Computation, PET images, and attention

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Abstract: Posner & Raichle (1994) is a nice addition to the *Scientific American Library* and the average reader will both enjoy the book and learn a great deal. As an active researcher, however, I find the book disappointing in many respects. My two major disappointments are in the illusion of computation that is created throughout the volume and in the inadequate perspective of the presentation on visual attention.

Introduction. Although I have many minor criticisms of Posner & Raichle's (P&R, 1994) book, I will focus on issues relating to computation and visual attention. The minor points concern the balance of the research hypotheses, results, and paradigms included in the presentation and the lack of rigor in scholarship (where at least part of the blame must be borne by the *Scientific American* editors since I find all *Scientific American* publications suffer from this problem).

Computational modeling. Although the word "computation" and words from the language of computing appear frequently, the models presented in the book are lacking in computational detail and realizability. For example, Posner's model of attention, if intended to be a general model of visual attention, is actually quite far from being a viable computational model. The ALERT operation on p. 49 is possibly not even tractable. Since no specification is given of what type of stimulus should trigger ALERT, the problem that ALERT must solve is the same as the Unbounded Visual Search Problem (Tsotsos 1989; 1990); this is probably in the class of computational problems that are on current evidence intractable in any implementation. Thus, not only are the various stages of the algorithm not sufficiently explained so that one might implement or test it and compare its performance to human behavior, but the algorithm itself depends on the solution of an intractable subproblem. If it is intended as only an explanation of the experiment described on those pages (and ALERT is intended only to detect cue onsets), it is not very interesting. The model of Farah (p. 92) is again not a computational model in any real sense. Kosslyn's model of imagination (p. 39) is simply a recasting of the standard computer graphics paradigm and does not answer the core question of why imagination is "imaginative" and not just a reproduction of known objects and events? Rather than focus only on these fuzzy and unilluminating explanations, P&R could have balanced those presentations with descriptions and commentary on some of the several implemented computational models of aspects of cognition, such as those for visual attention (see Koch 1993 for overview).

Images and attention. P&R imply that images of the PET or functional MRI variety can suffice in uncovering the details of attentional function in the brain. PET is a valuable method for exposing the gross changes in energy usage in the brain during various activities. I remain skeptical and would have appreciated more detailed discussions of the following:

(1) I feel that there is insufficient support for saying that areas of increased energy use are where cognitive energy is focused for a given task. It seems unjustified to assume that areas that are subtracted out are not contributing.

(2) There seems to be no way to detect different functionalities of a given area which require equal amounts of energy. For example, in my own model of visual attention (Tsotsos 1995), most of the attentional machinery is "on" all the time, operating in data-directed or task-directed modes, separately or in concert. This is one of the central hypotheses of the model: that meaningful vision is not possible without attention. Moreover, attention is integrated within the visual processing machinery itself for reasons of efficiency. PET cannot test this hypothesis since much of the brain would be using energy in both control and test images.

(3) There seems to be no available method to directly measure inhibition in the brain (Roland 1993). Again, in my own model, much of the attentional effect is in the inhibition of connections. Experimentally, the findings of Moran and Desimone (1985), Chelazzi et al. (1993), and Motter (1993) all show inhibitory effects of attentive processing in single cell responses. How can PET help here?

(4) The time scale of PET has always caused me difficulty. Since signals are summed over a period of 40 seconds, how exactly are attentional operations which seem to last anywhere from 20msec to 250msec (Duncan et al. 1994; Sagi & Julesz 1985) organized during this period? Is it hypothesized that they are simply repeated for the entire period and if so, what does this mean with respect to execution of the task? What happens in between fixations with respect to energy usage? How exactly do subjects cycle through these attentional fixations in such a way that the total energy usage means something?

(5) On p. 168 P&R seem to use the term "enhance" to mean that the output of the visual cortex (whatever that may be) is extracted and then enhanced for the selected item. Enhanced in what way? If the visual output is noisy, does this mean that the noise is enhanced along with the signal? There is a need to recompute the signal incorporating attentional biases in order to remove effects of conflicting stimuli and noise (Tsotsos 1990; 1995). The hypothesis that attention networks are distinct from processing systems thus makes little sense.

Conclusions. The average *Scientific American* reader will find this a nice volume that introduces the layperson to the wonders of exploring the brain using PET technology. The average reader will learn a great deal. P&R manage to convey a real sense of excitement and promise regarding their work and the reader is easily infected. However, as someone actively studying computational models of visual attention, I find much that I can argue with. The book succeeds in convincing me that the clinical uses of PET images are probably much more important than their role in illuminating the computations underlying cognition.

Authors' Response

Interaction of method and theory in cognitive neuroscience

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Abstract: We divided the many diverse comments on our book into categories. These are: theory, scope and goals of our project, methods, comments on specific anatomical areas, the concept of attention, consciousness and cognitive control, and finally other issues. Although many of the points of the critics are certainly well taken, we believe studies that have emerged since our book provide strong evidence that the general approach taken in our book is now yielding important new data on the relation of cognitive processes to underlying brain activity.

We are grateful to the commentators on our book for taking the time and effort first to read and view our work and then to write a very interesting set of commentaries. We enjoyed the praise of a number of our readers for our words and their strong support for our illustrations and format, but there were also reminders of how far we have