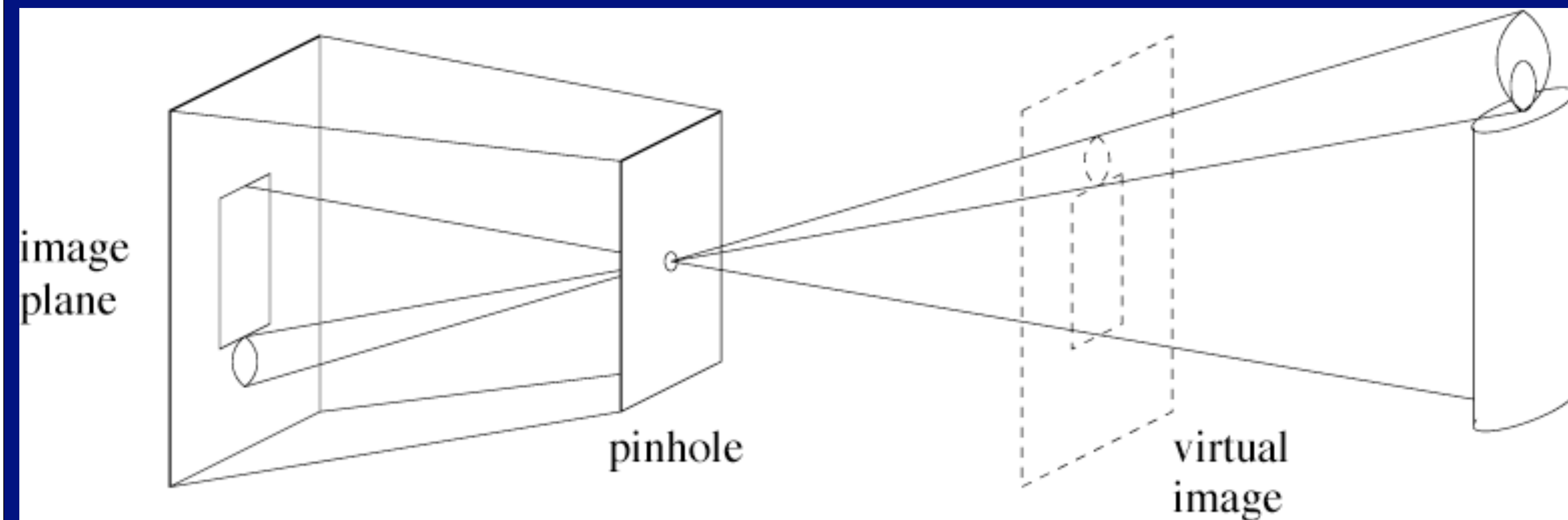
Cameras

CS-543, D.A. Forsyth

Cameras

- First photograph due to Niepce
- First on record, 1822
- Key abstraction
  - Pinhole camera

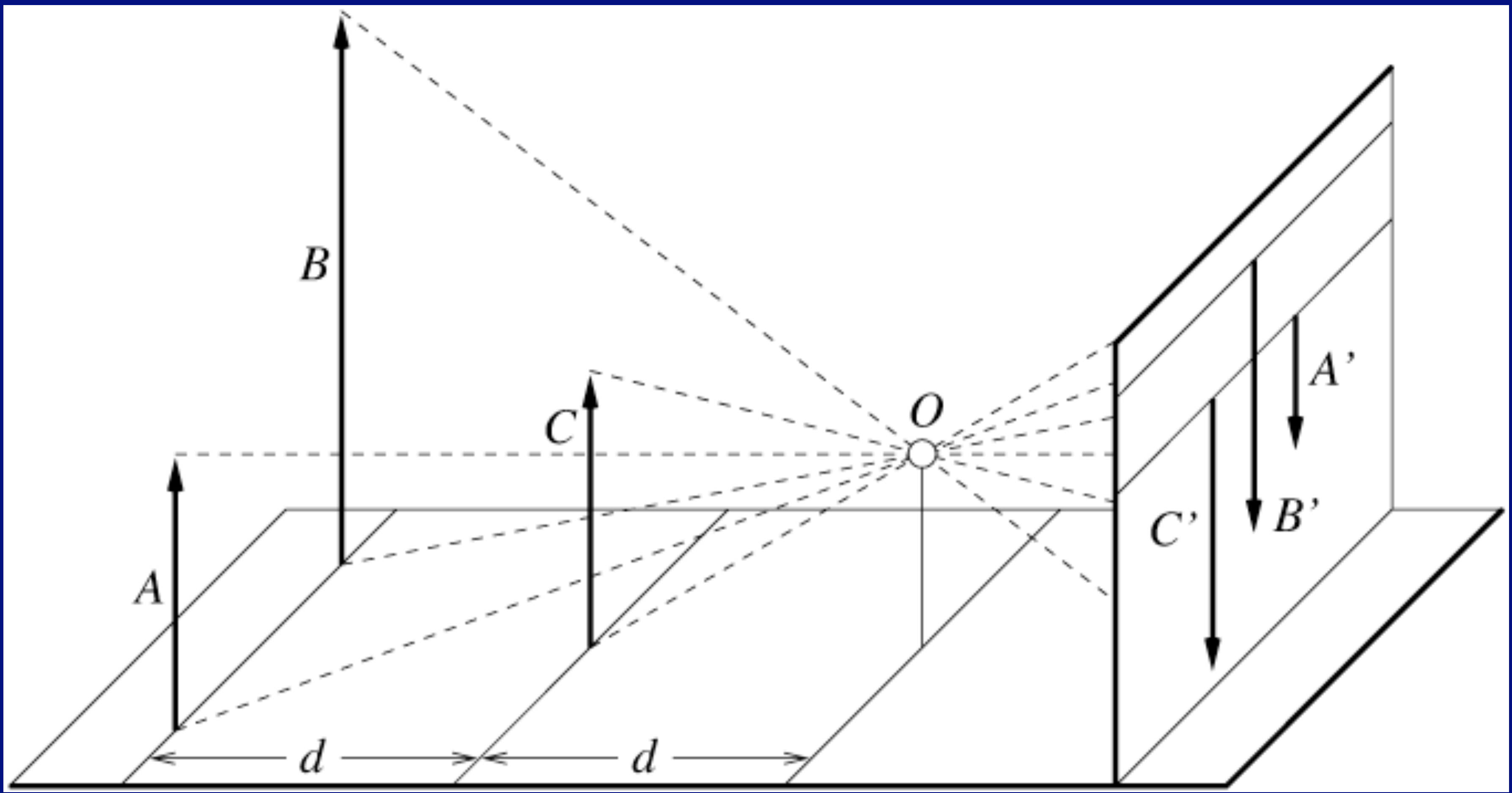
Pinhole camera



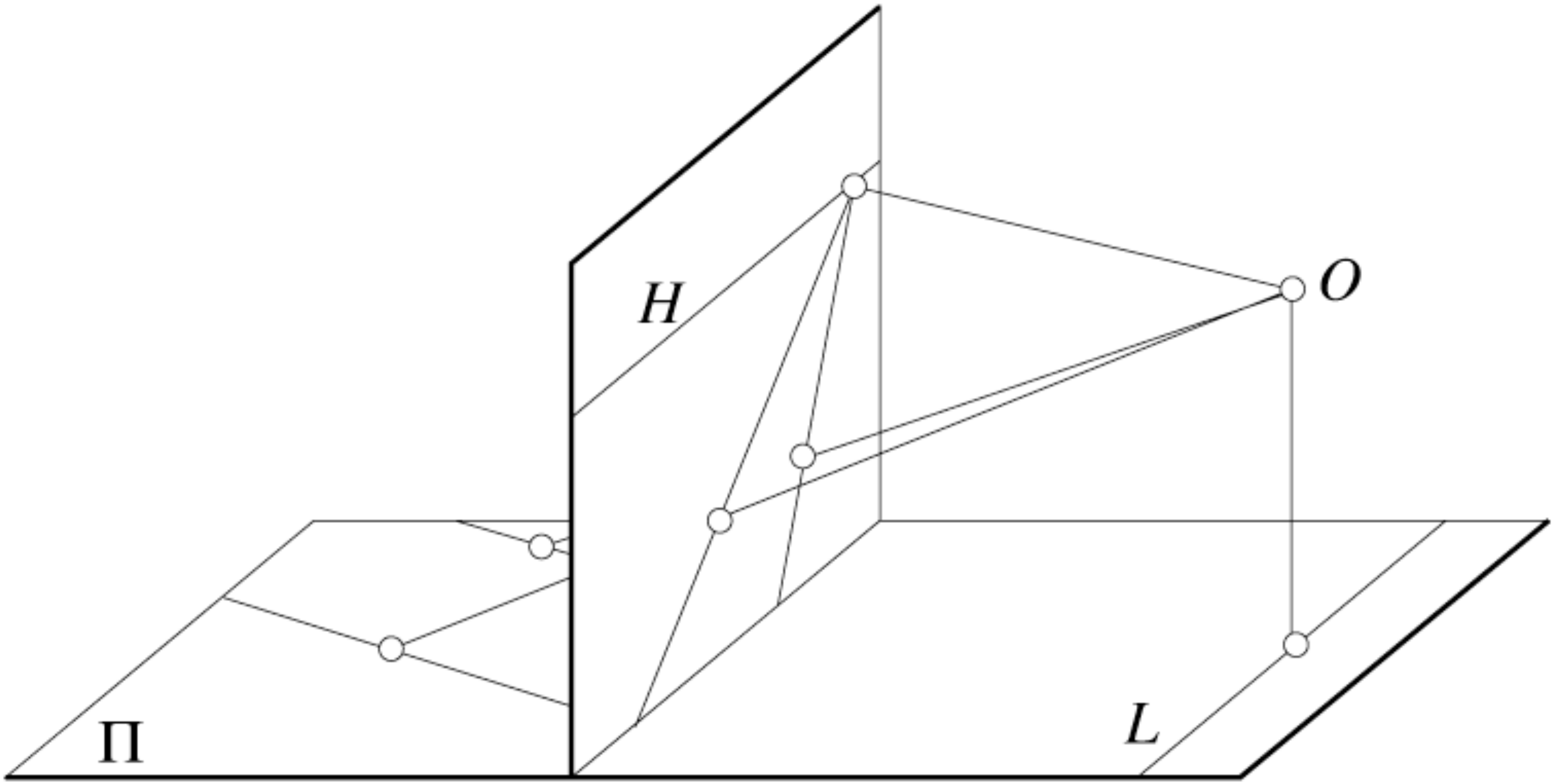
Freestanding room-sized camera obscura outside Hanes Art Center at the University of North Carolina at Chapel Hill. Picture taken by User:Seth Ilys on 23 April 2005 and released into the public domain.

A photo of the Camera Obscura in San Francisco. This Camera Obscura is located at the Cliff House on the Pacific ocean. Credit to Jacob Appelbaum of http://www.appelbaum.net.

Distant objects are smaller in a pinhole camera



Parallel lines meet in a pinhole camera



Vanishing points

- Each set of parallel lines meets at a different point
  - The vanishing point for this direction
- Coplanar sets of parallel lines have a horizon
  - The vanishing points lie on a line
  - Good way to spot faked images

Railroad tracks "vanishing" into the distance

Source

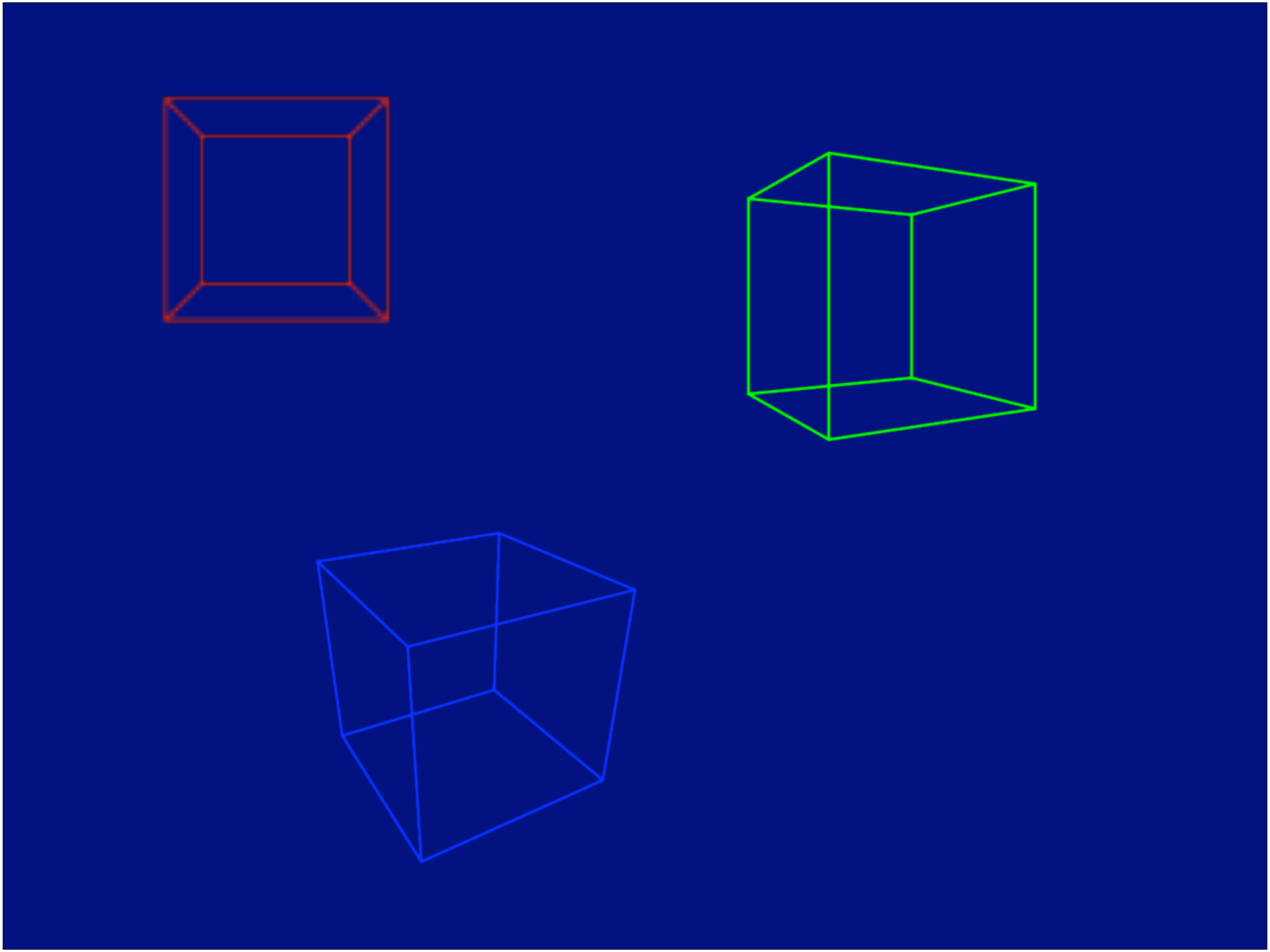
own work

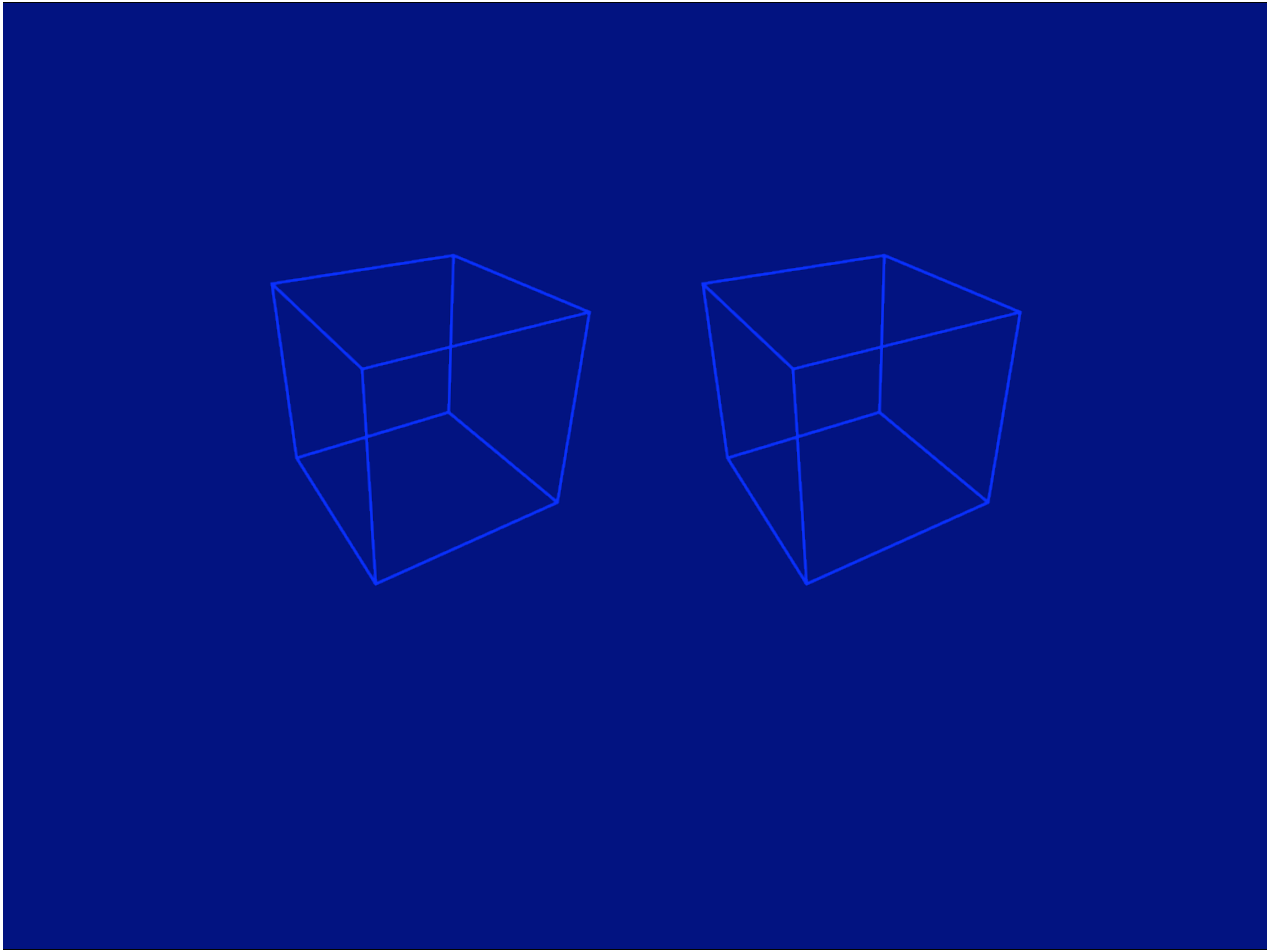
Date

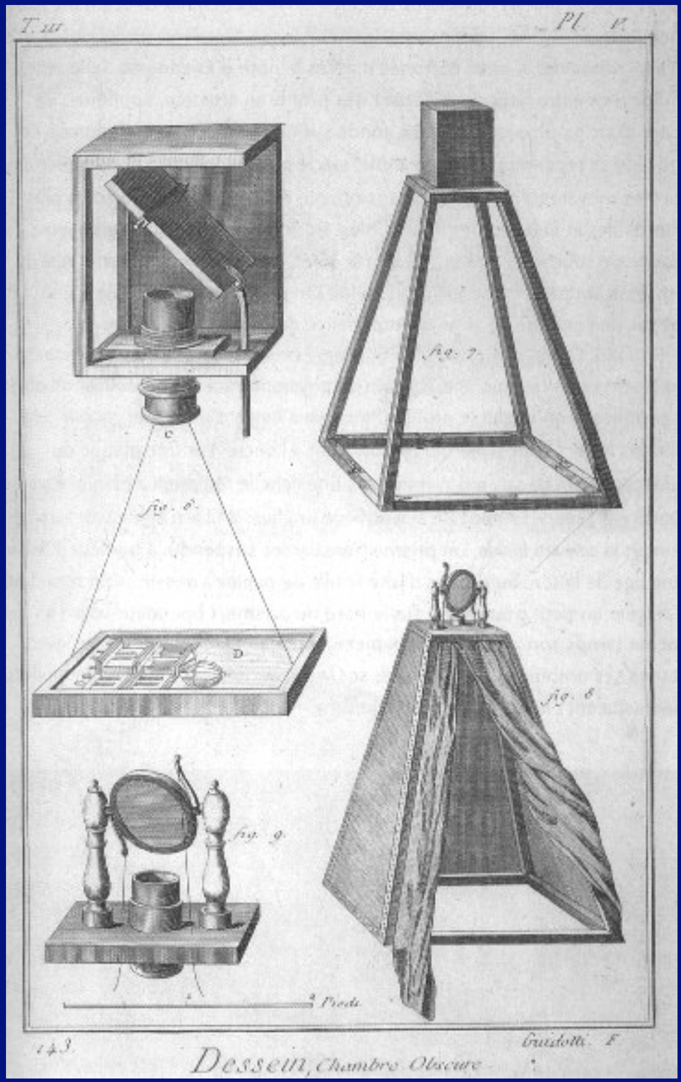
2006-05-23

Author

User:MikKBDFJKGeMalak





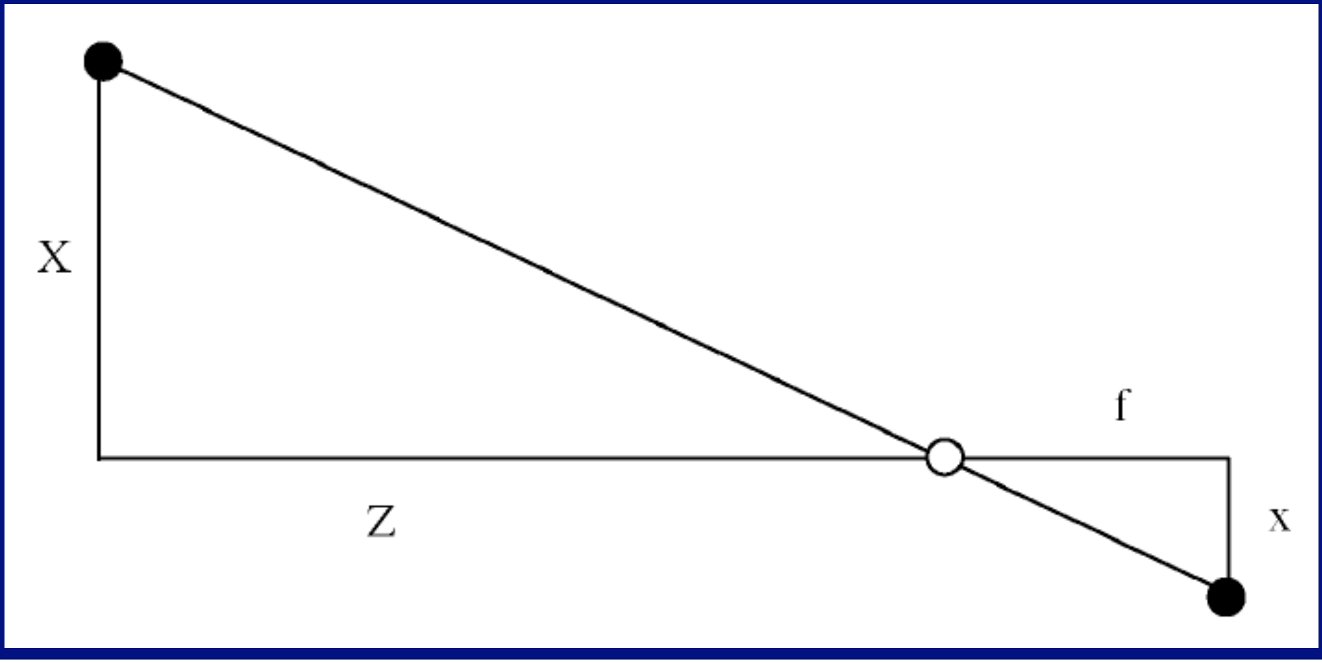


Camera obscura - aus einer franz. "Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers" von 1772

Public Domain

Projection in Coordinates

- From the drawing, we have $X/Z = -x/f$
- Generally



Homogeneous coordinates

- Add an extra coordinate and use an equivalence relation
- for 2D
  - three coordinates for point
  - equivalence relation
    k*(X,Y,Z) is the same as (X,Y,Z)
- for 3D
  - four coordinates for point
  - equivalence relation
    k*(X,Y,Z,T) is the same as   (X,Y,Z,T)
- Canonical representation
  - by dividing by one coordinate (if it isn’t zero).

Homogeneous coordinates

- Why?
  - Possible to represent points “at infinity”
  - Where parallel lines intersect (vanishing points)
  - Where parallel planes intersect (horizons)
  - Possible to write the action of a perspective camera as a matrix

A perspective camera as a matrix

- Turn previous expression into HC's
  - HC's for 3D point are (X,Y,Z,T)
  - HC's for point in image are (U,V,W)

$$\begin{pmatrix} U \\ V \\ W \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{1}{f} & 0 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ T \end{pmatrix}$$

A general perspective camera - I

- Can place a perspective camera at the origin, then rotate and translate coordinate system
- In homogeneous coordinates, rotation, translation are:

$$\mathcal{E} = \begin{pmatrix} \mathcal{R} & \mathbf{t} \\ \mathbf{0} & 1 \end{pmatrix}$$

- So rotated, translated camera is:

$$\mathcal{C}\mathcal{E}$$

A general perspective camera - II

- In the camera plane, there can be a change of coordinates
  - choice of origin
    - there is a "natural" origin --- the camera center
      - where the perpendicular passing through the focal point hits the image plane
  - rotation
  - pixels may not be square
  - scale
- Camera becomes

$$\mathcal{MCE}$$

Intrinsics - typically come with the camera

Extrinsics - change when you move around

What are the transforms?

$$\begin{pmatrix} U \\ V \\ W \end{pmatrix} = \begin{pmatrix} \text{Transform} \\ \text{representing} \\ \text{intrinsic parameters} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} \text{Transform} \\ \text{representing} \\ \text{extrinsic parameters} \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ T \end{pmatrix}$$

Camera Calibration

- Issues:
  - what is the camera matrix? (including intrinsic and extrinsic)
  - what are intrinsic parameters of the camera?
- General strategy:
  - view calibration object
  - identify image points
  - obtain camera matrix by minimizing error
  - obtain intrinsic parameters from camera matrix
- Error minimization:
  - Linear least squares
    - easy problem numerically, solution can be rather bad
  - Minimize image distance
    - more difficult numerical problem, solution is better

Problem: Vanishing points

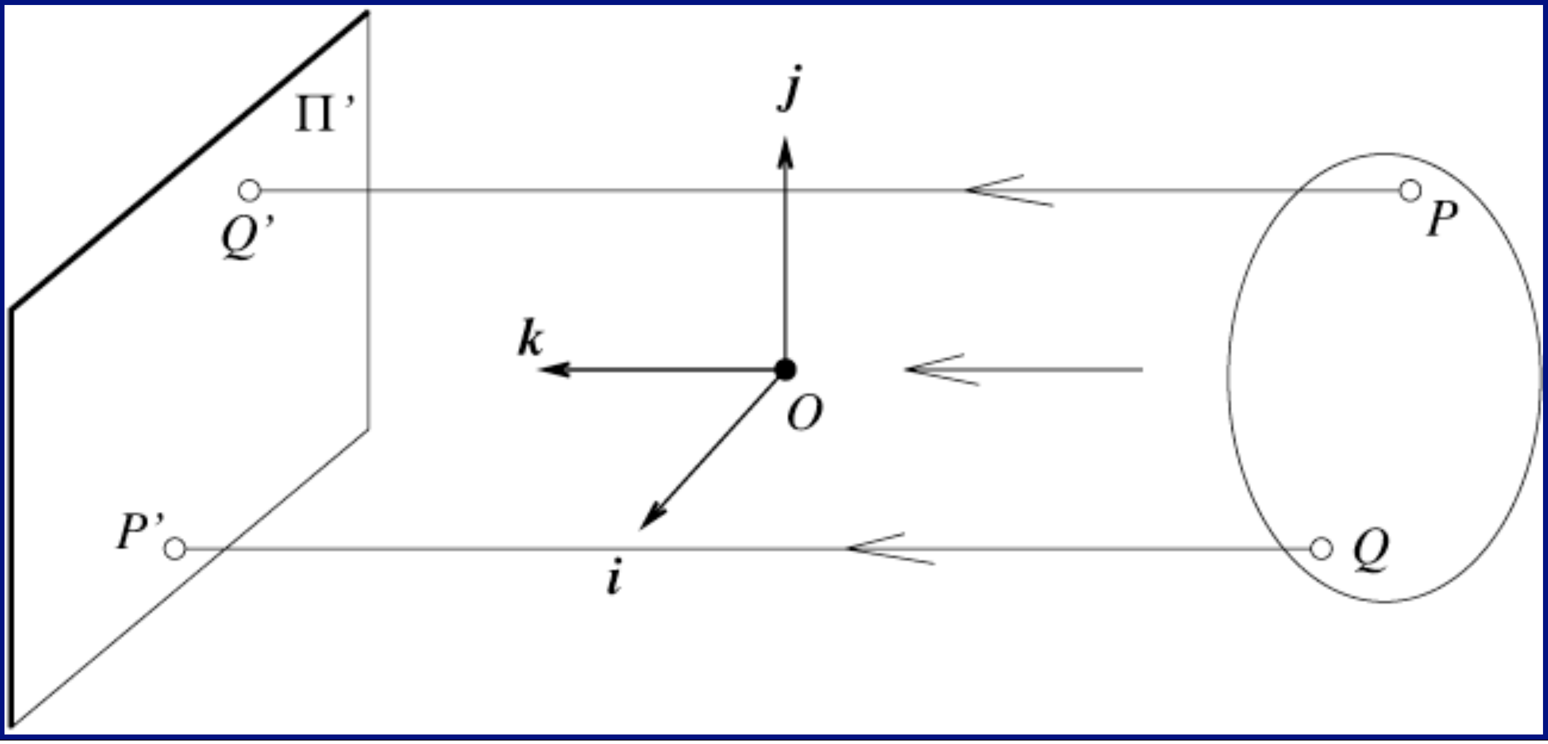
- Lines in world coordinates: $\mathbf{u} + t\mathbf{v}$
- Camera: $\mathcal{MCE}$
- Vanishing point in camera coordinates?

Weak perspective

- Issue
  - perspective effects, but not over the scale of individual objects
    - For example, texture elements in picture below
  - collect points into a group at about the same depth, then divide each point by the depth of its group
  - Adv: easy, useful when depth range is small
  - Disadv: wrong when depth range is large

Orthographic projection

- Perspective effects are often not significant
  - eg
    - pictures of people
    - all objects at the same distance



Orthographic projection in HC's

- In conventional coordinates, we just drop z
- In Homogeneous coordinates, can write a matrix

$$\begin{pmatrix} U \\ V \\ W \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ T \end{pmatrix}$$

Calibration and orthographic cameras

- Some parameters can’t be estimated
  - translation of camera perpendicular to image plane
- Intrinsics slightly different:
  - no “natural” origin in the image plane

Pinhole Problems

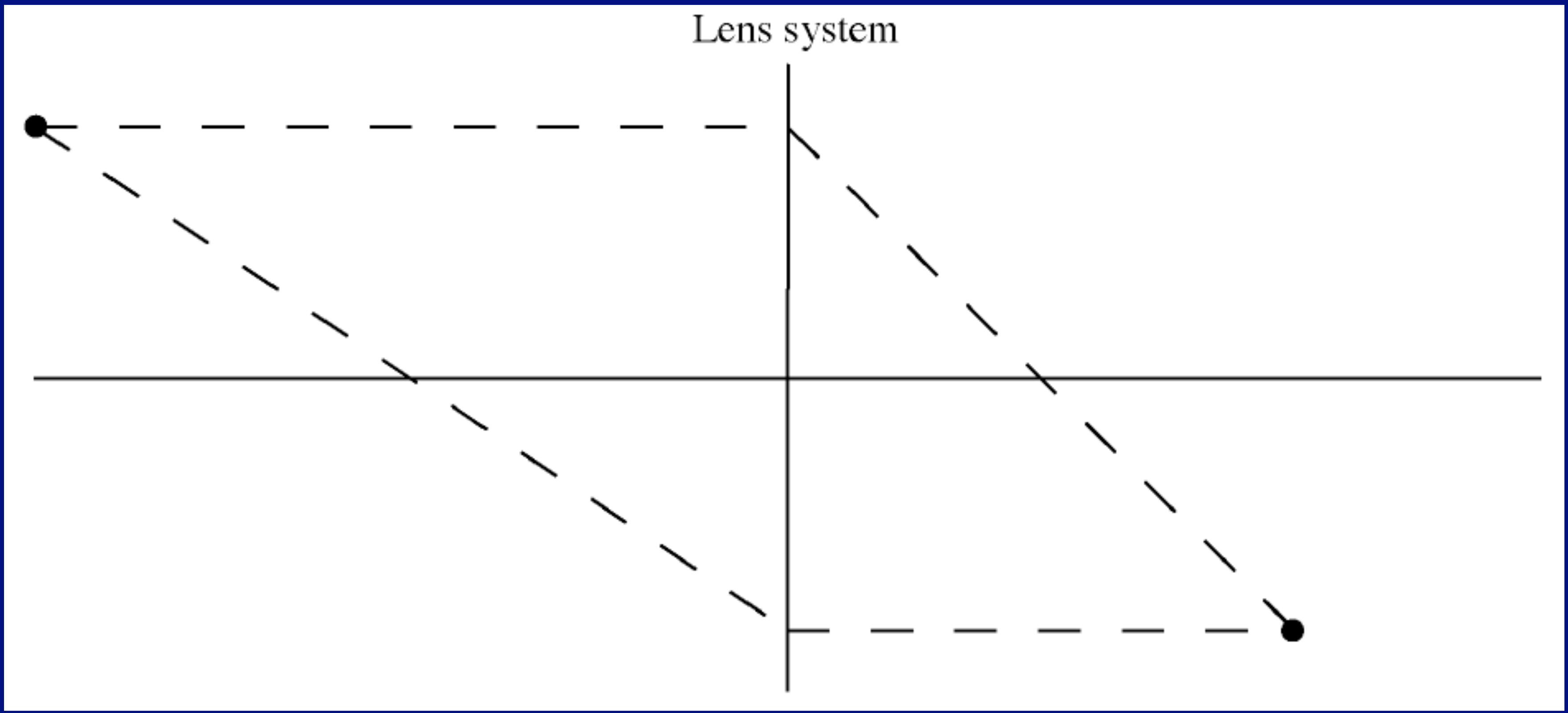
Pinhole too big: brighter, but blurred

Pinhole right size: crisp, but dark

Pinhole too small: diffraction effects blur, dark

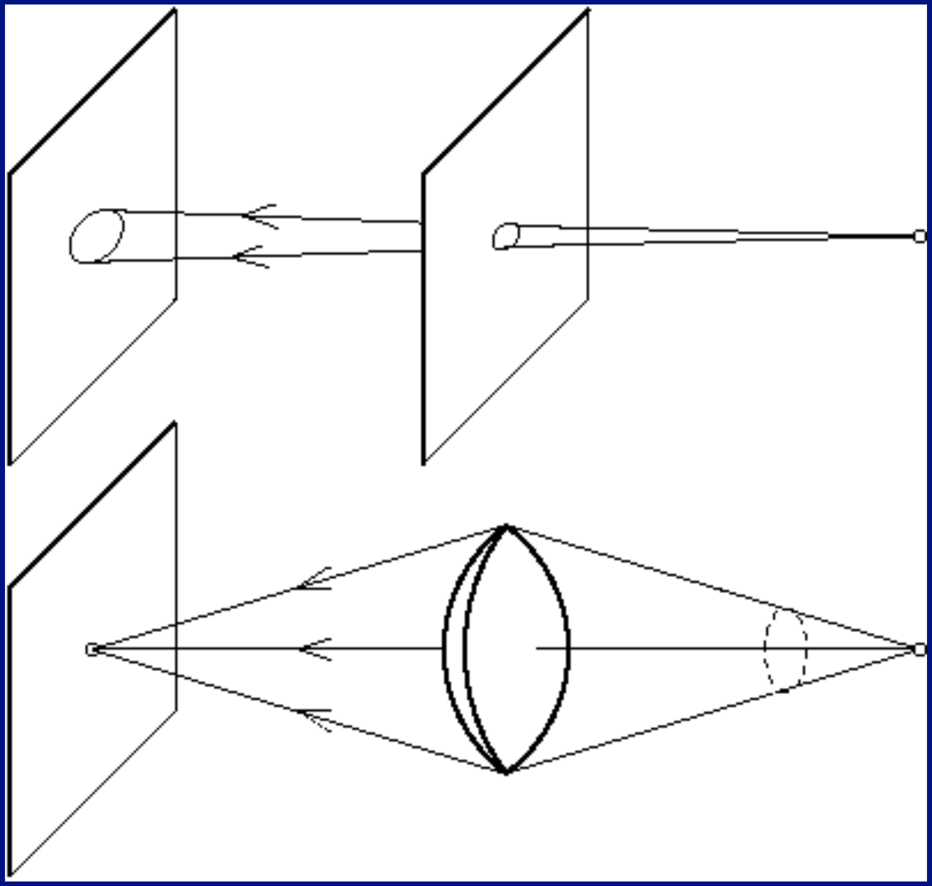
Lens Systems

- Collect light from a large range of directions

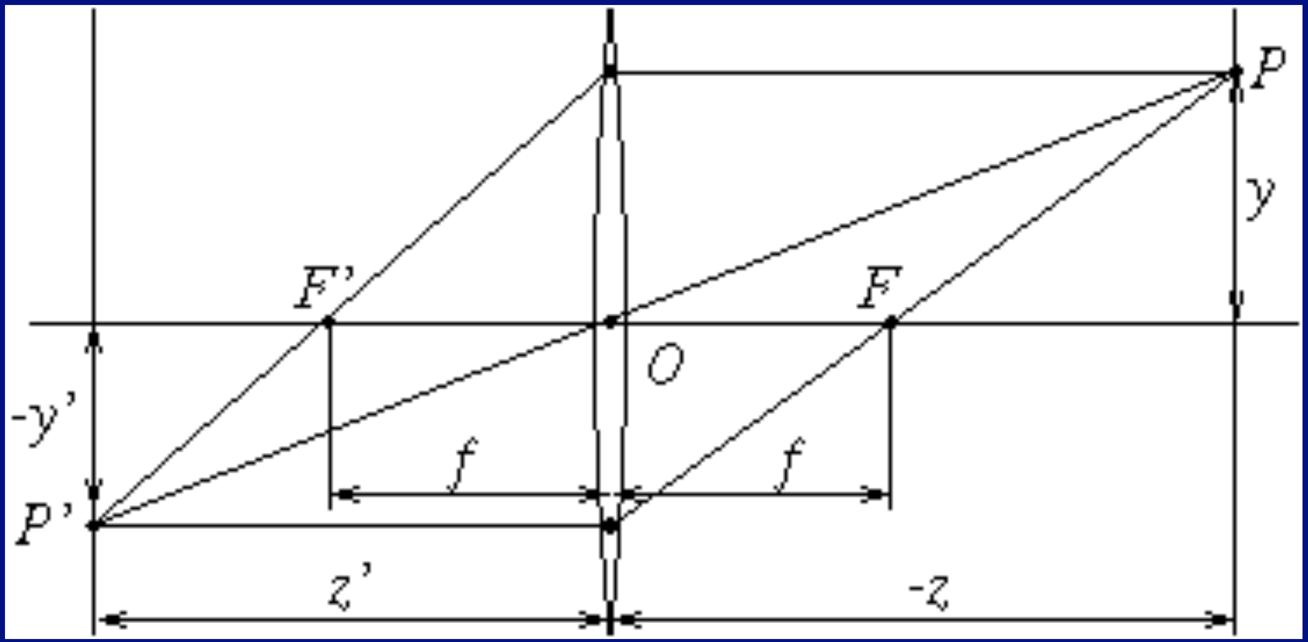


Lens Systems

- Collect light from a large range of directions



A lens model - the thin lens

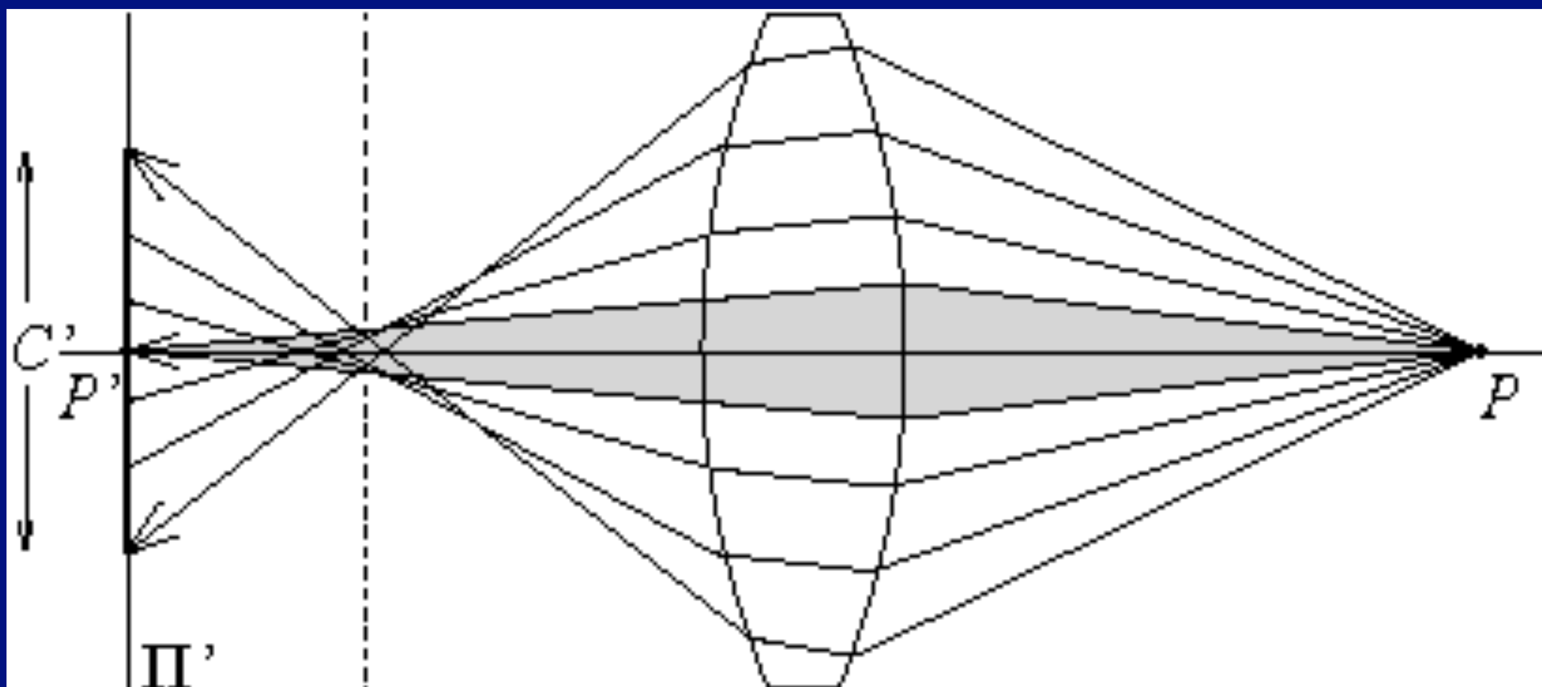


$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$

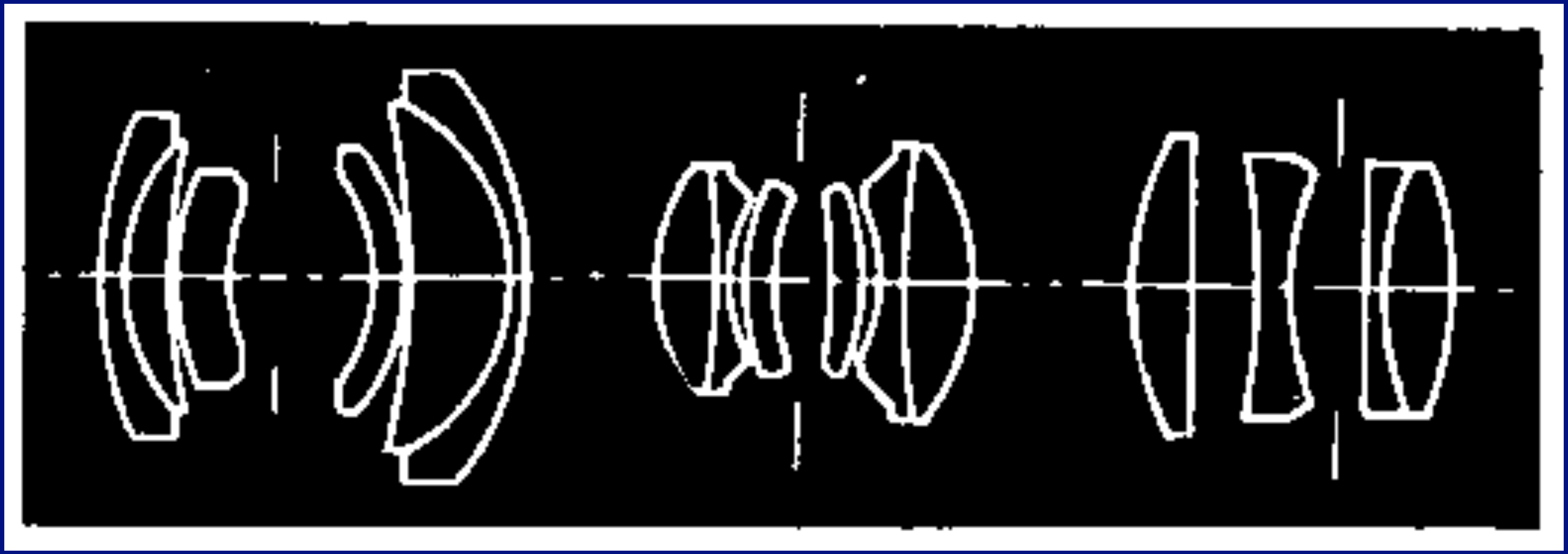
Lens Problems

- Chromatic aberration
  - Light at different wavelengths follows different paths; hence, some wavelengths are defocussed
  - Machines: coat the lens
  - Humans: live with it
- Scattering at the lens surface
  - Some light entering the lens system is reflected off each surface it encounters (Fresnel’s law gives details)
  - Machines: coat the lens, interior
  - Humans: live with it (various scattering phenomena are visible in the human eye)
- Geometric phenomena (Barrel distortion, etc.)

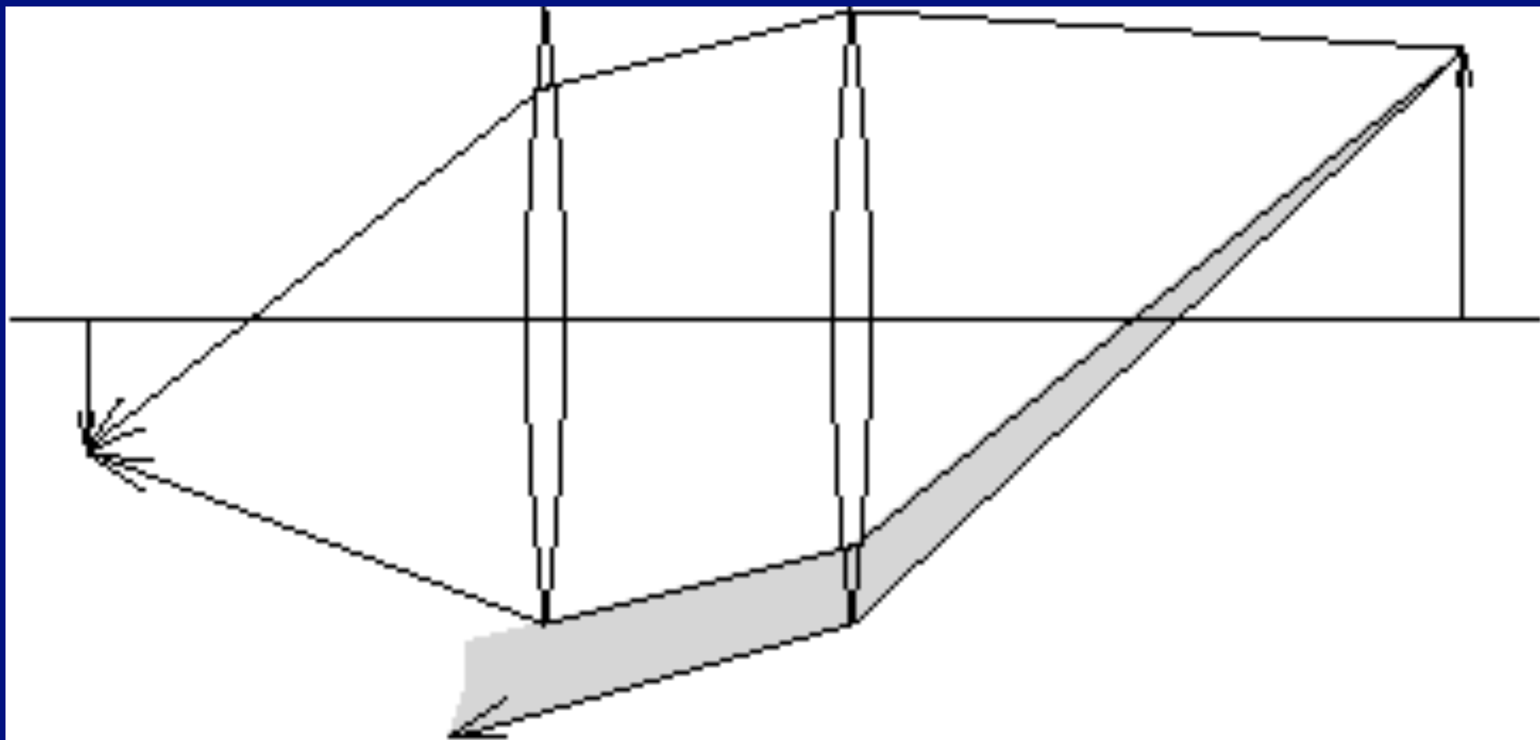
Lens Problems - Spherical Aberration



Lens Systems

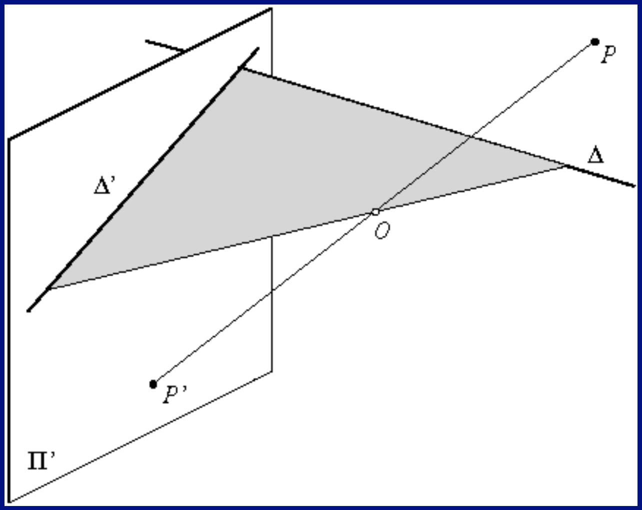


Vignetting



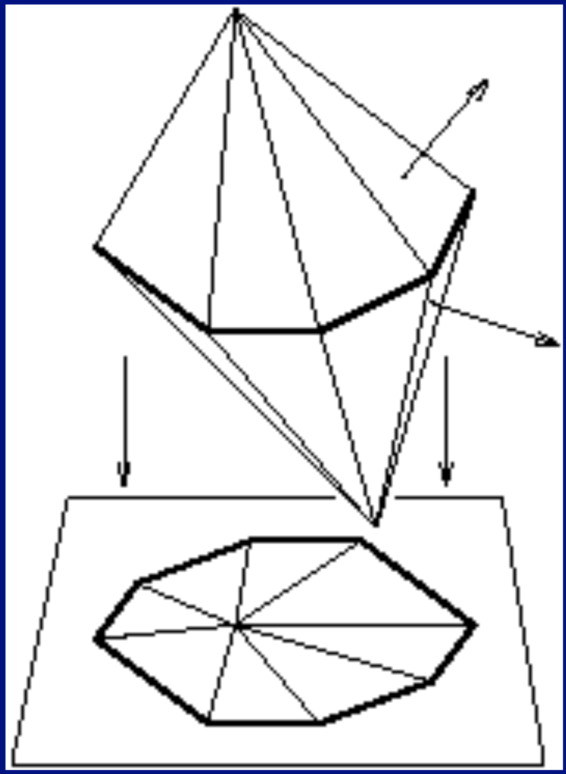
Geometric properties of projection

- Points -> points
- Lines -> lines
- Polyhedra -> polyhedra
- Degeneracies
  - line through focal point (pinhole) -> point
  - plane through focal point (pinhole) -> line
- Curved surfaces are complicated



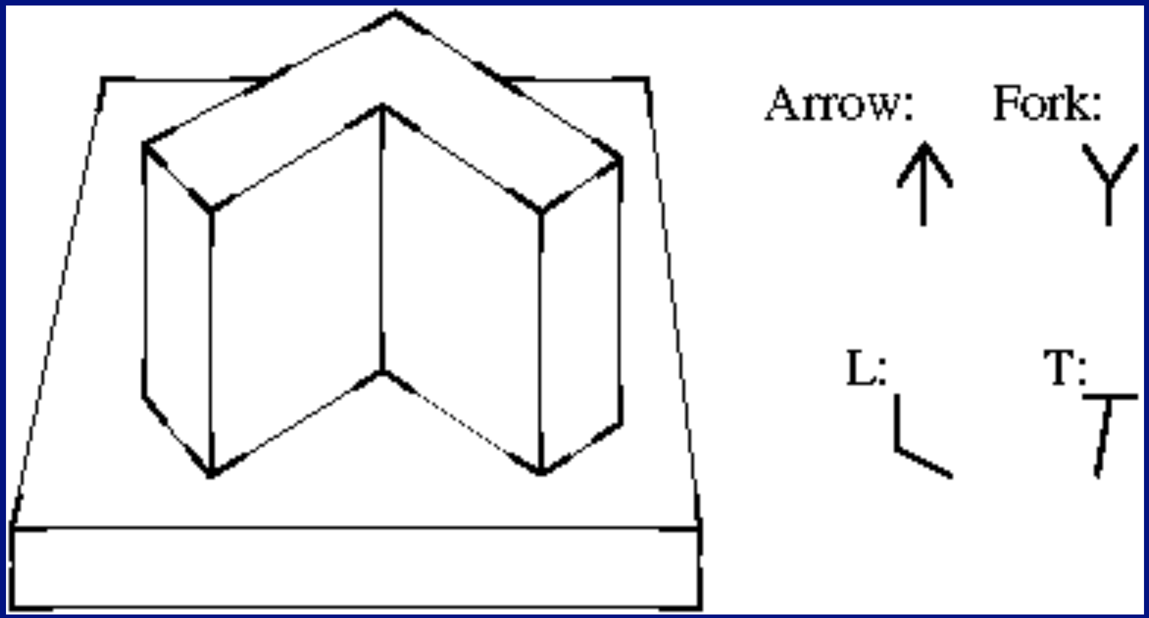
Polyhedra project to polygons

- because lines project to lines, etc



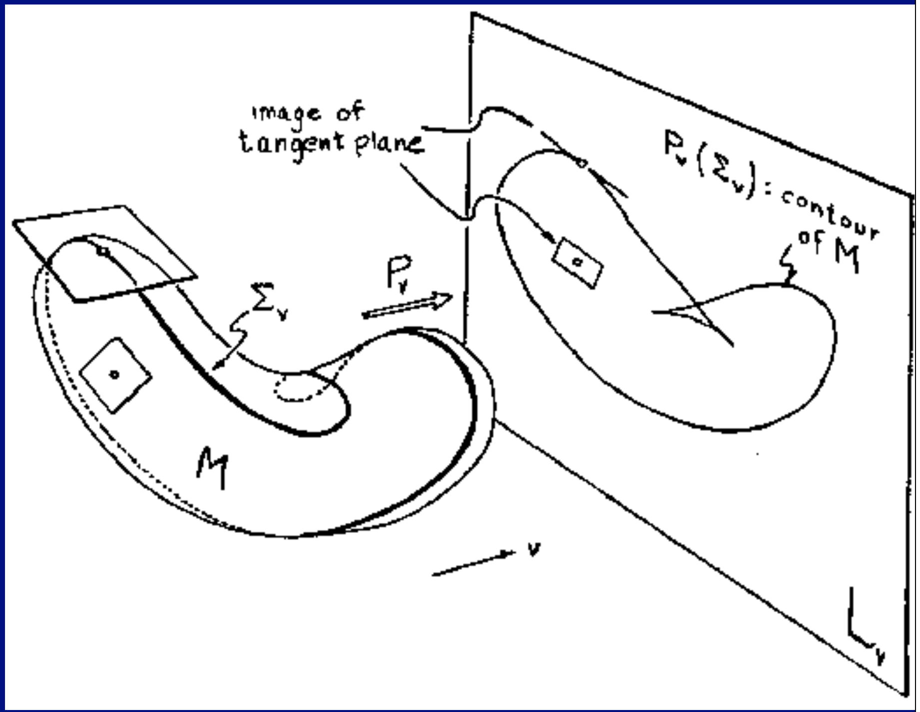
Junctions are constrained

- Which leads to a process called line labelling
  - look for consistent junction, edge labels
    - BUT can't get real lines, junctions from real images



Curved surfaces are more interesting

- Outline
  - set of points where view direction is tangent to surface
  - projection of a space curve which varies from view to view of a surface



Panagis Alexatos, by Jim Childs