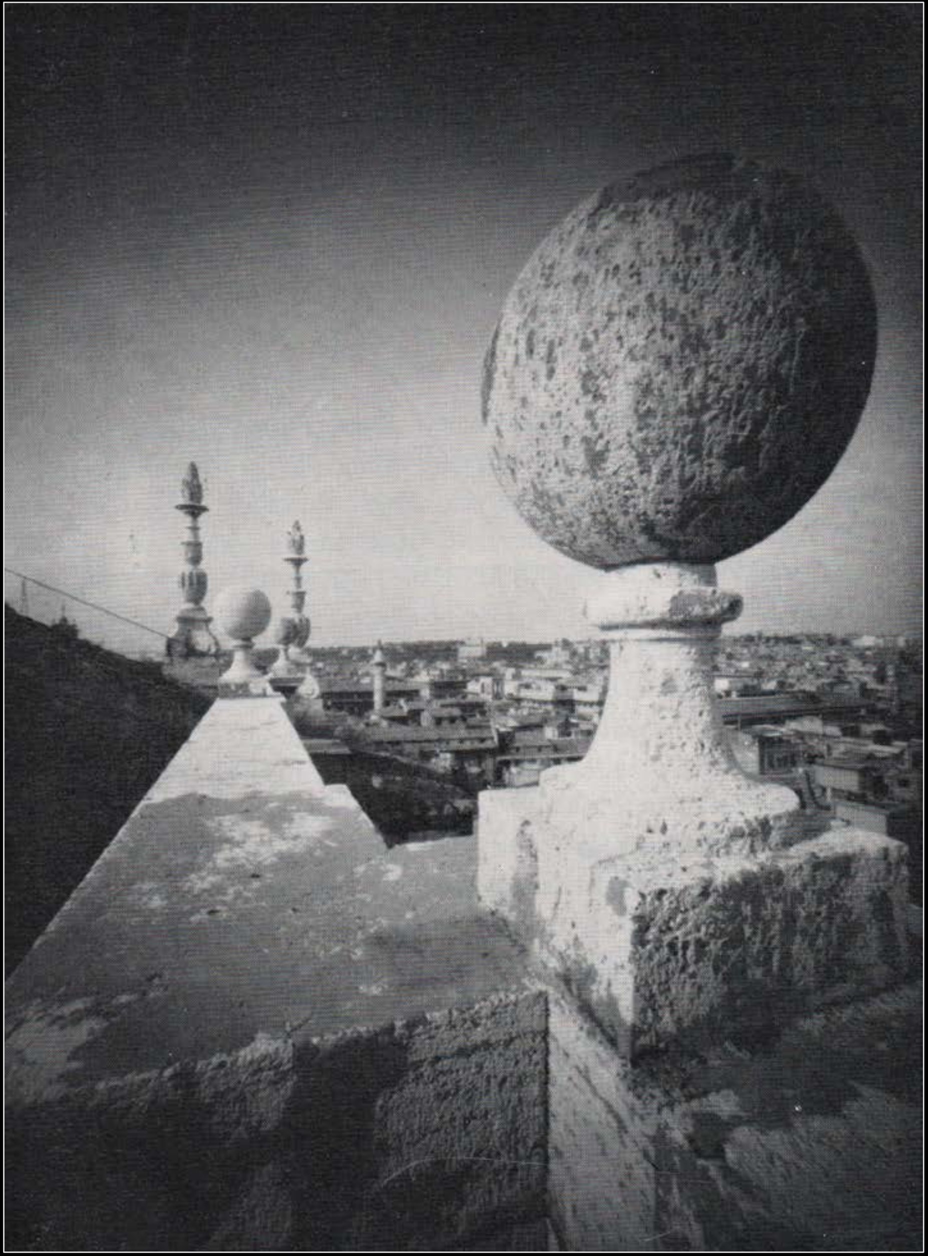
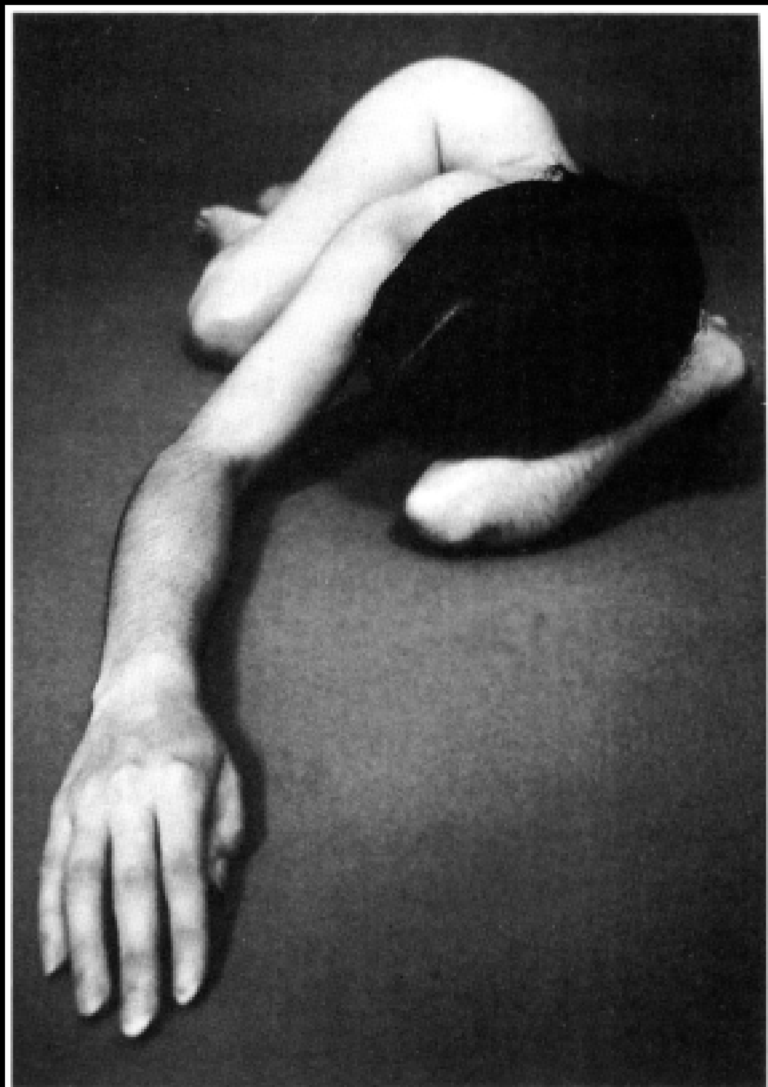
Perceptual Bases for Rules of Thumb in Photography

Martin S. Banks
Vision Science
UC Berkeley





Photographic Effects

- Wide-angle distortion

  Well known in photography, cinematography, computer graphics, and perspective painting.

  Texts recommend lens focal length of ~50mm (with 35mm film format) to avoid distortion.

- Depth compression/expansion

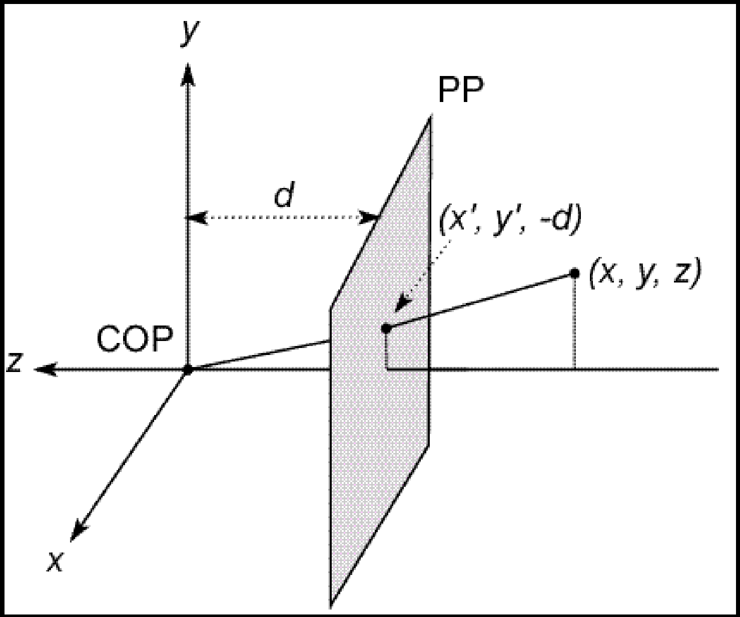
  Well known in photography and cinematography for manipulation of artistic effects.

  Texts recommend focal length of ~50mm to avoid compression or expansion.

- Depth of field effects

  Widely utilized in photography and cinematography to create artistic effects, attract viewer gaze, etc.

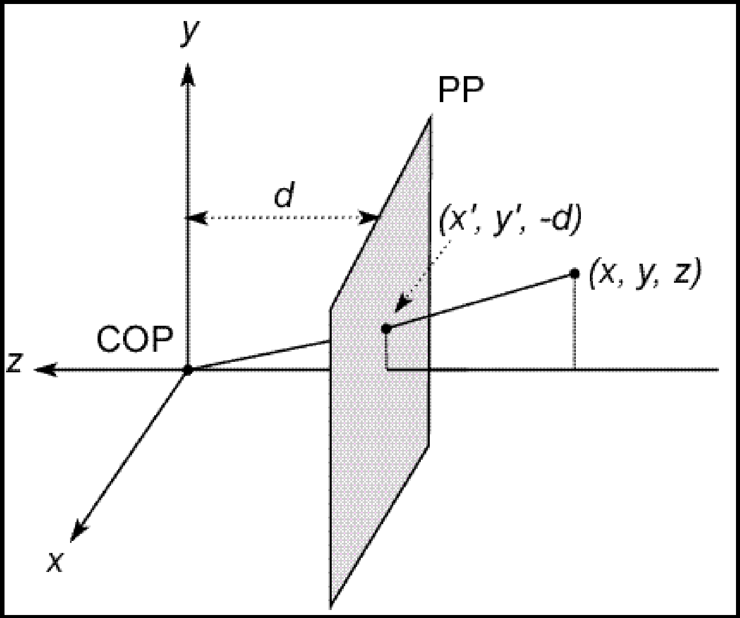
The Camera



The coordinate system

- Pin-hole model as an approximation
- Put optical center (**C**enter **O**f **P**rojection) at origin
- Put image plane (**P**rojection **P**lane) *in front* of COP
- The camera looks down *negative* z axis
  - we need this if we want right-handed-coordinates

The Camera



Projection equations

- Compute intersection with PP of ray from (x,y,z) to COP
- We get the projection by throwing out the last coordinate:

Photographic Effects

- Wide-angle distortion

  Well known in photography, cinematography, computer graphics, and perspective painting.

  Texts recommend lens focal length of ~50mm (with 35mm film format) to avoid distortion.

- Depth compression/expansion

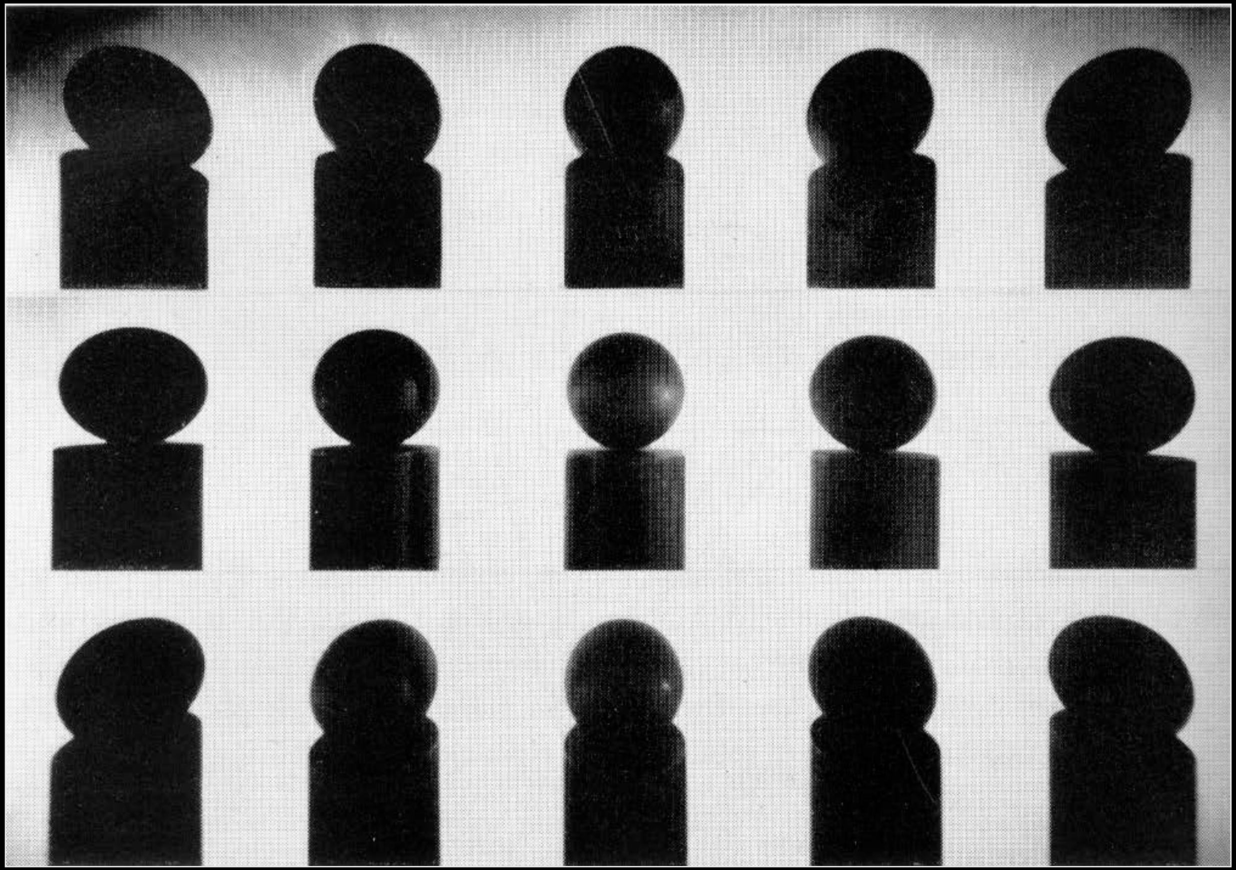
  Well known in photography and cinematography for manipulation of artistic effects.

  Texts recommend focal length of ~50mm to avoid compression or expansion.

- Depth of field effects

  Widely utilized in photography and cinematography to create artistic effects, attract viewer gaze, etc.

Wide-angle Distortions in Pictures



With short focal length, eccentric spheres in picture perceived as ellipsoidal when viewed (binocularly) from CoP.

Wide-angle Distortions in Pictures

original

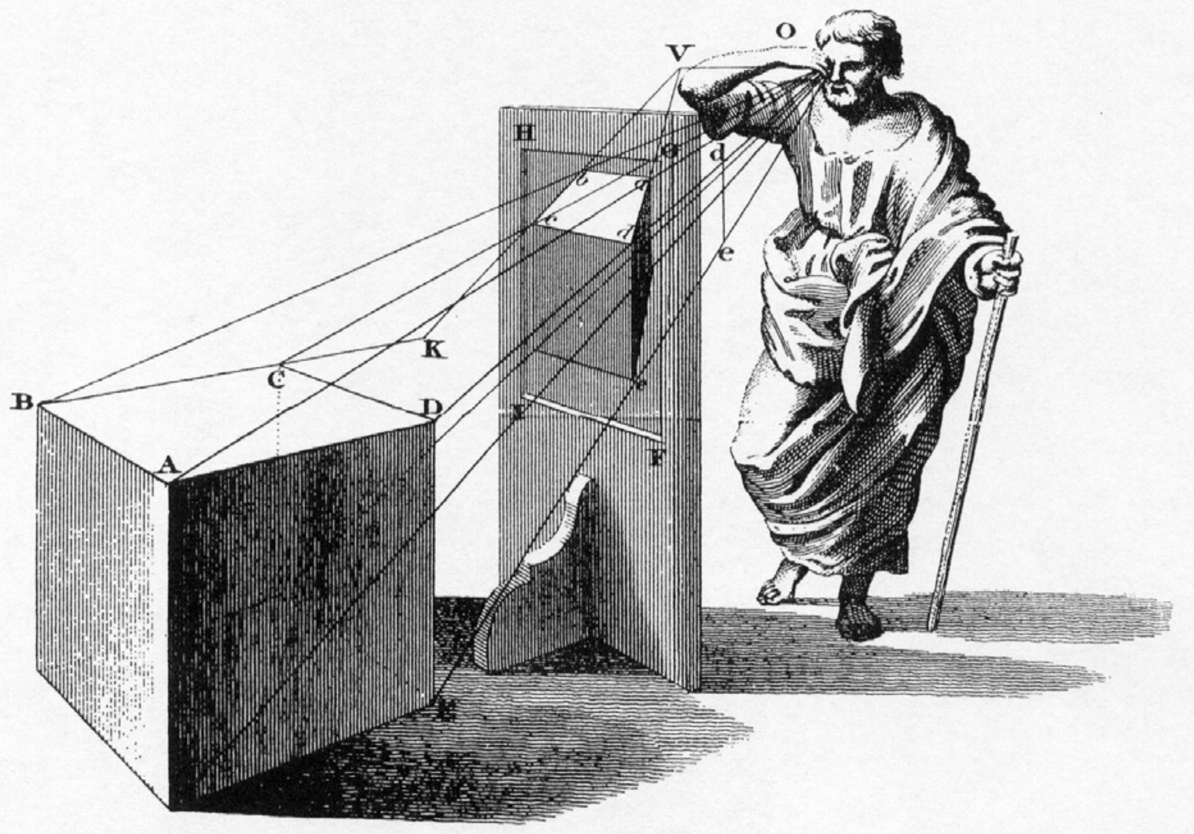
anamorphic correction

From: DXO Optics Pro

Photography Texts

- Wide-angle effect is well known in photography, computer graphics, and perspective painting (e.g., Kubovy, 1986).
- To avoid effect, photography texts recommend focal length 40–50% greater than film width; i.e., ~50mm for 35-mm film (Kingslake, 1992).
- Longer focal lengths yield small fields of view and are hence generally undesirable.
- What determines shortest focal length? The 40–50% rule creates ‘‘a field of view that corresponds to that of normal vision,’’ (Giancoli, 2000) or ‘‘the same perspective as the human eye’’ (Alesse, 1989).

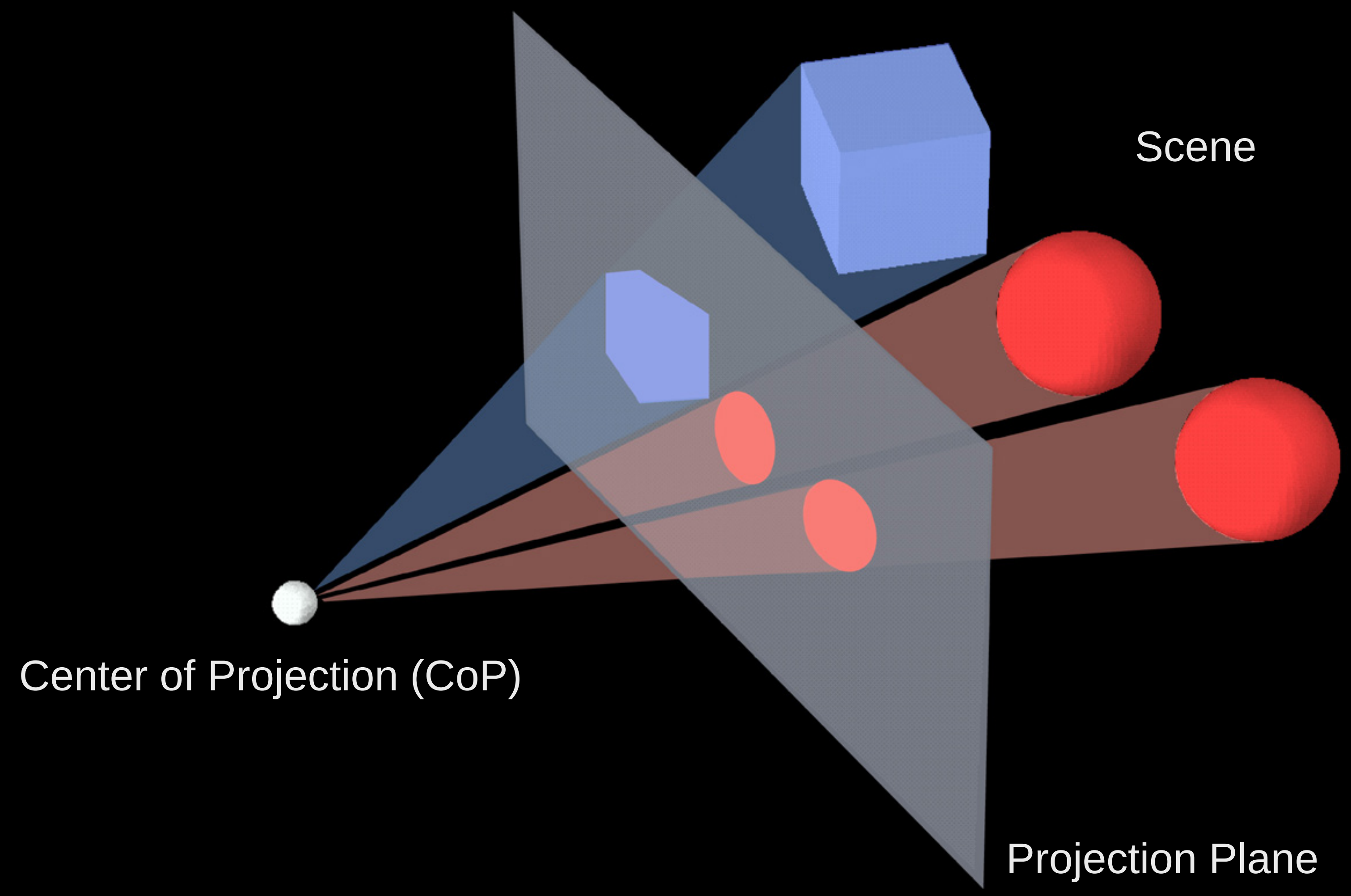
Perspective Projection



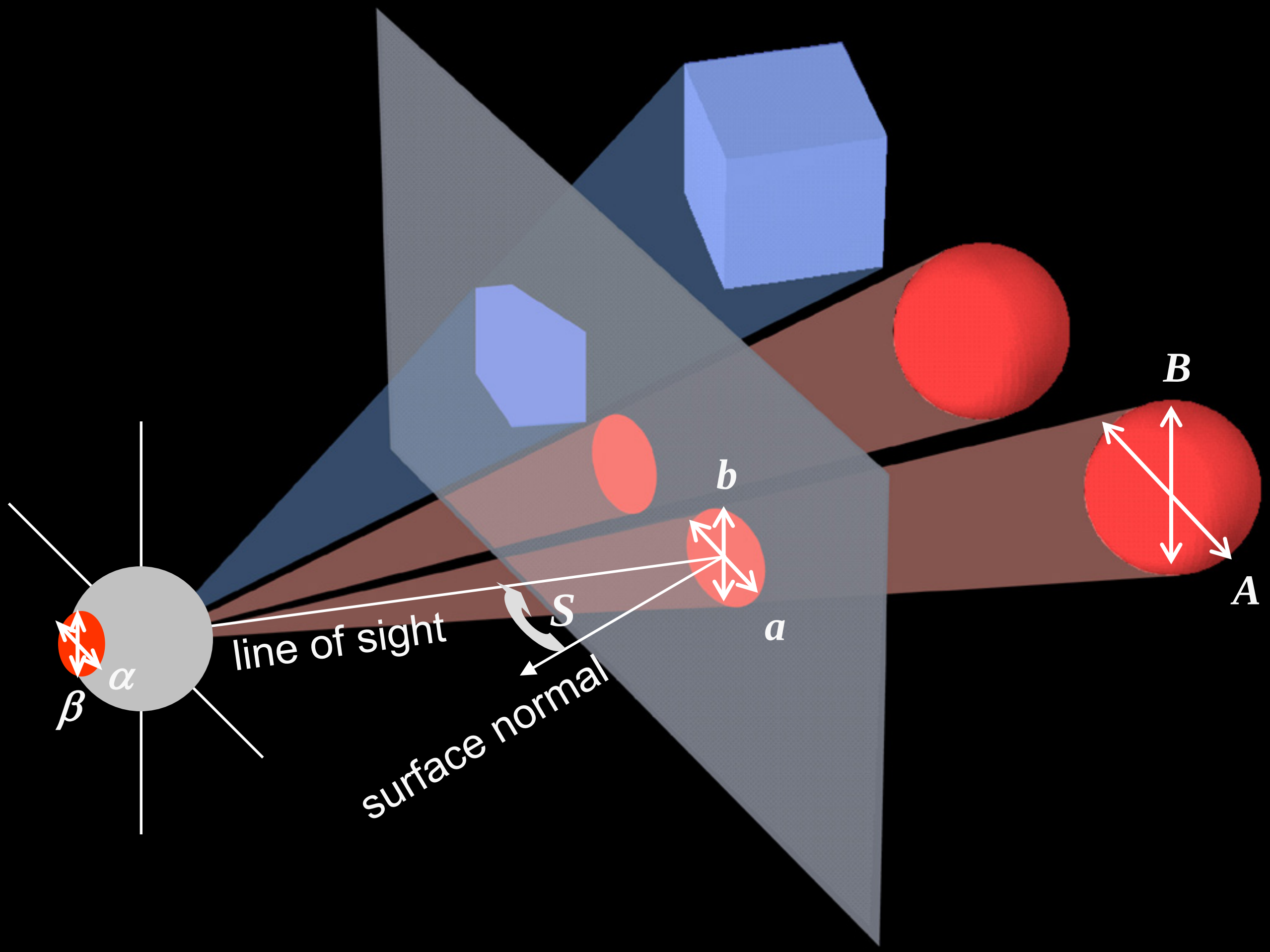
7.1 The principle of linear perspective

The pyramid of sight defined by the object *ABCDE* and the centre of rotation *O* of the eye of the spectator, who keeps his other eye shut, is intersected by the surface *FGHI*, thus forming on it the projection *abcde* in linear perspective. If the surface *FGHI* is a transparent Leonardo window, the eye sees this perspective covering the actual object exactly. (The whole figure here is of course shown in perspective including the picture *abcde*, which is seen foreshortened, and from the side opposite to the eye *O*. The spectator is depicted holding his hand to his eye presumably because in earlier illustrations of this period strings were used to materialize the lines constituting the pyramid of sight.) (From Brook Taylor (1811), *New Principles of Linear Perspective*.)

Perspective Projection



Picture Viewing

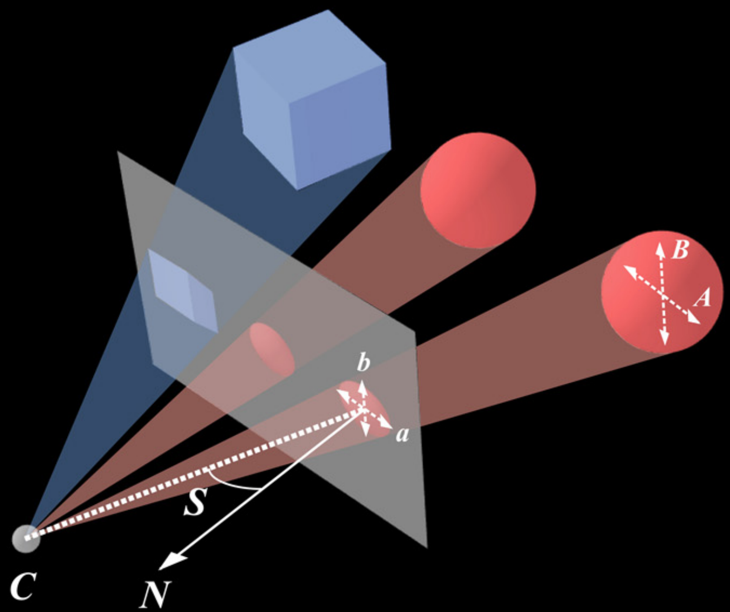


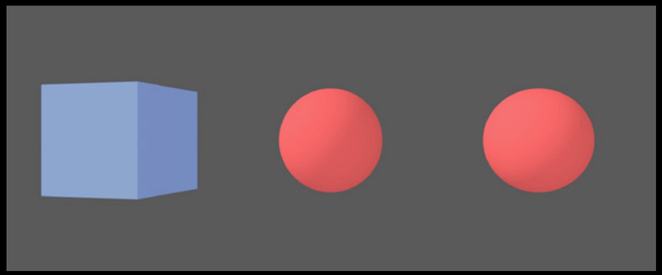
Projection to create picture:

Projection onto retina:

So at the retina:

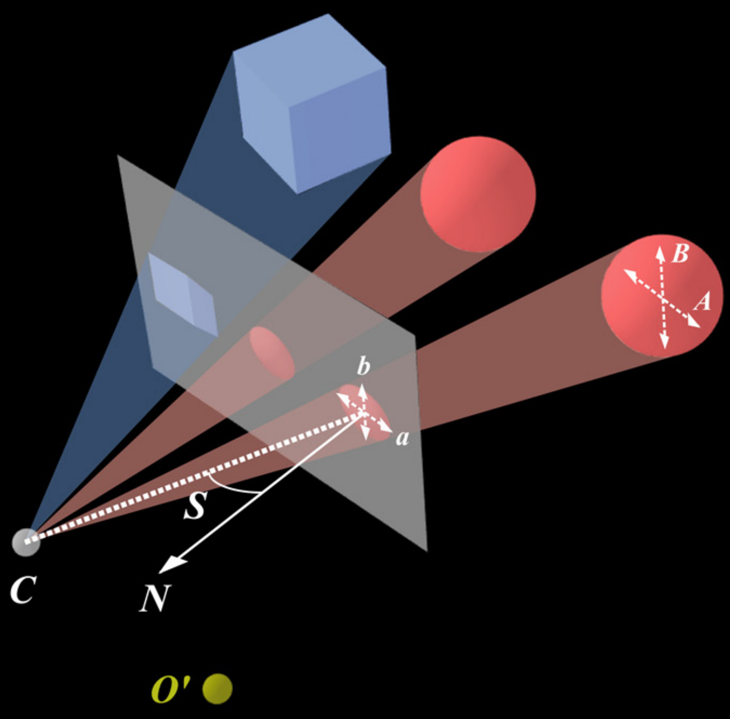
Oblique Viewing of Scenes & Pictures

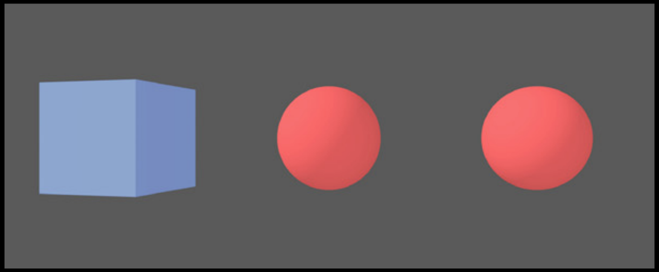




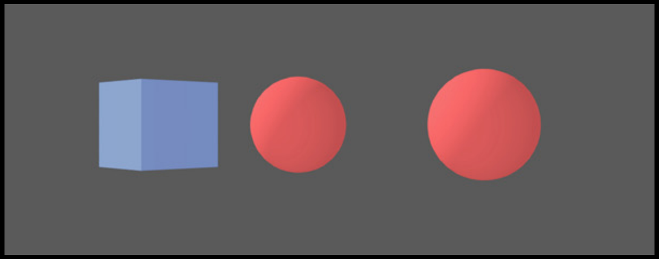
scene & picture viewed from *C*

Oblique Viewing of Scenes & Pictures



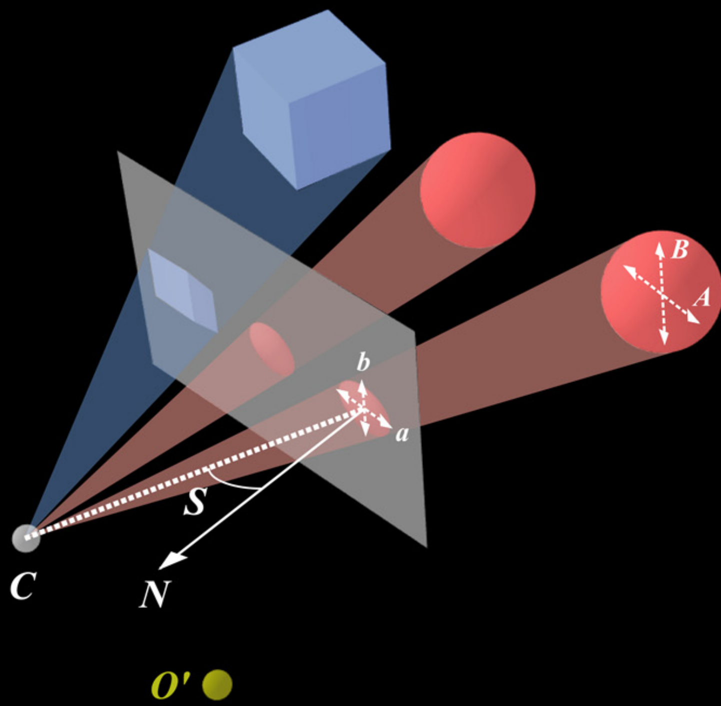


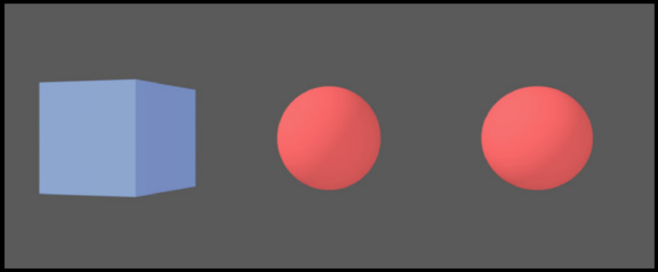
scene & picture viewed from *C*



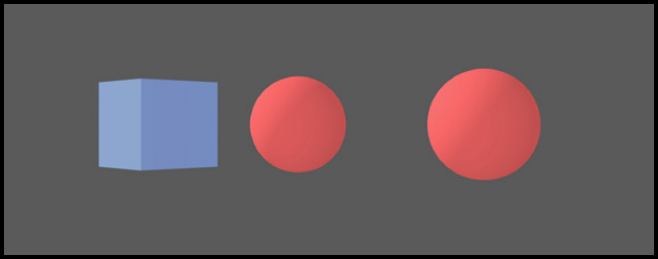
scene viewed from *O'*

Oblique Viewing of Scenes & Pictures

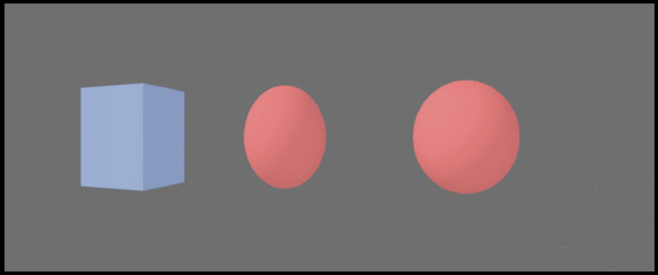




scene & picture viewed from *C*



scene viewed from *O’*

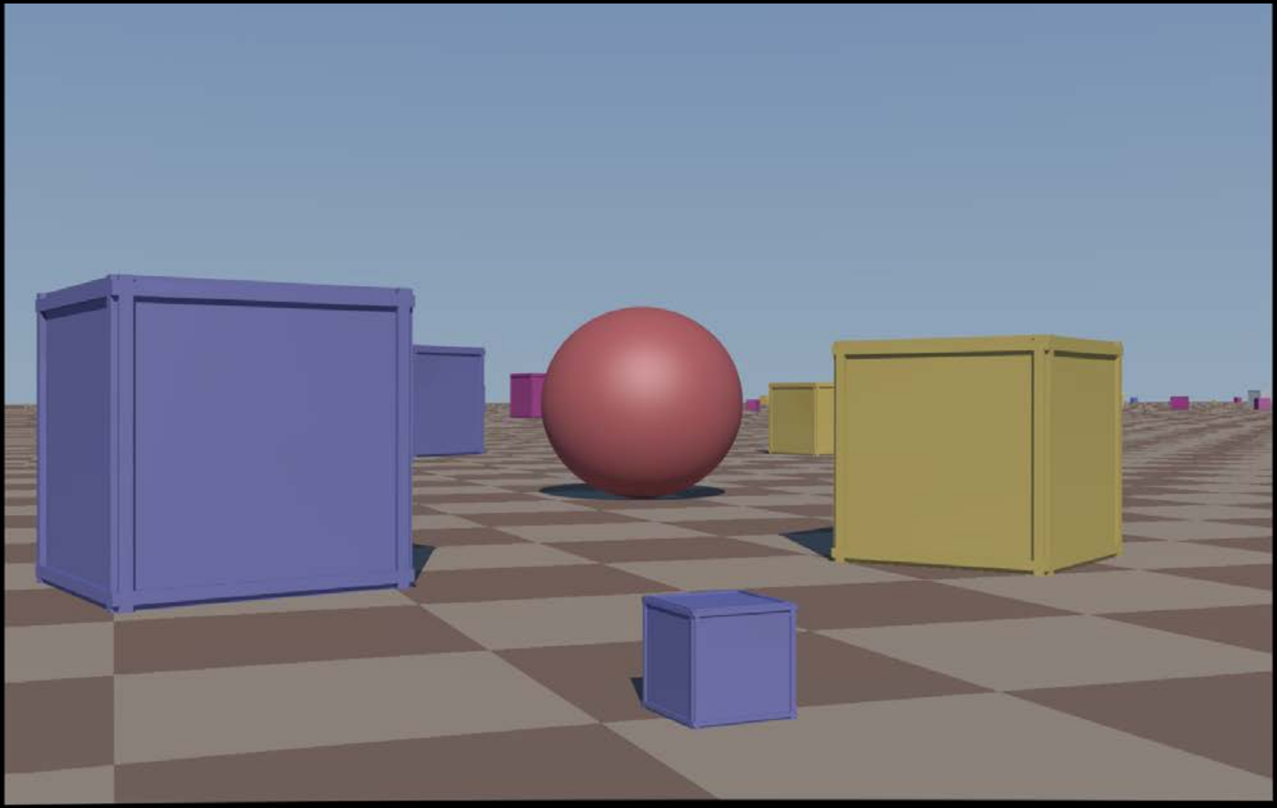


picture viewed from *O’*

Viewing Pictures in Real World

- Almost never view pictures from correct position.
- Retinal image thus specifies different scene than depicted.
- Do people compensate, and if so, how?

Ovoid Stimulus

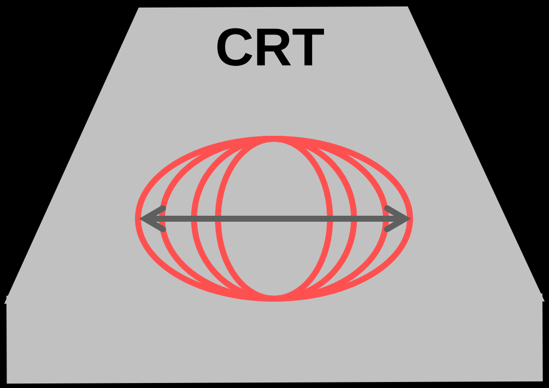


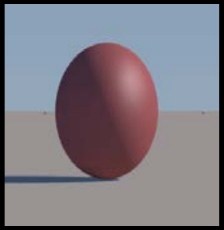
Vishwanath, Girshick, & Banks, *Nature Neuroscience* (2005)

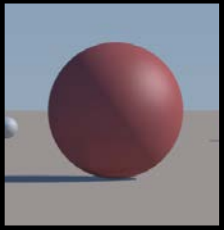
Experimental Task

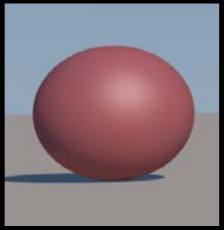
Stimulus: simulated 3D ovoid with variable aspect ratio.

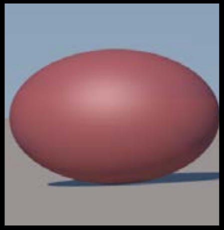
Task: adjust ovoid until appears spherical.











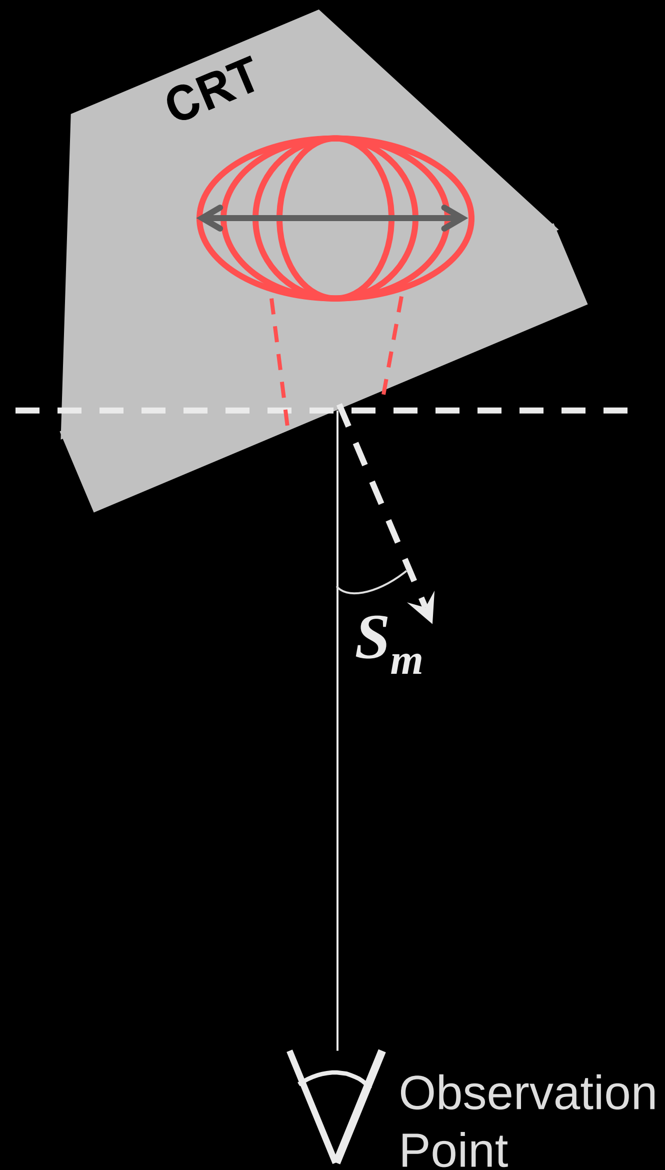
Experimental Task

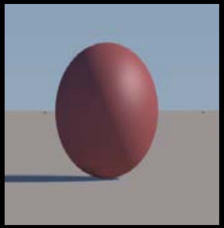
Stimulus: simulated 3D ovoid with variable aspect ratio.

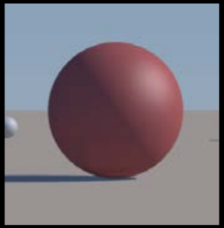
Task: adjust ovoid until appears spherical.

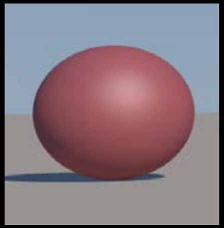
Vary monitor slant S_m to assess compensation for oblique viewing positions.

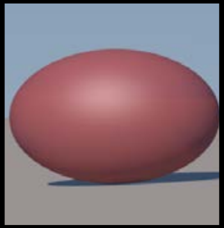
Spatial calibration procedure.







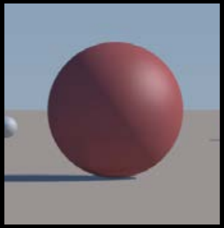




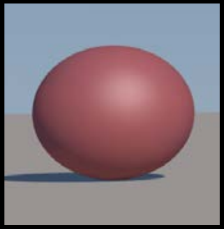
Predictions & Results

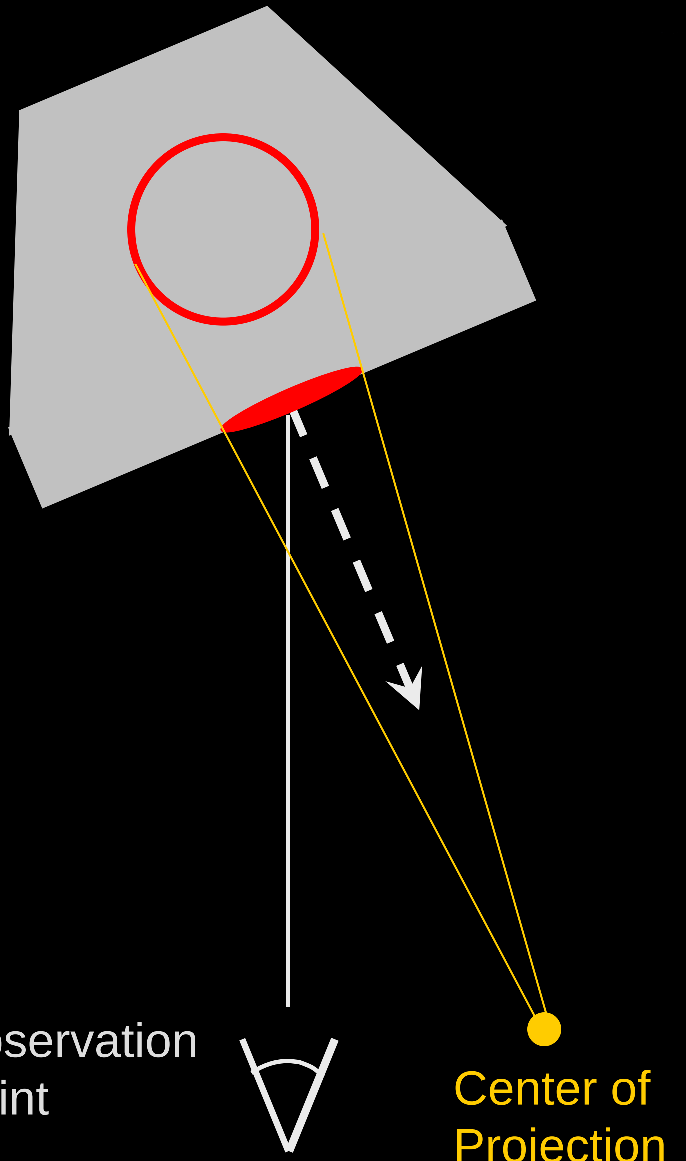
No compensation: set ovoid to make image on retina circular:

retinal coordinates



screen coordinates

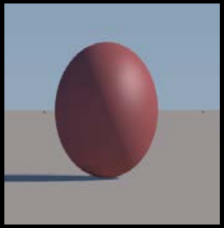




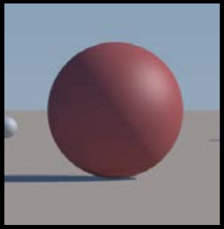
Predictions & Results

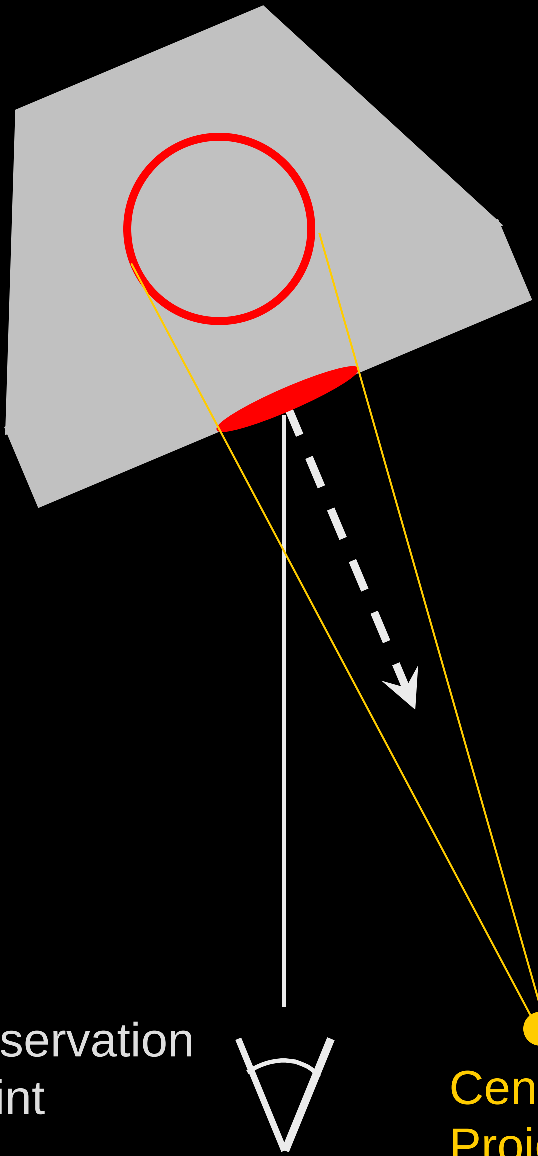
Compensation: set ovoid to make image on screen circular:

retinal coordinates

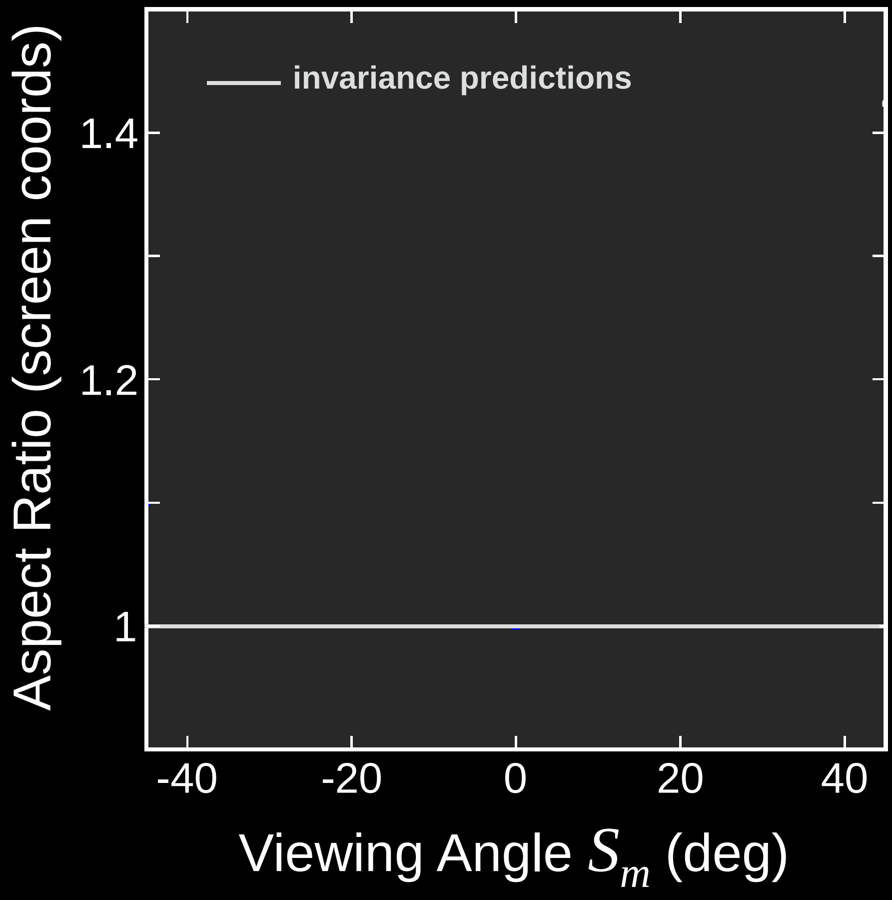


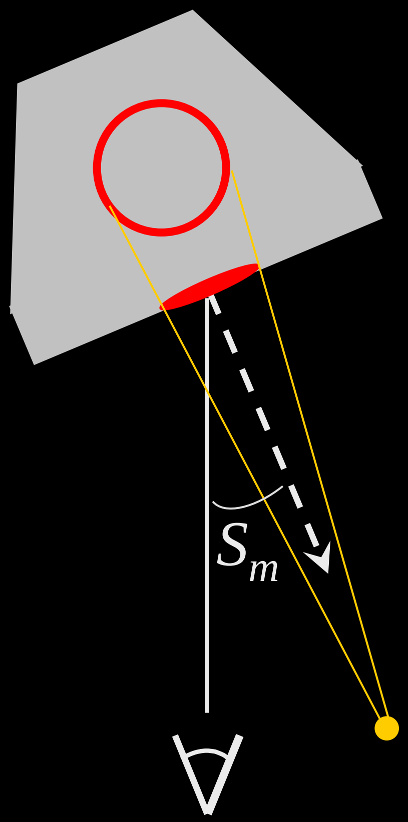
screen coordinates



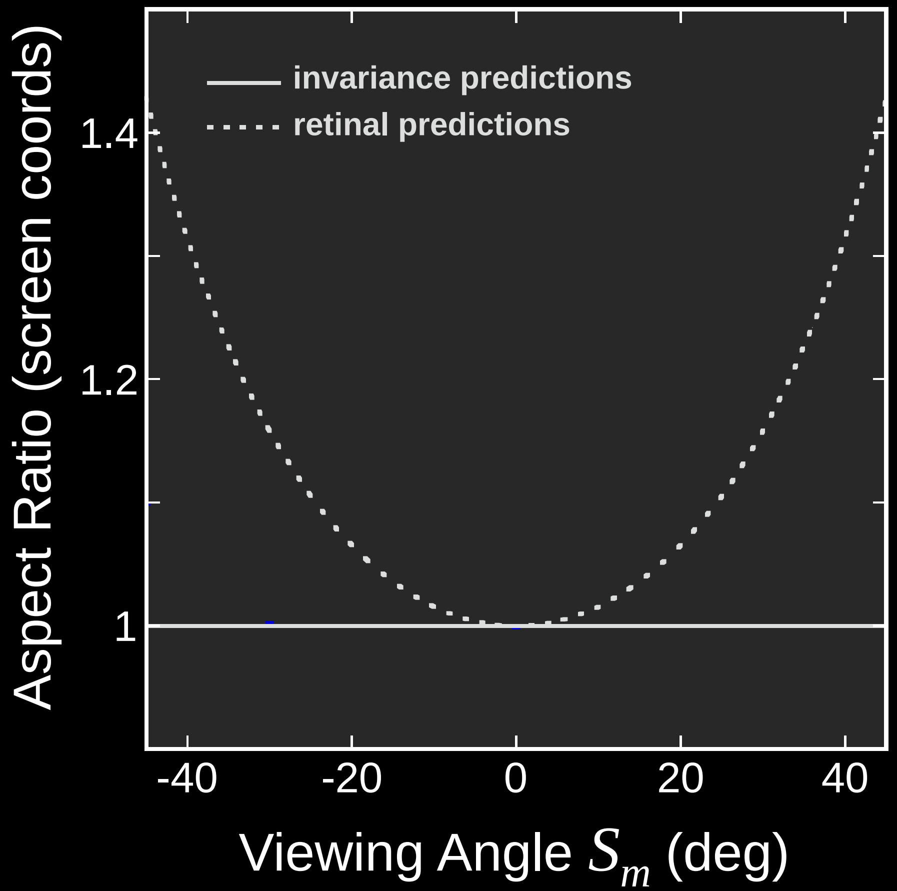


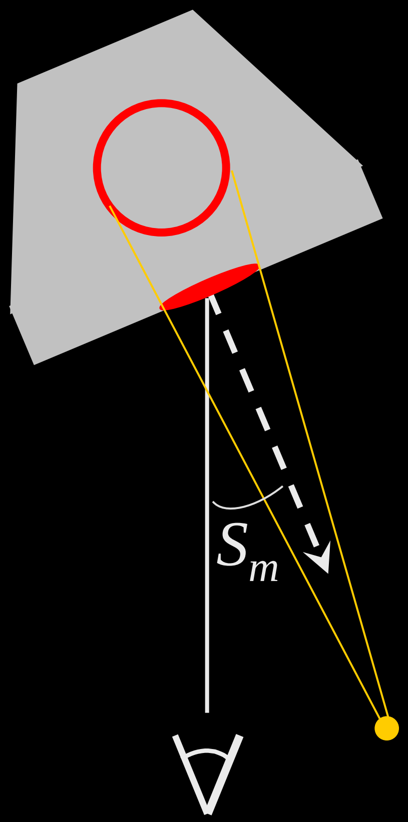
Predictions



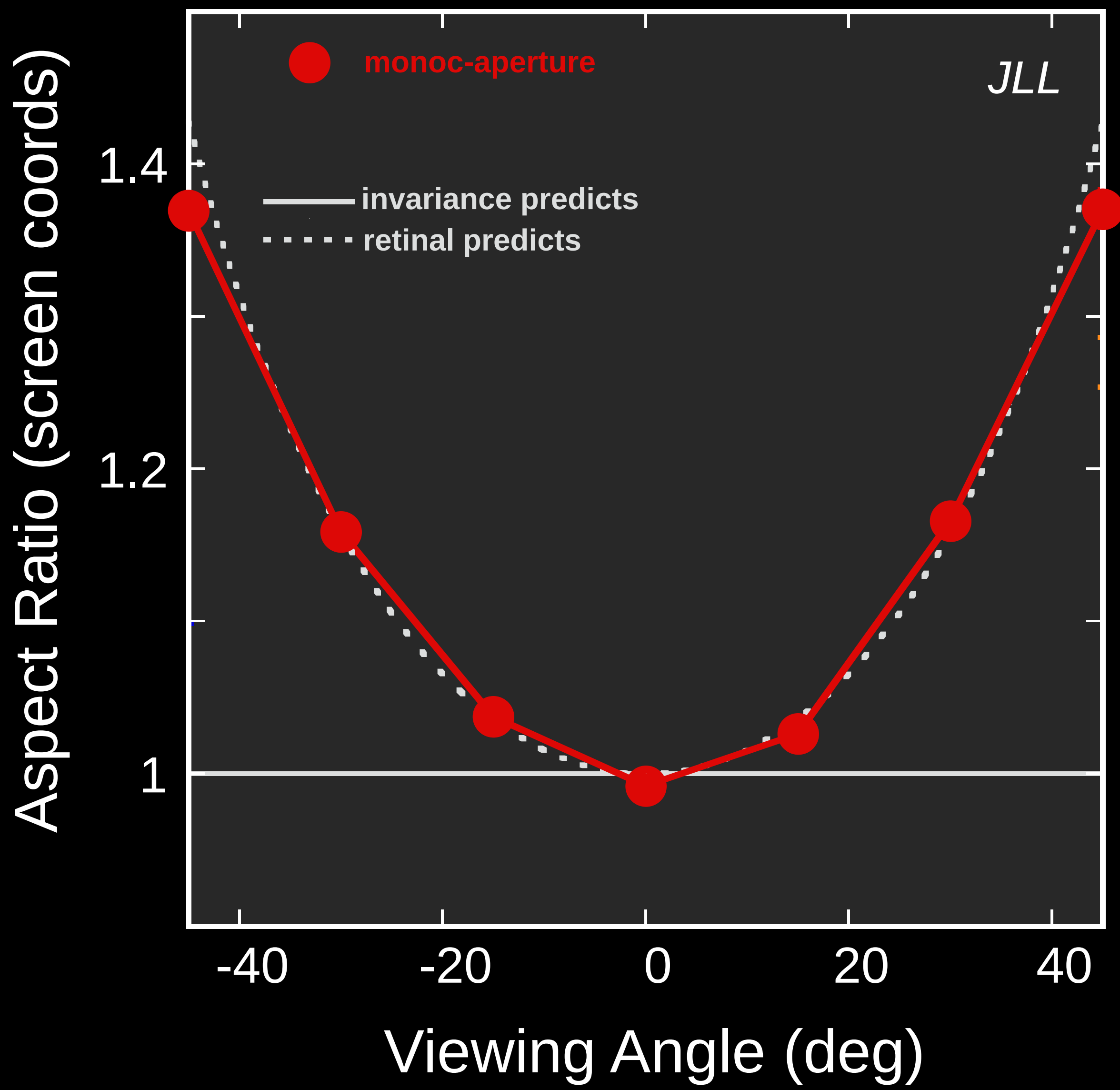


Predictions



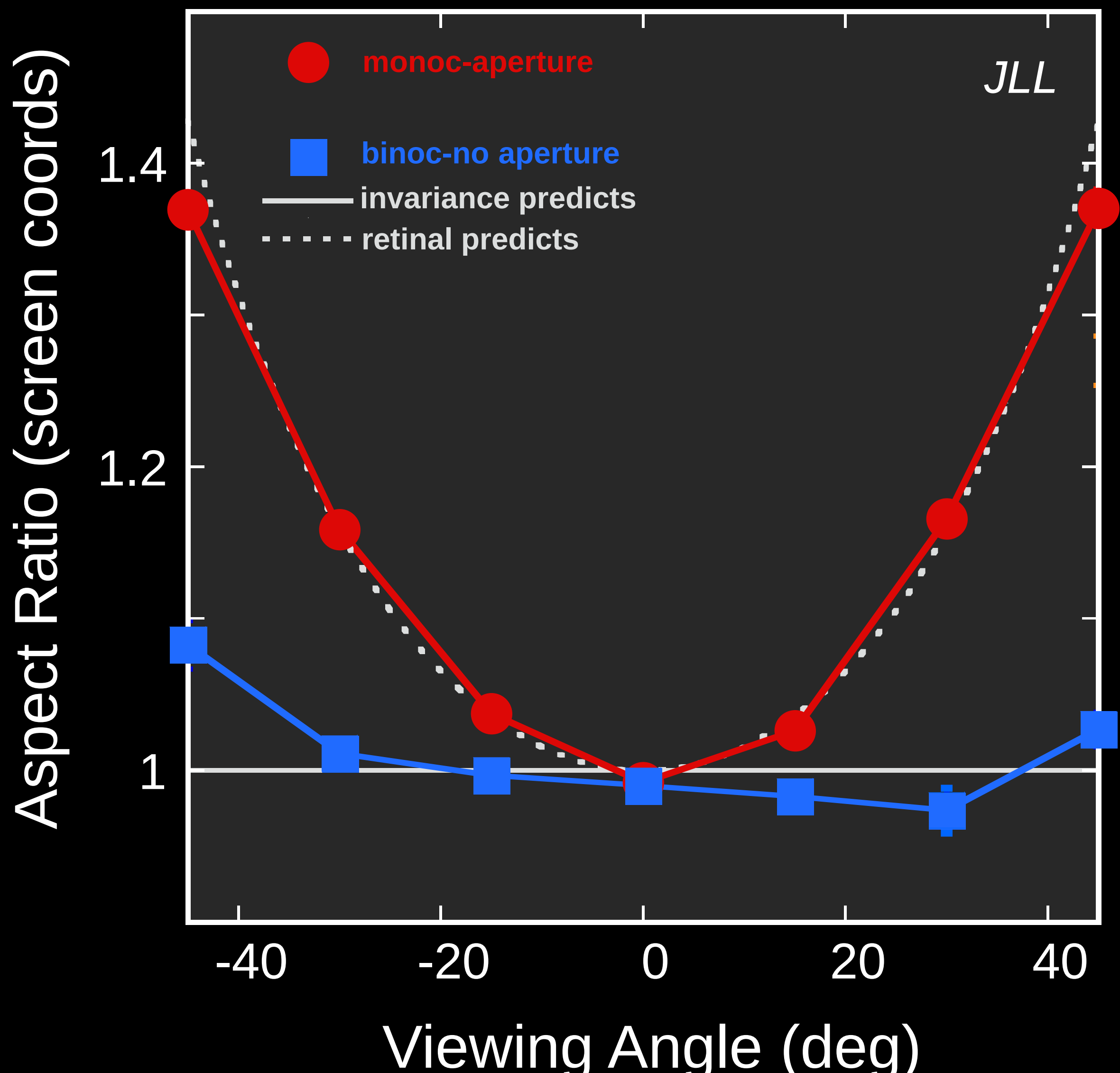


Results



Vishwanath, Girshick, & Banks, *Nature Neuroscience* (2005)

Results



Vishwanath, Girshick, & Banks, *Nature Neuroscience* (2005)

Compensation Hypotheses

Pictorial-compensation hypothesis

Different methods; all rely on geometric information in the picture (La Gournerie, 1859; Adams,1972; Greene,1983; Kubovy, 1986; Sedgwick, 1986, 1991; Caprile & Torre, 1990; Yang & Kubovy, 1999).

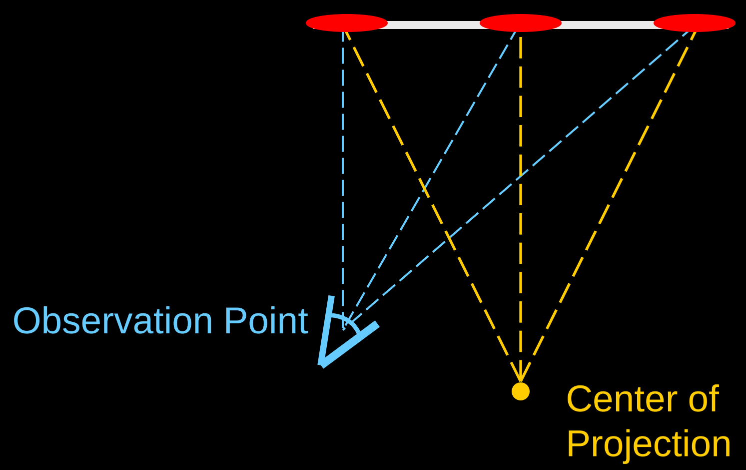
Surface-compensation hypothesis

Adjust retinal image based on measurement of picture surface slant (Wallach & Marshall, 1986; Rosinski & Farber, 1980; Rosinski et al., 1980).

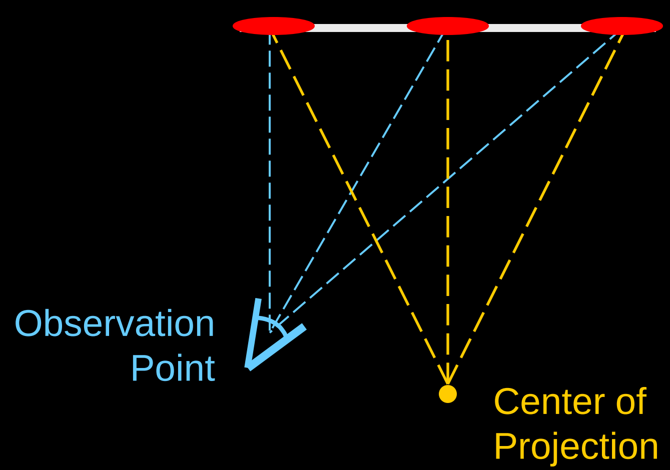
Experiment: Local or Global?

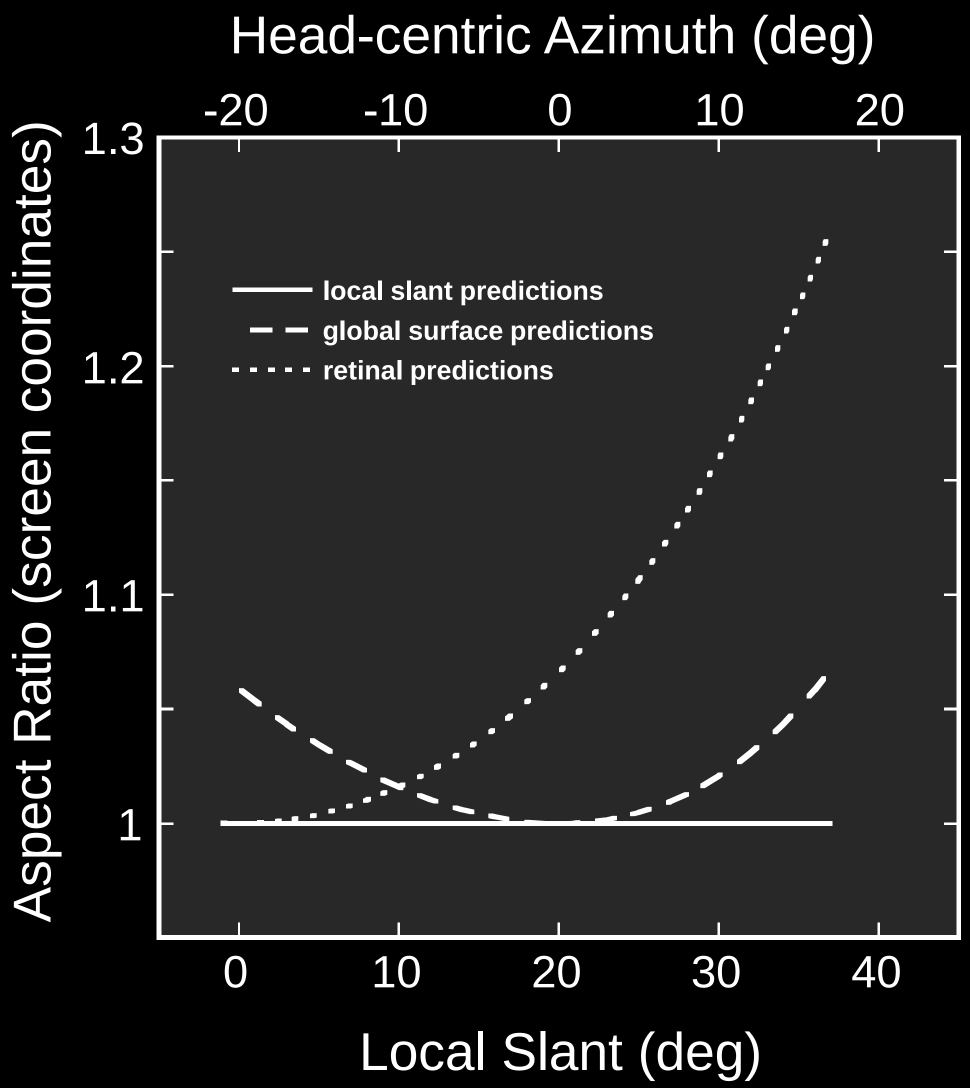
- In previous experiments, test objects presented at screen center.
- Thus, can't distinguish local vs global surface compensation.
- Presented test ovoids at different eccentricities on screen.

Frontal projection & oblique viewing



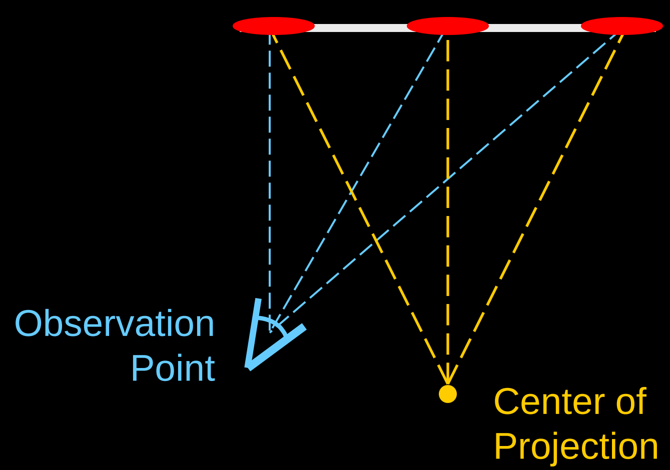
Results

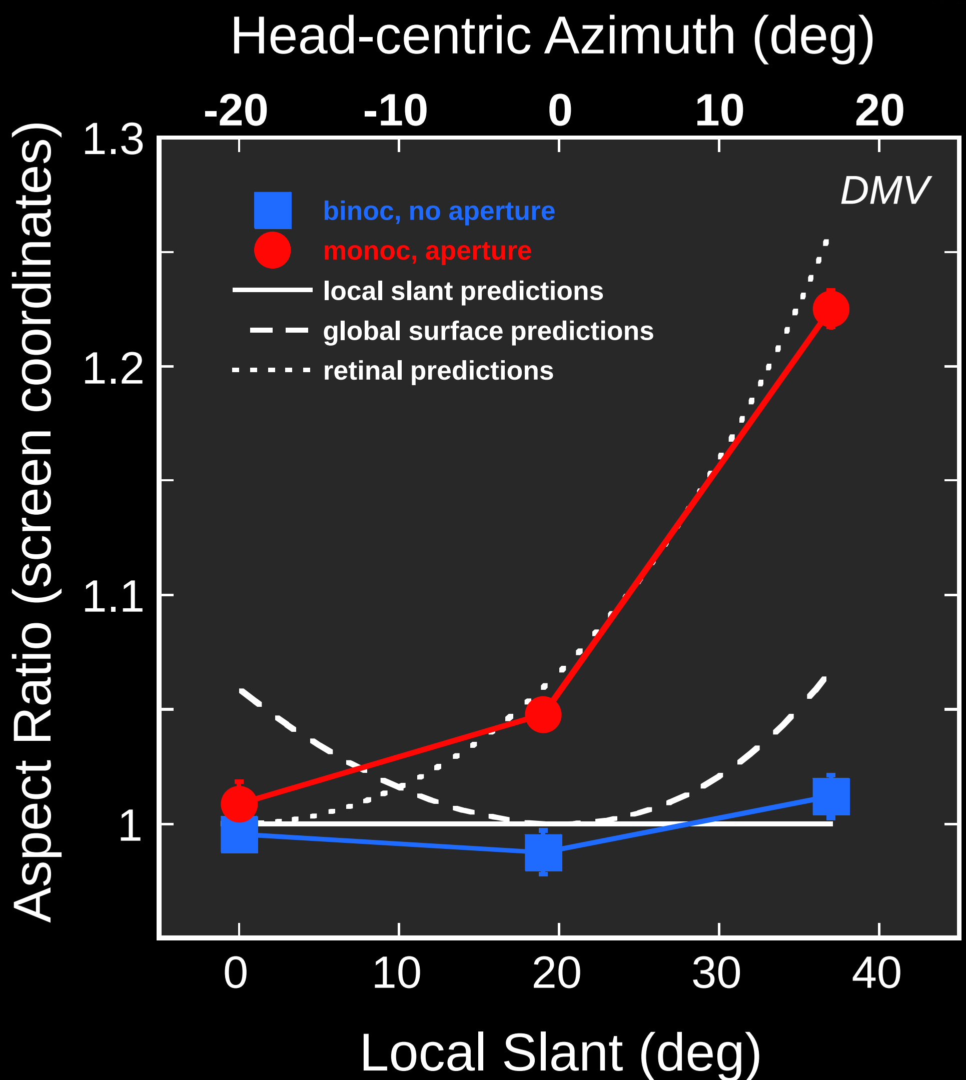




Vishwanath, Girshick, & Banks, *Nature Neuroscience* (2005)

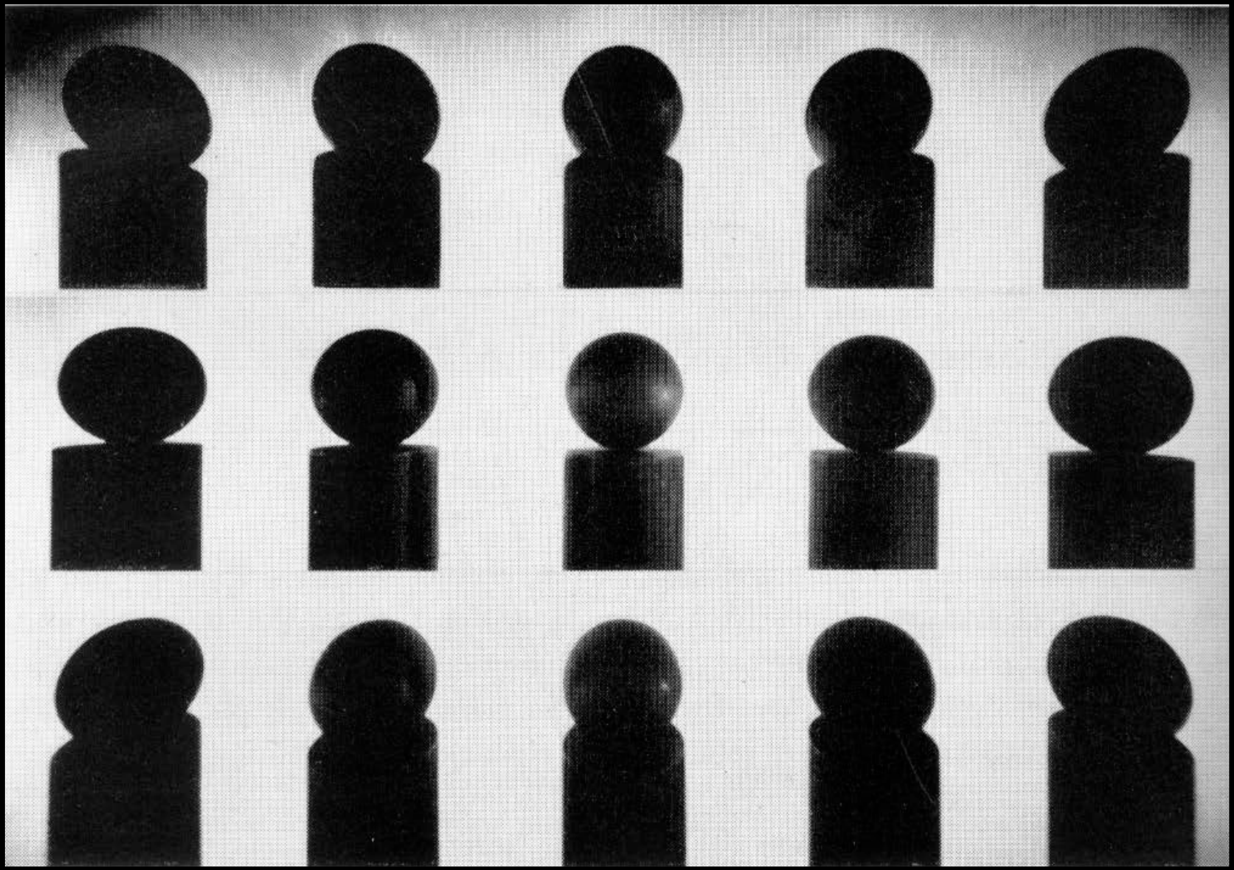
Results





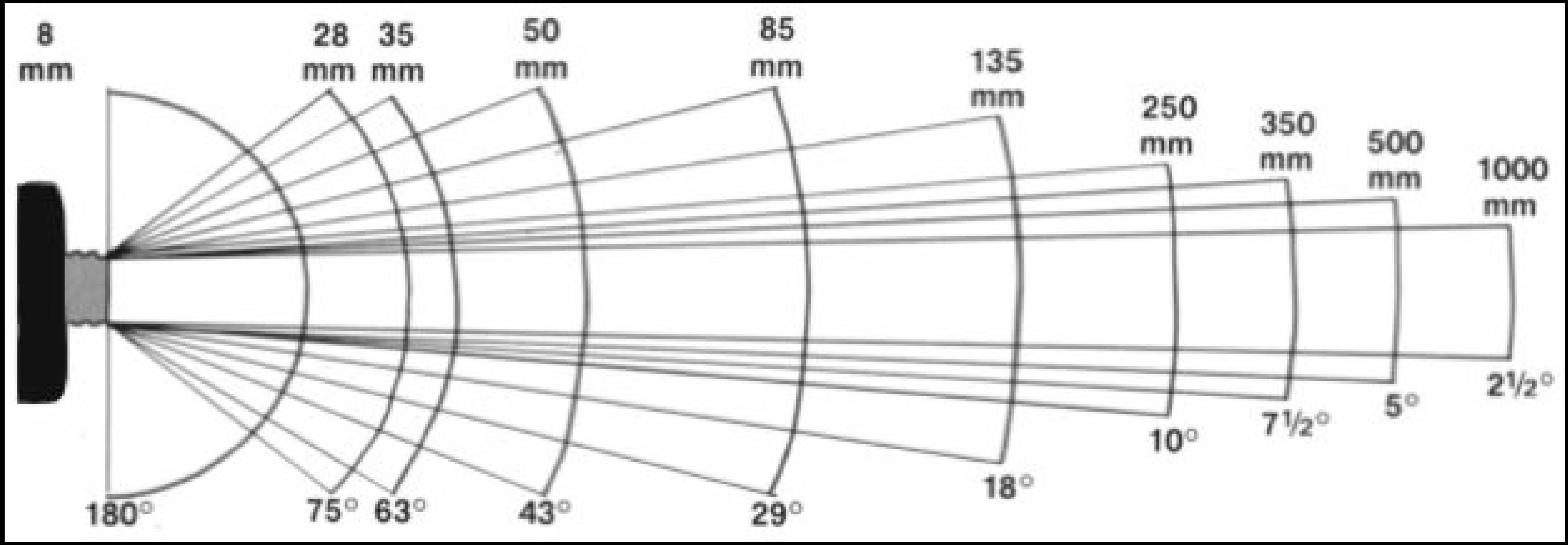
Vishwanath, Girshick, & Banks, *Nature Neuroscience* (2005)

Wide-field Distortion



With short focal length, eccentric spheres in picture perceived as ellipsoidal when viewed (binocularly) from CoP.

Focal Length & Field of View

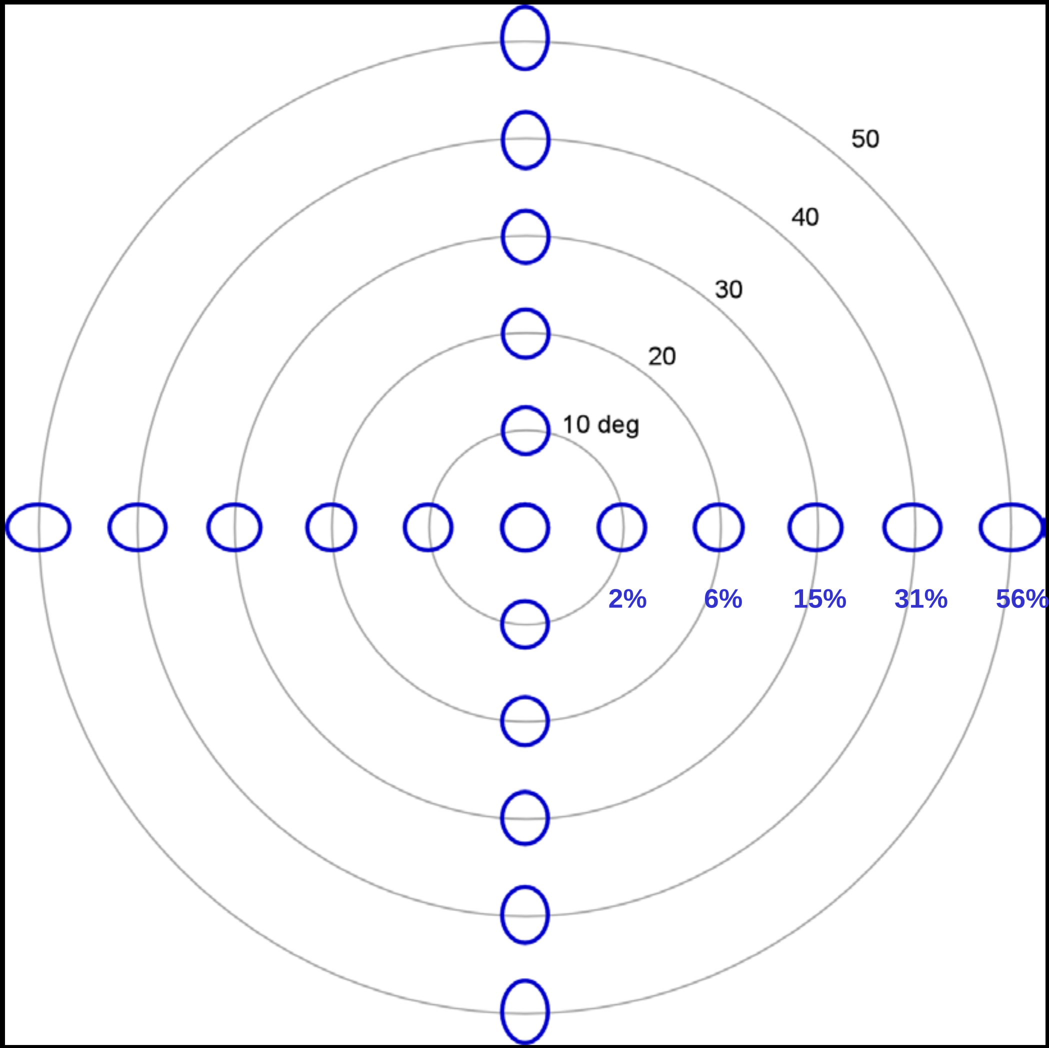


w = width of film
f = focal length
/ = angular subtense of photo from CoP

Recommended focal length for naturalistic photography:
50 mm for 35-mm film

Focal Length & Field of View

- Projections of spheres as a function of eccentricity.
- Ellipses perceived as non-circular when aspect ratio > 1.05 (Regan & Hamstra, 1992).



Preferred Focal Length

Recommended focal length for 35-mm film is 50 mm for natural-looking photographs.

Field of view for photograph given by:

w = width of film

f = focal length

/ = angular subtense of photo from CoP

We showed that critical / before distortion is ~40 deg (+/-20). Solving for f:

mm

Photographic Effects

- Wide-angle distortion

  Well known in photography, cinematography, computer graphics, and perspective painting.

  Texts recommend lens focal length of ~50mm (with 35mm film format) to avoid distortion.

- Depth compression/expansion

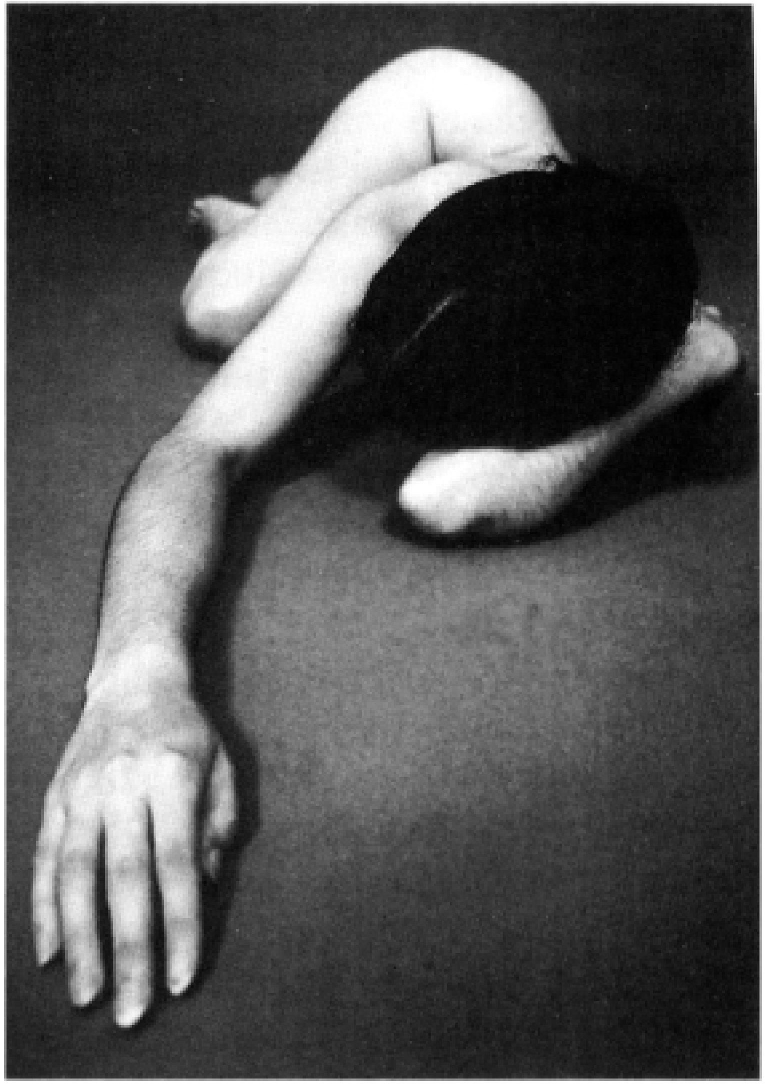
  Well known in photography and cinematography for manipulation of artistic effects.

  Texts recommend focal length of ~50mm to avoid compression or expansion.

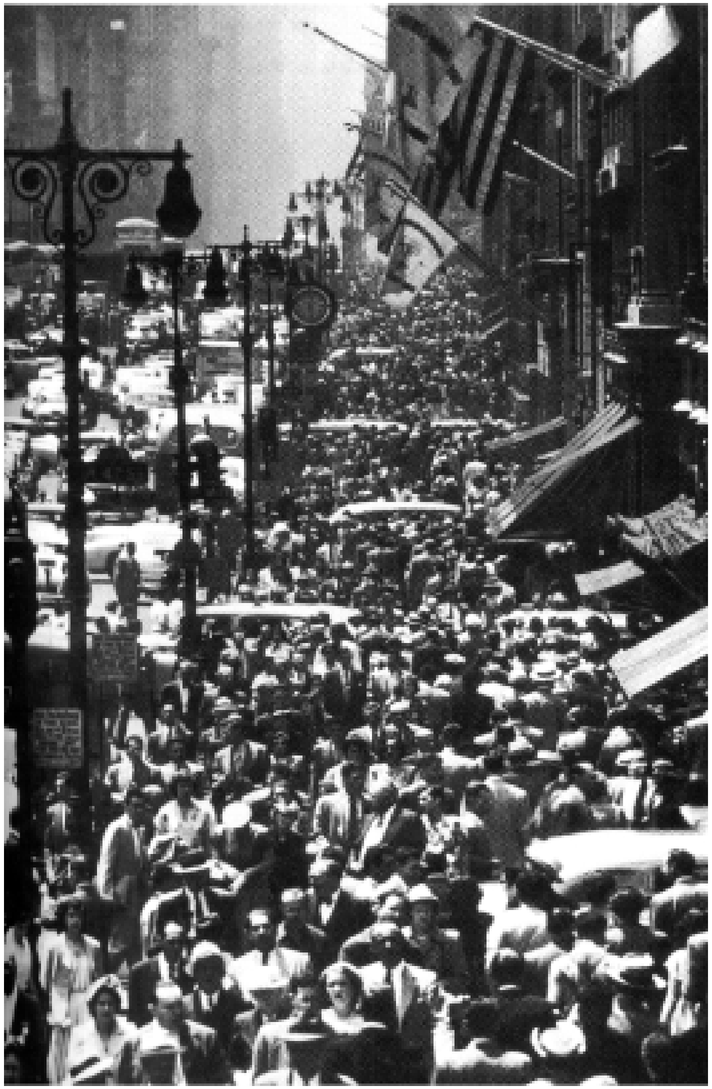
- Depth of field effects

  Widely utilized in photography and cinematography to create artistic effects, attract viewer gaze, etc.

Different Focal Lengths



short focal length

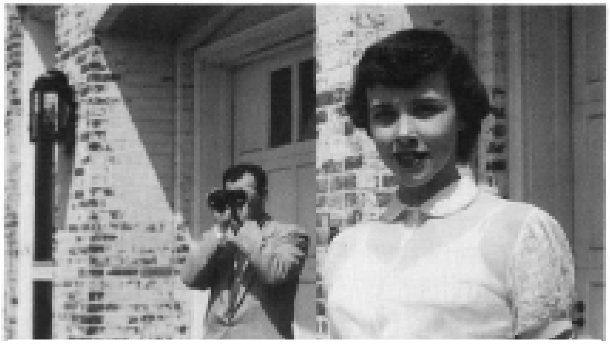


long focal length

London et al. (2005). *Photography.* Prentice Hall.

Depth Compression & Expansion

Short focal length



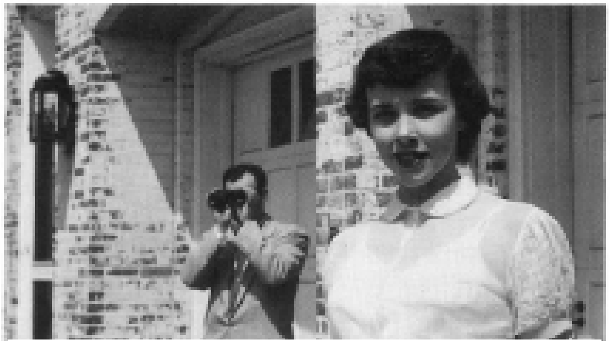
Medium focal length (f = ~50mm)

Long focal length

London et al. (2005). *Photography*. Prentice Hall.

Depth Compression & Expansion

Short focal length



Medium focal length (f = ~50mm)

Long focal length

Photography texts recommend particular lens focal length given film size to create most natural photographs.

Common rule: Normal focal length equals diagonal dimension of film. For 35-mm film equals ~50mm.

London et al. (2005): “The angle of view seems natural, and the relative size of near and far objects seems normal”.

London et al. (2005). *Photography*. Prentice Hall.

Depth Compression & Expansion

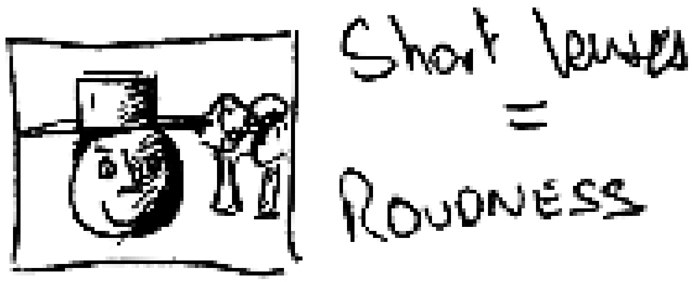


FIGURE 6.12
Short lenses and compact setup will give you great a 3D imagery.

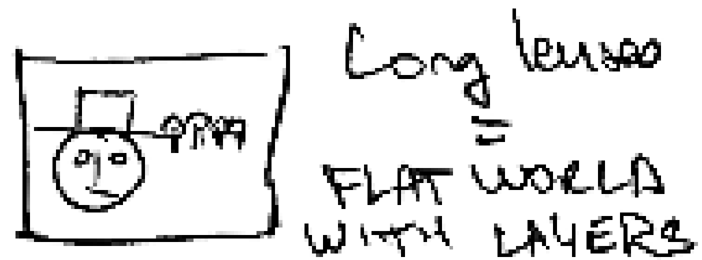


FIGURE 6.13
Long lenses' effects and faraway backgrounds will look bad on the screen.

"Wide lenses (short focal lengths) make the objects rounder and the background smaller on screen".

"Long lenses flatten the actors and make them look like cardboard stand-ups and 3D reveals the actual distance between scene elements."

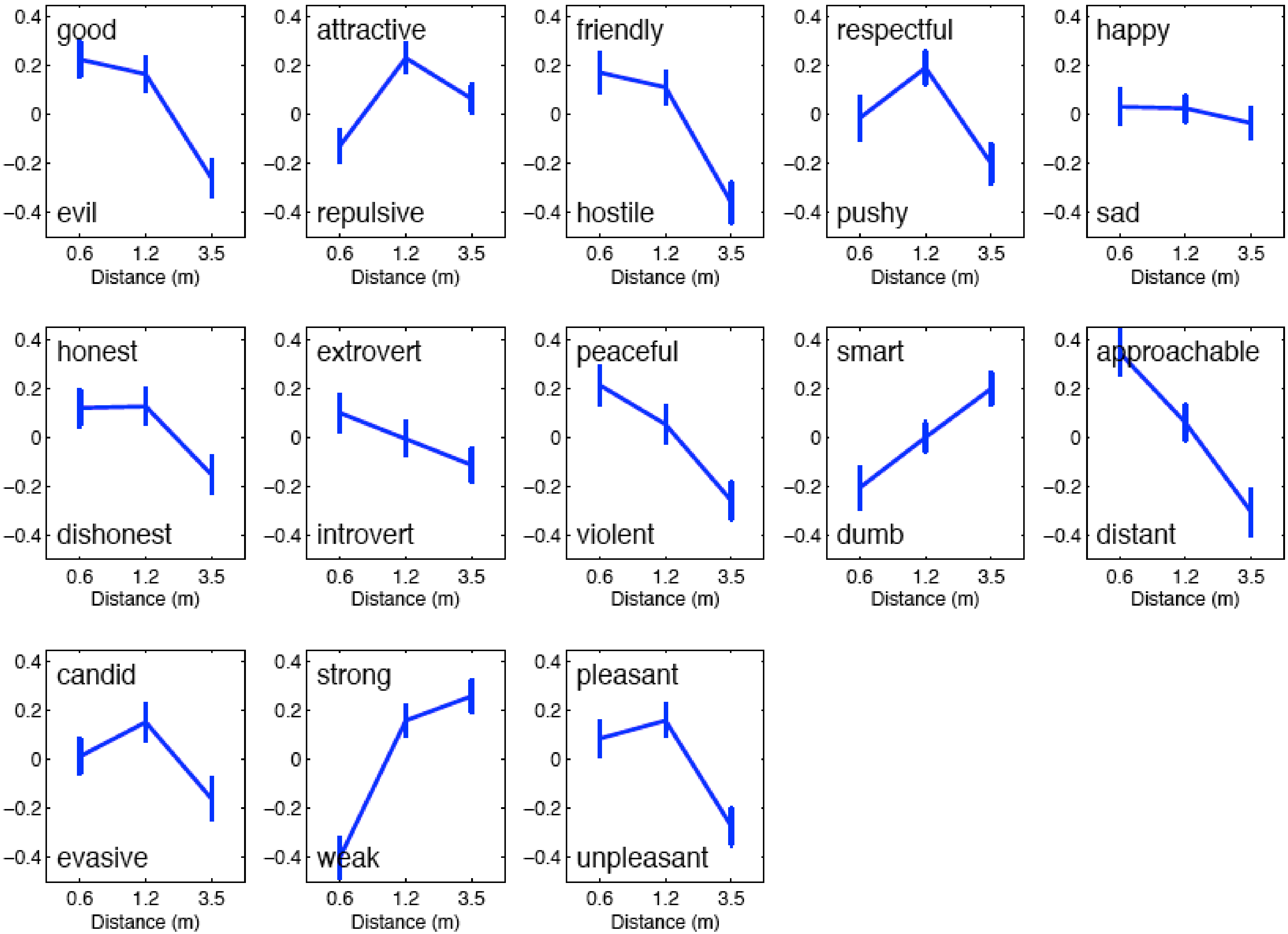
Mendiburu (2009). *3D Movie Making.* Focal Press.

Focal Length & Portraits

short focal length

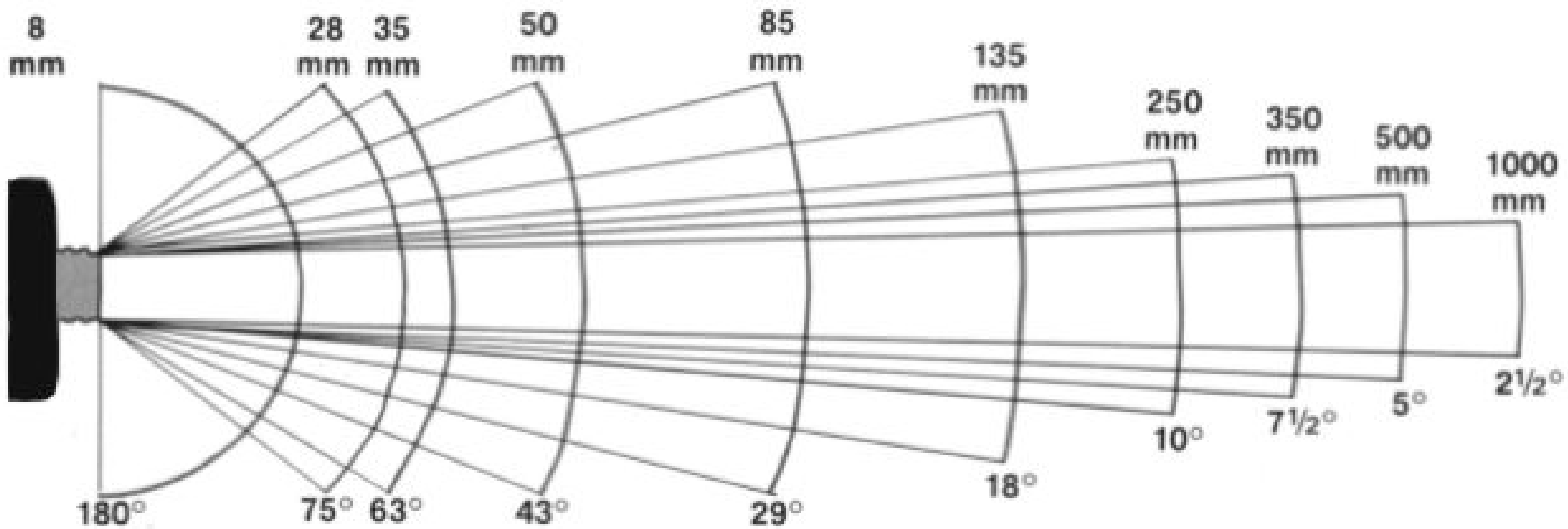
long focal length

Perona (2007)

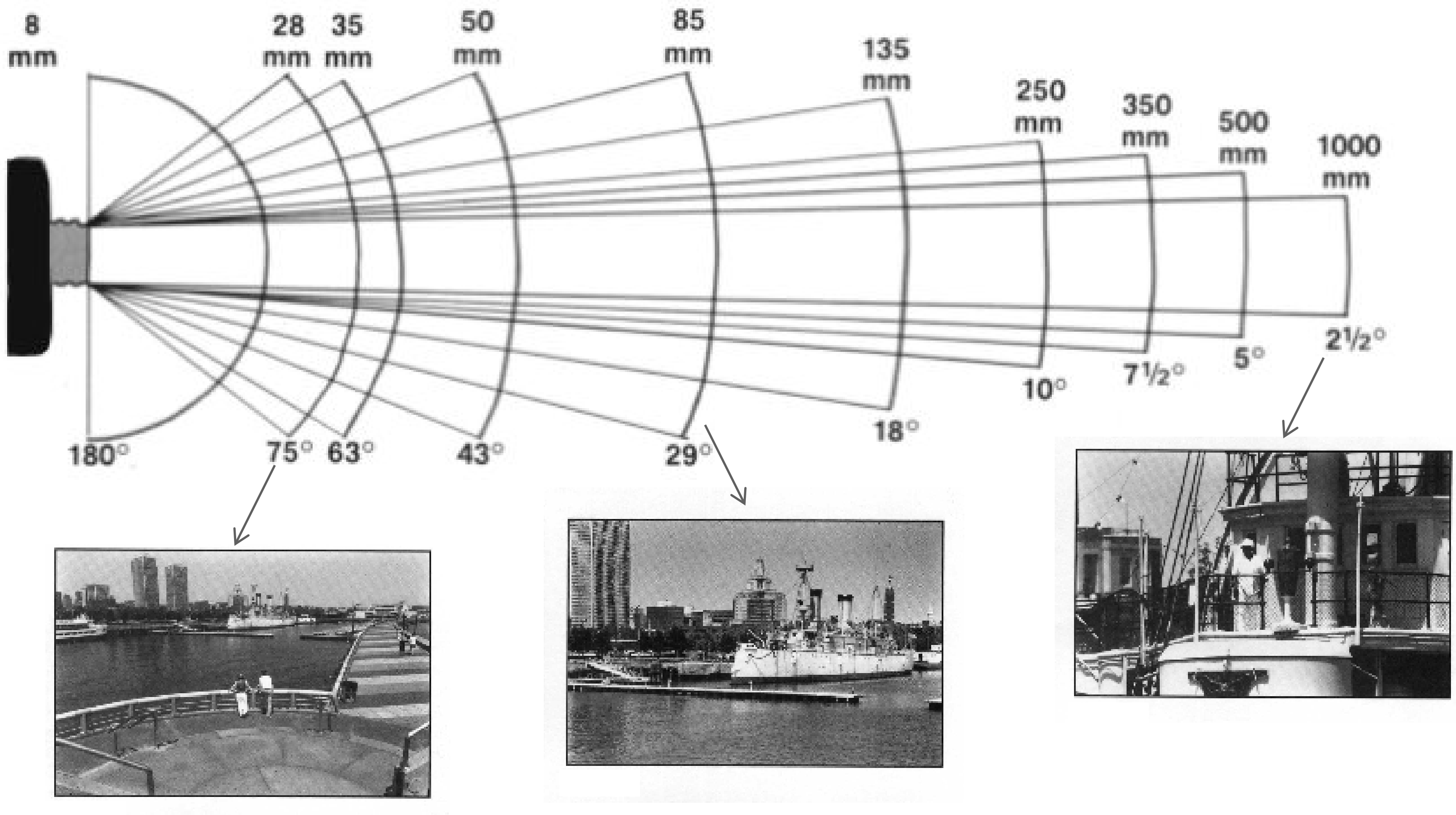


good
evil
attractive
repulsive
friendly
hostile
respectful
pushy
happy
sad
honest
dishonest
extrovert
introvert
peaceful
violent
smart
dumb
approachable
distant
candid
evasive
strong
weak
pleasant
unpleasant
0.4
0.2
0
−0.2
−0.4
0.6
1.2
3.5
Distance (m)

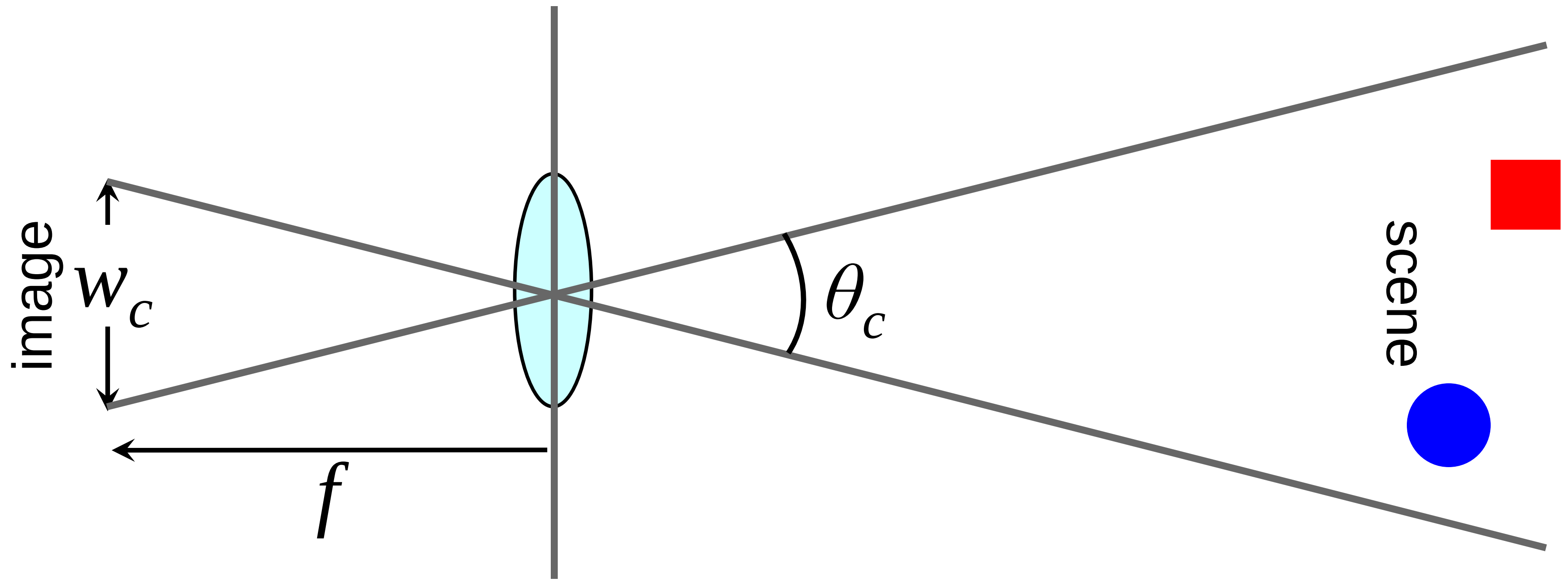
Focal Length & Field of View



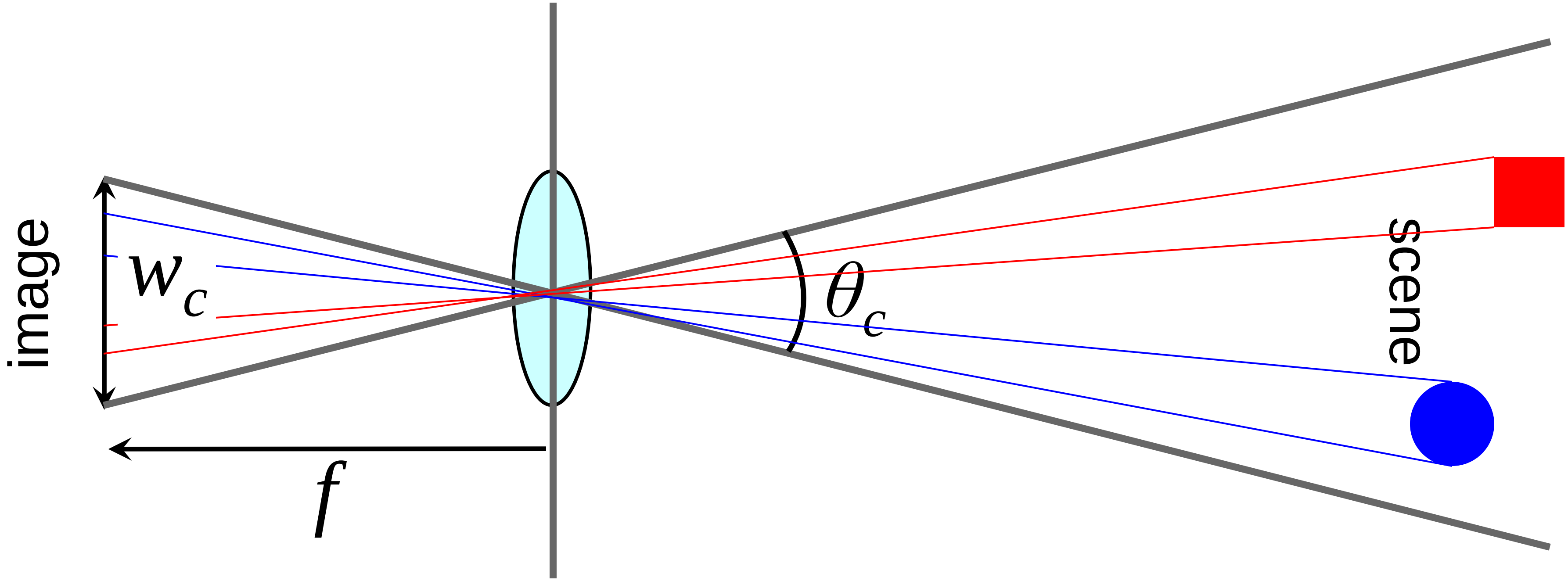
Focal Length & Field of View



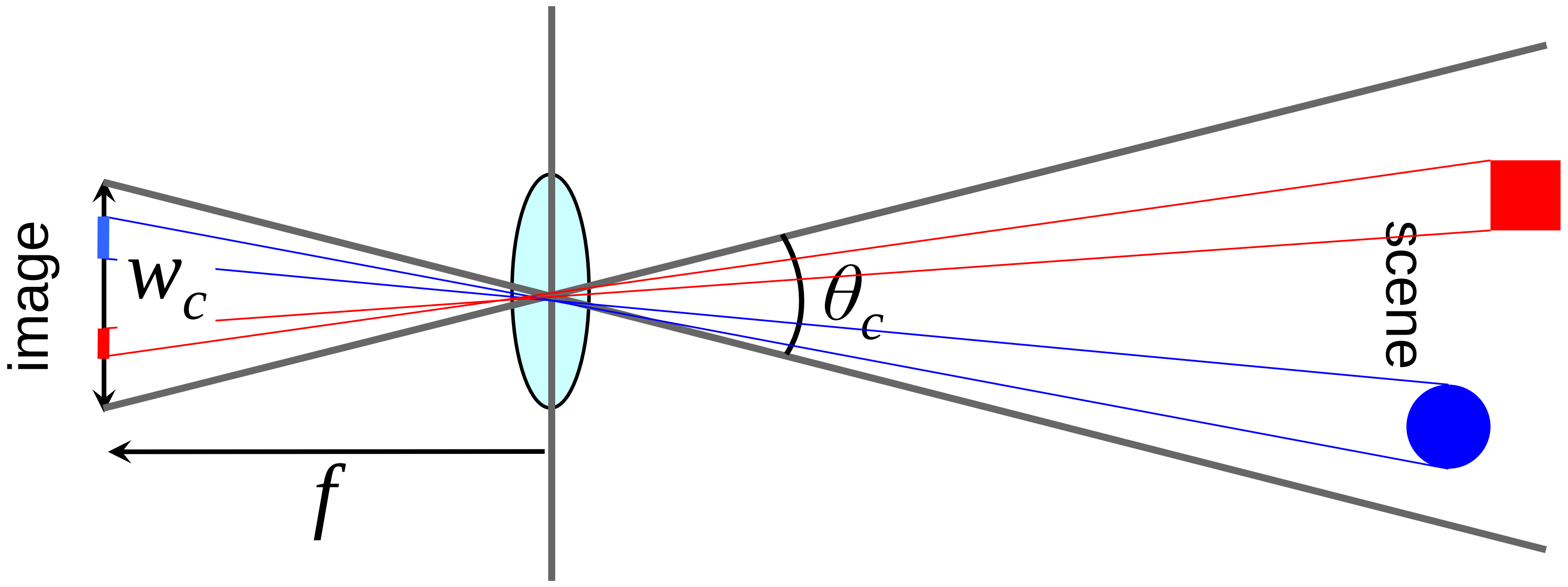
Focal Length & Field of View



Focal Length & Field of View

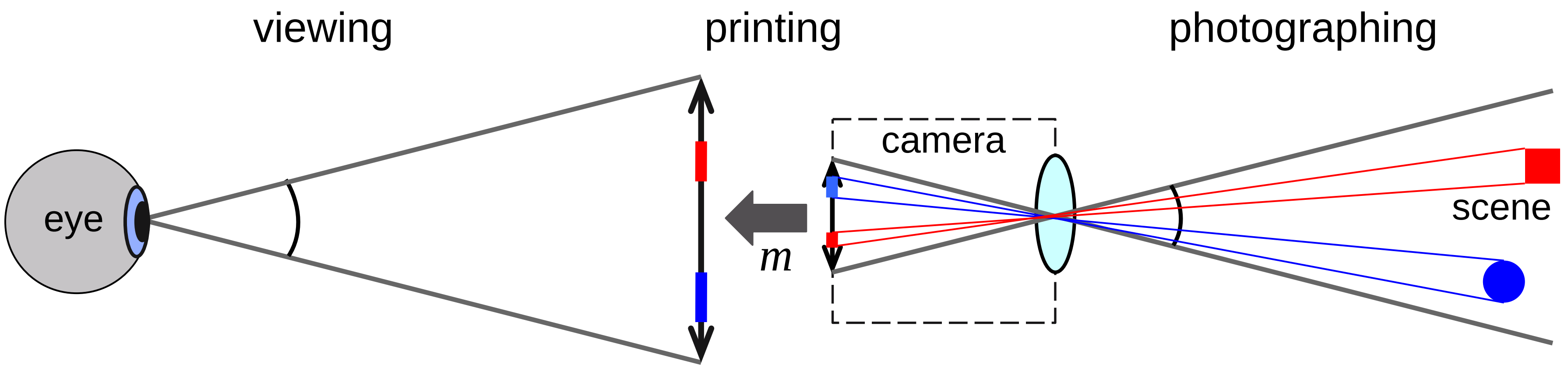


Focal Length & Field of View

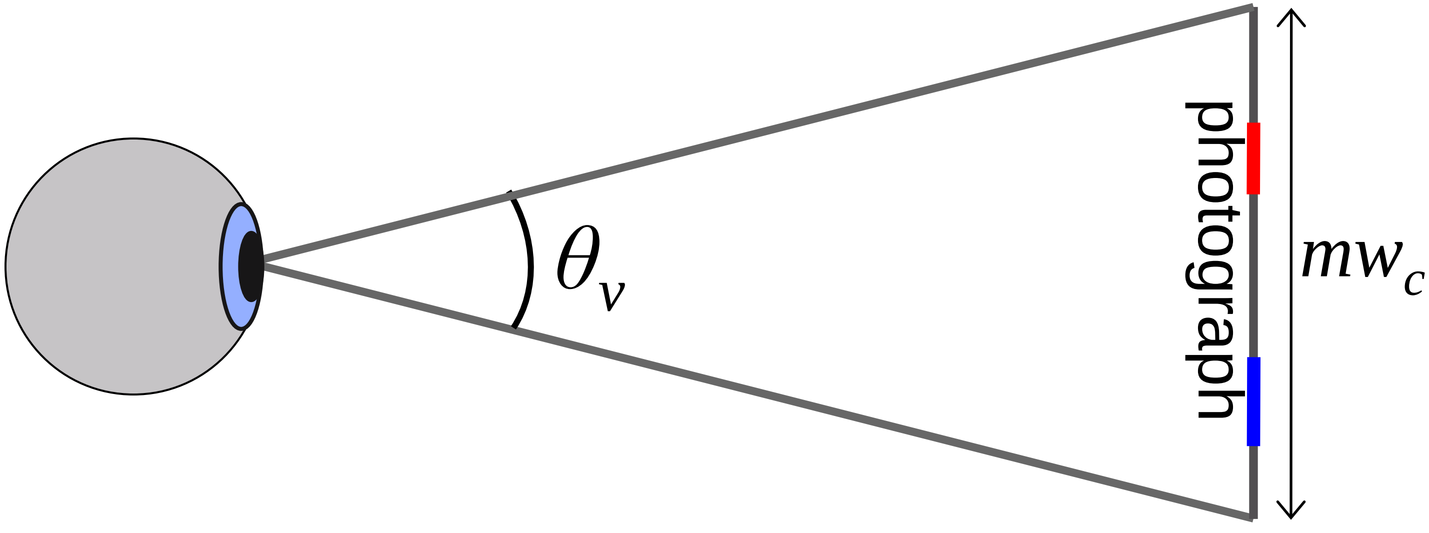


captured image: $\theta_c = 2\tan^{-1}(w_c/2f)$

Focal Length & Field of View



Viewing Captured Image

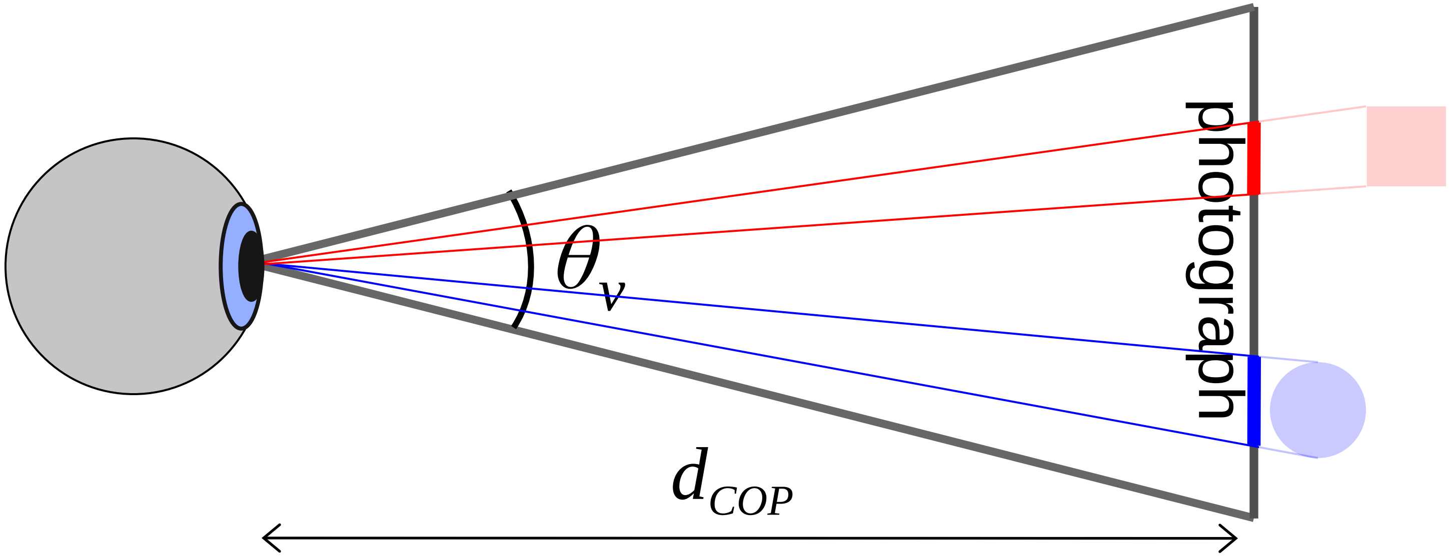


height of photograph = mw_c

where m is magnification of print

viewed photograph: $\theta_v = 2\tan^{-1}(mw_c/2d_{COP})$

Viewing Captured Image



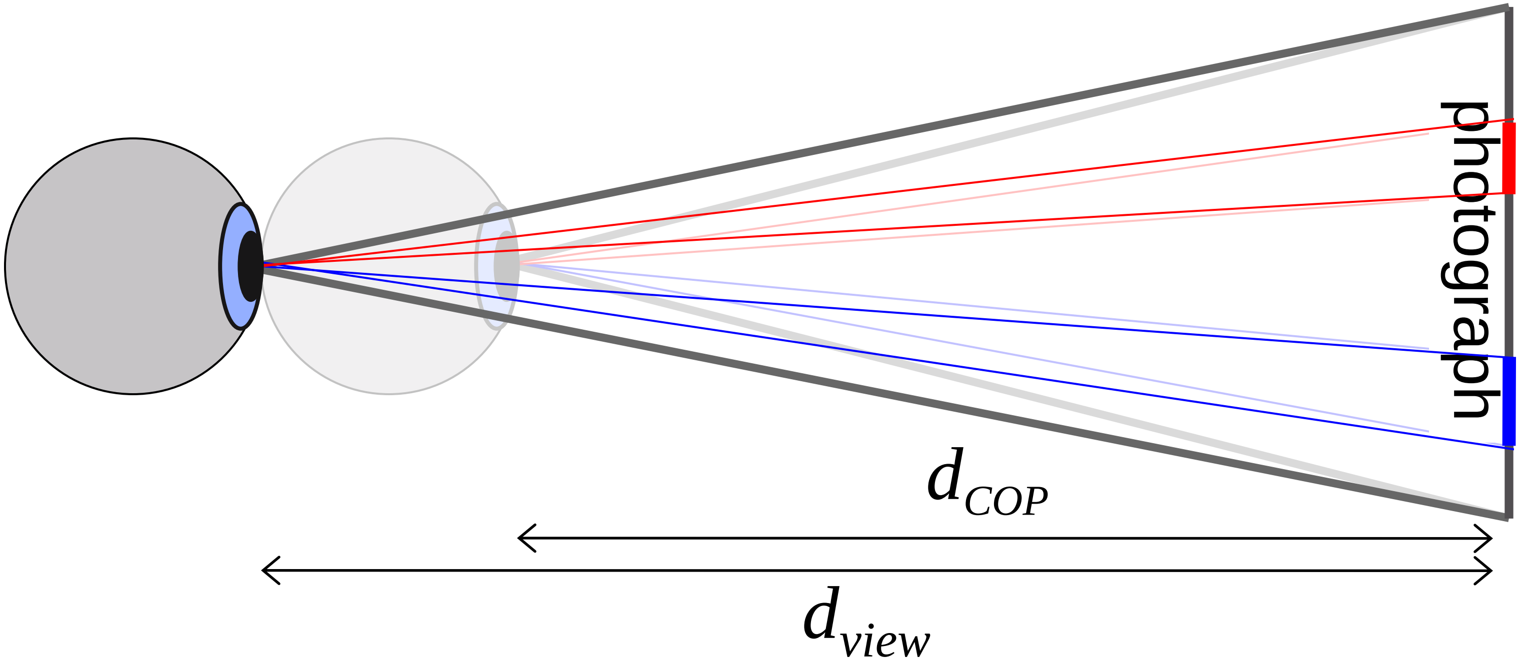
height of photograph = mw_c

where m is magnification of print

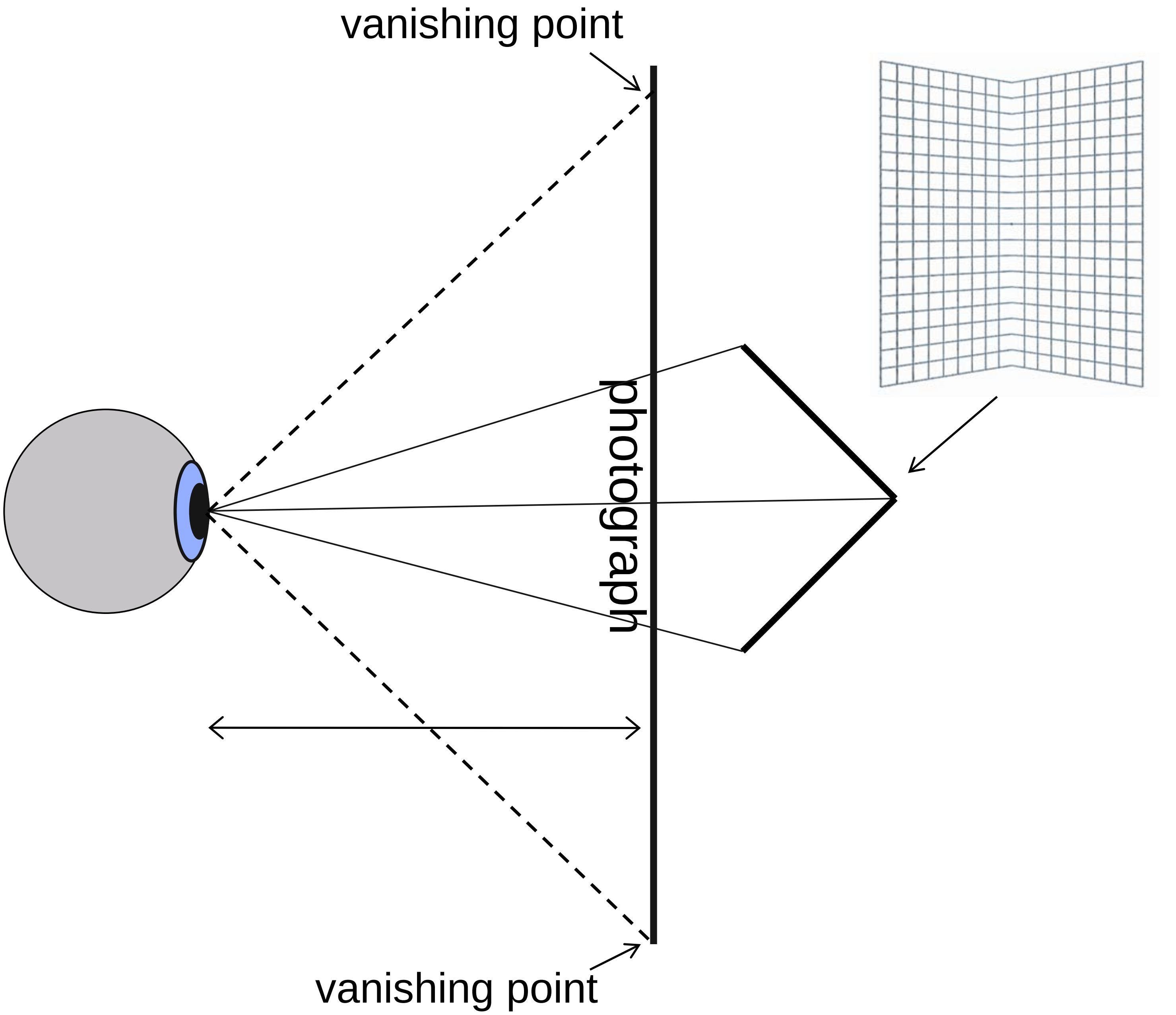
viewed photograph: $\theta_v = 2\tan^{-1}(mw_c/2d_{COP})$

$d_{COP} = mf$

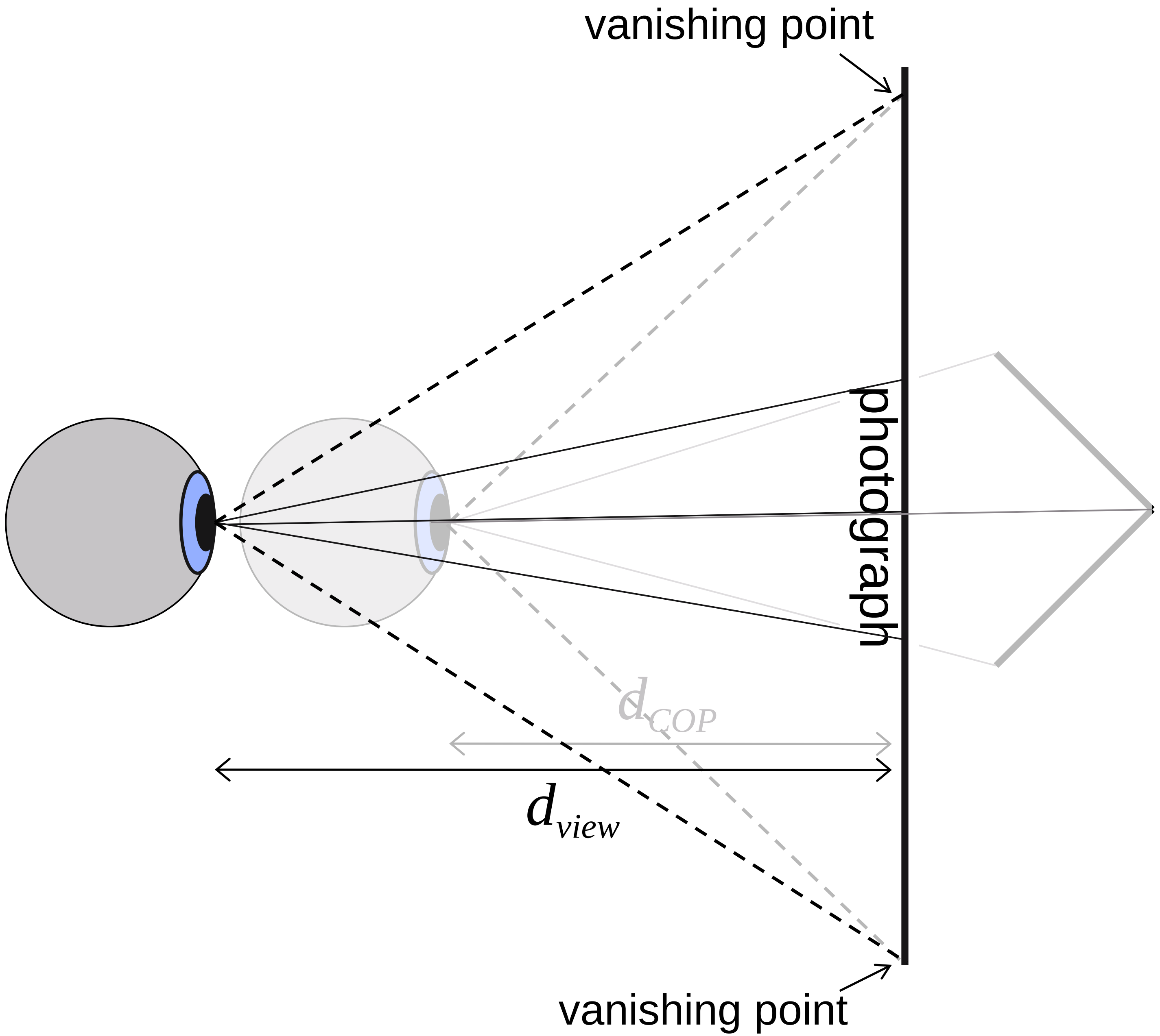
Viewing from Wrong Distance



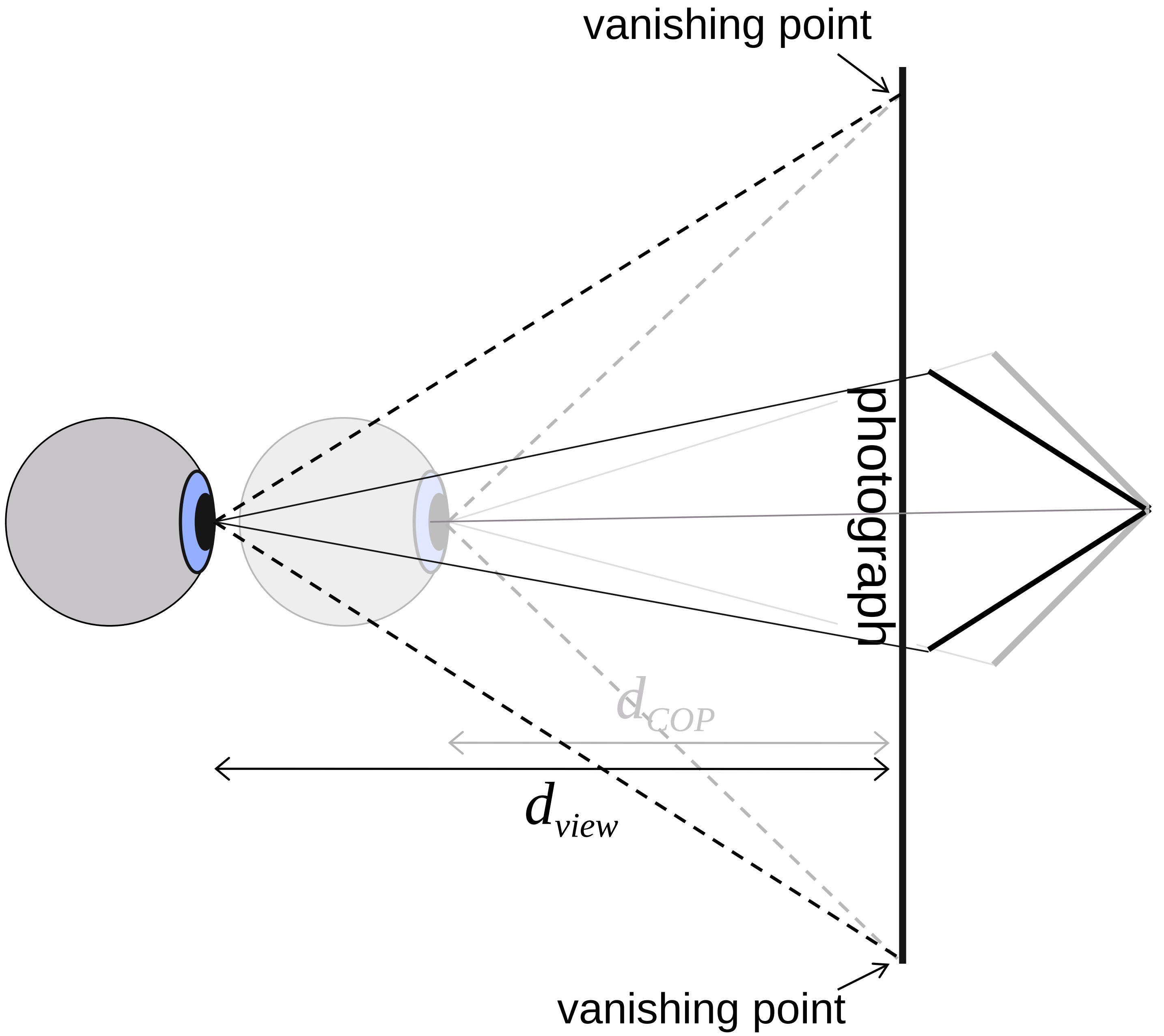
Depth Interpretation



Depth Interpretation



Depth Interpretation



Our Hypothesis

- Depth compression/expansion, associated with long and short focal lengths, caused by mismatches between correct viewing distance (d_{COP}) and actual viewing distance (d_{view}).
- People tend to set viewing distance to constant proportion of picture height (television: Ardito, 1994).
- Thus tend to view long focal-length pictures from too close ($d_{view} < d_{COP}$) and short focal-length pictures from too far ($d_{view} > d_{COP}$).
- "Normal focal length" corresponds to length for which viewing distance corresponds to correct distance ($d_{view} \approx d_{COP}$); roughly 50mm because consistent with 3-4 times picture height.

How do People Set Viewing Distance?

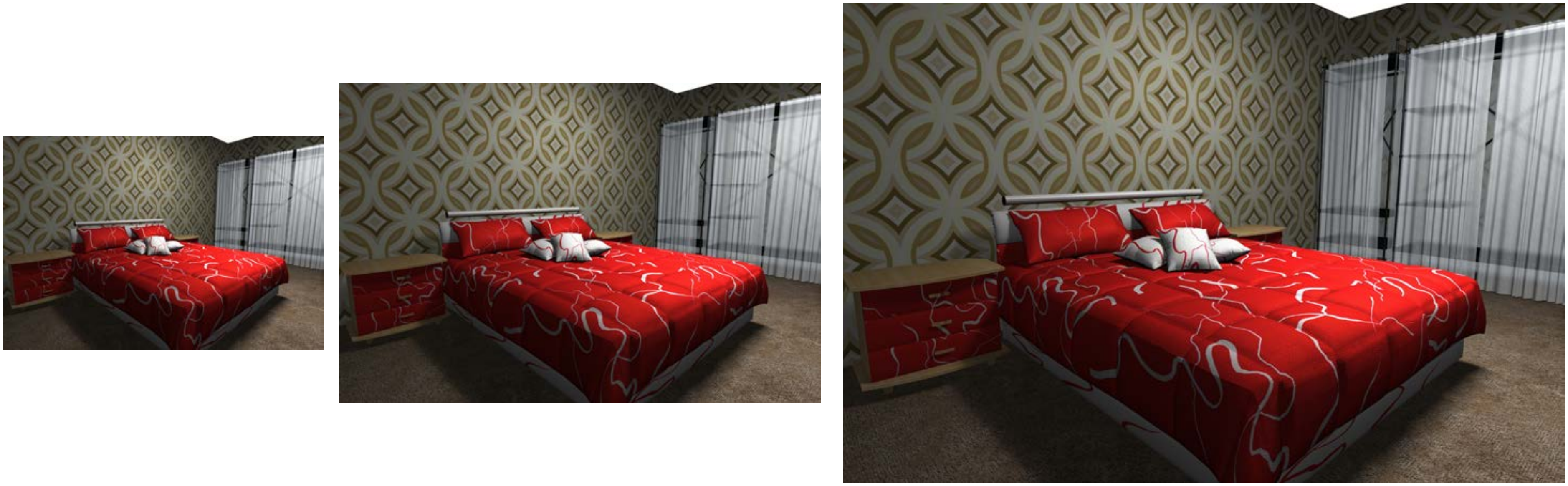
- Created several pictures
  - Photos of natural scenes (indoors, outdoors); computer-generated images (indoors, outdoors)
  - Varied focal length and distance from camera to central object in picture
  - Made prints with different magnifications and different croppings

Pictures with Different Focal Lengths

photographs with *f* = 22.4 – 160mm (35-mm equiv)

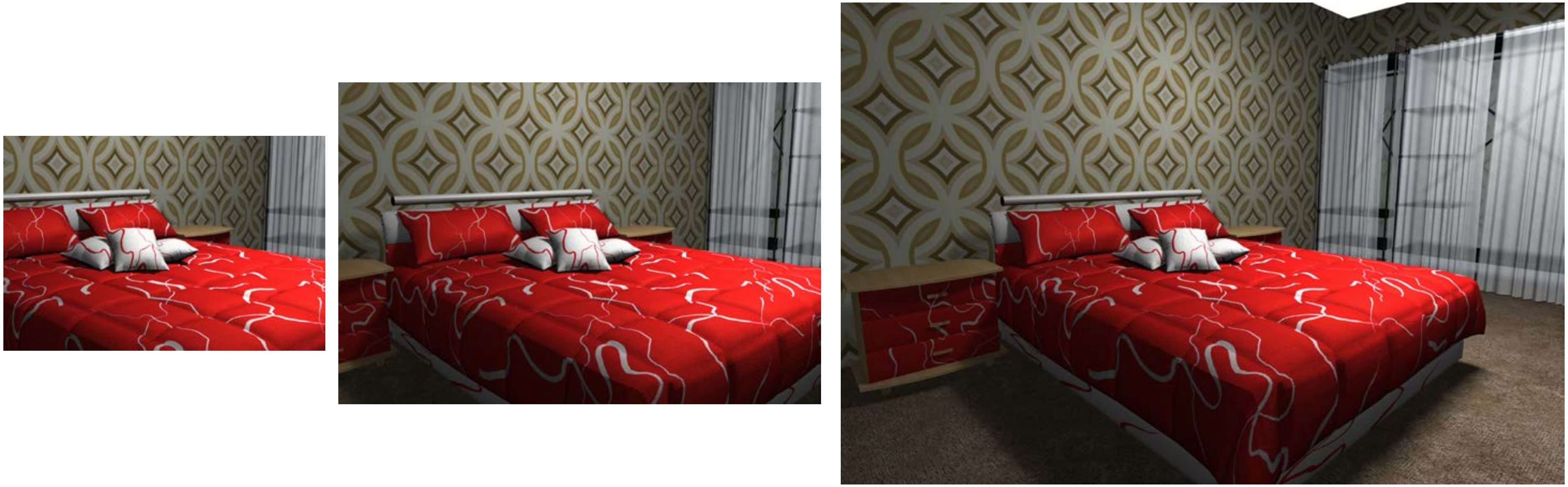
computer-generated images with *f* = 22.4 – 160mm (35-mm equiv)

Pictures with Different Magnifications



widths = 59 – 398mm

Pictures with Different Croppings



widths = 59 – 398mm

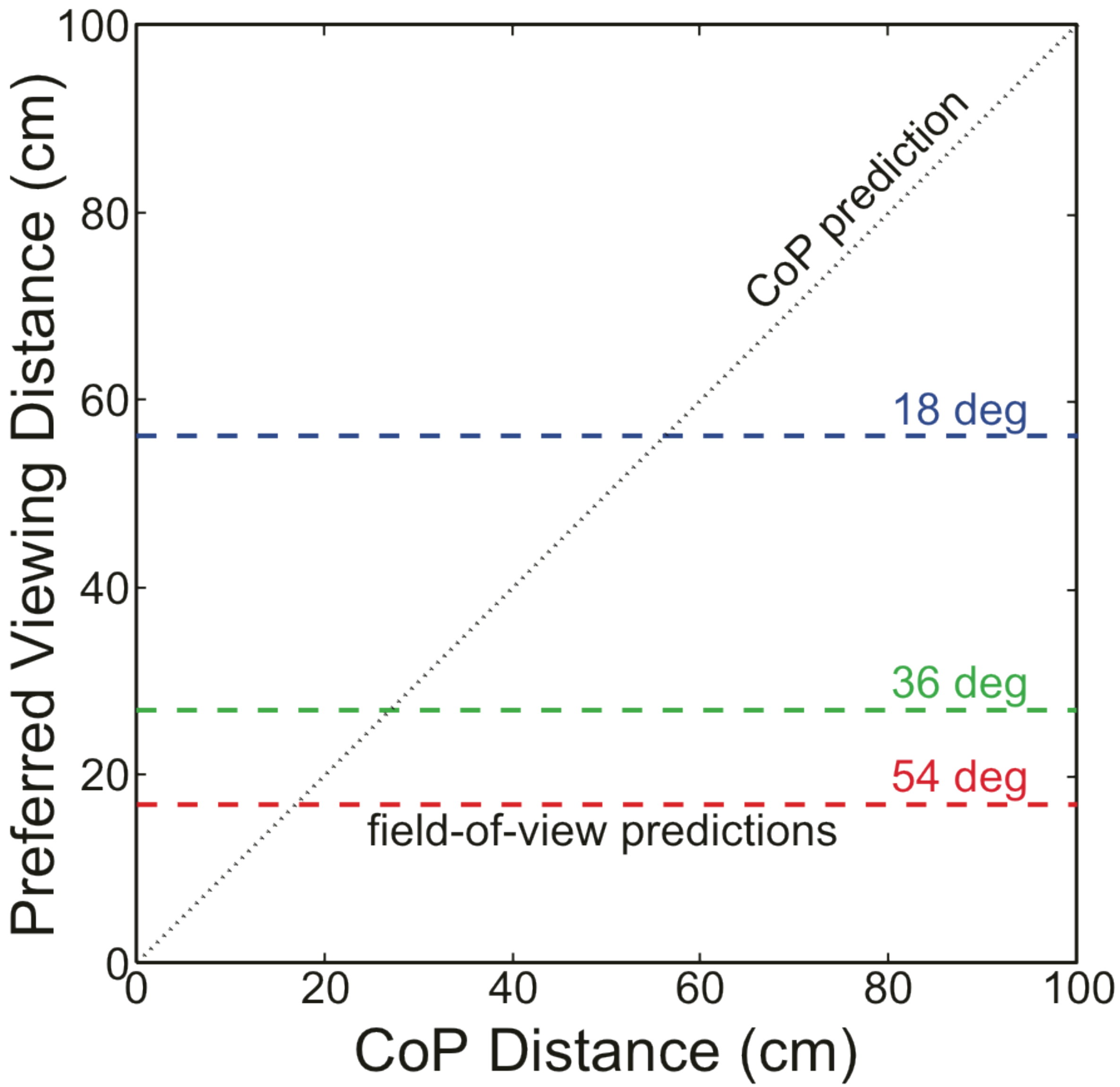
Preferred Viewing Distance

8 subjects adjusted viewing distance to preferred value.

Examined whether CoP distance or print width predicts preferred distance.

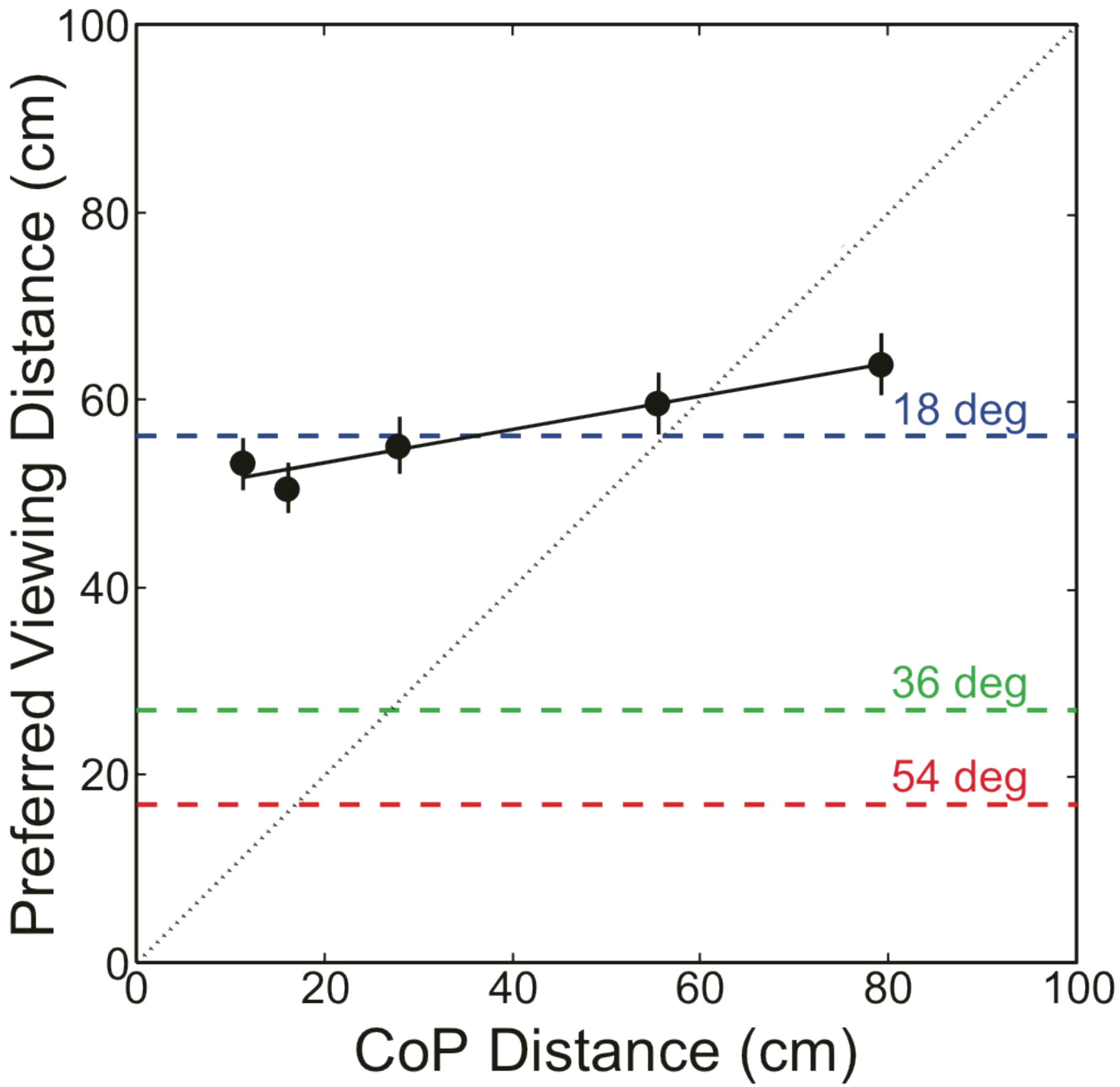
Viewing Pictures

For subset with print size 4.67×7 inches



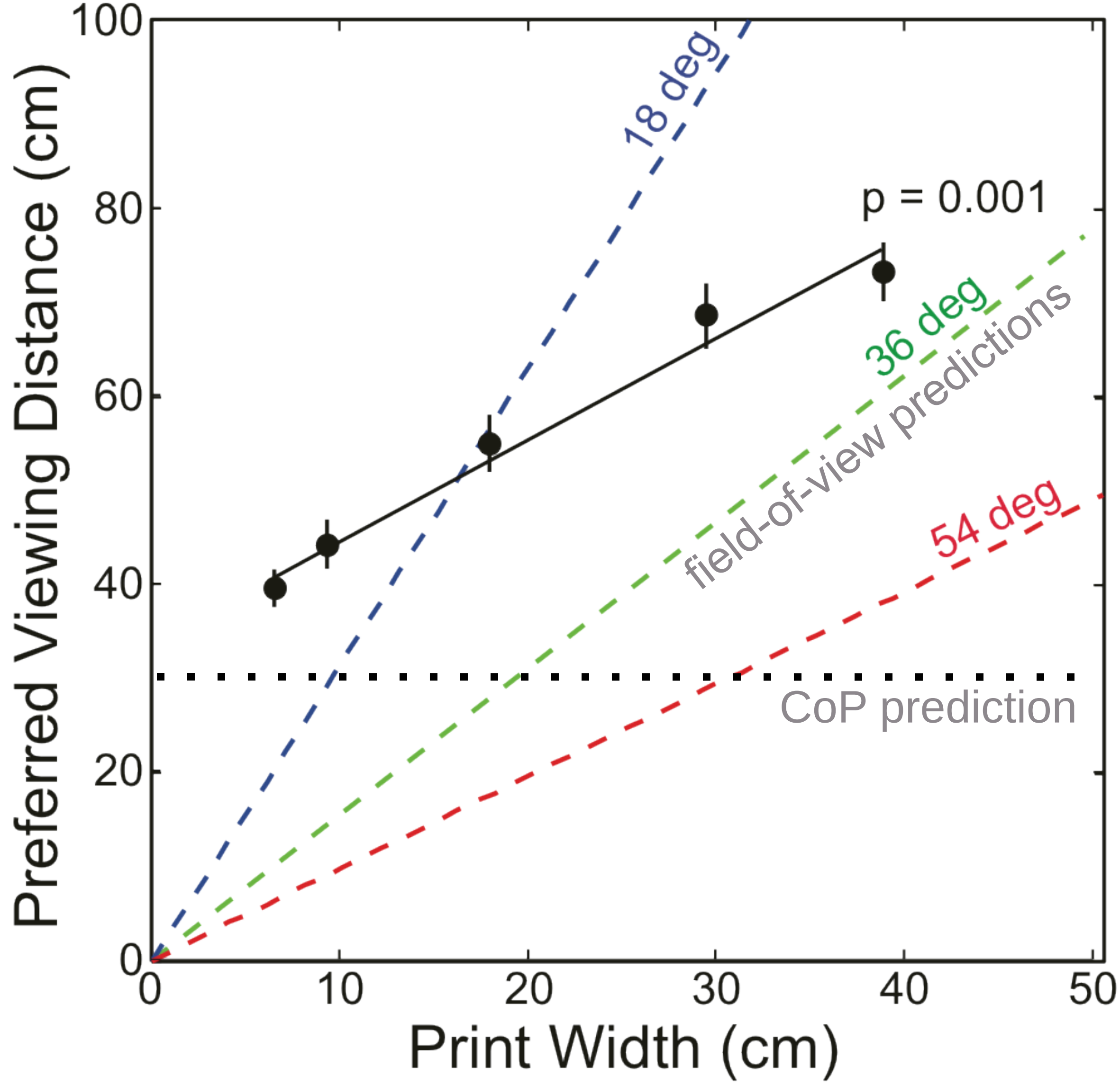
Viewing Pictures

For subset with print size 4.67x7 inches

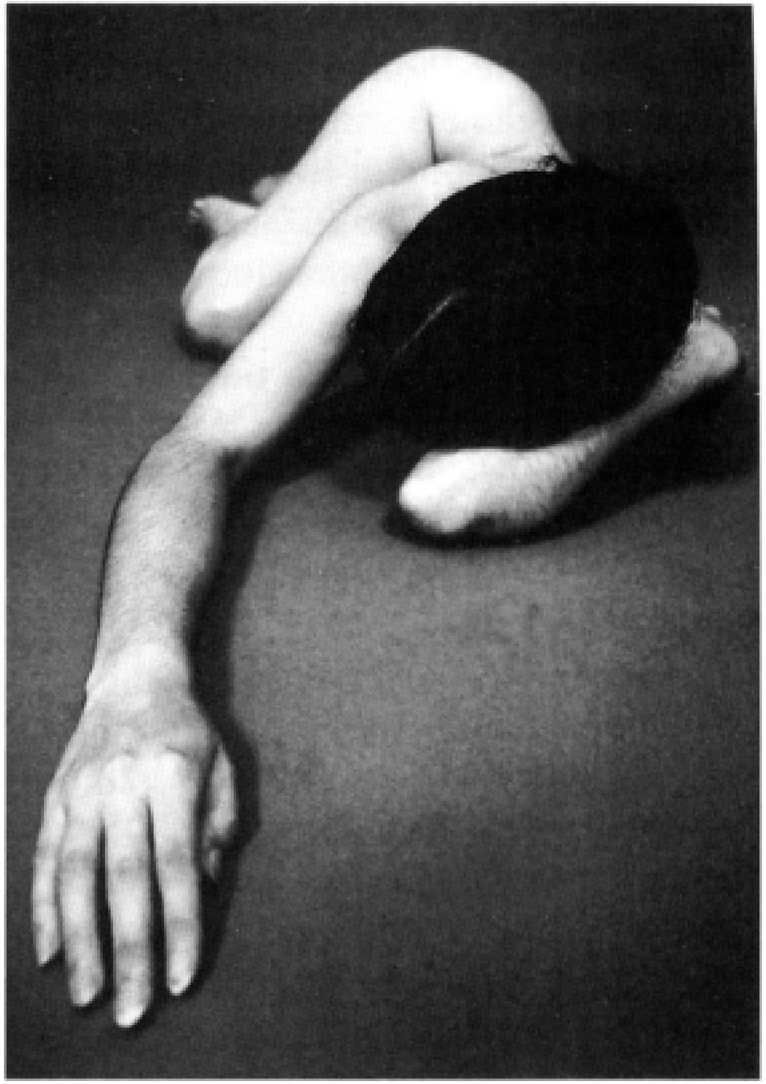


Viewing Pictures

For subset with f = 35mm, which is close to f = 50mm for 35-mm equivalent



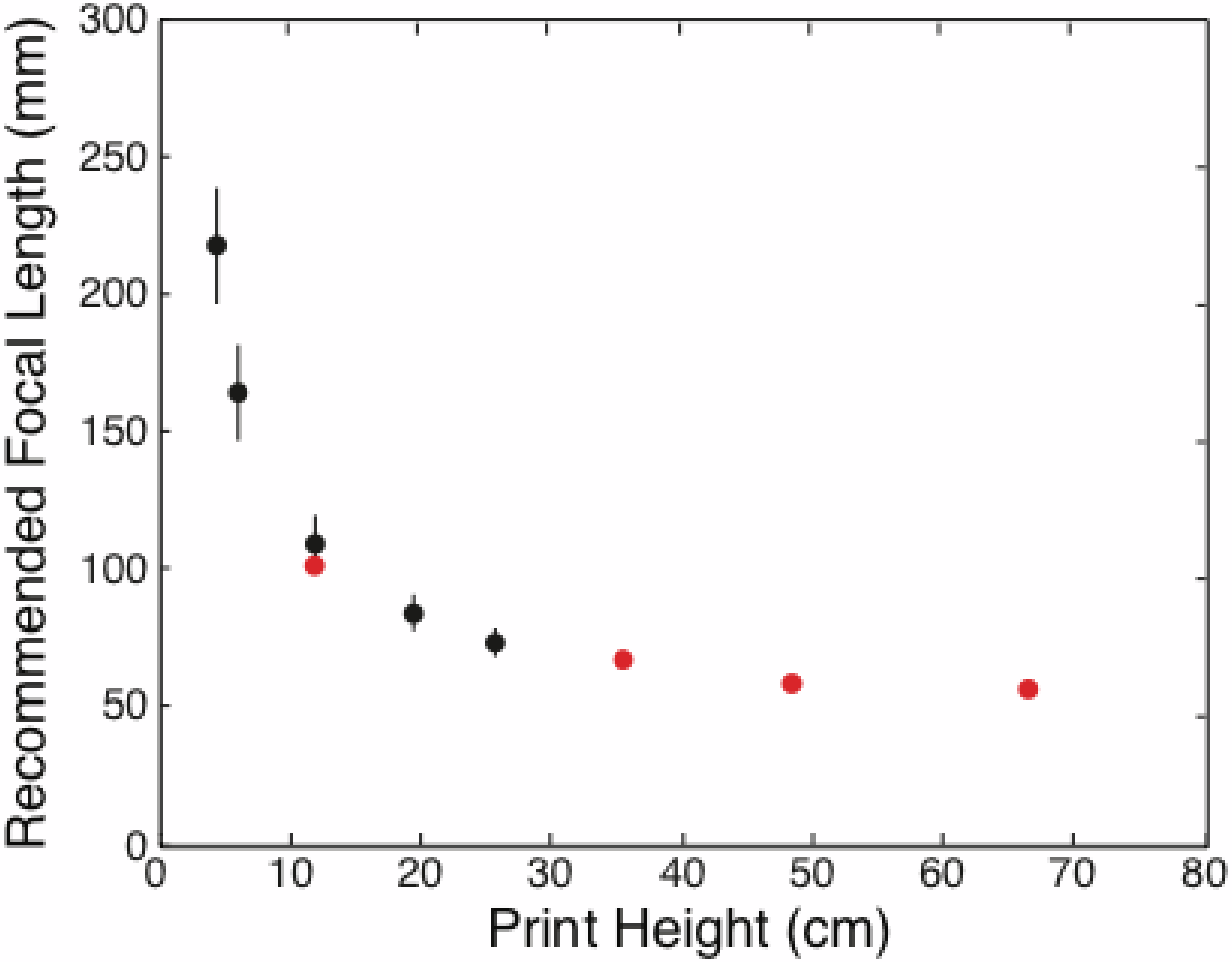
Depth Expansion & Compression



short focal length

long focal length

Recommended Focal Length



Photographic Effects

- Wide-angle distortion

  Well known in photography, cinematography, computer graphics, and perspective painting.

  Texts recommend lens focal length of ~50mm (with 35mm film format) to avoid distortion.

- Depth compression/expansion

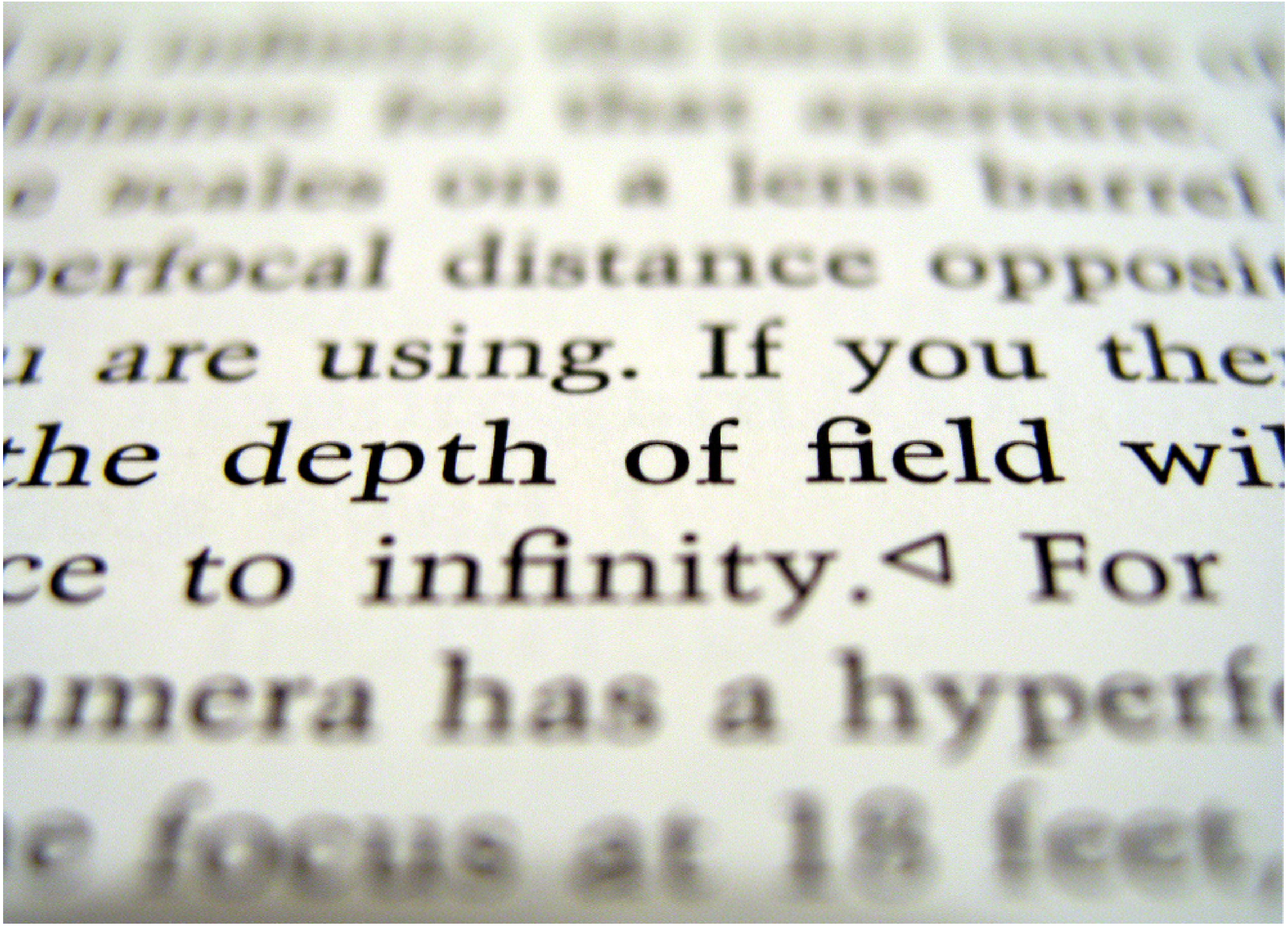
  Well known in photography and cinematography for manipulation of artistic effects.

  Texts recommend focal length of ~50mm to avoid compression or expansion.

- Depth of field effects

  Widely utilized in photography and cinematography to create artistic effects, attract viewer gaze, etc.

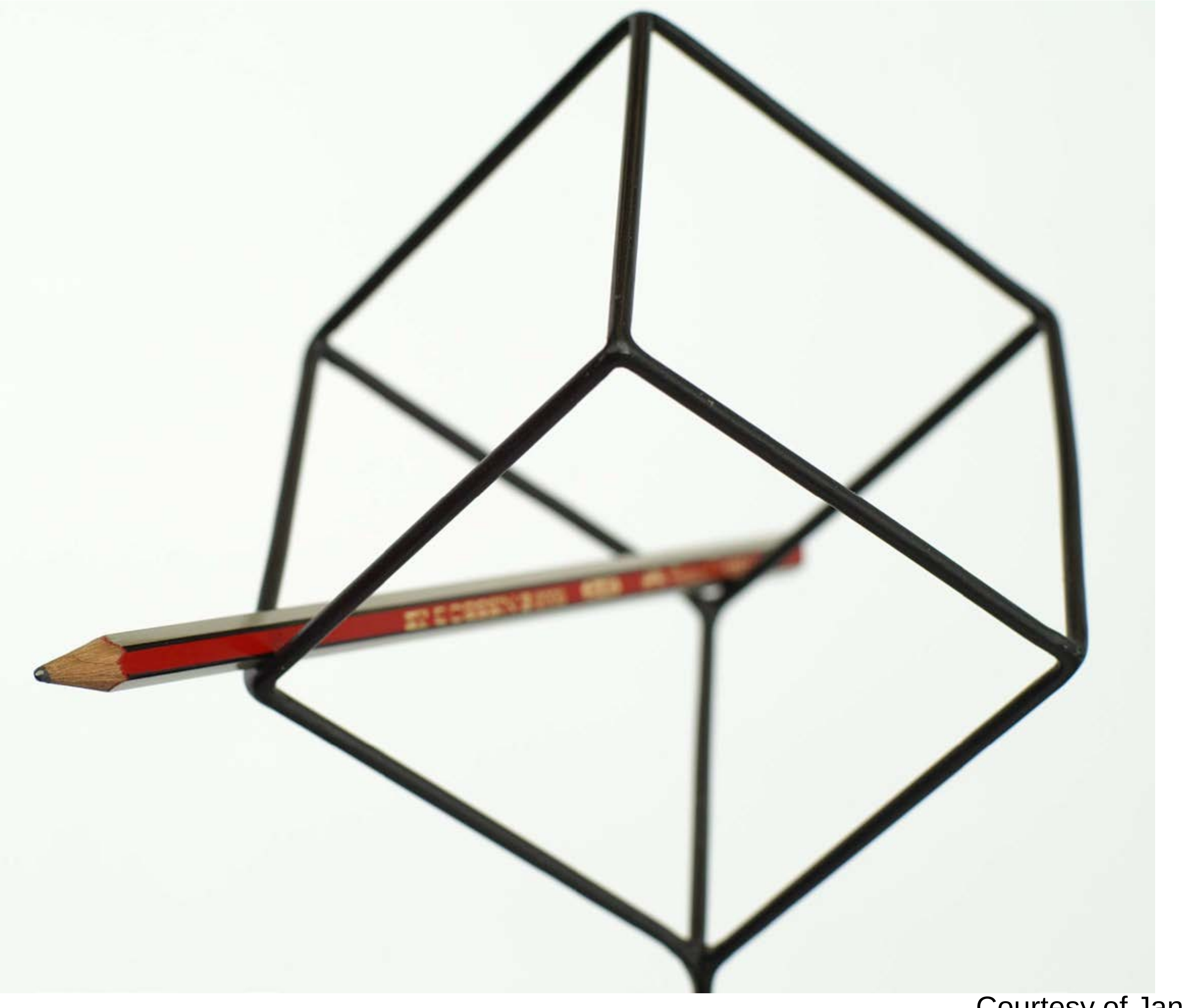
Depth-of-Field Blur



Depth of Field

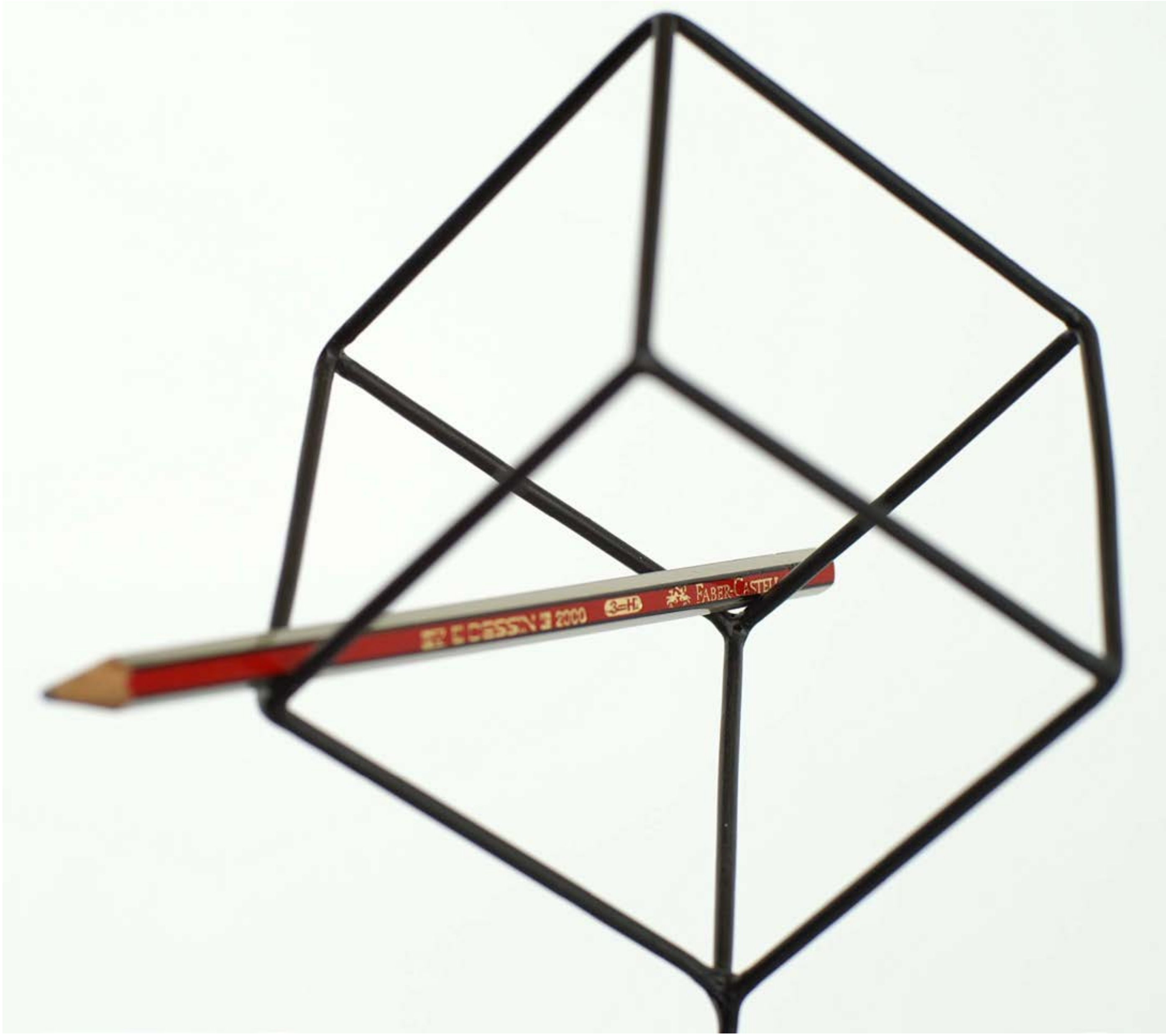
F-number = f/A; $A = f/$(F-number)

Resolving Perceptual Ambiguity



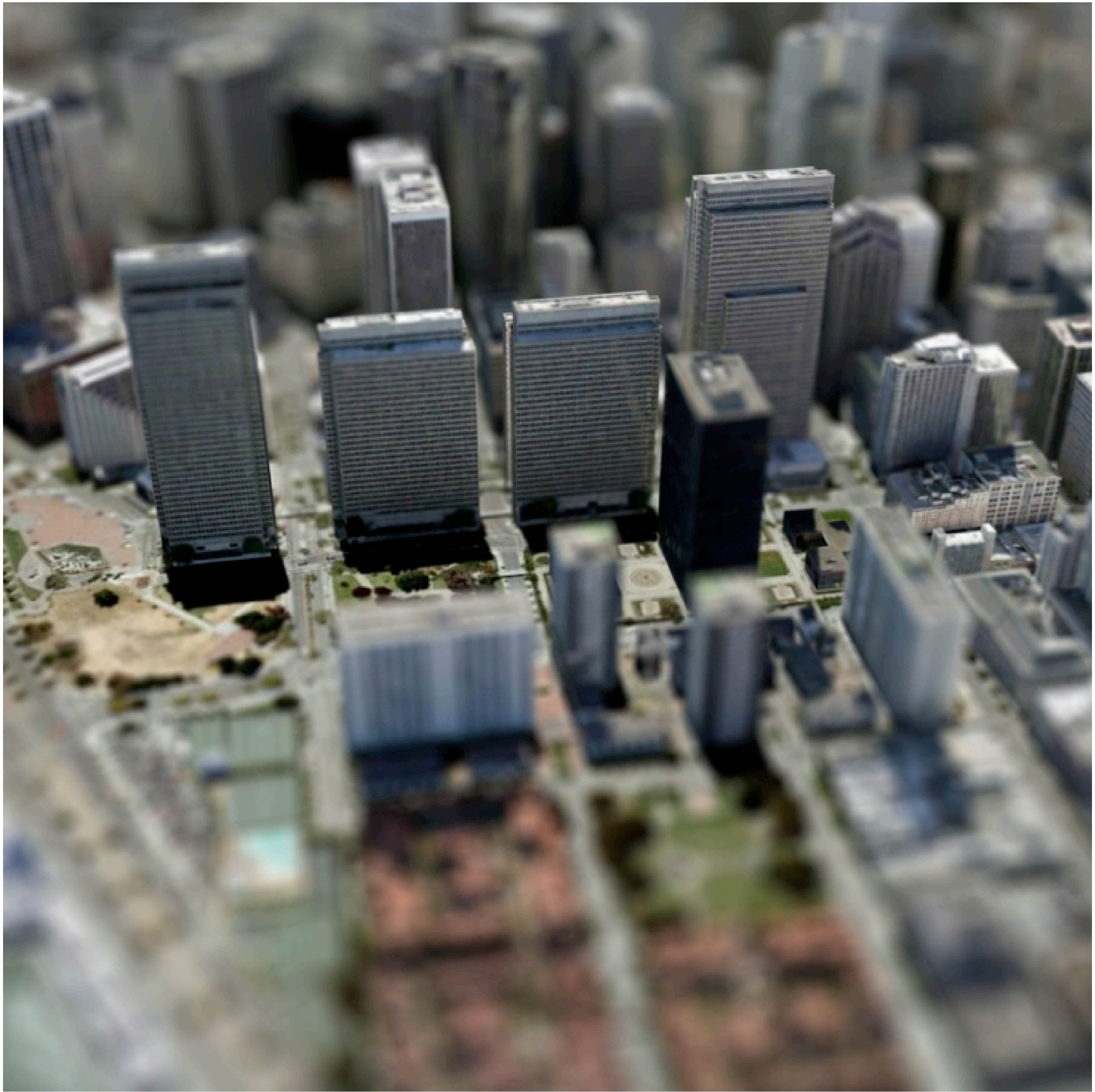
Courtesy of Jan Souman

Resolving Perceptual Ambiguity



Courtesy of Jan Souman

Blur as Cue to Absolute Distance



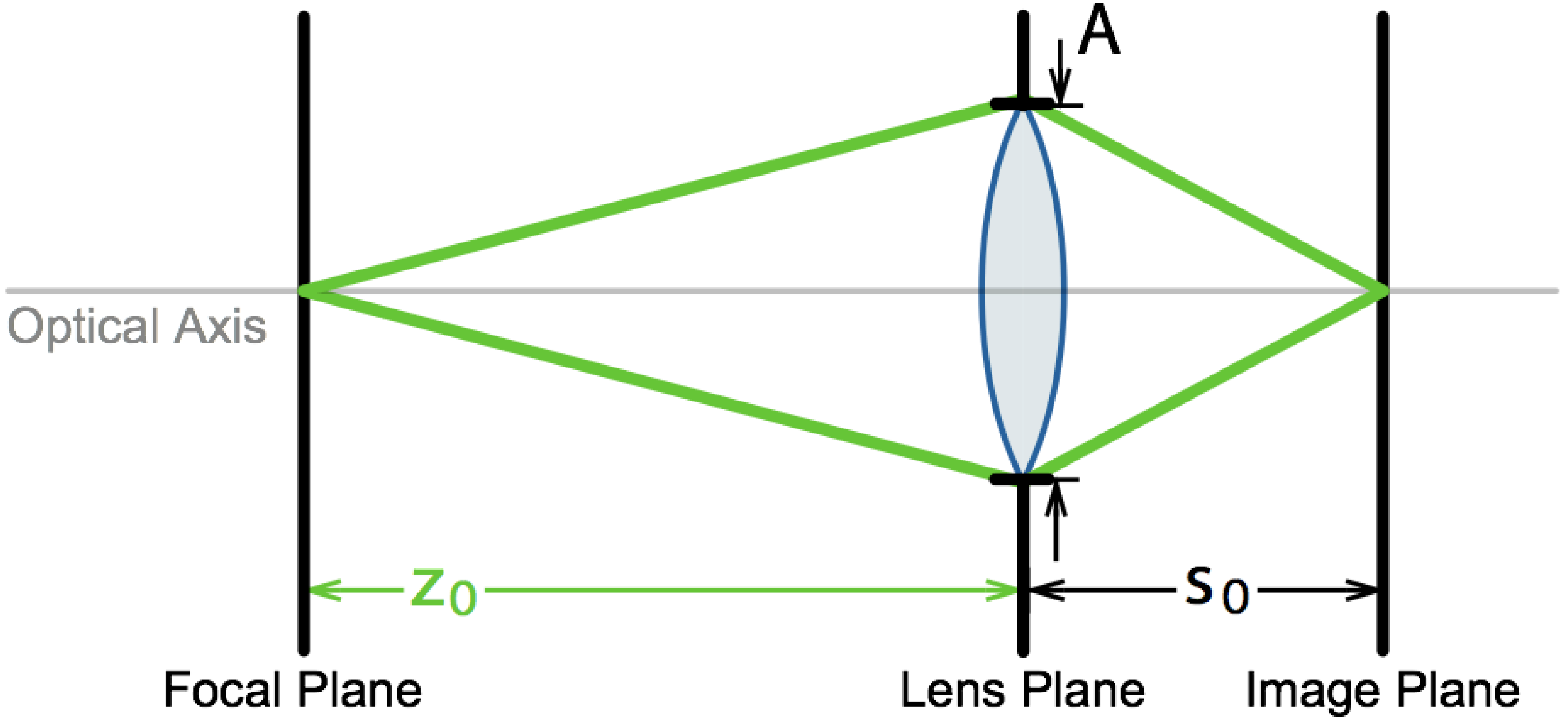
Tilt-shift Miniaturization

Blur in Cinematography

Small camera aperture to increase depth of field & minimize blur

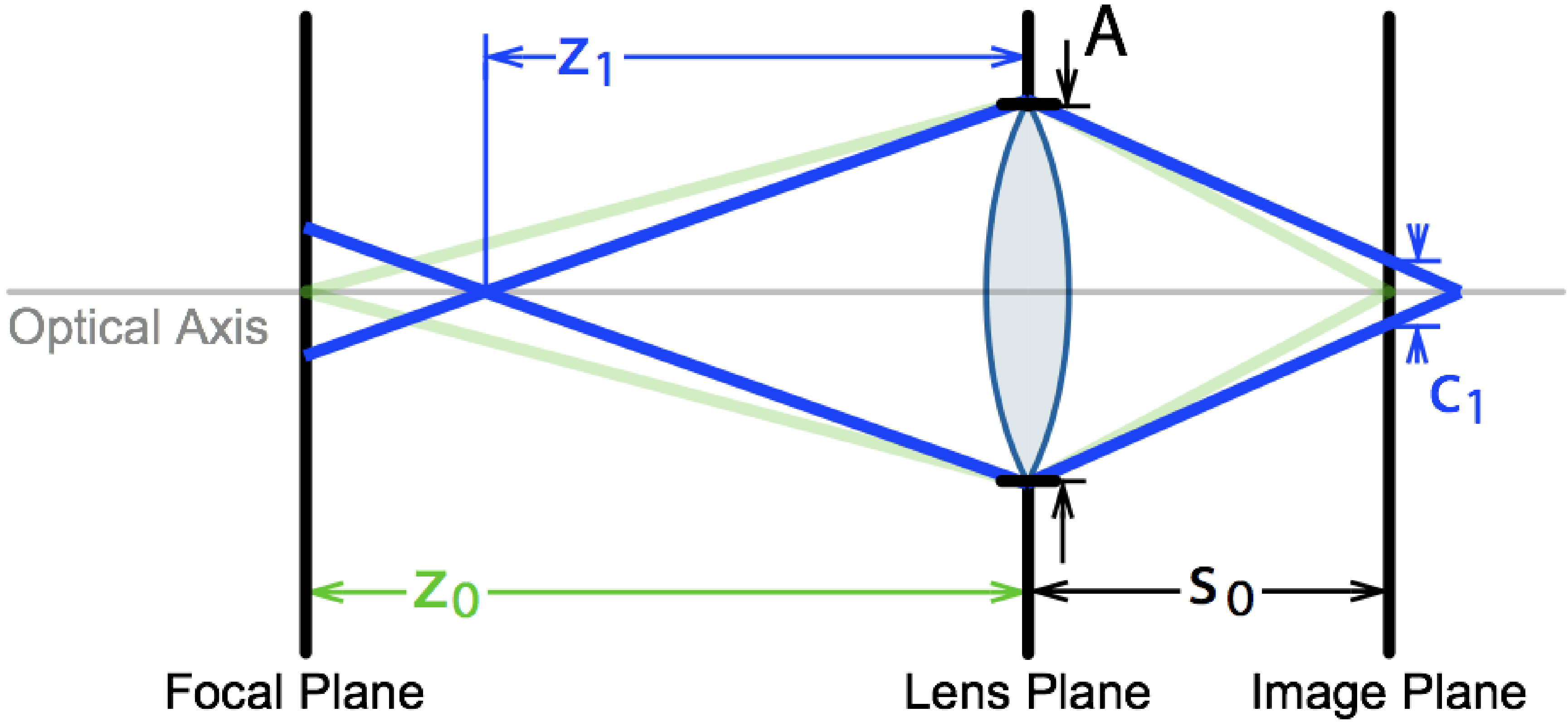
Scale models appear much larger

Image Formation & Blur



Focal (absolute) distance: z_0

Image Formation & Blur

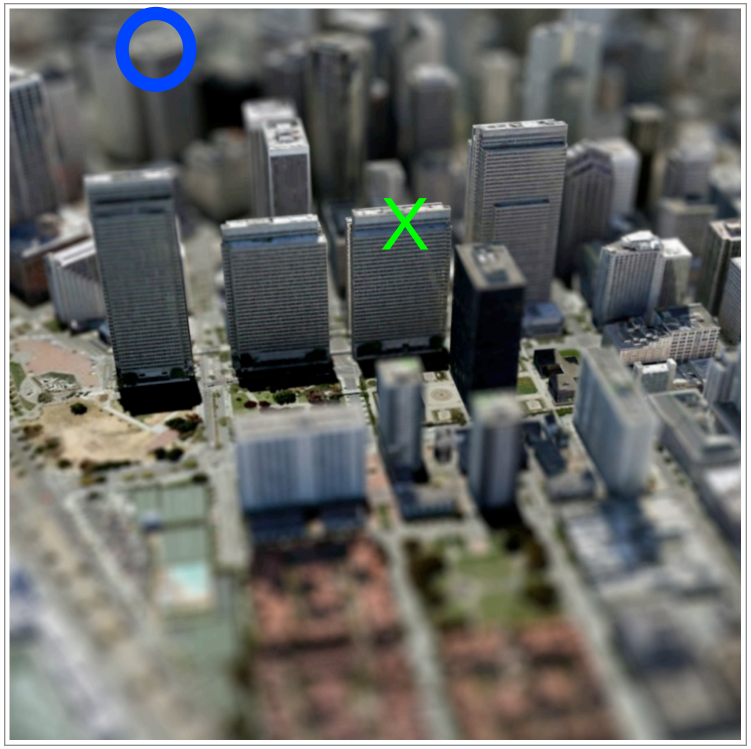


Focal (absolute) distance: z_0

Relative distance: z_1/z_0

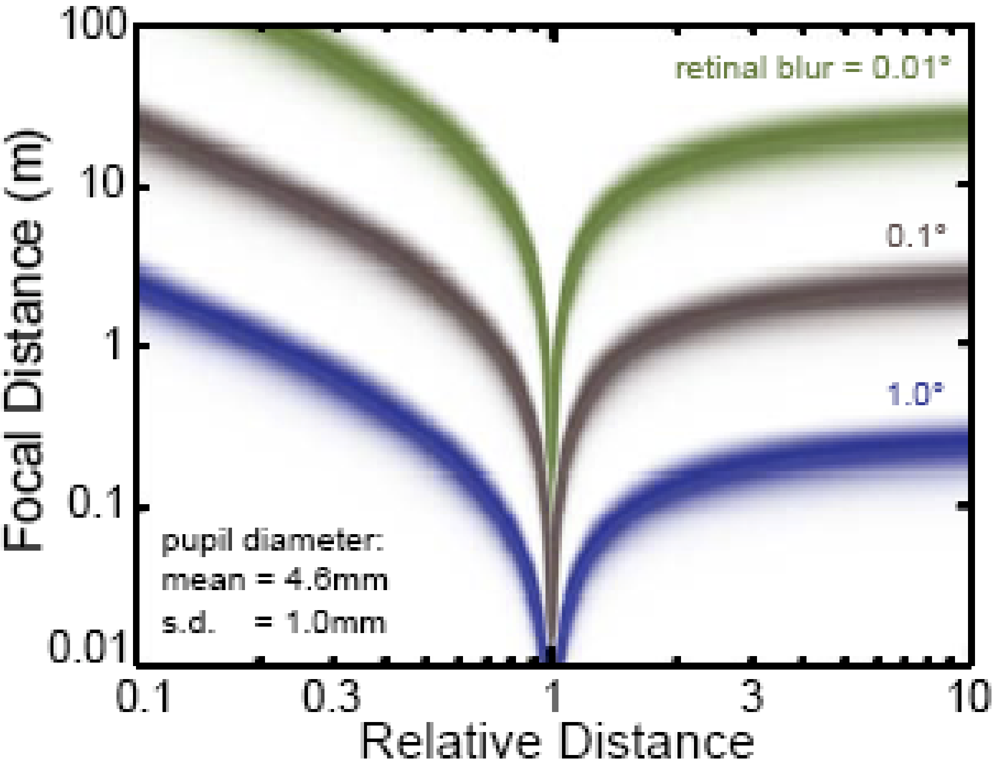
Blur magnitude: c_1

Distance Information from Blur



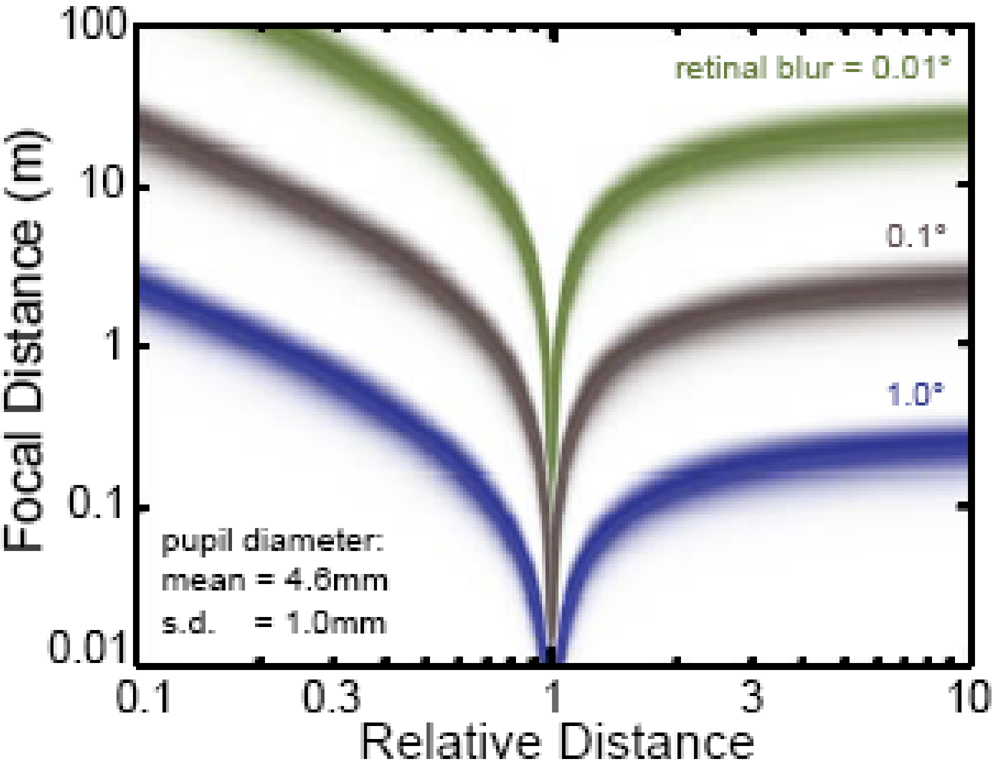
Solve for absolute distance (z_0) given blur, aperture, & relative distance (z_1/z_0)

Distance Information from Blur



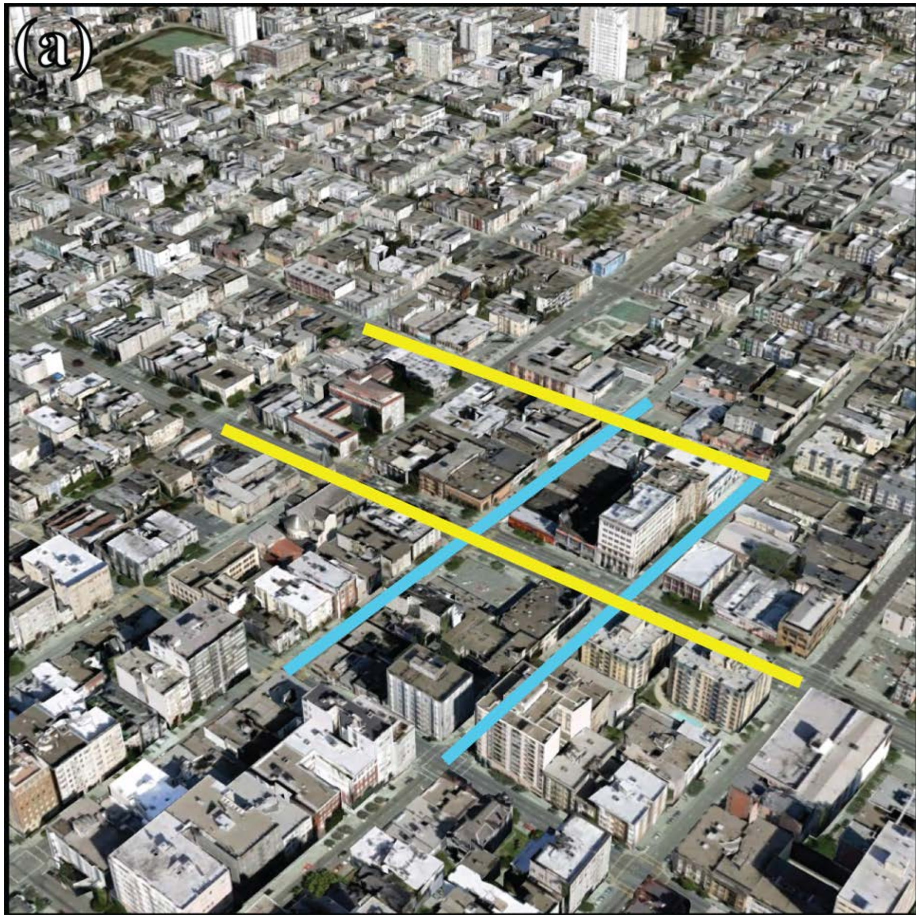
pupil data from Spring & Stiles (1948)

Distance Information from Blur



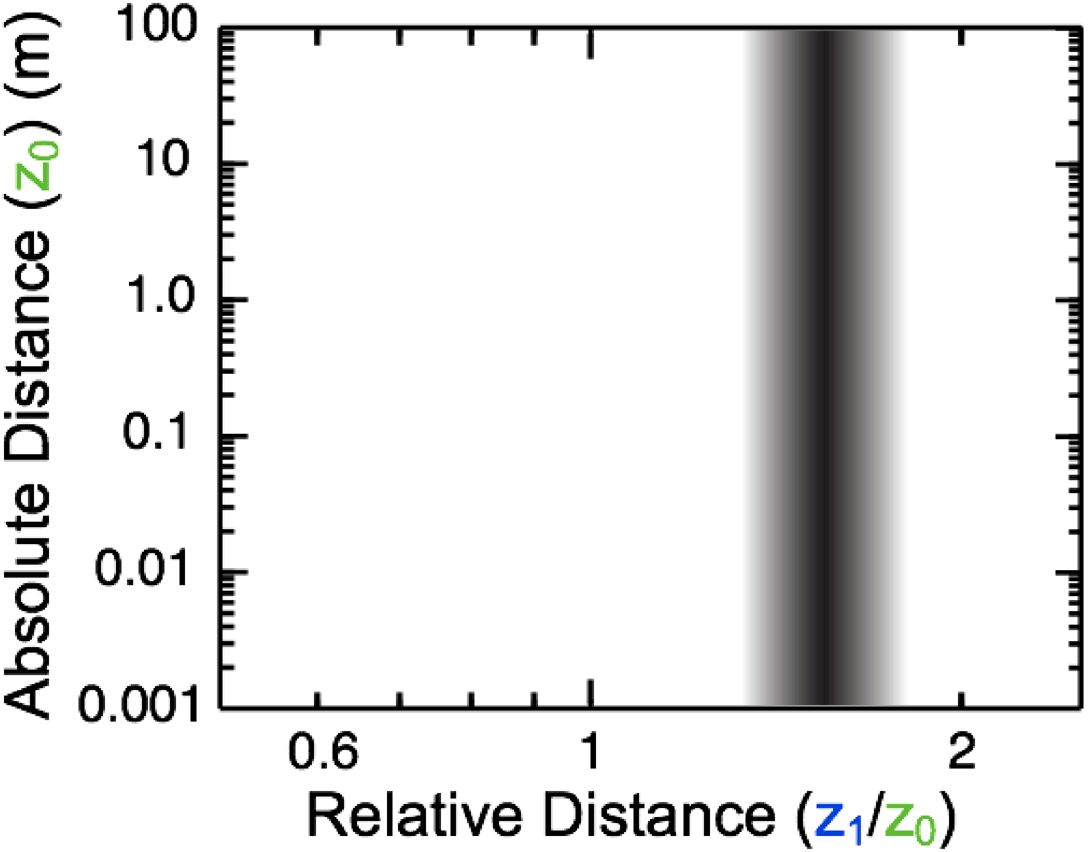
Can only place rough bounds on absolute distance from measurement of blur

Estimating Relative Distance from Perspective



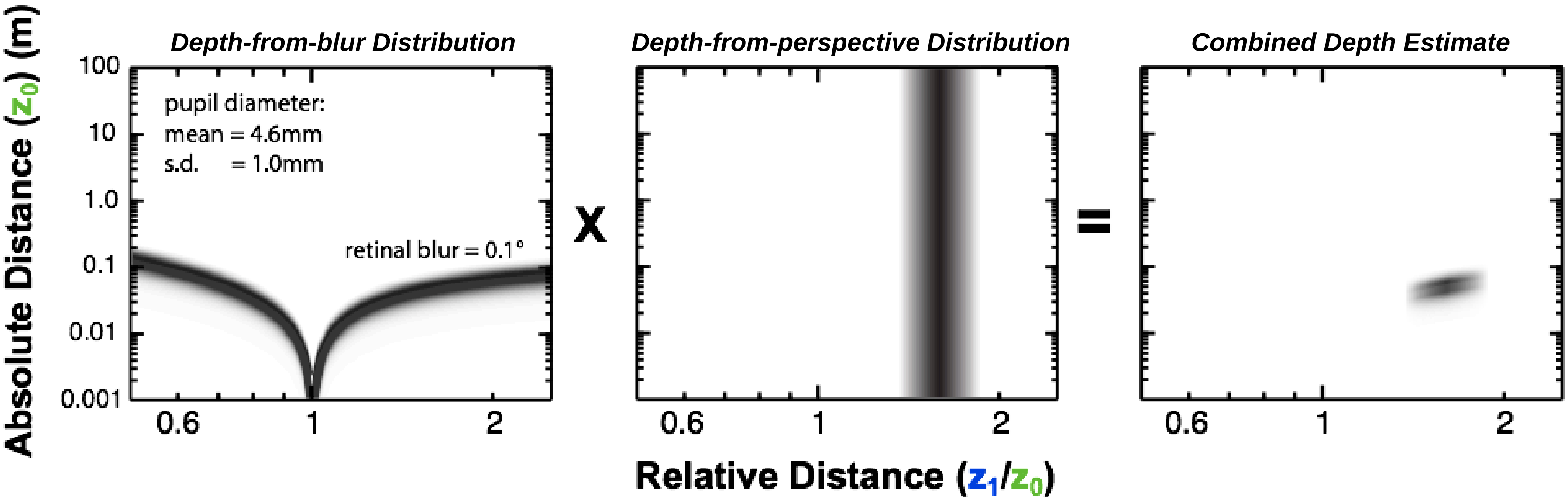
- Grid lines placed on image to determine vanishing points
- Estimate local slant from linear perspective
- Calculate relative distances

Distance Information from Perspective



Can’t estimate absolute distance from perspective

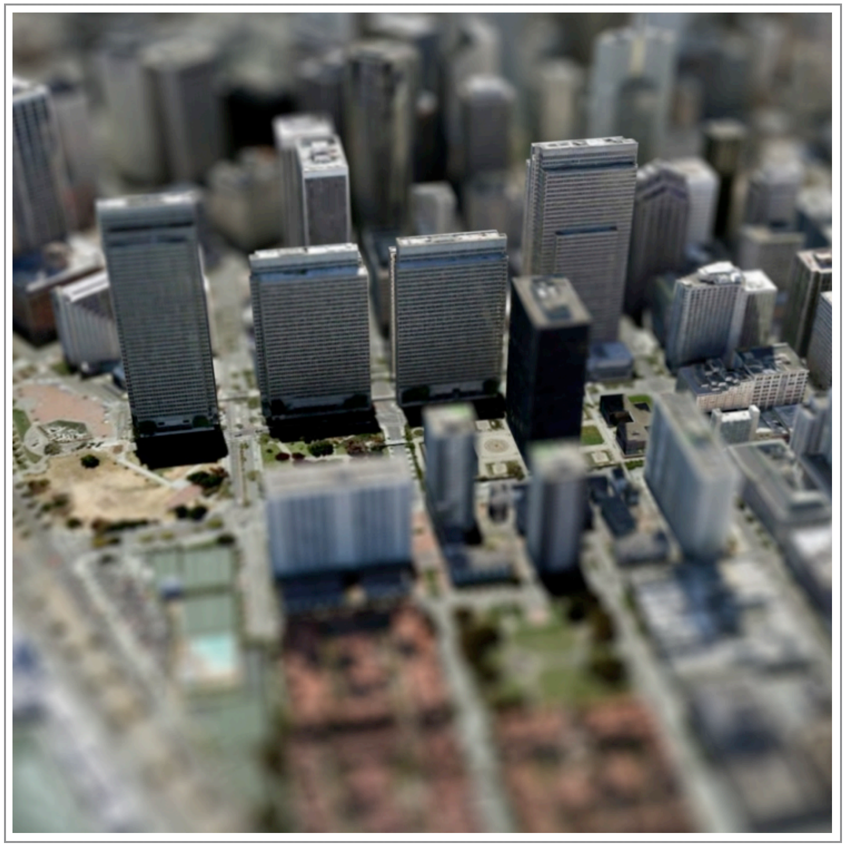
Probabilistic Model



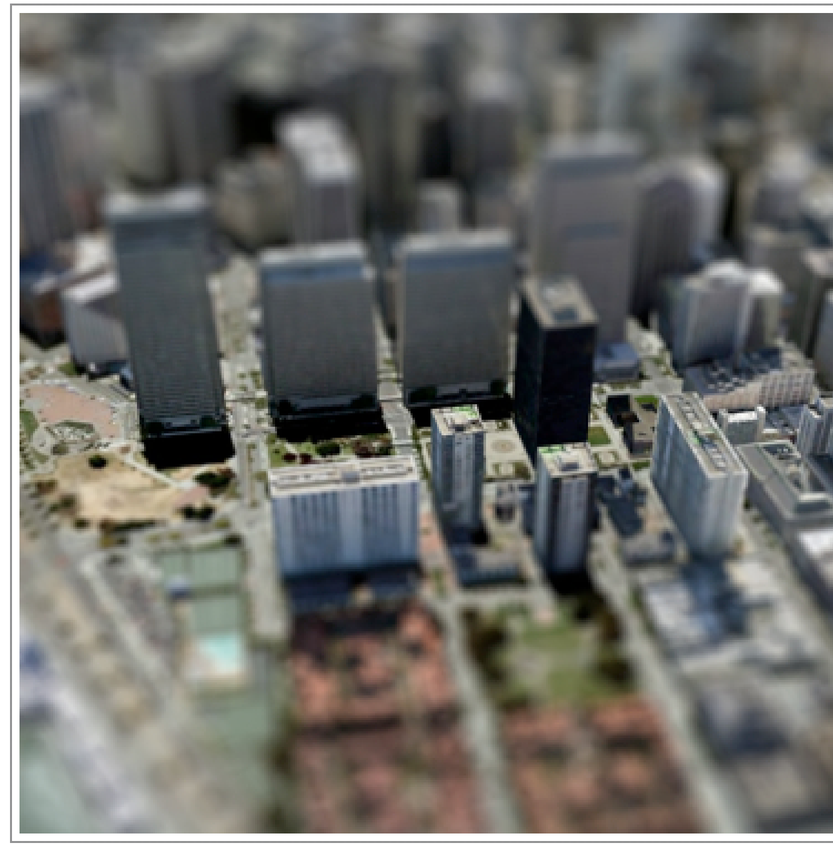
By combining information from blur & perspective, can estimate absolute distance & therefore absolute size

Held, Cooper, O'Brien, & Banks, *ACM Transactions on Graphics* (2010)

Accuracy of Blur-distance Signals

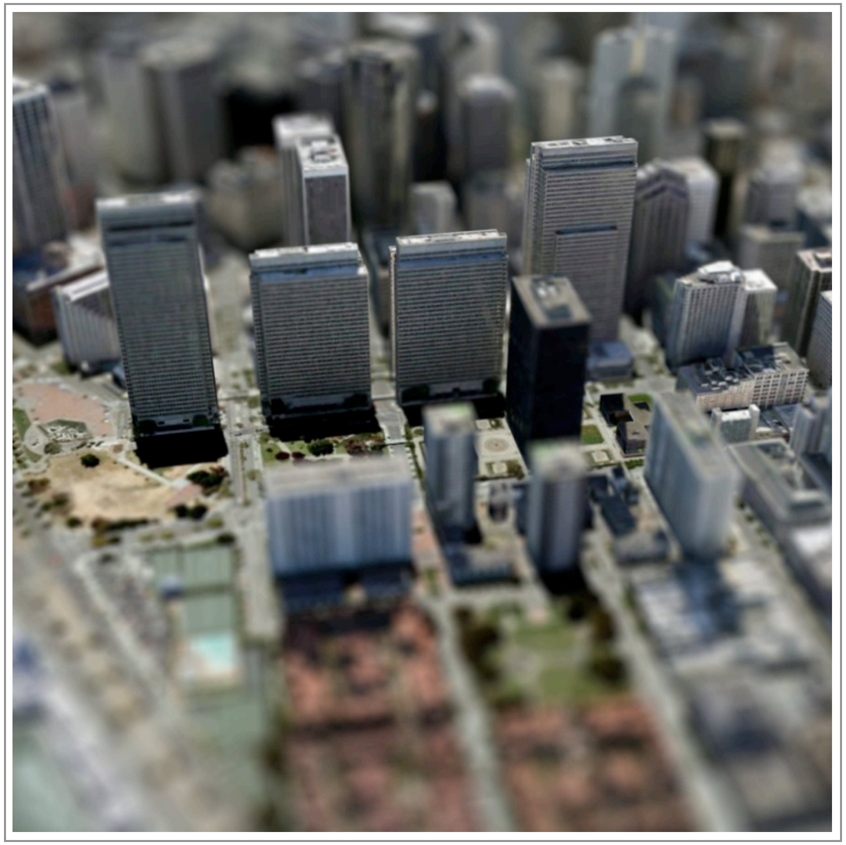


Blur consistent with distance

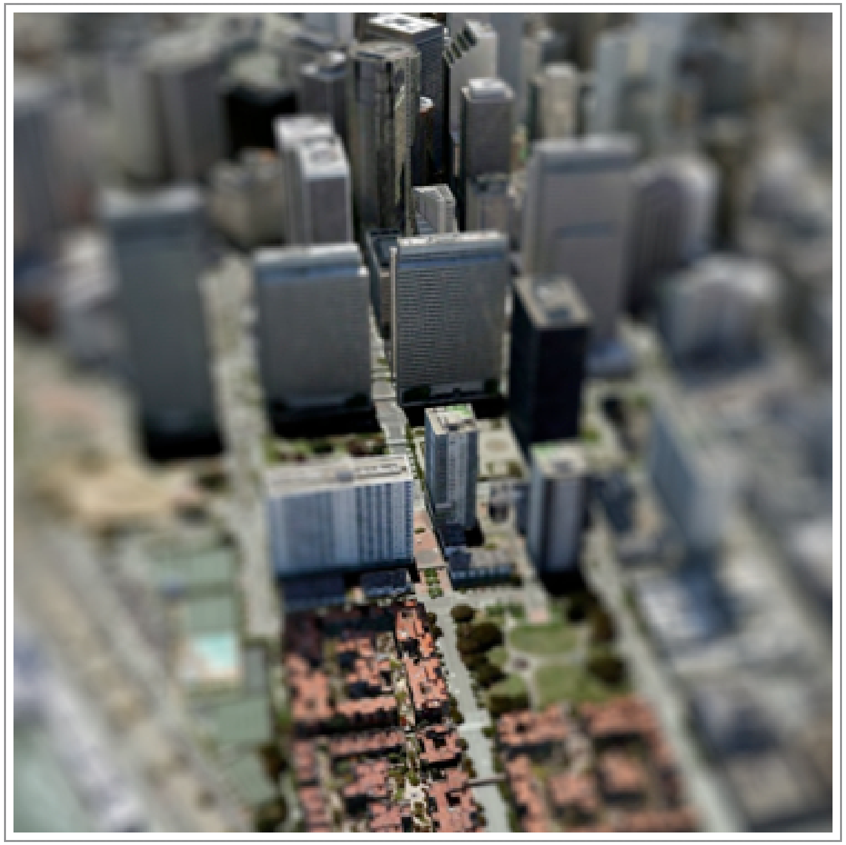


Blur & distance gradients aligned

Accuracy of Blur-distance Signals



Blur consistent with distance



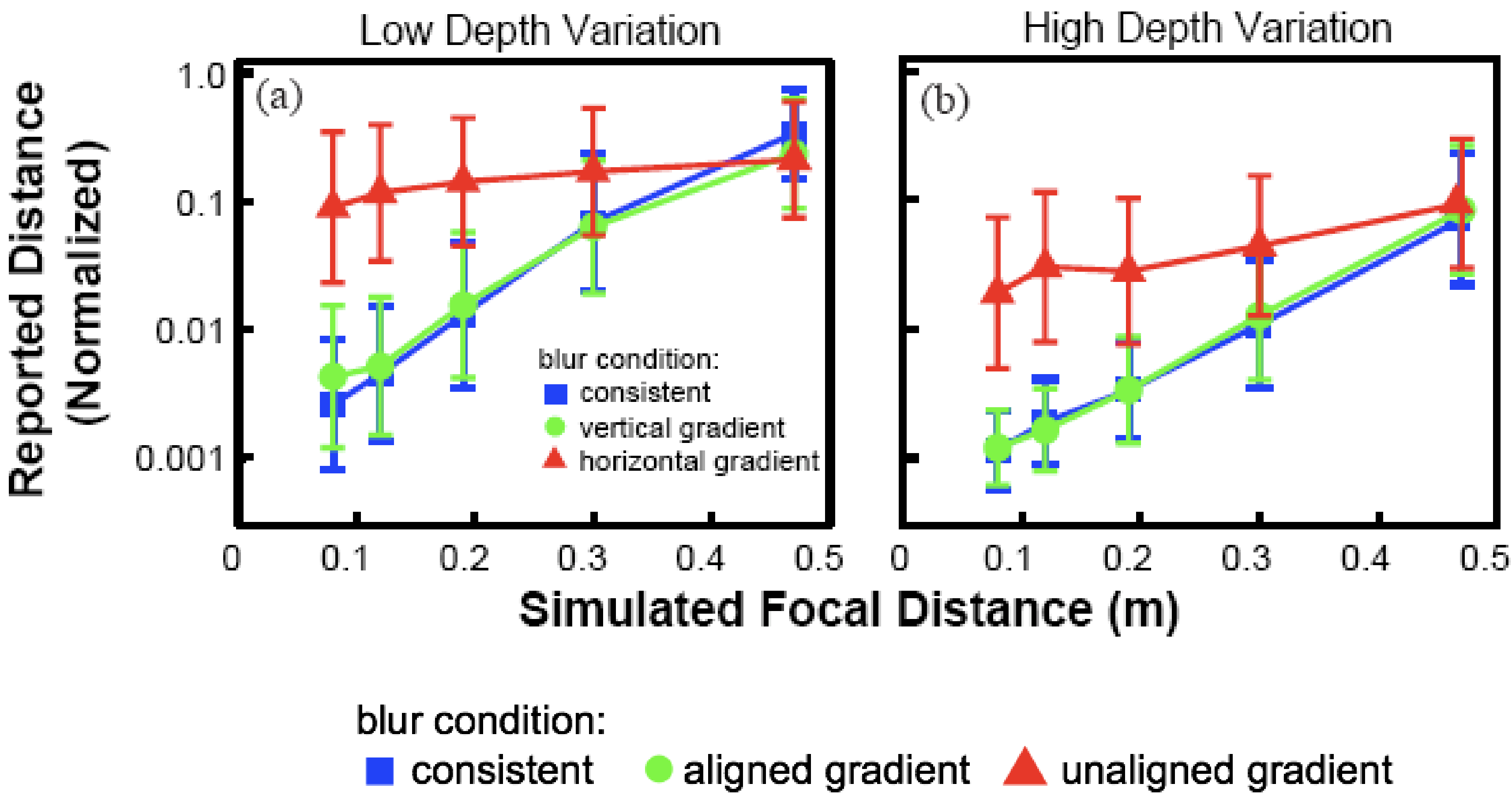
Blur & distance gradients not aligned

Psychophysical Experiment

- 7 scenes from GoogleEarth
- Each scene rendered 4 ways: no blur, blur consistent with distance, blur & distance gradients aligned, blur & distance gradients orthogonal
- 5 blur magnitudes
- Naïve subjects viewed each image monocularly for 3 sec
- Reported distance from marked building in image center to the camera that produced the image
- 7 repetitions, random order

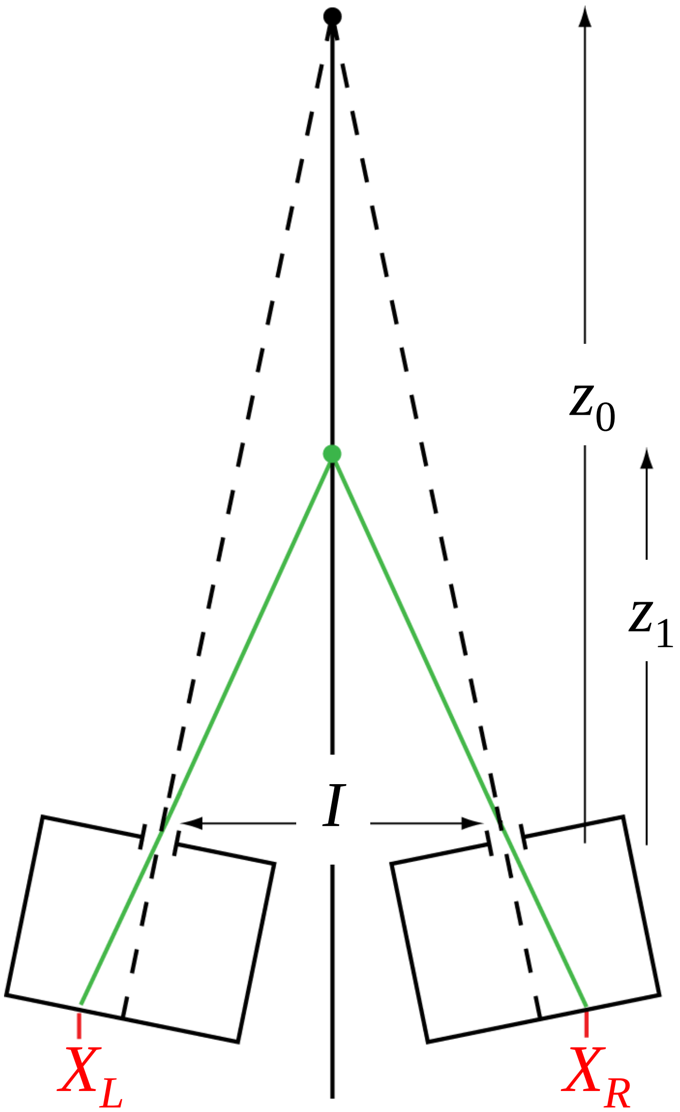
Held, Cooper, O'Brien, & Banks, *ACM Transactions on Graphics* (2010)

Experimental Results



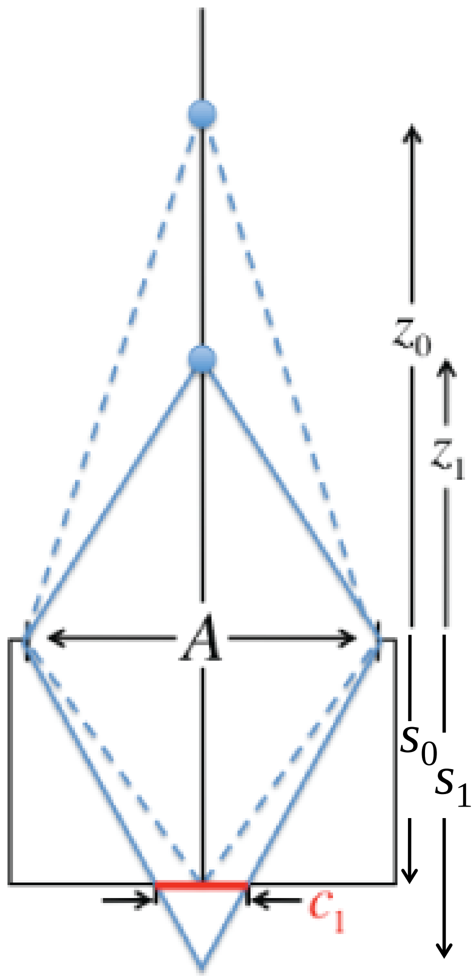
Held, Cooper, O'Brien, & Banks, *ACM Transactions on Graphics* (2010)

Disparity Geometry

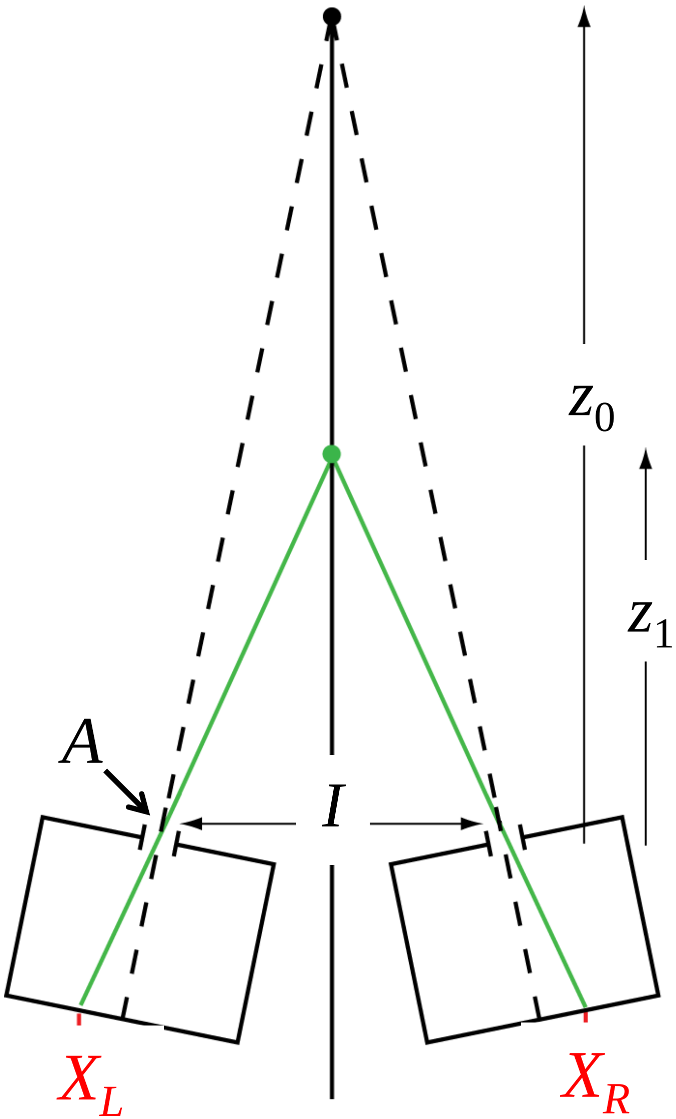


where

Blur Geometry



Geometries of Disparity & Blur



comparing disparity & blur:

Held, Cooper, O’Brien, & Banks, *ACM Transactions on Graphics* (2010)

Photographic Effects

- Wide-angle distortion

  Recommended focal length of ~50mm avoids distortion caused by local slant compensation.

- Depth compression/expansion

  People view short focal-length pictures from too far and long ones from too close. With large prints, recommended focal length of ~50mm matches viewing distance to correct distance. With small prints, recommended focal length should be longer.

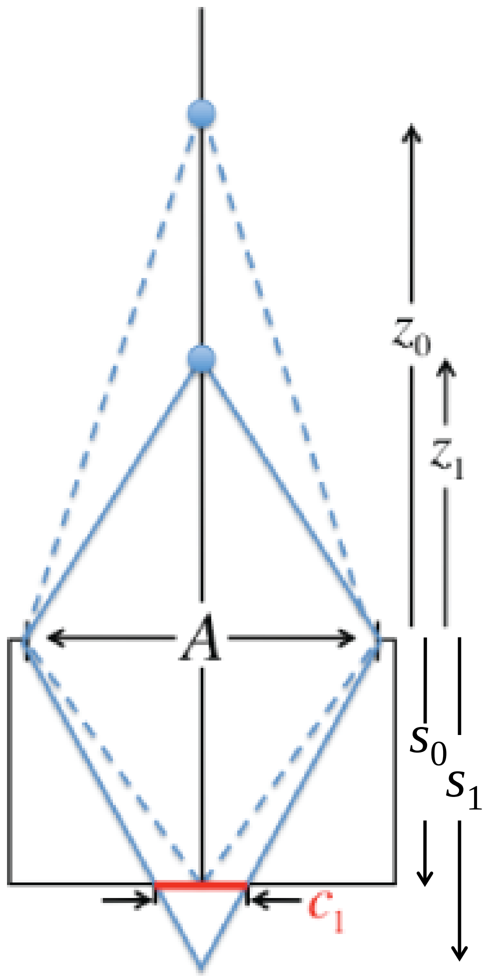
- Depth-of-field effects

  There is a natural relationship between depth-of-field blur and disparity (and other cues that specify absolute distance). For perceived distance & size to be correct, set blur appropriately to match those cues.

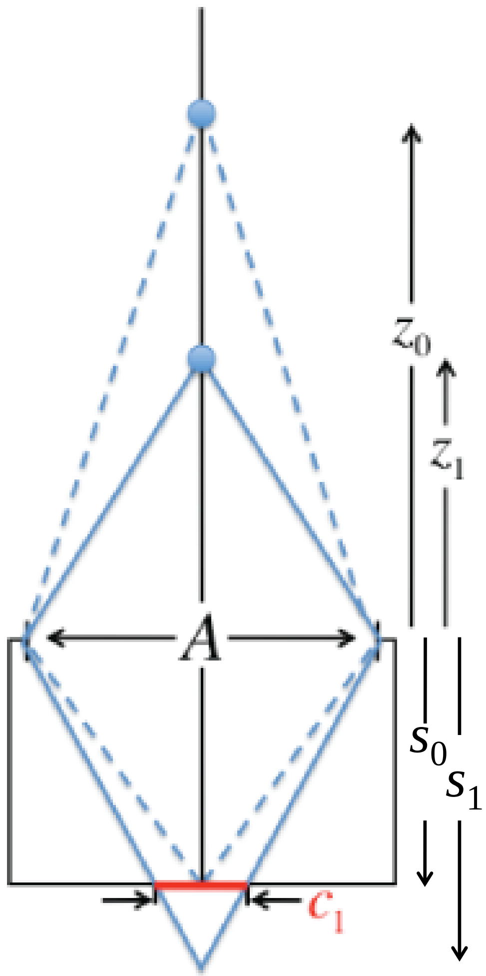
Acknowledgements

- Dhanraj Vishwanath (now at St. Andrews University)
- Ahna Girshick (NYU & Berkeley)
- Robert Held (Berkeley Bioengineering)
- Emily Cooper (Berkeley Neuroscience)
- James O’Brien (Berkeley Computer Science)
- Elise Piazza (Berkeley Vision Science)
- Funding from NIH and NSF

Blur Geometry

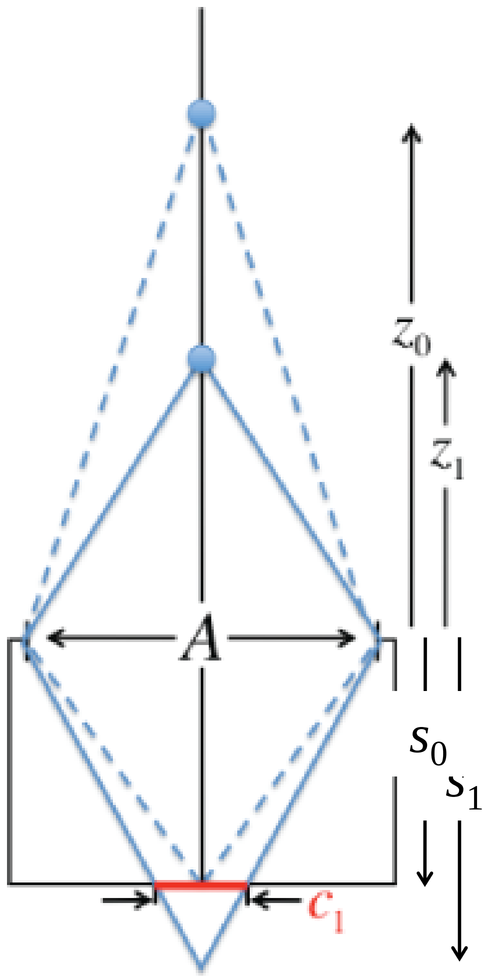


Blur Geometry



expressing blur in angular units

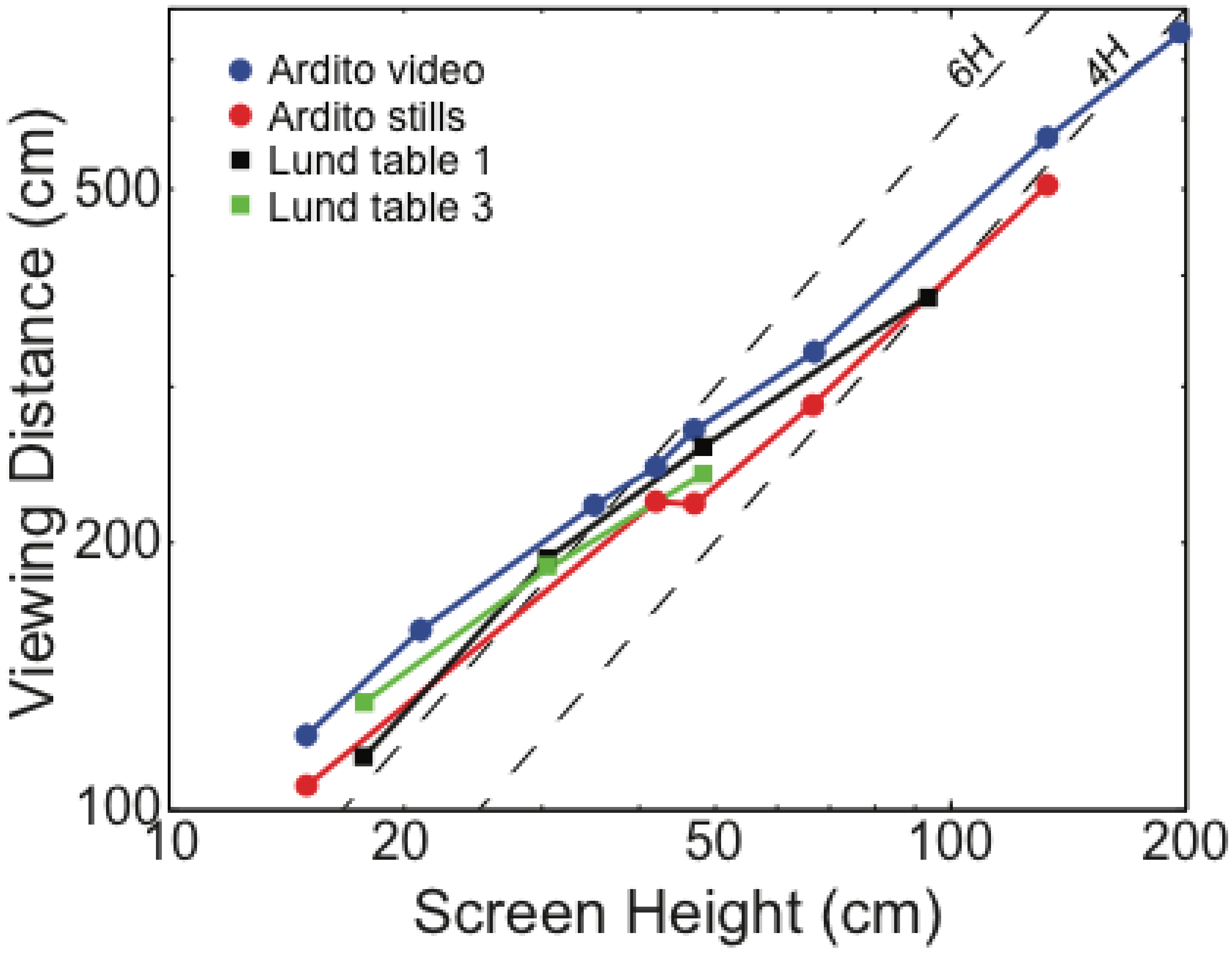
Blur Geometry



expressing blur in angular units

blur in angular units doesn’t depend on camera focal length

Preferred Viewing Distance for Television



Picture in a Picture

8.2 Another photograph of a photograph

This appeared in *Time* Magazine on 29 March 1968 during President Nixon's electoral campaign. The portrait of President Nixon, in the background, looks deformed for the same reason as the portrait in Fig. 8.1.

From Pirenne (1970); Optics, Photography, & Painting

Anamorphic Art

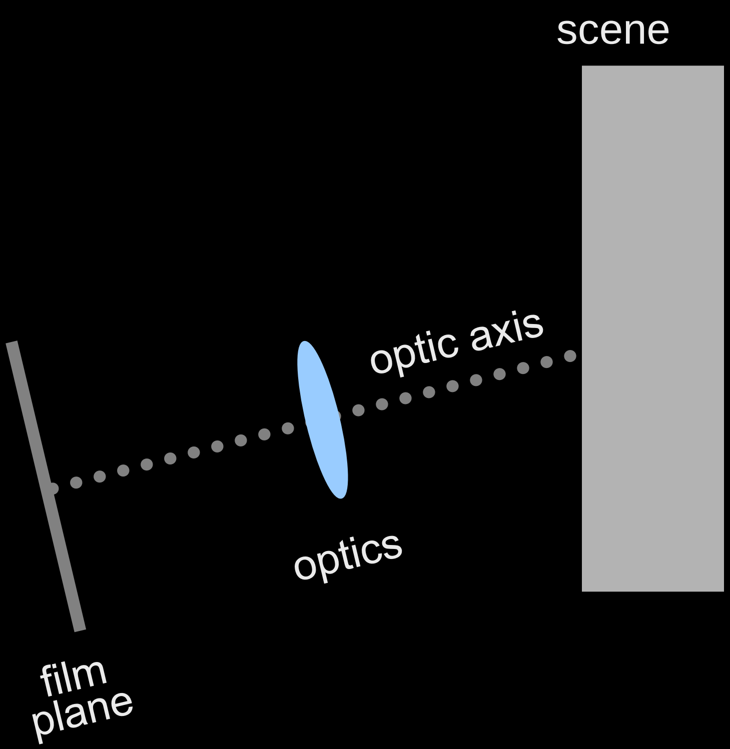
Julian Beever: Glasgow, High Street

Anamorphic Art

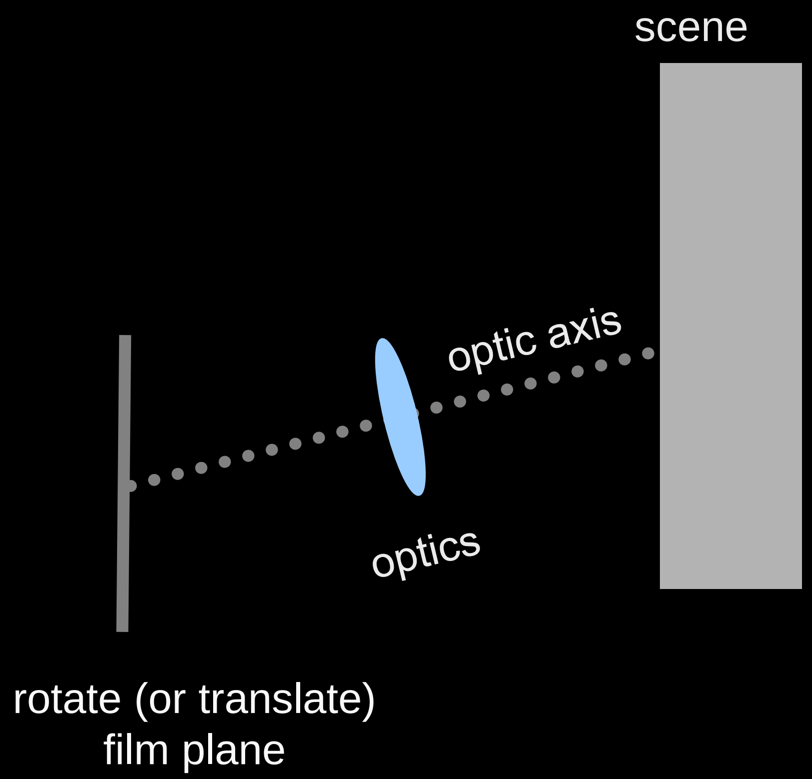
Julian Beever: Glasgow, High Street

Rafael's *School of Athens*

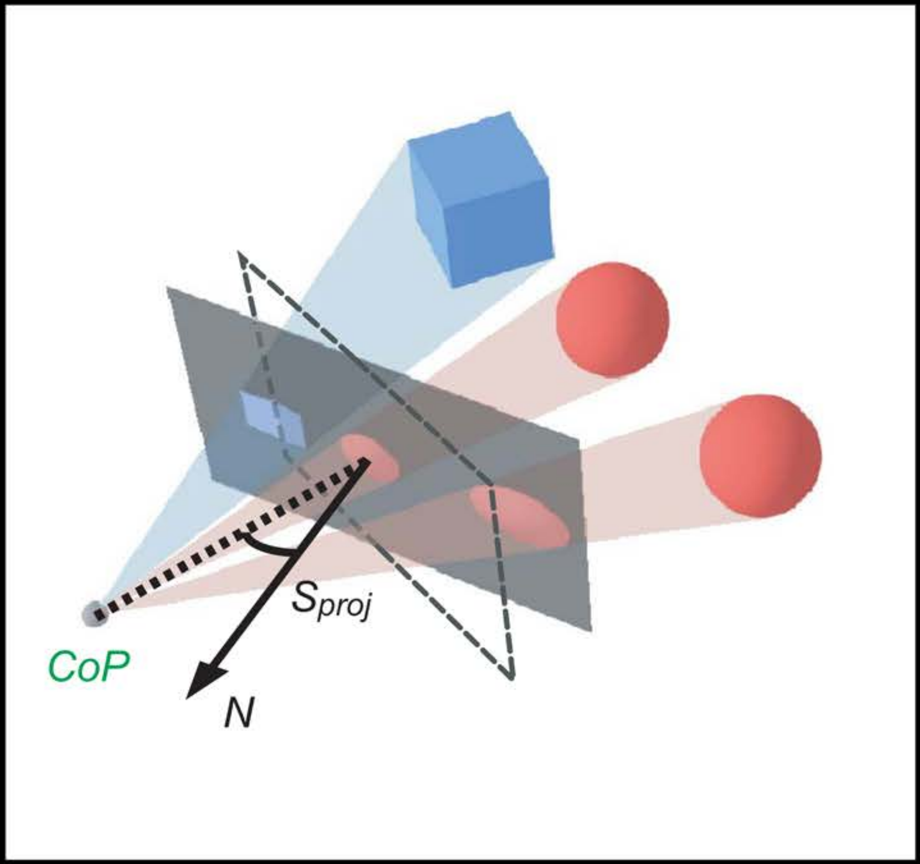
Architectural Photography

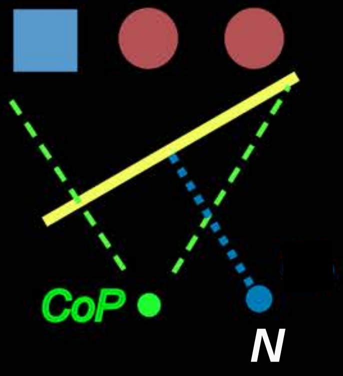


Architectural Photography



Rotated Projection Plane



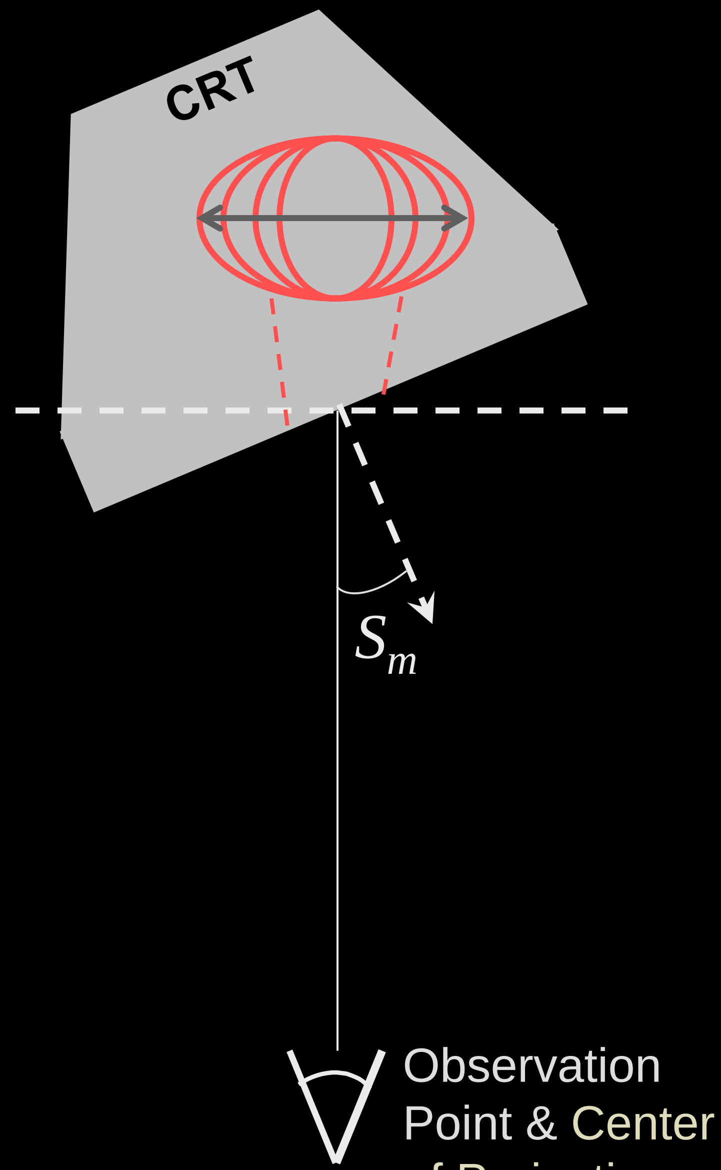


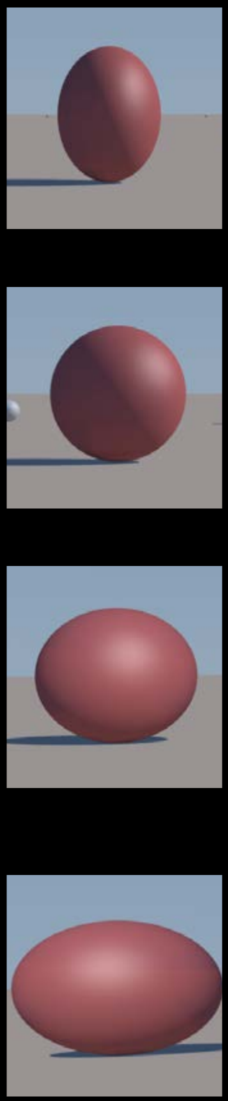
Experimental Task

Stimulus: simulated 3D ovoid with variable aspect ratio.

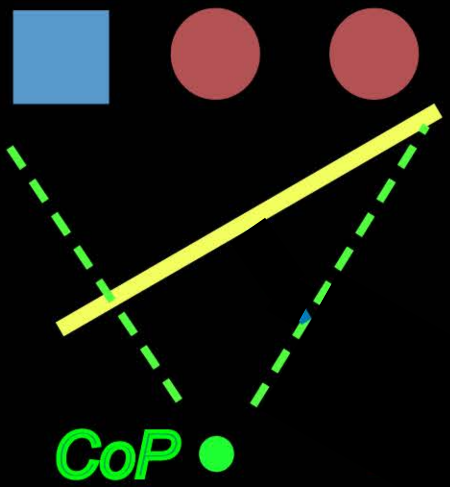
Task: adjust ovoid until it appears spherical.

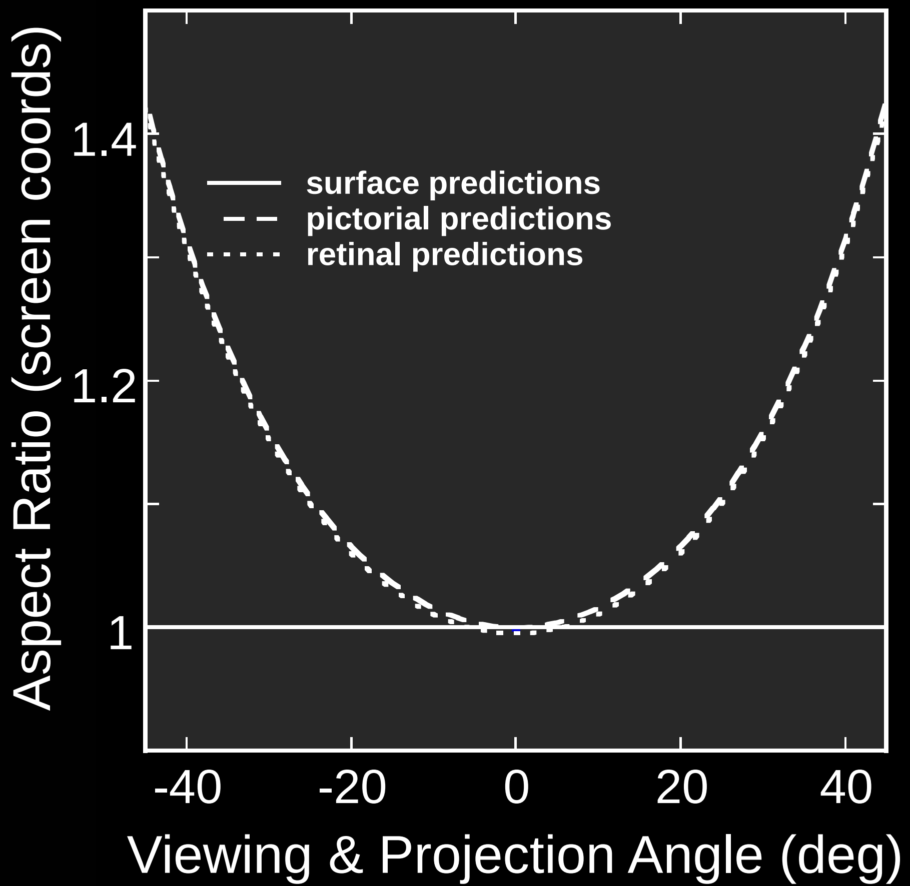
Monitor slant S_m projection angle S_p varied together ($S_m = S_p$).



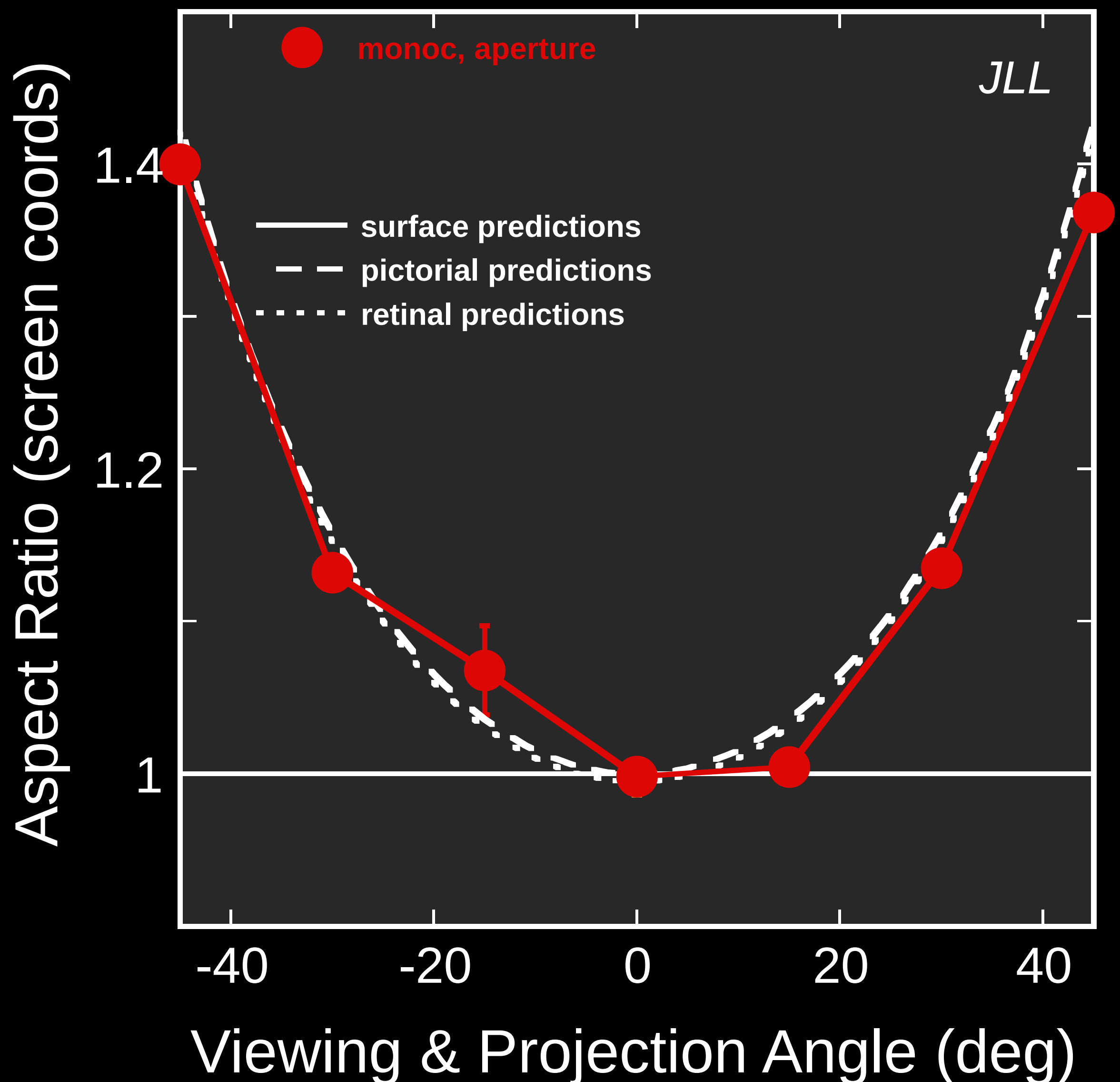


Predictions



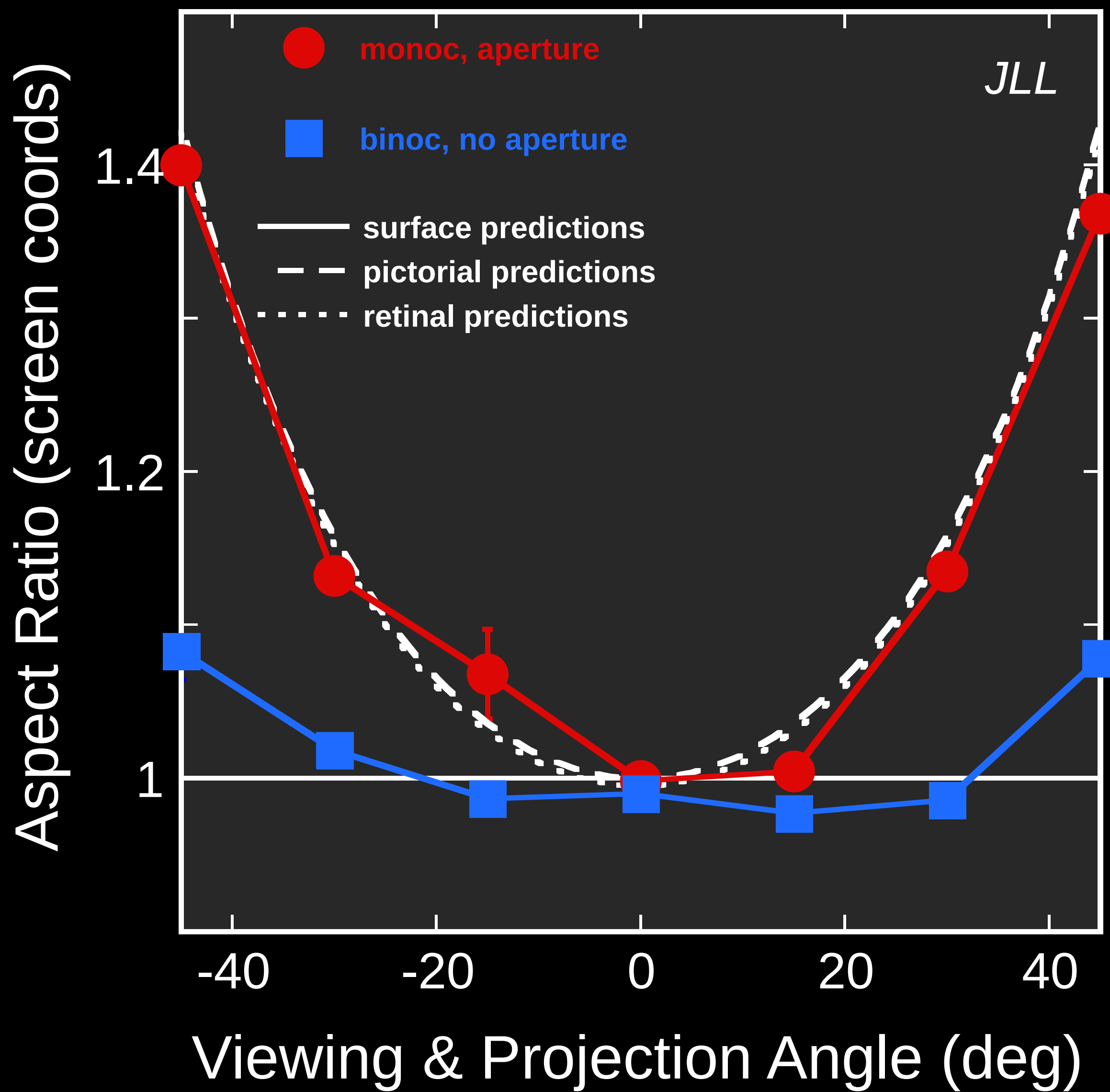


Results



Vishwanath et al., *Nature Neuroscience* (2005)

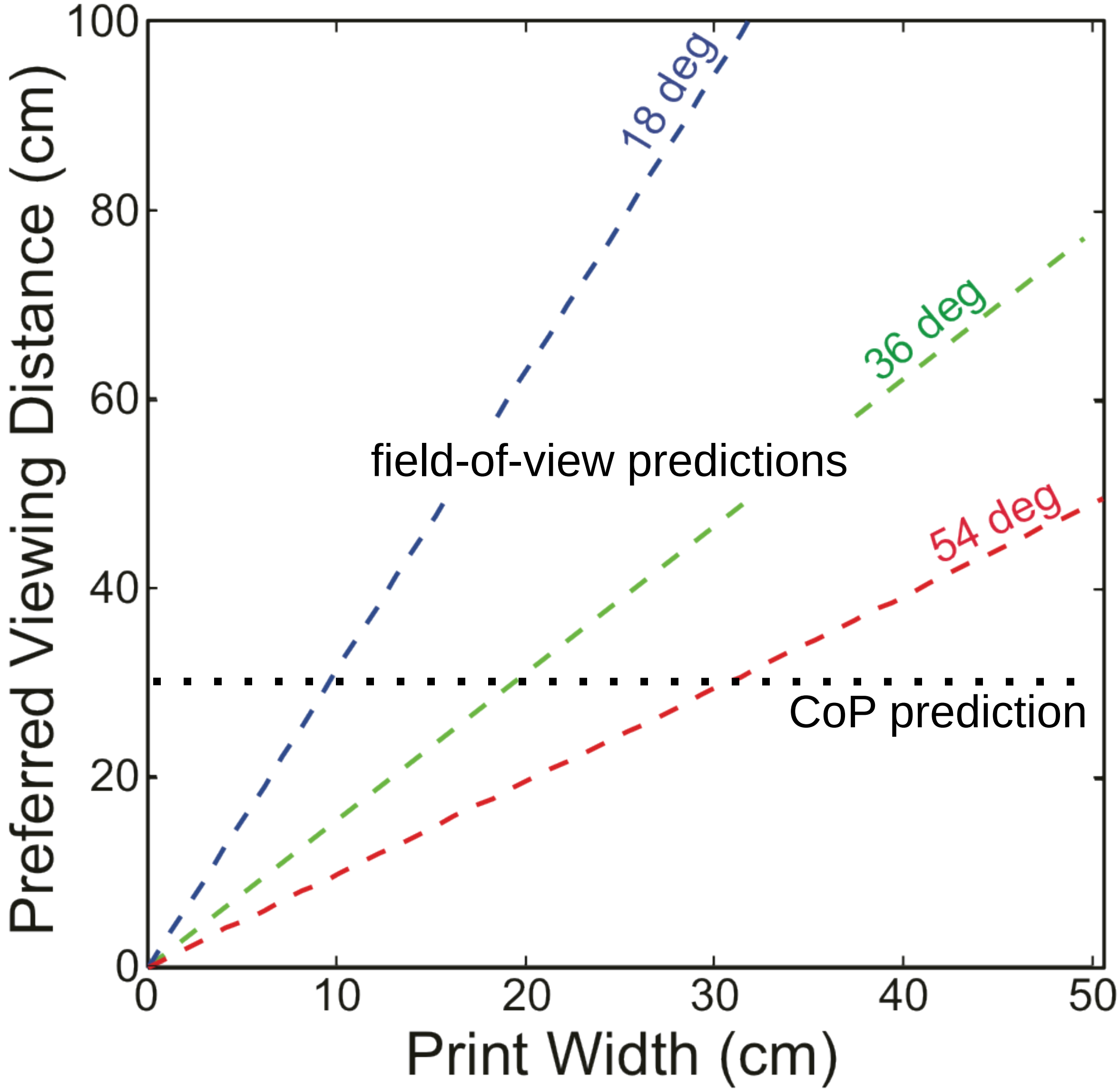
Results



Vishwanath et al., *Nature Neuroscience* (2005)

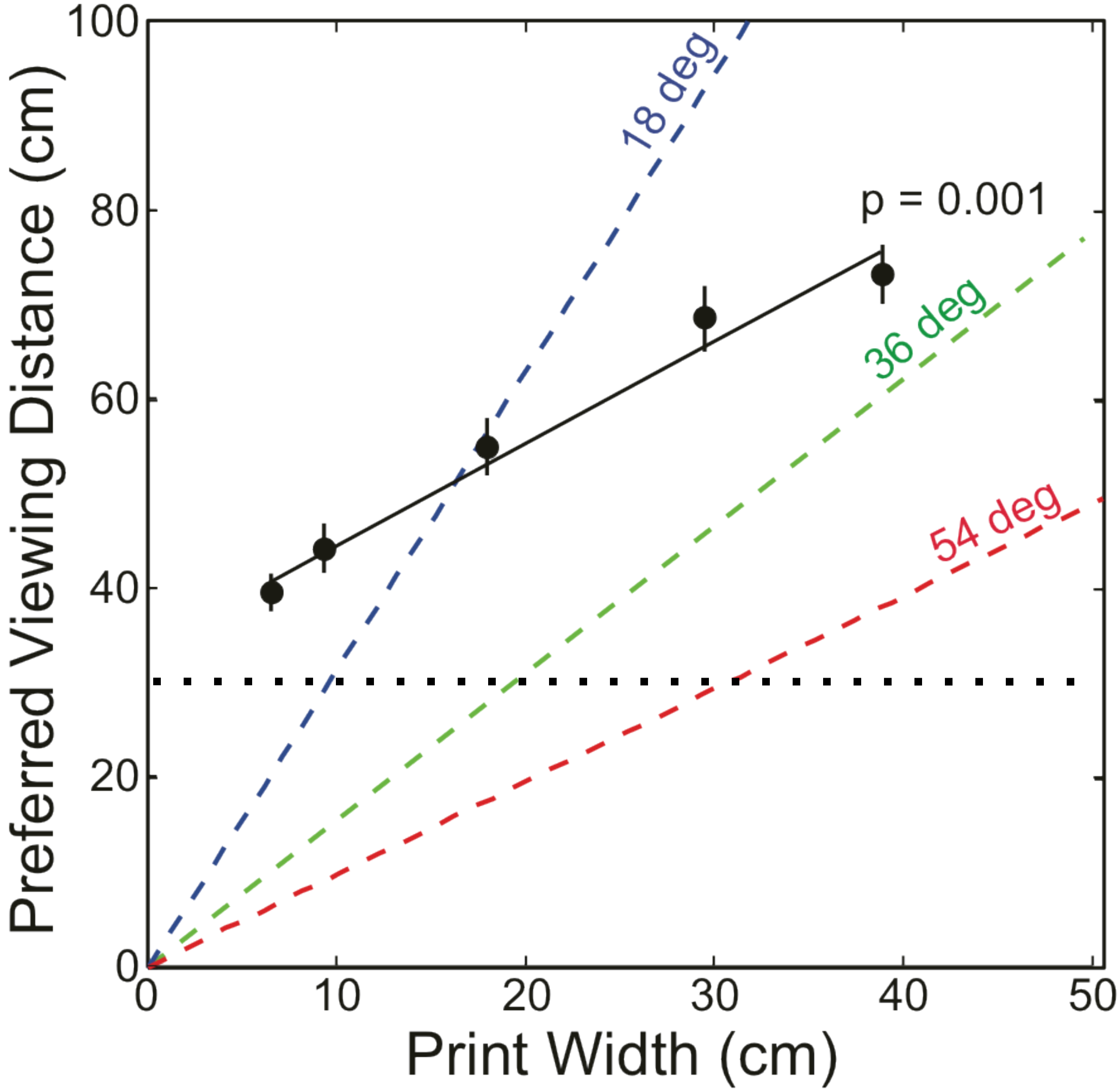
Viewing Pictures

For subset with f = 35mm, which is close to f = 50mm for 35-mm equivalent

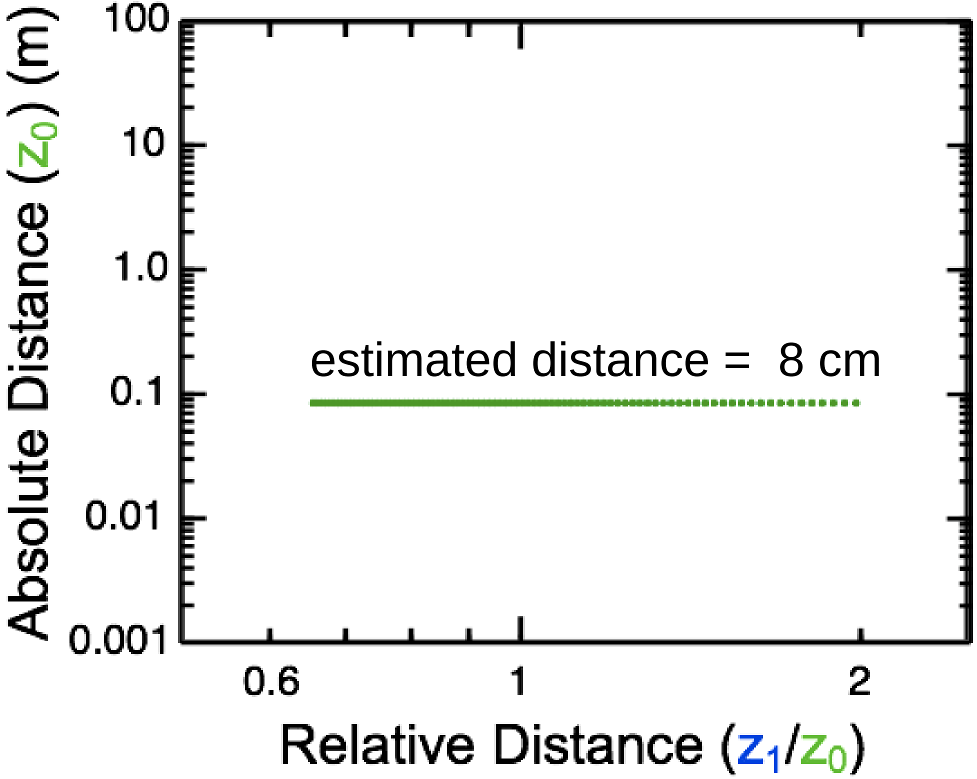


Viewing Pictures

For subset with f = 35mm, which is close to f = 50mm for 35-mm equivalent

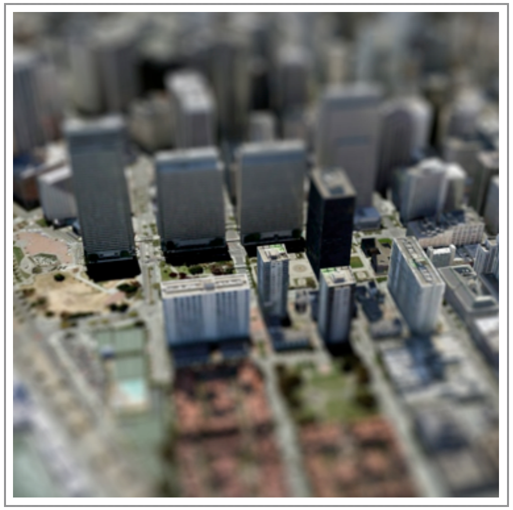


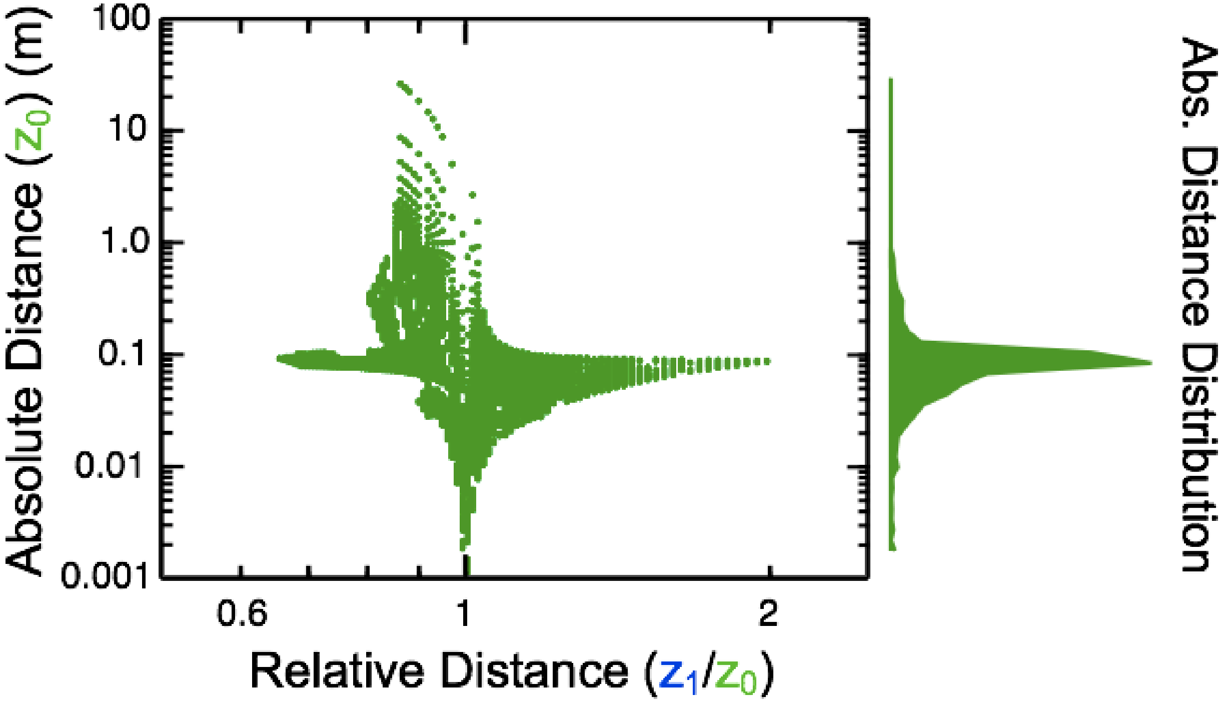
Estimating Absolute Distance



Held, Cooper, O'Brien, & Banks, *ACM Transactions on Graphics* (2010)

Distance Estimate with Aligned Gradients

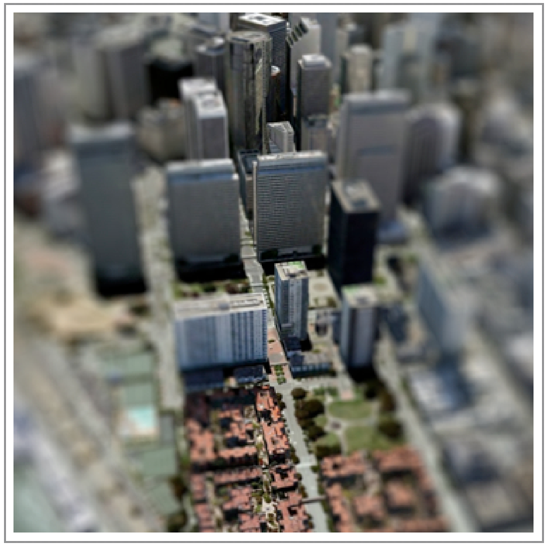


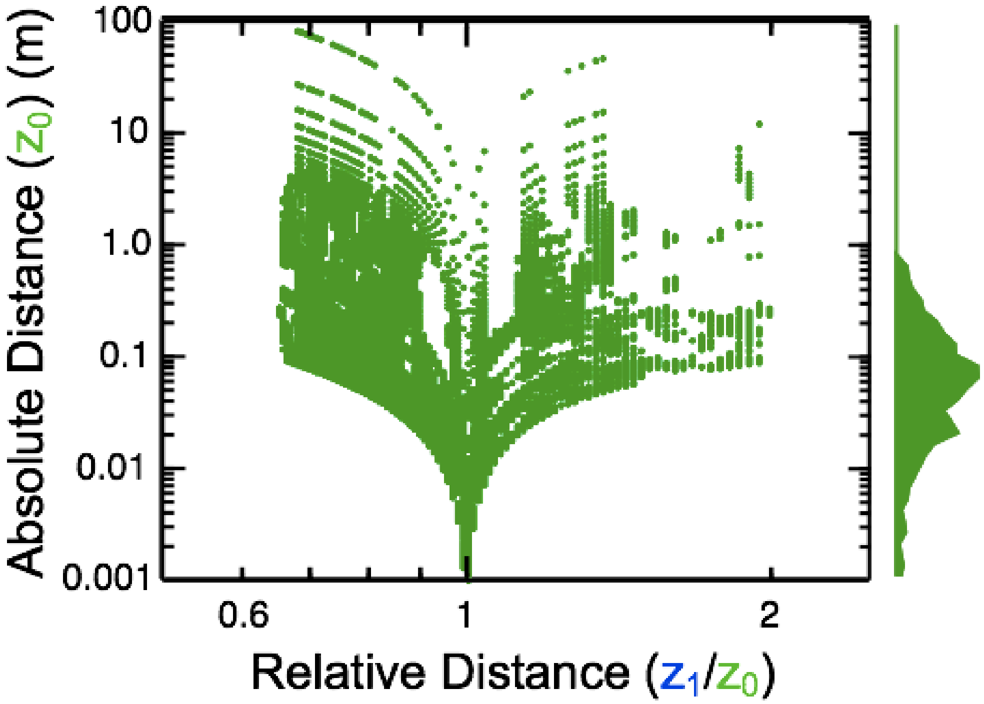


Estimated distance = ~10 cm

Held, Cooper, O'Brien, & Banks, *ACM Transactions on Graphics* (2010)

Distance Estimates with Unaligned Gradients





Uncertain distance estimate

Held, Cooper, O'Brien, & Banks, *ACM Transactions on Graphics* (2010)

Recommended Focal Length