Lens Design
Lecture #1

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What is imaging?

Photo credit:
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Imaging with rays: theories

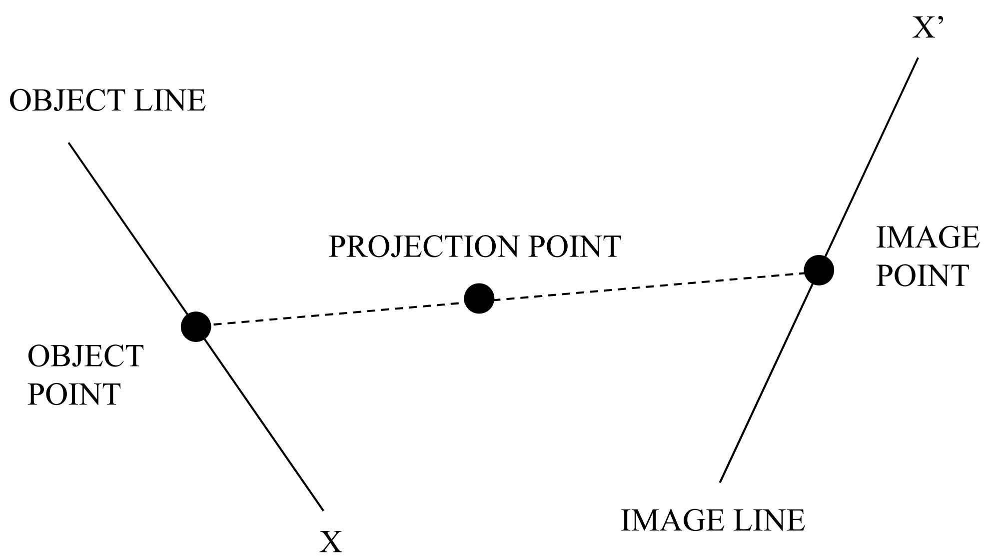
Maxwell's Ideal:

1) Each point is imaged stigmatically
2) The images of all points in an object plane lie on an image plane
3) The ratio of image to heights to object heights is the same for all points.

Collinear transformation

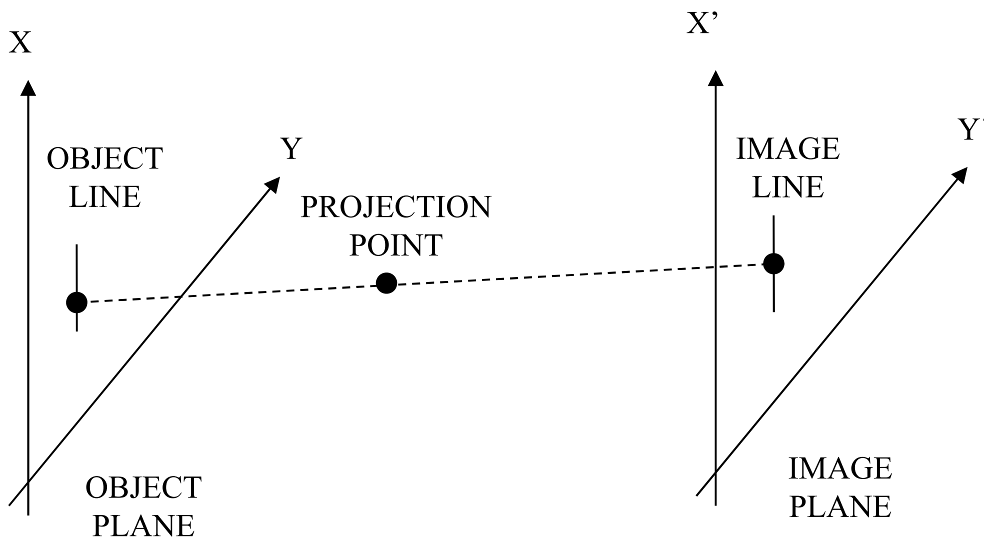
$$X' = \frac{a_1 X + b_1 Y + c_1 Z + d_1}{a_0 X + b_0 Y + c_0 Z + d_0} \qquad Y' = \frac{a_2 X + b_2 Y + c_2 Z + d_2}{a_0 X + b_0 Y + c_0 Z + d_0} \qquad Z' = \frac{a_3 X + b_3 Y + c_3 Z + d_3}{a_0 X + b_0 Y + c_0 Z + d_0}$$

Central Projection 1D



$$X' = \frac{a_1 X}{a_0 X + b_0}$$

Central Projection 2D



$$X' = \frac{a_1 X}{a_0 X + b_0 Y + c_0} \qquad Y' = \frac{a_2 Y}{a_0 X + b_0 Y + c_0}$$

Central Projection 3D

$$X' = \frac{a_1 X + b_1 Y + c_1 Z + d_1}{a_0 X + b_0 Y + c_0 Z + d_0}$$

$$Y' = \frac{a_2 X + b_2 Y + c_2 Z + d_2}{a_0 X + b_0 Y + c_0 Z + d_0}$$

$$Z' = \frac{a_3 X + b_3 Y + c_3 Z + d_3}{a_0 X + b_0 Y + c_0 Z + d_0}$$

Point into points, lines into lines, and planes into planes.

Axial symmetry I

$$\rho = \sqrt{x^2 + y^2} \qquad \rho' = \sqrt{x'^2 + y'^2}$$

ρ' and Z' must be only a function of ρ and Z, leads to:

$$X' = \frac{a_1 X}{c_0 Z + d_0} \qquad Y' = \frac{a_1 Y}{c_0 Z + d_0} \qquad Z' = \frac{c_3 Z + d_3}{c_0 Z + d_0}$$

- Origins transform into the origins: d3=0
- Origins located at the planes of unit magnification implies: a1 equal to d0

Axial Symmetry II

$$X' = \frac{X}{c_0 Z + 1} \qquad Y' = \frac{Y}{c_0 Z + 1} \qquad Z' = \frac{c_3 Z}{c_0 Z + 1}$$

$$m = \frac{1}{c_0 Z + 1} \qquad Z' = f' = \frac{c_3}{c_0} \qquad Z = f = \frac{-1}{c_0}$$

Gaussian equations

$$\frac{Z}{f} = 1 - \frac{1}{m}$$

$$m = \frac{1}{1 - Z \setminus f}$$

$$\frac{Z'}{f'} = 1 - m$$

$$m = 1 - \frac{Z'}{f'}$$

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

Newtonian Equations

$$\frac{Z}{f} = -\frac{1}{m}$$

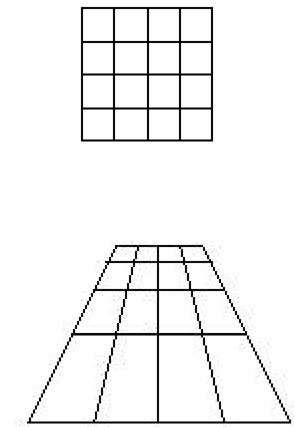
$$ZZ' = ff'$$

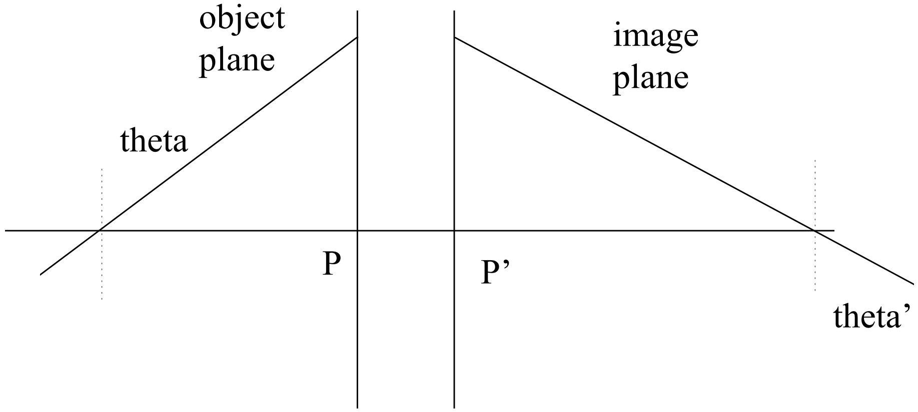
$$\frac{Z'}{f'} = -m$$

Scheimpflug condition

(Plane symmetry)

$$\tan(\theta') - (Z'\backslash Z)\tan(\theta) = 0$$





Scheimpflug construction

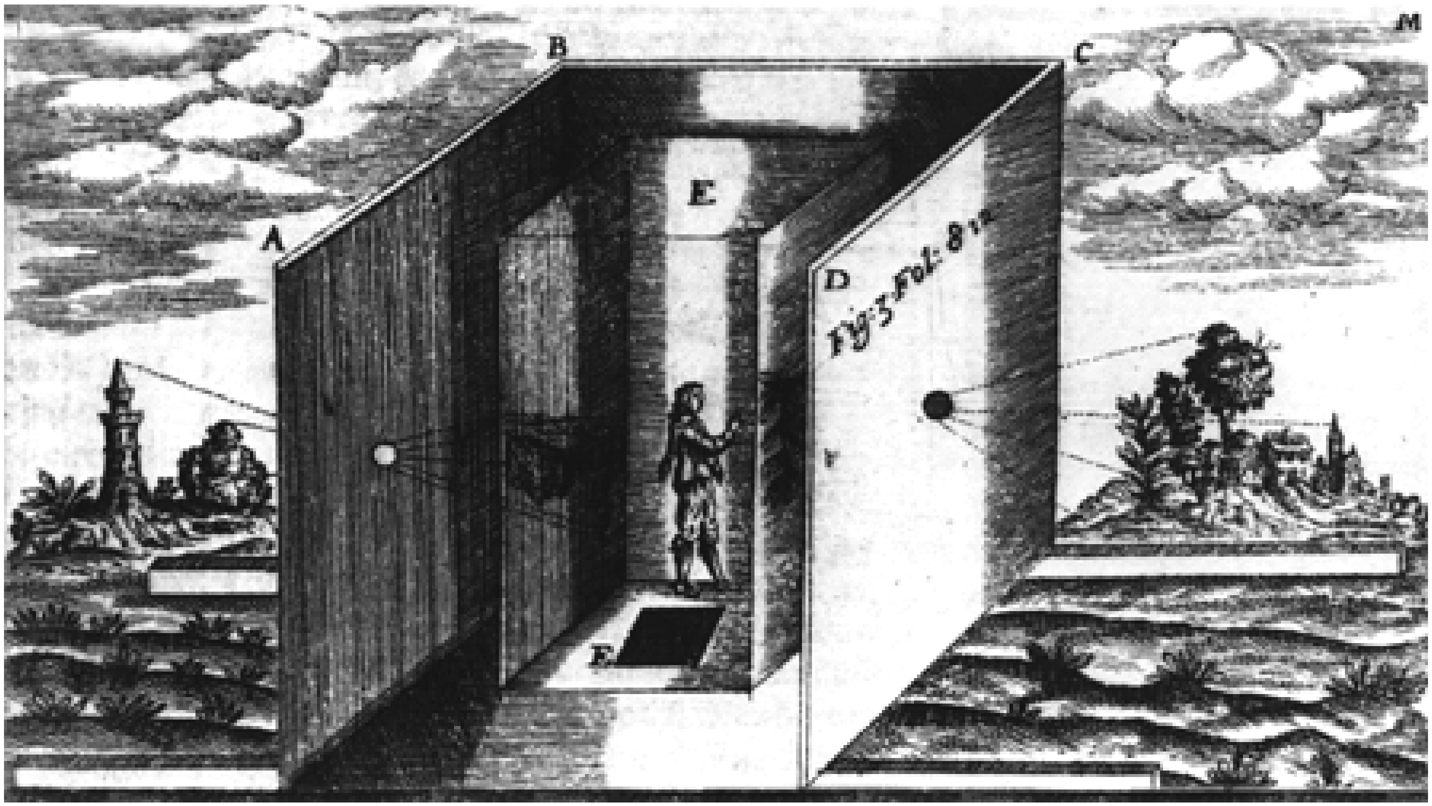
$$X' = m\frac{X}{1+KY} \qquad Y' = m\frac{Y}{1+KY} \qquad K = -m\frac{\tan(\theta)}{f} = \frac{\tan(\theta')}{f\,'}$$

Civil War 1859

And much more…

- Gaussian equations
- Newtonian equations
- Anamorphic systems
- Focal and afocal systems
- Scheimpflug condition
- Cardinal points
- Keystone distortion
- …and much more!

Collinear transformation, camera obscura and lenses



Camera Obscura, Athanasius Kircher, 1646

The secret in Vermeer's paintings

Johannes Vermeer, XVII century

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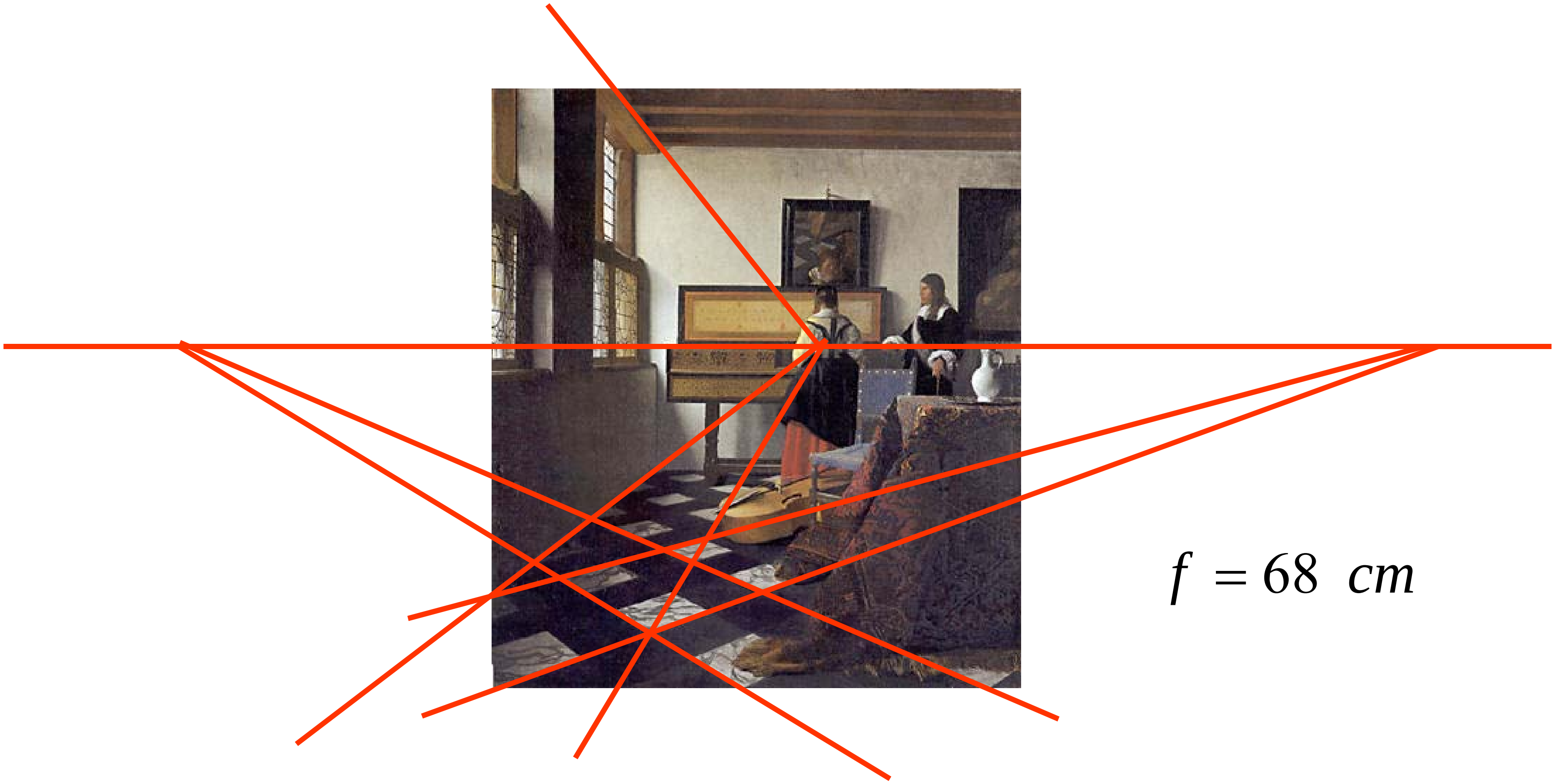
Perspective of the painting



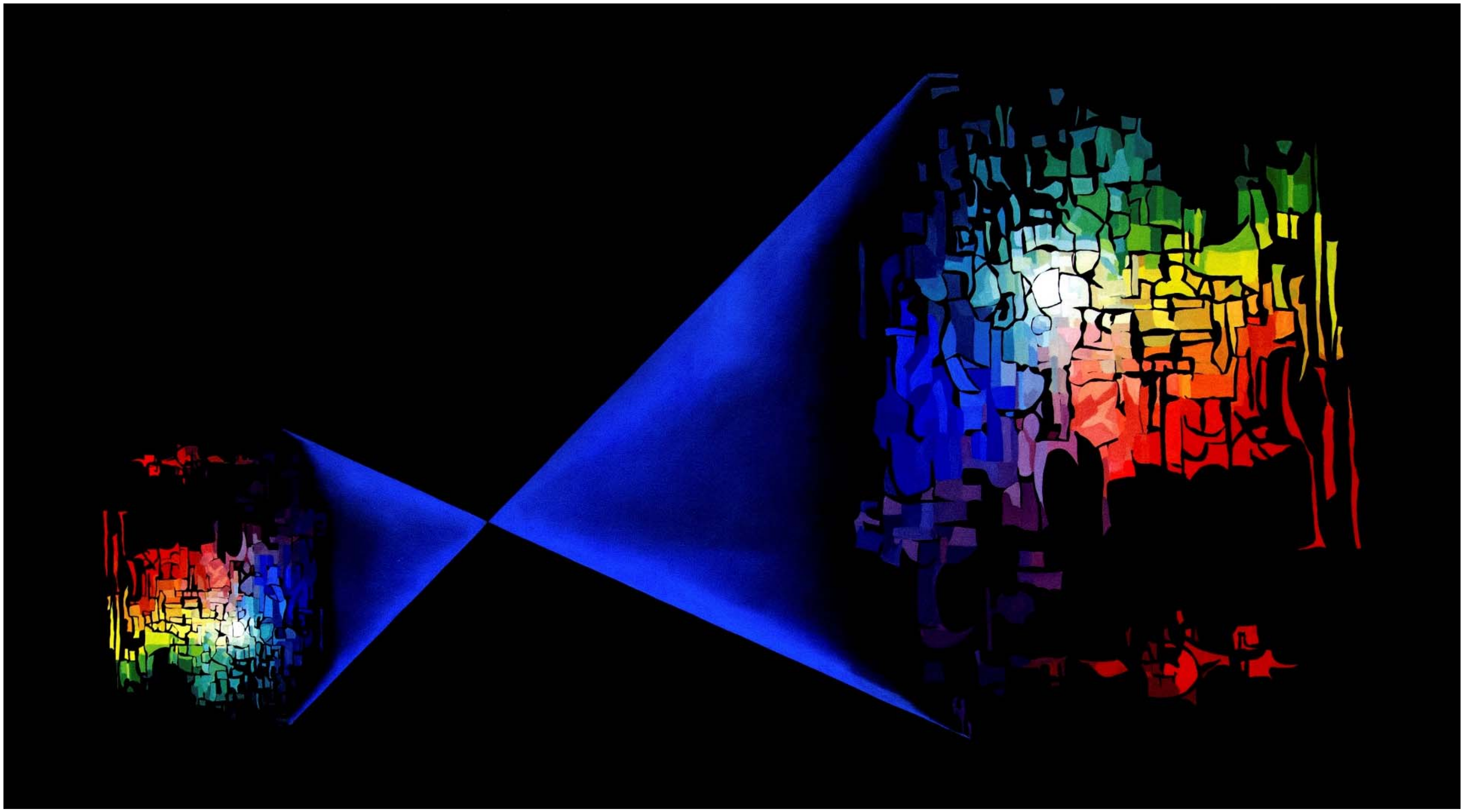
$$f = 68 \ \ cm$$

$$D = f \times \tan(\theta) = f \tan\left(45^\circ\right)$$

However…

- Image parity issues
- Needed a flat mirror or
- To copy again the image

Central projection



By Don Cowen

Other “perspectives”

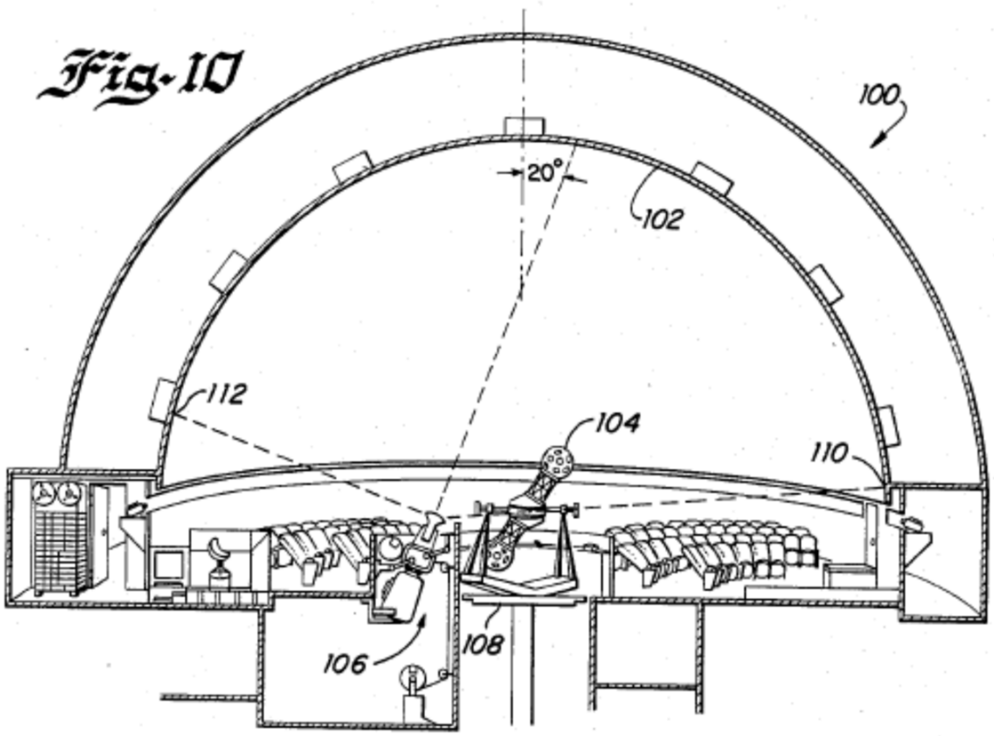
Classical

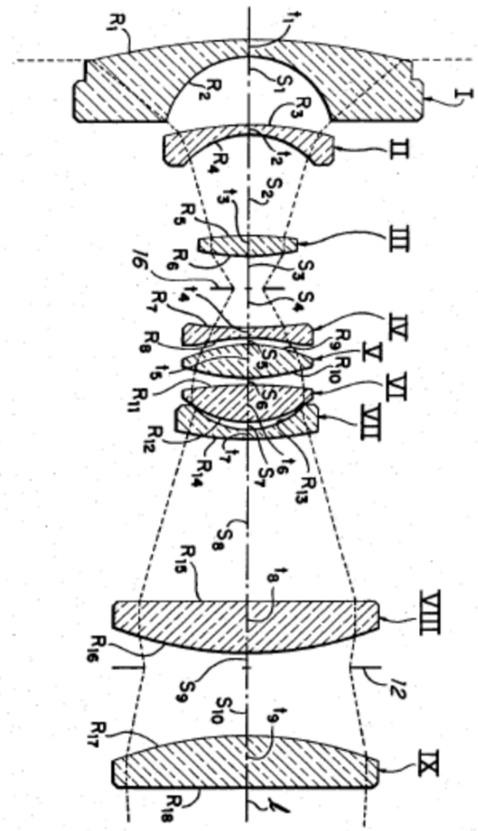
Impressionism

Cubism

A plurality of new and exciting
new concepts in imaging

Imaging on the sphere





IPAD Imaging

Class summary

- Syllabus
- Imaging
- Collinear transformation
- Art application

- Codev, OSLO, Zemax
- Review of first-order optics