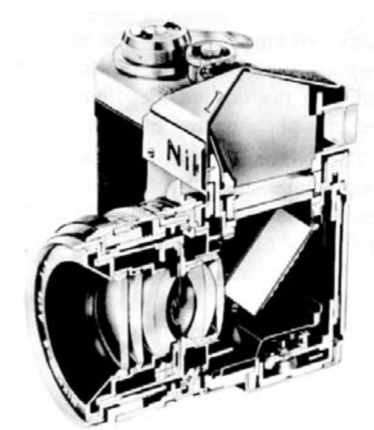
CS148: Introduction to Computer Graphics and Imaging

Virtual and Digital Cameras

Ansel Adams

Topics

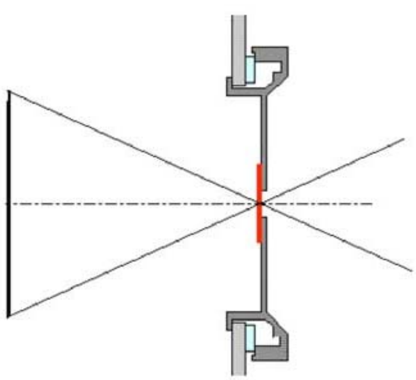


Effect	Cause
Perspective	Lens, focal length
Field of view	Film size
Focus	Lens vs. film plane
Exposure	Aperture, shutter, film speed,
Depth of field	Aperture, focal length
Motion blur	Shutter

References: Photography, B. London and J. Upton

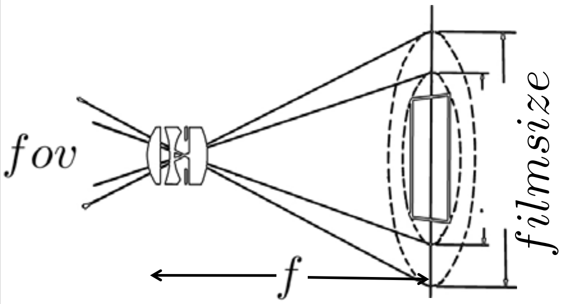
Pinhole Camera

Pinhole Camera



Camera obscura
Cliff house,
San Francisco

Field of View



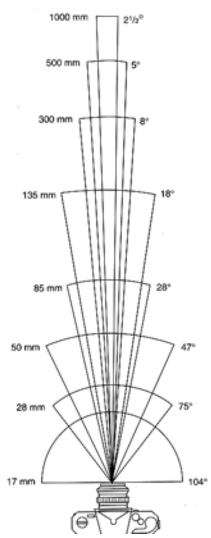
$$\tan \frac{fov}{2} = \frac{filmsize}{f}$$

Redrawn from Kingslake, *Optics in Photography*

Types of lenses

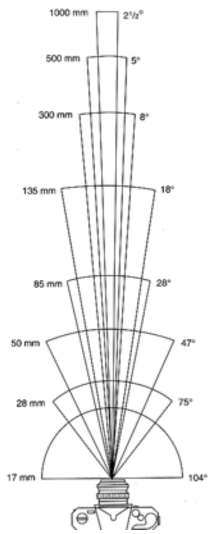
- **Normal** 26º
- **Wide-angle** 75-90º
- **Narrow-angle** 10º

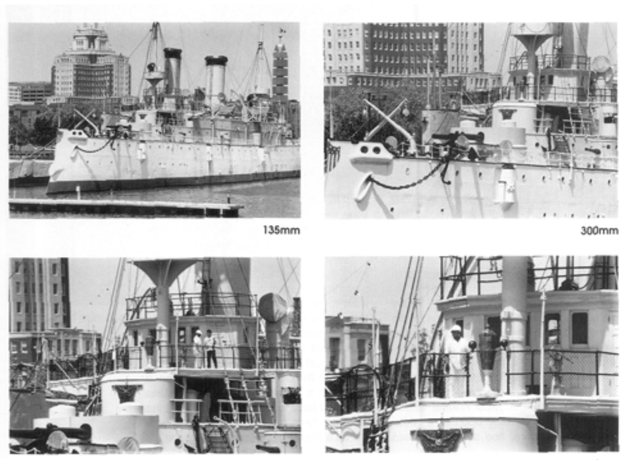
Field of View



From London and Upton

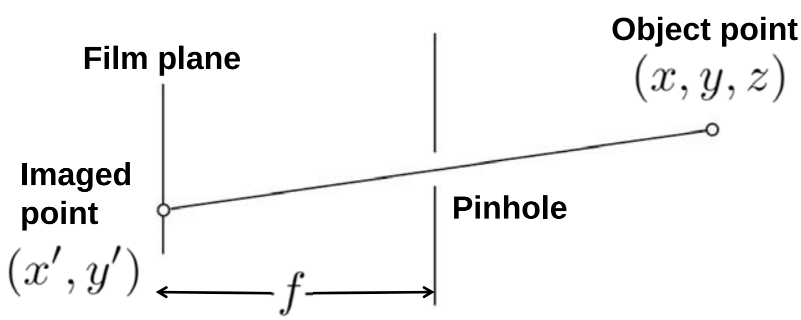
Field of View





From London and Upton

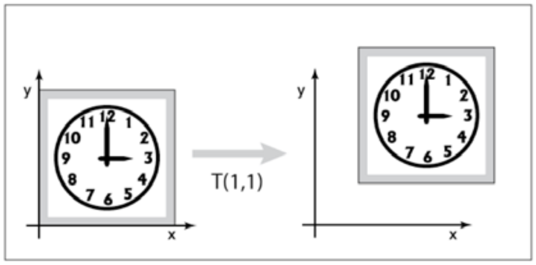
Perspective Projection



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

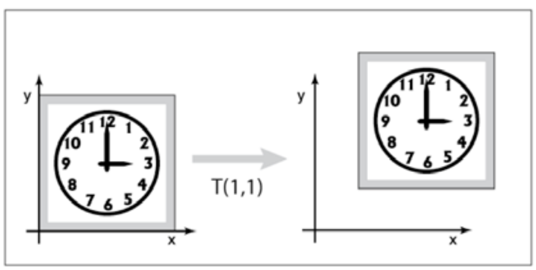
$$y' = -f\,\frac{y}{z}$$

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

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

$$xw' = -fx$$

$$yw' = -fy$$

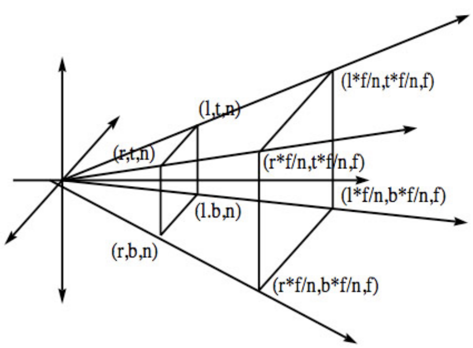
$$w' = z$$

Perspective Matrix

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

$$\begin{bmatrix} xw' \\ yw' \\ zw' \\ w' \end{bmatrix} = \begin{bmatrix} -f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ \text{—} & \text{—} & \text{—} & \text{—} \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Perspective Frustum



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

```
glFrustum(l, r, b, t, n, f)
glPerspective( fov, n, f )
```

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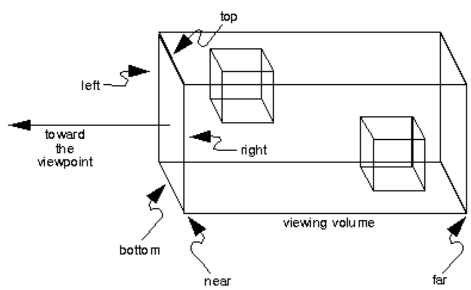
Orthographic Transformation



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

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


Viewing Coordinate Systems

Object or Model

↓ **Model matrix**

World

↓ **Camera matrix**

Camera

↓ **Projection matrix**

Window

↓

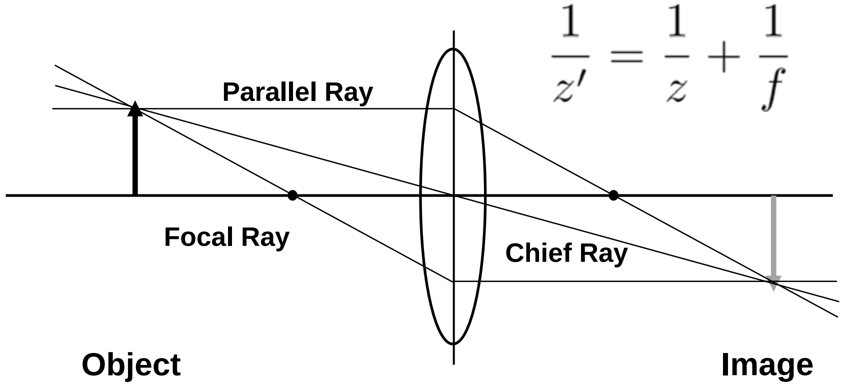
Viewport (Device)

Viewing in OpenGL

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

glMatrixMode(GL_PROJECTION)
glLoadIdentity()
glOrtho( -1., 1., -1., 1., -1., 1. );

glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookat( from, to, up );

glTranslate() …
```


Lenses

Gauss' Ray Tracing Construction

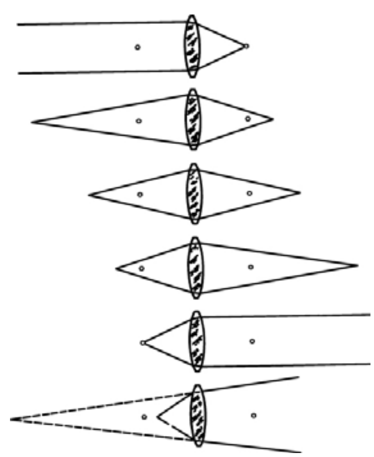


$$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f}$$

All rays from an object point converge on a single Image point; ideal imaging system

Same as the perspective transform

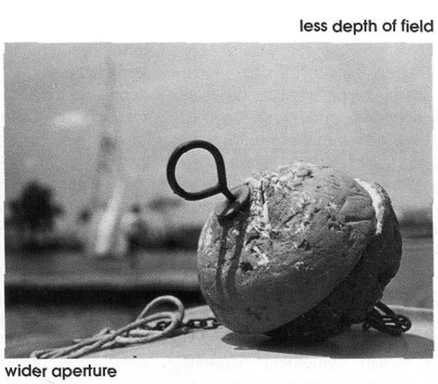
Focusing

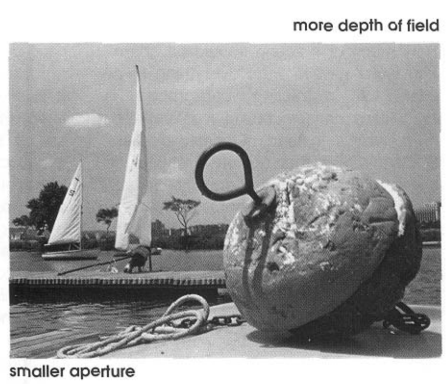


To focus: move lens relative to backplane

Depth of Field

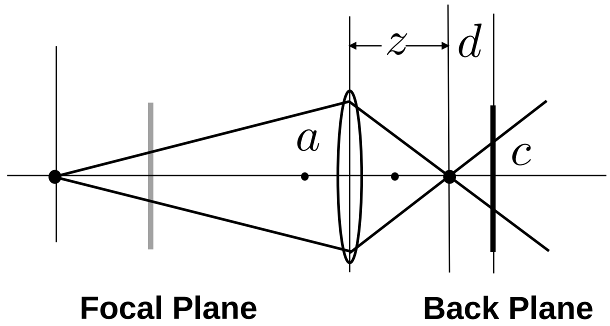
Depth of Field





From London and Upton

Circle of Confusion



Circle of confusion proportional to the size of the aperture

$$\frac{c}{a} = \frac{d}{z}$$

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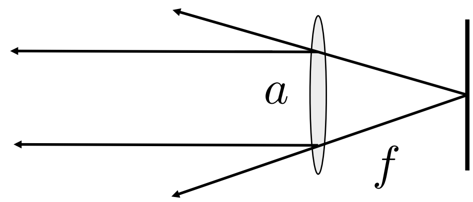
Exposure

Aperture and Exposure



$$a = \frac{f}{N}$$

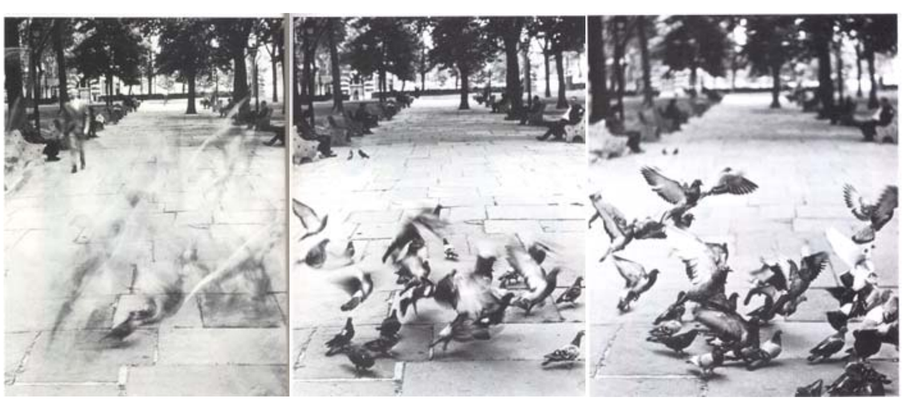
Exposure proportional to solid angle:

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

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



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

From London and Upton

Camera Simulation Difficult

Motion Blur

Cook, Porter, Carpenter, 1984

Depth of Field

Mitchell, 1991

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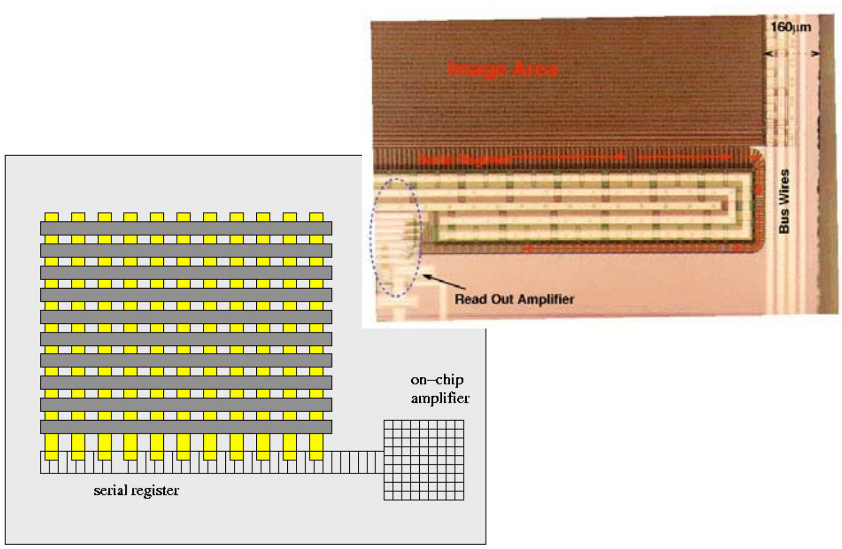
Sensors

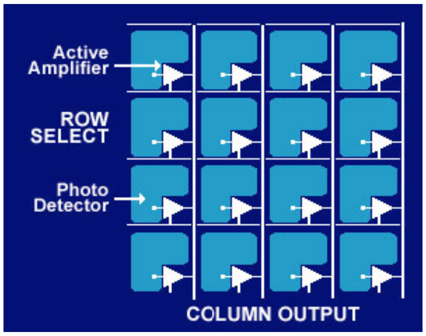
Charge Coupled Devices (CCDs)

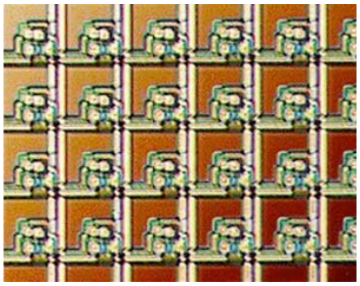
Developed by Wilford Boyle (L) and George Smith (R) at Bells Labs in 1969

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 lense 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 due to shutter
Depth of field and motion blur hard to implement
Revolution in sensors: CCD and CMOS