Making big things look small: Blur combined with other depth cues affects perceived size and distance

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Blur as a depth cue: Previous findings

• Blur is a weak cue to depth

  - Other depth cues, such as disparity, are much stronger (Mather 2000)

  - Blur only useful to reveal the depth ordering of surfaces that occlude each other (Marshall et al. (1996) and Mather (1996))
Revisiting blur as a cue

Important terms:
Focal (absolute) distance: $z_0$
Revisiting blur as a cue

Important terms:
Focal (absolute) distance: \( z_0 \)
Relative distance: \( d = \frac{z_1}{z_0} \)
Blur magnitude: \( c_1 \)

\[
c_1 = \left| A \left( \frac{s_0}{z_0} \right) \left( 1 - \frac{1}{d} \right) \right|
\]
Information from blur
Information from blur
Information from blur

- Blur alone could correspond to any combination of relative distance and focal distance

Pupil diameter: mean = 4.6mm, s.d. = 1.0mm

Retinal blur = 2°

Pupil data from Spring and Stiles (1948)
Other information

- Perspective information can estimate the relative distance to the building

Pupil data from Spring and Stiles (1948)
Model

- Combined with relative depth information, blur can act as a cue to absolute distance

- Bayesian approach:

\[ \text{Combined Depth Estimate} = \text{Depth-from-blur Likelihood} \times \text{Depth-from-perspective Likelihood} \]

\[ \text{Absolute Distance (} z_0 \text{) (m)} \]

\[ \text{Relative Distance (} z_1/z_0 \text{)} \]

- Model parameters:
  - Pupil diameter: mean = 4.6mm, s.d. = 1.0mm
  - Retinal blur = 0.1°
Recovering absolute distance

Absolute Distance \((z_0)\) (m)

Relative Distance \((z_1/z_0)\)

retinal blur = 1.0°
Recovering absolute distance

Absolute Distance ($z_0$) (m)

Relative Distance ($z_1/z_0$)

- Retinal blur = 1.0°
Recovering absolute distance

Absolute Distance ($z_0$) (m)

Relative Distance ($z_1/z_0$)

Retinal blur = 1.0°
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retinal blur = 0.1°
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Absolute Distance ($z_0$) (m)

Relative Distance ($z_1/z_0$)

Retinal blur = 2.0°
Recovering absolute distance

Absolute Distance ($z_0$) (m)

Relative Distance ($z_1/z_0$)

Absolute Distance ($z_0$) (m)

Relative Distance ($z_1/z_0$)

retinal blur = 2.0°
Recovering absolute distance

- Predicted perceived distance: 8cm
Inaccurate blur

Consistent blur

Aligned blur gradient
**Aligned blur gradient**

- Predicted perceived distance: \( \sim 10\text{cm} \)
  - Expect weaker influence of blur due to variance
Inaccurate blur

Consistent blur

Unaligned blur gradient
Unaligned blur gradient

- Predicted perceived distance: ambiguous
  - Expect weakest miniaturization effect, if any
Experiment

• 7 sample scenes from GoogleEarth
• Each scene rendered sharply and with consistent, aligned gradient, and unaligned gradient blur
• 5 blur magnitudes
• Subjects viewed each image monocularly for 3.0 sec, then reported the distance from a marked building in the center of the image to the camera that produced the image
• Each image repeated 7 times (randomly interleaved)
Results

Simulated Focal Distance (m)

Reported Distance (Normalized)

Subject RRR

All Subjects

blur condition:
- blue: consistent
- green: aligned gradient
- red: unaligned gradient
Discussion

- Previously, blur considered a weak depth cue
Discussion

• Previously, blur considered a weak depth cue
• **Blur can act as a strong cue to absolute distance and size**
  - Must be combined with other depth cues
  - Explains the perceptual basis of the tilt-shift effect
  - Also predicts previous findings in vision science literature
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Blur as a depth cue: Previous results

• Blur is a weak, ordinal cue to depth
  - Blur can reveal the depth ordering of surfaces that occlude each other (Marshall et al. (1996) and Mather (1996))
Theory

- Matching-task interpretation
• Peaks indicate estimated focal depth
• Variance reflects reliability of estimate
• Unreliable cues are given less weight by the visual system
  - Unaligned gradients should have a small affect on perceived distance and scale
Consistent Blur

- Sampled points perfectly match curve
Information from blur

\[ z_0 = 0.9 \text{m}, \quad \left( \frac{z_1}{z_0} \right) = 0.75 \]

\[ z_0 = 2.3 \text{m}, \quad \left( \frac{z_1}{z_0} \right) = 0.50 \]
**Information from blur**

Blur alone could correspond to any combination of relative distance and focal distance

- Focal Distance ($z_0$) (m)
- Relative Distance ($z_1/z_0$)

- Retinal blur = 0.1°
- Pupil diameter: 4.6mm
Theory applied to previous studies

• Consistent blur most reliable, followed by vertical and horizontal gradients
• Vertical gradients more reliable for low depth variation
Blur in Photography
Blur in cinema

• Small apertures and long exposures minimize blur

• Result: Scale models appear life-sized
Blur as a depth cue

- Compare strengths of disparity and blur as depth cues
- With disparity present, blur had little effect on percept, unless it was greatly exaggerated
- Conclusion: Blur provides coarse, qualitative information

Mather et al. (2000)
Revisiting blur as a cue

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**Blur magnitude:** \( c_1 \) (deg)

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