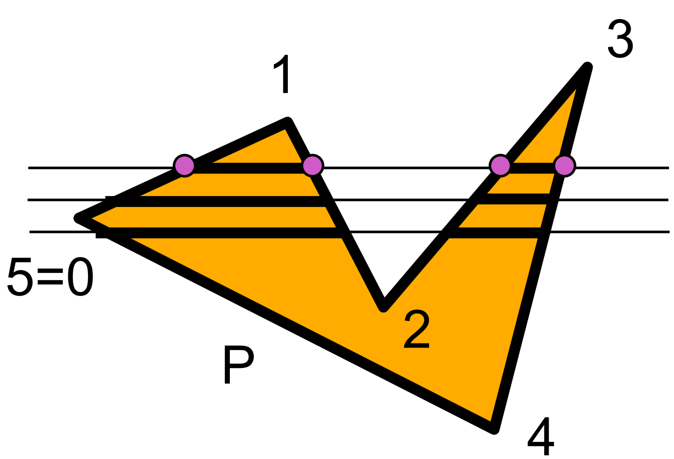
- simple algorithm
  - draw edges of polygon
  - use flood-fill to draw interior

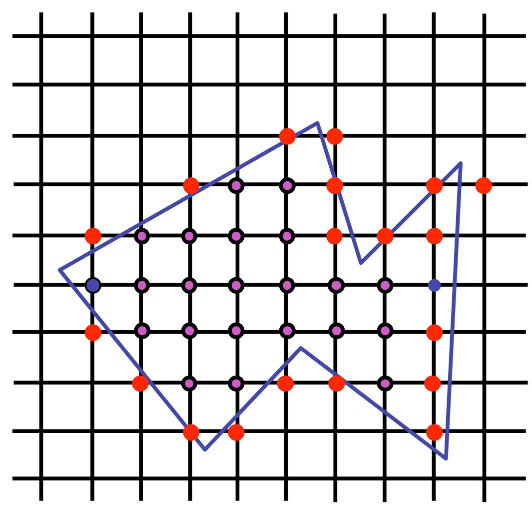


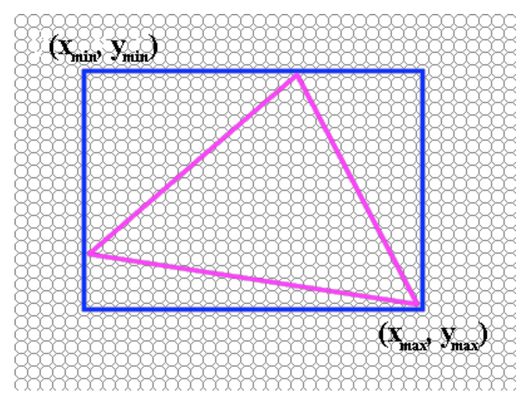


Review: Scanline Algorithms

- 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

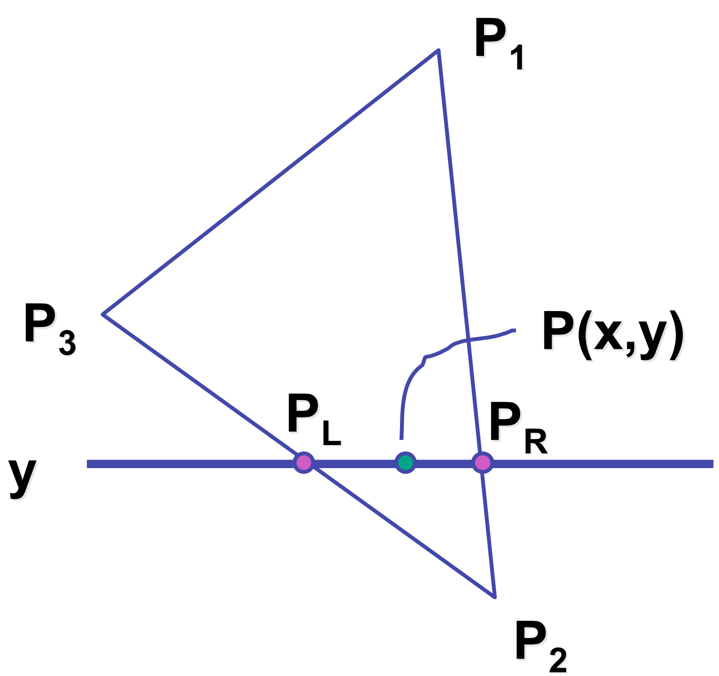






Review: Bilinear Interpolation

- 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)

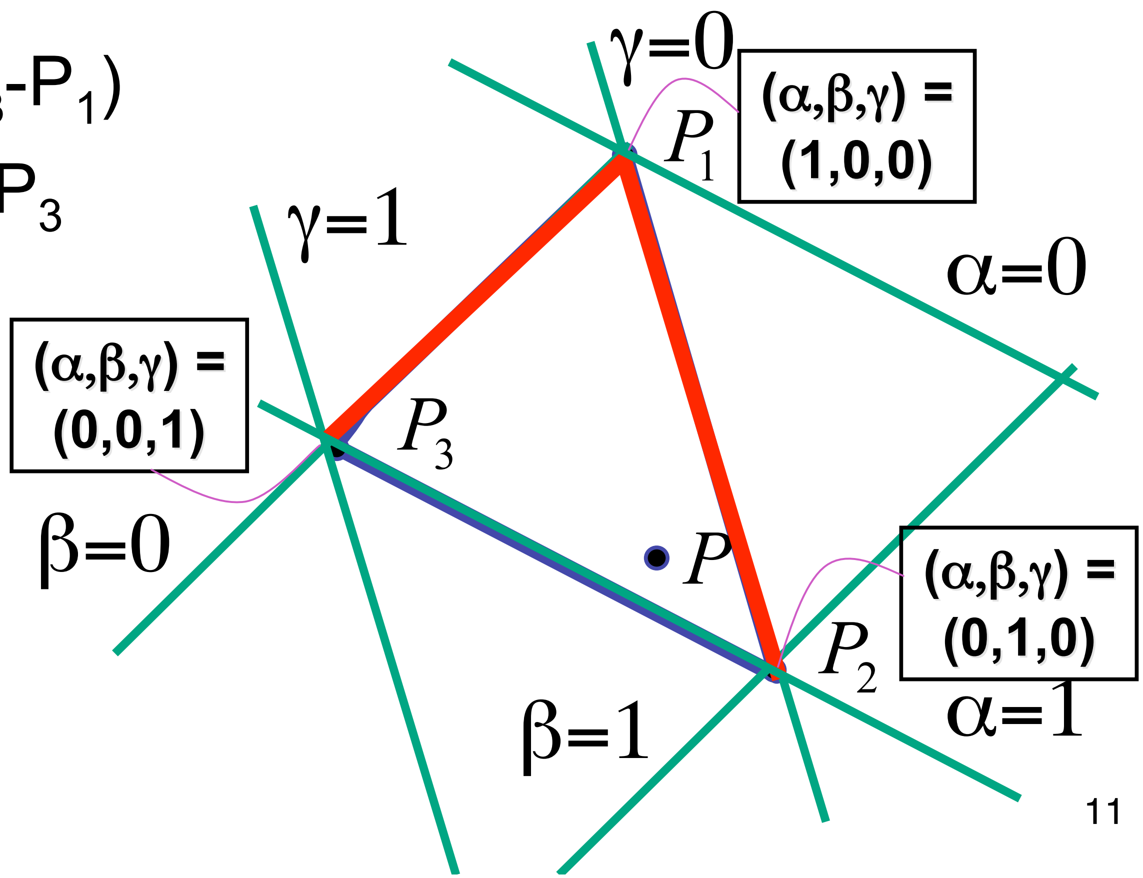
$P = P_1 + \beta(P_2-P_1)+\gamma(P_3-P_1)$

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

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

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

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



Interpolation

Computing Barycentric Coordinates

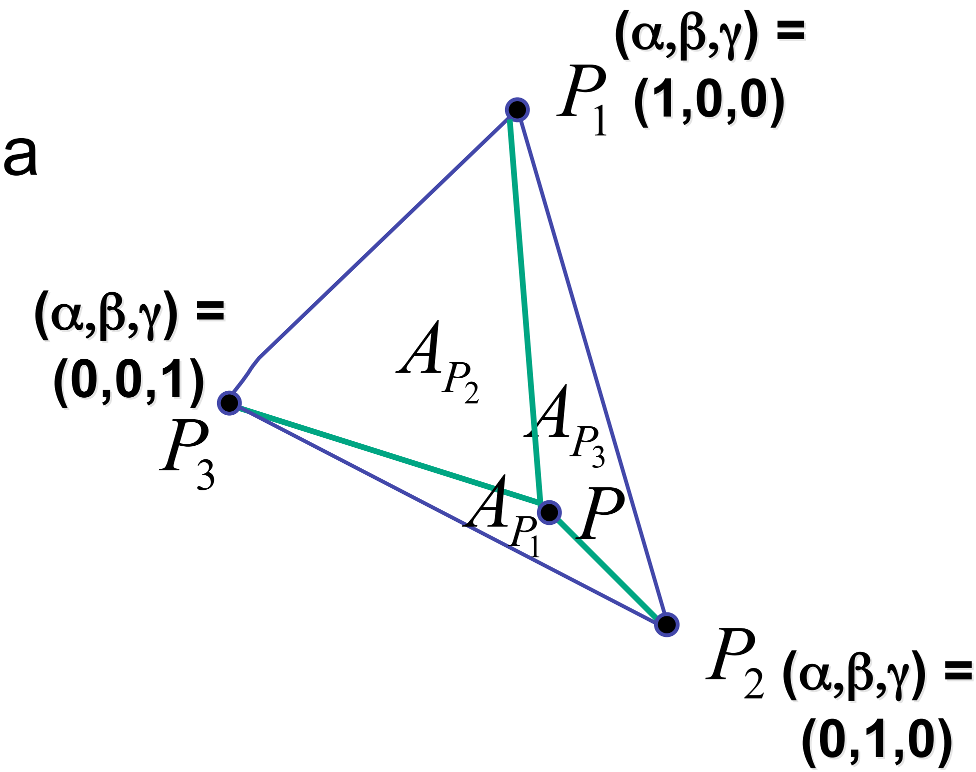
- 2D triangle area
  - half of parallelogram area
    - from cross product

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

$\alpha = A_{P1} / A$

$\beta = A_{P2} / A$

$\gamma = A_{P3} / A$

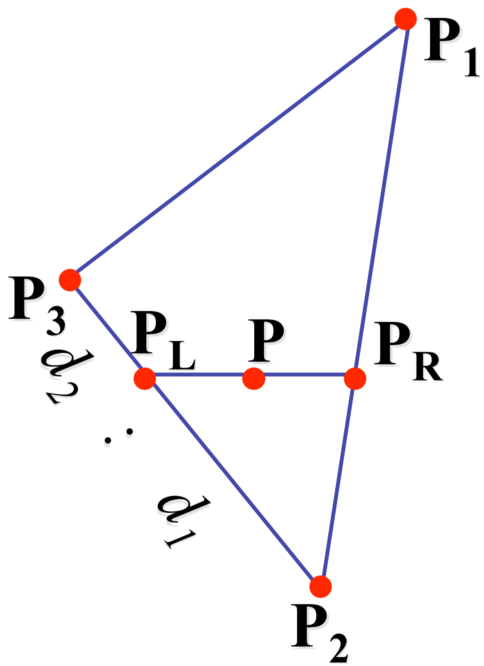


weighted combination of three points

[demo]

Deriving Barycentric From Bilinear

- from bilinear interpolation of point P on scanline



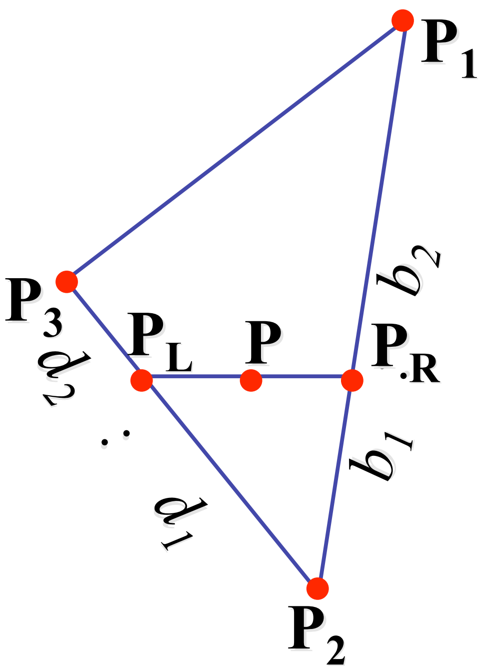
$$P_L = P_2 + \frac{d_1}{d_1 + d_2}(P_3 - P_2)$$

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

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

Deriving Barycentric From Bilineaer

- similarly



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

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

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

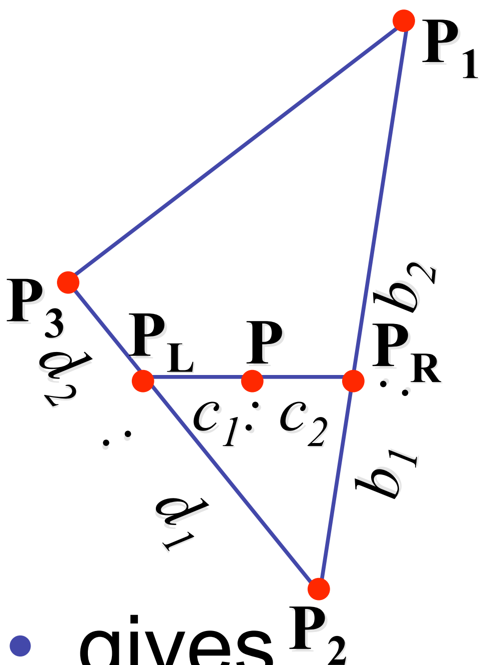
Deriving Barycentric From Bilinear

- 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

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

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

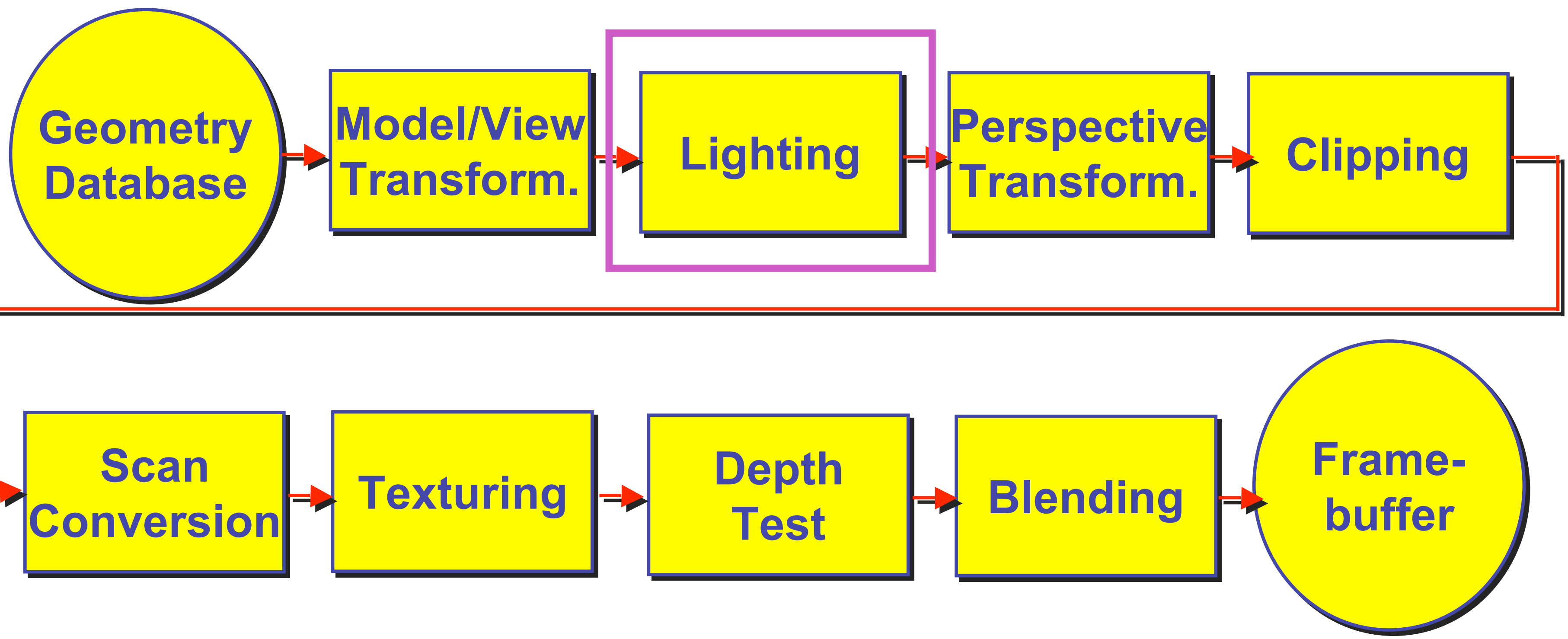
$$\gamma = \frac{c_2}{c_1 + c_2} \frac{d_1}{d_1 + d_2}$$

- can verify barycentric properties

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

Lighting I

Rendering Pipeline



Projective Rendering Pipeline

object
OCS

O2W

modeling transformation

world
WCS

W2V

viewing transformation

viewing
VCS

V2C

projection transformation

clipping
CCS

C2N

perspective divide

normalized device
NDCS

N2D

viewport transformation

device
DCS

OCS - object/model coordinate system

WCS - world coordinate system

VCS - viewing/camera/eye coordinate system

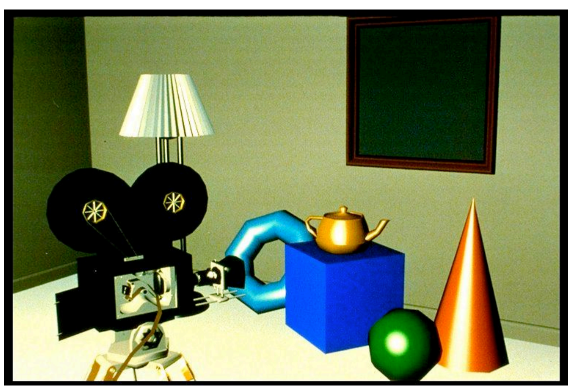
CCS - clipping coordinate system

NDCS - normalized device coordinate system

DCS - device/display/screen coordinate system

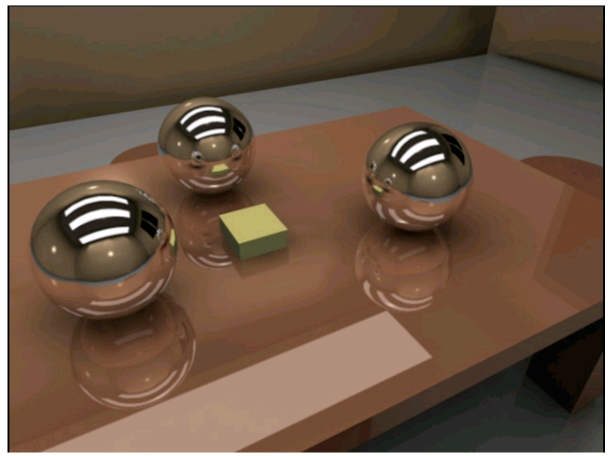
Goal

- 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

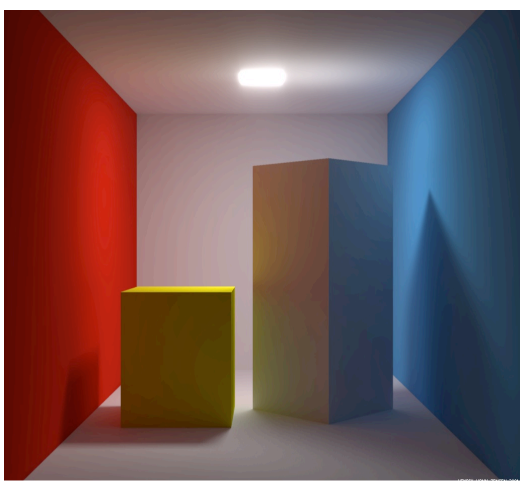


Photorealistic Illumination

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



[electricimage.com]



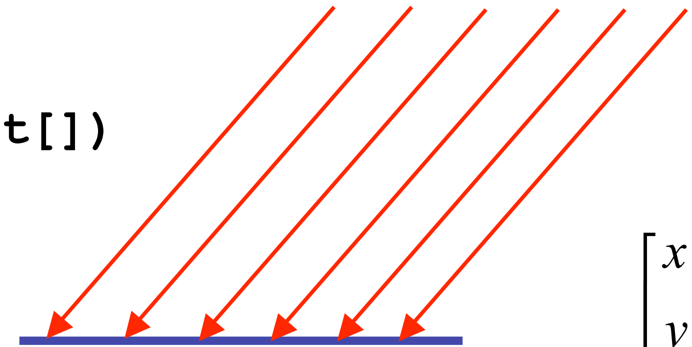
Henrik Wann Jensen

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

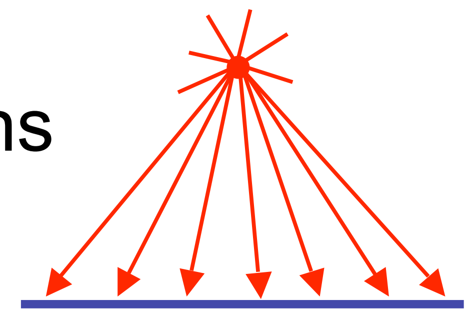
Light Sources

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



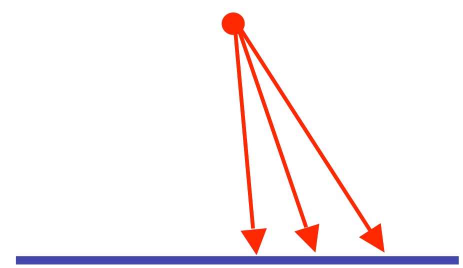
$$\begin{bmatrix} x \\ y \\ z \\ 0 \end{bmatrix}$$

  - point lights
    - same intensity in all directions



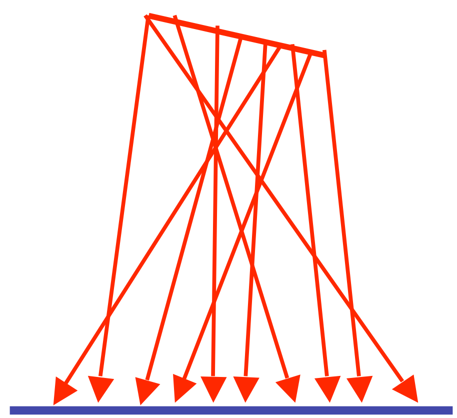
$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

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



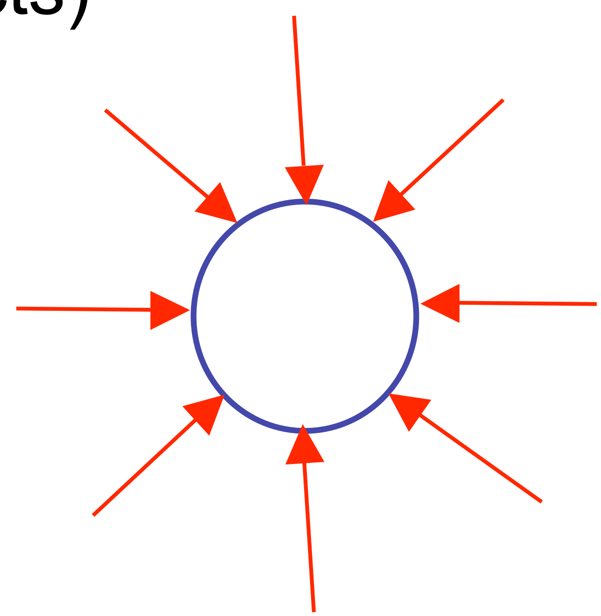
Light Sources

- 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

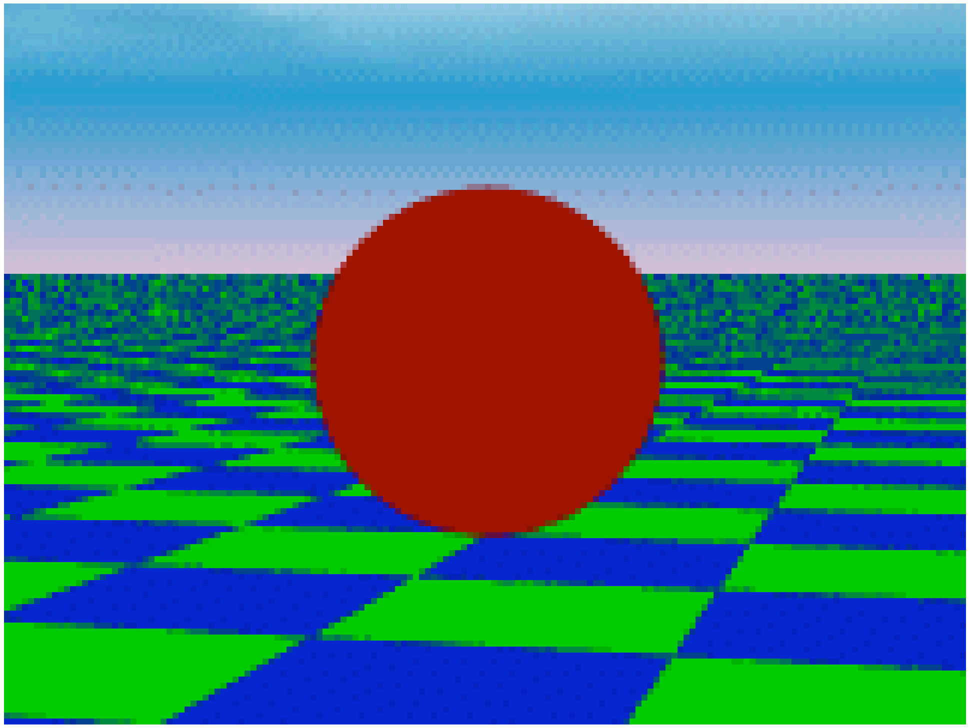
- ambient lights
  - no identifiable source or direction
  - hack for replacing true global illumination
    - (diffuse interreflection: light bouncing off from other objects)



Diffuse Interreflection

Ambient Light Sources

- scene lit only with an ambient light source



Light Position
Not Important

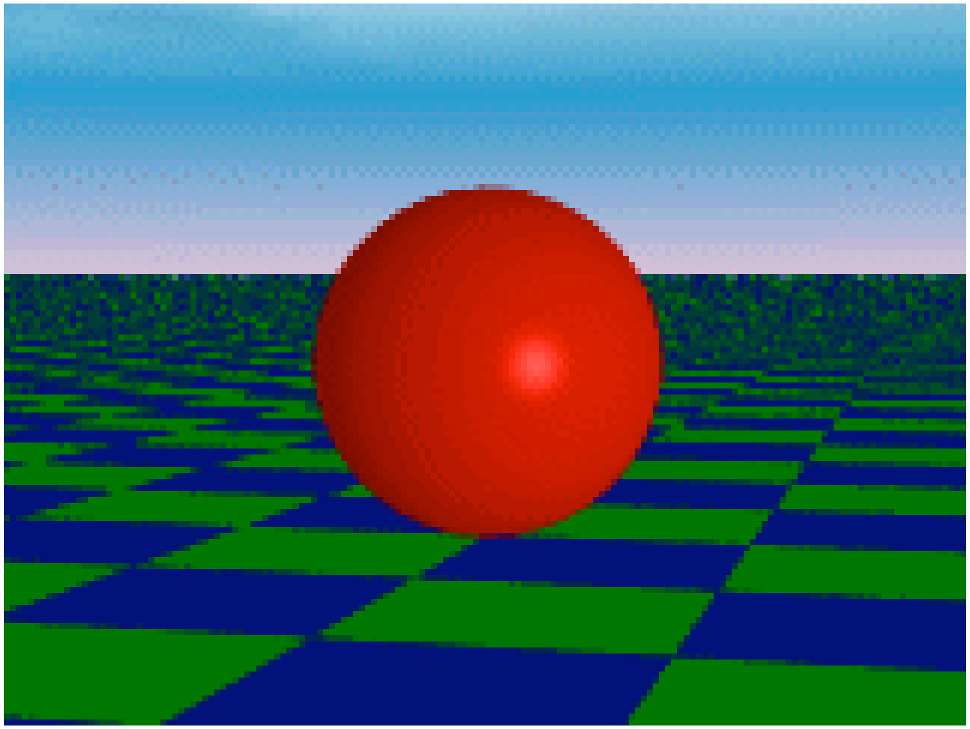
Viewer Position
Not Important

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

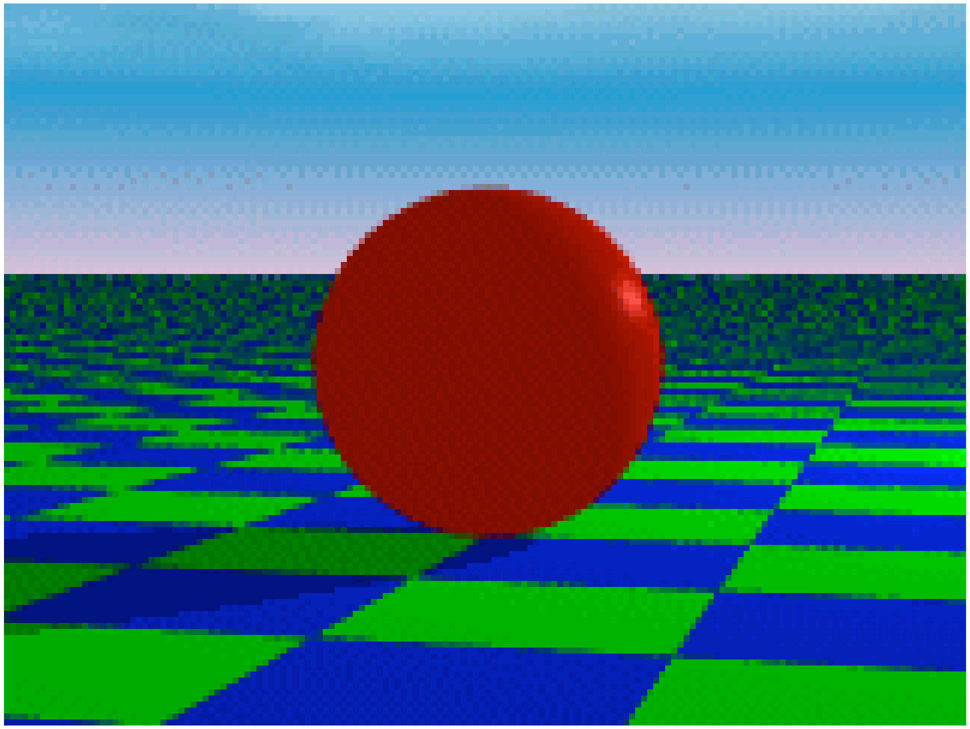
Point Light Sources

- scene lit with ambient and point light source

Light Position Important

Viewer Position Important

Surface Angle Important

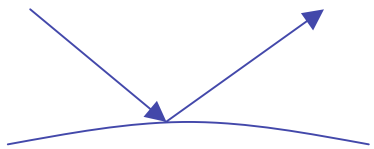


Light Sources

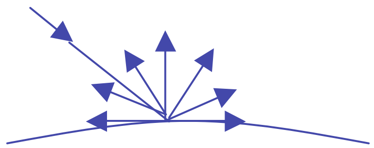
- geometry: positions and directions
  - standard: world coordinate system
    - effect: lights fixed wrt world geometry
    - demo: http://www.xmission.com/~nate/tutors.html
  - alternative: camera coordinate system
    - effect: lights attached to camera (car headlights)
  - points and directions undergo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

Types of Reflection

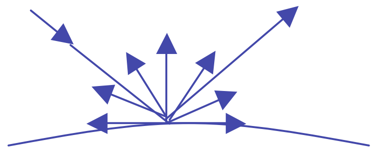
- *specular* (a.k.a. *mirror* or *regular*) reflection causes light to propagate without scattering.



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



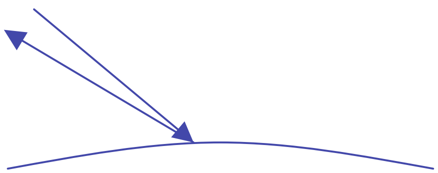
- *mixed* reflection is a weighted combination of specular and diffuse.



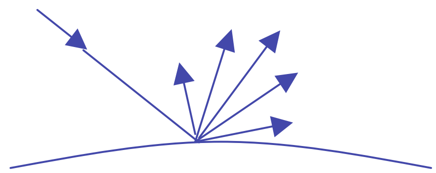
Specular Highlights

Types of Reflection

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

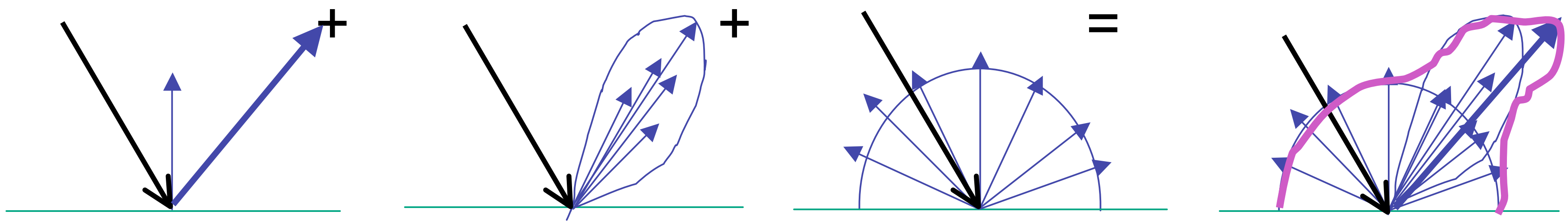


- *gloss* is the property of a material surface that involves mixed reflection and is responsible for the mirror like appearance of rough surfaces.



Reflectance Distribution Model

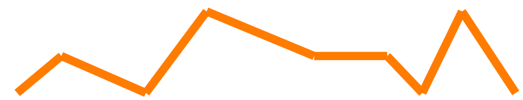
- most surfaces exhibit complex reflectances
  - vary with incident and reflected directions.
  - model with combination



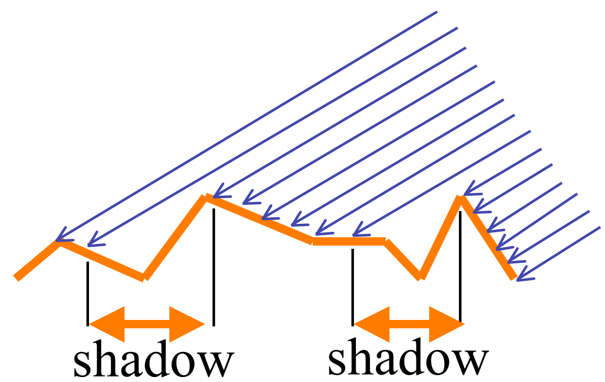
specular + glossy + diffuse =
reflectance distribution

Surface Roughness

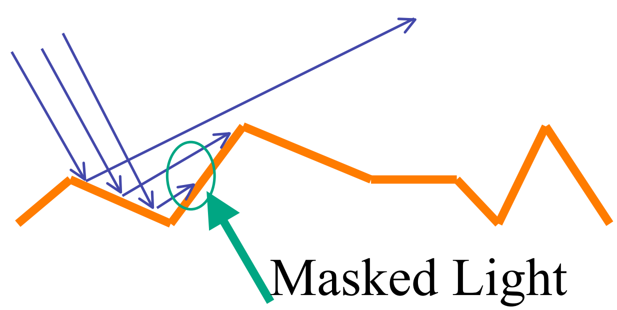
- at a microscopic scale, all real surfaces are rough



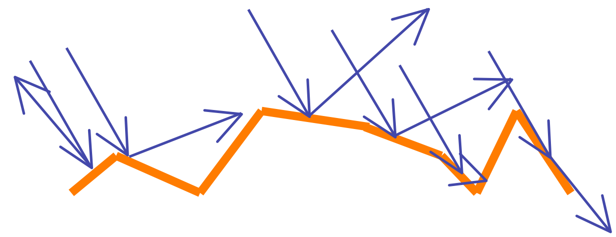
- cast shadows on themselves



- “mask” reflected light:



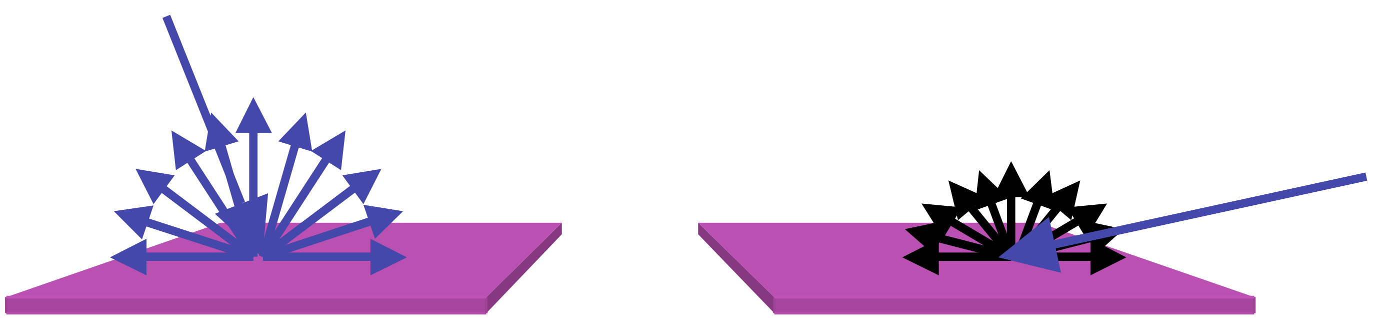
Surface Roughness



- 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?



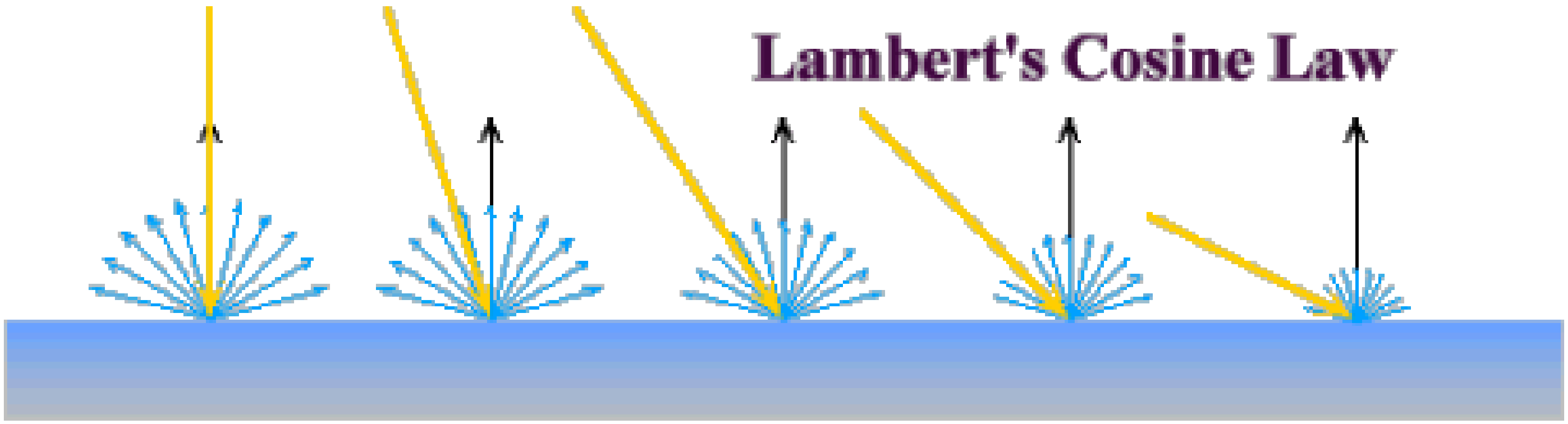
Lambert's Cosine Law

- ideal diffuse surface reflection

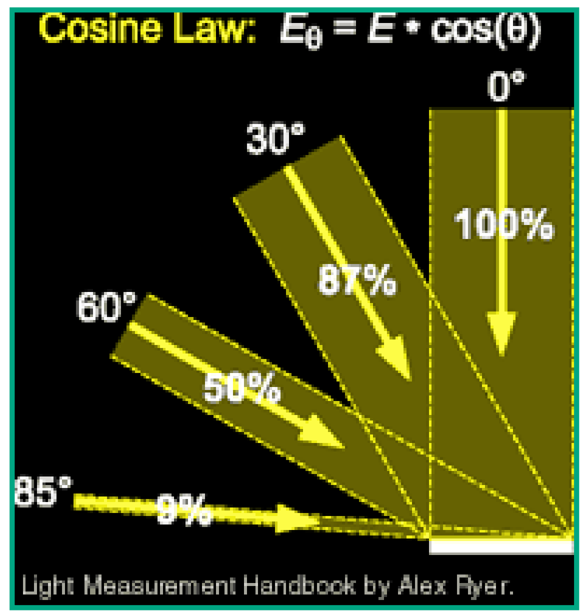
  the energy reflected by a small portion of a surface from a light source in a given direction is proportional to the cosine of the angle between that direction and the surface normal

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

Lambert's Law

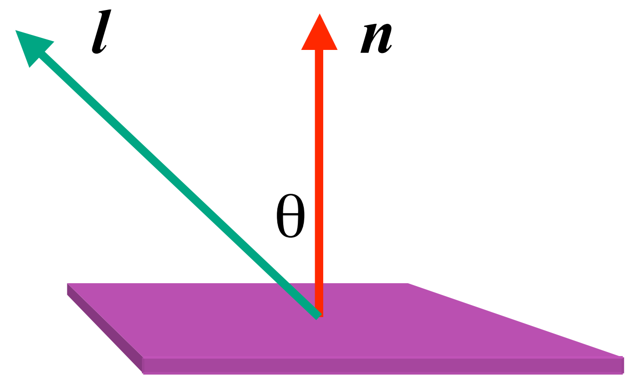


intuitively: cross-sectional area of the "beam" intersecting an element of surface area is smaller for greater angles with the normal.



Computing Diffuse Reflection

- depends on angle of incidence: angle between surface normal and incoming light
  - $I_{diffuse} = k_d I_{light} \mathbf{cos}\, \theta$



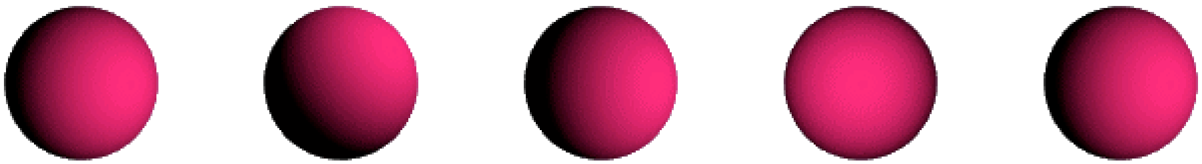
- in practice use vector arithmetic
  - $I_{diffuse} = k_d I_{light} (\mathbf{n} \bullet \mathbf{l})$

- **always normalize vectors used in lighting!!!**
  - **n, 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