Neurological models of size scaling

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Abstract: Lehar argues that a simple Neuron Doctrine cannot explain perceptual phenomena such as size constancy but he fails to discuss existing, more complex neurological models. Size models that rely purely on scaling for distance are sparse, but several models are also concerned with other aspects of size perception such as geometrical illusions, relative size, adaptation, perceptual learning, and size discrimination.

Lehar argues (sect. 2.2 and elsewhere) that there are no adequate neurological models to explain why we see the world the way we do, and that theorists have ignored the discrepancies between the proximal stimulus and our perceptual experience. He then presents a computational model to describe our perceptual experience of hyperbolic space. He rightly complains about the shortage of neurological models for size and shape constancy but he fails to discuss the models that do exist.

Psychologists have long been interested in size scaling, or discrepancies between perceived size and image size: The phenomena include size constancy, geometrical illusions, optical distortions, adaptation, and aftereffects. The classical account of size constancy maintains that size is scaled for distance in a quasi-geometric manner (the size-distance invariance hypothesis); this account is not productive of neurological models because it assumes that retinal image size is "correctly" encoded in the visual cortex and that the image is then scaled for distance in some unexplained "cognitive" manner. Kirschfeld (1999) argues that the image representation has to be scaled for distance neurologically before it enters consciousness and that this might be done in area V4. He notes that Dobbins et al. (1998) found that some neurons in this area varied their response to the angular size of lines depending on viewing distance.

The idea that image size is transformed at some preconscious stage of visual processing by mechanisms other than distance scaling (e.g., McCready 1985) may be more fruitful. Stuart et al. (1993) proposed a computational model based on broadly tuned layers of size detectors, which could account both for Weber's law in size discrimination and for the biasing effects of geometrical illusions; however, they did not extend the model to include scaling for distance. The main alternative approach to size constancy – generally supported by Gibsonians – is that object sizes are scaled in relation to the surrounding spatial scale. This approach has the advantage of embracing other size illusions in addition to size constancy and it is more productive of neurological models. Size contrast illusions have been attributed to adaptation of cells that detect spatial frequency or to other neural interactions in the brain (see Gillam 1998). However, spatial frequency is not the same thing as image size (the distance across an image), so spatial frequency models are unhelpful for general models of size perception.

Andrews (1964) proposed a perceptual learning model of size calibration in which the brain corrects the metric of the visual field according to the most recent information and attempts to equalize the spacing of contours. This would allow for learning in addition to explaining some illusions, aftereffects, and size constancy. Richards (1977) suggested that simple cells in the cortex might respond to relative rather than absolute size and he also discussed the properties necessary for the neural basis of size constancy.

Some authors have attempted to explain size constancy through the enlargement of perceived size for the central part of the visual scene, which occurs because the representation of the central part of the retinal image covers more cortical cells at later stages of analysis. Such an idea is based on the anatomical fact of cortical magnification, which enhances acuity for central vision. The fovea contains more densely packed cone cells than the surrounding area and it projects to a relatively larger region of the primary visual cortex. Schwartz (1980) incorporated this idea into his model of size constancy. When an observer fixates a distant object, it forms a small image in central vision, whereas close objects form larger images that spread further into the periphery: The small central image is therefore expanded neurologically relatively more than the larger image. Such a mechanism might contribute marginally to size constancy, but it fails to explain how objects of the same angular size can appear different in size even when both are viewed in central vision.

An example of this problem is the moon illusion (see Ross & Plug 2002). The moon illusion is the apparent enlargement of the sun or moon when low on the horizon compared with its size when higher in the sky; the effect is similar to size constancy but is hard to explain by the usual "scaling for distance" account. The difficulty is that the low moon appears nearer than the high moon, whereas size-distance invariance requires it to appear further. Trehub (1991, pp. 242–47) developed the "retinoid" model, which could account for both size constancy and the moon illusion. He argued that size magnification is expensive in neurological terms because it involves the use of more networks of cells. The brain husbands its resources by magnifying only the most "ecologically relevant" parts of the scene – that is, objects in the near distance when looking horizontally, and close overhead when looking up. Humans cannot normally interact with celestial objects or with distant terrestrial objects, so the images for such objects can safely be left relatively small. Size constancy is therefore poor for far horizontal distances and even poorer when looking upwards. The three-dimensional representation of distance is also shrunk vertically in comparison with horizontally, again for the purpose of minimizing neural resources. Distance is computed within the three-dimensional retinoid system and is represented by "sheets" of cells; the extent of size magnification is linked to the distance plane onto which the image is mapped. This biased mapping of the visual scene onto brain structures is largely the result of human evolution, but it can be further modified by individual experience.

There are neuropsychological findings that support multiple representations of three-dimensional space (see Previc 1998). There are also findings on micropsia and hemineglect that give clues as to how and where size might be coded (see Kassubek et al. 1999). Lehar may be correct that a simple Neuron Doctrine cannot account for size scaling, but more complex neurological models show promise.

Spatial phenomenology requires potential illumination

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Abstract: Collapsing three-dimensional space into two violates Lehar's "volumetric mapping" constraint and can cause the visual system to construct illusory transparent regions to replace voxels that would have contained illumination. This may underlie why color constancy is worse in two dimensions, and argues for Lehar to revise his phenomenal spatial model by putting "potential illumination" in *empty* space.

Lehar's phenomenological description of space neglects the fact that *empty* space is actually *full* of illumination. For example, if a cast shadow crosses half of this page and you move your finger from a word under shadow to one under full illumination, you are not surprised when your finger crosses the shadow, even though your finger is closer in depth than the page. This is because every voxel between your eye and the page contains some amount of light. It is unfortunate that Lehar overlooks this fact, because he correctly asserts that depth information is volumetric, whereas current neurological models fail to "represent transparency[,]