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

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Lighting/Shading I

Week 6, Wed Feb 14

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

News

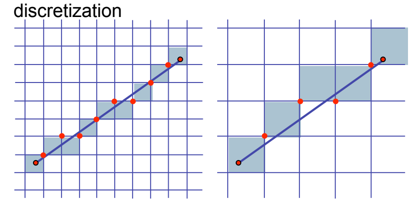
- Homework 2 out today
- Project 2 out Friday
  - due Mon Feb 26 instead of Fri Feb 23

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



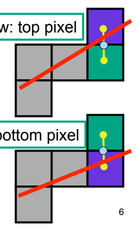
Correction: Making It Fast: Reuse Computation

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

```
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)
}
```

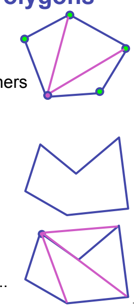

Review/Correction: Midpoint Algorithm

- 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



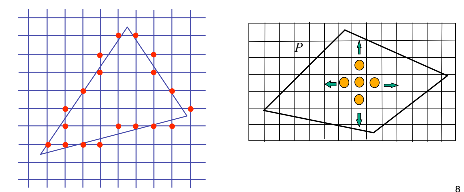
Review: Triangulating Polygons

- 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(), ...



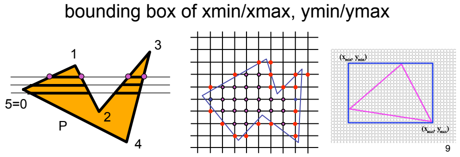
Review: Flood Fill

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



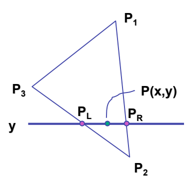
Review: Scanline Algorithms

- 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)

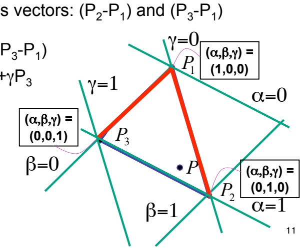
$P = P_1 + \beta(P_2-P_1)+\gamma(P_3-P_1)$

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

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

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

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



Interpolation

Computing Barycentric Coordinates

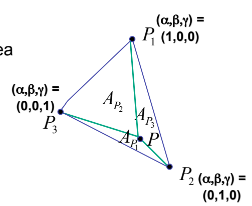
- 2D triangle area
  - half of parallelogram area
    - from cross product

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

$\alpha = A_{P1}/A$

$\beta = A_{P2}/A$

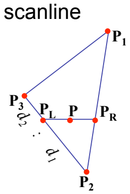
$\gamma = A_{P3}/A$



weighted combination of three points [demo]

Deriving Barycentric From Bilinear

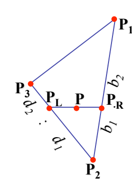
- from bilinear interpolation of point P on scanline



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

Deriving Barycentric From Bilineaer

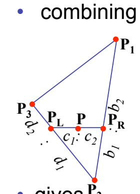
- similarly



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

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

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

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

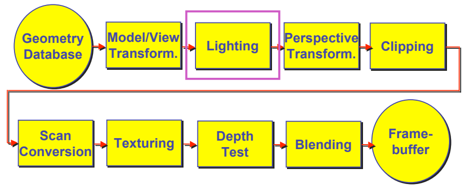
$$\gamma = \frac{c_2}{c_1+c_2}\frac{d_1}{d_1+d_2}$$

- can verify barycentric properties

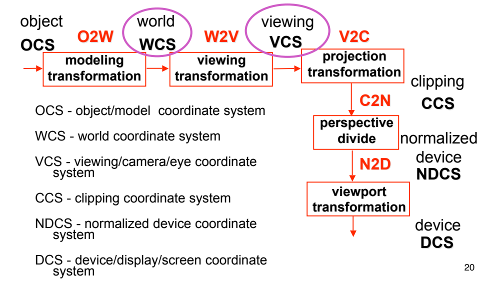
$$\alpha+\beta+\gamma = 1, \qquad 0 \le \alpha,\beta,\gamma \le 1$$

Lighting I

Rendering Pipeline



Projective Rendering Pipeline



OCS - object/model coordinate system

WCS - world coordinate system

VCS - viewing/camera/eye coordinate system

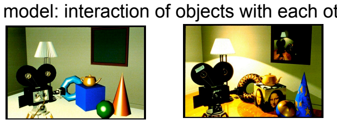
CCS - clipping coordinate system

NDCS - normalized device coordinate system

DCS - device/display/screen coordinate system

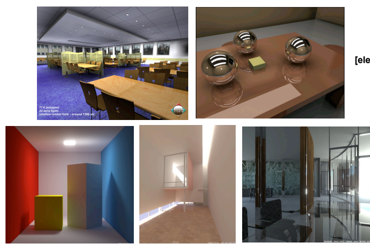
Goal

- 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]

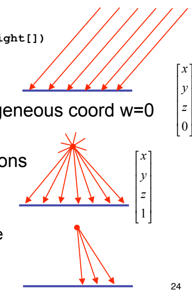
Henrik Wann Jensen

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

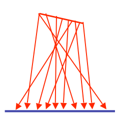
Light Sources

- 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



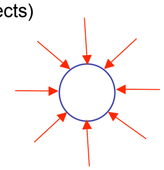
Light Sources

- 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

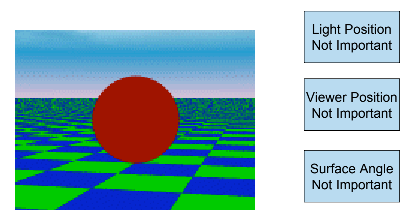
- ambient lights
- no identifiable source or direction
- hack for replacing true global illumination
  - (diffuse interreflection: light bouncing off from other objects)



Diffuse Interreflection

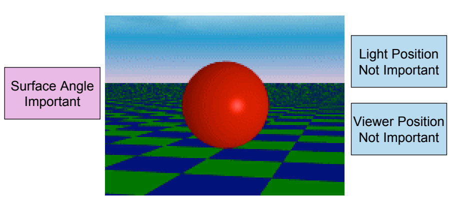
Ambient Light Sources

- scene lit only with an ambient light source



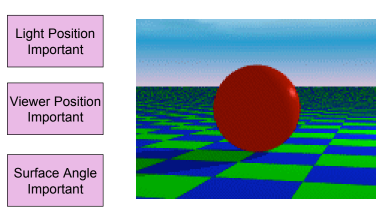
Directional Light Sources

- scene lit with directional and ambient light



Point Light Sources

- scene lit with ambient and point light source

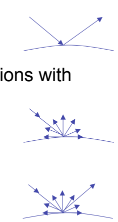


Light Sources

- 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

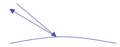
- *specular* (a.k.a. *mirror* or *regular*) reflection causes light to propagate without scattering.
- *diffuse* reflection sends light in all directions with equal energy.
- *mixed* reflection is a weighted combination of specular and diffuse.



Specular Highlights

Types of Reflection

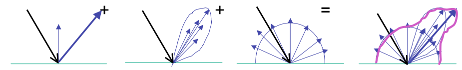
- *retro-reflection* occurs when incident energy reflects in directions close to the incident direction, for a wide range of incident directions.



- *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

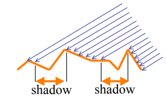


specular + glossy + diffuse = reflectance distribution

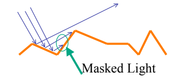
Surface Roughness

- at a microscopic scale, all real surfaces are rough

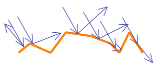
- cast shadows on themselves



- "mask" reflected light:



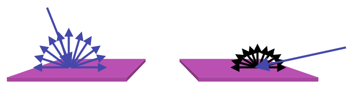
Surface Roughness



- 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?

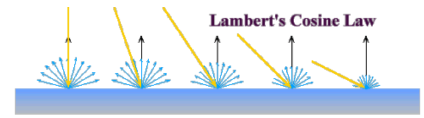


Lambert's Cosine Law

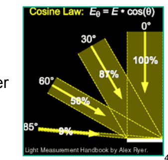
- ideal diffuse surface reflection

  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

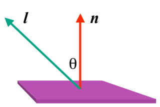


intuitively: cross-sectional area of the "beam" intersecting an element of surface area is smaller for greater angles with the normal.



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!!!**
  - **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