H42 848

The hidden scale of natural forms: a new cue to depth?

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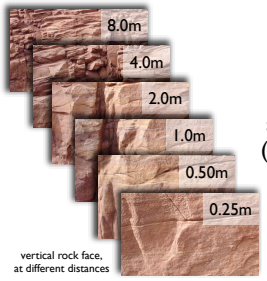
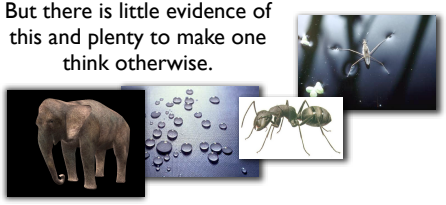
The motivation



The fractal structure of many natural forms (Pentland, 1988), coupled with the $1/f^2$ power spectrum for scenes (Simoncelli, 2001) has often led to the misunderstanding that these forms must *look identical* at every scale.

But there is little evidence of this and plenty to make one think otherwise.



After all, different physical factors dominate at different scales (e.g. surface tension dominates at small scales, gravity at larger; mass goes as the cube, surface with the square): no big water droplets, no small elephants. Just ask D'Arcy Thompson (1917), or Whitman Richards (1988).

Test yourself: *Which is closer?*

The question

Does a cue exist, hidden in the structure of natural forms (here, rocks), and can observers use it to estimate depth?

The method

Method of adjustment

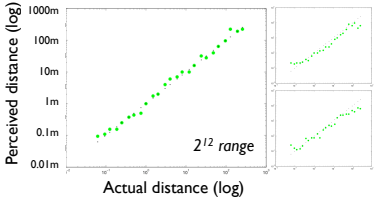
Observers *were not* required to report absolute distance. Observers zoomed in/out on a 'standard', full-cue image of a woman until its distance matched the experimental image

Experimental 'rock' images (92 in all)
2^{10} range: 0.125m to 128m in 2x increments

'Standard' images
2^{12} range: 0.0625m to 256m in ~1.44x increments

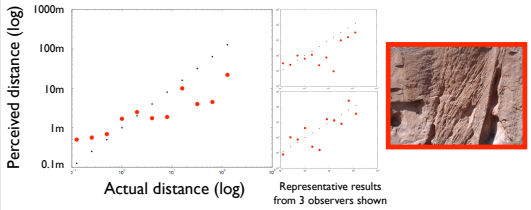
Images subtended same visual angle as in original scene.
An observer never saw the same distance twice.
An observer never saw the same 'rock' twice.

Observers are quite good at this task with familiar images, a *validation of the method*

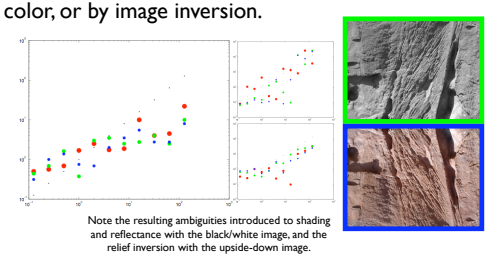


The results

All observers had depth estimates that were highly correlated with actual distances.



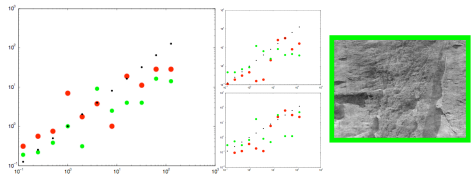
Performance was not noticeably reduced by the loss of color, or by image inversion.



Note the resulting ambiguities introduced to shading and reflectance with the black/white image, and the relief inversion with the upside-down image.

To rule out global spectrum cues, the average amplitude spectrum was applied to all images. Performance was not noticeably reduced.

example transformation with a familiar image



The conclusions

The cue exists, and all 25 naive observers can and do use it.

Performance is in the absence of known depth cues. *If these surfaces were completely self-similar, performance should be random.*

From the comparable performance with b&w, inverted, and amplitude-equalized images, the cue does not seem to rely on color, and is robust over ambiguities in reflectance/ shading and relief.

The cue is not based on global Fourier spectra.

Obviously contained in the phase structure, further specification of the cue is ongoing. A rock-by-rock analysis may provide some insight.

Actual distance vs. observers' estimate is shown above each image. Error increases left to right, top to bottom.

D'Arcy W Thompson (1917/1992). On Growth and Form. Cambridge University Press, Cambridge, UK.
Pentland, A. (1988). Fractal-based description of surfaces. In W. Richards, (Ed). Natural Computation. MIT Press, Cambridge, MA.
Richards, W. (Ed.) (1988). Natural Computation. MIT Press, Cambridge, MA.
Simoncelli, E. P., Olshausen, B. A.. (2001). Natural image statistics and neural representation. Annual Review of Neuroscience, 24:1193-216.