## Virtual and Digital Cameras

![Ansel Adams](image)

### Topics

<table>
<thead>
<tr>
<th>Effect</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of view</td>
<td>Film size, focal length</td>
</tr>
<tr>
<td>Perspective</td>
<td>Lens, focal length</td>
</tr>
<tr>
<td>Focus</td>
<td>Lens vs. film plane</td>
</tr>
<tr>
<td>Exposure</td>
<td>Aperture, shutter, film speed</td>
</tr>
<tr>
<td>Depth of field</td>
<td>Aperture, focal length</td>
</tr>
<tr>
<td>Motion blur</td>
<td>Shutter</td>
</tr>
</tbody>
</table>

References: Photography, B. London and J. Upton
Nikon D3 Cutaway

http://tokyobling.wordpress.com/2008/12/17/nikon-d3-cut-in-half/

Pinhole Camera
Pinhole Camera

Types of lenses

- Normal 26°
- Wide-angle 75-90°
- Narrow-angle 10°
Field of View

From London and Upton

CS148 Lecture 17  Pat Hanrahan, Winter 2009
**Perspective Projection**

- **Film plane**
- **Object point** \((x, y, z)\)
- **Imaged point** \((x', y')\)
- **Pinhole**

\[
x' = -\frac{f}{z} x \\
y' = -\frac{f}{z} y
\]

**Translation – 2D**

\[
\begin{bmatrix}
x' \\
y' \\
1
\end{bmatrix} = \begin{bmatrix}
1 & 0 & t_x \\
0 & 1 & t_y \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
x \\
y \\
1
\end{bmatrix}
\]
Translation – 3D

\[
\begin{bmatrix}
  x' \\
  y' \\
  z' \\
  1
\end{bmatrix}
= \begin{bmatrix}
  1 & 0 & 0 & t_x \\
  0 & 1 & 0 & t_y \\
  0 & 0 & 1 & t_z \\
  0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
  x \\
  y \\
  z \\
  1
\end{bmatrix}
\]

Homogenous Coordinates

\[
\begin{bmatrix}
  xw \\
  yw \\
  zw \\
  w
\end{bmatrix}
\]

\[
\begin{bmatrix}
  x \\
  y \\
  z
\end{bmatrix}
= \begin{bmatrix}
  xw/w \\
  yw/w \\
  zw/w
\end{bmatrix}
\]
Perspective Transform

\[ x' = -f \frac{x}{z} \quad y' = -f \frac{y}{z} \]

\[ xw' = -fx \]
\[ yw' = -fy \]
\[ w' = z \]

Perspective Matrix

\[ x' = -f \frac{x}{z} \quad y' = -f \frac{y}{z} \]

\[
\begin{bmatrix}
  xw' \\
yw' \\
z w' \\
w'
\end{bmatrix} = \begin{bmatrix}
  -f & 0 & 0 & 0 \\
  0 & -f & 0 & 0 \\
  - & - & - & - \\
  0 & 0 & 1 & 0
\end{bmatrix} \begin{bmatrix}
x \\
y \\
z \\
1
\end{bmatrix}
\]
Perspective Frustum

\[ \text{glFrustum}(l, r, b, t, n, f) \]
\[ \text{glPerspective}(\text{fov}, n, f) \]

Orthographic Transformation

\[ \text{glOrtho}(l, r, b, t, n, f) \]
Viewing Coordinate Systems

Object or Model
  ↓
Model matrix
  ↓
World
  ↓
View matrix
  ↓
Camera
  ↓
Projection matrix
  ↓
Window
  ↓
Viewport (Device)

Viewing in OpenGL

```
void glViewport(int x, int y, int w, int h)

void glMatrixMode(GLenum m)
void glLoadIdentity()

void gluLookat(const double *from, const double *to, const double *up)

void glOrtho(double l, double r, double b, double t, double n, double f)
```

```
void glMatrixMode(GLenum m)
void glLoadIdentity()

void glTranslate(double x, double y, double z)
```
Lenses

Gauss’ Ray Tracing Construction

All rays from an object point converge on a single image point; ideal imaging system
Same as the perspective transform

\[ \frac{1}{z'} = \frac{1}{z} + \frac{1}{f} \]
Focusing

To focus: move lens relative to backplane

Depth of Field
Depth of Field

From London and Upton

Circle of Confusion

Circle of confusion proportional to the size of the aperture

\[ \frac{c}{a} = \frac{d}{z} \]
Exposure

Aperture and Exposure

Exposure proportional to solid angle:

\[ E \approx \Omega \approx \frac{a^2}{f^2} \approx \frac{1}{N^2} \]

F-stops \( N \): 1.4 2 2.8 4.0 5.6 8 11 16 22 32 45 64

Square root of 2 progression

1 stop doubles exposure
Aperture vs Shutter

From London and Upton

f/16  f/4  f/2
1/8s  1/125s  1/500s

Camera Simulation Difficult

Motion Blur  Depth of Field

Cook, Porter, Carpenter, 1984  Mitchell, 1991
Sensors

Charge Coupled Devices (CCDs)

Developed by Wilford Boyle (L) and George Smith (R) at Bells Labs in 1969
Charge Coupled Devices (CCDs)

CMOS Imager
Sensor Size

35 mm SLR: 36 mm x 24 mm

APS: 24 mm x 16 mm
   Increases focal length of 35 mm lens by 1.5x

Point ‘n shoot: ¼” and 1/3”

Pixel Resolution and Size

For example: 6 megapixel sensor

36 mm x 24 mm
   ■ ~ 10 um pixel size
   ■ Large size gathers more light
   ■ Low noise since lots of photons

¼”
   ■ ~ 1.5 um pixel size
   ■ Captures less light
   ■ More noise
Concepts to Remember

Pinhole cameras form perspective images
Lenses also cause perspective
Perspective matrix uses homogenous coordinates
Field of view depends on film size and focal length
Focus by moving lens relative to sensor
Exposure increases with aperture
Lenses gather more light than pinholes
Depth of field decreases with aperture
Motion blur occurs during the time the shutter is open
Depth of field and motion blur hard to implement
Revolution in sensors: CCD and CMOS