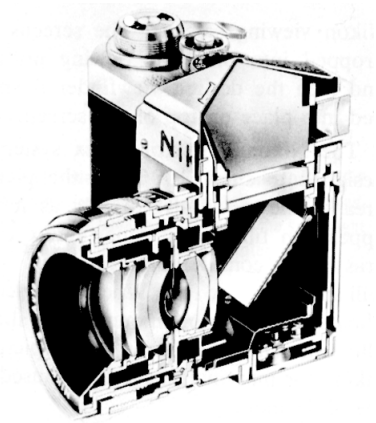
CS148: Introduction to Computer Graphics and Imaging

Virtual and Digital Cameras

Ansel Adams

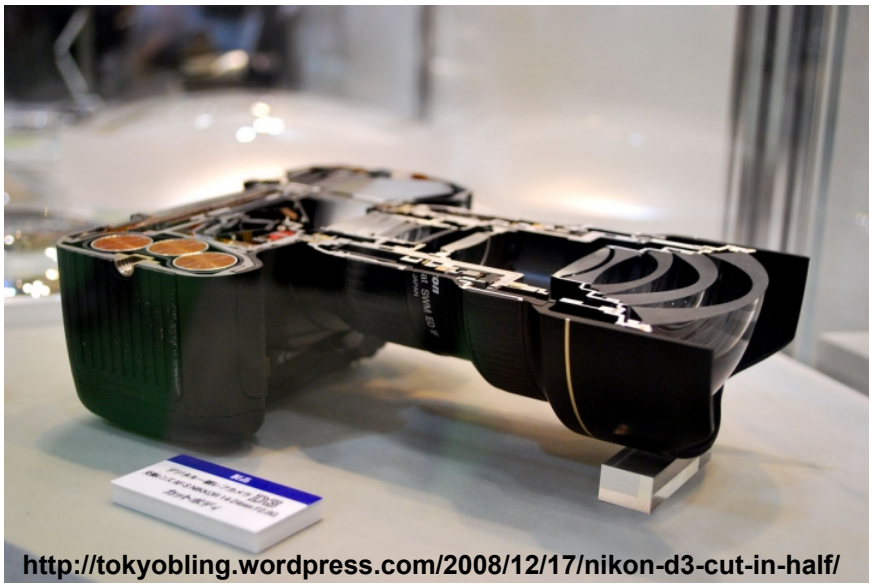
Topics



Effect	Cause
Field of view	Film size, focal length
Perspective	Lens, focal length
Focus	Dist. of lens to sensor
Exposure	Aperture, shutter, speed
Depth of field	Aperture, focal length

References: Photography, B. London and J. Upton

Nikon D3 Cutaway



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

Nikon D3 Cutaway

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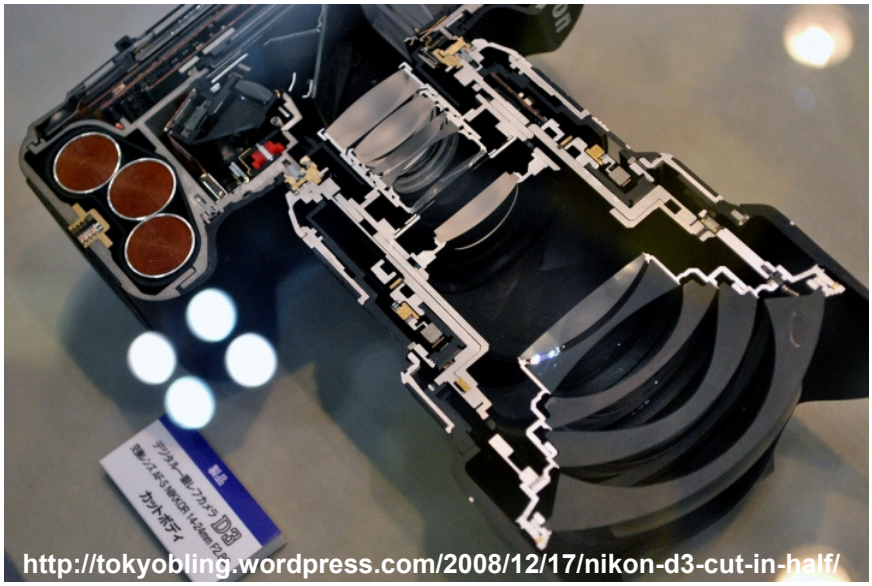
Nikon D3 Cutaway



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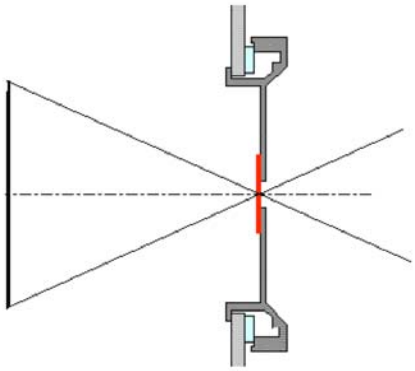
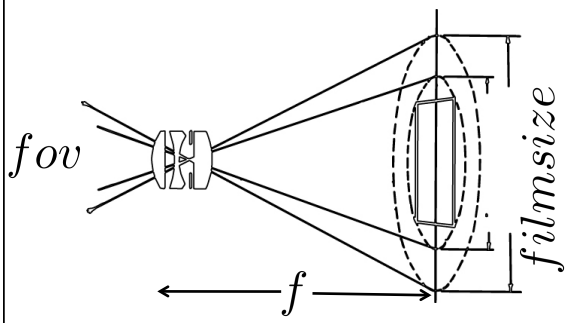
Pinhole Camera

Pinhole Camera



Camera obscura
Cliff house,
San Francisco

Field of View



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

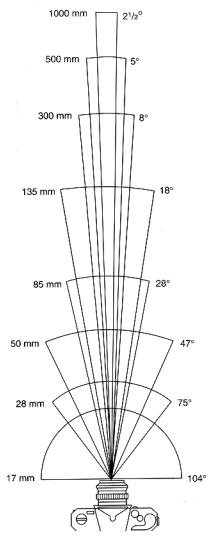
Redrawn from Kingslake,
Optics in Photography

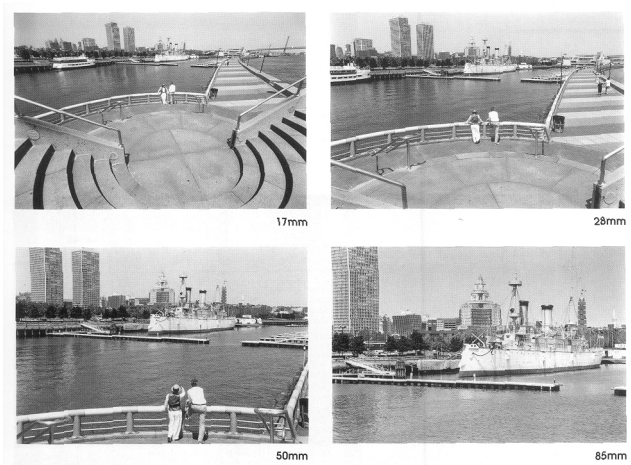
Film size measured diagonally

Types of lenses

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

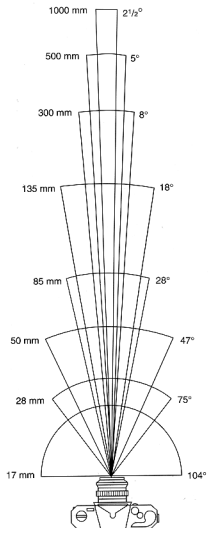
Field of View

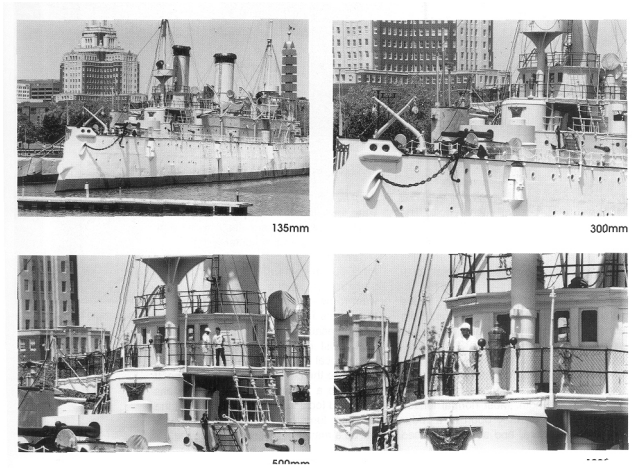




From London and Upton

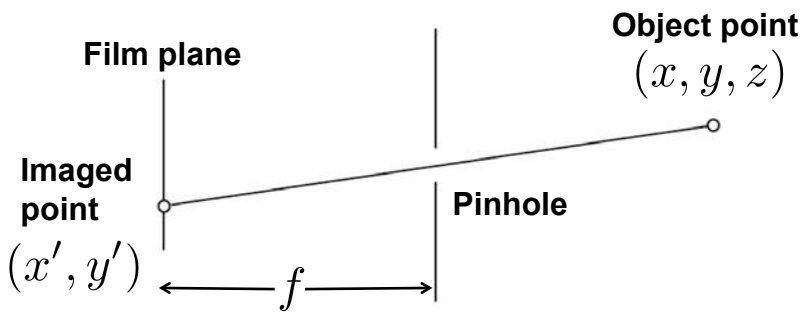
Field of View





From London and Upton

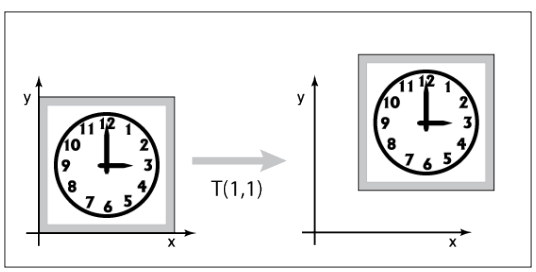
Perspective Projection



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

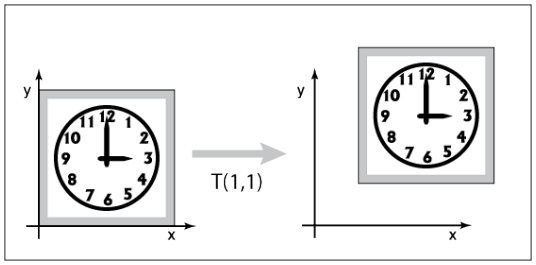
$$y' = -f\frac{y}{z}$$

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

Introduce a 4th coordinate *w*

$$\begin{bmatrix} xw \\ yw \\ zw \\ w \end{bmatrix}$$

3D position computed by dividing through by *w*

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} xw/w \\ yw/w \\ zw/w \end{bmatrix}$$

Perspective Transform

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

$$xw' = -fx$$
$$yw' = -fy$$
$$w' = z$$

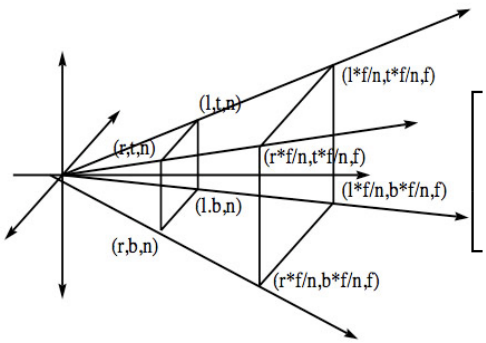
Perspective Matrix

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

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

Perspective Frustum

Transform from (l, r, b, t, n f) to (-1,1,-1,1,0,1)

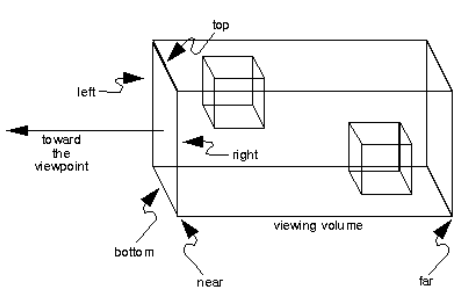


$$\begin{bmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & -\frac{f+n}{f-n} & -2\frac{fn}{f-n} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

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


Orthographic Transformation

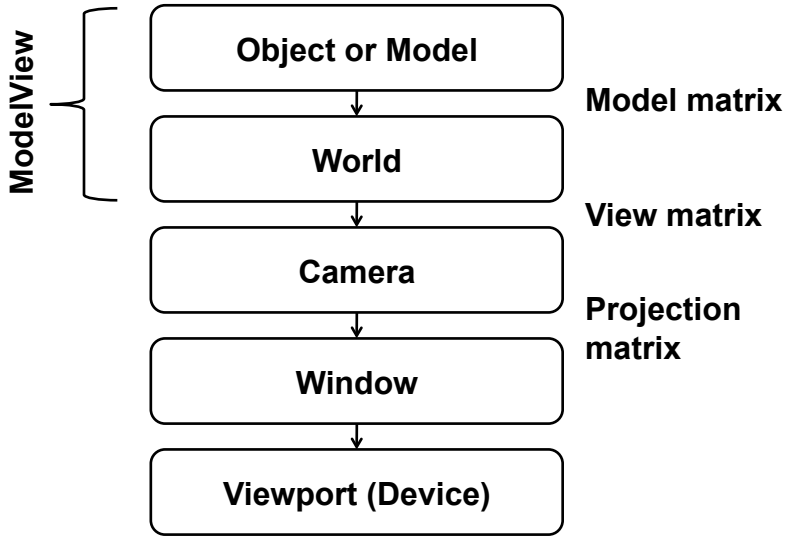
Transform from (l, r, b, t, n f) to (-1,1,-1,1,0,1)



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

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

OpenGL Coordinate Systems



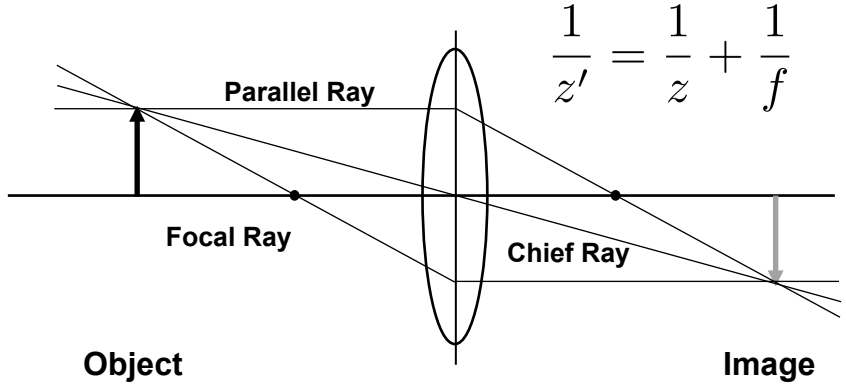
Viewing in OpenGL

```
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

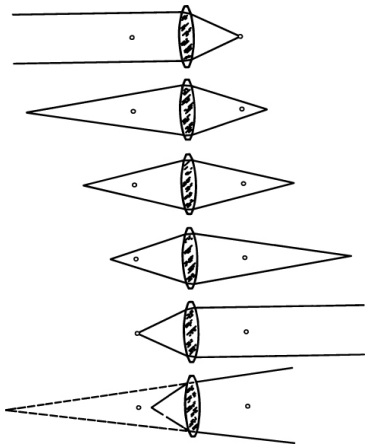
Gauss' Ray Tracing Construction

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



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

Focusing

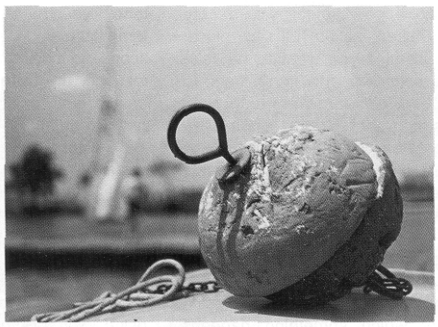


To focus: move lens relative to backplane

Depth of Field

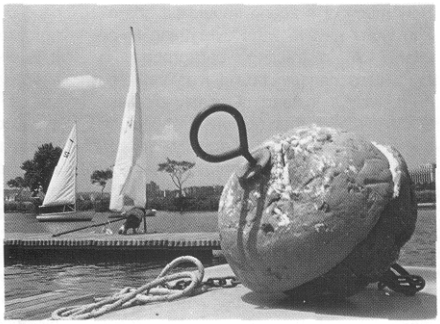
Depth of Field

less depth of field



wider aperture

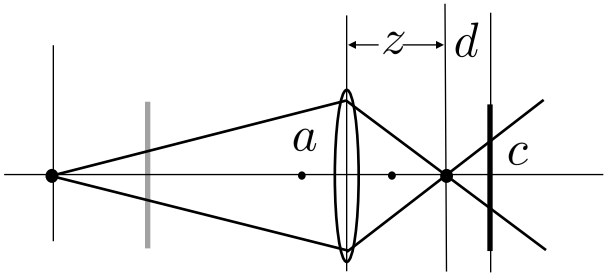
more depth of field



smaller aperture

From London and Upton

Circle of Confusion



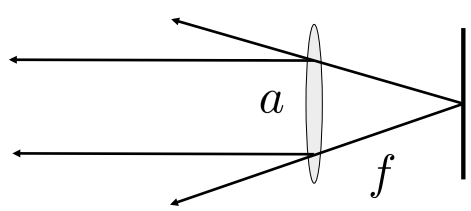
Focal Plane **Back Plane**

Circle of confusion proportional to the size of the aperture

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

Exposure

Aperture and Exposure



f-stop sets aperture

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

***N* is the f-stop**

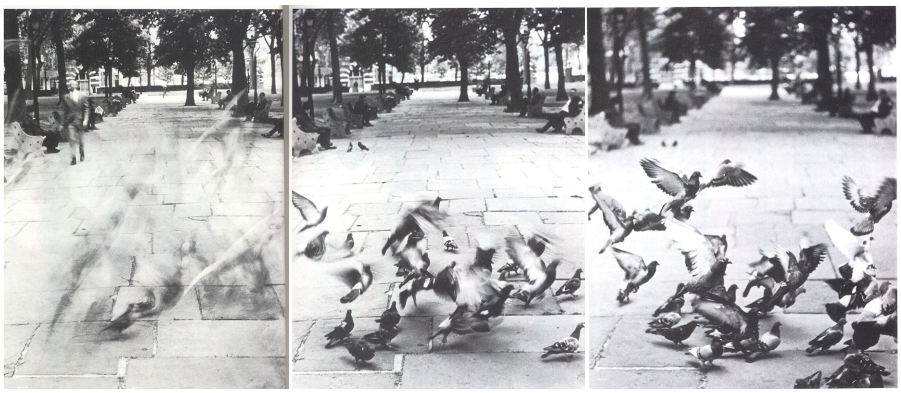
Exposure proportional to solid angle:

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

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

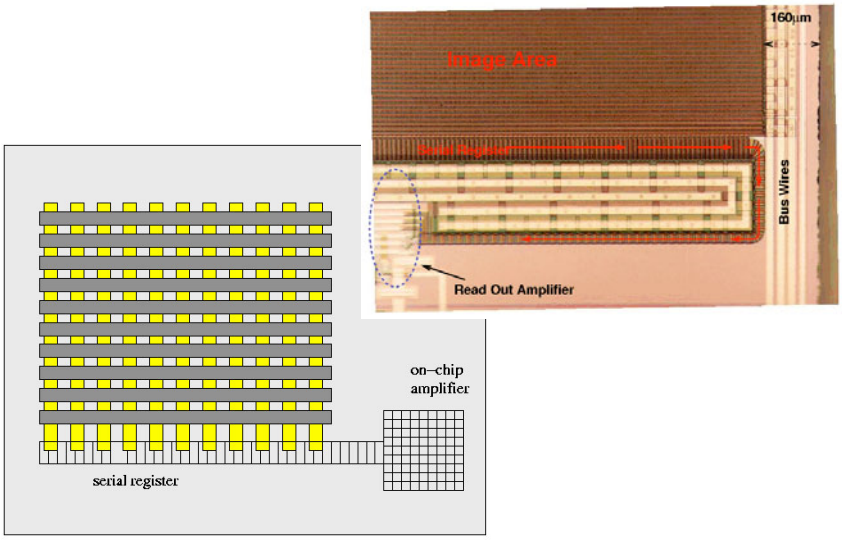
Mitchell, 1991

Sensors

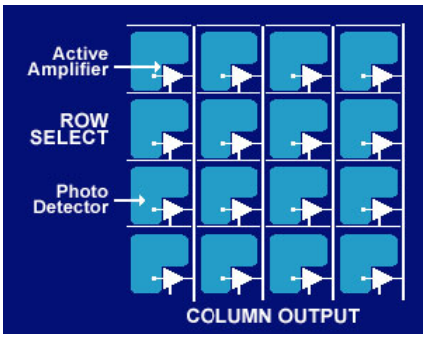
Charge Coupled Devices (CCDs)

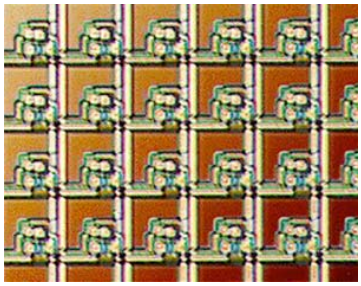
Developed by Wilford Boyle (L) and George Smith (R) at Bells Labs in 1969
Nobel Prize 2009 - *"for the invention of an imaging semiconductor circuit – the CCD sensor"*

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 occurs during the time the shutter is open

Depth of field and motion blur hard to implement

Revolution in sensors: CCD and CMOS