Digital Cameras

Ansel Adams, www.wisconsinhistory.org

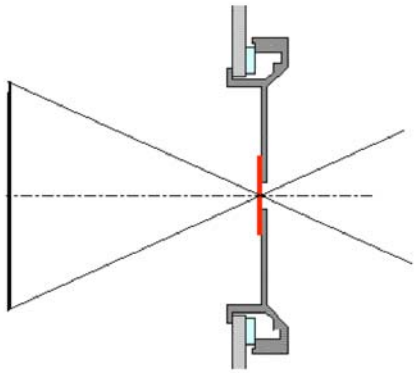
Cameras

Effect	Cause
Perspective	Lens, Focal length
Focus	Motion
Field of view	Film size, focal length
Exposure	Film speed, aperture, shutter
Depth of field	Aperture, focal length
Motion blur	Shutter

Reference: Photography, B. London and J. Upton

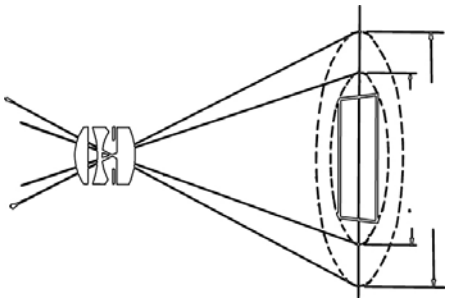
Pinhole Camera

Pinhole Camera



Camera Obscura
Cliff House, San Francison

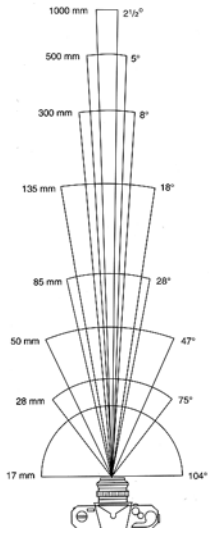
Field of View

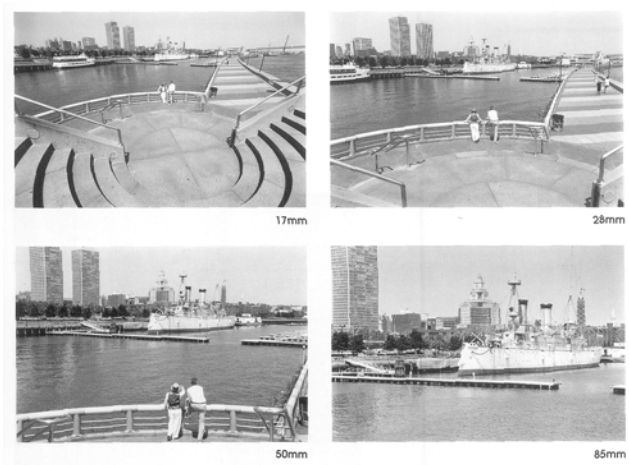


$$\tan\frac{fov}{2} = \frac{filmsize}{f}$$

Redrawn from Kingslake,
Optics in Photography

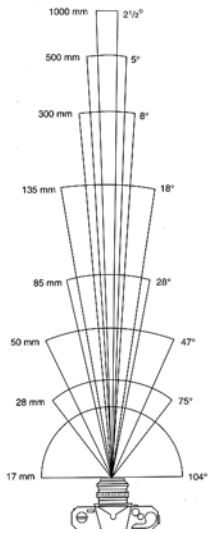
Field of View

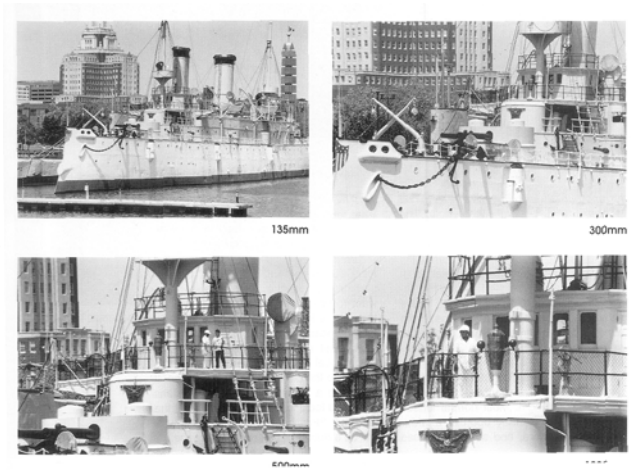




From London and Upton

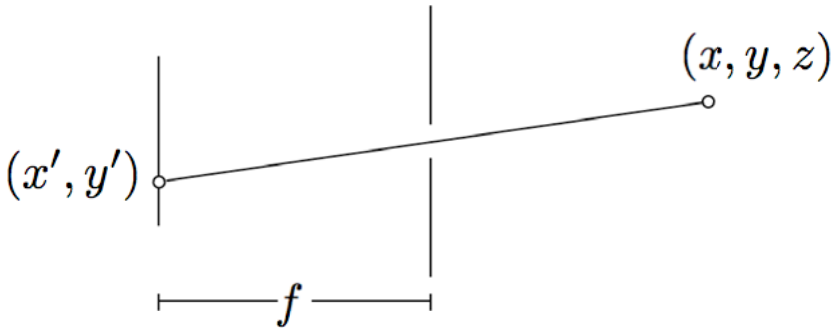
Field of View





From London and Upton

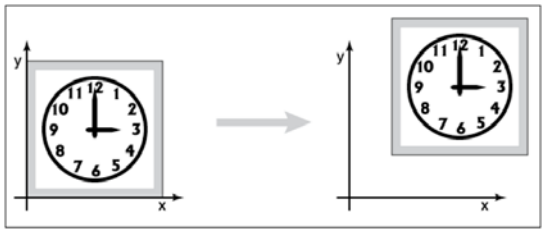
Perspective Projection



$$x' = -f\frac{x}{z}$$

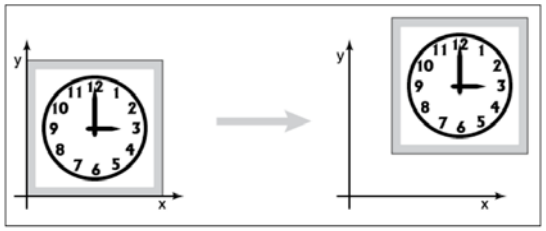
$$y' = -f\frac{y}{z}$$

Translations



$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Translations



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

Homogenous Coordinates

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

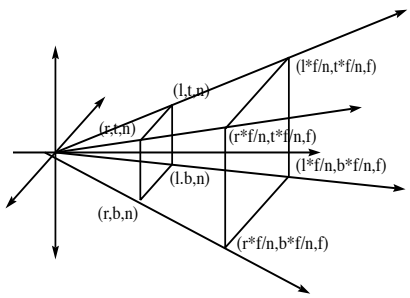
$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} x/w \\ y/w \\ z/w \end{bmatrix}$$

Perspective Matrix

$$x' = -f\frac{x}{z} \qquad y' = -f\frac{y}{z}$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ w' \end{bmatrix} = \begin{bmatrix} -f & 0 & 0 & 0 \\ 0 & -f & 0 & 0 \\ & * & * & * \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Perspective Frustum



$$\begin{bmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & -\frac{f+n}{f-n} & -\frac{2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

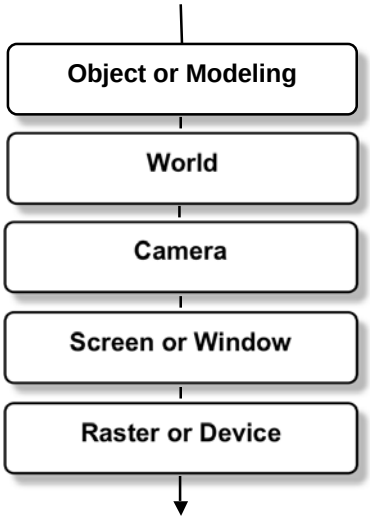
```
glFrustum(float l, r, b, t, n, f);
```


Orthographic Transformation

```
glOrtho(float l, r, b, t, n, f);
```

$$\begin{bmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & -\frac{2}{f-n} & -\frac{f+n}{f-n} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Viewing Coordinate Systems

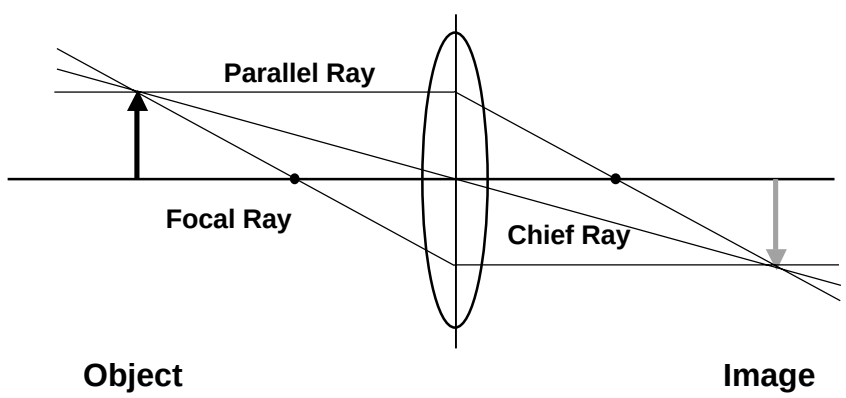


Projection and Modeling in OpenGL

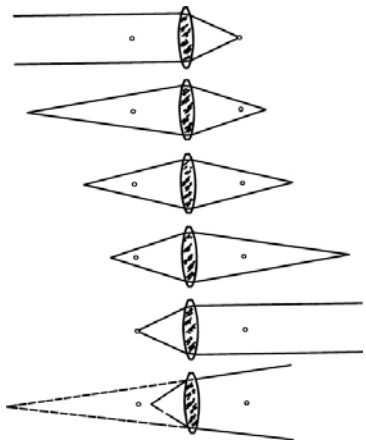
```
glViewport(0,0,w,h);

glMatrixMode (GL_PROJECTION);
glLoadIdentity ();
glOrtho(-1.0, 1.0, -1.0, 1.0, -1.0, 1.0);

glMatrixMode (GL_MODELVIEW);
glLoadIdentity ();
…
```

Lenses

Gauss' Ray Tracing Construction



Conjugate Points

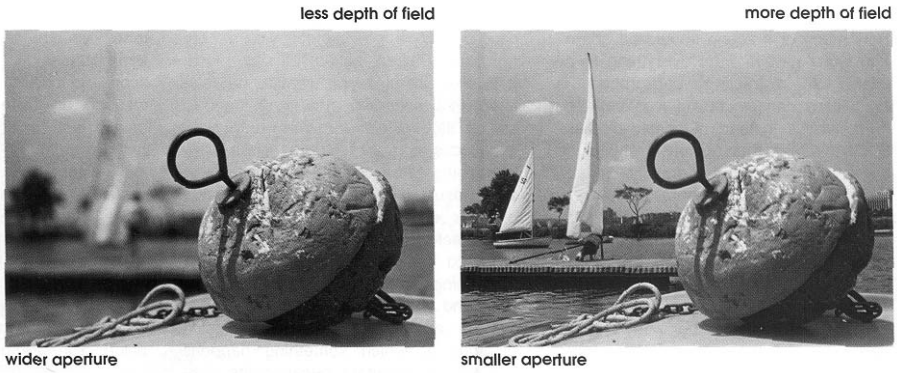


$$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f}$$

To focus: move lens relative to backplane

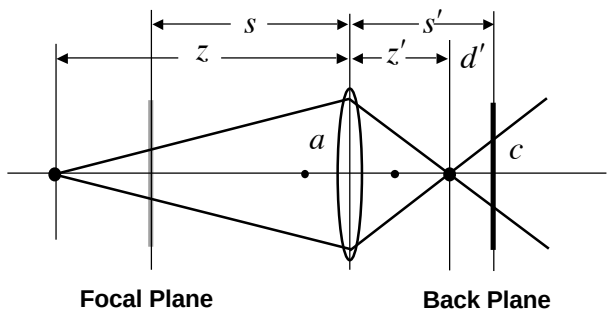
Horizontal rays converge on focal point in the focal plane

Depth of Field



From London and Upton

Circle of Confusion



Circle of confusion proportional to the size of the aperture

$$\frac{c}{a} = \frac{d'}{z'} = \frac{s' - z'}{z'}$$

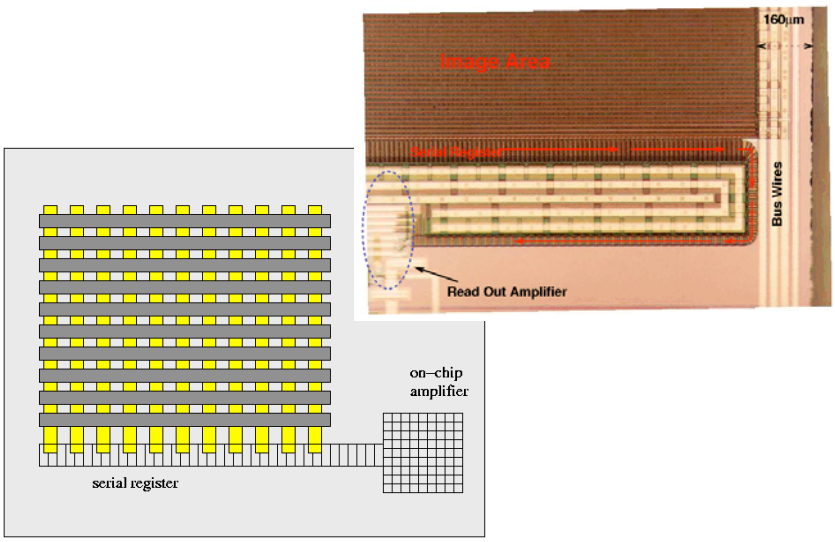
Sensors

CCDs

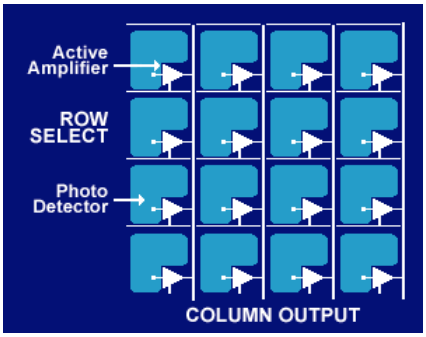
Developed by Willard Boyle (L) and George Smith (R) at Bell Labs in 1969

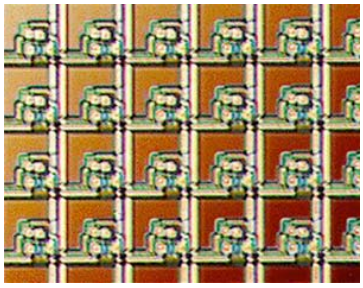
Received NAE Draper Prize in 2006

CCDs



CMOS





http://www.micron.com/innovations/imaging/pixel

Sensor Size

35mm SLR : 36mm x 24mm

APS: 24mm x 16mm

Increases focal length by 1.5x

1/4” & 1/3”

Point and shoot

Pixel Resolution and Size

6 MegaPixel Sensor

35mm

- ~10um pixels
- Efficiently gather light
- Low signal to noise

1/4”

- ~1.5um pixels
- Less efficient
- More noise

Bayer Mosaic