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Cognitive Neuroscience: spanning the void between cognitive science and neuroscience

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Abstract

Cognitive neuroscience is a field that has developed to bridge the gap between cognitive science, which focuses on the mind, and neuroscience, which focuses on the brain. Classically, cognitive scientists consider the mind to be software that runs on the hardware of the brain. We argue that this computer metaphor is flawed, and that there is no evidence that the mind exists independently of the brain. Thus, we need new cognitive neuroscience models that incorporate both cognitive and neural data.

Keywords: Mind; Brain; Neuroscience; Cognitive Models.

Introduction

A recent flurry of debate in cognitive science has focused on the relationship between the mind and the brain. This issue has of course been debated in the philosophical literature for centuries (Dehaene, 1997).

In a classic cognitive science approach, the brain is considered the hardware upon which runs the software of the mind (Broadbent, 1958). This has two fundamental premises: (1) cognitive processes are separate to the brain, and can be examined independently from neural processes; and (2) each cognitive process is akin to a separate computer program and is therefore independent or modular (Dehaene, 1997).

Here, we discuss this approach from the perspective of cognitive neuroscience, and argue that the computer metaphor is flawed. Cognitive models alone are too simplistic to explain the working of the mind, and need to acknowledge neural data and neural predictions. We conclude that the mind and brain are *not* separate and therefore further progress requires models that include both cognitive and neural predictions.

The computer metaphor is flawed

The metaphor often used by cognitive scientists of the mind being the software and the brain the hardware is misleading. The human brain is a biological system, not a machine. It has evolved over time, adapting to its environment, with all the complexity and redundancy that comes with this. In this section we discuss some of the problems with this approach.

There are no computers that even approach the complexity of the brain. The human brain is made up of billions of neurons, with adaptable interacting networks. This all fits within a small space in highly compact form. Even cutting-edge computing technology cannot replicate both the complexity and the size of the brain. Indeed, we still do not understand the brain of creatures like the fly, with many fewer neurons, well enough to adequately replicate their processes with a computer.

Although a computer can receive inputs through different ports, simultaneous inputs are impossible to deal with[1]. In contrast, the brain receives multiple inputs simultaneously and effortlessly integrates this with prior knowledge and current processes. Information is constantly streaming in from all the senses, including internal sensations and those of which we are unaware (for example, the brainstem modulation of heart-rate and respiration). This type of synchrony is not possible with computing technology.

The brain also constantly adapts based on the interaction between the incoming information and the goals of the organism. This adaptation and online change due to learning is very different from the reprogramming possible on a computer. Humans are not reprogrammable by inserting new programs! And computers are not able to learn adaptively, despite decades of research into artificial intelligence.

The hardware and software of a computer are clearly separable, and can be damaged independently. In contrast, there is no evidence that the mind exists separately to the brain. If you damage the structure of the brain, there are consequences for function. Similarly, if you activate neurons, a cognitive process occurs (Bradshaw & Mattingley, 1995). The software metaphor is misleading because it presupposes that there is a separate independent hardware for the mind to ‘run’ on.

Finally, humans are conscious beings. This self-awareness itself changes the brain. We have a long way to go to understand consciousness, and it is highly unlikely we could

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[1] Parallel processing is achievable but this involves simultaneous independent streams, not the integrated simultaneous processing of which the brain is capable.

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ever approach a replication of awareness using machine technology.[2]

A more appropriate metaphor?

The weather is perhaps a more appropriate metaphor for the mind. It does not exist independently of the elements that create it. Further, our understanding of the weather improves the more we learn about those elements at different levels of detail.

For many centuries, it was thought that the gods controlled the weather. Over time, some patterns were observed, making crude forecasting possible. Scientific investigation of the way in which water molecules interact with the environment, including processes like evaporation, increased our understanding. Similarly, knowledge of external forces, such as the sun, moon, and air currents, and internal forces, such as density and molecular energy, allowed development of better models. Satellites and radar then further improved predictions of weather patterns.

Although we are still a long way from the perfect model of the weather, the increased information about all levels of the component elements and influences has resulted in much better models. This is akin to our understanding of behaviour, and the mind. We need to garner information about the components of the brain, from molecules to neurons to populations of neurons right through to the macro structure of the brain and the behaviour of conscious humans. Only with all these levels of inquiry will we then be able to build appropriately detailed models to predict behaviour and understand the mind.

Cognitive models and neuroimaging

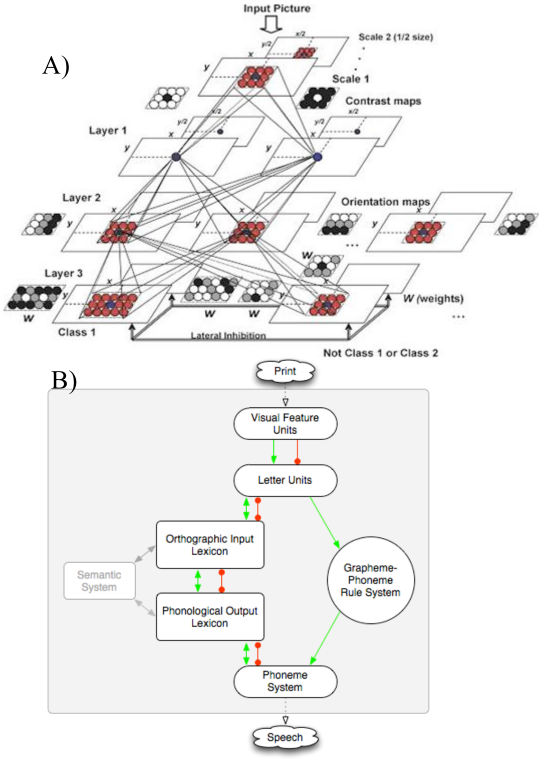
The recent debate initiated by Max Coltheart's provocative question "What has functional neuroimaging told us about the mind (so far)?" (Coltheart, 2006) has the basic premise that cognitive models are the gold standard for investigating the mind. Thus, the argument goes, neuroimaging has not told us anything about the mind because it has not distinguished between competing cognitive models.

On their own, however, cognitive models are too simplistic, and fail to take into account data about the brain. This creates a fundamental problem for testing cognitive models with neuroimaging data. It requires an additional step of inference: this network within the brain is associated with this cognitive process; thus, if this cognitive process is involved in behaviour X, we should see a particular pattern of activity. Of course, this assumes specificity of the activity (it only occurs during that cognitive process) and sensitivity of the measure (we will see it if it happens), neither of which are certain. If, as we argue, the mind is not separate from the brain, cognitive models need to contain neural predictions to be useful.

One can also raise a number of concerns about cognitive models that suggest they may be far from the gold standard for investigations of the mind. First, as with other models, cognitive models are not able to predict behaviour with 100% accuracy. In addition, they usually focus on a single cognitive process in isolation, a situation unlikely to occur in the mind. Finally, cognitive models ignore a lot of data regarding the neural plausibility of their outlined components and predictions. This limits their usefulness to, at best, an abstract approximation of what 'might be'. The goal of cognitive models often appears to be to replicate an output without concern for a plausible way this could occur in the mind.

Harking back to our weather example, if we simply look at the external forces in a model of weather patterns, our predictive accuracy would be poor. Similarly, reading a word requires a person to attend to the word, but models of reading rarely specify all the other components that precede this stage. For example, to individuate the word from the background requires figure-ground segmentation, perceptual grouping, and so on, not to mention the even earlier processes of detecting wavelengths of light.

Neural networks and dynamic systems models may provide better representations of the processes underpinning cognition than the standard cognitive models. To illustrate the differences, in Figure 1a we reproduce the neural network proposed by Wysoski and Benuskova (2006) as being involved in the first stages of visual perception. In Figure 1b, we reproduce a cognitive model of word reading (Coltheart, Rastle, Perry, Langdon, & Zeigler, 2001). The entire complex neural network (Fig. 1A) fits within a single underspecified box in the cognitive model (i.e. Visual Feature Units; Fig. 1B). With this sort of oversimplification, it may never be possible to test this cognitive model appropriately.



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[2] For a comprehensive discussion on this issue we recommend Dehaene (1997)

Figure 1: (A) Reproduction of a neural network (Wysoski & Benuskova, 2006) which represents the first stages of visual perception. (B) Reproduction of the Dual Route model of visual word recognition and reading aloud (Coltheart et al., 2001).

Cognitive neuroscience: bridging the gap

Obviously, there are many questions cognitive scientists ask that are adequately specified within the type of model shown in Figure 1b. Similarly, the questions neuroscientists ask are typically at the level of individual neurons. When one talks about the mind, however, we require more detailed models that incorporate data from many different methodologies and levels of specificity. Such cognitive-neural models fit within the field of cognitive neuroscience.

A term commonly attributed to Michael Gazzaniga, cognitive neuroscience incorporates notions of cognitive components, which can be separated and tested in a modular fashion, with neural data, and questions about the brain. Thus, analogous to our modeling of weather patterns, knowledge about the molecules through to the macro external forces are all important in improving predictive accuracy. For the mind, this means models need to encompass cognitive science data (e.g., reaction times), neuroimaging data (e.g., fMRI results), and neuronal data (e.g., single-cell recordings). Obviously this is a big ask. Although we do not have a model to fulfill these criteria, we review a neuroimaging study that illustrates the way in which neural data can be useful in provoking revision of cognitive models, in this case models of visual object perception.

Williams et al. (2008) presented novel objects in diagonally opposing parts of the peripheral visual field, while participants fixated centrally. The task was simply to determine if the objects were identical or different, and the objects on each trial could be from one of three different categories ('spikies', 'smoothies', or 'cubies'; Fig. 2A). We used multivariate pattern analyses, which look for systematic patterns in the activity across voxels. To do these analyses, one divides the data into two sets and looks to see if there is a consistent pattern that reliably (from one dataset to the other) discriminates different conditions – in this case different object categories. As the visual cortex is retinotopically mapped, it was not surprising to find a pattern in the regions of cortex representing the peripheral locations that could distinguish between the object categories. Consistent with such retinotopic representations, this pattern was present only when the objects were in the same location (e.g., left diagonal) in the two datasets. Intriguingly, however, we also found significant discrimination in the foveal confluence – the region of cortex representing central vision, where no objects were presented. Critically, this pattern was not dependent on the location of the objects (same or different diagonal locations; Fig. 2B,C) suggesting it is due to feedback from higher areas that are position-invariant. Thus, contrary to the traditional view of early visual cortex being strictly retinotopic in the mapping of visual space, here we have evidence of object-specific information about objects in the periphery being fed back to foveal cortex. There are many controls outlined in the original paper, as well as a number of subsequent experiments confirming the original finding. For our purposes here, however, the important point is that there are no cognitive models of object perception or object recognition that include position-invariant information being fedback to the earliest stages of processing. Thus, we need a cognitive-neural model that incorporates theories of object perception and recognition with neurophysiological data about the structure of the visual system (including complex feedback connections; Lamme & Roelfsema, 2000), and the neuroimaging data that suggest a functional role for feedback (Williams et al., 2008).

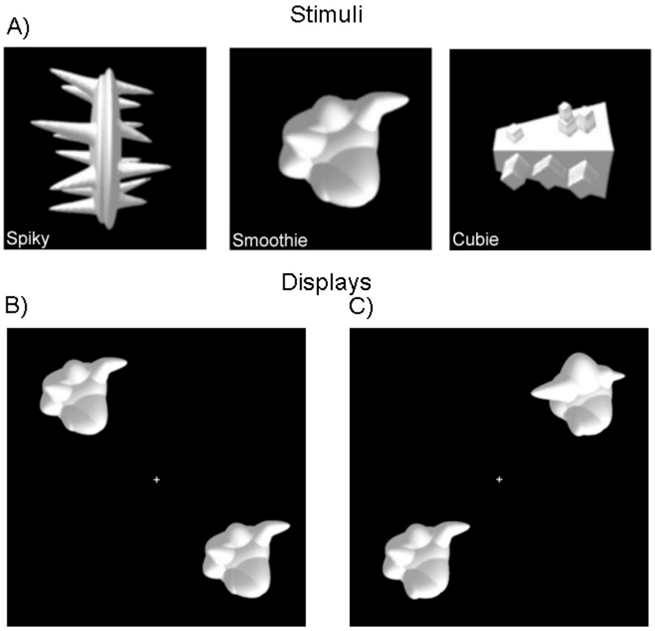

Figure 2: (A) A single exemplar from each of the three stimulus categories. (B) Example of the presentation display with identical 'smoothies' present in the top left and bottom right quadrants (left diagonal). (C) Example of the presentation display with different 'smoothies' present in the top right and bottom left quadrants (right diagonal; (Williams et al., 2008).

Conclusion

The challenge set by Coltheart (2006) has been valuable in provoking discussion and inviting researchers, particularly those using neuroimaging, to think more deeply about the inferences one can make using each type of data. It has also been useful, we hope, in provoking cognitive scientists to think more about the brain.

It is important, however, to ensure that the proverbial baby does not get tossed out with the bathwater by insisting that cognitive models are the gold standard in determining which data can tell us about the properties of the human mind. Cognitive neuroscience offers the possibility of combining the best from cognitive science and neuroscience to develop models that may some day be able to predict complex behaviours. Similar to predicting the weather, our understanding of the mind requires attention to all levels of inquiry. The new wave of cognitive-neural models will incorporate information from philosophy to molecular neuroscience, to enhance our attempts to understand our own minds.

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References

Bradshaw, J. L., & Mattingley, J. B. (1995). *Clinical Neuropsychology: Behavioral and Brain Science*. New York: Academic Press.

Broadbent, D. (1958). *Perception and Communication* London: Pergamon Press.

Coltheart, M. (2006). What has functional neuroimaging told us about the mind (so far)? *Cortex, 42*(3), 323-331.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Zeigler, J. (2001). DRC: A dual route cascade model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204-256.

Dehaene, S. (1997). *The Number Sense: How the Mind Creates Mathematics*. New York: Oxford University Press.

Lamme, V. A. F., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing
. *Trends in Neuroscience, 23*(11), 571-579.

Williams, M. A., Baker, C. I., Op de Beeck, H. P., Shim, W. M., Dang, S., Triantafyllou, C., & Kanwisher, N. (2008). Feedback of visual object information to foveal retinotopic cortex. *Nature Neuroscience, 11*(12), 1439-1445.

Wysoski, S. G., & Benuskova, L. (2006). Biologically Realistic Neural Networks and Adaptive Visual Information Processing. *Bulletin of Applied Computing and Information Technology, 4*(2).

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