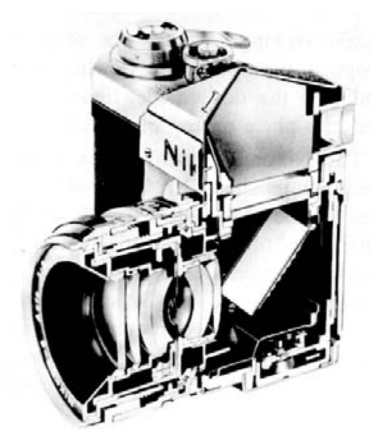
CS148: Introduction to Computer Graphics and Imaging

Virtual and Digital Cameras

Ansel Adams

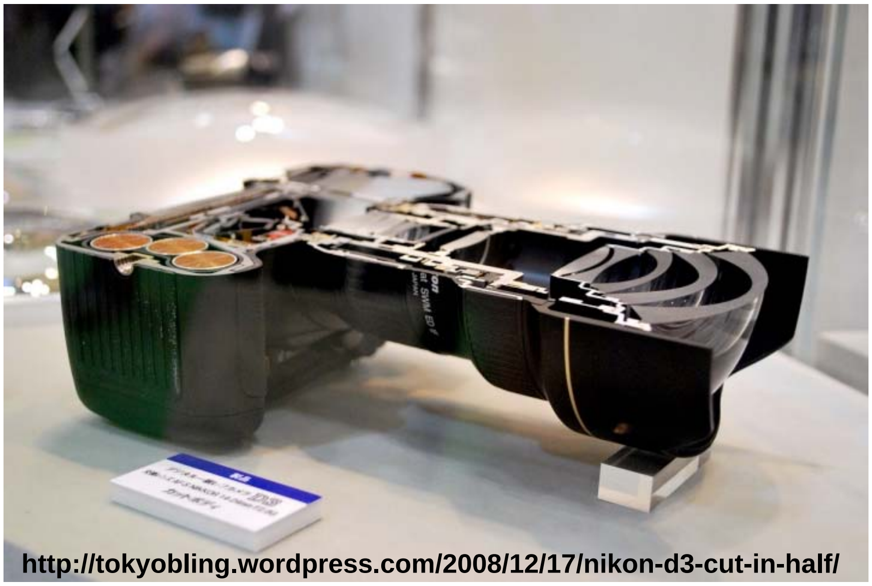
Topics



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

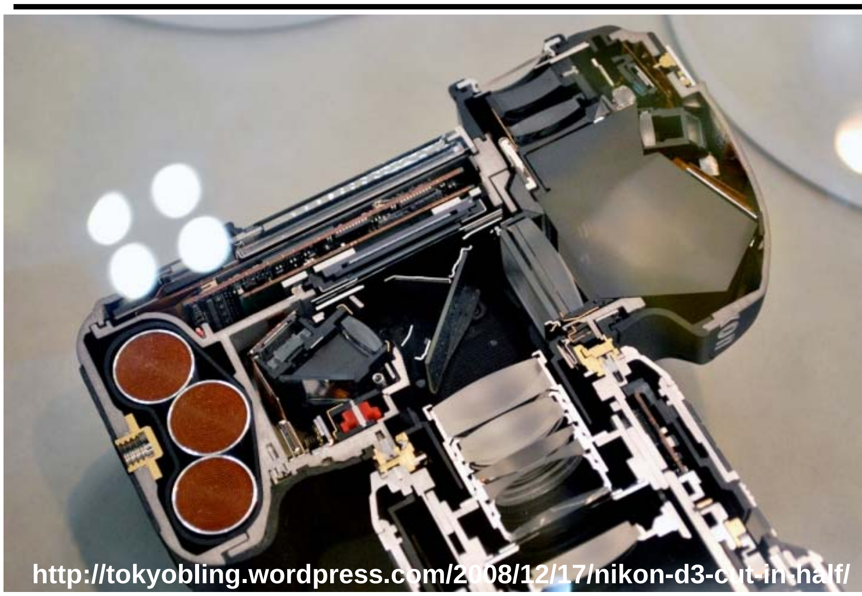
References: Photography, B. London and J. Upton

Nikon D3 Cutaway



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

Nikon D3 Cutaway



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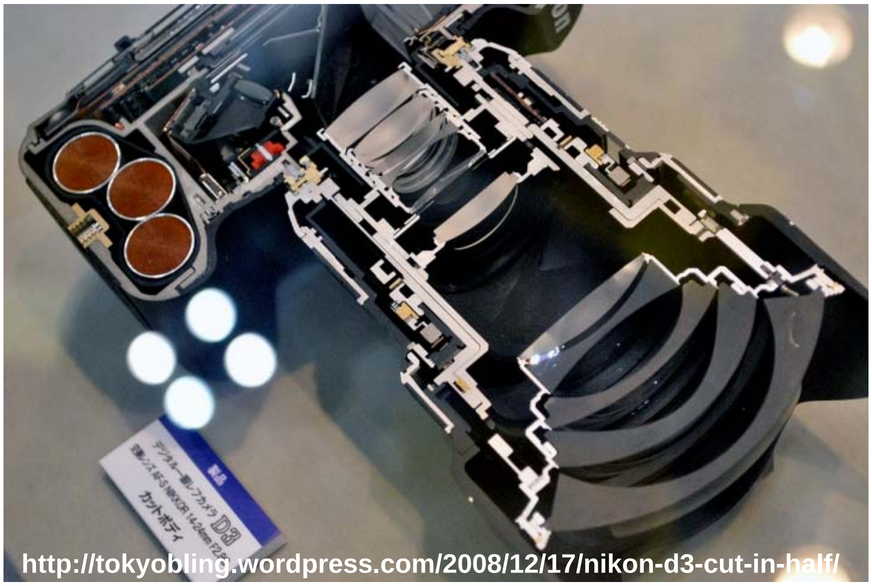
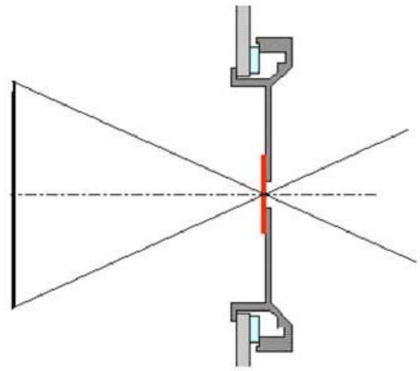
Nikon D3 Cutaway



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

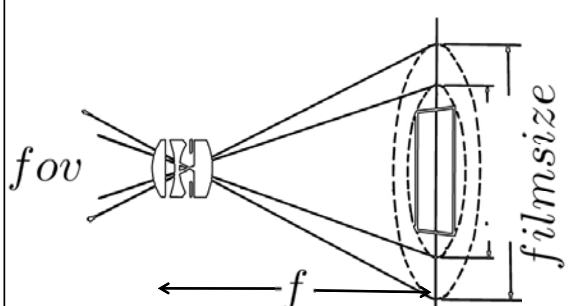
Pinhole Camera

Pinhole Camera



Camera obscura
Cliff house,
San Francisco

Field of View



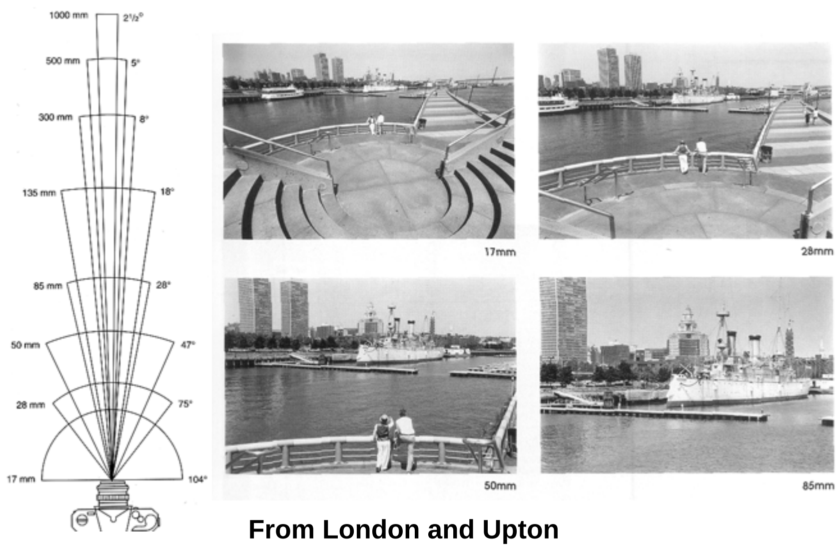
$$\tan \frac{fov}{2} = \frac{filmsize/2}{f}$$

Redrawn from Kingslake,
Optics in Photography

Types of lenses

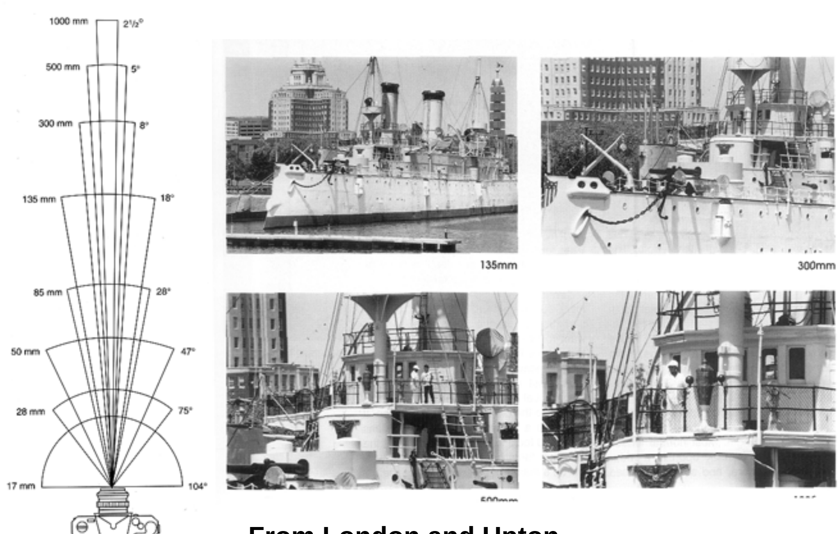
- **Normal** **26º**
- **Wide-angle** **75-90º**
- **Narrow-angle** **10º**

Field of View



From London and Upton

Field of View



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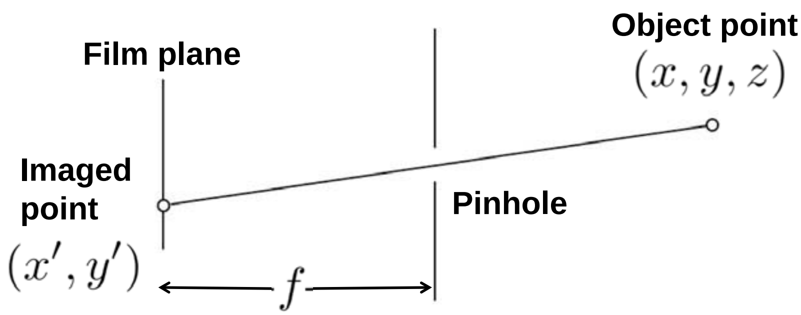
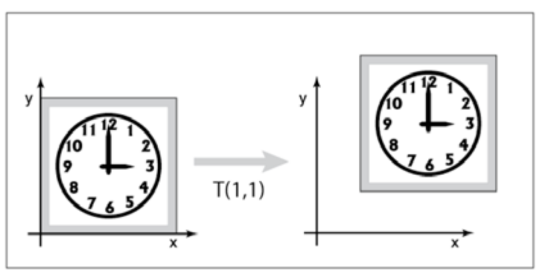
Perspective Projection



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

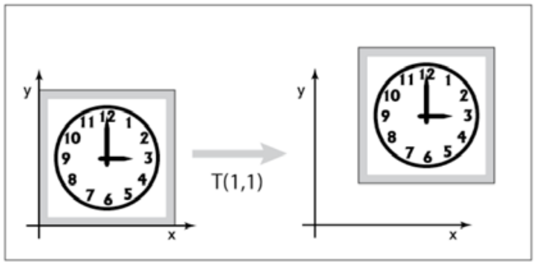
$$y' = -f\frac{y}{z}$$

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

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

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

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Perspective Matrix

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

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

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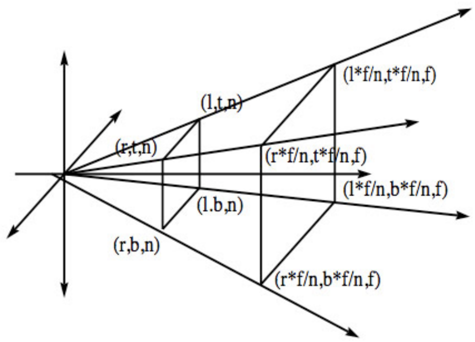
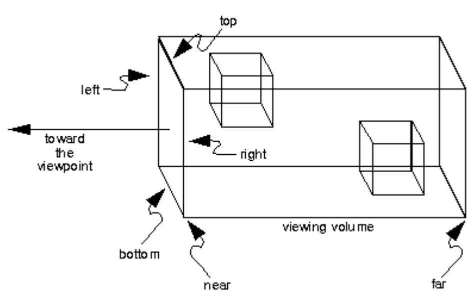
Perspective Frustum



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

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

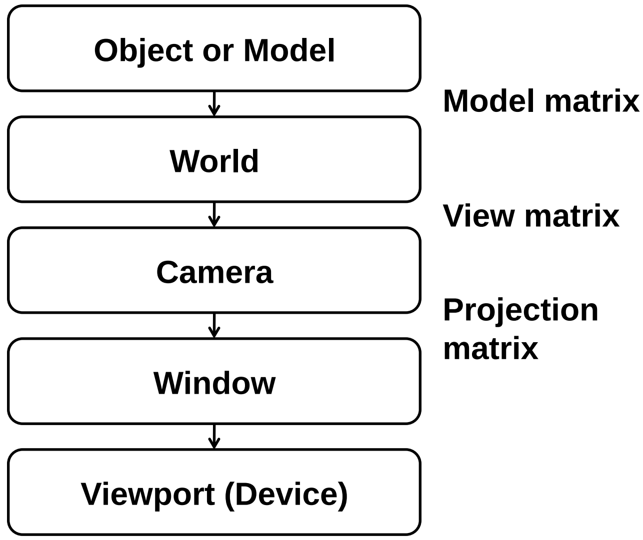

Orthographic Transformation



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

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

Viewing Coordinate Systems



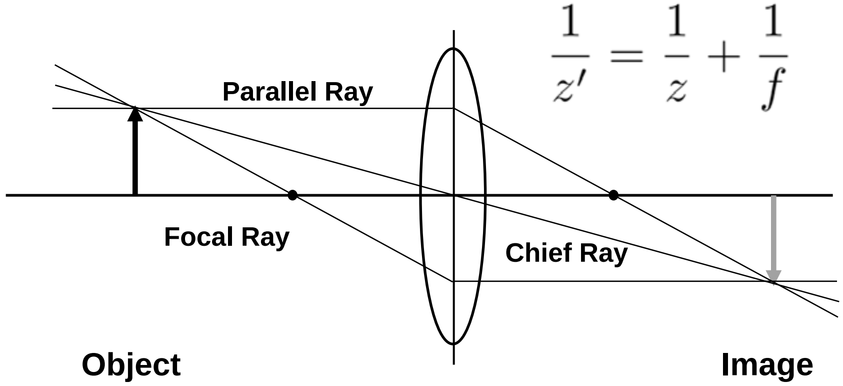
Viewing in OpenGL

```
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

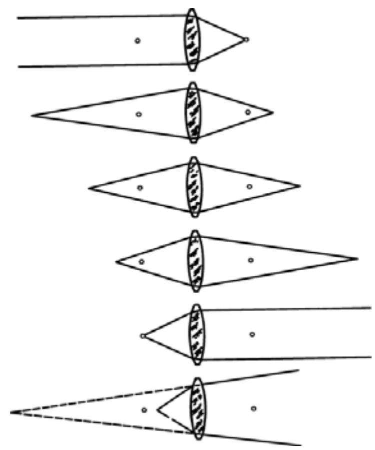
Gauss' Ray Tracing Construction

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



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

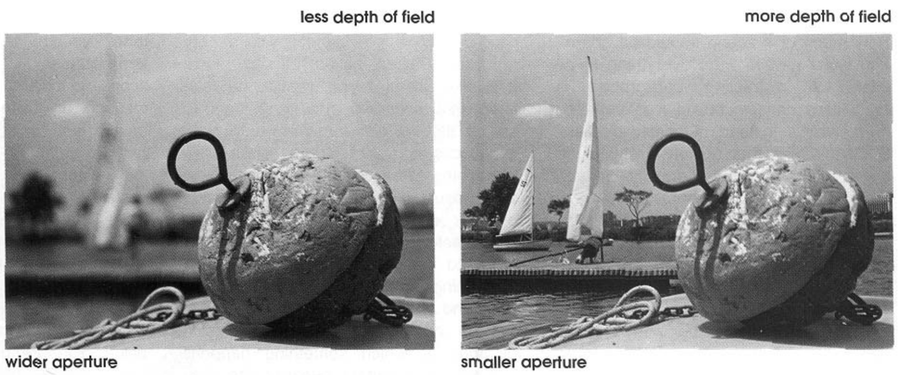
Focusing



To focus: move lens relative to backplane

Depth of Field

Depth of Field



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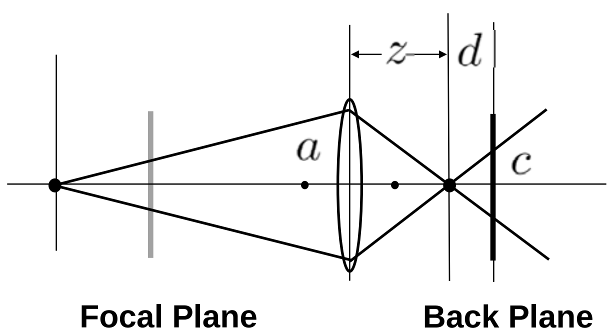
Circle of Confusion



Circle of confusion proportional to the size of the aperture

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

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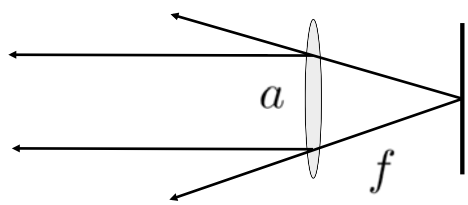
Exposure

Aperture and Exposure



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

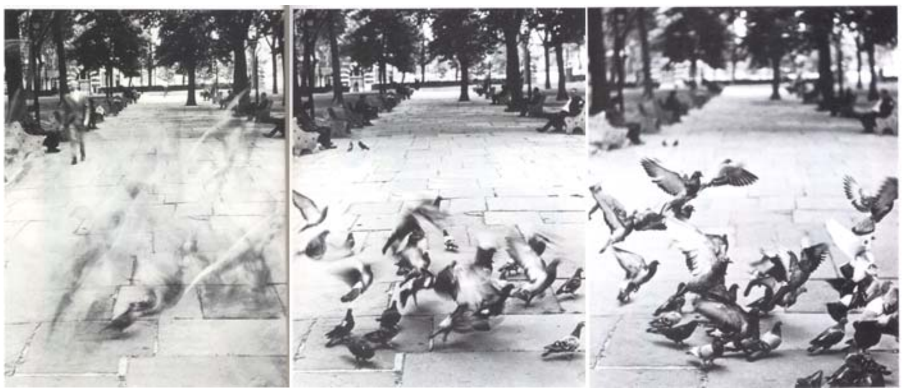
Exposure proportional to solid angle:

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

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
1/8s

f/4
1/125s

f/2
1/500s

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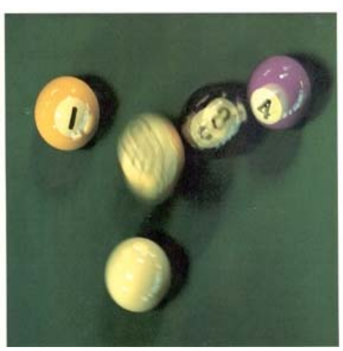
Camera Simulation Difficult

Motion Blur



Cook, Porter, Carpenter, 1984

Depth of Field

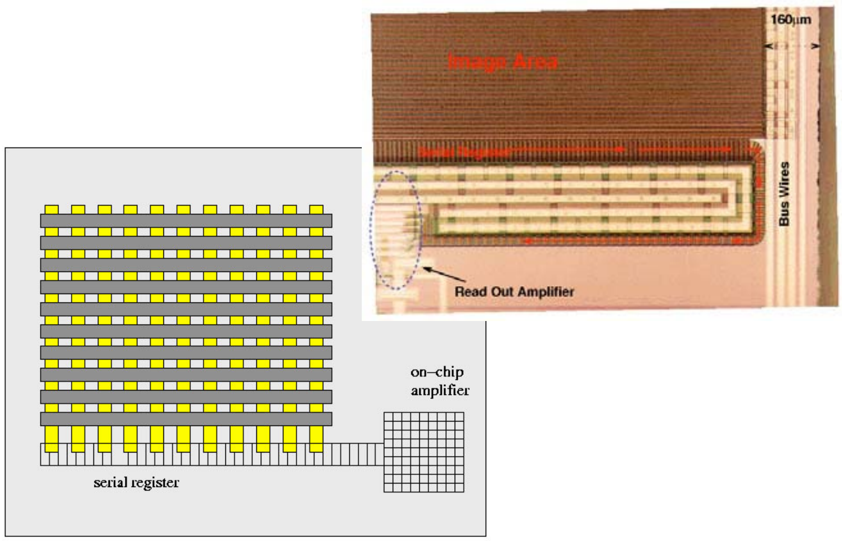
Mitchell, 1991

Sensors

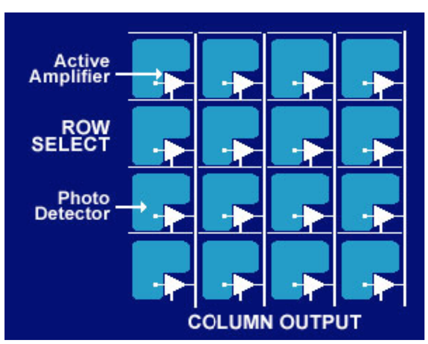
Charge Coupled Devices (CCDs)

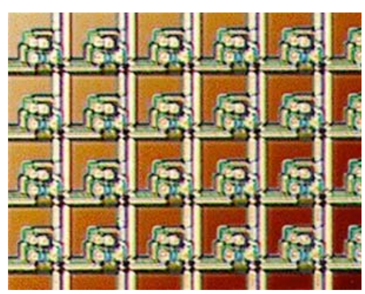
Developed by Wilford Boyle (L) and George Smith (R) at Bells Labs in 1969

Charge Coupled Devices (CCDs)



CMOS Imager



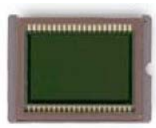


Sensor Size

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