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A computational neuroscience approach to consciousness

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Abstract

Simultaneous recordings from populations of neurons in the inferior temporal visual cortex show that most of the information about which stimulus was shown is available in the number of spikes (or firing rate) of each neuron, and not from stimulus-dependent synchrony, so that it is unlikely that stimulus-dependent synchrony (or indeed oscillations) is an essential aspect of visual object perception. Neurophysiological investigations of backward masking show that the threshold for conscious visual perception may be set to be higher than the level at which small but significant information is present in neuronal firing and which allows humans to guess which stimulus was shown without conscious awareness. The adaptive value of this may be that the systems in the brain that implement the type of information processing involved in conscious thoughts are not interrupted by small signals that could be noise in sensory pathways. I then consider what computational processes are closely related to conscious processing, and describe a higher order syntactic thought (HOST) computational theory of consciousness. It is argued that the adaptive value of higher order thoughts is to solve the credit assignment problem that arises if a multistep syntactic plan needs to be corrected. It is then suggested that it feels like something to be an organism that can think about its own linguistic, and semantically-based thoughts. It is suggested that qualia, raw sensory and emotional feels, arise secondarily to having evolved such a higher order thought system, and that sensory and emotional processing feels like something because it would be unparsimonious for it to enter the planning, higher order thought, system and *not* feel like something.

Keywords: Consciousness; Higher order thought; Synchrony; Oscillations; Backward masking; Binding

1. Introduction

Neural network theories of visual object recognition in the ventral visual stream are being developed that are consistent with much of the related neurophysiology (Rolls, 2008; Rolls & Deco, 2002; Rolls & Stringer, 2006). Neural network theories of attention are also being developed (Deco & Rolls, 2005a, 2005b; Rolls, 2008; Rolls & Deco, 2002). In this paper I consider whether some of the computational processing involved in these perceptual and attentional computations is closely linked to consciousness. Then I consider what computational processing may be closely related to consciousness. The architecture of some of the processing regions discussed is shown in Fig. 1.

2. Oscillations and stimulus-dependent synchrony: Their role in information processing in the ventral visual system, and in consciousness

It has been suggested that syntax in real neuronal networks is implemented by temporal binding (see Malsburg, 1990), which would be evident as for example stimulus-dependent synchrony (Singer, 1999). According to this hypothesis, the binding between features common to an object could be implemented by neurons coding for that object firing in synchrony, whereas if the features belong to different objects, the neurons would not fire in synchrony. Crick and Koch (1990) postulated that oscillations and synchronization are necessary bases of consciousness. It is difficult to see what useful purpose oscillations per se could perform for neural information processing, apart from perhaps resetting a population of neurons to low activity so that they can restart some attractor process (see e.g. Rolls & Treves, 1998), or acting as a reference phase to allow neurons to provide some additional information by virtue of the time that they fire with respect to the reference waveform (Huxter, Burgess, & O'Keefe, 2003). Neither putative function seems to be closely related to consciousness. However, stimulus-dependent synchrony, by implementing binding, a function that has been related to attention (Treisman, 1996), might perhaps be related to consciousness. Let us consider the evidence on whether stimulus-dependent synchrony between neurons

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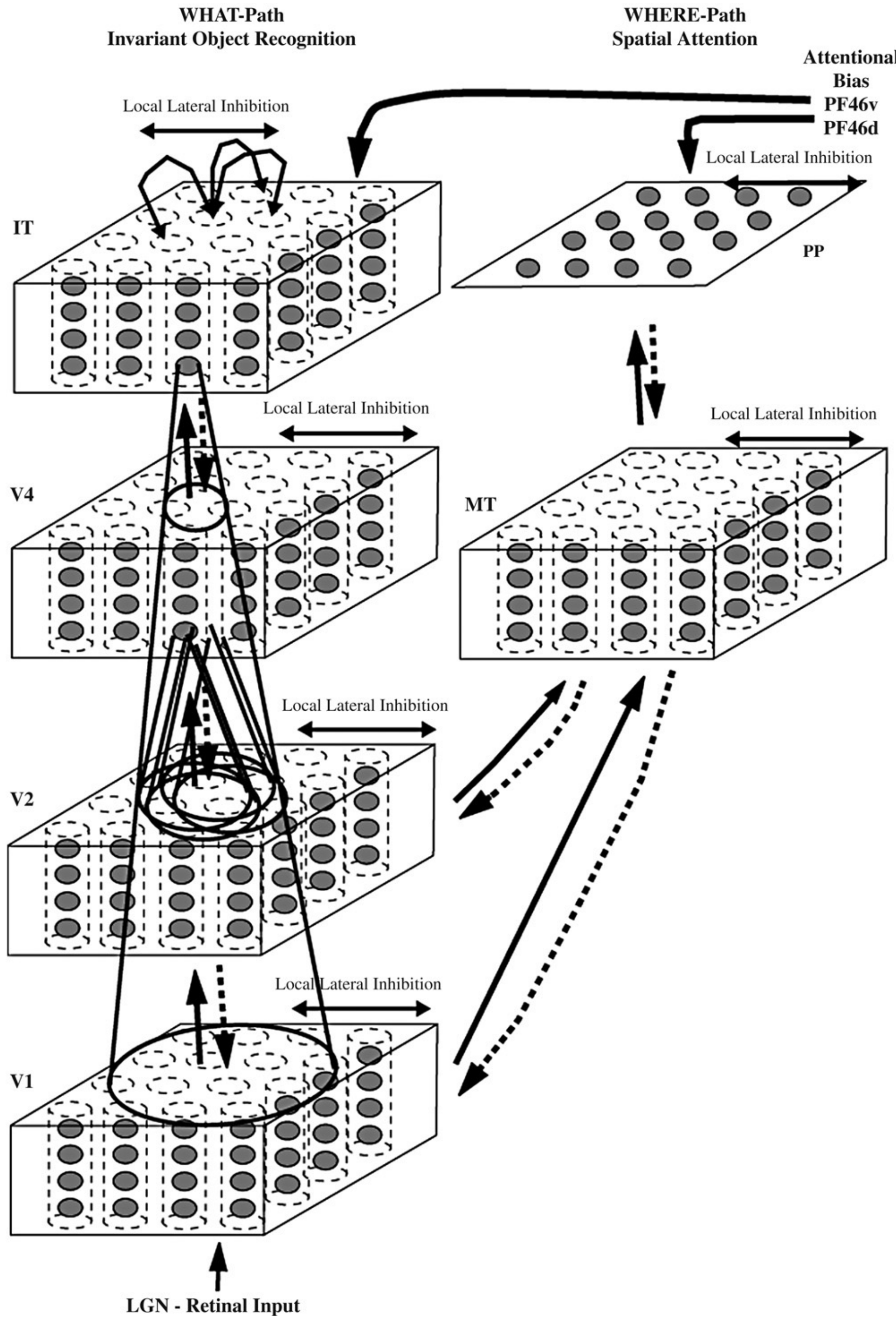

Fig. 1. Cortical architecture for hierarchical and attention-based visual perception after Deco and Rolls (2004). The system is essentially composed of five modules structured such that they resemble the two known main visual paths of the mammalian visual cortex. Information from the retino-geniculo-striate pathway enters the visual cortex through area V1 in the occipital lobe and proceeds into two processing streams. The occipital–temporal stream leads ventrally through V2–V4 and IT (inferior temporal visual cortex), and is mainly concerned with object recognition. The occipital–parietal stream leads dorsally into PP (posterior parietal complex), and is responsible for maintaining a spatial map of an object's location. The solid lines with arrows between levels show the forward connections, and the dashed lines the top-down backprojections. Short-term memory systems in the prefrontal cortex (PF46) apply top-down attentional bias to the object or spatial processing streams. (After Deco and Rolls 2004).

provides significant information related to object recognition and top-down attention in the ventral visual system.

This has been investigated by developing information theoretic methods for measuring the information present in stimulus-dependent synchrony (Franco, Rolls, Aggelopoulos, & Treves, 2004; Panzeri, Schultz, Treves, & Rolls, 1999; Rolls, 2003), and applying them to the analysis of neuronal activity in the macaque inferior temporal visual cortex during object recognition and attention. This brain region represents both features such as parts of objects and faces,