

## Somatotopically organized maps of near visual space exist

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Map me no maps, sir, my head is a map, a map of the whole world.

Henry Fielding

[JFS] Stein claims that there is no evidence for a region where egocentric space is represented topographically. In lieu of a map, he offers us a "neural network," that is, "a distributed system of rules for information processing that can be used to transform signals from one coordinate system into another." Such a computational scheme might indeed work; however, it is quite unnecessary, because a neuronal topographic map of visual space does exist, at least for the region adjacent to the body, that is, immediate extrapersonal space. As there is good evidence for more than one such map in the primate brain, the question would seem to be: What are their different functions? rather than How can we erect a computational network to do without them?

We recently found such a map in the monkey putamen (Graziano & Gross, submitted; Gross & Graziano 1990), and evidence for a similar organization has been found in area 6 and in portions of the parietal lobe. In this commentary, we first summarize our experimental evidence for a somatotopically organized map of visual space. Then we mention the earlier and very similar observations in other regions of the brain.

Neurons in the macaque putamen have tactile receptive fields that are somatotopically organized (Crutcher & DeLong 1984a). We found that cells with tactile receptive fields on the face or arms were often bimodal: They responded both to tactile and to visual stimuli. Furthermore, for each cell the location of the visual receptive field closely matched the location of the tactile receptive field. That is, the cell would respond to an object placed within about 10 cm of the skin and moving toward the tactile receptive field. Thus, these neurons formed a somatotopically arranged visual map of near extrapersonal space. A small proportion of the cells with tactile receptive fields on the arm had movable visual receptive fields: As the arm moved, the visual receptive field moved to remain in register with the arm. This suggests that the map of visual space in the putamen might be a "body-part-centered" one rather than a "head-centered" one.

Bimodal cells with similar properties were previously described in area 6 by Rizzolatti and his colleagues (Fogassi et al., submitted; Centilucci et al. 1983; Rizzolatti et al. 1981a; 1981b; Rizzolatti et al. 1983). Although the authors did not study the effect of varying limb position, they did study the effect of eye position. When the animal's eye moved, the visual receptive field remained in correspondence with the tactile receptive field. That is, the visual responses were somatotopically and not retinotopically organized. These investigators pointed out that area 6 cells could help program visually guided movements near the body and supported this view by demonstrating that monkeys with lesions of area 6 neglect nearby but not distant visual stimuli (Rizzolatti & Berti 1990).

Similar observations have also been made in area 7b. Cells in 7b were somatotopically organized (Robinson & Burton 1980a; 1980b) and many had visual receptive fields that corresponded to the tactile ones (Hyvarinen 1981; Hyvarinen & Poranen 1974; Leinonen et al. 1979; Leinonen & Nyman 1979). At least in some cases, when the arm was moved, the visual receptive field appeared to move so as to stay in correspondence (Leinonen et al. 1979).

In summary, there are at least three brain regions that contain a somatotopic map of the immediate visual space, namely, the putamen, area 6, and area 7b. These areas are monosynaptically

connected (e.g., Cavada & Goldman-Rakic 1989b; 1991; Kunzle 1978) and appear to form a system for the representation of extrapersonal visual space. All are egocentric maps. Some of their properties suggest that they are body part centered rather than strictly head centered. They presumably receive their visual, somatosensory, and proprioceptive information from the posterior parietal connections summarized by Stein. These maps might serve both sensory and motor functions in near extrapersonal space, perhaps each serving primarily one or the other function. They might also provide an input to the allotropic representation of visual space found in the hippocampus.

### ACKNOWLEDGMENTS

Supported in part by NIH Grant MH-19420 and NSF Grant BNS-9109743.

## Information processing styles and strategies: Directed movement, neural networks, space and individuality

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[GEA, EEF, DAR, JFS] **1. Neural networks, brain function and what's in between: Let's indeed have a new baby . . . and not throw out the old ones.** Having myself dared to say in print that the neuron is no longer the centerpiece of neuroscience (Grobstein 1987; see also Grobstein 1986; 1988a; 1988b), I can't argue with Robinson (or Alexander et al., Fetz, or Stein) on that score. "Discomfort, if not always openly acknowledged, has been increasingly expressed by neurobiologists of almost every sort. . . . While diagnoses of the problem vary in detail, a common theme is that characterization of functional populations is not only 'difficult to construct from individual elements' but frequently impossible" (Grobstein 1990). It's been a bit lonely out here, and so I welcome with open arms Robinson's decision (and anyone else's) to come out of the closet and join the community of skeptics.

Mild irony aside, there are real issues to be addressed by those who understand the limitations of not only "bottom-up" approaches to the brain, but "top-down" approaches as well. "Beginning with the computational task is fine if one is dealing with an engineering problem; it can be highly misleading if one is concerned with a preexisting complex information-processing device whose computational tasks, styles, and constraints are in fact part of what needs to be discovered" (Grobstein 1990). Robinson's thoughts are particularly welcome, given his leadership with top-down approaches. I gladly accept his correction to my remark: Not even all engineering problems are necessarily best solved with top-down approaches. Robinson's target article, and those of Alexander et al., Fetz, and Stein, are important contributions to the requisite discussion of the obvious question: Beyond bottom-up and top-down, what approaches to the analysis of complex information-processing devices are available? I have written elsewhere, in the context of sensorimotor integration (Grobstein 1988b), neuroscience as a whole (Grobstein 1990), and biological systems more broadly (Grobstein 1988c), about an "intermediate level approach" that proceeds from the middle outward. Here I want to test some of those ideas against the insights of my colleagues (and theirs, in turn, against my own) in the specific arena they have defined: Sensorimotor processing and the new insights into it that have been, and will be, gained from the use of artificial neural networks.

My first point is one of whole-hearted agreement with Robinson and the others: artificial neural networks have much to offer. Among the things they have to teach is that solutions to information processing problems may have a highly distributed character, which in turn could account both for difficulties in making