A Perceptual Reinterpretation of Non-Rigid Part-Length Change in Structure-From-Motion

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Background

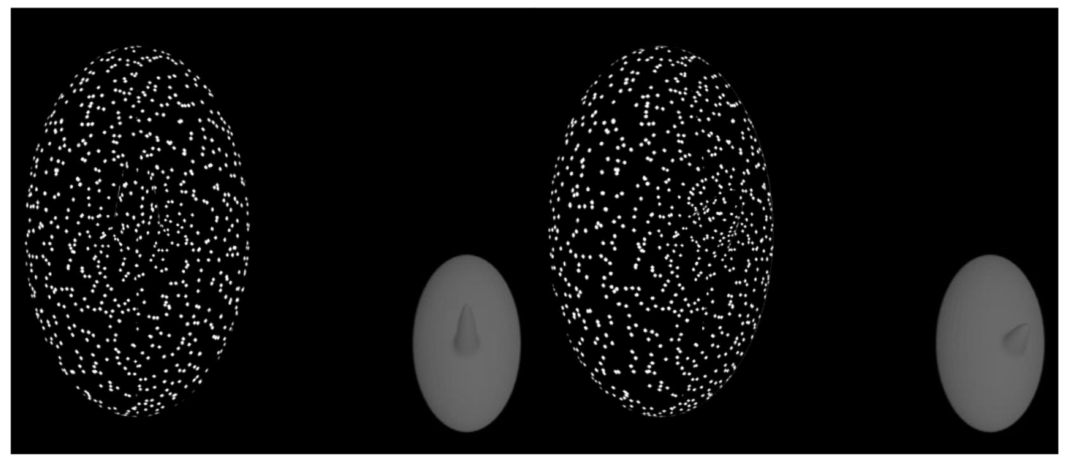
- Structure-From-Motion (SFM) is the ability to perceptually infer the 3D structure of an object from 2D image motion.
- The SFM literature has primarily focused on the perception of rigidly rotating objects.
- Models of SFM have mostly assumed rigidity as a constraint (e.g., Ullman, 1979).
- However, many of the objects in the environment move non-rigidly (especially biological entities) and recent studies have shown that observers are good at perceiving certain non-rigid transformations (e.g., Jain and Zaidi, 2011).

Motivation

Overarching goal:
- To understand what types of non-rigid transformations are perceivable through SFM
- Does the visual system prefer certain (e.g., more biologically plausible) shape transformations over others?

Previous Work

- In our previous work we investigated the role of biological plausibility of shape transformations by comparing the perception of **part-orientation change** (common in animate motion; more biologically plausible) and **part-length** change (less common/biologically plausible).
- Started with two-part object: an ellipsoid with a long and narrow protruding part.
- As the whole object rotated, the part underwent a non-rigid length change.
- *Observed a misperception of non-rigid part-length change as part-orientation change*.
- Manipulated degree of length change to investigate the parameters of this misperception.

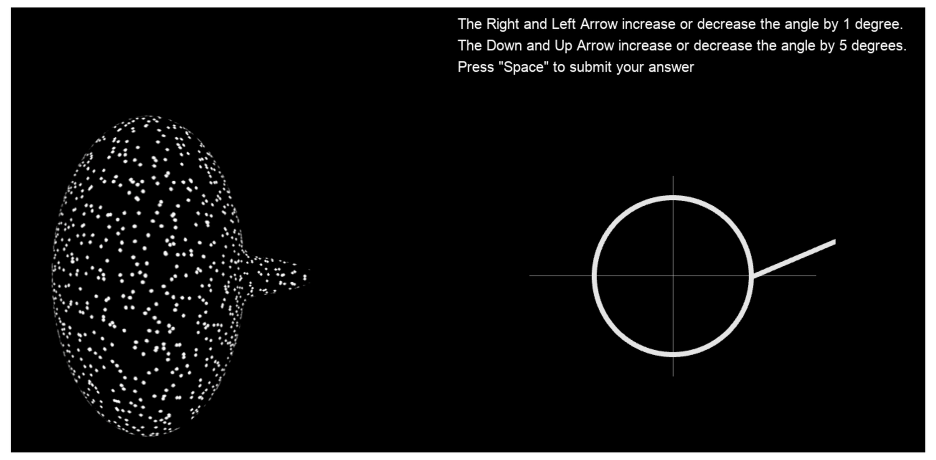


Stimulus from previous work. Left start of motion sequence. Part facing toward subject. *Right* object rotated 25°.(Gray 3D models not shown to subjects.)

- For all observers there was a clear range where **length change was misperceived as orientation change**.
- The visual system demonstrates a preference for the more biologically plausible transformation (dynamic part-orientation change) over the less plausible transformation (dynamic part-length change).

Experiment

- In our previous study the protruding part was always contained within the silhouette of the larger main body.
- For this experiment we allowed the part (and thus the length change) to be fully visible in the silhouette.
- Part perpendicular to main body (in both vertical and horizontal directions).
- Observed a **misperception of non-rigid part length change as a rigid part angled toward/away from the observer.**



Methods: Adjustment Task

Stimuli
- Whole object rotated back-and-forth between -45°and 0° (where the line of sight corresponds to -90°)
- Length changes as part rotates to 0°, returns to original length as object rotates back to -45°.

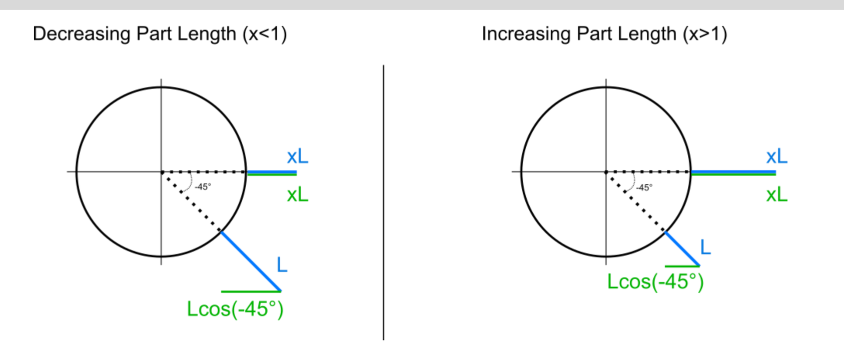
Method
- 7 levels of length change: 3 +ve (increase), 3 –ve (decrease), 1 no length change.
- Task: match perceived horizontal angle in the SFM display using an adjustment display (see figure above)

Models

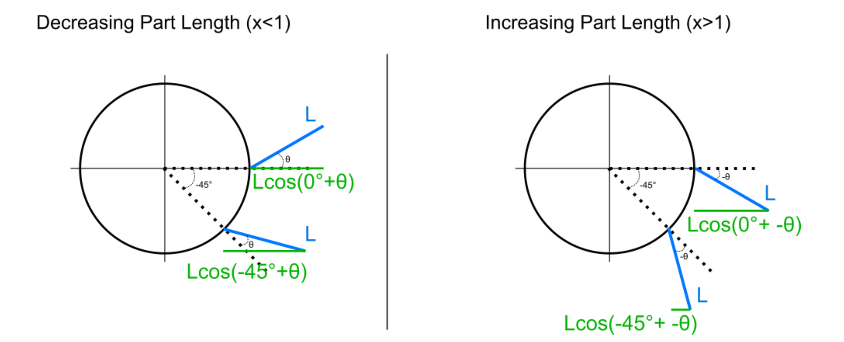
- Model based on the assumption that length change is being reinterpreted as a fixed horizontal angle with no length change.
- Equate ratio between projected length of the parts (in the image) at beginning and end of the motion sequence for the "Actual" and "Re-interpretation".

Model 1: Geometric model

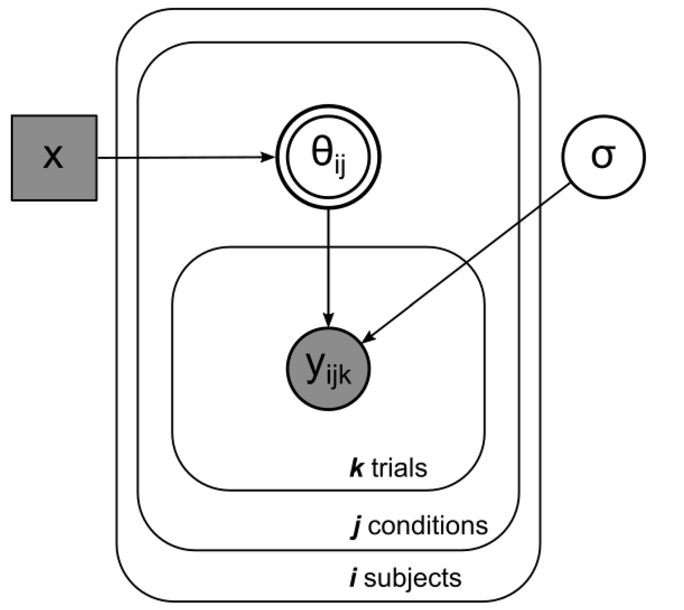
Actual:



Reinterpretation:



- Resulting equation predicts perceived horizontal angle, θ, as a function of length change x. $\theta = \tan^{-1}\left(\frac{1}{x} - 1\right)$



$\sigma \sim Uniform(0,10)$

$x \leftarrow \left[\frac{1}{1.72}, \frac{1}{1.48}, \frac{1}{1.24}, 1, 1.24, 1.48, 1.72\right]$

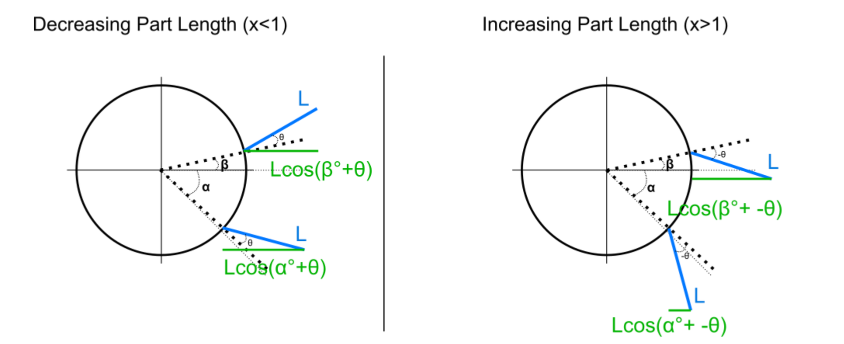
$\theta_{ij} \leftarrow tan^{-1}\left(\frac{1}{x} - 1\right)$

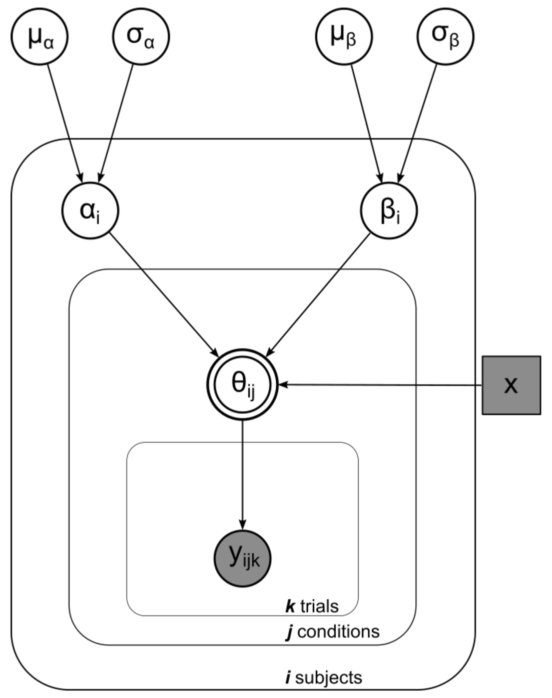
$y_{ijk} \sim \mathrm{Gaussian}(\theta_{ij}, \sigma)$

Model 2: Probabilistic Model

- We then relax the assumption that observers are perceiving the correct start and end orientation of the object and instead use α and β as free parameters for the start and end orientation.
- The resulting equation: $\theta = \tan^{-1}\left(\frac{\sqrt{2}x\cos\alpha - \cos\beta}{\sqrt{2}x\sin\alpha - \sin\beta}\right)$

Reinterpretation:





	$\alpha/\beta_{subject}$	Mean	SD
Ground truth: $\alpha = -45°$	α_1	-42.83	2.32
	α_2	-43.71	2.65
	α_3	-42.30	2.21
	α_4	-42.21	2.31
	α_5	-41.89	2.29
Ground truth: $\beta = 0°$	β_1	17.73	5.48
	β_2	21.22	5.91
	β_3	9.16	6.20
	β_4	19.35	5.72
	β_5	12.386	5.73

$\mu_\alpha \sim \mathrm{Gaussian}(-45, .001)$

$\mu_\beta \sim \mathrm{Gaussian}(0, .001)$

$\sigma_\alpha \sim \mathrm{Uniform}(0,10)$

$\sigma_\beta \sim \mathrm{Uniform}(0,10)$

$\alpha_i \sim \mathrm{Gaussian}(\mu_\alpha, \sigma_\alpha)$

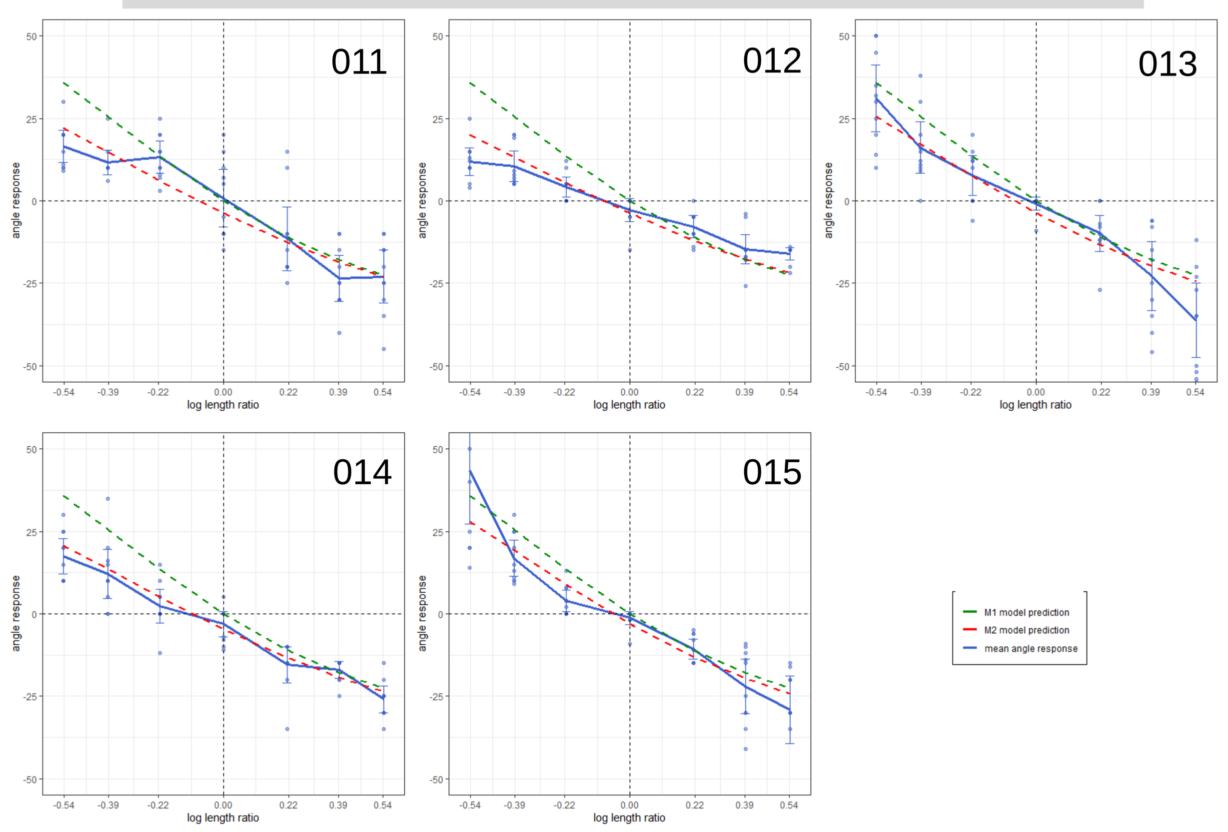
$\beta_i \sim \mathrm{Gaussian}(\mu_\beta, \sigma_\alpha)$

$\theta_{ij} \leftarrow \tan^{-1}\left(\frac{\sqrt{2}x\cos\alpha - \cos\beta}{\sqrt{2}x\sin\alpha - \sin\beta}\right)$

$y_{ijk} \sim Gaussian(\theta_{ijk}, .002)$

$x \leftarrow \left[\frac{1}{1.72}, \frac{1}{1.48}, \frac{1}{1.24}, 1, 1.24, 1.48, 1.72\right]$

Results



- Every observer reported perceiving a non-zero horizontal part angle.
- Perceived horizontal orientation was in the predicted direction:
  Part was perceived as angled away (+ve angle response) when length was decreasing (-ve log length ratio); and angled toward the observer (-ve angle response) when increasing (+ve log length ratio).
- Despite having no free parameters, the simple geometric model does surprisingly well in predicting observers' angle settings.
- We calculated the difference in DIC between the probabilistic model (DIC_M2 = 2902) and the simple geometric model (DIC_M1=3610) and found a difference (DIC_M2 - DIC_M1) = -707.8 – **strongly in favor of the probabilistic model.**

Discussion

- Our results show that the visual system is biased towards reinterpretations of non-rigid part-length change.
- In previous work we observed dynamic part-length change misperceived as a part-orientation change.
- In this experiment a part-length change was misperceived as having an "illusory" slant relative to the main body.
- Results of the Bayesian probabilistic model also show that subjects show some bias in perceiving the start and end orientation of the whole object (especially the end orientation at 0°).
- Given that part-orientation change is a common transformation in animate motion (e.g. limb articulation in animals), whereas part-length change is not, the results suggest that the visual system may be biased towards biologically plausible transformations (Hoffman & Flinchbaugh, 1982).
- The study of SFM should be expanded to include various forms of non-rigid motion.

References

Hoffman, D. D., & Flinchbaugh, B. E. (1982). The interpretation of biological motion. *Biological cybernetics*, *42*(3), 195-204.
Jain, A., & Zaidi, Q. (2011). Discerning nonrigid 3D shapes from motion cues. *Proceedings of the National Academy of Sciences*, *108*(4), 1663-1668.
Ullman, S. (1979). The interpretation of structure from motion. *Proceedings of the Royal Society of London. Series B. Biological Sciences*, *203*(1153), 405-426.