From Perceptual Consciousness to Cognitive Architectures

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This presentation explores implications of studying human visual consciousness on cognitive architectures. Based on an analysis of a perceptual phenomenon—binocular rivalry (BR)—and the relevant known facts about the human visual system, I show that layer-4C (i.e., the input layer) in visual cortical area V1 is involved in visual awareness and is the neural substrate for iconic memory. Furthermore, I extrapolate this conclusion to a more general one that input layers in other cortical areas correspond to various short-term memory systems known to cognitive psychologists. This conclusion implicates that at an abstract level the brain functions as a multi-level production system (corresponding to a Chomsky's type-0 grammar parser).

BR is a striking phenomenon where a viewer experiences alternating periods of different percepts when the two eyes are receiving different stimulus patterns. As Crick (1994) remarked, such a phenomenon can constitute a simple yet powerful paradigm for investigating the neural mechanisms (or correlates) of consciousness. As to the possible neural substrate(s) of BR, there has been a long-standing controversy between two views: a "peripheral view" holds that BR happens very early in visual pathway, while a "central view" insists that BR occurs at a central stage where perceptual and cognitive factors interact. In reality, there is abundant evidence in support of both views (e.g., Blake, 1989; Logothetis et al., 1996).

To reconcile these two views, I propose the following multi-stage model for BR: there are competitions (or rivals) at many levels of the visual pathway, including that between the two eyes at an early stage and that between different candidate percepts at a late stage; these competitions feedback to a monocular site to suppress the two eyes' inputs in a patch-wise manner so as to yield a final coherent percept. Since this model incorporates both monocular and binocular sites, it is not surprising that both peripheral and central factors (such as percept competition seen in Logothetis et al., 1996) can be found in BR.

Where is the monocular suppression stage in our visual system? Visual information from the retinae of the two eyes goes through the lateral geniculate nucleus (LGN) of the thalamus, enters the primary visual cortex (i.e., area V1 or striate cortex) in its layer-4C (α and β sublaminae), and then feeds to superficial layers 2&3 while undergoing some transformations; only up to this level of the visual pathway there are monocular neurons. Based on detailed neuroanatomical and physiological facts and corresponding psychophysical evidence, I suggest that layer-4C is the anatomical substrate for monocular suppression.

This conclusion concerning the site of monocular suppression has important implications concerning the neural correlates of visual consciousness. Recently, Crick and Koch (1995) have advanced an intriguing hypothesis stating that neural activity in V1 is not directly involved in visual consciousness. As monocular neurons are basically only found in V1, the conclusion about monocular suppression immediately suggests that their hypothesis is incorrect. Furthermore, my conclusion about the involvement of layer-4C in BR implies that Crick and Koch's (1996) another hypothesis concerning the neural correlates of consciousness, that only the "deep layers" (i.e., layers 5&6) of the cortex are concerned with consciousness, is incorrect as well. In short, I conclude that layer-4C in V1 is a neural substrate for an important part, the vivid aspect, of our visual consciousness.

It is easy to infer that the site of stimulus suppression in BR is also the site of iconic memory (or better termed visual buffer) well known to psychophysists/psychologists. This conclusion can easily be generalized to other cortical areas. Therefore, a general conclusion can be reached: all those cortical areas having a thalamic input layer (some areas lack this layer) are involved in consciousness, and their input layers are the neural substrates for various short-term memory (STM) systems with different contents (and with seemingly different persisting life-times).

Since STM is usually an important part of general-purpose cognitive architectures, this conclusion has important implications for cognitive architectures. Indeed, it can be shown that at an abstract level the general functional architecture of the brain maps onto a production system (e.g., Newell, 1990). Moreover, as there are multi-level cortical areas, this conclusion implies that brain functions as a multi-level production system, or a Chomskian machine since such a system is computationally equivalent to Noam Chomsky's type-0 grammar processor. As the "production rules" (or "rewriting rules") in the brain are certainly very experience-dependent, such rules may well be modeled as having constantly changing "weights" which can constitute an important aspect of conflict resolution in the working of such a Chomskian machine.

References

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