Influence of 2D Shape on Contour Depth Perception

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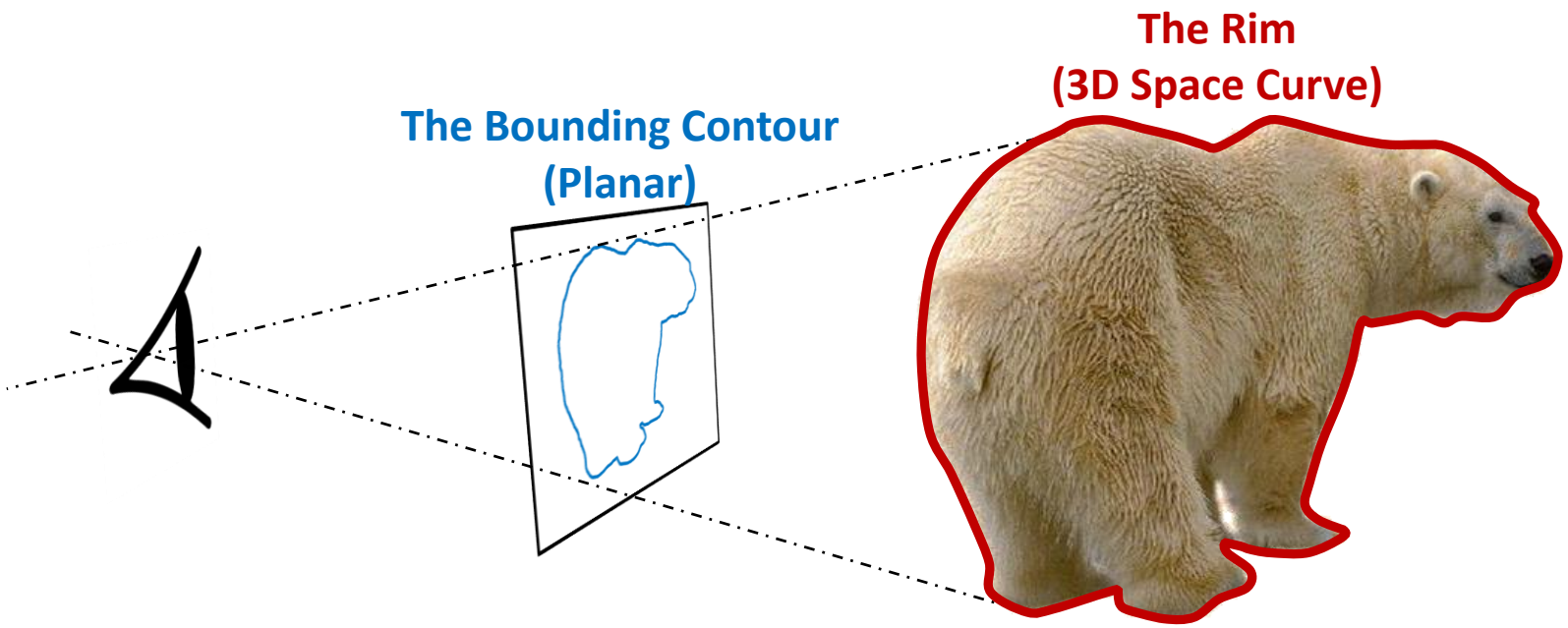
Bounding Contours

- The bounding contour in the image projects from a 3D space curve – the rim.
- In general, the rim is not fronto-parallel, or even planar.
- Can the 3D rim be estimated from the 2D bounding contour alone?



Koenderink, 1984

Prior Work

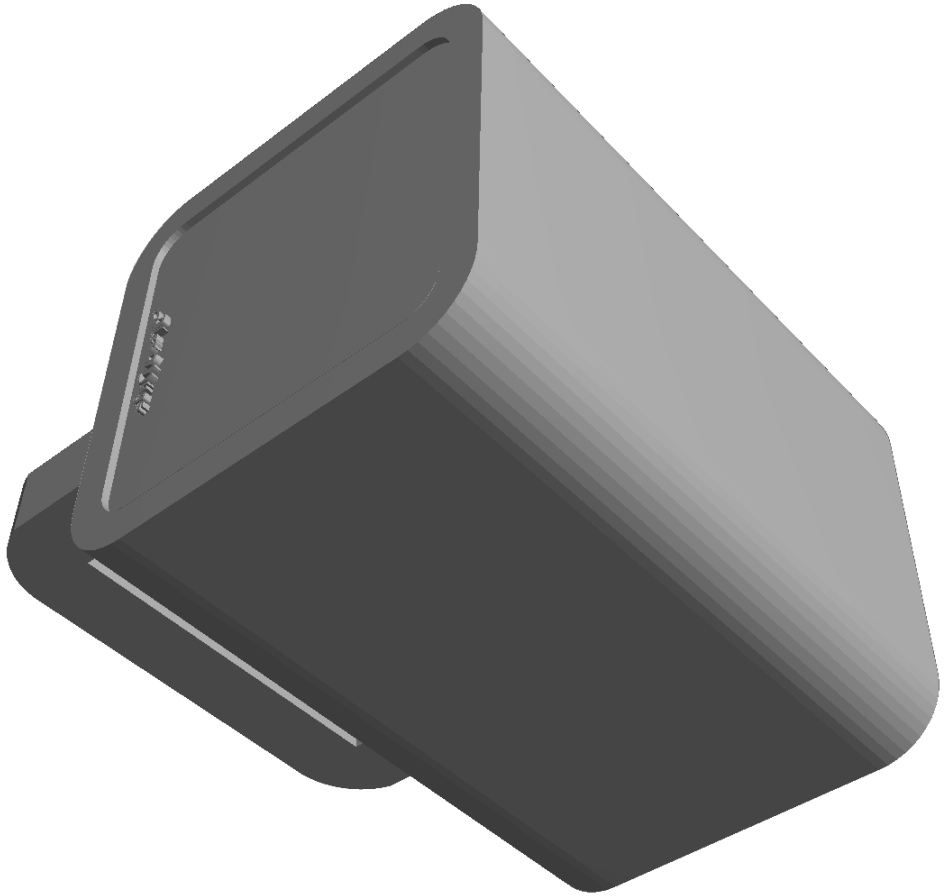
- Qualitative surface curvature from the bounding contour (Koenderink, 1984)
- Influence of the bounding contour on perceived object shape (Todd & Reichel 1989, Tse 2002, Todd 2004)
- Integration of bounding contour cues with surface cues (Karsch et al 2013, Barron & Malik. 2015)

Questions:

- Can people use monocular shape cues to judge the depth of points on bounding contours?
  - Exp. 1: Depth discrimination

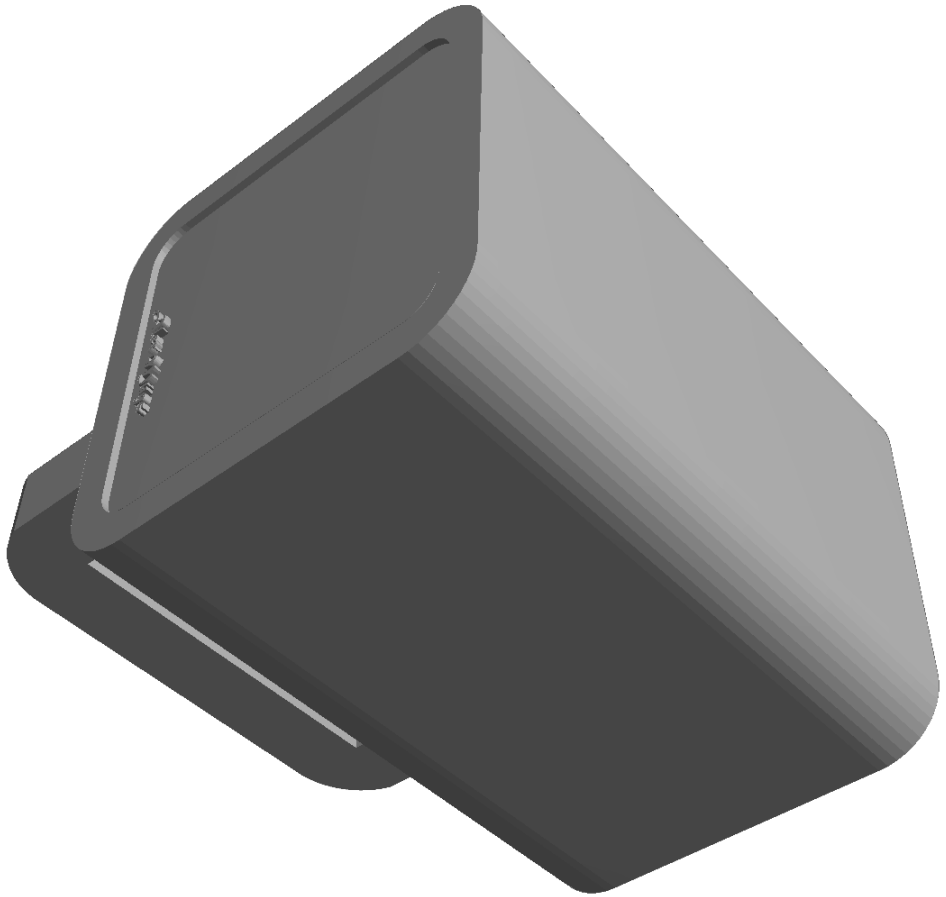
- Do these monocular contour cues interact with binocular cues?
  - Exp. 2: Depth discrimination
  - Exp. 3: Magnitude estimation

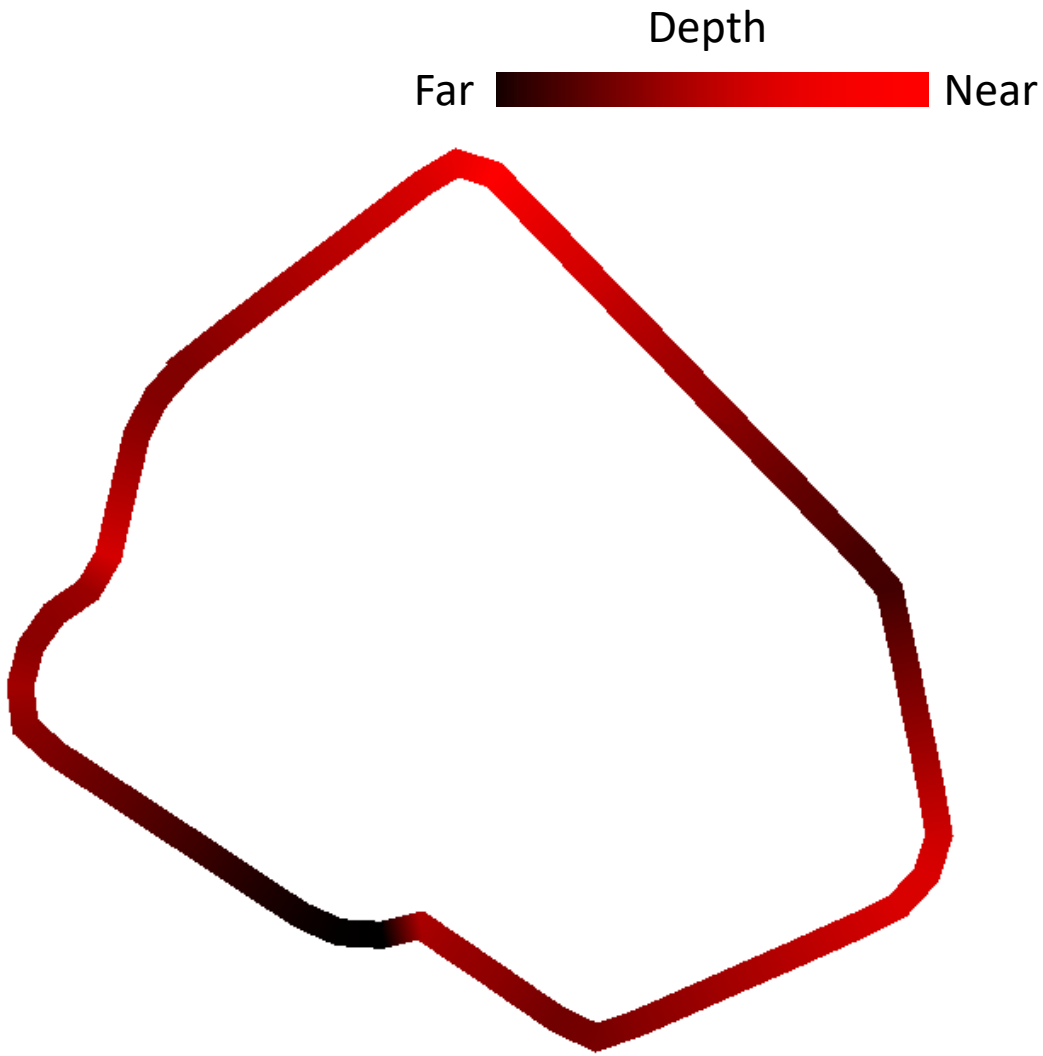
ShapeNet object contours



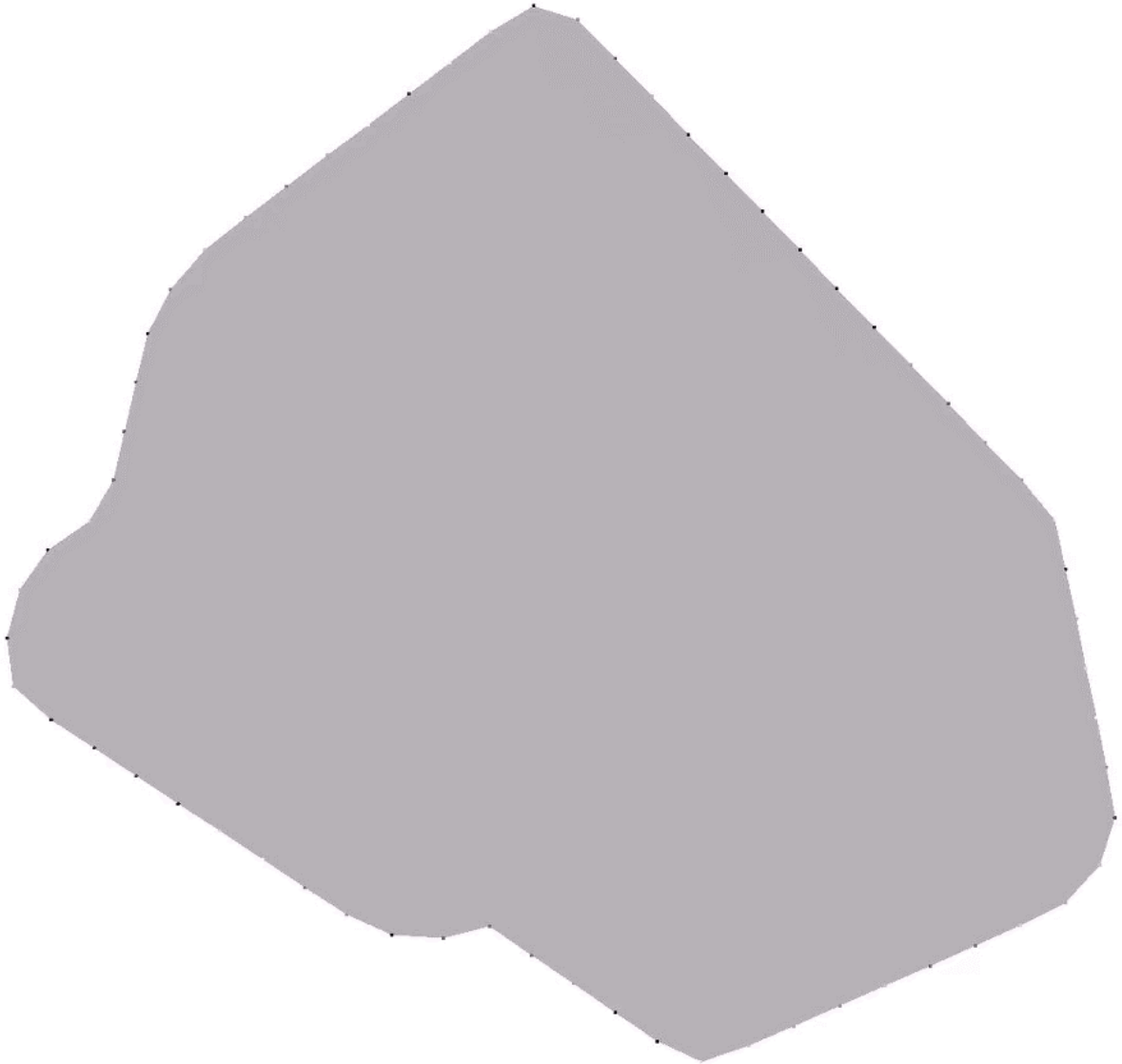
- 3D models from 55 man-made object categories
- Rendering parameters matched to the stereoscopic display:
  - Viewing distance = 40 cm
  - Objects subtend 28 deg
- Rim represented as a vector of 64 3D (X, Y, Z) points

ShapeNet object contours





Projected silhouette



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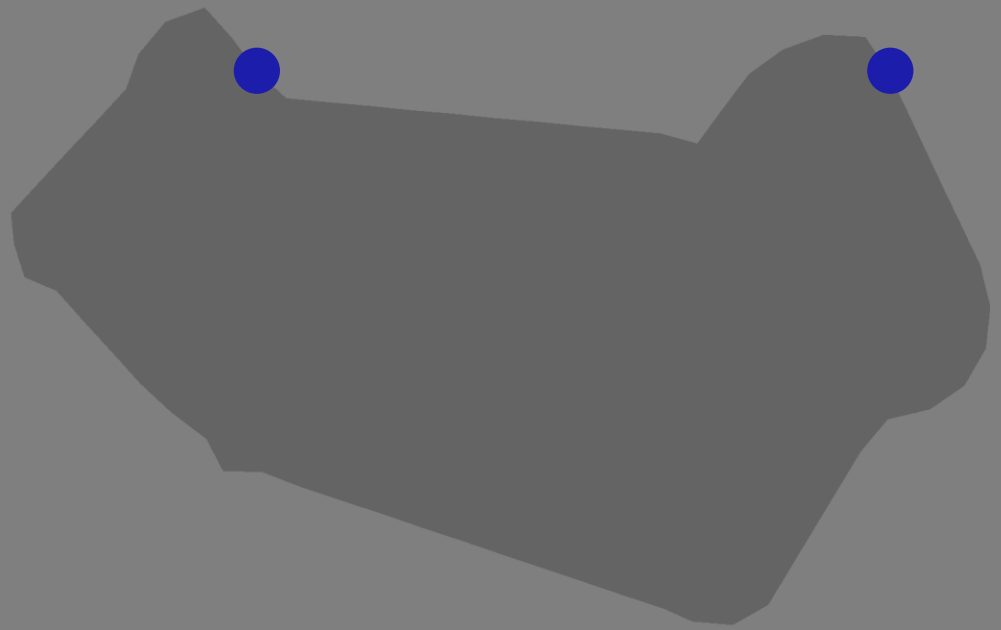
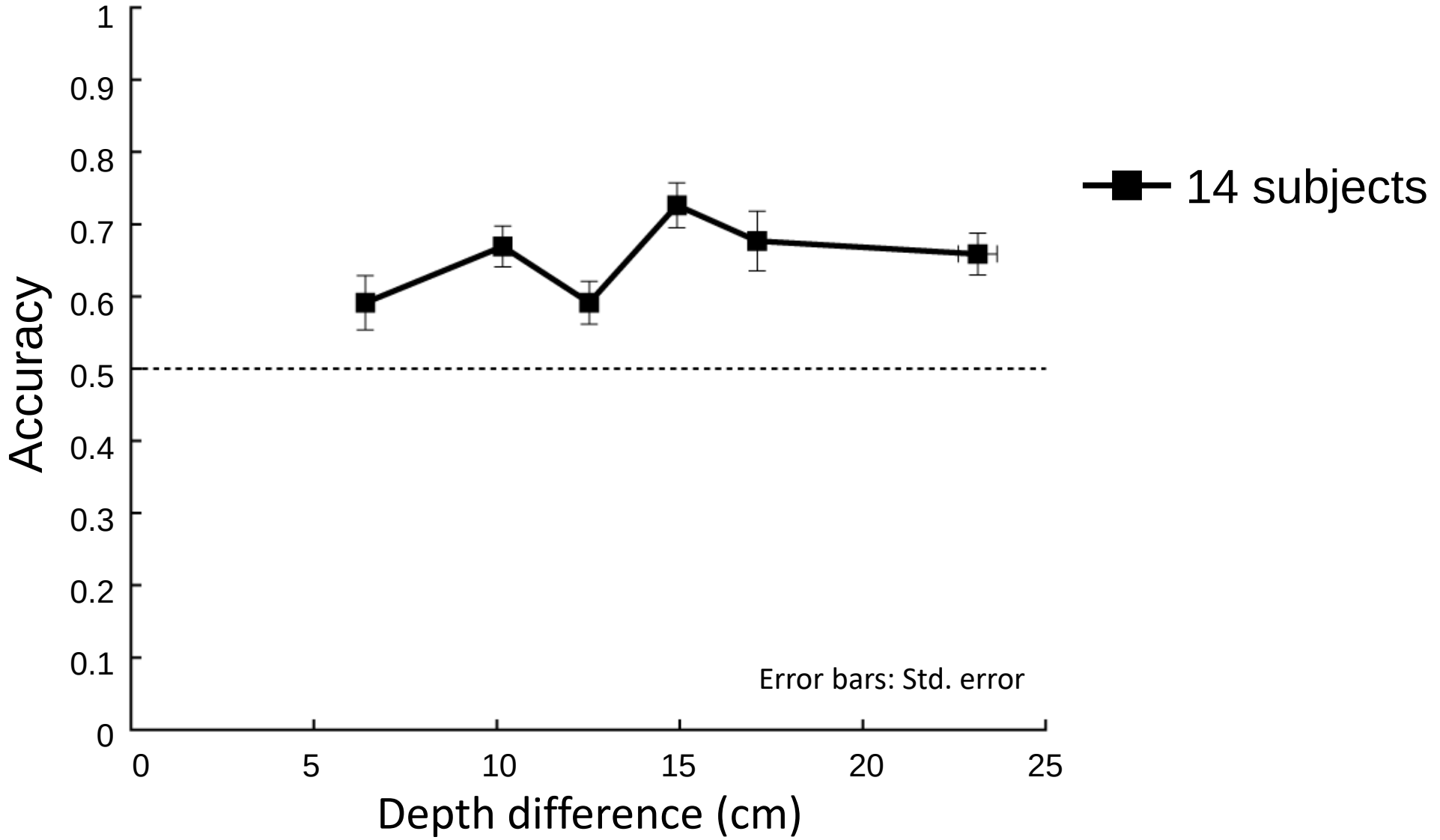


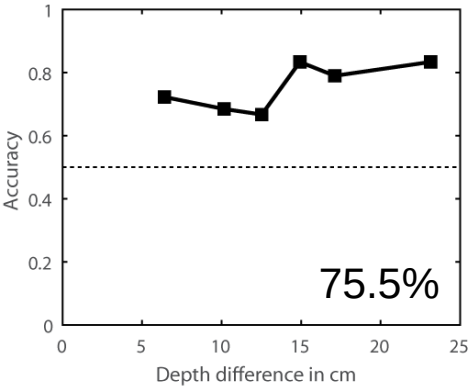
Exp. 1: Methods

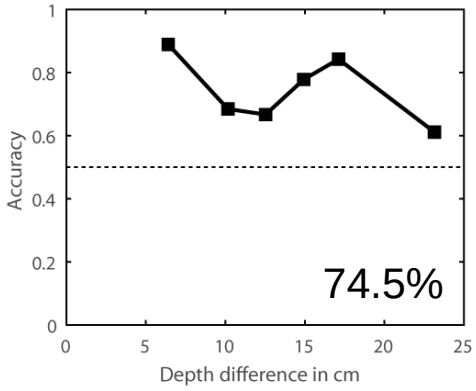
- 14 subjects
- 110 objects
- Monocular presentation
- Two points marked on contour, corresponding to minimum and maximum depth
- Task: Which point is closer?
- Unlimited response time, no feedback

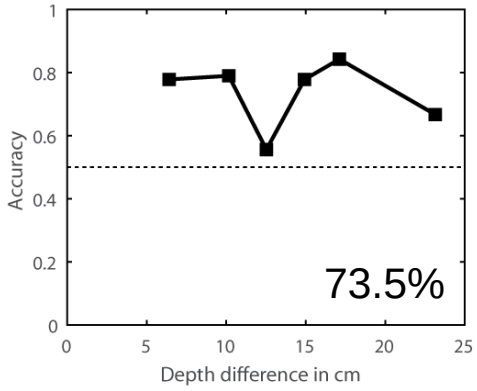
Exp. 1: Results

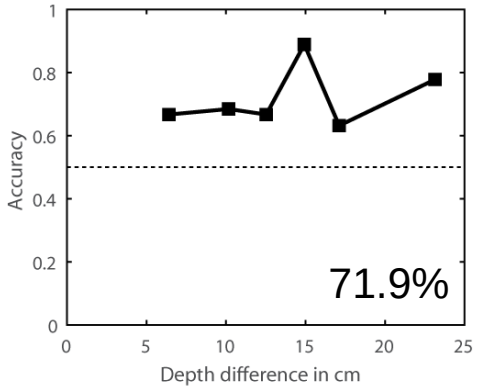


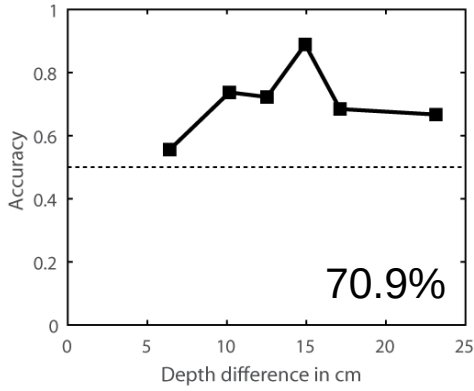
Accuracy, 14 individual subjects

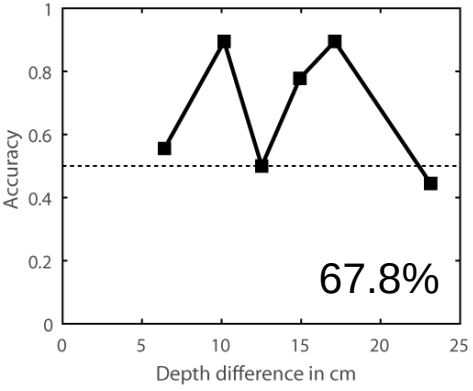


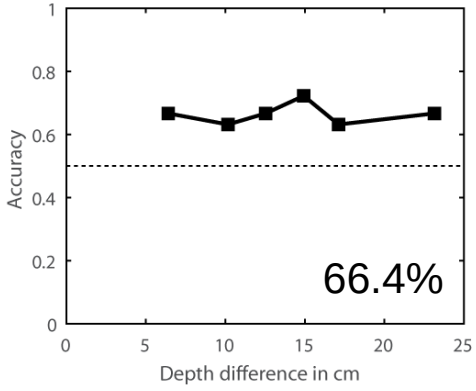


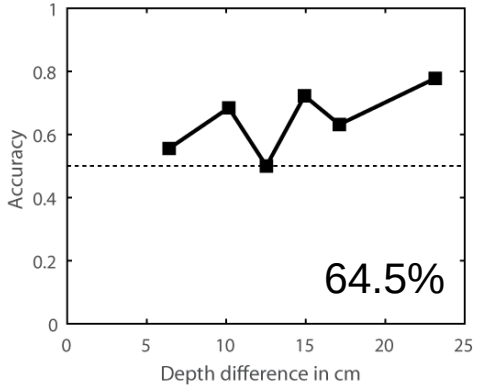


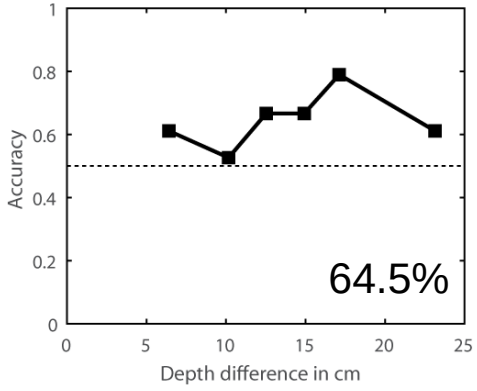


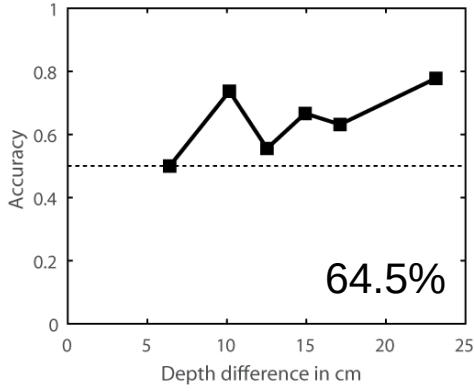


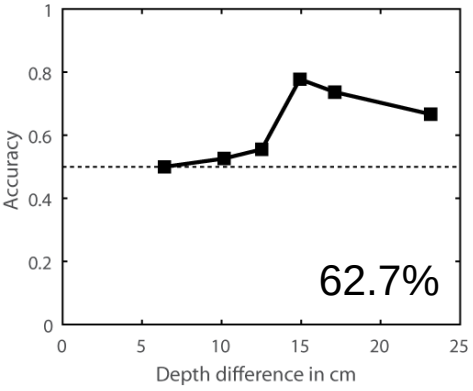


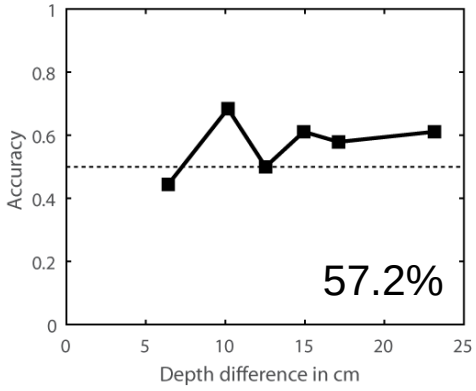


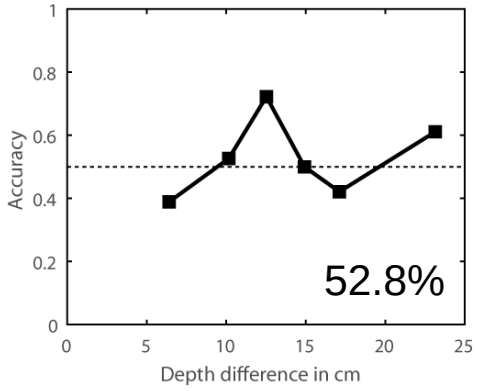


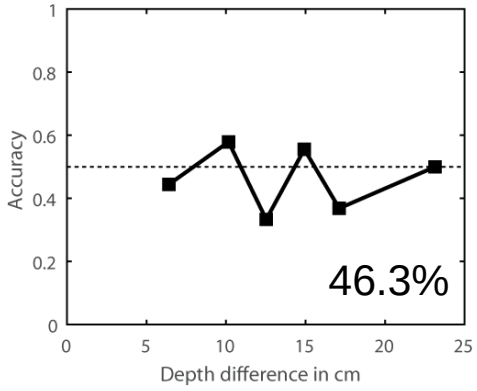








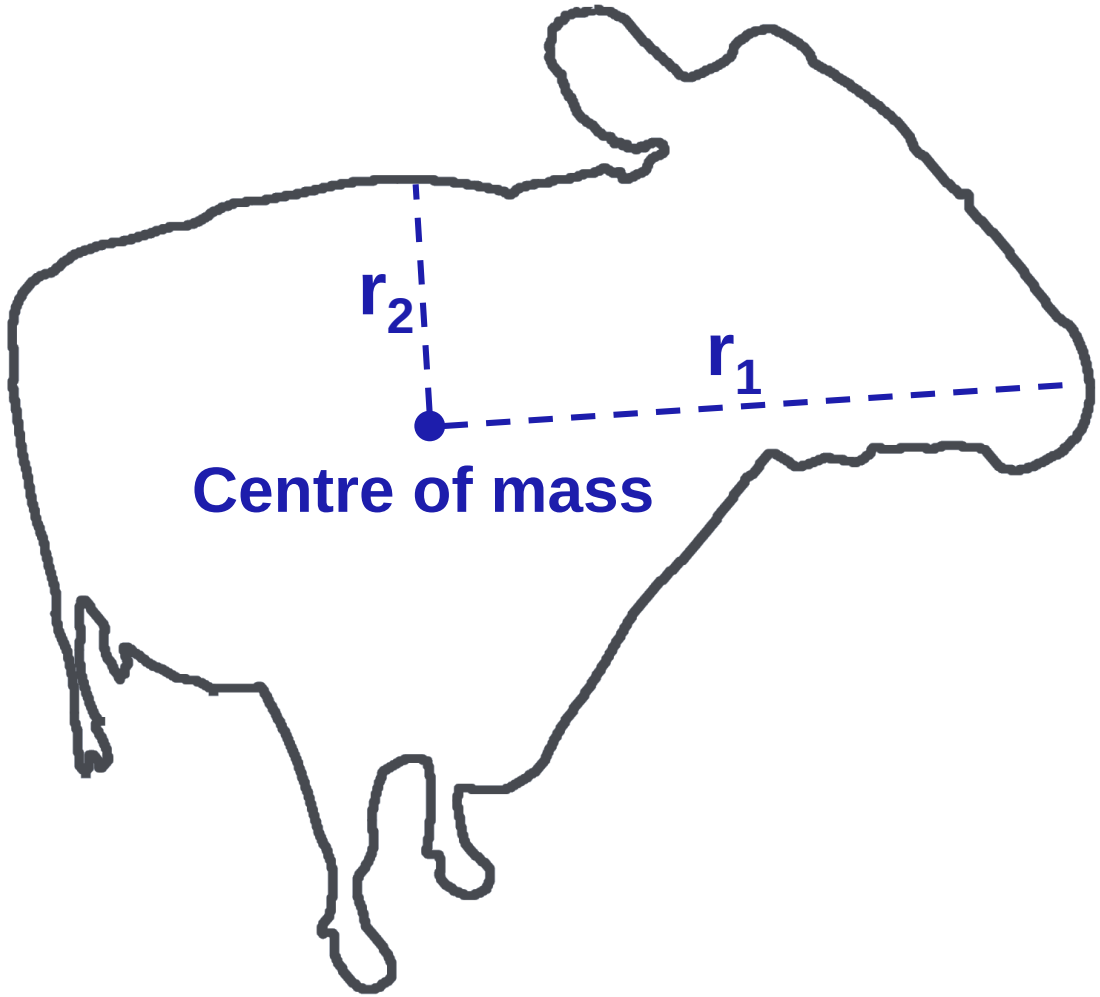




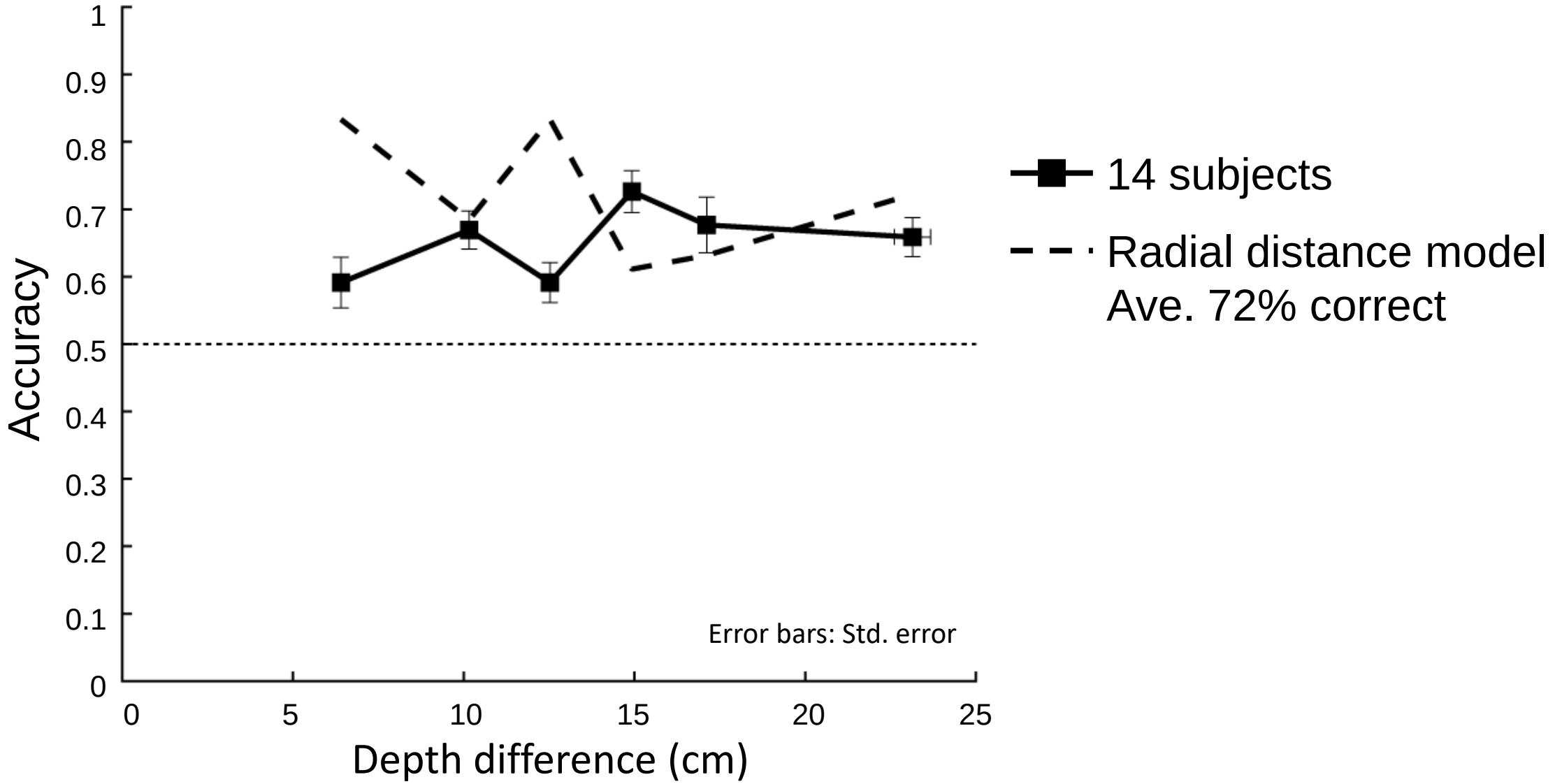
How do observers make these judgements?

A simple radial distance cue

- In perspective projection, visual features increase in size as they move closer to the observer in depth.
- **Hypothesis:** Boundary points further from the object center of mass are likely to be closer to the observer.
- **Algorithm:** $r_1 > r_2 \rightarrow Z_1 < Z_2$



Exp. 1: Human data and radial distance model



Exp. 1: Conclusions

- People can make depth judgments from 2D bounding contours (e.g., determine which side of the object is closer).
- A simple model based on radial distance to the centre of mass performs at 72% correct.
- Average human performance is somewhat lower (65%), but individual subjects may outperform the model.

Questions:

- Can people use monocular shape cues to judge the depth of points on bounding contours?
  - Exp. 1: Depth discrimination

- Do these monocular contour cues interact with binocular cues?
  - Exp. 2: Depth discrimination
  - Exp. 3: Magnitude estimation

Questions:

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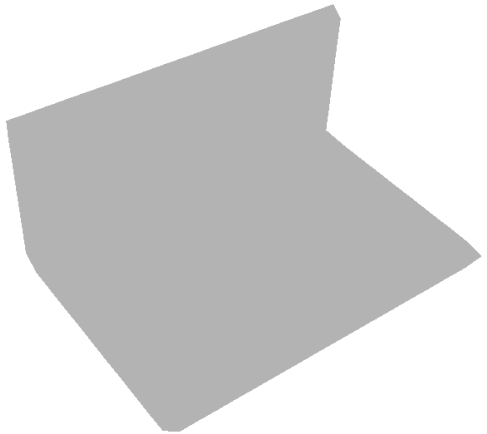
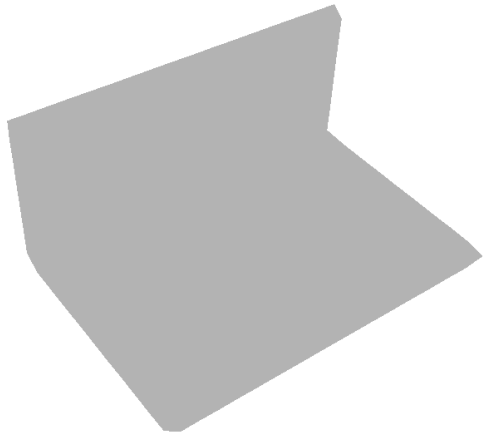
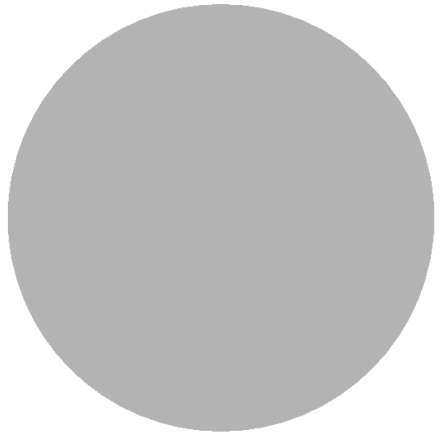
Exp. 2: Methods

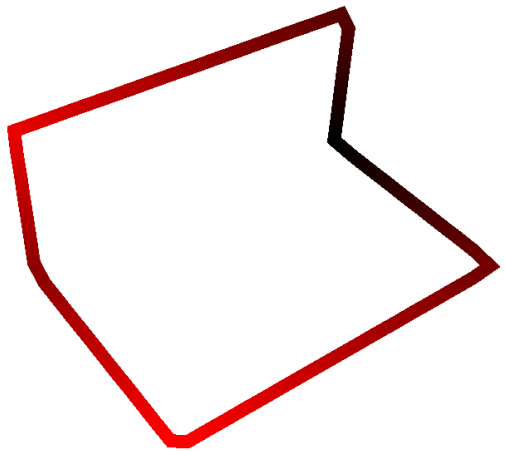
- 7 subjects
- 47 objects
- Binocular presentation
- Two points marked on contour at specific depth differences (0.125, 0.25, 0.5, 1, 2, 4, and 8 cm apart)
- Task: Which point is closer?
- Unlimited response time, no feedback
- Three contour conditions: original shape, shifted contour, circular contour

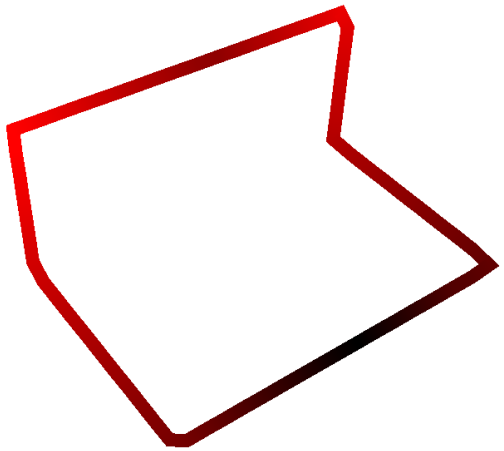
Contour conditions

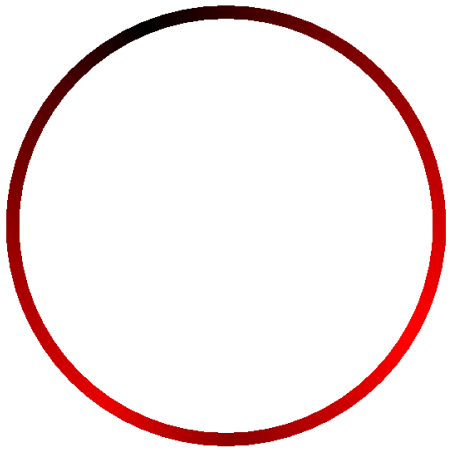










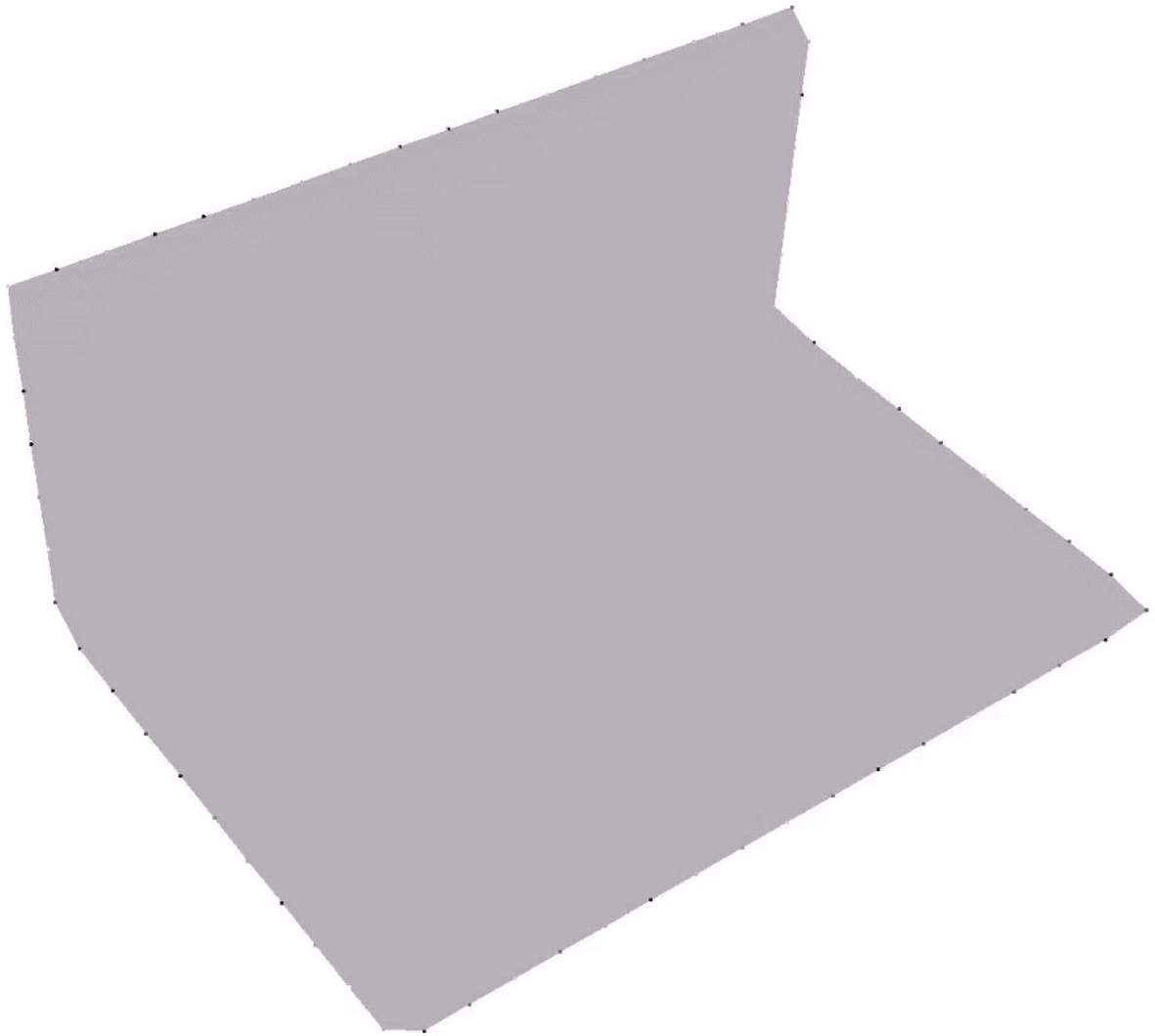


Original

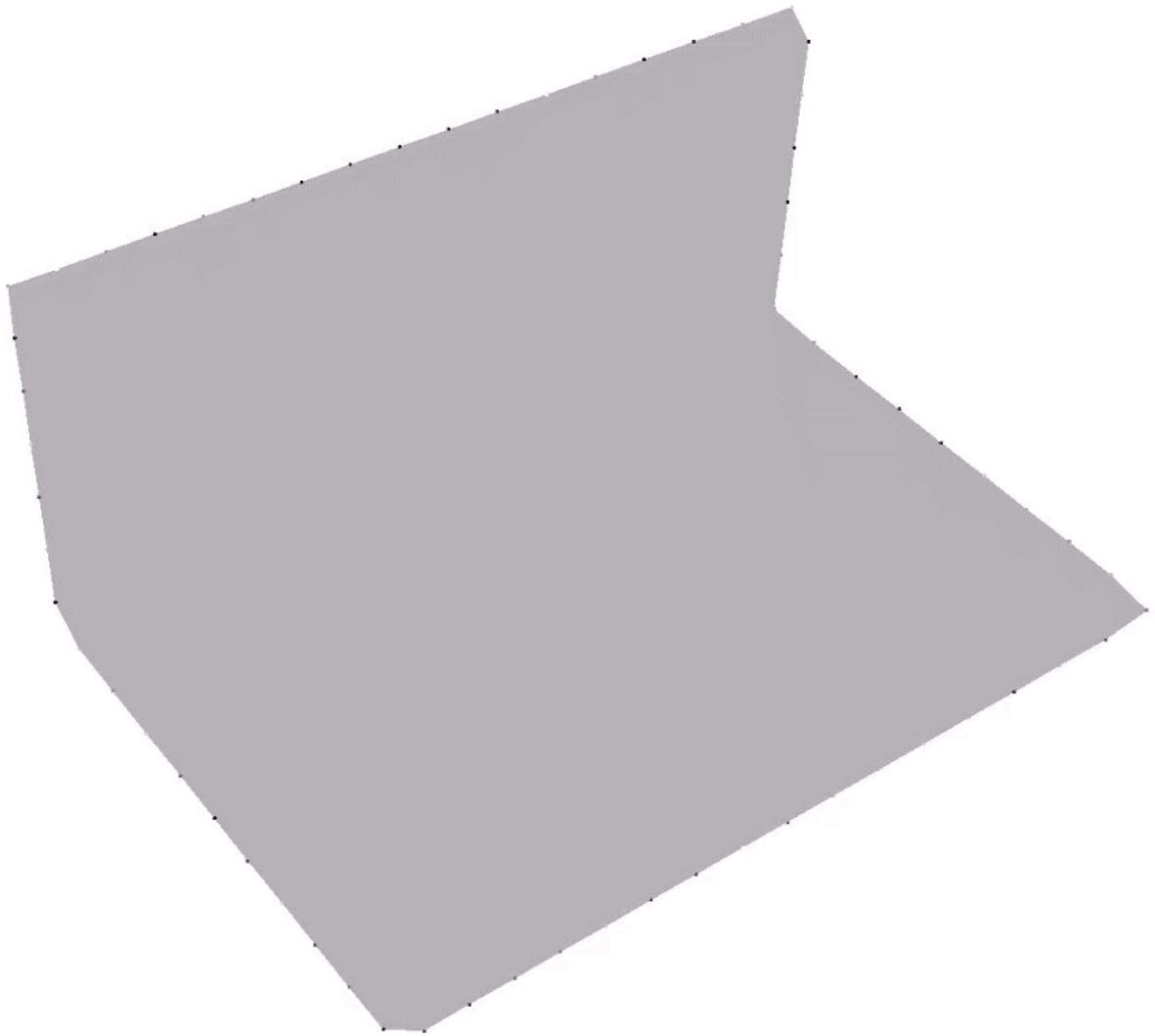
Shifted

Circle

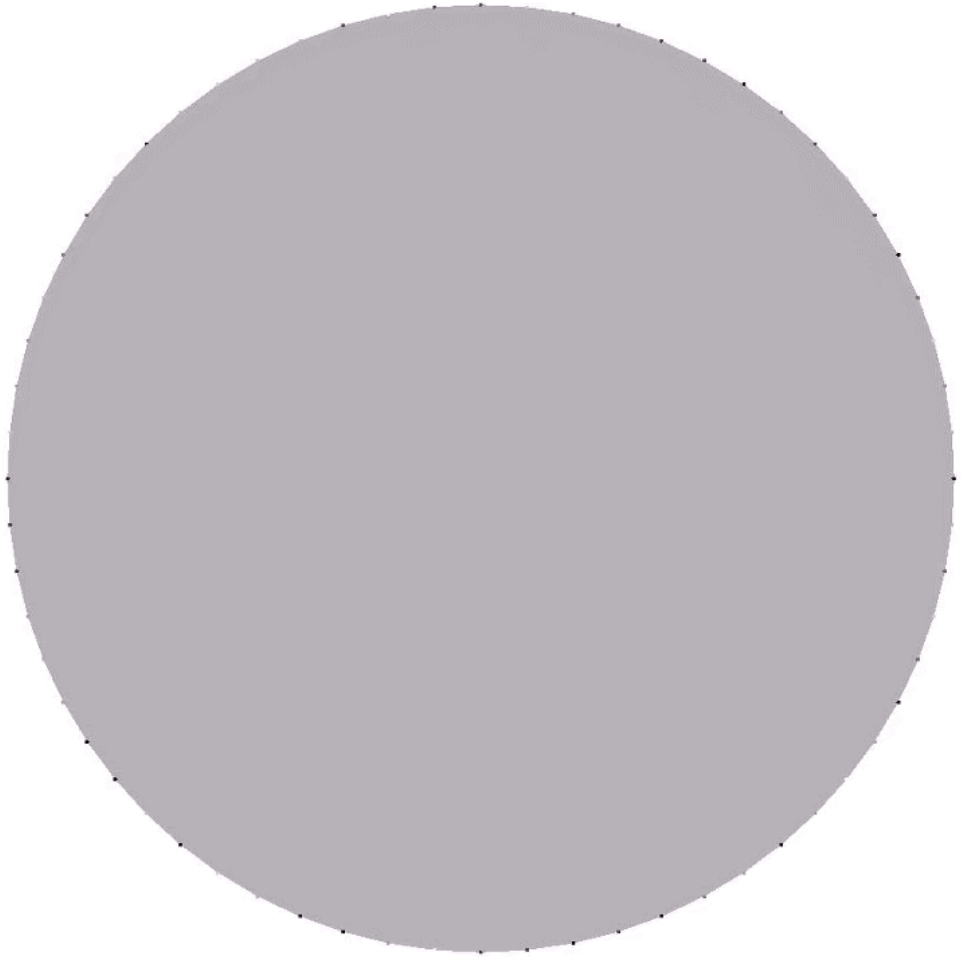
Original

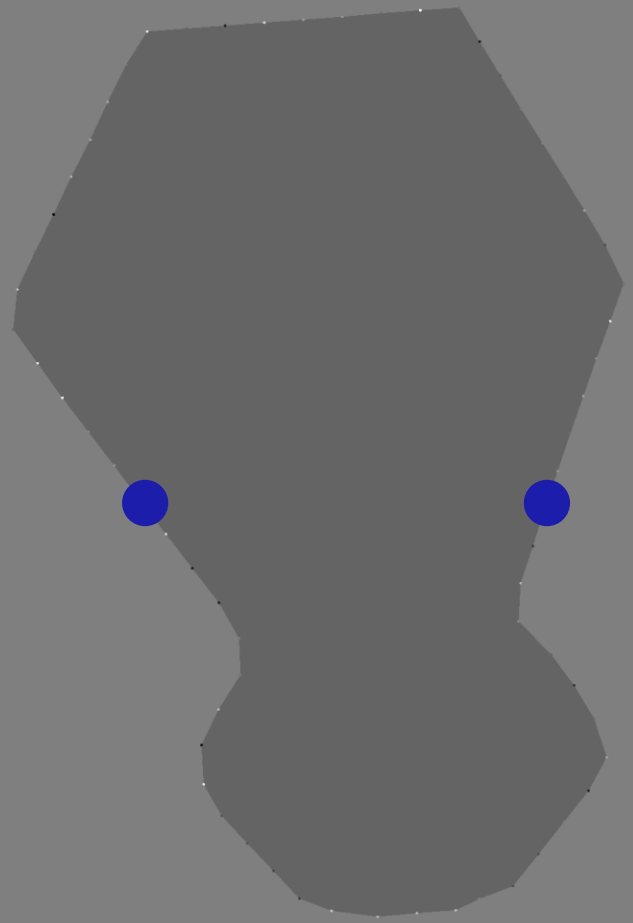


Shifted

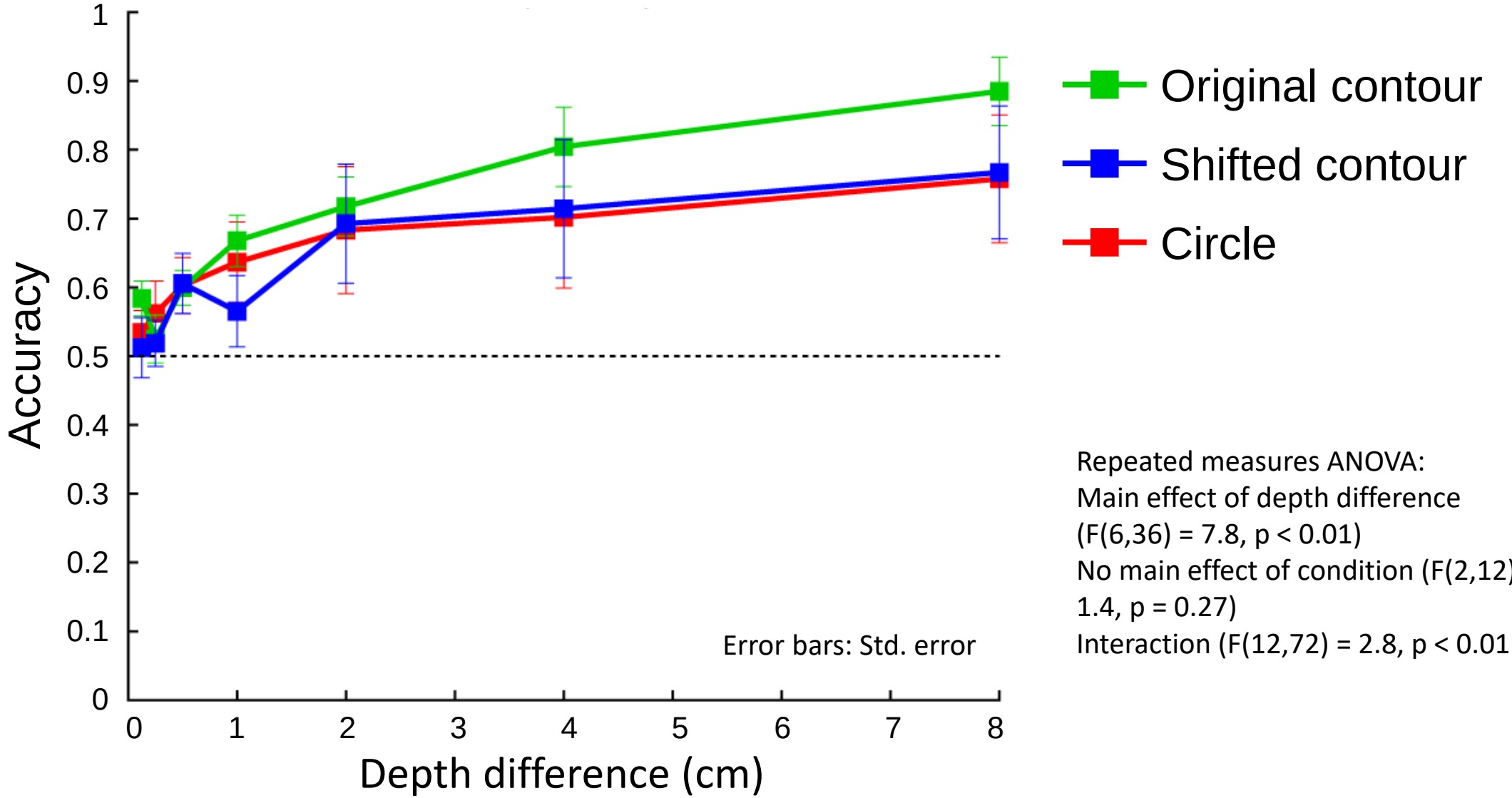


Circle



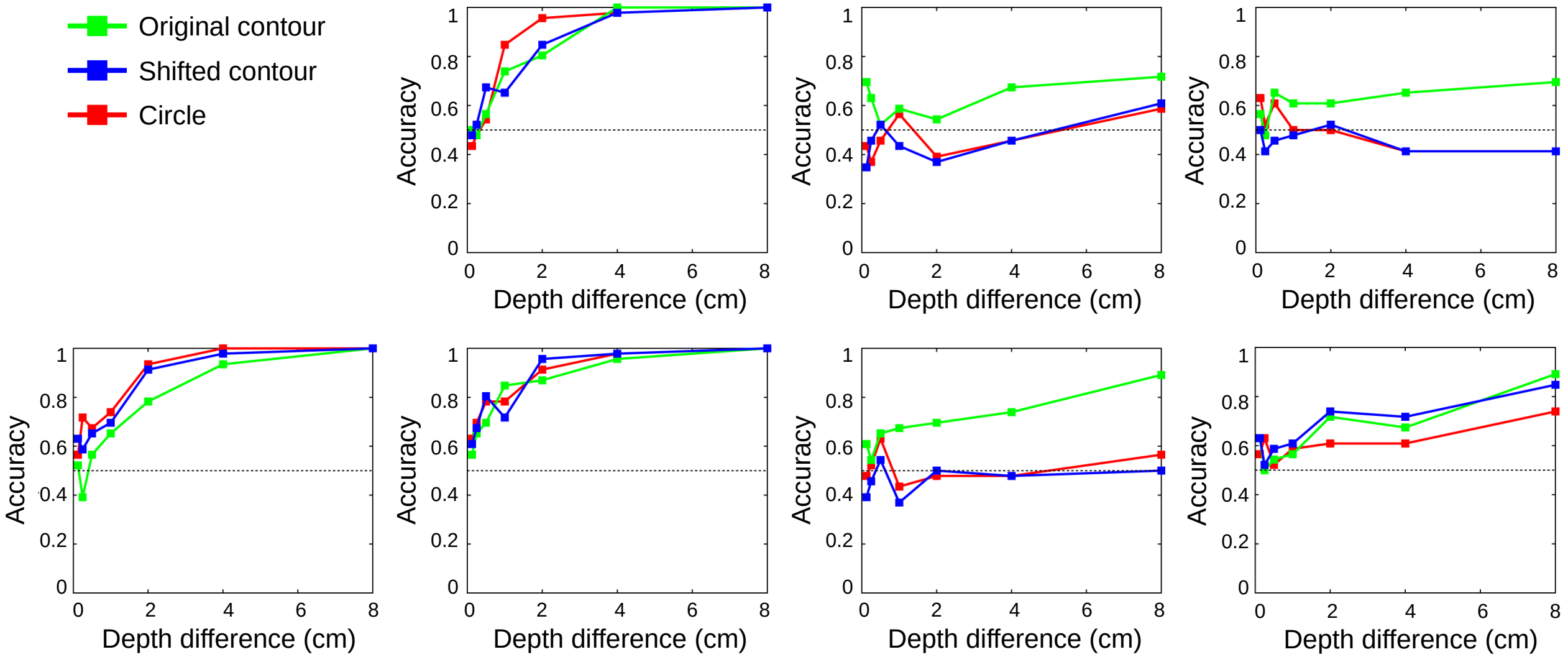


Exp. 2: Results



Repeated measures ANOVA:
Main effect of depth difference ($F(6,36) = 7.8$, $p < 0.01$)
No main effect of condition ($F(2,12) = 1.4$, $p = 0.27$)
Interaction ($F(12,72) = 2.8$, $p < 0.01$

Accuracy, 7 individual subjects



Exp. 2: Conclusions

- Overall, depth discrimination was most accurate when the 2D contour shape was consistent with the 3D depth information, and less accurate when the 3D depths were mapped to an inconsistent contour shape.
- Observers cluster into two groups:
  - Group 1 (Stereo dominant)
    - Stronger performance for original stereoscopic contours (asymptote to 100% accuracy)
    - No degradation with inconsistent monocular shape cues
  - Group 2 (Integrators)
    - Weaker performance for original stereoscopic contours (asymptote to < 100% accuracy)
    - Substantial degradation with inconsistent monocular shape cues

Questions:

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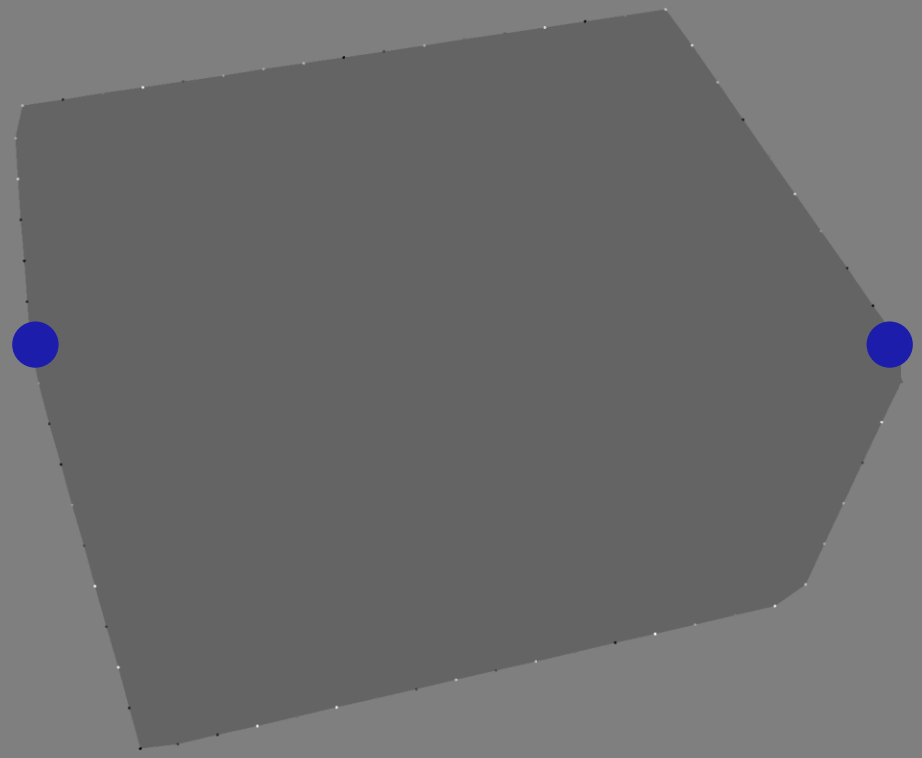
  - Exp. 1: Depth discrimination

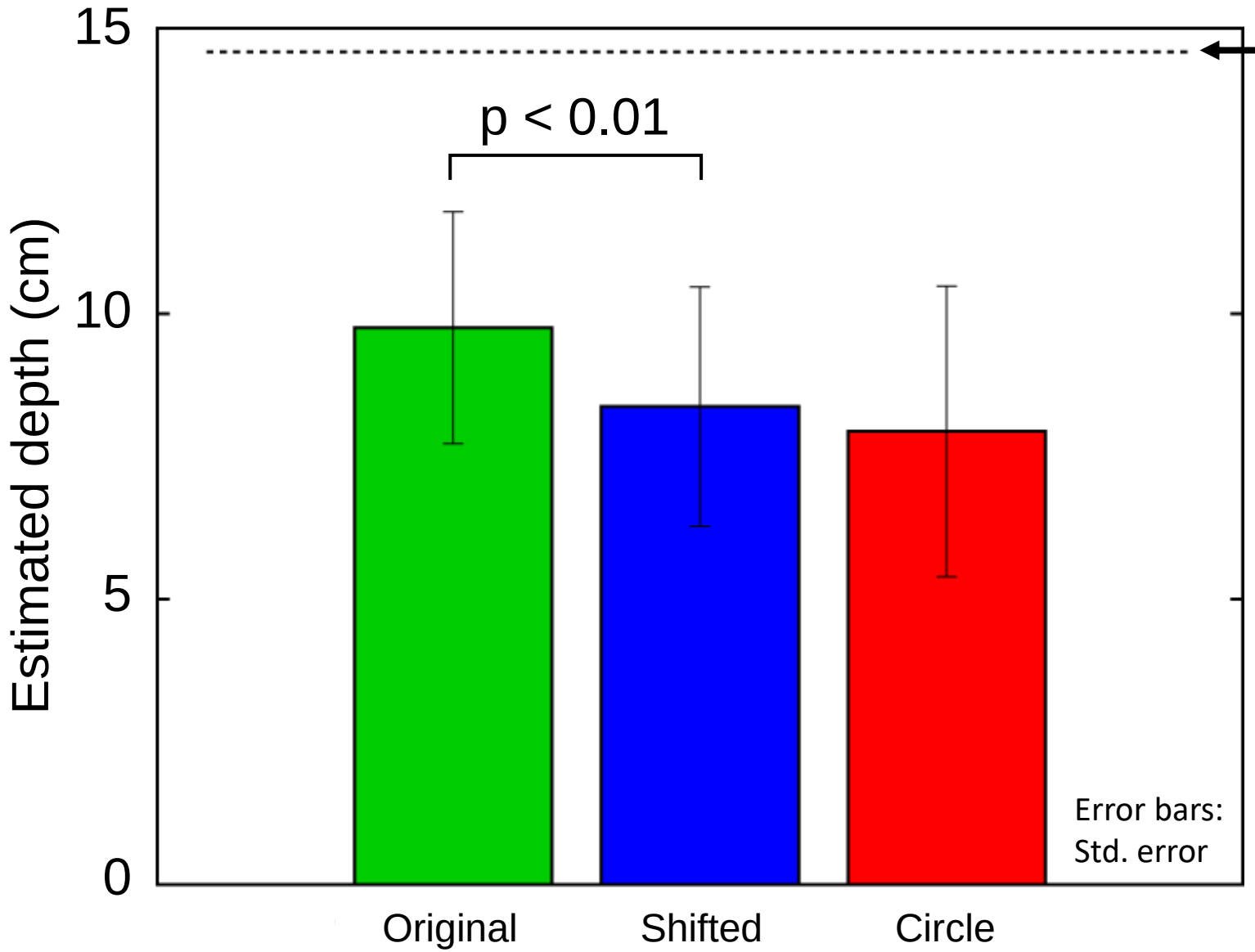
- Do these monocular contour cues interact with binocular cues?
  - Exp. 2: Depth discrimination
  - Exp. 3: Magnitude estimation

Exp. 3: Methods

- 8 subjects
- 47 objects
- Binocular presentation
- Three contour conditions: original shape, shifted contour, circular contour
- Two points marked on contour, corresponding to minimum and maximum depth
- Task: How far apart are the two points?
- Unlimited response time, no feedback



Exp. 3: Results



Mean actual depth (same in all three conditions)

Repeated measures ANOVA:
Main effect of condition
($F(2,14) = 79.4$, $p < 0.01$)

Exp. 3: Conclusions

- Depth estimation was most accurate when the 2D contour shape matched the 3D depth information, and less accurate when the 3D depths were mapped to an inconsistent contour shape.

Questions:

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  - Exp. 1: Depth discrimination

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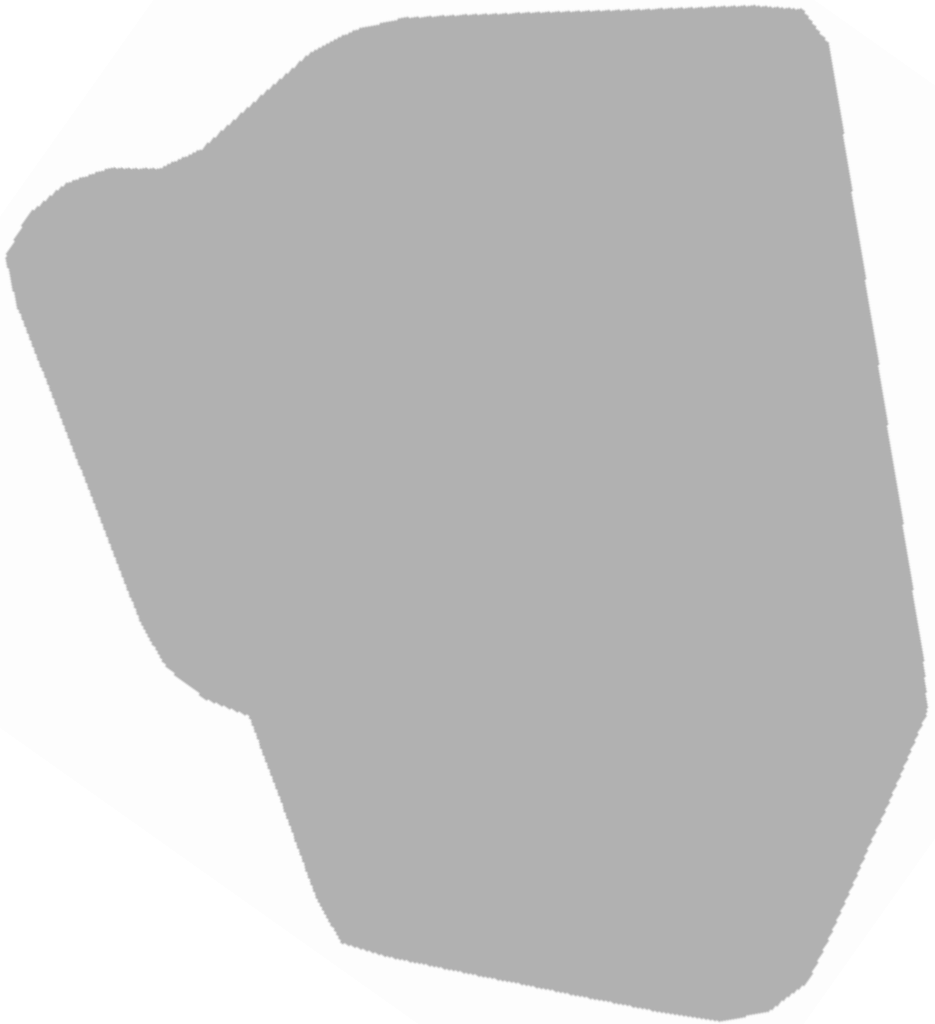
  - Exp. 3: Magnitude estimation

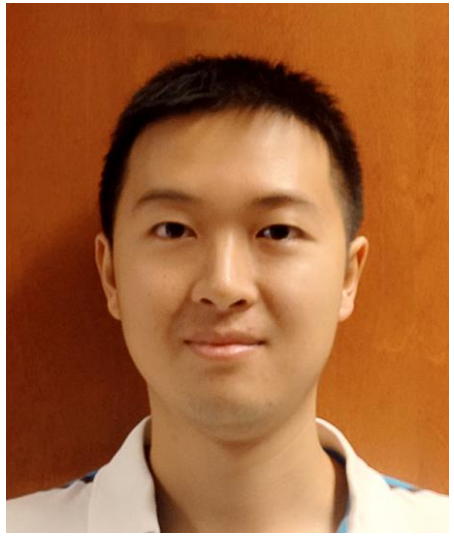
Conclusions

- People can use information from the 2D contour shape to judge 3D depth relations on object boundaries.

- These monocular boundary cues interact with binocular cues in determining depth judgements.



Acknowledgements



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