Reading (today, Mon, Wed)

- FCG
  - Chapter 8
- RB
  - Chapter Lighting
Correction from last time

- row vectors not column vectors might have been confusing
- but they’re mathematically equivalent

\[
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & \frac{d}{d-\alpha} & \frac{1}{d} \\
0 & 0 & \frac{-\alpha \cdot d}{d-\alpha} & 0
\end{bmatrix}
\begin{pmatrix}
x \\
y \\
z \\
1
\end{pmatrix}
= 
\begin{pmatrix}
x, y, (z-\alpha) \cdot d \\
\frac{z}{d}
\end{pmatrix}
\]
Perspective Warp

- matrix formulation (with column vectors)

\[
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & \frac{d}{d-\alpha} & -\alpha \cdot \frac{d}{d-\alpha} \\
0 & 0 & \frac{1}{d} & 0
\end{bmatrix}
\begin{bmatrix}
x \\
y \\
z \\
1
\end{bmatrix}
=
\begin{bmatrix}
x \\
y \\
\frac{(z-\alpha) \cdot d}{d-\alpha} \\
\frac{z}{d}
\end{bmatrix}
\]

\[(x_p, y_p, z_p) = \left(\frac{x}{z/d}, \frac{y}{z/d}, \frac{d^2}{d-\alpha} \left(1 - \frac{\alpha}{z}\right)\right)\]

- preserves relative depth (third coordinate)
- what does \( \alpha = 0 \) mean?
Review: NDC to Viewport Transformation

■ 2D scaling and translation

\[
x_{DCS} = w \frac{(x_{NDCS} + 1)}{2}
\]
\[
y_{DCS} = h \frac{(y_{NDCS} + 1)}{2}
\]
\[
z_{DCS} = \frac{(z_{NDCS} + 1)}{2}
\]

OpenGL

```c
glViewport(x, y, a, b);
default:
    glViewport(0, 0, w, h);
```
Review: Perspective Normalization

- perspective viewing frustum transformed to cube
- orthographic rendering of cube produces same image as perspective rendering of original
Review: Perspective Normalization

- distort such that orthographic projection of distorted objects is desired persp projection
  - separate division from standard matrix multiplies
  - clip after warp, before divide
  - division: normalization
Review: Coordinate Systems

View space (4-space, W=1)

Projection Matrix

Clip Space (4-space parallelepiped because COP is moved backwards to infinity)

Divide by W

NDC (3-space parallel piped)

Scale & Bias

Screen Space (3-space parallelepiped)

http://www.btinternet.com/~danbgsperspective/
Review: Perspective Derivation

\[
\begin{bmatrix}
\frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\
0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\
0 & 0 & -\frac{(f+n)}{f-n} & -2fn \\
0 & 0 & \frac{f-n}{f-n} & 0
\end{bmatrix}
\]

VCS

x=left

y=top

y=bottom

z=-near

z=-far

NDCS

(1,1,1)

(-1,-1,-1)
Review: Field-of-View Formulation

- FOV in one direction + aspect ratio (w/h)
  - also set near, far
Projection Taxonomy

planar projections
- perspective: 1,2,3-point
- parallel
- oblique
  - cabinet
  - cavalier
- orthographic
  - axonometric:
    - top, front, side
    - isometric
g - dimetric
g - trimetric

http://ceprofs.tamu.edu/tkramer/ENGR%20111/5.1/20
Perspective Projections

- classified by vanishing points

one-point perspective

two-point perspective

three-point perspective
Parallel Projection

- projectors are all parallel
  - vs. perspective projectors that converge
  - orthographic: projectors perpendicular to projection plane
  - oblique: projectors not necessarily perpendicular to projection plane
Axonometric Projections

- projectors perpendicular to image plane
- select axis lengths

3 Equal axes  2 Equal axes  0 Equal axes
3 Equal angles  2 Equal angles  0 Equal angles

A. ISOMETRIC  B. DIMETRIC  C. TRIMETRIC

http://ceprofs.tamu.edu/tkramer/ENGR%20111/5.1/20
Oblique Projections

- projectors oblique to image plane
- select angle between front and z axis
  - lengths remain constant
- both have true front view
  - cavalier: distance true
  - cabinet: distance half
Demos

- Tuebingen applets from Frank Hanisch
  - http://www.gris.uni-tuebingen.de/projects/grdev/doc/html/etc/AppletIndex.html#Transformationen
Goal

model interaction of light with matter in a way that appears realistic and is fast

- phenomenological reflection models
  - ignore real physics, approximate the look
  - simple, non-physical
  - Phong, Blinn-Phong

- physically based reflection models
  - simulate physics
  - BRDFs: Bidirectional Reflection Distribution Functions
Photorealistic Illumination

77 K polygons
24 area lights
solution render time: around 7200 sec
Photorealistic Illumination
Fast Local Illumination
Illumination

- transport of energy from light sources to surfaces & points
  - includes *direct* and *indirect illumination*

Images by Henrik Wann Jensen
Components of Illumination

- two components: light sources and surface properties
- light sources (or *emitters*)
  - spectrum of emittance (i.e., color of the light)
  - geometric attributes
    - position
    - direction
    - shape
  - directional attenuation
- polarization
Components of Illumination

- surface properties
  - reflectance spectrum (i.e., color of the surface)
  - subsurface reflectance
- geometric attributes
  - position
  - orientation
  - micro-structure
Illumination as Radiative Transfer

- radiative heat transfer approximation
  - substitute light for heat
  - light as packets of energy (photons)
    - particles not waves
  - model light transport as packet flow
Light Transport Assumptions

- geometrical optics (light is photons not waves)
  - no diffraction

- no polarization (some sunglasses)
  - light of all orientations gets through

- no interference (packets don’t interact)
  - which visual effects does this preclude?
Light Transport Assumptions II

- color approximated by discrete wavelengths
  - quantized approx of dispersion (rainbows)
  - quantized approx of fluorescence (cycling vests)
- no propagation media (surfaces in vacuum)
  - no atmospheric scattering (fog, clouds)
    - some tricks to simulate explicitly
  - no refraction (mirages)
- light travels in straight line
  - no gravity lenses
Light Transport Assumptions III

- light travels in straight line
  - no gravity lenses

- superposition (lights can be added)
  - no nonlinear reflection models
    - nonlinearity handled separately
Light Sources and Materials

- appearance depends on
  - light sources, locations, properties
  - material (surface) properties
  - viewer position
- local illumination
  - compute at material, from light to viewer
- global illumination (later in course)
  - ray tracing: from viewer into scene
  - radiosity: between surface patches
Illumination in the Pipeline

- local illumination
  - only models light arriving directly from light source
  - no interreflections and 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
    - (light bouncing off from other objects)
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
  - **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.
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

\[ \text{specular} + \text{glossy} + \text{diffuse} = \text{reflectance distribution} \]
Surface Roughness

- at a microscopic scale, all real surfaces are rough

- cast shadows on themselves

- “mask” reflected light:
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 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

- angle between surface normal and incoming light is \textit{angle of incidence}:

\[ I_{\text{diffuse}} = k_d I_{\text{light}} \cos \theta \]

- in practice use vector arithmetic

\[ I_{\text{diffuse}} = k_d I_{\text{light}} (n \cdot l) \]

\( k_d \): diffuse component
"surface color"
Diffuse Lighting Examples

- Lambertian sphere from several lighting angles:

- need only consider angles from 0° to 90°
  - why?
  - demo: Brown exploratory on reflection