Perceptual Bases for Rules of Thumb in Photography

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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.
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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
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).
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

Scene

Center of Projection (CoP)

Projection Plane
Picture Viewing

Projection to create picture:
\[ a = A \frac{p}{d} / \cos(S) \]
\[ b = B \frac{p}{d} \]

Projection onto retina:
\[ \alpha = ka \cos(S) \]
\[ \beta = kb \]

So at the retina:
\[ \alpha \propto A \]
\[ \beta \propto B \]
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 $O'$
• Almost never view pictures from correct position.

• Retinal image thus specifies different scene than depicted.

• Do people compensate, and if so, how?
Ovoid Stimulus

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.

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

Retinal coordinates

Screen coordinates

Observation Point

Center of Projection
Compensation: set ovoid to make image on screen circular:

- retinal coordinates
- screen coordinates
Predictions

![Graph showing invariance predictions for aspect ratio versus viewing angle $S_m$ (deg).]
Predictions

![Graph showing invariance and retinal predictions](image)

- Invariance predictions
- Retinal predictions

**Aspect Ratio (screen coords)**

**Viewing Angle $S_m$ (deg)**

$S_m$
Results

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

Results

Wide-field Distortion

With short focal length, eccentric spheres in picture perceived as ellipsoidal when viewed (binocularly) from CoP.
Focal Length & Field of View

\[ \theta = 2 \tan^{-1} \left( \frac{w}{2f} \right) \]

- \( w \) = width of film
- \( f \) = focal length
- \( \theta \) = 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:

\[
\theta = 2 \tan^{-1}\left(\frac{w}{2f}\right)
\]

- \(w\) = width of film
- \(f\) = focal length
- \(\theta\) = angular subtense of photo from CoP

We showed that critical \(\theta\) before distortion is \(~40\) deg (+/-20).

Solving for \(f\):

\[
f = \frac{w}{2 \tan\left(\frac{\theta}{2}\right)}
\]

\[
f = \frac{35}{2 \tan(20)} = 48 \text{ mm}
\]
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Different Focal Lengths

short focal length

long focal length

Different Focal Lengths

short focal length

long focal length

Depth Compression & Expansion

Short focal length

Medium focal length \((f \approx 50\,\text{mm})\)

Long focal length

Depth Compression & Expansion

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”.

“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.”

## Focal Length & Portraits

<table>
<thead>
<tr>
<th>Long focal length</th>
<th>Short focal length</th>
</tr>
</thead>
</table>

Focal Length & Field of View

8 mm, 28 mm, 35 mm, 50 mm, 85 mm, 135 mm, 250 mm, 350 mm, 500 mm, 1000 mm

180°, 75°, 63°, 43°, 29°, 18°, 10°, 7½°, 5°, 2½°
Focal Length & Field of View
Focal Length & Field of View

\[ f \]

\[ \theta_c \]

\[ w_c \]

image

scene

[Diagram of a camera lens with labels for focal length (f), field of view (\( \theta_c \)), and image width (\( w_c \)).]
Focal Length & Field of View

- $f$ represents the focal length of the lens.
- $\theta_c$ represents the field of view.
- $W_c$ represents the width of the image or field of view in the image plane.

Diagram shows light rays entering the lens from the scene and being focused onto the image plane, illustrating the concepts of focal length and field of view.
captured image: \( \theta_c = 2\tan^{-1}(w_c/2f) \)
height of photograph = $mw_c$

where $m$ is magnification of print

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

vanishing point

photograph

vanishing point
Depth Interpretation

vanishing point

photograph

d_{\text{COP}}

d_{\text{view}}

vanishing point
Depth Interpretation

vanishing point

photograph

$d_{COP}$

$d_{view}$

vanishing point
Our Hypothesis

• Depth compression/expansion, associated with long and short focal lengths, are caused by mismatches between correct viewing distance \(d_{COP}\) and actual viewing distance \(d_{\text{view}}\).

• 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 \(d_{\text{view}} < d_{COP}\) and short focal-length pictures from too far \(d_{\text{view}} > d_{COP}\).

• “Normal focal length” corresponds to length for which viewing distance corresponds to correct distance \(d_{\text{view}} \approx d_{COP}\); this is 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 differentcroppings
Pictures with Different Focal Lengths

photographs with $f = 22.4 – 160 \text{mm (35-mm equiv)}$

computer-generated images with $f = 22.4 – 160 \text{mm (35-mm equiv)}$
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 $f = 35\text{mm}$, which is close to $f = 50\text{mm}$ for 35-mm equivalent
Depth Expansion & Compression

short focal length

long focal length
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Depth-of-Field Blur

...depth of field will...
Blur (& Accommodation) in Vision Science Literature
• Blur and accommodation signals are always present.
• Literature mostly discounts influence of these focus cues
  Mather (2006): blur provides “coarse ordinal information”.
  Mather & Smith (2000): “…blur is always treated as a relatively weak depth cue by the visual system”.
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
Focal (absolute) distance: $z_0$
Image Formation & Blur

Focal (absolute) distance: $z_0$
Relative distance: $z_1/z_0$
Blur magnitude: $c_1$

\[
c_1 = \frac{A s_0}{z_0} \left| 1 - \frac{z_0}{z_1} \right|
\]
Distance Information from Blur

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

$$z_0 = \frac{A s_0}{c_1} \left| 1 - \frac{z_0}{z_1} \right|$$
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
By combining information from blur & perspective, can estimate absolute distance & therefore absolute size.

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

Experimental Results

Disparity Geometry

$$\delta_1 = X_R - X_L = \frac{I s_0}{z_0} \left[ 1 - \frac{z_0}{z_1} \right]$$

where

$$\frac{1}{s_0} = \frac{1}{f} - \frac{1}{z_0}$$
Blur Geometry

\[ c_1 = \frac{A s_0}{z_0} \left| 1 - \frac{z_0}{z_1} \right| \]
Geometries of Disparity & Blur

\[ \delta_1 = \frac{I s_0}{z_0} \left[ 1 - \frac{z_0}{z_1} \right] \]

\[ c_1 = \frac{A s_0}{z_0} \left| 1 - \frac{z_0}{z_1} \right| \]

comparing disparity & blur:

\[ \frac{c_1}{|\delta_1|} = \frac{A}{I} \]

Depth of Field

F-number = \( f / A \); \( A = f / (F\text{-number}) \)
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, should set blur appropriately to match those cues.
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- Funding from NIH and NSF
Blur Geometry

\[ c_1 = \frac{A s_0}{z_0} \left| 1 - \frac{z_0}{z_1} \right| \]
Blur Geometry

\[ b_1 = 2 \tan^{-1} \left( \frac{c_1}{2s_0} \right) \approx \frac{c_1}{s_0} \]

expressing blur in angular units

\[ c_1 = \frac{As_0}{z_0} \left| 1 - \frac{z_0}{z_1} \right| \]

\[ b_1 \approx \frac{A}{s_0} \left| 1 - \frac{z_0}{z_1} \right| \]
Blur Geometry

Expressing blur in angular units:

\[ c_1 = \frac{A s_0}{z_0} \left| 1 - \frac{z_0}{z_1} \right| \]

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

\[ b_1 = 2 \tan^{-1} \left[ \frac{c_1}{2 s_0} \right] \approx \frac{c_1}{s_0} \]

\[ b_1 \approx \frac{A}{z_0} \left| 1 - \frac{z_0}{z_1} \right| \]
Preferred Viewing Distance for Television
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.
Anamorphic Art

Julian Beever: Glasgow, High Street
Anamorphic Art

Julian Beever: Glasgow, High Street
Rafael’s *School of Athens*
Architectural Photography
Architectural Photography

rotate (or translate) film plane

optic axis

scene
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

- CoP

Aspect Ratio (screen coords)

- surface predictions
- pictorial predictions
- retinal predictions

Viewing & Projection Angle (deg)
Results

Results

Viewing Pictures

For subset with $f = 35\text{mm}$, which is close to $f = 50\text{mm}$ for 35-mm equivalent
For subset with $f = 35\text{mm}$, which is close to $f = 50\text{mm}$ for 35-mm equivalent.
Estimating Absolute Distance

Distance Estimate with Aligned Gradients

Estimated distance = \sim 10 \text{ cm}

Distance Estimates with Unaligned Gradients

Uncertain distance estimate

Recommended Focal Length

![Graph showing the relationship between Focal Length (mm) and Picture Width (cm).]